REPORT

TITLE: SVM DESIGN REPORT

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SIGNATURE AND APPROVALS ON ORIGINAL

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1. INTRODUCTION

HERSCHEL/PLANCK, the 4th cornerstone of the ESA Scientific Programme Horizon 2000 is a challenging mission for the European industry as well as for the European scientific community. Both HERSCHEL and PLANCK spacecraft will represent a major step forward in the knowledge of the Universe and of the mechanisms driving its evolution.

ALENIA Spazio part of the a core team, led by ALCATEL, is responsible for the design of both the SVMs

ALENIA Spazio is a major actor in the scientific programmes of ESA, currently Prime Contractor of the Integral programme and AIT Contractor of the two most recent scientific programmes ROSETTA and MARS EXPRESS.

As part of the Integral programme, ALENIA demonstrated its capability to maintain to the highest possible level the communality of the Integral Service Module design with the XMM bus, while adapting its performance to the requirements of the Integral mission. This approach will serve the HERSCHEL/PLANCK programme to maximize the

commonalties between the two satellites and therefore minimize costs and risks.

As part of their involvement in both Integral and the two ROSETTA and MARS EXPRESS programmes, ALENIA has acquired a thorough knowledge of recent ESGSE and testing techniques of current spacecraft design. In addition the stringent launch window of ROSETTA and MARS EXPRESS demonstrates ALENIA flexibility and adaptability to meet challenging milestone schedule.

For the establishment of the HERSCHEL/Planck technical baseline, the following basic objectives were considered:

- a design compliant with the scientific mission objectives
- a cost effective approach.

Application of proven and fault tolerant design, re-use of existing hardware were paramount input parameters into the design.

The HERSCHEL/PLANCK project started its phase B on April 2001 and the expected date for its completion and starting of phase C/D is planned on September 2002.

This Issue of the document has been prepared as part of the Data Package of the System Preliminary Design Review with the objective to document the technical Baseline for both the Herschel and Planck SVM’s.

1.1 PURPOSE

Purpose of this report is to document the current HERSCHEL/PLANCK SVM design. The Document is structured to be easily combined with the System Design Report provided by ALCATEL.

1.2 GUIDE TO THE REPORT

This Issue of the document is in line with the maturity of the design and is not fully completed. It will be upgraded at the time of the CDR.

Chapter 2 highlights the key SVM requirements and design drivers for the HERSCHEL/PLANCK SVM design.

Chapter 3 identifies the experiment interface and accommodation key parameters/constraints. The design of the Instruments is under the responsibility of the PI's and is documented in the relevant PI's Documentation that will be called out in this document. A definition of the Payload Instruments architecture (equipment and units), resources allocation (mass, power, data.....), interfaces with the PLM and SVM will be established and described to have a set of consistent boundaries conditions for the overall spacecraft sizing. The above considerations will be reflected in tabular form for the HERSCHEL/PLANCK Instruments.

Chapter 4 discusses the HERSCHEL/PLANCK Mission concept in terms of:

Identification of the HERSCHEL/PLANCK mission phases with particular emphasis on the Ariane V Dual launch configuration.
Description of the L2 Operational orbits derived from the mission requirements and evaluation of the G.S. coverage period and eclipse time.
Strategies for orbit insertion and subsequent orbit maintenance are explained.

Chapter 5 presents all the major trade-offs performed at SVM level to achieve the current design.
For completeness the trade-offs performed during the Proposal Phase are recalled as well.

The aim of the **Chapter 6** is to present the Operational Concept that have been considered for the System/Subsystem and Equipment design and performances characterisation.

Chapter 7 presents the SVM Functional design and performance analyses. This chapter is supported by the Chapter 8 and together with the Chapter 9 complete the description of SVM Subsystems and Equipment Design.

Chapter 10 gives a general descriptions of the GSE’s concepts and design

1.3 ACRONYMS AND ABBREVIATIONS

A	Applicable
A/D	Analogue to Digital converter
AAD	Attitude Anomaly Detector
ABCL	As Built Configuration List
AC	Alternating Current
ACC	Attitude Control Computer
ACC	ACMS Control Computer
ACK	Acknowledgment
ACM	Attitude Control and Measurement
ACMS	Attitude Control and Measurement Subsystem
Acronym	Description
ACS	Auto-Correlation Spectrometer
AD	Applicable Document
ADC	Analog to Digital Converter
ADD	Architectural Design Document
ADP	Acceptance Data Package
ADR	Architectural Design Review
ADV	Adverse
AFO	Automatic Fail autonomous
AFS	Automatic Fail Safe
AFT	Abbreviated Functional Test
AGN	Active Galactic Nuclei
AIR	ACMS In Reconfiguration
AIT	Assembly, Integration and Test
AIU	ACMS Interface Units
AIV	Assembly, Integration and Verification
AM	Alignement Model
AMA	Absolute Measurement Accuracy
AME	Attitude Measurement Error
AN	ANalog acquisition interface
AND	Alphanumerical Display
AO	Annuncement of Opportunity
AOCMS	Attitude & Orbit Control and Measurement Subsystem
AOCS	Attitude & Orbit Control Subsystem
AOS	Acousto-Optical Spectrometer
AP	Application Process and Alphanumerical Display
APD	Absolute Pointing Drift
APE	Absolute Pointing Error
APID	Application Process Identifier
APID	Application ID
AR	Acceptance Review
AR5	Ariane 5
ARE	Absolute Rate Error
AS	Auxiliary Supply
as	Central Data Management Unit
ASF	Additional Safety Factor
ASIC	Application Specific Integrated Circuit
ASW	Address and Synchronisation Word
ASW	Application Software

ATC	Active Thermal Control
AU	Astronomical Unit
AUHK	Authentication Unit House Keeping
AUT	Autonomy
AVM	Avionics Verification Model, Avionics model
BAF	Batiment d'Assemlage Final (AR5) Final Assem. Bui
BAU	Buffer Amplifier Unit
BB	Bread-board
BB	Broadband
BCR	Battery Charge Regulator
BD	(short name) for Expedited Service
BDR	Battery Discharge Regulator
BE	Back End
BEM	Back End Module (LFI)
BER	Bit Error Rate
BEU	Back End Unit (LFI)
BIB	Blocked Impurity Band
BIT	Built in Test
BMOS	Buckling Margin of Safety
BOC	Battery Over-Charge
BOL	Begin of Life
BOLA	BOLometer Amplifier (PACS)
BOLC	Bolometer/cooler Control (PACS)
bps	bits per second
BRDF	Bidirectional Reflectance Distribution Function
BRU	Battery Regulator Unit
BSF	Best Fit Surface
BSF	Basic Safety Factor
BSM	Beam Steering Mechanism
BSW	Basic SoftWare
BTb	Bandwidth Time bit (duration)
BUV	Bus Under-Voltage
BW	Bandwidth
BWO	Backward-Wave Oscillators
C/N	Carrier-to-Noise ratio
CaC	Cost at Completion
CASW	Common Application Software
CATR	Compact Antenna Test Range
CC	Configuration Control
CCB	Configuration Control Board
CCBS	Current Contract Baseline Schedule
CCC	Cryostat Cover and Cavity
CCD	Charged Coupled Device
CCE	Central Check-out Equipment
CCH	Cryostat Control Harness
CCI	Cryostat Control Instrumentation
CCN	Contractual Change Notice
CCS	Control Check-out System
CCSDS	Consultative Committee for Space Data Systems
CCU	Cryostat Control Unit
CCW	Counter Clock Wise
CDD	Configuration Data Document

CDMS	Command and Data Management Subsystem
CDMU	Central Data Management Unit
CDR	Critical Design Review
CDS2A	CCSDS Day Segmented A
CE	Conducted Emission
CEL	Critical Event Log
CEU	Cryo Electronics Unit
CFC	Carbon Fibre Compound
CFRP	Carbon Fibre Reinforced Plastic
CIDL	Configuration Item Data List
CIL	Critical Items List
CIR	CDMS In Reconfiguration
CL	Current Limiter
CLA	Coupled Launch Analysis
CLCW	Command Link Control Word
CLCW	Command Link Control Word
CLTU	Command Link Transfer Unit
CM	Common Mode
CMB	Cosmic Microwave Background
CMD	Command
CMOS	Complementary Metal Oxide Semiconductor
CMRR	Common Mode Rejection Ratio
CNRS	Centre National de la Recherche Scientifique
COBE	Cosmic Background Explorer
CoC	Certificate of Conformance/Compliance
CoG	Centre of Gravity
Co-I	Co-Investigator
CoM	Centre of Mass
COP-1	Command operation Procedure number 1
COTS	Commercial Off The Shelf
CPDU	Command Pulse Distribution Unit
CPDU	Central Processing Data Unit
CPI	Clocks Per Instruction
CQM	Cryogenic Qualification Model
CRC	Cyclic Redundancy Code
CRE	Cryogenic Read-out Electronics
CREMA	Consolidated Report on Mission Analysis
CRP	Contingency Recovery Procedure
CRTBT	Centre de Recherche sur les Tres Basses Temper.
CS	Conducted Susceptibility
CSG	Centre Spatial Guyanais
CSL	Centre Spatial de Lieges
CSL	Configuration Status List
CSSW	Common Service software
CSSW	Common SoftWare
CTE	Coefficient of Thermal Expansion
CTR	Control
CTS	Chirp-Transform Spectrometer
CTU	CTU Central Terminal Unit
CVCM	Collected Volatile Condensable Material
CVSE	Cryo Vacuum Service Equipment
CVV	Cryostat Vacuum Vessel

CW	Clock Wise
DACS	Digital Auto-Correlator Spectrometer
DAE	Data Acquisition Electronics (LFI)
DAIS	Digital Avionics Instruction Set
DBMS	Data Base Management System
DBU	Data Bus Unit
DC	Direct Current
DC/DC	Direct Current voltage converter
DCCU	Dilution Cooler Control Unit
DCL	Declared Components List
DCN	Document Change Notice
DDR	Detail Design Review
DDVP	Design, Development and Verification Plan
DEC	Decimal
DFT	Document Family Tree
DH	Data Handling
DK	Denmark
DLCM	Direct Liquid Content Measurement
DM	Dynamic Model
DM	Differential Mode
DMA	Direct Memory Access
DMA	Dynamic Memory Access
DMC	Detector/Mechanism Control (PACS)
DML	Declared Materials List
DMPL	Declared Mechanical Part List
DMS	Data Management System
DNEL	Disconnect Non Essential Loads
DoD	Depth of Discharge
DoF	Degree of Freedom
DPA	Destructive Physical Analysis
DPC	Data Processing Centre
DPL	Declared Process List
DPOP	Daily Prime Operational Phase (Observation Phase)
DPU	Digital Processing Unit
DR	Digital Relay
DR	Development Review
DRB	Delivery Review Board
DRC	Detector Readout and Control Unit
DS	Digital Serial acquisition
DS	Digital Serial
DSN	Deep Space Network
DSRI	Danish Space Research Institute
DTC	Direct TeleCommand
DTCP	Daily Telecommunications Phase
DTMM	Detailed Thermal Mathematical Model
DVC	Device Commanding
DVM	Design Verification Matrix
Eb/NO	Energy per bit / Noise power density
EBB	Elegant Bread Board
ECP	Engineering Change Proposal
ECR	Engineering Change Notice
ECSS	European Cooperation for Space Standardisation

EDAC	Error Detection And Correction
EDS	Electrostatic Discharge
EED	Electro-Explosive Device
EEE	Electrical, Electronic, Electro-mechanical
EEPROM	Electrically Erasable Programmable Read Only Mem.
EFE	ESA Furnished Equipment
EGSE	Electrical Ground Support Equipment
EIDP	End-Item Data Package
EIRP	Equivalent Isotropic Radiated Power
EM	Engineering Model
EM	Engineering Model
EMC	Electro Magnetic Compliance
EMC	Electromagnetic Compatibility
EMF	Electro-Motive Force
EMI	Electro-Magnetic Interference
EOL	End of Life
EoL	End of Life
EoM	End of Mission
EOP	Early Orbit Phase
EP	Entrance Pupil
EPC	Electric Power Conditioner
EPLM	Extended Payload Module
EPS	Etage a Propulsion Solide (ARIANE 5)
EQM	Engineering Qualification Model
ESA	European Space Agency
ESD	Electro Static Discharge
ESOC	European Space Operation Centre
ESTEC	European Space Research and Technology Centre
ESV	An ARIANE 5 launcher version
EVRP	Event Reporting
F/P	FIRST/Planck
FAR	Frame Analysis Report
FAR	Fligh Acceptance Review
FAV	Favourable
FCL	Fold back Command Limiter
FCP	Flight Control Procedure
FCS	Flight Control System
FD	Flight Dynamics
FDDB	Flight Dybamics Data Base
FDIR	Failure Detection Isolation and Recovery
FDR	Final Design Review
FEC	Front End Controller
FEC	Front Error Correction
FEE	Front End Electronic
FEM	Finite Element Model
FEM	Front End Module (LFI)
FEPLM	FIRST Extended Payload Module
FET	Field Effect Transistor
FEU	Front End Unit (LFI)
FH	Feed Horn (LFI)
FHFCU	FIRST HIFI Focal plane Control Unit
FHFPU	FIRST HIFI Focal Plane Unit

FHHRH	FIRST HIFI High Resolution spectrometer Oriz Pol.
FHHRI	FIRST HIFI High Resolution IF-processor.
FHHRV	FIRST HIFI High Resolution spectrometer Vert. Pol.
FHICU	FIRST HIFI Instrument Control Unit
FHLCU	FIRST HIFI Local oscillator Control Unit
FHLOU	FIRST HIFI Local Oscillator Unit
FHLSU	FIRST HIFI Local oscillator Source Unit
FHLWU	FIRST HIFI Local oscillator Wave Guide Unit
FHWBE	FIRST HIFI Wide Band spectrometer Electronics
FHWBI	FIRST HIFI Wide Band spectrometer IF-Processor
FHWBO	FIRST HIFI Wide Band spectrometer Optics
FHWIH	FIRST HIFI Warm Interconnect Harness
FID	FIRST HIFI Warm Interconnect Harness
FINDAS	FIRST Integrated Network and Data Archive System
FIR	Far Infrared
FIRST	Far Infra-Red and Sub-millimetre Telescope
FM	Flight Model
FM	Flight Model
FMD	Force Measurement Device
FMECA	Failure-Modes, Effects and Criticality Analysis
FMS	Failure Management System
FMT	Function Management Table
FOB	FIRST Optical Bench
FOP	Flight Operations Plan
FOR	Field of Regard
FOS	Factor of Safety
FOS	Factor of Safety
FOV	Field Of View
FP	Fabry-Perot
FPA	Focal Plane Assembly
FPBOLA	FIRST PACS BOLometer Amplifier
FPBOLC	FIRST PACS Bolometer/cooler Control
FPDMC1	FIRST PACS Detector/Mechanism Control 1
FPDMC2	FIRST PACS Detector/Mechanism Control 2
FPDPU	FIRST PACS Digital Processing Unit
FPFPU	FIRST PACS Cold Focal Plane Unit
FPGA	Field Programmable Gate Array
FPGA	Field Programmable Gate Array
FPLM	FIRST Payload Module
FPM	Fine Pointing Mode
FPSPU1	FIRST PACS Signal Processing Unit 2 (SPU Nominal)
FPSPU2	FIRST PACS Signal Processing Unit 2 (SPU Redundant
FPU	Focal Plane Unit
FPWIH	FIRST PACS “Warm” Interconnect Harness
FRR	Flight Readiness Review
FS	Flight Spare
FSC	FIRST Science Centre
FSDPU	FIRST SPIRE Digital Processing Unit
FSDRC	FIRST SPIRE Detector Read-out and Control Unit
FSEC	FIRST Science Evaluation Committee
FSFPU	FIRST SPIRE Cold Focal Plane Unit
FSFTB	FIRST SPIRE Focal plane JFET RF Filter Box

FSS	Fine Sun Sensor
FSVM	FIRST Service Module
FSWIH	FIRST SPIRE Warm interconnect harness
FTA	Fault Tree Analysis
FTP	File Transfer Protocol
FTS	In-flight Testing
FTS	Fourier Transform Spectrometer
G/S	Ground Station
G/T	Gain to Temperature Ratio
GFC	Glass Fibre Compound
GFRP	Glass Fibre Reinforced Plastics
Ghe	Gaseous Helium
GM	Ground Managed
GMM	Geometrical Mathematical Model
GMSK	Gaussian Minimum Shift Keying
GN2	Gaseous Nitrogen
GND	Ground
GPS	Global Positioning System
GRD	Graphical Display
GSE	Ground Support Equipment
GTD	Geometrical Theory of Diffraction
GTO	Geo-stationary Transfer Orbit
GYR	GYRo Blocks
H/W	Hradware
HC	High Speed CMOS
HCM	Angular Momentum Control Mode
He I	Normal Fluid Helium
He II	Helium II (Superfluid Helium)
He3	Helium 3 (Isotrope used in HFI dilution cooler)
He4	Helium 4 (natural isotope of Helium)
HEB	Hot-Electron Bolometer
HEMT	High-Electron Mobility Transistor
HEO	Highly Eccentric Orbit
HEX	Hexadecimal
HFI	High Frequency Instrument (Planck)
HGA	High Gain Antenna
HIFI	Heterodyne Instrument for FIRST
HK	House Keeping
HLC	High Level Command
HOOD	Hierarchical Object Oriented Design
HOT	Helium I Tank
HPA	High Power Amplifier
HPSDB	Herschel Planck System Database
HRS	High Resolution Spectrometer
HSC	Helium System Components
HSIA	Hardware/Software Interaction Analysis
HSK	House Keeping
HST	Helium System Tubing
HTT	Helium II Tank
HW	Hardware
IA	Interactive Analysis (software)
IABG	Industrie Anlagen Betriebsgesellschaft

IAR	Instrument Acceptance Review
IAS	Institut d'Astrophysique Spatiale
IBDR	Instrument Baseline Design Review
ICC	Instrument Control Centre
ICD	Interface Control Document
ICDR	Instrument Critical Design Review
ID	Interface Document
ID	Identifier
IDL	Interactive Data Language
IF	Interface
IF	Intermediate Frequency
IFAR	Instrument Flight Acceptance Review
IFEM	Interface Finite Element Model
IFEM	Instrument Finite Element Model
IFMS	Intermediate Frequency Mass System
IGES	Initial Graphic Exchange Specification
IHDR	Instrument Hardware Design Review
IID	Instrument Interface Document
IIDB	Instrument Interface Document Part B
IIDR	Instrument Intermediate Design Review
ILT	Instrument Level Test
INFT	In-flight Testing
IO	Input/Output
IOB	Instruments Optical Bench
IOCR	In-Orbit Commissioning Review
IOP	Initial Orbit Phase
IPT	Instrument Polling Table
IR	Infrared
IRU	Inertial Reference Unit
ISO	International Standards Organisation
ISO	Infrared Space Observatory
ISS	Integrated Switching System
IST	Integrated Satellite Test
ISV	Independent Software Validation
ISVR	Instrument Science Verification Review
ITT	Invitation To Tender
IVG	Inverted Voltage Gradients
JFET	Junction Field Effect Transistors
JPL	Jet Propulsion Laboratory
JT,J-T	Joule-Thomson
KAL	Keep Alive Line
KIP	Key Inspection Point
L2	Second Lagrangian Point
LAT	Lot Acceptance Test
LCDA	Launcher Coupled Dynamic Analysis
LCL	Latching Current Limiters
LCU	Local Oscillator Control Unit (HIFI)
LEOP	Launch and Early Orbit Phase
LET	Linear Energy Transfer
LFI	Low Frequency Instrument
LGA	Low Gain Antenna
LHC	Left Hand Circular

Lhe	Liquid Helium
LHV	Liquid Helium Valves
LISN	Line Impedance Stabilisation Network
LLI	Long Lead Items
LNA	Low Noise Amplifier
LO	Local Oscillator (HIFI)
LOBT	Local On-Board Time
LoS	Line of Sight
LOU	Local Oscillator Unit (HIFI)
LSB	Least Significant Bit
LSM	Line Scanning Mode
LSU	Local Oscillator Source Unit (HIFI)
LUM	LaUnch Mode
LV	Launch vehicle
LVDE	Low Vibration Drive Electronics (HFI 4K Cooler)
LW	Launch Window
M3	(ESA) Medium Size Mission
MAC	Modal Assurance Criterion
MAIT	Manufacture, Assembly, Integration and Test
MAP	Multiplexed Access Point
MCC	Mission Control Centre
MCM	Monitor and Control Module
MDD	Mimic Display Diagrams
MEA	Main Error Amplifier
MEOP	Maximum Expected Operating Pressure
MGA	Medium Gain Antenna
MGSE	Mechanical Ground Support Equipment
MIP	Mandatory Inspection Point
ML	Memory Load Command (=CS)
MLI	Multi-layer Insulation
MM	Mass Memory
MM	Memory Management
MNEM	Mnemonic
MOC	Mission Operations Centre
Mol	Moment of Inertia
Mol	Moments of Inertia
MoS	Margin of Safety
MPE	Max-Planck Institut für Extraterrestrische Physik
MPPT	Maximum Power Point Tracking
MPS	Mission Planning Subsystem
MPTS	Multi-Purpose Tracking System
MRB	Material Review Board (Previous name of NRB)
MS	Microsoft
MSB	Most Significant Bit
MSE	Mechanical Surface shape Error
MSI	Medium Scale Integrated Circuit
MSSW	Mission Specific SW
MTL	Mission Timeline
N/A	Not Applicable
NA	Not Applicable
NAM	Nutation Avoidance Manœuvres
NASA	National Aeronautic and Space Administration

NASTRAN	NASA Structural Analysis Tool
NB	Narrow-band
NC	Not Connected
NCA	Non explosive Command Actuator
NCR	Non Conformance Report
NEP	Noise Equivalent Power
NIDA	Honeycomb (french acronym Nid D'Abeille)
NOM	Nominal
NOM	Nominal Mode
NRB	Non-conformance Review Board
NRT	Near Real Time
NRZ	Non Return to Zero
NRZ-L	Non-Return to Zero-Level
NYA	Not Yet Available
OB	Optical Bench
OBC	On-board clock
OBCP	On-Board Control Procedure
OBDH	On Board Data Handling
OBH	Optical Bench Harness
OBMF	On-Board Monitoring Function
OBS	On Board Software
OBSM	On-Board Software Management
OBT	On Board Time
OBTM	On-Board Time Management
OCF	Operational Control Field
ODS	Orbital Disconnect Support
OFD	Operations Facilities Document
OFD	Operations Facility Document
OGSE	Optical Ground Support Equipment
OIRD	Operations Interface Requirements Document
OMT	Ortho Module Transducer (LFI)
OP	Observation Period or Observation Phase
OQPSK	Orthogonal Quadrative Phase-Shift Keying
OS	Operating System
OSR	Optical Solar Reflector
OTF	On Target Flag
P/A	Partially applicable
P/L	Payload
P/ST	Primary Structures
PA	Product Assurance
PACK	Packet (Telecommand or Telemetry)
PACS	Photo-conductor Array Camera Spectrometer (FIRST)
PAD	Parts Approval Document
PAU	Power Amplifier Unit
PCDU	Power Conditioning and Distribution Unit
PCH	PLM Cryostat Harness
PCM	Pulse Code Modulation
PCS	Power Control Subsystem
PCU	Power Control Unit
PDD	Payload Definition Document
PDE	Pointing Drift Error
PDF	(Adobe) Portable Document Format

PDR	Preliminary Design Review
PDU	Power Distribution Unit
PERP	Periodic Reporting
PF	Platform
PFC	Parameter Format Code
PFM	Proto Flight Model
PGSE	Pneumatic Ground Support Equipment (HFI dilution)
PH3HE	Planck HFI 0.1K Dilution Cooler 3He Tank (1)
PH4HE	Planck HFI 0.1K Dilution Cooler 4He Tanks (3)
PHCDU	Planck HFI 0.1K Dilution Cooler Control Unit
PHDPU	Planck HFI Data Processing Unit (DPU)
PHFET	Planck HFI J-FET Box
PHFPU	Planck HFI Instrument Focal Plane Units
PHJCE	Planck HFI 4K Cooler Cold Unit
PHJTA	Planck HFI 4K Cooler Ancillary Unit
PHJTC	Planck HFI 4K Cooler Compressor Unit
PHJTE	Planck HFI 4K Cooler Electronics Unit (4KCDE)
PHPAU	Planck HFI Pre-Amplifier unit (PAU)
PHREU	Planck HFI Readout Electronics Unit (REU)
PI	Principal Investigator
PID	Parameter Identification Number
PID	Proportional, Integral, Derivative (controller)
PLL	Phase Lock Loop
PLM	Payload Module
PM	Processor Module
PM	Project Manager
PM	Phase Modulation
PMD	Propellant Management Device
PND	Passive Nutation Damper
PO	Physical Optic
PPL	Parts and Processes List
PPLM	Planck PayLoad Module
PPS	Pulse Per Second
PPS	Passive Pahse Separator
PR	Primary Reflector
PRE	Pointing Reproducibility Error
PREF	Parameter Reference Number
PROM	Programmable Read Only Memory
PRT	Packet Routing Table
PSEC	Plank Science Evaluation Committee
PSF	Point Spread Function
PSK	Phase Shift Keying
PSS	Procedures, Specifications and Standards
PSVM	Planck Service Module
PT	Product Tree
PTC	Parameter Type Code
PTR	Post Test Review
PtV	Peak to Valley
PTXC	Packet Transmission Control
PUS	Packet Utilisation Standard
PVC	Polyvinyl Chloride
PWM	Pulse Width Modulation

QA	Quality Assurance
QFP	Quad Flat Pack
QLA	Quick Look Analysis (software)
QM	Qualification Model
QMWC	Queen Mary and Westfield College
QR	Qualification Review
QRS	Quartz Rate Sensor
QSL	Quasi-Static Loads
QSO	Quasi Stellar Object
R	Redundant Item
r.m.s.	Root Mean Square
RAA	Radiometer Array Assembly (LFI)
RAM	Random Access Memory
RCA	Radiometer Chain Assembly (LFI)
RCS	Reaction Control Subsystem
RCS	Reaction Control System
RCT	Reaction Control Thrusters
RD	Reference Document
RE	Radiated Emission
REBA	Radiometer Electronics Box Assembly (LFI)
RE-E	Radiated Emission E-field
RE-H	Radiated Emission H-field
REU	Readout Electronics Unit
RF	Radio Frequency
RFA	Request for Approval
RFDM	Radio Frequency Development Model
RFDN	Radio Frequency Distribution Network
RFDU	Radio Frequency Distribution Unit
RFI	Radio Frequency Interference
RFQ	Request For Quotation
RFQM	Radio Frequency Qualification Model
RFW	Request for Waiver
RH	Reference Hole
RH	Relative Humidity
RHC	Right Hand Circular
RHCP	Right Hand Circular Polarisation
RID	Review Item Discrepancy
RM	Reconfiguration Module
RML	Recoverable Mass Loss
RMS	Root Mean Square
ROM	Rough Order of Magnitude
ROM	Read Only Memory
RPE	Relative Pointing Error
RS	Radiated Susceptibility
RS-E	Radiated Susceptibility E-field
RS-H	Radiated Susceptibility H-field
RSP	Reference Star Pulse
RSS	Root Square Sum
RSS	Root Sum Square
RT	Real Time
RTA	Real Time Assessment (software)
RTMM	Reduced Thermal Mathematical Model

RTU	Remote Terminal Unit
RW	Reaction Wheel
RWA	Reaction Wheels Assembly
RWS	Reaction Wheels System
Rx	Receiver
S/C	Spacecraft
S/N	Signal to Noise Ratio
S/S	Subsystem
S/W	Software
S3R	Sequential Switching Shunt Regulator
SA	Solar Array
SAA	Solar Aspect Angle
SADM	Solar Array Drive Motor
SAM	Sun Acquisition Mode
SAS	Sun Acquisition Sensor
SBDL	Standard Balanced Digital Link
SCC	Sorption Cooler Compressor assembly (LFI)
SCC	Stress Corrosion Cracking
SCC	Space Components Co-ordination
SCCE	Sorption Cooler Cold End (LFI)
SCE	Sorption Cooler Electronics (LFI)
SCET	Spacecraft Elapsed Time
SCI	SCIence Mode
SCL	Spacecraft Control Language
SCOE	Special Check Out Equipment
SCOS	Spacecraft Control and Operations System
SCOS	Space Control and Operations Centre
SCOTE	Satellite and Check-Out Terminal Equipment
SCP	Sorption Cooler Piping (LFI)
SCS	Sorption Cooler Subsystem (LFI)
SDASW	Satellite Dependent Application Software
SDBP	Satellite Data Bus Protocol
SDE	Software Development Environment
SDS	System Definition Study
SE	Saab Ericsson Space AB
SECDED	Single Error Correction and Double Error Detection
SEL	Spacecraft Event Log
SEU	Single Event Upset
SF	Safety Factor
SFCG	Space Frequency Co-ordination Group
SFPT	System Requirement Review
SFT	Short Functional Test
SFW	Spatial Framework
SGICD	Space/Ground Interface Requirement Document
SGM	Safe-Guard Memory
SH	Safety Hazard
SHM	Safe and Hold Mode
SID	Structure ID
SIH	Scientific Instrument Harness
SIN	Straylight Induced Noise
SIRD	Science Implementation Requirements Document
SIS	Spacecraft Interface Simulator

SIS	Superconductor-Insulator-Superconductor
SIST	Short Integrated Satellite Test
SIT	System Integration Test
SIUB	Serial Internal User Bus
SIV	Software Independent Validation
SLD	Scrolling Log Display
SLE	Standard Laboratory Equipment
SLT	Static Load Test
SM	Star Mapper
SM	Structural Model
SM	Survival Mode
SOC	Science Operations Centre
SoW	Statement of Work
SP	Sun Pointing
SPC	Science Programme Committee
SPF	Single Point Failure
SPIRE	Spectral Photometer Imaging Receiver (FIRST)
SPL	Split Phase Level
SPT	Specific Performance Test
SPU	Signal Processing Unit
SR	Secondary Reflector
SRD	Software Requirements Document
SREM	Standard Radiation Environment Monitor
SRON	Space Research Organisation Netherlands
SRPE	Spatial Relative Pointing Error
SRR	Software Requirements Review
SRR	System Requirements Review
SRRC	Spare-Root Raised Cosine
SRS	Shock Response Spectrum
SRS	System Requirements Specification
SSAC	Space Science Advisory Committee
SSCE	Sun/SpaceCraft/Earth (Angle)
SSCM	Sun/SpaceCraft/Moon(Angle)
SSM	Second Surface Mirror
SSMM	Solid State Mass Memory
SSR	Solid State Recorder
SST	Stainless Steel
ST	Star Tracker
STC	Station Computer
STD	Standard
STM	STar Mapper
STM	Structural/Thermal Model
STMM	Simplified Thermal Mathematical Model
STR	Star-Tracker
STRP	Statistic Reporting
SUM	Satellite Users Manual
SVC	Service Call
SVF	Software Validation Facility
SVM	Service Module
SVT	System Validation Test
SW	Software
T°	Temperature

TA	Telescope Assembly
TAI	Temps Atomique International
TASW	Test Application Software
TB	Test Bed
TB	Thermal Balance
TBC	To Be Confirmed
TBD	To Be Determined
TC	Telecommand
TC	Tele-Communication mode
TC	Telecommand
TCE	Tele Command Equipment
TCS	Thermal Control Subsystem
TCU	Thermal Control Unit
TCV	Telecommand Verification
TE	Test Equipment (LFI)
TESRE	Istituto di Tecnologie e Studio delle Radiazioni E
TF	Test Factor
TID	Total Integrated Scattering
TIM	Total Integrated Scattering
TIS	Total Integrated Scattering
TM	Telemetry
TM	Telemetry
TML	Total Mass Loss
TMM	Thermal Mathematical Model
TOP	Transfer Orbit Phase
TOT	Thruster On Time
TPN	Telemetry Packet Number
TPT	Tank Pressure Transducer
TRP	Technological Research Programme
TRR	Test Readiness Review
TSF	Tank Support and Spatial Framework
TSMM	Transport Stimuli and Monitoring Unit
TT&C	Telemetry Tracking and Command
TT&C	Telemetry, Tracking and Command
TV	Thermal Vacuum
TWTA	Travelling Wave Tube Amplifier
Tx	Transmitter
UART	Universal Asynchronous Receiver Transmitter
UF	Ultimate Factor of Safety
UFT	Upper and Lower Thermal Shields
ULS	Upper and Lower Thermal Shields
UMOS	Ultimate Margin of Safety
URD	User Requirement Document
URR	User Requirements Review
USF	Ultimate Safety Factor
UTC	Unit Under Test
UUT	Unit Under Test
UV	Ultraviolet
VC	Visual Monitoring System
VCA	Virtual Channel Assembler
VCM	Virtual Channel Multiplexer
VEB	Visual Monitoring System

VHDL	Very High Speed Integrated Circuit Hw Descr Lang
VMC	Visual Monitoring System
VPP	Verification Programme Plan
VSWR	Voltage Standing Wave Ratio
WBS	Work Breakdown Structure
WBS	Wide Band Spectrometer
WC	Worst Case
WCA	Worst Case Analysis
WD	Watch Dog
WFE	Wave Front Error
WG	Wave-guide (LFI)
WP	Work Package
WPD	Work Package Description
WU	Warm Unit
XMM	X-ray Multi Mirror
XPND	Transponder
YF	Yield Factor of Sa
YMOS	Yield Margin of Safety

1.4 DOCUMENTS

1.4.1 Applicable Documents

The following documents, in their latest issue, form part of this Design Report and are referred in the text as AD(xx) in accordance with the alphabetic list below.

AD-01	SCI-PT-IIDA-04624	Instrument Interface Document, part A
AD-02	SCI-PT-IIDB/SPIRE-02124 HP-ASPI-MN-1238 HP-ASPI-LT-1380	Instrument Interface Document, part B: Bolometer Instrument
AD-03	SCI-PT-IIDB/HIFI-02125 HP-ASPI-LT-1380 HP-ASPI-MN-1367	Instrument Interface Document, part B: Heterodyne Instrument
AD-04	SCI-PT-IIDB/PACS-02126 HP-ASPI-LT-1380 HP-ASPI-MN-1369	Instrument Interface Document, part B: Photoconductor Instrument
AD-05	SCI-PT-IIDB/HFI-04141 HP-ASPI-LT-1380	Instrument Interface Document, Part B (IID-B): HighFrequency Instrument
AD-06	SCI-PT-IIDB/LFI-04142 HP-ASPI-LT-1380	Instrument Interface Document, Part B (IID-B): LowFrequency Instrument
AD-07	SCI-PT-ICD-07418	Herschel/Planck Space to Ground Interface Document
AD-08	SCI-PT-RS-07360	Herschel/Planck Operations Interface Requirement Document
AD-09	SCI-PT-ICD-07527	Herschel/Planck Packet Structure ICD
AD-10	SCI-PT-RS-04683	Herschel/Planck Product Assurance and Safety Requirements
AD-11	FP-MA-RP-0010	Herschel–Planck Consolidated Report on Mission Analysis (CREMA)
AD-12	H-P-1-ASPI-SP-0027	General Design and Interface Requirements (GDIR)
AD-13	H-P-1-ASPI-SP-0030	Environment and Tests Requirement
AD-14	H-P-1-ASPI-SP-0037	EMC Specification
AD-15	H-P-1-ASPI-SP-0035	Cleanliness Requirements Specification
AD-16	PL-AS-SP-011, Ed 1, Rev 1,7/7/2000	General requirements for the delivered structural mathematical models
AD-17	TBD	Requirements for the delivery of thermal mathematical models
AD-18	TBD	Requirements for the delivery of thermoelastic mathematical models
AD-19	ESA PSS-01-604, Jan 1988	Generic Specification for Silicon Solar Cells
AD-20	SPA/TS-0006	Generic Specification for Ga/As cells
AD-21	ESA PSS-04-105, Issue 1,December 1989	Radio Frequency and Modulation Standard
AD-22	ESA PSS-04-104, Vol. 1, Issue 2, March 1991	Ranging Standard ESA
AD-23	ESA PSS-04-103, Issue 1, September 1989	Telemetry Channel Coding Standard ESA
AD-24	ESA PSS-04-106, Issue 1, January 1988	Packet Telemetry Standard
AD-25	ESA PSS-04-107, Issue 2, 1991	Packet Telecommand Standard
AD-26	ESA PSS-02-10, Nov 1992	ESA Power Subsystem Standard Specification
AD-27	ECSS-E-30-00 Part 2-3	Space Mechanisms Standard Requirements Specification
AD-28	ECSS-E-40, Issue B	ESA Software Engineering Standards

AD-29	ECSS-Q-80	Software Product Assurance
AD-30	CCSDS 301.0-B-2 issue 2	Time Coded format
AD-31	Issue 3/Rev 0, March 2000	ARIANE 5 Users's Manual
AD-32	Not used	Not Used
AD-33	H-P-1-ASPI-0018, issue 1	Product Assurance Requirements for Subcontractors
AD-34	ECSS-E-30-01A	Fracture Control Requirements Specification
AD-35	CSG-RS-22A-CN, Vol 1 & 2	CSG Safety Regulations
AD-36	H-P-1-ASPI-SP-0046	Software Requirements Specification
AD-37	H-P-1-ASPI-SP-0044	Mechanical Ground Support Equipment Specification
AD-38	H-P-1-ASPI-PL-0009	Herschel-Planck Design and Development Plan
AD-39	SG-0-01, Issue 3	Ariane Specification
AD-40	H-P-1-ASPI-SP-0045	Electrical Ground Support Equipment Specification
AD-41	H-P-1-ASPI-PL-0038	EMC/ESD Control Plan
AD-42	H-P-RP-AI-0003 Issue 03	SVM Configuration Requirement
AD-43	H-P-4-ASPI-SP-0019	Service Module Requirements Specification
AD-44	H-P-1-ASPI-SP-0017	Radiation Requirements Specification
AD-45	ESA PSS-04-151	ESA Telecommand Decoder Specification
AD-46	H-P-1-ASPI-SP-0082	System Database Specification
AD-47	H-P-4-ASPI-IS-0042, is 3.0	SVM Interface Specification
AD-48	Not Used	Not Used
AD-49	SG-PR-AI-026Issue 1	Guidelines to Mathematical Model Preparation Description & Quality Assessment
AD-50	H-P-1-ASPI-SP-0014Issue 1	Herschel/Planck Mathematical Model Specification
AD-51	Not Used	Not Used

1.4.2 Reference Documents

The following documents, in the exact issue shown, have been used as complementary information of this Design Report in order to better understand the technical objective of the HERSCHEL/PLANCK SVM project. In the text they are referred as RD (xx) in accordance with the alphabetic list below.

RD-01	SCI-PT-RS-05991	Herschel/Planck System Requirement Specification
RD-02		ESA Pointing Error Handbook
RD-03	ECSS-E-70/41	Packet Utilisation Standard
RD-04	CCSDS 101.0-B-4	CCSDS Telemetry Channel Coding
RD-05	CCSDS 102.0-B-3	Packet Telemetry CCSDS blue book
RD-06	CCSDS 121.0.B.1	Lossless Compression
RD-07	ESA PSS-01-301	Derating Requirements
RD-08	ESA PSS-01-609	Radiation Design Handbook
RD-09	ESA TTC-B-01	ESA Spacecraft Data Handling Interface Standard
RD-10	Mil-Std-1553 notice 2	1553 Bus Standard
RD-11	H-P-RP-AI-0001 Issue 02	SVM Budget Report
RD-12	H-P-PL-AI-0009	SVM Software Design and Development Plan
RD-13	H-P-AI-SP-0006 Issue 2	ACC and CDMU Basic Software Requirements
RD-14	H-P-AI-SP-0031 Issue 1	CDMU Application Software Requirements Baseline
RD-15	P-HPL-NOT-00010-SE	ASW-BSW Software Interface Control Document
RD-16	H-P-IC-AI-0004	SVM SW Interface Control Document
RD-17	H-P-ASPI-MN-872	Data Handling Working Group Meeting #10
RD-18	H-P-ASPI-MN-345	Packet Structure ICD Discussion
RD-19	P-HPL-PRD-0001-SE	ACC and CDMU (incl. BSW) Technical Description
RD-20	H-P-MI-AI-0061	CDMU-ACC Progress meeting
RD-21	Not Used	Not Used
RD-22	SCI-PT/12759	Reference Mission Scenario
RD-23	H-P-1-ASPI-ID-0015	SDE definition
RD-24	SCI-PT-TN-11777	Autonomy – OBCP Concepts and Requirements
RD-25	H-P-SP-AI-0031	System Operation & FDIR Requirements
RD-26	H-P-SP-AI-0001is 3.	SVM Structure Specification
RD-27	H-P-SP-AI-0033, is 01	SVM Mecahnical Environment and Test Specification
RD-28	H-P-TN-AI-0019	SVM Acceleration Limit Load Factors
RD-29	H-P-TN-AI-0023, is. 1	H & P SVM Normal Mode and Sine response Analyses
RD-30	H-P-TN-AI-0028, is. 01,	Herschel Planck Vibro-acoustic Environment and Test Levels Definition
RD-31	H-P-TN-AI-0029, is. 01	Herschel Planck Shock Environment and Test Levels Definition
RD-32	H-P-PL-AI-0005, is 2	Fracture Control Plan
RD-33	H-P-4-CASA-RP-0013 Issue 2	SVM Structure Design Report
RD-34	H-P-4-CASA-RP-0012 Issue 2	Performance Analyses Report
RD-35	H-P-4-CASA-RP-0008 Issue 1	Herschel FEM Description
RD-36	H-P-4-CASA-RP-0030 Issue 1	Planck FEM Description
RD-37	H-P-4-CASA-NT-0029 Issue 2	Material and Standard Allowable
RD-38	H-P-4-CASA-RP-0007Issue 1	Stability Analyses Report
RD-39	H-P-TN-AI-0030 Issue 1	STR positioning Trade off
RD-40	H-P-4-CASA-NT-0017 Issue 1	Joint Verification Assessment
RD-41	H-P-MI-AI-0092	Minute of PM8
RD-42	H-P-RP-AI-0023 Issue 1	SVM Mechanical Performance analyses Reports
RD-43	H-P-4-CASA-RP-0010 issue 02	mass budget report
RD-44	H-P-4-CASA-NT-0015 issue 01	Mass Saving Options Evaluation

RD-45	H-P-1-ASPI-SP-0209 Issue 2	System Operation & FDIR Requirements
RD-46	H-P-TN-AI-0020 Issue 1	Planck Heat-Pipes Network Definition and Interfaces
RD-47	AEO 0037-1 Vol II Part 1	X-Band Transponder Proposal
RD-48	H-P-1-ASPI-TN-0204	Instrument Data Rates Allocation
RD-49	H-P-4-DS-TN-011	ACMS Design Report
RD-50	H-P-4-DS-TN-009	ACMS Baseline
RD-51	H-P-ASPI-TN-0130	Data Rates & Downlink Rates
RD-52	H-P-MI-AI-0077	PCDU Clarification Closure MOM
RD-53	H-P-SP-AI-0002	RCS Requirements Specification
RD-54	H-P-SP-AI-0003	CDMU HW Requirements Specification
RD-55	H-P-SP-AI-0008	ACC HW Requirements Specification
RD-56	H-P-SP-AI-0011	ACMS Specification
RD-57	H-P-SP-AI-0012	X-X Band Transponder Specification
RD-58	H-P-SP-AI-0014	PCDU Requirements Specification
RD-59	H-P-SP-AI-0015	Planck Solar Array Specification
RD-60	H-P-SP-AI-0016	X Band TWTAS (TWTA+EPC) Specification
RD-61	H-P-SP-AI-0022	Battery Requirement Specification
RD-62	H-P-SP-AI-0023	RFDN Specification
RD-63	H-P-TN-AI-0011	TCS Design Description
RD-64	OFR02/006-2-1	PCDU Technical Description
RD-65	P-HPL-NOT-00021-SE	CDMU Technical Design Report
RD-66	P-HPL-NOT-00022-SE	ACC Technical Design Report
RD-67	H-P-TN-AI-0016	Power Budget and Key Distribution
RD-68	H-P-TN-AI-0018	SVM TM-TC Budget
RD-69	H-P-TN-AI-0022	CDMU-XPND Interfaces
RD-70	H-P-TN-AI-0032	Voltage Drop Analysis
RD-71	H-P-RP-AI-0025	SVM Harness Configuration and Design Description
RD-72	H-P-TN-AI-0005	SVM thermal Analysis report
RD-73	H-P-TN-AI-0004	Active Versus Passive Nutation Dumping Trade Off
RD-74	H-P-RP-AI-0002	Battery Cell capacity redundancy Trade Off
RD-75	H-P-RP-AI-0001	Turbo Codes Implementation Trade Off
RD-76	H-P-MA-AI-0031	Module/Subsystem/Unit User Manual
RD-77	H-P-IC-AI-0002	SVM Meccanical ICD
RD-78	H-P-ASPI-MN-452	Solar Array Work Group #1 Minutes of Meeting
RD-79	H-P-4-TE-DD-2010 Issue 1	CCS System Design Document SW
RD-80	H-P-4-TE-DD-2020 Issue 1	CCS System Design Document HW
RD-81	H-P-4-TE-TS-2030 Issue 1	CCS System Test Plan

2. KEY SVM REQUIREMENTS AND DESIGN DRIVERS

The overall HERSCHEL/PLANCK System is broken down into two main blocks, the Ground Segment and the Flight Segment. The latter comprises the HERSCHEL/PLANCK Spacecraft, and the HERSCHEL/PLANCK Payload. The Spacecraft must be conceived in a modular way. The SVM (hardware-wise common for both the spacecrafts) and the PLM are the two modules that constitute the Spacecraft and must be compliant with the System Requirement Document and Instruments resources allocation specified in the AD(1).
The Spacecraft design must be compatible with the today implementation as it is reflected in the relevant EID-Bs AD (2 to 6).
The SVM has been conceived to bee in line with the requirement of AD(43). In each subsystem chapter (chapters 7 and 9) discussion of applicable requirements is included leaving at System Level the harmonisation with the relevant PLM assessment
This chapter highlights the driving requirements for the Herschel/Planck SVM which are constraining the design in terms of functions to be performed, performance to be obtained, resources to be fulfilled, external interface (both launcher and Instruments) to be respected and overall configuration constraints to be considered.

Resources

The specified SVM **Dry mass** is 415 kg for Herschel and 485 Kg for Panck. It do not includes the AR5 2624 Separation System nor the **System Margin**. AGENCY (ESA) and PRIME (ASPI) are managing their respective margin to cover System/SVM Design changes. Further mass requirement is the **maximum amount of fuel** to be embarked. They are expressed in terms of maximum mass to be filled in Fuel tanks. **No Mass Margin is required at launch.** . The **Battery and Solar Array** sizing are driven by the allocated power for Payloads operations. Transfer and operational orbits are eclipse free but the battery is included in the design to cover power peak requirement and to supply power in case of emergency situation.

Lifetime

The **lifetime** requirement:

- For Herschel
  - ☐ 6 months transfer to L2 + 3 years nominal (5,5 years for degradable items)
- For Planck
  - ☐ 6 months transfer to L2 + 15 mounths nominal (2 years for degradable items)

drives the design through the provisions needed to meet the extended life
Important considerations include the **reliability** of specific equipment items as well as of the satellite as a whole and hence functional redundancy.

Pointing and Attitude

The pointing requirements are fundamental for being satisfied in order to meet the Mission scientific objectives.

For Herschel, very stringent pointing and slew performance requirements combined with the need to guarantee complete autonomy of scientific operations without ground contact impose serious constraints on the selection of ACMS units and their mounting structure. Mission autonomy requirements can only be satisfied using star trackers with autonomous attitude recognition capability which in general provide lower accuracy than non-autonomous units optimised for very precise measurements of a single star,. In particular, STR biases must be kept at levels achieved only by the best autonomous units on the market in order to satisfy the absolute measurement and pointing requirements. The mounting of the STR must guarantee low thermoelastic distortions and a dedicated trade-off has been performed to select the most suitable location and support structure. Requirements on short term pointing stability have led to the selection of a very high quality gyroscope used for short term propagation of attitude derived from STR data. Additionally, slew efficiency requirements imply the use of reaction wheels with high torque capacities and may lead to simultaneous use of all four reaction wheels in order to satisfy the goals.

Fpr Planck the pointing requirements constrain a wider range of system parameters. The passively stabilised spacecraft has no direct closed loop attitude control but nevertheless requires accurate sensors to satisfy stringent requirements on *post facto* attitude reconstruction. Although not originally foreseen, the capability of autonomous determination of inertial attitude had to be introduced in order to satisfy the pointing drift requirements with worst case solar disturbance torque. This capability is provided by autonomous star trackers similar to the units selected for Herschel but with modifications necessary to allow operation at very high star tracking rates (nearly 6°/s) imposed by the rotation of the spacecraft. The performance characteristics of the STR are driven mainly by the absolute measurement acccuracy required for the SVM; however, the requirements on the accuracy of spin axis repointing are also constraining the unit specification. Because of the relatively high accuracy of spin axis control that can be provided by the ACMS, its contribution to the absolute pointing error is small, and the achievement of the required accuracy will be determined mainly by the mass distribution of the spacecraft (deviation of the principal axis of inertia from the desired direction). The Planck SVM will be operated under very stable thermal conditions and the contribution of thermoelastic terms appers to be minor.

Commonality

The Herschel and Planck SVM design must be optimised in order to minimise the needs for changing the design of the SVM Subsystems and or units developed in the frame of the two projects. This implies some over design (expecially on box dimensions and relative mass). The verification on EM (AVM) is conceived to minimize the hardware needs.

Instruments Accommodation

The instruments accommodation and operations strongly influence the SVM Configuration and the thetrmal design. This because mostly of the Instruments units (Warm part of the Payload) are located on the Panels of the SVM and will constraint the CoG and the thetrmal design

PLM configuration and lay-out.

Stringent Thermal Stability requirement on mostly of the Warm Units imply the utilization of dedicated Thermal Control Law.

Autonomy

Herschel and Planck Satellites will oparate for most of their lifetime without ground support. The Satellite autonomy must be conceived to meet the requested 48 hours of autonomy (i.e. worst case when one daily ground contact is lost). Implementation of the Mission TimeLine (MTL) concept (defined as a sequence of time-ordered Telecommands up-linked from ground during each daily communication period) will allow, in conjunction with the FDIR functionality and OBCP capabilities to control an manage the spacecraft funtion and the scientific observation with the required autonomy.

Table 2-1 summarises the Key requirements and Design Drivers in term of Characteristics and Performance

Launch characteristics	**HERSCHEL**	**PLANCK**
Launch Vehicle	**ARIANE-V**	
Launch Site	Kourou	
Launch Mode	Dual launch	
Lifetime • Nominal • Including Degradable itemsd	3,5 years (including 6 m to L2) 6 years (including 6 m to L2)	21 mon. (including 6 m to L2) 2,5 years (including 6 m to L2)
Ground Stations	New Norcia (Nominal) Kourou (Back-Up)	New Norcia (Nominal) Kourou (Back-Up)
Ground Station Coverage Time	3 hours per day max	3 hours per day max
RESOURCES		
Data Rate • TC • TM low • TM medium/ high	125 bps / 4kbps 500 bps/5 kbps/ 150 kbps /1,5 Mbps	125 bps / 4kbps 500 bps/5 kbps/ 150 kbps /1,5 Mbps
Instruments Mass on SVM (max value) VMC+ SREM	215,5 kg 2,5 kg	417,5 kg 2,5 kg
Spacecraft Mass • SVM Dry Mass at Launch • Max Loaded Fuel Mass	415 kg 264 kg	485 kg 396 kg
Power Availability (allocation) • From Battery (storage) • From S.A. (generation)	709 Wh 1600 W	709 Wh 2100 W
Stiffness • first axial eigenmode • first lateral eigenmode Strength • Mechanical Loads	65 Hz 23 Hz Launcher QSL H-PLM resonance loads	60 Hz 35 Hz Launcher QSL P-PLM resonance loads
POINTING AND ATTITUDE DOMAIN		
Sun Aspect Angle (SAA)	+/-30° about Y, +/-1° about X	10° half-cone centred on -X
Absolute Pointing Error (APE) Relative Pointing Error (RPE) Pointing Drift Error (PDE) Absolute Measurement Error (AME) Slew duration (Herschel) Spin axis repointing (Planck)	• 2.25”, 1.15”, 0.24” (bias, long and short term) • 0.25” over 60 seconds • 1.19” for up to 24 hours • 1.62”, 1.15”, 0.24” (bias, long and short term) • 41 seconds for 8’, goal = 27 seconds • N/A	• 33’, 1.5’ (long and short term) • 36.1’ around LOS • 1.5’ over 55 minutes • 6.19’ over 24 hours • 0.2’, 0.14’, 0.15’ (bias, long and short term) • N/A • 0.4’ for displacements up to 3’

Table 2-1 – Herschel/Planck SVM Key Requirements and Design Drivers

3. INSTRUMENTS INTERFACE AND ACCOMMODATION DATA

This chapter provides a brief description of the HERSCHEL and PLANCK Instruments and their scientific performances. A compilation of instruments interface data, as required in the Instrument Interface Documents part B (IID-Bs) for each experiment (see AD02-AD06), is also provided in the IID-A (see AD-01). It rappresents the formal baseline of SVM in answer to the IID-B requirements.

3.1 HERSCHEL INSTRUMENTS DESCRIPTION

The Herschel Warm Units in the SVM consist in three main instruments:

- PACS (Photoconductor Array Camera and Spectrometer)
- SPIRE (Spectral Photometer Imaging REceiver)
- HIFI (Heterodyne Instrument for the Far Infrared)

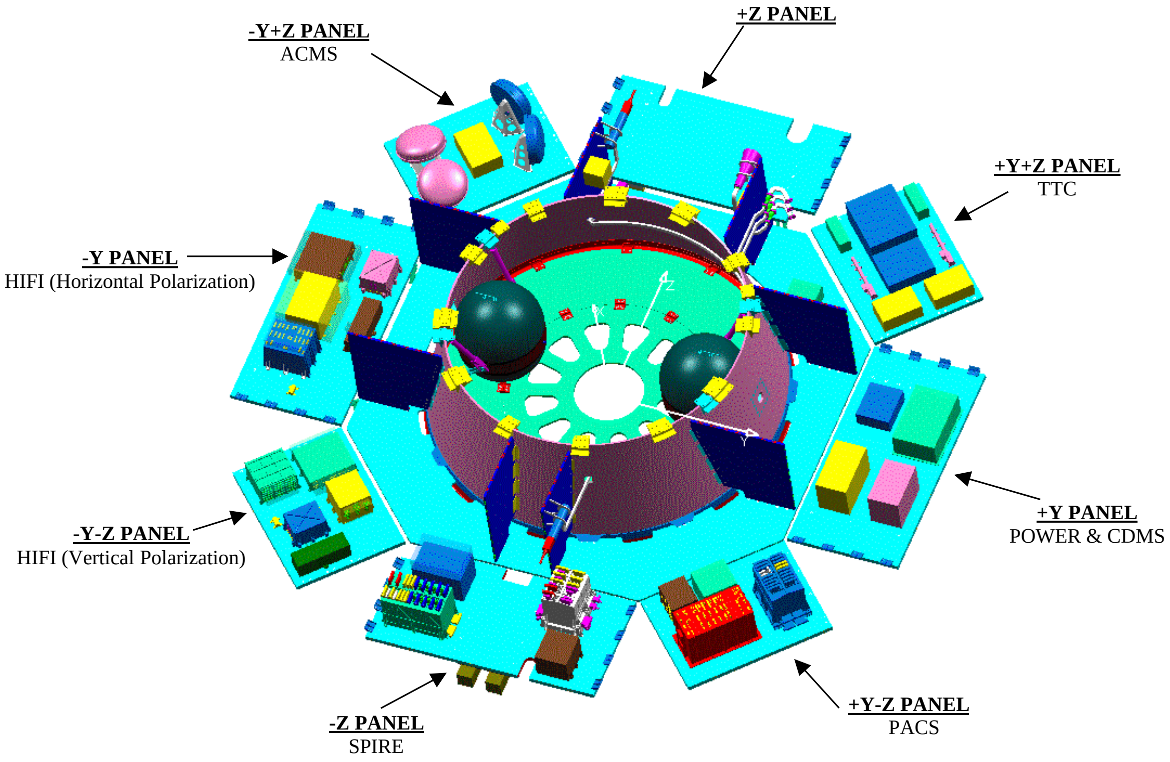

Fig.3.1-1 Herschel SVM layout

3.1.1 PACS INSTRUMENT OVERVIEW

The primary scientific goals of PACS concern the key questions of current astrophysics about the origins of star, planetary systems, galaxies, and the Universe. Star formation and galaxy formation are intimately related subjects, and planetary systems originate in the dust debris disks which surround newly formed stars. The spectral energy distributions of young stellar objects, young galaxies, and dust debris disks peak im the far-IR and submm domain, to which Herschel will have access with a sensitivity that cannot be obtained elsewhere than in space.
A main task of PACS (and SPIRE) is to carry out deep photometric surveys in several wavelenght bands in the far-IR and submm region. Only deep surveys enable the detection and subsequent study of the unbiased samples which are necessary to obtain a complete picture of young stars and galaxies over the whole relevant mass and luminosity range.
The opening of the 60-210 μm window by PACS to sensitive photometry and medium-resolution spectroscopy will provide a powerful facility to address a wide range of major questions concerning cosmology, the interstellar medium, star formation, stellar evolution, and planetary system formation.

The PACS instrument consists mainly of two parts, which are mounted on different locations on the spacecraft. One part is located inside the HSO cryostat in the focal plane on the optical bench (OB) at cryogenic temperatures. This part is the instrument “Focal Plane Unit” (FPU). The other part of the instrument is located outside the cryostat on the spacecraft SVM and on the CVV at ambient temperature. The part on the SVM are the instrument “Warm Electronics (WE) Units” and the warm interconnecting harness (WIH), the part on the CVV is the electronics preamplifier unit BOLA.

The Instrument Block Diagram below illustrates the electrical and configuration aspects. The manufacturer of the respective unit (PACS consortium partner) is indicated also.

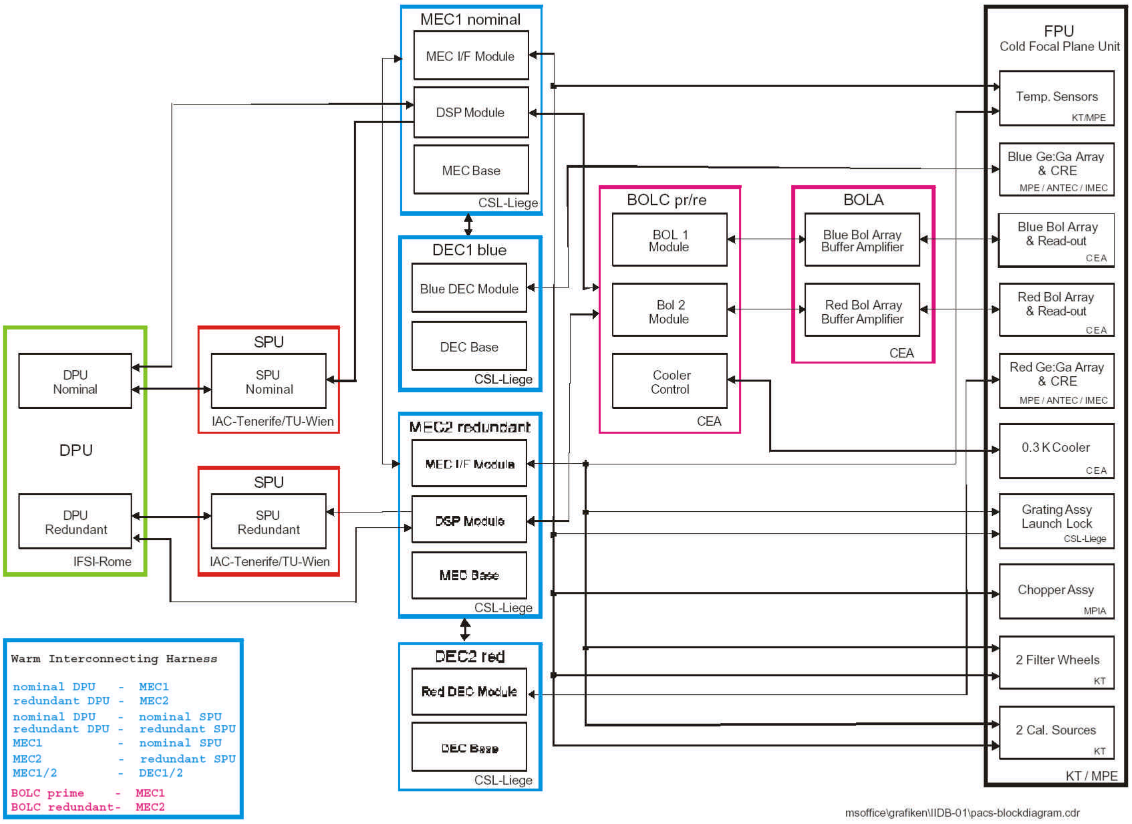

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Fig.3.1.1-1 PACS Instruments Block Diagram.

In particular, the PACS instrument consists of:

One cold focal plane unit FPU, containing structure, optics, filters, mechanisms, calibration sources and temperature sensors at approximately 4K, two photoconductive stressed-Ge:Ga detector arrays at approximately 1.7K and 2.5K, and a He3 sorption cooler assembly at 2K with two large bolometer arrays at 0.3K. The Ge:Ga photoconductor modules contain the cryogenic read-out electronics (CRE), which operates nominally at 4K. The 0.3K bolometer arrays are connected to a buffer electronics at 2K. The mechanisms comprise an instrument focal plane chopper with position sensors, a grating drive with position readout system and launch lock device, 2 filter wheels with position sensors. Furthermore, the optics contains 2 calibration sources and temperature sensors at different locations of the FPU structure. Cooling to about 4K is provided by the spacecraft cooling system level 1. The 1.7K temperature level 0 is provided by connection to the spacecraft super-fluid helium cryogen tank.

3.1.1.1 Warm Electronics Units:

The warm electronics boxes are five and they are located on the spacecraft service module SVM (panel +Y/-Z) at about 300 K; these boxes comprise:

1. DPU, one digital electronics box (prime and redundant sections) for instrument control and telemetry interface to the spacecraft.

2. SPU, two boxes (one prime and one redundant) containing the electronics required for the task of signal processing respectively data compression.

3. DEC1, MEC1 (prime) and DEC2, MEC2 (redundant), one combined analogue electronics box for supply and control of the Ge:Ga detector arrays, for transmitting the raw data rate to the signal processing unit SPU, for control of all moving mechanisms and calibration sources, for control/readout of the temperature sensors inside the FPU, and providing the interface to BOLC.

4. BOLC, one analogue electronics box (nominal and redundant sections) for control of the sorption cooler and for supply and read-out of the two bolometer arrays.

5. One preamplifier unit BOLA serving as a buffer amplifier for the bolometer signals, located on the CVV at around 120K.

3.1.2 SPIRE INSTRUMENT OVERVIEW

SPIRE is a Bolometer Instrument and it contains a three-band imaging photometer and an imaging Fourier Transform Spectrometer (FTS), both of which use 0.3-K “spider-web” NTD germanium bolometers cooled by a 3He refrigerator. The bolometers are coupled to the telescope by close-packed single-mode conical feedhorns. The photometer and spectrometer are not designed to operate simultaneously. The field of view of the photometer is 4 x 8 arcminute, the largest that can be achieved given the location of the SPIRE field of view in the Herschel focal plane and the size of the telescope unvignetted field of view. Three photometer arrays provide broad-band photometry ($\lambda/\Delta\lambda = 3$) in wavelength bands centred on 250, 350 and 500 μm. The 250, 350 and 500 μm arrays have 149, 88, and 43 detectors respectively, making a total of 280.

The field of view is observed simultaneously in all three bands through the use of fixed dichroic beam-splitters. Spatial modulation can be provided either by a Beam Steering Mirror (BSM) in the instrument or by drift scanning the telescope across the sky, depending on the type of observation. An internal thermal calibration source is available to provide a repeatable calibration signal for the detectors. The FTS uses novel broadband intensity beam dividers, and combines high efficiency with spatially separated input ports. One input port covers a 2.6-arcminute diameter field of view on the sky and the other is fed by an on-board calibration source which serves to null the thermal background from the telescope and to provide absolute calibration. Two bolometer arrays are located at the output ports, one covering 200-300 μm and the other 300-670 μm. The FTS will be operated in continuous scan mode, with the path difference between the two arms of the interferometer being changed by a constant speed mirror drive mechanism. The spectral resolution, as determined by the maximum optical path difference, will be adjustable between 0.04 and 2 cm-1 (corresponding to $\lambda/\Delta\lambda$= 1000 - 20 at 250 μm wavelength).

The focal plane unit has three separate temperature stages at nominal temperatures of 4K, 2K (provided by the Herschel cryostat) and 300 mK (provided by SPIRE’s internal cooler). The main 4-K structural element of the FPU is an optical bench panel which is supported from the cryostat optical bench by stainless steel blade mounts. The photometer and spectrometer are located on either side of this panel.

The majority of the optics are at 4K, but the detector arrays and final optics are contained within 2-K enclosures. The 3He refrigerator cools all of the five detector arrays to 0.3K. Two JFET preamplifier modules (one for the photometer an one for the FTS) are attached to the optical bench close to the 4-K enclosure, with the JFETs heated internally to their optimum operating temperature of ~ 120K.

The SPIRE warm electronics consist of two boxes with direct connection to the FPU, the Detector Control Unit (DCU) and the Focal Plane Control Unit (FCU) (together these boxes are termed the Detector Readout and Control Unit (DRCU)) plus a Digital Processing Unit (DPU) with interfaces to the other two boxes and the spacecraft data handling system. The DCU provides bias and signal conditioning for the detector arrays and cold readout electronics and reads out the detector signals.

The FCU controls the FPU mechanisms and the 3He cooler and handles housekeeping measurements. The DPU acts as the interface to the spacecraft, including instrument commanding and formats science and housekeeping data for telemetry to the ground.

3.1.3 HIFI OVERVIEW

The HIFI instrument will provide continuous frequency coverage over the range 480 to 1250GHz in five bands with approximately equal tuning range. An additional pair of bands will provide coverage of the frequency range 1410-1910 GHz. The instrument will operate at only one frequency at a time. In all mixer bands two independent mixers will receive both polarizations of the astronomical signal for maximum instrument sensitivity. The first 5 bands will use SIS (Superconductor-Insulator-Superconductor) mixers; band 6, consisting of two sub-bands 6L and 6H, will use Hot-Electron Bolometers (HEB's).
The instantaneous bandwidth of the instrument will be 4 GHz. The frequency coverage of the instrument is summarized in the following Table:

Band	Mixer type	Lower freq.	Upper freq.	Polarisation
1	SIS	480 GHz	640 GHz	DUAL
2	SIS	640 GHz	800 GHz	DUAL
3	SIS	800 GHz	960 GHz	DUAL
4	SIS	960 GHz	1120 GHz	DUAL
5	SIS	1120 GHz	1250 GHz	DUAL
6L+6H	HEB	1410 GHz	1910 GHz	DUAL

Table Proposed HIFI frequency coverage and band allocation

The HIFI instrument consists of 4 subsystems and an Instrument Control Unit.

The Focal-Plane subsystem consists of:

1a. A cold focal-plane unit (FHFPU) mounted on the 15K vapour-cooled optical bench, containing:

- relay optics (including the HIFI M3 in the telescope focal plane),
- 7 Mixer assemblies containing:
    - ☐ -14 mixers (SIS and HEB) cooled to 2K by a thermal strap to the helium tank,
    - ☐ -Optical combiners and mechanisms,
    - ☐ -14 low-noise IF HEMT pre-amplifiers operated at 15K,
- 14 additional IF amplifiers,
- 4 passive power combiners and two 3-dB couplers, providing two polarisations for both spectrometers,
- a chopping mechanism,
- a calibration source.

1b. A Focal-Plane control unit (FHFCU) operating at room temperature.

2. The Local Oscillator subsystem consists of:

2a. A local oscillator unit (FHLOU) located on the outside of the cryostat with optical beam-guides coupling the LO signals into the FHFPU via seven windows in the cryostat wall. The unit contains two times seven multiplier and amplifier chains to produce a LO signal in one of fourteen different frequency bands: each mixer band is split between two LO bands. FHLOU is radiatively cooled to a temperature of approximately 120K.

2b. A local oscillator control unit (FHLCU) and a local source unit (FHLSU), both located in the service module and opeated at room temperature. The FHLSU contains a high stability reference oscillator and phase-lock system to control the frequency of the local oscillator with a long-term precision . The oscillator signal is transmitted to the FHLOU through one of fourteen wave-guides, to be multiplied and amplified in the FHLOU.

2c. A local oscillator synthesiser unit (FHLSU) operating at room temperature, located on the service module.

3. The High-Resolution Spectrometer (HRS) consists of two units:

3a/b. Two High-Resolution Spectrometer Units (FHHRH and FHHRV), each containing an ACS, HRS controller and the DC/DC converters.

4. The Wide-Band Spectrometer (WBS) consists of four units:

4a. Electronics for Horizontal Polarisation (FHWEH)
4b. Electronics for Vertical Polarisation (FHWEV)
4c. Optics for Horizontal Polarisation (FHWOH)
4d. Optics for Vertical Polarisation (FHWOV)

An instrument control unit (FHICU), operating at room temperature within the service module. The FHICU interprets commands from the satellite telecommand system, controls the operation of the instrument, and returns science and housekeeping data to the satellite telemetry system.

The interconnecting cable harness (FHWIH). This harness interconnects the units residing in the SVM.
The Fig.3.1.3-1 is a block diagram of the HIFI showing the relationship between the various units of the instrument.

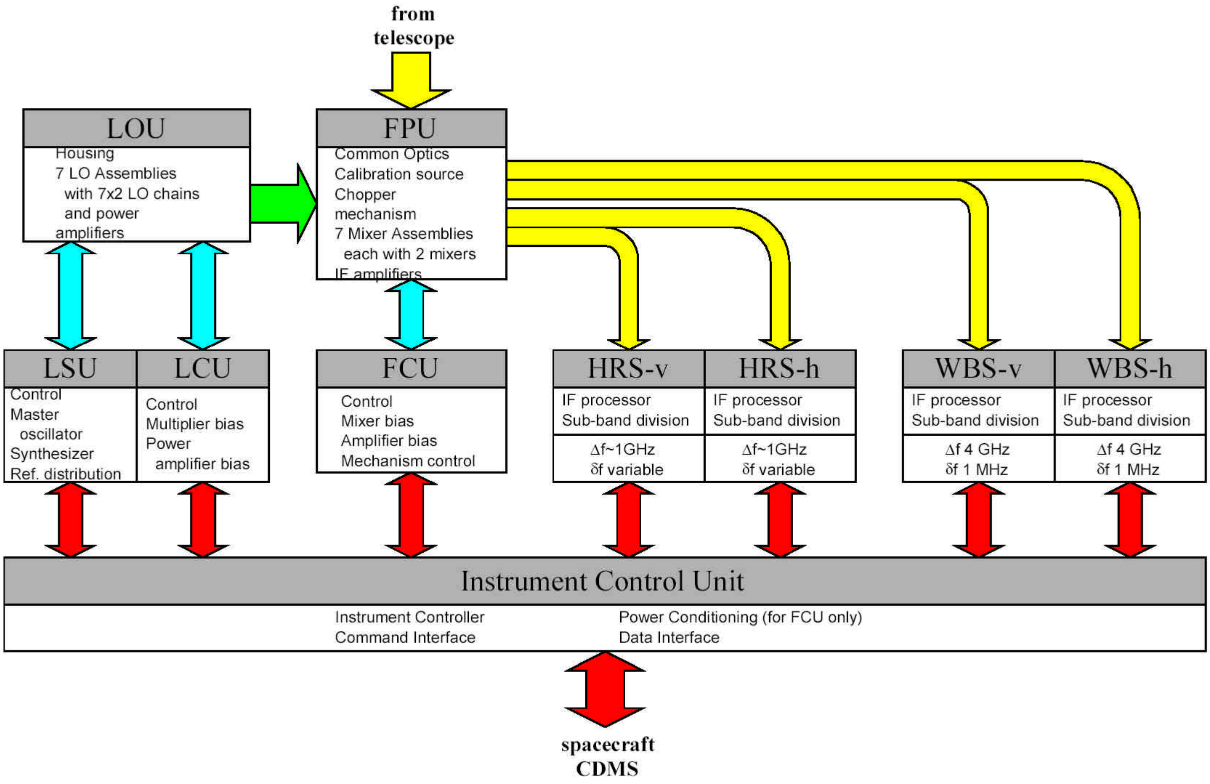


Fig.3.1.3-1 Block diagram of the HIFI

3.2 PLANCK INSTRUMENTS DESCRIPTION

The Planck Warm Units in the SVM consist in three main instruments:

- **HFI** (**H**igh-**F**requency **I**nstrument)
- **LFI** (**L**ow-**F**requency **I**nstrument)
- **SCS** (**S**orption **C**ooler **S**ubsystem)

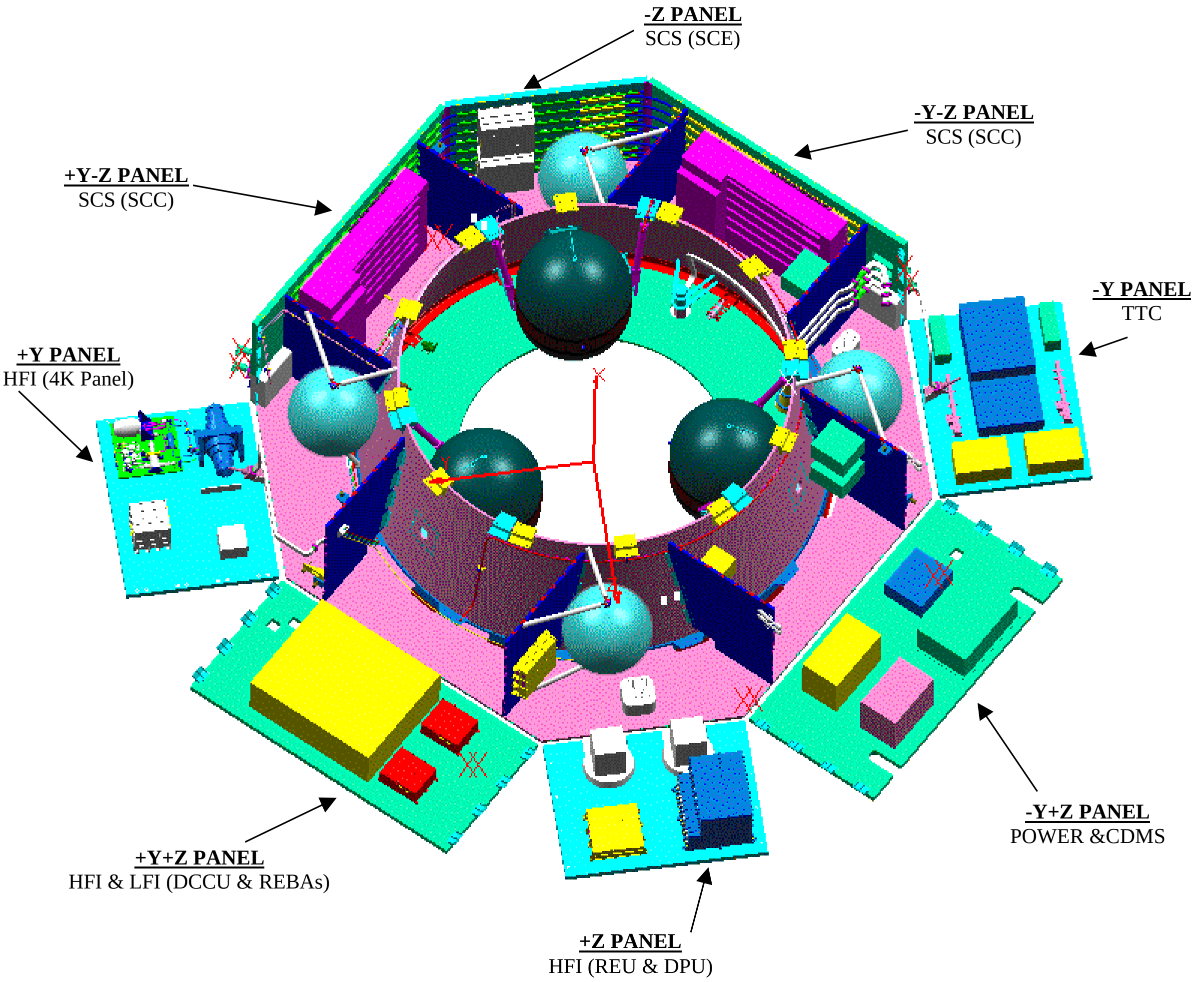


Fig.3.2-1 Planck SVM layout

3.2.1 HFI OVERVIEW

The High-Frequency Instrument (HFI) is designed to carry out high sensitivity, multifrequency microwave measurements of the diffuse sky radiation in the frequency range 83-1000 GHz.
These measurements will be used, together with those from the Low Frequency Instrument (LFI), to produce a map over most of the sky of the anisotropies of the Cosmic Microwave Background (CMB). This map will in turn be used to constrain the main parameters that determine the large scale structure of the Universe.

The heart of the HFI - the detectors - are bolometers, solid-state devices in which the incoming radiation dissipates its energy as heat that increases the temperature of a thermometer. The total number of bolometers is 48, split into 6 channels at central frequencies of 100, 143, 217, 353, 545, and 857 GHz.

The HFI instrument consists of the following subsystems :

The following units are located on the "cold part" of the Planck Payload Module:

- HFI Focal Plane Unit (FPU): the function of this unit is the detection at 0.1K. It is the most sensitive part of the instrument in terms of thermal radiation and electromagnetic field.

- J-FET box: the bolometers are read out via J-FETs which must be located close to them, but must at the same time be thermally insulated from them. They are enclosed in a 50/60K box (the J-FETs must operate at approx. 120 K). The J-FETs provide for the impedance matching with the following stages of amplification which are located farther from the detectors. The J-FETs and bolometers are located into a common Faraday cage.

The following unit are located inside the SVM:

- Readout Electronics Unit (REU): the readout electronics of the bolometers and of the 0.1K thermometers are based on a system able to cover the frequency range needed for HFI, i.e. 0.016 Hz to about 100Hz. This system uses a differential AC square bias current and has a uniform noise performance:√(5nV/Hz), i.e. less than the Johnson noise of the bolometers, over most of the useful frequency range.
This system allows a full control of the current and voltage of the measured resistor, so that in-flight optimisation of the bias voltage is possible. Dedicated thermometers and heaters will allow the control of the 0.1K stage temperature.
The other functions of the Readout Electronics Unit are:
to decode dedicated commands sent by the DPU and to control the various parameters of the Modulation/Amplifier card and the Digital pre-processing, to decode the commands received from the DPU for the parameters of the PID 0.1K temperature control, to compute PID commands from thermometer measurements and to adjust the heater current within a time delay compatible with the thermometer timeresponse, in a commanded mode: to measure for all bolometers, V(I) by incrementing I in a given range, to collect data from all bolometers and thermometers, and send them to the DPU, as well as housekeeping parameters of the Readout electronics.

- Data Processing Unit (DPU) nom. & red.: the main functions of this unit are:

1. to drive all the subsystems of the instrument and to get their data (bolometer readouts, cryogenics readouts, temperature sensors and various active device status),
2. to tag accurately the measurements with the On-Board Time,
3. to compress the detectors data to fit in the science telemetry allocation,
4. to produce the HFI various science and different types of housekeeping telemetry packets,
5. to receive the commands from the S/C, acknowledge and execute them, or transmit them to other HFI units for excution,
6. to receive on-board software uploads and to download all or part of the on-boardsoftware.

- 4K Cooler Subsystem: the main components of this subsystem are:

4K Cooler Compressor Unit (4CCU)
4K Cooler Auxillary Unit (4CAU)
4K Cooler Electronic Unit (4KCDE)
4K Pre-Regulator Unit

One of the stages in the HFI cooling chain is at “4K”. This is required for pre-cooling the dilution refrigerator isotopes and the focal plane unit. The 4K temperature will be achieved by the use of a He-4 Joule Thomson (JT) system. A helium JT system requires pre-cooling to a temperature well below the inversion temperature of the working gas which, in this case is Helium-4.
Pre-cooling of the system to 18K will be achieved by the use of an hydrogen Sorption Cooler. Additional cooling at an intermediate (50-60K) temperature is also required to reduce the load on the 18K cooler.

- Dilution Cooler Contr. Unit (DCCU) & 0,1 K Filling and Venting Panel:

The 0.1K Cooler uses the dilution of helium3 in helium4 into proper proportions in small capillary tubes in an open cycle. The gas mixture is then re-used in a Joule-Thomson expansion valve providing extra cooling at 1.6K.
The 0.1K structural plate supports the bolometers with horns and attached filters, blind bolometers, thermometers, heaters and the dilution heat exchanger.
Thermometers (using same readout electronics as the bolometers) and redundant heaters are used to regulate the 0.1K temperature.
In order to decrease the HFI Focal Plane Unit cooling-down duration during ground testing: a specific pre-cooling flyable capillary circuit is included in the Dilution Cooler Cold end Unit.

- Pre-Amplifier Unit (PAU): this unit shall preferably be located between the first, and warmest, V-groove and the SVM separation panel in order to have it as close as possible to the JFET box and ensure a relatively cool environment increasing its detection performances.

The figure 3.2.1-1 shows the HFI block diagram:

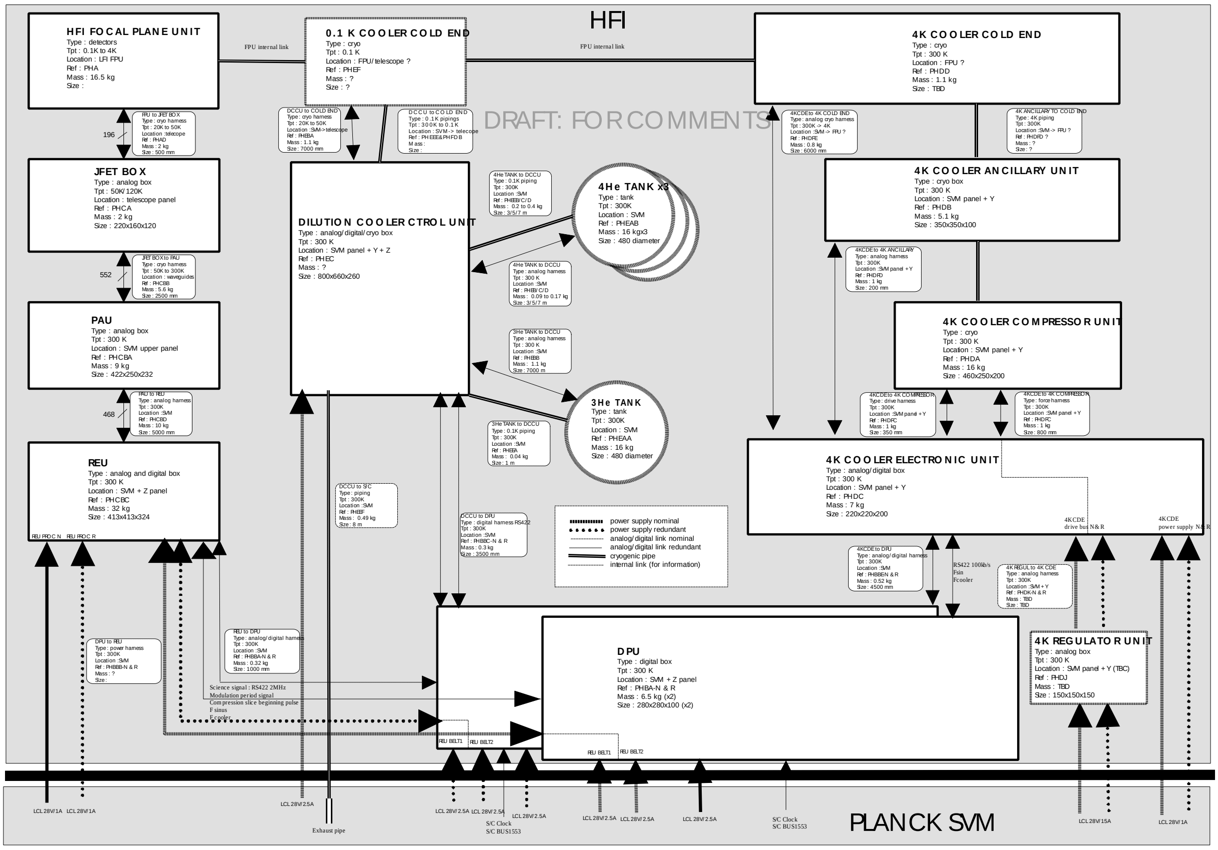


Fig.3.2.1-1 HFI Block Diagram

3.2.2 LFI OVERVIEW

The Low-Frequency Instrument (LFI) is designed to produce high-sensitivity, multifrequency measurements of the microwave sky in the frequency range 30-100GHz (2.3-10 mm wavelength). These measurements will be used, together with those from the High Frequency Instrument (HFI) to produce a full-sky map of the anisotropies of the Cosmic Microwave Background (CMB) with unprecedented precision. This map will in turn be used to extract a wealth of cosmological information, including the accurate determination of the main cosmological parameters which characterise the large scale structure and the evolution of the universe.

The LFI consists of the following subsystems:

· Radiometer Array Assembly (RAA)
· Sorption Cooler Subsystem (SCS)
· Radiometer Electronics Box Assembly (REBA)
· Sorption Cooler Subsystem (SCS) - Shared with HFI

The RAA includes the Front End Unit (FEU) and the Back End Unit (BEU), connected via waveguides.
The Front End Unit (FEU) is the heart of the instrument, and it is located at the focus of the telescope, as one component of the joint LFI/HFI Focal Plane Unit (FPU).
The functions of the Sorption Cooler Subsystem (SCS) are shared with the HFI instrument.
The Radiometer Electronics Box Assembly (REBA) is located on one of the lateral panels of the service module.

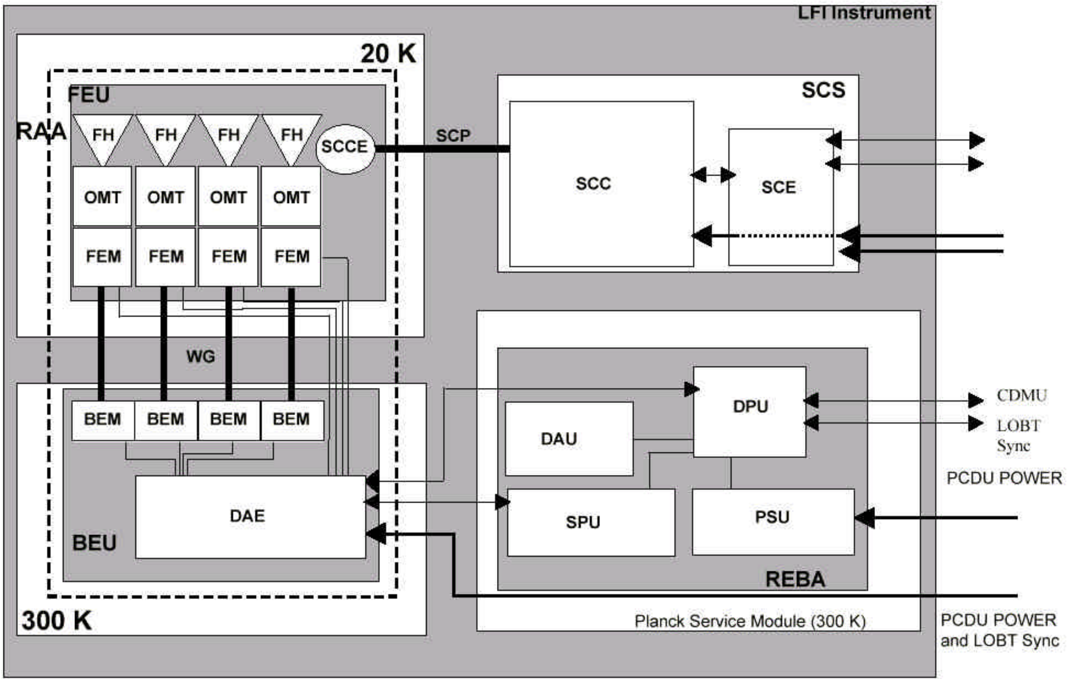


Fig.3.2.2-1 Block Diagram of LFI; the SCS is shared with HFI.

- Radiometer Array Assembly (RAA):

- Front End Unit (FEU): the FEU contains the feed array and associated orthomode transducers (OMTs), hybrid couplers, amplifiers, and phase switches, all cooled to 20 K by the sorption cooler.
The FEU comprises 27 modules, each containing one feed horn, one orthomode transducer (OMT), two hybrid couplers, and four cryogenic amplifiers. The modules are mounted on a plate that provides mechanical support and adds thermal inertia.

- Back End Unit (BEU): the BEU comprises the radiometer Back End Modules (BEM) and the Data Acquisition Electronics (DAE), which are connected by an internal harness. The BEU is connected to the FEU by 108 waveguides. Wires for DC biasing of the amplifiers and for switch control signal are also required. A unidirectional, synchronous serial interface is used for transmitting science data to the Signal Processing Unit (SPU).
Communication, timing, and analog housekeeping interfaces are transmitted to the Data Processing Unit (DPU). Internally, each back end analog output is connected, by coaxial cables, to the DAE.

- Data Acquisition Electronics (DAE): The Data Acquisition Electronics (DAE) comprises the analog conditioning electronics, the multiplexers, the analog-to-digital converters, the parallel-to-serial converters, the control electronics, the communication interface, and the power conditioning and distribution electronics.

It performs the following functions:

1. Communication with the REBA DPU, including simple commands reception and status transmission;
2. Acquisition, conditioning, and multiplexing of science signals;
3. Acquisition and conditioning of the LFI housekeeping;
4. Control of the data acquisition chain;
5. Transmission of raw data to the REBA SPU;
6. Power supply conditioning and distribution to the RAA;

7. DC biasing of the FEU and BEU amplifiers;
8. ON/OFF control of FEU and BEU amplifiers;
9. Time tagging of the science data

- Radiometer Electronics Box Assembly (REBA): The REBA consists of one nominal and one redundant unit. Internally the REBA is separated into four sub-units the Data Processing Unit (DPU), the Signal Processing Unit (SPU), the Data Acquisition Unit (DAU), and the Power Supply Unit (PSU).

3.2.3 SCS OVERVIEW

The Sorption Cooler Subsystem comprises the following units both main and redundant:

Sorption Cooler Compressor assembly (SCC)
Sorption Cooler Cold End (SCCE)
Sorption Cooler Electronics (SCE)

- Sorption Cooler Compressor assembly (SCC): Each SCC contains six compressor elements. With six compressor elements the SCS is designed to meet the total instrument (HFI+LFI) cooling requirement (active plus parasitics) for a cooler interface temperature and environment up to about 60K assuming that no margins are needed on either cooler requirements or cooler performance.
Cycling is accomplished by turning on and off at appropriate times heaters embedded in the compressor elements, using solid-state relays that are located in the Sorption Cooler Electronics SCE.

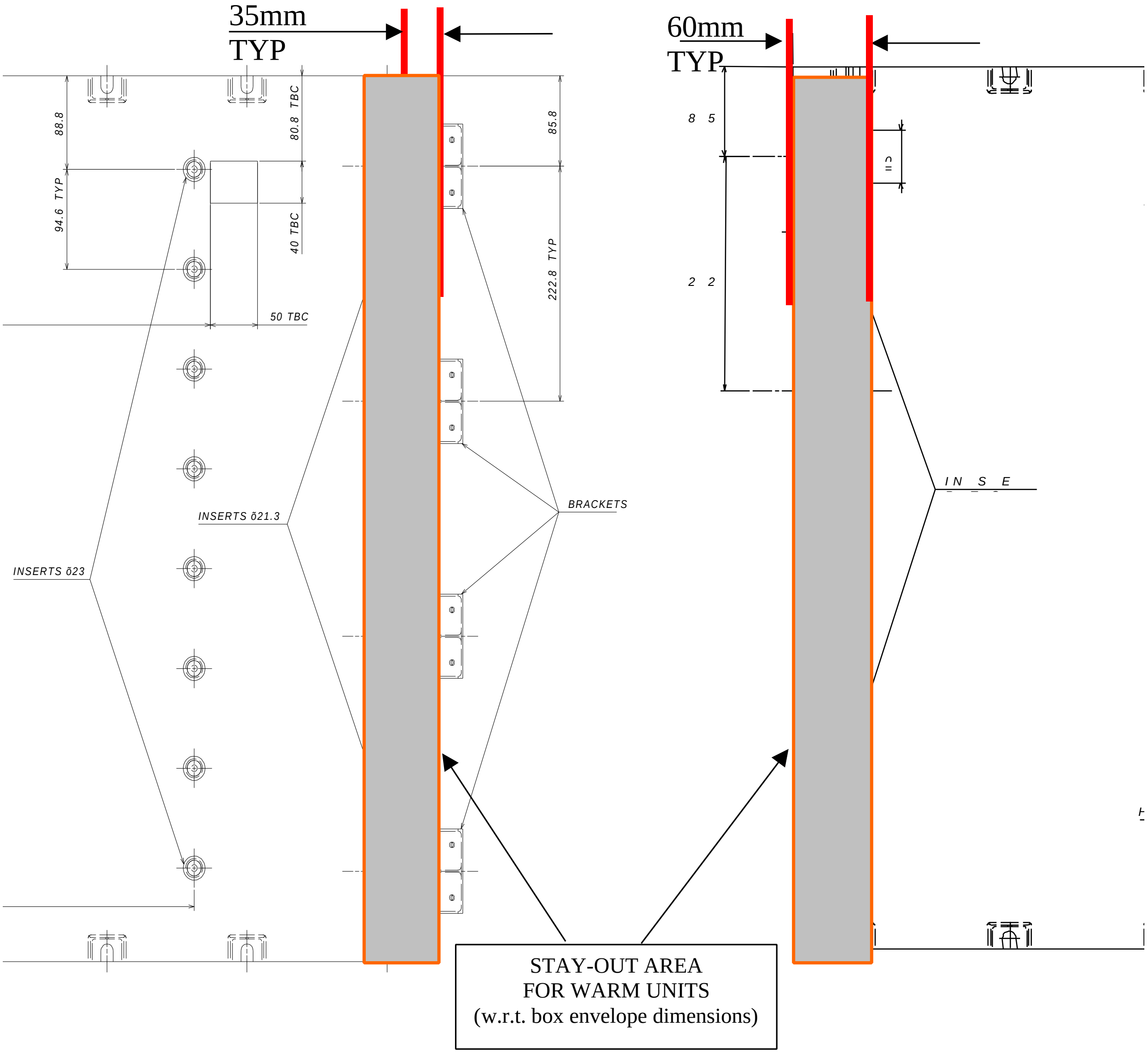
- Sorption Cooler Cold End (SCCE): the Sorption Cooler Cold End (SCCE), mounted on the LFI/HFI FPU, contains a filter, a J-T expander, three liquid reservoirs and interconnecting tubing.

- Sorption Cooler Electronics (SCE): the SCE provides the following functions for the coolers:

1. switching control for the sorption bed heaters,
2. switching control to the thermal switches,
3. timing signals for the switching,
4. power control of the compressor elements in the “out-gassing” state,
5. temperature control of one of the liquid hydrogen reservoirs,
6. control of a number of temperature, pressure, voltage, and current sensors,
7. Interface to the spacecraft communications bus for command receipt and housekeeping transmission.

3.3 WARM UNITS ACCOMODATION LAYOUT CONSTRAINTS

The accomodation of the warm units on SVM panel will have to hold in consideration the following major constraints:
- stay-out areas on SVM panels, namely:
i) 60mm-wide band on each panel-to-panel edge for structural cleats (see Fig.3.3-1 and Fig.3.3-2)



STAY-OUT AREA
FOR WARM UNITS
(w.r.t. box envelope dimensions)

SVM LONG LATERAL PANELS (TYP)
SVM SHORT LATERAL PANELS (TYP)

Fig.3.3-1 Structure Drawings

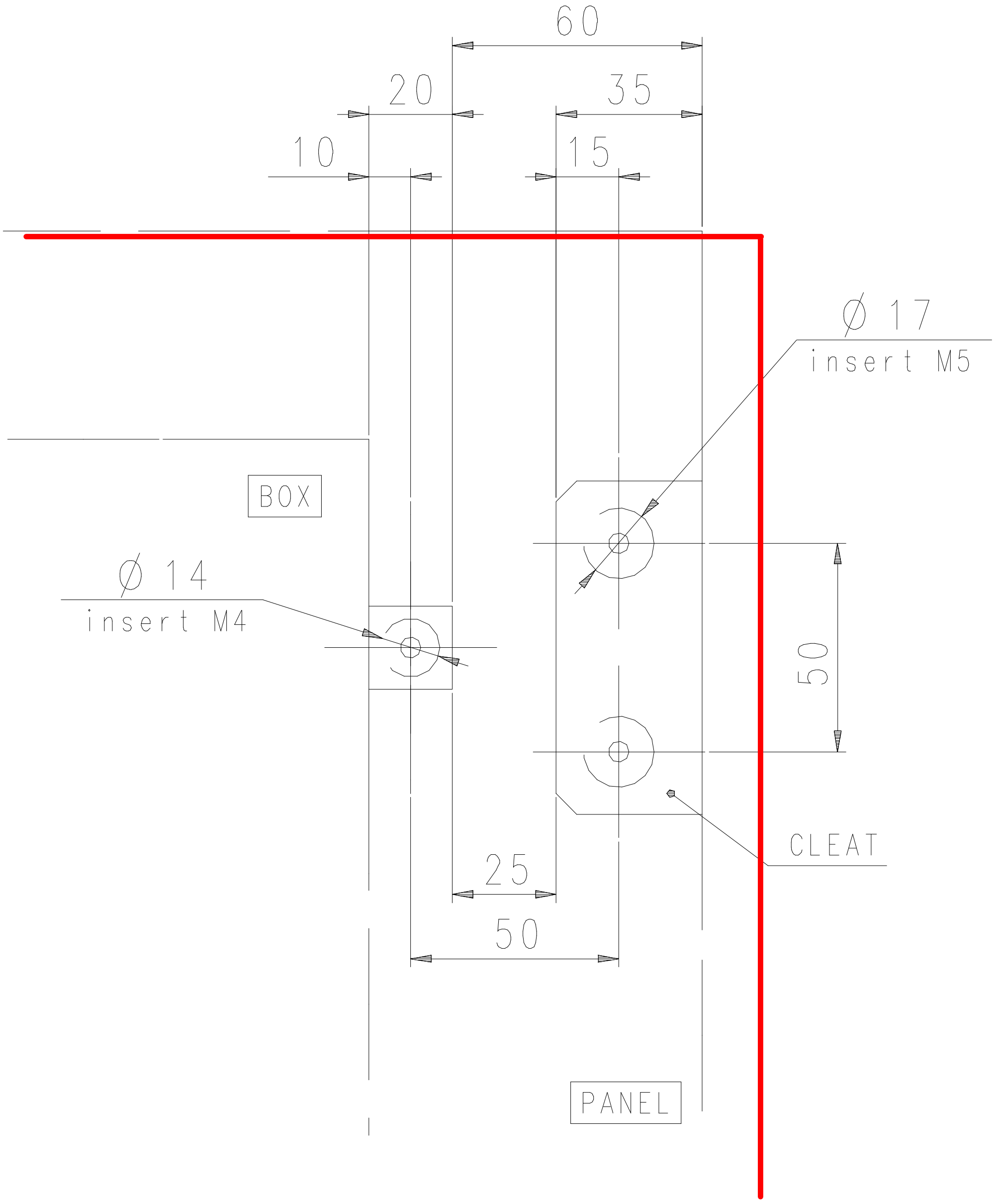
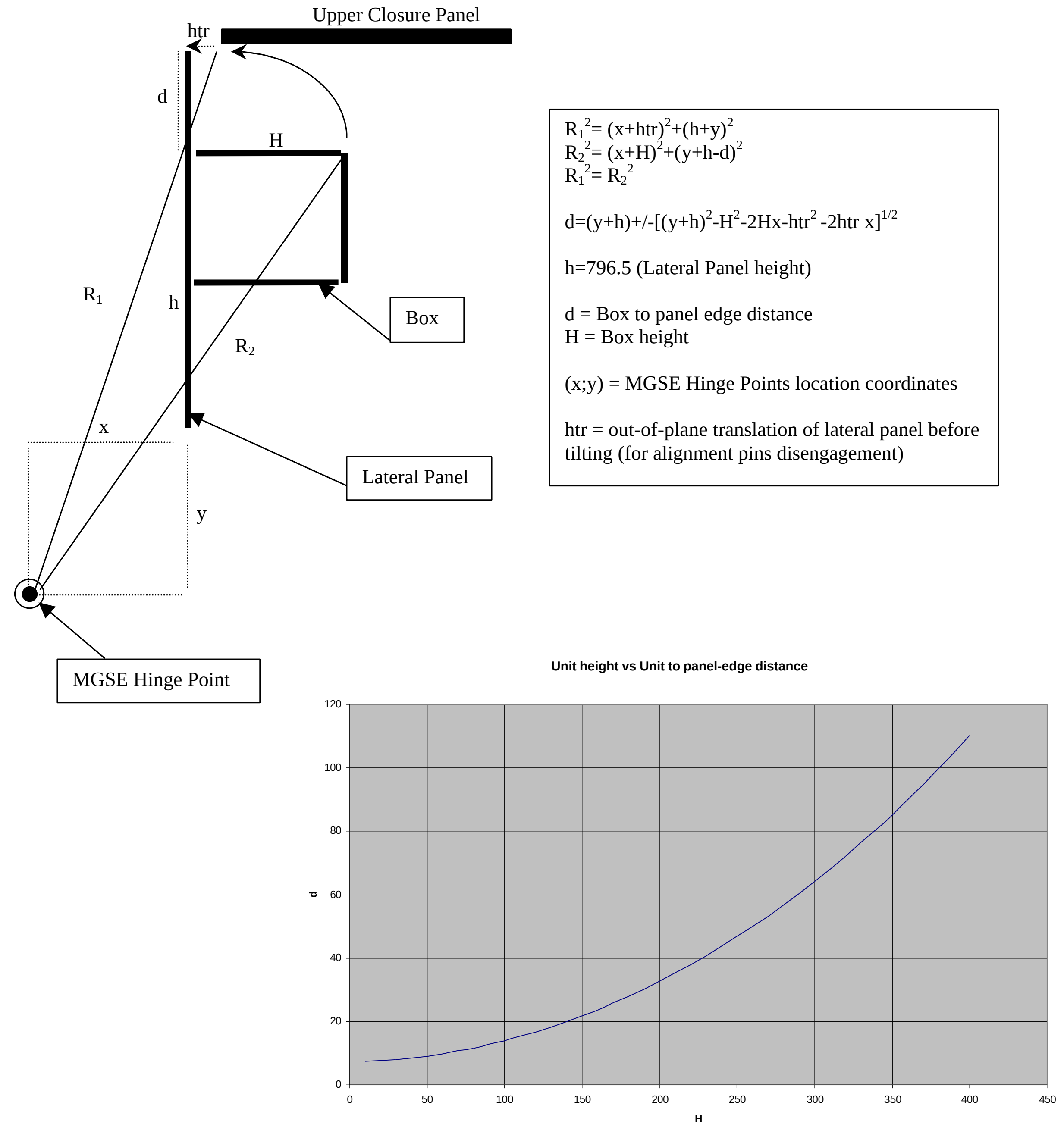


Fig.3.3-2 Structural cleat

ii) minimum distance of warm units from the upper edge (off the upper closure panel) as a function of the unit height (see Fig.3.3-3) to allow tilting of the panel itself during the AIT activities;



$R_1^2 = (x+htr)^2+(h+y)^2$
$R_2^2 = (x+H)^2+(y+h-d)^2$
$R_1^2 = R_2^2$

$d=(y+h)\pm[(y+h)^2-H^2-2Hx-htr^2-2htr\,x]^{1/2}$

h=796.5 (Lateral Panel height)

d = Box to panel edge distance
H = Box height

(x;y) = MGSE Hinge Points location coordinates

htr = out-of-plane translation of lateral panel before tilting (for alignment pins disengagement)

Fig. 3.3-3 Study of panel tilting

iii) warm unit harness accomodation: dedicated study of the harness has been performed with the aim of identify the stay-out areas (see RD-71)

iv) warm unit thermal requirement (both temperature limits and stability requirements) as required in the IID-B`s. Analysis has been carried out and result presented in the RD-72 (see also chapter 7.4 of this document)

v) SVM CoG constraints: to meet the requirement of CoG careful mass balance has to be considered especially for Planck

3.4 HERSCHEL WARM UNIT ACCOMODATION

A description of all warm unit accomodation inside Herschel SVM is provided in the following paragraphs. The relevant location, mass and dimensions data are detailed in the tables of the single paragraph.

3.4.1 HIFI WARM UNITS

The HIFI Warm Units are mainly grouped on two dedicated SVM panels (i.e. the –Y and the –Y/-Z panels), while the relevant instruments are accomodated on the Optical Bench (OB).
In the following table there are the project codes allocated to HIFI warm units:

Project Code	**Instrument Unit**
FHLCU	HIFI Local Oscillator Control Unit
FHLSU	HIFI Local Oscillator Source Unit
FHHRH	HIFI High-Resolution Spectrometer, Horizontal polarisation
FHHRV	HIFI High-Resolution Spectrometer, Vertical polarisation
FHFCU	HIFI Focal Plane Control Unit
FHWEV	HIFI Wide-Band Spectrometer Electronics Vertical Polarisation
FHWEH	HIFI Wide-Band Spectrometer Electronics Horizontal Polarisation
FHICU	HIFI Instrument Control Unit
FHWOV	HIFI Wide-Band Spectrometer Optics Vertical Polarisation
FHWOH	HIFI Wide-Band Spectrometer Optics Horizontal Polarisation
FHWIH	HIFI Warm Interconnect Harness

In the following table there are mass and dimensions of HIFI Warm Units (AD-03):

Project Code	**Instrument Unit**	**# of**	**Dimensions (mm) *)**	**Nominal Mass (kg)**	**Allocated Mass (kg)**
FHFCU	Focal Plane Control Unit	1	326 x272 x 175	7.300	10.0
FHLCU	Local Oscillator Control Unit	1	347 x 250 x 250	13.600	11.0
FHLSU	Local Oscillator Source Unit	1	428 x 290 x 220	14.000	12.0
FHHRH	HRS Horizontal polarisation	1	390 x 355 x 102	12.306	11.2
FHHRV	HRS Vertical polarisation	1	390 x 355 x 102	12.306	11.2
FHWEH	WBS Electronics Horizontal polarisation	1	290 x 240 x 169.2	8.095	9.0
FHWEV	WBS Electronics Vertical polarisation	1	290 x 240 x 169.2	8.095	9.0
FHWOH	WBS Optics Horizontal polarisation	1	400 x 170 x 130	6.400	7.0
FHWOV	WBS Optics Vertical Polarisation	1	400 x 170 x 130	6.400	7.0
	WBS internal harness HRS internal Harness	1 1	Average length 2000 Average length 2000	1.200 0.035	1.5 0.1
FHICU	Instrument Control Unit	1	274 x 258 x 194	7.621	7.0
FH3D V+H	3-dB-Coupler Vertical+Horizontal polar.	1+1	70 x 70 x 30	TBD	TBD
FHWIH	Warm Interconnect Harness		Average length 2000	5.000	6.0
Total				**102.358**	**102.0**

*) Dimensions are envelopes including mounting feet, excluding connectors.

The new configuration panels are based on the mechanical interface drawings for each box and, where they are not available, by the terms of our agreement during convergence meeting with HIFI instrument.

The Assumptions made to study the new HIFI panels configuration are:

- the 3db coupler has been split in two separate units (one per each polarization)
- All Horizontal polarization units on the -Y panel
- All Vertical polarization units on the –Y/-Z panel
- A CB to support the semirigid cables which link the HRH to the HRV has been defined on both panels; the allocated area/volume on the upper PLT for the cable jumpers has also been defined.
- LSU, it has been considered the option with the 14 WG's location in one single row, as preferred by ASED
- the LSU location has been proposed by ALS (Cryo-Hrn Convergence Meeting- MoM HP-ASPI-MN-1415 30/04/02) and is subject to confirmation from ASED side.
- The proposed accommodation of HIFI warm units has also been checked in the third dimensions by means of 3D CAD models against the configuration proposed for the adjacent panels. The 3D check provided positive results.

The status of HIFI Warm Units reconfiguration study on board Herschel SVM is shown in the following preliminary 2D sketches:

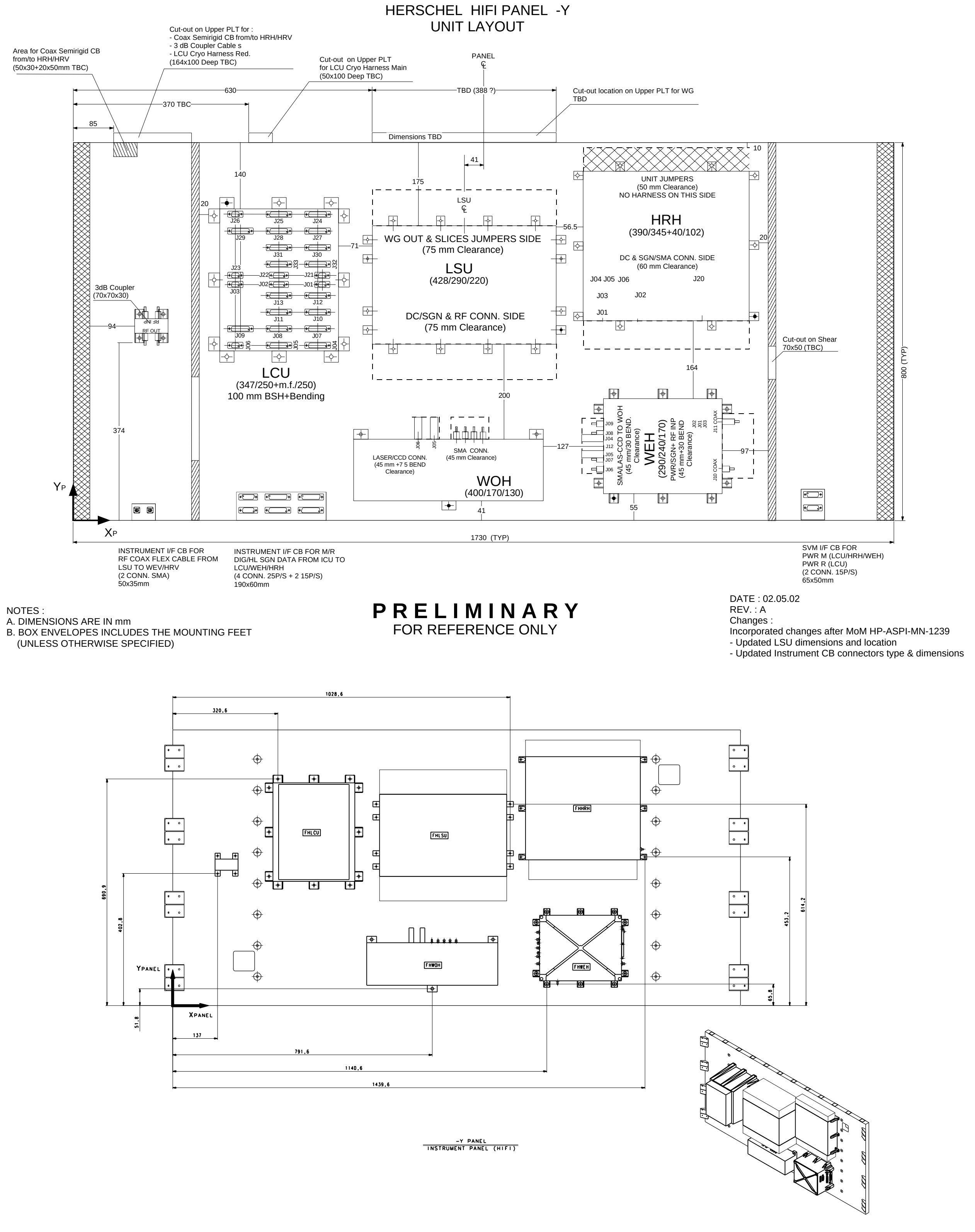
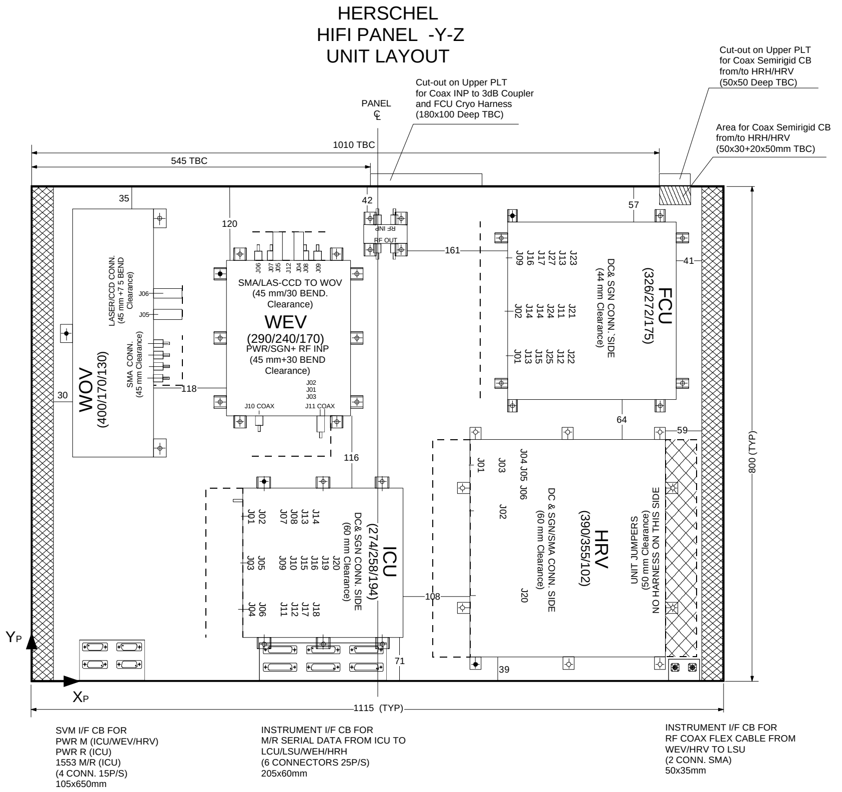


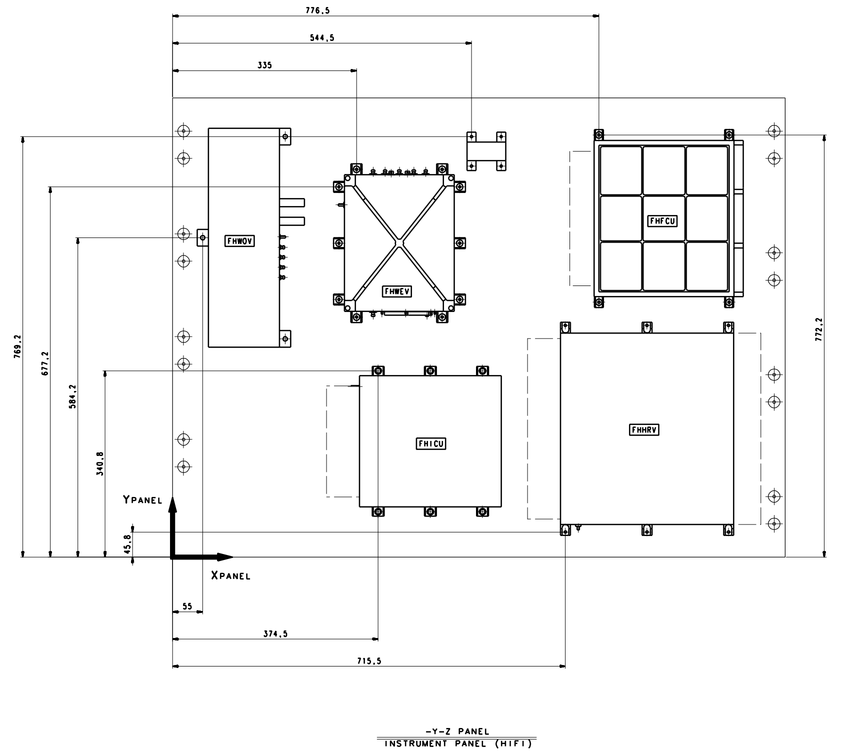
Fig. 3.4.1-1 Herschel HIFI panel –Y



NOTES :
A. DIMENSIONS ARE IN mm
B. BOX ENVELOPES INCLUDES THE MOUNTING FEET
(UNLESS OTHERWISE SPECIFIED)

PRELIMINARY
FOR REFERENCE ONLY

DATE : 15.04.02
REV. : A
Changes :
Incorporated changes after MoM HP-ASPI-MN-1239



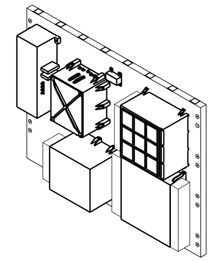


Fig. 3.4.1-2 Herschel HIFI panel –Y-Z

3.4.2 SPIRE WARM UNITS

The SPIRE Warm Units are mainly grouped on the dedicated SVM panel –Z with the CCU unit, while the relevant instruments are accomodated on the Optical Bench (OB).
Two Star Trackers and one LGA are accommodated on the outside of the panel -Z.

In the following table there are the project codes allocated to SPIRE warm units:

Project Code	**Instrument Unit**
HSDCU	SPIRE Detector Control Unit
HSFCU	SPIRE FPU Control Unit
HSDPU	SPIRE Digital Processing Unit
HSWIH	SPIRE Warm Interconnect Harness

In the following table there are mass and dimensions of SPIRE Warm Units (AD-02):

Project Code	**Instrument Unit**	**# of**	**Dimensions (mm) *)**	**Nominal Mass (kg)**	**Allocated Mass (kg)**
HSDCU	Detector Control Unit	1	494 x 289 x 305	15.5	13.0
HSFCU	FPU Control Unit	1	374 x 329 x 330	15.0	12.0
HSDPU	Digital Processing Unit	1	274 x 258 x 194	6.6	7.0
HSWIH	Warm Interconnect Harness			2.0	2.0
Total				**39.1**	**34.0**

*) Dimensions are envelopes including mounting feet, excluding connectors.

The new configuration panel is based on the mechanical interface drawings for each box and by the terms of our agreement during convergence meeting with SPIRE instrument.

The Assumptions made to study the new SPIRE panel configuration are:

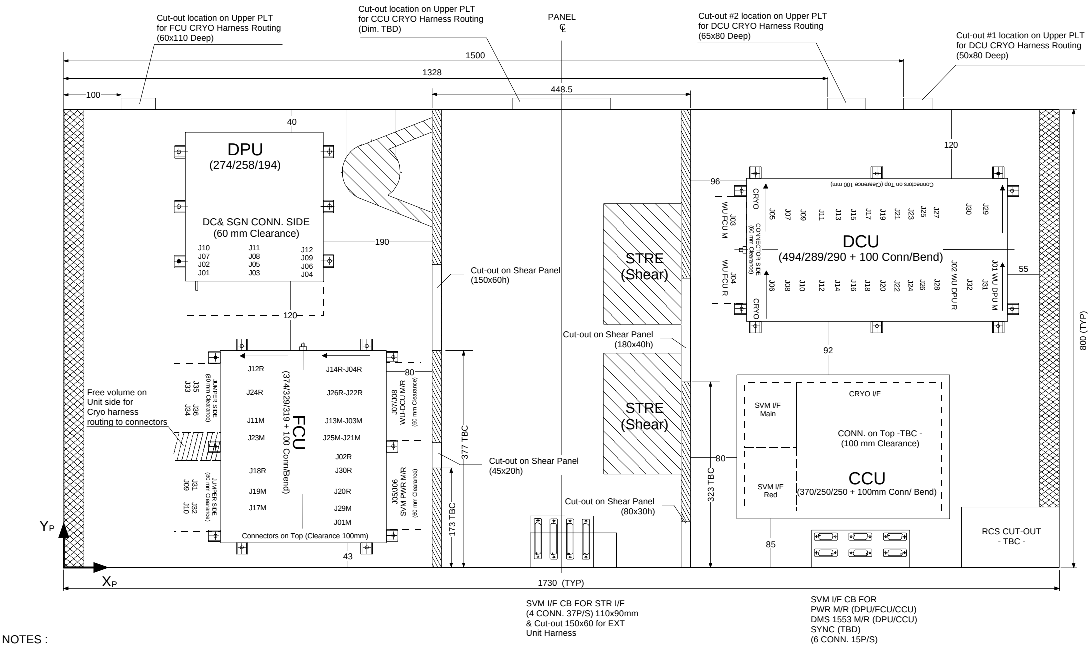
- CCU (not part of SPIRE WUs) dimensions, connectors list and location are still to be confirmed by Alcatel/Astrium

- FCU: unit's dimensions utilised for the accommodation exercise are i.a.w.mech. I/F dwg provided by SPIRE/ASPI. Confirmation of updated about DCU and FCU mechanical I/F drawings is awaited from SPIRE/ASPI side.

- The proposed accommodation of SPIRE warm units has also been checked in the third dimensions by means of 3D CAD models against the configuration proposed for the adjacent instrument panels. The 3D check provided positive results.

The status of SPIRE Warm Units reconfiguration study on board Herschel SVM is shown in the following preliminary 2D sketch:

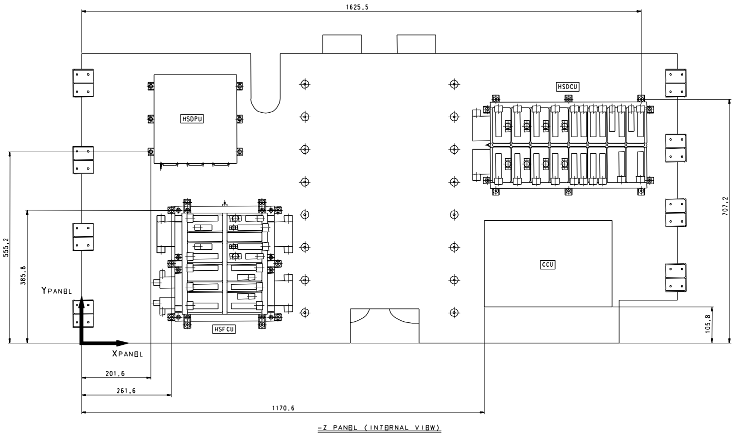
HERSCHEL SPIRE PANEL -Z
UNIT LAYOUT



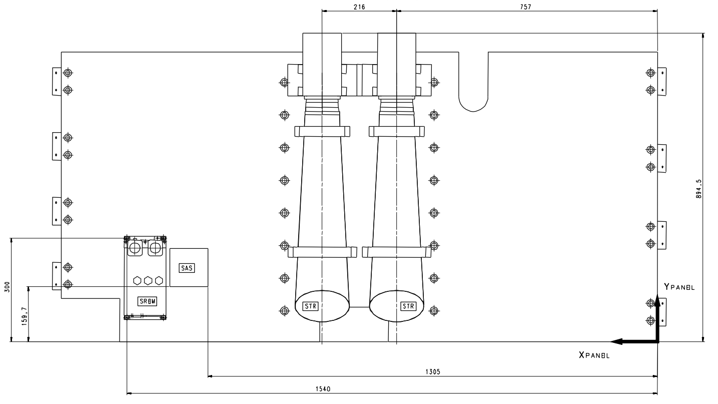
NOTES :
A. DIMENSIONS ARE IN mm
B. BOX ENVELOPES INCLUDES THE MOUNTING FEET
(UNLESS OTHERWISE SPECIFIED)

PRELIMINARY
FOR REFERENCE ONLY

DATE : 24.04.02
REV. : A WORKING
Changes :
Incorporated changes after MoM HP-ASPI-MN-1238
- Added dimensions of Shear panels cut-outs



-Z PANEL (INTERNAL VIEW)
INSTRUMENT PANEL (SPIRE)



-Z PANEL (EXTERNAL VIEW)
INSTRUMENT PANEL (SPIRE)

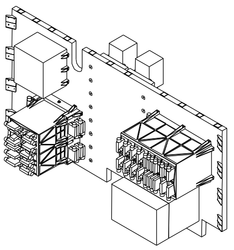


Fig. 3.4.2-1 Herschel SPIRE panel -Z

3.4.3 PACS WARM UNITS

The PACS Warm Units are mainly grouped on the dedicated SVM panel +Y/-Z, while the relevant instruments are accomodated on the Optical Bench (OB).

In the following table there are the project codes allocated to PACS warm units:

Project Code	**Instrument Unit**
FPMEC1	PACS Mechanism Control 1 (nominal)
FPDEC1	PACS Detector Control 1
FPMEC2	PACS Mechanism Control 2 (redundant)
FPDEC2	PACS Detector Control 2
FPBOLC	PACS Bolometer/Cooler Control
FPDPU	PACS Digital Processing Unit (DPU nom + red)
FPSPU1	PACS Signal Processing Unit 1 (SPU nom.)
FPSPU2	PACS Signal Processing Unit 2 (SPU red.)
FPWIH	PACS Warm Interconnect Harness

In the following table there are mass and dimensions of PACS Warm Units (AD-04):

Project Code	**Instrument Unit**	**# of**	**Dimensions (mm) *)**	**Nominal Mass (kg)**	**Allocated Mass (kg)**
FPDECMEC	Detector-MechanismControl	1	560 x 320 x 300	23.0	24.0
FPBOLC	Bolometer/Cooler Control	1	382 x 289 x 333	15.3	16.0
FPDPU	Digital Processing Unit (DPU nom+red)	1	274 x 258 x 194	6.6	6.9
FPSPU 1/2	Signal Processing Unit (SPU nom+red)	1	270x215x(2x97)	6.8	7.5
FPWIH	Warm Interconnect Harness		length ≤ 1000	1.5	1.6
Total				**53.2**	**56.0**

*) Dimensions are envelopes including mounting feet, excluding connectors.

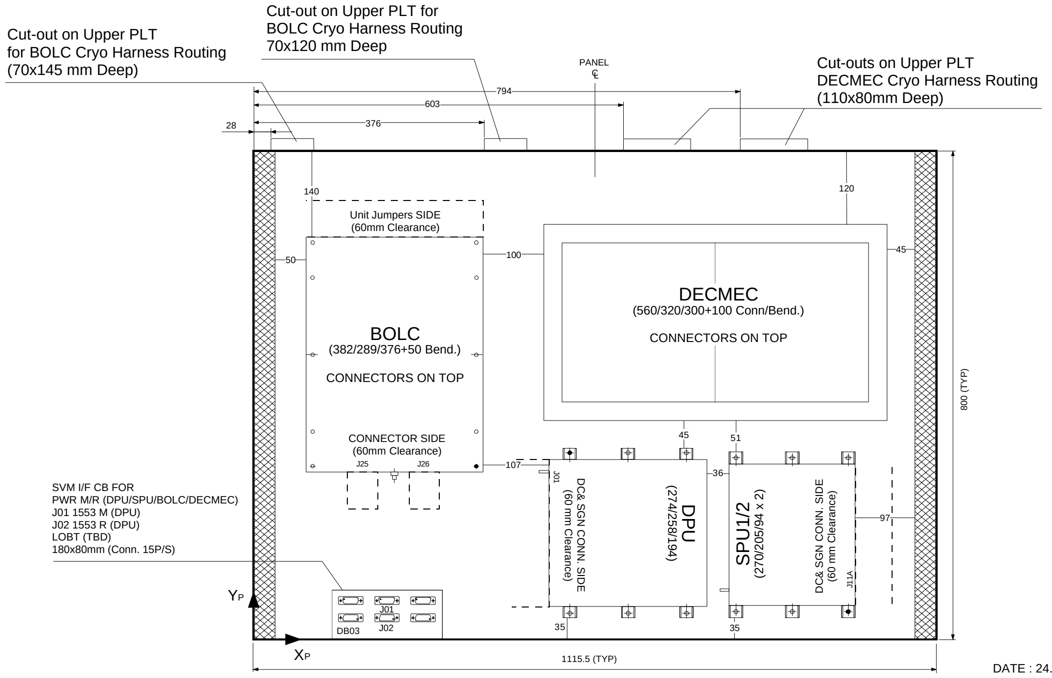
The new configuration panels are based on the mechanical interface drawings for each box and, where they are not available, by the terms of our agreement during convergence meeting with PACS instrument.

The Assumptions made to study the new PACS panel configuration are:

- DECMEC max dim = 560mm. Details relevant to the DECMEC unit are not present, being the relevant interface drawing not still not available.
- SPUs are stacked (as a single box with nom & red units inside and one single thermal I/F to the SVM panel). SPU1/2 updated drawings of the stacked configuration are still not available.
- The proposed accommodation of PACS warm units has also been checked in the third dimensions by means of 3D CAD models against the configuration proposed for the adjacent instrument panels. The 3D check provided positive results.

The status of PACS Warm Units reconfiguration study on board Herschel SVM is shown in the following preliminary 2D sketch:

HERSCHEL PACS PANEL +Y -Z
UNIT LAYOUT



NOTES :
1. DIMENSIONS ARE IN mm
2. BOX ENVELOPES INCLUDES THE MOUNTING FEET
(UNLESS OTHERWISE SPECIFIED)
3. CONNECTOR REFERENCE ON DB03 BRACKETS IS
OF LOWER PLT HARNESS SIDE. PLUGS ARE ON PANEL
HARNESS SIDE

PRELIMINARY
FOR REFERENCE ONLY

DATE : 24.04.02
REV. : A Changes :
- Added cut-out reference quotes
- SPU1/2 relocated

DATE : 17.05.02
REV. B Changes :
- Added reference of SVM Demountability
Connector bracket

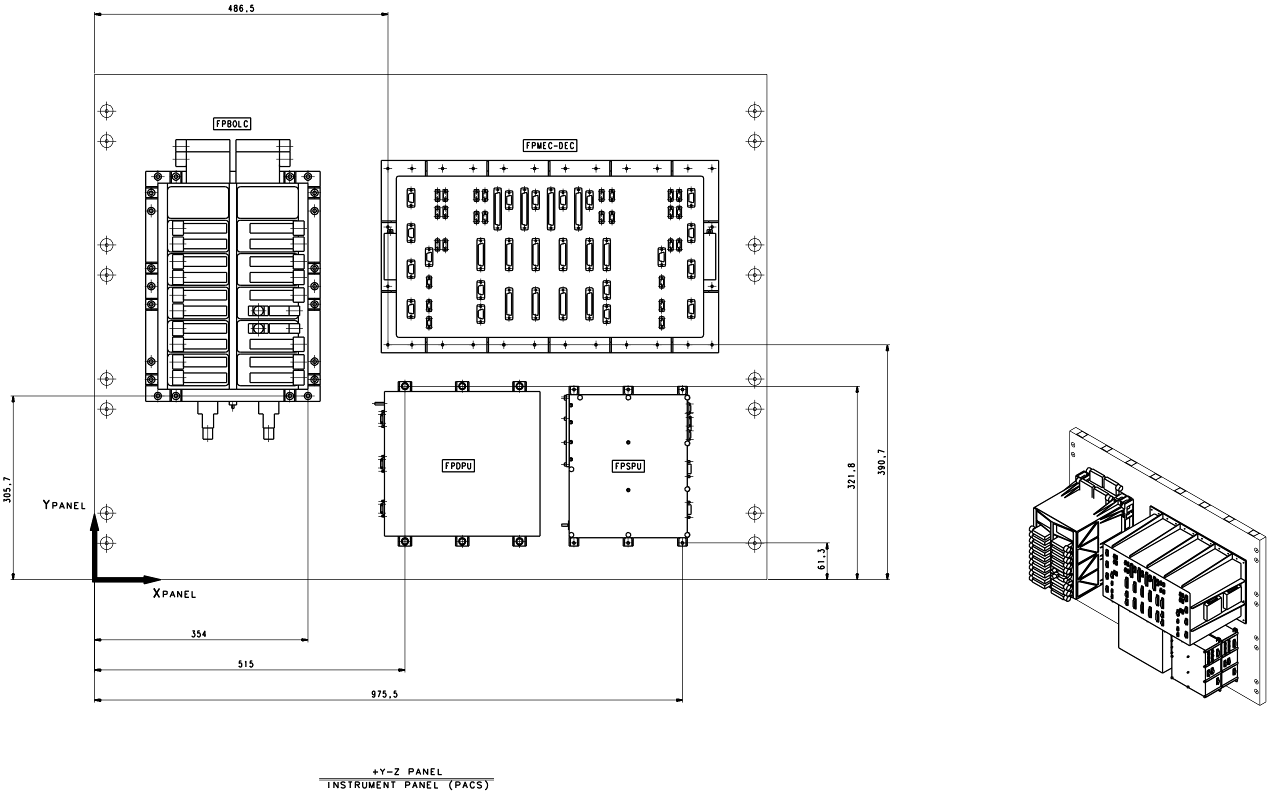


Fig. 3.4.3-1 Herschel PACS panel +Y-Z

3.5 PLANCK WARM UNIT ACCOMODATION

A description of all warm unit accomodation inside Planck SVM is provided in the following paragraphs. The relevant location, mass and dimensions data are detailed in the tables of the single paragraph.

3.5.1 HFI WARM UNITS

The HFI Warm Units are mainly grouped on three dedicated SVM panels, while the Pre-Amplifier Unit is located on the P/L sub. PLT:

- +Y panel: 4CCU, 4CAU, 4KCDE and 4K Current Pre-Regulator
- +Z panel: REU and DPU (nom.+ red.)
- +Y/+Z panel: DCCU
- P\L sub. PLT +X: PAU

In the following table there are the project codes allocated to HFI warm units:

Project Code	**Instrument Unit**
PHDA	HFI 4K Cooler Compressor Unit (4CCU)
PHDB	HFI 4K Cooler Ancillary Unit (4CAU)
PHDC	HFI 4K Cooler Electronics Unit (4KCDE)
PHBA-N	HFI Data Processing Unit (DPU) Nom.
PHBA-R	HFI Data Processing Unit (DPU) Red.
PHCBC	HFI Readout Electronics (REU)
PHEC	HFI Dilution Cooler Contr. Unit (DCCU)
PHDJ	HFI 4K Current Pre-Regulator
PHCBA	HFI Pre-Amplifier Unit (PAU)
PHEAA	0.1K Diluition Cooler 3He Tank
PHEAB	0.1K Diluition Cooler 4He Tank

In the following table there are mass and dimensions of HFI Warm Units (AD-05):

Project Code	Instrument Unit	# of	Dimensions (mm) *)	Nominal Mass (kg)	Allocated Mass (kg)
PHDA	HFI 4K Cooler Compressor Unit (4CCU)	1	460 x 250 x 200	14.20	14.90
PHDB	HFI 4K Cooler Ancillary Unit (4CAU)	1	350 x 350 x 130	7.00	7.90
PHDC	HFI 4K Cooler Electronics Unit (4KCDE)	1	220 x 197 x 194	6.50	7.50
PHBA-N	HFI Data Processing Unit (DPU) Nom.	1	316 x 280 x 90	6.50	6.80
PHBA-R	HFI Data Processing Unit (DPU) Red.	1	316 x 280 x 90	6.50	6.80
PHCBC	HFI Readout Electronics (REU)	1	436 x 411 x 321	33.50	33.50
PHEC	HFI Dilution Cooler Contr. Unit (DCCU)	1	800 x 660 x 260	25.00	26.50
PHDJ	HFI 4K Current Pre-Regulator	1	150 x 150 x 100	2.20	2.70
PHCBA	HFI Pre-Amplifier Unit (PAU)	1	444 x 243 x 215	10.00	11.00
PHEAA	0.1K Diluition Cooler 3He Tank	1	Φ 488	16.00	17.60
PHEAB	0.1K Diluition Cooler 4He Tank	3	Φ 488	48.00	52.80
	Harness (Cryo)	1		6.70	8.00
	HRN Warm Units Interconnecting	1		18.48	22.18
	Piping	1		1.72	2.06
Total				**202.30**	**220.24**

*) Dimensions are envelopes including mounting feet, excluding connectors.

The status of HFI Warm Units configuration on board Planck SVM is:

- <u>+Y Panel (4K panel)</u>:

  The 4K cooler is a set of panel mounted units (4CCU, 4CAU, 4KCDE and 4K Current Pre-Regulator).

The following fig. 3.5.1-1 show the 4K panel with 4CCU, 4CAU, 4KCDE and the 4K Current Pre-Regulator.

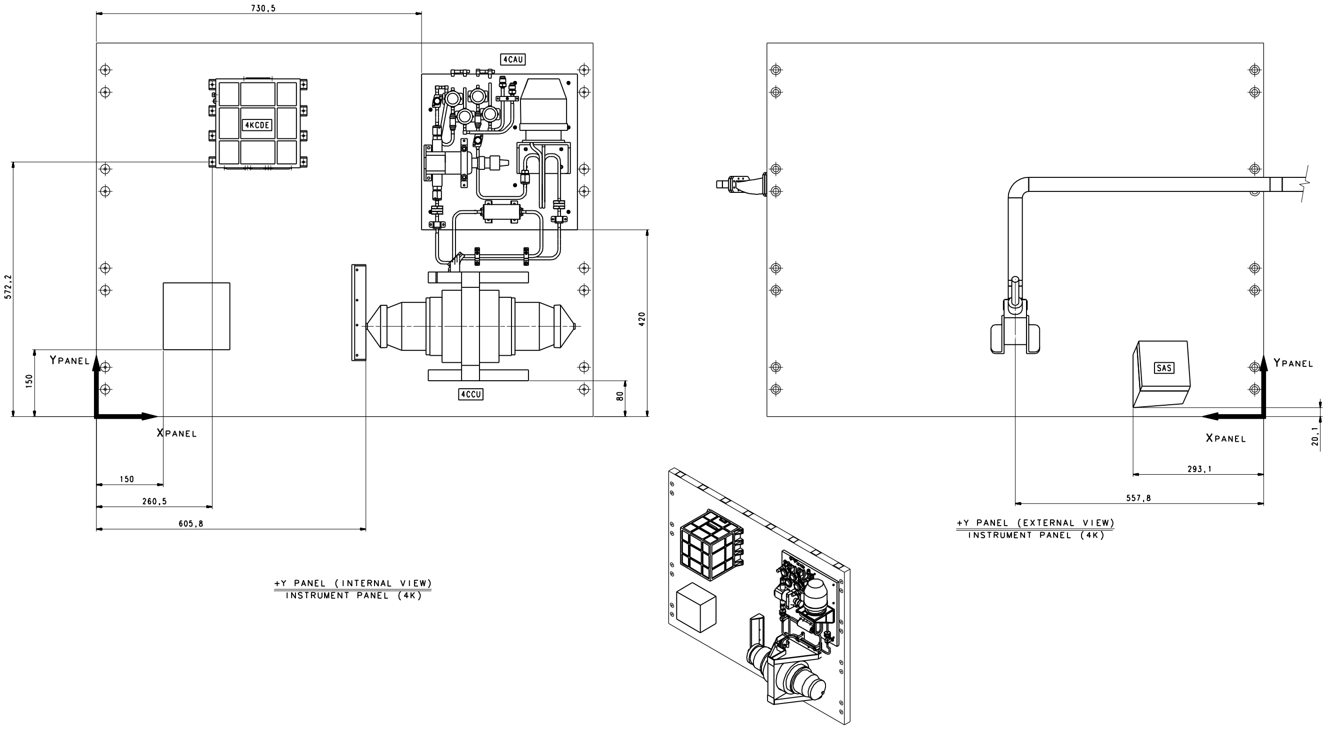


Fig 3.5.1-1 Top View +Y Panel

4CCU to 4CAU connection pipes are defined by the Instrument, while other pipes/harness routing is defined by ALS on the basis of the information provided by ASPI.

- +Z Panel:

Three HFI warm units are accomodated on this panel: the REU and the DPUs (nom + red).

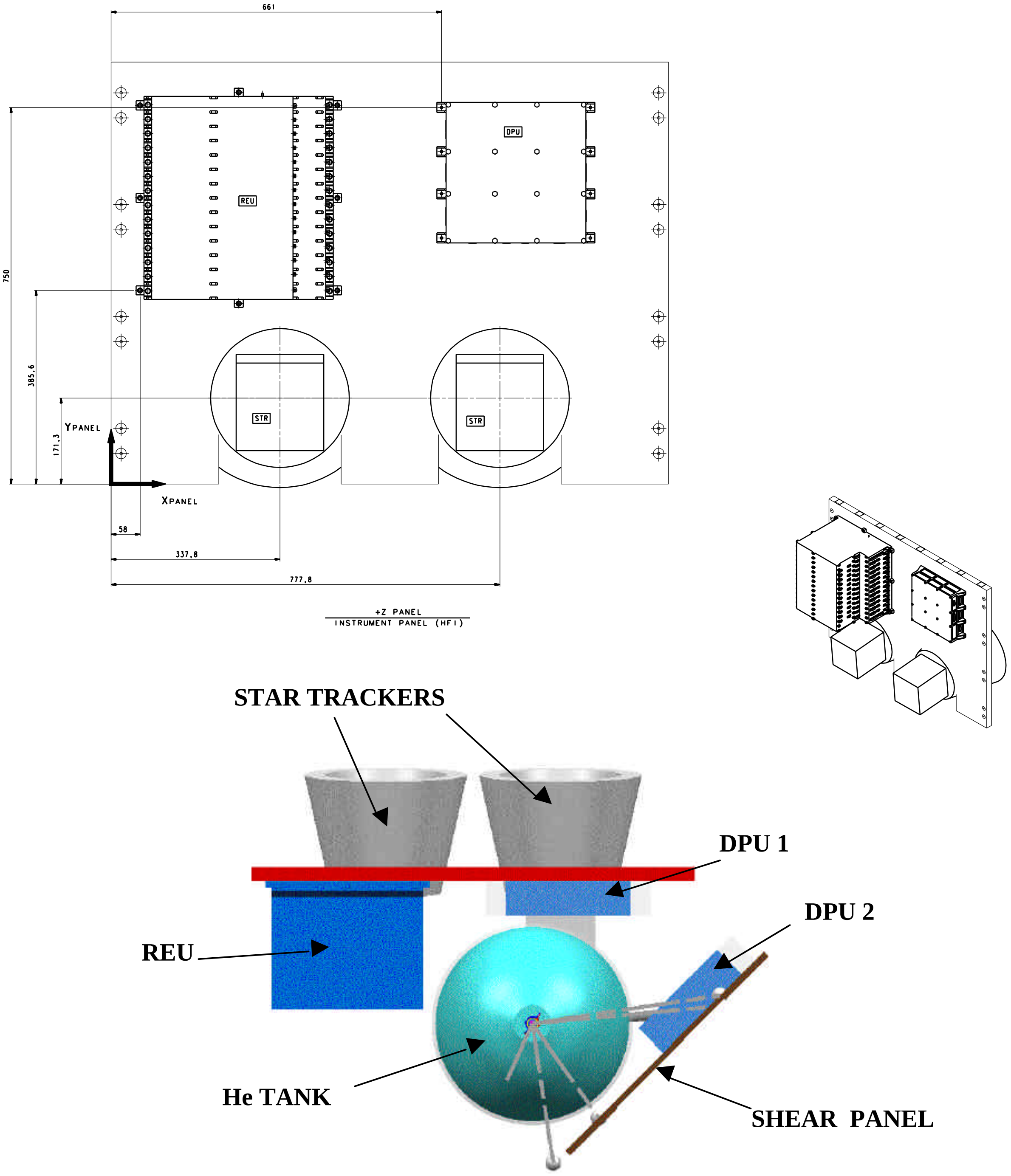


Fig 3.5.1-2 +Z panel and top view with shear panel

On this panel there are two Star Tracker then the DPUs (nom + red) are located as in fig 3.5.1-2; where DPU (nom) is accomodated on the panel, while DPU (red) is accomodated on the shear panel.

- +Y/+Z Panel:

Only one HFI warm unit is accomodated on this panel, the DCCU:

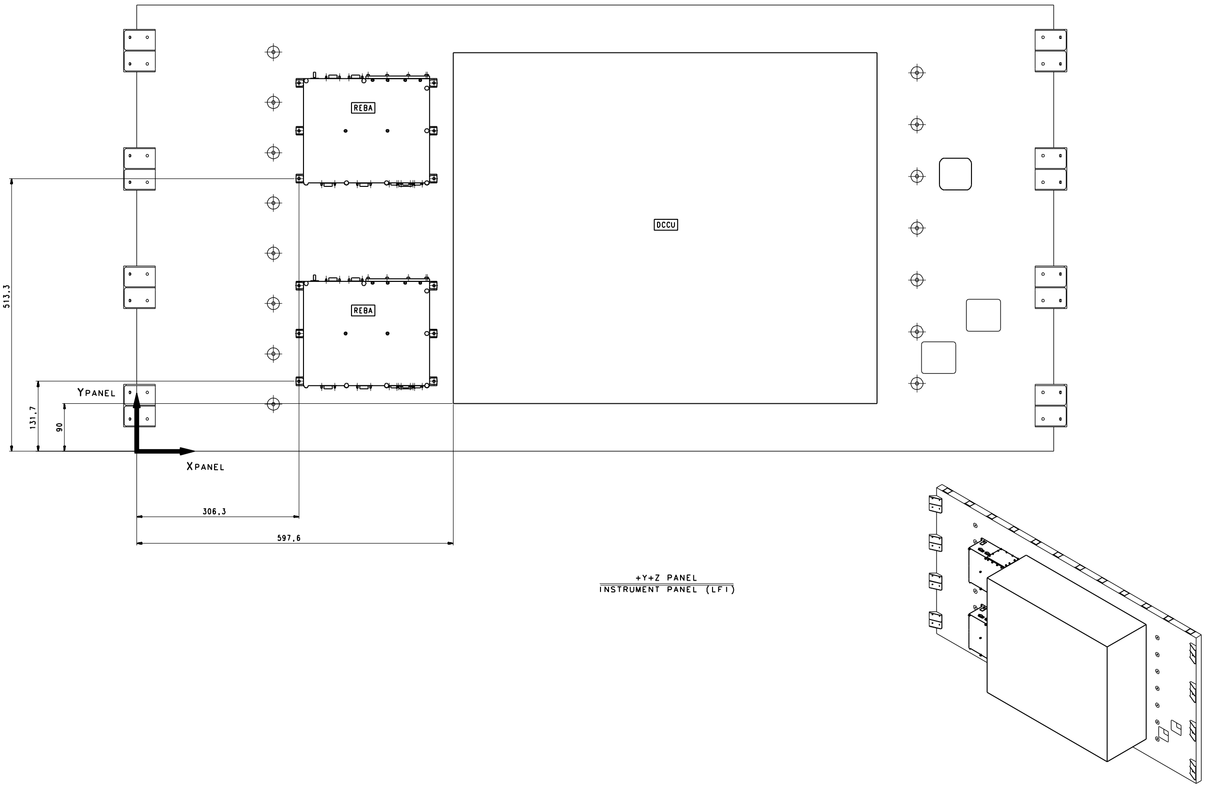


Fig 3.5.1-3 +Y/+Z panel (HFI DCCU; LFI two REBA boxes)

The DCCU is connected to the PLM by means of 5 pipes and to the He-Tanks by means of 4 pipes.
Accessibility to number of valves/connectors must be guaranted at all times (also with the upper closure PLT closed).
An exhaust pipe will be mounted to the DCCU baseplate, through a dedicated cut-out on the +Y/+Z panel.

- P/L sub PLT +X and -X:

The PAU is accomodated on the P/L sub PLT:

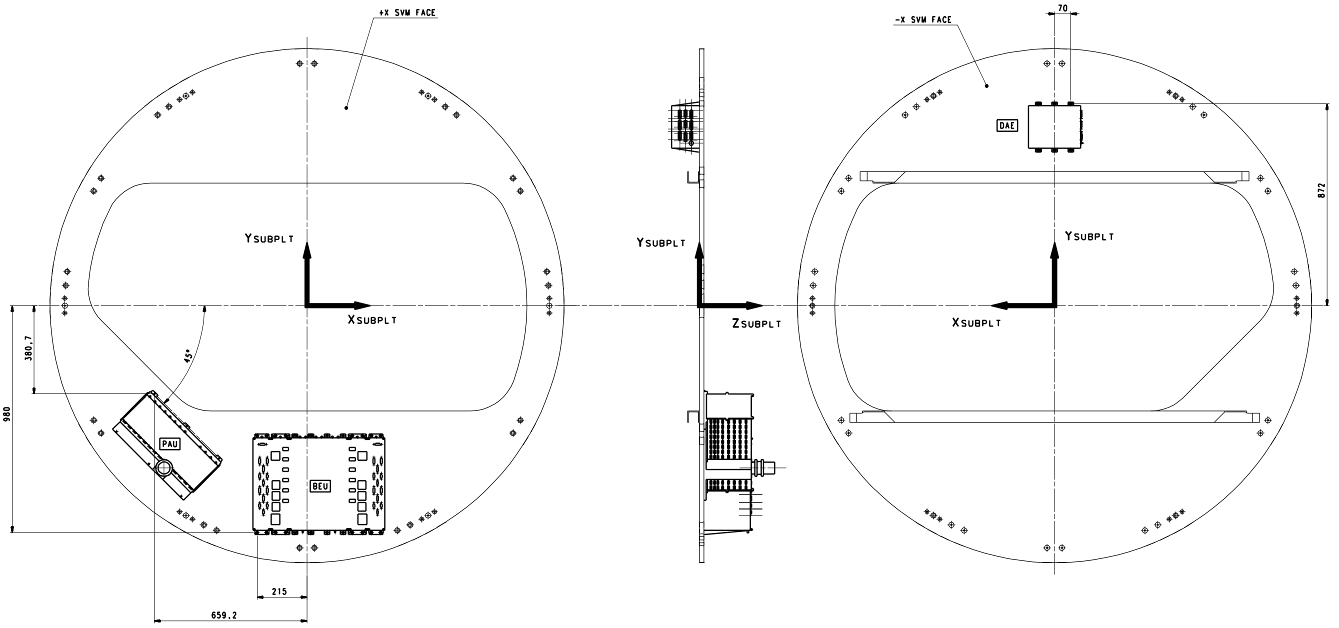


Fig 3.5.1-4 Top View P/L sub PLT +X and -X (HFI PAU; LFI BEU; LFI DAE Control Box)

The PAU and REU are connected and the length of their harness shall not exceed 5000 mm.

3.5.2 LFI WARM UNITS

The LFI Warm Units are four, they are accomodated on the P\L sub PLT +X and on +Y/+Z panel:

- P\L sub PLT +X: BEU (see fig.3.5.1-4 in HFI chapter)
- P\L sub PLT -X: DAE Control Box (see fig.3.5.1-4 in HFI chapter)
- +Y/+Z panel: two REBA (nom+red) (see fig.3.5.1-3 in HFI chapter)

In the following table there are the project codes allocated to LFI warm units:

Project Code	**Instrument Unit**
PLBEU	Back End Unit (BEU)
PLAEF	DAE (Data Acquisition Electronic) Control Box
PLREN	REBA (nominal)
PLRER	REBA (redundant)

The following table there are mass and dimensions of LFI Warm Units (AD-06):

Project Code	**Instrument Unit**	**# of**	**Dimensions (mm) *)**	**Nominal Mass (kg)**	**Allocated Mass (kg)**
PLBEU	Back End Unit (BEU)	1	570 x 432 x 210	30.60	36.70
PLAEF	DAE (Data Acquisition Electronic) Control Box	1	225 x 216 x 119	6.30	7.60
PLREN	REBA (nominal)	1	270 x 215 x 105	4.10	4.50
PLRER	REBA (redundant)	1	270 x 215 x 105	4.10	4.50
	HRN Warm Units Interconnecting	1		10.20	12.24
Total				**55.30**	**65.54**

*) Dimensions are envelopes including mounting feet, excluding connectors.

3.5.3 SCS WARM UNITS

The Sorption Cooler Subsystem is mainly grouped on three dedicated SVM panels (i.e. –Z, +Y/-Z and –Y/-Z):

- -Z panel: two SCE units
- +Y/-Z and –Y/-Z panels: two SCC units

In the following table there are the project codes allocated to SCS warm units:

Project Code	**Instrument Unit**
PSM3	SCS Sorption Cooler Compressor (SCC) nom.
PSR3	SCS Sorption Cooler Compressor (SCC) red.
PSM4	SCS Sorption Cooler Electronic (SCE) nom.
PSR4	SCS Sorption Cooler Electronic (SCE) red.

In the following table there are mass and dimensions of SCS Warm Units (AD-06):

Project Code	**Instrument Unit**	**# of**	**Dimensions (mm) *)**	**Nominal Mass (kg)**	**Allocated Mass (kg)**
PSM3	Sorption Cooler Compressor (SCC) nom.	1	967 x 720 x 250	41.80	50.20
PSR3	Sorption Cooler Compressor (SCC) red.	1	967 x 720 x 250	41.80	50.20
PSM4	Sorption Cooler Electronic (SCE) nom.	1	300 x 300 x 137	8.50	10.20
PSR4	Sorption Cooler Electronic (SCE) red.	1	300 x 300 x 137	8.50	10.20
	Harness (Cryo)	1		2.00	2.40
	HRN Warm Units Interconnecting	1		4.00	4.80
	Piping	1		5.00	6.00
	Spacer	2		6.30	7.56
Total				**117.9**	**141.56**

*) Dimensions are envelopes including mounting feet, excluding connectors.

The Sorption Cooler Compressors and Electronics are mounted to the SVM panels over the Heat Pipes network. The attachment solution proposed by Alenia (aiming to reduce the number of I/F points and to de-couple the I/Fs to the SCC. RD-46) is as follows:

- the horizontal heat pipes will be directly fixed to the SVM panels, by making use of a limited number of inserts by and leaving a number of through inserts free
- then the vertical heat pipes and the spacer panels will be mounted onto the SCC
- finally the SCC plus heat pipes and spacers assembly, will be connected to the SVM panels by means of screws mounted from the external side through the through inserts.

The aforementioned attachment concept is shown in fig. 3.5.3-1 to 3.5.3-6

All of the SCC I/F points have been used and no additional I/F points are required.

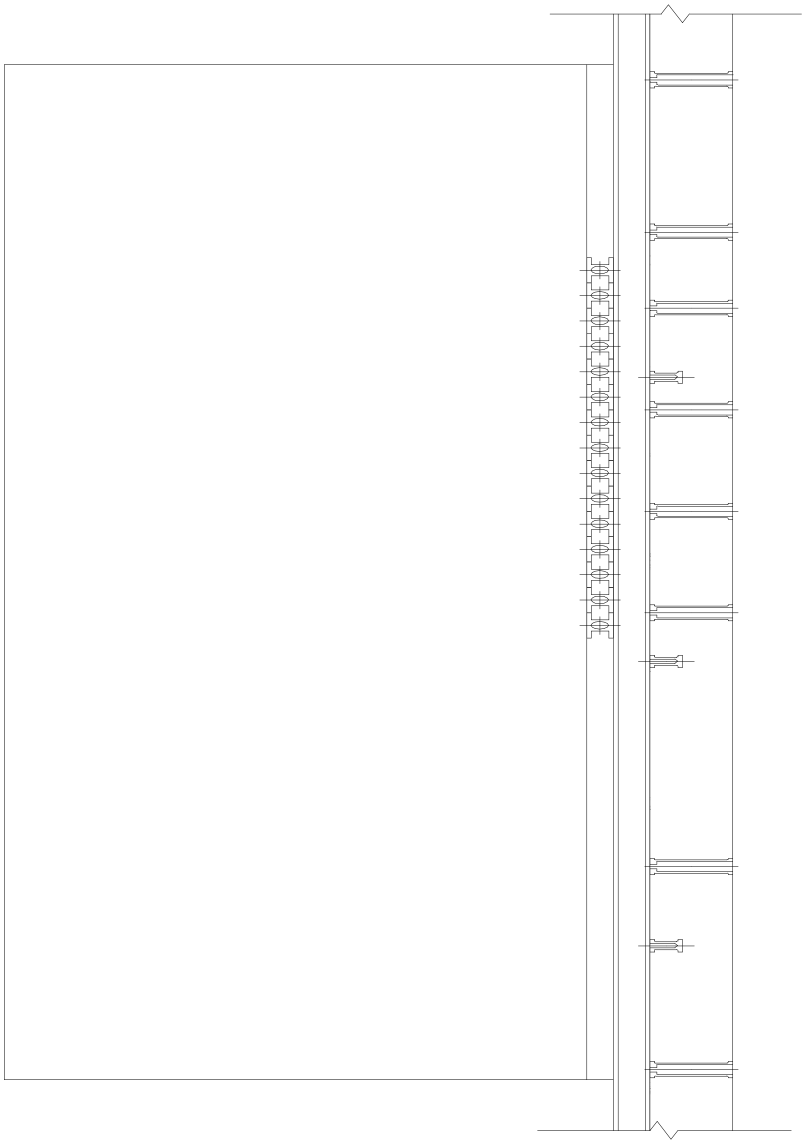


Fig 3.5.3-1 SVM-PLM I/F zone

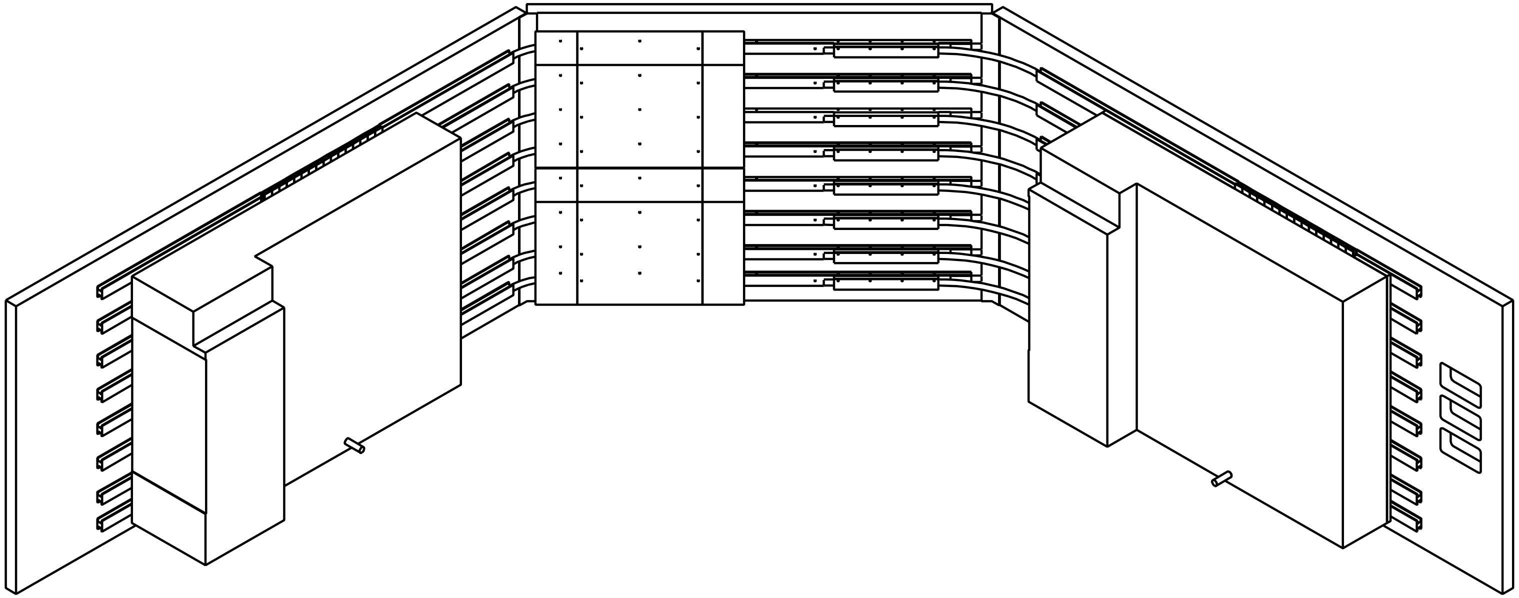


Fig.3.5.3-2 ISO VIEW of SCS Panels (+Y/-Z , -Z, -Y/-Z)

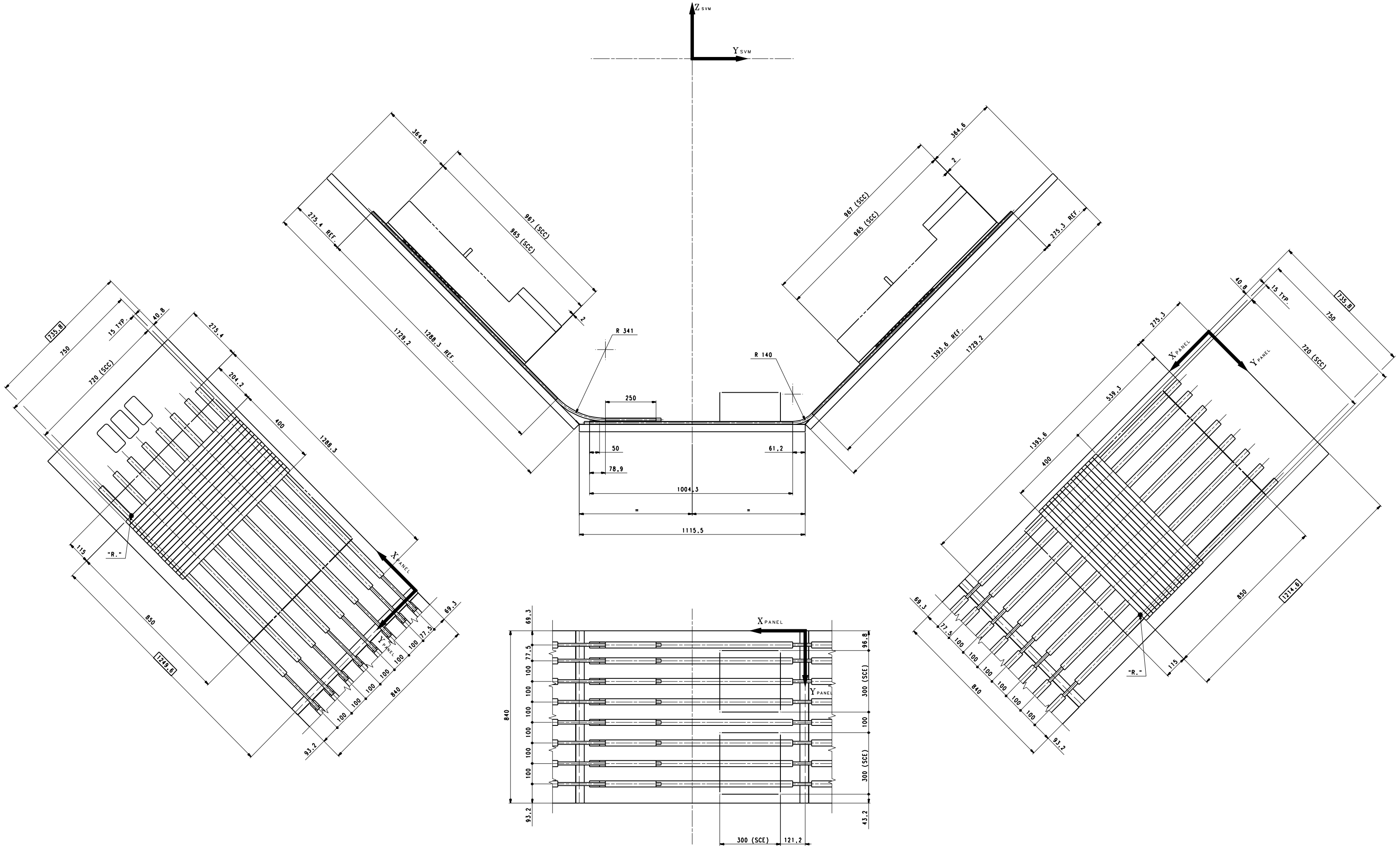


Fig.3.5.3-3 SCS OVERALL DIMENSIONS

SYMBOL	TYPE	QTY
◬	TYPE "A"	55
⊡	TYPE "B"	74
●	TYPE "C"	206

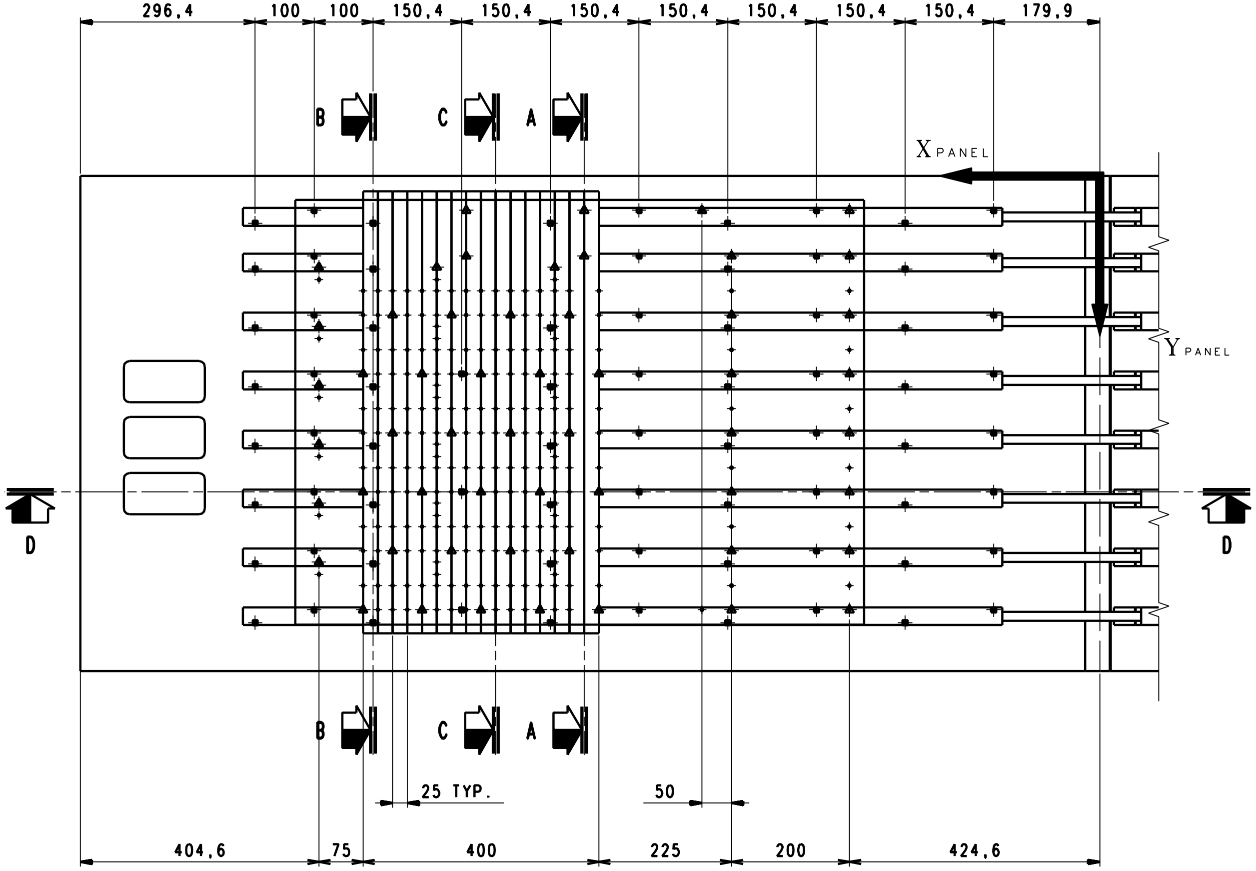
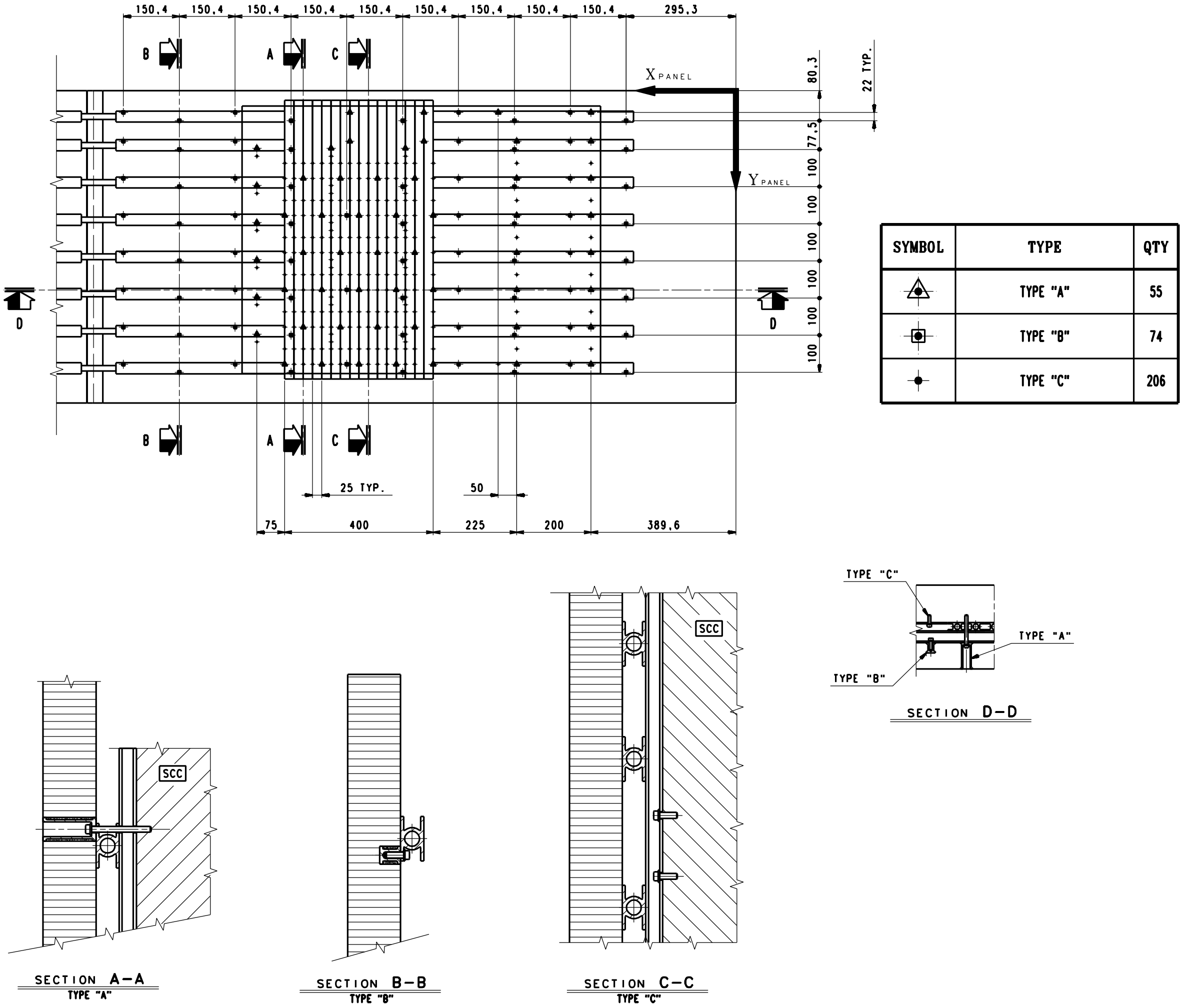


Fig 3.5.3-4 -Y-Z Panel FIXATION SCHEME



SYMBOL	TYPE	QTY
▲	TYPE "A"	55
■	TYPE "B"	74
●	TYPE "C"	206

Fig 3.5.3-5 +Y-Z Panel FIXATION SCHEME

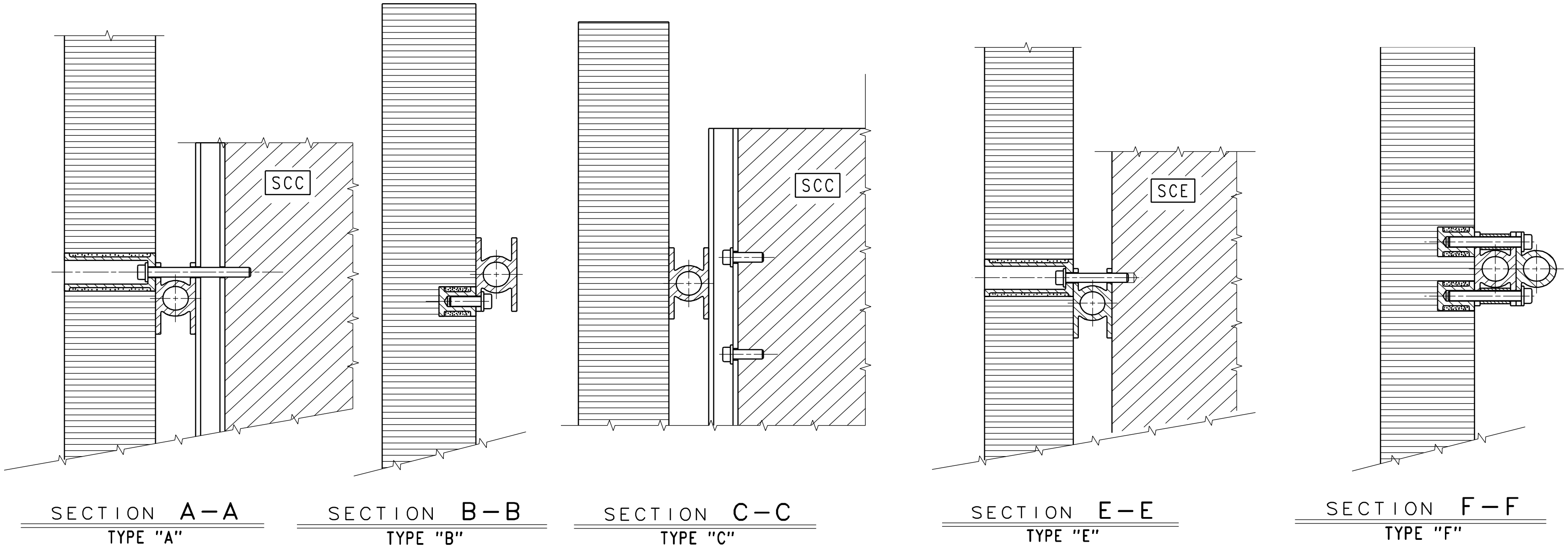


Fig 3.5.3-6 Heat Pipes Typical Connections

Typical "A" and Typical "E" connections are proposed without spacers, if and where spacers will be needed they will be added.
A possible type “G” fixation has already been studied in order to connect vertical and horizontal heat pipe through the panel, where no mounting holes on SCC is available. If the TCS subcontractor will verify the necessity of the additional fixation point at –Y side of the panel, type “G” will be implemented.
The solution presented allows to reduce the total number of panel connections to 110 type A, 178 type B, 412 type C, 36 type E and 64 type F.
The SCC beds are connected to the vertical heat pipe network via a large number of type C connections. The SCC plus heat pipes and spacers assembly is attached to the panel (on top of the horizontal heat pipes network) by means of type A connections. The number of type A connection seems great enough and placed in such a way that no big loads are foreseen for the heat pipes network and the thermal coupling can be assured.
Both SCC and SCE will provide threaded holes M4 with a minimum depth of 9 mm.

During the integration phase, the mechanical compatibility between
- the Sorption Cooler Compressors / Electronics
- the Heat Pipes network
- the SVM -Y-Z, -Z, +Y-Z panels

will be granted by designing very carefully the tolerances chain.

In order to prevent any integration risk, the through holes on the heat pipes will be drilled/milled with sufficiently loose tolerances (ϕTBD) and/or will be slotted. The same shall apply for the through inserts on the SVM panels (ϕTBD tolerance). On the other hand, the SCC/SCE mounting holes pattern will need to be drilled to comply with a 0.2 mm tolerance - as a minimum.

The use of a drilling template (to drill the SCC/SCE first, then the heat pipes and finally the SVM panels), was highlighted as a potential benefit in order to add some confidence to the whole integration process. Such an approach (valid only if used during the manufacturing phase) is to be regarded to as poorly useful if used for verification purposes. In fact, the drilling of the SVM panels will be carried out by means of numeric-control tools, which cannot make use of drilling templates. The same applies to the verification of the SCC drilling pattern, which cannot be done by making use of a template.

3.6 INSTRUMENTS THERMAL INTERFACES

Thermal interfaces of instruments warm units on service module, dissipation and required temperature ranges are shown on the following tables for Herschel and Planck

HERSCHEL PACS		**Power Dissipation [Watt]**			**Temperature Limits [°C]**				
Project Code	**Instrum. Unit**	**Standby Mode**	**Spectrosc. Mode**	**Photomet. Mode**	**Operating Design Range**	**Non Operat. Range**	**GOAL Operating Range**	**Start-up Temp.**	**Switch-off Temp.**
FPDMC	Detector Mechan. Control	20.9	65.0	21.6	-15/+45	-30/+60	N.A./N.A.	-30	+50
FPBOLC	Bolometer Cooler Control	6.6	6.6	48.6	-15/+45	-30/+60	N.A./N.A.	-30	+50
FPDPU	Digital Processing Unit	24.0	24.0	24.0	-15/+45	-30/+60	N.A./N.A.	-30	+50
FPSPU 1	Signal Processing Unit 1 (nom)	30.3	30.3	30.3	-15/+45	-30/+60	N.A./N.A.	-30	+50
FPSPU 2	Signal Processing Unit 2 (red)	0	0	0	-15/+45	-30/+60	N.A./N.A.	-30	+50

HERSCHEL SPIRE		Power Dissipation [Watt]			Temperature Limits [°C]				
Project Code	**Instrum. Unit**	**Standby/ Parallel/ Serendip. Mode**	**Spectrosc. Mode**	**Photomet. Mode**	**Operating Design Range**	**Non Operat. Range**	**GOAL Operating Range**	**Start-up Temp.**	**Switch-off Temp.**
HSDCU	Detector Control Unit	37.0	37.0	37.0	-15/+45	-35/+80	N.A./N.A.	-30	+50
HSFCU	FPU Control Unit	42.9	42.9	42.9	-15/+45	-35/+80	N.A./N.A.	-30	+50
HSDPU	Digital Processing Unit	15.3	15.3	15.3	-15/+45	-35/+80	N.A./N.A.	-30	+50

HERSCHEL HIFI		Power Dissipation [Watt]			Temperature Limits [°C]				
Project Code	**Instrum. Unit**	**Standby Mode**	**Scientific**	**Telecom phase**	**Operating Design Range**	**Non Operat. Range**	**GOAL Operating Range**	**Start-up Temp.**	**Switch-off Temp.**
FHLCU	Local Oscillator Control Unit	26.0	35.4	35.4	-10/+40	-25/+55	N.A./N.A.	-25	+40
FH3DH	3-dB-Coupler Horizontal polarization	0 TBC	0 TBC	0 TBC	-10/+40	-25/+55	N.A./N.A.	-25	+40
FH3DV	3-dB-Coupler Vertical polarization	0 TBC	0 TBC	0 TBC	-10/+40	-25/+55	N.A./N.A.	-25	+40
FHLSU	Local Oscillator Source Unit	5.0	45.8	45.8	-10/+40	-25/+55	N.A./N.A.	-25	+40

FHHRH	High Resolution Spectr. Horizontal polarisation	63.3	63.3	63.3	-10/+40	-25/+55	N.A./N.A.	-25	+40
FHHRV	High Resolution Spectr.Vertical polarisation	63.3	63.3	63.3	-10/+40	-25/+55	N.A./N.A.	-25	+40
FHFCU	Focal Plane Control Unit	13.0	13.0	13.0	-10/+40	-25/+55	N.A./N.A.	-25	+40
FHWEV	Wide-Band Spectr. Electronics Vertical Polarisation	26.9	26.9	26.9	0/+25	-25/+55	N.A./N.A.	-25	+40
FHWEH	Wide-Band Spectr. Electronics Horizontal Polarisation	26.9	26.9	26.9	0/+25	-25/+55	N.A./N.A.	-25	+40
FHICU	Instrument Control Unit	29.6	29.6	29.6	-25/+43	-30/+60	-25./+40	-30	+50
FHWOV	Wide-Band Spectr.Optics Vertical Polarisation	2.2	2.2	2.2	0/+15	-25/+55	0/+10	-25	+30
FHWOH	Wide-Band Spectr.Optics Horizontal Polarisation	2.2	2.2	2.2	0/+15	-25/+55	0/+10	-25	+30

PLANCK LFI		**Power Dissipation [Watt]**			**Temperature Limits [°C]**				
Project Code	**Instrum. Unit**	**Survival Mode**	**Scientific**	**Telecom phase**	**Operating Design Range**	**Non Operat. Range**	**GOAL Operating Range**	**Start-up Temp.**	**Switch-off Temp.**
PLBEU	Back End Unit (BEU)	0	58.7	58.7	-20/+40	-30/+70	-20/+28	TBD	TBD
PLREN	Radiometer Electr.Box Assemply (nominal)	0	41.5	41.5	-20/+50	-30/+70	N.A./N.A.	-30	TBD
PLRER	Radiometer Electr.Box Assemply (redundant)	0	0	0	-20/+50	-30/+70	N.A./N.A.	-30	TBD
PLAEA	DAE C.B.	0	20	20	-20/+45	-30/+70	-20/+28	TBD	TBD

PLANCK HFI		**Power Dissipation [Watt]**			**Temperature Limits [°C]**				
Project Code	**Instrum. Unit**	**Survival Mode**	**Scientific**	**Telecom phase**	**Operating Design Range**	**Non Operat. Range**	**GOAL Operating Range**	**Start-up Temp.**	**Switch-off Temp.**
PHDA	4K Cooler Compressor Unit (4CCU)	0	60	60	-10/+40	-20/+40TBC	N.A./N.A.	TBD	TBD
PHDB	4K Cooler Ancillary Unit (4CAU)	0	15	15	-10/+40	-20/+50	N.A./N.A.	TBD	TBD
PHDC	4K Cooler Electronic Unit (4KCDE)	0	41	41	-10/+40	-20/+50	N.A./N.A.	TBD	TBD
PHBA-N	Data Processing Unit (DPU) Nom	0	32	32	-10/+40	-20/+50	N.A./N.A.	TBD	TBD
PHBA-R	Data Processing Unit (DPU) Red	0	0	0	-10/+40	-20/+50	N.A./N.A.	TBD	TBD

PHCBC	Readout Electronics (REU)	0	92	92	-20/+35	-20/+50	-20/+30	TBD	TBD
PHEC	Dilution Cooler Contr. Unit (DCCU)	0	19	19	-10/+40	-20/+50	N.A./N.A.	TBD	TBD
PHDJ	4K Current PreRegulator	0	20	20	-10/+40	-20/+50	N.A./N.A.	TBD	TBD
PHCBA	Pre-Amplifier Unit (PAU)	0	15	15	-20/+40	-20/+50	-20/+30	TBD	TBD

PLANCK SCS		**Power Dissipation [Watt]**			**Temperature Limits [°C]**				
Project Code	**Instrum. Unit**	**Survival Mode**	**Scientific**	**Telecom phase**	**Operating Design Range**	**Non Operat. Range**	**GOAL Operating Range**	**Start-up Temp.**	**Switch-off Temp.**
PSM3	Sorption Cooler Comp.Nom	0	470*	470*	-13/+7	-20/+60	N.A./N.A	-20(**)	TBD
PSR3	Sorption Cooler Comp.Red	0	0	0	-13/+7	-20/+60	N.A./N.A	-20(**)	TBD
PSM4	Sorption Cooler Elec.Nom	0	110	110	-10/+40	-20/+60	N.A./N.A	-10	TBD
PSR4	Sorption Cooler Elec.Red	0	0	0	-10/+40	-20/+60	N.A./N.A	-10	TBD

*) Sizing case for SCC Panel 520 W

**) The SCC can be switched on at ambient temperature and pressure for only a very limited period of TBD minutes.
The SCC switch on temperature in vacuum (pressure TBD) is TBD.

3.7 POWER WARM UNITS INTERFACE

The power to the Herschel and Planck instruments is supplied from the SVM via Latching Current Limiters (LCL). PCDU interfaces with the Herschel Instruments are identified in the following table:

HERSCHEL Allocation	TO	TYPE	PROTECTED	CLASS
HIFI INSTRUMENT				
HIFI ICU Nom	FHICU	LCL	NO	II
HIFI ICU Red	FHICU	LCL	NO	II
HIFI LCU Nom	FHLCU	LCL	YES	III
HIFI LCU Red	FHLCU	LCL	YES	III
HIFI WEH	FHWEH	LCL	NO	II
HIFI WEV	FHWEV	LCL	NO	II
HIFI HRH	FHHRH	LCL	NO	II
HIFI HRV	FHHRV	LCL	NO	II
PACS INSTRUMENT				
PACS BOLC Nom	FPBOLC	LCL	YES	II
PACS BOLC Red	FPBOLC	LCL	YES	II
PACS MEC1	FPMEC1	LCL	YES	II
PACS MEC2	FPMEC2	LCL	YES	II
PACS DPU Nom	FPDPU	LCL	NO	II
PACS DPU Red	FPDPU	LCL	NO	II
PACS SPU Nom	FPSPU1	LCL	NO	II
PACS SPU Red	FPSPU2	LCL	NO	II
SPIRE INSTRUMENT				
SPIRE HSDPU Nom	HSDPU	LCL	YES	I
SPIRE HSDPU Red	HSDPU	LCL	YES	I
SPIRE HSFCU Nom	HSFCU	LCL	YES	III
SPIRE HSFCU Red	HSFCU	LCL	YES	III

PCDU interfaces with the Planck Instruments are identified in the following table:

PLANCK Allocation	TO	TYPE	PROTECTED	CLASS
HFI INSTRUMENT				
HFI REU Proc. Nom	PHCBC	LCL	YES	I
HFI REU Proc. Red	PHCBC	LCL	YES	I
HFI 4KCDE Nom	PHDC	LCL	NO	II
HFI 4KCDE Red	PHDC	LCL	NO	II
HFI DPU Nom	PHBAN	LCL	YES	II
HFI DPU Red	PHBAR	LCL	YES	II
HFI DCE	DCE	LCL	NO	I
HFI REU belts group 0;1	PHBAR	LCL	NO	II
HFI REU belts group 2;3	PHBAR	LCL	NO	II
HFI REU belts group 4;5	PHBAR	LCL	NO	II
HFI REU belts group 6;7	PHBAN	LCL	NO	II
HFI REU belts group 8;9	PHBAN	LCL	NO	II
HFI REU belts group10;11	PHBAN	LCL	NO	II
HFI 4KC Drive bus Nom	PHDC	Par-LCL	YES	III
HFI 4KC Drive bus Nom	PHDC	Par-LCL	YES	III
HFI 4KC Drive bus Red	PHDC	Par-LCL	YES	III
HFI 4KC Drive bus Red	PHDC	Par-LCL	YES	III
LFI INSTRUMENT				
LFI REBA Nom	PLREN	LCL	YES	II
LFI REBA Red	PLRER	LCL	YES	II
LFI DAE Nom	PLBEU	LCL	YES	III
LFI DAE Red	PLBEU	LCL	YES	III
SCS INSTRUMENT				
SCE Nom	PSM4	LCL	YES	III
SCE Red	PSR4	LCL	YES	III
SCC Nom 1	PSM4	Par-LCL	YES	III
SCC Nom 2	PSM4	Par-LCL	YES	III
SCC Nom 3	PSM4	Par-LCL	YES	III
SCC Nom 4	PSM4	Par-LCL	YES	III
SCC Red 1	PSR4	Par-LCL	YES	III
SCC Red 2	PSR4	Par-LCL	YES	III
SCC Red 3	PSR4	Par-LCL	YES	III
SCC Red 4	PSR4	Par-LCL	YES	III

3.8 CDMU HERSCHEL-PLANCK INSTRUMENTS

- Herschel InstrumentsTemperature Sensors:

On Herschel, the Thermistors to instruments are allocated as follows:

- 12 to **PACS**
As per AD-47 § 5.2.3.3 (which refers to AD-04 section 5.11, which refers to AD-04 section 5.7.4)
  - 2 to FPDMC1
  - 2 to FPDMC2
  - 2 to FPBOLC
  - 2 to FPDPU
  - 2 to FPSPU1
  - 2 to FPSPU2

- 0 from **HIFI**
As per AD-47 § 5.2.3.1 (which refers to AD-03 section 5.11)

- 0 from **SPIRE**
As per AD-47 § 5.2.3.2 (which refers to AD-02 section 5.11, which refers to AD-02 section 5.7.5.2)

- Herschel Instruments Digital Relay Status Acquisition Interfaces:

- 1N+1R from **SPIRE HSDPU**
As per AD-47 § 5.2.3.2 (which refers to AD-02 section 5.11)
- Digital Processing Unit (DPU) ON/OFF Status

- 1N+1R from **SPIRE HSFCU**
As per AD-47 § 5.2.3.2 (which refers to AD-02 section 5.11)
- Detector Readout and Control Unit (FSFCU) ON/OFF status

- Herschel Instruments Synchronisation Signals:

On Herschel, these Sync Signals are allocated as follows:

- 1N+1R to **SPIRE FSDPU** (TBC)
TBC is due to the fact that AD-47 § 5.2.3.2 refers to AD-02 section 5.11. In this section there are no requirements, while par. 5.10.4.2 seems including the above mentioned sync signals.

- 0 to **HIFI**
As per AD-47 § 5.2.3.1 (which refers to AD-03 section 5.11)

- 0 to **PACS**
As per AD-47 § 5.2.3.3 (which refers to AD-04 section 5.11)

- Herschel Instruments Spacecraft MIL-STD-1553 Bus:

On Herschel the Bus is allocated as follows:

- HIFI FHICU, as per AD-47 par 5.2.3.1
- SPIRE FSDPU, as per AD-47 par 5.2.3.2
- PACS FPDPU, as per AD-47 par 5.2.3.3

CDMU HERSCHEL INSTRUMENTS

Subsystem	Unit	Therm	Relay Status	131 kHz LOBT Sync	Spacecraft 1553 Bus Connections
HIFI	**FHICU**				2
PACS	**FPDPU**	2			2
	FPDMC1	2			
	FPDMC2	2			
	FPBOLC	2			
	FPSPU1	2			
	FPSPU2	2			
SPIRE	**FSFCU**		2		
	FSDPU		2	2 TBC	2

- Planck Instruments Temperature Sensors:

On Planck, the Thermistors to instruments are allocated as follows:

- 26N+26R from **HFI**
As per AD-47 § 5.3.3.1.1 (which refers to AD-05 section 5.11, which refers to AD-05 section 5.7.5)

  - 12+12 Spacecraft Powered Thermistors (AD-05 par. 5.7.5.1), allocated to the following Units
    - PHBA
    - PHCBA
    - PHCBC
    - PHDA
    - PHDB
    - PHDC
    - PHEC
  - 14+14 Spacecraft HSK Thermistors (AD-05 par. 5.7.5.2), allocated to the following Units
    - PHBA
    - PHCBA
    - PHCBC
    - PHDA
    - PHDB
    - PHDC
    - PHEC

- 1 from **LFI PLBEU**
As per AD-47 § 5.3.3.1.2 (which refers to AD-06 section 5.11, which refers to AD-06 section 5.7.5)

- Planck Instruments Synchronisation Signals:

On Planck, these Sync Signals are allocated as follows:

- 2 to **HFI**
As per AD-47 § 5.3.3.1.1 (which refers to AD-05 section 5.11)

- 1 to **PHBAN**
- 1 to **PHBAR**

- 1N+1R to **LFI DAE (PLBEU)**
As per AD-47 § 5.3.3.1.2 (which refers to AD-06 section 5.11)

- 1N+1R to **LFI REBA**
As per AD-47 § 5.3.3.1.2 (which refers to AD-06 section 5.11)

- Planck Instruments Spacecraft MIL-STD-1553 Bus:

On Planck the Bus is allocated as follows:

- HFI PHBAN and **PHBAR**, as per AD-47 par 5.3.3.1.1
- LFI PLREN and **PLRER**, as per AD-47 par 5.3.3.1.2
- SCE, as per AD-47 par 5.3.3.1.2

CDMU PLANCK INSTRUMENTS				
Subsystem	**Unit**	**Therm**	**131 kHz LOBT Sync**	**Spacecraft 1553 Bus Connections**
HFI	**PHBAN**	5	1	1
	PHBAR	5	1	1
	PHCBA	5		
	PHCBC	5		
	PHDA	5		
	PHDB	5		
	PHDC	5		
	PHEC	5		
LFI	**PLREN**		1	1
	PLRER		1	1
	PLBEU	1	2	
SCS	**SCE**			2

3.9 HERSCHEL-PLANCK SYSTEM MODES

To each satellite operational Life Phase is associated one or several System modes. The following table illustrates the correspondence between both. In the following status and constraints applicable to the instruments are identified.

SATELLITE LIFE PHASE		**SYSTEM MODE**
Launch Phase		Pre-Launch/Launch Mode
Transfer Phase	Initial Operation Phase	Housekeeping 1 Mode
Transfer Phase	Platform Commissioning & Performance Verification Phases	Housekeeping 2 Mode
Routine Scientific Phase	Science Commissioning Phase	Scienze Modes
	Observation Phase	Scientific Autonomy Mode
	Telecommunication	Telecommunication

3.9.1 PRE-LAUNCH/LAUNCH MODE

During launch, all instruments are switched off, except HFI (Planck) which is in launch mode to provide power to the 4K cooler for launch lock.

3.9.2 HOUSEKEEPING MODES

The housekeeping modes are the nominal system modes when no scientific operations are performed.
Two housekeeping modes have been defined:

- HK1 which is the initialization mode at separation
- HK2 which corresponds to the routine mode in the absence of scientific activity

3.9.2.1 HK1

In this HK1 mode, the payload instruments are OFF.
Transition from HK1 mode to HK2 mode is performed by ground command.

3.9.2.2 HK2

HK2 can be divided into sub-modes:
- When the spacecraft is in ground visibility: HK2/V sub-mode
- When the spacecraft is not in ground visibility: HK2/NV sub-mode

Transition between the two HK2 sub-modes (i.e. HK2/v and HK2/NV) is performed by ground command but can also be done by timeline service (TBC).

3.9.2.2.1 HK2/V

It is possible to use all Thermal Control Subsystem modes.
The instruments are individually powered ON by ground TC or MTL service and set to a safe mode (e.g. instrument safe mode), following procedures defined by instruments.
Only housekeeping data from the instruments are collected and trasmitted to the ground. The spacecraft receives TC from ground and download housekeeping telemetry.

3.9.2.2.2 HK2/NV

Housekeeping data from the instruments (if switched ON) and platform are stored in the mass memory.

3.9.3 SCIENCE MODES

Science modes are the spacecraft modes of operation during scientific mission.
Transition to Science modes is performed only from HK2 mode and only under ground telecommand or time-tagged command (MTL service).
It is possible to perform transition from Science modes to HK2 mode under ground telecommand or time-tagged command (MTL service).

Science mode is divided into 2 modes:
- Scientific Autonomy mode (SCI/AUT), which corresponds to nominal science observation without ground contact
- Telecommunication mode (SCI/TC), which corresponds to phases in ground contact during science activities.

Transition between the two science modes (i.e. SCI/AUT and SCI/TC) is triggered by ground command or by a time tagged command (defined in the MTL service).

Science modes are also used during science commissioning phase to validate proper functioning of the satellite and payload.

During science modes (i.e. both scientific autonomy mode and telecommunication mode), the operations on both Herschel and Planck follow the commands defined by the on-board mission timeline service.

3.9.3.1 SCI/AUT

On Herschel, the observations consist in a succession of slew and fixed pointing. Pre-programmed modes of observation in the on-board software allow to perform complex observation sequences without requiring complex telecommand sequences from ground.
These observation modes are:
- Raster pointing with or without OFF position
- Position switching
- Nodding.

In addition, a scanning mode is also specified for Herschel. It is used for Line scanning with or without OFF position.

Similarly, orbit control maneuvers can be programmed in the timeline and performed without ground link.

The Herschel scientific observation is basically performed by one instrument, which is in Prime mode while the other instruments are in standby. There are two other possible operational modes for the payload:

- SPIRE in Prime mode, PACS in parallel mode (parallel means PACS is opereted simultaneously with SPIRE. This allows more efficient large-scale multi-band mapping) performing photometer observations with a degraded sensitivity and spatial resolution. HIFI is in standby mode.

- During slew, HIFI and PACS are in standby (standby mode is characterized by the fact that no science data is produced by the Instruments, only HK). SPIRE can perform useful observations with its photometer in the so-called “serendipity” mode.

The following table summarizes the Herschel payload modes:

MODE	HIFI	PACS	SPIRE	COMMENTS
1	Prime	Standby	Standby	
2	Standby	Prime	Standby	
3	Standby	Standby	Prime	
4	Standby	Parallel	Prime	TM rates will be shared between PACS and SPIRE. PACS and SPIRE observe at the same time.
5	Standby	Standby	Specific mode: “Serendipity”	During slew. All TM bandwidth available for SPIRE.

On Planck, the basic operational mode is based on parallel operation of HFI and LFI. Alternative modes exist with one of the experiment in Prime mode and the other in standby mode, as shown in the following table.

MODE	HFI	LFI
1	Prime	Prime
2	Prime	Standby
3	Standby	Prime

The instruments are constantly scanning the celestial sphere and the spin axis direction is adapted regularly to follow the Planck scanning law at up to 10 deg. from the Sun, as defined in the on-board mission timeline.

During autonomy mode, the housekeeping data from the platform and instruments as well as scientific data are collected and stored in the mass memory for subsequent downloading during a telecommunication period.

The mass memory is sized to store 48 hours of data with margins.

3.9.3.2 SCI/TC

During telecommunication mode, the spacecraft are Earth pointed to download the scientific data stored in the mass memory during the whole duration of the visibility period.
On Planck, the scientific observation continues nominally in parallel to telecommunication.
On Hershel, the observations are also carried out in SCI/TC mode provided the antenna earth-pointed constraint is respected.
Scientific data collected during telecommunication mode are either transmitted real time or stored in the mass memory for transmission at the end of the telecommunication period or during a subsequent one.
(Herschel) wheel unloading is performed during Telecommunication mode (SCI/TC).
For both spacecraft, the payload modes of operations are similar to the ones in science autonomy mode (SCI/AUT). However, on Herschel, some specific payload housekeeping tasks such as coolers recycling will be preferably conducted in science telecommunication mode (SCI/TC).

3.9.4 SURVIVAL MODES

Survival modes are reached in case of:

- major on-board failures (i.e. system failures)
- computers failures.

When transitioned into survival modes the spacecraft:

- Perform a reconfiguration of the failed module
- Is put in safe conditions switching the instrument in safe or OFF

3.9.5 MODES LINKS AND TRANSITIONS

The following table summarizes the Herschel operational modes.

HERSCHEL SATELLITE			
Satellite Mode	**Sub-Mode**	**Payload Modes**	**Power Source**
Science (SCI)	**Autonomy (AUT)**	- 1 instrument Prime; others in a safe mode - PACS Prime, SPIRE parallel - SPIRE in serendipity	SA
	Telecom-munication (TC)	- 1 instrument Prime; others in a safe mode - PACS Prime, SPIRE parallel	SA
HK1		Instruments OFF	Battery or SA
HK2	**V**	Instruments OFF or in a safe mode	SA
	NV		SA
Survival	**SM1**	Instruments in a safe mode	Battery or SA
	SM2	Instruments OFF	Battery or SA
Launch	**LUM**	Instruments OFF	Battery

SA: Sun Acquisition

The following table summarizes the Planck operational modes.

PLANCK SATELLITE			
Satellite Mode	**Sub-Mode**	**Payload Modes**	**Power Source**
Science (SCI)	**Autonomy (AUT)**	- 2 intruments Prime - 1 Prime, 1 in a safe mode	SA
	Telecom-munication (TC)	- 2 instruments Prime - 1 Prime, 1 in a safe mode	SA
			SA
			SA
HK1		Instruments OFF	Battery or SA
HK2	**V**	Instruments OFF or in a safe mode	SA
	NV		SA
Survival	**SM1**	Instruments in a safe mode	Battery or SA
	SM2	Instruments OFF	Battery or SA
Launch	**LUM**	Instruments OFF	Battery

SA : Sun Acquisition

4. TRADE-OFFS AND SVM SELECTION

This section is included to help the comprehension of the selected HERSCHEL/PLANCK SVM design and to explain the steps and the alternatives investigated and traded in order to converge on the optimum/preferred solution.
The major SVM trade-offs are herein only summarised in terms of reasons for doing them, their link with the design drivers, major results obtained and conclusions. Details are left to dedicated technical Notes where all the peculiar aspects are treated.

This section is kept into the document to maintain the traceability of the design evolution, while some trade-offs have been deleted in this issue because they are superseded by events.

4.1 CONFIGURATION OPTIONS AND TRADE-OFFS

4.1.1 PND/AND

A trade-off has been carried out, between the different approaches to nutation damping depicted in proposal (see H-P-TN-AI-0004); namely:
a Passive Nutation Damping (PND) based on a dedicated damping device;
an Active Nutation Damping (AND), based on estimation with the STar Mapper (STM) measurements only; and actuation trough a set of 1 N thrusters
an AND based on estimation with the gyro (GYR) measurements only, and actuation trough the same set of 1 N thrusters.
A fourth alternative (AND based on the measurements of a Star Tracker, STR) has been discarded since the STR is unsuitable for relatively high rotation rates (higher than 4 ? /sec) like the one of Planck.
The feasibility of PND cannot be assessed without a long and expensive development activity, with uncertain prospects. In fact, the study on a Passive Nutation Damper, developed and manufactured by URENCO and applied to the Planck S/C requirements, led to dimensioning values of the model parameters outside the domain of the current established design of the Damper (which has been designed for faster spin rates). Then, an ad-hoc feasibility study (long and expensive) should be required and a positive conclusion is not ensured. For these reasons, the PND option has been judged unfit and then discarded.
Two different options of AND (based on STM or on GYR measurements) have been considered; the results obtained must be judged from two different points of view.
From the point of view of the NAM efficiency, the residual nutation left by AND (either with STM or with GYR) is acceptable with a good margin and no significant performance degradation is expected from the inertia uncertainty or variation.
On the contrary, with reference to the 0.02 arcmin requirement on RPE (which should still be reduced by the further contribution to nutation coming from the NAM), the AND performance does not meet the requirement.
Since the main limitation comes from the thrusters, no improvement can come from the utilisation of a GYR instead of a STM for nutation determination; furthermore, a GYR device is not included in the current baseline configuration for Planck and its utilisation should require the addition of one more unit, with impacts on budgets (mass, power) and costs.
Then, we can conclude that the 0.02 arcmin requirement on RPE is, in any case, not compatible with the present SVM baseline configuration, while the NAM feasibility is compatible with both the AND configurations (based on STM and on GYR). For this reason, the AND approach based on the STM measurement only is selected, since it appears to be feasible and suitable for NAM feasibility requirements, and it can be implemented with the baseline configuration devices (i.e., without adding a GYR unit).
Finally, in order to accurately estimate the control performance, it shall be necessary to perform a sensitivity analysis with respect to the values of the inertia tensor. In fact, these values are known with a certain margin of accuracy and, in any case, they vary along the mission (from the wet to the dry conditions).

4.1.2 Li-Ion Battery Cells

A trade-off has been conducted in order to choose the most appropriated technology to be adopted for Li-Ion Battery cells.
Two kind of Li-Ion battery cells have been identified:

- Low Capacity Cells
- High Capacity Cells

The analysis is treated in a dedicated Report, “Battery Cell Capacity and Redundancy Trade-Off”, H-P-RP-AI-0002.
The summary of the trade-off is reported in the following.

The following table presents a summary of the main characteristics of each kind of battery.

	Low Capacity	*High Capacity*
Configuration	6 series x 24 parallel	6 series
Cell Capacity	1.5Ah	38.6Ah
Theoretical Energy	777Wh	832Wh
Mass	6.75 kg	10 kg
Dimensions	320x220x100 mm (7l)	240x150x270 mm (9 l)
Effects of single cell failure	4.2% less Energy (1/24 strings) Same Voltage	16% Lower Energy and Voltage (1/6 cells)
Notes	Possible use of Rosetta modules (delta qualification may be required due to different environmental requirements) No requirement for active management	Active management included in the battery
Price (2 Bat)	2x	8x

Table 5.2.1-1 Battery Cells Trade-Off Summary

The low capacity cells battery emerges as the best one under all the aspects evaluated in this summary.
The growth potential is an additional factor, which must be taken into account in the choice. The low capacity cells give the highest flexibility in terms of future grown capability.

Based on the results presented in this trade-off, the present architecture is based on Low Capacity cells.
Nevertheless, the final sizing and selection of the battery will be finalised during phase B.

In order to have an open competition, Battery Specification has been issued in order to give the chance to both the battery cell technologies. The information used in this trade-off is derived from the proposal phase: possible improvements in the technology during the last year, as far as adaptation of already qualified hardware, could introduce some new data for the final choice of the battery cells and the redundancy approach.

4.1.3 Turbo Coding

The Turbo Coding Implementation Trade Off has analysed the impacts on the proposed hardware involved by this option. It has been considered the increased bandwidth impacts, the modifications to implement on the existing (proposed) hardware both in the CDMU and in the Transponder. At the same time it has been considered the performance improvement due to the Turbo Coding gain on the link budgets.
The table below presents a resume of the foreseen impacts:

R/S CONCATENATED	**TURBO**
3.441.300 sps (rate after encoding at transponder input)	6.024.300 sps (rate after encoding at transponder input)
Null-to-Null Bandwidth (QPSK) = 1*Rb = 3.441.300 Hz (SRRC-OPSK) = (1+a)Rb/2 = 2.580.975 Hz	Null-to-Null Bandwidth (QPSK) = 1*Rb = 6.024.300 Hz (SRRC-OPSK) = (1+a)Rb/2 = 4.518.225 Hz
99% of power bandwidth (QPSK) = 4Rb = 14 MHz (SRRC-OQPSK a=0,5) = 2.8 MHz (GMSK BTb=0,25) = 0,86 Rb = 3 MHz	99% of power bandwidth (QPSK) = 4Rb = 24 MHz (SRRC-OQPSK a=0,5) = 5 MHz (GMSK BTb=0,25) = 0,86 Rb = 5.2 MHz
Actual transponders capable of handling this rate.	Actual transponders known by ALENIA capable of handling up to 10 Mbit/s.
Supported by the proposed CDMU	THE CDMU MUST BE MODIFIED TO IMPLEMENT THE TURBO ENCODER (ASIC QUALIFICATION)
Supported by the actual transponders.	THE TURBO ENCODER CAN ALSO BE INCLUDED IN THE TRANSPODER. (ASIC QUALIFICATION)
Eb/No = 2,7 dB Frame loss probability = 10^{-5}	Eb/No = 0,3 dB Frame loss probability = 10^{-5}
All link budgets have positive margins.	The link budgets have lower carrier recovery margins, the coding gain in fact does not improve the carrier signal.
All ground networks can handle it.	It is not clear if all ground networks can handle it.

As presented in the Turbo Coding Implementation Trade Off (H-P-RP-AI-0001), the gain due to the Turbo Coding does not justify the extra costs so, the current Alenia baseline was to **not implement** the Turbo Coding option and to use the R/S concatenated encoding with SRRC-OQPSK modulation (*).

(*) Note: This Trade-Off was done for the SRR. Recent updating of SGICD selected GMSK modulation.

4.1.4 Battery Redundancy

During the proposal phase, a configuration with two battery set has been presented.
In the present phase, the possibility to have a different battery redundancy concept has been analysed.

A dedicated Report, “Battery Cell Capacity and Redundancy Trade-Off”, H-P-RP-AI-0002 shows the analyses made for redundancy at string level instead of battery level.

The summary of the trade-off is reported in the following.

With the result of the cells trade-off (leading to the choice of low capacity cells), the solution of one battery is the most attractive choice for the redundancy concept
The reliability and the failure tolerance can be easily achieved by adding one or two extra strings at relative low cost.

	One Battery	*Two Batteries*
Configuration	One module x 6 series x 24 parallel	Two modules x 6 series x 24 parallel
BDR Configuration	2 x 350W BDR	2 x 350W BDR
Theoretical Energy	777Wh	1554Wh
Mass	6.75 kg	13.5 kg
Harness and BDR modules Mass	1 kg	1.5 kg
Dimensions	320x220x100 mm (7l)	2x320x220x100 mm (14 l)
Energy at 70% DoD with One Cell failed	521 Wh	1065 Wh
Energy at 70% DoD with One Battery failed	N/A	544 Wh
Overall Price	X	1.5x

Table 5.1.4-1 Battery Redundancy Trade-Off Summary

The redundancy can be easily achieved at battery level, because this battery is made by 24 parallel strings, two of which are redundant. Furthermore, the battery is designed such that no single cell failure has a propagating effect on any other cell or part of the battery. Therefore, in all respects, this battery can be considered as a 24 individual battery systems working in the same environment.

Based on the above reported data, the solution of one single battery emerges as the baseline solution.
The resulting Charge-Discharge configuration is shown in the following figure.

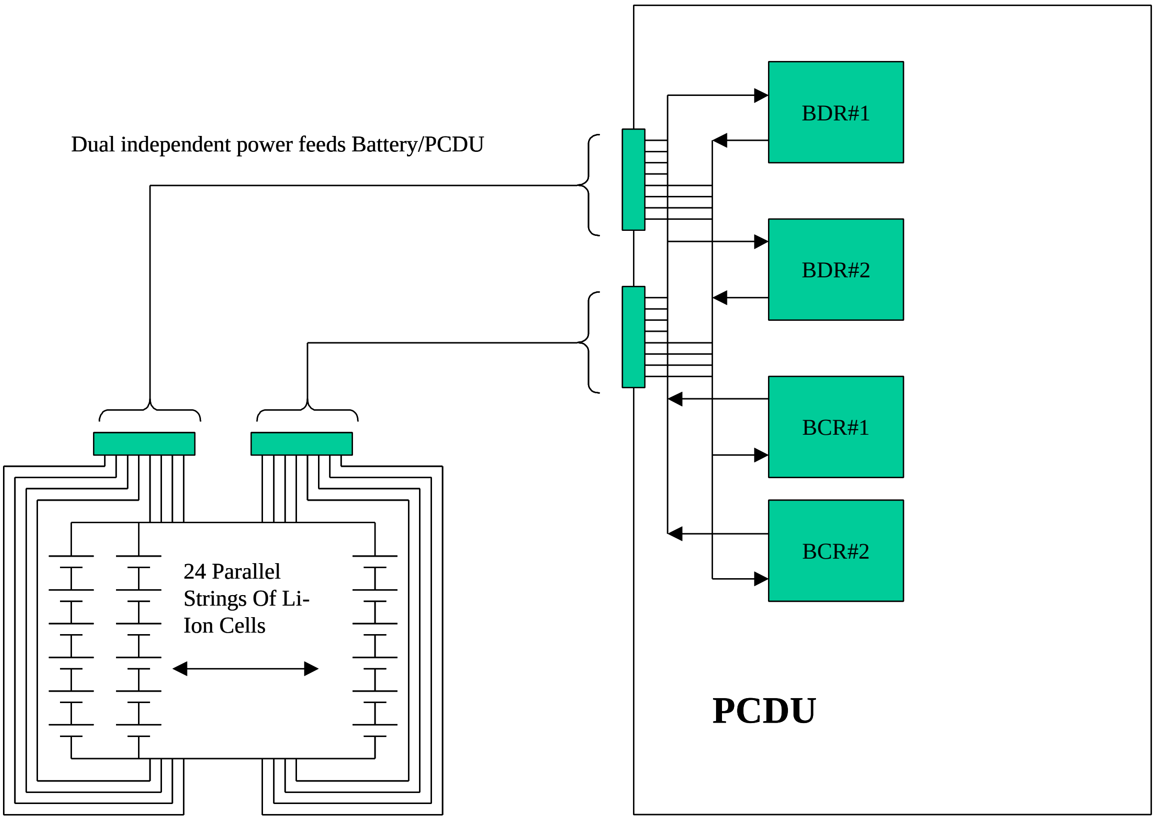


Figure 5.1.4-1 Battery Configuration

4.1.5 Star tracker Accomodation

The STR positioning on the Herschel SVM is considered extremely critical.

After the first thermoelastic analyses loop, the great inconsistency between the requirement and the proposed allocation has became evident. Several checks and trade off to evaluate the stability of the octagonal Box w.r.t the requirements have been performed. The results of such checks and investigations have been reported during PM8 [R.D. 41], and are summarised hereafter for clarity:

Comparison between -30 and +30

	Ry [° 1E-3]	Req. [° 1E-3]
STR1 on Panel -Z	15.3	0.22
STR2 on Panel -Z	14.7	
STR1 on Sh. Panel -Z	12.3	
STR2 on Sh. Panel -Z	12.8	
STR1/2 on PLD Subplatf.	17.7	
STR1/2 on Cone	20.2	

0.22° 1E-3 = 0.8 arcsec

Comparison between two extreme cases, (a) Winter solstice, pitch angle 30° and (b) Winter solstice, pitch angle -30° ; STR's set in different locations inside SVM.

Comparison between -30 and +30
Cone temperature stable within 1 C

	Ry [° 1E-3]	Req. [° 1E-3]
STR on Panel -Z	0.86	0.22
STR on Sh. Panel -Z	0.77	
STR1/2 on PLD Subplatf.	1.16	

Comparison between cases (a) and (b), but assuming to have a ΔT on the cone temperatures of 1° only (thermal analyses show ΔT about 25 ° on cone and 60 ° on LVA ring).

Figure shows the actual STR position:

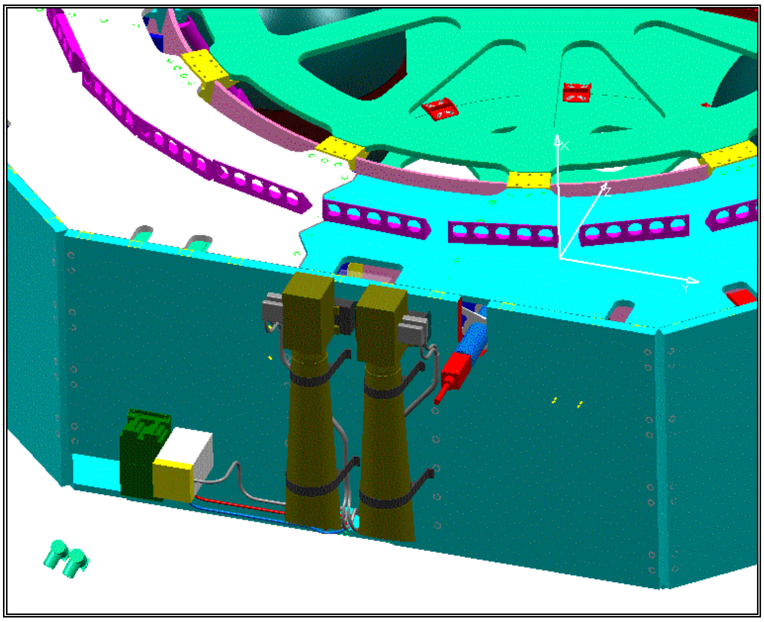


Figure 4.1.5-1 STR baseline position

Details about Thermoelastic and stability analyses are reported in [RD-41].
The requirement satisfaction seemed impossible to be reached in the actual positioning of the STR. Two different solutions where indicated:

- STR mounted on the PLM (close to the telescope): this study shall be performed at system level
- STR mounted inside the SVM Central cone, which is the most thermally stable area within SVM

According to ESA recommendations, Alenia started to verify the feasibility of the Isostatic mountig concept.
Details of the Trade off are reported in [RD 39].
The trade off is still on going, the most promising solution that seems feasible even if marginal, is given by a truss beam to be mounted inside the cone, the concept is presented in figure below.

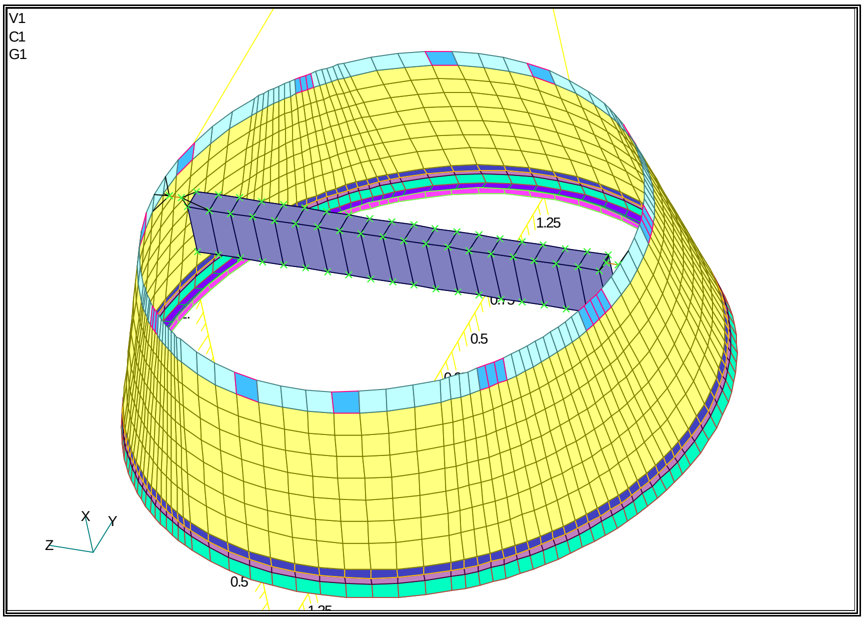


Figure 4.1.5-2 Trade off most promising concept

5. MISSION DEFINITION

Both HERSCHEL and PLANCK spacecraft are planned to operate from Lissajous orbits around the Lagrange point L2 of the Sun/Earth system. As shown in Figure 5-1, this point is aligned with the Earth and the Sun and located at 1.5 10 6 km from the Earth, away from the Sun.

Such orbits present the following advantages for the satellite operations: -thanks to the Earth and Sun almost constant distances, the thermal environment is very stable.

The thermal radiations from the Earth are reduced and induces a cold environment which is favourable for operating cryogenic satellites such as HERSCHEL and PLANCK.

-The radiation environment is low compared to an eccentric orbit such as ISO or XMM or even compared to geostationary orbits (see also chapter 7.8 of this document).

-As the Sun and the Earth remain close together from the spacecraft, the shielding of the Sun thermal radiation will also prevent straylight effects from the Earth. The satellite communication with the Earth is facilitated as the satellite remains Sun pointed.

Details can be found in the System Documentation. All the parameters to be considered for SVM design are made applicable by the [AD-13] Environmental and Test Requirement Specification.

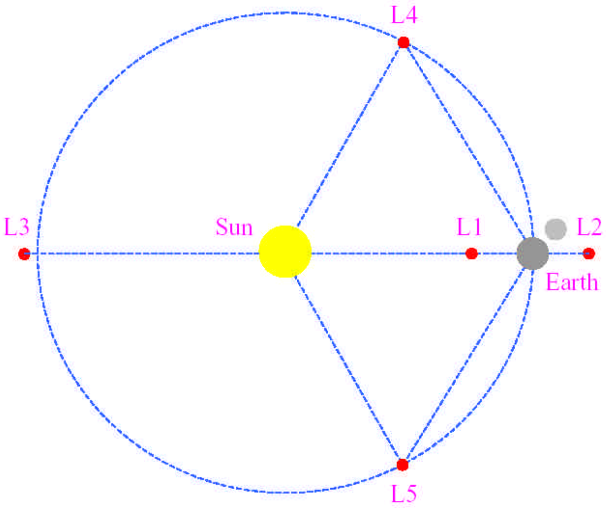


Figure 5-1 - L2 LAGRANGE POINT HERSCHEL ORBIT

6. OPERATIONAL CONCEPT

See [RD-76] MODULE/SUBSYSTEM/EQUIPMENT User Manual where in conjunction with the overall System Concept the SVM considerations are reported.

7. SVM FUNCTIONAL DESIGN AND PERFORMANCE ANALYSES

7.1 SVM OVERALL DESCRIPTION

7.1.1 Herschel SVM Configuration Overview

See H-P-RP-AI-0003 Issue 03, (SVM Configuration Requirement) [AD-42]

7.1.2 Planck SVM Configuration Overview

See H-P-RP-AI-0003 Issue 03, (SVM Configuration Requirement) [AD-42]

7.1.3 Service Module to Payload Module Interface

7.1.3.1 Maccanical Interfaces

7.1.3.1.1 Interface with PLM main module

7.1.3.1.1.1 HERSCHEL SVM

The Herschel SVM will support the Herschel PLM supported by the Cryostat support structure (which is part of the PLM structure) in 12 areas according to the following figure 7.1.3.1.1.1-1.

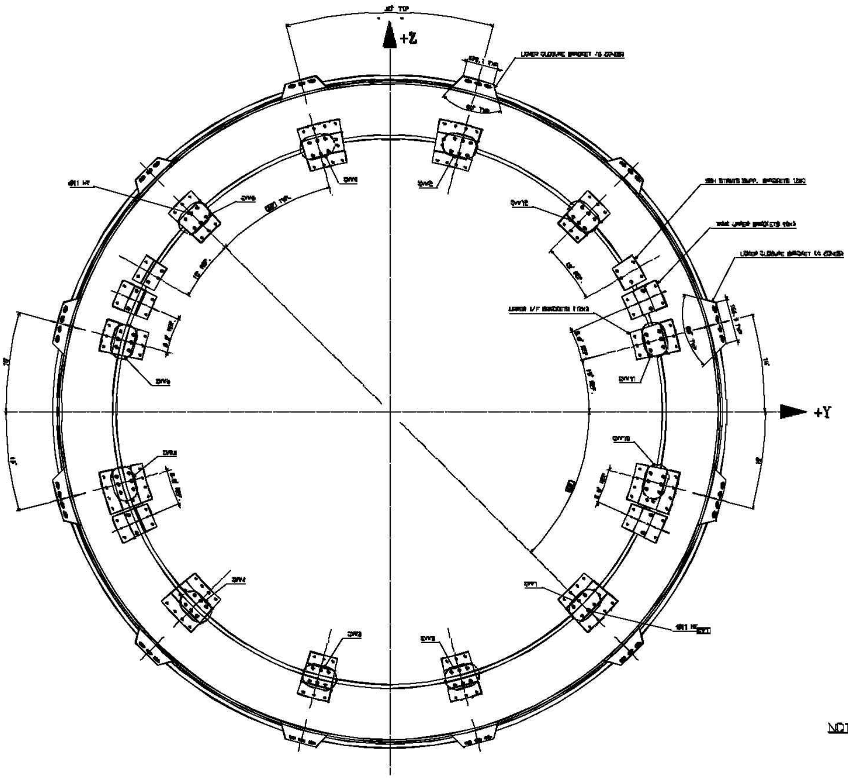


Figure 7.1.3.1.1.1-1 SVM to PLM Cryostat support structure Interface

In addition the Herschel SVM will support the Herschel Sunshield/Sunshade struts by seven struts connecting Herschel Sunshield/Sunshade to the SVM structure as outlined in figure 7.1.3.1.1.1-1
In particular

- 4 inclined CFRP struts connected on 2 nodes at the top of the Central tube, supporting the upper part of the SSH/SSD in axial direction mainly
- 3 struts or beam elements in horizontal position connected on the top of the Upper platform, providing a radial support to the bottom of the SSH

Herschel SVM will support the SVM Shield connected to the SVM structure by a set of structures according to the figure 7.1.3.1.1.1-2. In particular:

- 5 bipodes struts connected around the PLM sub-platform at the top of the Upper platform,
- 4 vertical struts connected at the top of the Upper platform.

TBD

Figure 7.1.3.1.1.1-2 SVM to SVM Shield Mechanical Interface

The Herschel SVM will be compatible with cryo harness and waveguide brackets mounted on the upper closure panel as depicted in figure 7.1.3.1.1.1-3.

TBD

Figure 7.1.3.1.1.1-4 SVM to Cyro Harness and Waveguide Brackets Mechanical Interface

In addition to the above, accommodation of Warm Units ,VMC and SREM will lead to mechanical interfaces of boxes to SVM structure. They are treated in the chapter 2 of this document and on [AD-42] and in the [RD-77]

7.1.3.1.1.2 PLANCK SVM

The PLM interface with the main module is ensured by 6 contact areas according to the figures 7.1.3.1.1.2-1 7.1.3.1.1.2-2.

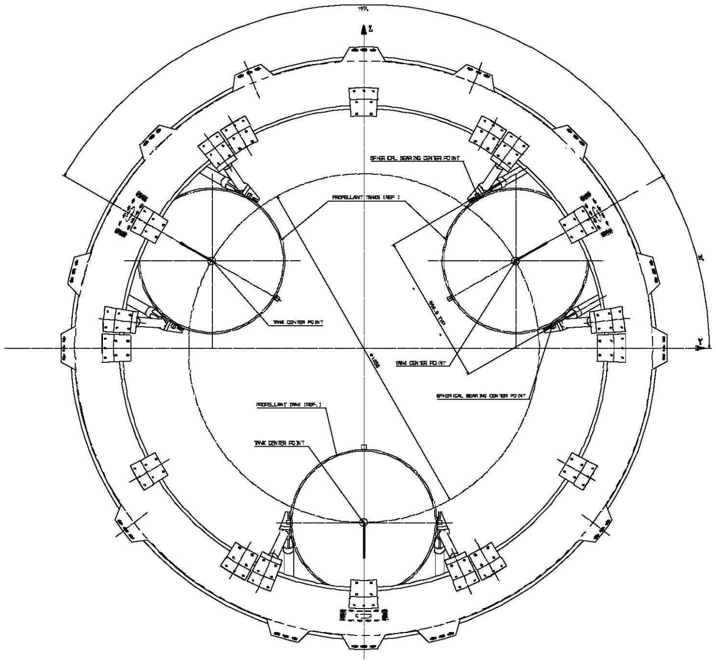


Figure 7.1.3.1.1.2-1 SVM/PLM Main Module Interface (Cone)

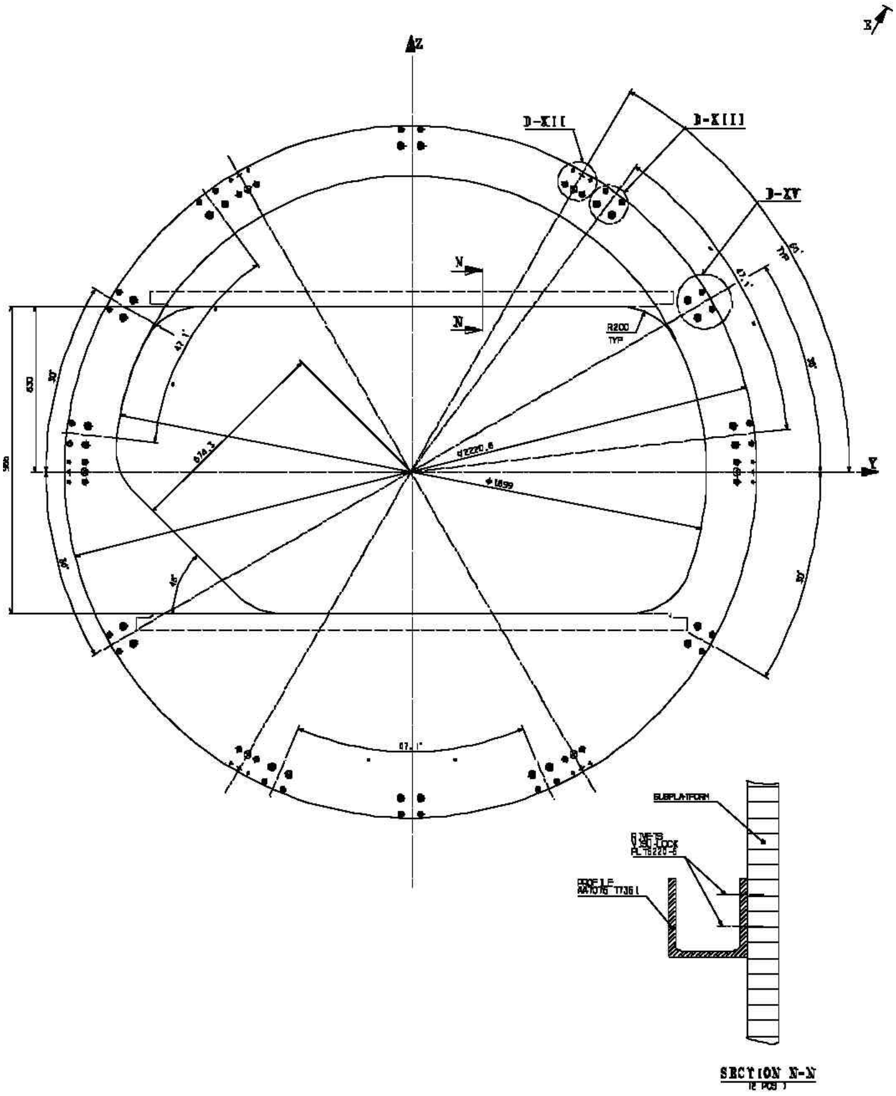


Figure 7.1.3.1.1.2-2 SVM/PLM Main Module Interface (Sub-platform)

4 Helium tanks are accommodated on the SVM. Planck SVM interfaces are depicted in figure 7.1.3.1.1.2-3

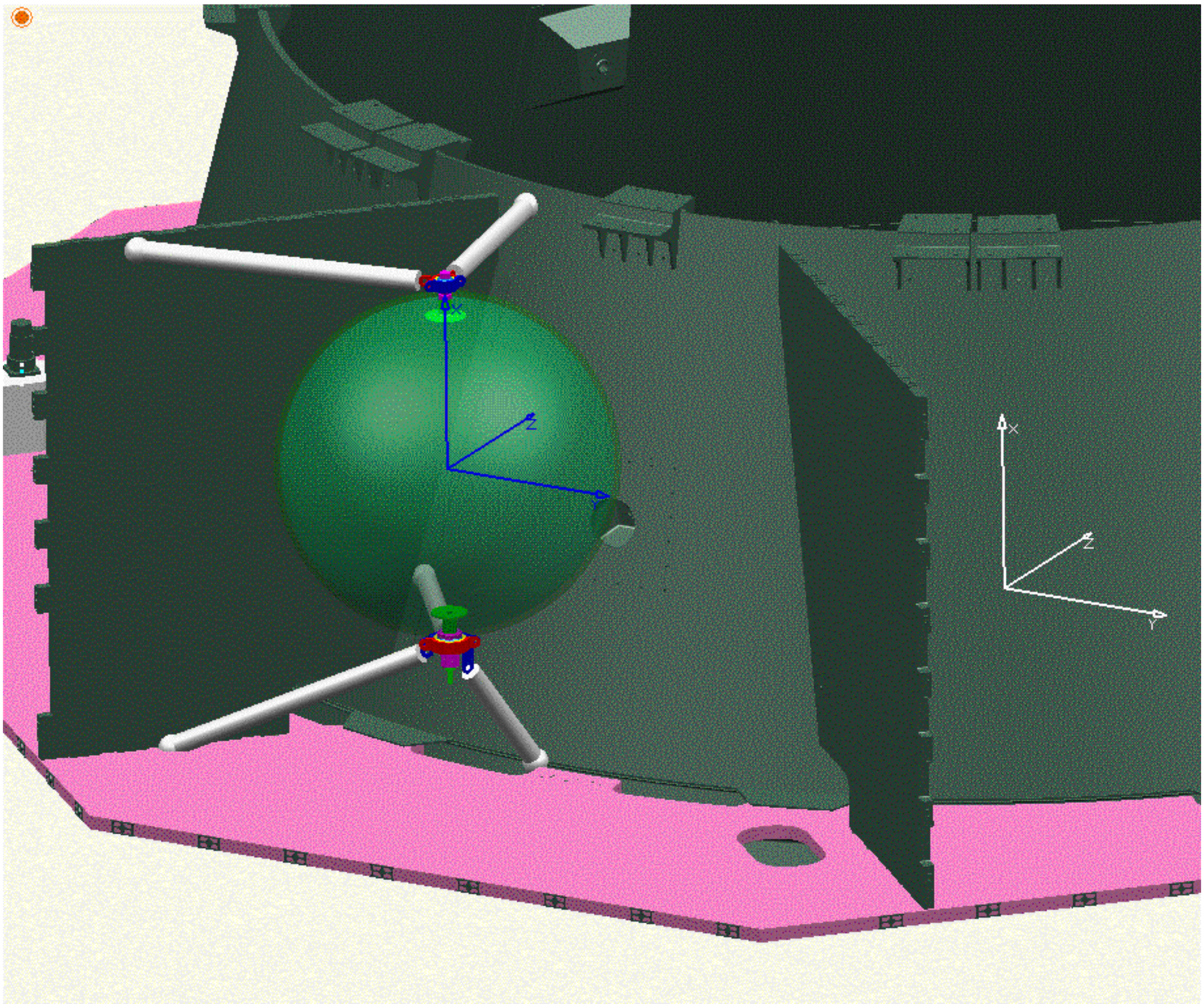


Figure 7.1.3.1.1.2-3 PLANCK Helium tanks tipical interface

In addition to the above, accommodation of Warm Units ,VMC and SREM will lead to mechanical interfaces of boxes to SVM structure. They are treated in the chapter 2 of this document and on [AD-42] and in the [RD-77]

7.1.3.2 Electrical Interfaces

7.1.3.3 SVM to PLM Electrical I/F

7.1.3.3.1 Herschel

The electrical interfaces between Herschel SVM and PLM are listed hereafter.

Solar Array Power

- 30 **Solar Array** Sections

As per AD-47 § 5.2.2.3: Herschel SVM conditions during the whole lifetime a solar array power up to 1400 W, on 30 sections.

Non Explosive Devices (Electrical characteristics: AD-12 section 6.7.12)

- 1+1 PLM **NCA Actuators**

As per AD-47 § 5.2.4: This interface is intended to provide the energy necessary to perform the cryostat Cryo cover opening using NCA’s.

Heaters (Electrical characteristics: AD-12 section 6.7)

- 7+2 Lines for **Decontamination Heaters**

As per AD-47 § 5.2.2.1.5: PCDU provides nine (7N+2R) power bus lines to the telescope decontamination heaters, each line providing 90 W.

Temperature sensor (Electrical characteristics: AD-12 section 6.8.2.2)

- 6 to **SOLAR ARRAY**

As per AD-47 § 5.2.3.6: to monitor temperature sensors located on the sunshield.

Cryo-Temperature sensors (Electrical characteristics: AD-12 section 6.8.2.3)

- 9N+9R to control **Telescope** temperature during Decontamination, as per AD-47 par. 5.2.3.6.

- 2 from **PACS FPBOLA**

As per AD-47 § 5.2.3.3 (which refers to AD-04, section 5.11, which refers to AD-04 par. 5.7.4)

Digital Relay Status Acquisition Interfaces (Electrical characteristics: AD-12 section 6.8.2.4)

- 2 from **Non Contaminating Actuators**

As per AD-47 § 5.2.4, to monitor NCA Status

The following figure summarises the above mentioned SVM to PLM Electrical interfaces.

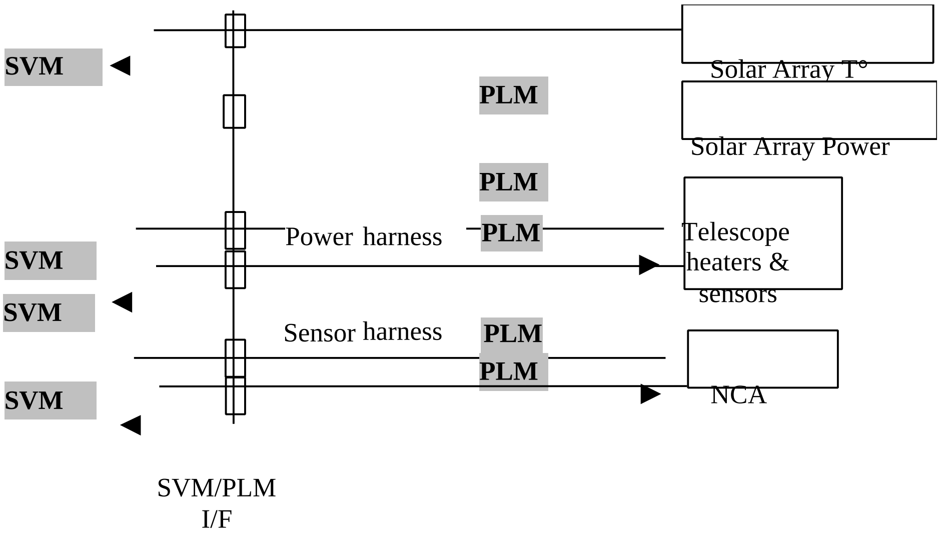


Figure 7.1.3.3-1 Herschel SVM/PLM Electrical I/F

7.1.3.3.2 Planck

The electrical interfaces between Planck SVM and PLM are listed hereafter.

Heaters (Electrical characteristics: AD-12 section 6.7)

- 2+1 Heater Lines for **Primary Reflectors**
- 1+1 Heater Lines for **Secondary Reflectors**

As per AD-47 § 5.3.2.1.3 PCDU provides three (2N+1R) heater lines to the primary reflector and two (1N+1R) heater lines to the secondary reflector, each one up to 60 W.

- 2+2 Heater Lines for **Focal Plane**

As per AD-47 § 5.3.2.1.4 PCDU provides four (2N+2R) heater lines to the focal plane, each one up to 60 W.

Temperature sensor (Electrical characteristics: AD-12 section 6.8.2.2)

- 10 from **PPLM**

As per AD-47 § 5.3.3.4 (IEP-146-P): for the temperature sensors associated with the decontamination heaters.

Cryo-Temperature sensors (Electrical characteristics: AD-12 section 6.8.2.3)

- 1N+1R from **HFI PHCA**

As per AD-47 § 5.3.3.1.1 (which refers to AD-05 section 5.11, which refers to AD-05 par. 5.7.5)

- 2 from **LFI**

As per AD-47 § 5.3.3.1.2 (which refers to AD-06 section 5.11, which refers to AD-06 par. 5.7.5)

- PLFEU
- PLWG

- 18N+18R from **PPLM**

As per AD-47 § 5.3.3.3:

- 3+3 from Instruments
  - LFI-FEU Interface
  - WG Interface
  - JFET Box
- 3+3 from Sorption cooler I/F (hot spot)
  - Warm Shield
  - Intermediate Shield
  - Cold Shield
- 2+2 from 4K Cooler I/F
  - On Cold Shield
  - Diluition interface
- 4+4 Telescope sensors
- 6+6 Shield Sensors

The following figure summarises the above mentioned SVM to PLM Electrical interf

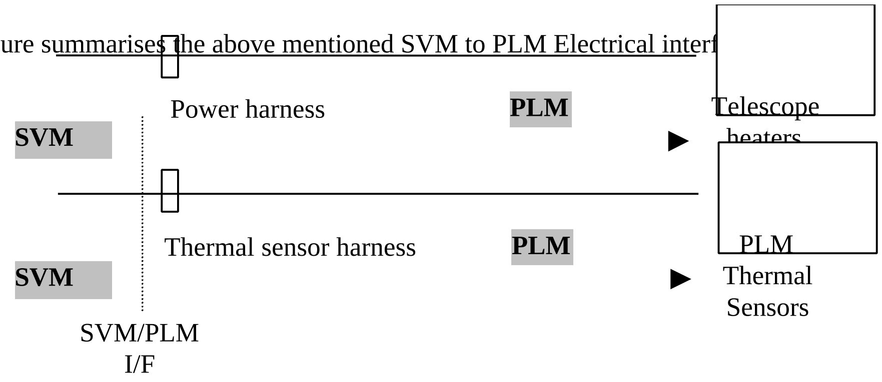


Figure 7.1.3.3-2 Planck SVM/PLM Electrical I/F

7.1.3.4 Thermal Interfaces

For each satellite, the two modules (PLM and SVM) can be considered independent from a thermal point of view since the conductive heat fluxes between the two modules are limited.

On Herschel satellite, for the Thermal Control point of view, the SVM/PLM I/F temperature fluctuation requirements are very severe and actually lead to avoid any temperature fluctuation inside the SVM. The temperature fluctuation derives from power variation that can have different sources:

- SAA changes with solar fluxes
- Units with different dissipation (in according to the operation mode)
- Heaters switching

On Planck satellite the limited SAA excursion (0°÷10°), and the Solar Array dimensions avoid actually any sun fluxes on the S/L lateral panels, and in addition to the use of MLI on the Solar Array rear-side provide a quite stable environment. Absorbed solar fluxes change at spin frequency, they have been evaluated and has been considered negligible without any impact on both lateral SVM panels and SVM/PLM interface.
Details on the analysis can be found in the chapter 7.4 of this document.

7.1.4 Service Module to Launcher Interface

Mechanical Interfaces.

Herschel and Planck are accommodated in double launch configuration on Ariane 5 with Long Fairing.
Planck is located in lower position on top of the EPS cone by means of the Adaptor 2624, beneath SYLDA 5.
Herschel is located in upper position, on top of SYLDA 5 by means of the Adaptor 2624.
The ARIANE 5 Adaptor 2624 Interface is shown in the figure 7.1.4-1 and 7.1.4-2 derived from ARIANE 5 User Manual.(A.D.31)
Both spacecraft interface to the Launcher by means of a rear frame, which is part of the SVM primary structure Central Tube as shown in the figure 7.1.4-3 derived from ARIANE 5 User Manual. .(A.D.31) In addition the interface between SVM Structure and 2624 Launcher Adapter is shown in figure7.1.4-4

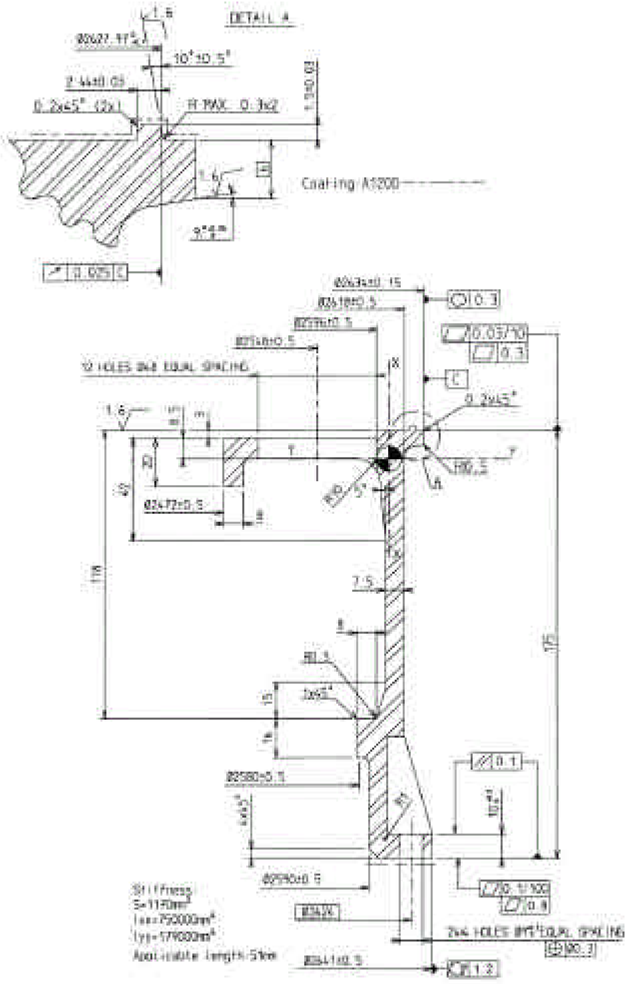


Figure 7.1.4-1 Adaptor 2624 Interface

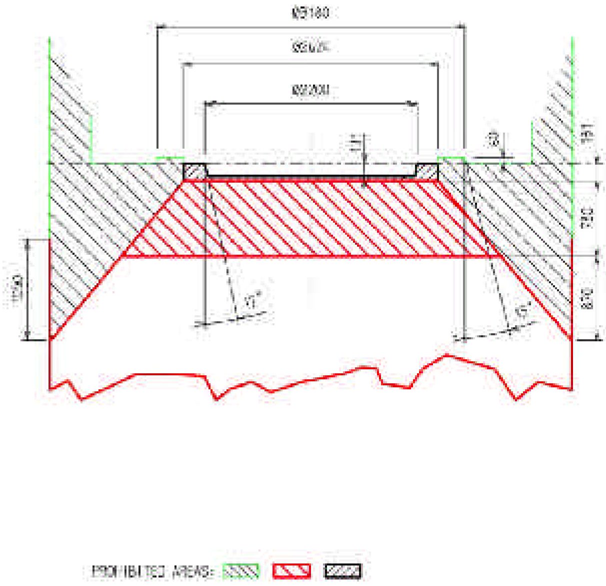


Figure 7.1.4-2 Adaptor 2624 Usable Volume

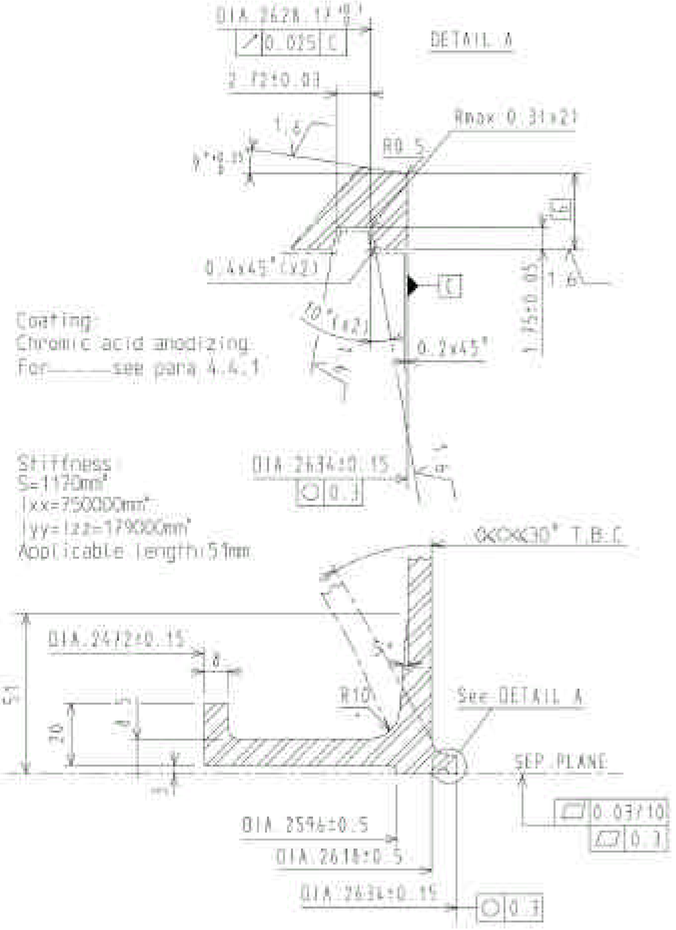


Figure 7.1.4-3 Adaptor 2624 Spacecraft rear frame

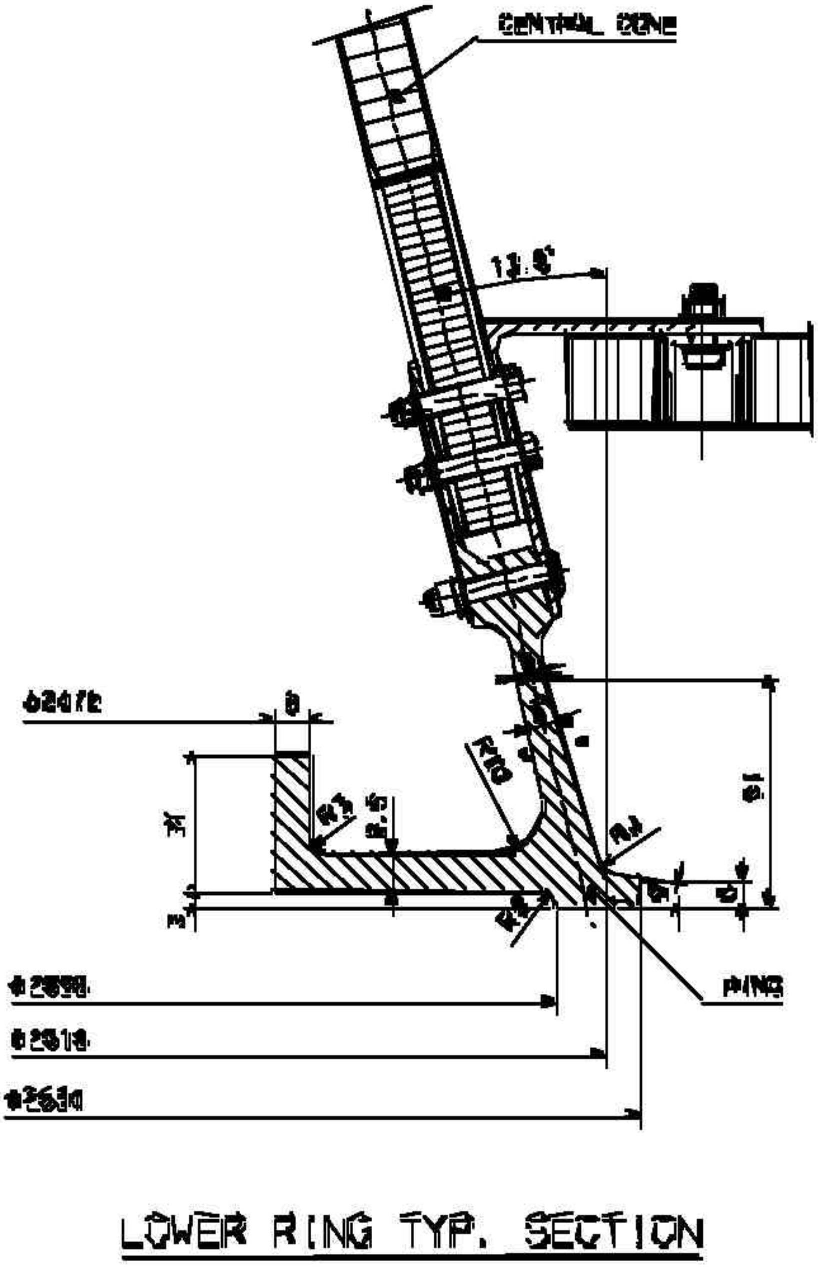
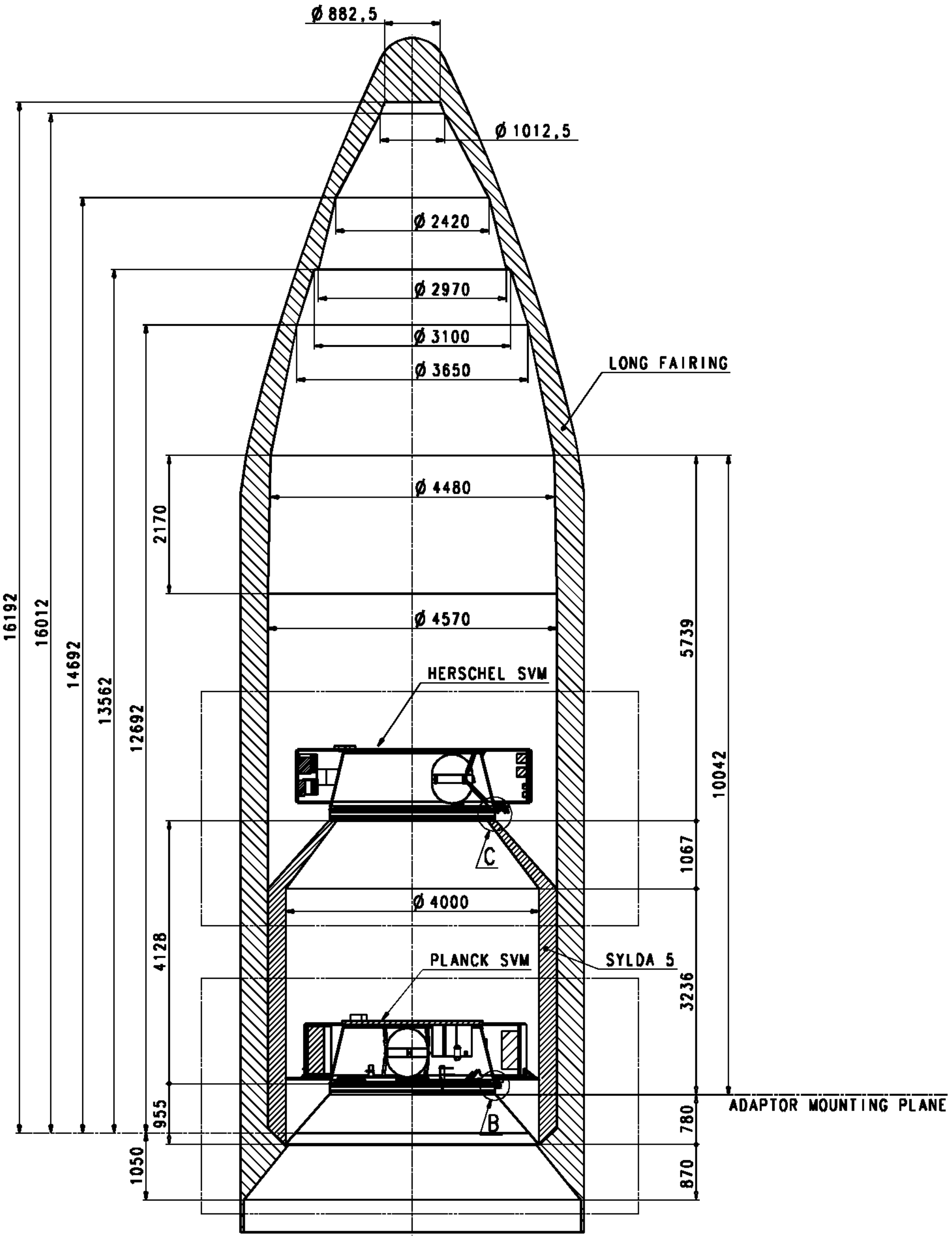


Figure7.1.4-4 interface between SVM Structure and 2624 Launcher Adapter

The figure 7.1.4-4 shows the installation of the SVM Herschel and Planck on A5 Launcher in accordance whit A5 User Manual (see fig. A5-1 Annex 5) requirements of Sylda 5 and requirements of Long Fairing fig. (see A5-3 Annex 5).
This exercise has found some problems, in the Catia file, concerning the size of the SVM Planck Solar Array (diam.4200 mm) which violate the static envelope of Sylda 5 (diam. 4000 mm).
Same problem has been encounterd also on the RCS brackets which violate the Sylda 5 constraint.



HERSCHEL and PLANCK PAYLOADS not SHOWN

Figure 7.1.4-4 SVM Herschel/ Planck launch configuration

Electrical Interfaces

The SVM of Herschel and Planck are equipped with umbilical connectors trough which the satellite will be provided with external power,telemetry etcc.The location of the connector brackets will be according to the ARIANE 5 User Manual requirements as shown in the figure 7.1.4-5.
The diameter location of the umbilical I/F is still TBD by A5 User Manual.

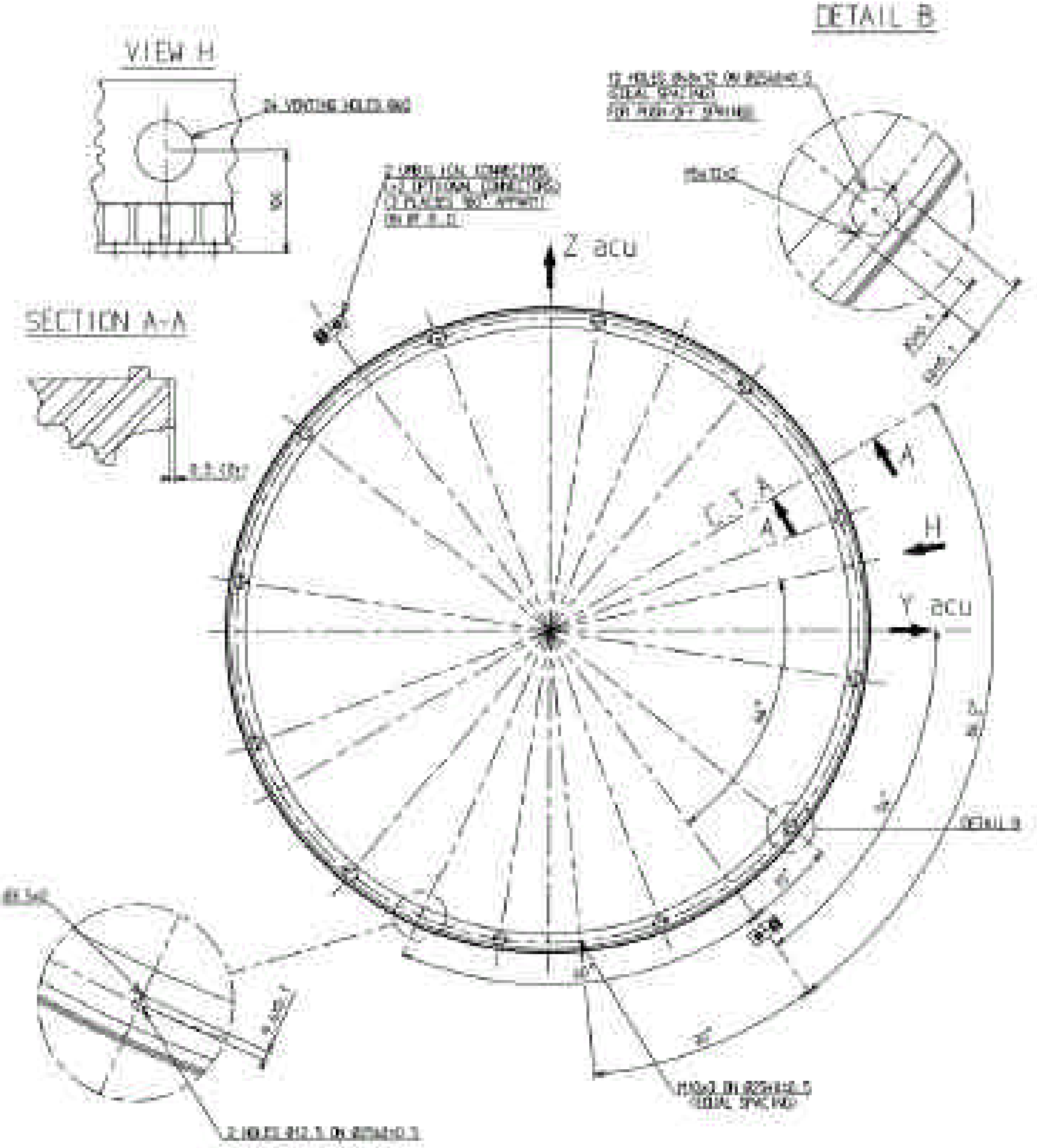


Figure 7.1.4-5 Adaptor 2624 General View with Umbilical connectors location.

The two umbilical Connectors (1 nominal + 1 redundant) are connected to the COTE and to the Spacecraft. The 61 pins scharing is 37 to COTE and 24 to spacecraft (TBC). The following tables are the summary of the available informations to be considered for the next design activities. Final confirmation is planned before the PDR colocation.

PIN allocation on nominal Connector to/from COTE		**PIN allocation on redund. Connector to/from COTE**	
Pin Quantity (TBC)	**Signal name**	**Pin Quantity (TBC)**	**Signal name**
1	+ 28 VDC Aux in 1	1	+ 28 VDC Aux in 1
1	+ 28 VDC Aux in 2	1	+ 28 VDC Aux in 2
1	+ 28 VDC Aux in 3	1	+ 28 VDC Aux in 3
1	+ 28 VDC Aux in 1 RTN	1	+ 28 VDC Aux in 1 RTN
1	+ 28 VDC Aux in 2 RTN	1	+ 28 VDC Aux in 2 RTN
1	+ 28 VDC Aux in 3 RTN	1	+ 28 VDC Aux in 3 RTN
1	SBDL TM N out	1	SBDL TM N out
1	SBDL TM N out RTN	1	SBDL TM N out RTN
1	SBDL TC N in	1	SBDL TC N in
1	SBDL TC N in RTN	1	SBDL TC N in RTN
1	Battery temperature	1	Battery temperature
1	Battery temperature RTN	1	Battery temperature RTN
1	Battery voltage	1	Battery voltage
1	Battery voltage RTN	1	Battery voltage RTN
22	Spare PINS	22	Spare PINS
1	Shielding	1	Shielding
1	Shielding	1	Shielding
8	Dry Loop Commands	8	Dry Loop Commands
6	Separation Straps	6	Separation Straps
3	SPARE	3	SPARE

Table 7.1.4-1 Herschel to Umbilical Pin allocation

PIN allocation on nominal Connector to/from COTE		**PIN allocation on redund. Connector to/from COTE**	
Pin Quantity (TBC)	**Signal name**	**Pin Quantity (TBC)**	**Signal name**
1	+ 28 VDC Aux in 1	1	+ 28 VDC Aux in 1
1	+ 28 VDC Aux in 2	1	+ 28 VDC Aux in 2
1	+ 28 VDC Aux in 3	1	+ 28 VDC Aux in 3
1	+ 28 VDC Aux in 1 RTN	1	+ 28 VDC Aux in 1 RTN
1	+ 28 VDC Aux in 2 RTN	1	+ 28 VDC Aux in 2 RTN
1	+ 28 VDC Aux in 3 RTN	1	+ 28 VDC Aux in 3 RTN
1	SBDL TM N out	1	SBDL TM N out
1	SBDL TM N out RTN	1	SBDL TM N out RTN
1	SBDL TC N in	1	SBDL TC N in
1	SBDL TC N in RTN	1	SBDL TC N in RTN
1	Battery temperature	1	Battery temperature
1	Battery temperature RTN	1	Battery temperature RTN
1	Battery voltage	1	Battery voltage
1	Battery voltage RTN	1	Battery voltage RTN
22	Spare PINS	22	Spare PINS
1	Shielding	1	Shielding
1	Shielding	1	Shielding
6	Separation Straps	6	Separation Straps
17	SPARE	17	SPARE

Table 7.1.4-1 Planck to Umbilical Pin allocation

7.2 POINTING AND DYNAMICS

Details are presented in RD [49] (ACMS Design Report H-P-4-DS-TN-011) produced by the subcontractors and in the Pointing Budget chapter of the RD [11] (HP-BD-AI-0001 SVM Budget Report).

7.3 MECHANICAL DESIGN AND PERFORMANCE

In this section, the overall SVM mechanical design is reported with the objectives to:

- identify main requirements/design objectives
- describe the design implementation and justification
- report the mechanical performances.

7.3.1 General Mechanical Requirements and Design Drivers

The definition of the mechanical design has been driven by the following major requirements:

Environmental Requirements

The SVM Structure and SVM S/S Equipment are designed to withstand, without degradation, the worst possible load combination of the following environments:

- manufacturing
- assembly
- transportation and handling
- storage
- pre-launch
- launch-ascent
- life in orbit
- testing

Functional Requirements

The SVM Structure has to provide the following main functions:

adequate interface with Ariane 5 and transfer of the launch loads to the launcher
adequate structural support and interfaces to the Scientific Instruments, equipment and subsystem, through all ground activities and mission phases, ensuring the required clearances and unobstructed field of view.
sufficient stiffness to achieve the frequency requirements at Separation System interface level with launcher.
compatibility with ARIANE 5 launcher.
structural integrity at the on-orbit environmental conditions.
limitation of the structural deformation in orbit, among different structural parts, within the limits requested by the overall structural stability.
thermal and electrical coupling/decoupling among all structural items.
handling and lifting points for the SVM and the entire Satellite (Planck).

Interface Requirements

The SVM Structure has to provide the following main functions:

Ensure the compatibility with the SVM/PLM interfaces
Ensure the compatibility with all Instruments, Equipment and Subsystems.
Ensure the compatibility with ARIANE fairing.
Provide mechanical I/F for the ARIANE 5 2624 Adaptor
Provide mechanical I/F for MGSE.
Provide adequate lifting points.

Design Requirements

Provide an adequate design to optimize the structural mass
Provide adequate structural dimensional stability for keeping the alignment errors within the defined limits.
Provide reliability, maintainability, interchangeability, safety, redundancy, low risk.
Provide sufficient accessibility to instruments, subsystem, equipment, and connectors in order to allow an easy integration, removal and maintenance.
Provide venting provision.

7.3.2 SVM Primary Structure Requirement

The complete set of requirements for the SVM Structure is included in RD-26 . Thus, for any detail, please, consult this document. This is in agreement with the last issues of the main System Level Specifications, particularly, AD-43, and AD-47.
The main mechanical requirements, like stiffness and strength, since SRR, have been changed several times up to the last version, namely AD-43, is. 2.1 and AD-47, is 3.0.
Because the Structure S/S, during the same period, went through the first loop of analyses and design processes, which was completed with the S/S PDR, a comparison, between the main last updated requirement (System PDR Requirement), with respect to those utilised for developing the S/S PDR documentation, is reported in the following paragraphs.

7.3.2.1 Frequency and Rigidity Requirements

As mentioned above, some summary/comparison tables reports the *SRR Requirements* (used to produce the Structure S/S PDR documentation) and the last updated requirements (*System PDR Requirement*).
These new requirements will be used to perform the second loop of analyses and design, leading to S/S CDR/MRR.

The requirement changes are deemed compatible with the already developed Primary structure design.
In addition, as explained in paragraph 9.1, some of the new requirement have been already checked, by means of preliminary analyses, summarised in RD-42.

In particular, the new (System PDR) frequency and rigidity requirements, here below reported, have been checked against the new SVM Central cone performances.

7.3.2.1.1 Frequency Requirements

	GLOBAL MODES				
	SRR Requirements		***System PDR Requirement***		**Remarks**
Item	**Herschel**	**Planck**	**Herschel**	**Planck**	
	Minumum Hz	Minumum Hz	Minumum Hz	Minumum Hz	
S/C Lateral direction	23 (1)	35	23	35	SRR: H-PLM= 2115Kg (2) PDR: H-PLM= 2400Kg SRR: P-PLM= 310Kg PDR: P-PLM= 336Kg
S/C Axial direction	58 (1)	60	65	60	
Octagonal box Lateral direct.	48	50	60	50	Without Payload Mass
Octagonal box Axiall direct.	51	60	45	45	

Notes:

(1) For Structure dimensioning, the following requirements have been used (in agreement with the ASPI System level requirements available in November):
- F lateral > 27 Hz
- F axial > 70 Hz

(2) The H-PLM location (along X) is also changed between SRR and PDR, namely:
H-PLM_{SRR} = 1.735 m from SVM I/F plane
H-PLM_{PDR} = 1.627 m from SVM I/F plane

PROPELLANT TANK SUPPORT STRUCTURE

	SRR Requirements		*System PDR Requirement*		**Remarks**
Item	**Herschel**	**Planck**	**Herschel**	**Planck**	
	Minumum Hz	Minumum Hz	Minumum Hz	Minumum Hz	PTSS i/f real boundary cond. Full tank at C.o.G
Lateral direction	80	80	80	80	
Longitudinal direction	145 (1)	145 (1)	100	100	

Note:
(1) For structure design: f axial > 100 Hz has been used

LATERAL PANELS

	SRR Requirements		*System PDR Requirement*		**Remarks**
Item	**Herschel**	**Planck**	**Herschel**	**Planck**	
	Minumum Hz	Minumum Hz	Minumum Hz	Minumum Hz	Panels hard mounted in the real boundary conditions, lumped masses
Any direction	50	70	50	50(target 70)	

PLANCK PAYLOAD SUB-PLATFORM

	SRR Requirements		*System PDR Requirement*		**Remarks**
Item	**Herschel**	**Planck**	**Herschel**	**Planck**	
	Minumum Hz	Minumum Hz	Minumum Hz	Minumum Hz	Sub-platform H-mounted in the real bound. Conditions, lumped masses
Any direction	NA	100 (1)	NA	32	

Note:
(1) For structure design: f > 32 Hz has been used

- SVM Secondary Structures shall have a frequency higher than 140 Hz.

7.3.2.1.2 Rigidity Requirements

CONE STIFFNESS

	SRR Requirements				***System PDR Requirement***				**Remarks**
Items	**Herschel**		**Planck**		**Herschel**		**Planck**		
	Min. N/m	Max. N/m	Min. N/m	Max. N/m	Min. N/m	Max. N/m	Min. N/m	Max. N/m	**Computed the centre of the rigid plate clamped at PLM interface points only.**
Global Longitudinal	3.5E8	4.55 E8	3.5E8	4.55 E8	5.6E8	6.5 E8	3.1E8	3.7 E8	
Global Lateral	8.2E7	1.07 E8	8.2E7	1.07 E8	2.2E8	3.0E8	1.5 E8	2.0 E8	

7.3.2.2 Strength Requirements

Also in this case, the complete set of requirement is included in the SVM Structure Spec. RD-26, is. 3.
The main SVM Structure strength requirements are reported below.

The design of Herschel and Planck shall guarantee survival under the worst load combination, during all the Satellite life, namely integration, testing, handling, transportation, launch and orbital life as defined in AD-13.

The design philosophy shall be in accordance with AD-12:
no failure shall occur at ultimate level
positive M.o.S. shall be shown

The acceleration shall be applied to the equipped SVM. The masses of the equipment are defined in AD-42.

Here below, the main loads (Limit Loads) for Launch Phase, utilised for the SVM Structure design are reported.

The following definitions are applied.

Limit Loads: limit loads are the load combinations which have a 99% probability of not being exceeded during the entire life of the structure, including manufacturing, handling, transportation, ground testing,
launch and in-orbit operations.

Design Loads: design loads are simplified load cases, which shall envelop the limit loads and the qualification loads of the environmental testing.

Qualification Loads: are the Limit Loads times 1.25.

Preliminary Design Loads: Are the design loads to initiate the design phase. They are here below defined. They will be superseded when flight loads, based on coupled load analysis with the launcher, and test loads will be available.

The design and dimensioning of Herschel and Planck Primary Structures must take into account :

- **Launcher QSL** : general loads defined by the Launcher authorities, and derived from the most severe loads combination that can be encountered at any given instant of flight with ARIANE 5.
  The Launcher QSL are defined as accelerations to be applied at Satellite C.o.G. level.

- **overflux** : defined by the Launcher authorities, induced by ARIANE 5 boosters

- **Subsystem QSL** : loads which cover local resonance of subsystems equipment’s or subsystems equipment’s supporting.
  The Subsystem QSL can be defined in term of:
  - accelerations to be applied at the level of equipment CoG
  - interface forces and moments to be applied at the level of units interfaces

The sizing cases relevant to **Launcher and Subsystem QSL (Limit Load Cases)** are summarised hereafter, and are defined assuming that Herschel and Planck Primary Structures comply with the stiffness requirements as defined in § 7.3.2.1.

Launch configuration: the Primary Structure is simply supported at the Launcher interface, but without considering the clampand stiffness at this interface.

7.3.2.2.1 SVM Flight Loads

The following table 7.3.2.2.1-1 reports the common Herschel and Planck launcher Limit Load cases.

Loading case	X Longitudinal	YZ Lateral	H Over line loads (N/mm)	P Over line loads (N/mm)
Lift-off	-1.7g ± 1.5 g	± 2g	5	30
Max dyn pressure	- 2.7g ± 0.5g	± 2g	7	30
SRB end of flight	– 4.55g ± 1.45g	± 1g	10	35
Main core thrust tail-off	- 0.2g ± 1.4g	± 0.25g	0	0
Max tension case	+2.5g	± 0.9g	0	0

Table 7.3.2.2.1-1 S/C Flight Limit Loads

7.3.2.2.2 SVM Structure S/S main resonance loads

In addition to the above A5 defined loads, several load cases are provided both in terms of accelerations as forces. They have been derived considering the responses resonance of the main SVM components, like the H-PLM and P-PLM, Herschel SSH/SSD, Herschel SVM shield as well as the H-P PTSS, Planck He tanks, Planck Solar Panel. These load cases are defined for Herschel (cases 1H to 4H) and for Planck (cases 1P to 5P) in paragraphs 5.1.3.2.2 for Herschel and 5.1.3.2.4 for Planck of the RD-26, is. 03.

Also in this case some changes have been introduced with respect to the SRR prescribed requirement.
The main are concerning the SSH/SSD acceleration forces combination with the PLM acceleration an the Herschel different PLM mass and location.
In addition, for the SVM panels (including the supported equipment) specific design load factors have been derived (cases 3H and 3P).

These requirement changes are deemed compatible with the already developed Primary structure concept.

They will be utilised in the next loop of analyses, starting in July, by the Structure S/S Contractor.

7.3.2.3 Safety Factors

The Primary Structure shall show positive margins of safety under worst case combinations of loading with application of the Safety Factors defined in table below.

Safety factors for components loaded in compression shall be used in conjunction with standard conservative design practices for the evaluation of allowable buckling loads.

APPLICATION	**Yield Safety Factor**	**Ultimate Safety Factor**	**Buckling Safety Factor**	**REFERENCE**
Conventional Materials	1.1	1.50	2.00	
Unconventional Materials	1.4	2.00	2.00	
Inserts and Joints	1.5	2.0	-	

Table 2.3-1 Safety Factors Summary

7.3.3 Mechanical Requirements for Equipment and Secondary Structures

The mechanical requirement for Equipment and Secondary Structures are reported in RD-27.
This document summarises and organises all the mechanical data, derived from applicable documents or analysis, to be utilised for the design and test (qualification and acceptance) of the Herschel & Planck SVM Primary Structure and for the items which will be installed on it, namely S/S Equipment and SVM Warm Units and the related secondary structures (e.g. brackets).

This specification recalls (from System level specifications as AD-13, AD-43)
- The SVM physical characteristics
- The S/C environmental requirement
- The SVM stiffness and rigidity requirements

In addition, starting from the above defined environment, it specify:
- The Design Load Factors (DLF), for the SVM box panels and for the equipment and unit
- The test requirements (qualification and acceptance) for the SVM Structure (Static Test) and the Sine Vibration, Random Vibration and Shock Tests for SVM Equipment.

7.3.4 SVM Fracture Control Plan

This document, RD-32 defines the program of activities that Alenia intends to perform in order to cover the requirements contained in AD-43 and AD-34. This document is applicable to the
sContractors throughout the related subsystem specifications.

The procedures and criteria of this plan are applicable to all HERSCHEL/PLANCK SVM structural items belonging to one of the categories listed in the following table, which failure can results in a catastrophic or critical hazard.
For Pressure Vessels and Rotating machinery (see definitions in appendix A of RD-32) this plan is always applicable.

- Pressurised System
- Rotating Machinery
- Fasteners in single point failure
- Welding, Forging and Casting (with Limit Stress > 25%UTS)
- Non Metallic/Composite structures

Table 1.1-1: List of structural items to be screened in order to determine the Fracture Control Applicability

7.3.5 Mechanical Justification

7.3.5.1 Mechanical Design Philosophy

The following points are considered important design objectives for the Herschel and Planck SVM structural design.

Equipment Accommodation Flexibility

The structural design provides the necessary flexibility to accommodate payload and Support S/S equipment evolution in terms of envelope and layout.

The I/F between equipment and SVM structure is dictated by a number of parameters and considerations such as: mass properties, dimensions, orientation w.r.t. alignment targets, configuration of radiators, compatibility with other instruments or subsystems, radiation shielding, contamination constraints, both on ground and in orbit operation constrains. The above needs can be translated into the following design implementation objectives:

- adoption of clear I/F among structure and equipments
- selection of structural elements capable to sustain a partial modification of the load paths
- adoption of adequate design margins in order to allow the required design flexibility.

The result is a decoupling of equipment design from the structure design together with the achievement of an easy integration.

Simplicity, Reliability and Cost Optimisation

To optimise reliability and cost the mechanical design has to be driven by the following objectives:

commonality among the structural elements constituting the SVM.
a structure having a limited number of items / interfaces
adoption of qualified “off-the shelf” structural solutions (joints) whenever possible
minimisation of manufacturing / assembly / integration steps and fluxes

7.3.5.2 Structure Configuration

The Herschel and Planck Structure Configuration is described in detail in paragraph 9.1. The design of the SVM Structure, there included, reflects the general configuration and lay-out and the Equipment/Units mass values as included in AD-42 Issue 02.

In AD-42, is. 03 a new configuration is reported. In this, more details, as cut-out, equipment interfaces, S/S definition, are included.
Obviously, the Structure design here presented is not completely in agreement with the updated SVM configuration reported in AD-42, issue 03. However, it is deemed that the modifications brought into the SVM configuration, are not jeopardizing the primary structure concept developed so far.

The SVM Structure is composed of a Primary and a Secondary structure, both largely described in paragraph 9.1 and Contractor documentation.

The **Primary Structure** is defined as that part of the structure, which carries the main launch loads and which determines the fundamental frequencies of the satellite. The primary structure consists of:

- Central tube
- Octagonal box
- Payload sub-platforms
- P.Tanks Support Structures (PTSS)

The **Secondary Structures** are not responsible for the main load transfer. They are fastened to the primary structure and transfer Units loads to the primary structure.

The main components of the Primary Structures are shown in the following figures. Figure 7.3.2-1 shows the Herschel SVM structure layout. Figure 7.3.2-2 shows the Planck SVM structure layout

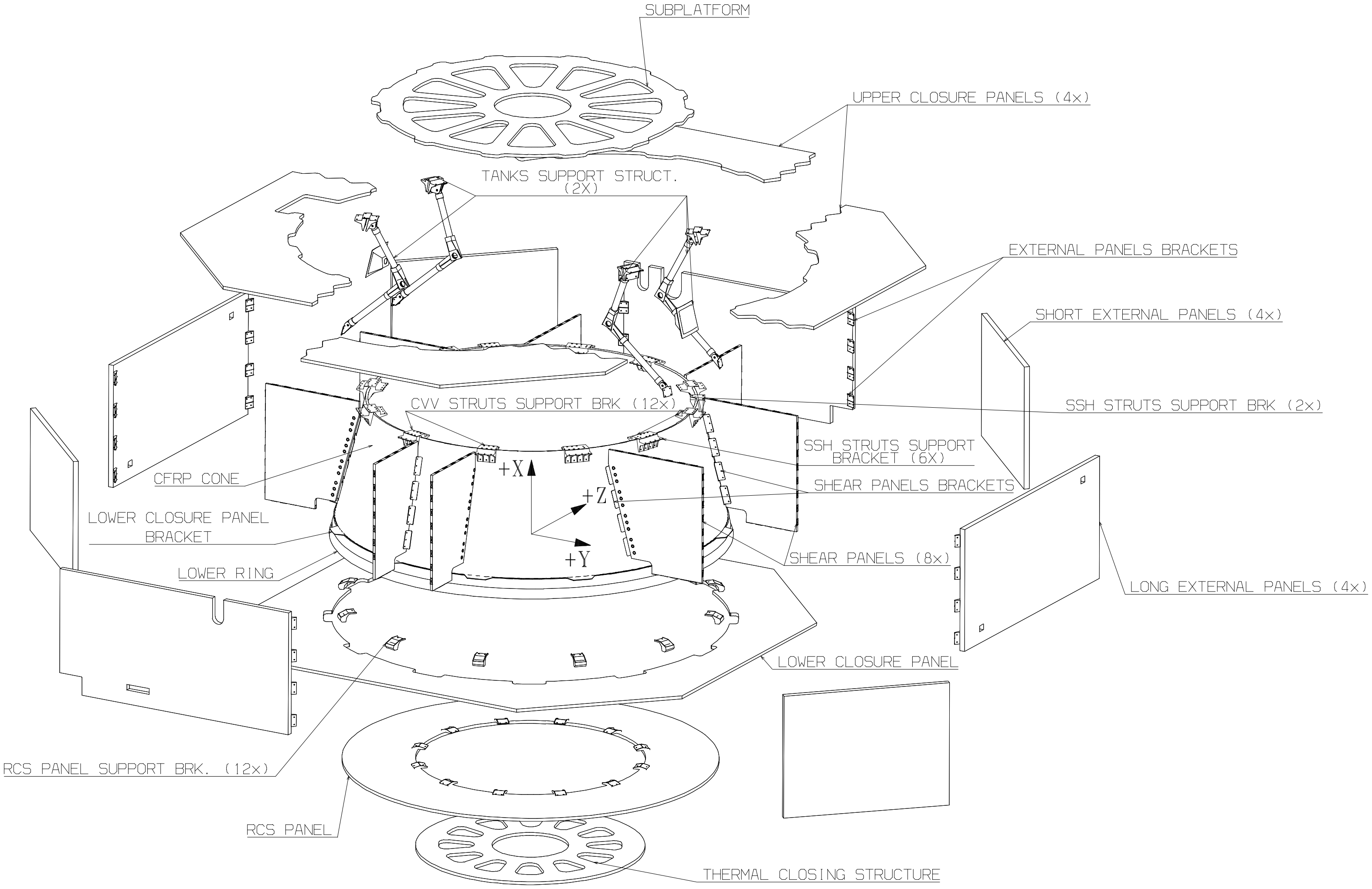


Fig. 7.3.2-1 Exploded view of Herschel SVM Structure

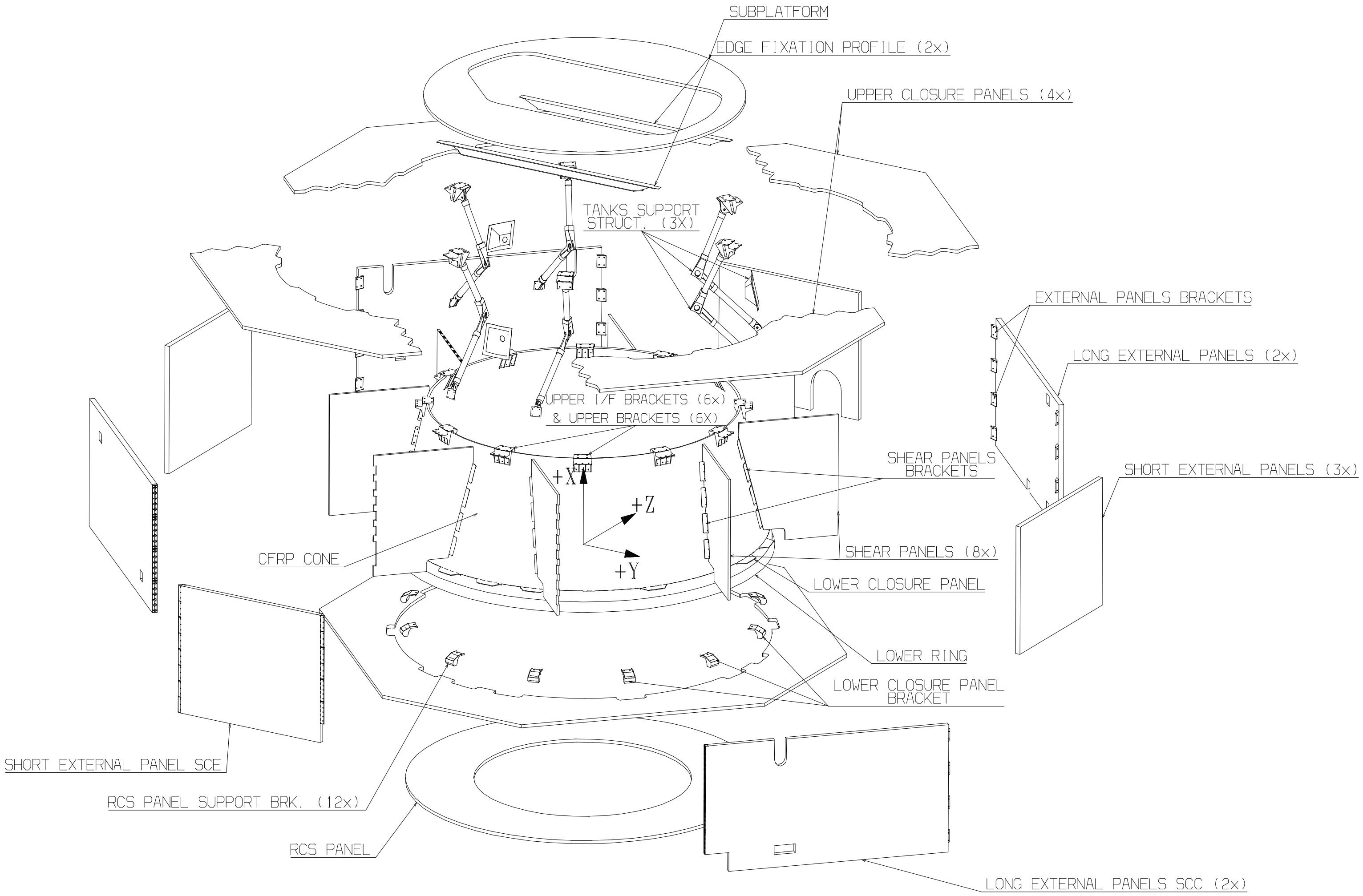


Fig. 7.3.2-2 Exploded view of Planck SVM Structure

7.3.5.2.1 Structure Design Justification

The SVM structure is designed for Herschel and Planck S/C. Due to the commonality approach, the SVM structure shall be able to satisfy the requirements applicable at both Satellites. In particular, when possible, the SVM structure performances are enveloping the two different set of requirement.

With the increasing of the design maturity, it became obvious that the great difference in the required performance of the two SVM led to two structure which general design and philosophy is still the same, while details are sometimes different, as different are the requirement to be satisfied.
In principle the primary structures are made of the same materials, shape and dimensions.

The deviations in the commonality requirements, as described in § 9.1, are not impacting the overall mechanical performances.

The design provides adequate stiffness to decouple both Spacecrafts modes from those of the launch vehicle.

7.3.5.2.1.1 Material Selection

The adopted materials have been selected to meet the requirements for lightweight, high stiffness, low distortions, thermal decoupling properties applied to Herschel and Planck SVM structure. In particular, the octagonal box is in CFRP, whilst the lateral panels and Planck Payload Sub-platform are in Aluminum.

7.3.5.2.1.2 Mass Justification

The majors mass driving factors of the SVM Structure are:
- Stiffness requirements (global and local)
- Equipment Layout
- PLM’s interfaces

The major differences between Herschel and Planck are here summarized:

- Different PLM masses between H and P
- Local differences between Herschel and Planck at the PLM interfaces, namely: 12 points in Herschel, 6 points in Planck, where, the Payload Sub-platform is interposedbetween PLM and Cone I/F brackets
- Interfaces for SSH/SSD on cone and Upper closure for Herschel only
- Interfaces for SVM Shield on cone and Upper closure for Herschel only
- Interfaces for Solar Array Panel for Planck only
- Different cut-out on the octagonal box panels
- Specific junctions for the 3 Planck SCC panels
- Different Secondary Structures

7.3.6 Mechanical Performances

- **SVM Structure**

The SVM Structure performances are reported in detail in § 9.1. and RD-42

As mentioned in the pervious paragraphs, due to schedule constraints, it is clear that the Structure design, summarised in RD-42 and reported in the Contractor documentation (RD-33 to RD-38, RD-40, RD-43, RD-44) is not in line with the System PDR baseline requirement and configuration.

The main discrepancies are here reported. In some cases, preliminary assessments of the new requirement have been already performed.
Starting from July, a new loop of analyses will be performed taking into account the System PDR baseline. The results of this new loop is expected by the S/S CDR.

System PDR	*versus*	*Structure S/S PDR inconsistencies*
➢ Global Stiffness / Rigidity	→	Check with the new cone material and lay-up, RD-42
➢ PLM resonance LLF and new H-PLM Mass and location	→	Check with the new cone material and lay-up, RD-42
➢ New H-/ P-PLM to SVM interface	→	To be implemented in the Structure design and verified w.r.t. the new LLF (e.g.SVM Shield)
➢ New SVM configuration baseline (AD-42, is.03)	→	To be considered for the next loop of design / analysis, also including the mass saving exercise outcomes (RD-42)

- **SVM Equipment and Secondary Structures**

For the SVM Equipment and Secondary Structures the mechanical requirements defined in RD-27 have been derived through dedicated analyses.

The analyses performed to derive the SVM Design Load Factor is widely described in RD-28
The analyses performed to derive the SVM Sine Vibration Test Environment is described into RD-29
The analyses performed to derive the SVM Random Vibration Test Environment is described into RD-30
The analyses performed to derive the SVM Shock Test Environment is described into RD-31

All the above technical notes have been prepared, utilising the two CASA NASTRAN FEM's, (H-SVM and P-SVM) prepared for S/S PDR. This FEM, as already said, reflects the SVM requirement / configuration status of AD-42, is 2 (November).

The **Sine response** analyses results are, generally, not critical both for the structure as for the equipment. A second loop is planned utilising the updated CASA FEM, to be prepared for the S/S CDR.

The **Vibro-acoustic** analysis, simulating the launcher acoustic spectrum, provides the Random Vibration Environment for each area (panels of the octagonal box) and at the interface with the main items (e.g propellant tanks). The first loop of analyses, performed with the CASA FEM, provided very severe environment, which was deemed not realistic, mainly due to the not adequate FEM representation of the structural junctions between panels and tanks to cone brackets.
Therefore, the two CASA FEM's have been updated, modifying the junction, but also introducing the W.U. updated masses. A second loop of vibro-acoustic analysis has been performed.
Concerning the thrusters RVE, to solve the criticality, new positions, namely in stiffer locations, have been proposed and accepted.
RD-30, describes these above mentioned tasks.

Generally, the new results are deemed acceptable, which means compatible with qualification levels used for existing equipment. Some areas, as RCS panel (and the RCS equipment mounted on) and Planck Central Solar Array Panel remain still critical.
Dedicated trade-off are planned to solve the criticality's, introducing local design solutions. The principal aim remains the utilization of off-the-shelf equipment (RCS).

Also for the RVE a second complete loop of analysis is planned utilising the updated CASA FEM, to be prepared for the S/S CDR.

For the **Shock** analytical assessment experimental data (i.e. SVM Integral) have been utilised, applying the new A% shock environment. From these, the shock environment, for each area (i.e. panels of the octagonal box) and at the interface with the main items (e.g propellant tanks), have been derived. Some criticality's is still shown. To solve them, local structural solution shall be found. The proposed solution is the utilization of shock absorber (multilayer washers), deemed capable of reducing the levels of 30% minimum (from 500 Hz). Their effectiveness has been already tested at laboratory level and a system test on RADARSAT SDM is planned in the next month.
Finally, more refined shock analyses are planned for the next loop, using AUTOSEA-Transient computer code, (planned to be purchased).

7.3.6.1 SVM FEM Analyses

The principal results are included in § 9.1 and details are provided in RD-42.

7.3.6.2 SVM Potential Fracture Critical Item List

On the basis of the Fracture Control Plan, RD-32 a preliminary PFCIL has been prepared.

7.3.7 SVM Mechanical Open Areas

7.3.7.1 SVM Structure

A summary of the main open areas found in the SVM Structure is here below included, in the order of criticality. The possible recovery actions are also indicated.

- **Structure Mass**

The H and P SVM Structure mass requirement, since the first months of S/S Contractor activity, has been recognised as the most critical one, such that the major efforts performed during the entire Structure S/S phase B was, in fact, addressed to design a real mass optimised structure.
The Structure mass evolution is presented in paragraph 9.1.5, where it is clearly shown that after a first mass assessment performed at the phase B beginning, several design iterations have been made.
The last exercise, leading to the present values, has been recognised as the minimum achievable.

- Herschel SVM Structure Mass (maximum value, including Secondary structure) = 239.8 Kg
- Planck SVM Structure Mass (maximum value, including Secondary structure) = 255.1 Kg

These values are still far from the requirement and from figures compatible with the entire H and P SVM mass requirement. However, no other recovery actions seem achievable, of course in compliance with the available Contractor developed technological level and with the Program schedule constraints.

- **Herschel Star Trackers Stability**

The second important noticed non-compliance is the STR stability, between two consecutive on-orbit calibrations. The order of magnitude of this non-compliance (20 times, w.r.t. the requirement) led to decide to study some alternative locations for the STR mounting inside the SVM. In paragraph 5.1.5 and RD-39 the trade-off studies, which are still in progress, are described.

Two possible location have been identified to be studied:

- STR mounted on the PLM (close to the telescope): this study shall be performed at system level
- STR mounted inside the SVM Central cone, which is the most thermally stable area within SVM

From the very preliminary results, the second solution is deemed achievable. Of, course, anyone of the possible traded solution has a mass impact, with respect to the present mass value, accounted inside the above reported figures.
For any detail see paragraph 5.1.5.

- **SVM Negative Margin of Safety**

One of the main non-compliance, reported at the S/S PDR were the negative MoS found on the SVM. The structural items involved are:

- Lateral panels and Planck P-load sub-platform (against wrinkling)

In order to solve this situation three recovery actions have been carried out:

- ☐ Utilisation of the new defined Design Load Factors (RD-27), less severe with respect to those preliminarily defined
- ☐ More refined modelization of the equipment to panels interfaces, introducing the real number of attachment feet.
- ☐ Utilisation of a more appropriate formulation for the wrinkling verification

As shown in RD-42 the new obtained MoS values on the most critical panel are now positive. In case some areas still show negative values, local reinforcements will be included.

- Cone Herschel (skins rupture)

For this, local reinforcements will be added.

- Joints

Generally, the joints present positive MoS except for some details for which the recovery action has been given in a dedicated document where also joint calculation and justification is presented [R.D. 40].

- **System tasks versus Structure Sub-system tasks schedule**

As already mentioned above (paragraph 7.3.4), whilst the System activities went through a typical phase B evolution, during which continuous changes of requirements and configuration are deemed “normal work”, the Structure S/S, should have started the phase C/D.

7.3.7.2 Equipment and Secondary Structure

The principal open areas for the Equipment and Secondary Structures are the Vibro-acoustic and Shock environment.

As explained in paragraph 7.3.4, for both types of environment, the research of local structural solutions for each area deemed still critical is in progress.

7.4 THERMAL DESIGN CONCEPT AND PERFORMANCE ANALYSIS

7.4.1 Thermal Requirements and Design Drivers

The HERSCHEL/PLANCK thermal design shall maintain all Instruments, equipment and structure temperatures within the specified limits (reported in AD-2/3/4/5/6) through all the phases of the S/L lifetime, including ground testing.
It shall also ensure the required temperature stability for equipment (where these requirements are applicable).

The Thermal Control of Herschel and Planck SVM are designed taking in to account these main guidelines:

- maximum commonality between the two satellites
- maintain the temperature of the equipment located on the panels internal sides within their operating ranges all over the mission phases
- Mass and Power budgets optimisation
- an adequate level of design flexibility
- minimise technical risks and the design uncertainty sources
- provide the appropriate thermal environment to the structural parts in order to maintain alignment and ensure its stability by minimising any thermal misalignments and gradients.
- use of well proven design solutions

In order to obtain whatever above described, the Thermal Control use the following items:

- MultiLayer Insulation blankets
- High and low emissivity tapes
- Paints
- Heaters, thermostats and thermistors
- Second Surface Mirrors (rigid and/or flexible)
- Interface fillers and low conductivity stand-offs for mounting equipment and equipment supports
- Aluminium doublers
- Heat pipes (limited to the thermal control of Planck SCC)

A detailed description of the SVM Thermal hardware is detailed in section 9.2.

7.4.2 Overall Thermal Design Description and Configuration

The SVM Thermal Control of the two satellites is developed trying to extent to the maximum commonality between them. The commonality concerns mainly the kind of design and the choice of material, while the sizing (radiator areas, heater powers etc.) will be different for the two satellites.

In Figure 7.4.2-1 (Herschel) and in Figure 7.4.2-2 (Planck) is shown a brief description of the units that are mounted on these panels; in the same picture are shown the respective external MLI/OSR area.

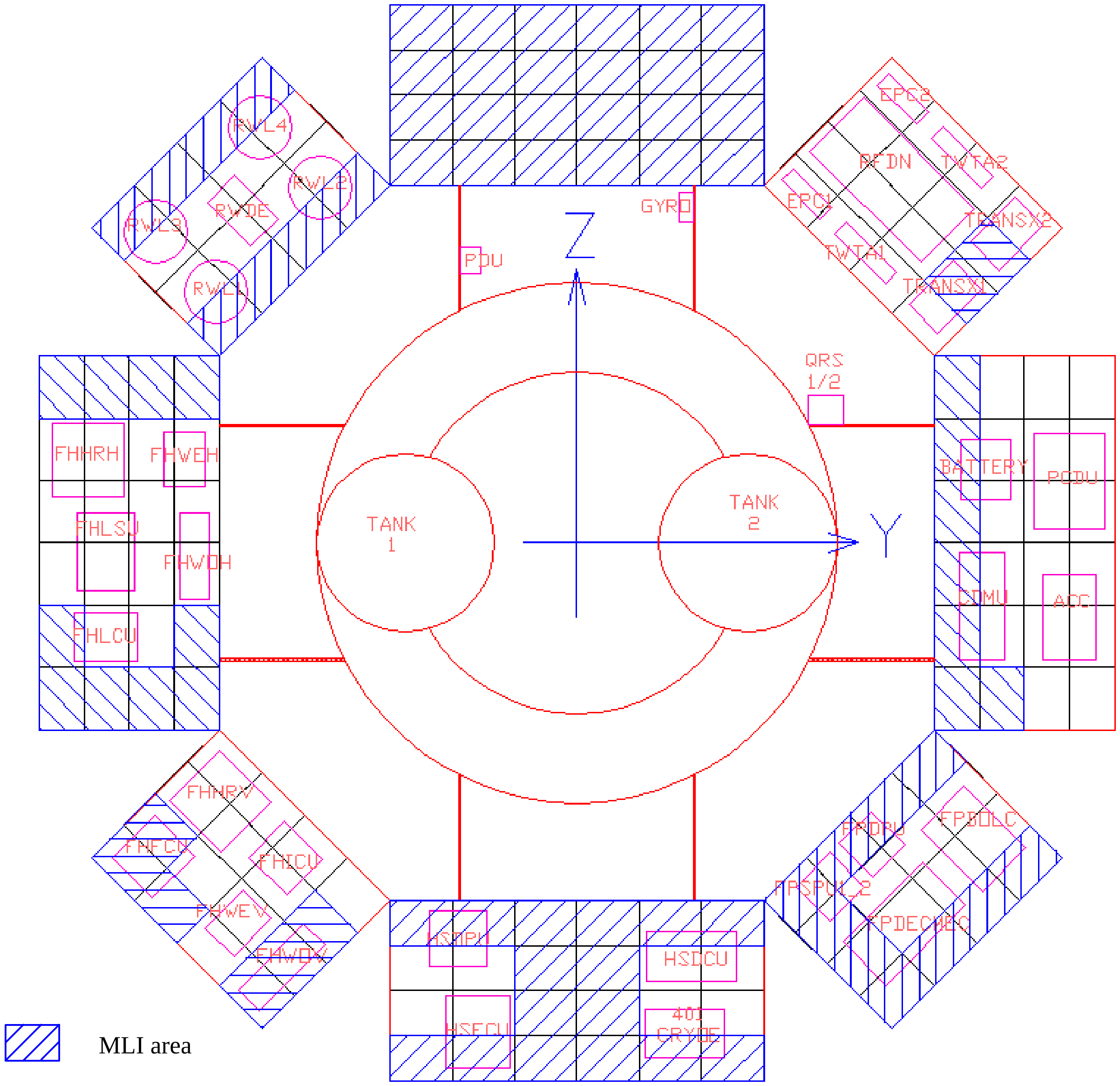


Figure 7.4.2-1 HERSCHEL lateral panels

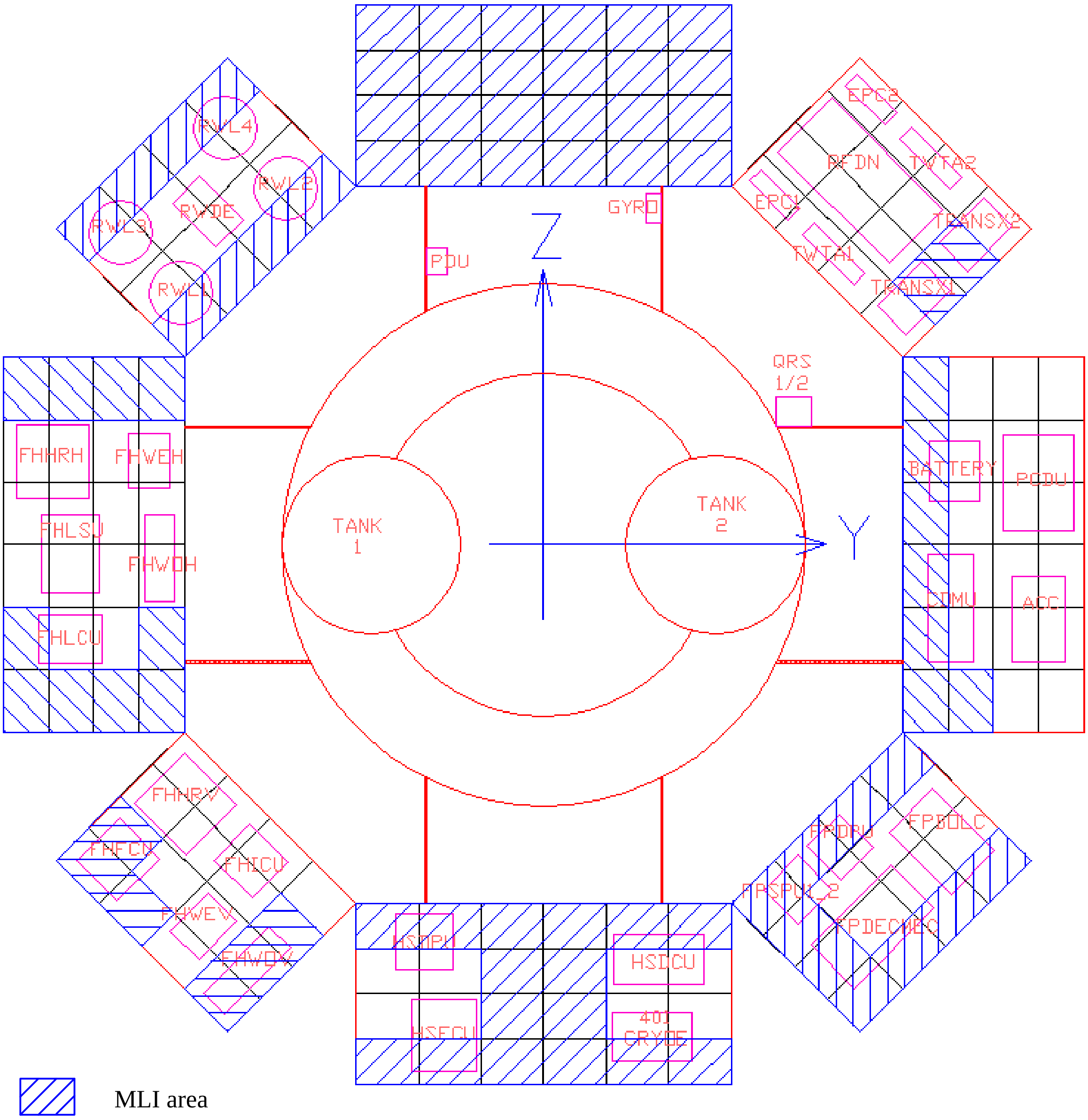


Figure 7.4.2-2 PLANCK Lateral Panels

7.4.3 Design Justification

For each satellite, the two modules (PLM and SVM) can be considered independent from a thermal point of view since the conductive heat fluxes between the two modules are limited.

The top and the bottom of the SVM are covered with MLI.
In order to reject the heat flux of the units , all lateral panels are used, when is requested, as radiators; to optimise at heaters power level this area, an accurate trimming between MLI and OSR was performed.

A particular attention have been dedicated to stability requirement on HI-FI units (Herschel) and SCC panel (Planck); to meet these requirements, these units will be covered with MLI to insulate the units from the other internal SVM parts.
Dedicate trade-off for the heaters operation will be performed to avoid that the heaters power switch-on/switch-off, introduce a thermal instability factors inside the Service Module.
The nominal operation heaters could be commanded by CDMU/PCDU and operate in Pulsed Width Modulation mode.

7.4.4 Thermal Performance Analyses

Dedicated trade-off thermal analyses have been carried out to identify/verify an adequate thermal control design.
The analysis has been performed separately for Herschel and Planck, preparing for each satellite a ESARAD geometrical mathematical model (GMM) and a ESATAN thermal mathematical model (TMM). For both Satellites worst Hot and Cold cases were considered, assuming the following parameters:

- Sun constant → Winter Solstice = 1405 W/m^2 (hot cases)
- Sun constant → Summer Solstice = 1285 W/m^2 (cold cases)
- No Albedo and Earthshine was considered from the Earth, due to the long distance from the spacecrafts.
- BOL/EOL thermo-optical properties are used for cold/hot cases.
- Several SAA (only for Herschel) as reported in paragraph 7.4.4.3

7.4.4.1 Geometrical Mathematical Model Description

The GMM has been prepared modeling the structural panels, the solar arrays, the tanks and the units. Each electronics units are modelled with a single box.
The lateral panels (1730*800mm) have been modeled with 24 internal nodes representing the structure of the panel, and 24 external nodes representing the external coating of the radiator. The lateral panels (115*800mm) have been modeled with 16 internal nodes representing the structure of the panel and 16 external nodes representing the external coating of the radiator.
Concerning PLANK SCC radiators, the meshing of the panels have been developed taking into account the presence of the heat pipes on the radiator. The SCC panels (1730*800mm) have been modeled with 48 internal and 48 external nodes. The SCE panel (1154*800mm) has been modeled with 54 internal and 54 external nodes.
The lower and upper floors were modeled by 8 internal and 8 external nodes.

7.4.4.2 Thermal Mathematical Model Description

The TMM has been completed introducing, for each node, thermal capacities and powers.
The completed and detailed GMM and the TMM results are described in the SVM Thermal Analysis Report (H-P-TN-AI-0005 Is.2)
The temperatures limits and power dissipation for the units located in the SVM are reported in Table 7.4.4.2-1/2 for HERSCHEL, in Table 7.4.4.2-3/4 for Planck.

IDENTIFICATION		Panel location	Dissipation [Watt]				Temperature Range [°C]									Remarks
			Survival mode	Standby mode	Primary Mode		TCS Operating Design range		TCS Not-Operating range		GOAL Operating range		Start-up	Switch-off	Radiative sink temperature	
Equipment	Name				Spectroscopy	Photometry	T. mini	T. maxi	T. mini	T. maxi	T. mini	T. maxi				
PACS	**Photoconductor Array Camera and Spectrometer**															
FPDECMEC	Detector Control + Mechanism Control	-Z/Y	0	20.9	65	21.6	-15	45	-30	60	N.A.	N.A.	-30	50		
FPBOLC	Bolometer / Cooler Control	-Z/Y	0	6.6	6.6	48.6	-15	45	-30	60	N.A.	N.A.	-30	50		
FPDPU	Digital Processing Unit 1 (prime + redundant)	-Z/Y	0	24	24	24	-15	45	-30	60	N.A.	N.A.	-30	50		
FPSPU	Signal Processing Unit	-Z/Y	0	30.3	30.3	30.3	-15	45	-30	60	N.A.	N.A.	-30	50		

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature Range [°C]									Remarks
			Survival mode	Standby mode	Primary Mode	TCS Operating Design range		TCS Not-Operating range		GOAL Operating range		Start-up	Switch-off	Radiative sink temperature	
Equipment	Name					T. mini	T. maxi	T. mini	T. maxi	T. mini	T. maxi				
SPIRE	**Spectral Photometer Imaging Receiver**														
HSDCU	HS Detector Control Unit	-Z	0	37	37	-15	45	-35	80	N.A.	N.A.	-30	50		
HSFCU	HS FPU Control Unit	-Z	0	42.9	42.9	-15	45	-35	80	N.A.	N.A.	-30	50		
HSDPU	HS Digital Processing Unit	-Z	0	15.3	15.3	-15	45	-35	80	N.A.	N.A.	-30	50		

Table 7.4.4.2-1 HERSCHEL - Warm Units temperature limits and dissipation

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature Range [°C]									Remarks
			Survival mode	Standby mode	Primary Mode	TCS Operating Design range		TCS Not-Operating range		GOAL Operating range		Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T. mini	T. maxi	T. mini	T. maxi				
HIFI	**Heterodyne Instrument for the Far Infrared**														
FHLCU	Local Oscillator Control Unit	-Y	0	26	35.4	-10	40	-25	55	N.A.	N.A.	-25	40		
FH3DH	3-dB-Coupler Horizontal polarization	-Y	0 TBC	0 TBC	0 TBC	-10	40	-25	55	N.A.	N.A.	-25	40		
FH3DV	3-dB-Coupler Vertical polarization	-Y/-Z	0 TBC	0 TBC	0 TBC	-10	40	-25	55	N.A.	N.A.	-25	40		
FHLSU	Local Oscillator Source Unit	-Y	0	5	45.8	-10	40	-25	55	N.A.	N.A.	-25	40		
FHHRH	High-Resolution Spectrometer, Horizontal polarisation	-Y	0	63.3	63.3	-10	40	-25	55	N.A.	N.A.	-25	40		
FHHRV	High-Resolution Spectrometer, Vertical polarisation	-Y/-Z	0	63.3	63.3	-10	40	-25	55	N.A.	N.A.	-25	40		
FHFCU	Focal Plane Control Unit	-Z	0	13	13	-10	40	-25	55	N.A.	N.A.	-25	40		
FHWEV	Wide-Band Spectrometer Electronics Veritical Polarisation	-Y/-Z	0	26.9	26.9	0	25	-25	55	N.A.	N.A.	-25	40		
FHWEH	Wide-Band Spectrometer Electronics Horizontal Polarisation	-Y	0/15	26.9	26.9	0	25	-25	55	N.A.	N.A.	-25	40		
FHICU	Instrument Control Unit	-Y/-Z	0	29.6	29.6	-25	43	-30	60	-25	40	-30	50		
FHWOV	Wide-Band Spectrometer Optics Vertical Polarisation	-Y/-Z	0	2.2	2.2	0	15	-25	55	0	10	-25	30		
FHWOH	Wide-Band Spectrometer Optics Horizontal Polarisation	-Y	0	2.2	2.2	0	15	-25	55	0	10	-25	30		

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature Range [°C]									Remarks
			Survival mode	Standby mode	Primary mode	TCS Operating Design range		TCS Not-Operating range		GOAL Operating range		Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T. mini	T. maxi	T. mini	T. maxi				
	CRYOSTAT EQUIPMENT														
CCU	Cryo elec. Warn unit	-Z	TBD	6	6	-15	45	-25	55	N.A.	N.A.	-25	TBD		

Table 7.4.4.2-1 HERSCHEL - Warm Units temperature limits and dissipation (continued)

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
			Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T.mini	T. maxi				
ACMS	**Attitude Control and Measurement Subsystem**												
ACC	Attitude Control Computer	+Y	24	24	24	-20	55	-30	65	-30 TBC			
AAD	Attitude Anomaly Detector	+Z	0	0	0	-70	80	-70	80	-30			
PDU	Power distribution unit	+Z shear		10	10	-15	45	-25	55				
GYR	GYR (Gyroscopes)	+Z shear	0	21	21	-15	45	-25	55	-30 TBC			
QRS	Quartz Rate Sensor	+Y shear	0	8	8	-15	45	-35	65	-35 TBC			
QRS	Quartz Rate Sensor	+Y shear		8	8	-15	45	-35	65	-35 TBC			
RWDE		+Z /+Y		7.7*3	7.7*3	-10	50	-20	60	-30 TBC			
RWS	React wheel	+Z /+Y		7.3	7.3	0	50	-10	60	-30 TBC			
RWS	React wheel	+Z /+Y		7.3	7.3	0	50	-10	60	-30 TBC			
RWS	React wheel	+Z /+Y		7.3	7.3	0	50	-10	60	-30 TBC			
RWS	React wheel	+Z /+Y		0	0	0	50	-10	60	-30 TBC			
SAS	Sun Acquisition Sensor	+Z		0	0	-70	80	-70	80	-80 TBC			
SAS	Sun Acquisition Sensor	-Z		0	0	-70	80	-70	80	-80 TBC			
STR	Star Trackers	-Z	0	13	13	-10	30	-20	40	-30			
STR	Star Trackers	-Z	0	0	0	-10	30	-20	40	-30			

Table 7.4.4.2-2 HERSCHEL - Equipment Units temperature limits and dissipation

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
Equipment	Name		Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Start-up	Switch-off	Radiative sink temp.	
						T. mini	T. maxi	T.mini	T. maxi				
CDMS & TTC	**Command and Data Management Subsystem**												
CDMU	CDMU-A (Central Data Manag. Unit)	+Y	36	36	36	-10	45	-20	55	-30 TBC			

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
Equipment	Name		Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Start-up	Switch-off	Radiative sink temp.	
						T. mini	T. maxi	T.mini	T. maxi				
TT&C	**Telemetry Tracking & Command**												
X/B LGA	Low Gain antenna	+Z											
X/B LGA	Low Gain antenna	- Z											
MGA	MGA (Medium Gain antenna)	+Z											
RFDN	RFDN	+Z / +Y	8	0	8	-40	70	-50	80				
TRANS X/B	X-Band Transponder	+Z / -Y	13	7	13	-10	50	-20	60	-30 TBC			
TRANS X/B	X-Band Transponder	+Z / -Y	7	7	7	-10	50	-20	60	-30 TBC			
TWTA	Travelling Wave Tube Assembly	+Z / +Y	38	0	38	-15	50	-25	60	-35 TBC			
TWTA	Travelling Wave Tube Assembly	+Z / +Y				-15	50	-25	60	-35 TBC			
EPC	Electrical Power Conditioner	+Z / +Y	9	9	9	-15	45	-25	55	-35 TBC			
EPC	Electrical Power Conditioner	+Z / +Y	0	0	0	-15	45	-25	55	-35 TBC			

Table 7.4.4.2-2 HERSCHEL - Equipment Units temperature limits and dissipation (continued)

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
			Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T.mini	T. maxi				
	POWER												
Battery	Lithium-Ion Battery	+Y	6	0	0	0	35	N.A.	N.A.				
PCDU	PCDU (Power Conditio.Distr. Unit)	+Y	87	153(*)	153(*)	-10	45	-20	55	-30 TBC			

(*)BOL sunlight case:= 153W ; EOL sunlight case:= 127.17W

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
			Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T.mini	T. maxi				
RCS	**RCS Reaction Control Subsystem**												
RCS	DV Thrusters (10N) Q.ty 12	RCS panel				10	40	10	40				
	Propellant Tank	RCS panel				10	40	10	40				
	Propellant Tank	RCS panel				10	40	10	40				
	Prop. filter	RCS panel											
	Latch valve 1	RCS panel											
	Latch valve 2	RCS panel											
	FW Nitrogen 1	RCS panel											
	FW Nitrogen 2	RCS panel											
	FDV Hydrazine	RCS panel											
	Pressure Transducer	RCS panel				10	40	10	40				
	Pipework	RCS panel											
	Test Port	RCS panel											
	Bracketry	RCS panel											

Table 7.4.4.2-2 HERSCHEL - Equipment Units temperature limits and dissipation (continued)

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature Limits [°C]									Remarks
			Survival mode	Scientific	Telecom phase	TCS Operating Design range		TCS Not-Operating range		GOAL Operating range		Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T. mini	T. maxi	T. mini	T. maxi				
HFI	**High Frequency Instrument**														
PHBA	Data Processing Unit (Nominal)	+Z	0	32	32	-10	40	-20	50	N.A.	N.A.	-20	TBD		
PHBA	Data Processing Unit (Redundant)	+Z	0	0	0	-10	40	-20	50	N.A.	N.A.	-20	TBD		
PHCBA	Pre-Amplifier Unit PAU	Sub pl.+X	0	15	15	-20	40	-20	50	-20	30	-20	TBD		
PHCBC	Readout Electronic REU	+Z	0	92	92	-20	35	-20	50	-20	30	-20	TBD		
PHDA	4K Cooler Compressor UNIT 4CCU	+Y	0	60	60	-10	40	-20	40	N.A.	N.A.	-20	TBD		
PHDB	4K Cooler Ancillary Unit 4CAU	+Y	0	15	15	-10	40	-20	50	N.A.	N.A.	-20	TBD		
PHDJ	4K Pre-regulator	+Y	0	20	20	-10	40	-20	50	N.A.	N.A.	-20	TBD		
PHDC	4K Cooler Electronic Unit 4CEU	+Y	0	41	41	-10	40	-20	50	N.A.	N.A.	-20	TBD		
PHEAA	0,1 K Dilution Cooler 3He Tank		0	0	0	-10	40	-20	50	N.A.	N.A.	-20	TBD		
PHEAB	0,1 K Dilution Cooler 4He Tank		0	0	0	-10	40	-20	50	N.A.	N.A.	-20	TBD		
PHEC	0,1 K Dilution Cooler 4He Tank		0	0	0	-10	40	-20	50	N.A.	N.A.	-20	TBD		
PHED	0,1 K Dilution Cooler 4He Tank		0	0	0	-10	40	-20	50	N.A.	N.A.	-20	TBD		
DCCU	Dilution Cooler Contr. Unit	+Z+Y	0	19	19	-10	40	-20	50	N.A.	N.A.	-20	TBD		

Table 7.4.4.2-3 PLANCK - Warm Units temperature limits and dissipation

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature Limits [°C]									Remarks
			Survival mode	Scientific	Telecom phase	TCS Operating Design range		TCS Not-Operating range		GOAL Operating range		Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T. mini	T. maxi	T. mini	T. maxi				
LFI	**Low Frequency Instrument**														
DAE Power box	Data Acquisition Electr. Control box	Sub pl.+X	0	20	20	-20	45	-30	70	-20	28				
PLBEU	Back End Unit	Sub pl.+X	0	58.7	58.7	-20	40	-30	70	-20	28				
PLREN	Radiometer Electronics Box Assembly (Nominal)	Sub pl.-X	0	41.5	41.5	-20	50	-30	70	N.A.	N.A.	-30	TBC		
PLRER	Radiometer Electronics Box Assembly (Redundant)	Sub pl.-X	0	0	0	-20	50	-30	70	N.A.	N.A.	-30	TBC		

IDENTIFICATION		Location Panel	Dissipation [Watt]			Temperature Limits [°C]									Remarks
			Survival mode	Scientific	Telecom phase	TCS Operating Design range		TCS Not-Operating range		GOAL Operating range		Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T. mini	T. maxi	T. mini	T. maxi				
SCC	**SORPTION COOLERS**														
SCC	Sorption Cooler Compressor (Nominal)	-Z+Y	0	470(*)	470(*)	-13	7	-20	60	N.A.	N.A.	(**)	(**)		
SCC	Sorption Cooler Compressor (Redundant)	-Z-Y	0	0	0	-13	7	-20	60	N.A.	N.A.	(**)	(**)		
SCE	LFI2D : Sorption Cooler Elec. (Nominal)	-Z	0	110	110	-10	40	-20	60	N.A.	N.A.	10	40		
SCE	LFI2D: Sorption Cooler Elec. (Redundant)	-Z	0	0	0	-10	40	-20	60	N.A.	N.A.	10	40		

(*) sizing case for SCC panel = 520 Watt

(**) The SCC can be switched on at ambient temperature and pressure for only a very limited period of TBD minutes.
The SCC switch on temperature in vacuum (pressure TBD) is TBD.

Table 7.4.4.2-3 PLANCK - Warm Units temperature limits and dissipation (continued)

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
			Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T.mini	T. maxi				
ACMS	**Attitude Control and Measurement Subsystem**												
PDU	Power Distribution Unit			10	10	-15	45	-25	55				
STR	Star Tracker		0	13	13	-20	40	-30	50				
STR	Star Tracker.		0			-20	40	-30	50				
SAS	Sun Acquisition Sensor		0			-70	80	-70	80				
SAS	Sun Acquisition Sensor		0			-70	80	-70	80				
SAS	Sun Acquisition Sensor		0			-70	80	-70	80				
AAD	Attitude Anomaly Detector		0			-70	80	-70	80				
QRS	Quartz Rate Sensor		8	8	8	-15	45	-25	55				
QRS	Quartz Rate Sensor		0	8	8	-15	45	-25	55				
QRS	Quartz Rate Sensor		0	0	0	-15	45	-25	55				
ACC	Attitude Control Computer		24	24	24	-10	45	-20	55	-30 TBC			

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
			Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Cold Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T.mini	T. maxi				
CDMS	**Command and Data Management Subsystem**												
CDMU	Central Data Manage. Unit	-Y+Z	36	36	36	-10	45	-20	55	-30 TBC			

Table 7.4.4.2-4 PLANCK - Equipment Units temperature limits and dissipation

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
			Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Cold Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T.mini	T. maxi				
TT&C	**Telemetry Tracking & Command**												
MGA	Medium Gain antenna	-X											
RFDN		-Y	8	0	8	-40	70	-50	80				
TRANS X/B	X-Band Transponder	-Y	13	7	13	-10	50	-20	60				
TRANS X/B	X-Band Transponder	-Y	7	7	7	-10	50	-20	60				
TWTA	Travelling Wave Tube Assembly	-Y	38	0	38	-15	50	-20	60				
TWTA	Travelling Wave Tube Assembly	-Y	0	0	0	-15	50	-25	60				
EPC	Electrical Power Conditioner	-Y	9	9	9	-15	45	-25	55	-35 TBC			
EPC	Electrical Power Conditioner	-Y	0	0	0	-15	45	-25	55	-35 TBC			
X/B LGA	Low Gain antenna	+Y											
X/B LGA	Low Gain antenna	-X											
X/B LGA	Low Gain antenna	-Y											

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
			Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T.mini	T. maxi				
	POWER												
Battery	Lithium-Ion Battery	-Y+Z	6	0	0	0	35	N.A.	N.A.				
PCDU	Power Conditionning Distr.Unit	-Y+Z	86	153	153	-10	45	-20	55	-30 TBC			

Table 7.4.4.2-4 PLANCK - Equipment Units temperature limits and dissipation (continued)

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
			Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Cold Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T.mini	T. maxi				
RCS	**Reaction Control Subsystem**												
RCS	DV Thrusters (10N) Q.ty =12					10	40	10	40				
RCS	DH Thrusters (1N) Q.ty =4					10	40	10	40				
	Propellant Tank 1					10	40	10	40				
	Propellant Tank 2					10	40	10	40				
	Propellant Tank 3					10	40	10	40				
	Propellant filter												
	Latch valves 1												
	Latch valves 2												
	FW Nitrogen 1												
	FW Nitrogen 2												
	FW Nitrogen 3												
	FDV Hydrazine												
	Pressure Trasducer												
	Pipework					10	40	10	40				
	Test Port												
	Bracketry												

Table 7.4.4.2-4 PLANCK - Equipment Units temperature limits and dissipation (continued)

IDENTIFICATION		Panel location	Dissipation [Watt]			Temperature limit [°C]							Remarks
			Survival mode	Scientific observation	Telecom phase	Operating mode		Not operating mode		Cold Start-up	Switch-off	Radiative sink temp.	
Equipment	Name					T. mini	T. maxi	T.mini	T. maxi				
	ESA Furnisched Items												
SREM		-Y ext.											
VMC		-Y ext.											

Table 7.4.4.2-4 PLANCK - Equipment Units temperature limits and dissipation (continued)

7.4.4.3 Analysis cases description and results

HERSCHEL Thermal Analysis

Herschel is a three axis stabilised S/L with Sun Aspect Angle (SAA) varying from 0° to ±30° around Y - axis, in the (X,Z) plane.and varying to ±1° around X axis in the (Y,Z). This SAA variation represents one of the critical aspects for the warm unit thermal stability requirement.

Preliminary trade-off analyses, performed to evaluate the unit layout, showed, as expected, hot temperatures for the +Z panel: the sun rays are perpendicular to this panel and therefore it has been decide to cover it completely with thermal blankets, avoiding to mount any unit on it.
Moreover the PLM warm units have been mounted on the anti-sun side panels and covered with MLI to reduce the effect of the SVM environment on the temperature fluctuation.

The analysis was carried out for cold and hot case.
The Cold cases are defined by:

- BOL thermal characteristics
- Scientific Observation phase SAA= +30° (sun on +X axis)
- Survival mode: SAA = +30° (sun on +X axis)

The Hot cases are defined by:

- EOL thermal characteristics
- Telecommunication phase considering three SAA position: SAA = -30 ° (sun on -X axis); SAA = -30/+1 ° (sun on -X/+Y axis); SAA = -30/-1 ° (sun on -X/-Y axis).

The following sizing cases have been performed:
Case 1) = Nominal Case (Hot and Cold)
Case 2) = Cold Case with worst Attitude, low power dissipation during various Operative Modes

- Mode 1 is sizing for HIFI
- Mode 3 is the lowest power dissipation mode (sizing for SPIRE)
- Survival = all the warm units are OFF

Case 7) = Hot Case in worst Attitude during various operative Modes

- Mode 2 is sizing for PACS

CASE	a Degradation	Sun on Panel	Solar Aspect Angle	Attitude	Solar Constant [W/m²]	Dissipation Mode
1	BOL	+Z	0	Rot X = 0 Rot Y = 0	1285	Scientific / MODE3
2A	BOL	+X+Y	30	Rot X = +1 Rot Y = +30	1285	Scientific / MODE3
2A	BOL	+X+Y	30	Rot X = +1 Rot Y = +30	1285	SURVIVAL
2B	BOL	+X-Y	30	Rot X = -1 Rot Y = +30	1285	Scientific / MODE3
2B	BOL	+X-Y	30	Rot X = -1 Rot Y = +30	1285	Scientific / MODE1
1	EOL	+Z	0	Rot X = 0 Rot Y = 0	1405	Telecom / MODE2 Photometry
7A	EOL	+X+Y	30	Rot X = +1 Rot Y = -30	1405	Telecom / MODE1
7A	EOL	+X+Y	30	Rot X = +1 Rot Y = -30	1405	Telecom / MODE2 Photometry
7A	EOL	+X+Y	30	Rot X = +1 Rot Y = -30	1405	Telecom / MODE2 Spectroscopy
7B	EOL	+X-Y	30	Rot X = -1 Rot Y = -30	1405	Telecom / MODE1
7B	EOL	+X-Y	30	Rot X = -1 Rot Y = -30	1405	Telecom / MODE2 Photometry
7B	EOL	+X-Y	30	Rot X = -1 Rot Y = -30	1405	Telecom / MODE2 Spectroscopy

Table 7.4.4.3-1 HERSCHEL – Steady State Orbit Cases description

The following table summarises the Herschel payload modes.

MODE	HIFI	PACS	SPIRE	COMMENTS
1	Prime	Standby	Standby	
2	Standby	Prime	Standby	
3	Standby	Standby	Prime	
4	Standby	Parallel	Prime	TM rates will be shared between PACS and SPIRE. PACS and SPIRE observe at the same time.
5	Standby	Standby	Specific mode : “Serendipity”	During slew. All TM bandwidth available for SPIRE.

Table 7.4.4.3-2 Herschel payload Mode

The temperature results hereafter presented refer to the Steady State analyzed cases reported in Table 7.4.4.3-1. The values are inclusive of 7°C of uncertainty. The Tables 7.4.4.3-3/6 present the unit results with the Temperature Limits (Operative and Not Operative).

Steady State Case BOL:

BOL		Operative Temperatures Limits [°C]		Not Operative Temperatures Limits [°C]		BOL1	BOL2A	BOL2B	BOL2B	BOL2A
						Scientific	Scientific	Scientific	Scientific	Scientific
						MODE3	MODE3	MODE3	MODE1	Survival
NODE	LABEL	MIN	MAX	MIN	MAX	T-UFP[°C]	T-UFP[°C]	T-UFP[°C]	T-UFP[°C]	T-UFP[°C]
101	RFDN	-40	70	-50	80	-16.24	-18.90	-19.17	-19.03	-18.10
102	EPC1	-15	45	-25	55	-7.88	-9.30	-9.43	-9.35	-0.53
103	EPC2	-15	45	-25	55	-12.05	-12.09	-12.09	-12.09	-12.10
104	TRANSX1	-10	50	-20	60	-7.03	-7.05	-7.06	-7.06	-7.01
105	TRANSX2	-10	50	-20	60	-7.01	-7.07	-7.08	-7.07	-7.12
106	TWTA1	-15	50	-25	60	-12.05	-12.09	-12.09	-12.09	6.48
107	TWTA2	-15	50	-25	60	-12.08	-12.15	-12.16	-12.16	-12.17
201	PCDU	-10	45	-20	55	23.19	22.42	22.33	22.46	3.74
202	CMDU	-10	45	-20	55	-0.12	-0.98	-1.18	-1.01	-6.93
203	ACC	-20	55	-30	65	-7.31	-8.27	-8.38	-8.20	-16.01
204	BATT	0	35			2.73	2.71	2.71	2.71	2.54
301	FPSPU1_2	-15	45	-30	60	6.22	5.35	5.32	5.53	-12.06
303	FPDPU	-15	45	-30	60	1.38	0.58	0.55	0.74	-12.15
304	FPBOLC	-15	45	-30	60	-12.08	-12.12	-12.12	-12.11	-12.45
305	FPMECDEC	-15	45	-30	60	-5.32	-6.13	-6.15	-5.96	-12.25
401	CRYOE	-15	45	-25	55	-10.77	-12.01	-12.01	-11.49	-12.28
404	HSDCU	-15	45	-35	80	-3.17	-4.56	-4.55	-3.80	-12.27
405	HSDPU	-15	45	-35	80	-9.67	-10.69	-10.72	-10.46	-12.27
406	HSFCU	-15	45	-35	80	3.38	2.31	2.28	2.56	-12.21
501	FHWOV	0	15	-25	55	2.93	2.93	2.93	2.93	2.89
502	FHHRV	-10	40	-25	55	8.23	7.86	7.86	8.17	-7.57
503	FHICU	-25	45	-30	60	-1.34	-1.66	-1.66	-1.41	-22.09
504	FHFCU	-10	40	-25	55	-1.74	-2.32	-2.32	-1.72	-7.14
506	FHWEV	0	25	-25	55	2.97	2.97	2.97	2.97	2.67
601	FHWOH	0	15	-25	55	2.77	2.77	2.78	2.79	2.74
602	FHWEH	0	25	-25	55	2.83	2.82	2.83	2.87	2.53
603	FHHRH	-10	40	-25	55	7.78	7.41	7.43	13.32	-7.35
604	FHLCU	-10	40	-25	55	-3.65	-4.78	-4.77	6.39	-7.26
605	FHLSU	-10	40	-25	55	-7.20	-7.21	-7.21	3.79	-7.43
701	RWL1_C	0	50	-10	60	2.93	2.90	2.90	2.91	2.79
702	RWL2_C	0	50	-10	60	2.94	2.90	2.90	2.90	2.76
703	RWL3_C	0	50	-10	60	2.94	2.90	2.90	2.91	2.78
704	RWL4_C	0	70	-10	60	2.93	2.89	2.89	2.90	2.83
705	RWDE	-10	50	-20	60	-0.99	-3.11	-2.91	-2.71	-7.15
706	QRS1	-15	45	-35	65	1.12	-0.33	-0.44	-0.27	-10.77
707	QRS2	-15	45	-35	65	1.24	-0.22	-0.33	-0.15	-10.92
801	GYRO	-15	45	-25	55	5.18	1.68	1.61	1.92	-10.61
802	PDU	-15	45	-25	55	5.87	2.84	2.86	3.24	-7.19
950	TANK1	10	40	10	40	12.98	12.97	12.97	12.98	12.97
960	TANK2	10	40	10	40	12.98	12.98	12.98	12.98	12.97
42	STRMZMY	-20	40	-30	50	27.50	26.30	26.29	26.77	-17.03
45	STRMZPY	-20	40	-30	50	-17.00	-17.01	-17.01	-17.00	-17.03
6	SASZ	-70	80	-70	80	14.00	11.21	11.18	11.49	7.02
46	SAS-Z	-70	80	-70	80	-22.07	-23.13	-23.14	-22.67	-23.71

Table 7.4.4.3-3 HERSCHEL - Units Temperature results: Case BOL.

Steady State Case EOL1:

EOL1		Operative Temperatures Limits		Not Operative Temperatures Limits		EOL1 Telecom MODE2 Photometry
		MIN	MAX	MIN	MAX	T+UFP
NODE	LABEL	[°C]	[°C]	[°C]	[°C]	[°C]
101	RFDN	-40	70	-50	80	18.53
102	EPC1	-15	45	-25	55	33.84
103	EPC2	-15	45	-25	55	15.36
104	TRANSX1	-10	50	-20	60	25.47
105	TRANSX2	-10	50	-20	60	21.81
106	TWTA1	-15	50	-25	60	40.55
107	TWTA2	-15	50	-25	60	15.64
201	PCDU	-10	45	-20	55	34.22
202	CMDU	-10	45	-20	55	17.63
203	ACC	-20	55	-30	65	9.86
204	BATT	0	35			9.80
301	FPSPU1_2	-15	45	-30	60	27.69
303	FPDPU	-15	45	-30	60	23.32
304	FPBOLC	-15	45	-30	60	16.31
305	FPMECDEC	-15	45	-30	60	17.28
401	CRYOE	-15	45	-25	55	7.06
404	HSDCU	-15	45	-35	80	14.54
405	HSDPU	-15	45	-35	80	10.90
406	HSFCU	-15	45	-35	80	23.55
501	FHWOV	0	15	-25	55	9.94
502	FHHRV	-10	40	-25	55	23.09
503	FHICU	-25	45	-30	60	13.44
504	FHFCU	-10	40	-25	55	13.66
506	FHWEV	0	25	-25	55	9.97
601	FHWOH	0	15	-25	55	9.79
602	FHWEH	0	25	-25	55	9.86
603	FHHRH	-10	40	-25	55	22.71
604	FHLCU	-10	40	-25	55	12.77
605	FHLSU	-10	40	-25	55	-0.17
701	RWL1_C	0	50	-10	60	20.87
702	RWL2_C	0	50	-10	60	22.78
703	RWL3_C	0	50	-10	60	21.06
704	RWL4_C	0	70	-10	60	20.41
705	RWDE	-10	50	-20	60	22.64
706	QRS1	-15	45	-35	65	24.42
707	QRS2	-15	45	-35	65	23.50
801	GYRO	-15	45	-25	55	30.76
802	PDU	-15	45	-25	55	27.15
950	TANK1	10	40	10	40	19.98
960	TANK2	10	40	10	40	19.99
42	STRMZMY	-20	40	-30	50	45.54
45	STRMZPY	-20	40	-30	50	1.37
6	SASZ	-70	80	-70	80	36.59
46	SAS-Z	-70	80	-70	80	-4.82

Table 7.4.4.3-4 HERSCHEL - Units Temperature results: Case EOL1.

Steady State Case EOL7A:

EOL7A		Operative Temperatures Limits		Not Operative Temperatures Limits		EOL7A	EOL7A	EOL7A
						Telecom	Telecom	Telecom
						MODE1	MODE2 Photometry	MODE2 Spectrometry
		MIN	MAX	MIN	MAX	T+UFP	T+UFP	T+UFP
NODE	LABEL	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
101	RFDN	-40	70	-50	80	27.82	28.19	28.26
102	EPC1	-15	45	-25	55	41.81	42.13	42.19
103	EPC2	-15	45	-25	55	26.03	26.36	26.42
104	TRANSX1	-10	50	-20	60	34.59	35.09	35.13
105	TRANSX2	-10	50	-20	60	33.55	34.04	34.08
106	TWTA1	-15	50	-25	60	47.90	48.22	48.28
107	TWTA2	-15	50	-25	60	27.04	27.37	27.43
201	PCDU	-10	45	-20	55	44.73	**45.86**	**45.81**
202	CMDU	-10	45	-20	55	28.15	30.22	30.03
203	ACC	-20	55	-30	65	21.24	23.34	23.11
204	BATT	0	35			19.67	20.99	20.94
301	FPSPU1_2	-15	45	-30	60	34.87	40.14	42.39
303	FPDPU	-15	45	-30	60	29.87	35.69	37.16
304	FPBOLC	-15	45	-30	60	14.93	28.26	21.90
305	FPMECDEC	-15	45	-30	60	23.42	29.81	36.59
401	CRYOE	-15	45	-25	55	21.39	21.39	21.72
404	HSDCU	-15	45	-35	80	27.41	27.39	27.71
405	HSDPU	-15	45	-35	80	19.32	23.49	25.25
406	HSFCU	-15	45	-35	80	32.67	36.41	37.53
501	FHWOV	0	15	-25	55	9.68	9.54	9.71
502	FHHRV	-10	40	-25	55	26.29	26.07	26.15
503	FHICU	-25	45	-30	60	16.08	15.91	15.99
504	FHFCU	-10	40	-25	55	18.67	18.21	18.34
506	FHWEV	0	25	-25	55	14.72	14.57	14.66
601	FHWOH	0	15	-25	55	9.25	4.25	4.38
602	FHWEH	0	25	-25	55	15.62	10.10	10.23
603	FHHRH	-10	40	-25	55	39.81	28.27	28.38
604	FHLCU	-10	40	-25	55	33.36	21.51	21.68
605	FHLSU	-10	40	-25	55	28.57	6.41	6.52
701	RWL1_C	0	50	-10	60	32.38	31.37	31.53
702	RWL2_C	0	50	-10	60	34.04	33.42	33.56
703	RWL3_C	0	50	-10	60	32.94	31.84	31.99
704	RWL4_C	0	70	-10	60	32.72	32.06	32.22
705	RWDE	-10	50	-20	60	31.93	31.31	31.43
706	QRS1	-15	45	-35	65	35.70	36.56	36.57
707	QRS2	-15	45	-35	65	35.25	36.14	36.15
801	GYRO	-15	45	-25	55	43.80	44.05	44.18
802	PDU	-15	45	-25	55	40.87	40.62	40.79
950	TANK1	10	40	10	40	33.32	33.07	33.35
960	TANK2	10	40	10	40	33.58	34.58	34.82
42	STRMZMY	-20	40	-30	50	58.77	59.77	60.25
45	STRMZPY	-20	40	-30	50	14.78	16.92	17.72
6	SASZ	-70	80	-70	80	50.10	50.06	50.18
46	SAS-Z	-70	80	-70	80	7.79	7.82	8.10

Table 7.4.4.3-5 HERSCHEL - Units Temperature results: Case EOL7A.

Steady State Case EOL7B:

EOL7B		Operative Temperatures Limits		Not Operative Temperatures Limits		EOL7B Telecom MODE1	EOL7B Telecom MODE2 Photometry	EOL7B Telecom MODE2 Spectrometry
		MIN	MAX	MIN	MAX	T+UFP	T+UFP	T+UFP
NODE	LABEL	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
101	RFDN	-40	70	-50	80	26.93	27.30	27.37
102	EPC1	-15	45	-25	55	41.04	41.37	41.43
103	EPC2	-15	45	-25	55	25.04	25.38	25.44
104	TRANSX1	-10	50	-20	60	33.71	34.22	34.26
105	TRANSX2	-10	50	-20	60	32.54	33.03	33.07
106	TWTA1	-15	50	-25	60	47.11	47.44	47.49
107	TWTA2	-15	50	-25	60	25.96	26.31	26.36
201	PCDU	-10	45	-20	55	43.70	44.84	44.79
202	CMDU	-10	45	-20	55	27.35	29.44	29.24
203	ACC	-20	55	-30	65	20.15	22.28	22.04
204	BATT	0	35			18.66	20.01	19.95
301	FPSPU1_2	-15	45	-30	60	34.61	39.89	42.15
303	FPDPU	-15	45	-30	60	29.60	35.43	36.91
304	FPBOLC	-15	45	-30	60	14.58	27.94	21.57
305	FPMECDEC	-15	45	-30	60	23.15	29.56	36.34
401	CRYOE	-15	45	-25	55	21.39	21.39	21.72
404	HSDCU	-15	45	-35	80	27.40	27.38	27.70
405	HSDPU	-15	45	-35	80	19.08	23.27	25.03
406	HSFCU	-15	45	-35	80	32.44	36.20	37.31
501	FHWOV	0	15	-25	55	9.69	9.55	9.72
502	FHHRV	-10	40	-25	55	26.31	26.10	26.18
503	FHICU	-25	45	-30	60	16.10	15.93	16.01
504	FHFCU	-10	40	-25	55	18.71	18.25	18.38
506	FHWEV	0	25	-25	55	14.73	14.58	14.67
601	FHWOH	0	15	-25	55	10.13	5.20	5.33
602	FHWEH	0	25	-25	55	16.52	11.07	11.19
603	FHHRH	-10	40	-25	55	**41.06**	29.65	29.76
604	FHLCU	-10	40	-25	55	33.91	22.13	22.29
605	FHLSU	-10	40	-25	55	29.69	7.66	7.78
701	RWL1_C	0	50	-10	60	32.92	31.92	32.07
702	RWL2_C	0	50	-10	60	34.49	33.88	34.02
703	RWL3_C	0	50	-10	60	33.44	32.35	32.50
704	RWL4_C	0	70	-10	60	33.09	32.44	32.60
705	RWDE	-10	50	-20	60	32.54	31.92	32.05
706	QRS1	-15	45	-35	65	34.91	35.78	35.80
707	QRS2	-15	45	-35	65	34.43	35.33	35.35
801	GYRO	-15	45	-25	55	43.41	43.66	43.79
802	PDU	-15	45	-25	55	40.93	40.68	40.85
950	TANK1	10	40	10	40	33.25	33.00	33.29
960	TANK2	10	40	10	40	33.24	34.24	34.49
42	STRMZMY	-20	40	-30	50	58.64	59.64	60.12
45	STRMZPY	-20	40	-30	50	14.48	16.63	17.43
6	SASZ	-70	80	-70	80	50.01	50.00	50.11
46	SAS-Z	-70	80	-70	80	7.78	7.81	8.09

Table 7.4.4.3-6 HERSCHEL - Units Temperature results: Case EOL7B.

In order to verify the thermal stability requirement for the PLM Warm units mounted on the Service Module –Y and –Y-Z panels three transient analyses have been performed.

The analysed cases are hereafter described:

- Cold Transient (Case 1A):
  Starting from S/S case BOL2B (Sun on +X -Y axis, SAA=+30°/-1°.
  Ending to case S/S case BOL7A (Sun on -X +Y axis, SAA=-30°/+1°.
  Power units dissipation: constant (Warm units dissipation in MODE3 (see table 7.4.4.3-2) and equipment Units see table 7.4.4.2-2).
  Heater dissipation: Constant
  Duration of change of attitude: 1200s
  Overall duration of transient case: 108000s (30 hours)

- Cold Transient (Case 1B):
  Starting from S/S case BOL2B (Sun on +X -Y axis, SAA=+30°/-1°.
  Ending to case S/S case BOL7A (Sun on -X +Y axis, SAA=-30°/+1°.
  Power units dissipation: constant (Warm units dissipation in MODE1 (see table 7.4.4.3-2) and equipment Units see table 7.4.4.2-2).
  Heater dissipation: Constant
  Duration of change of attitude: 1200s
  Overall duration of transient case: 108000s (30 hours)

- Cold Transient (Case 2):
  Starting from S/S case BOL2B (Sun on +X -Y axis, SAA=+30°/-1°,
  Power units dissipation: Constant (Warm units dissipation in MODE3 (see table 7.4.4.3-2) and equipment Units see table 7.4.4.2-2).
  Heater dissipation: Constant for the HIFI heaters line and variable for the others.
  Overall duration of transient case: 108000s (30 hours)

- Hot Transient (Case 3A):
  Starting from S/S case EOL7A (Sun on -X +Y axis, SAA=-30°/+1°.
  Ending to S/S case EOL2B (Sun on +X -Y axis, SAA=+30°/-1°.
  Power units dissipation: Constant (Warm units dissipation in MODE2 Photometry (see table7.4.4.3-2) and equipment Units see table 7.4.4.2-2).
  Duration of change of attitude: 1200s
  Overall duration of transient case: 108000s (30 hours)

- Hot Transient (Case 3B):
  Starting from S/S case EOL7A (Sun on -X +Y axis, SAA=-30°/+1°.
  Ending to S/S case EOL2B (Sun on +X -Y axis, SAA=+30°/-1°.
  Power units dissipation: Constant (Warm units dissipation in MODE1 (see table7.4.4.3-2) and equipment Units see table 7.4.4.2-2).
  Duration of change of attitude: 1200s
  Overall duration of transient case: 108000s (30 hours)

- Battery mode (Emergency)

Due to an emergency situation of the satellite, with the units in the power dissipation mode hereafter described.
A supplementary case should be study in order to evaluate, after how many times, the units will go out of their requirement temperature range (operative for the unit switch-on and not operative for the units switch-off):
All the units are OFF except the following items with reduced power dissipation:

☐ CDMU	20 W
☐ ACC	10 W
☐ 2 Transponder	7x2 W

- ☐ Degradation α = BOL;
- ☐ Rot. Around X axis = 0, Rot. Around Y axis = 0;
- ☐ Solar Constant = 1285[W/m^2]

In this situation only two heaters power line of 30 W (total 60W) are available.
A particular attention should be dedicated to the item necessary to the satellite to continue his mission (Battery, Thruster and ACMS units).

The following Tables 7.4.4.3-6/10 report the list of PLM Warm Units with their thermal stability requirements, and the delta temperature every 100s evaluated from the transient analysis cases.
For the units mounted on –Y panel, which are out of the range required, it is also reported when, from the start of the transient case, each unit re-entry inside the thermal stability requirement.

Transient Case 1A:

NODE	UNIT	Stability Requirement Delta T	TRANSIENT 1A From BOL2B to BOL7A	
			Dtmax [°C]	Re-entry Time [s]
401	CRYOE	+/- 3K/hr	0.070	
404	HSDCU	+/- 3K/hr	0.059	
405	HSDPU	+/- 3K/hr	0.044	
406	HSFCU	+/- 3K/hr	0.045	
501	FHWOV	+/- 0.03/100s	0.019	
502	FHHRV	+/- 0.03/100s	0.011	
503	FHICU	+/-0.14/100s	0.010	
504	FHFCU	+/- 0.14/100s	0.016	
506	FHWEV	+/- 0.03/100s	0.010	
601	FHWOH	+/- 0.03/100s	**0.037**	19420 (~5.4 hours)
602	FHWEH	+/- 0.03/100s	**0.039**	19410 (~5.4 hours)
603	FHHRH	+/- 0.03/100s	**0.035**	17910 (~4.9 hours)
604	FHLCU	+/- 0.03/100s	**0.035**	24790 (~6.9 hours)
605	FHLSU	+/- 0.03/100s	**0.034**	18610 (~5.2 hours)

Note: Bold values are out of range.

Table 7.4.4.3-6 HERSCHEL – Warm units Transient Case 1A: analysis results

Transient Case 1B:

NODE	UNIT	Stability Requirement Delta T	TRANSIENT 1B From BOL2B to BOL7A	
			Dtmax [°C]	Re-entry Time [s]
401	CRYOE	+/- 3K/hr	0.070	
404	HSDCU	+/- 3K/hr	0.059	
405	HSDPU	+/- 3K/hr	0.044	
406	HSFCU	+/- 3K/hr	0.045	
501	FHWOV	+/- 0.03/100s	0.019	
502	FHHRV	+/- 0.03/100s	0.011	
503	FHICU	+/-0.14/100s	0.010	
504	FHFCU	+/- 0.14/100s	0.016	
506	FHWEV	+/- 0.03/100s	0.009	
601	FHWOH	+/- 0.03/100s	**0.037**	19100 (~5.3 hours)
602	FHWEH	+/- 0.03/100s	**0.039**	19060 (~5.3 hours)
603	FHHRH	+/- 0.03/100s	**0.034**	16580 (~4.6 hours)
604	FHLCU	+/- 0.03/100s	**0.033**	22300 (~6.2 hours)
605	FHLSU	+/- 0.03/100s	**0.033**	17040 (~4.7 hours)

Note: Bold values are out of range.

Table 7.4.4.3-7 HERSCHEL – Warm units Transient Case 1B: analysis results

TRANSIENT CASE 2:

NODE	UNIT	Stability Requirement Delta T	TRANSIENT 2 BOL2B HTR POWER VARIABLE Dtmax [°C]
401	CRYOE	+/- 3K/hr	-0.009
404	HSDCU	+/- 3K/hr	-0.005
405	HSDPU	+/- 3K/hr	-0.009
406	HSFCU	+/- 3K/hr	-0.008
501	FHWOV	+/- 0.03/100s	-0.0015
502	FHHRV	+/- 0.03/100s	-0.0008
503	FHICU	+/-0.14/100s	-0.0008
504	FHFCU	+/- 0.14/100s	-0.0013
506	FHWEV	+/- 0.03/100s	-0.0007
601	FHWOH	+/- 0.03/100s	-0.0057
602	FHWEH	+/- 0.03/100s	-0.0070
603	FHHRH	+/- 0.03/100s	-0.0050
604	FHLCU	+/- 0.03/100s	-0.0038
605	FHLSU	+/- 0.03/100s	-0.0042

Note: The values are all in range.

Table 7.4.4.3-8 HERSCHEL – Warm units Transient Case 2 analysis results

Transient Case 3A:

NODE	UNIT	Stability Requirement Delta T	TRANSIENT 3A From EOL7A to EOL2B Dtmax [°C]	Re-entry Time [s]
401	CRYOE	+/- 3K/hr	-0.077	
404	HSDCU	+/- 3K/hr	-0.065	
405	HSDPU	+/- 3K/hr	-0.049	
406	HSFCU	+/- 3K/hr	-0.050	
501	FHWOV	+/- 0.03/100s	-0.021	
502	FHHRV	+/- 0.03/100s	-0.012	
503	FHICU	+/-0.14/100s	-0.011	
504	FHFCU	+/- 0.14/100s	-0.018	
506	FHWEV	+/- 0.03/100s	-0.011	
601	FHWOH	+/- 0.03/100s	**-0.048**	28300 (~7.9 hours)
602	FHWEH	+/- 0.03/100s	**-0.050**	27800 (~7.7 hours)
603	FHHRH	+/- 0.03/100s	**-0.064**	27640 (~7.7 hours)
604	FHLCU	+/- 0.03/100s	**-0.041**	31380 (~8.7 hours)
605	FHLSU	+/- 0.03/100s	**-0.054**	28330 (~7.9 hours)

Note: Bold values are out of range.

Table 7.4.4.3-9 HERSCHEL – Warm units Transient Case 3A analysis results

Transient Case 3B:

NODE	UNIT	Stability Requirement Delta T	TRANSIENT 3B From EOL7A to EOL2B Dtmax [°C]	Re-entry Time [s]
401	CRYOE	+/- 3K/hr	-0.073	
404	HSDCU	+/- 3K/hr	-0.062	
405	HSDPU	+/- 3K/hr	-0.032	
406	HSFCU	+/- 3K/hr	-0.033	
501	FHWOV	+/- 0.03/100s	-0.020	
502	FHHRV	+/- 0.03/100s	-0.011	
503	FHICU	+/-0.14/100s	-0.011	
504	FHFCU	+/- 0.14/100s	-0.017	
506	FHWEV	+/- 0.03/100s	-0.010	
601	FHWOH	+/- 0.03/100s	**-0.045**	24730 (~6.9 hours)
602	FHWEH	+/- 0.03/100s	**-0.048**	24320 (~6.8 hours)
603	FHHRH	+/- 0.03/100s	**-0.062**	23470 (~6.5 hours)
604	FHLCU	+/- 0.03/100s	**-0.038**	25860 (~7.2 hours)
605	FHLSU	+/- 0.03/100s	**-0.050**	23590 (~6.6 hours)

Note: Bold values are out of range.

Table 7.4.4.3-10 HERSCHEL – Warm units Transient Case 3B analysis results

In order to mantain all temperatures variation within stability requirement, an active control with heaters is envisaged.
The baseline foreseen to regulate the temperature of these critical components with a Pulsed Width Modulation, controlled by the CDMU. Detail description is provided in para 9.2.4.4.

PLANCK THERMAL ANALYSIS

Planck is a sun pointed spacecraft, spinning around X axis at 1 Round Per Minute.
The Sun Aspect Angle will be less than 10° with respect to X-axis.
For the Thermal Control point of view the SVM/PLM I/F temperature fluctuation requirements are very severe and actually lead to avoid any temperature fluctuation inside the SVM. The temperature fluctuation derives from power variation that can have different sources:

- SAA changes with solar fluxes
- Units with different dissipation (in according to the operation mode)
- Heaters switching

The limited SAA excursion (0°÷10°), and the Solar Array dimensions avoid actually any sun fluxes on the S/L lateral panels, and in addition to the use of MLI on the Solar Array rear-side provide a quite stable environment. Absorbed solar fluxes change at spin frequency, they have been evaluated and has been considered negligible without any impact on both lateral SVM panels and SVM/PLM interface.

The list of the orbital Steady State cases analysed is presented in the following table:

CASE	α Degradation	Solar Aspect Angle	Applied Rotation On TCS model	Solar Constant [W/m²]	Operative mode
1	BOL	0	Rot around X axis = 0 Rot around Y axis = 0	1285	Units in Scientific Mode
3	BOL	10	Rot around X axis = 0 Rot around Y axis = +10	1285	Units in Scientific Mode
8	EOL	0	Rot around X axis = 0 Rot around Y axis = 0	1405	Units in Telecom mode
Survival	BOL	10	Rot around X axis = 0 Rot around Y axis = +10	1285	Warm Units Off mode. Equipment units in Scientific Mode

Table 7.4.4.3-10 PLANCK – Steady State Orbit Cases description

TTC units (TWTA, TRANS) have different dissipation during receiving and transmission phase. Dedicated heaters shall compensate totally this difference in order to have always the same power on their panel.
The heater switching variation will be avoided feeding them in pulse mode, controlled by the CDMU: increasing the heaters switching frequency, and fixing a duty cycle, the final effect is to provide a constant dissipation at a specified value.

A summary of the Planck thermal analysis results (including 7 ºC of uncertainty) for the steady state operative cases is reported in Table7.4.4.3-3.

The most critical dissipation is due to the SCC units, which work in cold redundancy.
Each SCC is composed of 6 dissipating beds. The working SCC has a dissipation profile with a 667s period, while the single bed has a period of 4002 s (= 6 time 667 s).
The following pictures show the simplified EOL and BOL thermal mathematical model of the Sorption Cooler Compressor Assembly. It is composed of six thermal nodes for the Inner bed and six thermal nodes for outer shell. For each thermal node is considered the thermal capacity, the linear conductor and the power dissipation for each phase. This model shall be implemented in the Planck SVM Thermal Mathematical Model in order to study the SCC transient behaviour.

NODE	LABEL	Temp. Oper. [°C]		Temp. Non Oper. [°C]		BOL1 [°C]	BOL3 [°C]	EOL8 [°C]	SURV [°C]
11	STR1	-10	30	-20	40	8.7	8.4	24.6	-17.0
12	STR2	-10	30	-20	40	-1.4	-1.6	14.4	-17.1
13	DPU1	-10	40	-20	50	3.5	3.3	18.9	-17.3
14	DPU2 (on shear)	-10	30	-20	40	10.5	10.2	26.7	-14.2
15	REU	-20	30	-30	40	12.4	12.2	27.7	-17.4
101	DCCU + FV	-10	40	-20	50	12.9	12.5	29.4	-15.8
102	REBA1	-20	50	-30	70	3.4	3.1	19.7	-23.6
103	REBA2	-20	50	-30	70	27.1	26.8	42.9	-24.6
201	4 CCU	-10	40	-20	50	19.7	19.4	35.6	-17.2
202	4 CAU	-10	40	-20	50	3.5	3.2	19.7	-17.2
203	4 PRE-REG	-10	40	-20	50	0.2	-0.1	16.2	-17.2
204	4 CEU	-10	40	-20	50	20.4	20.1	36.4	-17.1
311	SCC1 - Outer shell	-13	7	-50	70	-7.7	-7.7	6.1	-28.5
312	SCC1 - Outer shell	-13	7	-50	70	-7.7	-7.7	6.1	-28.5
313	SCC1 - Outer shell	-13	7	-50	70	-7.7	-7.7	6.1	-28.5
314	SCC1 - Outer shell	-13	7	-50	70	-7.7	-7.7	6.1	-28.5
315	SCC1 - Outer shell	-13	7	-50	70	-7.7	-7.7	6.1	-28.5
316	SCC1 - Outer shell	-13	7	-50	70	-7.7	-7.7	6.1	-28.5
401	SCE1	-10	40	-20	50	-7.6	-7.6	2.9	-19.7
402	SCE2	-10	40	-20	50	-15.5	-15.5	-2.0	-19.6
511	SCC2 - Outer shell	-13	7	-50	70	-18.3	-18.3	-5.1	-31.6
512	SCC2 - Outer shell	-13	7	-50	70	-18.3	-18.3	-5.1	-31.6
513	SCC2 - Outer shell	-13	7	-50	70	-18.3	-18.3	-5.1	-31.6
514	SCC2 - Outer shell	-13	7	-50	70	-18.3	-18.3	-5.1	-31.6
515	SCC2 - Outer shell	-13	7	-50	70	-18.3	-18.3	-5.1	-31.6
516	SCC2 - Outer shell	-13	7	-50	70	-18.3	-18.3	-5.1	-31.6
521	BEU/DAE	-20	40	-30	50	23.3	22.9	39.8	-16.1
522	PAU	-20	40	-20	50	21.5	21.1	38.4	-10.3
525	DAE POWER UNIT	-20	45	-20	55	27.3	26.9	44.0	1.9
551	QRS3 (on shear)	-15	45	-25	65	12.9	12.5	30.6	-0.1
601	TRANSX/B1	-10	50	-20	60	17.4	17.1	34.5	10.1
602	TRANSX/B2	-10	50	-20	60	16.2	15.9	33.0	8.4
603	TWTA1	-15	50	-25	60	-4.8	-5.1	13.6	-11.8
604	TWTA2	-15	50	-25	60	25.9	25.6	43.0	19.6
605	RFDN	-40	70	-50	80	1.0	0.7	20.7	-5.2
606	EPC1	-15	45	-25	55	-21.9	-21.9	2.0	-19.0
607	EPC2	-15	45	-25	55	0.6	0.3	18.0	-6.7
701	CDMU	-10	45	-20	55	3.6	3.4	18.6	-6.2
702	ACC	-10	45	-20	55	1.8	1.5	16.1	-7.1
703	BATT1	0	35	-10	45	5.1	4.9	20.0	2.9
704	PCDU	-10	45	-20	55	31.8	31.6	41.2	18.8
705	QRS1	-15	45	-25	55	20.4	20.2	35.7	10.6
706	QRS2	-15	45	-25	55	16.4	16.1	34.2	8.9
707	PDU	-15	45	-25	55	15.1	14.9	30.2	-1.2
900	He TANK +Z	0	45	-10	55	10.0	9.7	25.9	3.0
905	He TANK +Y	0	45	-10	55	11.8	11.4	28.3	3.0
910	He TANK -Z	0	45	-10	55	16.9	16.3	34.1	3.0
915	He TANK -Y	0	45	-10	55	12.2	11.8	29.5	3.0
920	P TANK +Y+Z	0	45	-10	55	22.0	21.5	39.1	3.0
925	P TANK -Z	0	45	-10	55	22.5	22.0	39.9	3.0
930	P TANK -Y+Z	0	45	-10	55	21.8	21.4	38.7	4.4

Table 7.4.4.3-11 PLANCK thermal analysis results

Highly Simplified EOL Thermal Model of 20 K Sorption Cooler Compressor Assembly

(To be used by Alcatel to simulate compressor interface with radiator)

(Pradeep Bhandari, Mauro Prina, 11-15-2001) (Phone: 818-354-7597) Modified Model

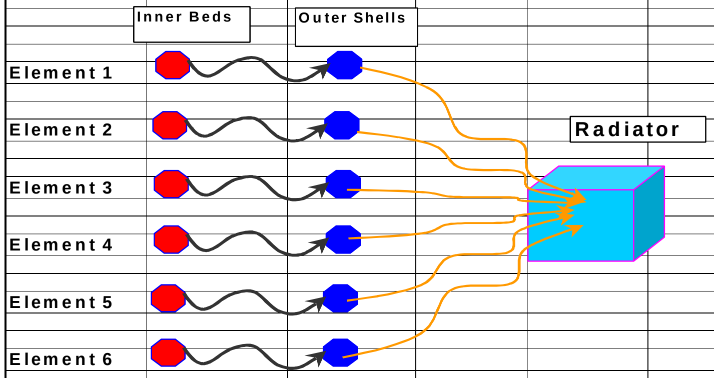
Parameter	Location	Units	Phase 1 Heatup 0-667 s	Phase 2 Desorb 667-1334 s	Phase 3 Cool 1334-2000 s	Phase 4 Absorb 2001-2667 s	Phase 5 Absorb 2668-3333 s	Phase 6 Absorb 3335-4000 s	← Phase ← Cycle Time
Therm. Mass	Inner Bed	MC_p (J/K)	800	3600	930	670	690	710	
	Outer Shell	MC_p (J/K)	720	720	720	720	720	720	
Conductance	*(Inner Bed to Outer Shell)*	W/K	0.02	0.03	***	6.53	6.53	6.53	
Heat Input	Inner Bed	W	216	183	0	36	36	36	**EOL Model**
	Outer shell	W	46	46	7	7	7	7	
	Total	W							519 Watts (EOL + Margin)

** see attached table

Use Table in "Gas-Gap Conductance" Workheet for values during Cool phase

Changed thermal capacitance from last model to get better heat balance

Notes:
1) The above values are for end of life (including margin)
2) The total cycle time is 667*6 = 4000 seconds.
3) There are 6 identical beds which are of phase, by one phase width of 667 sec., with respect to each other.
4) At any time one bed is heating up, one desorbing, one cooling, and three absorbing.
5) Outer shell is thermally and structurally connected to the radiator.
6) Additonal thermal masses for items outside of the compressor elements need to be accounted for to ensure that the radiator thermal oscillations are not excessive.



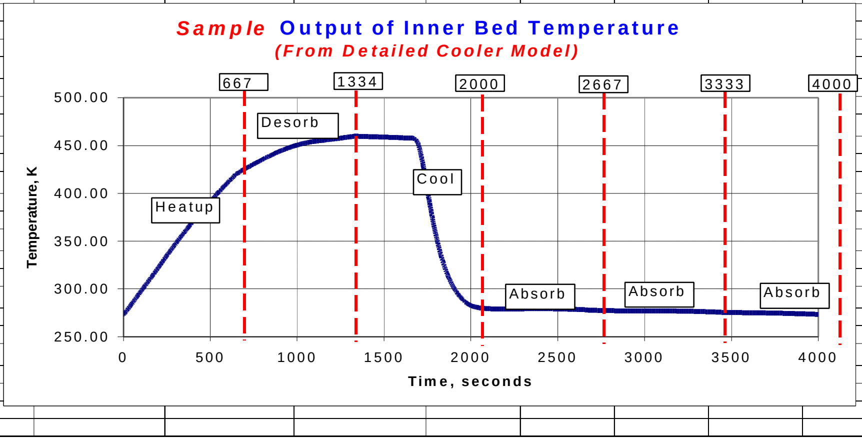
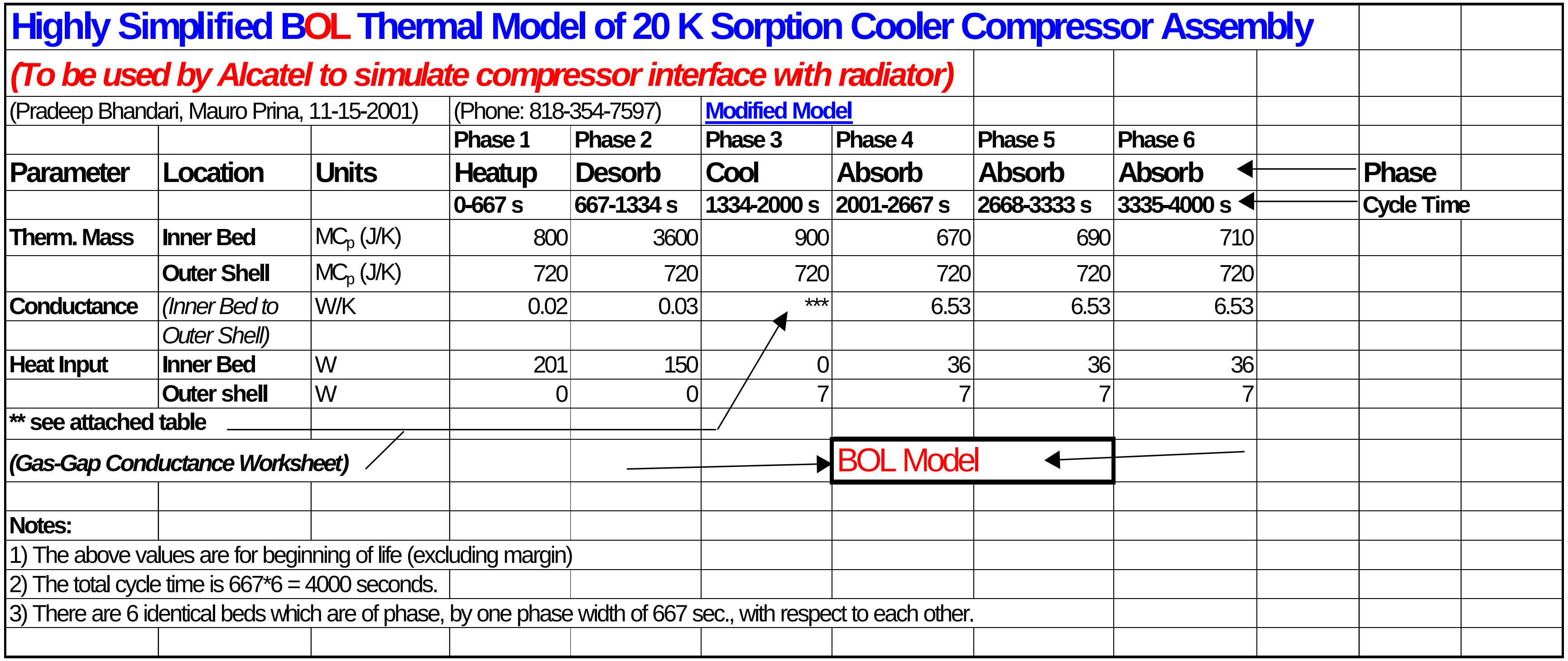


Figure 7.4.4.3-12 Highly Simplified EOL Thermal Model of 20 K Sorption Cooler Compressor Assembly



Highly Simplified BOL Thermal Model of 20 K Sorption Cooler Compressor Assembly

(To be used by Alcatel to simulate compressor interface with radiator)

(Pradeep Bhandari, Mauro Prina, 11-15-2001) (Phone: 818-354-7597) Modified Model

			Phase 1	**Phase 2**	**Phase 3**	**Phase 4**	**Phase 5**	**Phase 6**	
Parameter	**Location**	**Units**	**Heatup**	**Desorb**	**Cool**	**Absorb**	**Absorb**	**Absorb**	**Phase**
			0-667 s	**667-1334 s**	**1334-2000 s**	**2001-2667 s**	**2668-3333 s**	**3335-4000 s**	**Cycle Time**
Therm. Mass	**Inner Bed**	MC_p (J/K)	800	3600	900	670	690	710	
	Outer Shell	MC_p (J/K)	720	720	720	720	720	720	
Conductance	*(Inner Bed to Outer Shell)*	W/K	0.02	0.03	***	6.53	6.53	6.53	
Heat Input	**Inner Bed**	W	201	150	0	36	36	36	
	Outer shell	W	0	0	7	7	7	7	

**** see attached table**

(Gas-Gap Conductance Worksheet)

BOL Model

Notes:

1) The above values are for beginning of life (excluding margin)

2) The total cycle time is 667*6 = 4000 seconds.

3) There are 6 identical beds which are of phase, by one phase width of 667 sec., with respect to each other.

Figure 7.4.4.3-13 Highly Simplified BOL Thermal Model of 20 K Sorption Cooler Compressor Assembly

Time [s]	Gas gap Conductance [W/K]	Time [s]	Gas gap Conductance [W/K]	Time [s]	Gas gap Conductance [W/K]	Time [s]	Gas gap Conductance [W/K]
0	0.0313	341	2.3479	394	6.2940	447	6.5519
286	0.0314	342	2.6215	395	6.3069	448	6.5525
289	0.0316	343	2.8875	396	6.3187	449	6.5530
291	0.0318	344	3.1393	397	6.3307	450	6.5534
292	0.0319	345	3.3734	398	6.3420	451	6.5536
293	0.0321	346	3.5880	399	6.3526	452	6.5537
294	0.0325	347	3.7832	400	6.3634	453	6.5539
295	0.0329	348	3.9600	401	6.3728	454	6.5541
296	0.0331	349	4.2804	402	6.3824	455	6.5542
297	0.0337	350	4.4133	403	6.3914	667	6.5543
298	0.0344	351	4.5360	404	6.4003		
299	0.0352	352	4.6454	405	6.4086		
300	0.0359	353	4.7481	406	6.4171		
301	0.0368	354	4.8422	407	6.4247		
302	0.0383	355	4.9295	408	6.4321		
303	0.0397	356	5.0096	409	6.4391		
304	0.0414	357	5.0853	410	6.4456		
305	0.0434	358	5.1568	411	6.4516		
306	0.0459	359	5.2245	412	6.4578		
307	0.0487	360	5.2856	413	6.4636		
308	0.0519	361	5.3454	414	6.4689		
309	0.0558	362	5.4002	415	6.4738		
310	0.0602	363	5.4532	416	6.4793		
311	0.0653	364	5.5034	417	6.4837		
312	0.0709	365	5.5503	418	6.4887		
313	0.0775	366	5.5956	419	6.4932		
314	0.0849	367	5.6379	420	6.4971		
315	0.0934	368	5.6789	421	6.5009		
316	0.1029	369	5.7178	422	6.5049		
317	0.1137	370	5.7541	423	6.5083		
318	0.1258	371	5.7893	424	6.5119		
319	0.1393	372	5.8235	425	6.5151		
320	0.1546	373	5.8553	426	6.5183		
321	0.1716	374	5.8862	427	6.5214		
322	0.1908	375	5.9163	428	6.5242		
323	0.2123	376	5.9436	429	6.5264		
324	0.2366	377	5.9708	430	6.5291		
325	0.2641	378	5.9967	431	6.5315		
326	0.2956	379	6.0219	432	6.5335		
327	0.3317	380	6.0453	433	6.5356		
328	0.3735	381	6.0680	434	6.5373		
329	0.4224	382	6.0902	435	6.5393		
330	0.4799	383	6.1119	436	6.5409		
331	0.5482	384	6.1314	437	6.5423		
332	0.6297	385	6.1514	438	6.5436		
333	0.7276	386	6.1705	439	6.5450		
334	0.8556	387	6.1886	440	6.5463		
335	0.9855	388	6.2058	441	6.5473		
336	1.1518	389	6.2216	442	6.5480		
337	1.3457	390	6.2375	443	6.5488		
338	1.5667	391	6.2526	444	6.5497		
339	1.8118	392	6.2673	445	6.5505		
340	2.0749	393	6.2808	446	6.5512		

Table 7.4.4.3-13 Gas gap Conductance

To reduce the effect of this periodic dissipation the following solution will be implemented:

- Heat pipe network to distribute uniformly the dissipation over the three SCC panels
- The SCC panels will be decoupled from the SVM: the panels will be connected to the floors, to the shear web and lateral panels by a Titanium cleats (see SVM Mechanical Specification)
- MLI will cover the SCC and SCE units

To verify the thermal stability requirement for the SCC Radiative Panels and the SVM/PLM I/F points a transient analysis has been performed taking into account the variation of SCC Power dissipation on each bed.
The analysed case is the following :

- Hot Transient (Case 1):
  Starting from S/S case EOL8 (Sun on -X , SAA= 0°).
  Ending to S/S case EOL3 (Sun on -X , SAA=+10°).
  Duration of change of attitude: 1200s
  Overall duration of transient case: 259200s (72 hours)

- Battery mode (Emergency)

Due to an emergency situation of the satellite, with the units in the power dissipation mode hereafter described.
A supplementary case should be study in order to evaluate, after how many times, the units will go out of their requirement temperature range (operative for the unit switch-on and not operative for the units switch-off):
All the units are OFF except the following items with reduced power dissipation:

- CDMU 20 W
- ACC 10 W
- 2 Transponder 7x2 W
- Degradation α = BOL;
- Rot. Around X axis = 0, Rot. Around Y axis = 0;
- Solar Constant = 1285$[W/m^2]$

In this situation only two heaters power line of 30 W (total 60W) are available.
A particular attention should be dedicated to the item necessary to the satellite to continue his mission (Battery, Thruster and ACMS units).

A summary of the results of the transient analysis is reported in the following pages. In Table 7.4.4.3-14 are reported the temperature fluctuation, every 325 s and every 7200 s , relative to external unit and internal one :

		Requirement	**Goal**	Results
NODE	UNIT	Delta Temp.	Delta Temp.	Temp. Variation / 7200 s
		/ 7200 s	/ 7200 s	Dtmax
		[K]	[K]	[K]
521	BEU/DAE	+/-3 K/hour	+/-0.2 K/hour	0.07 K/hour
522	PAU	+/-3 K/hour	+/-1.1 K/hour	0.12 K/hour

Table 7.4.4.3-14 PLANCK - Transient Analysis Results

In Table 7.4.4.3-15 has been calculated the flux incident on V-groove shield due to radiative flux:

NODE	UNIT	Requirement Flux	**Calculated Flux**
521	BEU/DAE	2.3 W	1.6 W
522	PAU	2.3 W	0.4 W

Table 7.4.4.3-15 PLANCK - Flux requirement

Increase of the flux is due to an increasing of the power dissipation of these units and relative radiative area in order to satisfy the thermal requirement.

The graphics presented in Figure 7.4.4.3-1 represent the temperature variation of the working SCC and Figure 7.4.4.3-2/3 the amplitude of each outer shell and Heat pipes interface is showing the satisfy limit declared below in Table 7.4.4.3-16:

UNIT		Requirement	Goal
SCC	Sorption Cooler Compressor	+/-3 K	(3K,1K,0.5K)**

Note** - Data, applicablle only during the adsorption phase, are related to:
+/- 3K(TBC) for First adjacent element
+/- 1K(TBC) for the Next adjacent element
+/- 0.5(TBC) for Next most element

Table 7.4.4.3-16 PLANCK - SCC requirement

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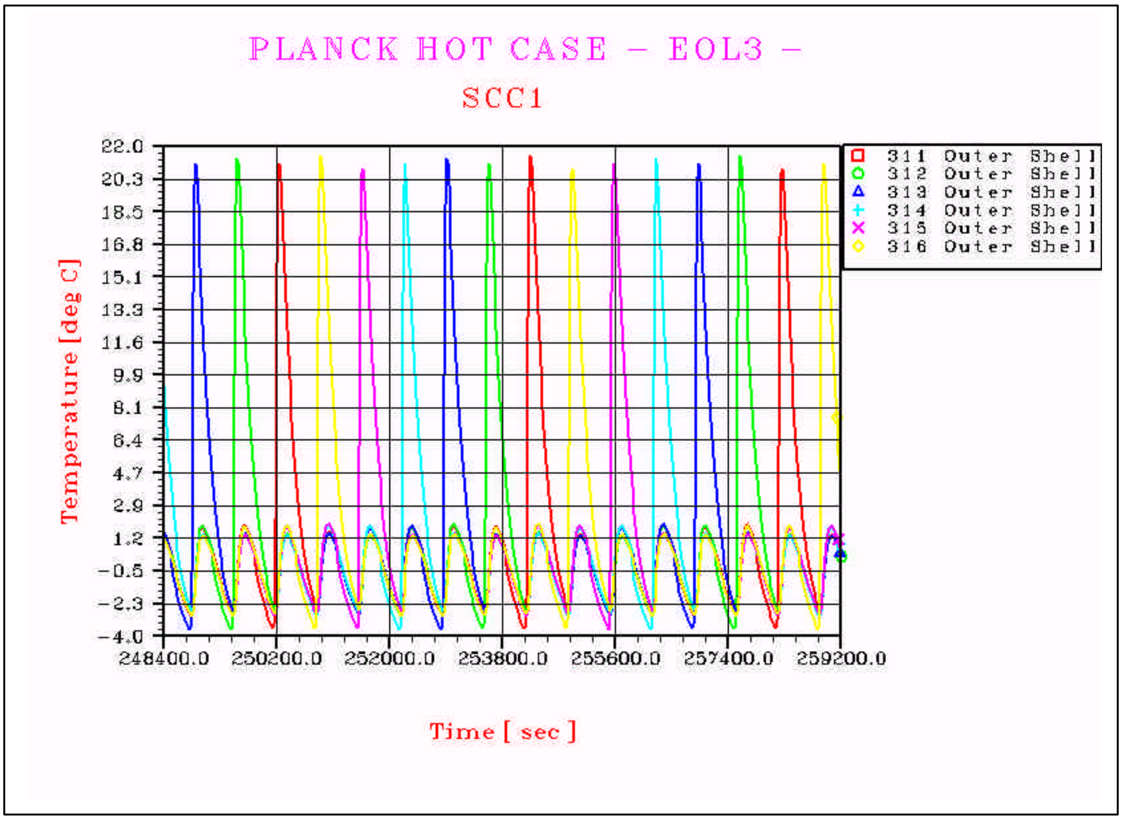


Figure 7.4.4.3-1 PLANCK – SCC Outer Shell's Temperature

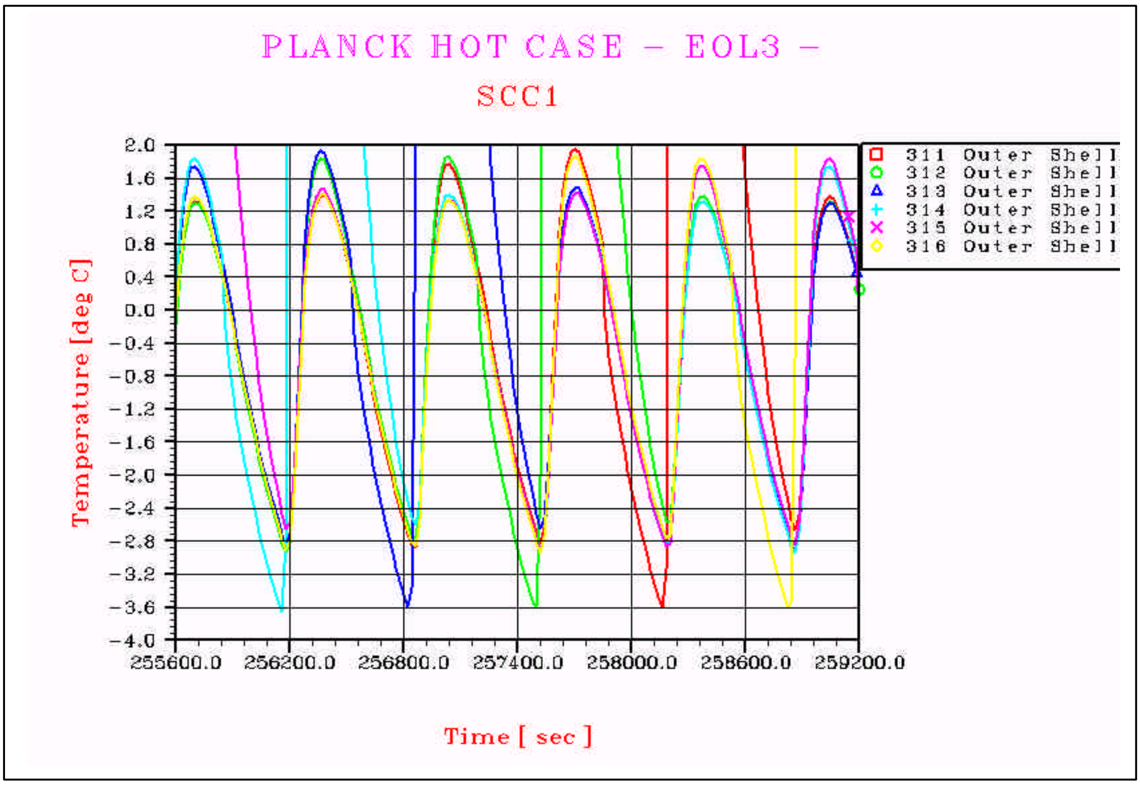


Figure 7.4.4.3-2 PLANCK – SCC Outer Shell's Temperature

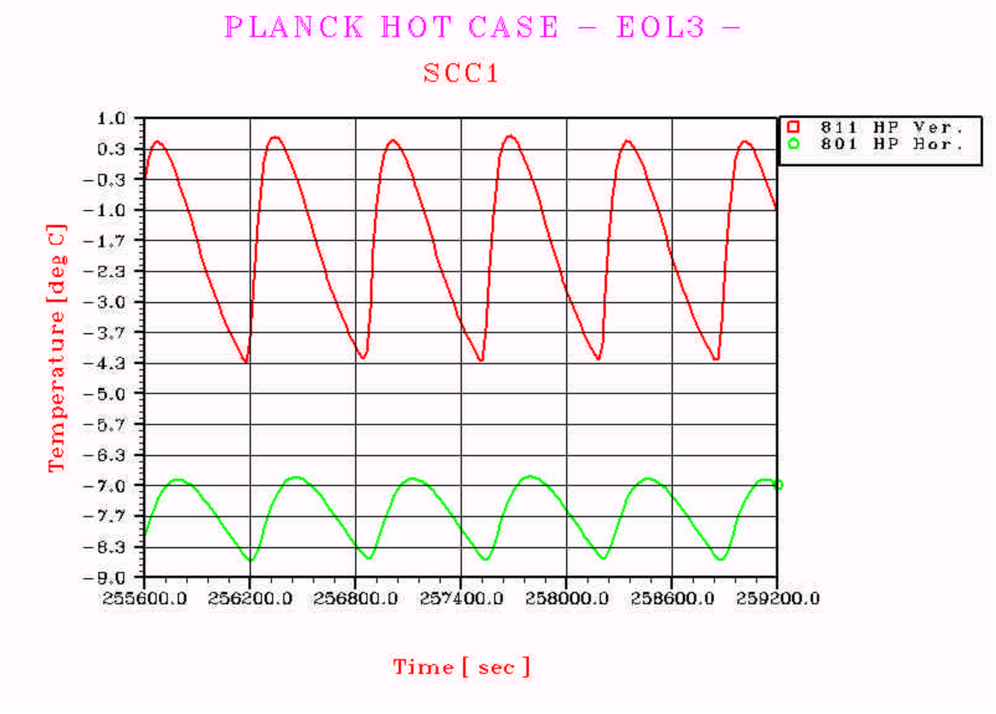


Figure 7.4.4.3-3 PLANCK – HEAT PIPES/SCC INTERFACE

For SCC panels and SVM/PLM interface points, the average value of all panel nodes temperature has been considered in the evaluation of the temperature variation with their respective limit requirements reporetd in Table 7.4.4.3-17, Table 7.4.4.3-18:
The spectral density has been calculated with one measurement every 20 sec , 7200 sec before the end of transient duration .

Panel Radiator	Requirement 1/60 Hz	Results
+Z	0.01	1.63 e-6
+Z,+Y	0.01	2.93 e-6
+Y	0.01	1.70 e-5
-Z,+Y	0.01	0.128
-Z	0.01	0.105
-Z,-Y	0.01	0.05
-Y	0.01	4.62 e-6
+Z,-Y	0.01	2.18 e-6

Table 7.4.4.3-17 PLANCK - SCC requirement results

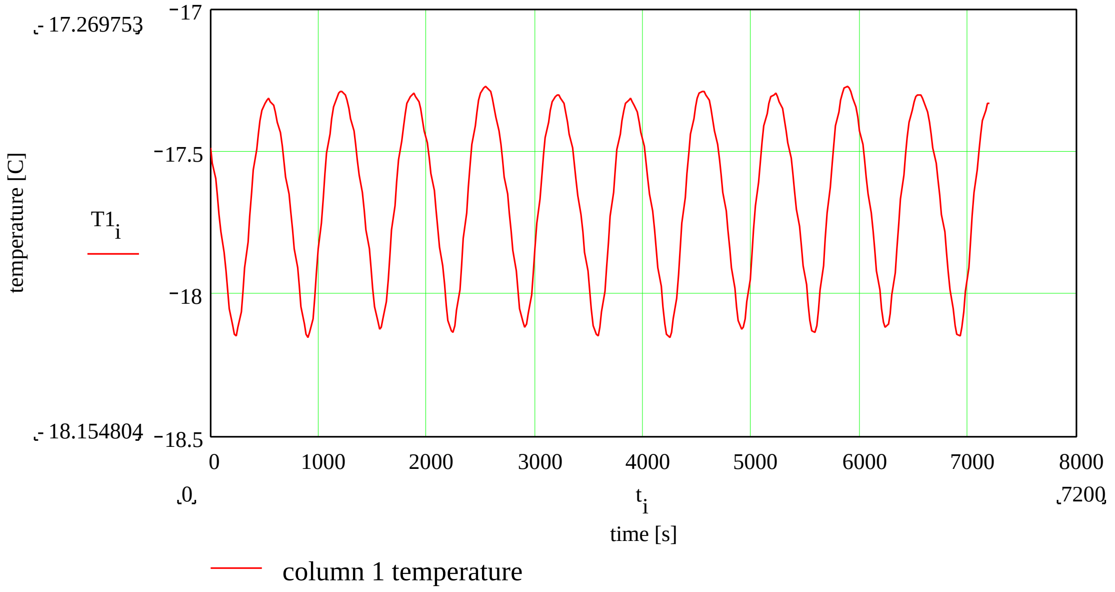
The spectral density has been calculated with one measurement every 20 sec , for all transient duration .

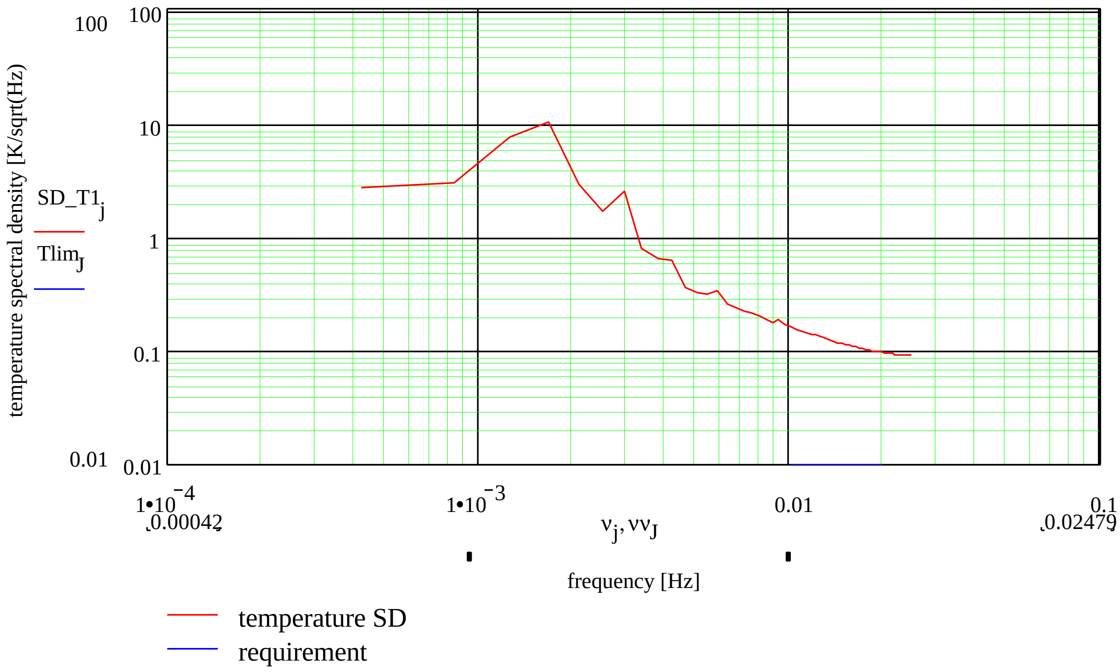
nodes(*)	description	Requirement	Results
		1/60 Hz	$K/Hz^{1/2}$
7304	I/F SVM	T.B.D.	2.46 e-6
7310	I/F SVM	T.B.D.	1.25 e-5
7315	I/F SVM	T.B.D.	1.27 e-5
7325	I/F SVM	T.B.D.	6.20 e-6
7330	I/F SVM	T.B.D.	1.13 e-5
7337	I/F SVM	T.B.D.	4.62 e-6

(*)See doc. H-P-TN-AI0005 SVM THERMAL ANALYSIS REPORT

Table 7.4.4.3-18 PLANCK - I/F SCM requirement results

Typical spectral density calculation:





Planck Solar Arrays trade-off Analysis

The analysis results shown that the SA (Solar Array) are out of the operative temperature range. Some trade-off analyses have been performed to solve or reduce this critical result.

The SA temperature results are 110°C for the disc and 111°C for the ring (these results are without uncertainty).

This result is obtained considering:

- linear conductor between the SA and the SVM cone = 0.01** W/K
- each SA are internally covered by MLI (emissivity= 0.05)

** =>Cleats manufactured in titanium or composite material

Additional configuration cases have been studied to reduce the Solar Array temperature.

Case A:

- linear conductor between the Solar Array and the SVM cone = 0.647 W/K in order to increase the heat rejection from the SA.

In this case the SA temperature is reduced of only a few degree (disc = 108°C and ring 109°C without uncertainty) but most of the units (more of the 50%) inside the SVM are out of the operative temperature range.

Case B:

- linear conductor between the SA and the SVM cone = 0.647 W/K
- No MLI is consider on the rear side of the SA ring (emissivity=0.05)
- Emissivity of the MLI on the internal side of the SA disc is equal to 0.76

The results are similar of the previous case A. The Temperature of SA ring = 106°C and SA disc=108°C (without uncertainty).

Several units inside the SVM are out of the operative temperature range.

Case C:

In this case we have been considered an extreme configuration:

- linear conductor between the SA and the SVM cone = 0.647 W/K
- No MLI is consider on the rear side of the SA ring (emissivity=0.05)
- No MLI is consider on the rear side of the SA disc (emissivity=0.76)
- All the external side of the SVM lateral panels are covered by OSR.

The SA temperatures are 101°C for the ring and 97° for the disc (without uncertainty).

A lot of the unit inside the SVM and the tanks are out of the operative temperature range.

Conclusions:

Is not possible to reduce the SA temperature under 110°C (no uncertainty is considered) without impact to the unit inside the SVM

In order to maintain the units inside the SVM between the operative temperature range, the SA have to be thermally decoupled as much as possible from the SVM structure; cleats in Titanium or composite material shall be implemented.

7.4.4.4 Analysis Results Discussion

HERSCHEL:

Steady State Analyses
All the units are maintained within their temperature limits with the exclusion of: the following minor out of specification:

☐ **PCDU:**	case EOL7A	45.8°C vs 45.0°C
☐ **FHHRH:**	case EOL7B	41.1°C vs 40.0°C

Transient Analyses
The temperature fluctuations on the HIFI units mounted on –Y panel are presenting some minor out of specification too.
In particular the stability goals (the requirements is +/-3K/hour) are not met during the attitude variation, but it is reached, for all units, after 6.9 hours in Transient Case 1,after 8.7 hours in Transient Case 2 and after 7.2 hours in Transient Case 3.
These out of spec during transient, relevant to thermal stability goal, have been pointed out in order to allow the assessment by all parts of the specific thermal stability behavior, and the possible relaxation of the requirement.
Is possible to recovery these out of spec on HI-FI units, maintain at their max temperature level by means of a similar heater control law, with an impact in terms of power budget of 80 watts (TBC)

Remarks:

- All transient cases presented have been performed based on "**constant power value of heater mounted on HIFI units".**
- The analysis of natural temperature response of HI-FI units to external disturbances (sun angle, heater operation) was evaluated to identify the major characteristics of the Heater Control Law: frequency of data monitoring, accuracy and sensitivity of thermistors, frequency of heater switching and heater power definition. According to the analysis, it seems viable to have a data monitoring frequency each 10 sec, a thermistor resolution of 0.01 °C and a fine heater command able to control temperatures within +/- 0.01°C in 10 seconds and consequently within +/- 0.03°C in 100 sec.
  According to above mentioned sensitivity figure, the induced unit temperature variation, can be compensate by means of heaters mounted on the units/panels having stringent stability requirement. The following approach will be implemented:

  - ☐ Temperature monitoring each 10 seconds with heater period command equal to 1 second
  - ☐ Temperature variation determination over in the last 10 seconds with a resolution of 0.01 °C
  - ☐ If this variation is higher than 0.01 °C over 10 seconds, the heater is operated according to the control laws to be defined by TCS supplier for the subsystem PDR

PLANCK:

Steady State Analyses
All units are within the required temperature range. The goal requirement is not met for:

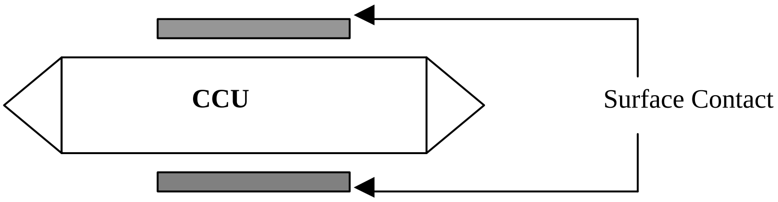
- ☐ **BEU/DAE:** T= 39.8 °C vs 28 °C as goal
- ☐ **PAU:** T= 38.4 °C vs 30 °C as goal
- ☐ **DAE POWER UNIT:** T= 44.0 °C vs 28 °C as goal

The analysis results show that **Solar Array** temperature is 116.3 °C.
S.A. temperature requirement to be verified when the supplier would be selected.

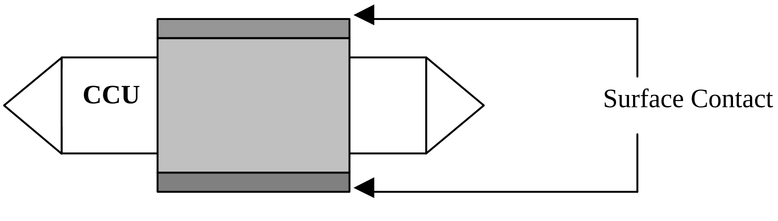
Transient analyses
All units are within specification.

For the SCC Panels average temperature see table 4.1.5.2-4.
Analysis has been performed besed on a requirement received in the last issue of the draft I/F Specification. Dedicated agreement on how to interpretate the requirement and the method of calculation to be apllied must be reached before to state a non-compliance.

SPECIFIC Open Point
Thermal dissipation of the 4CCU has increased; this unit is mounted on the +Y panel with a very low linear conductor due to a very reduced contact area (112.5 cm^2) as shown in the sketch.



Its power dissipation value is now 60 Watt.
To reject the heat flux in hot case, an over-sizing of the external radiator has been realized. During the cold case is necessary a large amount of heater power to maintain the item mounted on this panel within the temperature requirement.
As written in MoM- Planck configuration (H-P-MI-AI-0096), Alenia request to improve the baseplate contact area between the 4CCU and the panel (a possible proposal solution as shown hereafter) in order to optimize the thermal design and consequently reduce the heater power dissipation during the cold case..



7.5 Avionics Design and Performance

This section of the document describes the characteristics of the SVM Avionics System in terms of general architectures, key design and basic performance.

The content of this section is mainly focused on the hardware aspects of the avionics architectures and design, while for a deep and complete understanding of the system design implementation, also the sections relevant to flight software and operations should be consulted.

Details relevant to each subsystem are given in section 9 of this Report.

7.5.1 Avionics Requirements and Design Drivers

The requirements are derived from the SVM Requirement Specification (AD-43).

The definition of the Avionics design is driven by the exploitation of a design commonality between Herschel and Planck to the maximum possible extent.

As a first consequence of the above approach, the Avionics architecture has to be modular, with a physical separation between the SVM (including some Instrument warm Units) and PLM, to allow fairly independent development and testing of the SVM and PLM sections before their final integration.

The selected design solutions have been driven by the following criteria covering the overall system design, development and validation aspects:

- technical compliance, including sufficient flexibility to accommodate upgrade of the main requirements;
- Herschel and Planck commonalities
- hardware impact: the selected design is such that the hardware shall be optimised with regards to the mass and cost areas

As derived from the System Requirements, the overall SVM avionics architecture is designed to satisfy the spacecraft mission needs.

The functions mandatory for the proper spacecraft operation and mission achievement are encompassed with:
- On Board Data Management
- Radio Frequency Communications
- Power Generation, Storage and Distribution

7.5.2 Architectural and Functional Description

Modularity and standardisation are the main design drivers for the avionics electrical architecture, in view of the maximum commonality of the two Service Modules.

The Avionics Architecture is based on a decentralised concept. The overall SVM avionics architecture of Herschel and Planck are depicted in Figure 7.5-1 and Figure 7.5-2.
Detailed drawings showing different functions and their implementation down to equipment level are reported in H-P-DW-AI-0001, SVM Avionics Drawings.

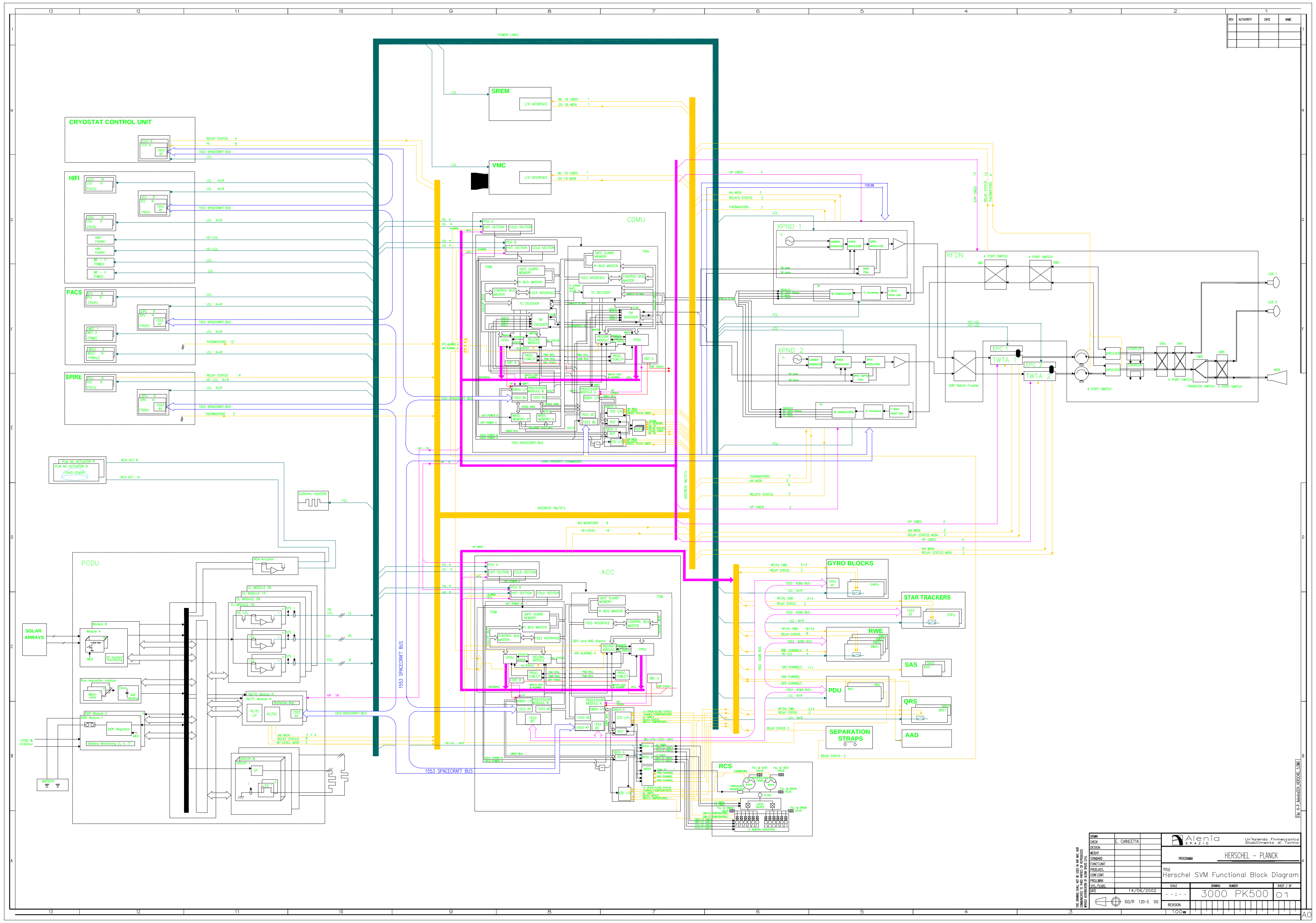


Figure 7.5-1 Herschel Block Diagram

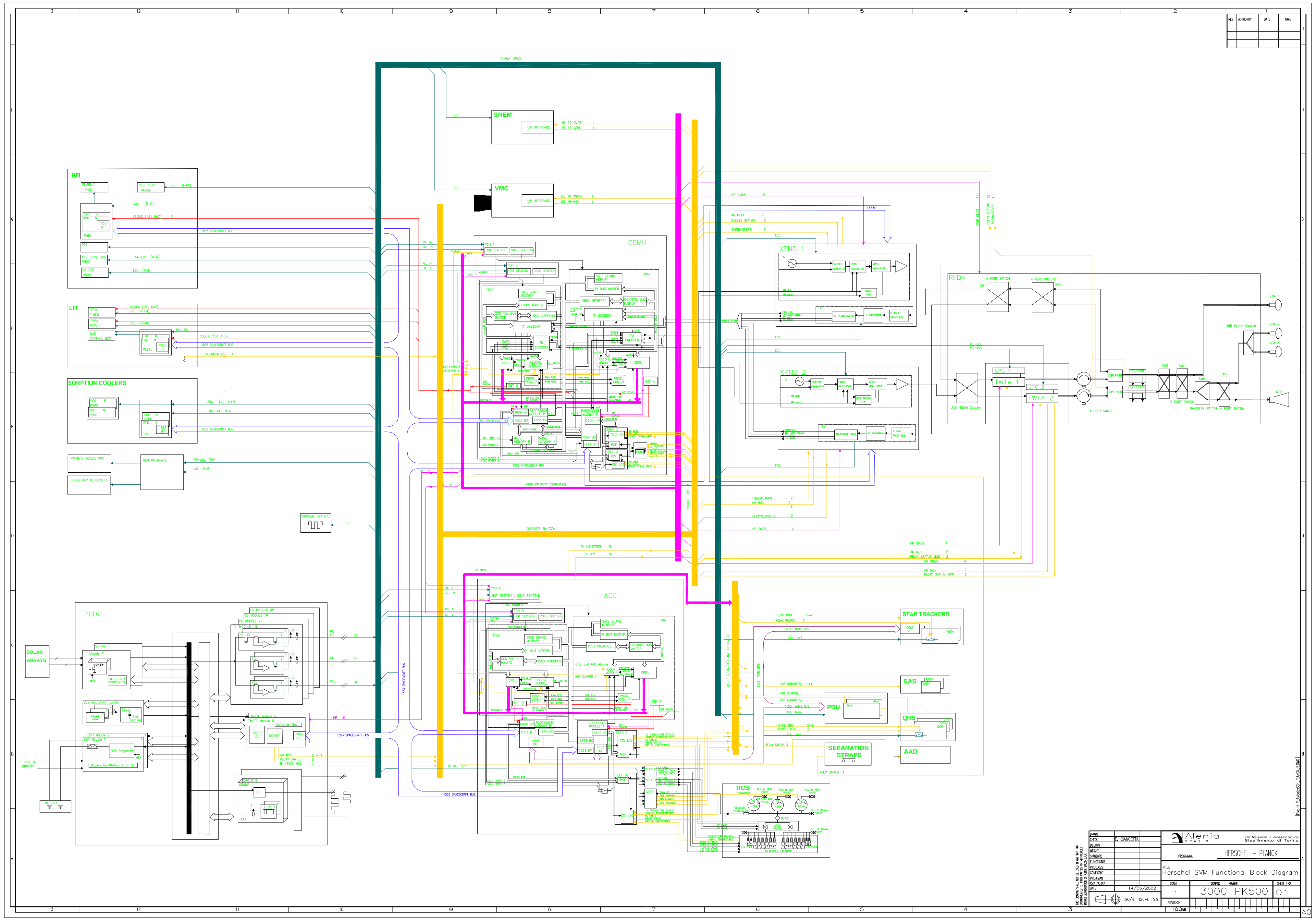


Figure 7.5-2 Planck Block Diagram

7.5.2.1 On Board Data Management

On Data Board Data Management has been suitably dimensioned to be compatible with both Herschel and Planck satellites, thus providing a high level of commonality.

On Board Data Handling is managed by one CDMU, which is in charge to perform the following functions.

- telemetry acquisition and formatting
- telecommand acquisition, decoding validation and distribution
- data storage
- time distribution and time tagging
- autonomy supervision and management.

Attitude Measurement and Control is managed by one Attitude Control Computer, identical for Herschel and Planck. The CDMU and ACC core and architecture are identical; the implemented microprocessor is an ERC32SC Processor.

The functional Block Diagrams of CDMU and ACC are shown in Figure 7.5-3 and Figure 7.5-4.

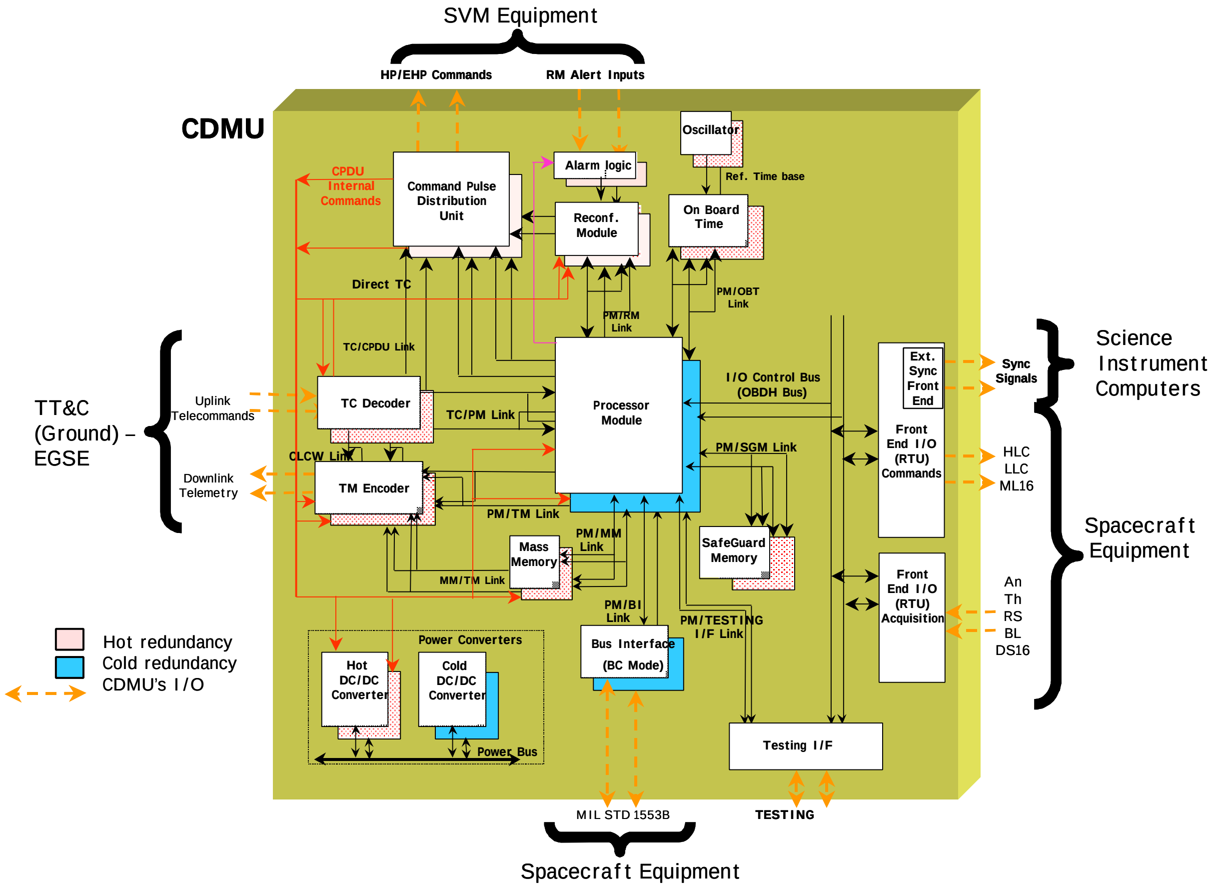


Figure 7.5-3 CDMU Block Diagram

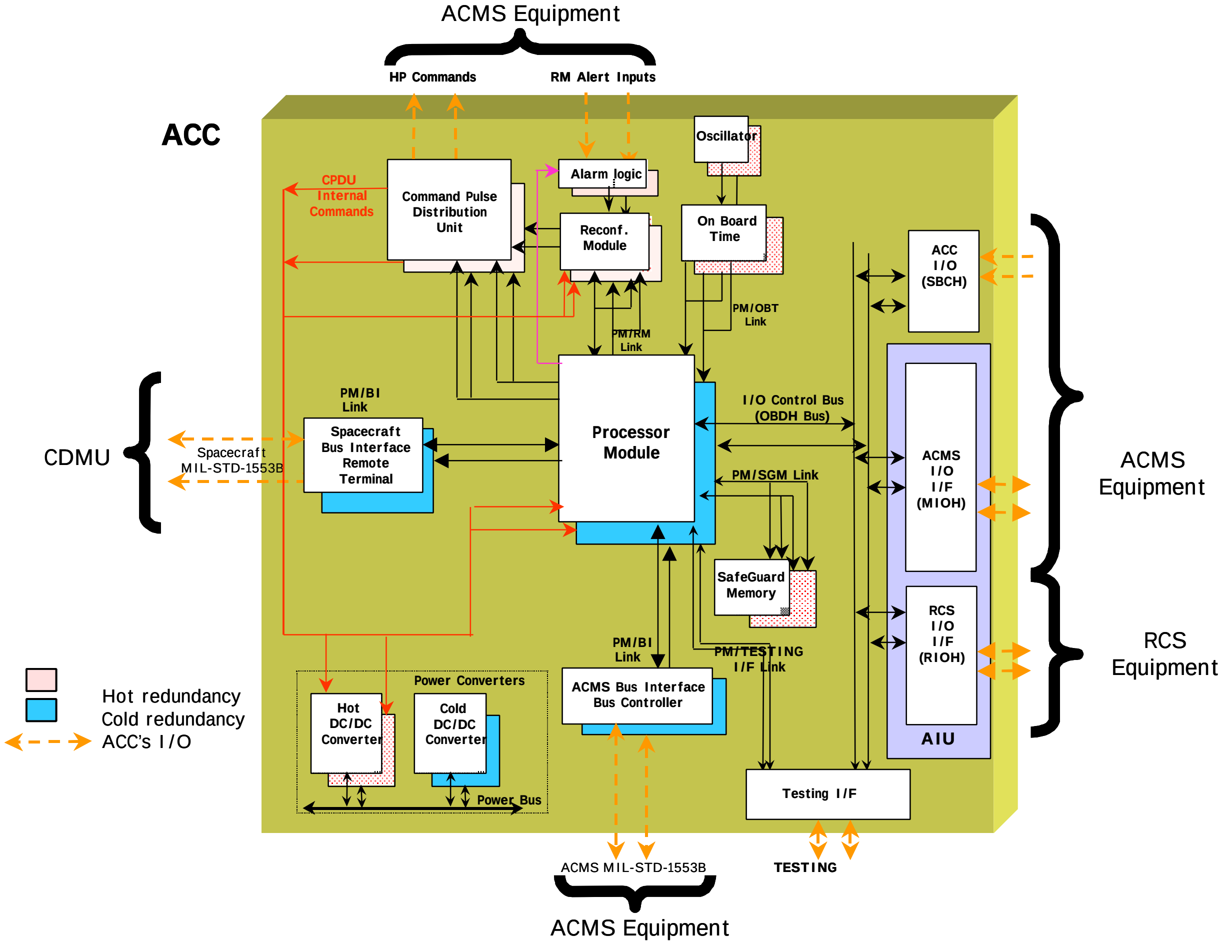


Figure 7.5-4 ACC Block Diagram

Data Handling functions are built around a Mil-STD-1553 Bus. CDMU can command and control the Spacecraft functions with the Bus, which Remote Terminals are:

- ACC
- PCDU
- Transponders (XPND1, XPND2)
- Non-SVM Computers: Science Instruments Computers, Cryostat Control Unit (on Herschel only), Sorption Cooler Electronics (on Planck only)

The CDMU acts as the central communication node between the Spacecraft and the active Ground Station distributing or executing commands received from Ground, collecting, formatting and transmitting the satellite telemetry. The CDMU provides also the reference signals for the Central Reference Time generation and synchronisation with the local timers of the other processors.

The CDMU provides a number of discrete telecommand lines for reconfiguration purposes. The CDMU provides condition inputs for discrete telemetry lines which will be used for housekeeping, to acquire status monitors and temperatures from the Thermal Control sensors. Power to Thermal Control heaters is provided by PCDU, under CDMU commands received on 1553 Bus.

Decoding and validation of telecommands uplinked from ground is performed by the TC decoder that is embedded in the CDMU. A set of High Priority Commands is available to command directly the end users from the decoders, by-passing any on board processor. These commands are used for time critical functions such as activation/deactivation of units, on board computers re-initialisation, back-up initiation of post-separation sequences.

CDMU include a Reconfiguration Module. This module is functionally independent from the Processor Module and the On Board Software; it is capable of processing some alarm signals via dedicated links and it can command directly the end users through High Priority Commands.

CDMU includes 2 CPDUs (Command Pulse Distribution Unit) which distribute High Priority commands generated by TC Decoder and by RM internally to CDMU or externally to the Users, without Software involvement.
The architecture of the Herschel/Planck CDMU foresees an additional link from Processor Module to CDPU. This architecture allows the generation of all the high priority commands also by the On-Board Software.
In fact each CPDU may receive CPDU packets from three sources:

- The TC Decoder
- The Reconfiguration Module
- The active Processor

The requests are prioritised such that the Reconfiguration Module Requests always have the highest priority if the RM is enabled. The Processor requests always have the lowest priority.
The CPDU has a capability to block some outputs from being used by packets from the processor. This blocking is programmed in a mission PROM and cannot be changed in flight.

Figure 7.5-5 shows the path of the High Priority Commands.

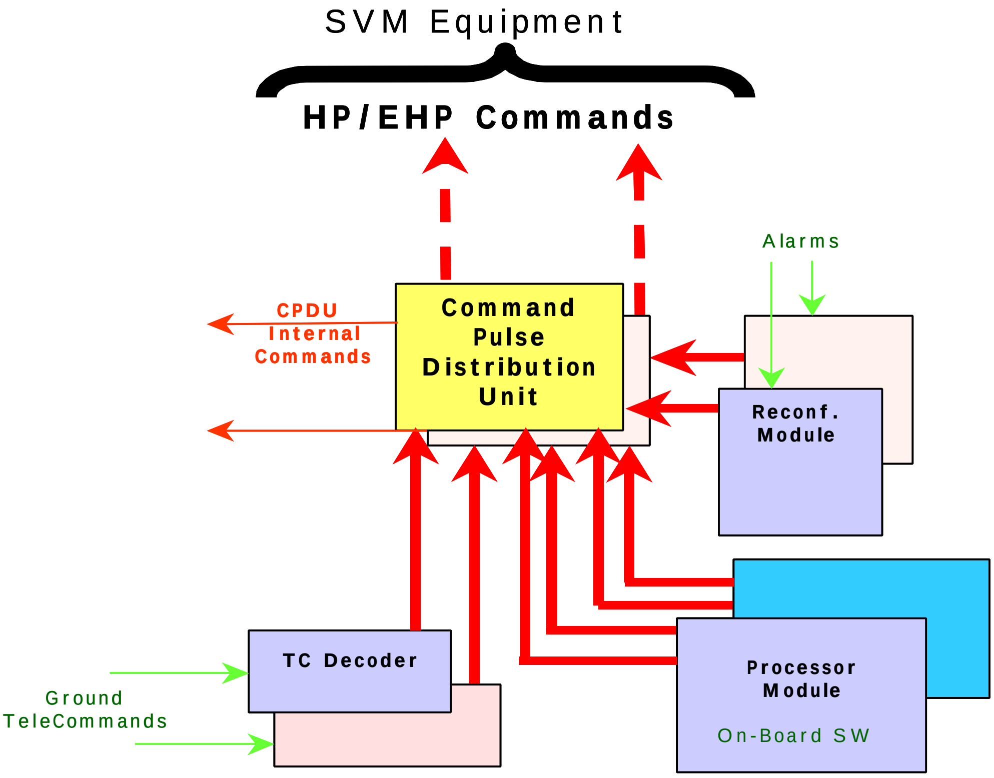


Figure 7.5-5 High Priority Command Generation and distribution

The CPDU commands distributed internally to CDMU allows the Processor Modules On/Off, Watchdog and RM Enable/Disable, Set/Reset of Status bits, TM encoder selection, Mass Memory On/Off/reset, Hot Converter reset.

CDMU High Priority Commands (external CPDU commands) are sent to:

- TT&C, for RF commanding: TX (Transmitter), TWTA (Traveller Tube Amplifier) and EPC (Electric Power Conditioner) On/Off, RFDN (Radio Frequency Distribution Unit) switches Set.
- ACC, for Reconfiguration Module Enable/Disable
- PCDU, for NCA fire and for On/Off of LCL (Latching Current Limiter) Output connected to CDMU Cold Converters and to SCC (Sorption Cooler Compressor, Planck only).

It must be taken into account that all the commands for LCL actuation are nominally sent to PCDU through 1553 bus commands. The above mentioned HP commands have been added in order to give direct access form RM (and from Ground) to critical functions: CDMU Cold converter supplies the PM, while the SCC load has to be carefully managed because its high load (535W) influence significantly affects the Power Bus.

CDMU can also send High level Commands generated by On-Board Software through the Front End I/O. These commands are sent to:

- ACC, for Latch Valves Arm/Inhibit and Processor Modules On/Off
- PCDU, for BCR/BDR On/Off, for reconfiguration of 1553 I/F and for direct commands of ACC LCLs.

The ACC includes all the functions and necessary provisions to

- reach and maintain the commanded attitude pointing within the required limits and constraints
- provide attitude determination and telemetry data necessary for attitude reconstruction on ground
- initiate and control the execution of commanded orbital manoeuvres
- execute commands received from the CDMU and transmit ACMS status telemetry to the CDMU.

A local ACMS Mil-Std-1553 Bus is implemented to support the data acquisition and command distribution function among ACC and the ACMS sensors and actuators.
Actuators commanding and sensor data acquisition by the ACC is implemented through the ACMS MIL-STD-1553 bus, while the communication with the CDMU is accomplished through the Spacecraft MIL-STD-1553 bus.

With the present baseline, Remote Terminals are allocated to:

- ACMS PDU
- Star Trackers
- Gyroscopes (Herschel only)

The ACC provides conditioning for analog interfaces for users which cannot interface with 1553 bus:

- Reaction Wheels (Herschel only)
- Sun Acquisition Sensors
- Quartz Rate Sensors
- Attitude Anomaly Detector

As the CDMU, the ACC include a Reconfiguration Module which provides the hardwired logic implementing the capability of ACMS reconfiguration and emergency mode initiation in case of detected anomalies attaining to attitude pointing and satellite rates.

As CDMU, ACC includes 2 CPDUs with the same characteristics (with the exception of TC Decoder which is not installed).
The internal CPDU commands are similar to the CDMU ones, while the external Commands can switch On/Off the Star Trackers, Quartz Rate Sensors, Gyro Channels and Reaction Wheels.

In addition, ACC is in charge to command the RCS thrusters and valves.

7.5.2.2 Radio Frequency Communications

The reference configuration of the RF elements has been chosen to guarantee full one failure tolerance with respect to all the RF functions. Low Gain hemispherical coverage Antennae (LGAs) and Medium Gain Antenna guarantee spherical coverage both for the uplink and for the downlink. The selection of the active antenna path is performed by operating the RF transfer switches which are part of RFDN and does not require active transmitter switch-over.

Two hot redundant receivers are provided, while the two redundant transmitters should be operated in cold redundancy, in order to minimise on-board power consumption and to avoid downlink signal interference at the Ground Station antenna in those regions where the two on-board LGA's gain patterns overlap.
The RF system is designed to support the RF link with the selected Ground Station operating in X-band.

The Radio Frequency communications essential functions are:

- to relay via X-Band link during the ground station the science and housekeeping data stored on-board. Downlink rates are 500 bps, 5 Kbps, 150 Kbps and 1.5 Mbps.
- to receive and demodulate the X-Band telecommand upstream. Uplink rates are 125 bps and 4 kbps
- to guarantee the satellite accessibility whatever the operating mode over the mission.

Considering the variety of downlink rates the transponders implement different modulation schemes: NRZ-L/PSK/PM, SP-L/PM and SRRC-OQPSK, while the specified uplink modulation scheme is PCM(NRZ-L)/PSK/PM. They are used in hot redundancy for the Rx part and cold redundancy for the Tx one. The telecommand and telemetry bit streams are respectively transmitted/received to/from the data handling computer. The transponders deliver a modulated signal to the 30 W RF amplifier stage.

As shown in Figure 7.5-6, the design features:

- Two X-Band Transponders
- Two 30 W TWTA (Travelling Wave Tube Assembly)
- A Radio Frequency Distribution Network
- 1 Medium Gain Antenna
- 2 Low Gain Antennae on Herschel, 3 on Planck.

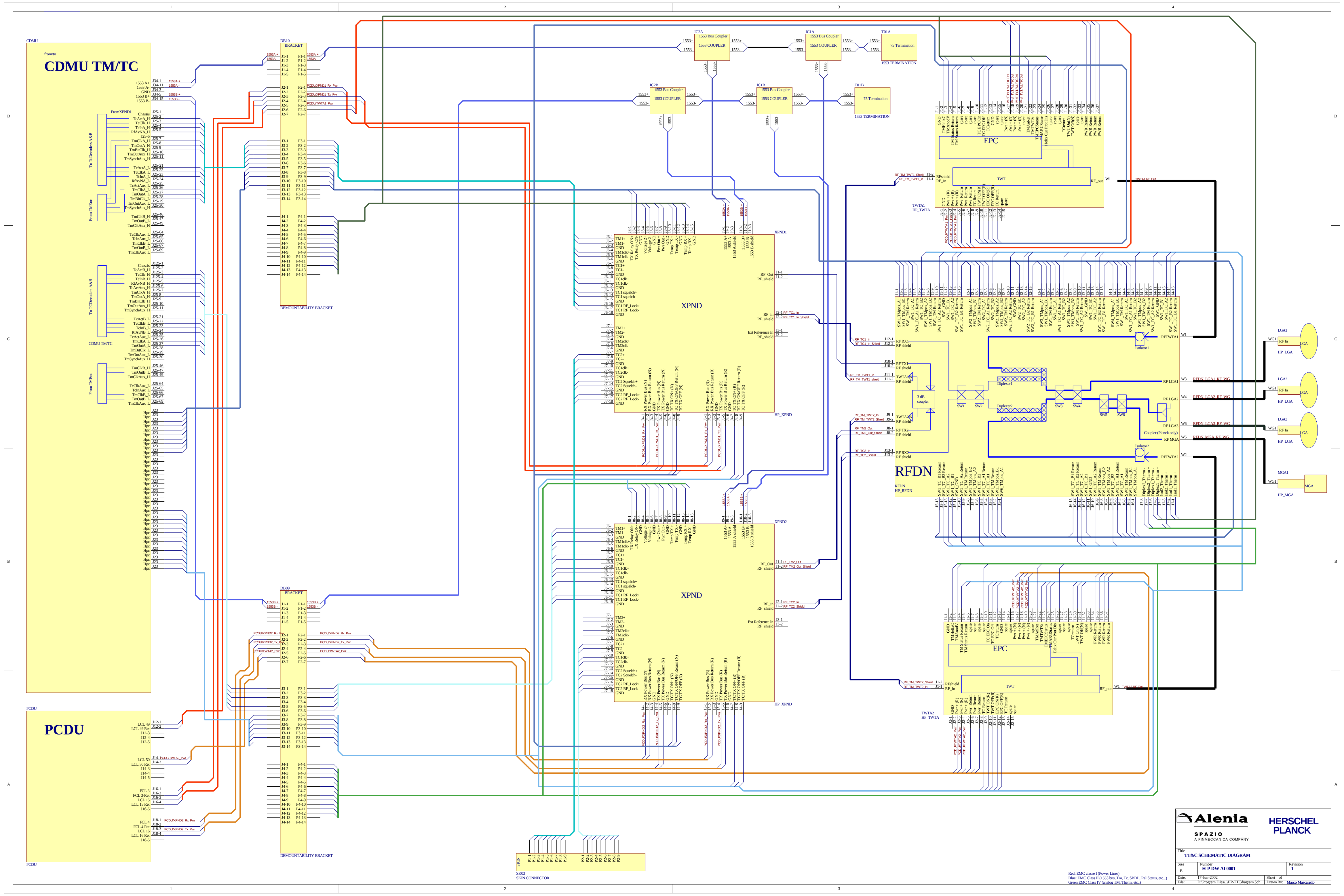


Figure 7.5-6 Telemetry, Tracking & Command system

7.5.2.3 Power Generation, Storage and Distribution

The Power System consists of the following units:

Power Control and Distribution Unit, PCDU, which provides:
- control of the electrical power generated by the solar array
- conditions the energy storaged in the battery when required
- controls, monitors and maintains the health of the PCS
- distributes power to the scientific instruments and spacecraft equipment
- Protects the power bus from external faults and prevents failure propogation
- heater switching control in response to 1553 commands
- interfaces for AIV and Launch support EGSE.

Battery, which provides:
- a store for the excess solar array energy
- a source of energy whenever there is insufficient power from the array (e.g. during launch, transient power demands and eclipse periods).

Solar Array, which provides:
- electrical power from the sun input
- a thermal shield between the sun and the SVM/PLM.

An overview on the configuration of the power system is given in Figure 9.3.3-1.

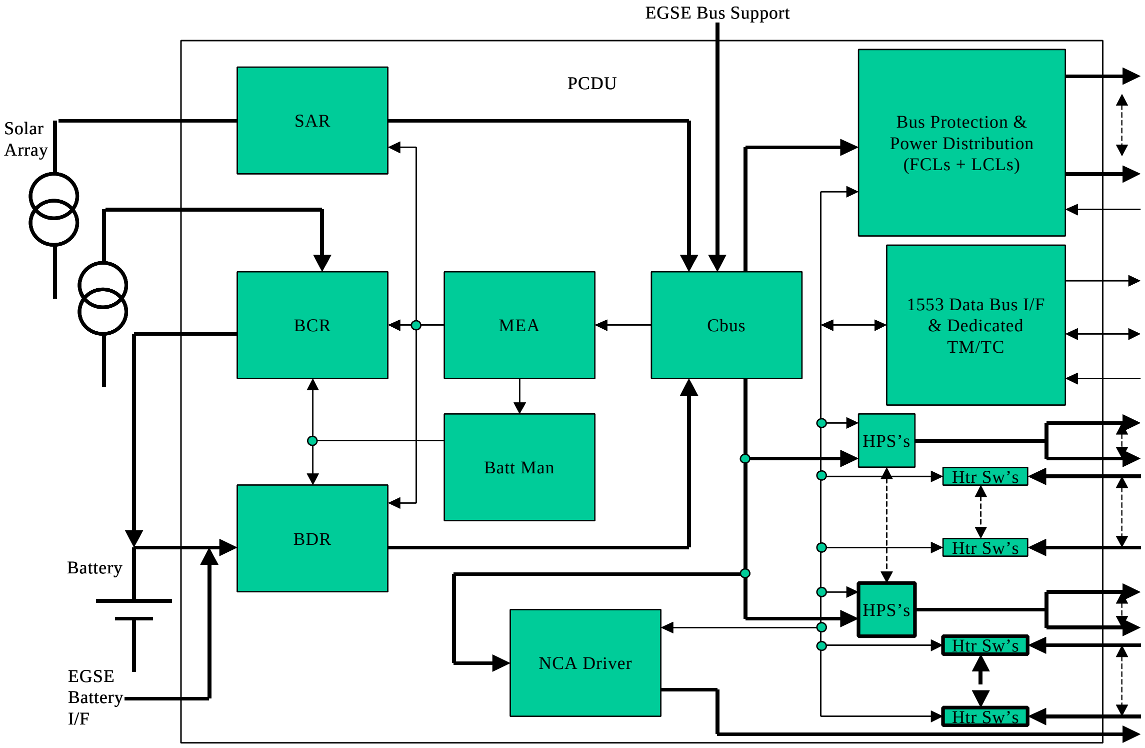
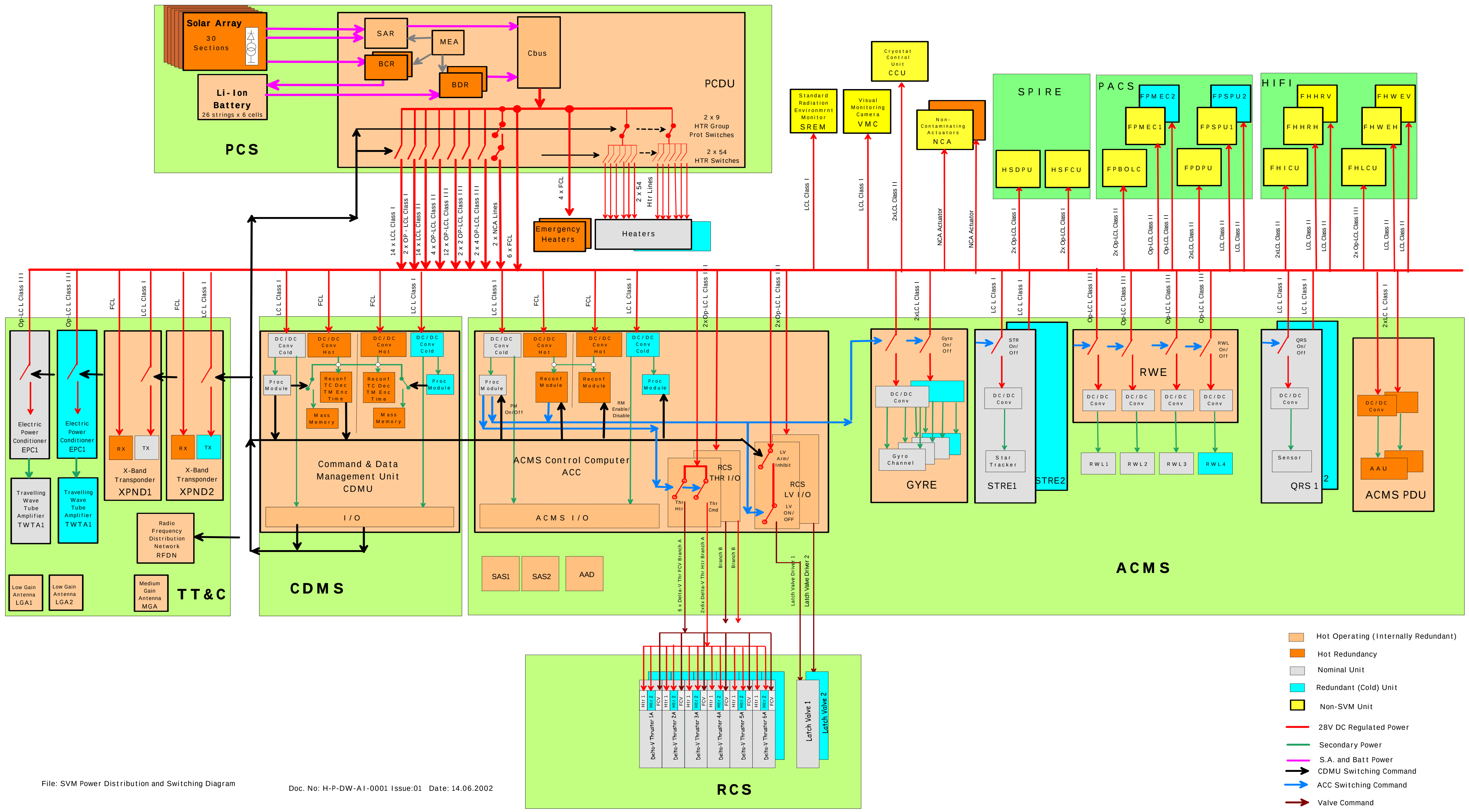


Figure 7.5.2-7 Power Control Subsystem

Details on Power system are given in section 9 of this report.
The Power Distribution and Switching diagrams are presented in Figure 7.5-8 and Figure 7.5-9.

HERSCHEL

SVM Power Distribution and Switching Diagram



File: SVM Power Distribution and Switching Diagram

Doc. No: H-P-DW-AI-0001 Issue:01 Date: 14.06.2002

Figure 7.5-8 Herschel Power Distribution and Switching Diagram

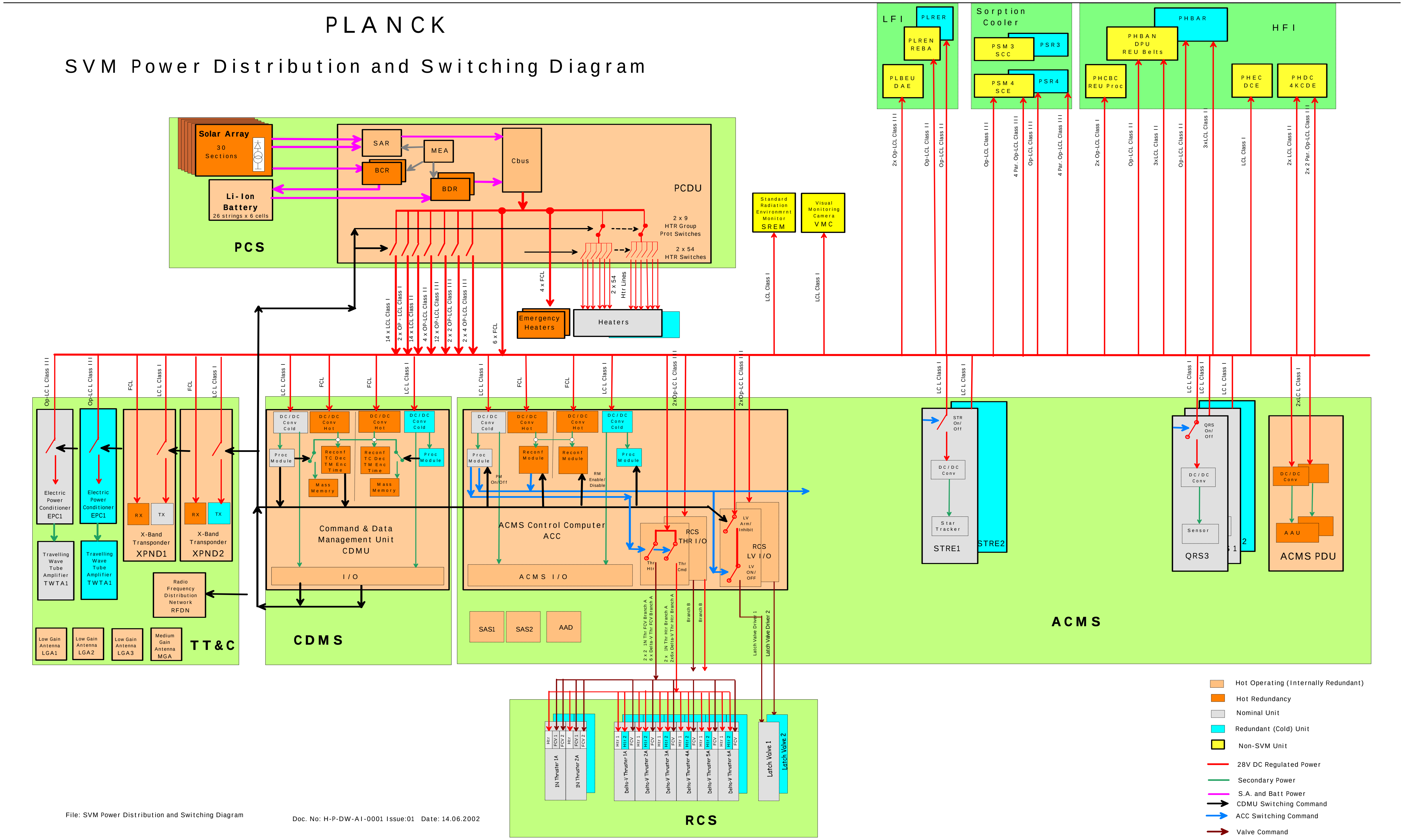


Figure 7.5-9 Planck Power Distribution and Switching Diagram

7.6 Herschel/Planck Software

This section is devoted to present the current software design of the Herschel/Planck Service Modules (SVMs). All the developed software belonging to the Payload Module (PLM) is not herein discussed because out of the scope of this document.

More precisely the following description is focused first on the main capabilities provided by the SVM software and then on the way it will be organised and structured from an architectural point of view. In this perspective a top level architectural design is provided. It has not to be considered as a way to address the relevant software subcontractors in their own design choices, but its intent is to identify and describe the main software components belonging to the flight software. This gives the chance to present a coherent and feasible design leaving to the related subcontractors the task to proceeding towards a more detailed analysis in order to produce the complete architectural design.

As far as the Ground software is concerned the description will be mainly devoted to identify the Software Tools and Components supporting the Ground activities (e.g. SW development, OBCP generation…).

In the context of the programme it is rather important to point out that, presently, some points about technical strategic decision are still under discussion/investigation. Unfortunately this is caused by the intrinsic functional dependence of the software w.r.t. other system design choices (e.g. FDIR analysis, units/equipment definition, HW constraints, etc). Consequently there are margins to improve and refine the final software design but this can be considered part of the normal work allocated to the different subcontractors.

7.6.1 Software Breakdown

The Herschel/Planck software related to the SVM can be split in two major items as shown in:

- the flight software
- the ground software

Figure 10 shows the main software components whose supervising responsibilities are in charge to ALENIA.

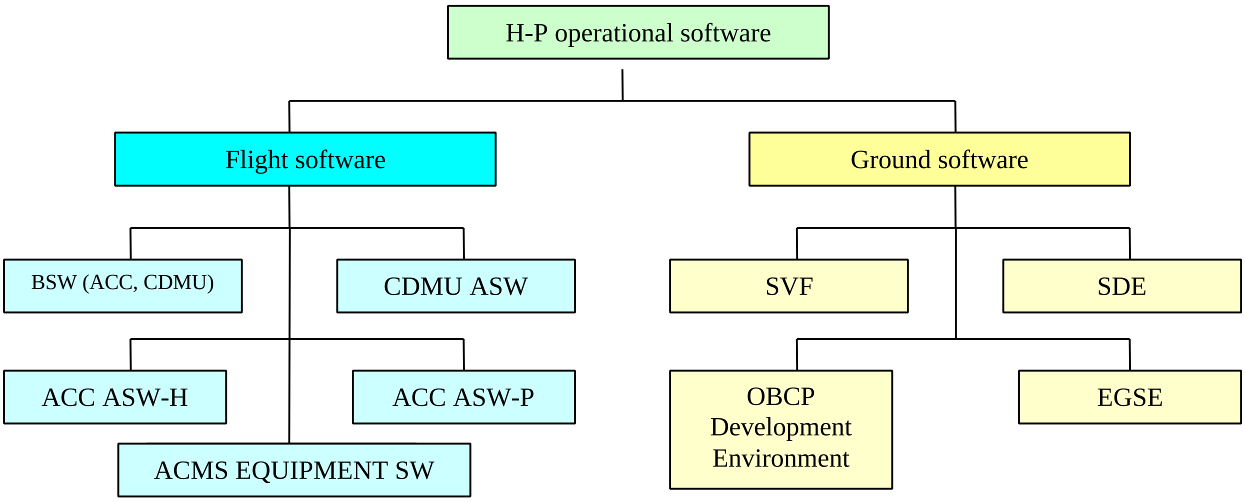


Figure 10 Herschel/Planck SW product tree

7.6.2 Flight Software

Before to analysing the main on-board software capabilities, it is presented a short overview about the avionics architecture and the software layers structure. Its intent is to better clarify the operating environment and its related characteristics/constraints.

7.6.2.1 Avionics Architecture

The SVM avionics architecture of the CDMS and ACMS subsystems comprises respectively two distinct control computers (CDMU, ACC) based on ERC-32 microprocessor. The two computers, identical both for Herschel and Planck, are connected by means of a 1553B bus. In particular the CDMU acts as bus controller w.r.t the other units connected on the 1553B spacecraft bus.
The bus is used for low-level word oriented data acquisitions and control (for non packet terminals), as well as for high-level packet transfers (for packet terminals).
Communications among the different units on the spacecraft bus are compliant to the Satellite Data Bus Protocol specified in [AD-09].

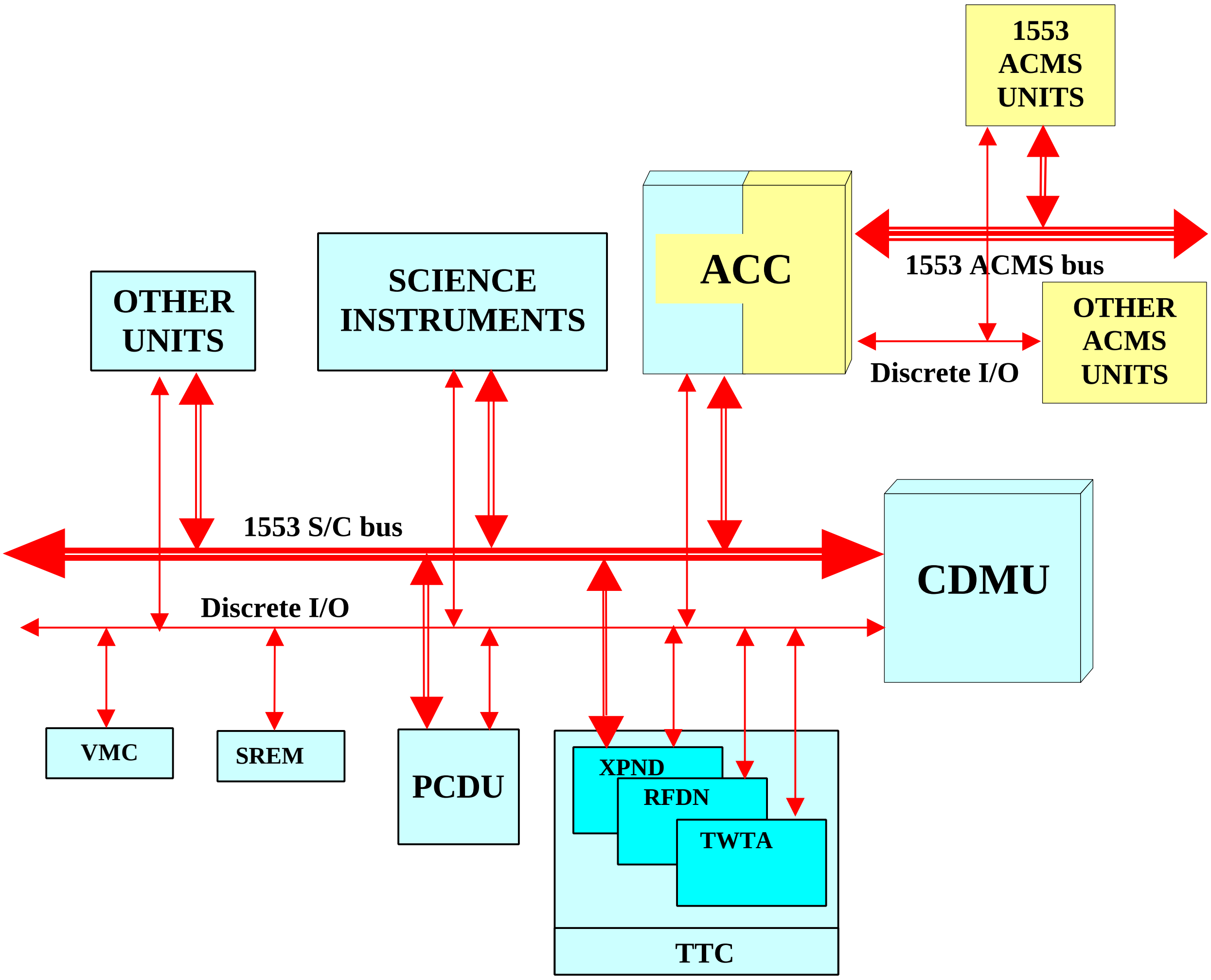


Figure 11 Herschel/Planck block diagram

In Figure 11 is depicted the common avionics architecture between Herschel and Planck spacecrafts.

Basically the Science Instruments, the Other Units and the ACC fully support the SDBP defined in [AD-09] and are therefore defined as Packet Terminals. The other terminals, on the 1553 Spacecraft bus, are the PCDU and the XPND (belonging to the TTC subsystem) and are referred as non Packet Terminals.
The “Science Instruments” block is in detail characterised, for the two spacecrafts, by the instruments listed in Table 1

HERSCHEL INSTRUMENTS
HIFI
PACS
SPIRE

PLANCK INSTRUMENTS
HFI
LFI

Table 1 Herschel/Planck Science Instruments

The “Other Units” block makes reference to the units, connected to the 1553B bus, reported in Table 2 and belonging to Herschel and Planck respectively.

HERSCHEL “OTHER UNITS”
CRYOSTAT CONTROL UNIT

PLANCK “OTHER UNITS”
SORPTION COOLER

Table 2 Herschel/Planck “Other Units”

Concerning the ACMS subsystem in Table 3 are detailed all the units belonging to the two spacecrafts.

HERSCHEL ACMS UNITS	
1553 units	Star Tracker (1+1) Gyro (3+1) PDU (1)
Other units	RWL (3+1) QRS (2) AAD (1+1) SAS (2+2)

PLANCK ACMS UNITS	
1553 units	Star Tracker (1+1) PDU (1)
other units	QRS (3) AAD (1+1) SAS (2+2)

Table 3 Herschel/Planck ACMS units

At present the ACMS subcontractors has still to define the high level protocol, relying on 1553 ACMS local bus. Moreover the possibility to accommodate the RWL on the 1553 bus is still under investigation.
The previous scheme depicted in Figure 11 shows how the avionics architecture of the spacecrafts has been structured. The block diagram is applicable both to Herschel and Planck.

7.6.2.2 Software Layers Breakdown

The whole CDMU and ACC OBSW of Herschel/Planck spacecrafts has been conceived in order to maximise the software re-use. Different software layers have been identified according to the SW breakdown depicted in Figure 12.

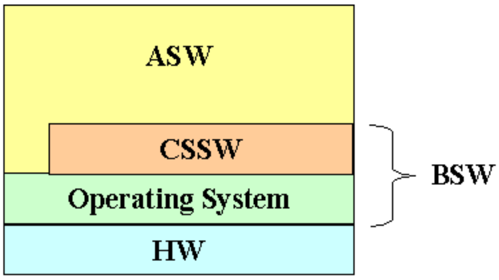


Figure 12 CDMU/ACC Software layers

The **Hardware (HW) layer** is represented by the physical devices (e.g. MIL-STD-1553B bus) that must be served.

The **Basic Software (BSW) layer** represents the lowest SW layer of ACC and CDMU computer and supplies basic services to interface the hardware devices and accomplishes important functionality by itself.
It is composed by two main layers:

- the Operating System (OS) which directly interfaces the HW. Basically it includes the main capabilities of a real time kernel (e.g. task scheduling, time management, events, inter-task communication services, ect), the I/O drivers and the bootstrap module.
- The Common Service SW (CSSW) represents the SW core package that can be considered common to both Herschel/Planck CDMU and ACC computers.

The relevant difference about ACC and CDMU BSW is mainly constituted by the I/O drivers related to the units belonging to the two spacecraft's subsystems (CDMS, ACMS).
From a functional point of view, one of the most important activity, carried out by the BSW, is the communication management of the units connected on the 1553 bus as well as the other units connected through proper discrete lines.

More precisely the BSW allows:

- 1553 management
  - ☐ TCs issuing management towards packet terminals and non packet terminals
  - ☐ Data gathering from packet terminals and non packet terminals. In this last case the BSW is in charge to properly packetise the data in the standard TM source packet defined in [AD-09]
- I/O channels management
  - ☐ command issuing
  - ☐ monitor acquisition
  - ☐ telemetry data gathering and packetisation in TM source packets for SSMM storing and real-time data downlink
- Updating of the data structures (contained in the Data Pool) with the last acquired data to be made available for further processing in charge to the ASW

The highest SW level is represented by the **Application Software (ASW) layer** which makes use of the BSW provided services [RD-15]. Basically the ASW implements the following main functionality:

- **Mission Management**
- **Power distribution management**
- **Thermal control**
- **FDIR**
- TTC management

Besides the described functionality the BSW and the ASW fully support the ESA standard packet services specified in [AD-09]. Each software layer is responsible of its own managed packets. The services allocation is shown in Figure 13.

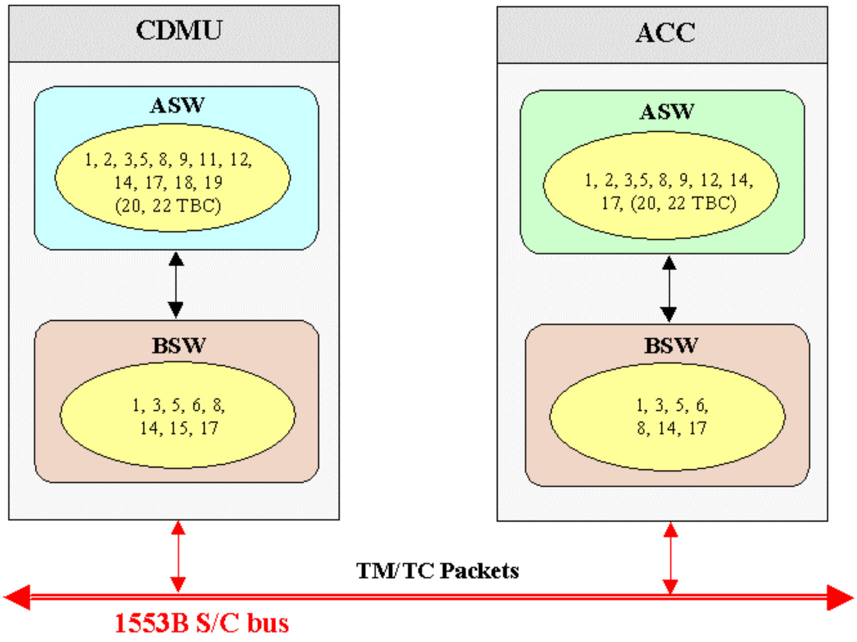


Figure 13 CDMU-ACC Standard Services allocation

As far as the BSW is concerned it is quite evident that, both for the CDMU and the ACC, it manages a set of common services, with the only exception of the on-board storage and retrieval service (Service 15) because the SSMM is only located in the CDMU.
Regarding the ACC, at ASW level, the on-board scheduling (service 11), the on-board control procedures (service 18) and the event/action (service 19) services are not requested.

It could seem rather odd to have some standard packet services supported both by the BSW and the ASW layers. However, as already stated, the BSW does not only provide interface services, but it has to be considered as an active component. For instance, concerning Service 3, both BSW and ASW are responsible for the generation of their own HK/diagnostic packets. The same principle is applicable to Service 1, Service 5 and Service 17.
Different considerations are related to the Service 8 support, because in this case it is only the BSW in charge to completely maintain the relevant data structures. The ASW will have access to these structures only through BSW provided services. However both BSW and ASW are able to define and manage their own system function.

Concerning the software implementation and provisioning, the BSW is totally in charge, both for CDMU and ACC, to the HW supplier of the two computers. In fact, the selected BSW supplier (viz. Saab Ericsson Space), is responsible over the development, verification and maintenance of the BSW product and also of the maintenance of the OS that has been identified to be a COTS product (i.e. RTEMS).

The ASW will be, as far as possible, the same for the CDMU of Herschel and Planck. Its development will be carried out by the same subcontractor. Vice versa two different ASW products will be developed for the ACCs, one for the ACC of Herschel and one for the ACC of Planck due to their intrinsic differences related to the attitude control algorithms and the used equipment/sensors. Anyway the commonality guideline, as far as possible, will be extended to this software too, trying to identify a subset of common supplied functionality and/or software utilities (e.g. mathematical libraries, data management functions, etc).

7.6.2.3 Top Level Architecture

7.6.2.3.1 BSW

The overall views depicted in Figure 14 and figure 6show the main functional blocks composing the CDMU BSW and the ACC BSW.

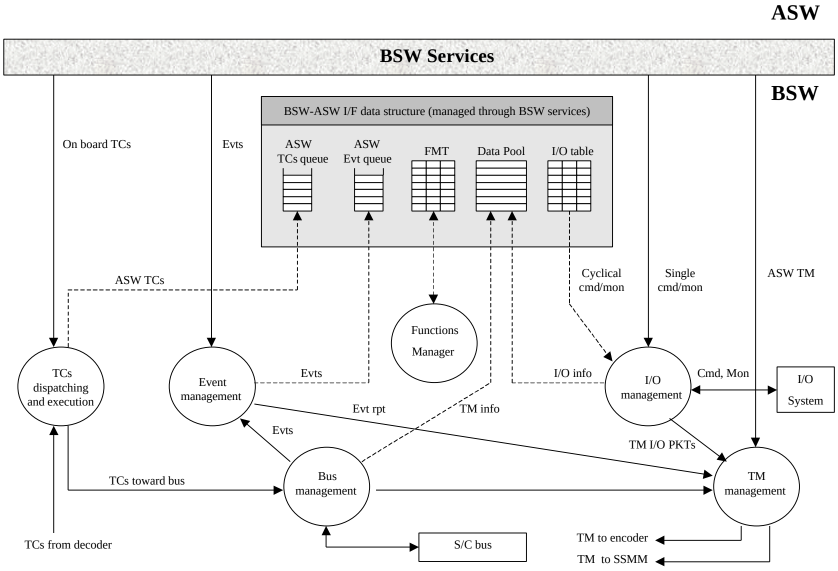


Figure 14 CDMU BSW layer

The main differences are related to the 1553 bus management and to the telemetry management.
As far as the bus management is concerned the CDMU BSW is in charge to manage communication on the 1553 spacecraft bus. The ACC BSW bus management is instead referring the ACMS internal bus connecting the ACMS units to the ACC computer.
Regarding the ACC “telemetry management” functional block all the telemetry packets generated by the ACC are addressed toward the spacecraft bus, while the CDMU BSW manages the storing of telemetry in the SSMM and the forwarding toward the TM encoder for real-time downlink.

The other depicted functional blocks can be considered similar except for those specific aspects that will be only detected during a more detailed design analysis carried out by the relevant software subcontractors.

Moreover the data exchanging between the two layers (ASW-BSW) is realised through proper interface data structures. They are completely maintained by the BSW and contain the relevant data necessary for further ASW processing. The access to these structures is also possible through provided BSW service calls (SVCs).

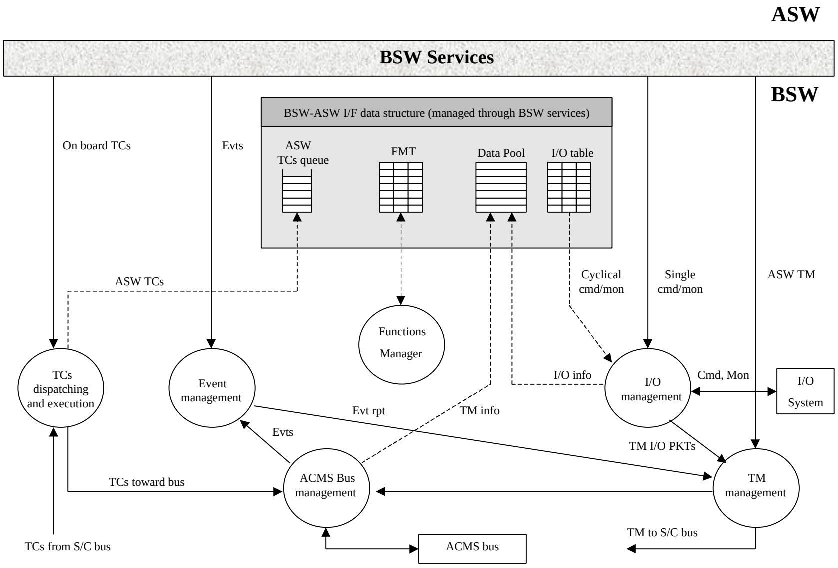


Figure 15 ACC BSW layer

The I/F data structures, shown in Figure 14 and in Figure 15, have the following purpose

- the I/O table contains all the parameters defined (by the BSW and the by the ASW) in order to perform a cyclic or asynchronous monitor acquisition;
- the data pool represents the most important RAM area where are stored all the I/O acquired data, HK TM data incoming from MIL 1553B RTs. This information will be elaborated by system functions and/or OBCPs;
- the Function Management Table (FMT) contains the information related to the system functions defined by the BSW and by the ASW;
- the ASW Event queue is devoted to the accomplishment of the Event/Action and it is therefore not present in the ACC BSW layer scheme where this service is not foreseen. All the on-board generated events are addressed to the CDMU and inserted in the queue for ASW processing;
- the ASW TCs queue contains all the received telecommands specifically addressed to the ASW.

7.6.2.3.2 CDMU ASW

The ASW for the CDMU of Herschel and Planck satellites will be, as far as possible, the same. Figure 16 depicts the ASW top level architecture showing the major components in terms of functional blocks.

Basically all the ASW implemented functionality are table driven. In this perspective several tables, containing information relevant to each performed ASW function, are foreseen.

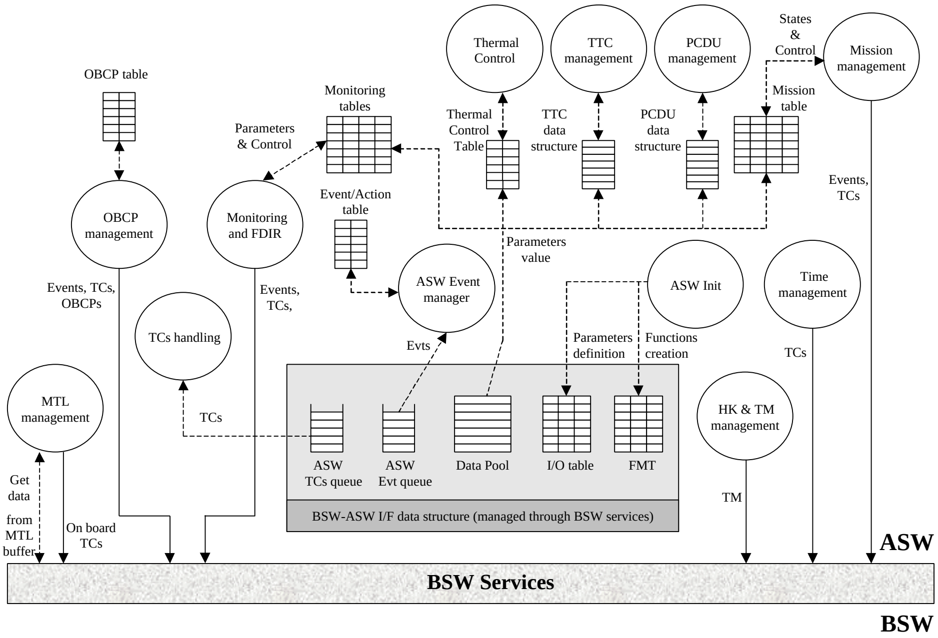


Figure 16 CDMU ASW layer

The access to the I/F data structures, maintained by the BSW, is mainly performed in read mode except for the "ASW Init" process that is in charge to define all the ASW functions and I/O parameters to be acquired.

7.6.2.3.3 ACC ASW

As far as the ACC is concerned two different ASWs will be vice versa developed, one for the ACC of Herschel and one for the ACC of Planck. The ASWs ACC top-level architecture will be provided by the relevant ACC ASW subcontractor which is responsible for the realisation of both products.

7.6.2.4 CDMU Software Capabilities

The following section contains a description of the main CDMU software capabilities. Exhaustive details are included in the relevant requirement documents (i.e. [RD-13] and [RD-14]).

7.6.2.4.1 Telecommands

Telecommands represent the main capability that shall allow ground to interact with the on-board users. Telecommands are also autonomously generated by the CDMU computer in order to properly command the interfaced units.

The CDMU software shall be fully compliant with the packet structure and format specified in the PS-ICD [AD-09].

The following restrictions are applicable to all TC packets both for those generated and uplinked from ground and for those ones on-board generated:

- all TCs shall be “stand-alone” packets, i.e. no segmentation will be used (this aspect is however TBC due the possibility to create segmented TCs for specific telecommands, e.g. OBCP load)
- the TC maximum length is 248 bytes.

In the framework of the proposed architecture the BSW layer is in charge to process and distribute all real time telecommands coming from ground, executed from the on-board scheduling service and directly generated on-board (e.g. from OBCP). The TCs are dispatched on-board to the proper addressed user according to the rules specified in [AD-09], basically referring to the relevant APID value.

The destination application process is in charge to validate the received TC packets at the moment of the acceptance.

Considering TCs addressed to the CDMU (viz. BSW and ASW), it means that each software layer is in charge of the acceptance of its own received telecommands.

As general rule to be followed, TCs that are not conform to the packet telecommand standard and/or are not recognised as valid TCs will be rejected at the earliest possible stage in the on-board acceptance and execution process. For this reason a first filtering, checking legal values for header fields (e.g. APID) and Packet Error Control telecommand fields specified in [AD-09], is performed by the BSW even for those TCs not specifically addressed to the BSW itself. It means for instance that TCs having a wrong checksum will immediately be discarded.
In any case the cause of the rejection will be indicated in the relevant generated telemetry packets.

In Figure 17 is depicted a schematic diagram showing the TC management performed at BSW layer.

The TC manager constitutes the core of the process. Basically it is in charge to retrieve ground TCs from the TC driver queue and to receive the on-board generated TCs from the ASW.
All BSW addressed TCs, are submitted to verification and validation and consequently executed if checks do not fail.

TCs addressed toward other units different from the ASW, are properly routed through the SDBP Manager. The TCs dispatching performed by the BSW does not take into account the operating status of the addressed user. It means that the TCs packets are always dispatched both when the user is functionally ready and when not to accept them.

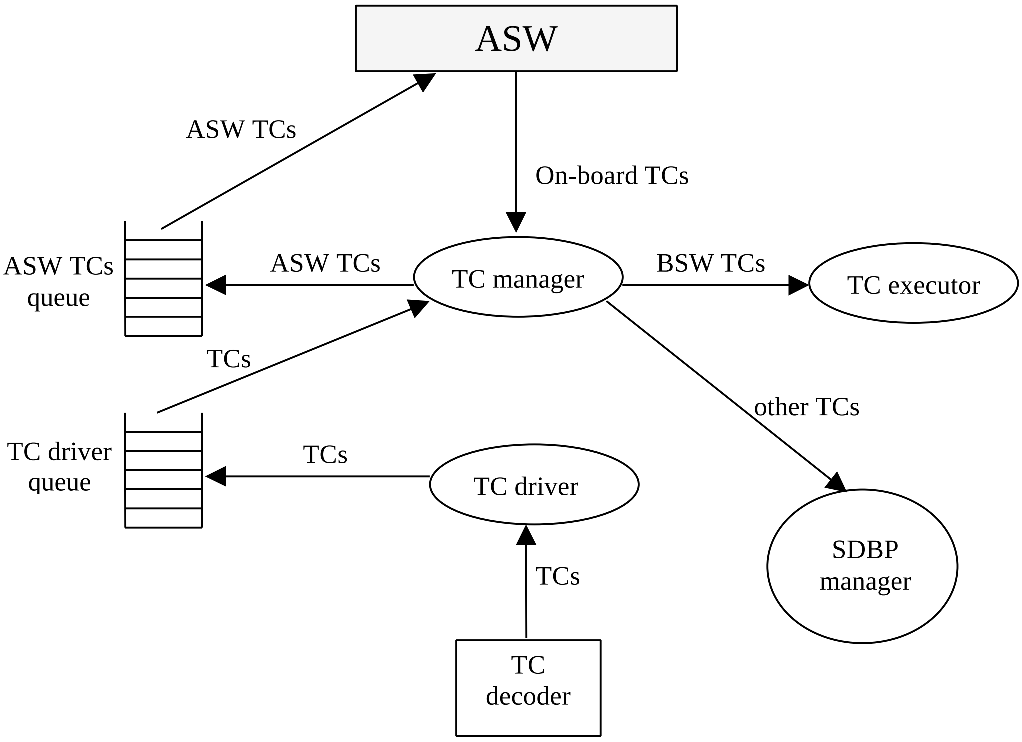


Figure 17 BSW TCs handling

The TC manager inserts all TCs addressed to the ASW in the ASW TCs queue that is part of the I/F data structures between BSW and ASW. The inserted TC is a complete copy of the TC received by the BSW except for the checksum field as its validity has been already checked.

The ASW handles TCs according to the scheme depicted in Figure 18 (for MTL TCs see the relevant section). All TCs gathered from the BSW and inserted in the ASW TCs queue are retrieved by the ASW with a polling mechanism through a BSW provided service. The ASW proceeds to their acceptance and then, if it is successful, to their execution. In any case a Report containing the verification status has to be generated.

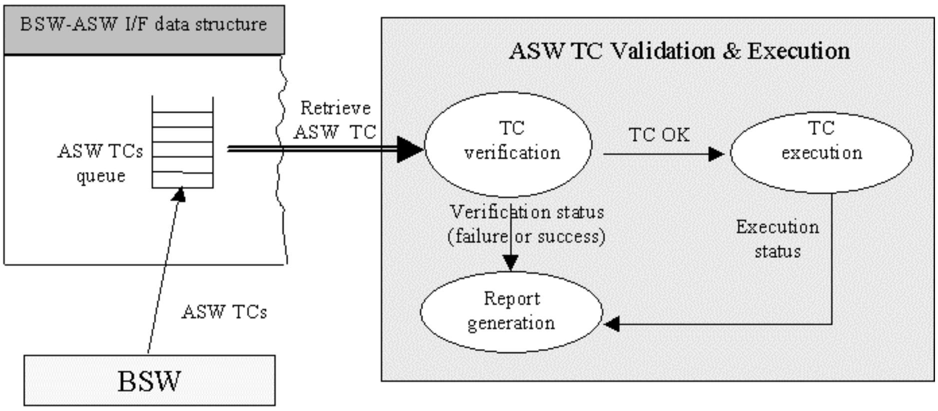


Figure 18 ASW TCs handling

Beyond the standard TCs defined in [AD-09], it has to be remarked that it will be possible to extend the used set of telecommands creating new TCs for specific user/application needs. For instance it will be necessary to define new TCs concerning the ACMS subsystem and in particular related to the ACC unit. Anyway all defined TCs (standard and new) will always respect format and rules stated in [AD-09].
All new defined TCs, related only to units belonging to the SVM, will be included in the SVM SW ICD [RD-16]. They will be detailed in terms of packet definition and usage.

7.6.2.4.2 Telemetry

Telemetry (TM) packets provide to ground information about the spacecraft status, the execution status of all mission operations and the acquired science data. Thus Housekeeping, Diagnostic and Science data acquisition are foreseen.
The CDMU software shall acquire the scientific, periodic and non-periodic Housekeeping/Diagnostic data packets from the scientific instruments as well as all the other HK data coming from the intelligent units connected to the 1553 bus.

Data shall be received by the BSW, from the source, according to the format specified in [AD-09]. Only if the source user cannot support the packet standard format, raw data are transmitted in MIL 1553B bus messages. A scheme of the 1553 bus management performed by the BSW is shown in Figure 19. The SDBP manager is the BSW function that supports the SDBP protocol. It is based on a cyclic scheme, the bus profile, that defines all the bus transactions. The SDBP manager, according to the bus profile, is then in charge to manage TC/TM data toward/coming from packet and non packet terminals connected to the 1553 bus.

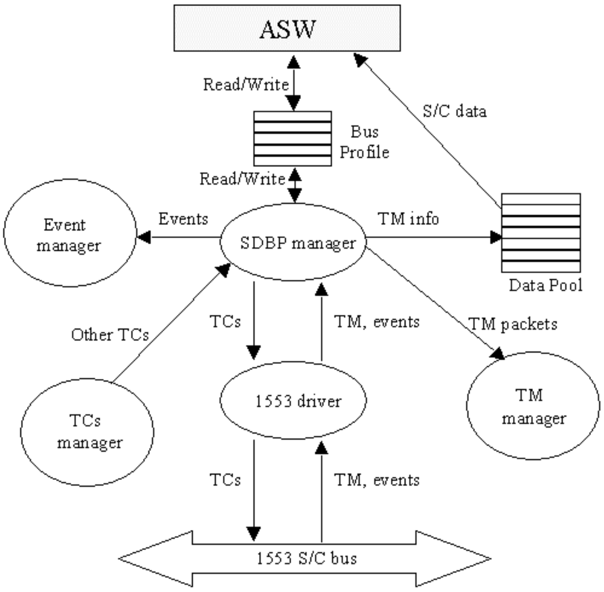


Figure 19 MIL-1553B bus management

The bus profile definition is maintained in a proper data structure accessible to the ASW, through BSW provided services. In this way, according to specific needs occurring during the mission, it is possible to enable/disable the communication flow to/from some unit as foreseen by the active bus profile. These operations must be carefully managed and carried out at the right instant in order to avoid any possible hang-up or probable side effects. It is also reminded that a complete new bus profile loading is totally in charge of the BSW.

Besides the 1553 transactions the BSW, through the I/O manager function, is able to handle the data acquisition from the I/O channels (in a cyclic or not cyclic manner) of those parameters defined in the relevant I/O table. Figure 20 shows a sketch of the process. The I/O table, maintained internally by the BSW, is accessible from the ASW for I/O parameter definition, through proper BSW services.

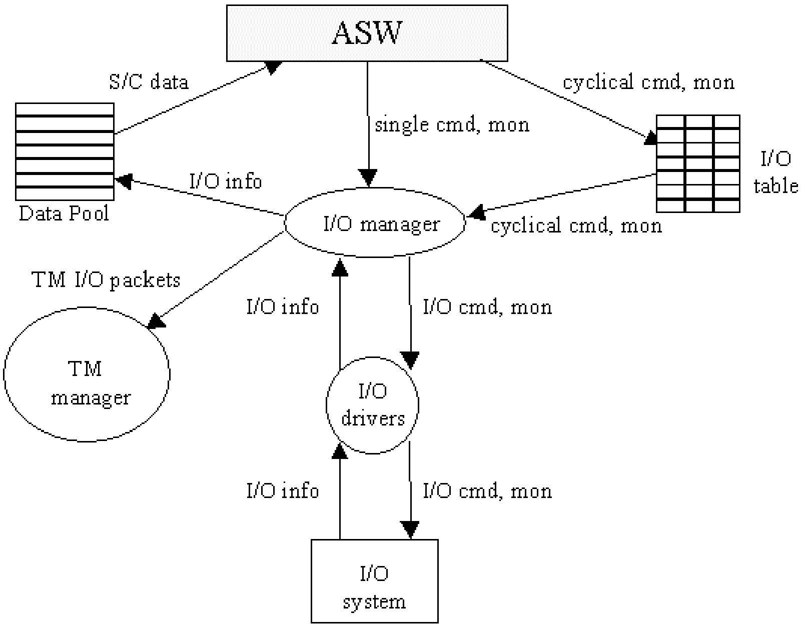


Figure 20 I/O management

The TM data coming from 1553 RTs and acquired from the I/O channels are properly handled by the relevant managers (e.g. SDBP manager, I/O manager). It means that they will be responsible over the packing of the received data w.r.t. the standard format before storing and transmission towards ground. Essentially, the prepared TM packets, will be then managed by the TM manager that is in charge to perform storing and downlinking (Figure 21).

All the HK data coming from the RTs, or acquired from the I/O channels, are arranged, after proper management, in the so-called Data Pool area for further elaboration. It means that, concerning HK data, it will be necessary to unpack (in case of Packet Terminals) or just extracting the received HK in order to save the needed information in the Data Pool. The Data Pool represents the most important I/F data structure (BSW-ASW) used to communicate to the ASW the relevant data acquired, through the bus or the I/O channels, or autonomously generated by the BSW.

Critical aspects have to be considered also for the possibility to re-define a (small) number of HK and Diagnostic TM packets. The standard packet service 3 allows the assignment of a new definition of a sequence of Parameter Identifiers to an existing packet definition, making coherent use of a new Structure Identifier.

This significant issue about the possibility to modify the definition of housekeeping packets, as foreseen in the PS-ICD [AD-09] could lead to potential problems. In fact it affects, together with the variable telemetry packets of instrument science data, some important aspects to be taken into account:

- SSMM sizing: the re-definition of the above mentioned packets can request a sizing change of the memory areas (Packet Stores) where these data will be stored. It could lead to sizing problems whenever Packet Stores have to be enlarged (in case of increasing number of parameters).
- Data rate budget: the number and the size of the HK telemetry packets generated by any 1553 RT has to be in accordance with the allocated bus budgets and the loaded bus profile.
- Data Pool re-arrangement: the BSW maintains in its reference tables all the used S/C HK packets definition in order to be able to refer correctly the parameters in the Data Pool structure. A re-definition of the HK imposes a not trivial re-arrangement of the reference table and of the Data Pool. A possible solution discussed with ESA and the Prime Contractor (but still under investigation) is to foresee 2 sets of HK packets. The first one contains HK whose parameters will be always stored in the Data Pool. The second one will give the chance to re-define the packets and won’t affect the Data Pool storage, they will only be transmitted to ground.

Another point to be also considered makes reference to the packets transfer efficiency. It is recommended to avoid the definition of more HK packets containing a small number of parameters. It is preferable to maximise the parameter number in the HK definition. Considering the information about the fields length of the HK definition TC, it will be possible to foresee HK containing at most 114 parameters (Note: this evaluation has been done assuming that the size of the number of parameters “N” field in the relevant HK TC definition, is 2 bytes. It is obviously enough to define all the parameters). However just taking into account of this maximum value (i.e. 114), it is possible to create/re-define short HK packets. To allow longer HK packets, a possible solution could be the usage of the parameter_id as identifier of a larger data structure or the usage of segmentation (that is at the moment not foreseen in [AD-09]).
As far as the instruments science data are concerning they are directly stored in the SSMM, as soon as they are received by the BSW, without any further elaboration.

During the daily Ground contact, the CDMU software shall support simultaneously the recording of all real time telemetry (only housekeeping or housekeeping + science) and one of the following telemetry mode transmission to Ground:

- Real time housekeeping (spacecraft and instruments);
- Real time science + real time housekeeping;
- Real time housekeeping + dump of stored telemetry
- Real time science + real time housekeeping + dump of stored telemetry

The transmission to ground will be possible by associating the relevant transmission mode to the dedicated Virtual Channel.
Presently four virtual channels are allocated for transmission and three are spare:

- VC0: realtime housekeeping telemetry
- VC1: realtime instruments telemetry
- VC2: dump science and HK telemetry
- VC3: dump science telemetry
- VC4,VC5,VC6: not used
- VC7: idle frames

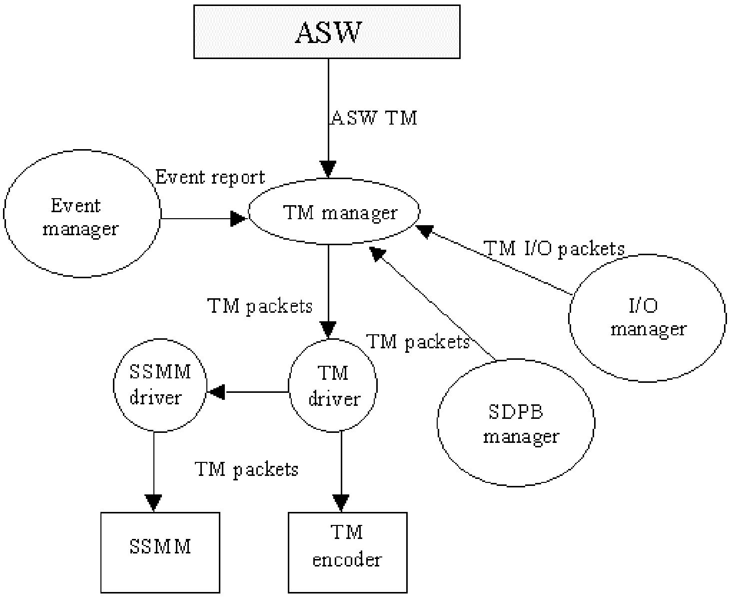


Figure 21 TM management

7.6.2.4.3 Event Management

On-board events of operational significance, that occurs on all S/C units/equipment, represent a class of extremely meaningful telemetry data. Those events, issued as Event Report packets (Service 5), will properly collected by the CDMU BSW and stored in the Event Queue data structure as well as stored in the different foreseen logs. Figure 22 shows the event reporting data flow.

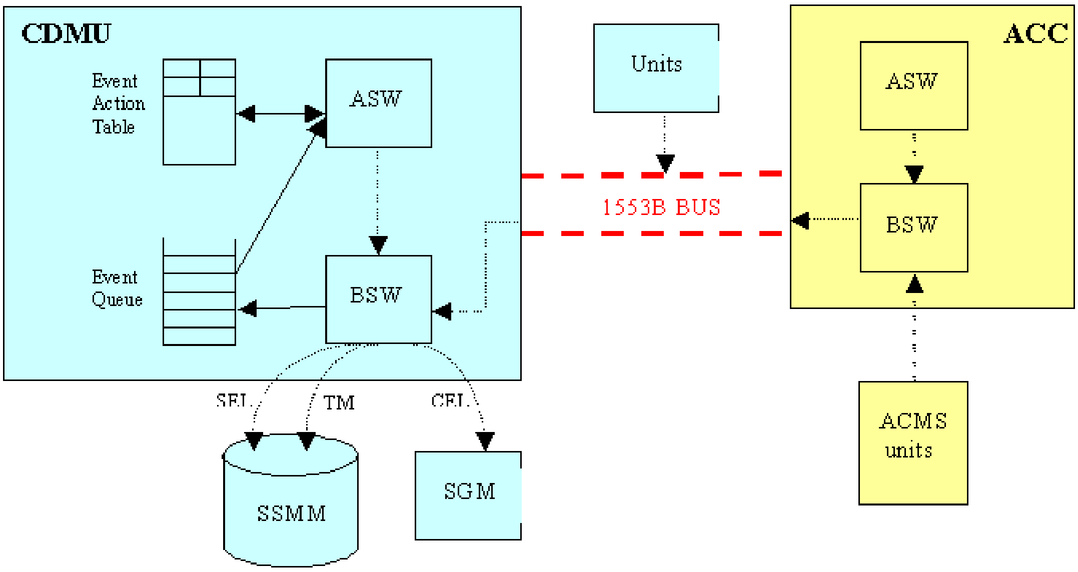


Figure 22 Event Reporting data flow

Three different sub-types of user-initiated event reports are defined for Herschel/Planck, to facilitate routing, on-board processing, and/or ground processing. The following event reports classes are foreseen:

- Normal events
  This subtype shall be used for passing on information for any asynchronous event, which has occurred within a unit or subsystem and for which no direct action is required (except recording on SSMM or transmission to ground).
- Exception Reports
  An Exception Report shall be generated, by a unit, in non-nominal cases for which an unscheduled on-board (recovery) action is required. This Report Packet is related to situations, which cannot be resolved by the unit alone but a CDMU support is requested to execute specific on-board procedures.
- Error/Alarm Report
  An Error/Alarm Report shall be generated for non-nominal events which require intervention from the ground mission control centre, i.e. no predefined recovery or saving procedures are resident on-board.

All the events stored by the BSW in the Event Queue data structure will be analyzed by the ASW in order to accomplish the Event/Action Service (Service 19). The ASW, with a polling mechanism (see Figure 23), retrieves from the queue, through BSW provided services (represented in double line), an event at a time in order to verify in its internal Event/Action table if any action has to be performed.
Each TC containing the action to be performed, if addressed to the ASW, is submitted to validation and, if it is successful, it will be executed. Vice versa if the TC is addressed towards a different on-board user it is dispatched to the BSW for proper re-routing. A report containing the complete TC copy is anyway generated.
If the validation fails an unsuccessful acceptance report is generated.

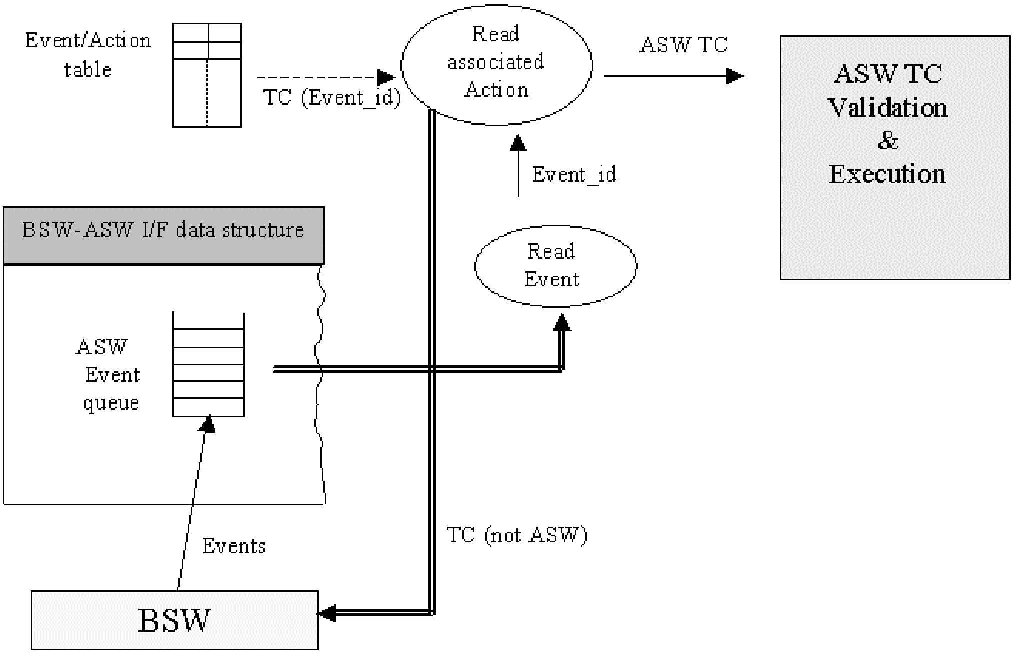


Figure 23 ASW Event /Action Service

As previously mentioned Event Report packets will be stored in a Spacecraft Event Log (SEL) located in the SSMM. Basically the SEL contains a list of all events happened on-board and will facilitate investigation operation performed by ground. The SEL will be partitioned, according to proper separation criteria, in order to be considered as a set of different logs. However, considering the storage impacts related to the necessity to allocate different Packet Stores (see SSMM section), the final trade-off between a single log (to be properly filtered on ground) and different on-board separated logs is still on-going..

Furthermore all Events classified as Exception Report and Error/Alarm Report (see for details [AD-09]) will be stored in a so called Critical Event Log (CEL) located in the SGM in order to guarantee the data persistency regardless of the SSMM status.

7.6.2.4.4 Patch and Dump

This capability is entirely implemented in the BSW layer as it directly interfaces the memory units. This support is also included in the bootstrap module, in order to cope with possible issues detected during the bootstrap itself.

The Patch and Dump can be considered as *vital capabilities*. Patches allow modification of the on-board software, either changing the image in the non-volatile memory (EEPROM) and/or by patching the image in the working memory when the spacecraft is operational (RAM).

Basically Patch and Dump can be accomplished by means of the Service 6 (Memory Management) defined in the PS ICD [AD-09] as far as the following memory units are concerned:

- EEPROM
- RAM
- SGM

The Memory Management Service provides also “check facilities” in order to perform data integrity verification of addressed memory areas.

The RAM and the SGM data integrity is ensured by dedicated Error Detection And Correction (EDAC) circuitry and a periodic scrubbing process.

Note that, in order to guarantee the correctness of the code running in RAM, it has been requested, to the BSW, to carry out a background activity in order to check out the data consistency vs predefined CRC values associated to the running codes (ASW-BSW).

As far as the SSMM is concerned, Service 6 is however not suitable (see [RD-18]) because of the restricted addressing area specified in the packet structure definition. It will be then necessary to foresee proper TC packets in order to allow the SSMM patch/dump capabilities that will be always accomplished by the BSW.
The SSMM data integrity is ensured by a multiple error detection and correction Reed Salomon Codec and a periodic scrubbing process.

7.6.2.4.5 Mission Timeline

The Mission TimeLine (MTL) is defined as a sequence of time-ordered Telecommands up-linked from ground during each daily communication period. On-board MTL sizing capabilities will be, anyway, in accordance with the requested 48 hours of autonomy (i.e. worst case when one daily ground contact is lost). The MTL supports also the concept of Subschedules: it means that set of TCs, which normally trigger the execution of a well defined activity (e.g. scientific observation), can be grouped for one or several users.
The On-Board Scheduling Service (Service 11, i.e. MTL management), that is completely in charge to the ASW, provides the capability to execute TCs stored into the MTL buffer. Figure 24 shows a scheme of MTL management. The ASW interfaces the SSMM through BSW provided services (sketched with double lines). Each retrieved time-tagged TC, when the execution time has arrived, is submitted to validation and, if it is successful, it will be sent to its on-board destination. If the validation fails an unsuccessful acceptance report is generated.
The execution of these TCs allows performing Herschel and Planck autonomy operations independently whether the spacecraft is in visibility or not.

Concerning the MTL organization the Prime Contractor has asked to maintain a clear logical separation between commands to be routed to the ACMS S/S and all the remaining telecommands. In this sense all the ACMS TCs will be part of a dedicated sub-schedule, in order to allow the possibility to easily stop, if necessary, telecommands issuing towards the ACMS. This subschedule ID shall always be the same throughout the mission. Such an approach guarantees the maximum independence to the ACMS and no sub-schedule specific stop will directly affect it. The alternative solution could be represented by telecommands having sub-schedule ID equal to zero (no sub-schedule related). When the ACMS TCs in MTL have to be stopped it really means that the whole MTL has to be suspended.
The MTL shall be stored in SSMM due to its large requested memory size. Detailed information about MTL buffer sizing is given in the relevant SSMM Data Storage section.

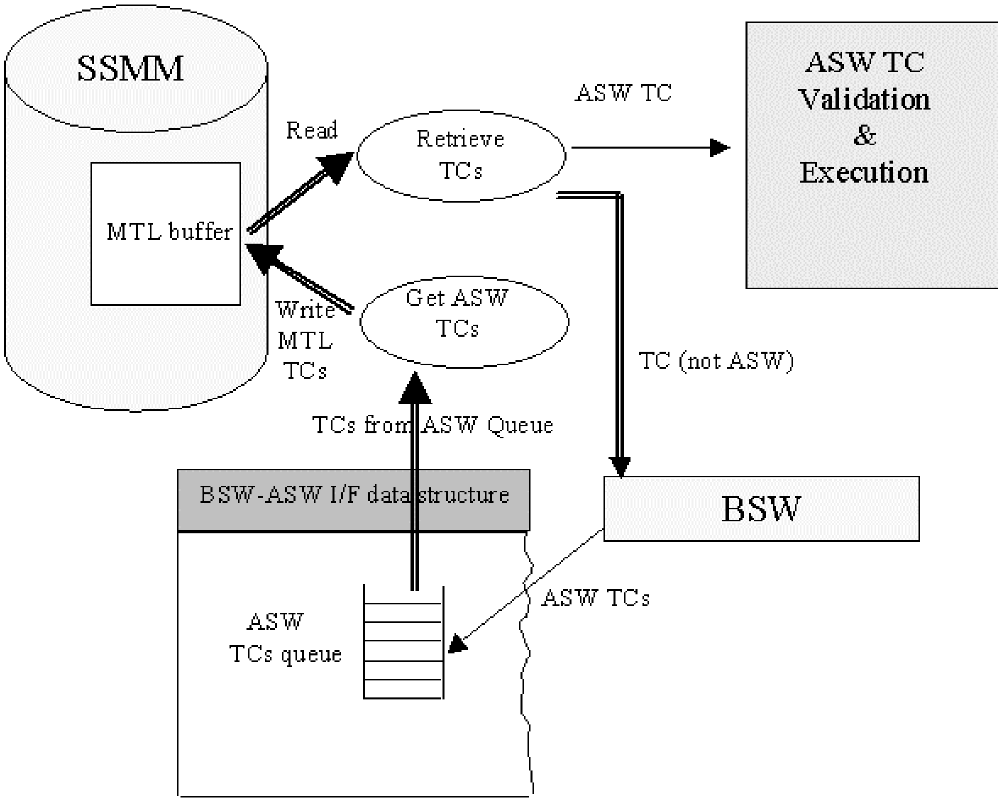


Figure 24 MTL management

Note that telecommands present in the MTL will always be issued by the CDMU without making any correlation or execution check with the previous issued ones. Whenever there exists an intrinsic dependency among a set of telecommands, Alenia recommend to start an OBCP. In this way it is possible to issue telecommnds and check the relevant associated monitors before sending other TCs. The conditional issuing can be thus easily satisfied without increasing the MTL management complexity. This also means that whenever the MTL has to be stopped, OBCPs started by the MTL have to be stopped too.

Last point to be considered is that, at the moment, no END_OF_SUBSCHEDULE information is specified in [AD-09]. The design of the ASW shall consider this limitation and will provide the guidelines, to be followed, in order to guarantee a feasible and safe implementation. It means that, at implementation level, this information (END_OF_SUBSCHEDULE) could drive the MTL related on-board data structure and activities. Anyway it is possible to find work around solutions.

7.6.2.4.6 On-board Monitoring and FDIR

The On-board Monitoring Service (Service 12) provides the capability to monitor the on-board parameters with respect to checks defined by ground for the purpose of initiating adequate actions on-board (during autonomy phases of the spacecraft) or on ground. These actions can be confined to issue reports or, in some cases, to perform predefined on-board functions (e.g. OBCPs,).
To achieve this, the on-board monitoring service maintains a monitoring table containing all relevant parameters. The monitoring table will be continuously updated with new parameter values acquired from the controlled units.

The Monitoring Service is considered to be a CDMU capability, as far as the spacecraft related parameters are concerned.

FDIR mechanism, which will be implemented using a table driven approach, works strictly tied to the on-board monitoring service, as it is mainly based on the monitoring table for the detection and isolation functionality. The relevant action to be executed in order to recover a detected failure will be performed through dedicated modules/commands (e.g. OBCPs, TCs…).

The table driven approach represents the most suitable solution to implement the FDIR mechanism. Reference values and thresholds are maintained in proper tables, updatable through ground telecommands, ensuring a high degree of flexibility.

Generally speaking, strategies involved in the FDIR mechanism are mainly based on:

- software monitoring for the surveillance of low level failures associated to recovery managed by software;
- hardware monitoring for the surveillance of high level failures and managed completely by hardware.

The purpose of the FDIR functionality is to provide the spacecraft sufficient autonomy to avoid that any failure can lead to the satellite loss.

In order to define faults criticality that can occur during the mission, several level of failures are considered according to potential effects on equipment, functions, computer (CDMU) or system performance as reported in [RD-25].

The following list shows failures classification (major severity are in increasing order) and related management entity:

- level 0: failure managed internally in the unit/equipment
- level 1: equipment alarms managed by SW
- level 2: satellite vital functions alarms managed by SW
- level 3: internal computer alarms managed by HW
- level 4: system alarms managed by HW

As shown previously level 1 and level 2 failures are managed by software and more precisely by the ASW
Regarding generic SW internal failures they will be detected, as far as possible, by the SW itself. It is also possible to deal with drastic error recoveries foreseen at higher levels (e.g. wrong code image in RAM could be detected by the BSW and will need a SW reset).

The schema of the FDIR mechanism implemented in the ASW is depicted in Figure 25.
Basically it is based on the following system functions:

- the On-Board Monitoring Service (Service 12)
- a FDIR system function in charge to perform “FDIR Cross-Correlated Checks”

The On-Board Monitoring Service allows analysis execution on simple health parameters defined in the Monitoring Table (MOT), essentially performing in-range/status checks.
The “FDIR cross-correlated checks” functionality allows failures detection by means of parameters values correlation. The FDIR system function execution is driven by the FDIR Cross-Correlation Table (FCCT). The

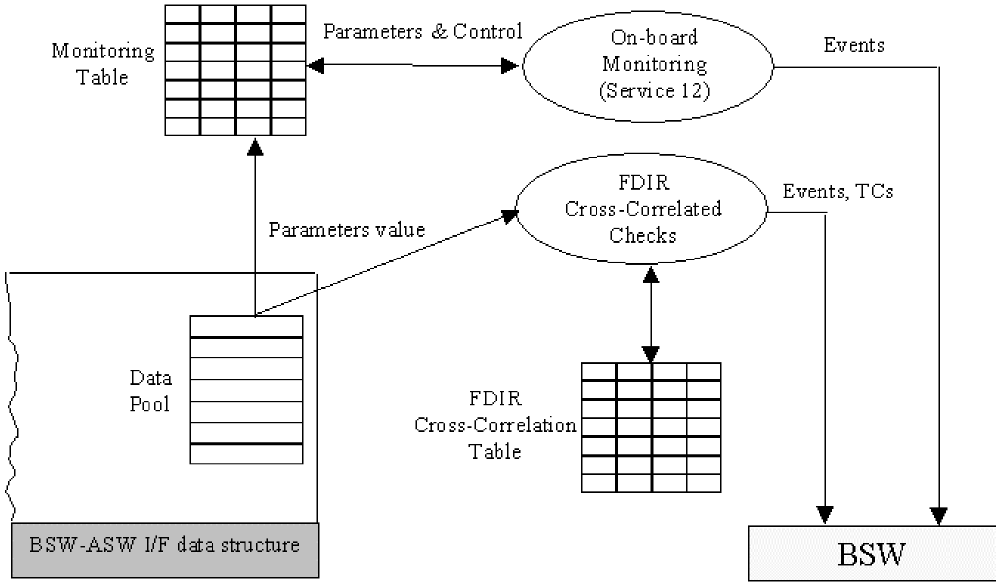


Figure 25 FDIR Management

purpose of the FFCT is to maintain all the information related to the controls that have to be carried out (e.g. flag enabling/disabling the control execution, thresholds parameter…). More precisely a control identifies a sequence of operation and checks to be performed by the FDIR system function in order to properly detect and manage anomaly conditions.

7.6.2.4.7 SSMM data storage

From hardware point of view the SSMM is structured in 2 boards (each of them organised in 4 banks) connected in hot redundancy each one supporting 32 Gbit at begin of life and 25 Gbit at end of life. In order to maintain a double copy of the stored data it will be necessary to perform writing operation in both memory boards: the data persistency will be then guaranteed if one of the boards fails. However this principle does not apply to the scientific data that are only stored in the current active memory. It means that in case of active SSMM switch-over it has been accepted to loose acquired science data, in favour of a nominal increased efficiency, storing data only in one memory branch. Housekeeping telemetry data will always be stored in both SSMM branches.

Basically data can be stored in the SSMM in form of:

- Buffer
- Packet Stores

The SSMM is mainly devoted to the storage of the following data:

1. Telemetry data
2. Mission TimeLine
3. OBCPs

Hereafter is provided a short description of each item.

1. The telemetry on-board storage management approach will be based on partitioning the relevant memories in several Packet Stores. They can be considered, from a logical point of view, as memory areas properly defined and formatted in order to store telemetry packets. Their management is particularly relevant for the

implementation of the Service 15 (On-board Storage and Retrieval) foreseen by the PS ICD [AD-09]. In fact all telemetry data acquired from the different on-board users are physically stored in the SSMM just in several Packet Stores identified by a proper Store Id. These recorded telemetry packets can be then transmitted to ground, in parallel with real time data, during daily periods of contact with Ground (i.e. using two different VCs).

The On-board storage capability (Service 15) is fully supported by the BSW layer that is in charge to store all TM packets. As far as the ASW is concerned, it will take care of its own telemetry data generation, but the effective storage is performed by the BSW also.

Two Packet Stores types are foreseen in [AD-09]:

- Circular Packet Stores: in this case when the full condition is reached, new incoming telemetry packets overwrite the old ones packets previously stored. This approach obviously implies the loss of the oldest data if not previously retrieved.
- Linear Packet Store: in this case, once the Store is full, the new incoming data are ignored and therefore lost. It will be then necessary that Ground proceed to delete the oldest ones before being able to store new packets.

Packet Stores will be properly sized, by Ground, in order to guarantee that the memory space freed after the downlink period, is enough for new incoming data.

For budget and dimensioning purposes, it is mandatory to maintain a small number of Packet Stores. This will allow, for example, to reduce the fragmentation of the free areas that, in the end, doesn’t help to store big amount of data. Furthermore for dimensioning evaluation purposes, it has to be taken into account that the on-board storage shall guarantee 48 hours of mission data (e.g. science and HK data, events, reports ..). In this sense ESA suggests [RD-17] that the number of Packet Stores shall be about 10.

A possible allocation policy can foresee the creation of different Housekeeping/Diagnostic TM and Science data, one for each instrument. Moreover 1 Packet Store shall be allocated for the TCs history, 1 for the ACMS subsystem and 1 for the CDMS. This last one comprises both the BSW HK data and the ASW HK data.

HK packets built by BSW and containing data related to the non Packet Terminal units and to the monitor acquired from the I/O channels, will be arranged also in the CDMS Packet Store.

Besides the above mentioned allocation it has to be considered a further Packet Store for the SEL that will contain all the on-board generated Events (Service 5).

Table 4 and Table 5 summarise the possible Packet Store allocation for each spacecraft.

HERSCHEL PACKET STORES	
Instruments Science Data	HIFI (1) PACS (1) SPIRE (1)
Instruments HK Data	CCU (1) HIFI (1) PACS (1) SPIRE (1)
ACMS	1
CDMS	1
TCs history	1
Event Reports (SEL)	1
TOTAL	**11**

Table 4 Planck Packet Stores Allocation

PLANCK PACKET STORES	
Instruments Science Data	HFI (1) LFI (1)
Instruments HK Data	SORP. COOLER (1) LFI (1) HFI (1)
ACMS	1
CDMS	1
TCs history	1
Event Reports (SEL)	1
TOTAL	**9**

Table 5 Herschel Packet Stores Allocation

As it is shown in previous tables the maximum number of Packet Stores allocated is 11 for Herschel and 9 for Planck that is in line with what was recommended.

2. Mission TimeLine

The best way for storing time-tagged TCs uplinked from ground is a list of data buffers that will practically constitute a list of fixed-sized chunks.
Considering 1 hour up-link time devoted to MTL commands only, at 4 Kbps, it follows that the needed size in SSMM will be around 1.5 Mbytes. This has to guarantee 48 hours of autonomy.

Note that this size does not take into account additional bytes needed to manage the data structure itself (e.g. queue pointers, status flags, etc). An additional overhead has to be considered. As anticipated, thinking about the possibility to store the telecommands in a list of chunks (each chunk being a data buffer, see SSMM) of maximum TC length, there will be:

1 byte for the status information (Valid/Not valid chunk, Free/Used chunk)
4 bytes for a list pointer

The overhead can be considered anyway negligible. It is related to 6664 (1.5 Mbytes * 1024*1024 / 236) packets, thus about 33 Kbytes.

3. OBCPs

All the OBCPs uploaded from ground during the mission will be stored in the SSMM.
Depending on their size they will be arranged in data buffer of proper length. Estimation about buffer sizing, maximum number of uploaded OBCPs and consequently the global SSMM usage are detailed in the relevant OBCP section.

Besides the following critical aspects have to be considered:

- According to a specific requirement (DMF-180-C) stated in [AD-43], it has expected the possibility to partition the Spacecraft Event Log in a way "that the various types of records can be easily separated and handled as separate logs". It means that 1 Packet Store for Event Reports is not enough and it is necessary to foresee the allocation of more than 1 Packet Store that is against what stated in [RD-17].
- It is essential to allow that the incoming data can be easily stored in the right defined Packet Stores taking into account of the previous allocation. This could be guaranteed maintaining an association between the Packet Store identifier and the APIDs of the source units. Concerning the ACMS and CDMS, as several units belong to them, it would mean that the relevant information would be stored in the Packet Store identified by a range of APIDs. Anyway the APID information along with the other ones related to the "Storage Selection Criteria" (viz. Packet Type and Storage time), will properly taken into account, at design level, by the CDMU BSW supplier.
- After a bad block detection the data validity, of ground received data (e.g. TM data) as well as on-board managed data, is not guaranteed. This is true both for Packet Stores and Data Buffers. In fact the relevant data structure should be deleted and created again. Data contained inside a Packet store could be, in principle, recovered on ground referring to the CRC embedded in each TM packet. Anyway this strategy does not guarantee a 100% reliability and it is suggested to be adopted just in case of real necessity (e.g. end of life of the SSMM when free good areas won't be likely available).
- As already anticipated the MTL is organised in a list of fixed-size chunks. The size of each chunk will allow storing TCs of maximum length that for the MTL means 236 bytes. Whenever a bad block is found, during operations on it, the whole MTL execution has to be stopped.

7.6.2.4.8 SGM data storage

The SGMs consist of 2 memories (nominal and redundant) connected in hot redundancy. The capacity of each SGM is 512 Kbytes.
Actually it is foreseen, at least in the CDMU, to operate the SGMs in order to guarantee the same data availability on both memories, thus also a complete branch switch-over will guarantee a consistent data retrieval of the most critical S/C parameters. In order to maintain a double copy of the stored data it will be necessary to perform writing operation in both memory branches: the data persistency will be then guaranteed if one of the boards fails. It is anyway important to highlight as wrong stored data, in the SGM, could potentially lead to repetition of system failures. Wrong data could be stored in SGM, for example, when a bit upset has modified a RAM variable content that is used for further computations whose final value (clearly wrong) has to be stored in SGM.
The analysis, the possible protection and recovery mechanism associated to each critical variable stored in SGM has to be carefully evaluated, case by case, when the system design will be more consolidated.

The SGM will be split into 2 main areas. The first one dedicated to the BSW and the second one dedicated to the ASW. The write/read operations will be properly supported by the BSW by means of dedicated service calls.

Actually the following data are foreseen to be stored in SGM and managed by the identified sw layer.

BSW	ASW
Critical Event Log (CEL)	Interfaced unit/equipment status (ON/OFF)
TC Acceptance Report (TBC by ESA/ASPI)	Other critical values (TBD)
First boot flag	
Other critical values (TBD)	

Table 6 SGM Stored Data

7.6.2.4.9 OBCPs

OBCPs are flight control procedures that can be resident on-board or that can be uploaded to the spacecrafts depending on ground needs. They can be controlled in terms of their loading, stopping and running through the capability provided by the On-board Control Procedures Service (Service 18) defined in [AD-09]. The OBCP management process is fully accomplished by the CDMU ASW.
OBCPs serve for controlling processes, which may be active for an extended period of time and which may involve the execution of a sequence of commands. Anyway it has to be guaranteed that the OBCPs execution do not affect the whole CDMU software performances. Moreover it is necessary to foresee that occurred runtime error could be detected and properly managed.

OBCPs represents, along with the Mission TimeLine, the most important capability that ensures a high degree of autonomy to the spacecrafts. It is however a mandatory issue to keep them simple, in term of design. Furthermore they have to be reduced to the essential minimum also [RD-25].

In [RD-22] several inputs are provided by ESA based on Rosetta experience. Concerning the maximum number of OBCPs loaded on-board, the recommended value is 200. The maximum indicated size for each OBCP is 4 Kbytes. Anyway some further considerations have to be taken into account.
Depending on particular contingency it could be necessary make use of more complex procedures. In this case it is proposed to foresee at least 15% of OBCPs (i.e. 30) longer than those estimated ones. In this sense OBCPs with a size of 8 Kbytes should be sufficient to guarantee this exigencies.

Summarising it will be foreseen:

- 170 OBCPs with maximum size of 4 Kbytes (corresponding to 680 Kbytes)
- 30 OBCPs with maximum size of 8 Kbytes (corresponding to 240 Kbytes)

Two categories of OBCPs can be identified, as far as their on-board availability is concerned:

- Resident OBCPs (stored in EEPROM and loaded in RAM during the boot phase)
- New uploaded OBCPs (new ground uploaded OBCPs, likely related to MTL TCs)

It is necessary to highlight that the foreseen values, 4 and 8 Kbytes, represent the maximum size value. Practically it means that the average value, of each OBCP belonging to a certain size-class, will be for sure lower and a sort of memory fragmentation is envisaged. This memory fragmentation has to be avoided, or reduced, in EEPROM, leaving , if the case, shorter empty spaces (w.r.t. RAM) to give, anyway, the chance to cope with possible upgrades.

Concerning resident OBCPs a valid assumption is to use the 20% of the EEPROM capacity (i.e. 200 Kbytes, TBC) for their storage. This could lead to 10 longer OBCPs (i.e. 80 Kbytes occupation) and 30 shorter OBCPs (i.e. 120 Kbytes occupation) as worst case sizing condition. Due to the previous explained concepts they could likely be more. Resident OBCPs are copied from the EEPROM in RAM during the bootstrap phase.

All new uploaded OBCPs will be stored in SSMM, in dedicated data buffers. Thus 20 long OBCPs (160 Kbytes) plus 140 short OBCPs (560 Kbytes), would lead to a global 720 Kbytes size.
Note that each OBCP will be protected by a CRC in order to be sure to retrieve the valid code when its relevant execution is requested.

In the end, all the OBCPs will run in RAM. It is assumed to run 16 (TBC) OBCPs in parallel.

Basically the OBCPs execution could be triggered by:

- Ground commands
- Mission TimeLine
- On-board events
- Detected Failures

Resident OBCPs should mainly be used for failure recoveries and reaction to events, being, those functionality, available from the bootstrap already.

The main OBCP capabilities shall ensure:

- TCs issuing
- High level commands issuing
- TM data accessing
- Tracing capabilities
- Event Reports generation
- Nested OBCP execution

As far as the on-board execution policy, that will be followed to run the OBCPs on board, essentially the following two possibilities could be adopted:

- OBCP on board interpretation (i.e. interpreter solution)
- OBCP binary execution (i.e. compiling solution)

It doesn’t exist a specific requirement asking for the first or the second alternative, anyway Alenia position is in favour of a binary code execution of the OBCPs. In fact it is possible to make extensive checks (using LEX, YACC), on ground, in order to be confident on the correctness and validity of the written OBCP code. The most demanding requirement, considered mandatory by ESA, requests for an absolute independence, of the up-loaded OBCP code, on the used on-board memory areas needed for its running. It means that a dynamic link, for code/data relocation, could be performed to directly run a binary code that would guarantee, undoubtedly, better timing performances of the whole CDMU flight software.
Presently the current baseline is that the final choice is in charge to the ASW subcontractor that shall also design and implement a tool to translate/compile the specified grammar in order to create the OBCP code to run on-board.

7.6.2.4.10 Functions

This section describes the main functions performed by the CDMU OBSW.

7.6.2.4.10.1 PCDU management

The Power Condition Distribution Unit (PCDU), is part of the Power Control Subsystem (PCS) and basically provides the following capabilities:

- controls the electrical power generated by the solar arrays
- manages battery energy storage
- provides a fully regulated power bus for the spacecraft and protects the power bus from failure overload.

The PCDU also responds to commands issued by the CDMU to control power distribution to the payload instruments, CDMS equipment and to perform thermal control, during all mission phases, for all operation modes including ground testing, pre-launch operations and contingencies.

Besides the FDIR mechanism, from a software point of view, the PCDU management is functionally performed by the ASW that is in charge to out monitoring and commanding (via 1553 interface and/or discrete commands) of the following devices belonging to the power conditioning and distribution unit:

- Latching Current Limiters (LCL)
- Heater Control Switches (HCS)
- Heater Protection Switches (HPS)
- Non Contaminating Actuator (NCA)
- Battery Charge Regulator (BCR)
- Battery Discharge Regulator (BDR)

As far as the HK telemetry packets are concerned, their construction is totally performed by the BSW. It is in charge to packetise the relevant monitoring parameters, acquired from the 1553 bus (as 32 words messages) and from the discrete I/O, in telemetry packets conforming to the structure stated in [AD-09].
Remaining PCDU devices (Solar Array Sections, Fold-back Current Limiters) provide only monitor values that will be acquired by the CDMU. These devices do not need any control command **(TBC)**.
The following equipment belongs to the PCS and is directly managed by the PCDU itself and no software operations are involved:

- 30 solar array sections which generate the electrical power (electrical function only)
- 1 battery which provide electrical power to spacecraft equipment.

7.6.2.4.10.2 TTC management

The TTC management function accomplished by the ASW is in charge to perform control and commanding of the following equipment/units belonging to the TTC subsystem:

- Transponder Receiver and Transmitter (XPND) nominal and redundant
- Radio Frequency Distribution Network (RFDN) nominal and redundant
- Travelling Wave Tube Amplifier (TWTA) nominal and redundant

Depending on the status of the controlled equipment, the ASW will be able to switch between nominal and redundant units to ensure:

- the correct working of the receiver that shall be always “ON” during the mission lifetime
- the correct working of the transmitter during daily telecommunication period

Parameter acquired from TTC equipment will be packetised by the ASW in telemetry packets conforming to the packet structure definition stated in [AD-09].

The TTC subsystem, part of the CDMS, will always maintain the receivers ON. Receivers status will periodically checked by the ASW to ensure their proper function. Vice versa transmitters will be switched on/off according to the daily ground contact period. The right configuration of all the switches as well as of the units being part of the TTC S/S shall likely be established by a specific resident OBCP. The OBCP shall be either activated basing on retrieved MTL TC or specific TC, received from ground

7.6.2.4.10.3 Thermal Control

The Thermal Control function is in charge to control the temperature of the service module of Herschel/Planck satellites.. The functionality, implemented in the ASW, will be basically founded on the management of protection/control heaters belonging, from a physical point of view, to the PCDU.
The Thermal Control will be essentially applied to two different control loop classes:

- control loop without thermal stability requirements (hereafter named class A)
- control loop with thermal stability requirements (hereafter named class B)

Each control loop is composed of 3 thermistors and 2 heater lines (1 prime and 1 redundant).

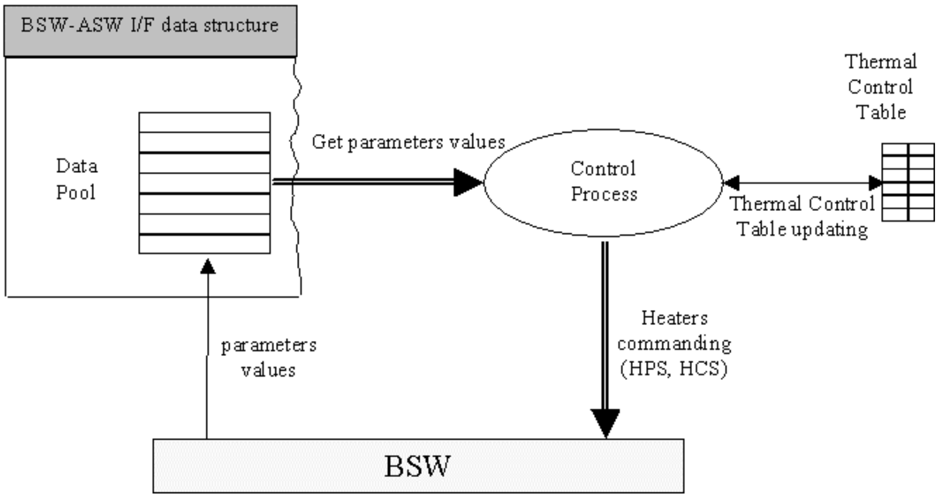


Figure 26 Thermal Control process

The software control process, shown in Figure 26, will be implemented according to a table driven approach. Basically it acquires the temperature of thermistors and operates consequently on the associated heater lines according to specific control laws.
The commanding toward the heater lines is performed managing the relevant Heater Control Switches (HCS) and Heater Protection Switches (HPS).
More precisely Table 7 and Table 8 detail the temperature regulation for class A and class B control loops.

Condition	Heater commands
$T_{mon} < T_{min}$	Switch-on HCS
$T_{mon} > T_{max}$	Switch-off HCS
$T_{min} <= T_{mon} <= T_{max}$	no commands

where:
- T_{mon}: thermistor value measured according to a majority voting approach.
- $T_{min,}$ T_{max}: lower and upper thermistors thresholds.

Table 7 Class A control loop commanding

Condition	**Heater commands**
($\Delta T_{mon} < 0$ and $\lvert\Delta T_{mon}\rvert > \lvert\Delta T_{ref}\rvert$ and $Tmon < Tmax$) or ($Tmon < Tmin$)	Send till the next monitoring a sequence of width modulated pulse commands according to a TBD control law.
Otherwise	No commands

Table 8 Class B control loop commanding

where:

- ΔT_{mon}: delta temperature between two consecutive measures.
- ΔT_{ref}: delta temperature resolution
- T_{mon}: thermistor value measured according to a majority voting approach.
- T_{min}, T_{max}: lower and upper thermistors thresholds

Basically the PCDU has 54 nominal and 54 redundant HCS. They are divided into groups of 6 HCSs, one group per HPS on both nominal+redundant heater busses. Whenever commanding issued toward relevant HPS or HCS fail, the thermal control function shall be able to switch between nominal and redundant (or vice versa) groups.

7.6.2.4.10.4 Mission management

The mission management function is in charge to keep track of information strictly related to the instruments, ACC and CDMU operating modes.

In particular it allows, depending on each mode transition that could occur during the mission, to perform specific associated actions. This functionality will be table driven in order to give the needed flexibility to enable/disable the relevant checks as well as to change the associated needed on-board actions. On-going activities, especially at system level, are trying to close this point verifying its real need. As a consequence it will be established the strategy to be adopted for data communication. In fact, basically two solutions have been identified:

1. Transitions will be notified to the CDMU by means of an event packet
2. Transitions will be identified by the CDMU basing on unit/equipment HK data

The second solution is considered safer due to data persistency inside the HK packets. If one HK packet is, for whatever reason, missed it will be possible to react basing on next acquired packet. Vice versa the event packet, being one-shot delivered, could deal to additional issues, in case it would be lost.

7.6.2.5 ACMS Software

All the ACMS Software, but the ACC BSW, shall be procured by the ACMS subcontractor and shall be under his responsibility. The ACMS supplier will provide to Alenia the whole S/S ready to be integrated in the SVM.
The ACMS Software is essentially related to the following units/equipment being part of the S/S:

- ACC
- Star Trackers
- Gyros (for Herschel only)

The relevant software life-cycles must be compliant with the ECSS-E-40B document. In case specific equipment (e.g. Star Tracker) will be supplied with an embedded software, already developed, the supplier has to provide full access to the SW design, source files and any other document/information needed for its understanding.

The ACC software is essentially conceived to be split in two main parts viz BSW and ASW.
As already anticipated, in the CDMU section, the ACC and CDMU BSW will be essentially the same, a part from specific services and needed I/O drivers. The ESA Standard Services implemented in the ACC BSW are shown in Figure 13.
The commonality has been extended to the two satellites. This means that the BSW of Herschel and Planck will be the same (a part from exclusively needed I/O drivers).
Vice versa the ASW of the two ACC’s will clearly be different being related to different attitude control laws. However it shall be possible to identify a subset of common services in order to re-use as much software as possible.

Presently only a preliminary software design has been presented by DUTCH Space. Additional efforts have to be carried out, by all the parties, in order to clearly address the final design. Anyway important choices have been confirmed at system level. In particular:

- The ACC won’t directly run any OBCP. OBCP will only run on the CDMU potentially affecting any S/C unit/equipment.
- The ACC won’t directly run specific local ACMS MTL. The MTL will be executed at CDMU level only and will affect the other S/C S/S-units-equipment.
- Basically the ACMS S/S will be highly autonomous and local detected failures won’t impact, as far as possible, the rest of the S/C.

Analogously a list of problems have currently been identified:

- The bus protocol on the ACMS local MIL 1553B bus has to be defined according to the S/S constraints
- Any potential issue that could lead to possible impacts on SGM data storage, FDIR strategy, patch and dump capabilities has to be carefully analysed.
- Actually the PS-ICD specifies the On-board Monitoring service (service 12) as optional for instruments and S/S other than the CDMS: thus, for example, the ACMS. In line with that document, the service could be used by the ACC. Besides that, the Event/Action service (service 19) is conceived to be supported by the CDMU only. This means that it should be possible to detect a particular failure, relying on the checks requested by ground through the monitoring service or stored as default. It should also possible to generate the associated event but it won’t be possible to use a reference table for searching the action linked to the event. This would imply a less flexible design on the ACC computer because the Event/Action associations should have to be hard-code, i.e. already established without the possibility to change them. Obviously it should be highly undesirable to create additional custom TC packets to accomplish a service that could be carried out with the already available PS-ICD services.
- The schedule policy has to be carefully defined according to S/S timing constraints (e.g. prompt reaction to events for actuators commanding, high frequency data sampling for ACMS sensors).
- This deferred selection of the ACMS subcontractor has potential important impacts on the whole Herschel/Planck software procurement and, in the end, on the program’s schedule.

However, beyond the previous considerations, in the following it will be given a brief description about the possible ACC software structure.

7.6.2.5.1 ACC ASW structure

As above mentioned the ACC ASW of Herschel and Planck are quite different. Anyway despite these differences it is possible to identify a Common Application Software (CASW) service layer that implements the functions common to both applications. Figure 27 shows the ACC ASW structure.

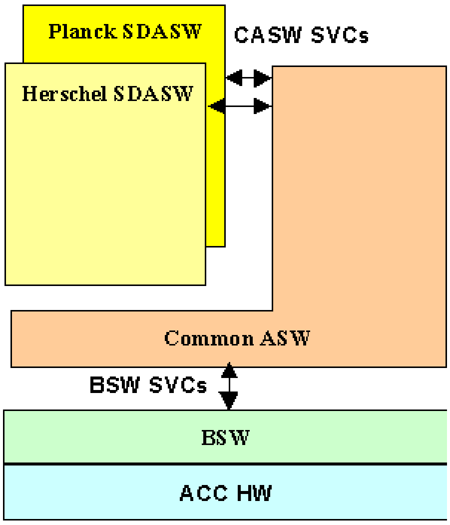


Figure 27 ACC ASW structure

The basic communication with the ACMS units and CDMU, realised through the BSW, is handled by the CASW as a single point of contact, and acts as an intermediary for the Satellite Dependent Application Software (SDASW). However, as much as possible, higher level common functions will be implemented in such a way that they could be used for any SDASW.

Moreover the CASW implements the remaining ESA standard services foreseen for the ACC (see Table 9).

		ACC ASW Standard Services
Service 1	:	Telecommand Verification
Service 2	:	Device Command Distribution
Service 3	:	Housekeeping and Diagnostic Data Reporting
Service 5	:	Event Reporting
Service 8	:	Function Management
Service 9	:	Time Management
Service 12	:	On-board monitoring
Service 14	:	Packet Transmission Control
Service 17	:	Test Service

Table 9 ACC ASW Standard Services

7.6.2.5.2 Equipment Software

TBW

7.6.3 Ground Software

The purpose of the Ground Software is to support all Ground activities foreseen from the Design, Development, Verification and Validation up to the Maintenance phase of the flight software. In this perspective it will be necessary the usage of several Software Tools and Components. Some of them will be appropriately created whilst some other ones will be COTS products.

7.6.3.1 Software Development Environment

The Software Development Environment (SDE) shall essentially include all the tools and utilities necessary to design/developing/testing the requested on-board software. The SDE that has been identified (see for details [RD-23]) is fully applicable to all subcontractors in charge to develop any part of the on-board software running on the ACC and CDMU computers of the service module. Just to foster the commonality across the on-board software development, performed by several subcontractors, ALENIA has identified the following items that shall be considered as the SDE baseline:

- The choice of the host computer and relative host OS to be adopted, has been done taking into account the main following considerations:
  - ☐ the host computer must be a commonly used HW platform
  - ☐ the OS maintenance must be guaranteed as longer as possible by the relevant vendor
  - ☐ there shall be several available tools in order to support all the various necessities (e.g. compiler, CASE tool, simulator…).

  All these elements led to naturally select the couple Sparc and Solaris as the best solution. Furthermore being the ERC-32 based on a Sparc V7 architecture the availability of simulators is in favour, at least about their declared reliability, of the Sparc/Solaris solution.
- The choice of the CASE tool represents an important issue for the Design activity. In this sense a common approach based on a standard CASE tool is essential in the framework of the programme and it is anyway requested by the Prime Contractor. In fact the software development process will be carried out by different subcontractors and choosing a common environment will allow an easier comprehension and integration among the different software components.

  The UML has been chosen as Design Language because of its flexibility, of a wide availability of tools and taking into account that ESA itself considers it as the most promising technology.

  Among the available tools Rational Rose has been selected: it offers a major support to the UML notation. Moreover the Rational suite includes a wide availability of tools that could be useful to manage specific aspects of the software life cycle. Even if at the moment their use were not foreseen the subcontractors would be free to add to their SDE valuable capabilities.
- The selected Cross Compilation System for the ERC-32 platform is based on LECCS. LECCS is based on the GNU family of freely available tools and includes various software packages, in particular:
  - ☐ GCC, C/C++ compiler
  - ☐ RTEMS, C/C++ real time kernel
  - ☐ Newlib, C library
  - ☐ GDB SPARC cross debugger
  - ☐ DDD graphical front-end for GDB
  - ☐ MKPROM boot-prom builder
- Concerning the selection of the Operating System available for the ERC-32 target platform, the choice was basically focused on VxWorks and RTEMS. From a technical point of view both products satisfy the need imposed by the on-board software. Nevertheless the great advantage offered by RTEMS is related to its open source nature. This is considered very important because gives the possibility to have always the full control of the software, modifying or updating it when is necessary. The other great advantage is that being an “open source” its distribution is royalty free. Anyway the support could be guaranteed (by OAR) at a moderate cost.

- The tool selected for the Configuration Management is Rational Clear Case. The justification that led to this choice is basically founded on the fact that being Clear Case widely used it is a quite powerful and robust tool. It includes also branching mechanism allowing to easy manage intermediate software deliveries.
- The tool identified for the on-board software testing activities is CANTATA. Cantata is largely adopted by the European space industries.

In Table 10 are summarised all selected SDE products.

HOST computer	Sun workstation
HOST OS	Solaris 8.0
CASE tool	Rational ROSE
Design Language	UML
Compiler/Debugger	GCC/GDB
Cross Compilation System	LECCS
Target OS	RTEMS
File configuration tool	CLEAR CASE
Testing tool	CANTATA[++]

Table 10 Software Development Environment items

The last important thing to be considered is related to the selection of the product to be used for testing/debugging the code on the target board (FUMO) as well as the ERC-32 simulator to be used during software unit-tests. Presently this issue is still open: a decision will be taken considering the solutions that will be proposed by the relevant software subcontractors during the foreseen software ITTs.

7.6.3.2 OBCP Development Environment

The OBCP development environment shall comprise a tool(s) that shall be used to create the OBCPs to run on-board through CDMU ASW supported services. Thus the OBCP tool(s) shall be designed/developed/tested by the CDMU ASW subcontractor. This solution looks like the most reasonable choice due to the strict relationship that will exist between the OBCPs and the used ASW data structures. The relevant tool(s) shall be implemented according to the requirements stated in [RD-14] and shall be used in the SVF, in the EGSE and especially in the Software Maintenance Facility at ESOC premises.

In the process of OBCPs creation an important issue to be taken into account is related to the definition of the Spacecraft Control Language. ESA’s requirements, stated in [AD-08], clearly identified the necessity to make use of a user-friendly language devoted to help operations engineers during the definition of the on-board control procedures. It mainly means that the proposed language should be very simple.
Essentially the Spacecraft Control Language will have to foresee the following basic programming statements and functions:

- assignment
- condition
- loop
- delay
- mathematical expressions
- types definition
- logical expressions
- variable declarations

However besides the previous listed grammar elements of the SCL, it will be also an ASW subcontractor task to propose a complete and formal (e.g. BNF) grammar definition.
Depending on the interpreter or compiler solution, Figure 19 shows the needed activities that must be carried out on ground in order to create an OBCP.

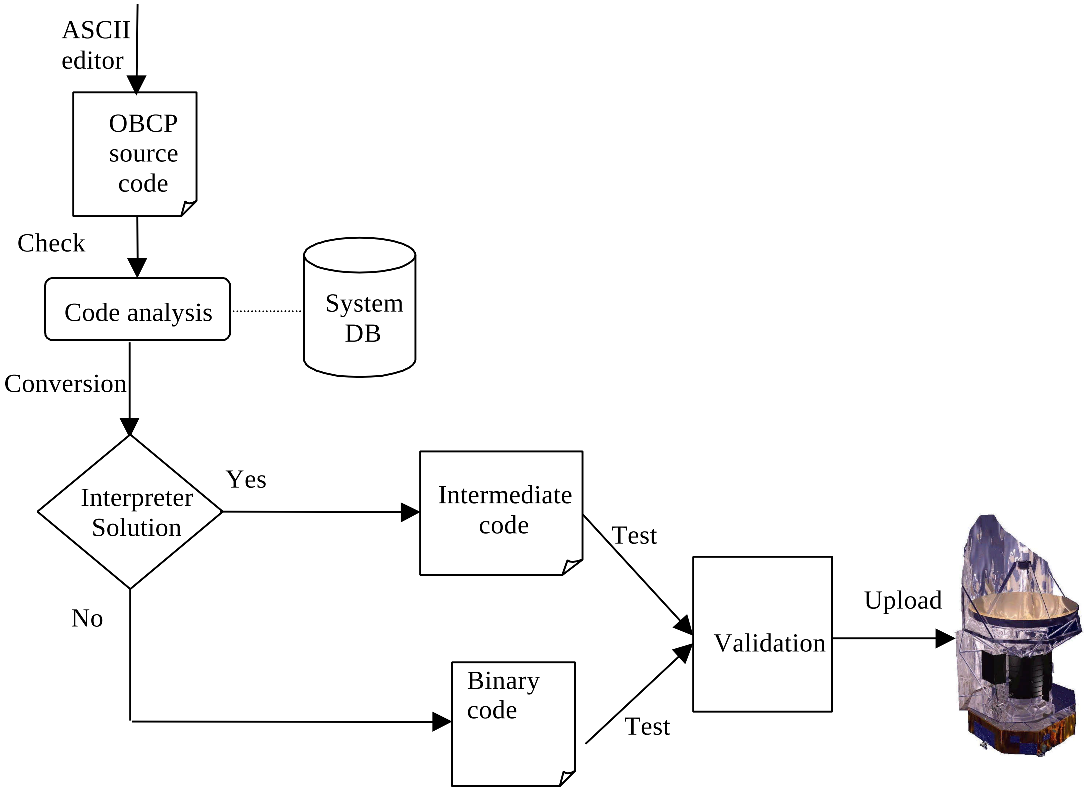


Figure 19 OBCP creation process

Basically ground activities consist of the following steps:

- Use a standard ASCII editor to create an OBCP source code written in Spacecraft Control Language.
- Perform the lexical and syntactical analysis (code analysis) of an OBCP source code written in SCL by means of a tool developed using LEX and YACC. This approach will give the possibility to easily define and maintain the SCL grammar. In any case if the supplier wants to reuse already existing software, he has to give evidence of the efficiency of the proposed solution that has to be agreed by the customer. At least the following conditions shall be checked:
  - ☐ Variables initialisation
  - ☐ Validity of the total needed memory size
  - ☐ Variables type consistency (applicable to: assignments, conditional statements, parameters, etc)
  - ☐ Existence of all used identifiers/parameters in the System DB (Event ID, TC , TM, etc)
  - ☐ Long needed execution time (in case a long sequence of statements is detected and his estimated time exceed the maximum envisaged value)
- Conversion of the OBCP source code depending on the chosen interpreter/compiler solution:
  - ☐ in case of interpreter solution the OBCP source code written in SCL will be translated in a Intermediate Code that will be properly interpreted by the on-board interpreter once it is uploaded on the spacecraft.
  - ☐ In case of compiler solution the OBCP source code written in SCL will be translated in a high level programming language. A next “Compile & Link” phase will allow the generation of a final binary code that can directly run on-board. For this phase it will be used the same compiler adopted for the development of the ASW.
- Test and validate the relevant procedure in the most appropriate test environment (e.g. SVF, SMF)
  In order to test and validate the written OBCP code it is, obviously, necessary to carry out specific test sessions in order to certify its behaviour and be confident about the absence of possible system impacts. This is a phase strictly necessary even if the adopted solution, whatever it is, is considered fully reliable.
- Upload the OBCP code on-board using the PS-ICD service 18 or include it as a resident part of the on-board flight software (in EEPROM).

7.6.3.3 System Database

The System Database for the Herschel and Planck (HPSDB) programme will be unique just to support the commonality of both satellites. Furthermore to guarantee the consistency between the different users (engineering, on-board software, AIT, flight operations…) the HPSDB will be the only repository for all the data needed by the different users.

The HPSDB responsibility is totally in charge to the Prime Contractor. The high level architecture depicted Figure 20 shows the main elements.

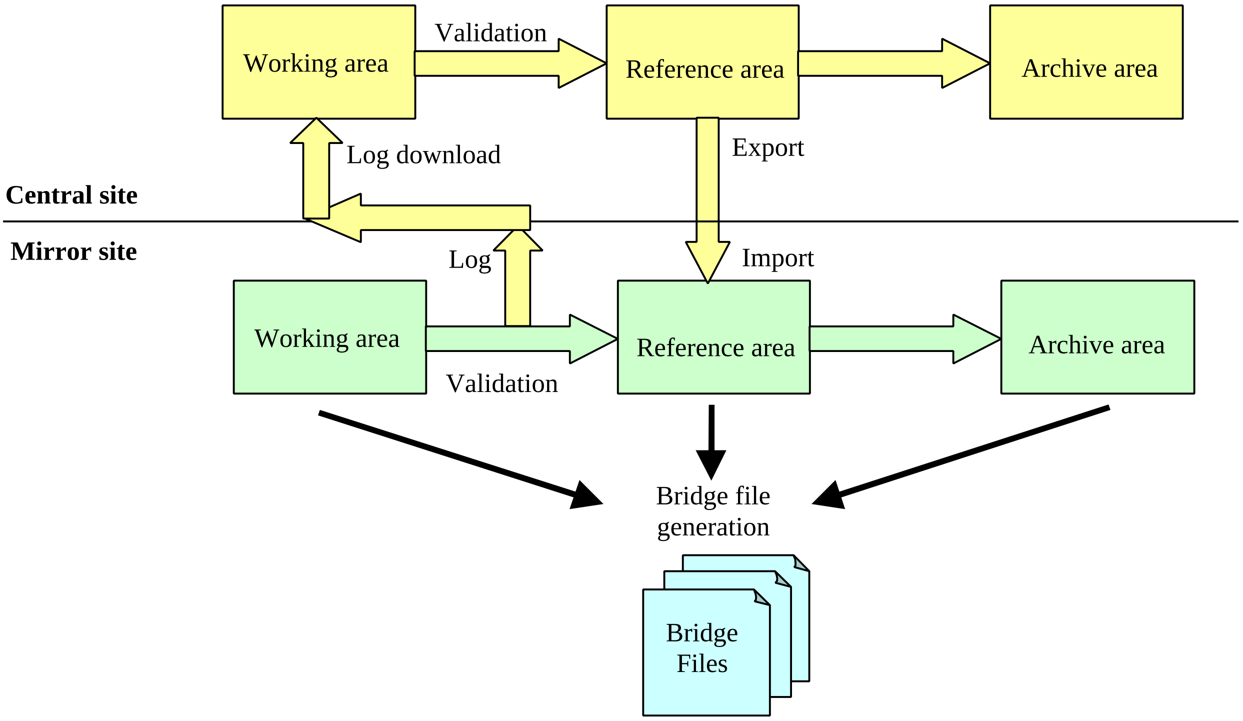


Figure 20 System Database Architecture

A complete and detailed description is provided in [AD-46]. Anyway just to identify the main components, the HPSDB is comprised of one central site in charge to the Prime Contractor and a set of mirror sites managed by the different subcontractors. The different sites maintain the same architecture being structured in a working area, a reference area and an archive area.

Whenever the modifications on the mirror sites are validated, it will be possible to update the central site through downloading of the mirror log file. Vice versa the mirror sites updating will be possible through an Export from the reference area of the central site and consequent Import in the mirror site.

As far the software generation is concerning the crucial point is represented by the Bridge Files. The Bridge Files are a set of ASCII files, extracted from the HPSDB through proper provided tool, used as input for the software development environment.

The Prime requested the possibility to automatically generate the .h header files starting from the Bridge Files. Although this can be thought a potentially advantageous solution there are some considerations to be taken into account.

1. The automatic header files generation (.h files), starting from the available bridge files, has never been a requirement.
2. The provided justifications in favour of an automatic files generation process are absolutely questionable:
   - *The automatic process would be free of human typing errors.*
     This is true by itself but it is not true if we consider the whole process related to a parameter change and its impacts on the System Database. Simply the parameter value is loaded in the System Database through dedicated forms filled in by, manually, an operator then a new bridge file can be generated. In the end, it is not understood why this last process should have to be safer than the one carried out, manually, by a SW supplier that has to modify a source file. Statistically the error probability, in the two cases, is exactly the same. Human intervention is always requested.
   - *The flight SW design has to be table driven in order to give the chance, to anybody, to easily modify S/C parameters.*
     Obviously the SW design has been conceived, from the beginning, to be table driven.
     This doesn't mean that anybody, able to push a button, will have the right to modify the flight SW, even if the requested update is related to a table's parameter. The only people authorised to modify the SW, up to the launch, are the SW suppliers. Vice versa, after the launch (i.e. during the mission) if some parameters have to be changed it won't be necessary to create a new SW image to upload on-board. Just few patches will be performed.
     Alenia considers this as a major critical point. The validation of the SW cannot practically deal with all the permutations of the S/C parameters. The fact that a subset of parameters will be changed in the flight SW, without any knowledge, could put the system under unsafe configurations.
3. The automatic file generation is in the perspective to avoid operator's editing actions. How will it be possible to track, into the file, all the reasons that dealt to the file update itself? In other words, how will it be possible to write the minute references, the document update, the agreements, the deviations, related ECP, etc?

In the end, the bridge files, as actually conceived, cannot be directly used by the software suppliers. In fact each software supplier should necessarily translate the various records, of a bridge file, in C (C++) programming definitions/declaration. The bridge files could be more realistically used just as reference tables that have to take into account to generate any updated flight software release. They are proposed to be part of the final “SVM Software ICD”. At the moment the readability of the bridge file is essentially very low. It should be necessary to integrate the foreseen information with descriptive textual parts in order to make the final files more readable.

7.6.3.4 Software Validation Facility

The Software Validation Facility (SVF), in the framework of the Herschel/Planck project, has been requested to only support the maintenance/test/verification of the SVM on-board software, thus it won't be used as far as the scientific instruments flight code is concerned.

The SVF shall basically operated, up to the launch, by the Independent Software Validation (ISV) team then shall be used to set-up the Software Maintenance Facility (SMF) at ESOC premises.

The SVF shall provide the capability to test/validate the flight software in a representative environment. In this perspective both the flight software and the foreseen simulated environment have to guarantee real time performances, perfectly in line with the real system ones.

Two possible alternatives have been identified:

1. A full software simulation, including the target processor.
2. A mixed HW/SW solution permitting to run the flight software on HW representative target boards.

The following table summarises the pro-cons of the two solutions:

	Fully SW Simulated Environment	**Mixed HW/SW environment**
Flexibility	High flexibility would be offered by a software environment. Patches, load of new SW images would be easier too. It should also be possible to easily get multiple instances of the SVF environment.	The possibility to modify the satellite environment simulation is practically the same offered by the other option too. Load of new SW images could be a little bit critical.
Representativeness	The software simulation cannot be considered representative at 100% of the real target system due to intrinsic latencies and simulation constraints.	Running the flight software on a HW target board would guarantee a high simulation fidelity level.
Tools reliability	A full software simulation can easily be accommodate on other Host Machine[s], in case of HW failures.	A failure in the HW boards would negatively impact the whole environment, because of its needed time-to-repair. The SVF activities could stuck.
Cost	The cost of this solution is for sure more appealing vs the HW/SW one. Basically a software simulator of the ERC-32 processor (for the ACC and CDMU computers) could be used instead of a target board. As far as the ACMS equipment (i.e. Star Tracker and Gyro) by now it is not officially known what will be the final target processor. Anyway it is assumed to have, at least for the Star Tracker, the possibility to operate by means of a software simulator (likely for DSP 21020 or ERC32). Vice versa the Gyro approach has to be verified.	This solution is mainly based on the utilisation of HW target boards. It is clear that, in case new boards, w.r.t. the already foreseen ones, should be necessary, the cost impact would be significant. As a work around solution it could be possible to re-use HW units already operated during AVM test campaign. This possibility has to be confirmed by ESA/ASPI, according to the their foreseen usage.

Table 11 SVF alternative approaches

It is important to highlight that one of the most important capabilities supported by the SVF is related to the on-board software patch generation/validation. Specific tools have to provide the possibility to easily generate and upload, as telecommands, the new valid flight code.
The SVF will be also used to stress the software behaviour. In fact the SVF will include the simulation or the real units (TBC) of the whole S/C and represent the most flexible test environment for a complete flight software validation. It is a benchmark that is expected to provide important feedback affecting other tests environment and the final software flight releases of the different products. Realistically speaking many interface/performance issues

will be discovered at this stage, due to several reasons. In particular the added value of the SVF is based on the following factors:

- The SVF test environment will be more complete w.r.t the test environment used by the single software subcontractors
- All the different software releases will be consolidated, thus really representative
- The test sessions are operated by people that are not the developers
- Other test environment (e.g. AVM) have to deal with many other aspects not strictly related to the software. The allocated time period doesn't allow to perform deeper investigations or exhaustive tests required by the software in his complete configuration and target environment.
- The flexibility and completeness of the available test tools will allow performing any kind of test activity

By now ASPI has provided to Alenia a sort of SVF guidelines document, not really a requirement doc. Additionally only the BSW subcontractor has been selected and some developing tools are still to be defined, as previously anticipated (see SDE section). The project's status is awaited to be more stable before issuing the relevant SVF specification that vice versa would be too floating.

The SVF supplier, anyway, will develop the simulation software taking into account the System Database S/C.
The main foreseen tools and capabilities of the SVF environment are hereafter summarised:

- Patch Facility Tool
- A simple and friendly test language used to write test procedures
- A simple and complete Graphic User Interface to create/control a test session
- A network support to provide concurrent engineering capabilities
- A S/C simulation environment able to cope with the simulation of all missing units/equipment
- A powerful configuration control tool (to be used for all SW releases, patches, test procedures, etc)
- OBCP development tool (to be provided by the customer, created by the CDMU ASW subcontractor)
- TM analysis tools

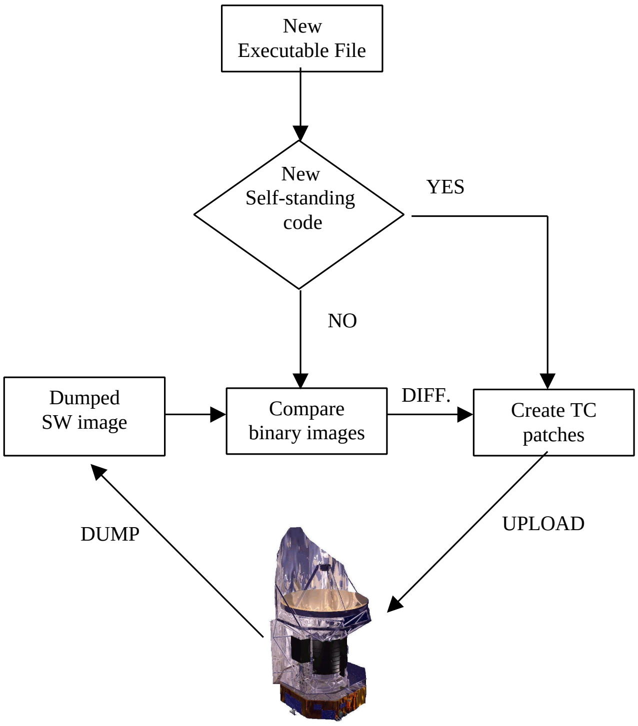


Figure 21 Flight Code update process

7.7 EMC/ESD

7.7.1 Bonding

Electrical Bonding for RF reference purposes is not considered problematic. The majority of the electronic units are located on the structural panels. The structural panels are aluminum faced honeycombed panels and will guarantee the required conductivity. There are a few units that could be mounted on the carbon structure, for these units special grounding arrangements will be planned to carry the zero volt reference back to the aluminum structure. Aluminum strips will be fixed to the carbon face sheets giving a link for the units' bondstraps and to provide a pseudo-ground plane for the associated harness routing. Moreover bonding will get a safe path to ground if an electrical fault occurs. Bonds, not associated with the referencing of electronics, will be provided to avoid build up of charge due to electrostatic phenomena. For the SVM bonding diagram the following bond classifications and general requirements have been used to distinguish among the bonding typology:

Class R

Bonding made by direct metal to metal contact or/and by the use of bond straps with DC resistance of 2.5 mOhm per junction. Class R will be used for referencing of circuitry (RF bond).

Class S

Bonding made by direct metal to metal contact or/and by the use of bond straps with DC resistance of 1 Ohm ? per junction

Class S bonds are intended for continuous bleeding of charged surfaces to structure, and due to the nature of the charge / discharge mechanism.

Class H

Bonding made by direct metal to metal contact or/and by the use of bond straps with DC resistance of 0.1 Ohm per junction. Class H bond are intended for powered equipment not requiring zero volt referencing. Bonds assembly will be sized to carry 150% of the in-line current protection device upstream of such equipment. Units required to have a Class R bond will also considered to meet the class H criteria.

The above SVM bonding approach is substantially in line with the General Design and interface Requirements Document and an adequate electrical continuity throughout the Satellites structure should be guaranteed even if the Structure Subcontractor foresees 10 mOhm instead of the required 5 mOhm for the bonding resistance between any adjacent metallic structure parts.

7.7.2 Grounding

The SVM design for the two Spacecrafts follows the Distributed Single Point Ground approach: primary power will be grounded to the Satellite Structure inside the PCDU. DC/DC converters will provide galvanic isolation to secondary power for each user. Signals will be referenced to equipment chassis (ie secondary ground) and the use of single ended interfaces at both sides will be avoided to reduce the common-mode coupling. To keep the structure impedance as low as possible also will contribute to reduce the common-mode noise.

The received equipment technical proposals are in line with the above grounding approach but the TWTA where the secondary power ground is connected to EPC and TWT structure. However, as EPC and TWT are close, the small ground loop shouldn't cause any impact at system level.

7.7.3 Coupling

Power and signal lines will be grouped in different EMC category in line with the General Design and interface Requirements Document. To minimize cross-coupling between wires or lines of different classes,
the separation distances, related to parallel lengths of cabling lines, will be maximized as much as possible relating the available room for the harness paths.

7.7.4 Plasma Charging/ESD

The protection against SVM equipment damage or malfunction due to electrostatic discharge is not considered problematic. If the conductivity requirements are met then no problems are expected from charge build up. Moreover the received equipment technical proposals are in line with ESD susceptibility required in the EMC Specification.

7.7.5 Conducted and Radiated Requirements

The received equipment technical proposals declared some not compliances against EMC specification that are hereafter reported.

7.7.5.1 PCDU

For the conducted requirements, Alcatel ETCA declared for the “Steady state ripple” to be compliant with the PCDU Specification requirement (that has precedence on the EMC Specification) based on ESA standards.

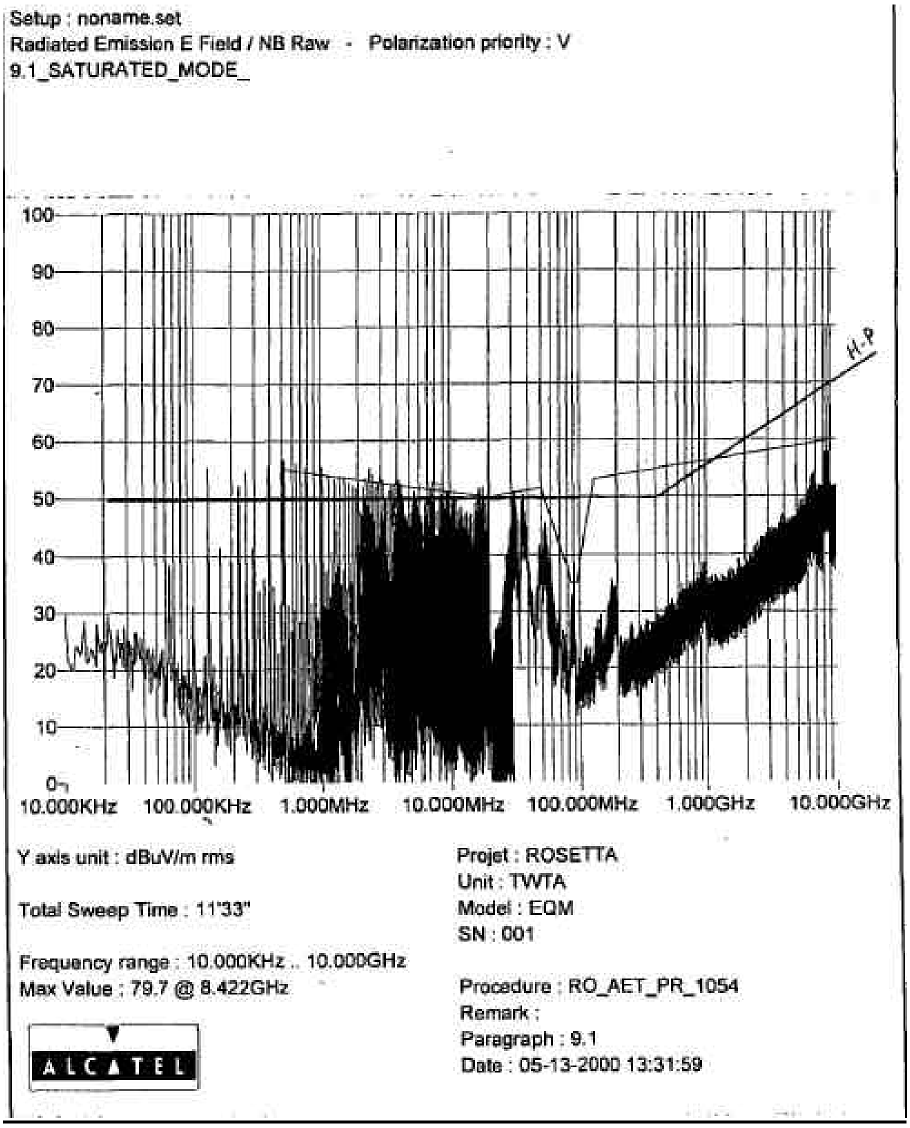
7.7.5.2 XPND

In line with the EMC Specification.
The major concern was the compatibility with HIFI instrument radiated susceptibility between 3.5 GHz and 9 GHz. It was expected that the receiver of the X-band transponder couldn’t be compliant with the requirement of 15 dBμV/m for the Radiated Emission in that band. But Alcatel Espacio solved the problem declaring that the X-band transponder will be in line with the RE requirement.

7.7.5.3 TWTA

For the RE H-field DC requirement, Alcatel ETCA declared to be compliant with the level of 106 dBpTat 1 m and not with the 94 dBpT at 1 m required if the closest unit is at a minimum 12 cm distance. However a different arrangement of the TT&C panel could increase the distance between the TWTA and its closest unit so 106dBpT could be enough.

For the RE E-field Alcatel ETCA declared that, from the ROSETTA experience, slight not compliance are foreseen. ETCA provided ROSETTA’s RE curve with the required Herschel-Plank mask to show the entity of the foreseen not compliance.



Setup : noname.set
Radiated Emission E Field / NB Raw - Polarization priority : V
9.1_SATURATED_MODE_

Y axis unit : dBuV/m rms

Total Sweep Time : 11'33"

Frequency range : 10.000KHz .. 10.000GHz
Max Value : 79.7 @ 8.422GHz

Projet : ROSETTA
Unit : TWTA
Model : EQM
SN : 001

Procedure : RO_AET_PR_1054
Remark :
Paragraph : 9.1
Date : 05-13-2000 13:31:59

ALCATEL

Rosetta-Radiated Emission E-Field

7.8 PROTECTION AGAINST RADIATION DAMAGE

The HERSCHEL and PLANCK spacecraft will conduct their mission around the L2 Lagrange point of the Earth/Sun system, where they will be substantially exposed to energetic protons and heavy ions from solar flares and galactic cosmic rays. During the launch phase the spacecrafts will be exposed to trapped particles.

General radiation related damage mechanisms to which the satellites will be subjected include:

- total dose ionization damage of electronics and Solar Arrays due to Electrons and Protons
- single event phenomena of electronics due to the cosmic ray, solar flare environments and trapped Protons
- displacement damage induced mainly by Protons affecting Solar Arrays, CCDs, and optocouplers and bipolar electronics.

7.8.1 Space Radiation Environment description

The units will be designed to survive the space radiation environment during 4 years for Herschel, and 2.5 years for Planck (AD-13).

The Solar Arrays will be designed to survive the space radiation environment during 4.5 years for Herschel and 2.75 years for Planck (AD-13).

The minimum allowable radiation level for active parts are:

- Minimum Total Dose Behavior 10 krad (Si)
- Minimum Displacement Damage Equivalent Fluence (Si) 6.10^{9} 10 MeV p/cm²

7.8.2 Herschel and Planck preliminary evaluation

Even if a detailed component part list for the SVM units is not available yet, a preliminary evaluation has been performed for the total dose ionization and the displacement damage.

7.8.2.1 Total dose

In figure 7.8.2.1-1 is reported the Herschel_Planck Dose Depht Curve. Considering the minimum susceptibility level of 10 krad (Si) for the active parts and the required Radiation Design Margin of 2 (AD-44), the aluminium solid sphere that guarantees a sufficient shielding has a thickness of 2 mm. Also not considering the Payloads shield, the shielding effect of the closure panels, the platforms, and the units' boxes should protect the SVM electronics by the total dose ionization damage. For the electronic units mounted on the external side of the SVM assembly an adequate box thickness, shielding or proper devices will be used.

A more detailed analysis will be provided when detailed component part lists and all the boxes' thickness will be available.

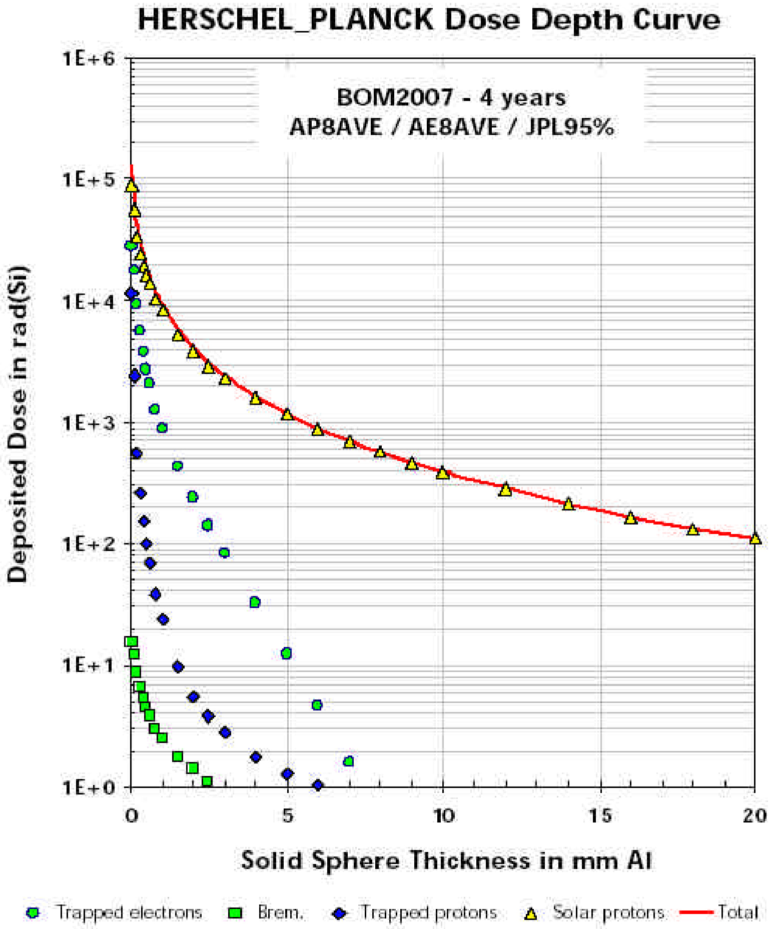


FIGURE 7.8.2.1-1 TOTAL DOSE CURVE

7.8.2.2 Displacement damage

In figure 7.8.2.2-1 is reported the Displacement Damage Equivalent Fluence. Considering the minimum susceptibility level of 6.10^9 p/cm² (in Si) for the active parts and the required Radiation Design Margin of 2 (AD-44), the aluminium solid sphere that guarantees a sufficient shielding has a thickness of 4 mm. The shielding effect of the closure panels, the platforms, and the boxes' units should protect the SVM semiconductor by the displacement damage. For the electronic units mounted on the external side of the SVM assembly an adequate box thickness, shielding or proper devices will be used.

A more detailed analysis will be provided when detailed component part lists and all the boxes' thickness will be available.

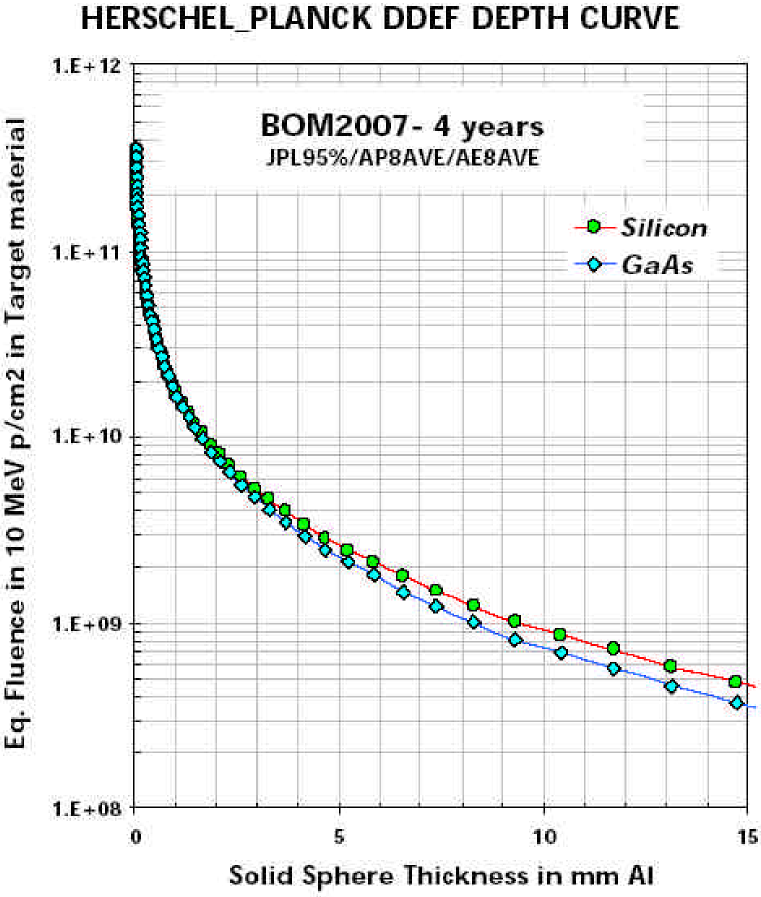


FIGURE 7.8.2.2-1 DISPLACEMENT DAMAGE FLUENCE CURVE

7.8.2.3 Single Event Effects

As baseline (AD-44) only parts insensitive to the following destructive events will be used:
Single Event Latch-up (SEL)
Single Event Burnout (SEB)
Single Event Gate Rupture (SEGR)

7.8.2.3.1 Single Event Upset (SEU)

In figure 7.8.2.3-2 is reported a Heavy ions induced SEU rate as a function of the LET threshold of the part. It will be used, together with the critical parts [cross section as a function of LET] characteristic, to compute a "single upset rate" in upset/bit (or/part)/s related to heavy ions.
In figure 7.8.2.3-1 is reported the Protons induced rate as a function of the Proton energy threshold A of the part. It will be used, together with the critical parts [cross section as a function of A] characteristic, to compute a "single upset rate" in upset/bit (or/part)/s related to Protons.
The “total SEU rate” will be composed by the “Heavy Ions SEU rate” and the “Proton SEU rate”.

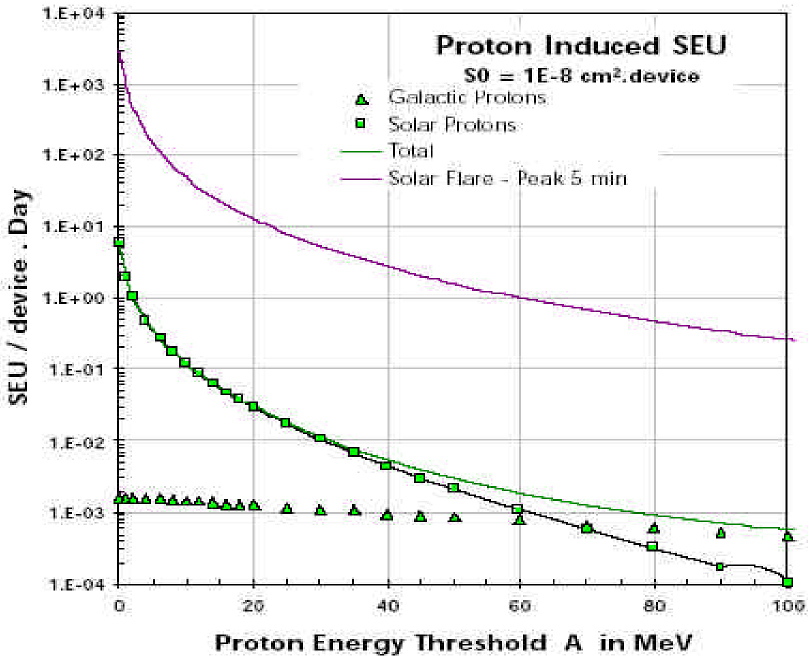


FIGURE 7.8.2.2-1 PROTONS INDUCED SEU RATE

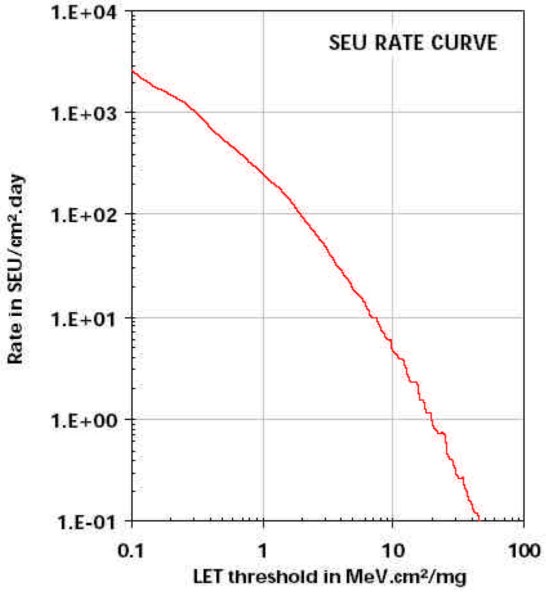


FIGURE 7.8.2.2-2 HEAVY IONS INDUCED SEU RATE

The SEP rates for all sensitive parts and a SEU effect analysis will be performed when the units' component part lists will be available.

Also a design analysis for SET (Single Event Transient) will be performed in order to assess the sensitivity of applications using sensitivity devices.

7.9 ALIGNMENT AND ALIGNMENT STABILITY

7.9.1 Requirements

The alignment and Stability Requirements are defined in have been derived from the SVM Pointing requirements for both the Satellite.
The following causes of misalignments shall be taken into account:

- Setting due to mounting procedures
- Setting due to launch distortions
- Gravity release
- Deformations caused by orbital temperature variation over the complete mission (including initial cooldown)
- Ageing
- Creep
- Composite structure deformations due to moisture release and radiation.

The following requirement apply:

Item	**H-P**	**Reference**	**Alignment (°)**			**Stability (°)**		
			X	Y	Z	X	Y	Z
STR	H	PLM I/F	-	0.25	0.25	10 arcsec	0.8 arcsec	0.8 arcsec
STR	P	PLM I/F	-	0.25	0.25	1	1	1
Gyroscope	H	PLM I/F	0.5	0.5	0.5	0.02	0.02	0.02
RW	H	PLM I/F	0.5	0.5	0.5	0.02	0.02	0.02
Thrusters	H-P	PLM I/F	0.5	0.5	0.5	0.05	0.05	0.05

Table –7.9.1-1 Herschel and Planck Alignment and Alignment stability table

7.9.2 Alignment and Alignment stability analysis summary

Detailed analysis is reported in chapter 5.4 of RD (42)

The stability analysis has been budgeted according to contributions as specified. Each potential cause of misalignment has been compared with its allocation.

7.9.2.1 Herschel

The following four load cases have been studied:

NAME	SEASON	PITCH ANGLE	ROLL ANGLE
CASE 1	Winter solstice	0°	0°
CASE 2	Winter solstice	30°	0°
CASE 3	Winter solstice	-30°	0°
CASE 4	Summer solstice	0°	0°

The thermal load cases are the ones derived with old configuration Baseline, a second loop of analyses will be performed with the frozen configuration.

The main interest of these results is related to the ACMS stability in order to allow the S/C pointing and manoeuvre. From the given analyses, the differential calculation leads to satisfy the requirement for the thruster, While for the STR the order of magnitude of the results is twice the requirement. Both the Gyro and the RW are out of the

requirement as they have to be calculated w.r.t the STR positioning. For RW and Gyro, the problem will be solved accordingly to the new STR position and stability.
The STR positioning lead to a deep investigation and several checks on this subject gave evidence that the in the actual positioning the STR cannot be kept stable.
Detailed analyses have been performed then with FEM models to better evaluate the result. The conclusion is that even a very low temperature variation on the cone can lead to a huge STR rotation w.r.t the requirement.
With the STR in the baseline location (namely on lateral panel -Z) no way to satisfy the requirements can be found (as presented during PM8). The effort has then been moved to the search of a suitable position for STR mounting, other Positions have been investigated as reported in dedicated Technical Note H-P -TN- AI -0030 issue 1.

7.9.2.2 Planck

The following two load cases have been studied:

NAME	SEASON	S.A.A
CASE 1	Winter solstice	0°
CASE 2	Winter solstice	30°

The thermal load cases are the ones derived with old configuration Baseline, a second loop of analyses will be performed with the frozen configuration.

For Planck the related requirements apply only to the Thruster positioning for which the present design is widely compliant.

8. RESOURCE BUDGETS

See [RD-11] (SVM Budget Report) H-P-BD-AI-0001 Issue 02

9. SERVICE MODULE

9.1 SERVICE MODULE STRUCTURE

9.1.1 General

The present chapter constitutes the design description for the Service Module (SVM) Structure.

The SVM Structures are designed so as to transfer the inertia loading to the launch vehicle interface and provide adequate stiffness to de-couple the spacecraft’s modes from those of the launch vehicle. The structures also provide the mounting area for all equipment and thermal hardware giving protection against the launch and in-orbit environment. The structure also acts as the common electrical return path.

Herschel and Planck SVM are two different structures for which the highest level of commonality was persecuted.

9.1.2 Commonality Requirements

Herschel and Planck Primary structures have been designed to preserve the maximum of commonality between them.

With the increasing of the design maturity, it became obvious that the great difference in the required performance of the two SVM led to two structure which general design and philosophy is still the same, while details are sometimes different as different are the requirement to be satisfied.

In principle the primary structures are made of the same materials, shape and dimensions. ,

The application of this concept is explained in paragraphs below where the main deviation from commonality are also tracked and explained.:

General Exploded View o SVM structure is reported in chapter 7.2 Figure 7.3.2-1 for Herschel and in Figure 7.3.2-2 for Planck.

9.1.3 Design description

The structure design has been divided into primary and secondary structure according to the different loading path passing through the structure

9.1.3.1 Primary Structure

The **Primary Structure** is defined as that part of the structure, which carries the main launch loads and which determines the fundamental frequencies of the satellite.
It is composed of:

- Central cone
  - Upper interface
  - Lower ring
- P.Tanks Support Structures (PTSS)
- Octagonal box
  - Payload sub-platforms
  - Equipment panels (SCC panels for Planck)
  - Upper and lower closures
  - Shear Panels

Detailed engineering drawings can be found in [R.D. 33]

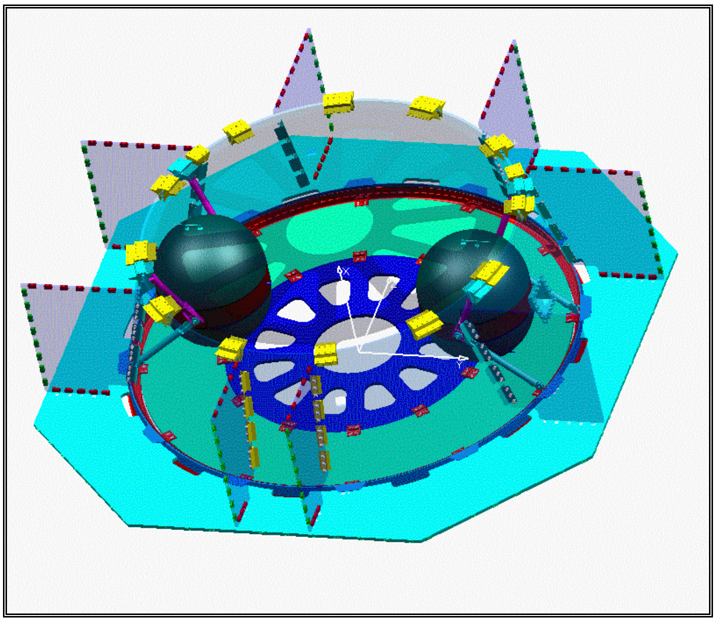


Figure 9.1.3-1 Herschel Structure overall view

Central Cone

It is a CFRP sandwich with aluminium honeycomb core, which provides the I/F's to the PLM and Octagonal box via the upper brackets and to the Launcher via the lower ring. In order to withstand the flux requirement the skin of the cone has been reinforced locally at the PLM and launcher I/F joints. These reinforcements improve the strength of the skin in membrane and bending stress states.

The Herschel and Planck structures are of the same material, shape and dimensions. Bigger differences are related to the cone holes, PTSS I/F (three on Planck, Two on Herschel) shear panel inserts on Herschel -Z side (Herschel presents a different shear panel configuration for STR Stability requirement), local cut out and equipment inserts, and local reinforcements.

Differences are introduced mainly at upper level ,as well as the two cone share the same I/F philosophy (discrete brackets instead of a continuos ring to save mass), but final results depends on different PLD I/F's and requirements.

The central cones provide also I/F to the:

- ❑ Octagonal box
- ❑ Payload subplatform
- ❑ PTSS
- ❑ 4 Helium tank support structure (Planck)
- ❑ RCS Piping (inserts)

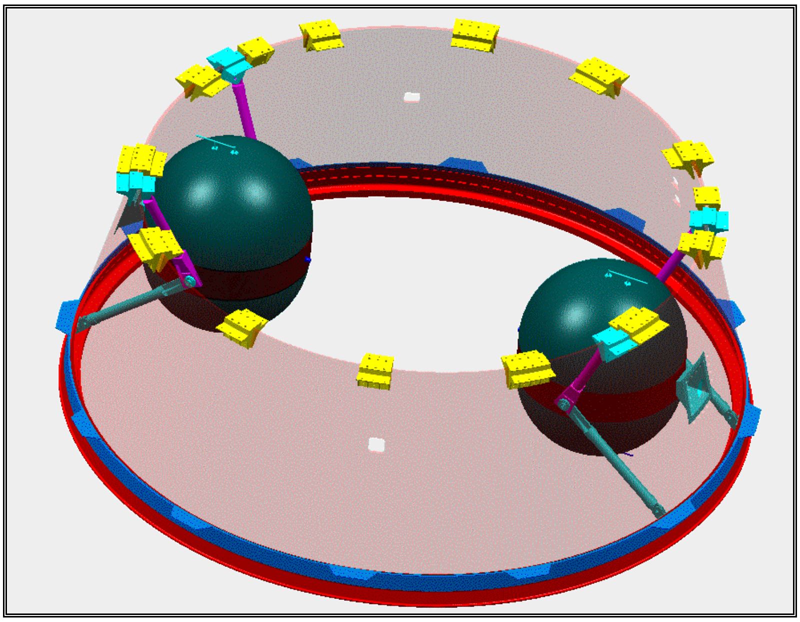


Figure 9.1.3-2 Herschel cone overall view

Upper Brackets

The upper brackets are the interface of the Central Cone with the upper SVM and PLM structure.

These brackets are used to connect different items depending on Herschel and Planck different requirement and configuration:

<u>Herschel</u>

- ❑ PLM I/F brackets
- ❑ Upper closure (integrated to all other brackets)
- ❑ SVM sunshield,
- ❑ SSH-SSD
- ❑ Payload Subplatform (integrated to all other brackets)
- ❑ PTSS. (connected to the PLD Brackets see sketch)

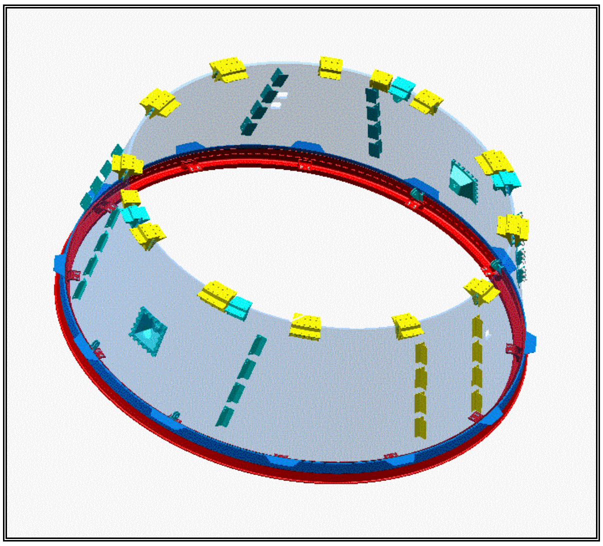


Figure 9.1.3-3 Herschel cone interface overview

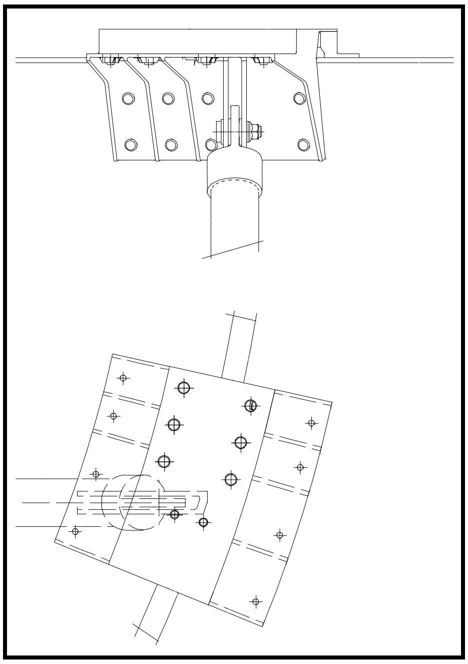


Figure 9.1.3-4 Herschel upper bracket interfacing PLM and PTSS

<u>Planck</u>

- ❑ Upper closure (integrated to all other brackets)
- ❑ Payload Subplatform (through 6 of these attachments the payload itself is attached)
- ❑ PTSS (independent from the PLD Brackets)

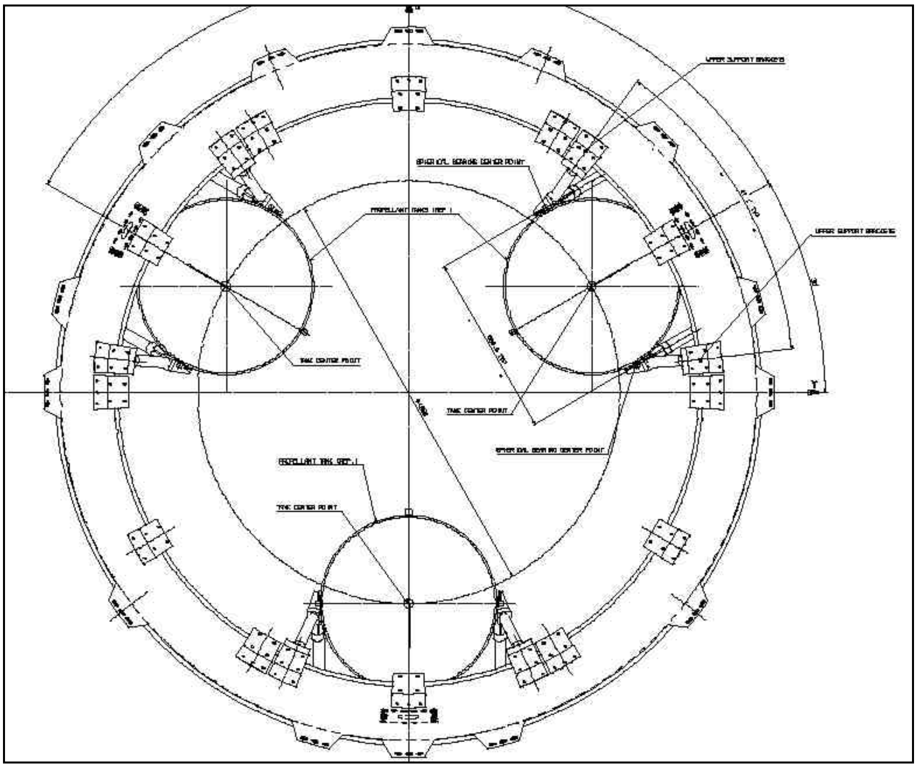
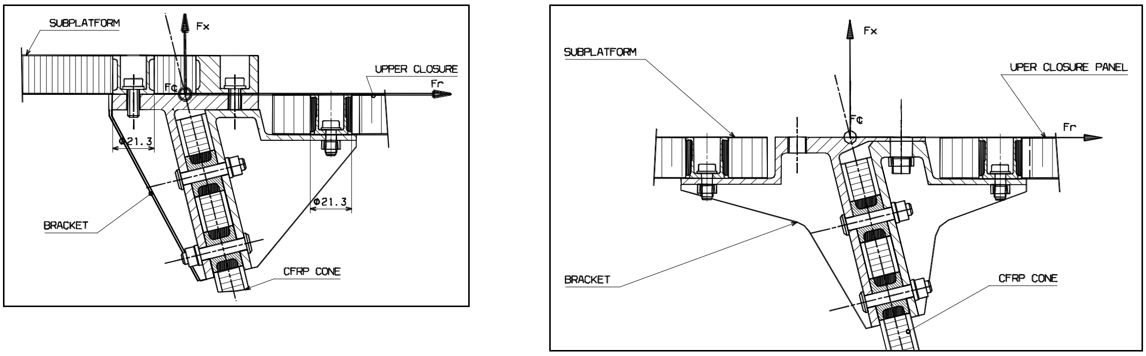


Figure 9.1.3-5 Planck upper bracket I/F

The attachment to the cone is made with rivets type HI-LITE plus structural adhesive that is also used as shimming and electrical isolation.
The attachment to the upper closure and sub-platform is made with Titanium bolts and A-286 anchor nuts. The PLD is attached via dedicated titanium Bolt.



HERSCHEL

PLANCK

Figure 9.1.3-6 Typical PLM I/F bracket sections

Lower Ring

The Lower Ring provides the interface of the cone to the launcher, lower closure, RCS panel, Solar Array Central panel (Planck) and PTSS. The commonality between Herschel and Planck is complete for this item.
The attachment to the cone is made with titanium bolts, hexagonal self-locking nuts and multimision adhesive (i.e. structural, shimming and electrical isolation function).
The lower part of the ring will be anodised chromically for thermal reasons.

Tanks Supports Structures (PTSS)

The PTSS are located inside the Central cone and are used to connect the P. tanks to the Central cone. In Herschel there are two tanks and in Planck three.
Each PTSS connect a P. tank via spherical bearings mounted on 3 of the P. tanks equatorials trunions , providing the P. Tank with a full isostatic mounting.
The PTSS is composed mainly of a set of CFRP struts with Al end-fitting bonded and riveted.

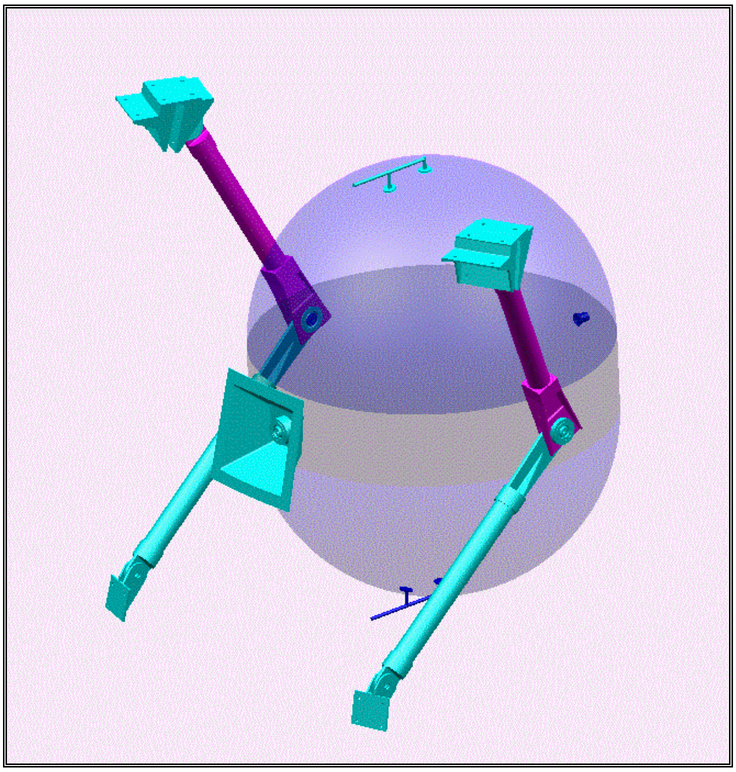


Figure 9.1.3-7 PTSS mechanical interfaces

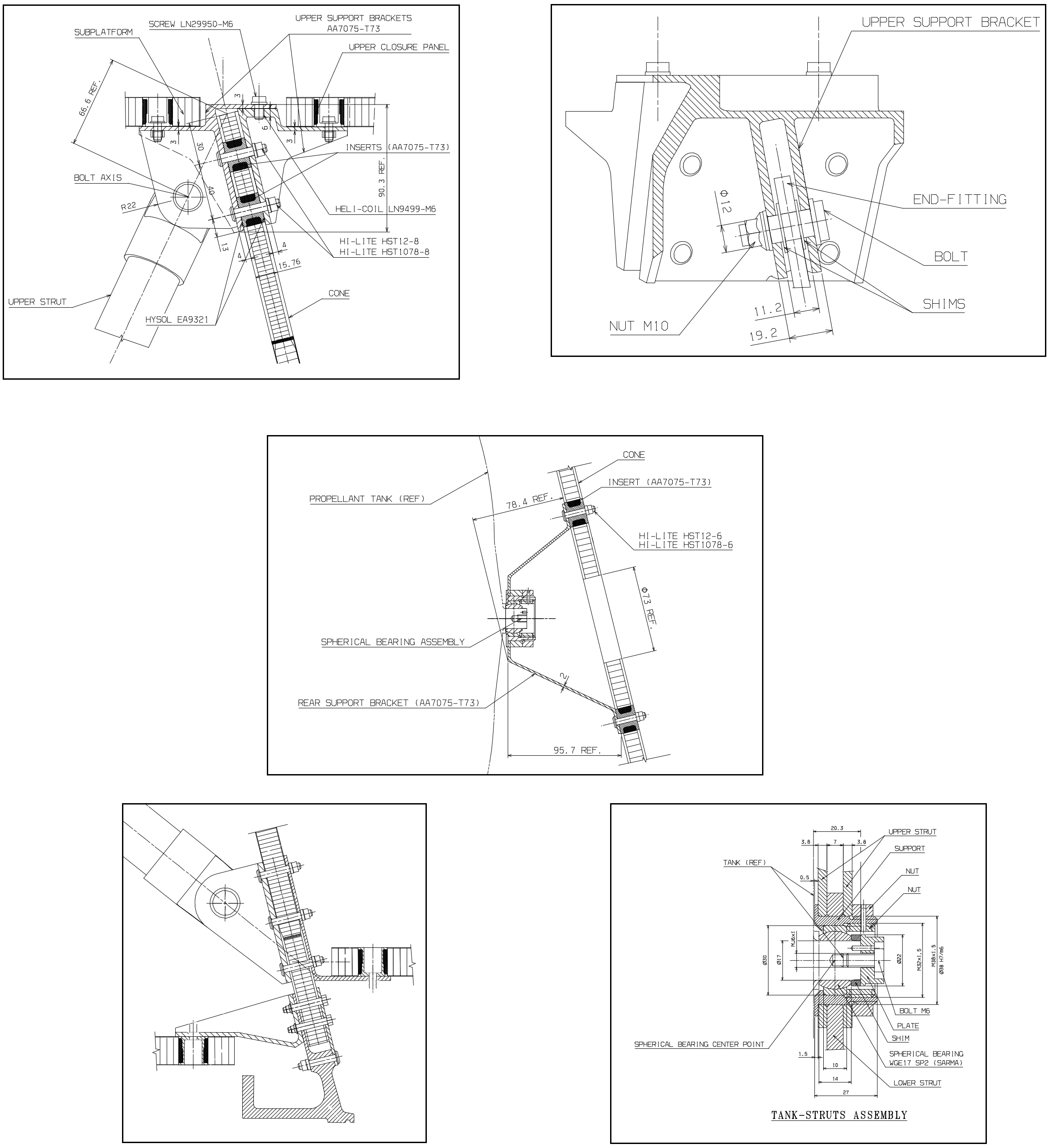


Figure 9.1.3-8 PTSS I/F concepts

Octagonal Box

The octagonal box is constituted by:

- ❑ 8 Equipment panels:
  - -4 Long Eq. Panels
  - -4 Short Eq. Panels
- ❑ 1 payload subplatform
- ❑ 2 closures panels:
  - upper closure
  - lower closure

- 8 shear panels

The main differences between Herschel and Planck can be found in the Payload Subplatform concept and in the SCC panel for Planck while the Shear panels present minor discrepancies due to the Herschel STR stability requirement. Details are explained directly in following sub-paragraphs.

Payload Subplatform

Paylod subplatform presents one of the main differences between the two SVM. The two structure are different for scope, shape and material. For this reason they will be presented separately:

Herschel

The payload sub-platform is manufactured in sandwich form with CFRP skins.
It is fixed inside the top of the Central Cone, and it is mainly used to increase radial stiffness of the top of the central cone when loaded by the Payload support struts. It doesn't carry any equipment but provides Interfaces for MLI support.
The interface with the Central Cone is made via inserts on the platform and brackets on the cone.

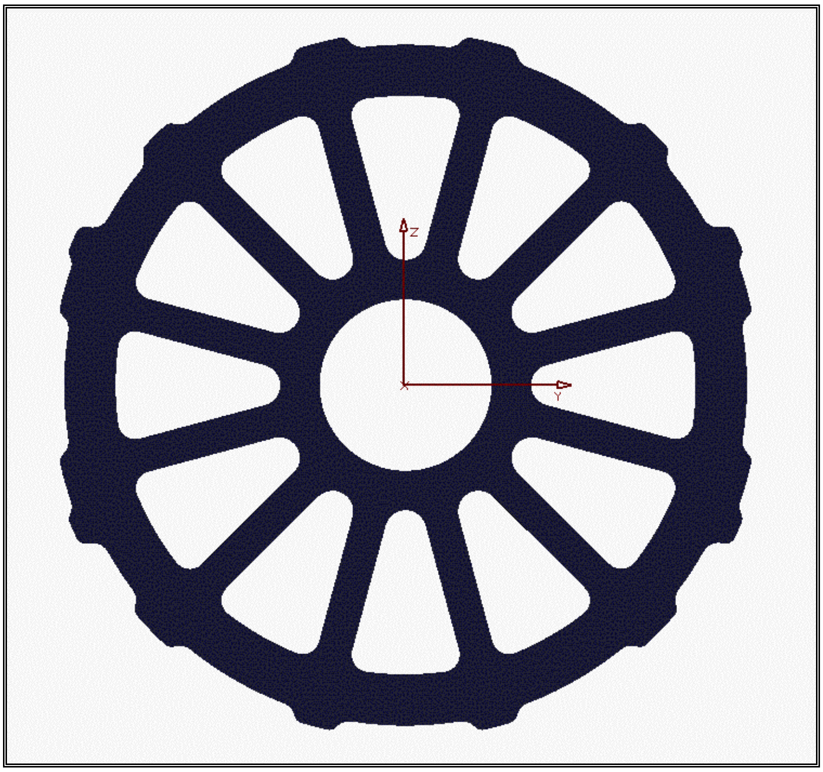


Figure 9.1.3-9Herschel PLD subplatform

Planck

The payload sub-platform is manufactured in sandwich form with Aluminium skins.
They are fixed on the top of the Central Cone above the upper I/F brackets, and it is used to support some Warm Units from the payload (For this reason has two reinforcing beams at its free edge), to stiff the top of the central cone when loaded by the Payload support struts.
The PLD-subplatform is also used for PLD integration purposes, for this reason the Interface concept is different form the Herschel one and the subplatform can be attached directly on top of the cone while carrying the payload.
The interface with the Central Cone is made via special inserts on the platform and brackets on the cone.

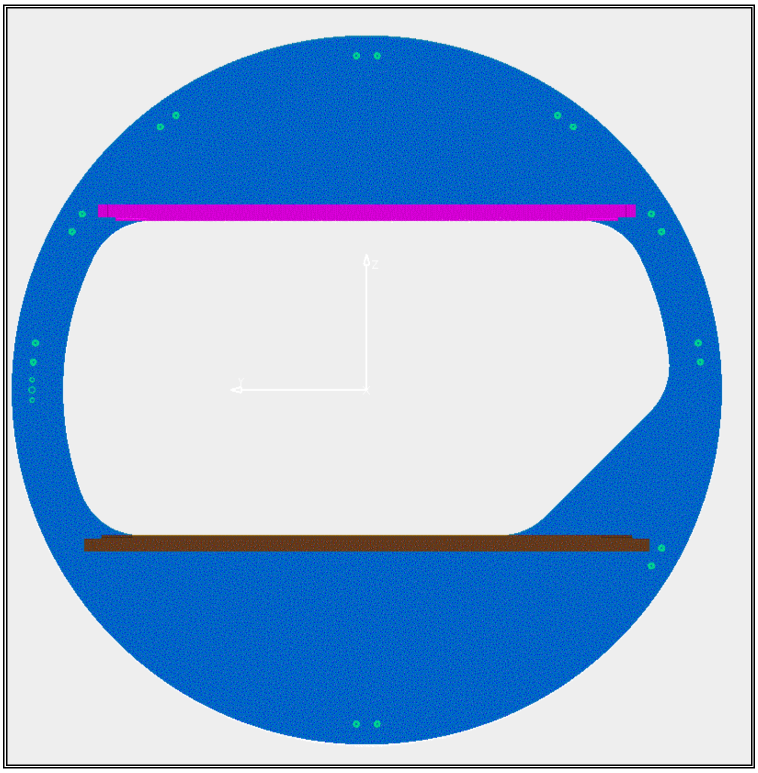


Figure 9.1.3-10 Planck PLD subplatform

Equipment Panels and SCC Panels

They are Aluminium sandwiches with aluminium honeycomb core. They accommodate the units (subsystem and some warms) and provide them a large dissipative surface.
All the external panels are detachable in order to allow the equipment integration or replacement if necessary; for this reason, four I/F brackets are used to connect the panels each other via cold bonded through inserts.

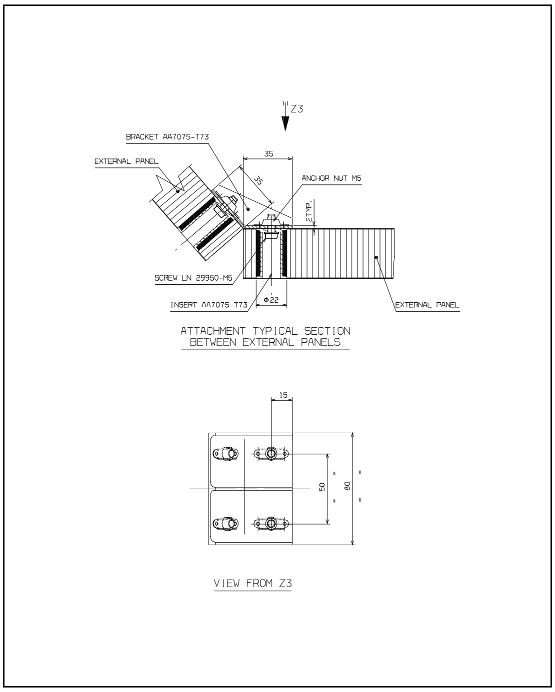


Figure 9.1.3-11 Panel to Panel typical I/F brackets

To allow the connection to the closures, these panels have aluminium hot bonded inserts in the upper and lower edges.

SCC Panels

In the Planck satellite there are 3 equipment panels (namely +Y-Z / -Z /-Y-Z) that, once assembled the first time, form an assembly which has to be manage as a single item. They are called SCC panels.
They are kept togheter by means of a dedicated connecting bracket showed in following figure.

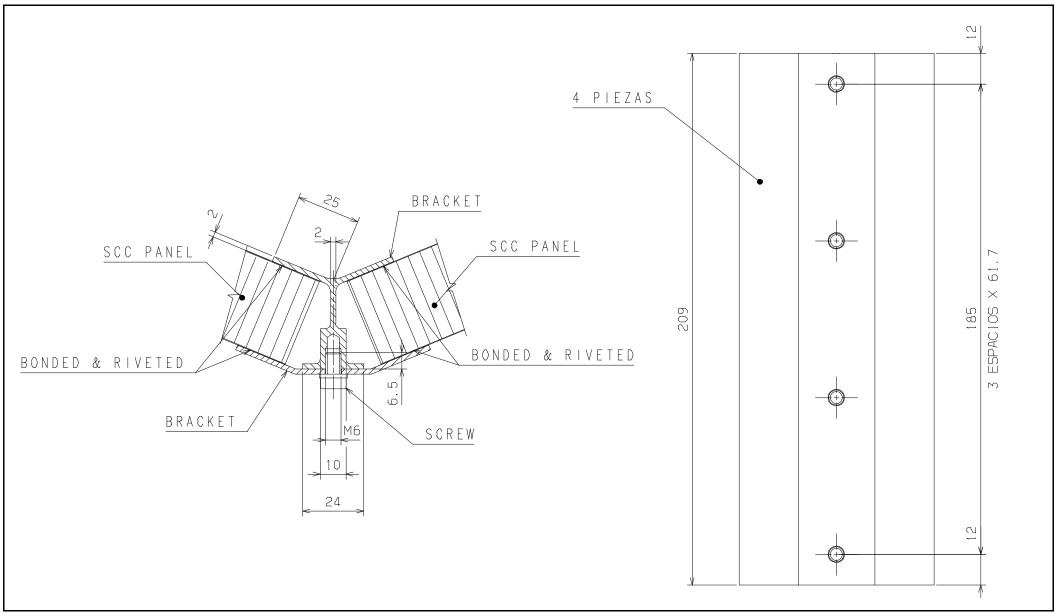


Figure 9.1.3-12 SCC Panel special connecting bracket

The panels are attached by means of Titanium brackets and inserts to the other part of the structure to limit the thermal flux between the attached parts. A scheme of the attachments is provided in figure below.

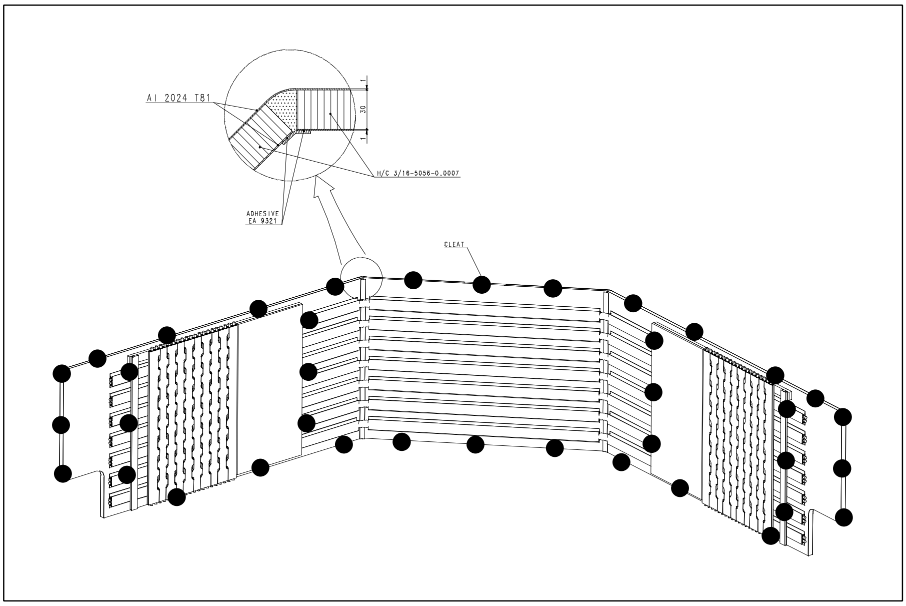


Figure 9.1.3-13 SCC concept and connection scheme

This panel carries the Sorption Cooler Compressors and Electronics that are mounted to the SCC panel over the Heat Pipes network.

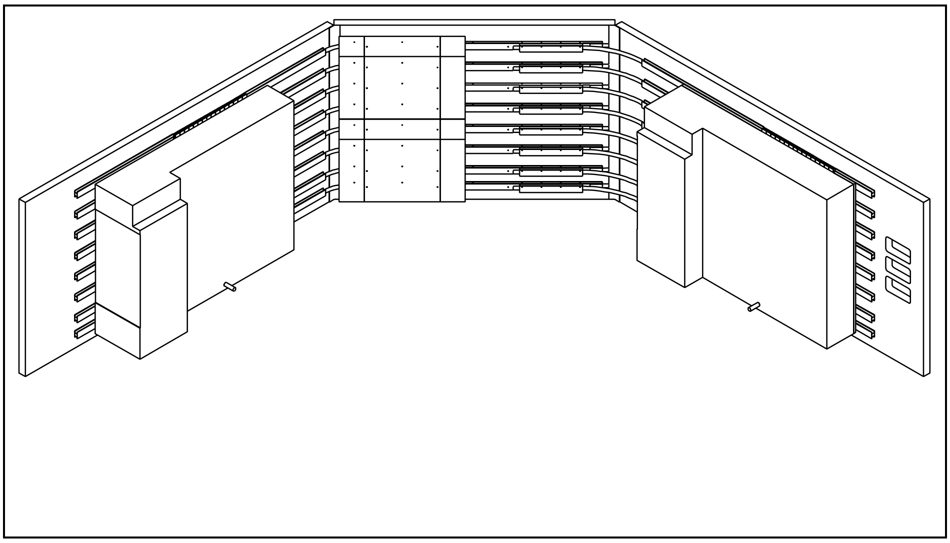
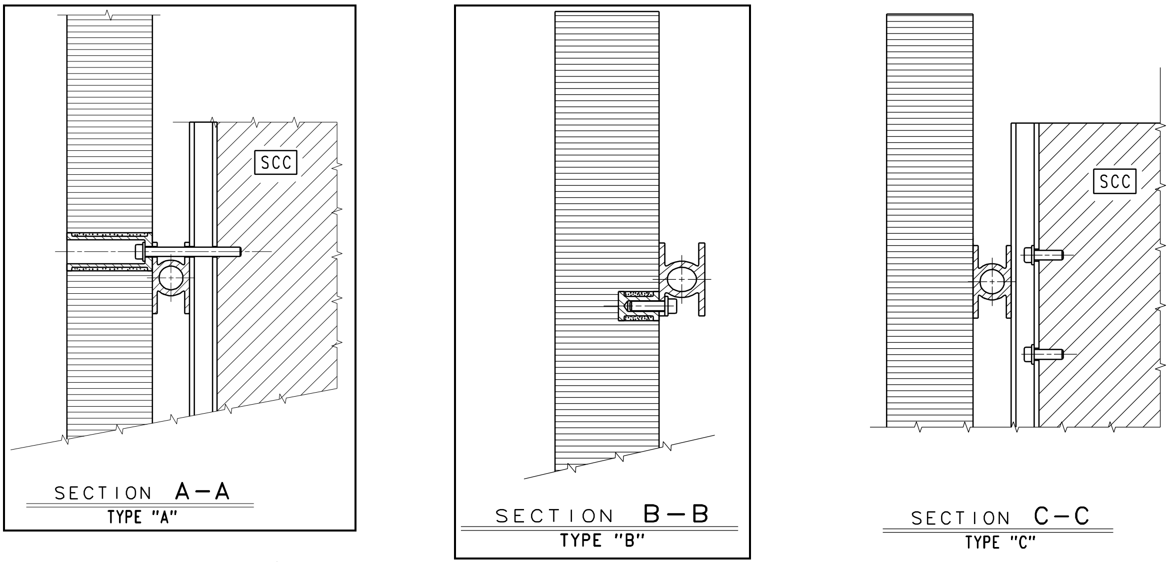


Figure 9.1.3-14 SCC Panel Assembly

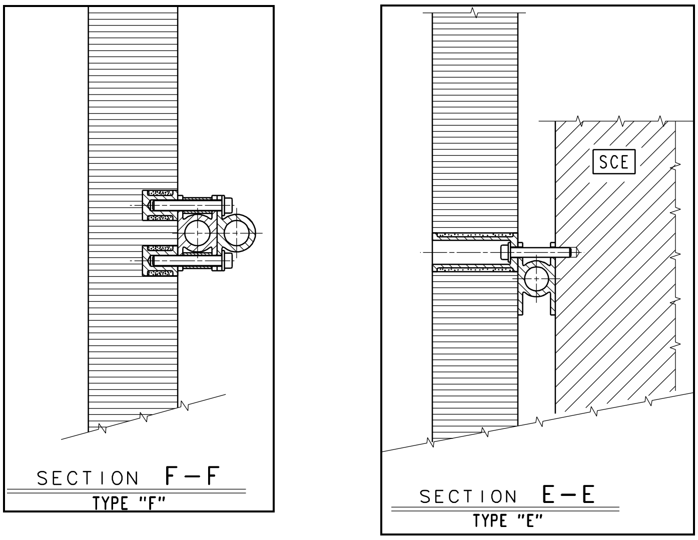
The attachment of both the network and the equipments to the SCC panel is a demanding target. A dedicated study has been developed in order to reduce the number of I/F points and to de-couple the I/Fs to the SCC. Details are described in [R.D 46].
Here below a summary of the developed concept and of mounting sequence is proposed:

- ❑ the horizontal heat pipes will be directly fixed to the SVM panels, by making use of a limited number of inserts by and leaving a number of through inserts free

- the vertical heat pipes and the spacer panels will be mounted onto the SCC equipment
- the SCC plus heat pipes and spacers assembly, will be connected to the SCC panels already equipped with orizontal H-P by means of screws mounted from the external side through the through inserts.



- proposed without spacers, if and where spacers will be needed they will be added.



- proposed without spacers, if and where spacers will be needed they will be added.

Figure 9.1.3-15 SCC typical Interfaces

A possible type "G" fixation has already been studied in order to connect vertical and horizontal heat pipe through the panel, where no mounting holes on SCC is available. If more I/F's will be required, additional fixation point of type "G" will be implemented.

Closure Panels

There are two different closure panels: Upper and Lower.
Both are CFRP sandwich panel with Aluminium Honeycomb core.
The Lower one will be only one-piece panel in both satellite, they will be used for harness routing and will provide I/F for the umbilical connector.
The upper will be in principle 4 pieces in both satellites. In Herschel it carries the Cryo-Harness and related brackets and some of the SVM-Shield and SSH/SSD I/Fs. For this reason it is considered not removable after payload integration.
In Planck the upper closure does not provide any I/F and do not carry equipment or harness as it should be potentially removable until the last moment before flight.
In Both Herschel and Planck several lightening holes on upper closure will be provided to reduce mass.

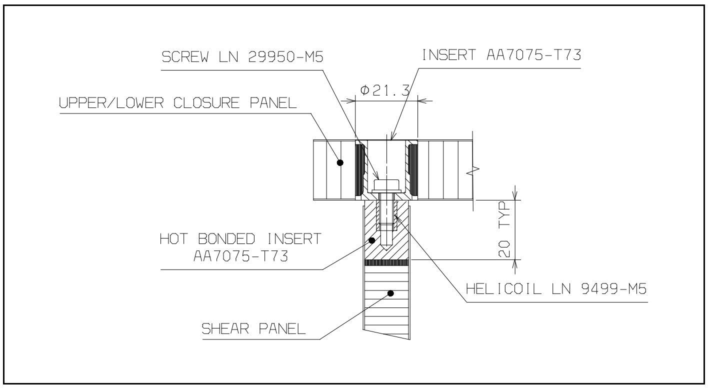


Figure 9.1.3-16 Closure to Shear panel I/F concept

To allow the connections to the Eq-panels, these panels have hot bonded inserts at the edge.

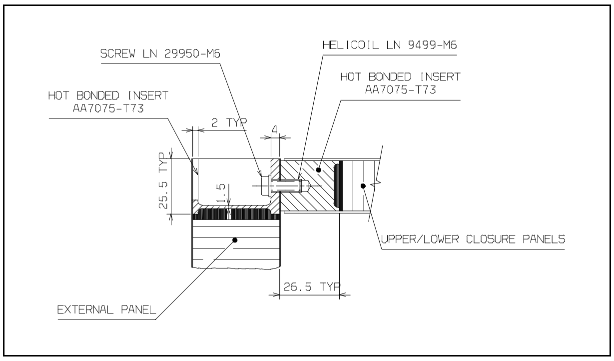


Figure 9.1.3-17 Panel to closure I/F concept

Shear Panels

There are 8 shear panels. There are CFRP sandwiches with aluminium core.
To allow the connections to the Eq. Panels and to the closures they have hot bonded inserts and for the connection to the cone they provide cold bonded inserts.
The -Z shear panels on Herschel are located in a different position for stability requirements and this lead to a different configuration of the described items.
Several cut outs are required along the Shear panel edges for harness, Piping and Wave guide routing.

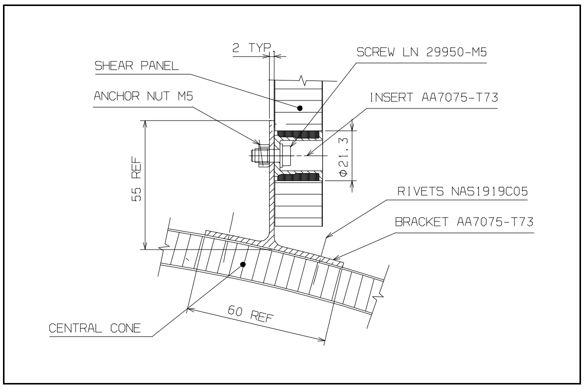


Figure 9.1.3-18 Shear web Vs cone typical I/F

9.1.3.2 Secondary Structure

The **Secondary Structures** are not responsible for the main load transfer. They are fastened to the primary structure and transfer Units loads to the primary structure. The secondary structure is still undefined as the equipment or systems to be carried are still not defined or waiting for a definitive configuration.
The already defined secondary structures consist of:

Thermal Closing Support (For Herschel)

It is a sandwich construction with CFRP face-sheets and aluminium core alloy which has been lightened making holes, being fastened through aluminium alloy brackets and through spool inserts at the inner of the RCS panel by 12 fixation points equally distributed (see AD-5).

The used materials are:

- Core: 3/16-5056-.0007P h = 20 mm
- Skins: M18/6801 (45, 0, -45) th = 0,3 mm
- Adhesive skins-core : Redux BSL 312L

RCS Support Panel

The RCS support panel consists in a sandwich ring form with CFRP face-sheets and aluminium core. It provides I/F to the Closing support (Herschel) and Central Solar Array (Planck) by means of the mentioned 12 aluminium brackets. In order to have the RCS support panel fastened to the Central tube 12 aluminium brackets have been foreseen. Consequently the supporting points for the different panels located at the Central tube bottom inner side are the following:

RCS Support panel : 12
Thermal Closing Support and Central Solar Array : 12 points.

The material used are:

- Core: 3/16-5056-.0007P h = 20 mm
- Skins: CFRP M18/G801 th = 0,3
- Adhesive skins-core : Redux BSL 312L

He Tanks Support (Planck)

The 4 He tanks are located at the outer side of the Central tube. Each tank will be supported in a TBD manner.

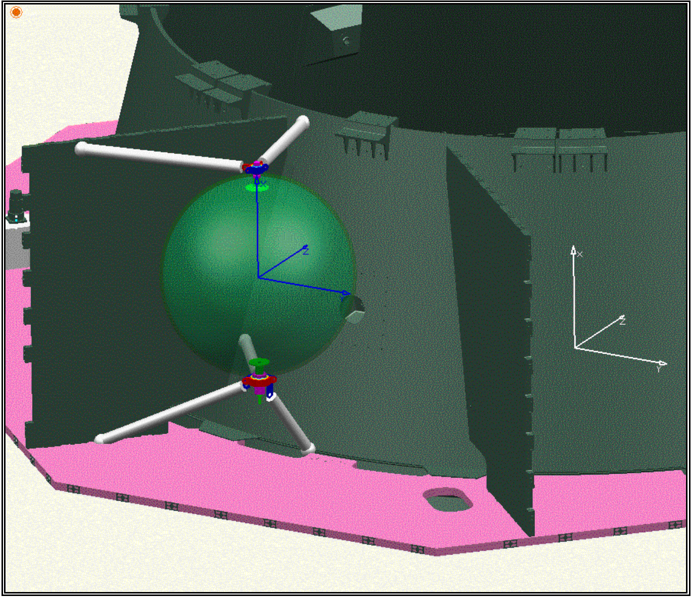


Figure 9.1.3-19 Helium tank support concept

Other undefined secondary structures are reported hereafter:

HERSCHEL

- Sensors supports, namely:
  - ❑ SAS (2)
  - ❑ AAD (1)
  - ❑ Two Star Trackers (STR): only one support for the two STR Heads
  - ❑ Two individual STR baffle supports.
- Antennae supports, namely:
  - ❑ MGA (1)
  - ❑ LGA (2)
- VMC (1) and SREM (1) supports
- RWD's (4) supports
- Thermal Blankets supports
- Brackets for Umbilical connectors to Launcher (2)

PLANCK

- Sensors supports, namely:
  - ❑ SAS (2)
  - ❑ AAD (1)
  - ❑ Two Star Trackers (STR): only one support for the two STR Heads
  - ❑ Two individual STR baffle supports.
- Antennae supports, namely:
  - ❑ MGA (1)
  - ❑ LGA (3)
- VMC (1) and SREM (1) supports
- Thermal Blankets supports
- Solar Array supports (5 stand-offs for each External SA sector, on the Octagonal box side, 12 stand-offs between RCS panel on the Central SA)
- Brackets for Umbilical connectors to Launcher (2)

9.1.4 Material Summary:

The materials summaries of the SVM structure are reported in Table 9.1.4-1 and Table 9.1.4-2. A detailed list of material characteristics, references and allowable for the used materials are reported R.D. 37]. Also the FEM models material properties [RD.35/36] are coherent with the referred document [R.D. 37]

ITEM	MATERIAL	SANDWICH		
		Core	Skin	Configuration
Upper Bracket	AA7075 T7351	-	-	-
LVA Ring	AA7075 T7351 Die Forging	-	-	-
Central Cone	CFRP - Sandwich	3/16-5056-.001 Hc = 15	M40 th = 0.135	(35 , -35.)$_s$ th = 0.54
Equipment Panel	AL - Sandwich	3/16-5056-0.0007 Hc = 15	AA7075 T6 th = 0.3	-
Payload Subplatform	CFRP - Sandwich	3/16-5056-0.0007 Hc = 20	M18/G801 th = 0.1	(45, 0, -45) th = 0.3
PTSS:				
End-Fitting	AA7075 T7351			
CFRP Struts	M18/M55J			
Closure Panels	CFRP - Sandwich	3/16-5056-0.0007 Hc = 20	M18/G801 th = 0.1	(45,0,90,-45) th = 0.4
Shear Panels	CFRP - Sandwich	3/16-5056-.001 Hc = 15	M18/G969 th = 0.19	(60, -60)$_s$ th = 0.76

Table 9.1.4-1 HERSCEL SVM Structure Material Summary

ITEM	MATERIAL	SANDWICH		
		Core	Skin	Configuration
Upper Bracket	AA7075 T7351	-	-	-
LVA Ring	AA7075 T7351 Die Forging	-	-	-
Central Cone	CFRP - Sandwich	3/16-5056-.001 Hc = 15	M40 th = 0.135	(35 , -35.)$_s$ th = 0.54
Equipment Panel	AL - Sandwich	3/16-5056-0.0007 Hc = 15	AA7075 T6 th = 0.3	-
Payload Subplatform	AL - Sandwich	3/16-5056-0.0007 Hc = 19.4	AA7075 T6 th = 0.3	-
PTSS:				
End-Fitting	AA7075 T7351			
CFRP Struts	M18/M55J			
Closure Panels	CFRP - Sandwich	3/16-5056-0.0007 Hc = 20	M18/G801 th = 0.1	(45,0,90,-45) th = 0.4
Shear Panels	CFRP - Sandwich	3/16-5056-.001 Hc = 15	M18/G969 th = 0.19	(60, -60)$_s$ th = 0.76

Table 9.1.4-2 PLANCK SVM Structure Material Summary

9.1.5 Analyses Summary:

The main Structural performances of the SVM Structure are reported [RD 42], and summarised in Table 9.1.4-4 and Table 9.1.4-5 for Herschel, and Table 9.1.4-6 and Table 9.1.4-7 for Planck.
More details (e.g. local stiffness requirements and detailed stress analysis) are provided in the above document and in structure subcontractor documentation also referenced [RD 34], which shall be considered as an integral part of this chapter.

HERSCHEL

REQUIREMENTS	SPECIFIED VALUES	ACHIEVED VALUES
FREQUENCY		
SVM Global Modes		
Axial (X)	> 23	23.9
Lateral	> 65	65.7
SVM Box Modes		
Axial (X)	> 45	45.1
Lateral	> 60	> 100
Propellant Tanks		
Axial (X)	> 100	208.3
Lateral	> 80	103.8
Lateral Panels	> 50	> 49.1
STIFFNESS		
Global Stiffness		
K Longitudinal	>2.2E8 <3.0E8	2.37E+8
K Axial	>5.6E8 <6.5 E8	**5.13E+8**

Table 9.1.5-1 HERSCHEL SVM Structure Performance Summary

ITEM	FAILURE MODE	MIN. MOS
Lateral panels	Wrinkling	**-0.32**
shear panels	Core rupture	>>1
PLD Sub-Platforms	Wrinkling	**-0.44**
Central cone	Skin rupture	**-0.03**
Closure panels	Wrinkling	**-013**

Table 9.1.5-2 HERSCHEL SVM Summary of MoS

The negative margins of Safety have been discussed, case by case in RD 42 where the dedicated recovery actions are proposed.

Generally, the joints present positive MoS except for some details for which the recovery action has been given in a dedicated document where also joint calculation and justification is presented [R.D. 40].

PLANCK

REQUIREMENTS	SPECIFIED VALUES	ACHIEVED VALUES
FREQUENCY		
SVM Global Modes		
Axial (X)	60	>100
Lateral	35	59.5
SVM Box Modes		
Axial (X)	45	>100
Lateral	50	57.5
Propellant Tanks		
Axial (X)	100	208.3
Lateral	80	103.8
Lateral Panels	50	> 53.7
Payload Sub-platform	32	**31.7**
STIFFNESS		
Global Stiffness		
K Longitudinal	>3.1E8 <3.7 E+8	3.26E+8
K Axial	>1.5 E8 <2.0 E+8	1.76E+8

Table 9.1.5-3 PLANCK SVM Structure Performance Summary

ITEM	FAILURE MODE	MIN. MOS
Lateral panels	Wrinkling	**-0.52**
shear panels	Core rupture	>>1
PLD Sub-Platforms	Wrinkling	**-0.89**
Central cone	Skin rupture	0.21
Closure panels	Wrinkling	1.68

Table 9.1.5-4 PLANCK SVM Summary of M.o.S.

The negative margins of Safety have been discussed, case by case in RD 42 where the dedicated recovery actions are proposed.

Generally, the joints present positive MoS except for some details for which the recovery action has been given in a dedicated document where also joint calculation and justification is presented [R.D. 40].

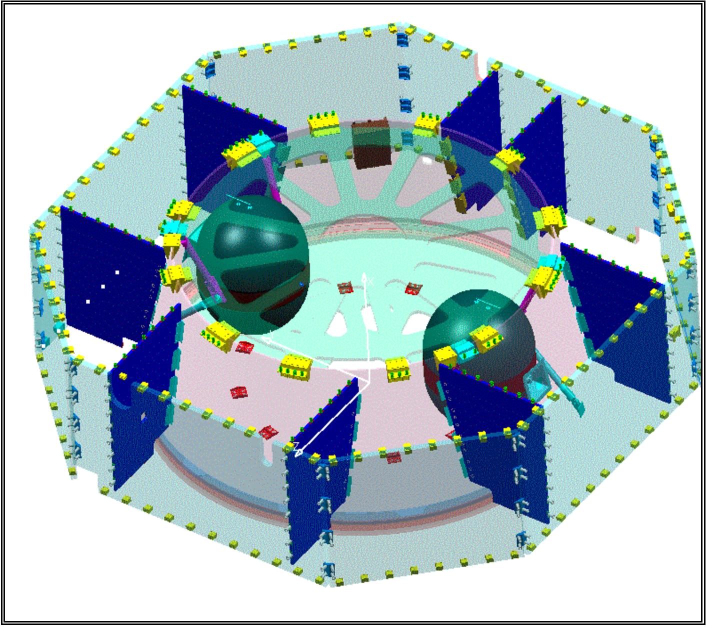
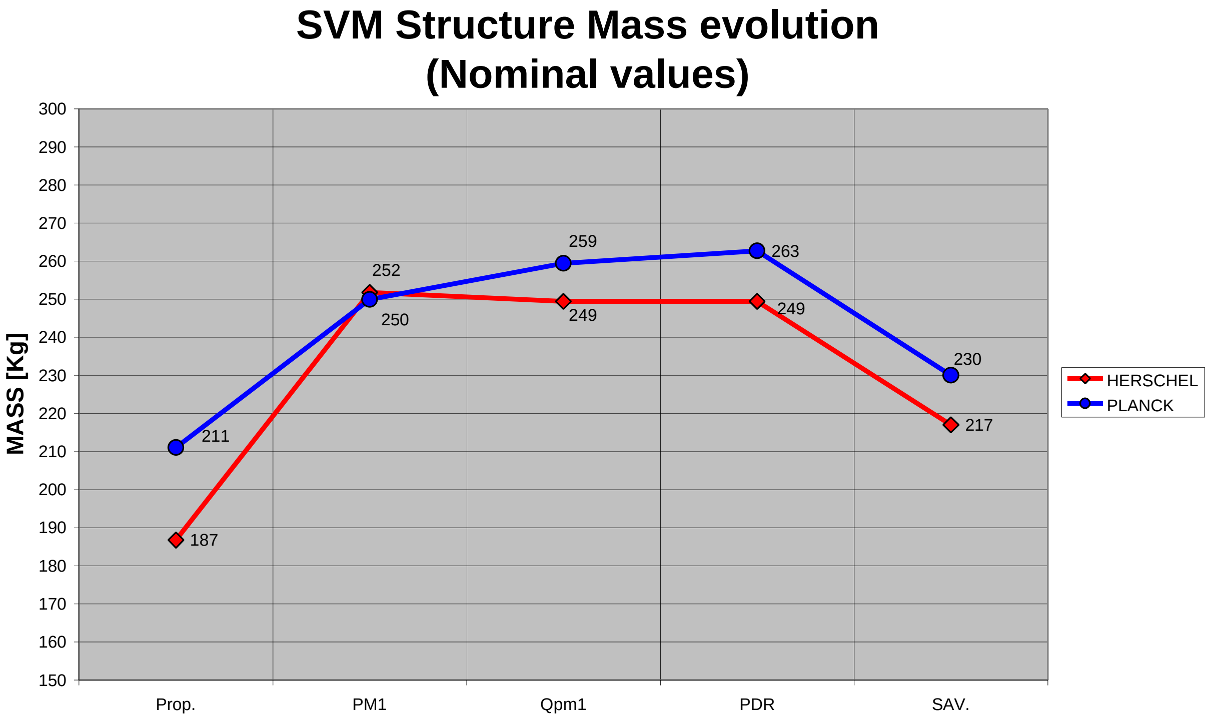


Figure 9.1.5-1 Herschel internal Joints overall view

9.1.6 Mass budget summary:

The mass budgets summary of the SVM Structures are reported in Table 9.1.4-8 and Table 9.1.4-9 where nominal masses are presented, contingencies and details are reported in document [R.D. 43] and [R.D. 44]
Mass has been considered a critical requirement since the beginning of the program and big effort to reduce the mass have been done. At least the current Requirement cannot be satisfied. The mass budget evolution is presented hereafter.



The last achieved value should be considered as the lowest values that can be obtained, applying all the mass saving identified during the Structure PDR process and summarised in [R.D 44].
The secondary structures are still under definition as the equipment they have to carry.
The layout of reinforcements has not been proposed as the final configuration is still not frozen and detailing this information at this level can only lead to the loosening of the control on mass growth.

PLANCK MAIN ITEMS	MASS [Kg]
CENTRAL CONE	69,26
LATERAL PANELS	44,90
UPPER CLOSURE PANELS	14,09
LOWER CLOSURE PANELS	13,20
SHEAR PANELS	20,10
PAYLOAD SUBPLATFORM	5,86
PTSS	7,35
RCS SUPPORT PANEL	4,21
STRUCTURAL BRACKETS (PI-Brackets, cleats)	19,98
EQUIPMENT INSERTS	6,00
BRACKETS FOR SECONDARY STRUCTURE	20,66
BOLT, NUTS, WASHERS, RIVETS	5,22
TOTAL	**230,83**

Table 9.1.6-1 Planck SVM Structure Mass Budget (nominal)

HERSCHEL MAIN ITEMS	MASS [Kg]
CENTRAL CONE	75,1835
LATERAL PANELS	37,216
UPPER CLOSURE PANELS	17,032
LOWER CLOSURE PANELS	14,64
SHEAR PANELS	20,08
PAYLOAD SUBPLATFORM	8,53
PTSS	4,9
THERMAL CLOSING SUPPORT	1,892
RCS SUPPORT PANEL	4,3
STRUCTURAL BRACKETS (PI-Brackets, cleats)	14
EQUIPMENT INSERTS	6
BRACKETS FOR SECONDARY STRUCTURE	8,527
BOLT, NUTS, WASHERS, RIVETS	4,72
TOTAL	**217,0205**

Table 9.1.6-2 HERSCEL SVM Structure Mass Budget (nominal)

9.1.6.1 C.o.G. and Inertias

The C.O.G. and INERTIAS values for the structure subsystem are given with respect to the SVM physical axes and in nominal conditions.

Herschel

C.O.G. [m]	Inertias [Kg m^2]
Xs = 0.453033	Ixx = 407.59
Ys = 0.029557	Iyy = 281.53
Zs = -0.0041378	Izz = 280.48

Planck

C.O.G. [m]	Inertias [Kg m^2]
Xs = 0.45525	Ixx = 423.86
Ys = -0.002	Iyy = 289.84
Zs = -0.02937	Izz = 280.04

9.1.7 Mountability and Dismountability

At the sight of the SVM proposed design for both satellites the Primary Structure components as well as the Secondary Structure are detachable, even the Shear Panels attached to the Central tube outer skin by special adjusted bolts, being a potentially dismountable items.

To facilitate the mounting / dismounting process, assuring the position repeatability, two centering (guide) pins / holes per item are necessary.

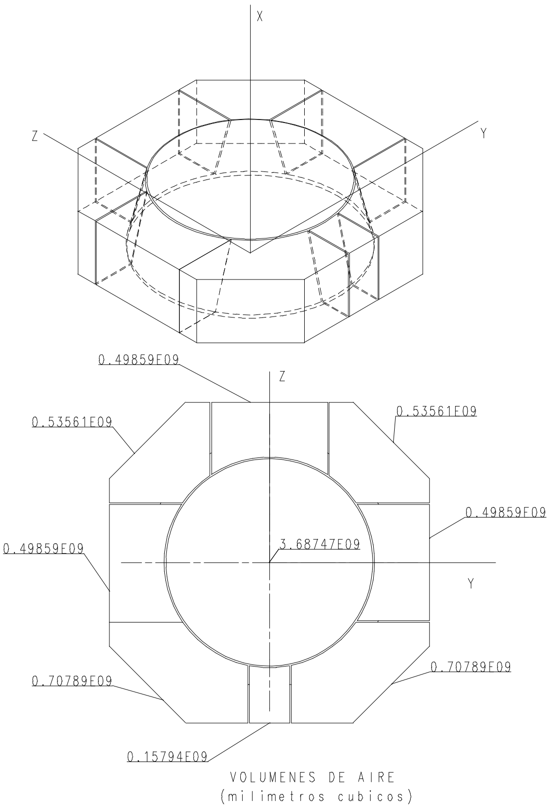
Details related to main items are showed in RD 33.

9.1.8 Venting

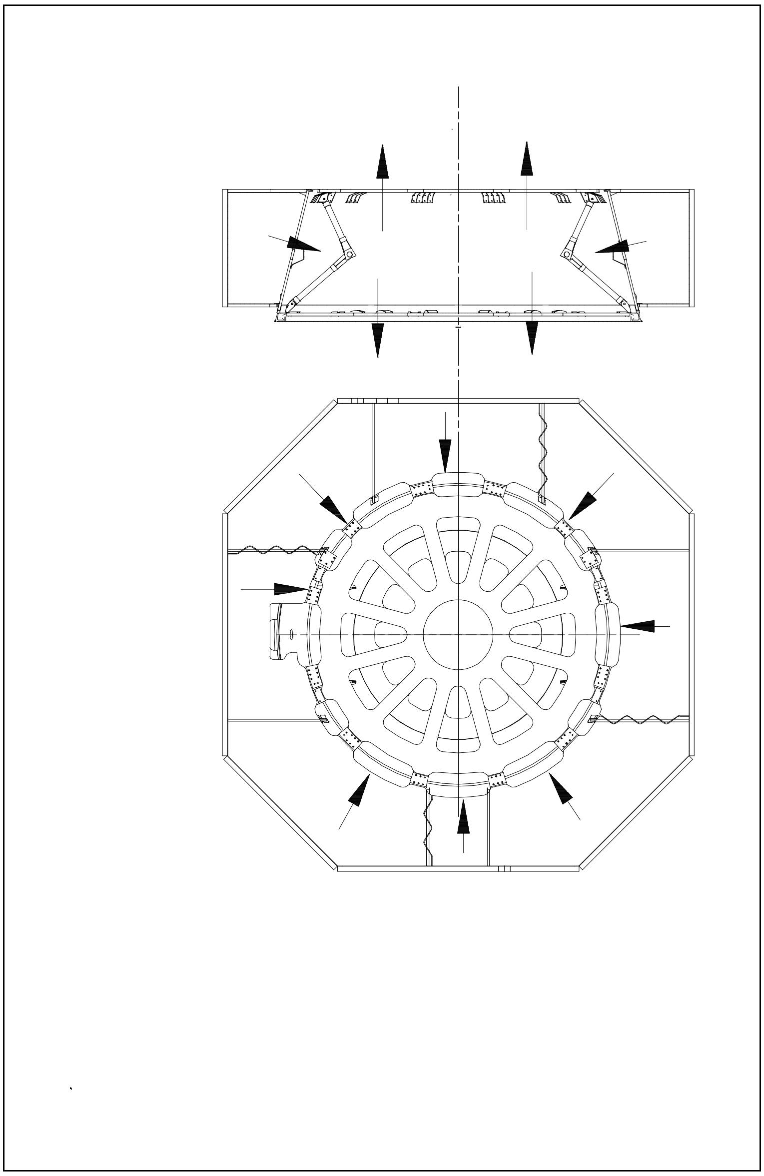
Due to the dimensions of SVM, a large volume of air needs to be evacuated during launch to ensure no damage is caused to any system or component or part of the structure.All the air contained in the Service Module between the panels and the cone will be evacuated through 8 holes to the cone.All the air contained in the cone will be evacuated through the existing holes of the payload subplatform and the thermal lower closing.
The design of the Service Module Structure will take into account the venting requirements using the solutions as follows:

- The air contained in the SVM will pass to the cone box through 8 dedicated holes of the cone and will be evacuated through the holes of the pay-load subplatform and thermal lower closing.
- Venting holes around the ring to evacuate the air caught between the CFRP cone and the ring:
- .Lower ring: 1 hole of ϕ 3.5 mm
- Venting holes in PTSS struts: 1 x ϕ 2 mm.

In the following figure are included the volumes of air to be vented.



In the next figure is shown the venting philosophy.



The size of the holes, already defined for both Herschel and Planck, will be frozen after RCS pipe routing definition, in order to utilise the same holes for Venting and RCS pipes routing, avoiding additional cut-outs in the cone.

9.1.9 Electrical Bonding

The bonding baseline of the SVM is based on four basic concepts.

Electrical connection between the elements which form a panel

If we consider a typical sandwich, one skin is connected to the other one through the metallic core. This is valid also for CFRP skins.

Connection between equipment insert and panel

The connection will be guaranteed through the unit foot and the bolt by direct contact. In cases it is found that some equipments are using isolation washers and they are not in contact with the panel (at this moment we consider that all equipment are in contact with the panel) a strap, connecting the underneath zone of the bolt with the top surface of the equipment insert, will be included.

Connection between structural insert and panel

The structural insert is connected to one metallic part by direct contact and through this part to the skin of the sandwich, them we can consider that the insert is connected to the sandwich.

Connection between Hot Bonded Insert and Sandwich

The connection will be guaranteed riveting the skin to the insert. Details are reported in [R.D.33]

9.2 SERVICE MODULE THERMAL CONTROL

9.2.1 General

The Thermal Control Subsystem of Herschel and Planck SVM are designed taking in to account these main guidelines:

- maximum commonality between the two satellites
- use of well proven design solutions
- minimum cost and budget (mass, power)
- fulfil the thermal requirements

Due to the different units/equipment layouts and to the different solar aspect angles, HERSCHEL and Planck SVM are quite different from a thermal point of view and therefore also the two thermal control configurations will be quite different. Consequently, the commonality approach is mainly followed for material procurement and for generic design solutions:

Concerning the procurement, the main components will be procured together for the two satellites, allowing reduction in the spare quantity.

The attitude and orbit constrains are usually important in defining the operative condition for the TCS. The long distance from the earth reduces their effects on the two satellites: albedo and earth-shine fluxes will act only during the launch phase and the LEO time, while on station only the sun fluxes will be considered.

9.2.2 Requirements and Design Drivers

The SVM Thermal Control Subsystem is requested to maintain all the SVM components, within their flight temperature limits, during all the mission phases and in the different operational modes.
The temperature limits shall be guaranteed also for the PLM warm units that are mounted onto the SVM; for some of these units it is also request to limit the temperature fluctuation.
While the temperature requirements of the SVM equipment are the typical ones for scientific satellite, the thermal requirements of the PLM units are much more stringent.
For these reasons, it is mandatory to limit as much as possible the heat transfer at the SVM/PLM interface level.
Goal requirement: define the value over the design requirement which is desired to be obtained. The TCS subsystem shall provide in each case , specified in this document, a detailed assessment of the specific conditions which are to be respected to achieve the required goal and if deemed not achievable, the limit performances with an adequate justification.

The main particular thermal requirements for HERSCHEL and Planck SVM are reported hereafter.

HERSCHEL SVM

IDENTIFICATION		Location Panel	Requirement	GOAL	Remarks
			Temp. stability DT/dt	Temp. stability DT/dt	
Equipment	Name				
HIFI	**Heterodyne Instrument for the Far Infrared**				
FHLCU	Local Oscillator Control Unit	-Y	+/-3 K/hour	+/-0.03 K/100s	
FHLSU	Local Oscillator Source Unit	-Y	+/-3 K/hour	+/-0.03 K/100s	
FHHRH	High-Resolution Spectrometer, Horizontal polarisation	-Y	+/-3 K/hour	+/-0.03 K/100s	
FHHRV	High-Resolution Spectrometer, Vertical polarisation	-Y	+/-3 K/hour	+/-0.03 K/100s	
FHFCU	Focal Plane Control Unit	-Y/-Z	+/-3 K/hour	+/-0.14 K/100s	
FHWEV	Wide-Band Spectrometer Electronics Veritical Polarisation	-Y/-Z	+/-3 K/hour	+/-0.03 K/100s	
FHWEH	Wide-Band Spectrometer Electronics Horizontal Polarisation	-Y/-Z	+/-3 K/hour	+/-0.03 K/100s	
FHICU	Instrument Control Unit	-Y/-Z	+/-0.14 K/100s TBC	N.A.	
FHWOV	Wide-Band Spectrometer Optics Vertical Polarisation	-Y/-Z	+/-3 K/hour	+/-0.03 K/100s	
FHWOH	Wide-Band Spectrometer Optics Horizontal Polarisation	-Y/-Z	+/-3 K/hour	+/-0.03 K/100s	
SPIRE	**Spectral Photometer Imaging Receiver**				
HSDCU	HS Detector Control Unit	-Z	+/-3 K/hour	N.A.	
HSFCU	HS FPU ControlUnit	-Z	+/-3 K/hour	N.A.	
HSDPU	HS Digital Processing Unit	-Z	+/-3 K/hour	N.A.	

- The total heat fluxes exchanged at the PLM-SVM I/F shall be less than 1 Watt

Discussion about the status of compliance with temperature stability requirement is provided in para 7.4.4.4.

SVM Thermal interface requirements

Status of compliance of the blankets requirements, installed on top of the SVM upper panels and as on top of the PLM subplatform, in according to AD-47, is hereafter presented:

- infrared emissivity ≤0.05 ⇒ COMPLIANCE (0.05)
- external layer Temp.< 220K (TBC) ⇒ COMPLIANCE (<220K)

In addition, SVM/PLM Temperature I/F req. are requested:

- CVV truss attachment points T < 293K (TBC) ⇒ COMPLIANCE (<293K)
- SVM shield attachment point T < 293K (TBC) ⇒ NOT COMPLIANCE (max 300K)

PLANCK SVM

For Planck, the most important requirements are related to the temperature stability needed on the radiative panels on one hand, and on the SVM/PLM interface level on the other hand:

- The SVM TCS shall ensure the following interface temperature stability performances at I/F truss attachment point level: component at $^{1}/_{60}$ Hz of temperature < TBD

- The SVM TCS shall ensure the following interface temperature stability performances at radiative panels level: spectral density at $^{1}/_{60}$ Hz of temperature < 0.01 K $Hz^{-1/2}$

Stringent requirements are concerning the temperature stability of some warm IFI and LFI payload units:

Planck

HFI	**High Frequency Instrument**	Requirement	Goal
PAU*	Pre-Amplifier Unit	+/-3 K/hour	+/-1.1 K/hour
LFI	**Low Frequency Instrument**		
BEU/DAE*	Back End Unit	+/-3 K/hour	+/-0.2 K/hour
SCC	Sorption Cooler Compressor	+/-3 K	(3K,1K,0.5K)**

Note* The radiative loads from the instrument units mounted on top of the sub-platform (PAU and BEU, together, MLI surfaces excluded) shall not exceed 2.3 W.
Note** - Data, applicablle only during the adsorption phase, are related to:
+/- 3K for First adjacent element (TBC)
+/- 1K for the Next adjacent element (TBC)
+/- 0.5 for Next most element (TBC)

A specific requirement is also put on the temperature difference between the propellant tanks:
For Planck only, the stability of the gradient between each Propellant Tank shall be less than 0.1 °C over the entire mission life.

In addition to the previous constraints, the SVM must accommodate a very dissipate unit, the Sorption Cooler Compressor (two SCC in cold redundancy), which furthermore exhibits a highly fluctuating power .
An additional major feature of the SCC lies in its rather low operating temperature range, compared to usual equipments:

- 260 K < SCC Bed Temperature <280 K

All these characteristic lead to provide a very large radiative surface to keep this equipment inside the operating limits.

Discussion about the status of compliance with temperature stability requirement is provided in para 7.4.4.4

SVM Thermal interface requirements

Status of compliance of the blankets requirements, installed on top of the SVM upper panels and as on top of the PLM subplatform, in according to AD-47, is hereafter presented:

- infrared emissivity ≤0.05 ⇒ COMPLIANCE (0.05)
- external layer Temp.< 220K (TBC) ⇒ COMPLIANCE (<220K)

Status of compliance of the blanket requirements installed on the SVM units (BEU and PAU)mounted on the sub-platform:

- infrared emissivity e <0.05 ⇒ COMPLIANCE (0.05)
- external layers Temp.< 200K (TBC) ⇒ COMPLIANCE (<200K)

Status of compliance of the blanket requirements installed on the backside of the solar array:

- infrared emissivity e <0.05 ⇒ COMPLIANCE (0.05)
- external layers temperature < 300 K (TBC) ⇒ COMPLIANCE (<300K)

In addition, SVM/PLM I/F req. are requested:

- Temp. at PLM truss attachment points <293 K (TBC)⇒ NOT COMPLIANCE (max 310K)

- The radiative loads from the instrument units mounted on top of the sub-platform (PAU and BEU, together, MLI surfaces excluded) do not exceed 2.3 W as required ⇒ COMPLIANCE

9.2.3 Functional Description

The Thermal control of the SVM will maintain the temperature requirements during all the lifetime. For this purpose it will:

- Reject the unit dissipation to the deep space (OSR, Black paint).
- Insulate the external surfaces of units and module not used for the heat rejection (MLI's, Aluminised tapes).
- Increase the linear conductance for the units that need to be cooled via conduction (fillers and thermal doublers).
- Conductively insulate the units/items whose sink is too hot or cold (thermal washers).
- Provide power dissipation for the units/items/enclosures (heaters, thermostats, thermistors).

The external surfaces of lateral panels, where there are not radiators will be covered by MLI's. The adapter/separation ring will be insulated by MLI as much as possible, except for those surfaces that shall be left free for adapter or Ariane 5 interfaces.

9.2.4 Design and Performance

9.2.4.1 Herschel Design

The main HERSCHEL Thermal Control components are MLI and radiators.
The lateral panels are partially covered with radiators to reject the internal dissipation except for +Z panel (always completely sun-exposed), that are totally cover with MLI.
For the others sun-exposed panels, the radiators will be made of OSRs, (low α and high ε, both at beginning and end of life).

The amounts of radiator/MLI areas for each lateral panel are reported in Table 9.2.4.1-1 while Figure 9.2.4.1-1 shows the radiator area location:

Panel	**Radiators [m^2]**	**Blankets [m^2]**
+Y +Z	0.852	0.122
+Z	0	1.462
-Y+Z	0.487	0.487
-Y	0.853	0.609
-Y-Z	0.609	0.365
-Z	0.487	0.974
+Y-Z	0.365	0.609
+Y	1.035	0.426
Total	**4.688**	**5.054**

Table 9.2.4.1-1 HERSCHEL SVM lateral panels - Radiators/MLI areas

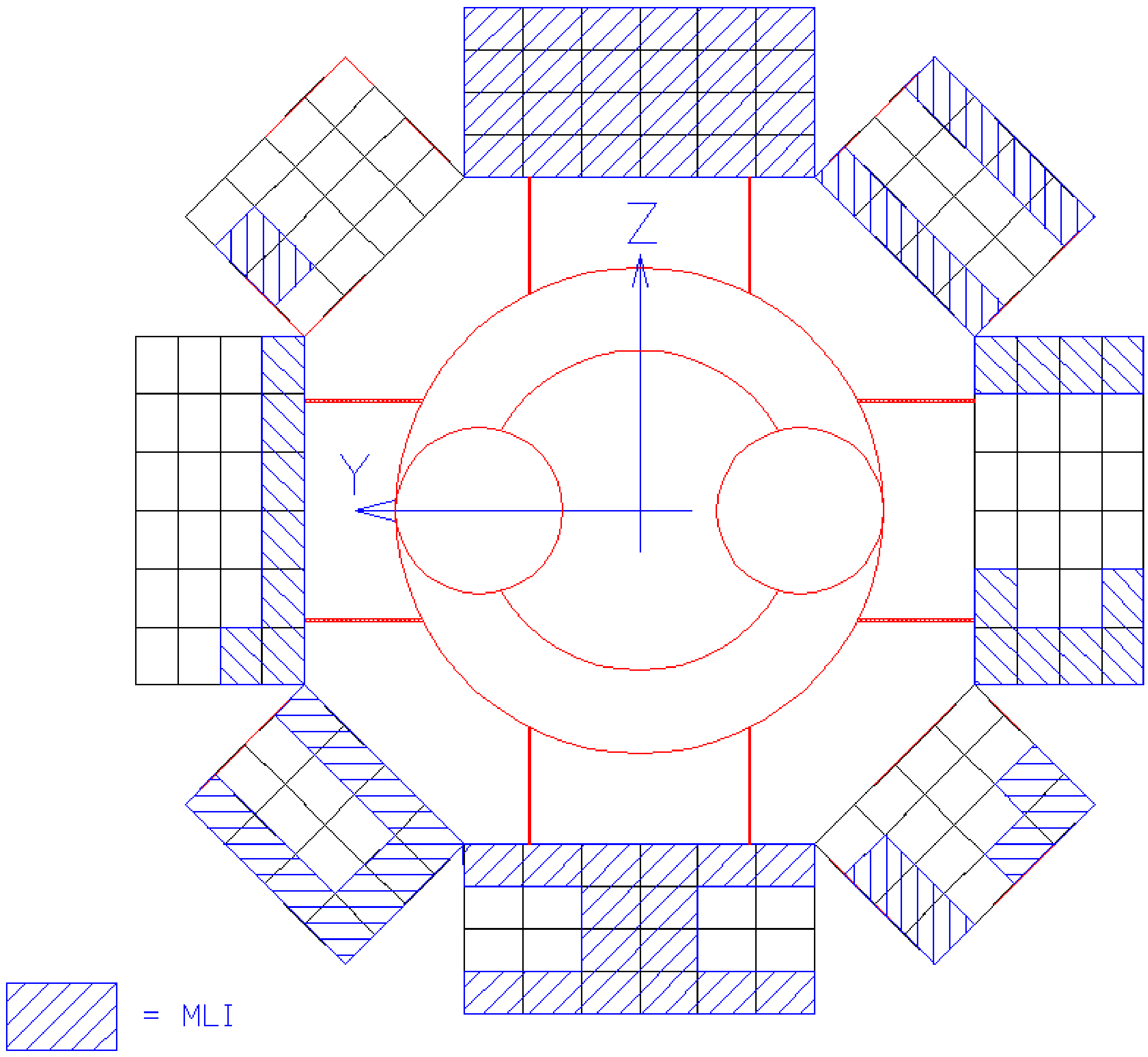


Figure 9.2.4.1-1 HERSCHEL radiator areas

Thermal blankets are also mounted on the two SVM floors, for radiative insulation from the cold environment on –X side, and thermal insulation from the cold PLM.

The central cone is closed in the lower side by a set of blankets. This prevents sun illumination of the inner part of the central cone when the SAA is < 0°, and then reduce the temperature variation of the SVM when tilting the spacecraft; MLI are moreover used internally for RCS Tanks.

The PLM warm units (FHWBE, FWHBO, FHWBI FHFCU, FHICU, FHHRH, FHHRV, FHHRI, FHLCU and FHLSU) are also covered with MLI to meet the temperature requirement stability. A secondary structure is necessary to support the thermal blankets.

The entire internal surface are considered black (CFRP skin or paints), at the same time all the units are considered with high emissivity surface (typically black paint). Figure 9.2.4.1-2 shows the internal SVM thermal control main components:

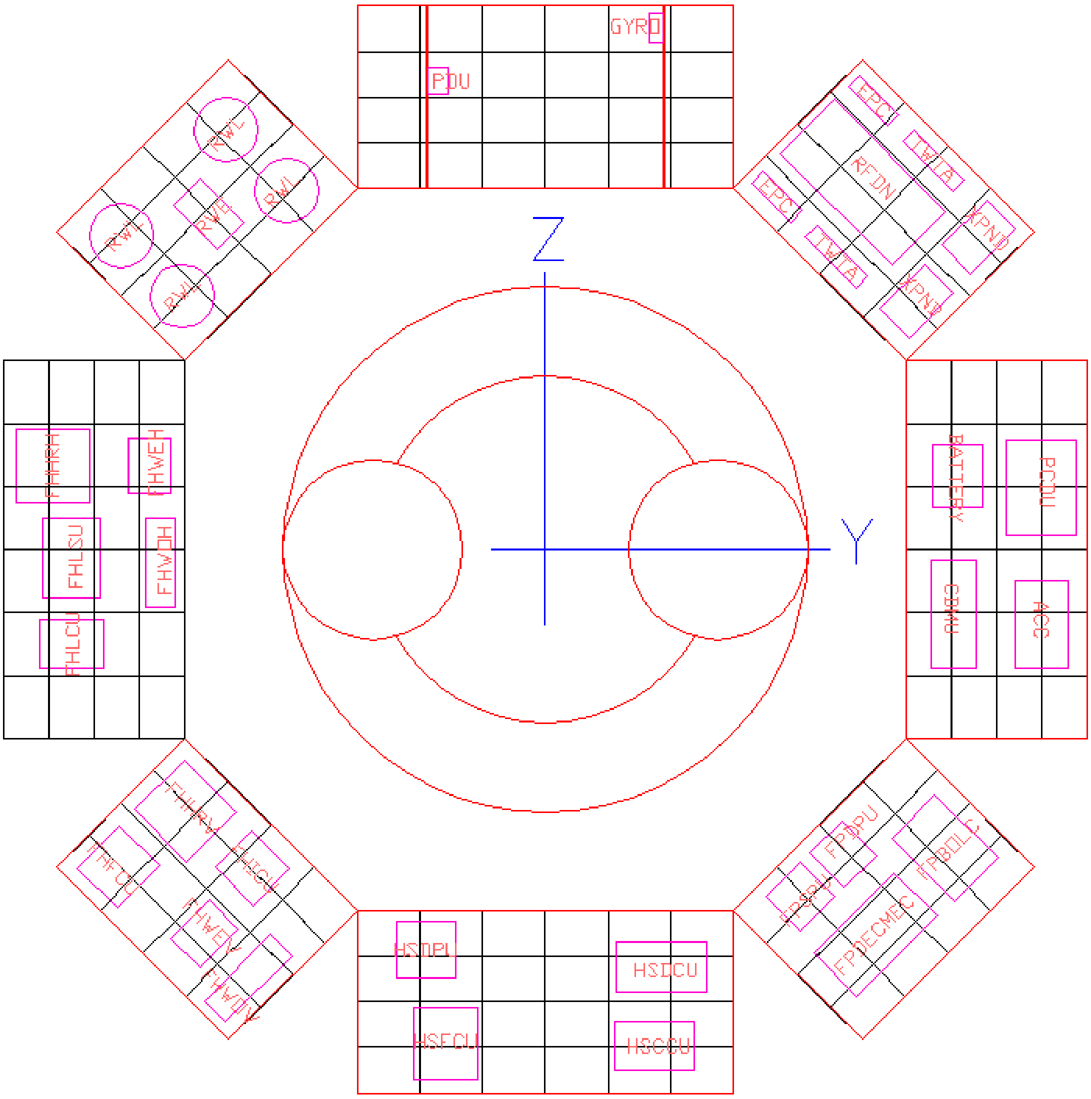


Figure 9.2.4.1-2 HERSCHEL internal SVM thermal control components

9.2.4.2 Planck Design

The Planck Thermal Control design is schematically represented in Fig 9.2.4.2-1.

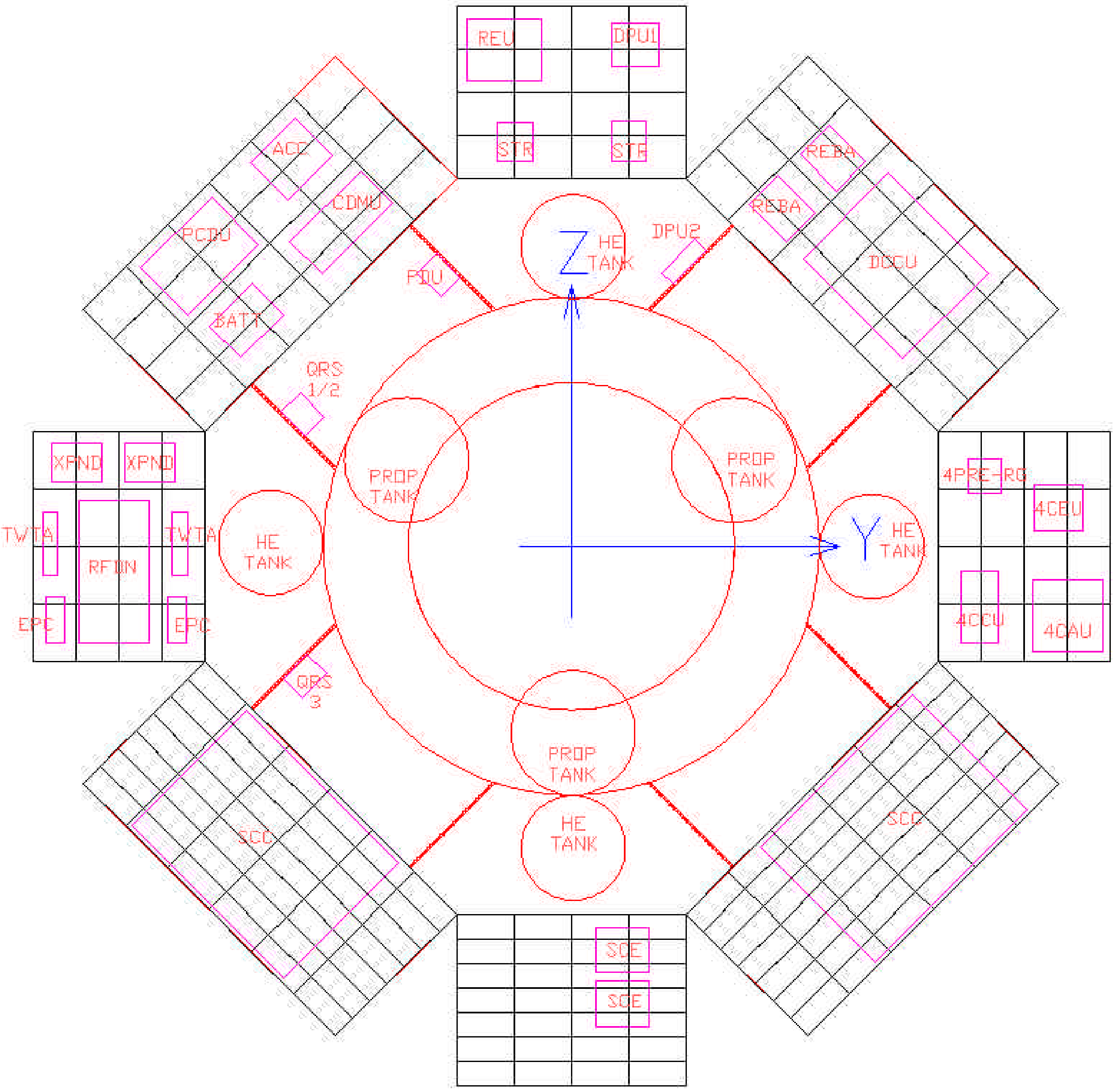


Figure 9.2.4.2-1 PLANCK internal SVM Thermal control components

The main component of the Planck Thermal Control Design is the Heat pipes (HP) network installed on the three SCC panels. The HP configuration (for one SCC panel) are reported para 9.2.4.12.

The SCC/SCE boxes and panels are covered with MLI blankets in order to avoid the transmission of the temperature fluctuation to the internal SVM.

Also the other SVM lateral panels are partially covered with radiators to reject the internal dissipation. For Planck satellite the radiator material can be chosen among various type of material with high emissivity because in nominal operation no sun impinges on the panels and therefore there is no absorbed solar fluxes. Analysis will carried on considering black paints (for cost and mass saving).

On the top of Planck SVM sub-platform are mounted the BEU and PAU boxes. In order to increase the heat rejection flux, a portion of one lateral side for each box is coupled directly with the space. This radiative area is not covered by MLI and the surface finish is black paint.

All the other SVM external surfaces are covered with thermal blankets. In particular the Solar Arrays have the rear side covered with MLI.

Internally thermal blankets are used for the He and RCS tanks.

The amounts of radiator area for each panel are reported in table Table 9.2.4.2-1, while in Figure 9.2.4.2-4 the radiator area location is reported.

Panel	**Radiators [m^2]**	**Blankets [m^2]**
+Y	0.73	0.244
+Y +Z	0.241	1.220
+Z	0.609	0.365
-Y+Z	0.669	0.305
-Y	0.364	0.610
-Y-Z	1.461	2.335(*)
-Z	0.974	1.31 (*)
+Y-Z	1.461	2.335 (*)
Total	**6.509**	**8.724**

(*) On the internal side

Table 9.2.4.2-1 Planck SVM lateral panel - Radiators/MLI areas

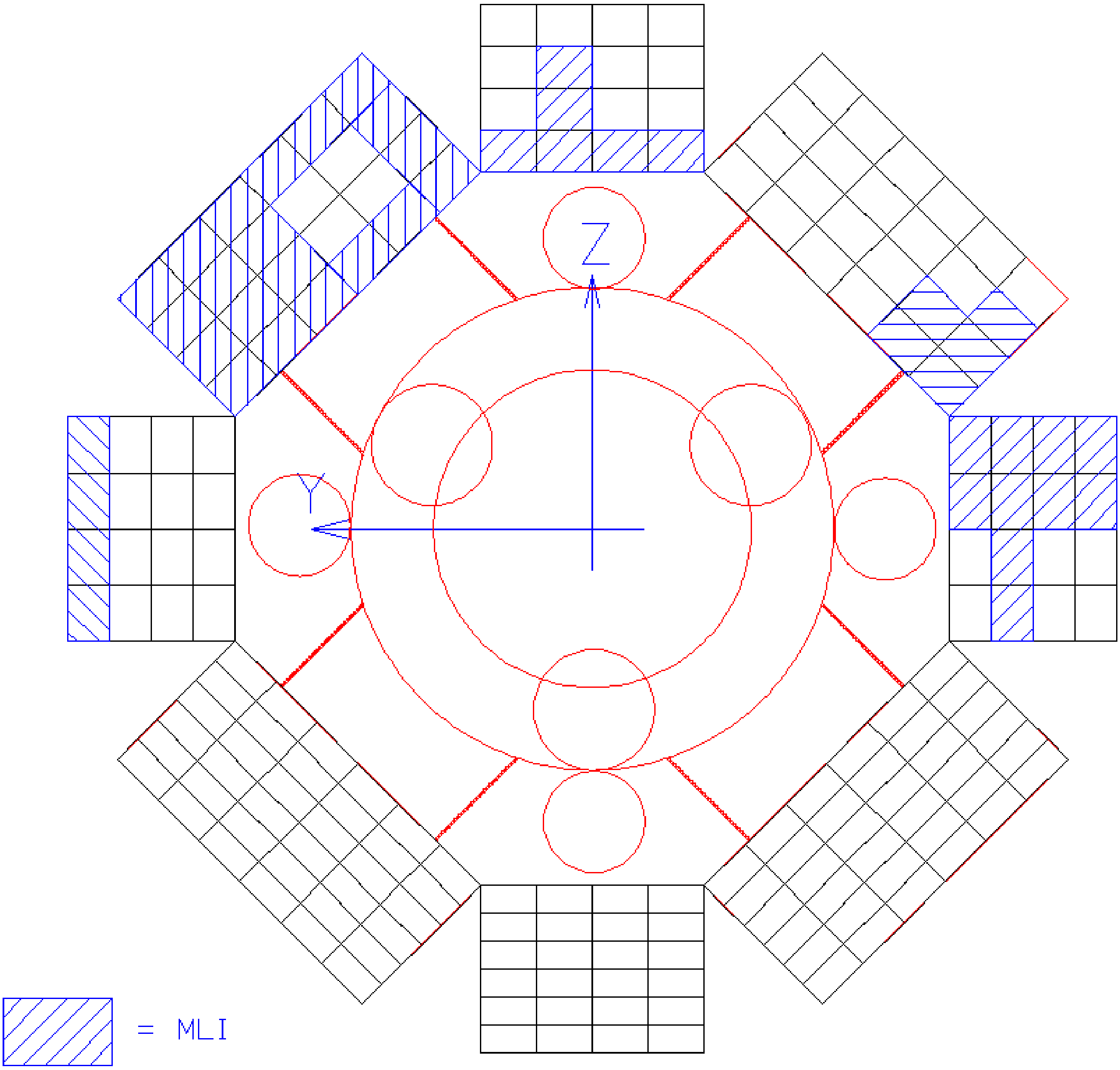


Figure 9.2.4.2-1 Planck Radiators Lay-out

9.2.4.3 MLI Blankets

The MLI blankets insulate the covered items from the external environment. This is obtained manufacturing together a certain number of KAPTON and MYLAR Aluminised foils. Generally a DACRON net is interposed between two layers, reducing their contact and improving the insulation performance. Number and composition of the layers vary for the different parts of the satellite. Another important point is the surface finish of the external layer, and its choice is driven mainly by electrical and optical requirements: according to the foreseen radiation environment no particular surface treatment is requested. Nevertheless if particular ESD request should be issued during phase B, the external layer will be covered with ITO conductive layer deposited on KAPTON foils or the Carbon filled KAPTON, which provides low electrical surface resistivity, will be used where black surfaces can be used.
Examples of possible SVM MLI types are reported in Table 9.2.4.3-1 where:

- SAK = Single Aluminised KAPTON
- DAK = Double Aluminised KAPTON
- DAM = Double Aluminised MYLAR

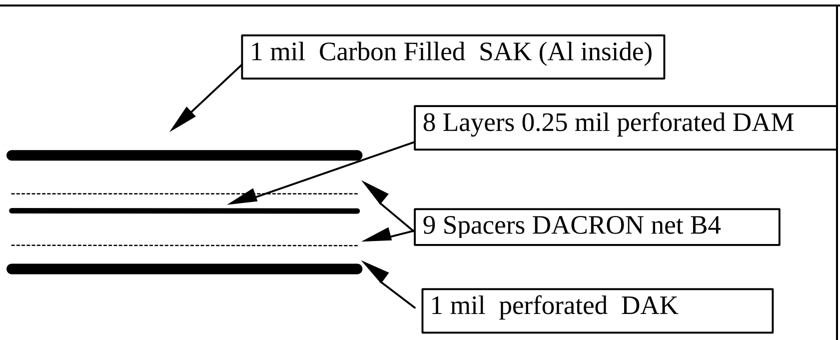
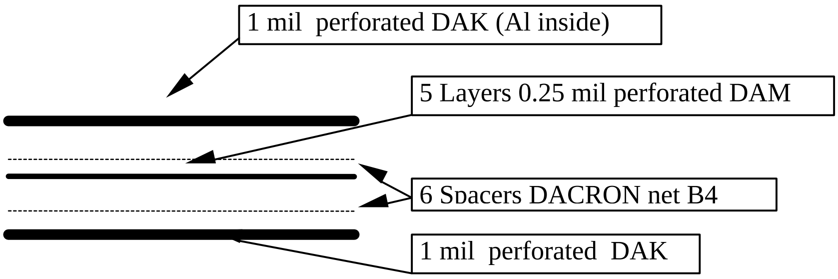
	**MLI TYPE 1** **PANELS**
	**MLI TYPE 2** **INTERNAL SIDE**

Table 9.2.4.3-1 SVM MLI Types

The blankets will be installed taking in to account grounding requirements: Grounding points, see will be included in each blanket with area larger than 100 cm^2.
Use of perforated layers guarantee internal blanket venting capability, while dedicated provision are manufactured in the blanket to allow the venting of the Satellite.

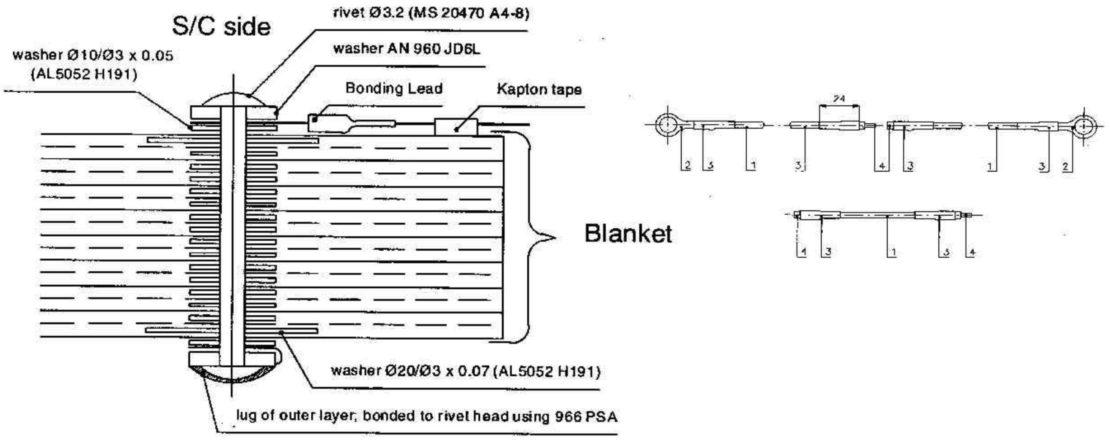


Figure 9.2.4.3-1 PLM MLI Grounding point design

9.2.4.4 Heaters, thermistors and thermostats

The heaters will be used to maintain the units above their lower temperature during the cold phases and/or to maintain the units at a constant temperature if required. They will be fed by the PCDU while they can be switched (ON-OFF) in different ways:

- by a command send by CDMU following temperature sensor measurement (nominal cases and survival)
- autonomously by thermostat at fixed thresholds (emergency case)

Thermostats are mechanical thermal switches which open/closed an electrical circuit when their temperature reach predefined thresholds. They will be used on emergency heater lines.
For failure recovery reasons, each heater line will be split in two separate lines: a nominal one and a redundant one. Moreover Nominal and Redundant heaters will be physically separated.

Thermistors are used as temperature sensors to monitor the SVM equipment temperature providing information about spacecraft health and reference for heater control.

The heaters mounted on the Herschel & Planck satelites will be subdivided in nominal (including survival phase) and emergency heaters line.

Nominal heaters: Used to maintain the minimum operative temperature during the nominal phases. They are divided in two different control loop classes:

- control loop without thermal stability requirements (Class "A")
- control loop with thermal stability requirements (Class "B")

Each control loop is composed of 3 thermistors and 2 heater lines (1 prime and 1 redundant).
The thermal regulation will follow the reading of 3 thermistors; for failure tolerance reason a majority voting policy is applied to the 3 sampled values. The control process acquires the temperature of thermistors and operates consequently on the associated heater lines according to specific control laws. The commanding toward the heater lines is performed managing properly relevant Heater Control Switches (HCS) and Heater Protection Switches (HPS) belonging physically to the PCDU.

All nominal heaters lines will be commanded by the CDMU application software.

For class "B" a Pulsed Width Modulation mode commanding is carried out with a control loop check frequency equal to 10 seconds (TBC) and the heater command period equal to 1 second (TBC).
Viceversa a sample switch ON/OFF is performed for control loop belonging to class 'A" with a control loop check frequency equal to 60 seconds (TBC).

The preliminary temperature regulation, are hereafter showed:

CLASS "A":

Condition	Heater commands
$T_{mon} < T_{min}$	Switch-ON HCS
$T_{mon} > T_{max}$	Switch-OFF HCS
$T_{min} \leq T_{mon} \leq T_{max}$	No commands

where:
- T_{mon}: thermistor value measured according to a majority voting approach.
- T_{min}, T_{max}: lower and upper thermistors thresholds.

CLASS "B":

- evaluation of delta temperature (ΔT_{mon}) between two consecutive monitors to be performed at the monitoring frequency (10 sec)

-Condition	Heater commands
($\Delta T_{mon} < 0$ and $\lvert\Delta T_{mon}\rvert > \lvert\Delta T_{ref}\rvert$ and Tmon < Tmax) or (Tmon < Tmin)	Send till the next monitoring a sequence of width modulated pulse commands according to a TBD control law.
Otherwise	No commands

where:
- ΔT_{mon}: delta temperature between two consecutive measures.
- ΔT_{ref}: delta temperature resolution
- T_{mon}: thermistor value measured according to a majority voting approach.
- T_{min}, T_{max}: lower and upper therm.rs thresholds

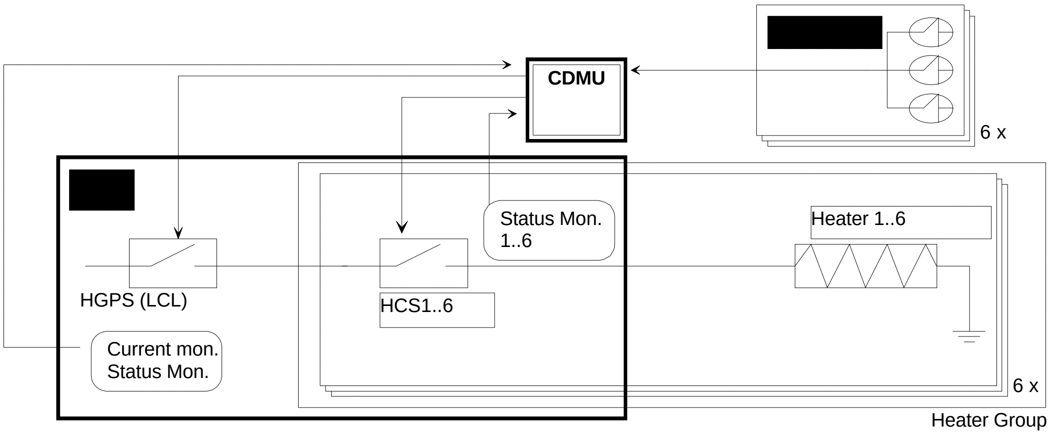


Figure 9.2.4.4-1 Nominal Heaters Electrical scheme

Emergency heaters:

Used to provide dedicated heaters power for thermally critical units to maintain them within the minimum operative temperature. This heaters line are connected directly at the battery (by PCDU) such that no other units nor subsystem must be active to energise these lines; for safety reason, these heaters shall be controlled by dedicated thermostats. Figure 9.2.4.4-2 shows the electrical scheme.

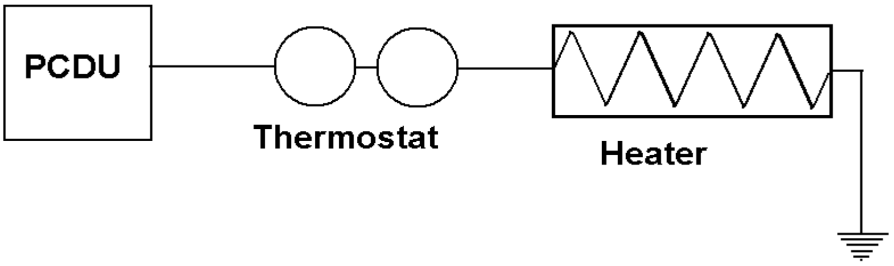


Figure 9.2.4.4-2 Emergency Heaters Electrical scheme

9.2.4.5 Surface Finishes

High emissivity values increase the heat exchanges from units and to the structure. As baseline, all the units will have high emissivity ($\varepsilon > 0.85$) finishes, generally black paint. The SVM internal structure surfaces are made of honeycomb sandwich with Al or CFRP face-sheets. The CFRP has a high emissivity value ($\varepsilon > 0.85$), while the Al skin provides a low value ($\varepsilon = 0.1$). If required, Al skins may be black painting as well. The external surfaces of lateral panels, where there are not radiators, and the external side of the lower platform will be covered with MLI's. The adapter/separation ring will be insulated by MLI as much as possible, except for those surfaces that shall be left free for ARIANE 5 interfaces.The thermo-optical propertiers are riassumed in the table 9.2.4.4-1

SURFACES	MATERIALS	Alpha	Alpha	Epsilon
		BOL	EOL	
Internal surfaces (black paint, carbon fibre & Units)	Black Paint	0.9	0.9	0.9
Radiators	OSR	0.1	0.18	0.78
Internal MLI and Top MLI	Kapton Aluminized	0.15	0.15	0.05
External MLI	Carbon Filled	0.92	0.92	0.86
Launcher Adaptor Ring	Alumnium	0.15	0.15	0.05

Table 9.2.4.4-1: Thermo-optical properties

9.2.4.6 Thermal Interfaces Modifiers

The thermal contact between units and mounting panel can be varied using dedicated items:

- Interface filler to increase the thermal conductance increasing the heat exchanges and reducing the temperature differences between equipment and mounting structure
- thermal insulating washer to decouple the units from the panel and reduce the thermal exchanges

Thermal filler interposed between equipment mounting feet/baseplate and structure is used, where required, to increase the thermal conductance in order to allow a correct thermal control of the equipment.
SIGRAFLEX Type F has been chosen as solid thermal filler. DC 93500 (liquid) is considered an alternative solution.
Thermal washers (material NARMCO) could be installed at the units mounting interface where a thermal decoupling is required. Washers could also be used for cleats connecting lateral panel and shear webs, where decoupling is required between panels.

The PLM has been thermally insulated by the SVM by means of:

- GFRP struts (limiting the conductive exchanges)
- SVM shield (reducing the radiative exchanges)

9.2.4.7 Thermal Doublers

Thermal doublers are Al plates interposed between units and mounting panel to increase the lateral thermal exchanges. This allows to optimise the use of radiator areas larger than those facing the baseplate.
Thermal doublers (thicknes=1mm) are used under the PCDU area for both satellite.

9.2.4.8 Radiator areas

Radiator areas will be used to reject the thermal dissipation of the electronic units. Selected finishes will provide high emissivity (ε) and low absorbivity (α) values: typical thermo-optical properties are reported in Table 9.2.4.8-1.

Material	a		e	**Remarks**
	BOL	**5 yrs**		
OSR	**.1**	**.18**	**.78**	**XMM/INTEGRAL data**
Black Paint	**.9**	**.9**	**.8**	**Typical values**
ITO Silver TEFLON	**.12**	**.27**	**.76**	**Sheldahl Data File**

Table 9.2.4.8-1 Thermo-optical properties

9.2.4.9 SVM Local Thermal Design

For PDR objective only the SCC local thermal model has been introduced in the overall TMM. For the other Local model, they will be included in the next thermal analysis, as soon they will by available by the units suppliers.

9.2.4.10 RCS Piping Thermal Control

Local TMM will be performed as soon as the relevant detail information will provide by RCS subcontractor

9.2.4.11 Thruster FCV

Local TMM will be performed as soon as the relevant detail information will provide by RCS subcontractor

9.2.4.12 Heat Pipes

The main component of the Planck Thermal Control Design is the Heat pipes (HP) network installed on the three SCC panels.
It is composed by vertical and horizontal HPs. 16 vertical HPs are mounted directly under each SCC unit covering the whole bed I/F surface.
The HP width is 25 mm to be compliant with the bed I/F mounting holes. The HP length covers actually all the internal SVM panel height (750 mm).
Each set of vertical HPs are mounted on a bench of 8 horizontal HPs. Figure 9.2.4.12-2 and Figure 9.2.4.12-3 show schematically the HP configuration under the SCC beds.
Heat pipes network is shown in the Fig 9.2.4.12-1.

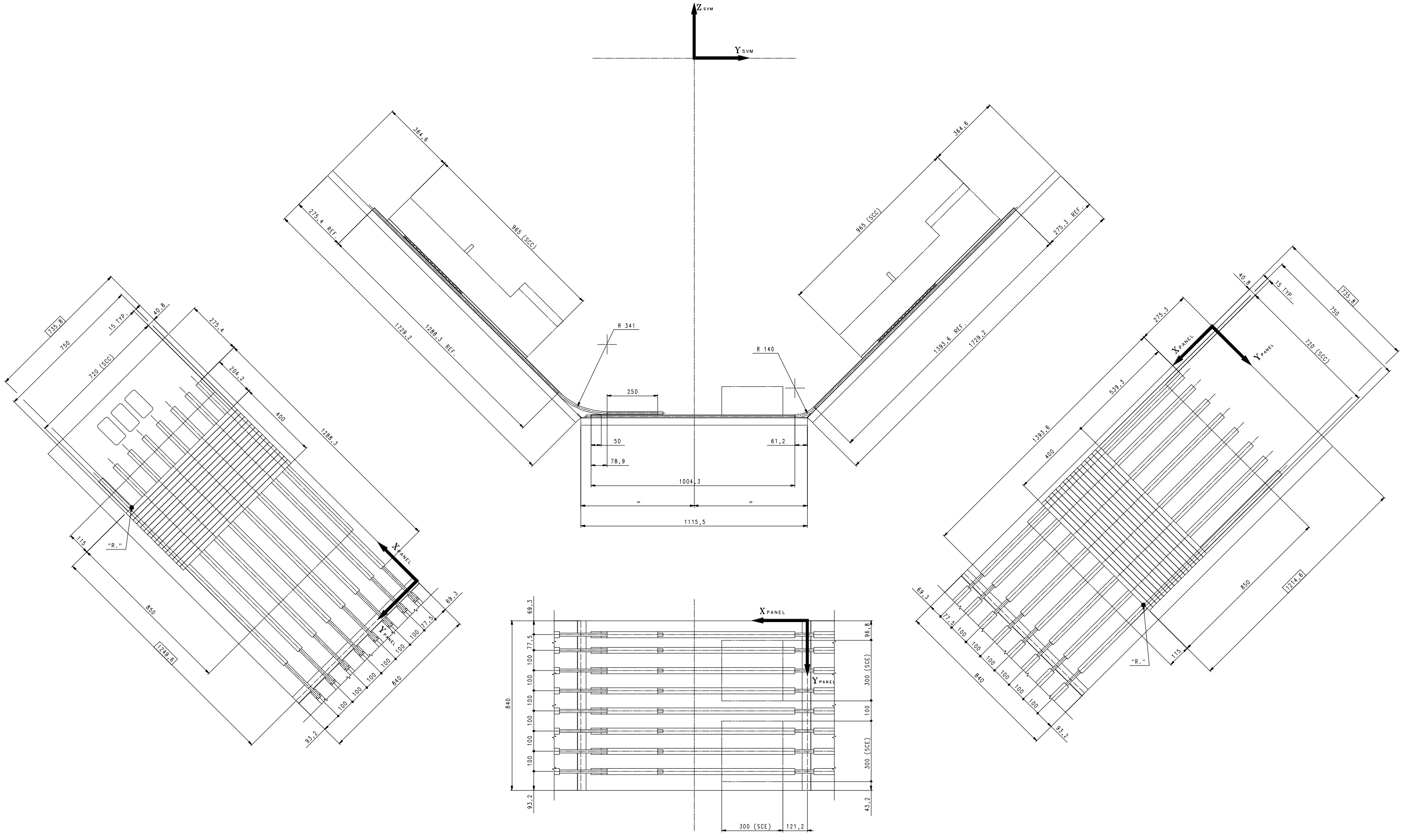
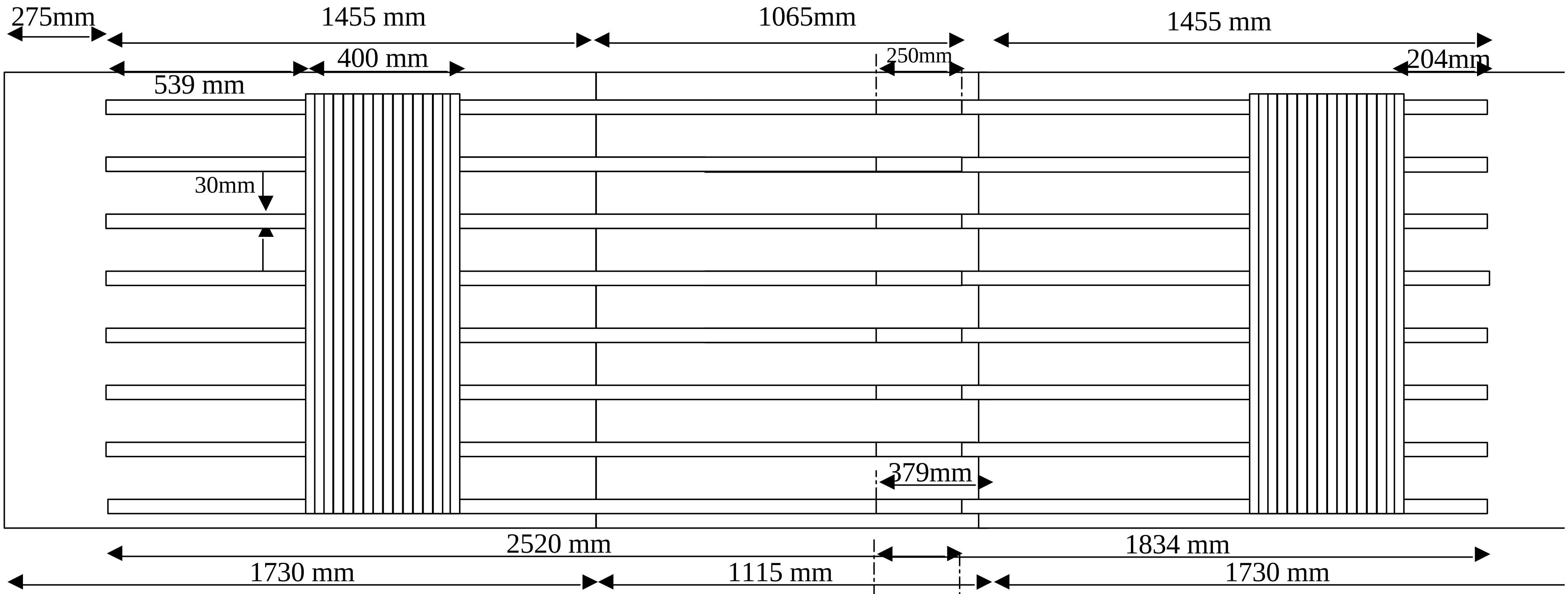


Figure 9.2.4.12-1 Planck Heat Pipe network



Type “A”--> N° 8 Horizontal Heap pipes: Width = 30mm, Length = 2520 mm (TBC)
Type “B”--> N° 8 Horizontal Heap pipes: Width = 30mm, Length = 1834 mm (TBC)
Type “C”--> N° 16+16=32 Vertical Heap pipes: Width = 25mm, Length = 750 mm (TBC)
Note: Drawing not in scale

FIGURE 9.2.4.12-2: HEAT PIPES NETWORK (Frontal view)

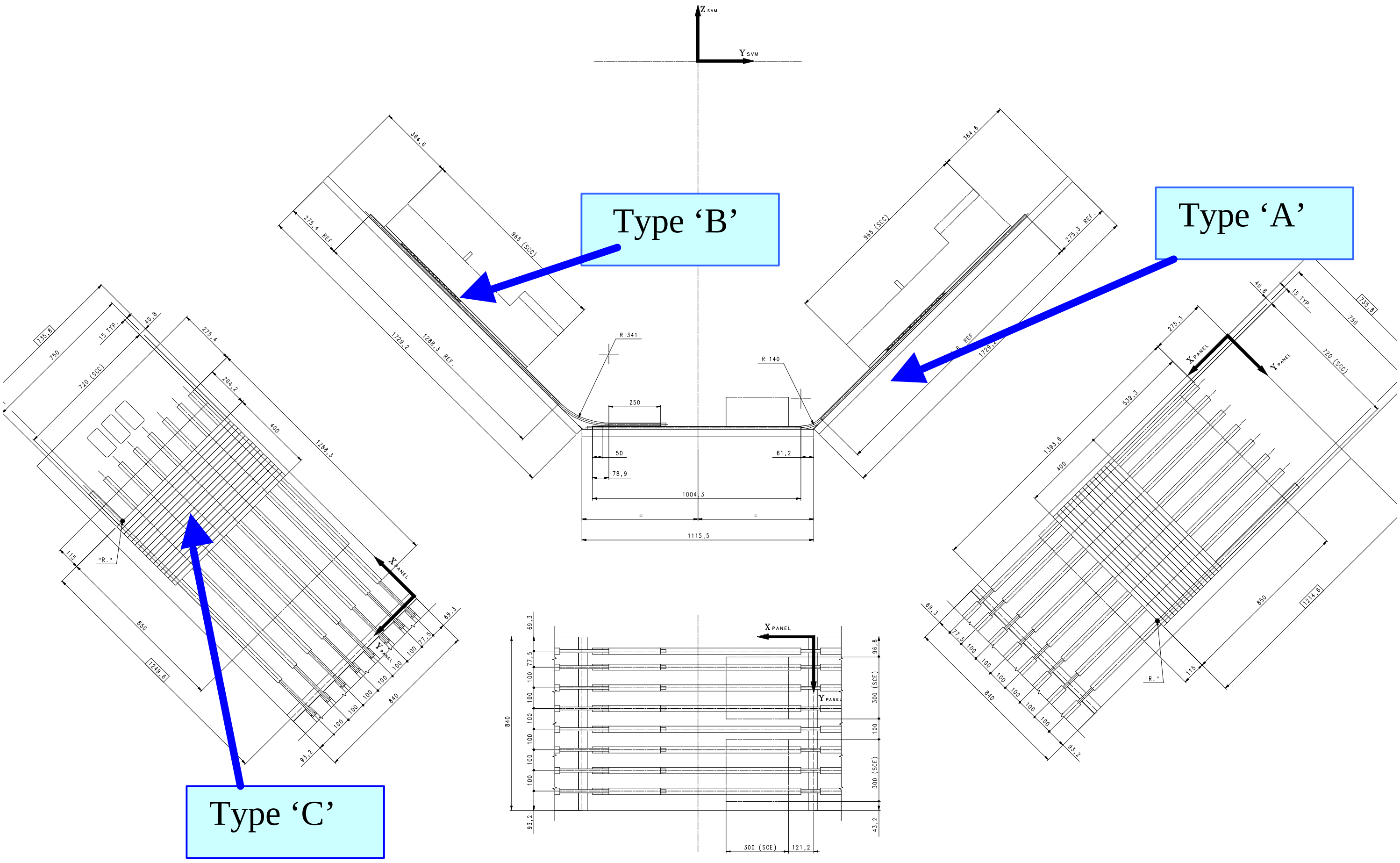


FIGURE 9.2.4.2-3 HEAT PIPES NETWORK (Top view)

9.2.5 Commonality Assessment

The SVM TCS of the two satellites will be developed trying to extent to the maximum the commonality between them.
The commonality will concern mainly the kind of design solutions which will be used, while the their sizing (radiator areas, heater powers etc.) will be different for the two satellite.
The common design solutions for the two S/Ls will be based on the same Thermal Hardware components:

- Multi Layers Insulation
- Heaters, thermistors, thermostats
- Paints and coatings
- Filler and washers

9.2.6 Budget Summary

HERSCHEL budget

- **Mass budget**

HERSCHEL TCS mass budget is reported in Table 9.2.6-1:

DESIGNATION	REFERENCE	STATUS				UNCERTAINTY %			CURRENT
		EST.	CALC.	WEIGHT	MASS [kg]	EST.	CALCUL.	WEIGHT	MASS [kg]
MLI EXTERNAL			100%		10.023		10%		11.025
MLI INTERNAL			100%		0.987		10%		1.086
FILLER			100%		0.858		10%		0.944
RADIATORS			100%		3.154		10%		3.469
BLACK PAINTS			100%		1.169		10%		1.286
MISCELLANEOUS			100%		3.44		10%		3.784
TOTAL MASS [kg]					19.631				21.594

Table 9.2.6-1 Herschel TCS Mass Budget

- **Thermistors Budget**

To monitoring the status of SVM Thermal Control, 120 thermistors will be installed. Defintion and location of them will be provided by TCS sucbcontractor at the S/S PDR.The preliminary list is provided in table Table 9.2.6-2.

HEATER LOCATION	HEATER LINE	Thermistors Number
EPC1	1	THR-001/THR-002
TRANSX1	1	
TWTA1	1	
EPC2	2	THR-003/THR-004
TRANSX2	2	
TWTA2	2	
BATT	3	THR-005/THR-006
FPSPU1_2	4	THR-007/THR-008
FPDPU	4	
FPMECDEC	4	
FPBOLC	5	THR-009/THR-010
CRYOE	6	THR-011/THR-012
HSDCU	6	
HSDPU	7	THR-013/THR-014
HSFCU	7	
FHWOV	8 - 9 - 10	THR-015/THR-016 (Heater Line 08)
FHWEV	8 - 9 - 10	THR-017/THR-018/THR019 (Heater Line 09)
FHICU	8 - 9 - 10	THR-020/THR-021/THR022 (Heater Line 10)
FHHRV	11 - 12 - 13	THR-023/THR-024 (Heater Line 11)
FHFCU	11 - 12 - 13	THR-025/THR-026/THR027 (Heater Line 12)
		THR-028/THR-029/THR030 (Heater Line 13)
FHLCU	14 -15 - 16	THR-031/THR-032 (Heater Line 14)
FHLSU	14 -15 - 16	THR-033/THR-034/THR035 (Heater Line 15)
FHWOH	14 -15 - 16	THR-036/THR-037/THR038 (Heater Line 16)
FHWEH	17 - 18 - 19	THR-039/THR-040 (Heater Line 17)
FHHRH	17 - 18 - 19	THR-041/THR-042/THR043 (Heater Line 18)
		THR-044/THR-045/THR046 (Heater Line 19)
RWL1	20	THR-047/THR-048
RWL2	20	
RWL3	21	THR-049/THR-050
RWL4	21	
RWDE	22	THR-051/THR-052
TANK1	23	THR-053/THR-054
TANK2	24	THR-055/THR-056
STREMY	25	THR-057/THR-058
STREPY	25	
RCS (*)	26 - 28	From THR-059 to THR-064
THRUSTERS (*)	29 - 40	From THR-065 to THR-088
Spare		From THR-089 to THR-120 to be define

Table 9.2.6-2 Herschel Thermistors Budget

- **Power Budget**

The HERSCHEL heater power budget is reported in para 8.8 while the heater line budget is reported in table 9.2.6-3.

HEATER LOCATION	HEATER POWER [W]	HEATER LINE Number	HEATER LINE Main+Red.	SURVIVAL MODE SAA= 30° / -1°
EPC1	0.0	1	1 + 1	0.0
TRANSX1	10.2	1		10.2
TWTA1	0.9	1		0.9
EPC2	11.7	2	1 + 1	11.7
TRANSX2	0.0	2		0.0
TWTA2	17.1	2		17.1
BATT	45.9	3	1 + 1	45.9
FPSPU1_2	6.1	4	1 + 1	6.1
FPDPU	15.0	4		15.0
FPMECDEC	44.8	4		44.8
FPBOLC	25.2	5	1 + 1	25.2
CRYOE	28.2	6	1 + 1	28.2
HSDCU	27.2	6		27.2
HSDPU	26.7	7	1 + 1	26.7
HSFCU	20.7	7		20.7
FHWOV	11.4	8 - 9 - 10	3 + 3	11.4
FHWEV	56.8	8 - 9 - 10		56.8
FHICU	8.8	8 - 9 - 10		8.8
FHHRV	13.9	11 - 12 - 13	3 + 3	13.9
FHFCU	33.0	11 - 12 - 13		33.0
FHLCU	26.0	14 -15 - 16	3 + 3	26.0
FHLSU	47.2	14 -15 - 16		47.2
FHWOH	35.0	14 -15 - 16		35.0
FHWEH	26.2	17 - 18 - 19	3 + 3	26.2
FHHRH	43.4	17 - 18 - 19		43.4
RWL1	21.0	20	1 + 1	21.0
RWL2	24.1	20		24.1
RWL3	21.3	21	1 + 1	21.3
RWL4	16.3	21		16.3
RWDE	15.1	22	1 + 1	15.1
TANK1	3.1	23	1 + 1	3.1
TANK2	3.1	24	1 + 1	3.1
STREMY	2.6	25	1 + 1	2.6
STREPY	2.7	25		2.7
RCS (*)	24.0	26 - 28	3 + 3	12.0
THRUSTERS (*)	32.0	29 - 40	12 + 12	16.0
Total	746.7	40	40 + 40	718.7

(*) Estimated on the basis of 50% duty cycle

Table 9.2.6-3 Herschel heater line power budget

PLANCK budget

- **Mass budget**

Planck TCS mass budget is reported in Table 9.2.6-4:

DESIGNATION	REFERENCE	STATUS				UNCERTAINTY %			CURRENT
		EST.	CALC.	WEIGHT	MASS [kg]	EST.	CALCUL.	WEIGHT	MASS [kg]
MLI EXTERNAL			100%		14.624		10%		16.086
MLI INTERNAL			100%		2.142		10%		2.356
FILLER			100%		0.902		10%		0.992
HEAT PIPE			100%		26.474		10%		29.122
BLACK PAINTS			100%		2.009		10%		2.210
MISCELLANEOUS			100%		3.440		10%		3.784
TOTAL MASS [kg]					49.591				54.551

Table 9.2.6-4 Planck TCS Mass Budget

- **Thermistors Budget**

To monitoring the status of SVM Thermal Control, 100 thermistors will be installed. Defintion and location of them will be provided by TCS sucbcontractor at the S/S PDR.The preliminary list is provided in table Table 9.2.6-5.

HEATER LOCATION	HEATER LINE	Thermistors Number
EPC1	1	THR-001/THR-002
TRANSX1	1	
TWTA1	1	
EPC2	2	THR-003/THR-004
TRANSX2	2	
TWTA2	2	
RFDN	2	
STR1	3	THR-005/THR-006
STR2	3	
DPU1	4	THR-007/THR-008
DPU2 (on shear)	5	THR-009/THR-010
4 CCU	6	THR-011/THR-012
4 CAU	6	
4 PRE-REG	7	THR-013/THR-014
4 CEU	8	THR-015/THR-016
SCC + SCE Panels	9 - 10 - 11 - 12	THR-017/THR-018 (Heater Line 09)
		THR-019/THR020 (Heater Line 10)
		THR-021/THR022 (Heater Line 11)
		THR-023/THR024 (Heater Line 12)
SCC + SCE Panels	13 - 14 - 15 -16	THR-025/THR-026 (Heater Line 13)
		THR-027/THR028 (Heater Line 14)
		THR-029/THR030 (Heater Line 15)
		THR-031/THR032 (Heater Line 16)
BATT1	17	THR-033/THR-034
He TANK +Z	18	THR-035/THR-036
He TANK +Y	19	THR-037/THR-038
He TANK -Z	20	THR-039/THR-040
He TANK -Y	21	THR-041/THR-042
P TANK +Y+Z	22	THR-043/THR-044
P TANK -Z	23	THR-045/THR-046
P TANK -Y+Z	24	THR-047/THR-048
RCS (*)	25 - 27	From THR-049 to THR-054
THRUSTERS (*)	28 - 39	From THR-055 to THR-078
Spare		From THR-079 to THR-100 to be define

Table 9.2.6-5 Planck Thermistors Budget

- **Power Budget**

The PLANCK power budget is reported in para 8.8 while the heater line budgets are reported in table 9.2.6-6.

HEATER	HEATER	HEATER	HEATER	SURVIVAL
LOCATION	**POWER**	**LINE**	**LINE**	**MODE**
	[W]	**Number**	**Main+Red.**	
EPC1	0.0	1	1 + 1	0.0
TRANSX1	6.0	1		0.0
TWTA1	0.0	1		0.0
EPC2	0.0	2	1 + 1	0.0
TRANSX2	0.0	2		0.0
TWTA2	38.0	2		0.0
RFDN	8.0	2		0.0
STR1	2.61	3	1 + 1	2.61
STR2	10.41	3		10.41
DPU1	30.19	4	1 + 1	30.19
DPU2 (on shear)	35.7	5	1 + 1	35.7
4 CCU	20.64	6	1 + 1	20.64
4 CAU	20.67	6		20.67
4 PRE-REG	23.2	7	1 + 1	23.2
4 CEU	12.96	8	1 + 1	12.96
SCC + SCE Panels	265.7	9 - 10 - 11 - 12	4 + 4	265.7
SCC + SCE Panels	263.4	13 - 14 - 15 -16	4 + 4	263.4
BATT1	12.23	17	1 + 1	12.23
He TANK +Z	0.72	18	1 + 1	0.72
He TANK +Y	0.68	19	1 + 1	0.68
He TANK -Z	0.16	20	1 + 1	0.16
He TANK -Y	0	21	1 + 1	0
P TANK +Y+Z	0.18	22	1 + 1	0.18
P TANK -Z	0.13	23	1 + 1	0.13
P TANK -Y+Z	0	24	1 + 1	0
RCS (*)	24.0	25 - 27	3 + 3	12.0
THRUSTERS (*)	32.0	28 - 39	12 + 12	16.0
	807.6	39	39 + 39	727.6

(*) Estimated on the basis of 50% duty cycle

Table 9.2.6-6 Planck heater line power budget

9.3 POWER CONDITIONING AND DISTRIBUTION

9.3.1 General

The Power Control Subsystem is in charge to condition, control and distribute the electric power to all payload instruments and spacecraft equipment during all mission phases and for all operation modes including ground testing and pre-launch operations and contingencies.

PCS is suitably dimensioned to be compatible with both Herschel and Planck satellites, thus providing a high level of commonality.

Power Control Subsystem will be implemented as one PCDU and one Battery.

Power Generation is provided by Solar Array. SVM will procure S.A. only for Planck. Herschel S.A. will be part of the Herschel PLM and is not described in this document except for those interface issue affecting the Herschel SVM.

Planck solar array is composed of a internal circular panel and four external panels forming an outer ring, all utilising high efficiency multi junction GaAs cells common with those used for Herschel.

9.3.2 Requirements and Design Drivers

9.3.2.1 Power Generation and Conditioning

The Herschel and Planck Power Generation and Conditioning is designed in agreement with SVM Requirements Specification [AD-43]; functional requirements are given in para. 4.1.5, performance requirements are given in para. 4.2.5.

The main requirements of SRS [RD-01] have been traced in the following for reference purpose.

The Power Control Subsystem is in charge to provide for the following functions.

- Power conditioning, control and storage of the electrical power coming from the Solar Array and Battery.
- Power bus protection and power distribution to the scientific instruments and spacecraft equipment (SMPC-005 ÷ 020, 080)

- The subsystem is required to manage the following.
    - ☐ To provide power from approximately 100W up to 1.5 kW (average) or 1.9 kW (peak)
    - ☐ Power is generated by 30 solar array sections
    - ☐ Energy is stored in one battery
    - ☐ The s/s distributes power via 108 thermal control switches to the SVM units, instruments and decontamination heaters
    - ☐ The PCS distributes power via 72 (see Note) individually controlled power lines to the spacecraft equipment (10 of which are permanently ON for essential SVM units).

- Monitoring and telecommand interfaces are provided as necessary to operate the subsystem, to determine its status and performance, to determine the state of charge of the batteries, to meet power users switching, reconfiguration and autonomy requirements, to select between redundant equipment and to override the autonomous and protection functions by ground command (SMPC-040 ÷ 055)
    - ☐ The PCDU gets its command and report its status or monitoring results using a redundant MIL-STD-1553 Remote Terminal interface or via direct discrete commands and monitors.

- The subsystem provides dedicated heater outputs for thermally critical units, directly connected to the power bus via Fold-back Current Limiters (FCLs) such that no other unit apart from the PCDU and Battery must be active to energise them. These lines act as additional redundancy. The heaters are controlled by independent and dedicated thermostats (SPMC-065)
  - ☐ The Power Control and Distribution Unit is self starting and will therefore automatically be active to energise these lines.
  - ☐ Over discharging Li-Ion battery technology causes irreversible damage therefore it is considered too dangerous to connect these heaters directly to the batteries. In the event that the battery is discharged and unable to support the power bus, the FCLs will eventually disconnect the essential loads in order to prevent loss of the battery. This will enable the battery to store any remaining solar power and facilitate a recovery when sufficient charge is available.

The present design of Herschel and Planck does not foresee any pyro-technical device; for this reason, PCDU architecture does not include any driver and control for these devices, and relevant requirements (SMPC-025, 030) are not treated in this section.

Design and performance requirements:

No damage or degradation shall result from intermittent or cycled operation. A safe predefined start-up at power up, at restart and after a complete loss of all main bus power is required (SMPC-070, 075, 085)
A regulated 28 VDC bus shall be provided to the users in accordance with the requirements of ESA Power Standard PSS-02-10. Ripple voltage and transient voltage, including spikes, shall be compatible with the overall EMC requirements and the science instrument requirements. Transition and sharing between Solar Array mode and battery mode shall be performed in a continuous way without the main bus voltage variations being outside the specified tolerance. No single component failure shall cause an over-voltage or permit short circuit on the main bus (SMPC-090 ÷120, 125, 135).
A capacitor bank is foreseen at main bus level in order to stabilise the bus voltage regulation loop, to ensure low output impedance and to filter the switching noises due to the regulation.
The ESA power standard recommends bus impedance proportional to the mean power with a specific mask versus frequency. In the range 100Hz to 10kHz the requirement is $Z_{BUS} \leq 0.02 \times \frac{U_{BUS}^{2}}{P_{nom}}$.
The total power required is around 1500W, however only the Planck LFI Sorption cooler compressor accounts for significant part of the overall power (520W). GaAs multi junction cell technology is known to have higher junction capacity that silicon solar cell technology. Consequently an allowance has been made for the increased rise time of each solar array section in the S3R mode. Taking these factors into account and applying adequate margins, the capacitor bank has been sized between 4 and 6 mF.

The power available from Solar Array exceeding the system demand shall be left in Solar Array. Large circulating currents between Solar Array and the spacecraft shall be avoided (SMPC-145)
When the available SA power exceeds the total bus power demand, parts of SA sections are disconnected from the main bus and are short-circuited or re-routed to the batteries for recharging.

Full protection against short circuit or overload shall be provided by limiting the maximum current in any supply line. The load shall be switched-off automatically in case of an overload lasting longer than TBD ms. Essential functions shall not rely on centrally generated auxiliary functions. Provision must be included to inhibit or enable all mission critical automatic protection circuits by telecommand (SMPC-180 ÷ 190)
The baseline is to protect output lines to essential loads (transponder receiver, telecommand decoder, reconfiguration module, and emergency heaters) by Fold-back Current Limiters (FCL). The other lines will be protected by means of Latching Current Limiters (LCL).

Latching Current Limiters (LCLs) are designed initially to limit the current demanded by any load to a predefined level, then to disconnect the load if the current limit action persists for more than nominally 10 ms.

Similar protection is provided for the heater control systems but, since heater load characteristics are essentially resistive (minimal inrush current) and the amplitude of the limiting current is higher than the LCL, the time out function is set to a lower level of typically 3 ms.

The energy required by the Battery is derived by the following requirements.

SMPC-015: In case there is no solar array power or if its power is not sufficient to meet the scientific instruments and/or spacecraft power demand, the required (additional) power shall be provided by the batteries of the Power Control Subsystem.
SMPC-130: Battery selection and design shall ensure fulfilment of the satellite power requirements to be compliant with the battery depth of discharge requirements.
MISS-015: The spacecraft shall be compatible with a delayed ignition of the launcher upper stage; in particular they shall run on internal power and withstand the thermal environment. The maximum duration of ignition delay is 96 min (TBC)
MISS-020: During the launch phase, both spacecraft shall be in a minimum power mode using on-board batteries

AD-11 specifies a time from lift off to S/C separation including delayed ignition of 133.2 min (Table 3.1).

In order to benefit from a possible commonality between Herschel and Planck, the Battery design shall be identical. The sizing case for the battery design, over the two spacecraft, is the long launch phase for Planck.

Based on the power budget presented in RD67, the battery shall provide 256W power to the spacecraft during the 133.2 minutes of launch. This means that the Launch energy requirement amounts to 568 Wh.

This requirement includes the ALS power margins associated with unit development maturity and the ESA 30% margin applied to the combined PLM and SVM equipment consumptions. Both these margins appear as an additional load at the output of the PCDU.

9.3.2.2 Solar Array

A supplier for the solar array has not yet been selected, conseqyently the contents of this section are based on the design requirements RD59.

Herschel and Planck solar array provides electrical power to the relevant spacecrafts in sunlight.
This chapter provides also the description of the HERSCHEL SA even though it is not part of the HERSCHEL SVM Configuration and procurement. Description is included to give the set of electrical assumption necessary to comply with the power Subsystem concept.
Solar panels also act as a sunshield and thus provide shielding from Sun illumination to the PLM while heat transfer has to be minimised. The backside is thermally insulated to avoid thermal loads on the satellite upper part and the heat transfer through the fixation points to the spacecraft shall be reduced to the minimum.

Based on the power budget presented during phase B, the power required to the solar array is the following.

Herschel solar array is required to deliver:

- 1500 W at beginning of life (BOL)
- 1350 W at end of mission life (EOL).

Planck solar array is required to deliver:

- 1816 W at beginning of life (BOL)
- 1640 W at end of mission life (EOL).

The above power figures include the 100 W of system reserve as per req. SPMC-200 and SMPC-205 and the Alenia unit level development margins associated with design maturity.

Table 9.3.2-1 gives the sun aspect angles and solar flux extremes to be taken into account for solar array sizing.

	BOL max 0° incidence	BOL min 0° incidence	EOL max 0° incidence	EOL min
Herschel solar array	1425 W/m^2	1328 W/m^2	1405 W/m^2	30° incidence 1113 W/m^2 0° incidence 1287 W/m^2
	BOL max 0° incidence	BOL min 0° incidence	EOL max 0° incidence	EOL min 10° incidence
Planck solar array	1425 W/m^2	1328 W/m^2	1405 W/m^2	1265 W/m^2

Table 9.3.2-1 Sun aspect angle and solar flux

For Herschel, the EOL conditions are computed with maximum distance to Sun (Summer Solstice and maximum distance to Earth). The solar incidence has an angle of 30° with the Z axis in the X-Z plane.

For Planck, the EOL conditions are computed with maximum distance to Sun (Summer Solstice and maximum distance to Earth), with a 10 deg solar incidence on the solar array and taking into account the degradation over the lifetime.

Voltage at the solar array Interface connector shall be above 30.0 V for both the satellites.

The Planck solar array implementation constraints are shown in Figure 9.3.2-1. In case of a dual launch, the ARIANE 5 User's Manual shows a diameter of 4 m under SYLDA 5. However, as the solar array is located at the bottom of the SYLDA 5 volume, the constraints coming from dynamic envelope and SYLDA separation are reduced. According to a discussion with ARIANESPACE, a diameter of 4.2 m is acceptable.

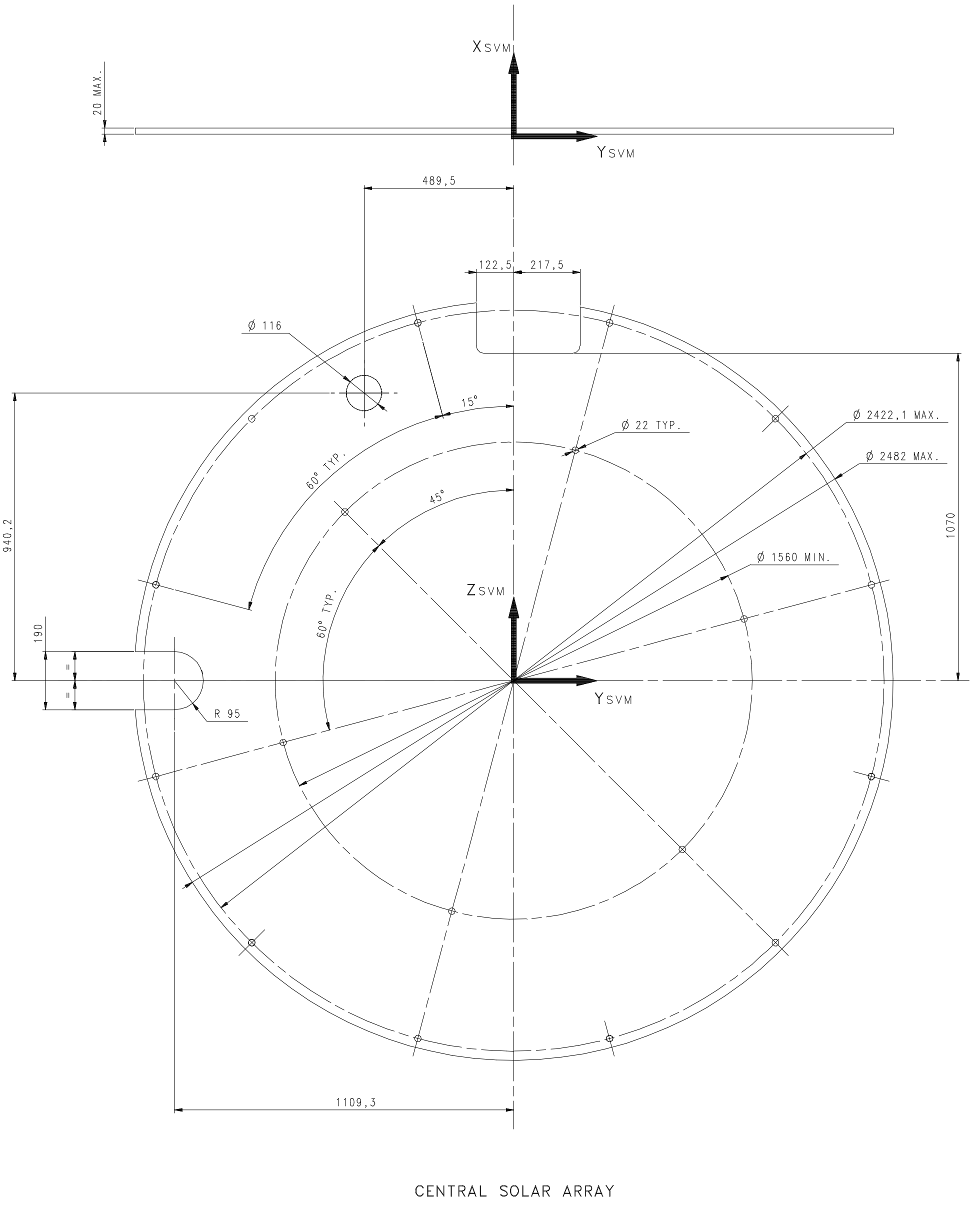


Figure 9.3.2-1a Planck solar array implementation constraints (INTERNAL)

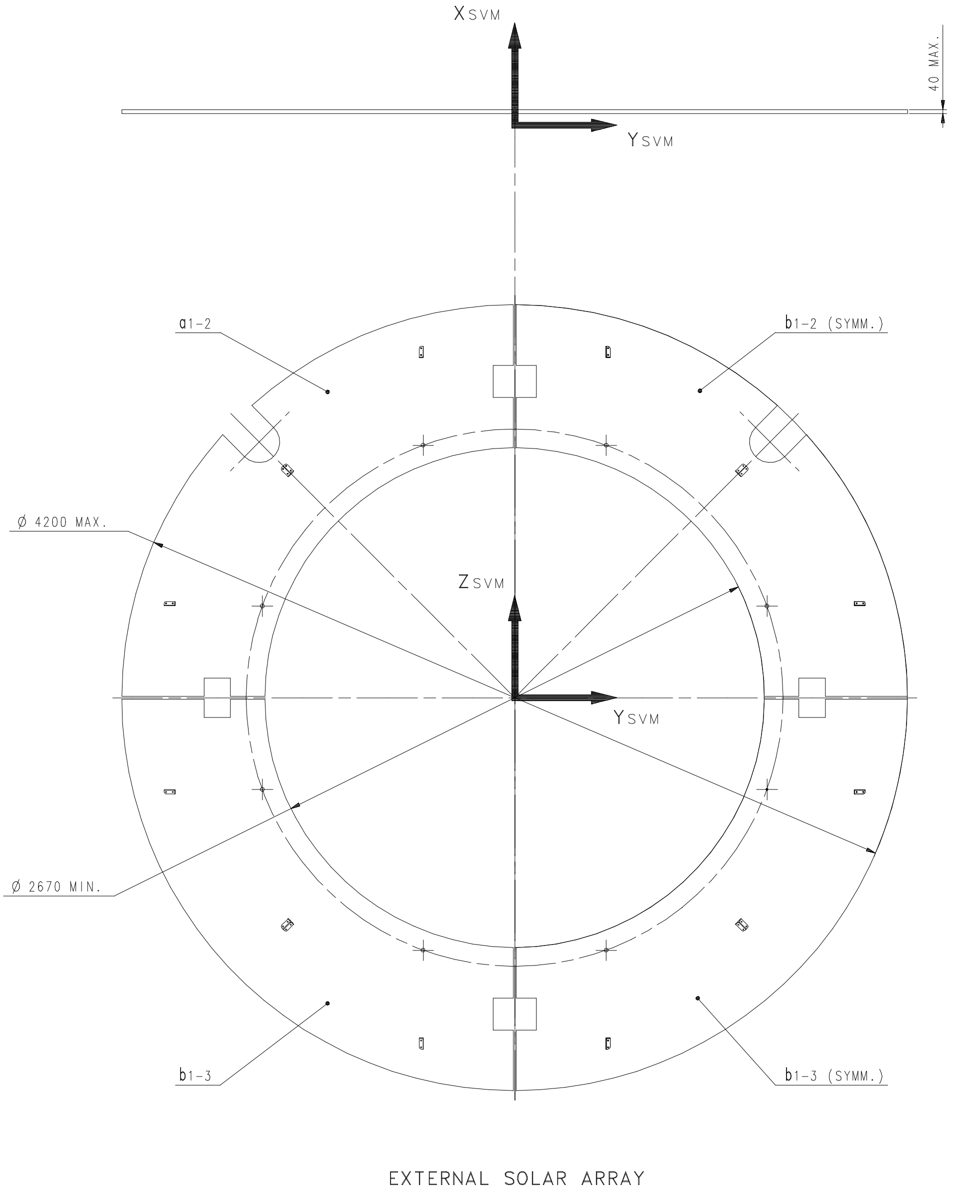
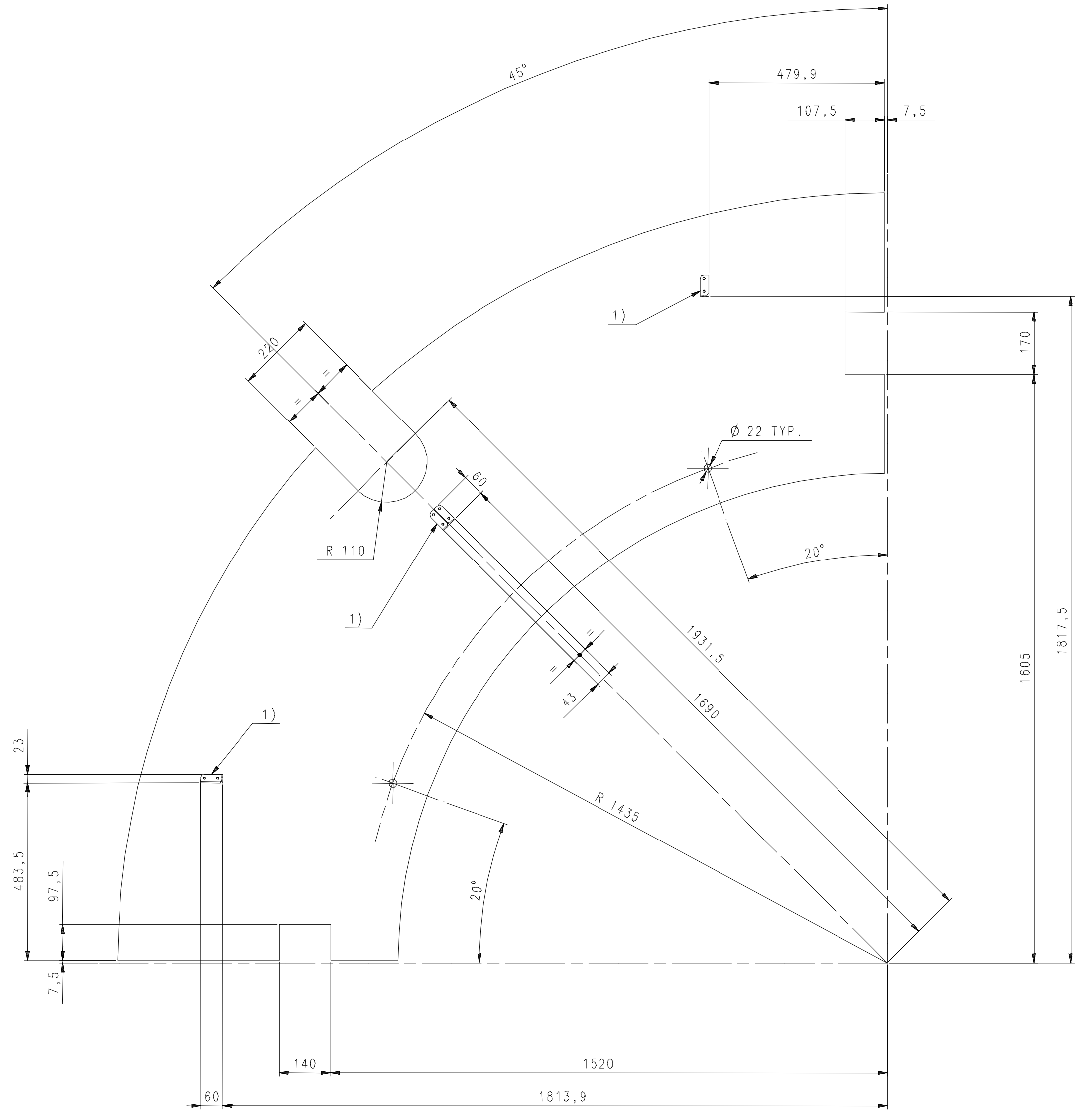


Figure 9.3.2-2b Planck solar array implementation constraints (4xEXTERNAL)

The external array consists of 2 types of panel (see figures 9.3.2-1c and 9.3.2-1d).



DETAIL a1-2

1) MECHANICAL ATTACHMENT DEDICATED AREA.

Figure 9.3.2-3c Planck solar array implementation constraints (2xEXTERNAL)

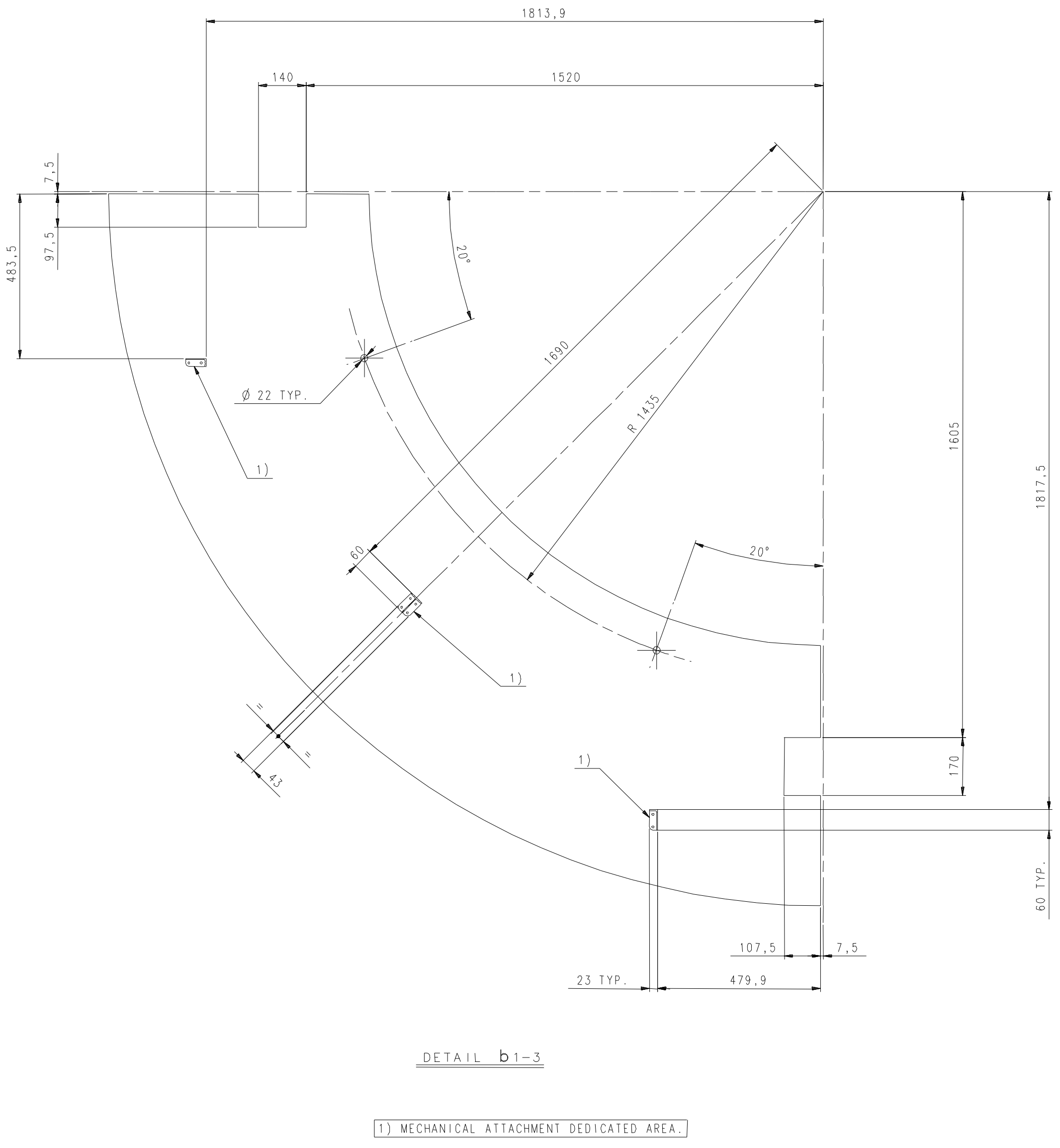


Figure 9.3.2-4d Planck solar array implementation constraints (2xEXTERNAL)

The following requirements from the System Requirement Specification [RD-1] apply to the solar array:

- SENV-140: Spacecraft design and materials selected shall be such as to ensure that no parts of the spacecraft are charged to high potentials. The differential charging potential shall not exceed 10 V as a design goal.

- SENV-145: All spacecraft surfaces exposed to the plasma environment shall be conductive and grounded to the spacecraft structure.
    - ☐ The last revision of SRS gives an exception to this requirement for Solar Array. The effects in terms of thermal environment and power efficiency are still to be analysed. Also, it was agreed during the first Solar Array Working Group RD-78 (ref HP-ASPI-MN-452) that for the Herschel and Planck mission orbits, ITO covering would not be required.

- SMSA-030: All solar array cell strings shall have individual blocking diodes and shunt diodes where required
    - ☐ Blocking diodes are implemented at the end of each string, Individual shunt diode against shadowing are integrated onto the cell substrates (to protect the next cell in the string). These diodes in effect are protecting the preceding cell of the string therefore external diode shall be implemented at the end of the string. Cell placement will be implemented to avoid as much as possible spot shadowing on Planck solar array caused by antennas, thrusters or other appendices protruding over the solar array.

- SMSA-035: The solar array shall be designed to be one string failure tolerant.
    - ☐ This requirement is satisfied by the available power margin of the solar array. With the cell string arrangement, a fail string is calculated as a 10W loss of power. Additionally, the power budget accounts for the loss of an entire section (1/30th of the panel power output).

- SMSA-040: The power transmission elements such as connectors and harness, etc; up to power control/regulation unit shall be two failure tolerant.
    - ☐ For the solar array this requirement is considered applicable only up to the interface point with the spacecraft. Connectors and wires redundancy is implemented by design.

- SMSA-045: The electrical network shall be composed of identical electrical sections. It shall minimise the resulting magnetic moment and ensure the insulation of solar network with respect to the solar array structure.

    - ☐ Planck solar array will be composed by 30 sections. Due to different shapes, the four sectors of the external solar array cannot have identical lay-out. As a goal, the Planck sections have a requirement to not to deviate by more than 1 string between section designs.

9.3.3 Functional Description

The PCS consists of the following units:

Power Control and Distribution Unit, PCDU, which provides:

1. control of the electrical power generated by the solar array
2. conditions the energy storaged in the battery when required
3. controls, monitors and maintains the health of the PCS
4. distributes power to the scientific instruments and spacecraft equipment
5. Protects the power bus from external faults and prevents failure propogation
6. heater switching control in response to 1553 commands
7. interfaces for AIV and Launch support EGSE.

Battery, which provides:

8. a store for the excess solar array energy
9. a source of energy whenever there is insufficient power from the array.

Solar Array, which provides:

10. electrical power from the sun input
11. a thermal shield between the sun and the SVM/PLM.

An overview on the configuration of the power control subsystem is given in Figure 9.3.3-1.

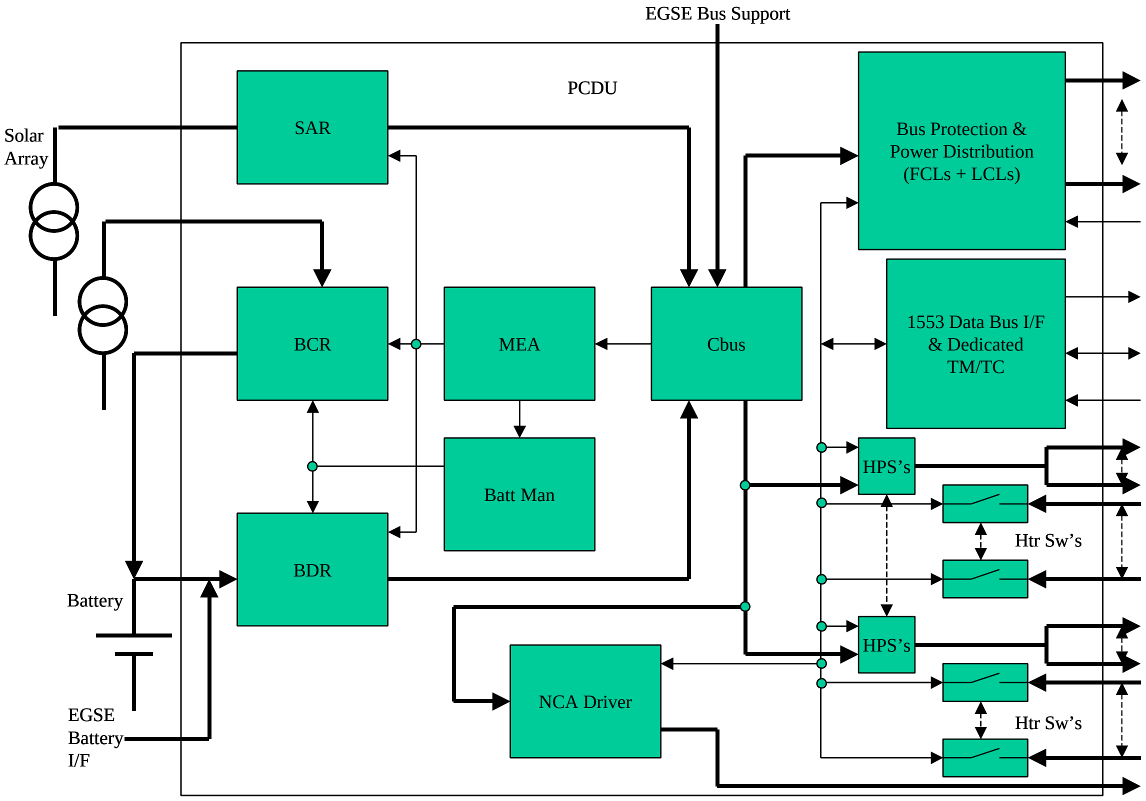


Figure 9.3.3-1 Power Control Subsystem

9.3.4 Design and Performance

9.3.4.1 PCDU Design Description

ALCATEL ETCA was selected as the supplier for the PCDU at the beginning of June. The functional configuration of the PCDU is still being finalised following changes requested at the PCDU clarification closure meeting (see AD-47). Accordingly, the requirements baseline for the PCDU is AD-46 and AD-47.

9.3.4.1.1 Power Bus Regulation

The main functions of the Power Conditioning and Distribution Unit (PCDU) are to generate and distribute a single and fully regulated bus of 28V providing the necessary power (around 1.5kW) to the satellite.

Two types of energy source are used to supply this regulated bus:

30 Solar Array sections
1 Li-Ion batteries ($V_{BAT} < V_{BUS}$)

The PCDU provides a 3 domain power bus regulation concept as illustrated on figure 9.3.4.1.1-1 below:

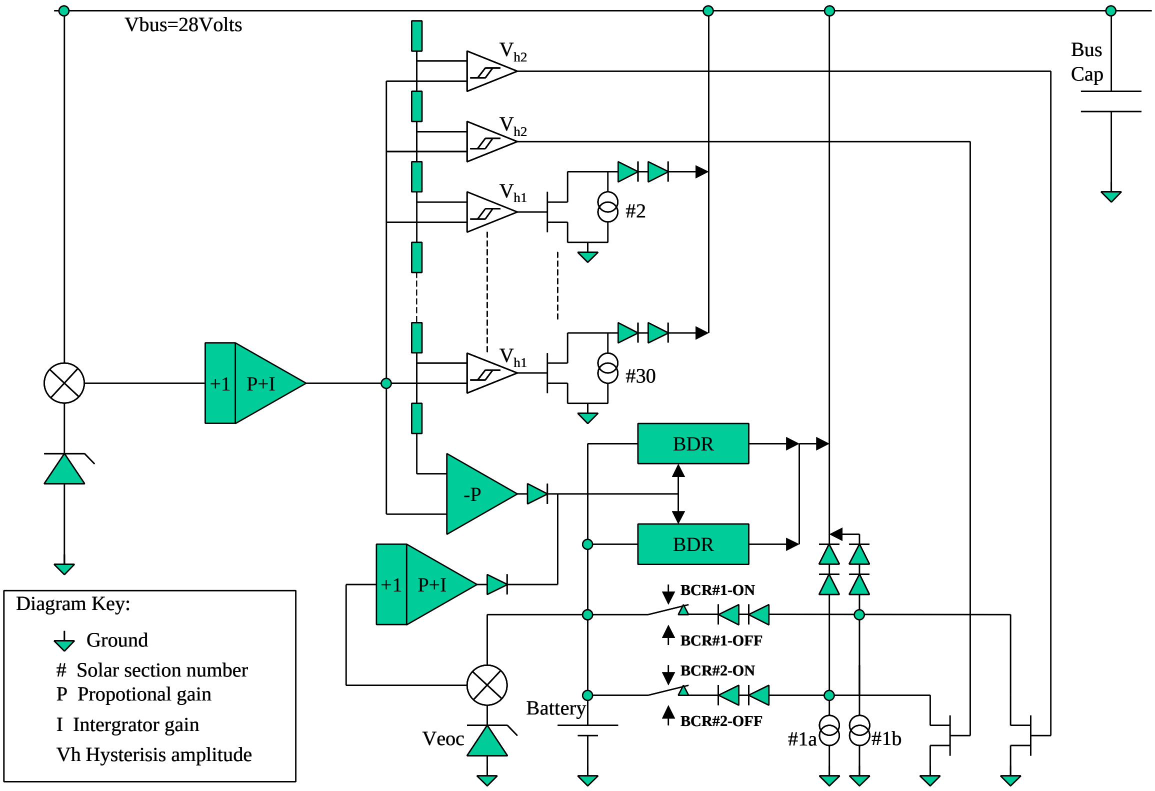


Figure 9.3.4.1.1-1 Foreseen PCDU 3 Domain Bus Control Concept

SUNLIGHT DOMAIN

During Sunlight period, the power is delivered by the 30 SA sections. Twentynine sections are connected to the main bus through dedicated electronic switches working under S^{3}R concept. One section (divided into 2 parts #1a and #1b) provides power directly to the bus when telecommands BCR#1-OFF and/or BCR#2-OFF are sent. In this domain, the MEA output voltage is in the S3R voltage range #2 to #30. In the default configuration, the system configuration is with commands BCR#1-ON and/or BCR#2-ON and solar aray power provided to the battery is accessible via the BDR utilisting the BCR Domain.

BATTERY CHARGE REGULATOR DOMAIN

This paragraph concerns only the bus regulation aspect of the BCR domain, see also “Battery Charge Control”

When BCR#1-ON and/or BCR#2-ON are sent (default PCS configuration), solar array power is connected to the battery. As the MEA falls below the last S3R section (#30), the BDRs start to operate via the normal high speed control loop. However, instead of discharging the battery, they consume the current provided to the battery by the BCR solar sections.

A comparison with a typical BCR converter system is given below in figure 9.3.4.1.1-2

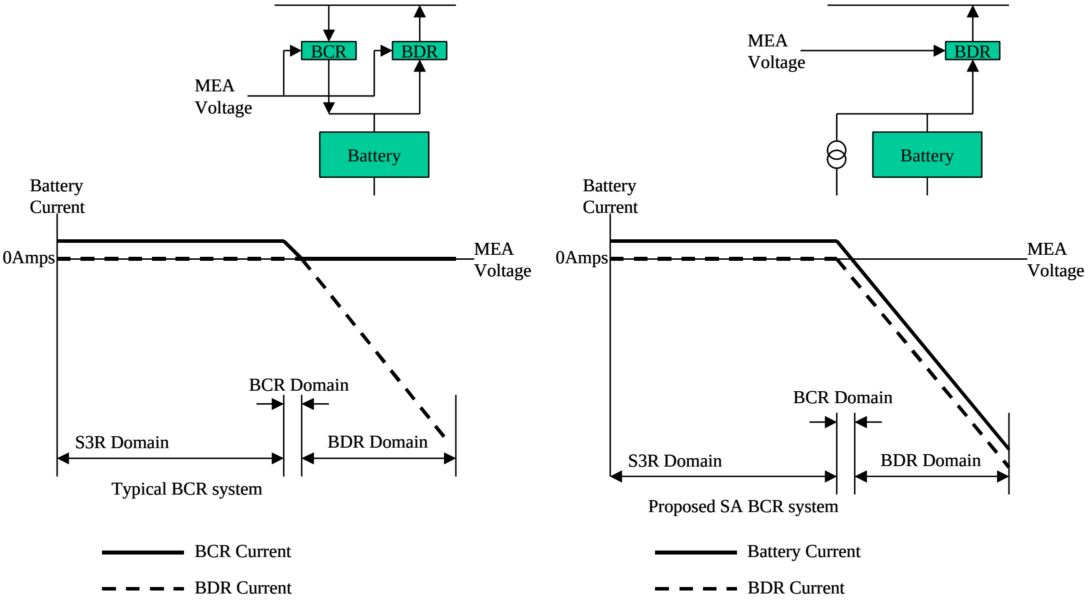


Figure 9.3.4.1.1-2 Proposed BCR Domain

TYPICAL BCR Control System.

The typical BCR/BDR example above (left), illustrates the behavior of the battery current (Y axis) with respect to the MEA output voltage (X axis). The X axis also identifies the zero battery current level. Above the zero line indicate current flowing into the battery (charge) while below the zero line indicates current flowing out of the battery (discharge). The MEA signal indicates minimum bus demand to the left and increasing power demand to the right.

When the MEA voltage is in the S3R domain, the battery current remains constant (defined by the BCR current limit). When the MEA voltage is in the BCR range, the BCR output current is reduced according to the MEA signal, falling to zero just before the MEA enters the BDR domain. When the MEA voltage is in the BDR domain, the BDR takes current from the battery.

Solar Array BCR Control System.

The solar array BCR/BDR example above (right), illustrates the behavior of the battery current (Y axis) with respect to the MEA output voltage (X axis). The X axis also identifies the zero battery current level. Above the zero line indicate current flowing into the battery (charge) while below the zero line indicates current flowing out of the battery (discharge). The MEA signal indicates minimum bus demand to the left and increasing power demand to the right. Note the change of graph legends, the Bold line indicates Battery Current and the dotted line BDR current.

When the MEA voltage is in the S3R domain, the battery current remains constant (defined by the BCR solar array current). When the MEA voltage is in the BCR range, the BDR input current is increased according to the MEA signal. Battery current = solar array current – BDR input current, consequently when the BDR is diverting all the solar array current the battery current falls to zero. After all the array power is delivered to the bus, the MEA voltage is in the BDR domain and the BDR takes current from the battery.

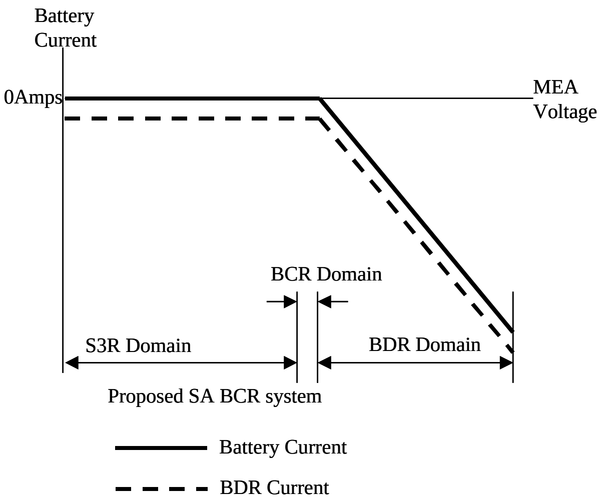


Figure 9.3.4.1.1-3 Proposed BCR Domain in Fully Charged Condition

When the battery is fully charged, the BDR is diverting the solar array current to the bus and the battery current is zero. When the bus load exceeds the solar array capability, the MEA voltage moves into the BDR domain and the Battery delivers power to the bus (see figure 9.3.4.1.1-3).

BDR DOMAIN

When the SA power is no longer sufficient to satisfy the bus power consumption, the MEA voltage continues to fall and enters the BDR domain. Power is then delivered by the battery via two Battery Discharge Regulators (BDR).

PEAK BDR POWER REQUIREMENTS

The solar array power requirement includes the effects of all failures (including a complete string loss) and degradation mechanisms and the array shall satisfy these needs. In addition, the power budget for the spacecraft includes the loss of one of the 30 solar array sections. Therefore the solar array power actually needed to satisfy the mission is 29 x Psection. One of these sections will be connected to the bus by the BDRs.

If one of the BDRs fails in the OFF state, there will be no loss of solar array sections therefore Psolararray = 30 x Psection. The bus configuration, at EOC, will be 28 sections connected to the bus and one connected via the BDR.

The peak power demanded under AOCS mode (e.g. Herschel Raster) = 400W. If the battery is fully charged, the PCS will provide this power from the 30th solar array section (approximately 56W EOL) leaving 344Watts to be provided from the BDR. The total power provided by the BDRs will be 344 + 56 = 400W (56W comes from the charge section). The peak power requirement of the remaining BDR is therefore 400 Watts.

If a solar array section is lost from the bus (due to a S3R shunt ON failure for example), then both BDR's will be functioning. The combined BDR power capability is therefore 2 x 400 Watts.

Consequently there is no peak power penalty for BDRs over the nominal peak power requirement.

To provide for 2 battery charge sections, the single BDR rating will be 460W.

9.3.4.1.2 Battery Discharge Regulator

The BDR module is based on a PWM push-pull topology (step-up converter) switching at 100 kHz. This topology has been selected from among the following 4 topologies to optimise the BDR module in terms of mass and electrical performances.

The boost converter, this classical topology has been directly rejected due to:

- its bad dynamic behaviour (none minimum phase converter),
- its impossibility to control the output current (mandatory for the conductance control concept) and
- its sensibility to the battery inductance,
- leading to increase the bus capacitance.
- Moreover, the boost offers a poor efficiency due to important switching losses.

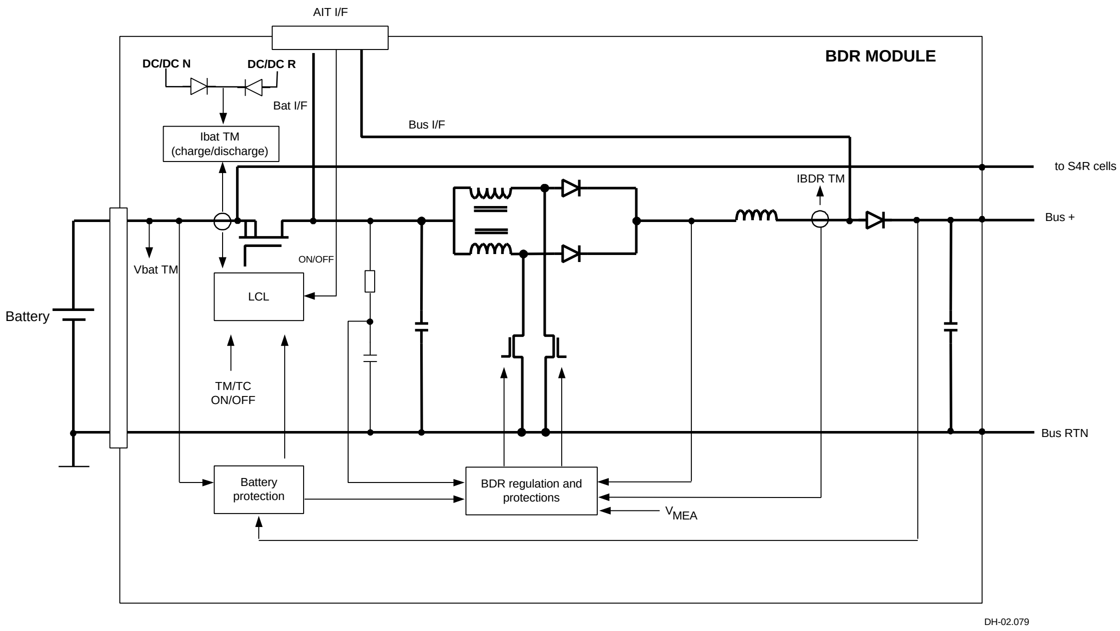
The super boost (adaptation of the conventional boost by implementation of two inductances, instead of one, located at output and foot of the boost power cell) eliminates the boost dynamic drawback but has been also rejected due to

- its poor efficiency (like convential boost), and
- its complexity (boost power cell not referenced to the return line, leading to design isolated MosFet driver and additional EMC filter).

The HE-Boost (ETCA topology based on the Weinberg Boost, using transformer and inductance located at input level) has been designed and developed in the frame of SB4000-PCU program (regulated bus at 100V). This converter has a good dynamic behaviour and an attractive efficiency but its DC conductance (Iout/Umea) is slightly sensitive to the battery voltage (due to the localisation of the inductance -its current is controlled by the regulation- before the transformer). This sensivity, acceptable at 100V, is accentuated at low bus voltage and is not compatible with the Herschel-Planck impedance requirement. Moreover, this SB4000-BDR cannot be directly used for the H-P application, important reviews are requested :

- 100V-28V adaptation,
- protection philosophy (LCL used as battery isolation, protection reset during bus under-voltage, ..)
- auxiliary supply to be up-dated.

The Push-Pull PWM converter (Based on an auto-transformer and an inductance located at output) presents the same characteristics (dynamic and efficiency) as the HE-Boost without the DC conductance drift with battery voltage (due to the inductance localisation at the output). The single constraint of the topology is to implement an additional low frequency control loop in order to avoid saturation of the auto-transformer by slight imbalance of the duty-cycle between the two Push-Pull MosFet working alternately. This specific function is implemented in the standard PWM regulation circuit (already studied and developed in the frame of the HE-Boost design).
The Push-Pull topology is therefore retained for the Herschel-Planck BDR.



During the mission, the BDRs are required to supply between 260W watts (continuously) and 400W (for 10 minutes) when performing battery charge control and supplying the peak demands of the ACMS RWDE attitude positioning manoeuvres. The BDR will be rated for a peak power capability of 460 Watts.

The BDR module will be designed for a optimum performance at BOL for a power output of 260W at the power regulation point for the launch support mode (assuming one BDR fails or is switched OFF at start of mission). The battery input voltage range is 15V to 26.5V.

Each BDR module is protected against internal failure (which may result in activation of internakl inhibits) and shorts to the power return or to the bus.

In the event that the BDR inhibit function is prematurely activated, the following automatic resets are provided:

1. If the bus voltage falls below 26.5 volts (tbc) inhibits will be reset.
2. If the MEA exceeds the BDR domain control voltage range then inhibits will be reset.

Operation of the HLC OFF command is foreseen only during safety critical ground operations or if it is necessary to isolate a BDR in flight. Operation of the HLC ON command is also available to reset the flight configuration or to reset an islolated BDR module.

During the launch and AIT phases, the BDR can be individually switched ON/OFF by direct commands available on a dedicated connector.

9.3.4.1.3 Battery Discharge and Charge Management

Battery discharge management will ensure that the PCDU cannot damage the battery by over discharging it. Three levels of protection are foreseen:

- Battery Voltage Low. At typically 18 volts, the PCDU initiates a direct telemetry alarm to the CDMU to initiate safe mode. Under control of the FDIR system, all non-essential bus loads will be removed and the spacecraft enters a sunfacing attitude until receipt of a ground command.

- End of Discharge. At typically 16 volts (Veodmax), the PCDU will disable both BDRs by inhibiting the control circuits. Once activated, the BDRs will remain inhibited until the battery voltage exceeds 18 volts (tbc), when the inhibit will be reset and the BDRs will be ready to support the bus.
- Minimum End of Discharge. At typically 15 volts (Veodmin), the PCDU will activate the BDR isolation switches to prevent the battery from being over discharged and damaged. Such an event can only be initiated as a result of a BDR control fault which may damage the inhibit function. Once activated, the BDRs will remain isolated until the battery voltage exceeds 18 volts (tbc), when the isolation switch will be closed and the BDRs will be ready to support the bus.

Note: The EOC reset and battery voltage low threshold shall correspond to 90% DOD under discharge at 460W (battery voltage low) and 10% SOC under charge conditions at a rate of nominally 6Amps. These values to be confirmed by the battery PDR.

These battery management circuits are located in each BDR module and shall be independent in their function so that loss of one will ensure the battery is protected by the other.

The input isolation switch is provided with dv/dt limitation to prevent excessive inrush current from the battery to the bus capacitor during BDR switch ON.

BDR Telemtery includes:

- Output current status and
- Battery Voltage (at BDR input).

Battery charge management will ensure that the battery voltage does not exceed a predefined maximum charge voltage (25.2±0.05 volts tbc). The proposed design is based on figure 9.3.4.1.3 below:

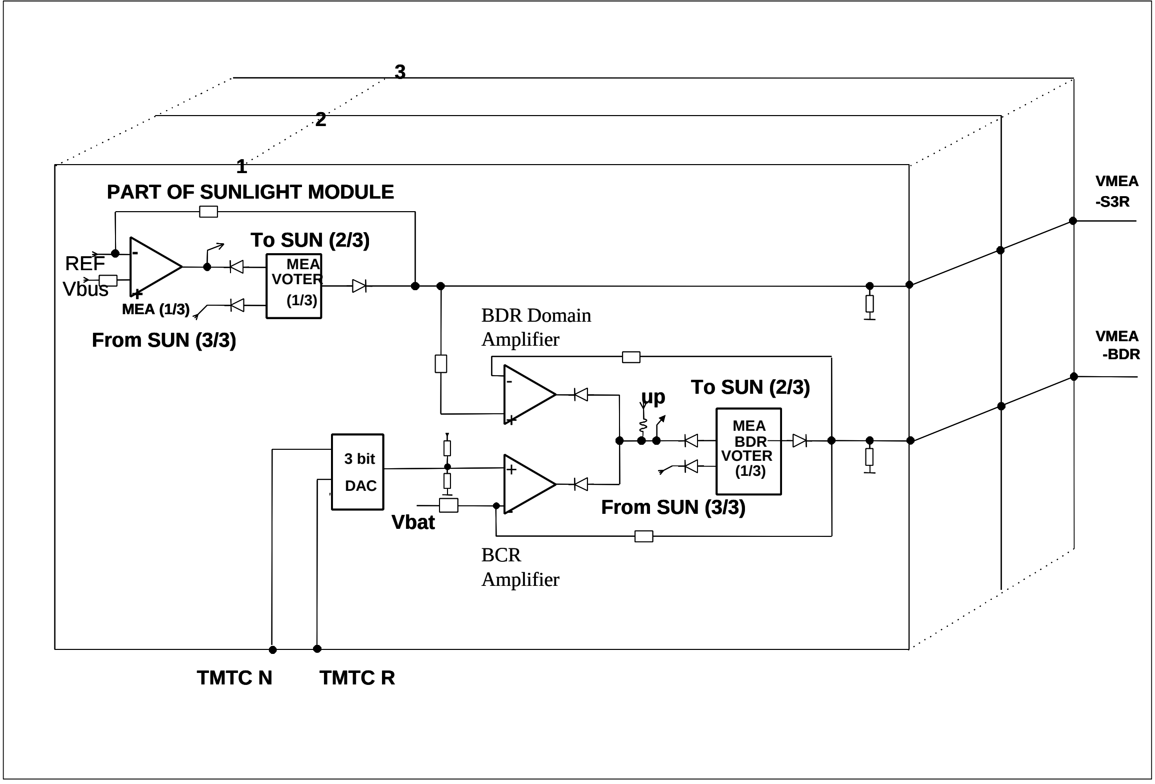


Figure 9.3.4.1.3-1 BCR Management

End of charge (EOC) voltage references are supplied via the prime and redundant PCDU TMTC functions. These are converted into analogue voltage via a 3 BIT DAC one on each of the 3 MEA PCBs. A BCR amplifier compares the battery voltage with the voltage reference and provides an error signal for the BDR voter.

If the battery voltage is lower than the reference, the BCR amplifier output voltage is high and the MEA control voltage is passed by the BDR majority voter. As the battery voltage approaches the voltage reference, the BCR error amplifier output voltage reduces and begins to control the BDRs, diverting the charge current from the BCR SA section.

Due to the majority voting action, the BDRs will always respond according to the output signal from the operating PCDU TMTC module. To ensure that the design is “fail safe”, each of the redundant parts of the BCR amplifier has a preset maximum value (e.g. equivalent to a battery voltage of 26.2 Volts tbc). The function of the external TMTC circuit will be only to reduce the signal to achieve a lower voltage needed to preserve battery life during the mission. A failure in the TMTC can thus only return the battery to is maximum rated voltage, which is already specified in the battery requirements for the longest survival period of 7 days. Failures of any kind on each of the MEA cards are eliminated by majority voting.

Two BDRs will ensure that any ON or OFF state failures in the BDR itself are prevented from harming the battery or the PCS. A BDR ON state failure will be removed at BDR module level by the BDR inhibit (e.g. bus overvoltage, BDR over current or when a BDR output current exisits and there is no demand signal) while an OFF state failure leaves one of the BDR still working. Details of the inhibit control will be finalised at PCDU PDR.

Should both the BDR’s be inhibited (due to an extra-ordinary SED or SEU event) the bus will be protected by the bus under voltage signal (see BDR description). The the risk of not being able to divert the BCR SA section is prevented by the BDR error signal exceeding the maximum BDR demand threshold by more then 0.5 volts (see para 9.3.4.1.2). If the battery exceeds the defined EOC threshold, the BCR error amplifier will generate an error signal and when the BDR does not respond, the error will be integrated until the maximum BDR demand is exceded and the BDR modules are reset.

In the event that any solar array section fails on the bus the power input to the bus will be in excess of the minimum load (2 sections > 90W). Two comparators/shunts, positioned at the very beginning of the connection sequence, will shunt the charge sections under the normal MEA control sequence. Thereby reducing the amount of power being diverted by the BDRs and avoiding a bus over voltage (see figure 9.3.4.1.3-2).

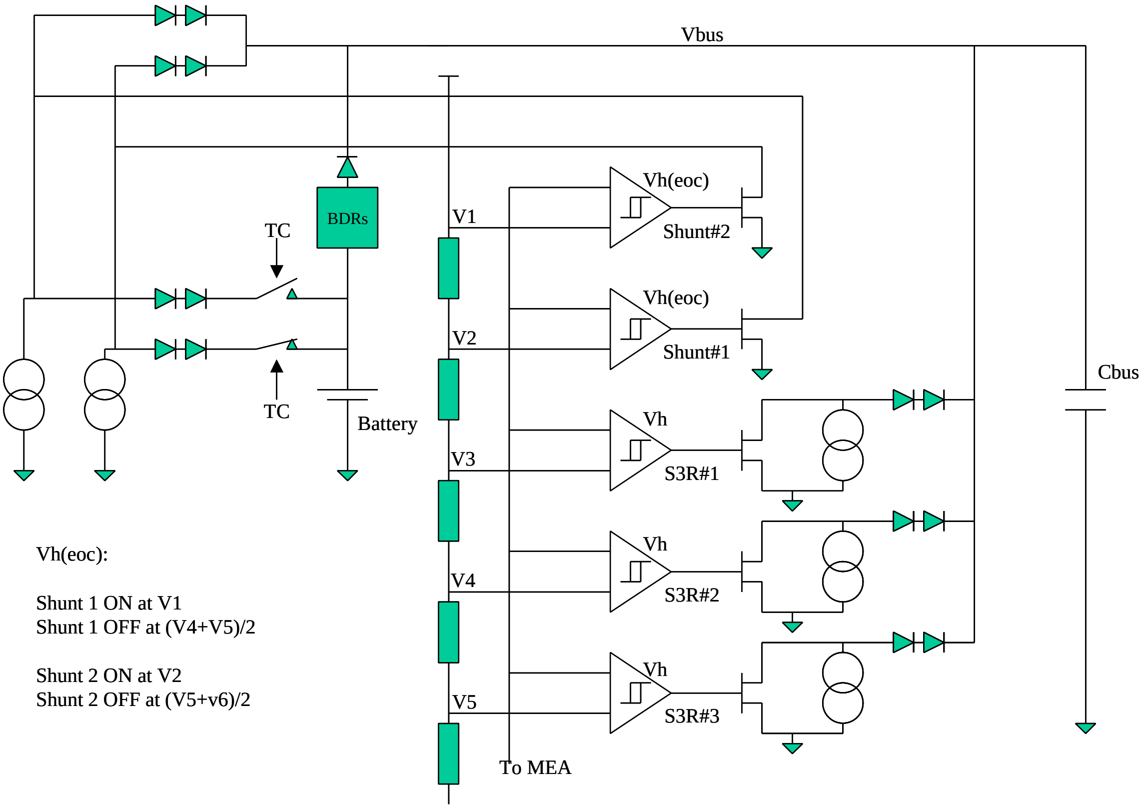


Figure 9.3.4.1.3-2 Bus O/V Protection

To avoid pulse width modulating these charge section shunt switches (and hence the battery) the amplitude of the hysterisis on the charge control shunt comparators ($Vh_{(eoc)}$) is increased. The amplitude of $Vh_{(eoc)}$ will be set to ensure that the first and second S3R section can regulate the bus. This is because it could be either of these sections which failed and becomes connected to the bus.

Minimum bus load before a fault:

In the event of:

- a minimal load (i.e. 90W)
- a battery being fully charged
- Shunt#1 is OFF and the charge section is configured to put power on the bus.
- Shunt#2 is OFF, and the charge section is being fully diverted to the bus via the BDRs.
- The MEA will be driven off the S3R domain and switch ON shunt#1, removing one section from the bus.
- Leaving only one section on the battery, being diverted to the bus, the used array power is <90W.
- The MEA voltage will drop down and control the bus via the first S3R section.

Fault 1: Charge shunt#1 does not work.

- ❑ PCDU MEA continues to increase and Shunt#2 operates removing the charge power to the battery.
- ❑ Leaving only one section on the bus the used array power is <90W.
- ❑ The MEA voltage will drop down and control the bus via the first S3R section.

Fault 2: Charge shunt#2 does not work.

- ❑ Not important, only required if shunt#1 fails to operate (only single failure tolerant).

Fault 3 & 4: Shunt #1 OR #2 fail ON.

- ❑ Not important, PCDU allowed to lose one solar array section due to a PCDU failure.

Fault 5: S3R#1 leaves section connected to power bus.

- ☐ Power on bus = 3 sections (S3R#1. Shunt#1 OFF and Shunt#2 diverting via BDR) Parray>90W.
- ☐ The MEA will be driven off the S3R domain and switch ON shunt#1, removing one section from the bus and leaving 2 section on the bus >90W.
- ☐ The MEA will continue to rise and switch ON shunt#2, removing another section from the bus.
- ☐ Power on bus <90W MEA voltage reduces.
- ☐ MAE reaches S3R#2 and the bus is regulated.

Fault 6: S3R#2 leaves section connected to power bus.

- ☐ Power on bus = 3 sections (S3R#2. Shunt#1 OFF and Shunt#2 diverting via BDR) Parray>90W.
- ☐ The MEA will be driven off the S3R domain and switch OFF S3R#1, removing one section from the bus and leaving 2 section on the bus >90W.
- ☐ The MEA will continue to rise and switch ON shunt#1, removing another section from the bus.
- ☐ Power on bus <90W MEA voltage reduces.
- ☐ MAE reaches S3R#1 and the bus is regulated.

Fault 7: S3R#3 to #28 leaves one section connected to power bus.

- ☐ Power on bus = 3 sections (S3R#n. Shunt#1 OFF and Shunt#2 diverting via BDR) Parray>90W.
- ☐ The MEA will be driven off the S3R domain and switch ON shunt#1, removing one section from the bus and leaving 2 section on the bus >90W.
- ☐ The MEA will continue to rise and switch ON shunt#2, removing another section from the bus.
- ☐ Power on bus <90W MEA voltage reduces.
- ☐ MAE reaches S3R#1 and the bus is regulated.

IF THE MAIN BUS LOAD RETURNS

- The shunted charge sections will remain shunted until the MEA demand moves past the S3R#3
- Shunt#1 is switched OFF and the solar array power is returned to the bus.
- If this is not sufficient to regulate the bus, the MEA continues to reduce and goes past S3R#4
- Shunt# 2 is switched OFF returning the section the the battery.
- If battery is charged the BDR will divert this power to the bus.
- If battery is not charge, the section is not available to power the bus and the MEA continues to drop until the next available S3R powers the bus.

MAIN BUS LOAD RETURNS (NOT ENOUGH TO USE MORE THAN S3R#3)

If the spacecraft remains in a low power state with both charge sections shunted for a long periods of time the battery may discharge (BDR APS). For this reason it is necessary to have a separate charge shunt reset associated with the battery EOC control (refer to para 4.1.3.6.1 of PCDU requiremnt Specification). This is the reason for having an automatic reset of the EOC status related to the battery voltage (at Veoc-0.25V). When the battery discharges to this threshold, it will be safe to release the charge shunts (even under low load conditions) because the state of charge will be below EOC and the BDRs will not divert charge current from the battery.

9.3.4.1.4 Main Error Amplifier and bus capacitors

The triple redundant majority voted Main Error Amplifier (MEA) produces a reliable error signal which manages the available energy sources, in order to guarantee a permanent regulated bus. The MEA out put voltage is devided into Domains. The bus voltage is controlled first by 29 main solar array sections, then by modulating the current from 2 solar array sections dedicated to battery charge then by driving the two battery discharge regulators. The interface designs of each domain circuit are such that no single failure can result in the loss of the error signal.

The transitions between these modes are automatic and lead to negligible transients to the main bus voltage.

A large capacitor bank forms the central regulation point of the 3 domain controller ensuring a large signal first order response in sunlight mode and an abundant cut-off frequency margin between the BCR/BDR control regimes and the associated converter switching frequencies, thus keeping alias phase distortion to an acceptably low level. The bus capacitor comprises series redundant parallel configuration of CTC21 high frequency ceramic capacitor technology providing:

- Stability for the bus voltage regulation loop
- Contributing to a low output impedance
- Supressing the switching noise due to the regulation

The predicted bus output impedance for the PCDU voltage reference point is given in figure 9.3.4.1.4-1.

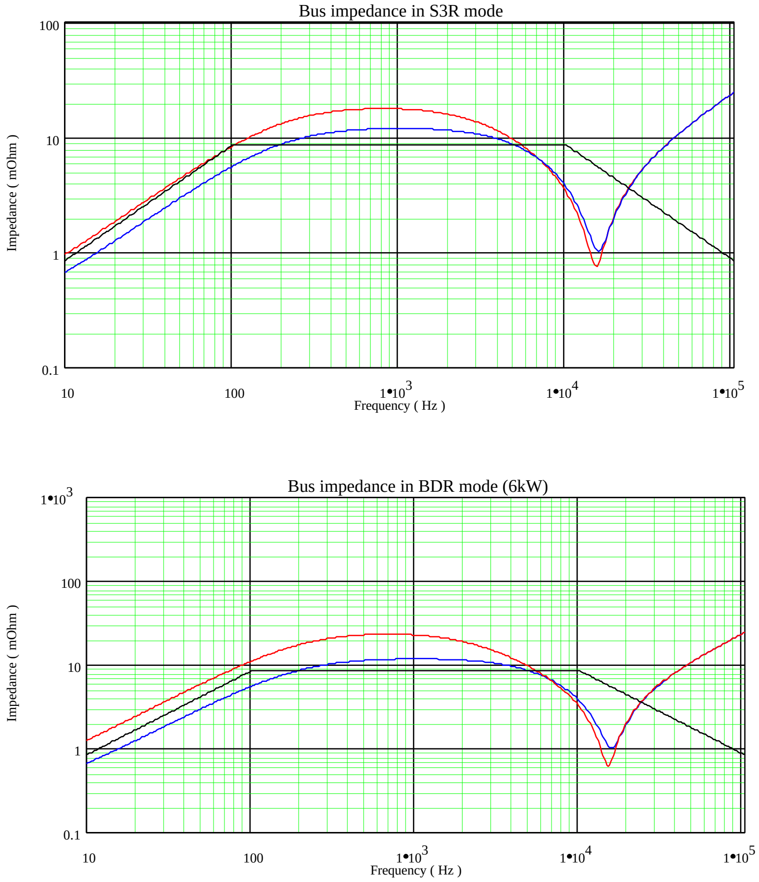


Figure 9.3.4.1.4 Predicted bus impedance.

9.3.4.1.5 PCDU Power Distribution and Bus Protection

The PCDU distributes the 28V regulated bus through the following types of Current Limiters:

- Standard Latching Current Limiter (LCL)

- Protected Output Latching Current limiters (PO-LCL)
- Fold-back Current Limiter (FCL)
- Heater Protection Switches (HPS)
- Heater Control switches (HCS)
- NCA Drivers.

The Standard LCL is commanded by a bi-level command; output status signal and output current telemetry are provided. The bi-level command is generated by addressable latches controlled by the 1553 interface. In the event of an overload, the LCL protects the bus by current limiting. After a 10ms nominal trip time, the LCL latches OFF, isolating the fault from the power bus.

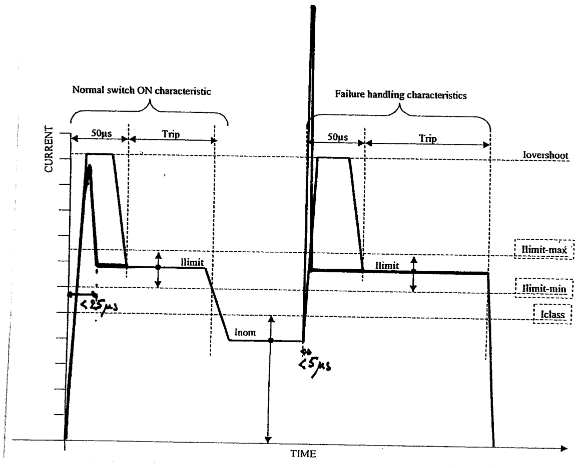
The PO-PCL consists of a standard LCL with a series saturated switch. The PO-LCL is commanded by a bi-level signal (as per the standard LCL) and the series switch, with a separate control circuit, ensures that the line is single failure tolerant to switch off. This device is used wherever simultaneous operation of main and redundant units is not allowed or where PCDU dissipation limits prevents the linear failure of the LCL from remaining ON.

The current limit protection is based around a current limiter with a limitation value that set between 120% to 150% of the nominal LCL protection rating. Rate of rise of current is limited during the ON and OFF time but not if a fault developes during the ON time. The PCDU will be designed to prevent di/dt transients under these conditions from disturbing the bus and generating spurious switch-off events in other protection devices.

There are 3 classes of LCL:

- Class I - has a maximum rating of 1.0A;
- Class II - has a maximum rating of 2.5A;
- Class III - has a maximum rating of 5A.

LCLs can be connected in parallel to create higher value LCL, for example, 4 class III LCL can be used to provide a 20A LCL. Configuration of the multiple LCL group is done outside the PCDU by the spacecraft harness. Control of the parallel LCL is done by ensuring that all 4 LCLs are turned on via a single 1553 command containing instructions for all 4 LCLs. Failure to send all 4 commands will not harm any one of the LCLs in the group because each LCL is capable of surviving any over load.



LCLs are further divided into 2 groups, essential and non essential. The PCDU provides two bus undervoltage detection thresholds. Bus users connected to non-essential LCLs will be disconnected if the power bus falls below the NE threshold (23 to 26 volts) for more then 50 µS. Essential bus users will be disconnected if the bus voltage falls below the ES level (21 to 23 volts) for more then 50 µS.

An output status and current telemetry of each LCL is provided on 1553 bus.

The Fold-back Current Limiter cannot be switched off by command. It will guarantee the uninterrupted supply of the relevant line and the automatic restore of the nominal conditions after the downstream fault has been removed. It is designed to withstand the maximum power dissipation due to continuous limitation condition. This is achieved by reducing the current supplied by the CL once the limitation condition is triggered, thus reducing the power dissipation on the power stage.

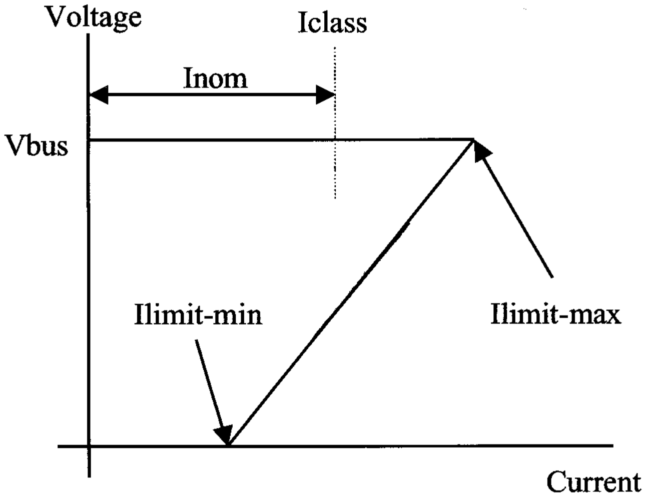


Figure 9.3.4.1.5 –1 illustrate the configuration of one of two types of distribution module. The difference between the two being the number of each type of LCL in a module.

FCLs will be disconnected from the power bus if the bus voltage falls below 18 volts (tbc).

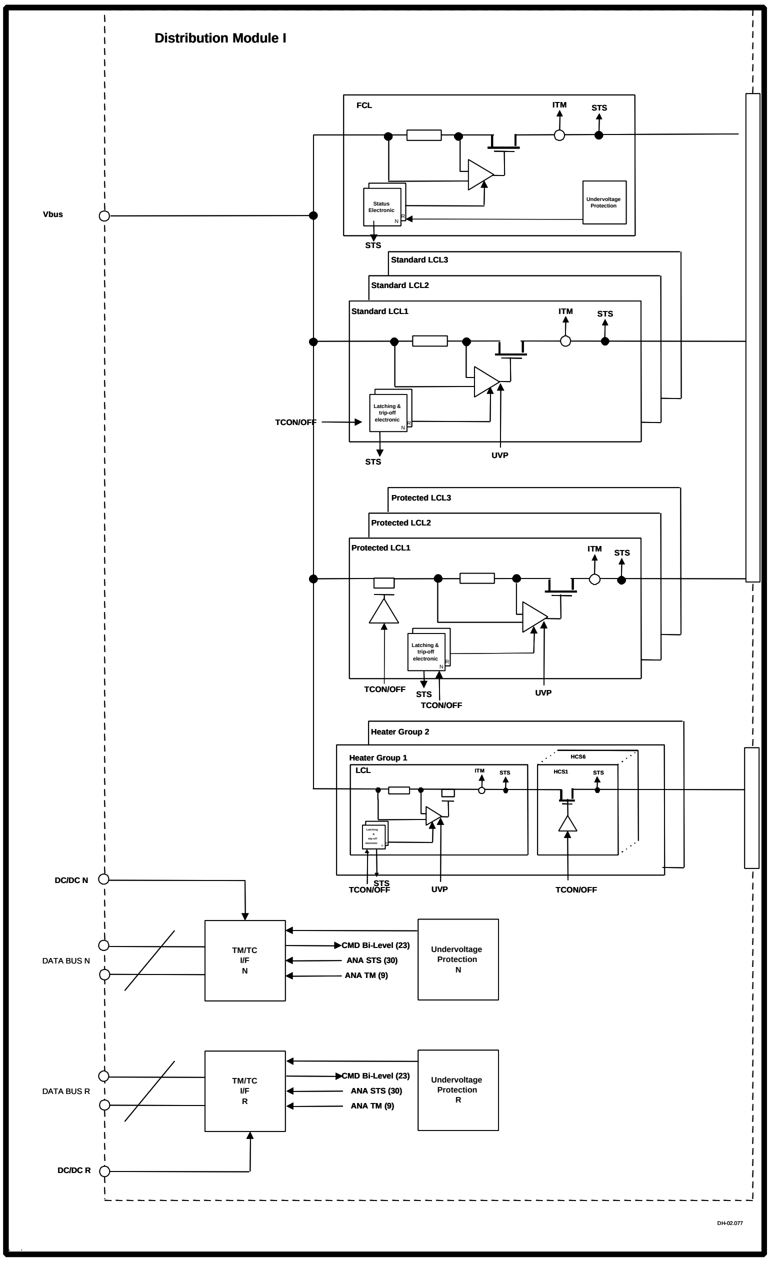


Figure 9.3.4.1.5-1 Type 1 Distribution Module

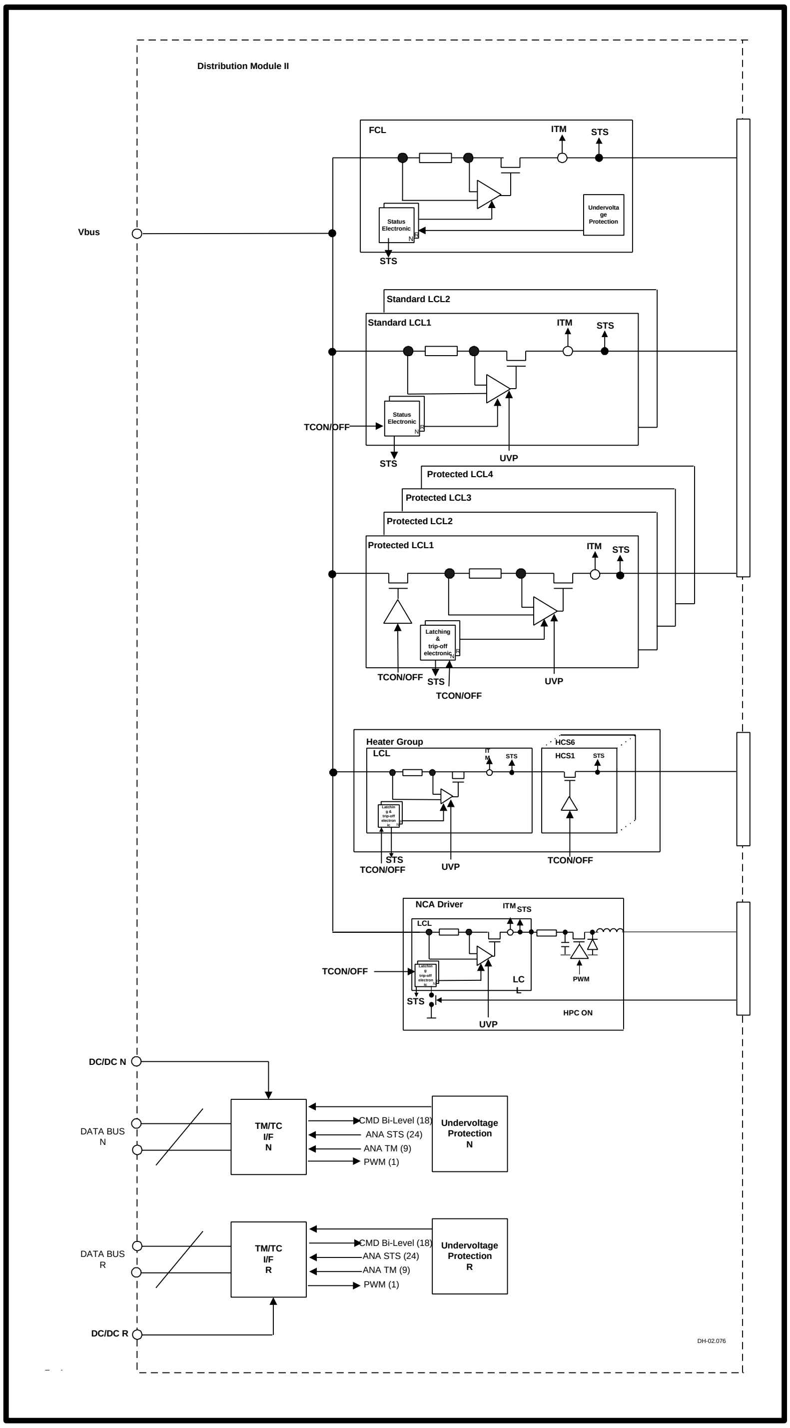


Figure 9.3.4.1.5-2 Type 2 Distribution Module

Heater Distribution

The 28V regulated bus is also distributed to 2 x 54 Heater Control Switches. The HCS are distributed among 2 x 9 Heater-group Protection Switches (HPS), 9 prime and 9 redundant.

Each HPS provides power to 6 HCS and forms the largest element of protection against failures (i.e. not possible to lose more than one HPS containing 6 HCSs). Loss of any prime HPS can be replaced by it's redundant counterpart and vice versa. The HPS has a similar characteristic to the Standard LCL in that it current limits and isolates after a time out period.

The HPS is rated at 10Amps and the HCSs are each rated at 3.75 Amps EOL, due to a connector pin derating requirement.

The current flowing through an HPS is provided in telemetry and the ON/OFF status of any HCS is also provided via the 1553 data bus.

Figure 9.3.4.1.5-2 illustrate the Heater Switching configuration:

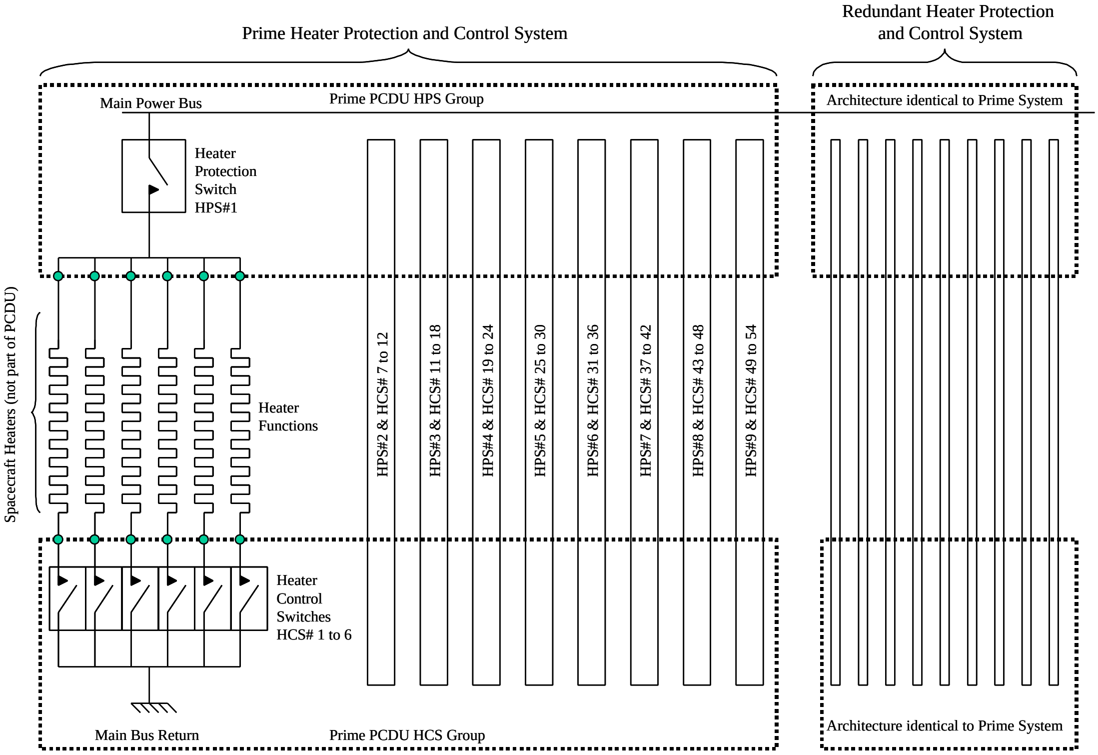


Figure 9.3.4.1.5-2 HPS and HCS configuration

Decontamination heaters will be placed only on the redundant side of the heater distribution system then switch to the prime control system during the mission phases. Any subsequent failures of decontamination HCSs will not result in large loads being placed on the bus and the effects of such a failure on the temperature sensitive instruments they serve can be avoided. Decontamination redundancy is managed by dividing the heaters into 9 groups (7 prime elements and 3 redundant) one per HPS. The current rating of each heater is 4 Amps. However, since these heaters are only used at BOL for a few weeks ALS proposes to raise a deviation against derating and use 7 pins (one per heater element) at 4 Amps instead of 3.75 Amps.

NCA DRIVER

The Non-Contaminating Actuator device is only required for the Herschel mission. It is located in a thermally sensitive location and special cables are provided to reduce the conducted heat loss. The nominal resistance of the NCA is 0.9 Ohms and is only used once for 500ms at the beginning of the mission. The PLM harness is nominally 3.1 Ohms. A maximum firing current of 5.2 Amps is required, consequently the interface voltage at the SVM is 5.2 x 4 Ohms = 20.8 volts. The NCA driver is foreseen to be a Protected LCL and an internal PCDU ballast resistor to drop the remaining 8 volts. To make the LCL available to Plank the LCL will be routed out of the PCDU before passing through the ballast load.

The two series element of the protected LCL will be used to ARM then FIRE the NCA. The fire command is a HLC and is streached by the PCDU from 20ms to 500ms. A simplified schematic of the NCA driver is shown in the follwing figure:

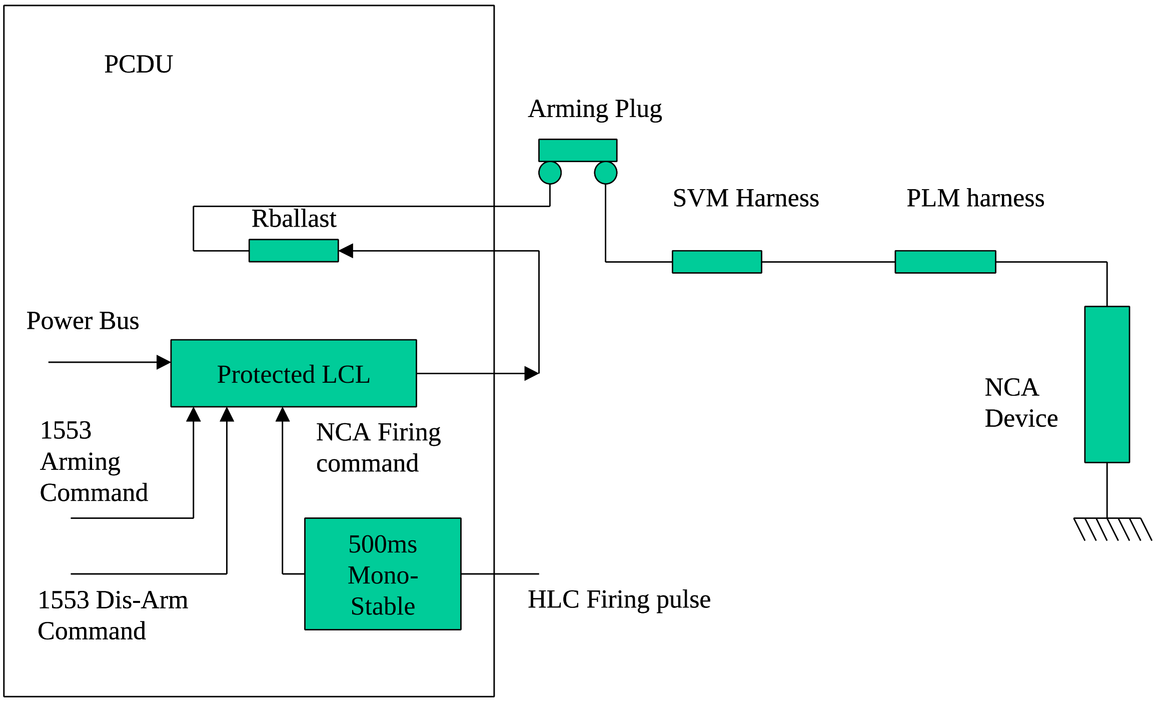


Figure 9.3.4.1.5-3 Typical NCA Driver.

9.3.4.1.6 TMTC Interface Module

The TM/TC interface module of the Herschel-Planck PCDU

- controls the I/F of the PCDU with the OBC via redundant Remote Terminal Interfaces (1553 protocol);
- answers to a set of commands and reports a reduced set of status through direct lines interfaces;
- ensures the interpretation and generation of discrete commands and the reading plus storage of the discrete and analogue telemetry signals;
- manages the battery charge / discharge and
- generates auxiliary power supplies necessary for PCDU needs.

The TM/TC module is fully redundant, all the functions described hereafter are present in nominal TM/TC module and in redundant TM/TC module.

Cold redundancy of the two modules is the baseline. Consequently a reconfiguration of the system may be required after failure. The redundancy configuration is defined by external commands that activate a relay in the supply line of the nominal (or redundant) FPGA. Two relays are implemented (one per TM/TC module) to avoid loss of both interfaces with one single failure.

If reconfiguration is needed (after an internal failure), the following sequence is requested:

- Activation of the redundant FPGA by commanding ON relay of redundant interface.
- Redundant FPGA automatically memorises distribution lines configuration (ON and OFF state).
- Main TM/TC interface is switched OFF via a command of its relay.

This sequence guarantees that distribution configuration remains unchanged in case of TM/TC reconfiguration.

Nominal and redundant auxiliary supplies work in hot redundancy and are cross strapped. No failure can trip OFF both auxiliary supplies.

TM/TC management (including 1553 bus coupler) and BCM interfaces (DAC, ADC) are supplied only by one DC/DC converter through a configuration relay (N. functions by N. DC/DC cvt, R. functions by R. DC/DC cvt).

The BCM function defaults to a preset value and the battery charging function is mainatained even with the TMTC powered OFF.

The auxiliary supply provides the low-level supply voltages to:

- TM/TC interface (including 1553 bus coupler, FPGA circuit, TM/TC conditioning),
- BCM interfaces (ADC, DAC) in TM/TC modules.
- Decentralised TM/TC interface located in distribution modules,
- SA and battery TM sensing (in hot redundancy with redundant auxiliary supply).

The auxiliary supply converter has an output power capability of 12 W and provides non-isolated regulated output voltages (+5 V, +15 V, -15 V).

The following functions can be identified:

- Power cell (flyback topology),
- EMI input filter,
- PWM control circuit (based on an integrated PWM controller, including current limitation loop),
- Start-up circuit (including input under-voltage detection),
- Input protections (FCL type) that prevent propagation to the main bus in case of a failure in the converter.
- Output current limitation and an output overvoltage trip OFF.

The TM/TC module connects the PCDU to a 1553 serial link, compliant with MIL-STD-1553B notice 2 standard. The 1553 remote terminal is able to dialog with both 1553 serial busses (A and B). The physical connection to the busses is made through separated transformers and transceivers.

The FPGA of the TM/TC module performs the following functions:

- It interfaces, via buffers, with the 1553 remote terminal.
- It ensures the interpretation and generation of discrete commands via both 1553 busses (A and B).
- It ensures the reading plus storage of the discrete and analogue telemetry signals.
- It receives direct commands and processes them.
- It provides a reduced set of status through direct lines interface.
- It manages all these information and dialogs with other modules via :

  - ☐ an internal digital bus (data and address) ; TC's and digital statuses are sent and gathered via that mean,
  - ☐ an analogue acquisition chain, made of analogue to digital converters controlled by the FPGA and analogue multiplexers.
- At start-up or bus recovery, it automatically configures PCDU in a deterministic state (all LCLs, HPS and HCS are OFF and all FCL are ON).

The following table summarises the telemetry, status and commands managed by each TM/TC interface module.

Description	Type	Number	Remark
Commands			
Main TM/TC interface ON	HLC	1	
Main TM/TC interface OFF	HLC	1	
Redundant TM/TC interface ON	HLC	1	
Redundant TM/TC interface OFF	HLC	1	
OP-LCL protection ON	HLC	12	
OP-LCL protection OFF	HLC	12	
BDR#1-ON	HLC	1	To be made available to UMB and SVM interfaces
BDR#1-OFF	HLC	1	To be made available to UMB and SVM interfaces
BDR#2-ON	HLC	1	To be made available to UMB and SVM interfaces
BDR#2-OFF	HLC	1	To be made available to UMB and SVM interfaces
BCR#1-ON	HLC	1	To be made available to UMB and SVM interfaces
BCR#1-OFF	HLC	1	To be made available to UMB and SVM interfaces
BCR#2-ON	HLC	1	To be made available to UMB and SVM interfaces
BCR#2-OFF	HLC	1	To be made available to UMB and SVM interfaces
Heater control switch ON	1553	108	1 per heater line
Heater control switch OFF	1553	108	1 per heater line
Heater protection switch ON	1553	18	1 per heater protection switch
Heater protection switch OFF	1553	18	1 per heater protection switch
EoC selection	1553	1	Analogue command coded on 3 bit
EoD selection	1553	1	Analogue command coded on 3 bit
BDR ON	1553	2	1 per BDR
BDR OFF	1553	2	1 per BDR
LCL ON	1553	50	1 per LCL, commands to 20 A LCL and 15 A LCL are grouped in one
LCL OFF	1553	50	1 per LCL, commands to 20 A LCL and 15 A LCL are grouped in one
OP-LCL protection ON	1553	22	1 per OP-LCL, commands to 20 A OP-LCL and 15A OP-LCL are grouped in one
OP-LCL protection OFF	1553	22	1 per OP-LCL, commands to 20 A OP-LCL and 15A OP-LCL are grouped in one
NCA Fire	1553	2	1 per NCA driver
NCA Fire	1553	2	1 per NCA driver
NCA ARM	1553	2	Coded on 4 bits to provide NCA ON command duration
NCA DisArm	1553	2	1 per NCA driver

Telemetries and statuses			
Main 1553 I/f Status	RS	1	
Redundant 1553 I/f Status	RS	1	
Battery Overcharged	RS	1	
Battery Low	RS	1	
Bus undervoltage	RS	1	
SAS current	1553	3	1 per sunlight module
BDR output current	1553	2	1 per BDR
Battery charge current	1553	1	N. Battery monitoring are routed to the OBC via N. TM/TC I/F ; R. one via the R. TM/TC I/F (without cross-strapping).
Battery discharge current	1553	1	
Battery voltage	1553	1	
Bus voltage	1553	1	
MEA voltage	1553	1	
FCL current	1553	10	1 per FCL
LCL current	1553	60	1 per LCL
Heater group current	1553	18	1 per heater protection switch
NCA driver current	1553	2	1 per NCA driver
EoC setting	1553	1	
EoD setting	1553	1	
MEA output voltage	1553	4	
MEA BDR output voltages	1553	7	

9.3.4.1.7 EGSE Interfaces

The PCDU provides the following interfaces for operating the spacecraft during AIV and at the launch site.:

Parameter	Herschel/Planck Limit (at PCDU interface)
Battery support eclipse	- 0 to 28 Volts - 0 to 25 Amps - PCDU to provide protection from external s/c or supply reversal.
Power bus Support in Sunlight Mode	- 0 to 31 Volts - 0 to 20 Amps - PCDU to provide protection from external s/c or supply reversal.
Battery monitor lines	- 2 voltage monitor lines 0 to 28 volts and 2 returns - 100kΩ ±0.1% line protection resistors in series with the positive lines.
Bus monitor lines	- 2 voltage monitor lines 0 to 28 volts and 2 returns - 100kΩ ±0.1% line protection resistors in series with the positive lines.

BATTERY SUPPORT MODES

There are 2 battery support modes:

- AIV support: This mode is used during AIV acivities to power the spacecraft in the absence of a real battery. The battery simulator will be used. Access to the BDR input is provided via the battery safe plug as shown in figure 9.3.4.1.7-1. In the launch configuration this access is prevented by the safe plug which links the battery to the PCDU.
- Launch configuration: In the launch configuration the battery will be present and the PCDU provides it's own access to the battery via an "AIV" interface connector. This access is provided to enable charging of the battery prior to launch. It will be necessary to set the PCDU battery Taper Charge Voltage Threshold slightly above the launch voltage setting in order to avoid the PCDU from diverting the external battery charge current to the power bus. This will be adusted during LEOP as part of the initial early operations function when the spacecraft is separated from the launch vehicle.

The launch interfaces are extremely robust and resilient to potential induced noise external to the spacecraft. In the case of the battery the PCDU offers a high power MOSFET body diode very well damped by the BDR's own power input filters.

The power interfaces used by the EGSE are voltage controlled current sources. Redundant highly accurate voltage sensing resistors are provided at battery and bus level for remote voltage feedback and protection. The battery simulator is connected externally to the PCDU (via the Battery Arming Plug).

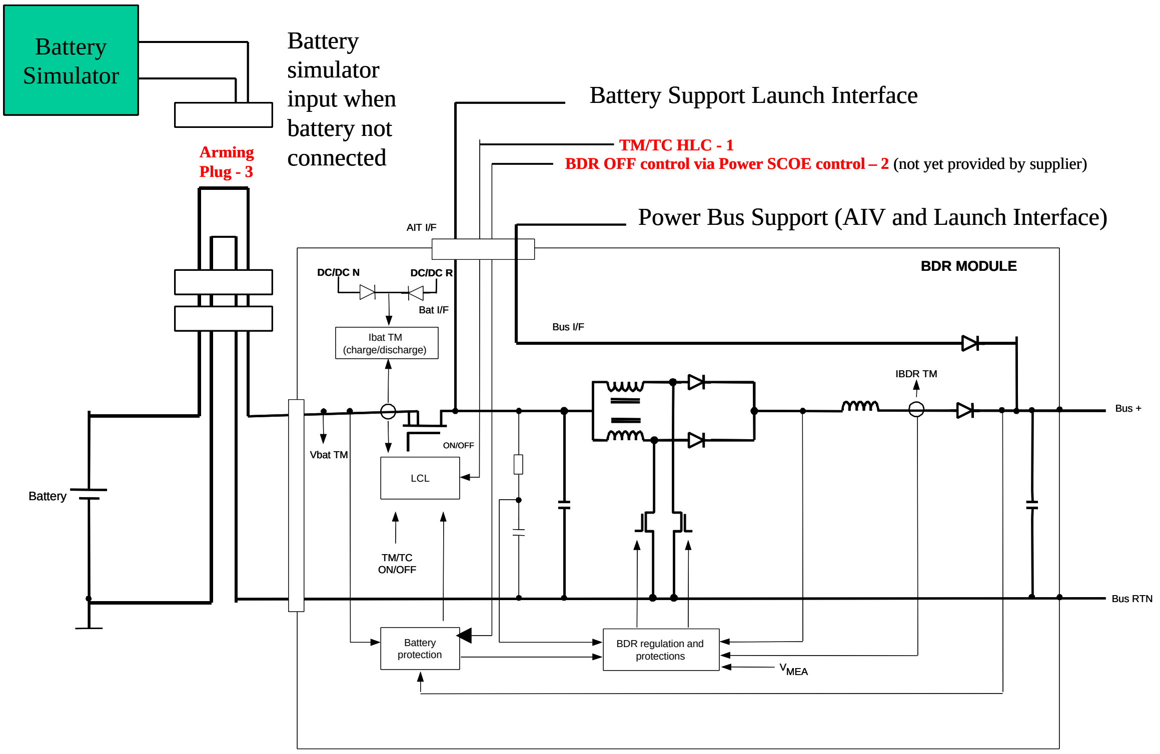


Figure 9.3.4.1.7-1 Batter and Power Bus Support Interfaces

A simplified schematic of the remote power configuration is shown in figure 9.3.4.1.7-2.

When the battery voltage is below the selected battery voltage control threshold, the Power unit in the EGSE has a constant current characteristic. The high output impedance of the current source dominates the line impedance between the EGSE and the spacecraft battery providing a highly stable charging environment. When the battery voltage reaches the desired taper charge voltage for the battery, the remote voltage feedback (isolated from the EGSE local floating ground by a differential amplifier) provides feedback to the current generator. A voltage error amplifier shall be included in the current source to compare the feedback voltage with the a local voltage reference. The output from this erro amplifier modulates the EGSE current output and stabilises the battery voltage. In the launch configuration the battery will not be used except possible for a short check of the BDRs prior to the actual launch. There are therefore no major dynamic current performance requirements.

A sample of the battery voltage is also fed back to a local protection crowbar in the EGSE. If the Battery voltage should exceed the maximum specified battery voltage, a thyristor is operated shorting the EGSE power output. The induced short circuit is prevented from reaching the spacecraft by local diodes in the EGSE and by diodes at the spacecraft end of the umbilical cable.

Fold back cross strapping between the primary EGSE and the secondary unit implements a SET/RESET latch arrangement between the two systems. By switching ON the primary system, a bias is introduced into the control system of the secondary system. This makes the secondary system appear to over voltage and hence the power supply folds back. Another bias to the secondary over-voltage protection prevents the secondary system from being shorted by the crowbar.

In the event that the primary system does shut down, the bias to the secondary system is lost. The system sees the real battery voltage and the feedback signal drives the secondary EGSE error amplifier and the secondary current source charges the battery. It is safe to remove and replace the failed primary system as the primary (seeing a bias from the secondary) behaves as the new secondary system.

To ensure that the remote end of the EGSE does not deliver a potentially dangerous voltage to the end of the cable when it is disconnected from the satellite, remote snubbing and local voltage drop diodes in the EGSE feedback path are provided.

Battery charge system similar to bus support

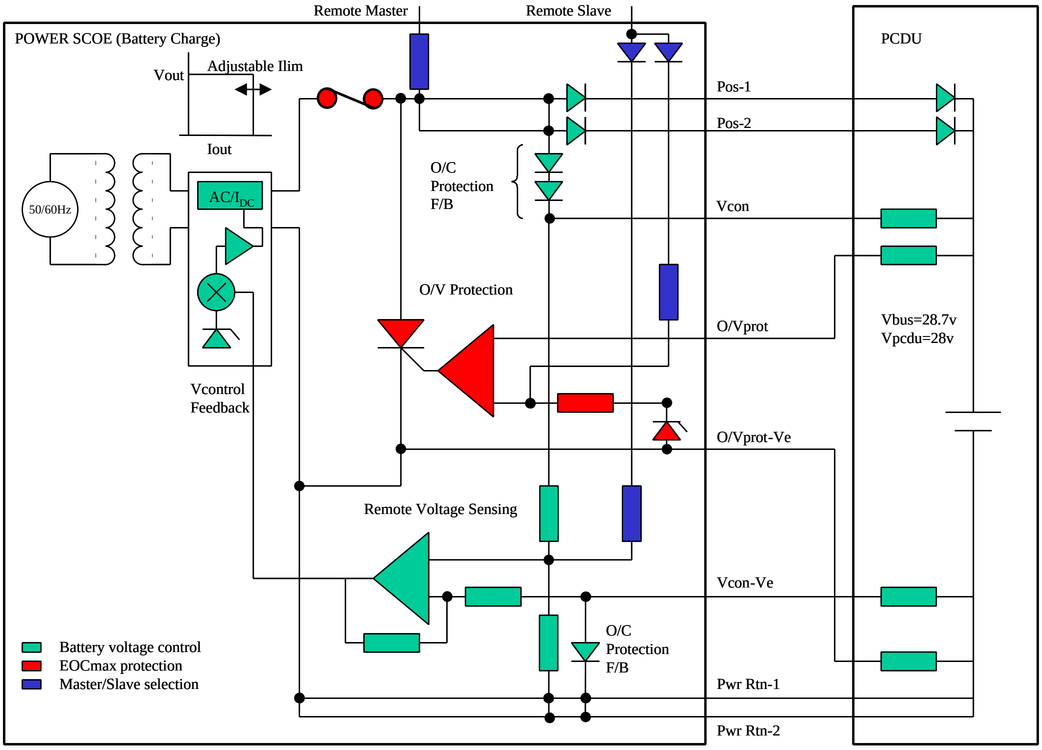


Figure 9.3.4.1.7-2 PCDU Battery support schematic

Battery charge system similar to bus support

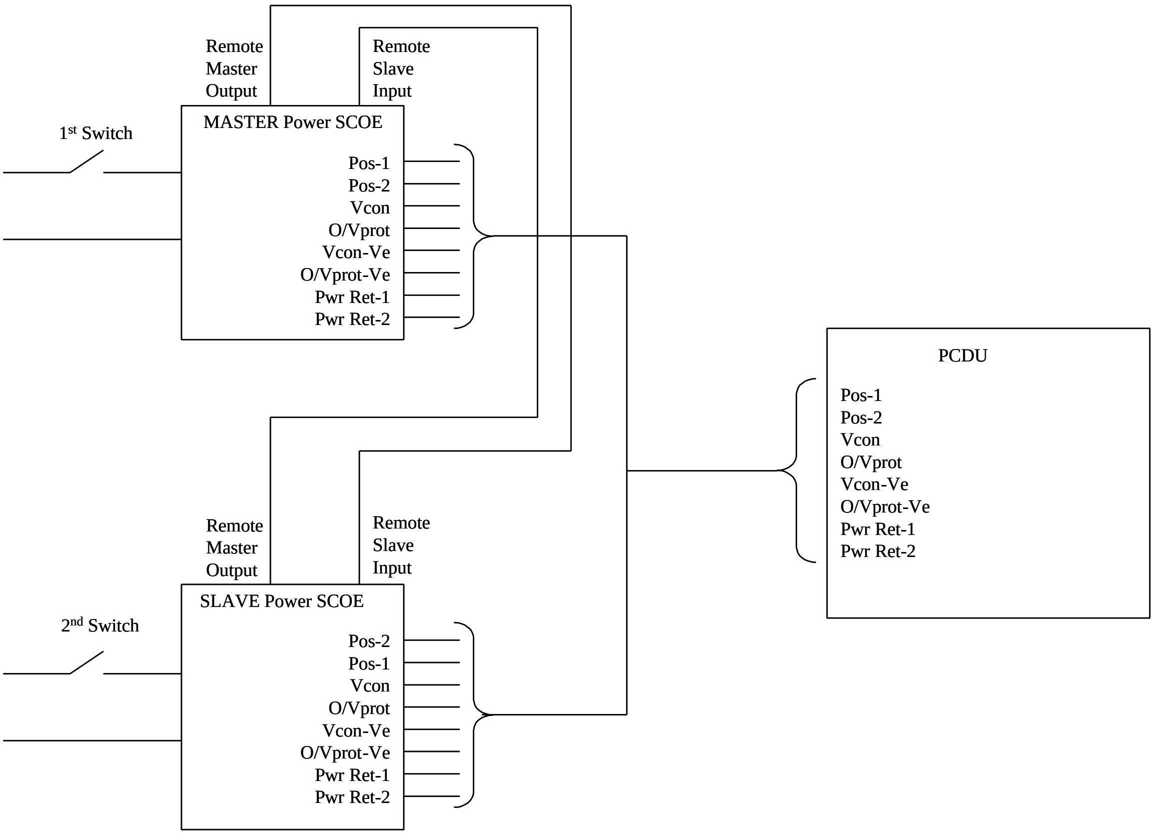


Figure 9.3.4.1.7-3 Battery support cross-coupling

Finally, the two battery voltage sensors are cross strapped at the EGSE ensuring that each sensor supplies the voltage feedback from one EGSE and the overvoltage protection of the other. That way, a control failure in one cannot effect the control system of the other.

MAIN BUS SUPPORT MODES

The main bus may be powered in the launch support and AIV advanced test mode usint the EGSE power supply and vai the Solar Array/Battery simulator mode using the PCDU control interfaces. This paragraph describes the EGSE power supply support mode.

In the EGSE support mode, it is possible to operate the spacecraft in test conditions which cannot be created by the PCDU internal control system. With the BDRs OFF, the bus voltage can be controlled below and above the nominal working voltage so that the following key redundancy and protection functions can be validated.

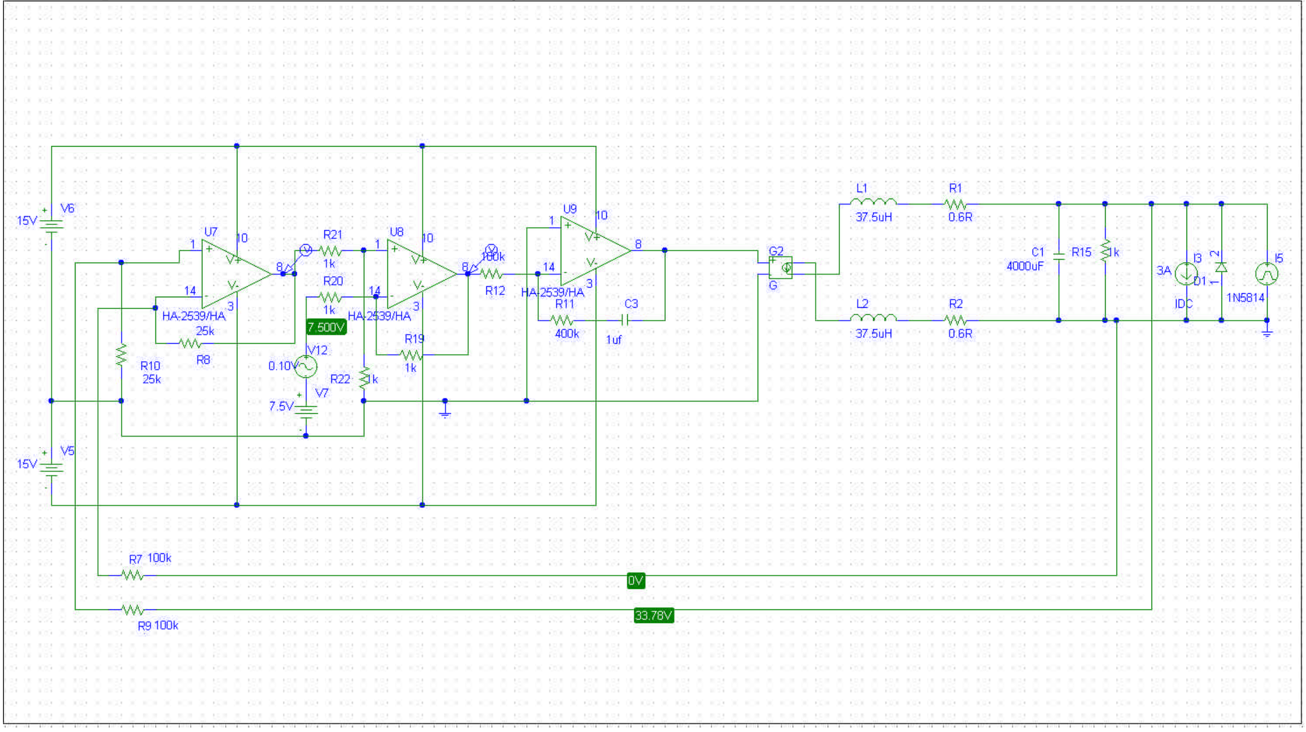
- Verification of the Bus Overvoltage protection in the BDRs.
- Verification of the Bus Undervoltage reset of the PCDU BDRs (26.5V)
- Verification of the Bus Undervoltage alarm to the CDMU (26V)
- Verification of the non-essential LCL switch OFF (23V)
- Verification of the essential LCLswitch OFF (20V)
- Verification of the FCL bus undervoltage switch off (18V)
- PCDU Majority Voter health.

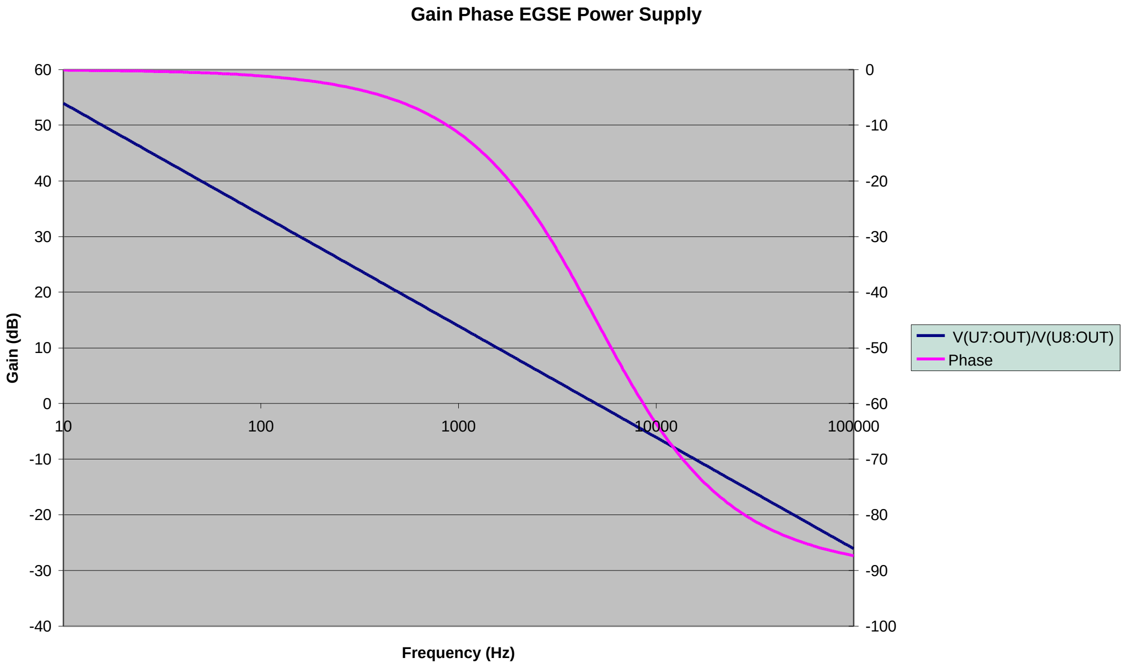
The main bus support power supply works in a similar way as the battery support power supply. Howerver, the EGSE voltage controlled current source is connected to the PCDU main bus capacitor (sized at nominally 4000uF), via local EGSE protection and diode protection inside the PCDU see figure 9.3.4.1.7-1. Thje main bus voltage is controlled by remote bus voltage sensing via the umbilical. A bus impedance of 8 mOhms will be maintained, therefore the cut off frequency for the EGSE current source is 1/(2*π*Cbus*Zbus) = 5kHz.

The main considerations are:

- To set the remote control voltage to 0.5 tbc above the working voltage of the PCDU to ensure that the PCDU control systems back-off and do not discharge the battery (discussions with the PCDU supplier confirm that transient bus voltages above the 0.5V bus bias voltage will not engauge the PCDU's control systems. The proportional gain of the MEA needs a large signal amplitude to bring the MEA out of saturation)
- To avoid inrush transients between the umbilical line inductance (50m @ 1.5µH/m) and the main bus capacitor which provide a potentially high Q tuned circuit. This will be achieved by a slow start ramp in the EGSE power supply and an over current protection in the EGSE power output.
- To avoid resonance between the harness and the bus capacitor entering into the EGSE power supply control loop. This will be avoided by ensuring an adequate open circuit voltage for the EGSE supply. The maximum di/dt from the EGSE supply is limited by the rate of change of bus load and the main bus capacitor. Frequencies above 5kHz will be supplied by the main bus capacitor. Given a maximum load of 15 Amps the maximum di/dt experienced by the EGSE supply will be Ipk*2*π*F=7.5*2*π*5000=0.235A/uS. The inductance of the 50m umbilical cable is typically 50*1.5uH/m=75uH. The voltage headroom needs to be 17 volts.
- To provide sufficient dynamic band width in the EGSE current power supply to avoid slew rate limiting from influencing the output impedance at the spacecraft interface.

A PSPICE simulation of the interface between the Spacecraft and the EGSE bus support supply with 50m of cable has been performed. The results are shown in figures below.





9.3.4.2 Battery

The battery is designed to provide electrical power during launch and to supply the peak demands of the power system.

The only case where the battery is used is during launch, in the event of an attitude loss and in support of bus transient. Duration of this attitude loss cannot be estimated.

The battery is sized to provide power to the spacecraft during the 133.2 minutes of launch.

Including margins, the worst case power need during launch is 256 W for Planck. As it is intended to use the same battery for Herschel and Planck, it has been sized for the Planck case. An energy requirement of 568Wh for the battery has been derived.

As part of the SAFE MODE 2 scenario, the power bus loads will be reduced to the minimum essential for the survival of the spacecraft.

Other design requirements are the following.

- <90% DoD
- Voltage: 15 to 26.4 V
- No maintenance (i.e. reconditioning)

Cell Characteristics

Each of these cells has a capacity of 1.5Ah. These are assembled into modules, and a battery will comprise multiple modules.
The cells proposed are derived from commercial cells with high production rate then there is high possibility of screening at low cost.
Cells are assembled in series strings to achieve the required battery voltage. The strings are connected in parallel to provide the required battery capacity.

The main features are the following.

- Each cell has a built-in protection circuit to ensure that the cell itself will enter a permanent open circuit status in case of over-voltage failure.
- In case of internal over-temperature the failure mode is also an open circuit
- No cell management electronics are required. Charge and discharge is performed at battery level.
- Redundancy (one or more additional strings with respect to the minimum requirement) can be incorporated in the battery with only a small mass penalty.
- These cells are used on Rosetta and Mars Express; battery qualification campaign is completed. A comparison is being made between these requirements and the H-P requirements and will be presented at the PDR.
- Two series redundant thermostate controls for the incorporated emergency heaters.
- Two integrated heaters for normal in flight temperature control.
- Four thermisters.

The key parameters of the cell are shown in the following table.

Parameter	Value
Dimensions	∅ 18 mm x 65 mm
Mass	41.2 g
Maximum Cell Voltage	4.35
Nominal EOC Cell Voltage	4.2 ± 0.05V
Minimum Cell Voltage	2.5V
Nameplate Cell Capacity	1.5 Ah
Nameplate Cell Energy	5.4 Wh
Nameplate Specific Cell Energy	125 Wh/kg
Nameplate Volumetric Cell Energy	318 Wh/l

The characteristics of these cells virtually guarantee that only the open circuit failure mode is the one expected for the cell and therefore at string level.
Discharge Regulator circuits shall be compliant with temporary voltage/current reduction during the protection circuit reaction time

Overcharge
If the cell is overcharged beyond 4.8 V EMF, a chemical breakdown within the cell leads to gas generation and an increase in cell internal pressure. The pressure causes a cell internal disk to bow and physically break an electrical connection within the cell. This disconnect protection mechanism is not reversible and constitutes an open-circuit failure mode of the cell. A considerable overcharge is required to operate the cell-disconnect, typically over 100% additional charge above 4.2V. The cell is designed to remain hermetically sealed if the disconnect is operated.

Cell-level electronics
If a cell fails to open circuit, the whole string is lost. In case of small cells, this represents only a small loss in the capacity of the battery.
In case that a cell short circuit occurs, the string behaves as a load so the other cells in the string will become overcharged. This will activate the overcharge protection mechanism, causing them to fail open circuit

The above considerations lead to consider the open circuit failure mode for any string the only possible one. For this reason, there is no need for cell-level management electronics.

String-level electronics
For the cells in subject an electronics at string level is not required; in fact the purpose of a string-level electronic is to ensure that all of the cells are equally charged and discharged so that the battery operates efficiently and cell overcharge is prevented.
These cells are sufficiently uniform in properties and are closely matched before assembly. Good matching is possible due to the high production rate of the cells and to the low capacity that allows uniformity of manufacturing.

Configuration of the battery
Although the proposed battery design specifies 26 parallel strings, a recent clarification meeting indicated that a 24 string solution would be possible. The proposed battery configuration therefore foresees 24 parallel strings, each one made by 6 cells in series.
Theoretical Energy (@ 100% DoD) is 777Wh. The maximum discharge rate for the battery will be 256 W giving a battery energy requirement of 568 Whrs. At this discharge rate the battery efficiency is typically 95% giving an available energy of 738 Whrs before a failure. The DOD is therefore 76% before a failure and 80% after a string failure.

The predicted mass of the battery is 6.7kg based on a similar design for ROSSETA.

9.3.4.3 Solar Array

Herschel solar array has the following features:

- flat and fixed panels: no deployment are foreseen.
- backside of the solar arrays have to be insulated to avoid heat transfer on the PLM.
- Area limitation: on Herschel it is desirable to limit implementation of solar cells above the telescope level.

Planck solar array has the following features:

- flat and fixed panels: no deployment are foreseen
- Planck needs a very homogeneous surface in view of the PLM. It needs to be circular and without discontinuities in order avoid any disturbing signal at 1 rpm which would affect the Planck payload.
- backside of the solar arrays have to be insulated to avoid heat transfer on Planck PLM.
- Area limitation: Planck solar array is located at the bottom of the spacecraft.
- Solar array diameter is limited by the launcher fairing diameter and surface available for cells is reduced by the cut outs needed by thrusters, ACMS sensors and antennas. Furthermore the plume impingement due to thrusters firing shall be considered.
- Also, the circular shape of the array has an impact on the filling factor.

The solar array for Herschel and Planck is composed by structure and electrical network.

Panel structure

The panel structure of Herschel and Plank solar array is identical and is basically a sandwich structure with aluminium honeycomb. The core thickness is around 22 mm and is covered with high modulus carbon fibre sheets (M55J). Nominally four unidirectional pliers are used on both face sheets. Additional layers are locally used to increase the stiffness e.g. at the interface points.
At the interface point the honeycomb core will be of higher density and if necessary with carbon fibre block inserts.
On front side (the cells side) a 2 mil kapton layer is bonded with two extra layers of epoxy resin to the cured carbon fibre sheet to provide the proper insulation between electrical circuits and the conductive structure of the panel.
The thermal hardware to avoid heat transfer to the spacecraft is not part of the solar array however appropriate fixation points shall be provided on the rear side of the panels.

Solar cells

The power requirement and the maximum panel dimension, together with the commonality dictate the type of solar cells. The characteristics of the chosen cells are listed hereafter.

Type of cell	GaAs multi junction
Dimensions	38.2 * 60.6 mm^2
Thickness	150 μm
Electrical Characteristics Conditions	AM0 25°C
Isc	15.9 mA/cm^2
Voc	2350 mV
Imp	15.1 mA/cm^2
Minimum Vmp	2060 mA/cm^2
Efficiency	23 %

Table 9.3.4-1 solar cells characteristics

Cells are covered with CMG 100 micron thick coverglass.
A shunt diode is already included in the cell assembly to cope with shadow that was proven possible in survival mode.

9.3.4.3.1 Planck Solar Array

Structure

The Planck solar array structure is a disk surface shared into two concentric areas at the launcher interface ring. The part inside the launcher interface ring is called “internal solar array” and the part outside the launcher interface ring is called “external solar array”.
The internal solar array is a unique panel whereas the external solar array is formed by four separated sectors.
The configuration of the Planck solar array is shown in Figure 9.3.4-1.

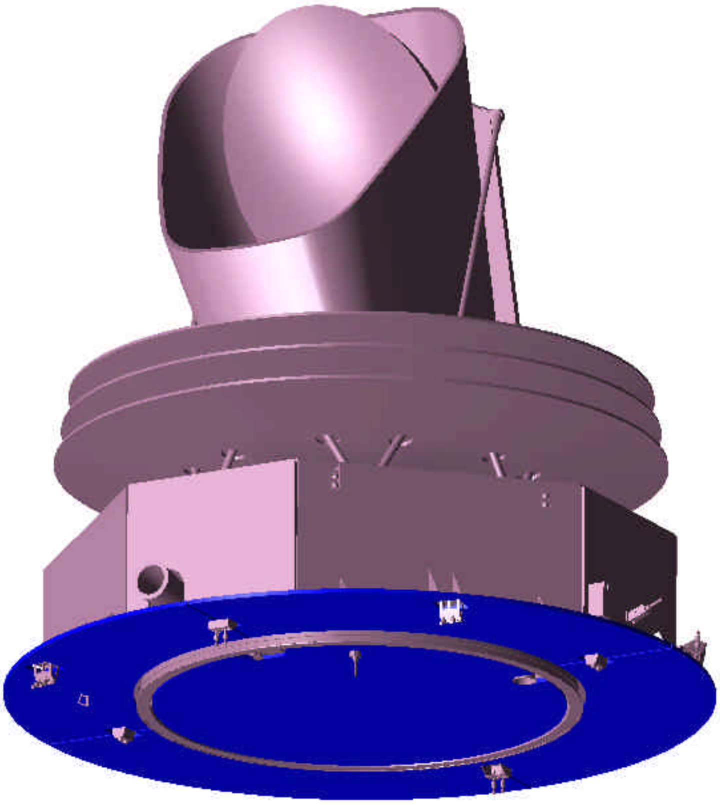


Figure 9.3.4-1 Planck Solar Array Configuration

Mechanical interface

The mechanical interfaces of the solar array panels to Planck spacecraft corresponds to the hard points provided by the spacecraft structure.
Panels shall be fixed with M6 bolts. Usage of M5 bolts is allowed only if their adequacy to withstand maximum loads is demonstrated by analysis.
Adequate cut outs are provided to avoid interference with thrusters.
Figure 9.3.4-2 shows the mechanical interface

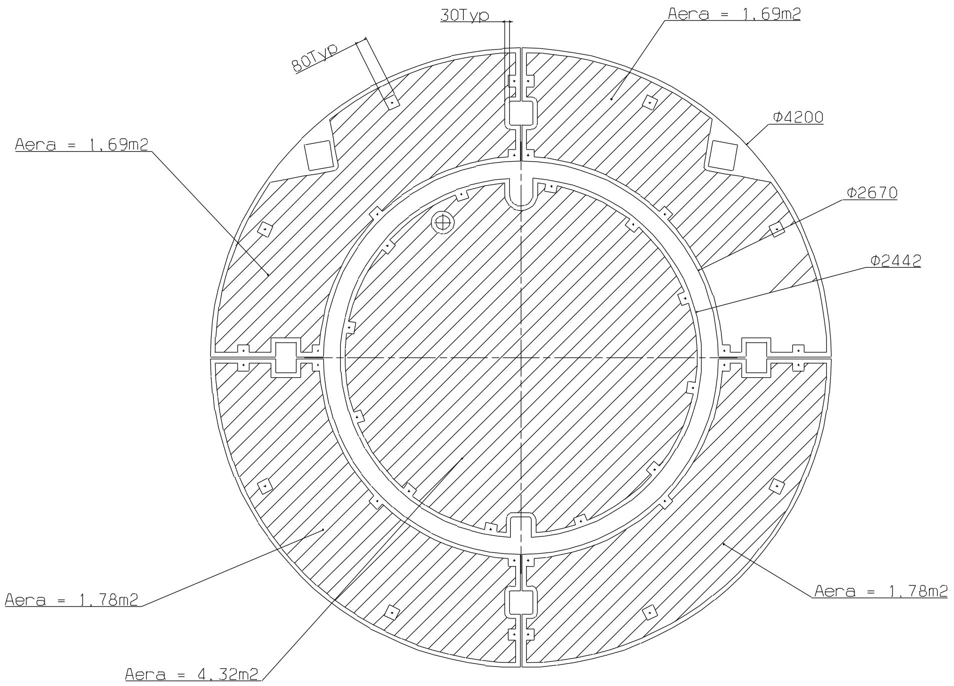


Figure 9.3.4-2 Planck Solar Array Mechanical Interface

Electrical network

The solar array for the Planck satellite is divided into two main solar arrays called Internal Solar Array and External Solar Array.

The internal solar array is a disk surface with an usable area of 4.32 m^2.

The external solar array is a ring with an internal diameter of 2670 mm and an external diameter of 4200 mm. The ring is divided into 4 segments. The usable area is 6.94 m^2.

Therefore the total usable area is 11.26 m^2.

The panels are not deployable and are directly mounted on the spacecraft. The panels also acts as thermal shield so heat transmission to the spacecraft shall be avoided to the maximum extend.
The panels are electrically insulated from each other and from the spacecraft structure unless that for the bleed resistors.

A solar array supplier has not yet been selected however, the foreseen cells configuration is the following.

- Internal solar array
  - ☐ 8 section formed by 6 strings in parallel
  - ☐ 4 sections formed by 5 strings in parallel

- External solar array
  - ☐ 2 quadrants, each of 4 sections formed by 7 strings in parallel
  - ☐ 2 quadrants, each of 5 sections formed by 5 strings in parallel

For each string 21 cells in series have been considered enough to ensure a minimum voltage of 30.5 V at the interface connector while compensating the losses on diodes and harness.

Routing and connection of the strings is such to obtain a nearly complete compensation of the magnetic moment. Residual momentum even in case of failure is lower than the specified 2 A/m.
Each individual string is equipped with a blocking diode mounted on the front side (cells side).

Strings are terminated on a collection bus that is connected via redundant wires to the connectors. Positive and return lines are routed in parallel to meet the EMC requirements.
On each of the four sectors there is a thermal sensor and other two are located on the internal solar array.
These thermal sensors are integrated on the front side.
Furthermore each sector and the internal solar array are provided with 2 grounding points each one connected to 2 bleed resistors in parallel.
Connections to the panel redundant connectors are by means of AWG22 (power lines) and AWG26 (signal lines).

Power prediction

The power prediction is based on the described configuration and taking into account the losses and the array temperature. Power is predicted at BOL and at EOL i.e after 6 years.
Losses and degradation factors to be taken into account for power prediction are listed hereafter.
The maximum SAA expected is 10° resulting from a conical rotation around X axis

BOL degradation factors	I	V
Sun intensity	1.034	
Radiation	0	0
UV and micrometeorites	1	
Cell mismatch	0.99	
Calibration	0.98	
Random losses	1	
Loss of one string	0.994	
Coverglass & ESD protection	0.97	
Wiring and diodes losses		2
Temperature	113 °C	113 °C
SAA field-of-view 10°	0.985	

EOL degradation factors	I	V
Sun intensity	1	
Radiation	1.3E+14	4.0E+14
UV and micrometeorites	0.985	
Cell mismatch	0.99	
Calibration	0.98	
Random losses	0.985	
Loss of one string	0.994	
Coverglass & ESD protection	0.97	
Wiring and diodes losses		2
Temperature	113 °C	113 °C
SAA field-of-view 10°	0.985	

Table 9.3.4-2 Planck Cell Degradation Factors

The power value is given at the interface point already considering the losses on diodes and wiring at a minimum voltage of 30.5 V.
The solar panels are assumed populated at 87% of the available area (no OSR are assumed).
The packing factor is 85%.

BOL performances

External solar array	1100 W
Internal solar array	706 W
Total	1806 W

EOL performances

External solar array	1014 W
Internal solar array	650 W
Total	1664 W

Table 9.3.4-3 Planck solar array performance

The anticipated mass of the array is 39 kg with a margin of 5.9kg making 44.9kg.

9.3.5 Commonality Assessment

Power Control Subsystem has been suitably dimensioned to be compatible with both Herschel and Planck satellites, thus providing a high level of commonality.

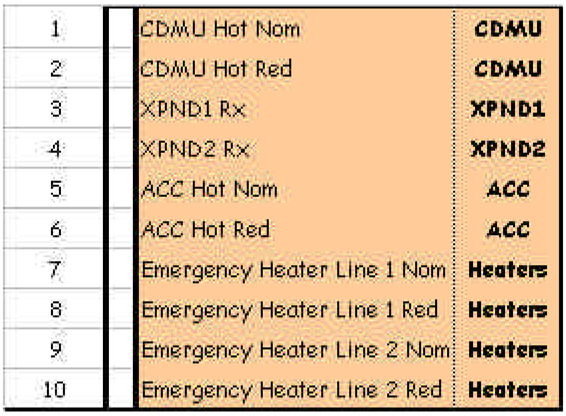
PCDU and Battery will be the same for the two satellites.
The energy margin due to the lower Herschel power demand in safe mode will result in higher margin at launch and longer time available to recover from attitude loss.
Due to the specificity of the Science Instruments needing, the Planck PCDU has more spare lines with respect to the Herschel PCDU.

The Solar Array is different, due the different shapes of the two satellites.
The commonality is realised at level of Solar Cells, Grounding Network and kind of Panel Structure.

9.3.6 Budget Summary

9.3.6.1 FCL and LCL Budget

The PCDU power lines connected to Fold-Back Current Limiters are listed in the following table. This configuration is valid for both Herschel and Planck.



1		CDMU Hot Nom	**CDMU**
2		CDMU Hot Red	**CDMU**
3		XPND1 Rx	**XPND1**
4		XPND2 Rx	**XPND2**
5		ACC Hot Nom	**ACC**
6		ACC Hot Red	**ACC**
7		Emergency Heater Line 1 Nom	**Heaters**
8		Emergency Heater Line 1 Red	**Heaters**
9		Emergency Heater Line 2 Nom	**Heaters**
10		Emergency Heater Line 2 Red	**Heaters**

Table 9.3.6-1 PCDU FCL Budget

The PCDU power lines connected to Herschel and Planck Latching Current Limiters are listed in Table 9.3.6-2 and Table 9.3.6-3.
Information on Protected Lines and Direct Commands (in addition of 1553) is also given.

	Herschel Allocation	To	Planck Allocation	To	Protected	Class	Direct Command
11	SPIRE HSDPU Nom	HSDPU	HFI REU Proc Nom	PHCBC	YES	I	
12	SPIRE HSDPU Red	HSDPU	HFI REU Proc Red	PHCBC	YES	I	
13	CDMU Cold Nom	CDMU	CDMU Cold Nom	CDMU	NO	I	YES
14	CDMU Cold Red	CDMU	CDMU Cold Red	CDMU	NO	I	YES
15	XPND1 Tx	XPND1	XPND1 Tx	XPND1	NO	I	
16	XPND2 Tx	XPND2	XPND2 Tx	XPND2	NO	I	
17	ACC Cold Nom	ACC	ACC Cold Nom	ACC	NO	I	YES
18	ACC Cold Red	ACC	ACC Cold Red	ACC	NO	I	YES
19	SREM	SREM	SREM	SREM	NO	I	
20	VMC	VMC	VMC	VMC	NO	I	
21	STR 1	STRE1	STR 1	STRE1	NO	I	
22	STR 2	STRE2	STR 2	STRE2	NO	I	
23	QRS1	QRS1	QRS1	QRS1	NO	I	
24	QRS2	QRS2	QRS2	QRS2	NO	I	
25	GYRO Nom	GYRE	QRS3	QRS3	NO	I	
26	GYRO Red	GYRE	HFI DCE	PHEC	NO	I	
27	PACS BOLC Nom	FPBOLC	LFI REBA Nom	PLREN	YES	II	
28	PACS BOLC Red	FPBOLC	LFI REBA Red	PLRER	YES	II	
29	PACS MEC1	FPMEC1	HFI DPU Nom (PHBA-N)	PHBAN	YES	II	
30	PACS MEC2	FPMEC2	HFI DPU Red (PHBA-R)	PHBAR	YES	II	
31	ACMS PDU Nom	PDU	ACMS PDU Nom	PDU	NO	II	
32	ACMS PDU Red	PDU	ACMS PDU Red	PDU	NO	II	
33	PACS DPU Nom	FPDPU	HFI 4KCDE Nom (PHDC)	PHDC	NO	II	
34	PACS DPU Red	FPDPU	HFI 4KCDE Red (PHDC)	PHDC	NO	II	
35	PACS SPU Nom	FPSPU1	HFI REU belts 0 & 1	PHBAR	NO	II	
36	PACS SPU Red	FPSPU2	HFI REU belts 2 & 3	PHBAR	NO	II	
37	CCU Nom	CCU	HFI REU belts 4 & 5	PHBAR	NO	II	
38	CCU Red	CCU	HFI REU belts 6 & 7	PHBAN	NO	II	
39	HIFI ICU Nom	FHICU	HFI REU belts 8 & 9	PHBAN	NO	II	
40	HIFI ICU Red	FHICU	HFI REU belts 10 & 11	PHBAN	NO	II	
41	HIFI HRH	FHHRH			NO	II	
42	HIFI HRV	FHHRV			NO	II	
43	HIFI WEH	FHWEH			NO	II	
44	HIFI WEV	FHWEV			NO	II	

Table 9.3.6-2 PCDU LCL Budget – Class I and II

45	ACC RCS Thrusters Nom	**ACC**	ACC RCS Thrusters Nom	**ACC**	YES	III	YES
46	ACC RCS Thrusters Red	**ACC**	ACC RCS Thrusters Red	**ACC**	YES	III	YES
47	ACC RCS LV Nom	**ACC**	ACC RCS LV Nom	**ACC**	YES	III	YES
48	ACC RCS LV Red	**ACC**	ACC RCS LV Red	**ACC**	YES	III	YES
49	TWTA 1	**EPC1**	TWTA 1	**EPC1**	YES	III	
50	TWTA 2	**EPC2**	TWTA 2	**EPC2**	YES	III	
51	SPIRE HSFCU Nom	**HSFCU**	LFI DAE Nom	**PLBEU**	YES	III	
52	SPIRE HSFCU Red	**HSFCU**	LFI DAE Red	**PLBEU**	YES	III	
53	HIFI LCU Nom	**FHLCU**	Sorption Cooler Electronics Nom	**PSM4**	YES	III	
54	HIFI LCU Red	**FHLCU**	Sorption Cooler Electronics Red	**PSR4**	YES	III	
55	Reaction Wheel 1	**RWE**			YES	III	
56	Reaction Wheel 2	**RWE**			YES	III	
57	Reaction Wheel 3	**RWE**			YES	III	
58	Reaction Wheel 4	**RWE**			YES	III	
59			HFI 4KC Drive bus Nom	**PHDC**	YES	III	
60			HFI 4KC Drive bus Nom	**PHDC**	YES	III	
61			HFI 4KC Drive bus Red	**PHDC**	YES	III	
62			HFI 4KC Drive bus Red	**PHDC**	YES	III	
63			Sorption Cooler Compressor Nom 1	**PSM4**	YES	III	YES
64			Sorption Cooler Compressor Nom 2	**PSM4**	YES	III	
65			Sorption Cooler Compressor Nom 3	**PSM4**	YES	III	
66			Sorption Cooler Compressor Nom 4	**PSM4**	YES	III	
67			Sorption Cooler Compressor Red 1	**PSR4**	YES	III	YES
68			Sorption Cooler Compressor Red 2	**PSR4**	YES	III	
69			Sorption Cooler Compressor Red 3	**PSR4**	YES	III	
70			Sorption Cooler Compressor Red 4	**PSR4**	YES	III	
71	PLM NCA Actuators Nom	**PLM I/F**			NO	NCA	
72	PLM NCA Actuators Red	**PLM I/F**			NO	NCA	

Table 9.3.6-3 PCDU LCL Budget – Class III

9.3.6.2 Heater Lines Budget

The following tables list the allocation of Heater switch lines and Heater Group Protection Switches.

		Herschel				Planck		
Heater Group Protection Switch	**Heater switch line**	**Heater Location**	**Heater Power (Watts)**	**HERSCHEL Heater Group Load**	**Heater switch line**	**Heater Locations**	**Heaters Power (W)**	**PLANCK Heater Group Load**
1	**1**	EPC1	10,2		**1**	EPC1	0,0	
		XPND1	11,7			XPND1	6,0	
		TWTA1	17,0			TWTA1	38,0	
	2	EPC2	10,2		**2**	EPC2	0,0	
		XPND2	11,7			XPND2	6,0	
		TWTA2	17,0			TWTA2	38,0	
						RFDN	8,0	
	3	BATT	45,8		**3**	DPU2 (on shear)	35,70	
	4	FPSPU1_2	6,1		**4**	4 CCU	20,64	
		FPDPU	15,0			4 CAU	20,67	
		FPMECDEC	25,2					
	5	Spare 1			**5**	4 PRE-REG	23,20	
	6	Decon Htr 1	90,0	259,9	**6**	4 CEU	12,96	209,2
2	**7**	CRYOE	28,1		**7**	SCE-1 Htr 1	66,43	
		HSDCU	27,0					
	8	HSDPU	26,7		**8**	SCE-1 Htr 2	66,43	
		HSFCU	20,6					
	9	FHWOV Htr 1	3,8		**9**	SCE-1 Htr 3	66,43	
		FHWEV Htr 1	11,0					
		FHICU Htr 1	2,9					
	10	FHWOV Htr 2	3,8		**10**	SCE-1 Htr 4	66,43	
		FHWEV Htr 2	11,0					
		FHICU Htr 2	2,9					
	11	FHWOV Htr 3	3,8		**11**	He Tank +Z	0,72	
		FHWEV Htr 3	11,0					
		FHICU Htr 3	2,9					
	12	Decon Htr 2	90,0	245,6	**12**	He Tank +Y	0,68	267,1
3	**13**	FHHRV Htr 1	18,9		**13**	SCE-2 Htr 1	65,85	
		FHFCU Htr 1	4,6					
	14	FHHRV Htr 2	18,9		**14**	SCE-2 Htr 2	65,85	
		FHFCU Htr 2	4,6					
	15	FHHRV Htr 3	18,9		**15**	SCE-2 Htr 3	65,85	
		FHFCU Htr 3	4,6					
	16	FHLCU Htr 1	8,3		**16**	SCE-2 Htr 4	65,85	
		FHLSU Htr 1	8,3					
		FHWOH Htr 1	8,7					
	17	FHLCU Htr 2	8,3		**17**	He Tank -Z	0,16	
		FHLSU Htr 2	8,3					
		FHWOH Htr 2	8,7					
	18	Decon Htr 3	90,0	211,1	**18**	He Tank -Y	0,00	263,6

Table 9.3.6-4 PCDU Heater Lines – Heater Group 1, 2 and 3

		Herschel				Planck		
Heater Group Protection Switch	**Heater switch line**	**Heater Location**	**Heater Power (Watts)**	**HERSCHEL Heater Group Load**	**Heater switch line**	**Heater Locations**	**Heaters Power (W)**	**PLANCK Heater Group Load**
4	**19**	FHLCU Htr 3	8,3		**19**	BATT	12,23	
		FHLSU Htr 3	8,3					
		FHWOH Htr 3	8,7					
	20	FHWEH Htr 1	11,6		**20**	P TANK +Y+Z	0,18	
		FHHRH Htr 1	11,4					
	21	FHWEH Htr 2	11,6		**21**	P TANK -Z	0,13	
		FHHRH Htr 2	11,4					
	22	FHWEH Htr 3	11,6		**22**	P TANK -Y+Z	0,00	
		FHHRH Htr 3	11,4					
	23	RWL1	20,8		**23**	Primary Reflector 1	60,00	
		RWL2	24,1					
	24	Decon Htr 4	90,0	229,2	**24**	Primary Reflector 2	60,00	132,5
5	**25**	RWL3	21,3		**25**	Primary Reflector 3	60,00	
		RWL4	16,3					
	26	TANK1	3,1		**26**	Secondary Reflector	60,00	
	27	TANK2	3,1		**27**			
	28	RCS(*) Htr 1	8,0		**28**	RCS(*) Htr 1	8,0	
	29	RCS(*) Htr 2	8,0		**29**	RCS(*) Htr 2	8,0	
	30	Decon Htr 5	90,0	149,8	**30**	Spare 1		136,0
6	**31**	RCS(*) Htr 3	8,0		**31**	RCS(*) Htr 3	8,0	
	32	Thrusters(*) Htr 1	2,7		**32**	Thrusters(*) Htr 1	2,7	
	33	Thrusters(*) Htr 2	2,7		**33**	Thrusters(*) Htr 2	2,7	
	34	Thrusters(*) Htr 3	2,7		**34**	Thrusters(*) Htr 3	2,7	
	35	Thrusters(*) Htr 4	2,7		**35**	Thrusters(*) Htr 4	2,7	
	36	Decon Htr 6	90,0	108,7	**36**	Spare 2		18,7
7	**37**	Thrusters(*) Htr 5	2,7		**37**	Thrusters(*) Htr 5	2,7	
	38	Thrusters(*) Htr 6	2,7		**38**	Thrusters(*) Htr 6	2,7	
	39	Thrusters(*) Htr 7	2,7		**39**	Thrusters(*) Htr 7	2,7	
	40	Thrusters(*) Htr 8	2,7		**40**	Thrusters(*) Htr 8	2,7	
	41	Thrusters(*) Htr 9	2,7		**41**	Thrusters(*) Htr 9	2,7	
	42	Decon Htr 7	90,0	103,3	**42**	Spare 3		13,3
8	**43**	Thrusters(*) Htr 10	2,7		**43**	Thrusters(*) Htr 10	2,7	
	44	Thrusters(*) Htr 11	2,7		**44**	Thrusters(*) Htr 11	2,7	
	45	Thrusters(*) Htr 12	2,7		**45**	Thrusters(*) Htr 12	2,7	
	46	STREMY	2,6		**46**	Focal Plane Htr 1	60,00	
		STREPY	2,7					
	47	FPBPOLC	44,8		**47**	Focal Plane Htr 2	60,00	
	48	Decon Htr 8	90,0	148,1	**48**	Spare 4		128,0
9	**49**	RWDE	15,1		**49**	STR1	2,61	
						STR2	10,41	
	50	Spare 2			**50**	DPU1	30,19	
	51	Spare 3			**51**	Spare 5		
	52	Spare 4			**52**	Spare 6		
	53	Spare 5			**53**	Spare 7		
	54	Decon Htr 9	90,0	105,1	**54**	Spare 8		43,2

Table 9.3.6-5 PCDU Heater Lines – Heater Group 4 to 9

9.3.6.3 Mass Budget

The PCS mass budget is detailed in the following table.

Unit	Qty	Nominal Mass	Margin	Maximum Mass
PCDU	1	25.8	10%	28.4
Battery	1	7	15%	8.1
Total		32,8		36,5

Table 9.3.6-6 Power Control Subsystem Mass Budget

Planck Solar Array

The mass of the bare panels has been estimated as 16 kg for the external solar array and as 10 Kg for the internal solar array. This mass includes reinforcements and inserts.
The PVA mass is assumed to be 18 kg .
This gives a total mass of about 44 kg.

The solar array mass does not include the thermal hardware for panels thermal insulation and the bolts for fixation.

9.4 SVM Harness

9.4.1 General

The Herschel/Planck SVM Harness provides the interconnections between all electrical and electronic equipment installed on SVM Platform and Panels.
The Harness connecting equipment of the SVM to equipment functionally allocated to the PLM but installed on SVM WU Panels will be part of the SVM harness (up to the first WU unit interface)

The Harness between equipment within the instruments will not be part of the SVM Harness. The electrical and mechanical/routing design responsibility of this WU Interconnecting Harness and Cryo Harness shall be of the relevant supplier.

The SVM Harness shall include the following items:

- Cables, connectors and contacts/screws required to perform the electrical connections
- In Line Couplers (ILC) necessary to implement the MIL-Bus-1553B connections of DMS Bus and ACMS Bus
- MIL-Bus-1553B Termination (in-line and/or with termination loads assembled in a connectors)
- Shielding provisions for the wiring (overall shields/conductive tape, straps to ground)
- Connectors accessories to allow shield termination (RFI backshell included)
- SVM Harness fixation devices and associated hardware required to install the cabling on the structure
- Connector protective caps, edge protections and grommets/tape
- All the Connector Bracket necessary to install the receptacle connectors with the relevant fixation screws
- All the structural support as stand- off, spacers, necessary to perform the harness routing with relevant fixation devices
- Harness Grounding Rail necessary to distribute the grounding plane along the harness routing with relevant fixation devices/media
- Splice and/or connecting devices necessary to connect devices having flying leads

In addition the SVM Harness shall provide the electrical connections for :

- All TCS subsystem items (heaters, thermistors and thermostats) mounted on SVM up to the component and up to CB interface connectors for those dedicated to PLM
- All RCS subsystem items (Thrusters/sensors) mounted on spacecraft up to the component

The following cabling will not be part of SVM Harness

- The Coaxial cable connecting the antenna to the Transponders through the TWTA will be part of the TT&C Subsystem.
- The TWTA to EPC HV cables will be part of the TT&C Subsystem.
- The RWE to RWL cabling will be part of the ACMS Subsystem

9.4.2 Requirements and Design Drivers

The Herschel/Planck Harness maintain the modularity concept of the Herschel/Planck structure separation.
Due to the different Configuration constraints and approach the SVM to PLM module separation will be implemented in different manner in between the two S/C.

On Herschel a limited set of interface connectors are provided between the SVM and PLM modules in order to provide the requested interface (Cryo Temperature Monitors, Heaters and NCA lines). Also the Solar Array Interface connectors will be at this level.

In addition to the above interface all there will be the interface connectors belongs mainly to the PLM Cryo Harness and other segments of the Instrument WU Harness (not under ALS responsibility).

All these connectors will be place on the Upper Platform which shall remain fixed to the main structure.

On Planck the Upper platform is requested to be removable for accessibility purpose. Therefore the SVM/PLM interface connectors shall be place on the Shear Panel or on the PLM Sub Platform.

In addition the SVM Harness shall maintain the Lateral Panel Tilting requirements by means of a dedicated connector brackets which are placed on the Lower Platform as much as possible close to the panel hinging point.

The definition of harness routing on the structure will be performed using a System Configuration Model generated on 3-D CAD Model . This model will be representative of all the mechanical data and interface requirements, as well as of constraints, that have to be considered in routing definition.

Routing will be designed in order to guarantee easy access to connectors for insertion and removal from equipment, and to provide sufficient slack in the harness in order to enable termination and mate/demate operation at connector level.
Routing will be, as far as possible, the most direct, in order to minimize cable length, maintaining the cables close to the primary structure.

The bending radius of harness will be maintained greater than 3 times the outside bundle diameter.
Ty-bases, ty-raps and P-clamps are planned to be used, as applicable, to fix the cables to the structure, in order to allow for easy replacement of cables and bundles.
Fixing points shall be adequately spaced to provide safe harness mounting and relief to the structure.
Protections will be used in correspondence of sharp edges, cut-outs and on the harness slacks.

Looms of different EMC classes that run close to each other on the same side of the panel, are separated as much as possible.
As a general rule, the harness looms are routed as close to each unit connector front face as possible without interfering with the unit mounting feet and maintaining the requirement for unit/structure removal.

9.4.3 Functional Description

The Herschel/Planck SVM Harness design will be carried out taking as input the applicable Electrical and Mechanical Interface Information collecting all the electrical interconnections, defined down to equipment level, and mechanical requirements for the harness.
On this basis, the harness will be defined considering the following design requirements:

- separation of SVM/PLM and interface to Launcher/Check-Out (i.e.EGSE) through a Skin connector
- maximum modularity (each bundle was defined with the aim of keeping to a minimum the number relevant connectors);
- class separation, as far as possible with reference to the interface signal assignment on each connector;
- performance requirements (length, voltage drop, mass,...).

The following Figure 9.4.3-1 shown the SVM Harness architecture and relevant harness segment responsibility.

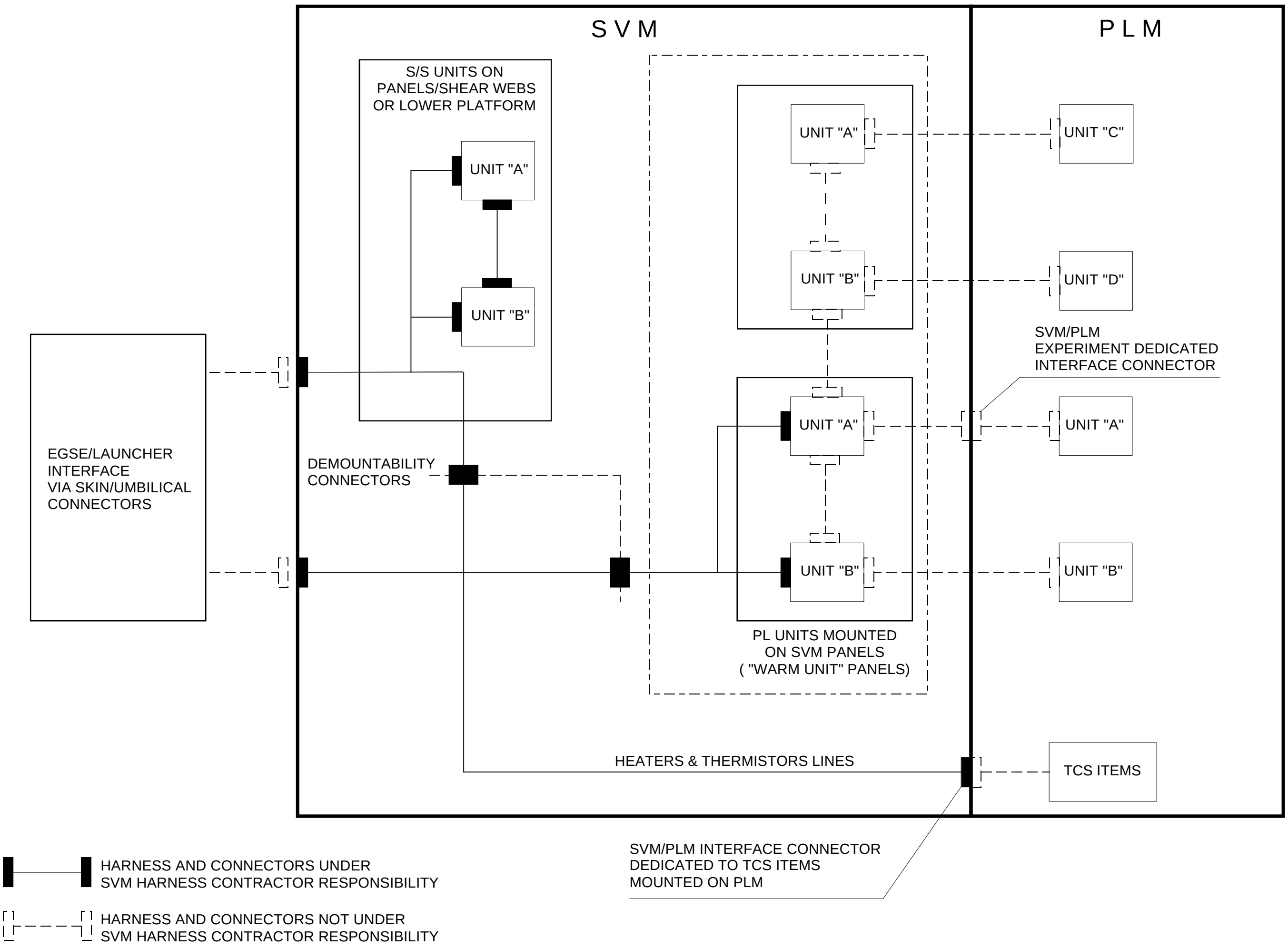


Figure 9.4-3-1 SVM Harness architecture

9.4.4 Design and Performance

The SVM Harness Electrical Items is subdivided in groups which shall be identified in accordance with the module configuration (lateral panels and platform/cone).

Each group shall be composed by physically separable sub-assemblies called Harness Manufacturing Unit (HMU) which identification shall reflect relevant location on SVM.
In addition each group shall include also the installation hardware necessary to mount the HMU on relevant structures

The SVM Harness Mechanical Items shall include all the non-electrical components of harness as Connector Brackets, Stand-off Support, Grounding Rails and all the hardware necessary to mount these items on SVM.

9.4.5 Commonality Assessment

The Herschel/Planck SVM harness will be conceived to reach to the maximum extent commonality between the two projects.
Due to some minor differences between the Herschel and Planck architecture, connectivity and equipment location, full commonality (especially on routing) cannot be achieved.
Materials and design methods will however be common.
The following table summarizes the commonality between the Herschel and Planck on the harness design.

FUNCTION	EQUIPMENT	LEVEL OF COMMONALITY
Launcher Interface	Umbilical Connector	It is assumed that the interface with the selected Launcher will be the same but place on different location with respect to the reference frame
EGSE Interface	Skin Connectors	Commonality not fully achievable. Skin connectors accessible from EGSE when the panel are closed are placed on the same panel (PWR). The relevant routing on Planck is not common.
Power	Power Conditioning and Distribution Unit	Both Planck and Herschel will use the same PCDU (same connector) but some outputs are not connected to the same users. Different routing is expected on the relevant panel . Minor difference on materials
	Solar Array Interface	This is actually the major items of non-commonality. Due to the different SA location on the two S/C the relevant harness to the PCDU on panel shall be completely different.
	Battery	Full commonality on material and routing can be achievable.
CDMS	CDMU	Both Planck and Herschel will use the same PCDU (same connector) but some I/O lines are not connected to the same users. Minor Differences on routing and wiring arrangement are expected. Minor difference on materials for cables has to be considered
AOCS	ACC	Both Planck and Herschel will use the same ACC (same connector) but some I/O lines are not connected to the same users on Planck due to the reduced s/s configuration. Minor differences on routing and wiring arrangement are expected. Minor difference on materials for cables has to be considered
	RWS	Equipment used only in Herschel design.
	STR	Equipment used on both S/C but located on different place. Routing ion Lower Platform is not common
	GYR	Equipment used only in Herschel design.
	SAS	Equipment used on both S/C but located on different place. Routing ion Lower Platform is not common
	QRS	Commonality partly achievable only for 2 units (QRS1/2), the third unit is used only on Planck desing.
	AAD	Equipment used on both S/C but located on different place. Routing ion Lower Platform is not common
	PDU	Equipment used on both S/C but located on different place. Routing on Lower Platform is not common
TTC	All equipment	Full commonality on routing can be achievable on relevant panels.
Thermal Control	Heaters/ Thermistors	Full dedicated set of harness connecting the TCS items specific for Herschel and Plack design.
RCS	All equipment	Full dedicated set of harness connecting the RCS items specific for Herschel and Plack design.

9.4.6 Budget Summary

The definition of the harness mass budget is strongly related to the definition and implementation of the electrical interface as well as to the mechanical configuration/layout electrical interfaces.
Therefore the mass figures presented must be considered preliminary and subject to modification in the frame of the overall Herschel/Planck System design evolution and definition.
In order to establish the Harness mass is necessary to define a list of units connectors, external interface connectors, harness bracket mounted connectors, the related cable interconnections and all the hardware necessary to realize and install the cabling on the structure.
The preliminary SVM Harness mass budget has been performed as estimation in terms of connectors and signal/cables typology and quantity due to the unavailability of a specific EICD (Electrical Interface Control Document) .
In order to track the mass evolution down to item level, the SVM Harness has to be divided into two main group :

- SVM Harness Electrical Items
  - ❑ This includes all connectors, cables, accessories and mounting provisions (ty-bases,ty-rap, connector mounting screw) necessary to realize and perform the electrical interconnection.

- SVM Harness Mechanical Items
  - ❑ This include all the mechanical parts on the Harness as connector brackets, harness stand-off and supports, Grounding Rail and all the necessary hardware to install these components on the structure.

The achieved mass figures are reported in the following table.

ITEM	Component	HERSCHEL	PLANCK
Electrical Item	**Connector Mass (Kg)**	11,44	10,46
	Total Power Harness Mass (Kg)	9,34	10,97
	Total SVM SGN Harness (Kg)	23,8	21,66
	Mounting Provisions (Kg)	2	2
TOTAL		46,81	45,24
Mechanical Item	**Connector Brackets (Kg)**	2,12	1,7
TOTAL		2,12	1,7
SVM Harness Basic Mass (Kg)		**48,93**	**46,94**

Note : The harness stand-off and supports, Grounding Rail and all the fixation hardware mass is not included in the budget

9.5 ACMS

The ACMS Design Report (H-P-4-DS-TN-011) produced by the subcontractors and a technical note titled ACMS FDIR Issues (HP-TN-AI-0035) are included as part of SVM PDR data package to cover the following aspects:

- ACMS Configuration
- FDIR Design
- Functional Design
- Control Design
- Operations Design
- External Interfaces
- Resource Budgets

In addition to what is presented in the above mentioned documents, some drawings are provided:

- Functional block diagram provided in Figure 9.5-1 shows the ACMS subsystem internal interfaces between the ACC and the ACMS sensors/actuators envisaged for Herschel. The Planck block diagram is provided in Figure 9.5-2. In these schematics the alarm conditioning electronics is implemented in the PDU according to the current baseline. As described in the PDU trade-off in ACMS Design Report document, the possibility to implement this logic inside the ACC is under evaluation.
- The power control and monitoring logic for the selected ACMS unit that do not have the internal power switch is presented in Figure 9.5-3. In this schematic the power control and monitoring logic is implemented in the PDU according to the current baseline. As described in the PDU trade-off in ACMS Design Report document, information from potential ACMS unit suppliers indicates the possibility to have the logic internal to all the ACMS units.
- The ACMS external interface towards the RCS is presented in Figure 9.5-4 for Herschel and in Figure 9.5-5 for Planck.
- The ACMS external interfaces with CDMU and PCDU not described in the figures are available in the document SVM TM/TC Budget (HP-TN-AI-0018).
- The accomodation in the SVM of the Star Trackers is presented in Figure 9.5-6 for Herschel and in Figure 9.5-7 for Planck

The ACMS design and development concept has been identified in the frame of the subsystem specification and is reported in paragraph 9.5.1. The ACMS design and development plan has been presented in the proposal of the ACMS subcontractor and the most significant parts are reported in paragraph 9.5.2.

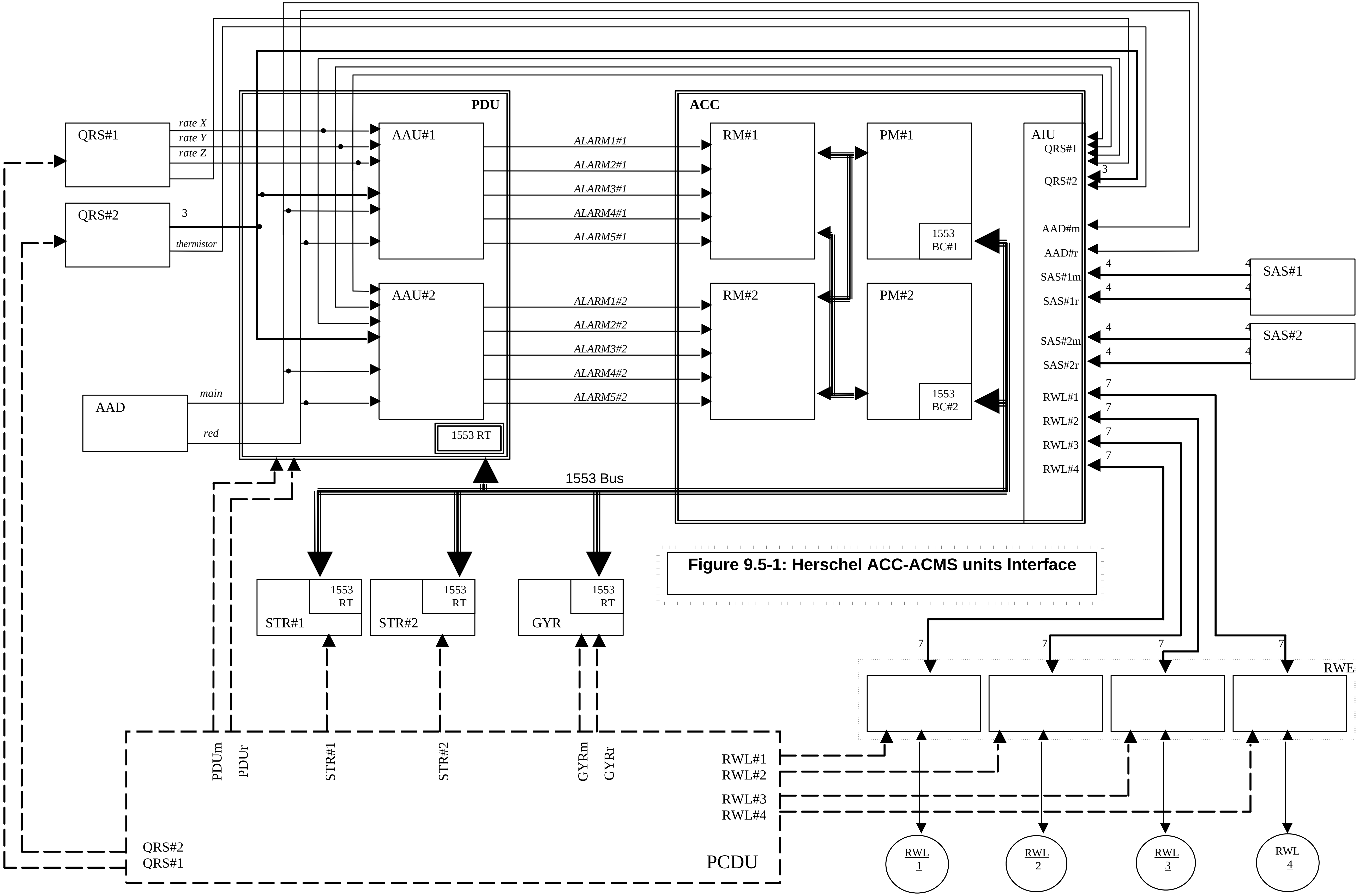


Figure 9.5-1: Herschel ACC-ACMS units Interface

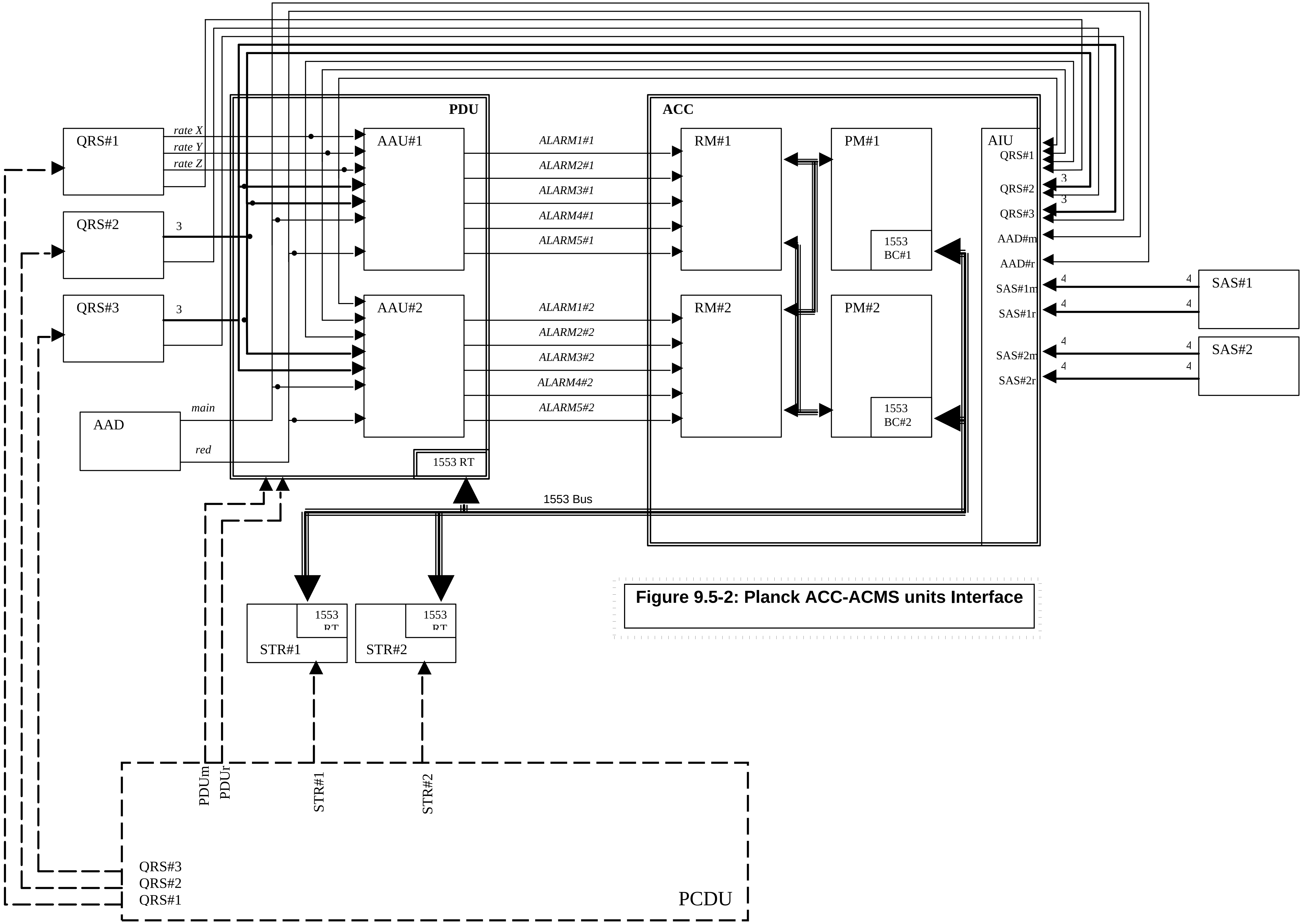


Figure 9.5-2: Planck ACC-ACMS units Interface

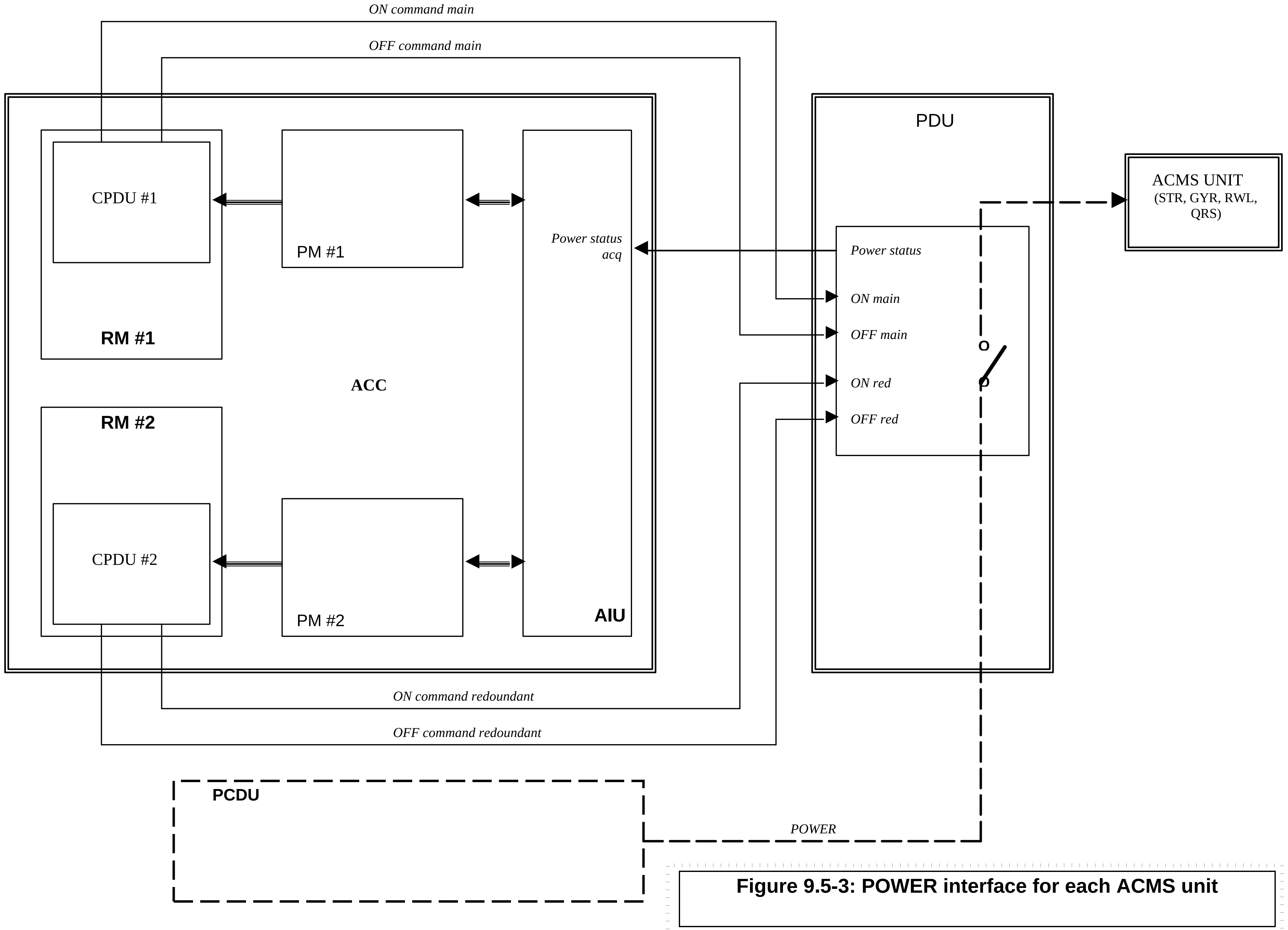


Figure 9.5-3: POWER interface for each ACMS unit

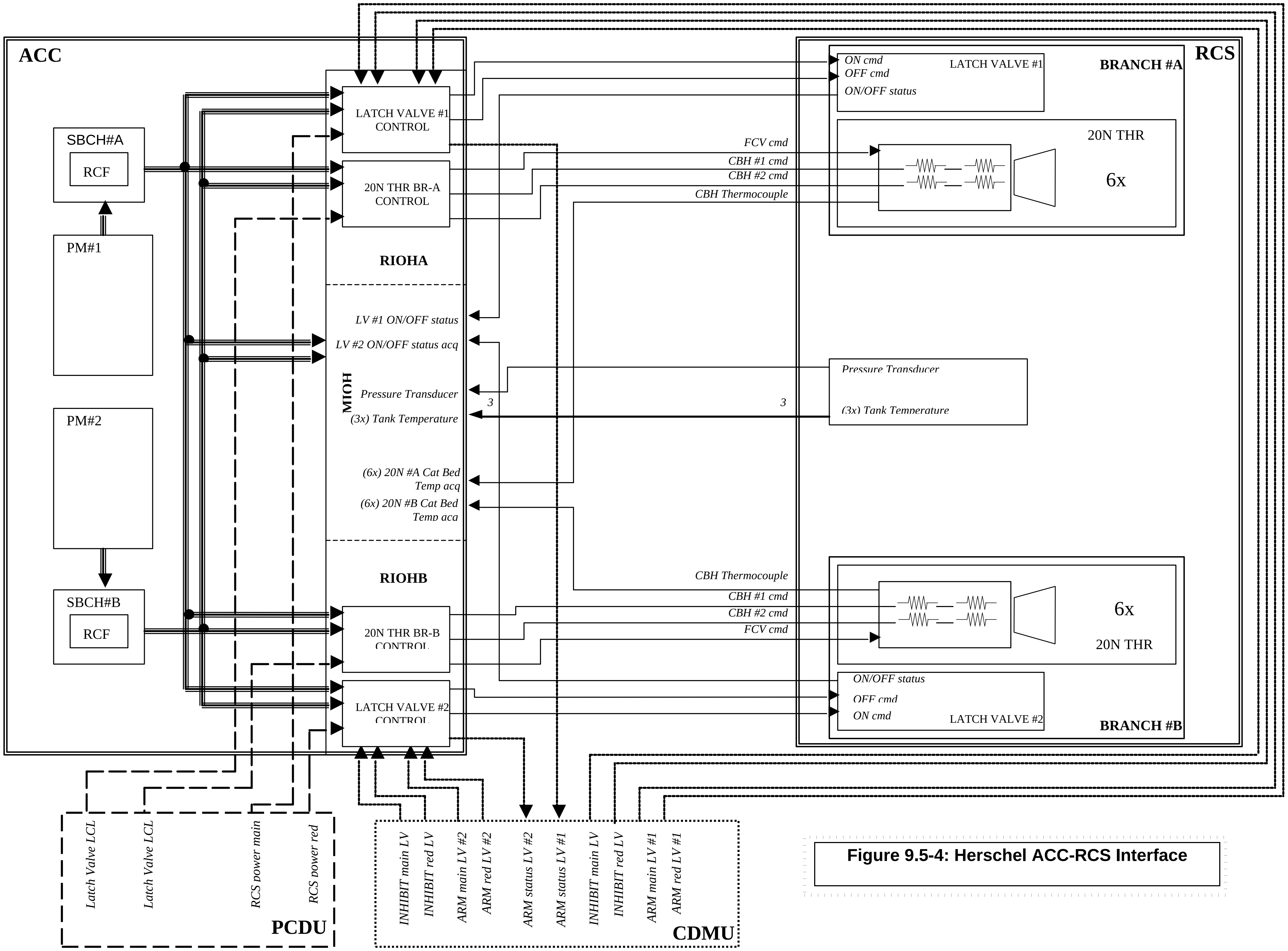


Figure 9.5-4: Herschel ACC-RCS Interface

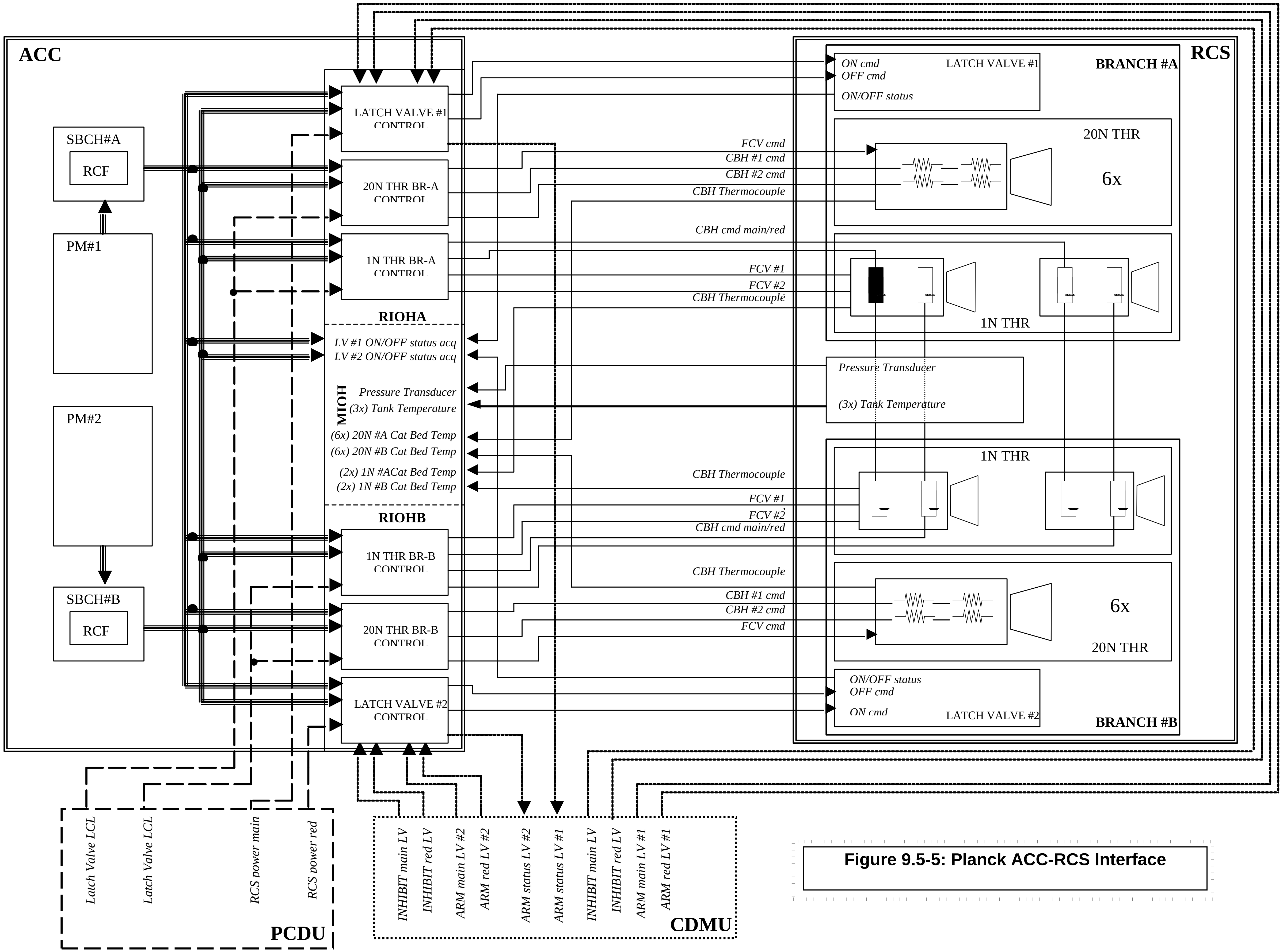


Figure 9.5-5: Planck ACC-RCS Interface

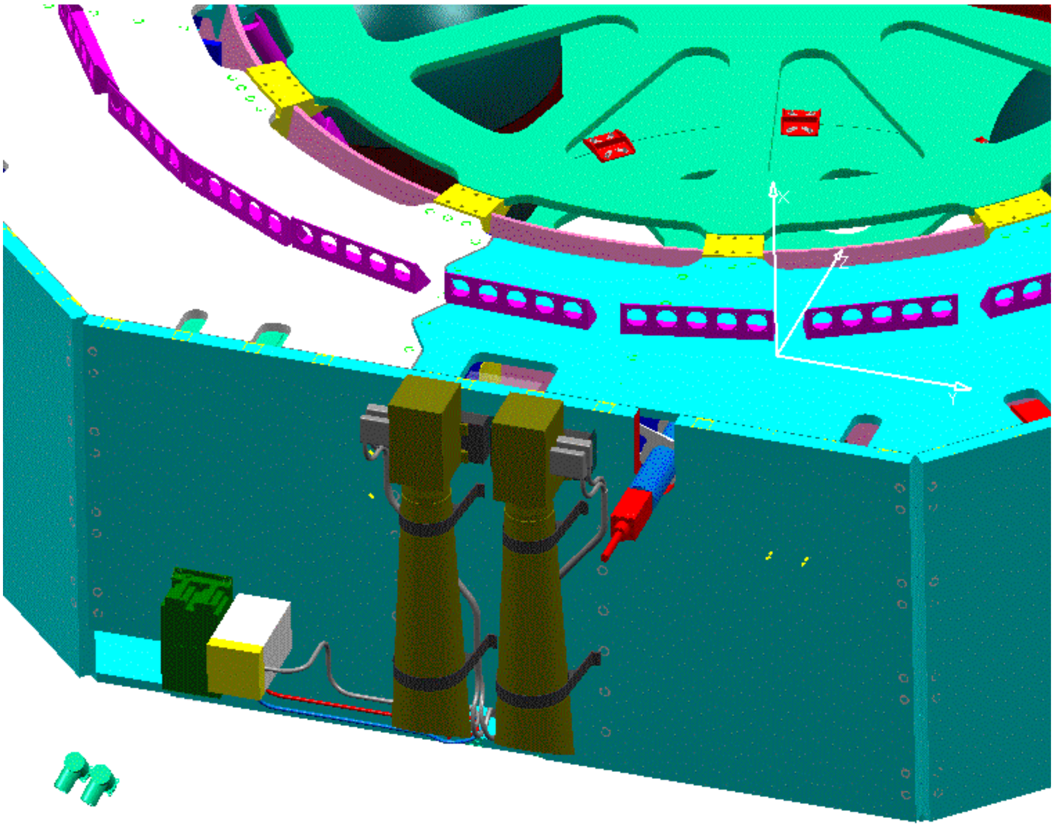


Figure 9.5-6: Herschel Star Tracker baseline accommodation (see alternative configuration in section 4.1.5)

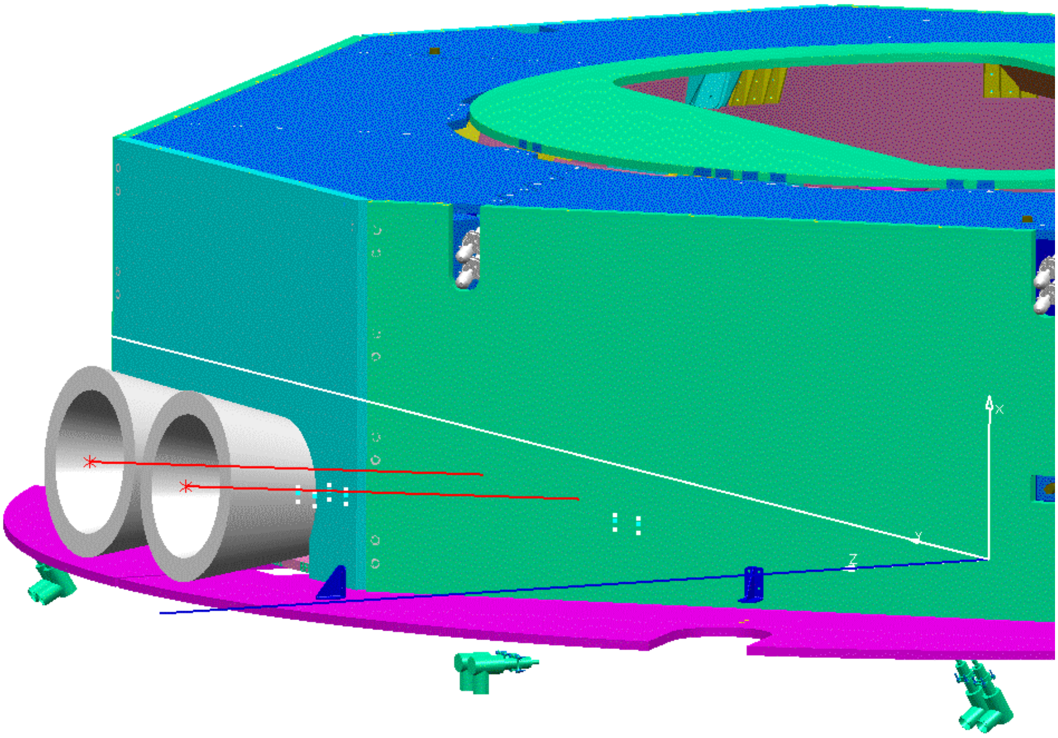


Figure 9.5-7: Planck Star Tracker accomodation - The angle between the STR LOS and YZ plane is 5°

9.5.1 ACMS development and validation concept

In general, the development and validation of the ACMS can be divided in three phases:

- Design of algorithms
- Development of onboard software
- Integration of subsystem with actual hardware units.

Definitive validation of all subsystem functions can be achieved only at the end of the development process using first the subsystem test bench and then completing the verification at satellite level. However, the development process should be organised in a way that allows the essential aspects of the design to be validated as early as possible. This requires a number of test environments:

- control design and simulation environment
- off-line simulation environment with a model of flight software
- Software Development Environment (SDE)
- ACMS test bed
- Off-line simulation environment with flight application software

Control design and simulation environment is a set of software tools based on a standard commercially available product used in the design of control algorithms and in their functional validation. The tools must allow analytical characterisation of control performance as well as closed loop simulation including mathematical models of spacecraft dynamics as well as orbital environment (e.g., disturbance torques) and ACMS units modelled with at a level sufficient for control analysis of individual modes (for instance, sensor noise, wheel torque saturation, RCS thrust errors need to be modelled but modelling of physical interfaces between HW units and fault injection are not required). At the end of the control design phase, a full set of algorithms covering all necessary control configuration (operating modes, all possible combinations of sensors and actuators) will be available with the main performance parameters (stability margins, scanning and slew performance, etc.) fully characterised.

Off-line simulation environment with a model of flight software. In the development phase following the design of basic attitude control algorithms, the functional architecture of the ACMS and all detailed algorithms for attitude determination, mode control and all other functions required for the ACMS (for instance, FDIR) will be designed. It is essential to validate the functional correctness of the subsystem design prior to its implementation in flight software. This can be achieved most efficiently using an off-line simulation environment modelling accurately spacecraft dynamics, orbital environment and ACMS hardware (the selection of units to be included in the subsystem will have been carried out in this stage so that models more accurate than generic mathematical descriptions used in control design can be developed). The simulation will be completed by a software prototype of designed for subsequent implementation in flight software. The OBSW prototype should represent as far as possible all algorithms, including as far as possible aspects such as FDIR and external interfaces (especially TM/TC handling). The validation will consist of an extensive set of simulations covering all functional and performance aspects of the ACMS. In order to support such validation, the simulation must include all aspects of spacecraft dynamics and environment that have impact on the ACMS and should allow extensive fault injection options in HW modelling for the validation of FDIR. At the end of this phase, a mature subsystem design will be available (with the flight software URD as the main output) for the implementation phase. To guarantee reliability of validation results, the simulator must be validated independently against analytical results or other previously validated software tools. The prototype model of flight software should be written in a standard high level language, preferably the same as that to be used subsequently for flight software. This model of subsystem software can be written without the rigorous development approach required for flight software and it should allow the designers to prototype the implementation of their algorithms and to verify their functionality. For complex algorithms, it may be desirable to reuse parts of prototype code in the actual flight software. The entire closed loop environment will run off-line on a workstation; in general the execution should be much faster than real time.

The simulation modules developed in this phase will be re-used in all closed test facilities in subsequent phases of development up to the subsystem test bed.

Software development environment must provide all the tools necessary for the development (design, coding, integration) and validation of flight code. In particular, the SDE will provide the possibility to execute the flight software on the target CPU platform (using either original hardware or emulation in HW or SW). The environment will provide a set of debugging tools, including as a minimum a possibility to set breakpoints and to control and trace the contents of RAM and I/O address space of the processor. A closed loop facility based on the simulation kernel developed in the previous phase will be integrated within the SDE.
The SDE will be used in the following validation steps:

- static and dynamic verification of ASW modules using dedicated SW analysis tools
- module level tests in which each function can be tested independently by stubbing other modules
- integrated software tests (ASW linked together with BSW)

Off-line simulation environment with flight application software. The software environment and tools are the same as in the design validation phase, however the actual flight application software will be integrated with the simulation loop using an emulator of BSW. The tests executed in this phase should consist of a subset of simulation runs used for design validation. The objective of their re-execution in this phase will be to verify that the behaviour of the actual flight software complies with the intended design.

Subsystem test bed will be used for the validation at subsystem level, starting from HW/SW integration on representative ACC HW and including the testing of interfaces between the ACC and other ACMS units. The test bed will include facilities necessary to support the inclusion of ACMS HW in the loop (power supply, electrical interfaces), simulation of external interfaces (CDMS, RCS) and a front end (ACMS EGSE) providing facilities for real-time closed loop testing as well as user interfaces necessary for preparation and execution of tests. During subsystem validation, the test bed will be used in different configuration depending on the type of ACMS HW included. In the minimum configuration, the only HW unit present will be an ACC FUMO and all other units will be simulated down to the level of the electrical interface with the ACC. Engineering models will then be introduced and the test bed will provide the possibility to select simulation or EM model independently for each unit. The test bed will also support the inclusion of FM units in the test loop both at subsystem level and during subsystem system units. During the integration of SVM avionics, the test bed will be part of the SVM EM test environment. The ACMS EGSE will also be used in SVM FM integration where it will act as a SCOE interfaced with the SVM EGSE. For each optical sensor, an optical stimulator adequate for polarity test shall be procured. It shall be possible to configure the subsystem test bed for use of optical stimulation at least in open loop.

9.5.1.1 Subsystem validation phases.

The functional validation shall be performed in the following steps:

- **Step 1:** functional validation performed in the Functional Model ACMS Test Bed, with all units except for the ACC simulated
- **Step 2:** functional and electrical design validation performed in the Engineering Model ACMS Test Bed. In this configuration one EM unit of each category shall be included in the loop with the possibility of electrical stimulation. Exceptions (units not present as hardware in the loop) shall be justified and agreed by the SVM Prime contractor.
- **Step 3:** verification with FM units. The ACMS Test Bed shall be compatible with the execution of tests including a partial or complete set of subsystem FM hardware.

9.5.1.2 Test bed components

The ACMS Test bed shall consist of:

- An ACMS Control Computer in a functionally representative configuration (at least an elegant redundant breadboard)
- A simulation of spacecraft environment (only in stand-alone configuration) that shall implement those aspects of the CDMU and SVM that are necessary for the validation of ACMS functions (e.g., TM/TC transfer through the onboard bus, direct signal interfaces such as separation straps). The simulation will include the RCS interface incorporated in the closed loop environment.
- A spacecraft dynamic simulator. The simulator shall be inserted in the real time execution loop and shall provide the possibility to drive either HW simulator of ACMS units described below and to stimulate electrically the actual unit hardware.
- A combination of ACMS Unit Simulation Modules and / or real unit hardware. Unit simulation modules shall consist of a software functional model provided in the spacecraft simulator environment and a hardware simulator of the electrical data exchange interfaces of the units.
- A data acquisition and management facility with following functions :
  - ❑ Data Acquisition to acquire all TM/TC the MIL-1553 buses (both the system and the internal bus), equipment traffic trapped data, environment state variables.
  - ❑ Data Storage to store all the acquired data for up to TBD test hours.
  - ❑ Data Management to export, store on hard copies and display the test activity.
  - ❑ Man Machine Interface shall be provided to easy handle the simulation
  - ❑ Previous test results shall be accessible during test performances.
- A test management I/F with the following functions:
  - ❑ Synchronization of all ACMS Test Bed real-time element with a TBD accuracy
  - ❑ Definition and storage of all the test scenarios required for the simulation
  - ❑ On line Telecommand sending capabilities
  - ❑ Time-tagged telecommand to facility simulation of Mission Time Line.
  - ❑ Real time display capability of all observed parameters.
- SVM EGSE interface for use in system AIT configuration as ACMS SCOE.

The simulation of all ACMS interfaces (including test harness) shall be flight representative both in terms of electrical characteristics and software protocols.

9.5.2 ACMS Design and Development Plan

A mixture of a normal QM, FM and Proto-flight approach has been chosen for the ACMS DDP.
Engineering Models (EM) will be built for the ACC, STR, QRS, PDU, GYR, SAS, AAD and RWS (electronics and 1 wheel only). These EM’s will be functional representative for the flight model.

The DD & V logic is shown in Fig. 9.5-8.
The considerations for this logic are:

- Design supported by design simulations as much as possible in the PSF
- Verification of the ACMS software by ample simulations in the PSF
- Early HW in the Loop Simulation Facility with ACC-BB and 1553 I/F (AILF)
- HW/SW integration and further ACMS software testing in the AILF
- Staggered ASW delivery
- Step by step integration of EM Units
- Delivery Test Bench after EM testing to Avionics Test Bench
- Simulator Validation Tests required
- Step by step integration of (P)FM Units

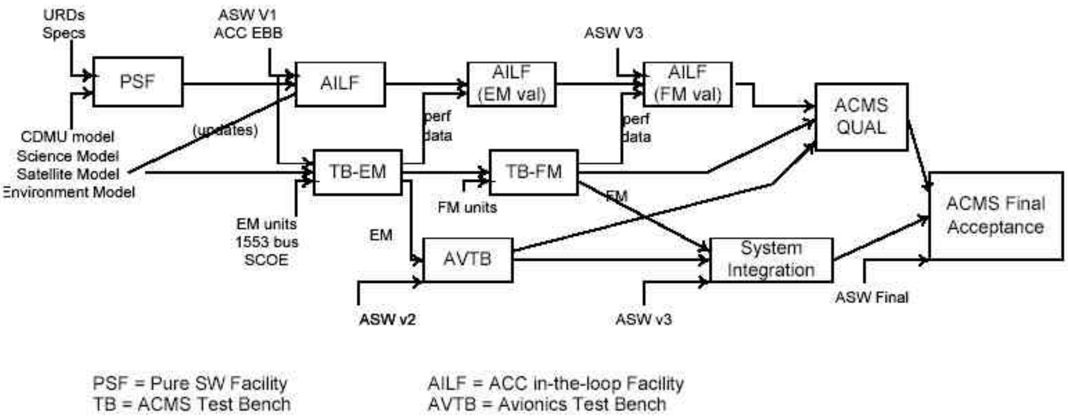


Figure 2.1 Design, Development & Verification Logic

Figure 9.5-8: Design Development & Verification Logic

9.5.2.1 Design And Analysis Activities

9.5.2.1.1 Subsystem Engineering

The Subsystem engineering consists of:

- Subsystem requirements analysis
- Definition of key requirements
- Flow-down of subsystem requirements to Unit Requirements Specifications
- Functional analysis and design
- Mode design
- Generation of the ASW URD
- Technical performance management, via budget reports
- Risk analysis resulting in a Risk Map and a Risk Mitigation Plan
- Definition of the Verification Approach
- Generation and maintenance of Verification Control and Interface Control Document.
- Organisation of the different design reviews

9.5.2.1.2 FDIR Engineering

The FDIR engineering concerns the design, performance analysis and verification of the failure detection, safing, diagnosis and recovery (reconfiguration) functionality. With the objective to have a safe and reconfigurable Satellite. The FDIR engineering consists of:

- Engineering at ACMS level
- Design necessary and sufficient checks (algorithms) to be implemented in the ACC (phase B)
- Design the safing and reconfiguration functionality (phase B)
- Determine the actual values of check parameters (thresholds) by Analysis and Simulation (phase C/D)
- Fine-tune FDIR parameters when more detailed H/W performance parameters become available from Sub-System test results (Phase C/D)
- Specify Tests and write Test Reports for the FDIR verification (Phase C/D)
- Specify FDIR requirements for the units (Phase B)
- Generate requirements for the simulation/test facility from FDIR perspective (error injection) (Phase B)
- shadow engineering of the activities performed on Unit level at the suppliers.

For the design, development and verification of ACMS FDIR, three main lines of activities are distinguished:

- technical system design, and rationales analyses
- simulations with MATLAB and H-P Simulator
- tests with PSF, AILF and Test Bench

9.5.2.1.3 Control Engineering

The objective of the Control Engineering is to ensure that the instruments point with the required accuracies and with a minimal loss of scientific measurement time.

The control engineering is concerned with the design and performance of the control algorithms in combination with the sensors and actuators, which are part of the (control) system. This has to be achieved for different (control) modes. Control engineering supports the subsystem design in:

- the definition of modes
- the selection of sensors and actuators and other hardware,
- the definition of software by specifying requirements applicable to meet the control performances.

Control engineering supports FDIR on control transitions in order to prevent unwanted triggering of FDIR functions.

The Control Engineering consists of:

- controller design:
- design of control algorithms
- error determination from provided sensor data by means of estimators or other (kalman) filters
- define inputs for sensor processing (specific filtering if needed)
- define inputs for actuator handing (command scaling)
- define pathplanner
- generate detailed software specifications for controller design
- define input and support to unit specifications
- performance evaluation, verification and close out of motion control requirements
- including sensitivity simulations
- define input and support to system engineering such as a control testplan
- define limited input and support to
- simulator validation
- testbench
- operations

For the design, development and verification of ACMS Control, three main lines of activities are distinguished:

- technical system design, and rationales analyses
- simulations with MATLAB and H-P Simulator
- tests with PSF, AILF and Test Bench

First specifications of control processes (modules) are/will be defined in such a way that possible changes do not affect the architectural design of the software. This can be realised by defining all the (possible) inputs and outputs of the control processes in a robust way.

Verification of the control algorithms relies heavily on results from simulations. To make the verification of control in this manner credible, it is required to demonstrate that the real-time simulator sufficiently matches the true behaviour of the ACMS with the HW Units, i.e. the real-time simulator has to be validated.

For the validation of the simulator in the real-time environment the same incremental validation philosophy as for the previous development stages will be used. The simulator will be validated by comparing the actual test results from the EM Test Bench with the outcome of the simulations. Validated unit simulation models should be procured from suppliers. Tests on the EM Test Bench are mainly end-to-end validation. Realistic validation criteria will/must be defined in an early phase.

The results of the FM Test Bench will in principle not be used for validation. These results are used for tuning of the settings in the database. Up-to-date model parameters of unit simulation models should be procured from suppliers. Test on the FM Test Bench will be used for final check and tuning of remaining model parameters.

The definition of the test plan for control will be defined and agreed upon in early phase. It will define:

- the scope (type of moves, worst case conditions to be paralysed)
- (maximum) amount of simulations and tests
- specify constraints on the software (user selectable data) and test hardware.

9.5.2.1.4 Electrical Engineering

The objective of the electrical engineering is to ensure that all Units receive the correct power and signals

The Electrical engineering consists of:

- engineering at ACMS level
- definition of overall electrical architecture
- flow down of the Electrical ACMS Requirements to the Unit Requirement Specifications
- verify Electrical requirements
- shadow engineering of the activities performed on Unit level at the suppliers

9.5.2.1.5 EMC

The objective of the EMC engineering is to ensure that all Units together, and the ACMS with the remainder of the Satellite will work not disturbed by each others Electrical and Magnetic emittance.

The EMC engineering consists of:

- Engineering at ACMS level
- Flow down of ACMS EMC requirements to Unit Requirements Specification
- Provide customer with agreed documentation to show adequate system margins for all the types of EMI.
- Specify CS EMC test at S/S level
- Verify ACMS EMC requirements
- shadow engineering of the activities performed on Unit level at the suppliers.

9.5.2.1.6 Operations Engineering

The objective of Operations Engineering is to ensure that the Satellite can be operated on an effective and efficient way.

Making use of the lessons learned from previous design the operations concept and methodology will be established derived from the Herschel-Planck ACMS requirements.
The methodology of operating ACMS will be converted in operating procedures. The operation procedures will be verified by simulations and tests.
Finally the verified operations will be written down in the ACMS User manual. This User manual will also contain ground operation procedures.

9.5.2.1.6.1 Operations Support

Operations support will be given both from the engineering and from the operations expertise. The support will comprise:

- General engineering support
- Support during the launch campaign.
- Support during the H-P in orbit commissioning phase
- Training Customer personnel in operation of the Herschel and Planck ACMS

The operation support will be offered as a fixed amount of manhours and costs.
Operation support beyond this fixed amount is offered as an option on time and material basis.

9.5.2.1.7 Software Engineering

Within the HERSCHEL/PLANCK program the software engineering methods and tools used will be standardised as much as possible to establish a common software development approach for maintainable flight software and non-maintainable software (firmware). Firmware software shall be treated in the same way as maintainable software. The ECSS- E-40B is the ESA software engineering standard and the "Software Design Requirements Specifications [SDRS]" (H-P-1-ASPISP-0046) specify additional requirements for the HERSCHEL/PLANCK software. The Software Product Assurance standard is the ECSS-Q-80B.

We can distinguish the following types of software in the program

Flight Software		
	Maintainable	**Non maintainable (firmware)**
ACC software	Runtime kernel, runtime libraries	driver layer in PROM
	Operating system	communication layer in PROM
	Common Software layer	bootstrap software in PROM to provide the software maintenance functions
	Application software layer for HERSCHEL	
	Application software layer for PLANCK	
STR software PROM	Application software layer	residence drivers, communication, bootstrap software
Non Flight software		
ACMS SCOE software	EUROSIM kernel	
	Pure software facility (i.e. the HP simulation facility)	
	Unit FUnctional MOdels which are used in the PSF, AILF to provide the software in the loop facility (PSF) and in the mixed situation where Hardware in the loop and Software in the loop are present in the Test Bench	
	driver software as intermediary between the simulation kernel and the electrical STimuli InterFace (STIF) of the ACMS units	
	Basic checkout system as a shell around EUROSIM (SCOS 2000 compatible) to provide a test conductor test environment	
	Unit Check-out Equipment (UCE) software	
	Software Development Environment (SDE)	

9.5.2.1.7.1 ACC Flight Software Engineering

ACC Flight computer hardware

The Flight computer hardware is CFE and will be based on the ERC32 (Sparc architecture), it will comprise of several interfaces from analogue to MIL-STD-1553 to communicate with the ACMS sensor and actuator units. The interfaces to the sensors and actuators will be standardised as much as possible. The flight computer hardware shall also communicate with the ACMS Power Distribution Unit, to switch sensors/actuators on and off and to convert the standard +28 Vdc to the unit voltages needed. The ACC is the gateway between the CDMU and the ACMS units, at the CDMU site it communicate as a Remote Terminal to the CMDU Bus Controller via MIL-STD-1553B protocol. The flight computer hardware is cold redundant and a dedicated Reconfiguration Manager (RM) determines which ACC will be powered.

Flight Software Development Environment

The SDE is also customer furnished equipment. It will consist of:

- standard development platform,
- Software emulator of the ERC32 architecture and command package
- commercial evaluation boards of the ERC32 to accommodate runtime environment of the target processor
- Standard ANSI C compiler and environment
- Static analysis of the code by automatic tools. Criteria are:
  - ☐ identify language features prohibited by the project coding standards,
  - ☐ identify operating system features prohibited by the project coding standards,
  - ☐ identify unreachable code,
  - ☐ identify endless loops,
  - ☐ identify multiple exit point in any single unit,
  - ☐ identify variables used before they are initialised,
  - ☐ identify unused data,
  - ☐ identify shared data between tasks,
  - ☐ identify the volume of code in each unit,
  - ☐ measure the complexity of code in each unit, in accordance with the project coding standards.
- Dynamic analysis of the code by automatic tools. Criteria are:
  - ☐ instrument the source code of the unit under test without manual intervention.
  - ☐ instrument source code without functional effect on that code.
  - ☐ measure source code statement coverage achieved by the test being performed.
  - ☐ measure source code branch coverage achieved by the test being performed.
  - ☐ collate measured statement and branch coverage in a summary for each unit after integration.
  - ☐ support batch testing
  - ☐ identify untested branches in source code and test them.
  - ☐ identify unexecuted lines of source code and test them.
  - ☐ measure path coverage achieved by a test.

ACC Flight Software Architectures

Flight software for the ACC is based on a HW/SW layer with driver software, a common layer for Herschel and Planck and a specific Herschel and Planck ASW layer.

Interface between ACC hardware and ACC software:

ACC HW - SW interface:
The ACC hardware and operating system are a deliverable item from the customer to Fokker Space and thus the interface between HW and SW is the responsibility of the customer.

OS - ASW interface:
The philosophy, to be adopted in Herschel/Planck ACMS, is presented in the following. The underlying software which provides services to the higher level layer is the owner of the interface and thus responsible for the definition and maintenance of an interface control document where the services and the interface to the services are described in all details, in agreement with the higher level software manufacturer.

The SW/SW interface between the OS and the Common SW reside at the contractor who provides the Common software layer.

9.5.2.1.7.2 STR Flight Software Engineering

The STR flight software will be developed in the tbd programming language using the tbd Software Development Environment. The controller of the STR is tbd

For the STR the flight software architecture is fully the responsibility of the Unit supplier in accordance with sub-system level specification and standard.

9.5.2.1.7.3 Simulations

There are three phases of the simulation program:

- analysis phase, to determine proper parameter settings for the different algorithms and to determine their robustness
- functional test phase, to make sure that the Herschel/Planck ACMS SW products will work with the hardware and to obtain confidence in their performance
- performance verification phase, to prove that ACMS sub-system meets its specifications

For each of these phases, a qualified version of the simulator is needed. For the:

- analysis phase: based on model specs and ACMS specification
- functional test phase: simulator models must be validated with Unit EM test results and/or PFM test results This will go on as data comes available, but the running analysis campaign will
- keep using the “as designed” baseline until the test prediction milestone is due.
- performance verification phase simulator tests with the (P)FM H/W models. For some tests it is not mandatory to have all H/W models in place. In these cases simulator models are allowed tuned with (P)FM H/W test results.

Unit Model Validation
The Unit design description documentation will give the parameters to put into the Simulator models.

These parameters will be replaced by the as-tested parameters when these test results come available. In principle the Unit suppliers will provide the as-tested parameters from their test program at Unit level.

9.5.2.1.7.4 Simulation Facility

The development of the Simulation Facility is supporting the following elements:

- a PSF with simulated onboard software
- an AILF for ACC Hardware in the Loop testing
- an AOTB for integration of the hardware Units

The objective is to realise common software models (dynamics, sensor and actuator) for PSF, AILF and AOTB, as this will create facilities which are more effective from configuration control and maintenance point of view.

9.5.2.1.7.5 Software validation concept

The software validation will be based on a philosophy which matches as closely as possible the approach used for hardware units for qualification and acceptance are clearly distinguished.

- The qualification of an ASW release shall be reached at the completion of the testing activity against a specific version of the Requirement Baseline. An ASW release shall be considered qualified only after testing in a closed loop environment including at least a functional model of the ACC. This implies that validation (similar concept is applied also in delta-qualification and acceptance tests discussed below) will consists of tests at both SW (SDE) and subsystem (ACMS test bed) level.
- The delta-qualification of the ASW release shall be required in case of a major ASW change. An ASW change shall be considered major if it is related to a change of the Requirement Baseline. In this case the delta-qualification shall require dedicated tests to verify the modified functionality, and regression tests (corresponding to the acceptance level described below) to demonstrate correct functioning of the entire flight executable module after the change.
- New acceptance of the ASW release shall be required in case of a minor ASW change, i.e., a modification resulting from the SW development and validation process (internal SW change requests, bug fixes, etc.) and not related to a change of the Requirement Baseline. The tests executed must specifically cover the function directly affected by the change and must include a standard acceptance set. The acceptance test suite will be established by the supplier with the objective of validating the overall functionality of the ASW both during delta-qualification and acceptance.

9.5.2.1.8 AIT Engineering

The objective of the AIT engineering is to ensure that the ACMS is integrated and tested on an effective and efficient way.

The AIT engineering on ACMS level consists of:

- Specify the SCOE
- Flow down the ACMS AIT Requirements to the Unit Requirements Specifications and the Unit Check-Out Requirements Specifications
- Specify and manufacture the Electrical test bench including cable harness
- Specify and manufacture the required transport containers (for the Units reusable containers will be specified as much as possible)
- Specify and generate the automated test sequences
- Specify and manufacture several supporting tools, like break-out boxes, test leads etc
- Verify the AIT requirements
- In order to provide full visibility an AIT plan will be generated containing:
- all AIT activities and its sequence
- the required organisation to perform the AIT activities
- the required Facilities, Test set-up’s and GSE

The AIT engineering consists partly of shadow engineering of the activities performed on Unit level at the suppliers

9.5.2.1.8.1 SCOE Development

The commonality for Herschel and Planck SCOE is high. Most of the H/W and the basic software are common. Only the application software is dedicated to either Herschel or Planck. This applies also for the UCE of the not-common Units.

For the development of the SCOE the experiences from previous and current designs will be used as much as possible.

This leads to a concept where the real-time simulator being the core of the SCOE, is based on Eurosim. This real-time simulator is also used in the PSF and the AILF. In the SCOE the real-time simulator will be kept up-to-date by transferring the real-time simulator SPR’s from the PSF and the AILF into the SCOE. In a later phase SPR’s found during Bench testing will be fed into the PSF and AILF as well. It is obvious that for this process during parallel simulation and testing regular CCB’s are required on weekly, maybe sometimes daily bases.

The specific features of the SCOE like checking TM on warning and danger levels, etc., are developed in the period before the start of the Test bench testing, making use of the real-time simulator and the OBS emulated in the host of the SCOE.

The automated test sequences will be reused from testing on PSF and AILF as much as possible.

The SCOE will be validated before the start of the Test Bench Testing by executing an acceptance test. The fact that the SCOE is used first with the EM Units, guarantees that the SCOE will be fit and safe for use for the FM Test Bench testing.

9.5.2.1.8.2 Test Bench Development

The real-time simulator is the core of the SCOE being part of the Test Bench For the development of the Test Bench the real-time simulator development is phased:

- a first version of the real-time simulator has to be available prior to EBB ECC hardware/software integration testing and then EM integration testing.
- the final version of the real-time simulator is required for the Test bench testing with (P)FM hardware

On the test bench the electrical system integration will be performed prior to functional testing of the ACMS.

On the electrical test bench the Units will be electrically fully integrated (via additional intermediate cables and pin savers). The following tests are foreseen on the test bench:

- bonding
- grounding
- cable harness health check (resistance, capacitance)
- electrical I/F check:
- supplied voltage check
- communication check (HW/SW interfaces) between ACC and other Units and between ACC and CDMU simulator.
- redundancy management
- ACC S/W verification
- functional test
- mode switching
- nominal and non-nominal tests

For addressing any late deliveries of Units one has to consider a set of work-arounds. The ACMS
Control Computer should be integrated as first Unit. As substitutions for other Units on the Test Bench the simulated software models will be used.

9.5.2.1.9 Mechanical and Structural Engineering

The Mechanical and Structural engineering consists of:

- Flow down of Mechanical and Structural ACMS Requirements to the Unit Requirement Specifications
- Verify the Mechanical and Structural ACMS Requirements
- shadow engineering of the activities performed on Unit level at the suppliers

9.5.2.1.10 Thermal Engineering

The Thermal Engineering consists of:

- Flow down of Thermal ACMS Requirements to the Unit Requirement Specifications
- Verify the Thermal ACMS Requirements
- shadow engineering of the activities performed on Unit level at the suppliers

9.5.2.1.11 RAMS Engineering

The RAMS engineering consists of:

- Engineering at ACMS level
- Generate FMECA and provide input to the design if required
- Generate HSIA
- Generate the CIL and Critical Item Control Plan, and execute the plan
- Perform reliability analysis.
- Generate the Safety Analysis (Hazard Reports)
- Flow down of RAMS requirements to the Unit Requirement Specification
- Verify ACMS RAMS requirements
- shadow engineering of the activities performed on Unit level at the suppliers.

9.5.2.2 Verification

For the verification of the ACMS requirements different methods will be used:
Verification by Similarity, for equipment coming from another program and is reused as-is for Herschel-Planck. This will be supported by analysis, that proves that the requirements are fully covered by the qualification status.
Review of design review of design documentation (drawings) will show that requirements are covered
Inspection Under inspection are categorized the observation and recording of simple product characteristics, by a certified inspector and subject to dedicated procedures by means of either the naked eye or comparatively simple instruments.
Examples are:

- physical checking of form, fit and function
- mass determination
- verification of workmanship (MIP's)

Also included is the verification by validation of records, whereby design, manufacturing or other records are used to verify design or construction features and processes for flight hardware

Analysis Analysis is an analytic method such as calculation or computation used for the determination of parameters or performance

Test Qualification of the design through test shall be accomplished using hardware and software according to the flight design in flight standard configuration supported by verification analysis to show that the test results and the test conditions covers the requirements
Simulation Simulations are actual tests on the AILF (ACC H/W connected to the realtime simulator) for those requirements where it is not required to have unit hardware available.

For the test the following performance test categories have been identified:

Sensitivity Tests:

Executed on the simulator, meant to explore the robustness of the control design against variations in the conditions (e.g. higher cross coupling)

Typical number: Six large test suites

Performance Tests: Mainly executed on the simulator (but some also on the TB), meant to demonstrate all performance-related requirements, e.g. control performance and long duration autonomy. Typical number: Nine (relatively complex) tests, one per (sub) mode

Functional Tests: Done both on the simulator and the TB, meant to demonstrate the correct functioning of the ACMS as a whole under certain mission conditions/objectives. As an example, a test covers separation, initial Sun Acquisition and stable pointing in Safe Mode. Typical number: Fifteen tests

A subset of these tests will be declared “**Signature Tests**”, tests which are rerun after each (S/W) modification to show that the changes have not affected the overall requirements

Typical number: Seven tests

Off Nominal Tests: Done both on the simulator and the TB, meant to demonstrate that the FDIR design is solid. Typical number: Fifteen tests

Validation Tests: Done on the TB, meant to provide data to validate the unit models in the simulator against the actual HW. Typical number: One test per ACMS unit

Communication Tests: Done on the TB, to demonstrate the correctness of the interfaces within the ACMS, i.e. between the ACC and the ACMS Units. Typical number: One test per ACMS unit

Avionics Tests: Prepared on the TB and done on the Avionics Test Bench, meant to demonstrate the correctness of the interfaces between the ACMS and the CDMU. Typical number: Three (very extensive) tests

Alternative Tests: These are small tests done on the TB “designed on the spot”. Goal is to explore the robustness of the ACMS as a whole. Conditions will be created for which the manner in which the ACMS solves the situation cannot be clearly predicted analytically. The list below demonstrates the concept:

AT-1: RWL reconfiguration resulting in autonomous unloading
AT-2: Sun Acquisition under extreme adverse conditions
AT-3: Separation with the Sun close to the –Z axis
AT-4: Sun Acquisition with a SAS lit-failure
AT-5: Robustness against multiple AM <-> SM transitions
AT-6: RCS thruster open failure

9.6 RCS

9.6.1 General

The Reaction Control System (RCS) provides for both Herschel and Planck satellites the necessary forces and torques to achieve spacecraft linear and angular momentum changes necessary for orbit transfer/insertion/maintenance and attitude control, respectively, during all phases of the mission.
The Herschel and Planck RCS's s are designed to the maximum extent to have a high level of commonality between the two satellites SVM' s.
This applies to both the S/S configuration in terms of components and as far as possible for the layout (i.e. RCS component and ducting interfaces to S/C structure).
The RCS includes the propellant storage tanks, ducting, fill and drain valve, fill and vent valves, latching valves, filters, pressure transducers and thrusters.
The thrusters activation is commanded by the ACMS and allows the execution of the tasks as listed in the performances requirements.

9.6.2 Requirements and Design Drivers

The Herschel and Planck Reaction Control System (RCS) requirements are reported in the H-P SVM Requirements Specification, H-P-4-ASPI-SP-0019. The main requirements driving the design are reported in the following paragraphs with the indication of the source requirements from the above document.

9.6.2.1 Lifetime

The Herschel and Planck RCS's shall be dimensioned, to satisfy the relevant nominal mission lifetimes:

3.5 years for Herschel (GLP-070-H);
21 months for Planck (GLP-075-P).

The RCS components shall be selected to satisfy to the mission lifetime worst case of 6 years (GLP-085-C).
For Herschel, propellant for orbit maintenance, attitude control and momentum management is dimensioned for 6 years (GLP-090-H).
For Planck, propellant for orbit maintenance, attitude control and momentum management is dimensioned for 2.5 years (GLP-095-P).

It is requested to install adequate means for determination of the remaining propellant quantities (RCD-090-C). The requested accuracy is:

Better than 5 % of the remaining propellant or less than 3 kg if less than 60 kg of hydrazine remains in all the tanks

9.6.2.2 Thruster Configuration

The following requirements concern the thruster layout:

the residual forces during manoeuvres which require pure torques shall be minimised;

- the thruster configuration shall be optimised with respect to overall manoeuvre performance so that propellant consumption for attitude and orbit control is minimised (RCD-055-C)
- the location and direction of the thrusters shall be selected to avoid, or at least minimise, contamination and plume impingement effects (RCD-065-C).

The RCS components/piping accommodation are organised as follows:

- ☐ components that do not need frequent accessibility (e.g.: Propellant Filter, Pressure Transducer, and Latch Valves) shall be accommodated on the RCS Support Panel
- ☐ components that need external accessibility (e.g. Fill & Drain, Fill & Vent Valves, and Test Ports) will be accommodated through the Lateral Panels and/or the Upper Closure Panels
- ☐ a main distribution loop shall be routed along the external surface of the cone, approximately at the same height as the Venting Holes
- ☐ the SVM structure shall provide the mechanical interfaces to the pipes which distribute propellant from the main loop to the Thrusters and from the Fill and Drain valves to the Propellant Tanks

NOTE
The mechanical interface of each Thruster support bracket to the SVM Primary Structure must be defined as the best possible compromise between AOC/mission and mechanical requirements. Therefore, all Thrusters have been located as close as possible to the Shear Panels, compatibly with AOC/mission needs. This means that the present Thrusters location detailed in Paragraph 4.6 (Herschel) and in Paragraph 5.6 (Planck) is not in line with AD-43. The new Thrusters location has been discussed and agreed between ASPI and ALS.

9.6.2.3 Design Requirements

Both Herschel and Planck RCS’ s are based on hydrazine propulsion system (RCD-005-C).

The feeding of propellant is performed in blow down mode (RCD-010-C) and nitrogen is used to pressurize the propellant (RCD-015-C).

The RCS includes two redundant thruster branches each of one capable to perform the complete mission and use of both branches simultaneously is possible (RCD-040-C).

Isolation of each branch from the fuel tanks is possible to prevent inadvertent firings (RCD-045-C).

The RCS provides sufficient telemetry data to provide unambiguous status information of all the command and program controlled variables and modes and all parameters required for subsystem monitoring and performance evaluation (RCF-025-C).

9.6.3 Functional Description

9.6.3.1 Herschel RCS Description

The Herschel RCS functional diagram is shown in Figure 9.6.3.1-1.

Two thruster branches, main and redundant compose the Herschel RCS.

Thruster monopropellant hydrazine types in the range 10-20 N are used for both Delta-V manoeuvres and Attitude Control purposes. In the schematic the reference to 10 N thrusters only is reported and in the description reference to 20 N thrusters is made.

Two fuel tanks, with a positive expulsion device (diaphragm) are implemented. They supply the propellant to both the branches in blow down mode from a maximum of 24 bar down to 5.5 bar. The propellant is loaded via a common Fill and Drain valve. The pressurant (nitrogen) is loaded separately by means of one Fill and vent valve per tank.
Each branch is equipped with a test port, to facilitate the internal leak check of the components. A Pressure Transducer monitors the pressure in the tanks.

Two Latch valves isolate the two thruster branches. A filter, downstream the Latch Valves prevent the branches from any contamination.

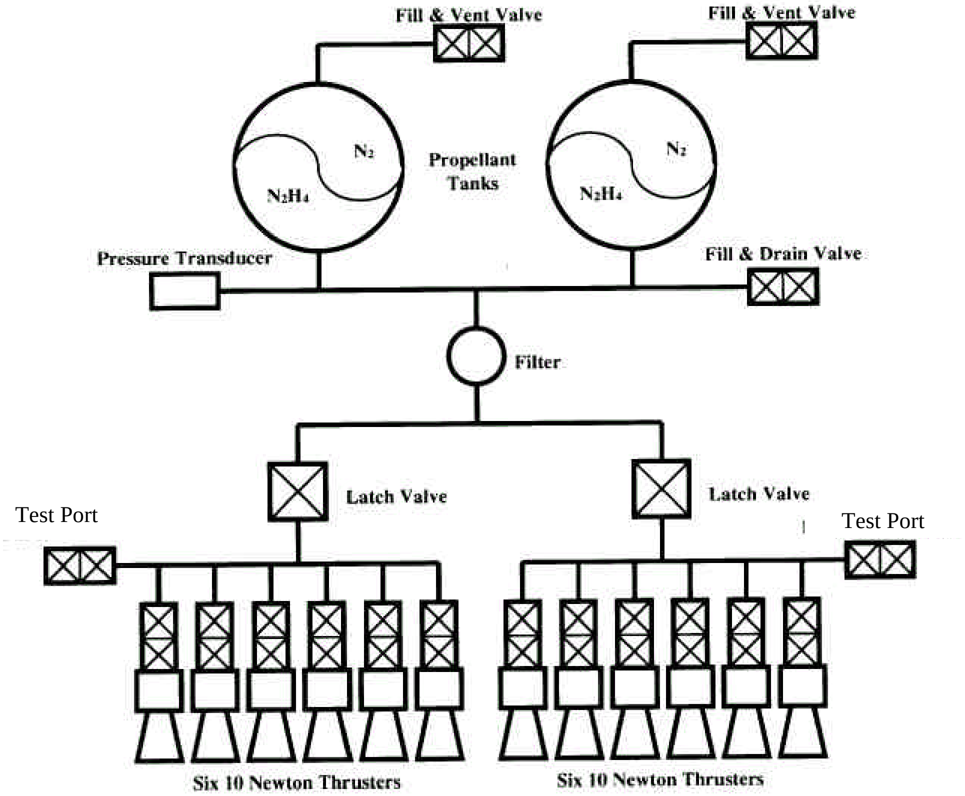


FIGURE 9.6.3.1-1 HERSCHEL RCS FUNCTIONAL DIAGRAM

Two 10-20 N thrusters are used to produce the desired acceleration in ΔV mode (one for ΔV with SAA < 90 deg, ones for ΔV with SAA > 90 deg), and 4 to produce the control torque both in ΔV mode and in wheel off-loading phases. They are respectively named as acceleration (thrA1 and thrA2) and attitude control (thrC1, thrC2, thrC3 and thrC4) thrusters, respectively.

There are in total 2 branches of 6 thrusters each and the relevant layouts are reported in Table 9.6.3.1-2.
The thruster redundant branch is identical to the nominal one.

HERSCHEL					
			X	Y	Z
Branch A	10N	A1A	-7,4	570,6	1863,8
		A2A	-7,4	-790,7	-1863,8
		C1A	-41,4	1770,0	-557,6
		C2A	-41,4	1770,0	557,6
		C3A	-41,4	-1770,0	557,6
		C4A	-41,4	-1770,0	-557,6
Branch B	10N	A1B	-7,4	635,2	1835,0
		A2B	-7,4	-855,3	-1835,0
		C1B	-41,4	1710,0	-557,6
		C2B	-41,4	1710,0	557,6
		C3B	-41,4	-1710,0	557,6
		C4B	-41,4	-1710,0	-557,6

Table 9.6.3.1-2 Herschel Thruster Layout

9.6.3.2 Planck RCS Description

As for Herschel, the RCS selected baseline (three tanks) is designed to work in blow-down mode starting from a MEOP of 24 bar.

The Planck RCS functional diagram is shown in Figure 9.6.3.2-1.

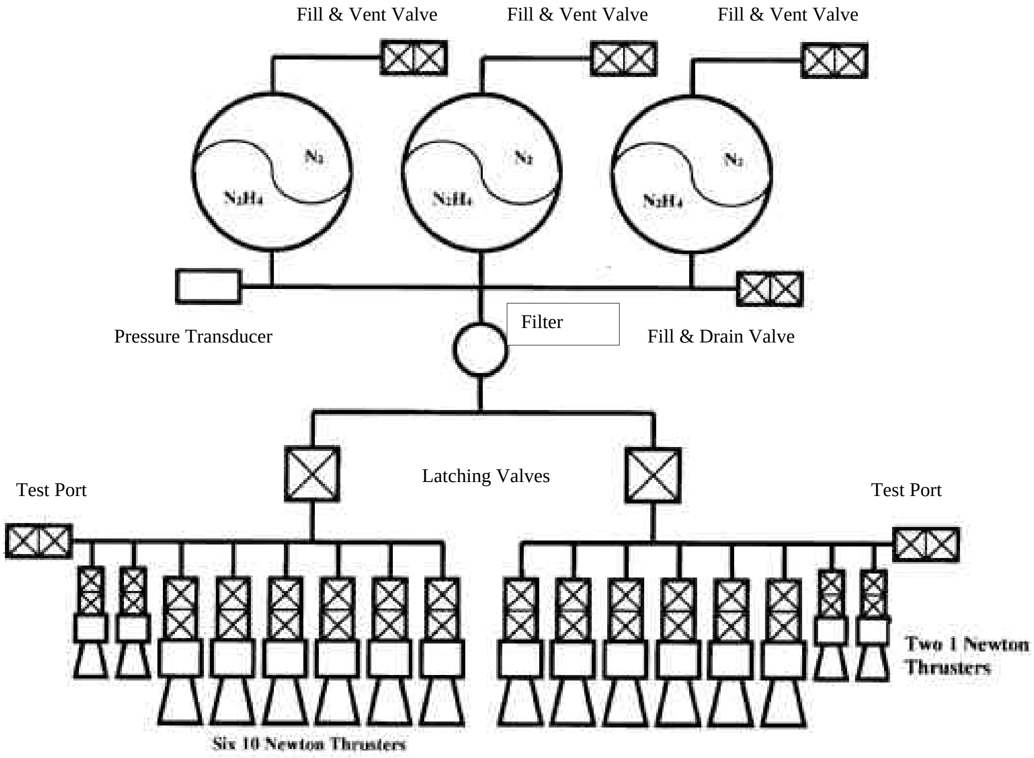


Figure 9.6.3.2-1 Planck RCS layout

Two thruster branches, main and redundant constitute the Planck RCS. The thrusters are the 10N-20 N range and 1N monopropellant hydrazine types. There are three tanks, with a positive expulsion device (diaphragm). They supply the propellant to both the branches in blow down mode from a maximum of 24 bar down to 5.5 bar. Two Latch valves isolate the two branches. The propellant is loaded via a common Fill and Drain valve. The pressurant (nitrogen) is loaded separately by means of one Fill and vent valve per tank. Each branch is equipped with a test port, to facilitate the internal leak check of the components. The pressure in the tanks is monitored by a Pressure Transducer. A filter, downstream the Latch Valves prevent the branches from any contamination.

The Planck RCS layout is shown in Figure 9.6.3.2-2.

			PLANCK		
			X	Y	Z
Branch A	10N	D1A	-73,5	-590,4	1656,2
		D2A	-73,5	590,4	-1565,2
		F1A	-65,2	-1791,4	925,3
		F2A	-65,2	959,8	1756,8
		U1A	215,8	1853,8	-744,8
		U2A	215,8	-1853,1	-744,8
	1N	A1B	785,0	-762,0	1672,9
Branch B	10N	D1B	-73,5	-650,4	1565,2
		D2B	-73,5	650,4	-1565,2
		F1B	-65,2	-1732,7	935,7
		F2B	-65,2	959,8	1767,2
		U1B	298,2	1826,9	-795,2
		U2B	298,2	-1826,9	-795,2
	1N	B1B	785,0	1672,9	762,0

Figure 9.6.3.2-2 Planck thruster configuration

There are two different types of thrusters, 10 - 20 N and 1N for, arranged in the following configuration:

3 pairs of 10 to 20 N thusters for ΔV corrections:

1 pair directed towards the +X hemisphere (“up thrusters”) for manoeuvres with a SAA below 90 deg;

1 pair directed downwards (“down thrusters”) with its thrust direction along –X;

1 intermediate pair (“flat thrusters”) with a thrust direction at 122 deg from X-axis. This pair is optimized for the orbit insertion manoeuvre.

1 pair of 1N thrusters for angular momentum correction and Active Nutation damping (TBC).

There are in total 2 branches of 8 thrusters each.

9.6.4 Design and Performances

9.6.4.1 RCS Subsystem Design

The RCS adopted for Herschel and Planck is a monopropellant system using hydrazine in blow-down mode. The baseline pressurant is gaseous Nitrogen.

The propellant is supplied to two thruster branches, main and redundant, that are both capable to perform the full mission profile. If needed, it is possible to operate the two thruster branches simultaneously.

It is possible to isolate each branch from the propellant tanks to prevent inadvertent firing, by means of Latch Valves, one for each thruster branch.

The design of the RCS is such that a single component/part failure does not cause the failure of functions that are vital for mission success.

The layout of the RCS and the arrangement of the tanks ensure a symmetrical depletion of the propellant in all tanks during all thruster firings in order to minimise the lateral shift of the spacecraft COM.

The characteristics of the thrusters and their accommodation on the spacecraft are selected to avoid any deleterious effects on either the spacecraft or the science instruments during firings.

In order to supply sufficient telemetry data the RCS includes:

- Latch valves status monitor;
- Pressure Transducer to monitor the pressure inside the tanks;
- Thermocouples to monitor the temperature of the thruster catalytic bed;
- Thermistors, one provided by the RCS contractor and others provided by TCS, and placed on each tank to monitor the temperature during ground loading operations and in orbit for Fuel gauging purposes.

The RCS assembly is studied and designed to allow:

full compliance with safety and cleanliness requirements

easy integration with the S/C structure, without welding operations

easy access to the tanks and pipeline rings from the bottom of the cone through removable circular panel

easy access and operability to the FDV and FVV which are at skin on the equipment panels.

Particular attention is dedicated to the propellant gauging method.

All components will be connected by means of 1/4 or 3/8 (TBC) inch titanium tubing. In the case of the pressure transducer (TBC) and thrusters, connections will be made using highly reliable MS 33656-4 fitting connections using conical seals in order to support the integration of the satellite. All other connections will be made by TIG Orbit Arc welding.
The liquid propellant and pressurant gas are to be loaded into the tank through dedicated fill/drain and fill/vent valves.
A propellant filter is to be installed downstream of the storage tanks in order to safeguard the seat/seal arrangements in the latching valves and thruster valves. Each flow control valve exhibits its own filter situated at the valve inlet.
Each thruster is equipped with a series-redundant flow control valve, which features two independently operable coils (important for leakage measurement of the individual valve seat) and two seat/seal arrangements in the flow path. Both valves have to be opened simultaneously with the same command to achieve thruster firing.
The thruster is also furnished with a redundant catalyst bed heater element consuming about 3.2 Watts per heater element, resulting in 6.4 Watts per thruster.
The supply conditions during loading of the propulsion subsystem will be monitored by means of a pressure transducer. This pressure transducer is equipped with the necessary electronics for both, ground and flight operations. The pressure transducer will also provide operators with the ability to monitor the level of the propellant in the storage tanks at any given time, by utilising the PVT method. This by comparing temperature rise resulting from a known pressure increase in a fixed volume to determine the gas ullage, thereby deducing the propellant remaining in the volume.

9.6.4.2 Equipment Design

9.6.4.2.1 Propellant Tank

The same type of tank is considered for Herschel and Planck RCS’s. The propellant tank has a diaphragm configuration with a elastomeric diaphragm used to separate the hydrazine propellant from the nitrogen pressurant and to avoid liquid hydrazine sloshing.
The baseline propellant tanks for use on HERSCHEL/PLANCK are those originally designed for use on the INTEGRAL spacecraft. They have a nominal volume of 174 litres at 20°C and incorporate a positive expulsion device in the form of an elastomeric membrane. This membrane applies the gas pressure on its upper side equally to the propellant, without gas ingesting into solution. The applied pressure will reduce throughout the mission from 24 bars at BOL to around 5.5 bars at EOL.
Characteristics of the propellant tanks are given in Table 9.6.4.2.1-1.

FUNCTIONAL PARAMETERS	QUALIFICATION
Total internal volume	174 liters
Maximum Propellant Capacity	135 kg
MEOP	24 bar
Proof Pressure	36 bar
Burst Pressure	42 bar
Expulsion Efficiency	99.8 %
Material	Titanium 6AI4V for shell and inlet/outlet tubes
Lifetime	8 years
External leakage	10E-8 scc/s Ghe
Temperature Range	4 – 55 deg C
Mass	14.86 kg

TABLE 9.6.4.2.1-1 TANK CHARACTERISTICS

9.6.4.2.2 10-20 N Thrusters

Thrusters in the range between 10 and 20 N thrust will be used on both Herschel and Planck RCS's. In the following the description of 20 N thrusters is reported.

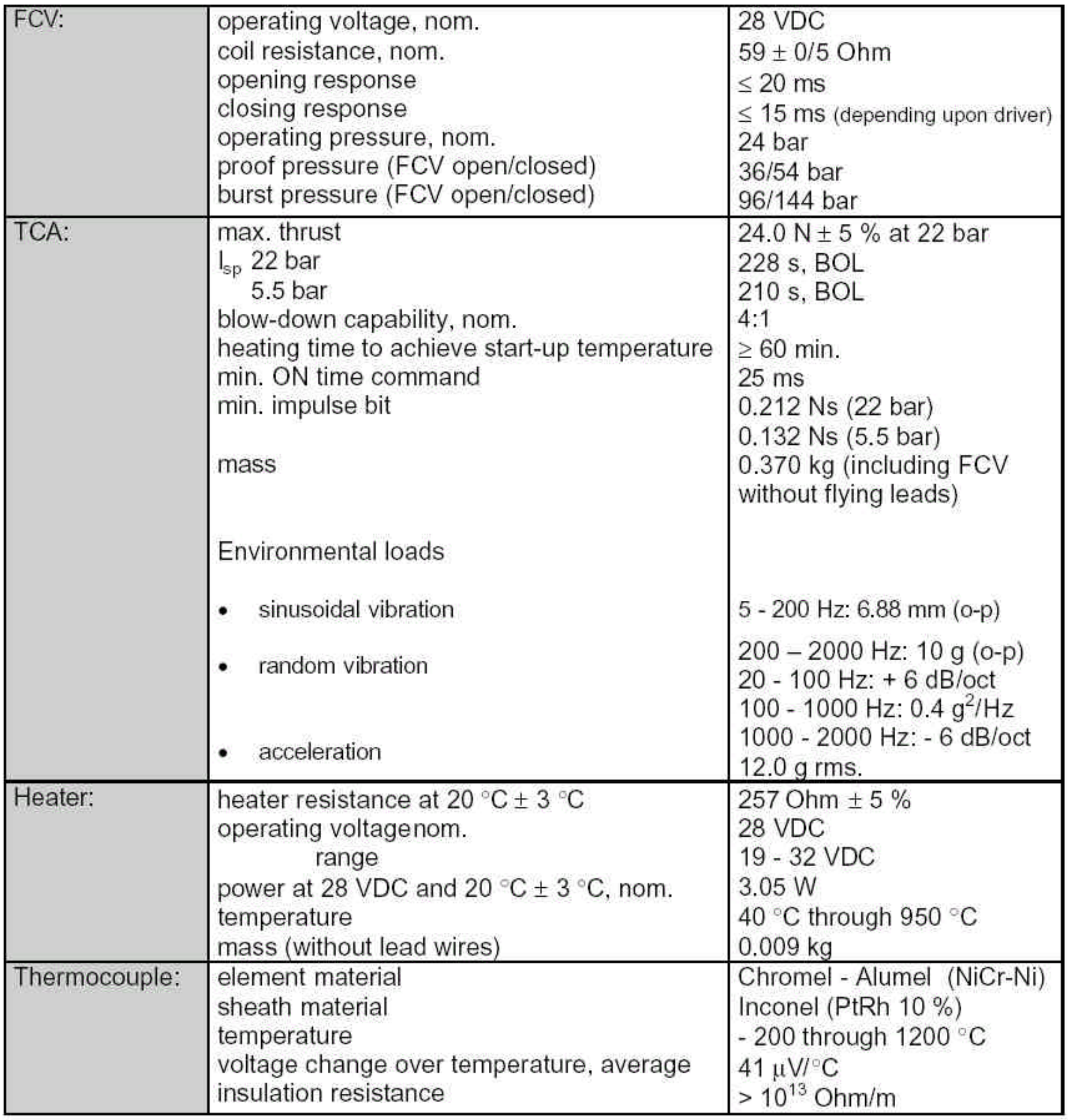
This thruster has been designed, developed and qualified for the XMM/Integral satellites, and later delta-qualified for the MetOp program. More than 60 thrusters of this type have been manufactured, all of them have been delivered to customers, and 8 thrusters perform flawlessly on orbit on the XMM spacecraft.
The 20 N thruster consists of the following elements, described in detail below:

- the Thrust Chamber Assembly (TCA)
- the Flow Control Valve
- the Catalyst bed Heater, and
- the thermal cover, or heat shield, required for thermal balancing during and after a firing.

A thermocouple is attached to the decomposition chamber that indicates the thruster temperature condition prior to and during firing.
The thruster is manufactured, assembled and acceptance tested by Astrium while the catalyst bed heaters are procured from manufacturers in the USA.

A performance summary is presented in the following.

Mode of Operation	HAPS	EURECA	XMM/Integral / MetOp
Steady state duration [s]	3880	16880	20035
Longest continuous burn [s]	3 x 800	3600	5400
Cold starts [at -10 °C]	11	20	-
Cold starts at [0°C-20°C]	-	-	28
Preheated starts [at » 200 °C]	1011	275403	>22300
Overall hydrazine consumed [kg]	70.5	427.5	>290
Total Impulse [Ns]	148750	901696	>517000



FCV:	operating voltage, nom.	28 VDC
	coil resistance, nom.	59 ± 0/5 Ohm
	opening response	≤ 20 ms
	closing response	≤ 15 ms (depending upon driver)
	operating pressure, nom.	24 bar
	proof pressure (FCV open/closed)	36/54 bar
	burst pressure (FCV open/closed)	96/144 bar
TCA:	max. thrust	24.0 N ± 5 % at 22 bar
	I_{sp} 22 bar	228 s, BOL
	5.5 bar	210 s, BOL
	blow-down capability, nom.	4:1
	heating time to achieve start-up temperature	≥ 60 min.
	min. ON time command	25 ms
	min. impulse bit	0.212 Ns (22 bar) 0.132 Ns (5.5 bar)
	mass	0.370 kg (including FCV without flying leads)
	Environmental loads	
	• sinusoidal vibration	5 - 200 Hz: 6.88 mm (o-p) 200 – 2000 Hz: 10 g (o-p)
	• random vibration	20 - 100 Hz: + 6 dB/oct 100 - 1000 Hz: 0.4 g^2/Hz 1000 - 2000 Hz: - 6 dB/oct 12.0 g rms.
	• acceleration	
Heater:	heater resistance at 20 °C ± 3 °C	257 Ohm ± 5 %
	operating voltage nom.	28 VDC
	range	19 - 32 VDC
	power at 28 VDC and 20 °C ± 3 °C, nom.	3.05 W
	temperature	40 °C through 950 °C
	mass (without lead wires)	0.009 kg
Thermocouple:	element material	Chromel - Alumel (NiCr-Ni)
	sheath material	Inconel (PtRh 10 %)
	temperature	- 200 through 1200 °C
	voltage change over temperature, average	41 µV/°C
	insulation resistance	> 10^{13} Ohm/m

9.6.4.2.3 1 N Thrusters

The 1 N thrusters are used on Planck RCS’ s only.

The Thruster comprises of the thrust chamber assembly (TCA) and the flow control valve (FCV),
The main elements of the Thrust Chamber Assembly are:

- decomposition chamber;
- head end device;
- feed tube;
- heat barrier;
- nozzle;
- catalyst bed heater (CBH);

· Insulation means.

The decomposition chamber houses the catalyst bed, positioned between inlet and outlet screens, in which the Hydrazine propellant is decomposed. The decomposition chamber is joined to the head end device on the one side and to the nozzle on the other. The body of the decomposition chamber also provides the attachment for the thruster heater. The head end device closes-off the decomposition chamber at its front side, connects the heat barrier, and supports the feed tube and the outer insulation.

The feed tube provides the flow path between the flow control valve and the decomposition chamber.

It is well protected inside the heat barrier. The feed tube is calibrated for the appropriate Hydrazine flow rate required to achieve the specified thrust. The heat barrier is the structural member between the flow control valve and the main thruster elements. It is sized to avoid severe heat soak back from the thruster to the flow control valve and acts to protect the sensitive flow calibration adjustment within the feed tube. The nozzle is sized to provide the required exhaust velocity and is designed to achieve the required thrust level at a high specific impulse. The nozzle shape is conical with an exit-to- throat area ratio of 80:1.

The catalyst bed heater (CBH) provides the means to ensure the catalyst bed is warm to achieve spontaneous and repeatable pulses. The CBH supports a long life application. Two independent heater elements are housed in the same cartridge type body. The heater is slotted into the sleeve on the body of the decomposition chamber and contains transition joints, which are supported by means of clamps onto the flow control valve. A thermal insulator is joined to the head end assembly.

The valve is manufactured and supplied by Perkin Elmer (ex-EG&G Wright Components) of the US. This particular valve has a long and successful flight heritage.

The valve exhibits a coaxial design, in which the solenoid coil is wound around the flow path of the valve. The design incorporates a soft seat of elastomeric material, mounted to the plunger of the solenoid, which engages a high-precision metal seat, to prevent leakage through the valve. The seat material used is AF E-411 (ethylene propylene terpolymer). Metal-to-metal mechanical stops prevent the seat from deforming the elastomeric material beyond a controlled amount. This design protects the elastomeric sealing member from damage and over-stress. This feature assures excellent leakage control throughout the valve lifetime.

In the de-energised condition the valve is kept closed by the action of both spring force and system pressure force acting on the plunger.

In the energised condition, the plunger, containing the seat material, translates with the solenoid, thus allowing flow through the valve. All wetted parts of the valve are made of vacuum-melted stainless steel.

The solenoid spool which provides the magnetic loop is made from metal parts that are electron beam (EB) welded. The type of design is simple and exhibits high reliability. Testing has proven these valves capable of several million cycles of wet operation while maintaining specified performance requirements. The valves have been qualification tested in excess of 5 million cycles for various satellite programs.

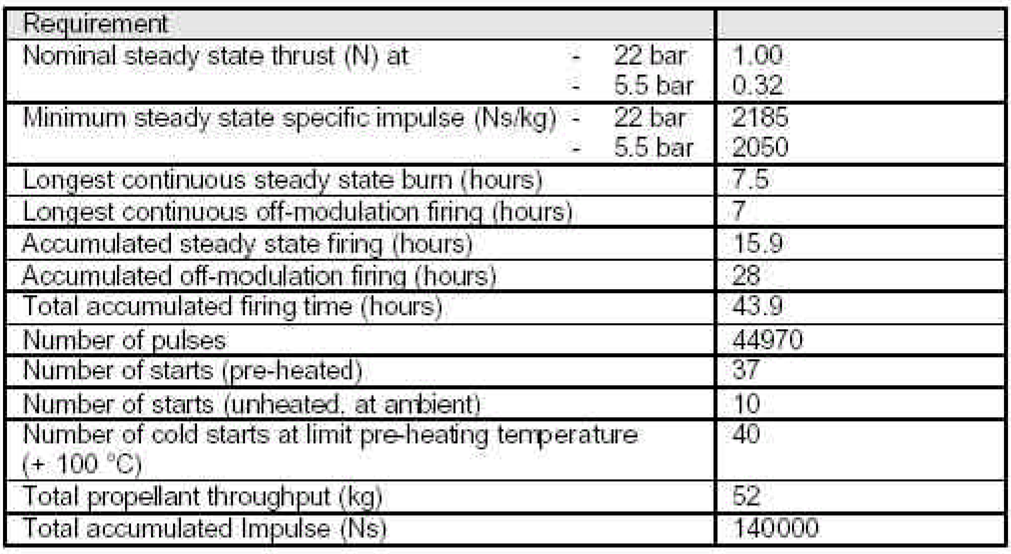
The normal solenoid plunger is made of 430 CRES and contacts the head plate or endplate of the solenoid assembly, made of the same material. In order to minimise galling, a piece of 300-series stainless steel is welded to the 430 CRES plunger. The non-magnetic piece of 300-series CRES is relatively small, and does not affect the magnetic circuit. An undercut on the side of the plunger allows for less metal contact, and the modified plunger affords faster response time opening and lower pull-in voltage along with increased life capability.

The valve is based on the standard design of a single valve with a single solenoid coil. Two standard valves are combined in order to achieve a dual coil, dual seat configuration, that is, one coil operates one seat and the second coil operates the second seat. This valve design allows for valve seat redundancy.

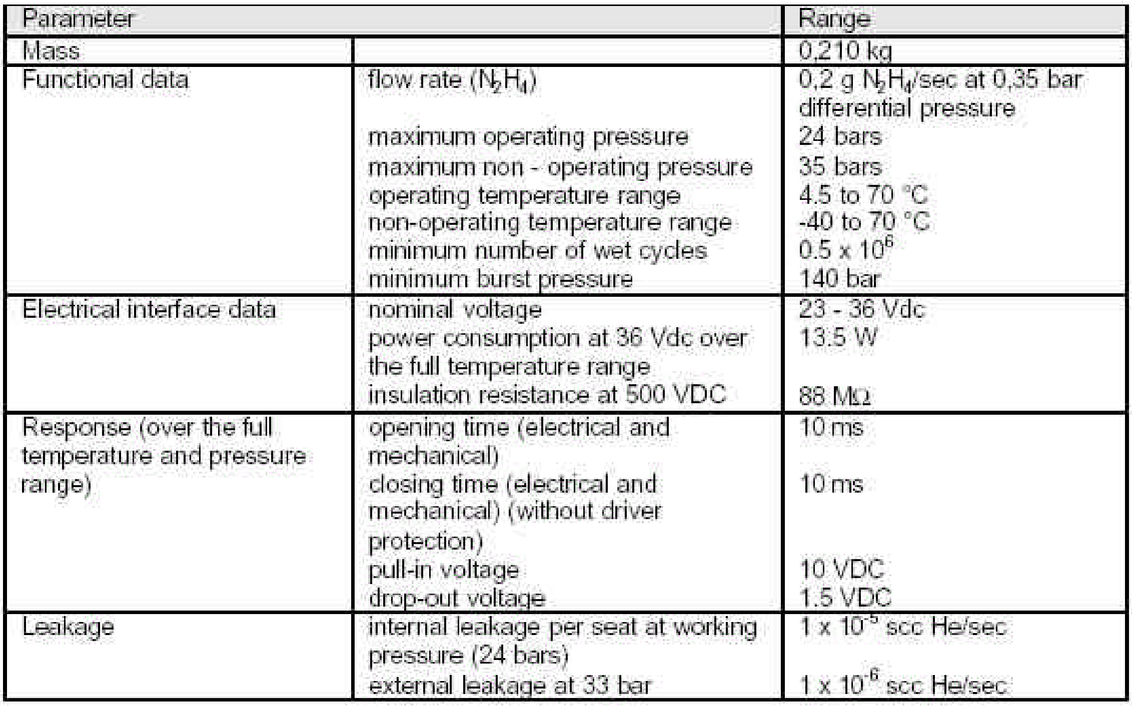
The valve provides ease of assembly and use. All identical parts are completely interchangeable. Shims are incorporated in the assembly to ensure maintenance of dropout voltages and response time requirements.

A 20-micron absolute filter is incorporated at the inlet of each valve.

The thruster steady state performance in terms of specific impulse and thrust versus feed pressure is shown graphically in the following.



Requirement		
Nominal steady state thrust (N) at	- 22 bar - 5.5 bar	1.00 0.32
Minimum steady state specific impulse (Ns/kg)	- 22 bar - 5.5 bar	2185 2050
Longest continuous steady state burn (hours)		7.5
Longest continuous off-modulation firing (hours)		7
Accumulated steady state firing (hours)		15.9
Accumulated off-modulation firing (hours)		28
Total accumulated firing time (hours)		43.9
Number of pulses		44970
Number of starts (pre-heated)		37
Number of starts (unheated, at ambient)		10
Number of cold starts at limit pre-heating temperature (+ 100 °C)		40
Total propellant throughput (kg)		52
Total accumulated Impulse (Ns)		140000



Parameter		Range
Mass		0.210 kg
Functional data	flow rate (N_2H_4) maximum operating pressure maximum non - operating pressure operating temperature range non-operating temperature range minimum number of wet cycles minimum burst pressure	0,2 g N_2H_4/sec at 0,35 bar differential pressure 24 bars 35 bars 4.5 to 70 °C -40 to 70 °C 0.5×10^6 140 bar
Electrical interface data	nominal voltage power consumption at 36 Vdc over the full temperature range insulation resistance at 500 VDC	23 - 36 Vdc 13.5 W 88 MΩ
Response (over the full temperature and pressure range)	opening time (electrical and mechanical) closing time (electrical and mechanical) (without driver protection) pull-in voltage drop-out voltage	10 ms 10 ms 10 VDC 1.5 VDC
Leakage	internal leakage per seat at working pressure (24 bars) external leakage at 33 bar	1×10^{-5} scc He/sec 1×10^{-6} scc He/sec

9.6.4.2.4 Latch Valve

The same Latch Valve is used on both Herschel and Planck RCS’ s.

The latching valve, manufactured by MOOG Inc., is a direct-acting, torque motor-operated latching valve. The valve is electrically actuated to either the open or closed position. Once the valve has transferred to the commanded position, it is no longer necessary to apply electrical power to the valve. For the latching valve the torque motor is shimmed to operate in a bi-stable mode. The magnetic flux from a pair of permanent magnets, located in parallel between the upper and lower pole pieces, produces the force, which latches the valve in either the open or closed position. The motor armature extends into the working air gap between the top and bottom pole pieces. Two driving coils surround the armature, one on either side of the flexure sleeves. One coil is used to open the valve and the other is used to close the valve. It is possible, however, that one coil can be used in the event of a coil failure. Electrical power for the coils is provided through the electrical connector at the top of the motor cap. The armature is welded onto a flapper/flexure sleeve assembly. The flapper is welded to the flexure sleeve and transmits the torque from the torque motor to the valve poppet. The flexure sleeve is welded to the valve body and provides the welded isolation of the torque motor from the propellant.

In the closed position, the valve poppet is in contact with the nozzle. The armature is latched against the top pole piece due to the magnetic force produced by the permanent magnets. In this position, the flapper and flexure sleeve have been deflected. The spring force of the flapper/flexure sleeve combination provides the seating force for the poppet. The poppet itself is a three-piece assembly consisting of a steel mandrel. a steel sleeve and a Teflon seal. The mandrel and sleeve are pressed together and retain the Teflon seal. In the open position the poppet is no longer in contact with the nozzle. Propellant is free to flow through the orifice created by the displacement of the poppet from the nozzle. The poppet and flapper are stabilised in the open position by a flapper stop pin.

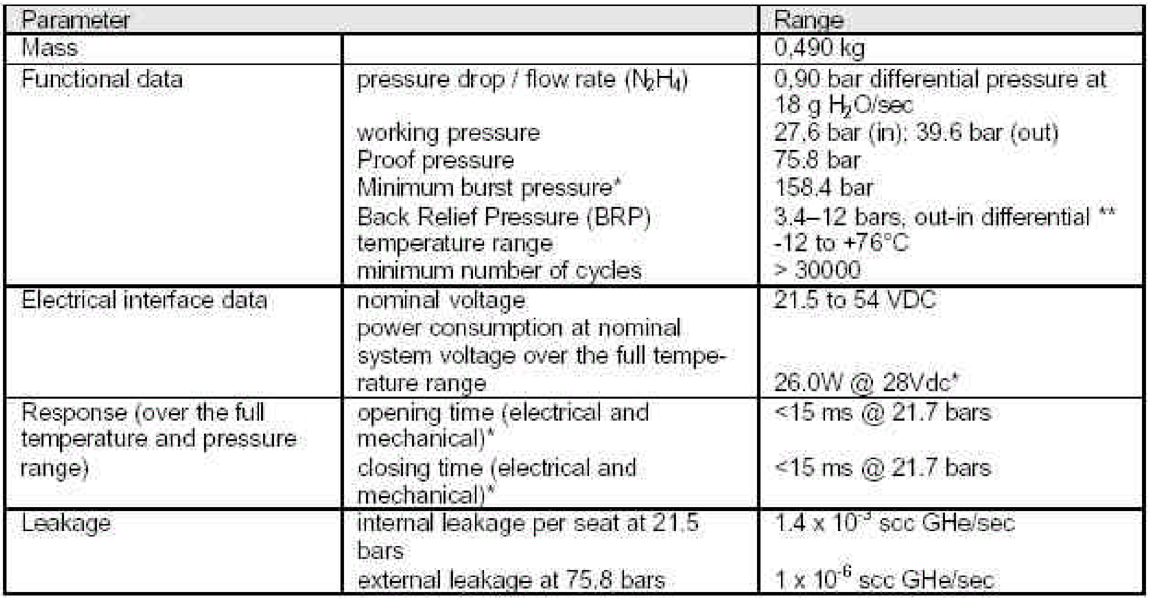
The flapper stop pin is adjusted to set the desired valve stroke. The flapper and flexure sleeve are deflected in the open position just as they are deflected in the closed position. The spring force of the flapper/flexure sleeve combination provides the force retaining the flapper against the stop pin. This force allows the poppet and flapper to remain in the open position while the propellant is flowing.

The propellant flows axially through the valve from the valve inlet to the valve outlet. This direct path provides for a low-pressure drop and reduces the possibility of contamination due to "dead zones".

A 50-micron filter is located in the inlet assembly to protect the valve from large system contamination.

The valve utilises a micro-switch for position indication The micro switch is actuated by an extension of the flapper. The electrical interface for the micro-switch is also via the electrical connector located at the top of the motor cap.

The valve is of an all-welded construction. The armature, flexure sleeve and flapper are a completely welded assembly. The flexure sleeve is welded to the body to isolate the torque motor from the propellant, The inlet and outlet fittings are welded to the body. The inlet filter is welded to the inlet fitting. All of the above welds are of the electron beam type. The flapper top pin is TIG welded to the body after the valve stroke adjustments have been made.



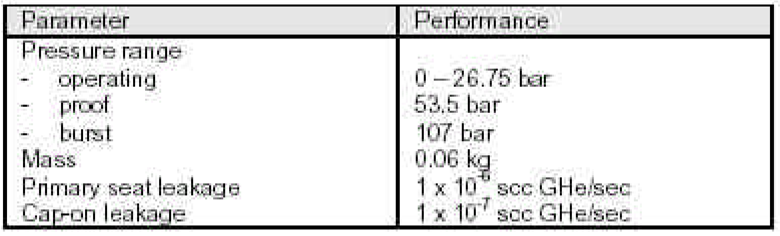
Parameter		Range
Mass		0,490 kg
Functional data	pressure drop / flow rate (N_2H_4)	0,90 bar differential pressure at 18 g H_2O/sec
	working pressure	27.6 bar (in); 39.6 bar (out)
	Proof pressure	75.8 bar
	Minimum burst pressure*	158.4 bar
	Back Relief Pressure (BRP)	3.4–12 bars, out-in differential **
	temperature range	-12 to +76°C
	minimum number of cycles	> 30000
Electrical interface data	nominal voltage	21.5 to 54 VDC
	power consumption at nominal system voltage over the full temperature range	26.0W @ 28Vdc*
Response (over the full temperature and pressure range)	opening time (electrical and mechanical)*	<15 ms @ 21.7 bars
	closing time (electrical and mechanical)*	<15 ms @ 21.7 bars
Leakage	internal leakage per seat at 21.5 bars	1.4×10^{-3} scc GHe/sec
	external leakage at 75.8 bars	1×10^{-6} scc GHe/sec

9.6.4.2.5 Fill and Drain/Vent Valve

The fill and vent or drain valves used in both Herschel and Planck RCS' s allow loading and draining operation with the hydrazine propellant and nitrogen pressurant in the tanks.

The design of FD and FV valves is identical, but different thread sizes are envisaged in order to avoid confusion during propellant and pressurant loading.

The fill and drain/vent valve is used for all loading and draining operations with liquids or gases into the propulsion subsystem. The same item is used as test ports. They have no function after launch, other than to provide mechanical barriers against external leakage. The design is identical for propellant and pressurant fill and drain valves, but different thread sizes at the flight unit/service unit interface are provided to avoid confusion and misconnection during propellant and pressurant loading.
The valve consists of a flight unit and a service unit. The flight unit is TIG-welded to the RCS Subsystem tubing, whereas the service unit forms part of the propellant and pressurant loading system. The flight unit provides redundant sealing using a primary metal-to-metal seal and a secondary elastomeric cap seal. The primary seal is realised by a tungsten carbide ball in a retainer. This retainer can only be moved by means of the actuator incorporated into the design of the service unit.
After RCS Subsystem servicing operations and with the flight unit in the closed condition, the service unit may be disconnected, and the flight unit capped, and secured into place, using locking wire. The fill and drain valve is an Astrium design, which has been used on many European satellite propulsion subsystems, with more than 200 units being manufactured.



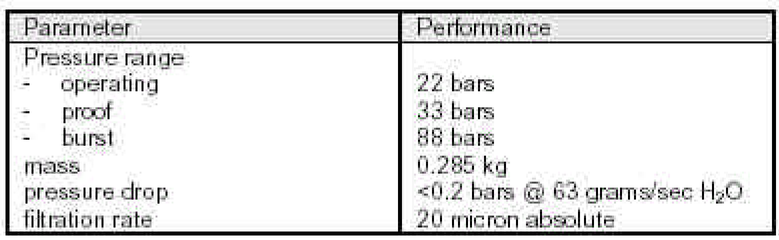
Parameter	Performance
Pressure range	
- operating	0 – 26.75 bar
- proof	53.5 bar
- burst	107 bar
Mass	0.06 kg
Primary seat leakage	1 x 10^{6} scc GHe/sec
Cap-on leakage	1 x 10^{7} scc GHe/sec

9.6.4.2.6 Pressure Transducer

The pressure transducer provides telemetry information on actual propellant supply conditions to the thrusters.
The transducer sensor and electronics are combined in an all-welded assembly. Four strain gauges in a Whetstone Bridge configuration are placed on a flexure diaphragm. System pressure deflects the diaphragm, changing the resistance of the strain gauges. The output of the Whetstone Bridge is conditioned through an Amplibridgeä electronics system, providing input/output isolation, voltage regulation, amplification of the sensor output from 0 to 5 VDC for telemetry, temperature compensation and an internal set point calibration for functional checkout.
All parts of the transducer in contact with the Hydrazine propellant are of stainless steel.
The transducer is manufactured by the AMETEK and is flight proven on several space programs, as ATV.

9.6.4.2.7 Propellant Filter

The propellant filter is designed to trap any remaining particles carried by the propellant before it enters the thruster branches. The filter is manufactured by VACCO Industries, and incorporates etched-disc technology. The etched disc construction provides absolute micron rating due to the precise chemical etching of each flow path. The body and discs are made of titanium, allowing maximum fluid compatibility while minimising the weight. The filter has a 20 micron absolute filtration rate.
The structural integrity of the filter element provides the capability of withstanding 100 % system differential pressure. The filter is also able to withstand extreme temperatures from -200 to +148 °C. The filter is an all welded external construction offering reliability and structural integrity.
The propellant filter is 100 % cleanable in detail, components to assure initial cleanliness; no media migration or weld induced contaminates.



Parameter	Performance
Pressure range	
- operating	22 bars
- proof	33 bars
- burst	88 bars
mass	0.285 kg
pressure drop	<0.2 bars @ 63 grams/sec H_2O
filtration rate	20 micron absolute

9.6.5 RCS Commonality Assessment

Both Herschel and Planck RCS' s are designed to use the same following equipment:

- Propellant Tanks;
- 10-20 N thrusters;
- Fill & Vent Valves;
- Fill & drain Valves;
- Filter;
- Test Ports;
- Pressure Transducers;
- Latch Valves.

Peculiar to Planck is the use of 1 N Thruster.

As far as the ducting connecting the propellant tanks to the thrusters and their fixation to the SVM' s structure are concerned, due to the different Herschel and Planck RCS' s layouts, the configuration can not be exactly the same, but commonality will be implemented in terms of:

- Ducting material and diameter;
- Fluid connections;
- Bracketry.

Both systems are standard monopropellant ones using anhydrous hydrazine in blow down mode, with different EOL pressures, due to the different initial propellant mass. However, both RCS' s stay within the minimum EOL pressure required by the chosen thruster types.

9.6.6 RCS Budget Summary

9.6.6.1 Mass

9.6.6.1.1 Herschel RCS Mass

All the Herschel RCS components except ducting and bracketry are considered off-the-shelf and therefore a 5 % margin has been applied. Table 9.6.6.1.1-1 reports the mass budget.

ITEM	HERITAGE	UNIT MASS (kg)	QUANTITY	NOMINAL MASS (kg)	MARGIN	TOTAL MASS (kg)
Tank	Integral	14.86	2	29.72	5 %	31.2
10 –20N thrusters	XMM	0.370	12	4.44	5 %	4.66
Latch valve	XMM	0.42	2	0.84	5 %	0.88
Pressure transducer	ATV	0.14	1	0.14	5 %	0.147
Fill/Drain valve	Integral	0.06	1	0.06	5 %	0.063
Fill/Vent valve	Integral	0.06	2	0.12	5 %	0.126
Test port	Integral	0.06	2	0.12	5 %	0.126
Filter	Integral	0.285	1	0.285	5 %	0.3
Ducting	2	2	1	2	20 %	2.4
Bracketry	1.5	1.5	1	1.5	20 %	1.8
TOTAL				**39.2**		**41.7**

TABLE 9.6.6.1.1-1 HERSCHEL RCS MASS BUDGET

The above table is reflecting the configuration with 20 N Thrusters while for budgetting purpose (see H-P-BD-AI-0001 SVM Budget Report) the 10 N Thrusters have been considered

9.6.6.1.2 Planck RCS Mass

As for Herschel, Planck RCS components except ducting and bracketry are considered off-the-shelf and therefore a 5 % margin has been applied. Table 9.6.6.1.2-1 reports the mass budget.

ITEM	HERITAGE	UNIT MASS (kg)	QUANTITY	NOMINAL MASS (kg)	MARGIN	TOTAL MASS (kg)
Tank	Integral	14.86	3	44.58	5 %	46.8
10 –20N thrusters	XMM	0.370	12	4.44	5 %	4.66
1 N thruster	GLOBALSTAR	0.210	4	0.84	5 %	0.88
Latch valve	XMM	0.42	2	0.84	5 %	0.88
Pressure transducer	ATV	0.14	1	0.14	5 %	0.147
Fill/Drain valve	Globalstar	0.06	1	0.06	5 %	0.063
Fill/Vent valve	Globalstar	0.06	3	0.18	5 %	0.189
Test port	Globalstar	0.06	2	0.12	5 %	0.126
Filter	Integral	0.285	1	0.285	5 %	0.3
Ducting	2	2	1	2	20 %	2.4
Bracketry	1.5	1.5	1	1.5	20 %	1.8
TOTAL				**54.98**		**58.24**

TABLE 9.6.6.1.2-1 PLANCK RCS MASS BUDGET

The above table is reflecting the configuration with 20 N Thrusters while for budgetting purpose (see H-P-BD-AI-0001 SVM Budget Report) the 10 N Thrusters have been considered

9.6.6.2 RCS Power Budget

9.6.6.2.1 Herschel RCS Power Budget

Table 9.6.6.2.1-1 shows the power budget for the Herschel RCS.
Catalytic Bead Heater (CBH) consumption is a worst case and has to be further defined since the thrusters facing Sun require less power than anti-Sun thrusters.

ITEM	HERITAGE	UNIT POWER (W)	QUANTITY	REMARKS
20 N thruster	XMM/ Integral		12	
FCV		13.6		When activated
CBH		3.05		for preheating purposes only (2 hr)
Latch valve	XMM	26	2	for <20 ms only
Pressure transducer	ATV	0.33	1	Continuously ON

TABLE 9.6.6.2.1-1 Herschel RCS POWER BUDGET

9.6.6.2.2 Planck RCS Power Budget

Table 9.6.6.2.2-1 shows the power budget for the Planck RCS.
Catalytic Bead Heater (CBH) consumption is a worst case and has to be further defined since the thrusters facing Sun require less power than anti-Sun thrusters.
It has been considered in the system budget that 1 N thrusters and 10 N thrusters are not operated simultaneously. So, at system level, the heating budget of the 10 N thrusters is taken as an envelope.

ITEM	HERITAGE	UNIT POWER (W)	QUANTITY	REMARKS
20 N thruster	XMM / Integral		12	
FCV		13.6		when activated
CBH		3.05		for preheating purposes only (2 hr)
1 N thruster	GLOBALSTAR		4	
FCV		9		when activated
CBH		6.4		for preheating purposes only (2 hr)
Latch valve	XMM	26	2	for <20 ms only
Pressure transducer	ATV	0.33	1	continuously ON

TABLE 9.6.6.2.2-1 PLANCK POWER BUDGET

9.7 Control and Data Management

9.7.1 General

This section provides the Control and Data Management functional description and gives a design overview of every single module with the relevant performances.

The section reflects the lower level report from SES. For more details refer to the RD-65 (P-HPL-NOT-00021 issue 2).

The Control and Data Management has been suitably dimensioned to be compatible with both Herschel and Planck satellites. The CDMS provides such a high level of commonality to lead to an identical unit design for both Herschel and Planck SVMs.

Subsystem functions will be implemented in one Control and Data Management Unit (CDMU).

9.7.2 Requirements and Design Drivers

The Control and Data Management is designed in agreement with SVM Requirements Specification [AD-43]; functional requirements are given in para. 4.1.9, performance requirements are given in para. 4.2.9.
The main requirements of SRS [RD-01] have been traced in the following for reference purpose.

The CDMS shall perform the following general functions (SMCD-030):

- telemetry acquisition and formatting
- telecommand acquisition, decoding validation and distribution
- data storage
- time distribution and time tagging
- autonomy supervision and management.

Functional and performance requirements:

- The CDMS shall be connected to the instruments via on-board data bus architecture according to MIL 1553B. It shall exchange TM-TC packets with all the on-board units, which can eventually encode/decode TM/TC packets (SMCD-035 to 055):
  - ☐ Control and Data Management Unit (CDMU) is the Bus Controller on 1553 Data Bus, where Science Instruments, Power Control and Distribution Unit (PCDU) and ACMS Control Computer (ACC) are Remote Terminals
  - ☐ A separated 1553 bus is dedicated to ACMS. ACMS Control Computer (ACC) is the Bus Controller on 1553 ACMS bus.

- The equipment shall be able to distinguish between permanent faults and transient ones and shall be able to reconfigure or adopt a safe mode autonomously as well as by ground command (SMCD-100):
  - ☐ this implies the usage of a Reconfiguration Module inside the CDMU.

- It shall be possible to transmit to ground at programmable different telemetry modes:
  - ☐ real-time housekeeping data (spacecraft and payload)
  - ☐ real-time science + real-time housekeeping data
  - ☐ real-time housekeeping data + dump of on-board mass memory
  - ☐ real-time housekeeping + real-time science + dump of the on-board mass memory

- and simultaneously record the real-time housekeeping data or the real time housekeeping data and real-time science data (SMCD-060, MOGE-030).
  - ☐ In order to allow the transmission of the above telemetry modes, different Virtual Channels have been allocated to each mode.
  - ☐ As per SGICD (AD-07), the required bit rates are the following:
    - ✓ low bit rate: 500 bps, 5 kbps
    - ✓ medium rate: 150kbps
    - ✓ high rate: 1.5 Mbps

- The CDMS shall distribute all commands from ground, stored, and/or generated on board. The telecommand rate shall be switchable between the high bit rate of 4 kbps and low bit rate. (SMCD-065, 130):
  - ☐ as per SGICD (AD-07), uplink low bit rate is 125 bps
  - ☐ uplink high bit rate is 4 kbps.

- All commands necessary to recover from the survival mode shall be executable on board without the intervention of on board software (SMCD-140):
  - ☐ these commands shall be generated by Reconfiguration Module.

Data storage function:

- the CDMS shall store all housekeeping and science data generated on board. It shall be possible to dump the non-periodic housekeeping, periodic housekeeping and other data separately (SMCD-070 to 080).
- The size of the on-board storage medium shall be sufficient to store all the mission data generated during 48 hours (MOOM-220, SMCD-145):
  - ☐ For this reason, the size of the mass memory shall be greater than 25 Gbit. Sizing justification is given in the following.

The major contributor to mass memory sizing is the payload, which generates average data rates up to 130 kbps (SINT-040, SINT-045).

Taking into account a 9 kbps average rate for satellite housekeeping (TBC, see TM/TC Budget RD-68), the required storage is 24 Gb. A mass memory of 25 Gb End of Life is planned on Herschel and Planck thus providing a further margin of 4 %.

- As required by SMCD-150, the mass memory shall behave as a disk unit to users and support a filing system. It shall support partial readout, manage free space and automatically mark bad areas; it shall make available on request information about free space, files stored and bad areas. It shall support simultaneous read and write operations.

Time distribution and time tagging function:

- The CDMS shall provide electrically isolated synchronisation signals and timing signals as required by the science instruments or spacecraft units (SMCD-085):
  - ☐ as required by IID-A and IID-Bs (AD-01 to AD-06), 131072 Hz synchronisation signals have to be generated and distributed
  - ☐ Synchronisation between Local On Board Time and On Board Time will be achieved by synchronising a 1553 time code packet with a 8 Hz broadcast pulse generated within the CDMU.

9.7.3 Subsystem Overview

The Control and Data Management is devoted to the SVM and some payload units management.
The Control and Data Management functions are combined in a single **Control and Data Management Unit, CDMU**, partitioned into a Core system and I/O system, which is responsible for the following main functions:

- Data processing
- ESA Packet TC decoding
- ESA Packet TM generation and encoding
- TC distribution
- CDMU (and spacecraft) reconfiguration
- HK, Science data storage
- On Board Time generation and on-board users distribution
- Safeguard data storage
- Data exchange via I/O channels and MIL-STD-1553B bus with platform and payload units
- Data exchange via test and umbilical I/Fs.

In addition a Basic Software (BSW) can be seen as an integral part of the CDMU. Its purpose is to handle hardware abstraction, runtime system and some higher level services.

The CDMU is a highly integrated unit where a processing function is available together with an extensive set of interface modules, enabling external interfaces with several other satellite units.

The following functional blocks can be identified:

- Telecommand Decoder, Telemetry Formatter, Safeguard memory, On Board Time and Reconfiguration Module housed in the TTR board.
- CPU, Communication I/Fs housed in the PM board
- Mass Memory Module
- Standard I/O interface (SBCH and SIOH)
- Power Converter

A Block Diagram of the CDMU is shown in the following figure.

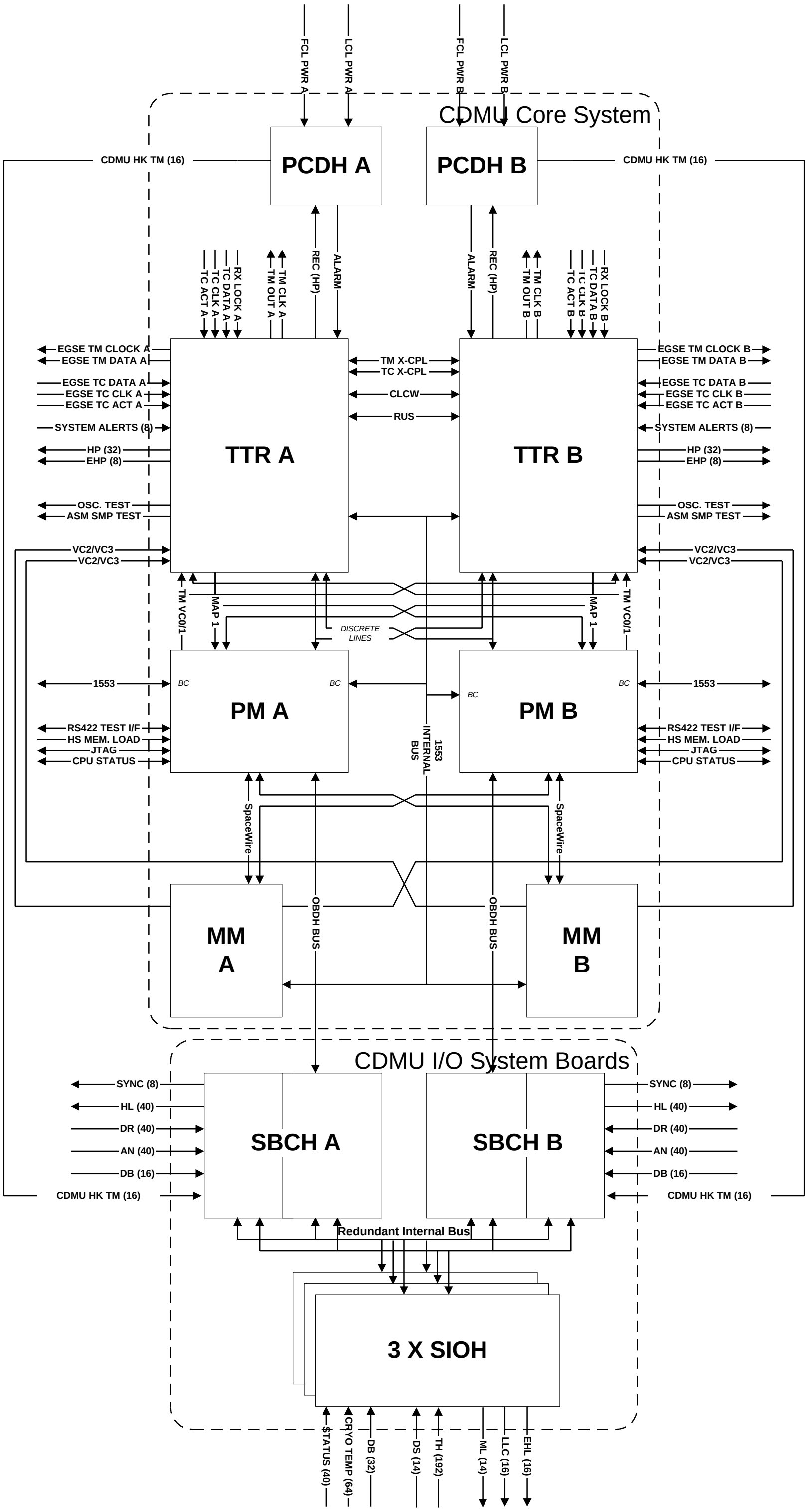


Figure 9.7.3-1 CDMU Functional Block Diagram

From the previous list the following blocks operate in redundancy mode:

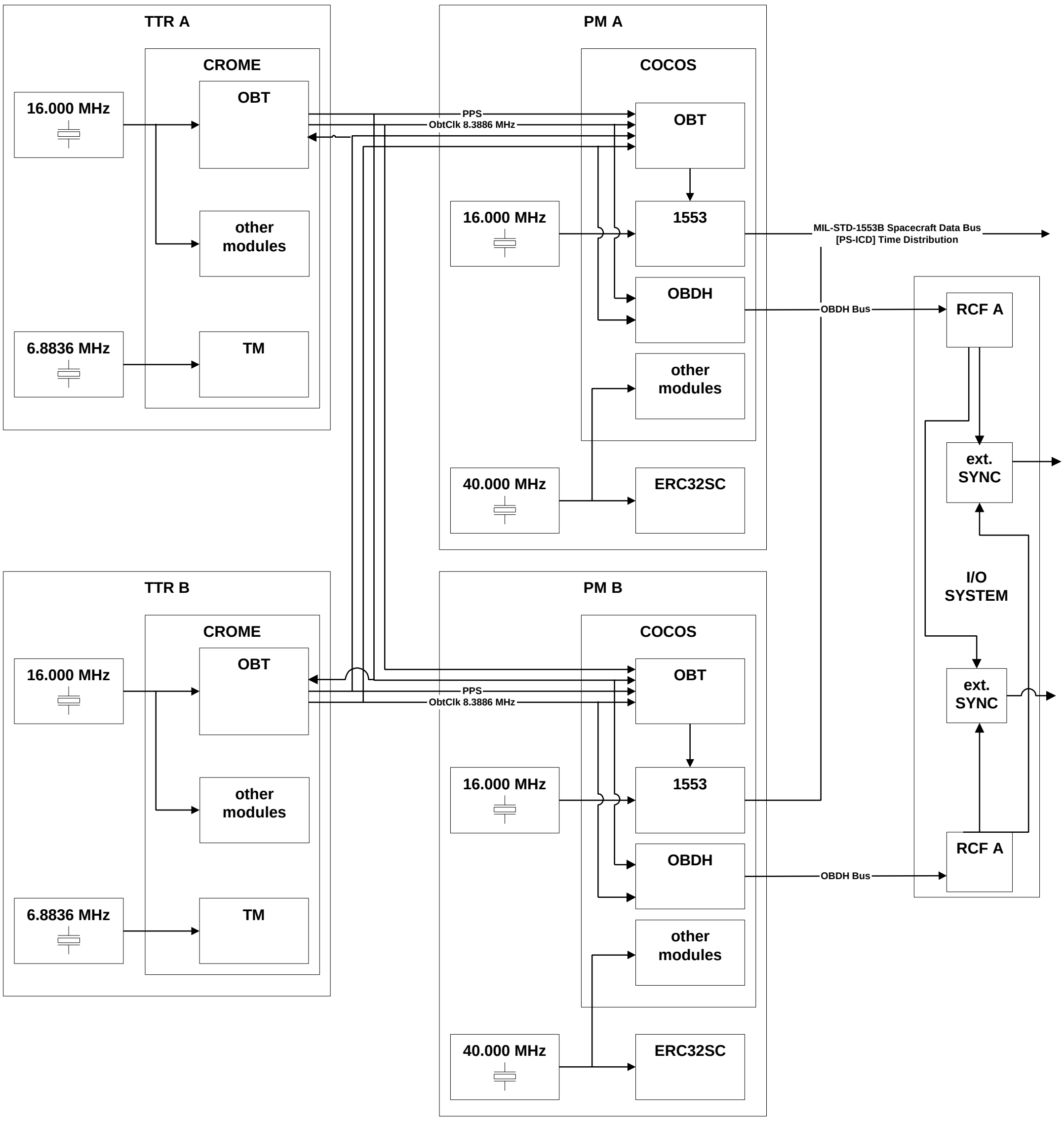
- Blocks operating in hot redundancy with no power cross strapping:
  - ☐ Mass Memory (MM) A and Hot Power Converter A
  - ☐ Mass Memory (MM) B and Hot Power Converter B.

- Blocks operating in cold redundancy with no power cross strapping:
  - ☐ Processor Module (PM) A, Remote Core Function (RCF) A and Cold Power Converter A
  - ☐ Processor Module (PM) B, Remote Core Function (RCF) B and Cold Power Converter B.

- Blocks operating in hot redundancy with (partial) power cross strapping
  - ☐ Telemetry Telecommand & Reconfiguration (TTR) A and Cold Power Converter A
  - ☐ Telemetry Telecommand & Reconfiguration (TTR) B and Cold Power Converter B.

- Hot operating, non-redundant blocks. They are supplied from Cold Power Converter A or B. The redundancy achieved depends on how they are connected to the users:
  - ☐ Standard I/O Board (SIOH) 1
  - ☐ Standard I/O Board (SIOH) 2
  - ☐ Standard I/O Board (SIOH) 3
  - ☐ I/O part of Serial Bus Controller Board (SBCH) A
  - ☐ I/O part of Serial Bus Controller Board (SBCH) B

The Synchronisation Signal generation and distribution is shown in the following block diagram:



9.7.4 Functional Blocks description

The following paragraphs give more detail on the functional aspects, design and performance of the internal modules.

9.7.4.1 Telemetry Telecommand and Reconfiguration Board (TTR)

There are two TTR Boards operating in hot redundancy.
Each TTR Board includes the following functional blocks housed in a CROME ASIC:

- Telecommand Decoder
- Telemetry Encoder
- Command Pulse Distribution Module
- Reconfiguration Module
- On Board Time
- Internal Control Bus Remote Terminal
- Memory control Interface.

and other associated support functions which are represented by separate interface circuits as buffers, drivers,filters and protections.

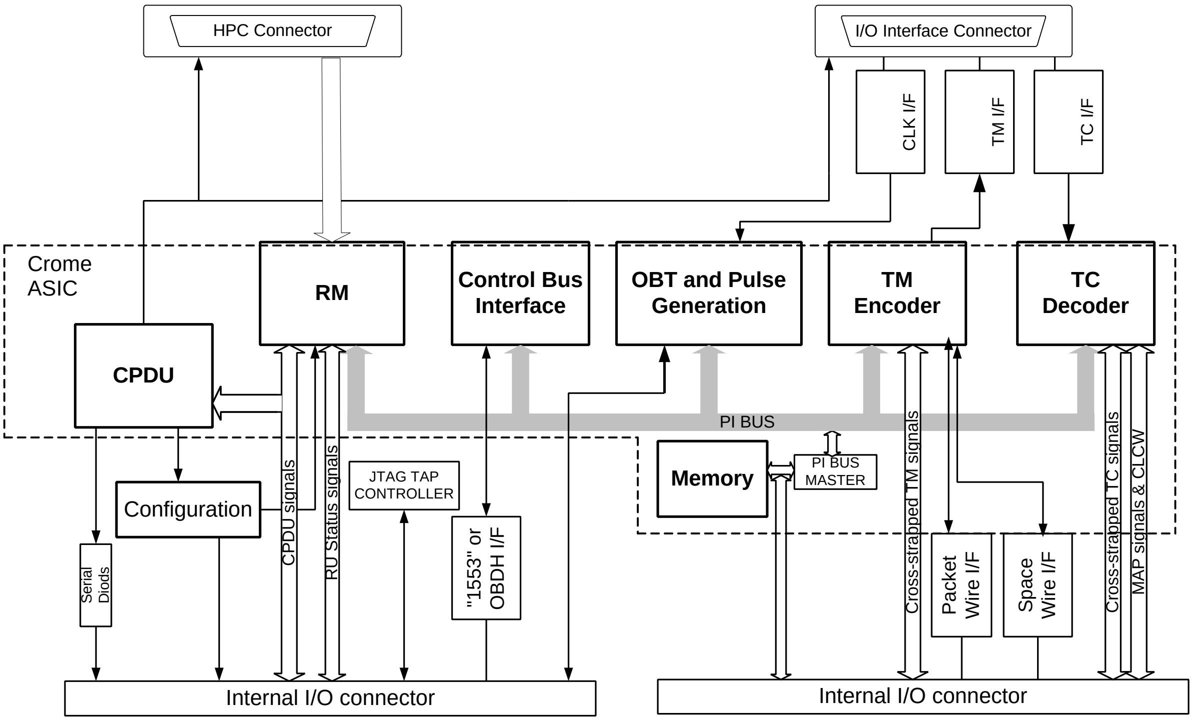


Figure 9.7.4-1 TTR Block Diagram

The initialisation is performed as soon as power is received from the PCDH hot section (INIT mode). After that, three possible modes are possible: only RM operating (RM INIT), all the other functions which involve TC, TM, OBT, SGM are fully operating (BASIC mode) or all functions are operating (FULL mode). Any way no HP TC can be issued before the TTR leaves the INIT mode and no HP TC from RM can be issued if the TTR is not in FULL mode.

9.7.4.1.1 Telecommand Decoder

Functional Description.
The TC Decoder is represented by the latest generation of SES PTD and implements the Packet Telecommand Protocol in compliance with AD-25.
Each CDMU TC decoder is connected with the two Transponder receivers to get demodulated digital telecommand signals. In addition two interfaces for EGSE TC inputs are provided (one per decoder). Of the TC inputs, each decoder selects one of them via priority selection logic. The CDMU performs TC decoding in accordance with ESA Packet Telecommand Standard [AD-25]. Three types of commands are possible:

- high priority commands (HP TC), that are directly output as pulse commands from the TC decoder via CPDU
- telecommands that are distributed to the CDMU Processor Module
- telecommands that disable the RM.

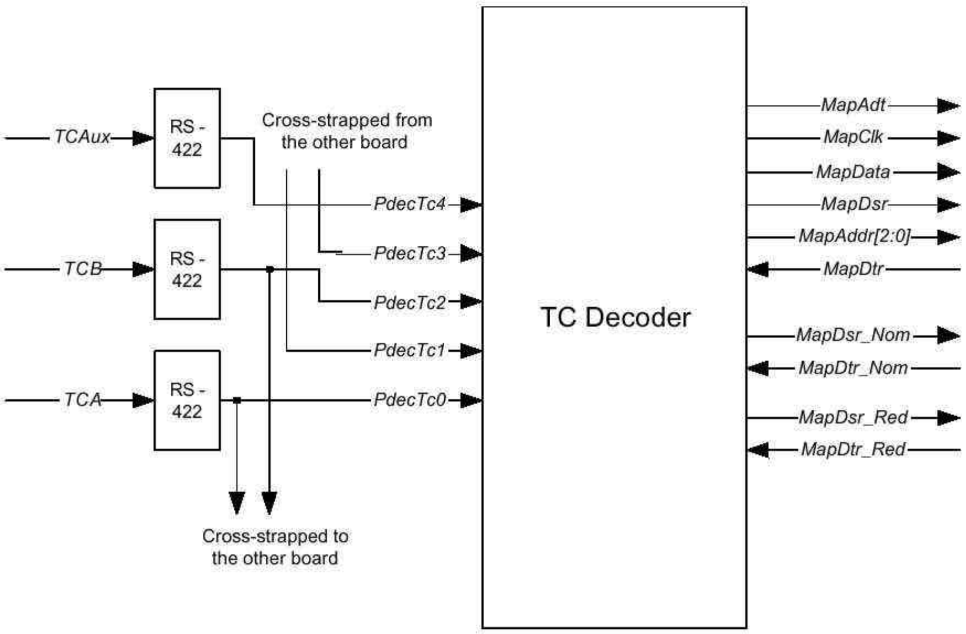


Figure 9.7.4-2 Command Decoder Interfaces

The Command Decoder is built using the following blocks:

- Serial Input Block (SIB)
- Authentication Block (AUB)
- Segmentation Layer and Router Block (SLRB)
- TeleMetry Block (TMB).

The received data stream is checked for a proper Start Sequence and the subsequent data codewords are decoded, with possible bit corrections.
The derived Transfer Frame is now checked to verify that the Frame Error Control and Frame Header are conform and contain the Spacecraft and the Virtual Channel Identification.
Finally the TF is processed by the Authentication Unit that checks the Frame Data Field and authorises the access to the spacecraft. The authorised frame is sent to the Physical port indicated in the Segment Header. For the CDMU there are four MAP addresses which refer to the CPDU, PMs and RM.

Design and performance.

As per SGICD (AD-07), uplink bit rates are **125 bps** and **4 kbps**.

9.7.4.1.2 Telemetry Encoder

Functional description.
The TM Encoder receives TeleMetry data on a variable number of separate serial input interfaces, each connected to a Virtual Channel.

Eight Virtual Channels are provided and they are allocated to the following data:

VC0	Real-time HK telemetry from the active processor
VC1	Real-time Science telemetry from the active processor
VC2	Dump Science and HK telemetry from the active Mass Memory
VC3	Dump Science telemetry from the active Mass Memory
VC4	Real-time Science HK telemetry from the active processor
VC5	Not used
VC6	Not used
VC7	Idle frames

The VCA blocks then generate, as main output, complete Transfer Frames where the Telemetry Packets coming from different sources are embedded.
Three types of frame stream can be selected depending on the type of coding:

- uncoded frames (up 1115bytes)
- reed-solomon coded frames (up 1115bytes plus 160 for check symbols)
- turbo-coded frames (up 1115bytes reduced by a factor R)

to which the Synchr Marker (4 octets) must be added.

In addition to the selected coding there is also the possibility to perform data randomisation of the single TF, or to perform Convolutional encoding of the entire output stream.

Other options are the selection of PSK o SPL modulation. If no randomisation or convolutional code is selected the output will be NRZ-L. The selected TM encoder drives all serial TM output. The unselected TM encoder is disabled, placed in a reset state and is not operating although it is continuously powered.

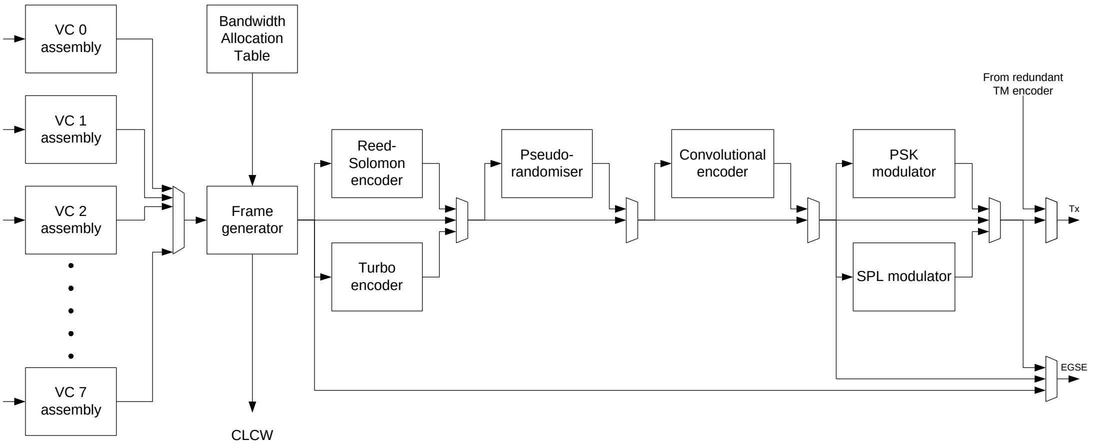


Figure 9.7.4-3 Telemetry Encoder Block Diagram

A reduced number of TM packets, if enabled, can be collected, with or w/o the processor involvement, only for failure investigations and addressed to a selected VC.
For a complete list of programmable parameters refer to the RD-(P-HPL-NOT-00021-SE issue 1)

Design and performance.
The foreseen interfaces between CMDU TC Encoder and the Transponder are RS422.
The modulation can be selected between None,SPL.PSK.

As per SGICD [AD-07], the required bit rates are the following:
* low bit rate: **500** bps, **5**kbps; medium rate: **150**kbps; high rate: **1.5**Mbps
The downlink bit rate can be programmed between 1bps and 8Mbps.
The subcarrier frequency can be chosen between 128Hz and 1MHz.

The TM clock is chosen so that the required TM bit rates and subcarrier frequency can be generated using an integer division. The ratio between the generated clock and the subcarrier shall a multiple of 4.

9.7.4.1.3 On-Board Time Master

Functional Description.
The OBT master, resident in the hot redundant TTR modules, provides the reference time and distributes synchronised pulses in the system.

There are four main functions in the OBT module:

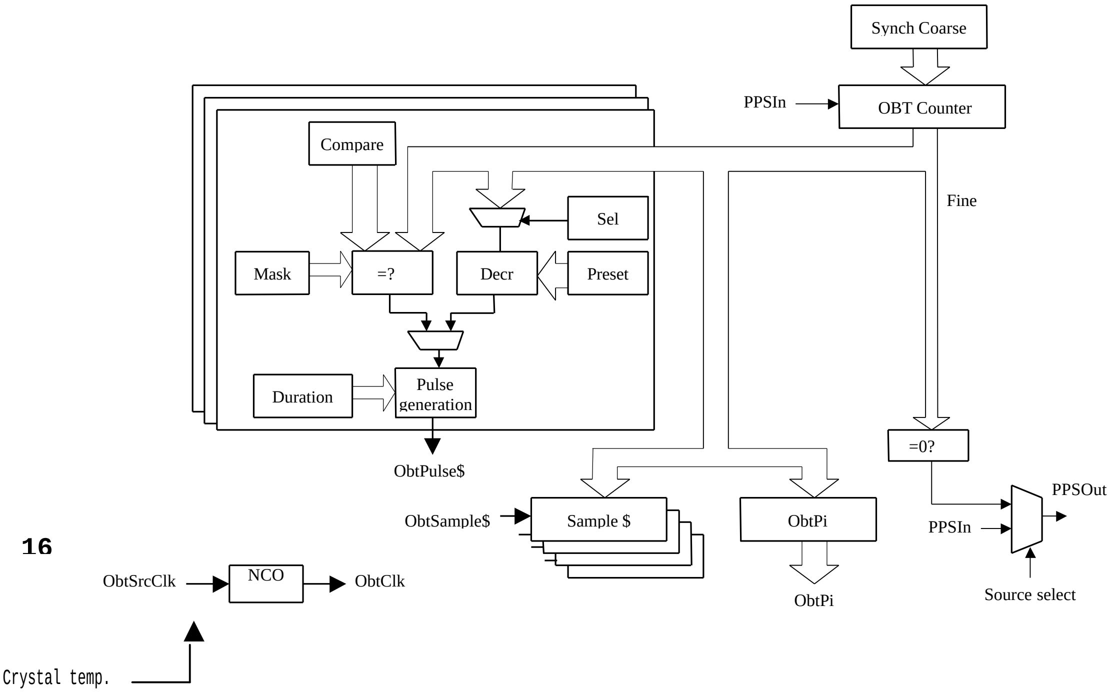
- OBT counter
- Numerical Controlled Oscillator (NCO)
- Sampling of OBT counter
- Pulse generation

The OBT counter can be sampled through an external hardware triggered signal or by software generated event.

The NCO is programmable to handle different relationship between the external source clock, which can use no-power-2 frequency, and the synchronised OBT generated clock.

The OBT also includes a programmable OBT synchronous pulse generator. This will be used for generating two types of pulses: one is generated when the counter reaches a certain value and the other is generated when a selected bit of the counter is used to decrement a preset value and zero value is reached.

A Pulse Per Second (PPS) is exchanged between the two OBTs, main and redundant, to maintain the synchronisation.



Design and performance.

The OBT is implemented in the CROME ASIC.

The capability of the OBT counter is 56bit, where the 24 least significant bits represent sub seconds and the 32 most significant bits represent seconds. The 16.77 MHz is the necessary input frequency of the oscillator, which allows using the full resolution. The requested frequency accuracy 1ppm is achieved using a standard crystal oscillator and adequate thermal compensation using a calibration table in EEPROM.

9.7.4.1.4 Reconfiguration Module

Functional description.
The reconfiguration function in the CDMU system is handled by two hot redundant Reconfiguration Modules that process up 8 external and 8 internal incoming alarms and generates CPDU packets for execution by the CPDU.
It also handles three additional alarms: the Active PM and the watchdog using two additional inputs (WdTrig and WdEnable) .
The generated packets depend on the different alarms and H/W configurations.
All the incoming alarms are submitted to a conditioning process which includes the following steps:

- synchronisation
- filtering for glitch suppression
- polarity recognising
- temporisation delay and mode (active or watchdog)
- pattern filtering
- majority voting
- enable/disable mask

after that the conditioned alarms will be handled for:

- predefined pattern matching
- CPDU packet generation

and in the end, subject to a CPDU command mask eventually.

All the above steps, relating to the RM functions, need of default values programmed in a non-volatile TBD memory during manufacturing.

Moreover, the RMs generate a log when the reconfiguration is started in order to save the time, the current alarm situation and the CDMU H/W configuration in the TBD memory, to be sent as a TM packet.

The following 8 internal alarms are received:

SW Alarm A
SW Alarm B
CPU Alarm A
CPU Alarm B
COCOS Alarm A
COCOS Alarm B
UVD Alarm A
UVD Alarm B

and the already mentioned three additional alarms:

Active Pm A
WdTrig
WdEnable

Information on external alarms allocation are given in TM/TC Budget (RD-68).

Design and Performance

The figure below shows the reconfiguration function, which consists of alarm sensors and command relays (not part of TTR) and two identical Reconfiguration Modules (RM).
The Reconfiguration Modules communicate to ensure that only one RM at a time can drive the Command Relays.

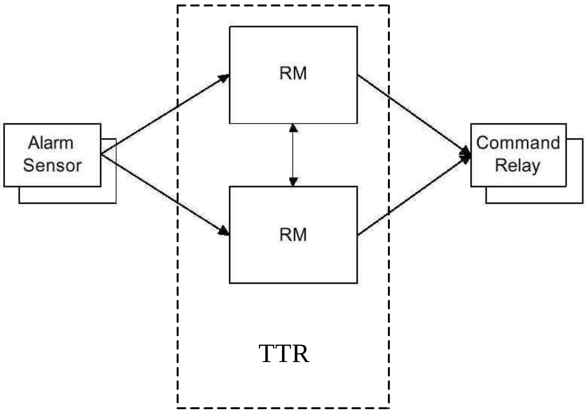


Figure 9.7.4-4 Reconfiguration Function

The glitch filter allows the suppression of all signals shorter than 100µs.
The temporisation delay can be programmed from 100µs to 836s.
The pattern filter suppresses every signal shorter than 50µs.

9.7.4.1.5 Safeguard Memory

Functional description.

The Memory is used for storage of essential housekeeping TM Source Packets and command data needed in case of automatic reconfiguration.
The SGM memory is powered in hot redundancy as part of TTR board.
The SGM will be written and read via Internal Control Bus.

Design and Performance.

The capacity of each SGM is 512 Kbytes. It includes EDAC protection. The memory consists of two areas, one accessible for writing new data and the other, protected, save last written complete context.

9.7.4.1.6 Command Pulse Distribution Unit

Functional description.

The CPDU can receive CPDU packets from three sources:

- the TC Decoder
- the Processor Modules (generated by the On-Board Software).via the Serial Link with the lowest priority
- the Reconfiguration Module with the highest priority.

The CPDU, after validation, executes packets forming a sequence of one or more HP On/Off commands

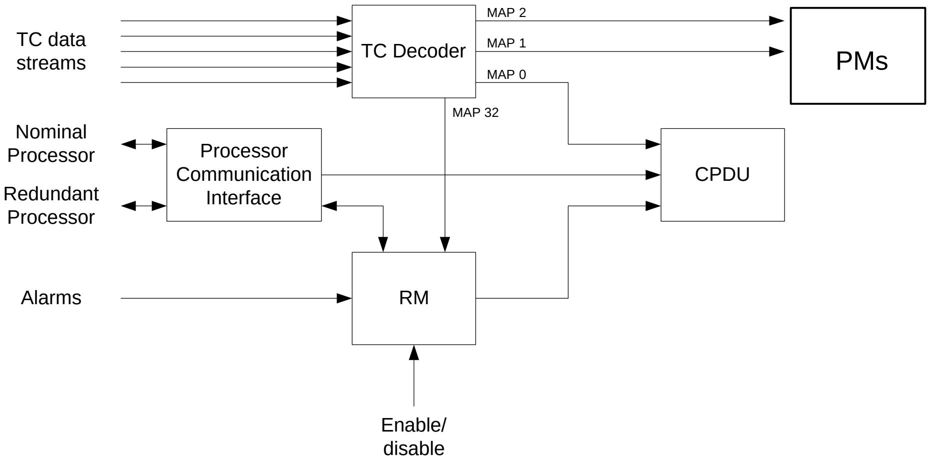


Figure 9.7.4-5 Handling of commands by the Decoder, RM and Processor

Arbitration and priority between these sources is handled by an input selector

The CPDU has a capability to block some outputs from being used by packets from the processor.
The CPDU packets from RM and Processor can be temporarily inhibited but allowing CPDU packets from TC Decoder to be still received.
The CPDU implements a direct telecommand capability by processing one or more CPDU commands present in the CPDU packets stored in the external RAM. Since these commands are critical, the packet is first verified to be clean and legal before being executed. The CPDU packet parameters are read from the external ROM.

The duration of the pulse is specified as part of each CPDU command. The interpulse gap is set up by a parameter in the mission PROM.
The following 32 internal CPDU commands are generated:

CPDU commands
1. PM A on
2. PM A active
3. PM A off
4. PM B on
5. PM B active
6. PM B off
7. Watchdog enable
8. Watchdog disable
9. Set PM A/B status bit 1
10. Reset PM A/B status bit 1
11. Set PM A/B status bit 2
12. Reset PM A/B status bit 2
13. Set PM A/B status bit 3
14. Reset PM A/B status bit 3
15. Reset PM A processor
16. Reset PM B processor
17. RM A enable
18. RM A disable
19. RM B enable
20. RM B disable
21. Select TM Encoder1 and ObtClk 1 for Processor OBT sync
22. Select TM Encoder 2 and ObtClk 2 for Processor OBT sync
23. AU enable
24. AU disable
25. MM A on
26. MM A off
27. MM A reset
28. MM B on
29. MM B off
30. MM B reset
31. PcHot A Reset (from TTR B)
32. PcHot B Reset (from TTR A)

The allocation of External HP Commands is given in TM/TC Budget (RD-68).

Design and performance.

A total of 72 (40 external, 32 internal) High Priority Commands and Extended High Priority Commands are provided by each TTR Board.
The outputs are driven by OCD (Output Command Driver) ASICs. Each OCD will drive eight outputs. The group switch, which also performs the pulse shaping, is shared between 4 OCDs, i.e 32 commands.

9.7.4.1.7 Communication with the Processor Modules

The hot redundant TTR boards communicate with the two cold redundant Processor Modules, when active, using:

One Internal Control Bus, the protocol and timing of which is compliant with MIL-STD-1553B.

Two SpaceWire links to transfer telemetry from the two PMs. One SpaceWire handles VC0 and VC1 from one PM.

Two PacketWire links to transfer the TC Segments on MAP1 to the two PMs.

There is also a number of discrete signals:
- PM Interrupt (from TTR to PM)
- OBT Clock Synchronisation Signal (from TTR OBT to PM OBT)
- OBT Clock Temperature compensated frequency (from TTR OBT to PM OBT)
- PM Alarms to the RM (from PM to TTR)
- PM Watchdog to the RM (from PM to TTR).

9.7.4.1.8 Communication with the Mass Memory

Each TTR board receives TM Source Packets from the Mass Memory over four discrete Packet Wire serial links, two from each MM board (VC2 and VC3).

9.7.4.2 Processor Module

Functional description.
The function of the Processor Module is mainly:

- to acquire messages, commands and provide responses via the Platform Interface bus
- to perform overall commanding, housekeeping collection and monitoring
- controlling the Mass Memory.

The main blocks of the Processor Board are:

- ERC32SC Processor
- COCOS ASIC
- Memories (Boot Prom, EEPROM, RAM, Mezzanine board)
- Oscillator
- Interfaces (MIL-STD-1553B, UART serial link, OBDH Data bus, Packet wire, Space wire, Parallel port, Configuration relays, Interrupts)
- Test Interfaces.

The PM initialisation starts when, in addition to the presence of LCL power from the cold converter, the PM latching relay is ON (INIT mode). After that the BSW and ASW initialisation follows to reach at the last, when they are fully operating, the NOMINAL OPERATION mode or the STANDBY OPERATION mode depending on the selected PM module.

The two CDMU Processor Modules operate in cold redundancy.

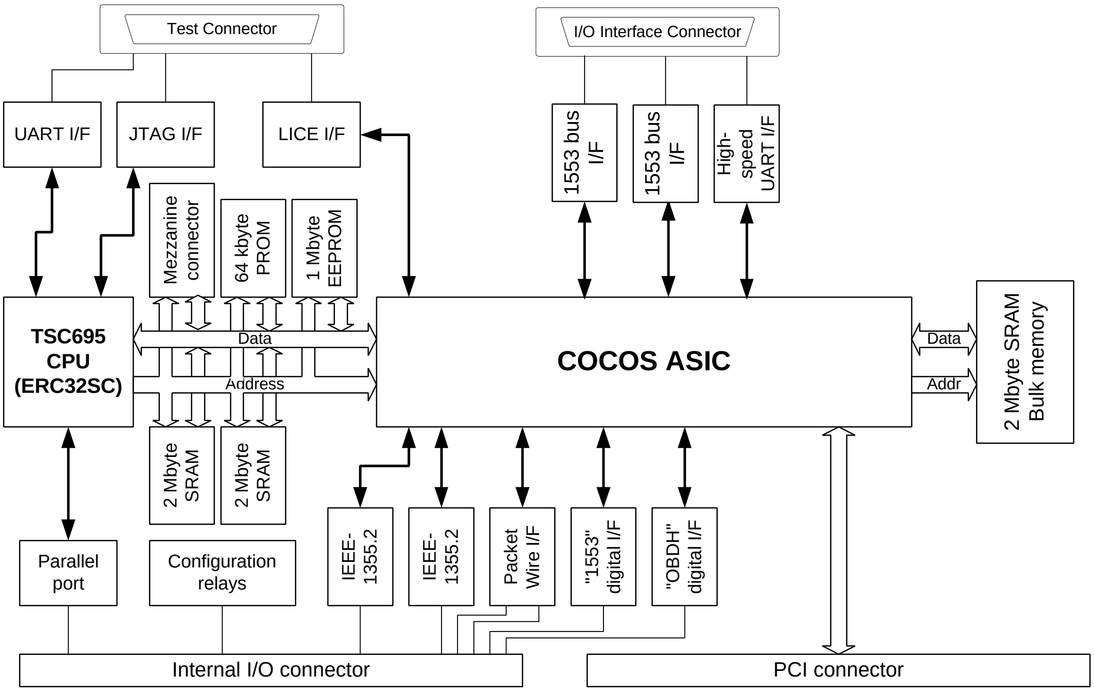


Figure 9.7.4-6 Reconfiguration Function

9.7.4.2.1 Processor

Design and performance.
The Processor Board will include the ERC 32SC radiation hardened single chip microprocessor (TSC695F).
It gives 14 MIPS with a clock frequency of 20MHz and will operate at 5V.

The processor TSC695F includes EDAC. It uses a seven Hamming code, which detects double bit errors and corrects all single bit errors on the 40-bit data bus (including EDAC bit and parity). The processor can be programmed to use the parity different modes and EDAC protection towards memory and to use the parity different modes towards I/O. The EDAC does not write back automatically to memory when a correctable error occurs, but an interruption is generated and the correction in memory is done by the Basic S/W. Also the scrubbing is under the Basic S/W control.

9.7.4.2.2 COCOS ASIC.

Design and performance.
It is developed by SE and implements the following functions:

- One processor interface towards ERC32SC.
- Two external High-speed UART interfaces.
- One motherboard PCI interface (Not used in Herschel/Planck).
- Alarm signal generator (connects to the RMs on the TTR boards).
- Watchdog.
- Two motherboard PacketWire transmit interface (The VC0 and VC1).
- Two external MIL-STD-1553 interfaces (Only one used in the CDMU).
- One motherboard MIL-STD-1553 interface (The ICB)
- One motherboard OBDH interface (Connected to a SBCH board for I/O system control).
- On-board time (Operating as slave to the OBTs on the TTR board).
- Interrupt controller.
- Two external and two motherboard SpaceWire interfaces (IEEE 1355).
- One TAP controller (IEEE-1149.1 JTAG).
- One external LICE interface.
- EDAC

The COCOS ASIC will run on the system clock provided by the ERC32SC and at the voltage of 3.3 V. The high level output is CMOS 3.3 V and the inputs are TTL compatible and tolerant to 5 V on the inputs.
The EDAC function is as described for the processor, but with a scrubbing function which checks periodically the memory and with a programmable rate.

9.7.4.2.3 Memories

Design and performance.
For booting of the processor, using 64Kbyte CMOS PROM is foreseen. Using a Boot PROM ensures a safe start up since the PROM is SEU and latch up free.

For storage of the application S/W, EEPROMs have been selected. 1Mbyte of memory is considered. The use of EEPROMs makes it possible to easily reprogram the PM during on-ground operations without the need to open the box. The EEPROM is radiation hardened and has not SEU problems in read mode.

The RAM devices foreseen for the baseline are 4 Mbytes. The RAM memory will be protected by the EDAC available in the ERC32SC, thus minimising the impact of Single Event Upsets, but it can be accessed by the COCOS. There is also a 2Mbytes RAM for the COCOS allowing DMA transfer to operate without affecting CPU operation.

The Mezzanine Board is provided to extend memory or change memory type.

9.7.4.2.4 Interfaces

Design and performance.
The PM provides communication with Science Instruments on a **MIL-STD-1553B data bus**. The data rate will be up 490kbps.Three dual redundant MIL-STD-1553B are implemented on each PM. Two of them are available on external connector (only one used on CDMU). One is used for internal control bus.
The interface can be configured as Bus Controller, Remote Terminal or Bus Monitor.

The PM board includes an **OBDH data bus**, used as link to the RCF part of the SBCH board, which controls the I/O system. An OBDH module is used to transmit and receive data over the OBDH data bus.
The I/O interface consists of two Litton-coded serial buses - the interrogation bus driven by the Central Terminal and the response bus on which Remote Terminals respond. The nominal bus frequency is 524288 Hz. The data to be sent is written to memory by the CPU and the OBDH module then reads the memory block via DMA and transmits the data on the bus. Data that is received from the bus is written to a memory area via DMA.

The **PacketWire** receive interfaces are used to receive telecommand packets from the TC Decoders. Two interfaces are connected over the backplane so that PM can receive from any of the two TTR boards.

Four IEEE 1355 interfaces (**SpaceWire)** for internal connections are implemented on the PM board. Two links are connected to the Mass Memory boards handling data transfers. The two other links are used to transfer PM generated TM data to the TM Encoders on the TTR board (VC0 and VC1). The link is full duplex.
A SpaceWire module is used to transmit and receive packets over either a nominal SpaceWire link A or a redundant link B. The packet(s) to be sent are written to the memory by the CPU and the SpaceWire module then reads the memory blocks via DMA and transmits the data on the link.

The PM board includes an 8-bit wide **Parallel Port** towards the motherboard. Every bit is configurable as in- or output individually. The control of the parallel port is handled from the General Purpose Port on ERC32SC.

The PM board implements three **Relays** used as configuration bits that can be configured from another module inside the equipment. The status from two of the relays is readable from the General Purpose Port. The third is used to disable the watchdog in the COCOS ASIC. The relay statuses are controlled by internal HP commands from the TTR board.

The PM board provides seven **Input Interrupts** from the backplane.

9.7.4.2.5 Test Interface

Design and performance.
A test interface is provided on the Processor Board allowing communication for the S/W monitor. The test interface uses two UARTs connected with ERC32 on-chip serial links RS-422. The baud rate for this interface is up 38400baud.
In addition a high-speed interface for the quick software loading uses two of the UARTs in the COCOS ASIC, which is conform to 38Kbps.

The ERC32 has a IEEE-1149.1 Standard (**JTAG)** Test Access Port (TAP), which may be used during CDMS testing and SW debugging in complement to the UART serial link. It is possible to control CPU.

9.7.4.2.6 Oscillators.

Design and performance.
The OBT on the PM board is synchronised to the OBT Master in TTR.
The ERC32SC and the COCOS ASIC operate using a 40MHz oscillator. The MIL-STD-1553B bus and the OBDH bus operate using a 16MHz oscillator.

9.7.4.2.7 Power Board Interface (Supply Voltages)

Design and performance.
The baseline design of the Processor Board uses 5 V and 3.3 V.

9.7.4.3 Mass Memory

Functional description.

The Mass Memory system of the CDMU consists of two redundant Mass Memory modules operating in hot redundancy, powered from the hot power supply but individually on/off switchable. Each memory is cross-coupled to both the PM and TTR boards.

The MM initialization starts when, in addition to the presence of FCL power from the hot converter, the MM latching relay is ON (INIT mode). After that the MM is operating under control from the PM (NOMINAL mode).
The Mass Memory stores TM data and housekeeping.

The Mass Memory Board is constituted by the following key blocks:
- COCOS ASIC
- FPGA
- SDRAM
- Interfaces

Each Mass Memory board interfaces with the two Processor Modules and the two telemetry encoder on the TTR Boards. The Control of memory is performed by means the CDMU internal digital 1553 bus, under the PM Bus controller. Data from the PM is received via two internal SpaceWire links while telemetry data to the TTR boards is transmitted using two Packet Wire buses which handle the VC2, VC3 virtual channels..

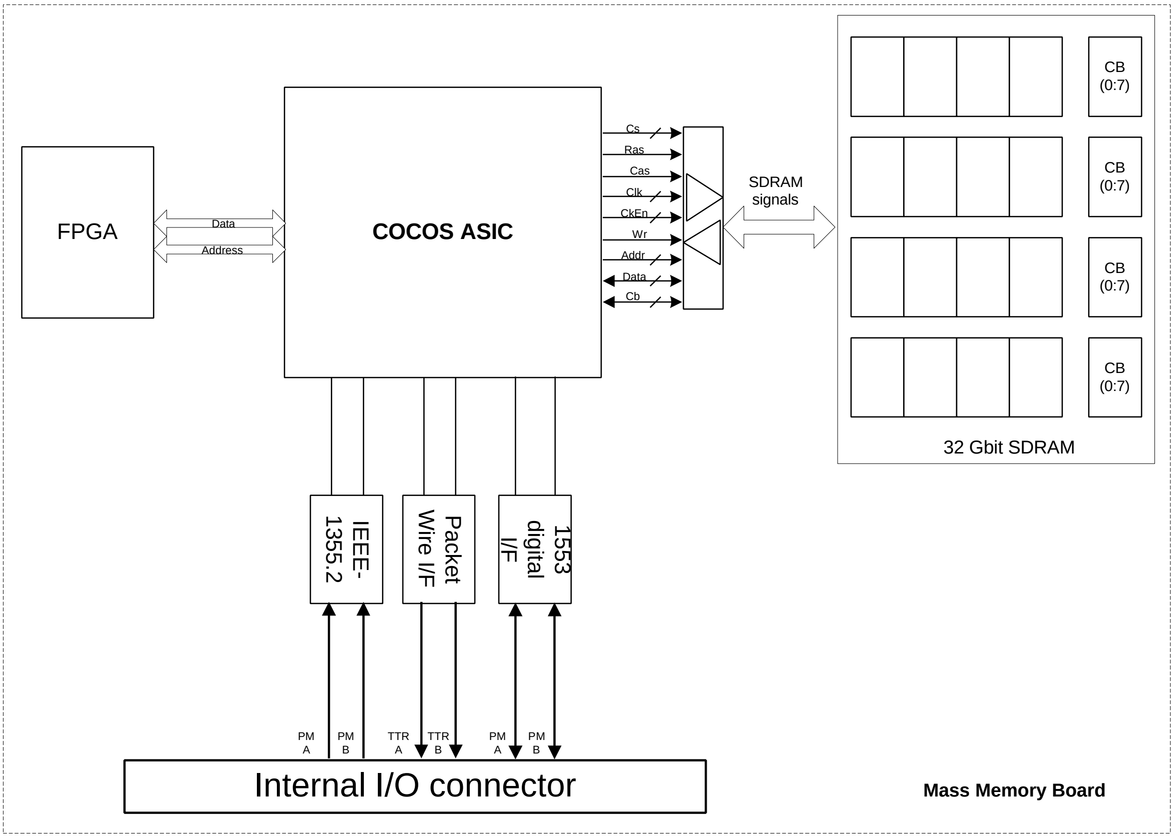


Figure 9.7.4-TBD Mass Memory Board block diagram

The COCOS ASIC handles the interface towards the memory including functions such as refreshing, scrubbing and Reed-Solomon encoding. The ASIC also supports all the internal buses, SpaceWire, Packet Wire and digital 1553 configured as remote terminal. The memory controllers are realised in hardware.

The FPGA acts as a support for the COCOS ASIC, containing functions not supported by the ASIC or functions that requires faster interaction than what can be provided by the processor. The FPGA also helps to minimise the software load on the processor.

Design and performance.

The proposed Mass Memory Board provides 32 Gbit (34.36 $*10^9$ bits) storage using SDRAM memory cube devices where each device consists of 8 stacked 256 Mbit memory chips giving a 2 Gbit device. Twenty of these devices will make a 32 Gbit memory area, including checkbits, in 4 sections with 8 Gbit in each section. One of these sections is treated as redundant and can replace any of the other section. Calculating a loss of one section during mission leads to a memory capacity of 24 Gbit (25.77 $*10^9$ bits) End-Of-Life.
It has simultaneous record and play capability of up to 1.5Mbit/s.

The Mass Memory board also contains logic for power-on-reset and a 3.3V to 2.5V converter to support the FPGA core.

9.7.4.4 I/O System

Functional description.

The I/O system consists of two redundant Serial Bus Controller Board (SBCH), each split internally in two sections with different functions:

- the Remote Core Functions (RCF), interfacing with one PM through an internal OBDH bus and with three End Terminal Blocks (SIOH) via redundant crosscoupled SIUB busses. The two RCFs are powered in cold redundancy.

- the I/O boards provide standard I/O-functions to external and internal users. Internal signals are connected to the power converter boards, where telemetry signals are monitored for housekeeping. The capability is represented by 8 AN and 8 TH channels. The external signals include the synch pulse 131KHz signals. The I/O boards are forced in the ON mode as at least one of the cold converters are ON.

and three SIOH modules which implement the End Terminals blocks.

The SIOH modules are not redundant, implying that redundancy shall be made on channel allocation level. The allocation of the I/O channels on the I/O modules is made so that there will be 2 redundancy groups. One failure may cause loss of the interfaces connected to one of the groups.

The CDMU I/O interconnections are shown in Figure 9.7.4-6. The entire I/O system is controlled from the active Processor Module through its OBDH bus controller.
The I/O bus uses the ESA standard OBDH bus protocol.

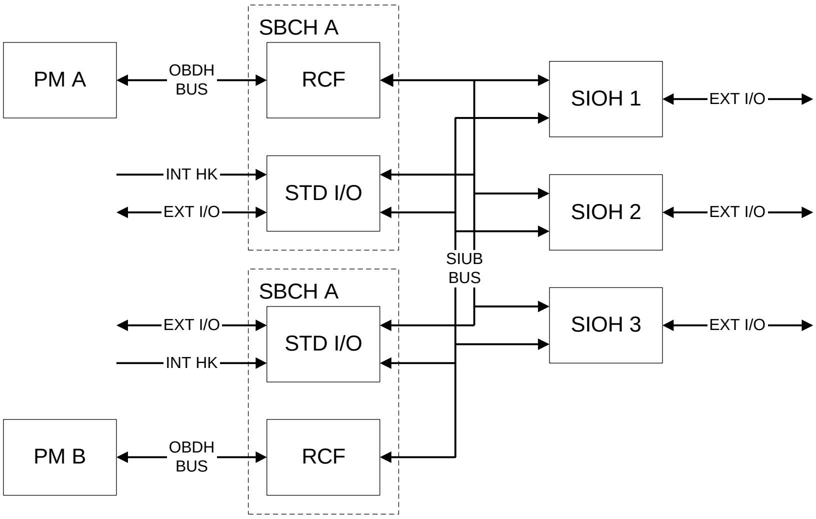


Figure 9.7.4-7 CDMU I/O Organisation

A basic set of standard I/O channels is included on the SBCH board. The remaining channels are partitioned on the three SIOH.

The SIOH external I/O channels capability is provided in the following table:

Interface	*Channels*
LLC	8
ML16	7
AN	48
CRYO TH	64
TH	192
DR	80
DB	40
SBDL (STATUS)	8
DS16	7
HL	80

Design and performance.

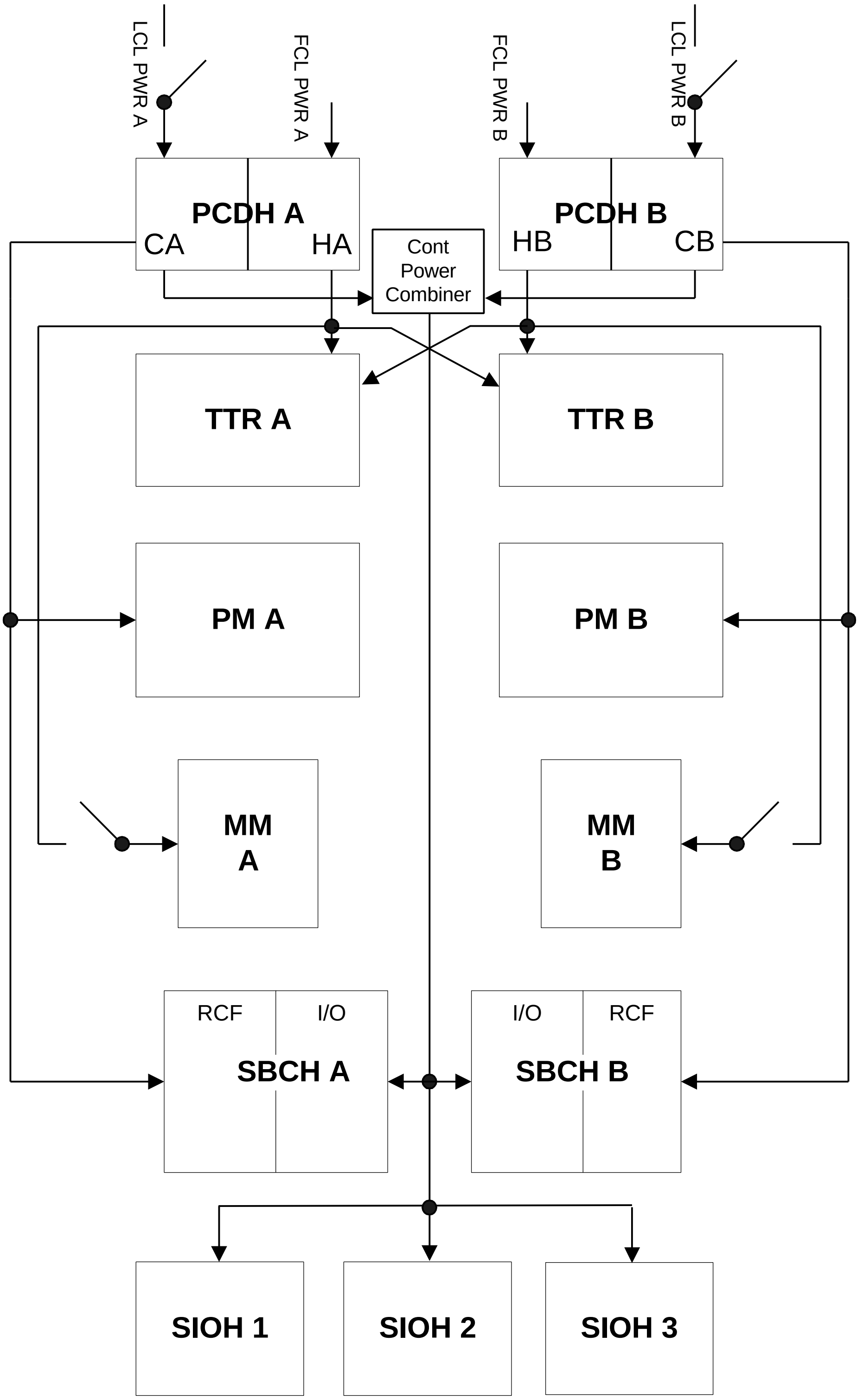
The main part of the RCF is implemented in an FPGA, but the RCF also controls a second level of multiplexers for analog signals and the relevant 12-bit A/D converter. All interfaces in the I/O system are based on the concept of using End Terminals based on the highly configurable MARS ASIC. Each MARS contains support for handling two I/O groups.
For the analog (AN) acquisition each group contains 16 channels selected by a first level of multiplexer.
For the Temperature monitor (TH) and Cryo temperature acquisition it is similar to AN with the addition of conditioning resistors connected to a reference voltage.
For the Digital Bi-level (DB) acquisitions the MARS acts as controller for a 16 channels analogue multiplexer connected to a comparator.
For the Digital Relay (DR) acquisitions the MARS is used in the same way as for the DB with the addition of conditioning resistors on the inputs connected to a reference voltage
For Status Lines acquisitions the MARS is used in the same way as for the DB with the addition of Standard Balanced Digital Link (SBDL) input receivers on the inputs.
For the ML commands and the DS acquisitions the MARS can be configured as a ML1DS1 controller, providing an I/O group with 1 ML and 1 DS channel. Only SBDL interface circuits have to be added.
For the High Level (HL) and Extended High Level (EHL) commands the MARS acts as controller for two OCD ASICs each being capable of driving 8 pulse outputs. The pulse length can be programmed.
The Lower Level Command (LLC) commands will be distributed using the MARS in the same configuration as used for HL/EHL. The difference is that the OCDs will be replaced with SBDL drivers.
The I/O channels including the two RCF blocks shall be implemented using 5 boards.

9.7.4.5 Power Converter and Cross-Coupling Board

Functional description.

The main function is to distribute Secondary Voltages to the internal CDMU modules.
The Power converters (PCDH) provide two section: hot and cold. The first one is automatically powered ON as soon as power is applied and the second one is ON/OFF switchable by means of PM HP TC commands received from RM. The hot and cold converter will share some design blocks (CM-filter, start-up supply etc.) in order to reduce the parts count. The power converter consists of the following blocks:

- the Hot converter which supplies two TTR Boards and one MM board.
- the Cold converter which supplies one PM board and one RCF as part of SBCH.
- the CONT voltages, generated by the two cold sections and which supply the end terminals of the I/O system. They are automatically configured ON as soon as at least one of the cold converters are switched ON.


LCL PWR A
FCL PWR A
FCL PWR B
LCL PWR B
PCDH A
CA
HA
Cont Power Combiner
PCDH B
HB
CB
TTR A
TTR B
PM A
PM B
MM A
MM B
RCF
I/O
SBCH A
I/O
RCF
SBCH B
SIOH 1
SIOH 2
SIOH 3

Design and performance.

Each converter is supplied from a regulated power bus (26-30V).

The hot converter provides 4 output voltages: + 3 V, + 5 V, + 15 V and + 28 V.
The hot converter is based on an established current mode topology operating at fixed frequency, suitable for low power level.
The cold converter provides 5 output voltages: + 3 V, + 5 V, + 15 V, - 15 V and + 28 V.
The cold converter, which requires a considerably higher power capability, is based on a current fed dual switch topology.

A thermistor monitors the board temperature at the hot spot, other monitors are provided for the U/V detection and secondary voltages.

9.7.5 Commonality Assessment

The Control and Data Management function has been suitably dimensioned to be compatible with both Herschel and Planck satellites, thus providing a high level of commonality.

CDMU will be the same for the two satellites.

9.7.6 Budget Summary

The following budgets are foreseen for the CDMU. The same numbers are applicable to both Herschel and Planck design.

Mass Mass with 5 % contingency	16.0 kg 16.8 kg
Unit Dimensions (incl. mounting feet)	273 mm x 235 mm x 408 mm (ZxYxX)
Board size	233 x 160 mm 14 boards
Power Dissipation Nom average Peak	 33 W 44 W
Performance CPU performance RAM memory EPROM memory PROM memory Mass Memory Safeguard memory	 14.3 MIPS 6 Mbytes 1 Mbytes 64 Kbytes 2 x 32Gbit BOL; 25 Gbit EOL 2 x 512 Kbytes

Table 9.7.6-1 CDMU Budget Summary

CDMU External Channels budget :

High Prior. Cmds	Ext. High Prior. Cmds	High Level Cmds	Low Level Cmds	Memory Load 16	An	Therm	Cryo sens	Digital Relay Status	Digital Bi-level	SBDL Status Lines	DS16	RM Alert Inputs	UART high speed	UART RS422	SBDL EGSE TM	SBDL EGSE TC	SBDL TC	SBDL RX lock status	1553B dual rdt	TBD (OBT test)	LICE I/F	131 kHz LOBT Sync
56	**24**	**80**	**8**	**7**	**48**	**192**	**64**	**80**	**40**	**8**	**7**	**16**	**4**	**4**	**2**	**2**	**4**	**4**	**2**	**3**	**2**	**8**

Table 9.7.6-2 CDMU I/O Budget Summary

9.8 RF

9.8.1 General

In this chapter, the Tracking, Telemetry and Command function is described. Its main scope is the RF communication up and downlink between the spacecraft and the 2 ground stations baselined for Herschel and Planck missions, New Norcia and Kourou.

9.8.2 Requirements and Design Drivers

This paragraph presents an overview of the major requirements derived from the SVM Specification, driving the TT&C, providing consideration and discussion on their indented implementation.
Herschel and Planck missions are essentially characterized by the following features:

- Both use X-Band for Up and Downlinks. Frequency allocations however are specific for each spacecraft.The Earth to spacecraft distances during operation are very comparable for both spacecraft.
- The spacecraft to Earth aspects angles from telecommunication point of view are similar for both spacecraft:
  - ❑ +/-15° maximum for Planck with New Norcia G/S and +/-10° in case of Kourou G/S,
  - ❑ +/-10° maximum for Herschel with both New Norcia and Kourou G/S.
- the uplink and downlink data rates requirements are the same for the 2 spacecrafts.

Which calls for an obvious hardware commonality between Herschel and Planck TTC subsystems.

9.8.2.1 General Requirements

TEF-005-C
The TT&C Subsystem shall be able to receive and demodulate telecommands, modulate and transmit the telemetry, and transpond the ranging signal, simultaneously. < SMTT-05>

TEF-010-C
The SVM shall have no requirements for telecommand and telemetry operation during the launch phase via its RF links. <SMTT-025>

TEF-015-C
The TT&C Subsystem shall support the following modes for the uplink:
- Carrier only
- Telecommand
- Ranging
- Simultaneous Telecommand and Ranging. <SMTT-030>

TEF-020-C The TT&C Subsystem shall support the following modes for the downlink:
- Carrier only
- Telemetry
- Ranging
- Simultaneous Telemetry and Ranging
- Doppler (to allow Doppler measurement by the ground) <SMTT-035>

TEF-025-C
The TT&C subsystem shall accept uplink signals and provide a demodulated digital telecommand signal to the CDMS for further processing. This function shall always be enabled without any possibility of switching it off. <SMTT-040>

TEF-030-C
The TT&C subsystem shall accept a digital telemetry signal from the CDMS and modulate it onto a downlink carrier. It shall be possible to disable this function. <SMTT-045>

TEF-035-C
The TT&C subsystem shall provide a range and/or range rate measurement capability. For ranging, it shall be capable to demodulate ranging tone from the uplink carrier and modulate the downlink carrier with this tone. <SMTT-050>

TEF-080-C
The receiver shall provide a status signal indicating the presence of an uplink signal. <SMTT-095>

TEF-085-C
Limited housekeeping data will be routinely delivered to the LGA's for transmission upon ground request. <SMTT-100>

TEF-095-C
The subsystem design shall ensure that all its relevant operational parameters are acquired via suitable sensors and provided to the CDMS for incorporation into the HK telemetry. <SMTT-165>

TEF-100-C
The TT&C subsystem shall be designed such as to be launched power "ON"; however, the telemetry function shall be disabled during launch. <SMTT-170>

The XPND receivers are designed to be always “ON” and are connected to PCDU FCL lines while the EPC of the nominal TWTAs is foreseen to be launched “ON” in the preheating mode.

9.8.2.2 ANTENNA CONFIGURATION AND COVERAGE

TEF-060-C
The antenna configuration shall ensure sufficient coverage and up-and downlink rate capability for all mission phases. <SMTT-075>

TEF-070-C
Telecommands shall be via the LGA's and the MGA, and the subsystem shall provide the required telecommand capabilities at maximum distance from the Earth and in any S/C attitude. <SMTT-085>

TEF-090-C
A Medium-Gain Antenna (MGA) shall provide the primary communication for the downlink during the scientific operations phase and during the Commissioning and Performance Verification Phases. <SMTT-105>

The link coverage is ensured by LGA antennas independently from spacecraft attitude . A different configuration has been selected from HERSCHEL and PLANCK; in particular, an additional Antenna is considered necessary for Planck in order to avoid utilization of experiment “cold” area where measurement interferences can be generated.

9.8.2.3 REDUNDANCY AND RF SWITCHING

TEF-040-C
Hot redundancy shall be provided for the receive function and cold redundancy for the transmit function. <SMTT-055>

TEF-045-C
The receiver outputs shall be cross-coupled with the inputs of the CDMS command decoders. <SMTT-060>

TEF-050-C
The configuration shall be such that both receivers can receive and both decoders can decode simultaneously. <SMTT-065>

TEF-055-C
The transmitters shall be able to receive the telemetry stream from both parts of the redundant CDMS. <SMTT-070>

TEF-065-C
When switching between antennas it shall not be necessary to switch off the transmitter. <SMTT-080>

TEP-060-C
The TT&C subsystem shall not have any single point failure except for the radiating elements of the antennas and their associated cabling. It shall have the capability of recovering from a failure autonomously. In all cases, it shall be possible to override the autonomous recovery action by use of ground commands. <SMTT-160>

TEP-065-C
The radio frequency switching between antenna and transponders shall be done without single point failure. <SMTT-175>

The requirements for full redundancy and 0-SPF are implemented throughout all the TT&C Architecture where HW redundancies of Units and relevant interconnections allow parallel commanding paths through CDMS Decoder High Priority TC and RTU TC).
In addition, the use of on-board SW automated procedure (Time-Tag TC activated) is foreseen to activate the RF Switches in case of intermediate neutral positioning.

9.8.2.4 HERSCHEL/Planck COMMONALITY

GEF-025-C The components and interfaces of the both SVM shall be optimised as much as possible. <SGEN-005>

TEP-005-C
The uplink/downlink signals shall be in the range 7190-7235 MHz for telecommands and 8450-8500 MHz for telemetry. <SMTT-110>

[S/G-ICD - 2.1.1]
The satellite telecommunication subsystem will be allocated for a Category A (non Deep Space) Mission with a down link frequency in the 8450 – 8500 MHz frequency band (X-band) as follows:

- **Herschel**
  - ☐ 8468.5 MHz (TBC) Emission bandwidth: 7 MHz
- **Planck**
  - ☐ 8455.0 MHz (TBC) Emission bandwidth: 7 MHz

[S/G-ICD - 2.2.1] The satellite telecommunication subsystem will be allocated for a Category A (non Deep Space) mission with an uplink frequency in the 7190 - 7235 MHz frequency band (X-Band) as follows:

- **Herschel**
  - ☐ 7207.8483 MHz (TBC) Emission bandwidth: 3 MHz
- **Planck**
  - ☐ 7196.3580 MHz (TBC) Emission bandwidth: 3 MHz

Commonality between Herschel and Planck has been implemented to the maximum extent, taking into consideration the envelope of the requirements. In particular, as far as the TT&C is concerned, the following three aspects are worth to be mentioned:

<u>LGA antenna configuration</u> (2 on Herschel, 3 on Planck): the RFDN is designed to support connection of up to three LGA’s.

<u>Uplink/downlink frequencies:</u> all equipments are designed to cover both Tx and Rx frequencies and the transponders are designed to be adapted to both frequencies.

9.8.2.5 LINK BUDGETS AND DATA RATE

TEP-015-C
The link budget margins shall be computed under the following assumptions :

- Telemetry : Telemetry bit error rate associated with 99.999% of transfer frame delivery corresponding to Eb/No = 2.7 dB theoretical for ESA standard concatenated FEC coding (AD2-4).
- Telecommand : a) Under all conditions specified by the mission Telecommand Bit Error Rate of 10 -5 corresponding to Eb/No = 9.6 dB (theoretical), b) Under "no signal" conditions, the mean rate of spurious command generation must be less than one per two years.
- Ranging: to be commensurate with Herschel and Planck navigation requirements for range bias and range noise (TBD). range bias : 1 meter range noise : 1 sigma random error of 2 meters. <SMTT-120>

TEP-020-C
Link budgets for all mission phases shall be computed as defined in ESA PSS-04-105, RF and Modulation Standard (AD2-6). <SMTT-125>

TEP-025-C
The minimum values of those margins shall be :

- nominal margin : 3dB
- RSS worst case margin : 0dB
- mean - 3 sigma margin : 0dB

The applicable ground station characteristics are defined in the Space to Ground Interface Specification (AD1-7). The link budget calculation shall include in addition to TM and TC budget calculation: carrier acquisition, tone recovery, data recovery and minimum S/N for ranging. <SMTT-130>

TEP-030-C
The probability of frame loss on the downlink shall be < 10 E-5. <SMTT-135>

TEP-035-C
The LGA's shall support an uplink high command rate of 4Kbps using the 35 m station at Perth / New Norcia and a low command data rate of 125 bps (TBC) using the 15 m station at Kourou up to a distance from the Earth of 1.8 x 10^6 km for Herschel and 1.6 x 10^6 km for Planck. <SMTT-140>

TEP-040-C
The MGA shall support an uplink command rate of 4 kbps for both Perth / New Norcia and Kourou stations, up to a distance from the Earth of 1.8 x 10^6 km for Herschel and of 1.6 x 10^6km for Planck. <SMTT-142>

TEP-045-C
The LGA's shall support the downlink of real time housekeeping data (spacecraft and payload) telemetry using the 35 m station at Perth / New Norcia and 500 bps (TBC) using 15 m station at Kourou up to a distance from the Earth of 1.8 x 10^6 km for Herschel and 1.6 x 10^6 km for Planck. <SMTT-145>

TEP-050-C
The omni-directional coverage of the LGA's shall overlap to the extend necessary to ensure that the antenna switching is never time-critical. <SMTT-150>

TEP-055-C
The MGA shall allow for the telemetry downlink with the Perth / New Norcia 35 m station and with the 15 m station at Kourou up to a distance from the Earth of 1.8 x 10^6 km for Herschel and 1.6 x 10^6 km during the telecommunication period at 10° elevation. <SMTT-155>

ESA recommended margins are satisfied both for the Up and Downlink, except for minor deviation, only for the Planck Satellite (Kourou GS), in case of simultaneous use of the 2 redundant Antennae at the distance of 1.6 10^6 Km.

9.8.2.6 MODULATION SCHEMES

[S/G-ICD-2.1.4]
The telemetry modulation scheme is a function of the bit rates to be transmitted as follows

Rate	**Information rate**	**Modulation scheme**	**Subcarrier frequency**
Low	500 bps	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine)
Low	5 kbps	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine)
Medium	150 kbps	PCM(SP-L)/PM	Not applicable
High	1.5 Mbps	GMSK	Not applicable

[S/G-ICD-2.2.4]
For telecommand rates below or equal to 4 kbps the telecommand modulation scheme is PCM(NRZ-L)/PSK/PM on a sinusoidal subcarrier. The selected subcarrier frequency is 16 kHz.

Rate	**Modulation scheme**	**Subcarrier frequency**
125 bps	PCM(NRZ-L)/PSK/PM	16 kHz (sine)
4 kbps	PCM(NRZ-L)/PSK/PM	16 kHz (sine)

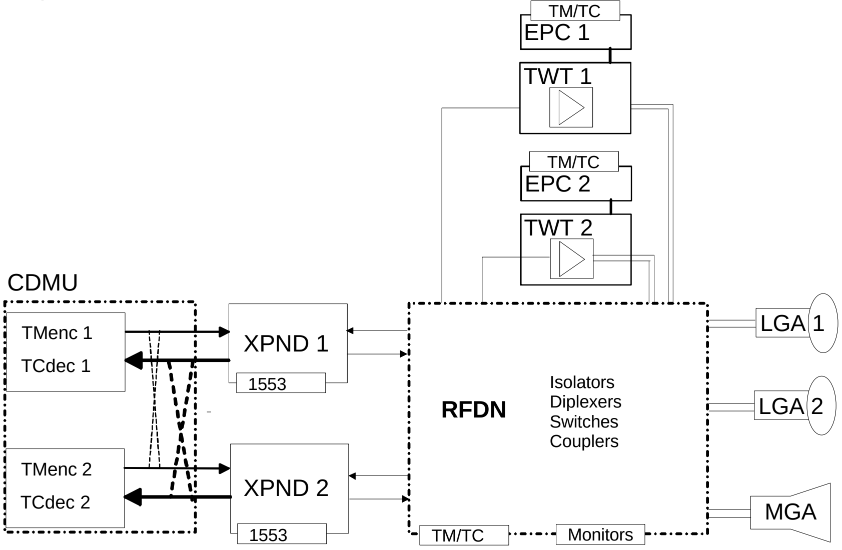
The ranging signal directly phase modulates (PM) the uplink carrier. For simultaneous ranging and telecommand, the two signals are added prior to phase modulation of the uplink carrier.
The telecommand bit rates refer to the digital bit stream at the physical layer, consisting of CLTUs and Idle/Acquisition sequences.

As far as the Ranging Tone concern, according to ESA clarification, it shall be placed on the range 600 – 700 kHz.
The driving modulation scheme for the selection is the MBR with SPL modulation because of possible interference with TM at 150 kbps.
MPTS tone should in fact be placed in the neighborhood of a TM spectrum nulls (2*n*fs’), TM where spectral density is lower, but not exactly in a null because the XPND filtering present a clock residue just on top of it.
Available null is a 688.260 kHz so, a possible selection is 688.250 kHz (TBC)

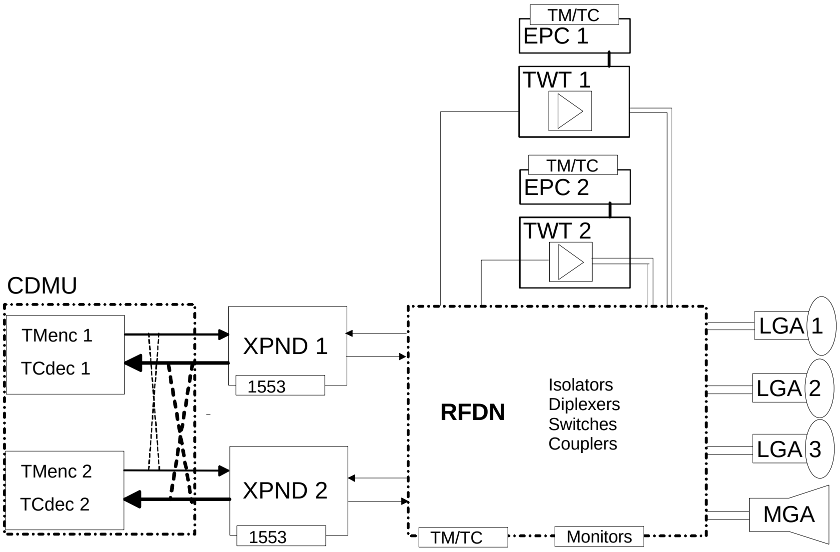
9.8.3 Functional Description

The TT&C function addresses the RF communication up and downlink between the spacecraft and the 2 ground stations baselined for HERSCHEL and Planck missions: New Norcia (Perth) and Kourou.

The H/P TT&C design is based on the maximum commonality between HERSCHEL and Planck TTC subsystems as presented in the diagrams below:



HERSCHEL TT&C Subsystem redundancy concept



PLANCK TT&C Subsystem redundancy concept

The TTC function thus comprises:

Two Telemetry Encoders/Decoders allocated in the CDMU operated in hot redundancy for the receiving part and cold redundancy for the Tx one.
In particular the TM encoders on the CDMU TTR boards are in charge of the TM stream generation and the Reed-Solomon and Convolutional Coding.
They can generate the required TM data rates and provide the Transmitted Symbol Rate to the XPND TM interface according to the table below:

TM Rate	*Information Rate fb*	*Transmitted Symbol Rate fs'*
LOW-1	500.0065	***1147.1000***
LOW-2	**5000.0645**	***11471.0000***
MEDIUM	**150001.93511**	***344130.0000***
HIGH	**1500019.3511**	***3441300.0000***

At the same time they include two TC Decoders that receive the digital TC signal from XPNDs TC Demodulators, decode it and provide the Telecommands to the CDMU Processor Module and Command Pulse Distribution Unit (CPDU).
Two TC Rates are foreseen according to the requirements:

TC Rate	*TC Rate*	*TC SubCarrier*
LOW	125	***16 kHz***
HIGH	**4000**	***16 kHz***

Two X-Band Transponders (XPND) operated in hot redundancy for the receiving part and cold redundancy for the Tx one. They are identical for Herschel and Planck with the obvious exception of the carrier frequencies setting; especially, the down and uplink data rates Telecommand and Telemetry streams are made common between Herschel and Planck, for sake of highest commonality.
The Transmitting part accepts the Transmitted Symbol Rate from the CDMU TM Encoders and generates all the Modulations required according to the different data rates:

TM Rate	*Transmitted Symbol Rate fs'*	*Modulation scheme*	*Subcarrier frequency*
LOW-1	***1147.1000***	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine)
LOW-2	***11471.0000***	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine)
MEDIUM	***344130.0000***	PCM(SP-L)/PM	Not applicable
HIGH	***3441300.0000***	GMSK	Not applicable

Digital Shaping is used to implement GMSK and to limitate the RF signal occupied bandwidth for SP-L

Two cold redundant 32W TWTA used to guarantee the required downlink rates.

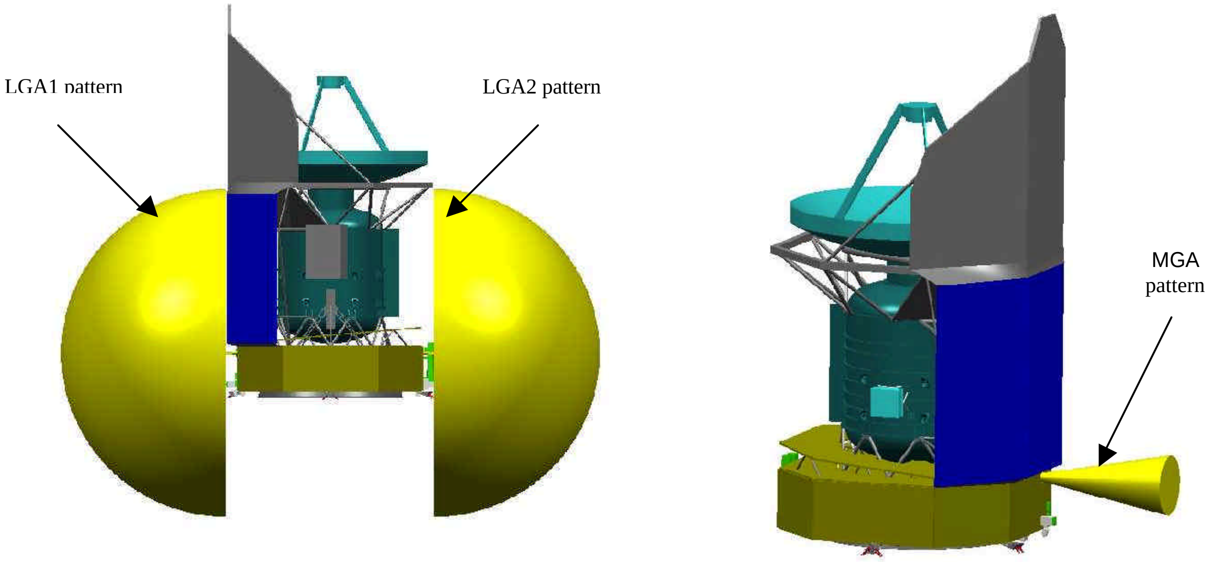
One X-Band Medium Gain Antenna, to perform the High and Medium data rate downlink during the planned telecommunication sessions. It can also be used for Telecommand Uplink.

Identical Dual band Rx/Tx Low Gain antennas, to perform the low rate downlink, mainly at start of the missions and in emergency cases, and to receive the telecommand uplink streams. They are accommodated in order to guarantee a quasi omnidirectional coverage in both TM and TC, thus making the spacecraft robust to the “attitude loss” failure mode. Specificities due to the different geometries, different attitude controls, and different Payload Module constraints, have led to use 2 LGAs for HERSCHEL, and 3 LGAs for Planck.

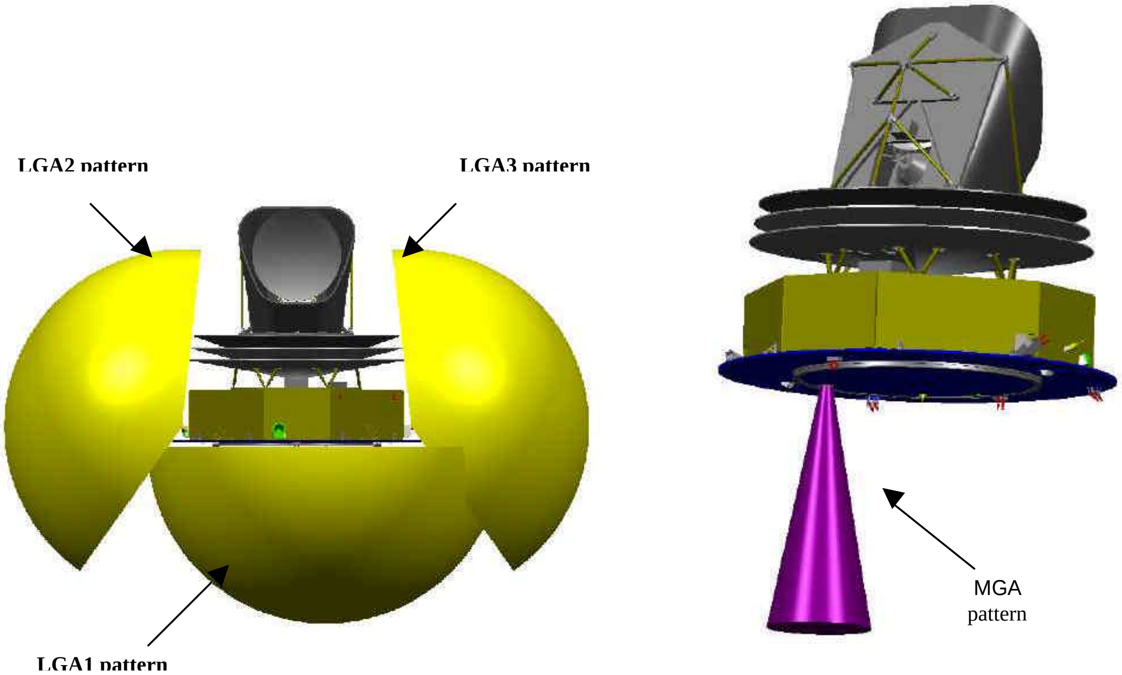
The TTC architecture also comprises the suitable set of diplexers, hybrids and switches integrated in the so-called RFDN, with optimized trade-off between passive losses and number of switch/Tc..

In the figures above the satellites models with the antennas position are presented in order to clarify the main differences between the two spacecrafts.

Herschel 2 LGAs and MGA accommodation and indicative radiation patterns



Planck 3 LGAs and MGA accommodation and indicative radiation patterns



9.8.4 Design and Performance

The TT&C architecture proposed for HERSCHEL and PLANCK is here below described.
As previously mentioned there is a common architecture between the two spacecraft. Both the spacecraft use the same transponders, TWTA, Low Gain Antennas and same Medium Gain Antenna.

In particular:

HERSCHEL configuration:

- Up and Down link via 2 LGAs (LGA 1 nominal, in the Earth direction and LGA 2 redundant, in the opposite direction)
- Up and Down link with MGA (in the Earth direction)

PLANCK configuration:

- Up and Down link via 3 LGAs (LGA 1 nominal, in the Earth direction and LGA 2 & 3 redundant and coupled in order to cover the opposite direction)
- Up and Down link with MGA (in the Earth direction)

The use of the LGA antennas assures an almost complete coverage independently on the spacecraft attitude and operational phases of the mission for Low data rates and emergency communication.

The RF output power from the transponder is raised through a TWTA up to 32 W. The output power from TWTA and the gain assured by the MGA are sufficient to transmit the high data rate required for the long range distance (1.8 Mkm for Herschel and 1.6 Mkm for Planck) in accordance with the ESA requirements.

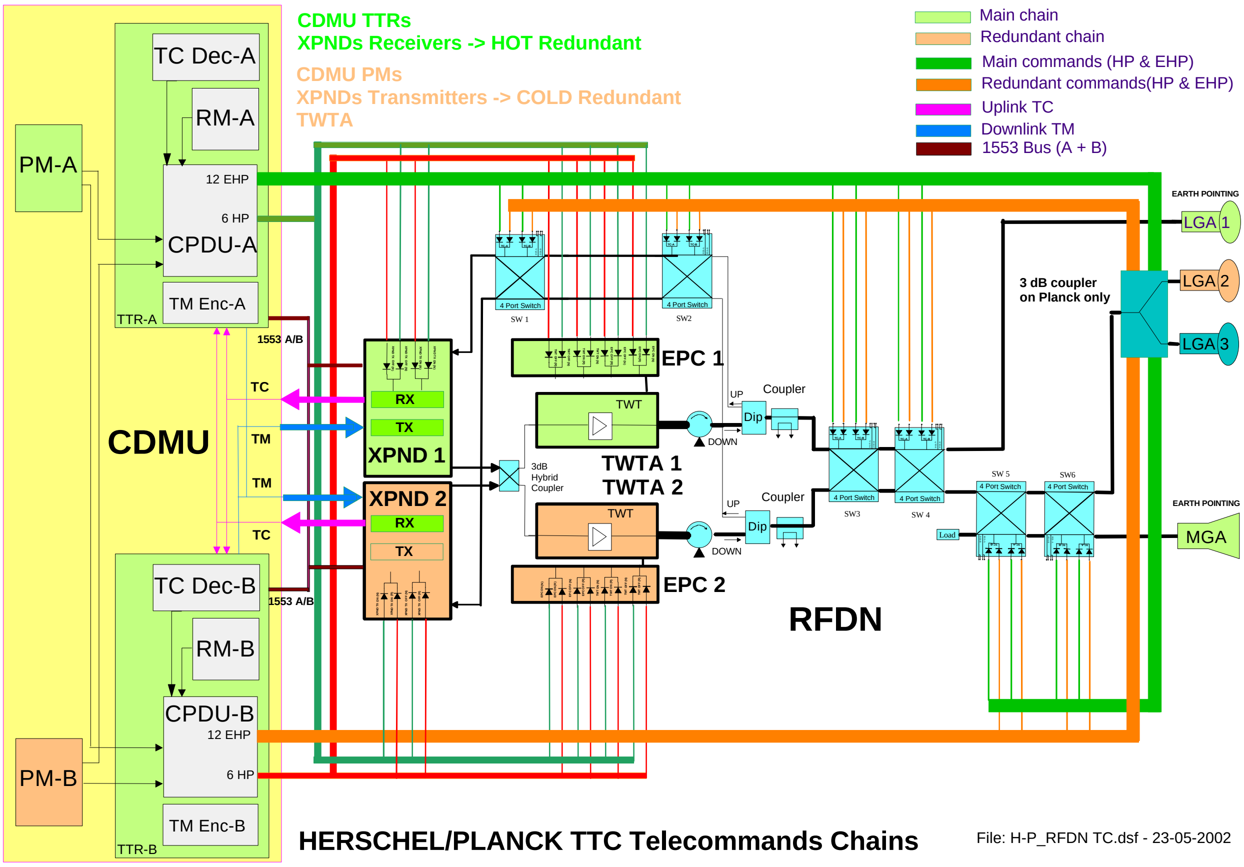
Particular efforts have been given on the RFDN design in order to respect the requirement of a single point failure free switching network. The use of waveguide technology is used the downlink path between the output of two TWTAs and the different antennas characterised by high RF power. The low power downlink distribution network between the Transponders TX outputs and the TWTAs inputs and the uplink path from will use coaxial technology (TBC).
The RFDN is equipped with a diplexers filter in charge to separate the uplink and downlink frequencies.
Directional couplers are connected after the diplexer to permit to measure the RF output transmitted to the antennas.
The RFDN has been designed to support both the Herschel and Planck configuration. The only difference is a coupler in the LGA2 path that permits to split this to the Planck LGA2 and LGA3.

All equipments have been designed to accept Telecommands from two independent sources in order to have a redundant chain of command. The TWTA and RFDN use discrete commands only (HP) while the Transponders used HP commands to switch ON/OFF the transmitters and Mil-1553 redundant bus for all other necessary commands.

As depicted in the picture below, the two CPDUs inside the CDMU TTR boards are used to generate the High Priority commands directed to XPNDs and TWTAs and the Extended High Priority commands directed to RFDN Switches.
One CPDU outputs are connected to the Nominal equipments commands and the other CPDU outputs are connected to the redundant ones.
Each CDPU can generate the HP commands under request from TC decoder, Reconfiguration Module and both Processor Modules.
With the configuration presented here commands coming from on-board SW (PM-A or PM-B) can be generated by both CPDUs (so SW can access to both Nominal and Redundant XPND, EPC (TWTAs) and RFDN command chains). At the same time, commands coming from Reconfiguration Modules and/or TC Decoders, can use the nominal command chain for TC Dec-A, RM-A and the redundant command chain for TC Dec-B, RM-B.

The Uplink TC and Downlink TM:
the XPND1 is connected to the CDMU TTR-A and XPND2 is connected to CDMU TTR-A. Cross strapping is inside the CDMU.

Power redundancy:
the TC receiving part is designed to be Hot Redundant (TC Decoders, CDPU, XPND-1 and XPND-2 Receivers) while the transmitting part (XPNDs Transmitters, TWTAs) is designed to be operated in Cold redundancy.



HERSCHEL/PLANCK TTC Telecommands Chains

File: H-P_RFDN TC.dsf - 23-05-2002

9.8.5 Equipment Design

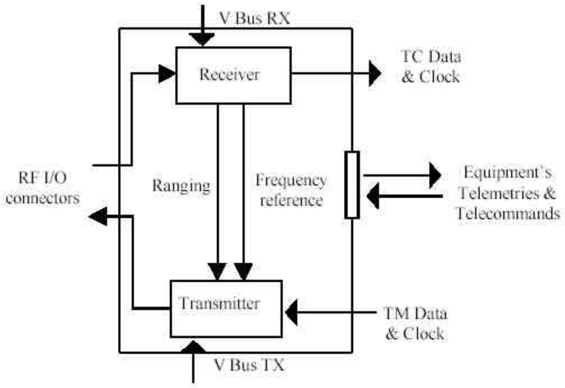
In the following pages the major equipment or components are described in detail.

9.8.5.1 Transponder (XPND)

The chosen Transponders are based on a digital architecture. In fact, the modern communication theory associated to digital signal processing has enabled the application of digital solutions instead of analog approach. In particular, the increasing of the maximum sampling rate achievable makes possible to move the boundary between analog and digital domain at higher frequency. This, in many cases, has allowed to increase performances reducing cost and maintenance requirements.

Two identical separate transponders are placed on each satellite, the main and the redundant.

The architecture of the transponder is depicted of the Figure below. The transponder is composed of two main blocks: The receiver and the transmitter.



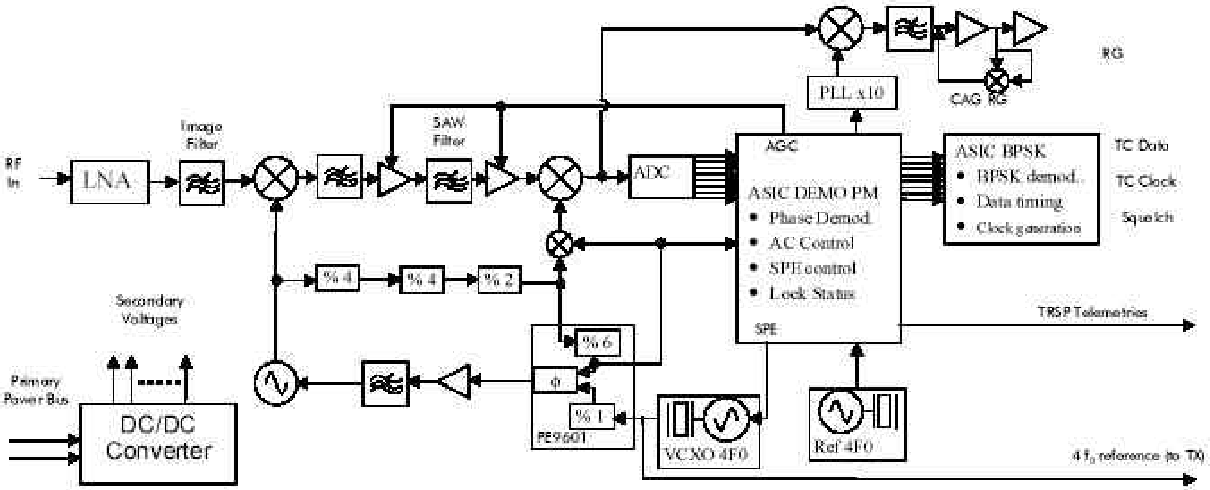
9.8.5.1.1 Receiver

The receiver performs the Low noise amplification, the double frequency conversion with a local oscillator phase locked to the received signal, the variable gain amplification to compensate the input level variations, the phase demodulation of the carrier and the BPSK demodulation of the TC subcarrier.

The receiver generates two signals that are delivered to the transmitter: The ranging baseband signal and a frequency reference coherent with the received uplink signal.

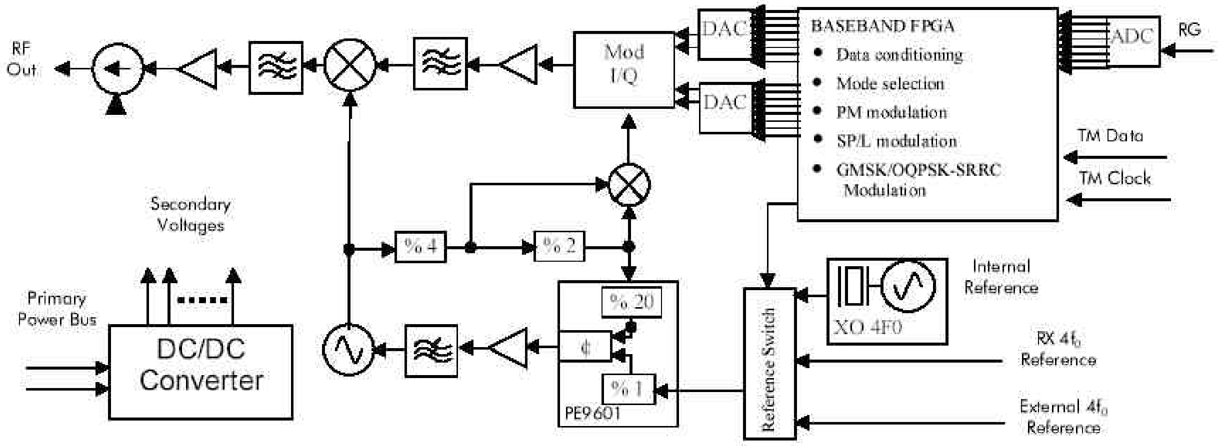
The transmitter will generate the downlink carrier coherent using the selected reference frequency depending on the selected mode (coherent with the receiver, not coherent or external reference). The downlink carrier is generated coherent with this frequency reference by means of a phase locked loop. This carrier will be modulated, filtered and amplified up to the required output level.

Three modulation formats are implemented depending on the TM stream data rate. For Low data rate, PCM/NRZ-L/BPSK/PM modulation is implemented. With this type of modulation, the Ranging signal is added to the TM subcarrier before the final phase modulation of the carrier. For medium data rates, SPL/ PM modulation is implemented. This modulation is also a phase modulation but it is not compatible with simultaneous Ranging. Finally for High data rate, GMSK is implemented by means of a digital pulse shaping and an I/Q linear modulator.



9.8.5.1.2 TRANSMITTER

The picture below shows a detailed block diagram of the transmitter. In this block diagram the different modules that generate and process the downlink signal can be appreciated.



A X band VCO has been selected due to its better performances in terms of phase noise compared with lower frequency oscillators multiplied to reach the desired output frequency. A phase locked loop is used to lock it to a reference signal that can be the reference delivered by the receiver (in this case the transponder will work in coherent mode allowing Doppler and Doppler rate measures), a transmitter internal reference or an external reference.

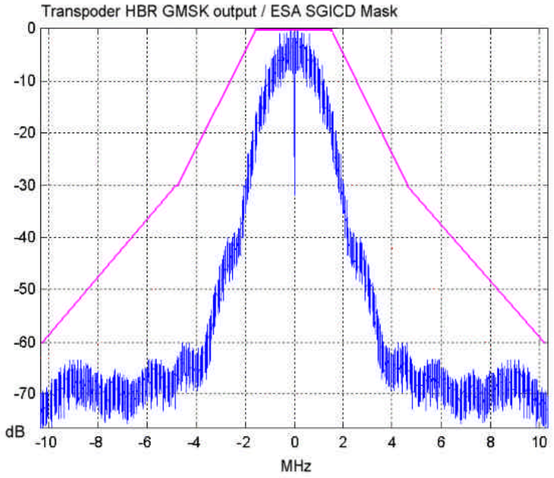
The processing of the baseband signals is made digitally. An FPGA contents the digital circuitry that processes the input TM data stream and generates two 8 bit signals I and Q, that, after being converted to analogue signals, will modulate the carrier in a I/Q modulator generating the PM or GMSK signal.

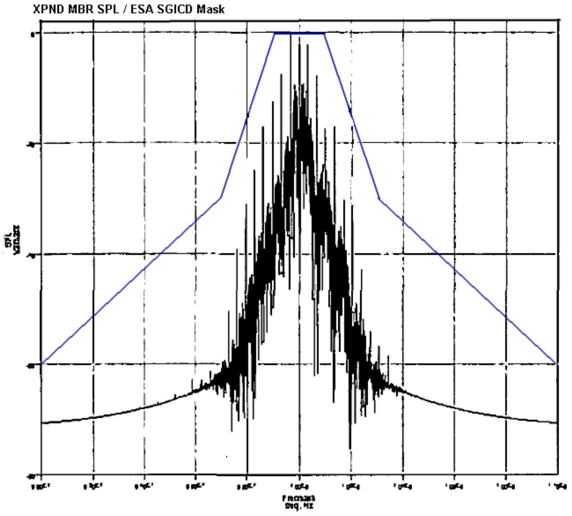
Finally the modulated IF signal is up-converted and filtered. The output amplifiers will be in charge of the signal buffering and amplitude control of the transmitter output signal.

A DC/DC converter will generate, from the primary bus voltage, the secondary voltages required by the rest of modules of the receiver. Independent DC/DC converters feed the receiver and the transmitter to increase the reliability of the equipment.

In order to comply with the Emission Masks requested in the Space to Ground ICD, the transponder will use GMSK for TM High Bit Rate and filtered SP-L for TM Medium Bit Rate.

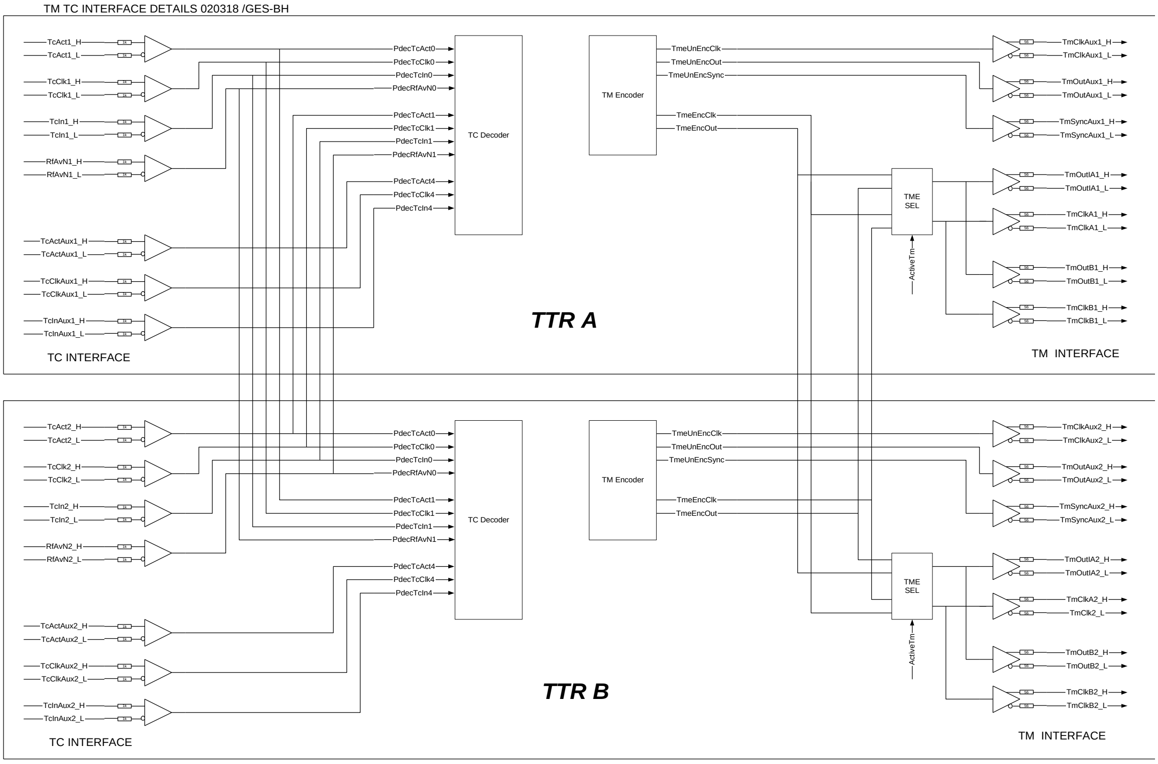
Preliminary Transponder RF output simulation have been performed showing the compliance with required emission mask. No degradation is expected after the TWT amplification while the GMSK is know not to suffer of amplifier distortion.





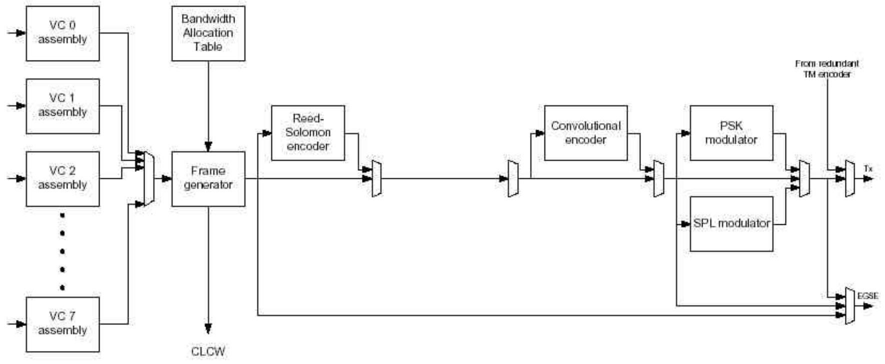
9.8.5.1.3 TRANSPONDER – CDMU Interface.

The transponder is connected to the CDMU through SBDL digital interfaces for Uplink TC and Downlink TM. Each Transponder is provided with two connectors with TM/TC signals. One connector is directed to the CDMU while the other is used for EGSE.
The cross-strapping is made inside CDMU as showed in the following diagram:

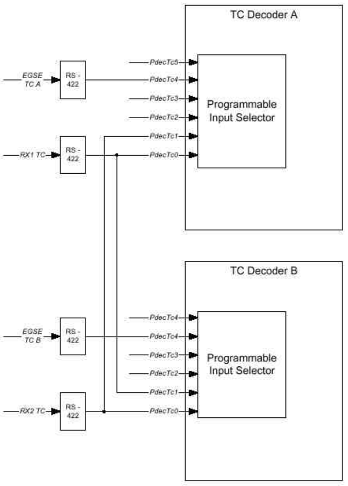


The use of digital interfaces, means that all the modulations required are completely performed inside the transponder. For this reason it is important that the digital modulation section will be synchronised to the CDMU TM generator. For this reason each CDMU TM Encoder foresees a Data and a Clock output and the XPND digital interface is synchronised to the this Clock signal.

The different TM bit rates and associated modulation scheme are selectable by TC.



The TC interface foresees also RF_Lock and Squelch signal that is used by the CDMU TC Decoders to select the XPND receiver best signal.



This interface is often critical in a satellite design and failures has occurred in some past programs (i.e. XMM). To avoid problems a new kind of priority selection scheme, the **Dynamic Mode** is used in the CDMU TC Decoders.

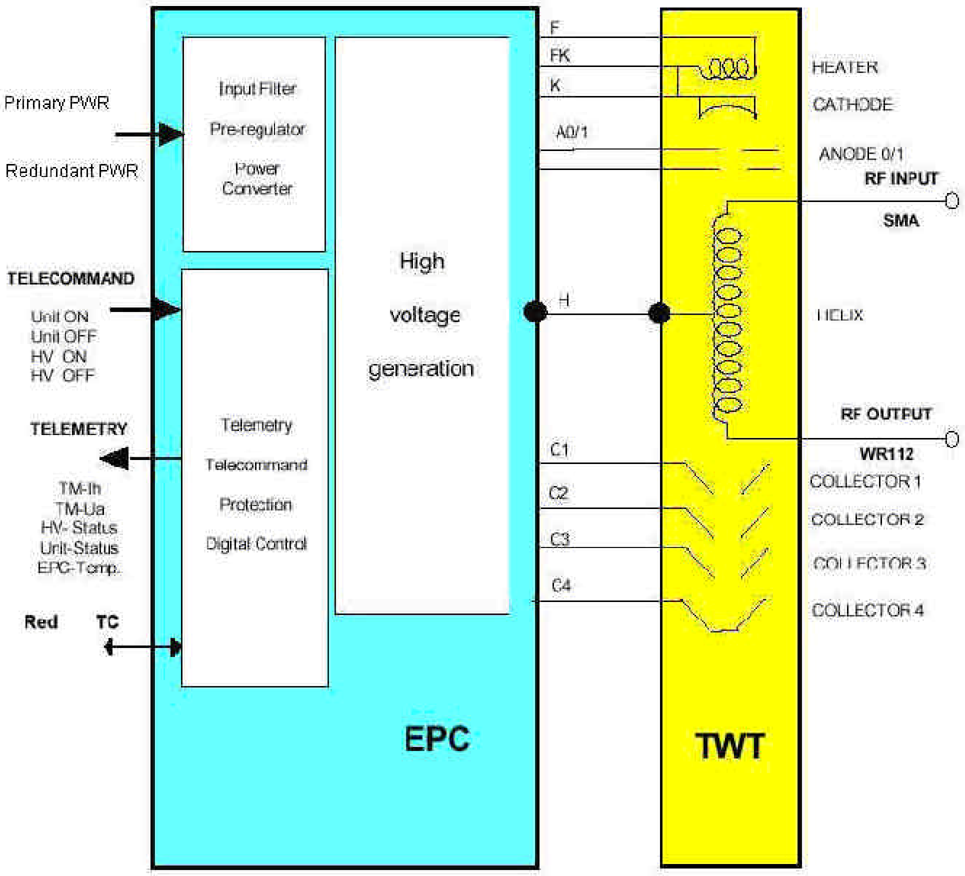
The **DynamicMode** operates as follows:

TCActive Receiver1	***TCActive Receiver2***	***TC Decoder 1 Input***	***TC Decoder 2 Input***
Active	**Active**	The first activated *i.e. RX1 TC Signal*	The first activated *i.e. RX1 TC Signal*
Active	Not Active	RX1 TC Signal	RX1 TC Signal
Not Active	**Active**	RX2 TC Signal	RX2 TC Signal
Not Active	Not Active	RX1 TC Signal	RX2 TC Signal

Once a channel has been deselected due to an error, i. e. the frame was abandoned, the ***search for a valid synchmarker on this channel will be delayed by one BitClk internally in the telecommand decoder***.
This implies that another TC channel with a better signal quality will have a chance to be selected before the marginal channel. The delay of one BitClk internally will be removed once a channel has been selected Proposed selection scheme (dynamic mode)

9.8.5.2 TWTA

The equipment is an X band Travelling Wave Tube Assembly consisting in a Travelling Wave Tube (TWT) and an Electronic Power Conditioning unit connected by a High Voltage Cable.
The assembly block diagram is presented in the picture below. The EPC is equipped with redundant Pwr/TM/TC connectors to improve reliability.
The TWT RF input is a SMA connector coming from the RFDN power splitter while the RF output is a WR112 flange that is connected to the RFDN waveguide circulator to protect the tube.



9.8.5.2.1 EPC TECHNICAL DESCRIPTION

The EPC is mainly constituted by a high efficient high voltage converter providing the various voltages required by the TWT and secondly by functionality such as:

- Telecommand interfaces.
- Telemetry signals
- Process adapted for TWT operation (optimised start-up, and shutdown sequence, IK regulation).
- Protections circuits for spurious switch off of TWT as well as any high voltage short circuit
- Power Bus interface.
- Auxiliary voltages generation.

The EPC topology is a buck type pre-regulator followed by a quasi resonant push-pull inverter. The main bus voltage is pre-regulated via the buck which supplies the input of the HV transformer through the resonant push-pull.
An input filter is placed before the power chain to cope with the EMC specification.
The EPC is designed to be switched on by a EPC “ON “command and in this mode it provided the TWTA filament pre-heating current. After the preheating time (3 minutes typical) the TWTA is ready to be powered with the High Voltage with the command to EPC “TWT ON”.
All the management of the EPC is made by an ASIC circuit.

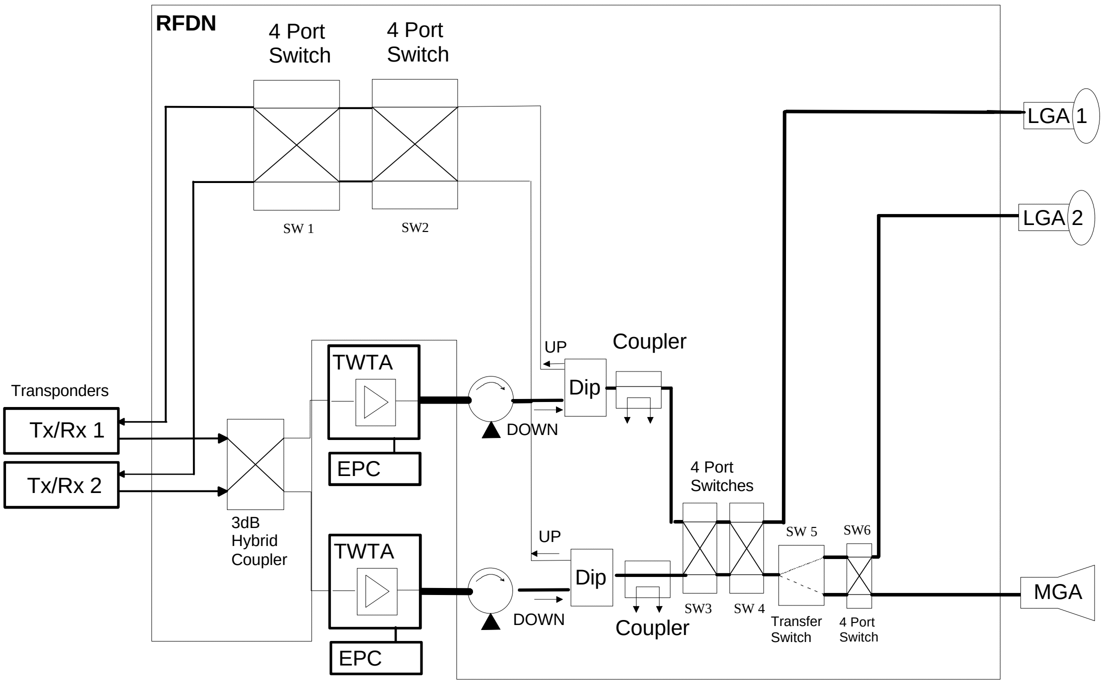
9.8.5.2.2 TWT DESCRIPTION

The proposed TWT is a direct derivative and improved version of in-orbit units on which a 4-stage collector has been implemented for global efficiency improvement and subassembly standardisation (vs commercial devices for Ka, Ku and X-Band applications) purposes.
This 4-stage collector is the standard collector design already implemented on the Ku-Band family up to 150W and most of the Ka and X-band programs delivered by TTE Velisy from six years. In addition the proposed TWT will mainly use the 100/150W Ku band TWTs technology.
This 100/150 W Ku band family is designed according to well established, conservative and safe layout rules.

9.8.5.3 Radio Frequency Distribution Network (RFDN)

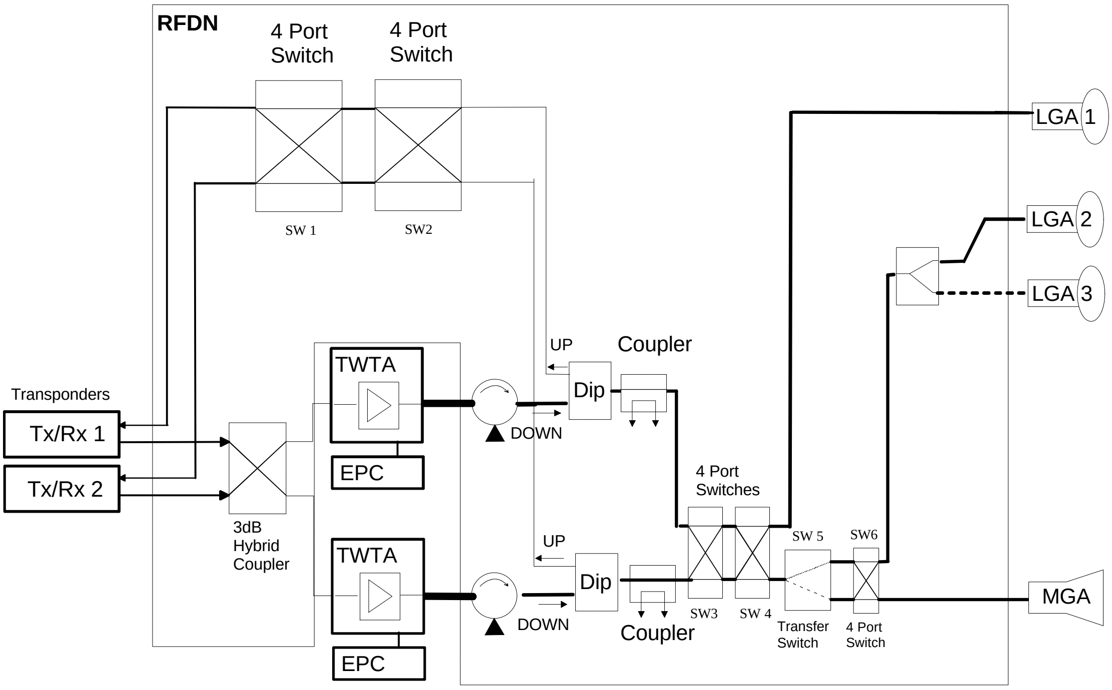
The RFDN proposed has the following characteristics:
The high power downlink distribution network between the output of the TWTAs and the antennas will use waveguide technology type WR112.
The low power downlink distribution network hardware between the outputs of the transponders and the TWTAs and the uplink path shall use coaxial technology (TBC).
Both uplink and downlink are in X-Band.

The above figure shows the block diagram of the HERSCHEL/PLANCK TTC configuration.



HERSCHEL RFDN proposed architecture

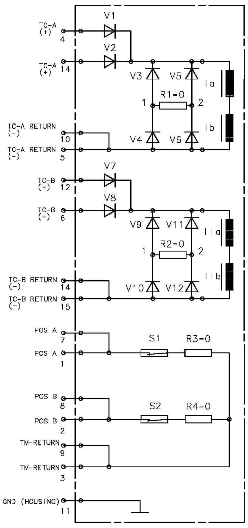
File: Herschel_RFDN.dsf - 05-02-2002

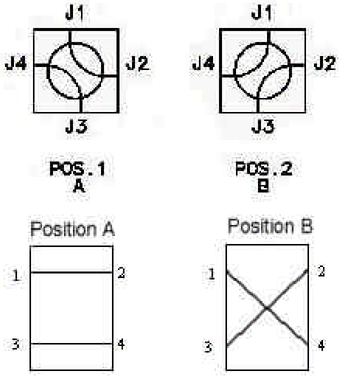


PLANCK RFDN proposed architecture.

File: Planck_RFDN.dsf - 05-02-2002

All the RFDN is based on usage of two 4 cascade port switches to assure that the configuration chosen is single point failure tolerant. In particular the 4 PS operational mode is described in the figure here below:





In uplink the received signal from the two LGAs passes through SW3 and SW4 towards the two Diplexers and then the Transponders RX inputs.

In downlink the output from one of the two transponders feed a 3 dB Hybrid Coupler that supply contemporarily the two TWTA. This solution is more reliable with respect to 4 Port Switch solution because it is only passive connection without any moving mechanical parts. The RF losses due to the 3 dB Hybrid Coupler insertion not relevant because the RF signal will be amplified by the TWTA.
From each TWTA a RF signal output level close to 32 W is obtained. The TWTAs are in cold redundancy: this means that only one is powered on at the same time. Each TWTA output supplies an isolator to protect it from mismatches then a Diplexer and two 4 PS. From these 4PS it is possible to feed directly the LGA1 or another two Switches (SW5 and SW6) to route the RF output signal toward LGA2 or the MGA.

Two Directional Couplers are also foreseen to permit RF output power measurements without disconnecting the RFDN inputs/outputs.

Some pictures of the RFDN devices are presented here after:

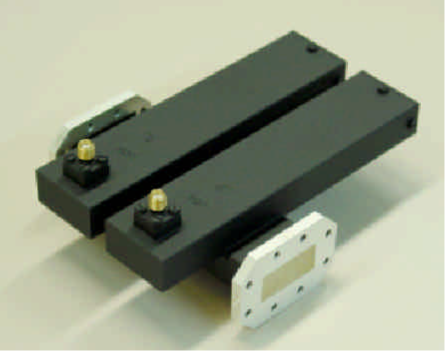


Figure 9.8-1: WR112 Coupler

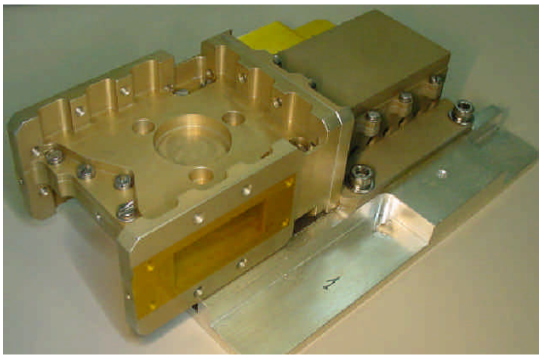


Figure 9.8-2: WR112 Isolator

In the table here below are summarised the main operational modes available in the H/P RFDN configuration:

Uplink:

From	To	SW1	SW2	SW3	SW4	SW5	SW6
LGA1	**Rx1**	A	A	A	A	NA	NA
LGA1	**Rx2**	A	A	B	A	NA	NA
LGA2/3	**Rx1**	A	A	B	A	A	A
LGA2/3	**Rx2**	A	A	A	A	A	A
MGA	**Rx1**	A	A	B	A	B	A
MGA	**Rx2**	A	A	A	A	B	A

Downlink:

From	To	SW1	SW2	SW3	SW4	SW5	SW6
TWTA1	**LGA1**	NA	NA	A	A	A	A
TWTA2	**LGA1**	NA	NA	B	A	A	A
TWTA1	**LGA2/3**	NA	NA	B	A	A	A
TWTA2	**LGA2/3**	NA	NA	A	A	A	A
TWTA1	**MGA**	NA	NA	B	A	B	A
TWTA2	**MGA**	NA	NA	A	A	B	A

The downlink hardware, in particular the switches interfacing with the TWTAs power handling, will guarantee at least 3 dB of margin with respect to the TWTAs RF output power of 32 W.
The switches design is different between downlink path and uplink path.

Concerning uplink path the two 4PS are made by a reliable relay switch designed and already space qualified for coaxial connection.
In the downlink path the 4PS and 3PS are realised with a unique transactor actuator. Typical insertion loss is 0.05 dB. The isolation cross coupling typical is 60 dB.
The impulse current required for this 4PS realised in waveguide usually presents a switching time close to 100-150 ms and a maximum sink current of 0.5-1 A. To drive them dedicated Extended High Priority Command lines will be used by the CDMU.
Both the switches design shall minimise the probability to go in neutral position for imperfect commands and vibration / shock excitations.
The RFDN hardware components shall be selected to minimise Insertion loss and VSWR.

The system will be completely single point failure tolerant:

- considering an approach that uses a redundant switches configuration foreseeing Time Tagged Command approach to recover from an unlikely switch neutral (midpoint) position .
- having the possibility to command the switches both by PM, RTU and TcDec.
- Implementing an on-board software routine that is able (by looking at the Transponder and AOCS attitude monitors) to position correctly the switches in case of a failure on the transponder Receiver or a loss of the expected attitude.

The foreseen RFDN interfaces are:

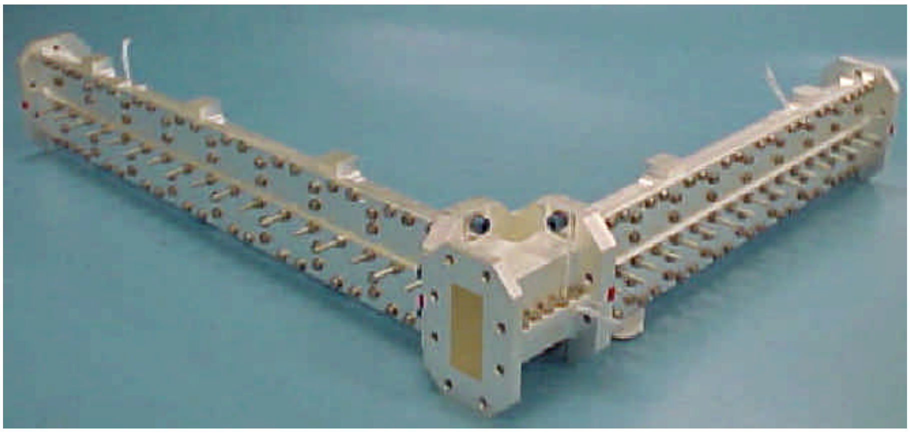
Telemetry:
- 6 Switch position A status
- 6 Switch position B status

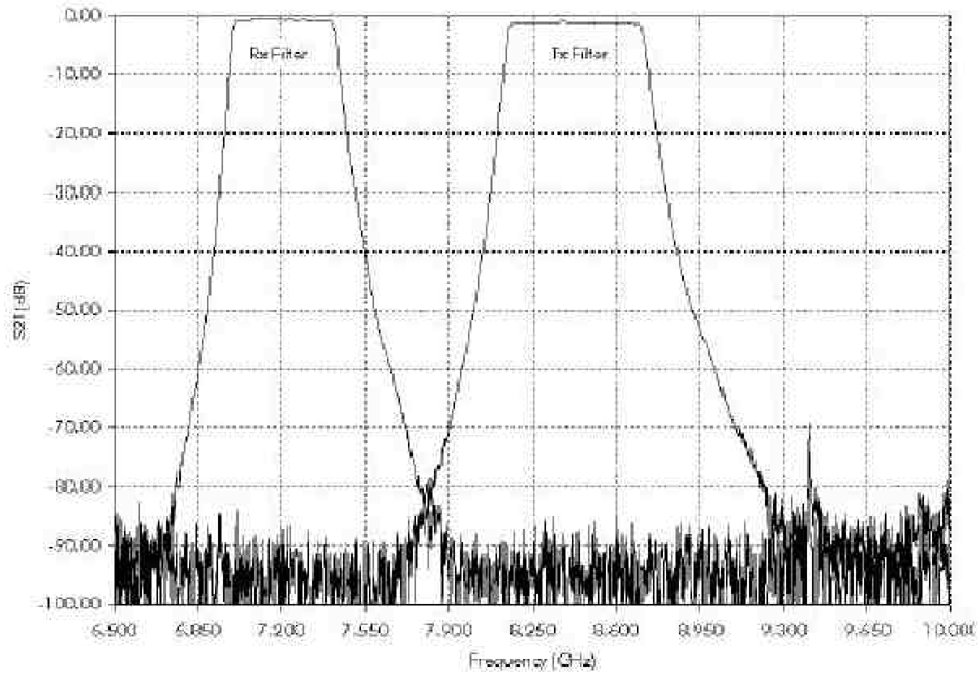
- 2 High Power Isolator temperature.
- 2 Diplexers temperature

Telecommand:

- 6 Switch position A Extended High Priority Command (nominal)
- 6 Switch position A Extended High Priority Command (redundant)
- 6 Switch position B Extended High Priority Command (nominal)
- 6 Switch position B Extended High Priority Command (redundant)

Two Diplexers are also included in the RFDN to split the TX signal from the RX one, these will be a Rosetta program heritage and a preliminary transfer curve is presented here below:





The preliminary RFDN insertion losses data are:

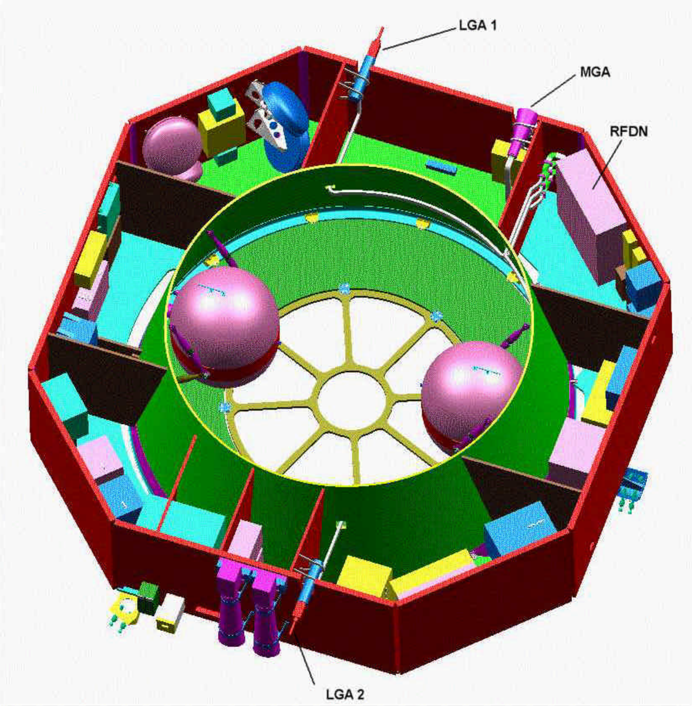
From	To	Insertion Losses [dB]
LGA1	**Rx1/2**	2.5
LGA2	**Rx1/2**	2.7
LGA2/3 (Planck)	**Rx1/2**	5.5
MGA	**Rx1/2**	2.7
TWTA 1/2	**LGA1**	1.1
TWTA 1/2	**LGA2**	1.1
TWTA 1/2	**LGA2/3 (Planck)**	4.5
TWTA 1/2	**MGA**	1.1

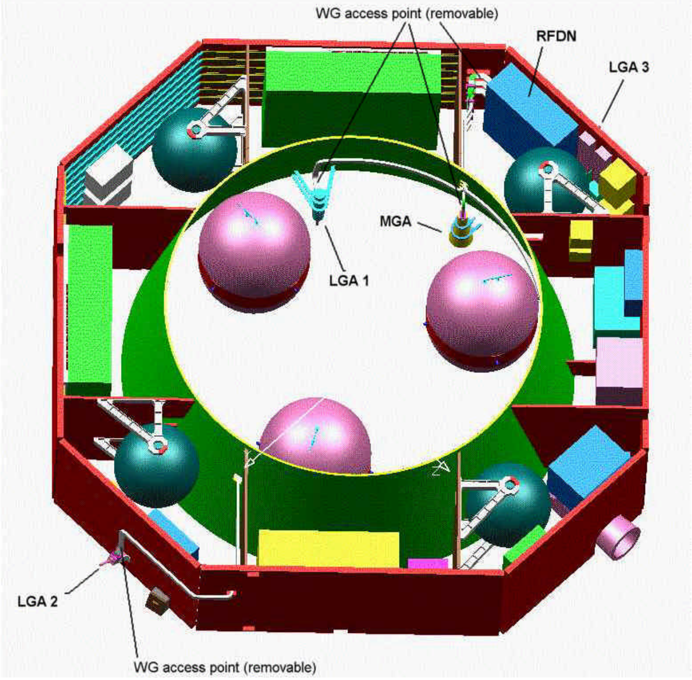
While the Input/Output return loss will be better that 20dB

9.8.5.4 Waveguide Routing

In order to connect the RFDN outputs to the antennas, WR112 waveguides will be used. Preliminary routing has been performed on the Herschel and Planck SVM CATIA models.

The SVMs configuration and layout have been optimized in order to maximize the similarity between the two waveguides routing. The feasibility of the resulting waveguides sets will however have to be discussed with the RFDN supplier.





The following waveguides, external to RFDN are foreseen:

HERSCHEL SVM

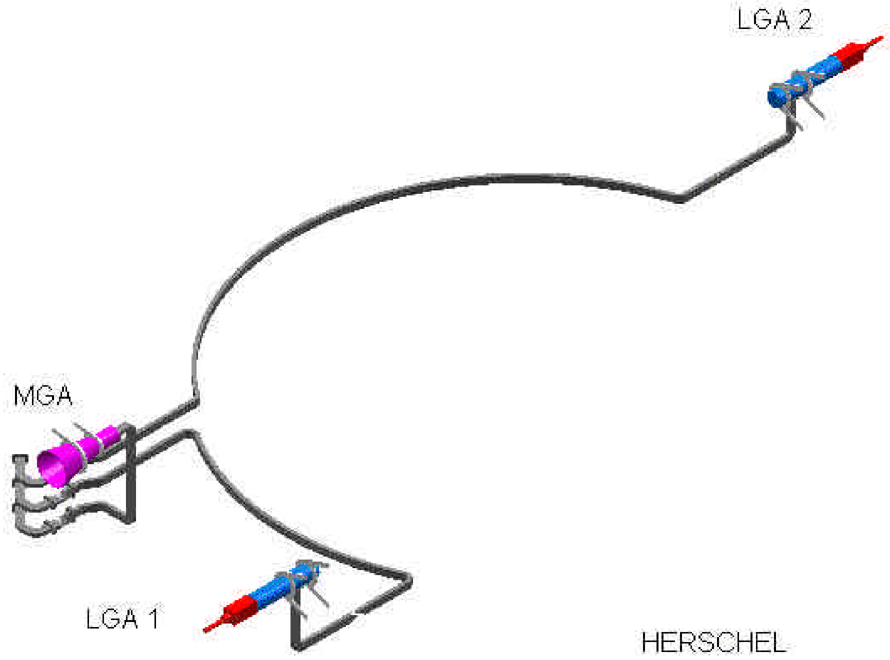
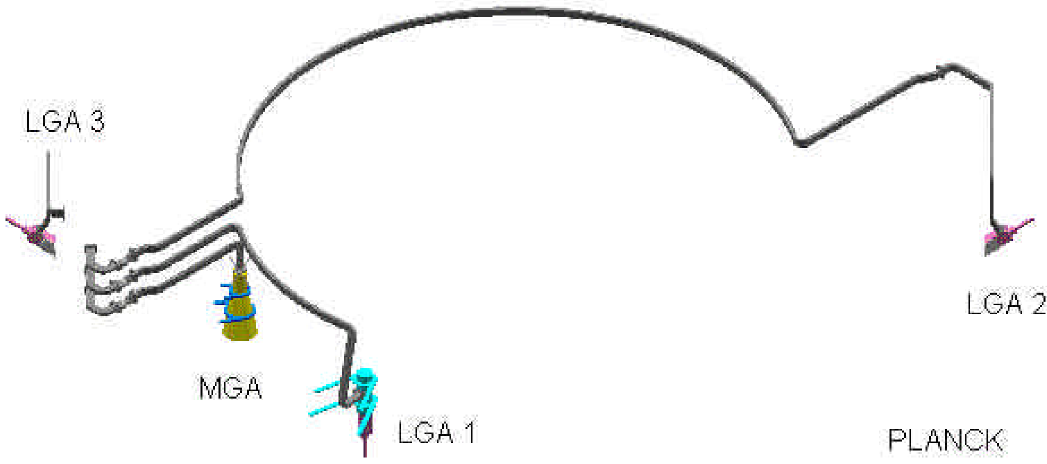


Figure 9.8-3: Herschel preliminary Waveguides routing

Path	*Type*	*Lenght [mm]*	*Attenuation [dB]*
TWTA1 – RFDN in 1	WR112	TBC	
TWTA2 – RFDN in 2	WR112	TBC	
RFDN Lga1 out – LGA1	WR112	< 2500 TBC	< 0.3 dB (TBC)
RFDN Lga2 out – LGA2	WR112	< 4500 TBC	< 0.5 dB (TBC)
RFDN Mga out – MGA	WR112	< 1000 TBC	< 0.12 dB (TBC)

PLANCK SVM

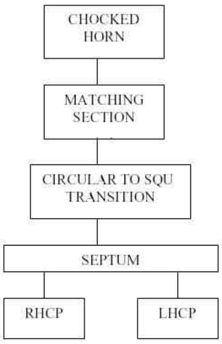


Path	*Type*	*Lenght [mm]*	*Attenuation [dB]*
TWTA1 – RFDN in 1	WR112	TBC	
TWTA2 – RFDN in 2	WR112	TBC	
RFDN Lga1 out – LGA1	WR112	TBC	< 0.4 dB (TBC)
RFDN Lga2 out – LGA2	WR112	TBC	< 0.6 dB (TBC)
RFDN Lga3 out – LGA3	WR112	TBC	< 0.6 dB (TBC)
RFDN Mga out – MGA	WR112	TBC	< 0.4 dB (TBC)

9.8.5.4.1 Low Gain Antenna (LGA)

The X band Low Gain Antennas will be a low gain chocked antennas which are designed for Telemetry and Command on board satellite missions.
Each single antenna covers in radiation pattern an hemisphere and it works at a moderate frequency band. Rear radiation is poor in such a way that interference effects with the satellite are diminished, is very important in the case of Herschel /Planck program because of the possible influence of the s/c over the antenna radiation pattern.

The block diagram of each antenna is the following:



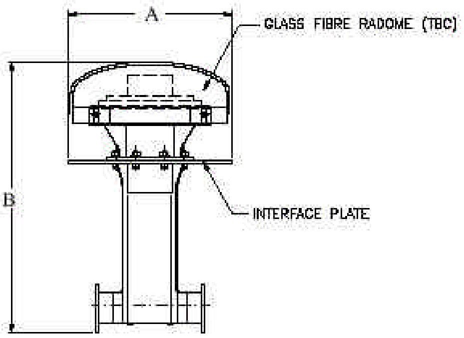
From electrical point of view, each antenna is composed by a radiating element, an OMT/Septum polarizer and electrical interfaces.

Radiating element set.
This element includes a small chocked horn with corrugations placed behind the circular aperture. These corrugations improve the axial ratio of the antenna in the front radiation pattern and diminish the influence of the backed antenna structure. The aperture is excited by the TE11 mode in circular waveguide and the corrugations allow to get reduced crosspolar excitation. The radiation pattern shows a good axial symmetry and it is characterized by a single Ø-cut.
A matching section is used to improve the return loss of the horn. It consists in a change to different diameter in circular WG. Furthermore, a transition from circular to square waveguide is included.

Septum set.
This block includes the septum polarizer itself made in rectangular & square waveguides (see figure 2.1). The element allows to join two separate inputs (rectangular WG a/b ratio equal to 1/2) to a common output (square WG) with different sense of circular polarization. Dominant modes work in the septum/OMT ports. The internal plate, separately both half waveguides, will be five steps because wide bandwidth is required for operating both TX & RX frequencies.
For Herschel/Planck, one of the ports is closed and one load is included.

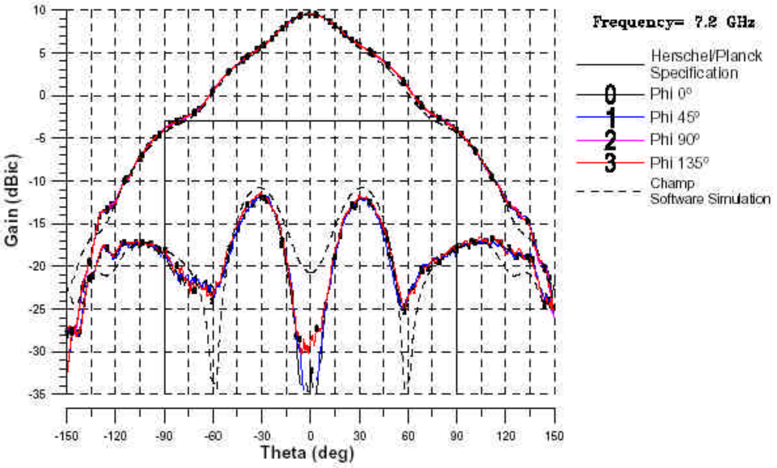
Electrical Interfaces.
WR112 WG electrical interface is used for the open port, it could be placed with its direction parallel or perpendicular to the antenna boresigth.

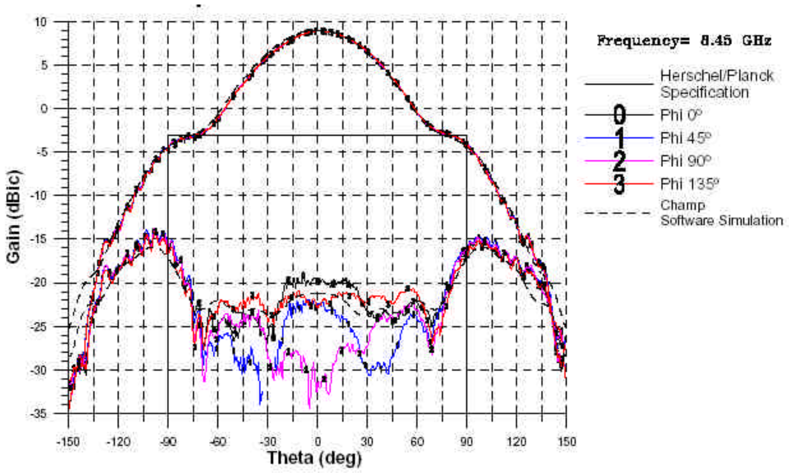
A drawing of the antenna is showed in the figure below:



X–BAND ANTENNA PROPOSED CONFIGURATION (WG RF INTERFACE)

The preliminary pattern diagrams are presented in the following graphs. It’s considered achievable by the antenna bidders to obtain a –3dBi gain and 90°.



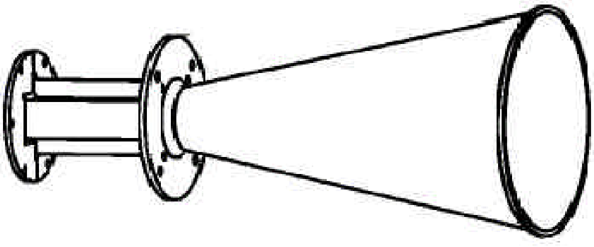


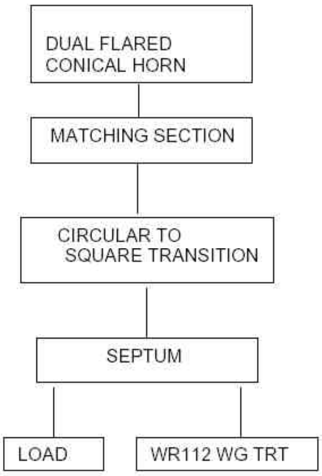
9.8.5.4.2 Medium Gain Antenna (MGA)

The proposed MGA is a conical dual flared horn already space qualified. Even in this case the septum polarizer is also made by escalation of previous developed ones. The MGA is composed from the electrical point of view, by the following elements:

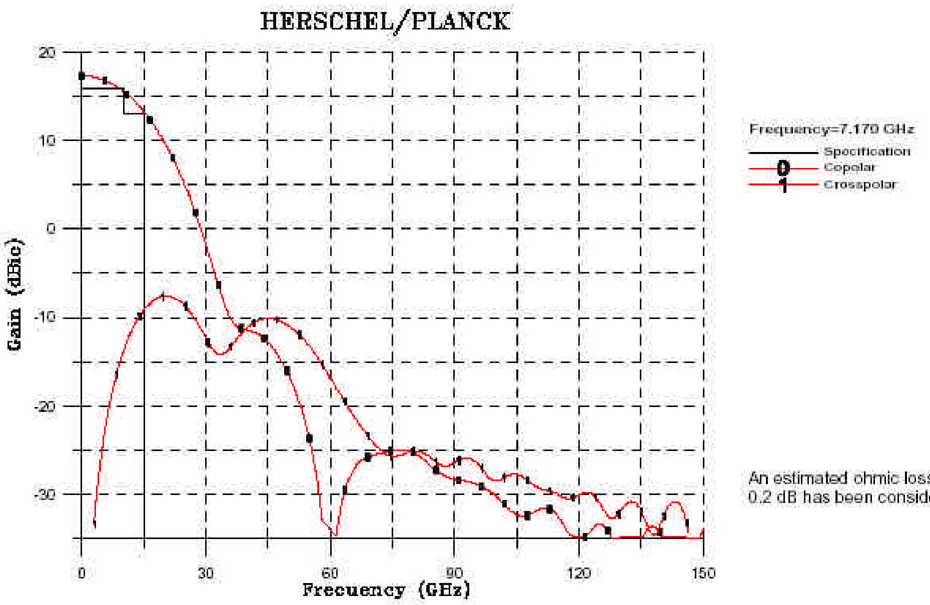
- Transition to WR 112 waveguide (axial or normal to septum main body)
- 5 Step septum polarizer (because requirement is broad band)
- Waveguide load
- Square to circular transition
- Dual flared conical horn

The minimum antenna gain has been ensured to be close to 16 dBi at 10° and 13 dBi at 15°.
In particular it withstands up to 70 W RF in input.

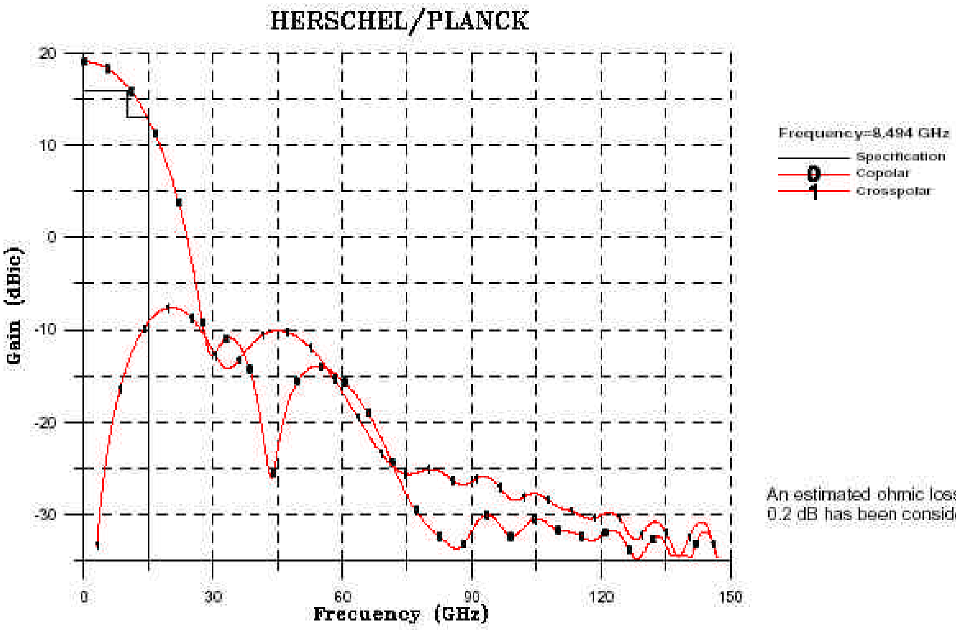




Typical MGA pattern are presented here below:



An estimated ohmic losses of 0.2 dB has been considered.



An estimated ohmic losses of 0.2 dB has been considered.

9.8.6 Commonality Assessment

For both Herschel and Planck satellite, omni-directional coverage of the low gain antennas is specified in order to cover cases such as:

Launch: at separation from launcher, the Sun/SC/Earth angle is above 90 deg during around 20 minutes.
Survival Mode: in case of attitude loss, omni-directional coverage has to be provided to be able to communicate with the spacecraft.

While this is not a constraint for Herschel, the specific configuration of Planck makes it more difficult to achieve.

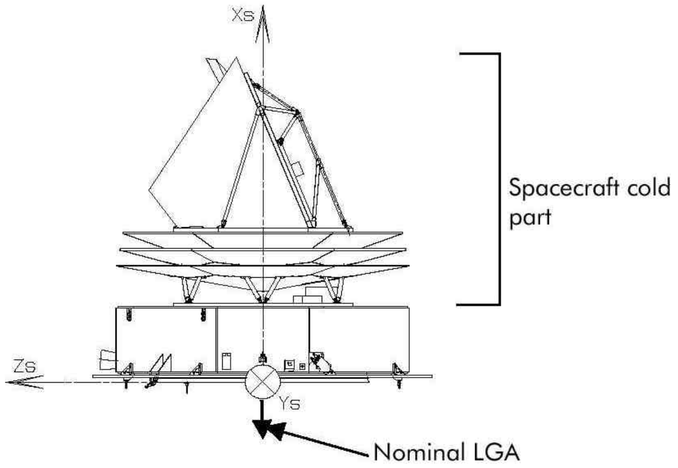
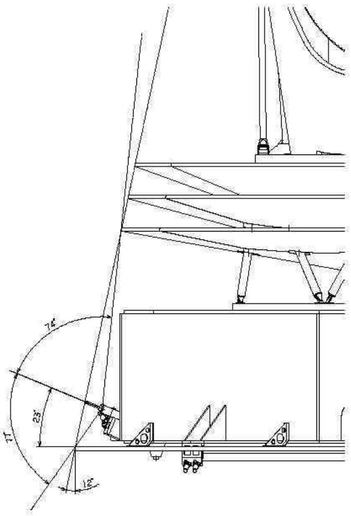


Figure: Planck nominal LGA position

As shown in the figure above, the nominal LGA is implemented on the spacecraft –X side which is nominally facing Sun and Earth. Ideally, to complete the coverage, an antenna on +X side should be implemented, i.e. on the Planck PLM top in order to have hemispherical coverage.
This has been rejected for the following reasons:

- modularity: the antenna belongs to the SVM and will have to be connected to it by a long waveguide. This will create a complex interface between SVM and PLM
- antenna environment: the thermal environment at the PLM top is below 60 K. Qualification of an antenna at that temperature can be complex
- PPLM performance: the antenna implementation with its waveguide will create a direct thermal link between the cold PPLM (< 60 K) and the warm SVM (...300 K). Very efficient thermal decoupling would have to be implemented to avoid heat leaks to the PLM and performance degradation.

An alternative configuration has been preferred which avoids the above mentioned drawbacks. It consists in implementing, on the SVM, a pair of LGA connected by an hybrid coupler. The antennas are implemented in the (X,Y) plane, on the +Y and –Y panels.
In order not to induce thermal fluctuations on the PPLM, it has to be located inside the shadow of the Planck SVM Sunshield. This leads to an accommodation in a narrow space below the grooves, almost like a cavity and this results in a slightly distorted pattern of the LGA as the structural environment generates reflections and therefore some phase interference phenomenons within the antenna field of view.

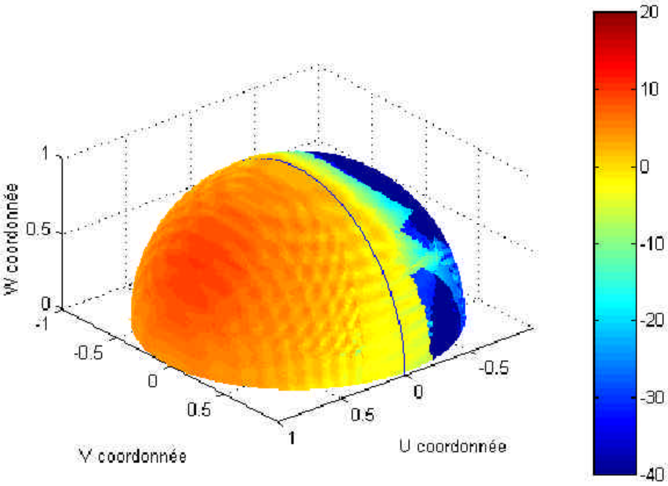


Planck redundant LGA position.

The redundant LGAs implementation is shown in the figure above. For commonality reasons, the same LGA as for Herschel or for the Planck nominal LGA has been considered.
The use of three LGA antennas for PLANCK with respect to the two ones used in Herschel should increment the visibility time of the ground station.
In particular an assessment on the two LGAs mounted laterally on the body spacecraft has been achieved and, to select the better solution, a GTD analysis has been performed using the LGA available data.

To achieve it, the antenna tilt angle has been optimised (35°) to improve the coverage efficiency.

The result of the GTD analysis show that, for what concerns the two redundant LGAs interfering with the satellite structure, a better behaviour is obtained with the second LGA type.
To achieve it, the antenna tilt angle has been optimised (35°) to improve the coverage efficiency.

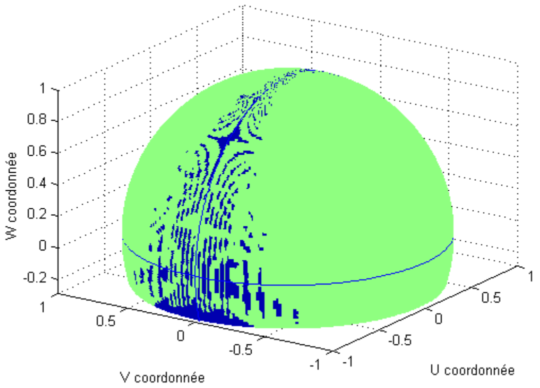


PLANCK GTD analysis with horn lateral LGA.

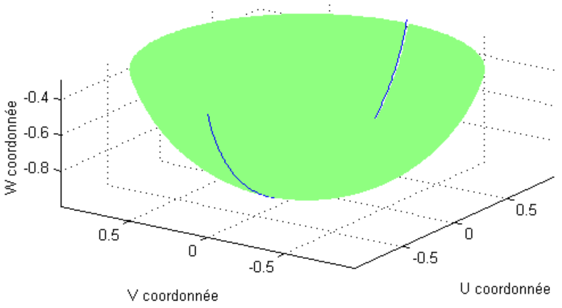
Using an elementary antenna with a narrower pattern than a usual LGA conical helix type antenna, like a choked horn concept limits the side and backward radiations, and thus the phase interferences within the pattern. However, the omni-directionality of the antenna is difficult to predict and will be measured on a mock-up model.
The foreseen solution permits to use for all the LGAs a Dual Horn Antenna

The foreseen solution permits to use all for all the LGAs a Dual Horn Antenna, modified to achieve a wider pattern (-3dB at 90 degree).

The GTD results in fact show a coverage of 94.85% with a - 3 dBi level.



GTD analysis -3dBi LGA2 & LGA3 coverage.



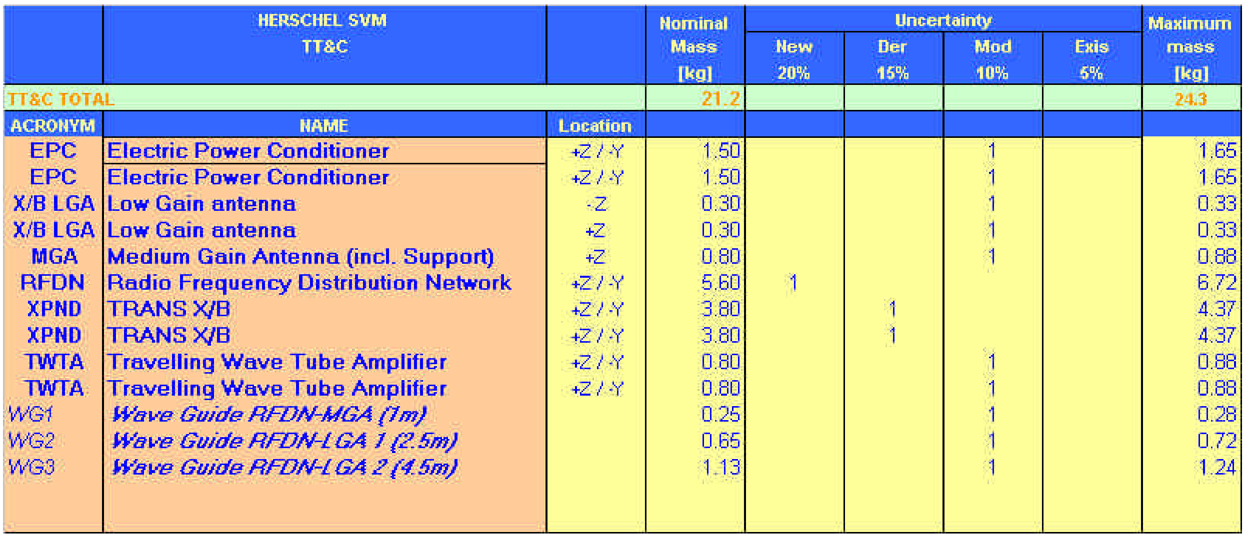
GTD analysis -3dBi LGA1 coverage.

The use of three LGA antennas impose the use of a 3 dB Hybrid Coupler on Planck RFDN in charge to distribute the RF output signal from the two TWTA to LGA2 or LGA3 antenna. Vice versa the receiving signal from LGA2 or LGA3 pass through the 3 dB Hybrid Coupler feeds the 4 Port Switch toward the transponders. A part this 3 dB Hybrid Coupler the Planck RFDN is of the same design as for Herschel.

9.8.7 Budget Summary

9.8.7.1 HERSCHEL Mass budget

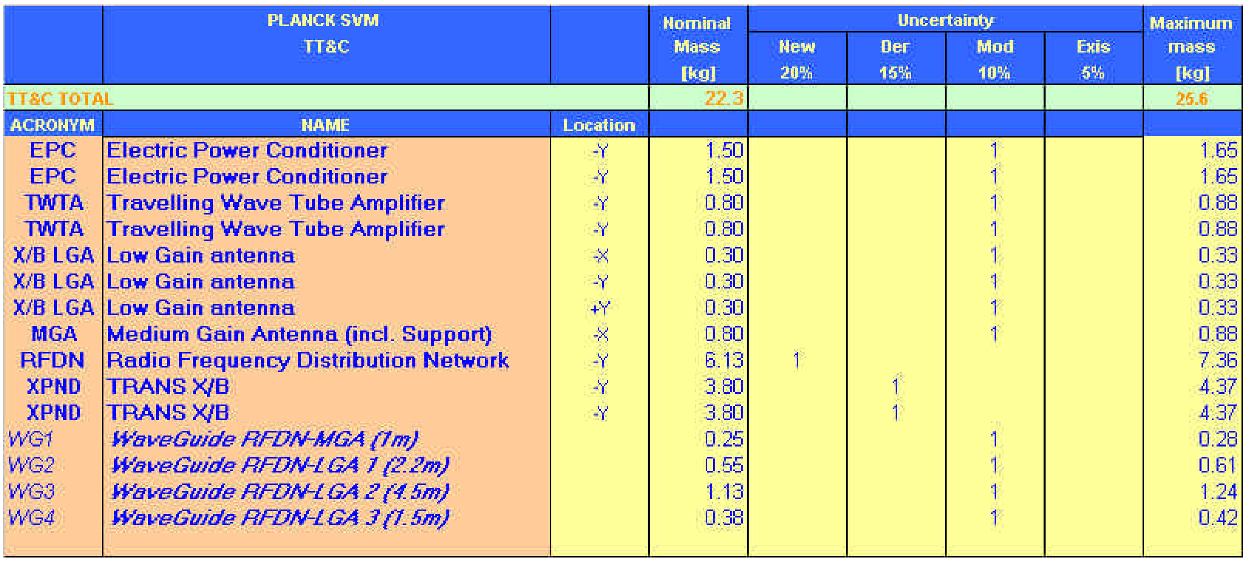
In the table below the mass budget estimated for the Herschel TTC configuration is presented:



	HERSCHEL SVM TT&C		Nominal Mass [kg]	Uncertainty				Maximum mass [kg]
				New 20%	Der 15%	Mod 10%	Exis 5%	
TT&C TOTAL			21.2					24.3
ACRONYM	NAME	Location						
EPC	Electric Power Conditioner	+Z / -Y	1.50			1		1.65
EPC	Electric Power Conditioner	+Z / -Y	1.50			1		1.65
X/B LGA	Low Gain antenna	-Z	0.30			1		0.33
X/B LGA	Low Gain antenna	+Z	0.30			1		0.33
MGA	Medium Gain Antenna (incl. Support)	+Z	0.80			1		0.88
RFDN	Radio Frequency Distribution Network	+Z / -Y	5.60	1				6.72
XPND	TRANS X/B	+Z / -Y	3.80		1			4.37
XPND	TRANS X/B	+Z / -Y	3.80		1			4.37
TWTA	Travelling Wave Tube Amplifier	+Z / -Y	0.80			1		0.88
TWTA	Travelling Wave Tube Amplifier	+Z / -Y	0.80			1		0.88
WG1	*Wave Guide RFDN-MGA (1m)*		0.25			1		0.28
WG2	*Wave Guide RFDN-LGA 1 (2.5m)*		0.65			1		0.72
WG3	*Wave Guide RFDN-LGA 2 (4.5m)*		1.13			1		1.24

9.8.7.2 Planck Mass budget

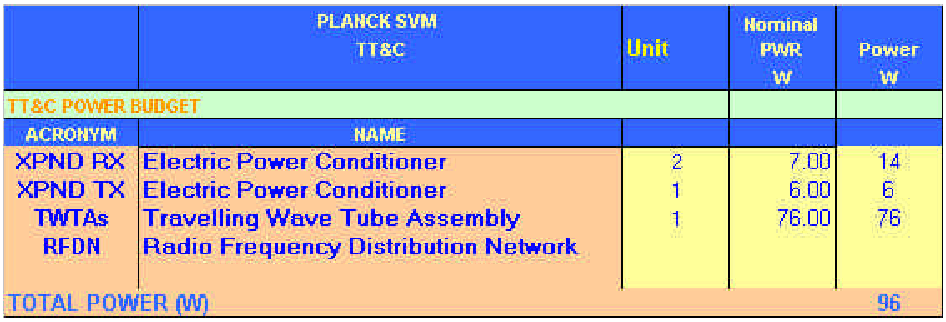
In the table below the mass budget of the Planck TTC configuration is presented:



	PLANCK SVM TT&C		Nominal Mass [kg]	Uncertainty				Maximum mass [kg]
				New 20%	Der 15%	Mod 10%	Exis 5%	
TT&C TOTAL			22.3					25.6
ACRONYM	NAME	Location						
EPC	Electric Power Conditioner	-Y	1.50			1		1.65
EPC	Electric Power Conditioner	-Y	1.50			1		1.65
TWTA	Travelling Wave Tube Amplifier	-Y	0.80			1		0.88
TWTA	Travelling Wave Tube Amplifier	-Y	0.80			1		0.88
X/B LGA	Low Gain antenna	-X	0.30			1		0.33
X/B LGA	Low Gain antenna	-Y	0.30			1		0.33
X/B LGA	Low Gain antenna	+Y	0.30			1		0.33
MGA	Medium Gain Antenna (incl. Support)	-X	0.80			1		0.88
RFDN	Radio Frequency Distribution Network	-Y	6.13	1				7.36
XPND	TRANS X/B	-Y	3.80		1			4.37
XPND	TRANS X/B	-Y	3.80		1			4.37
WG1	*WaveGuide RFDN-MGA (1m)*		0.25			1		0.28
WG2	*WaveGuide RFDN-LGA 1 (2.2m)*		0.55			1		0.61
WG3	*WaveGuide RFDN-LGA 2 (4.5m)*		1.13			1		1.24
WG4	*WaveGuide RFDN-LGA 3 (1.5m)*		0.38			1		0.42

9.8.7.3 Herschel/Planck Power budget

In the table below the power budget of the two satellites TTC configuration is presented. It has been assumed that only one Tx is powered on during the visibility window and two receivers are always powered on.



	PLANCK SVM TT&C	Unit	Nominal PWR W	Power W
TT&C POWER BUDGET				
ACRONYM	NAME			
XPND RX	Electric Power Conditioner	2	7.00	14
XPND TX	Electric Power Conditioner	1	6.00	6
TWTAs	Travelling Wave Tube Assembly	1	76.00	76
RFDN	Radio Frequency Distribution Network			
TOTAL POWER (W)				96

If TX is active, during DTCP, the power consumption is **96 W**,
while during science mode, when only two receivers are “ON”, the power consumption is **14W**.
During Launch, it’s foreseen to have two receivers “ON” and one EPC in preheating mode, so the power consumption will be **23W** (EPC power consumption is 9W).

9.8.7.4 RF link budgets

The link budgets have been calculated considering the Ground Station characteristics ad data given in the Space to Ground ICD

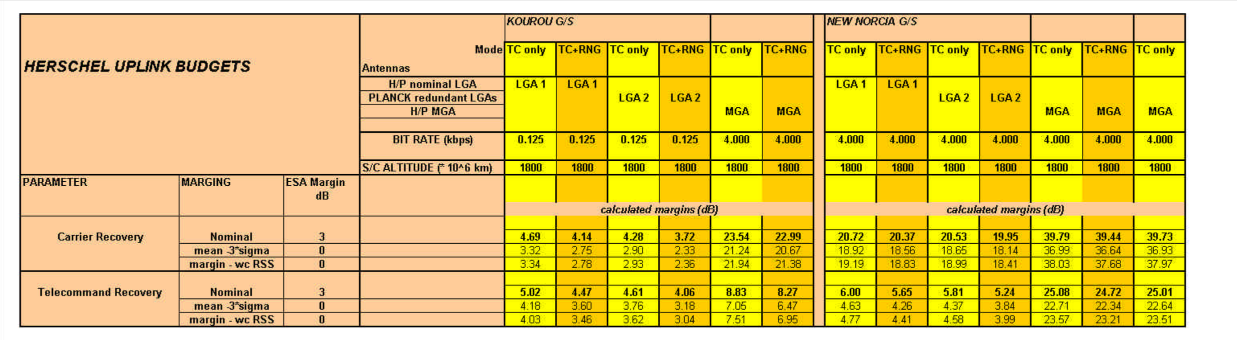
Kourou
Herschel and Planck nominal configuration

- Uplink	125 bps with LGA, 4 kbps via MGA
- Downlink	500 bps via LGA and 150 kbps via MGA

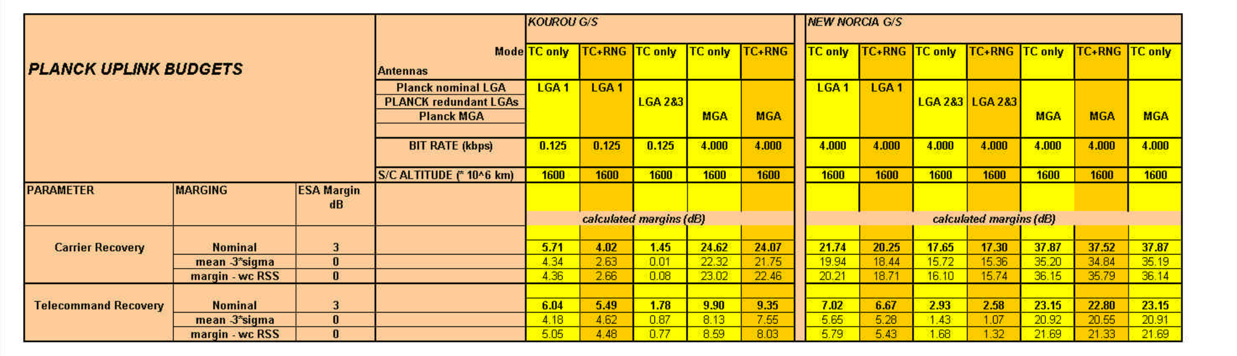
New Norcia
Herschel and Planck nominal configuration

- Uplink	4 kbps with LGA and MGA,
- Downlink	5 kbps via LGA, 150 kbps via MGA 1.5 Mbps via MGA

As a support to the complete set of link budgets provided in the SVM Budget Report, this section summarises the system margins in the same format as the one used during the proposal:



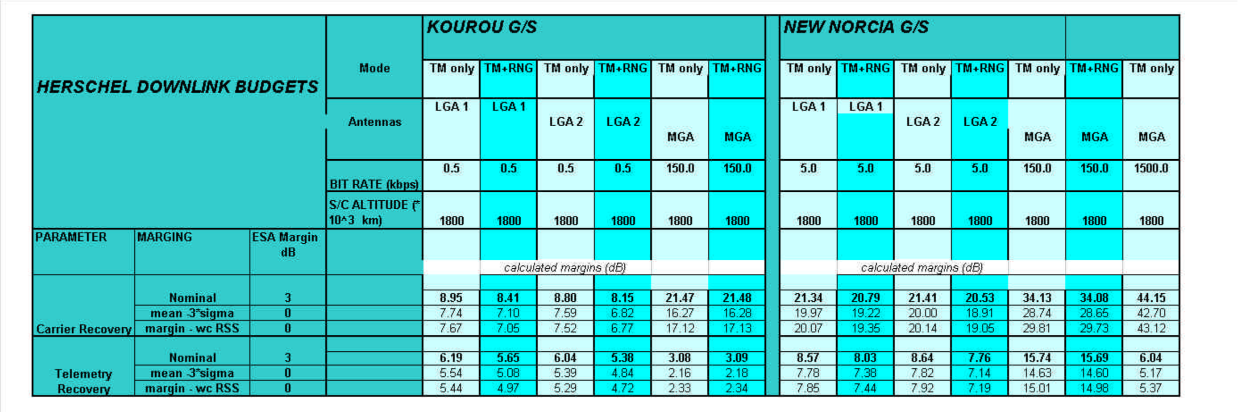
HERSCHEL UPLINK BUDGETS				KOUROU G/S						NEW NORCIA G/S						
			Mode	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only
			Antennas													
			H/P nominal LGA	LGA 1	LGA 1					LGA 1	LGA 1					
			PLANCK redundant LGAs			LGA 2	LGA 2					LGA 2	LGA 2			
			H/P MGA					MGA	MGA					MGA	MGA	MGA
			BIT RATE (kbps)	0.125	0.125	0.125	0.125	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
			S/C ALTITUDE (* 10^6 km)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
PARAMETER	MARGING	ESA Margin dB		calculated margins (dB)						calculated margins (dB)						
Carrier Recovery	Nominal	3		4.69	4.14	4.28	3.72	23.54	22.99	20.72	20.37	20.53	19.95	39.79	39.44	39.73
	mean -3*sigma	0		3.32	2.75	2.90	2.33	21.24	20.67	18.92	18.56	18.65	18.14	36.99	36.64	36.93
	margin - wc RSS	0		3.34	2.78	2.93	2.36	21.94	21.38	19.19	18.83	18.99	18.41	38.03	37.68	37.97
Telecommand Recovery	Nominal	3		5.02	4.47	4.61	4.06	8.83	8.27	6.00	5.65	5.81	5.24	25.08	24.72	25.01
	mean -3*sigma	0		4.18	3.60	3.76	3.18	7.05	6.47	4.63	4.26	4.37	3.84	22.71	22.34	22.64
	margin - wc RSS	0		4.03	3.46	3.62	3.04	7.51	6.95	4.77	4.41	4.58	3.99	23.57	23.21	23.51



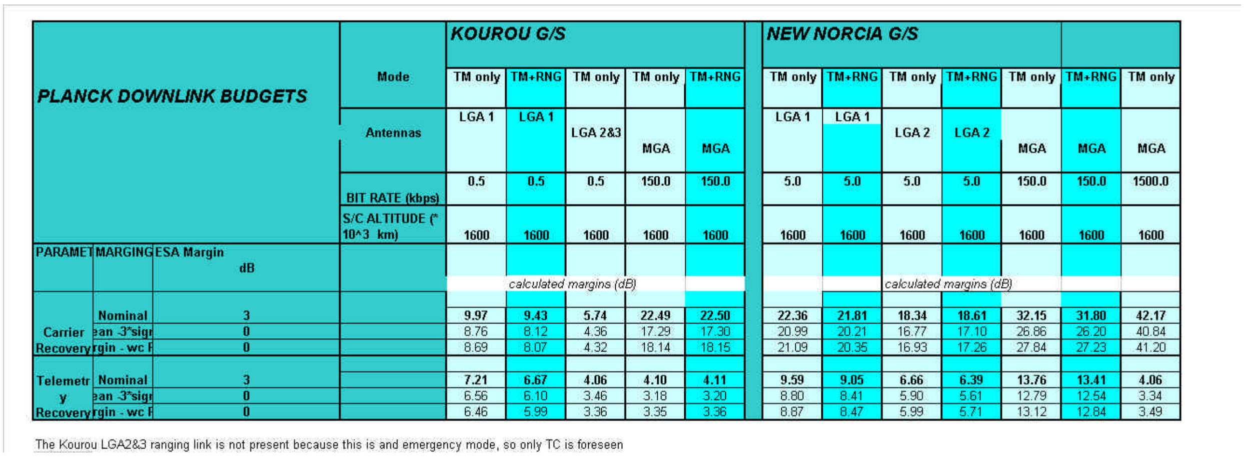
PLANCK UPLINK BUDGETS				KOUROU G/S					NEW NORCIA G/S						
			Mode	TC only	TC+RNG	TC only	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only
			Antennas												
			Planck nominal LGA	LGA 1	LGA 1				LGA 1	LGA 1					
			PLANCK redundant LGAs			LGA 2&3					LGA 2&3	LGA 2&3			
			Planck MGA				MGA	MGA					MGA	MGA	MGA
			BIT RATE (kbps)	0.125	0.125	0.125	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
			S/C ALTITUDE (* 10^6 km)	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
PARAMETER	MARGING	ESA Margin dB		calculated margins (dB)					calculated margins (dB)						
Carrier Recovery	Nominal	3		5.71	4.02	1.45	24.62	24.07	21.74	20.25	17.65	17.30	37.87	37.52	37.87
	mean -3*sigma	0		4.34	2.63	0.01	22.32	21.75	19.94	18.44	15.72	15.36	35.20	34.84	35.19
	margin - wc RSS	0		4.36	2.66	0.08	23.02	22.46	20.21	18.71	16.10	15.74	36.15	35.79	36.14
Telecommand Recovery	Nominal	3		6.04	5.49	1.78	9.90	9.35	7.02	6.67	2.93	2.58	23.15	22.80	23.15
	mean -3*sigma	0		4.18	4.62	0.87	8.13	7.55	5.65	5.28	1.43	1.07	20.92	20.55	20.91
	margin - wc RSS	0		5.05	4.48	0.77	8.59	8.03	5.79	5.43	1.68	1.32	21.69	21.33	21.69

As identified in the first issue of link budgets, the uplink performances are marginal (on Planck only) with Kourou ground station (identified to be used not as nominal) when using the low gain antennas (LGA2&3 in emergency mode). Though, the telemetry subcarrier recovery margins remain acceptable. The Planck to Kourou link through the two redundant LGAs has been evaluated at the 1,6 10^6 km distance and only in the TC mode as this is an emergency situation.

No criticality identified on the uplink budgets.



HERSCHEL DOWNLINK BUDGETS				KOUROU G/S						NEW NORCIA G/S						
			Mode	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only
			Antennas	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	MGA
			BIT RATE (kbps)	0.5	0.5	0.5	0.5	150.0	150.0	5.0	5.0	5.0	5.0	150.0	150.0	1500.0
			S/C ALTITUDE (* 10^3 km)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
PARAMETER	MARGING	ESA Margin dB			calculated margins (dB)						calculated margins (dB)					
Carrier Recovery	Nominal	3		8.95	8.41	8.80	8.15	21.47	21.48	21.34	20.79	21.41	20.53	34.13	34.08	44.15
	mean -3*sigma	0		7.74	7.10	7.59	6.82	16.27	16.28	19.97	19.22	20.00	18.91	28.74	28.65	42.70
	margin - wc RSS	0		7.67	7.05	7.52	6.77	17.12	17.13	20.07	19.35	20.14	19.05	29.81	29.73	43.12
Telemetry Recovery	Nominal	3		6.19	5.65	6.04	5.38	3.08	3.09	8.57	8.03	8.64	7.76	15.74	15.69	6.04
	mean -3*sigma	0		5.54	5.08	5.39	4.84	2.16	2.18	7.78	7.38	7.82	7.14	14.63	14.60	5.17
	margin - wc RSS	0		5.44	4.97	5.29	4.72	2.33	2.34	7.85	7.44	7.92	7.19	15.01	14.98	5.37



PLANCK DOWNLINK BUDGETS				KOUROU G/S					NEW NORCIA G/S						
			Mode	TM only	TM+RNG	TM only	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only
			Antennas	LGA 1	LGA 1	LGA 2&3	MGA	MGA	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	MGA
			BIT RATE (kbps)	0.5	0.5	0.5	150.0	150.0	5.0	5.0	5.0	5.0	150.0	150.0	1500.0
			S/C ALTITUDE (* 10^3 km)	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
PARAMET	MARGING	ESA Margin dB			calculated margins (dB)						calculated margins (dB)				
Carrier Recovery	Nominal	3		9.97	9.43	5.74	22.49	22.50	22.36	21.81	18.34	18.61	32.15	31.80	42.17
	ean -3*sig	0		8.76	8.12	4.36	17.29	17.30	20.99	20.21	16.77	17.10	26.86	26.20	40.84
	rgin - wc	0		8.69	8.07	4.32	18.14	18.15	21.09	20.35	16.93	17.26	27.84	27.23	41.20
Telemetry Recovery	Nominal	3		7.21	6.67	4.06	4.10	4.11	9.59	9.05	6.66	6.39	13.76	13.41	4.06
	ean -3*sig	0		6.56	6.10	3.46	3.18	3.20	8.80	8.41	5.90	5.61	12.79	12.54	3.34
	rgin - wc	0		6.46	5.99	3.36	3.35	3.36	8.87	8.47	5.99	5.71	13.12	12.84	3.49

The Kourou LGA2&3 ranging link is not present because this is and emergency mode, so only TC is foreseen

Comfortable margins achieved on all downlinks and here as well no criticality identified.

10. GSE

The Ground Support Equipment comprises all mechanical and electrical support equipment necessary for Satellite transportation, handling, assembly, integration and testing including the launch preparation activities.

The following types of GSE are foreseen-:

- Mechanical Ground Support Equipment (MGSE)
- Electrical Ground Support Equipment (EGSE)

10.1 MGSE

MGSE IDENTIFICATION	QTY	REMARKS
INTEGRATION & HANDLING		
EQUIPMENT PANEL TROLLEY (EPT)	2 sets	in total 13 items
PANEL TILTING TROLLEY (PTT)	6	
EQUIPMENT PANEL LIFTING DEVICE (ELD)	3	
SCC PANELS STIFFENING DEVICE (SPSD)	1	
MULTI-PURPOSE TROLLEY (MPT)	3	
VERTICAL INTEGRATION STAND (VIS)	5	
SVM LIFTING DEVICE (SLD)	3	
TRANSPORT & HANDLING ADAPTER (THA)	5	
HANDLING CLAMP BAND (HCB)	4	
TEST CLAMP BAND (TCB)	3	
ADJUSTABLE INTEGRATION PLATFORM (AIP)	1	
EQUIPMENT DRIVE UNIT (EDU)	3	
SVM STIFFENER SET (SSS)	2 sets	
HORIZONTAL LIFTING ADAPTER	1	
TRANSPORT & STORAGE		
SVM TRANSP. & STORAGE CONTAINER (TSCS)	2	
MLI TRANSP. & STORAGE CONTAINER (TSCMLI)		Provided by Thermal H/W Supplier
SOLAR ARRAY TRANS. & STOR. CONT. (TSCSA)		Provided by S/A H/W Supplier
TESTING SUPPORT		
GENERAL TEST ADAPTER (GTA)	1	
THERMAL TEST ADAPTER (TTA)	1	
SPACECRAFT MASS DUMMY (SMD)	1	
RCS OPERATION		Provided on loan by RCS Supplier
PROPELLANT AND PRESSURANT LOADING EQUIPMENT (PPLE)		
SIMULANT LOADING EQUIPMENT (SLE) (TBC)		
LEAK TEST EQUIPMENT (LTE)		
MECH. & CLEANLINESS PROTECTION		Provided by relevant H/W Supplier
PLANCK SOLAR ARRAY PROTECTIVE COVER		
SENSORS PROTECTIVE COVERS		
THRUSTERS PROTECTIVE COVERS		
OSR PROTECTIVE COVERS (TBC)		
MISCELLANEOUS		
EQUIPMENT DRIVE UNIT (EDU)	3	
SPACECRAFT MASS DUMMY (SMD)	1	

Figure 10.1-1

Additional information about SVM MGSE are given hereafter.

10.1.1 EQUIPMENT PANEL TROLLEY (EPT)

Function

The Equipment Panel Trolley (EPT) will be used for horizontal support of the SVM panels via the Panel Support Frame (PSF). Due to different panel sizes two types of EPTs as well as LPHs will be proposed. Functions and performances are equal only die length and the mass are different. A self standing working platform for each EPT provides a working height of the panel top surface of about 1094 mm.

Performance

- EPT (general)

The EPT will comprise a simple structure for horizontal attachment of the Herschel and Planck SVM panels.
The EPT will provide castors with brakes for in facility movement and levelling screw-jacks.
The EPT will provide grounding points.
The design provides a height of the panel top surface of about 1785 mm (minimum panel height on VIS and MPT – 10 mm)

- EPT_l (for long length panels)

The EPT_l will have a load capability of 80 kg Flight Hardware + 23 kg MGSE.
The mass of the item is 417 kg

- EPT_s (for short length panels)

The EPT_s will have a load capability of 60 kg Flight Hardware + 17,5 kg MGSE.
The mass of the item is 357 kg

- PSF (general)

The LPH will support one SVM Panel partly or fully equipped. 6 Inserts (TBC) will be used for the Herschel and the Planck SVM panels.
2 different sizes of frames will be provided, 1 for the small and 1 for the large panels
3 types of different brackets are foreseen per frame with a maximum overall number of 10 different brackets for all the PSFs
2 additional brackets/frame will be provided. These brackets can be attached to the frame also after final assembly of the frames.
The flatness of the I/F plane for the panel will be =0.3 mm.
The max. SWL and the LPH masses are:

Panel	Designation Max. SWL	LPH Mass
SVM_long length panel	80 kg	23 kg
SVM-short length panel	60 kg	17,5 kg

The MGSE/MGSE I/F is designed in a way to allow quick installation/de-installation of the LPH on the different items. The I/F is composed of alignment pins and self locking latches on all I/F points to other MGSE items.

Design Description

- EPT

The design of the EPT item comprises a simple rectangular bolted box section design with attached castors and screw jacks at the bottom side of the legs and stainless steel support areas for attachment of the Panel Handling Frame.
The I/F to the PSFs is composed of the shear/centring pins and 4 self locking latches.
The flatness of the MGSE to MGSE interface areas will be better than 0.5 mm.
Two grounding points will be provided.
Main material used is stainless steel. The surfaces will be passivated for stainless steel parts. The material of the wheels is polyamide.

- PSF

Each PSF is a bolted structure assembled from standard aluminium alloy extrusions.
The I/F to the panels are L-shaped profiles aluminium brackets, which will be bolted to the aluminium extrusions (120 mm clearance between frame and panel). A washer (Mat. Vetronite) bonded to the top of the brackets forms the actual I/F to each panel's surface to avoid damages to the panel's surfaces.
The panel is fixed to the frame via M6 (tbc) bolts, the number of fixations foreseen per panel is 6 (tbc) brackets.
Two Grounding points are provided, one internal and one external.
Each PSF is equipped with a resetable shock indicator for ±5 g in all three directions.
On the four outer sides of the frames, provisions are made to fix the frame onto the ELD, PTT and EPT by means of four catchplates for the self locking latches, attached to the interfacing MGSE items. Additional plates with a hole in the middle mounted in line with the catchplates to the bottom side of the frames complete the I/F to the interfacing MGSE. The distance (510 mm) between the two I/F points and the hole diameter in the plate on each side of the frame is the same for all frames to form a uniform interface for all interfacing MGSE items.
Two additional fixation brackets plus fixation hardware for each frame are part of the item.
The brackets can be put on the frame also after final assembly of the frame.
All materials used are aluminium alloy or stainless steel. The surfaces will be anodised or alodined for aluminium alloy parts or passivated for stainless steel parts.

- Working Platform

The design of the working platform comprises a simple rectangular bolted box section construction with a dedicate Al platform (1600 x 800 mm) steps and handrails on two sides.
Main material used is stainless steel and aluminium. The surfaces will be anodised or alodined for aluminium alloy parts or passivated for stainless steel parts.

10.1.2 PANEL TILTING TROLLEY (PTT)

Function

The Panel Tilting Trolley (PTT) will be used for separate assembly, integration and testing of the Herschel and Planck SVM panels standing in front of the SVM which can be mounted either on the VIS or on the MPT. It will give support and best accessibility to these items.

Performance

The Panel Tilting Trolley will be capable of accepting the fully integrated mass of the most constraining Panel, plus applicable MGSE, in both the vertical and horizontal orientation.
The PTT will allow tilting of the integrated panel from the horizontal position to the vertical position (90° ±3°). The rotation will be free from vibrations and will be a self locking if not operated.
The PTT will be equipped with wheels compatible with clean room operations. The wheels will be equipped with swivels and brakes that can be locked in both, direction and rotation.
4 screw down jacks will be incorporated into the rear ends of the trolley, to allow levelling of the PTT.
The tilting mechanism will be electrically operated.

The Panel can be adjusted in plane (plane parallel to the floor) by ±50 mm for both axis.
Limit switches are implemented to restrict tilting operations when the alignment pins are still engaged.
An additional adjustment possibility will be implemented to allow an angular alignement of the panel about the X axis of the spacecraft when in vertical position. The adjustment range will be ? 10 mm measured at the outermost edge of a long panel.
The Panels can be moved away from the SVM by 25 mm before tilting The PTT will be equipped with lifting eyes and forklift provisions for handling of the MGSE item alone.
The Panel, mounted on the PSFs (long length panel or short length panel version), will be attached to the PTT via L-shaped I/F-brackets and fixed with 6 self-locking latches.

Safe Working Load: 80 kg (Panel) + 23 kg MGSE (LPH)
Mass of the item: 477 kg (tbc)

Design Description

The PTT consists of a steel frame table (same as EPT), which support the lateral movement tilting unit which is made of aluminium. The steel frame table has four adjustable jacks and four wheels for movement of the PTT.

The lateral adjustment of the panel can be done in both directions with a range of ± 50 mm.

In addition a small rotation around the vertical axis is possible.

For tilting the PTT is equipped with an electro-mechanical tilting mechanism with a possible over-travel of 3°. The rotation / tilting axis is parallel to the panel lower inner corner with a displacement of 10 (tbc) mm in vertical and horizontal direction. An electrical motor with an interface to the facility power supply (single phase 220 V ± 10%, 50 Hz ± 1 Hz) is part of the tilting unit.

A integrated platform in front of the PTT with a height of minimum 305 mm over facility floor and a additionally platform on the PTT with a height of minimum 1492 mm over facility floor (after tilting the panel from the horizontal into the vertical position) are foreseen to reach the panel attachment points in vertical position in front of the SVM. On two sides of the platforms are handrails as well as a ladder is foreseen.

The item can be used together with the EPTs although if all panels are put in horizontal position in front of the SVM structure. There is no restriction if used on a long or short panel.

Stowable steps will be provided to fix or loose the longer panel to/ from the SVM structure.

Two grounding points will be provided.

Main material used is stainless steel and aluminium. The material of the wheels is polyamide.

The surfaces will be anodised or alodined for aluminium alloy parts or passivated for stainless steel parts.

10.1.3 EQUIPMENT PANEL LIFTING DEVICE (ELD)

Function

The Equipment Panel Lifting Device (ELD) allows hoisting of the completely or partly integrated subsystem panels with top faces oriented horizontally.

Performance

The ELD will provide a loading capacity of max. 80 kg panel + 23 kg MGSE mass. It will allow fine COG adjustment in both horizontal directions (? 250mm; tbc) to allow easy installation, removal and handling of the panel up to fully integrated lateral subsystem panels.

The ELD will allow hoisting and lowering of the complete integrated subsystems panels in two orthogonal orientations of the panel with the panel face vertically oriented. The frames will be attached via I/Fs on the small side. Two lifting configurations will be foreseen to comply with the two PSF sizes

The ELD will provide a distance of more than 1000 mm between panel surface and crane interface for panel integration purposes.

The slings of the ELD will provide 50 mm clearance to the panels.

The mass of the fully integrated item is 65 kg (tbc)

Design Description

The ELD is designed to support all handling and AIV activities related to the lateral panels. It is a multiple handling device, which can be operated in several configurations to allow all required integration and handling procedures.

It consist of the following main structural parts:

- Base frame
- Adjusting Mechanisms
- Attachment slings

The base frame is assembled from aluminium alloy extruded profiles bolted together to a rectangular shaped frame.

On top of the frame the sliding unit for the crosswise adjustment of the COG is mounted.

Operating these devices will change the crane I/F position.

Both units will be operated by handwheels sized to guarantee adequate handforce. Scales will indicate the positions of both devices.

The ELD is equipped with an oil shield protection under the adjustment mechanism.

The attachment slings interface with the handling frames of the panels via lockable, quick release latches.
In each shackle two slings, made from synthetics, are hooked. On the lower end of each sling a free adjusting load ring is incorporated. This ring interfaces to a structural part, which form the real interface to the LPH. It will put into the centre hole of the aluminium alloy made extruded profile of the LPH and will be secured by a latch.
Main material used is stainless steel and aluminium.
The surfaces will be anodised or alodined for aluminium alloy parts or passivated for stainless steel parts.

10.1.4 MULTI-PURPOSE TROLLEY (MPT)

Function
The Multi Purpose Trolley will be used to support the SVM, PLM or the entire S/C during all stages of integration and testing with S/C x-axis in any position between vertical and horizontal.

Performance Description
Safe Working Load: 3200 kg S/C + MGSE over the entire tilting range and 5200 kg for the docking procedure with the Planck HLD.
The Multi Purpose Trolley is capable of tilting the above payloads through 90°, with associated MGSE and / or test equipment, to any position between x-axis vertical and x-axis horizontal, with an approx. tilting time of 10 minutes.
Tilting can also be done with the Planck satellite supported by its dedicated Horizontal Lifting Adapter (height 600 mm, mass 600 kg)
The Multi Purpose Trolley is capable of rotating the above payloads about the x-axis through 360° with associated MGSE and or test equipment, to any position, with a rotation time of approx. 10 minutes.
The length of the power cord will be 25m. It will be stored within the MPT on a roll up device
The maximum allowable out-of-balance moment may not exceed 6500 Nm.
Tilting will not be possible during rotation, and vice versa.
Both motions will be electrically driven, via self-locking mechanisms with soft start and stop function.
The maximum power consumption (during tilting) will not exceed 7.5 kW (tbc).
A control panel for actuating the tilting and rotating will be provided.
The Multi Purpose Trolley is equipped with brakeable castors and lifting jacks.
The mass of item is 6.5 tons (tbc)
To comply with European Safety Regulations, the item will be equipped with a power-supply-limiter. This switch will prevent the item from tilting operation when overloaded by 20% of the SWL + MGSE. This switch will be manually adjustable to allow specific test operations.

Design Description
The Multi Purpose Trolley main structural components are a table supporting the PLM, SVM or the entire S/C via an Adapter, and a base frame to which this table interfaces. The Trolley structural material is high strength carbon steel. Stainless Steel is used where necessary, i.e. areas which cannot be surface protected (I/F).
Base frame construction is in the form of a rectangular box. Its hollow outer longitudinal members are connected by two welded boxes at rear and front of the mainframe to provide torsional rigidity against asymmetric jacking etc.
Overall dimensions of the base are as small as possible to permit maximum access to S/C, whilst assuring adequate stability.
The tilting mechanism is fully enclosed in the longitudinal base frame members. The brushes covering the needed slot for table motion cover the lubricated spindles and the slideways.

The mechanism consists of tilting brackets, spindles, and slideway systems. Its motion along the base causes the table to tilt 90°, one end of the table being restrained by the mechanism and its midpoint (each side) by links connecting it to the base.
The table interfaces through self - aligning bearings to the tilting brackets.
Each bracket is mounted on a proprietary slideway system. These consists of a pairs of slides on their matching track rails. They are capable of withstanding loads in two axes and moments about two axes. Tilting bracket stiffness is optimised to minimise excess bearing loads arising from base frame deflections.

Control of the motion is by the spindles. They are standard - trapezoidal threaded so they are self locking. Drive to the brackets is by cylindrical bronze nuts. Vertical sliding motion minimises bending of the spindle arising from base frame deflections.
Each spindle is supported at one end by a bevel gearbox and at the other end by a thrust bearing housing. This housing contains a self aligning thrust ball bearing to react spindle axial loads. This bearing also supports the small radial loads from the spindle weight.
Drive of the spindles goes via the bevel gearboxes and shafts from a centrally mounted integral electric motor - bevel gearbox unit. A handwheel can be fitted to the motor back extension shaft for manual operation when required.
The Trolley is equipped with hoisting points at each corner of the base frame to interface to facility - furnished slings. Four levelling jacks, which consist of a trapezoidal threaded spindle and a wormgear box, operated by hand crank, are fitted.
Four swivelling, brakeable castors and a removable towbar assist In Facility mobility.
Interface of Payload to the table is via various adapters, which are bolted to the slewing ring an adaptor I/F Plate. This plate has an outer diameter of 2640 mm (tbc). The slewing ring fulfils the rotation - about spin axis under control of an electric motor - wormgear box unit, selected on account of its self - holding characteristics. Alternatively, manual operation may be performed with the incorporated extension shaft and the handwheel.
The inner aperture of the slewing ring provides an open diameter of about 1000 mm (tbc) through the table.
Limit switches are fitted to prevent driving the tilt mechanism against its stop rotation under electric power. Interlocks prevent simultaneous rotation and tilting of the S/C.
Overload protection will be implemented by (adjustable) over-current-switches (one for each tilting position).
The electric control box is attached to the base frame. This box contains the interface provisions for the voltage/current supplies.
Operation requires both use of a key - operated main switch, and continual depression of the required functional switch. A flashlight on the control box will indicate if one of the drives is working. All functional switches will be arranged on the remote control box.
The main structural material of the Trolley will be white painted carbon steel, except I/F areas, where mounting/dismounting has to be performed during operation.

These areas will be either alodined or anodised aluminium (S/C Adapter Interface), stainless steel (lifting eyes) or Teflon coated steel on areas, where mounting/dismounting is not required very often (e.g. tilt support beams attachment).
2 grounding points, M8 brass, are located one at the base and one on the tilting table of the trolley.
The Multi Purpose Trolley will be delivered with a softcover installed to protect the item from adverse environmental conditions during transport and storage. The softcover is not intended to be used in cleanroom environments.
Material: Structural Material is carbon steel, with stainless steel attachments, and aluminium alloy interface ring to adapters. White, gloss paint (2 layer PU paint) as corrosion protection for carbon steel, passivating for stainless steel and alodine 1200 or anodising for aluminium interfaces

10.1.5 VERTICAL INTEGRATION STAND (VIS)

Function

The Vertical Integration Stand (VIS) will be used as a support for the different Flight Hardware subsystems (up to fully integrated Herschel / Planck SVM, dry or wet) during all stages of integration and testing. The S/C x-axis is in all cases vertical.

Performance

The VIS will be capable of accepting the mass of the integrated S/C in the vertical position (3000 kg + MGSE).
The VIS will be equipped with castors compatible with clean room operations.
Three single acted screw down jacks operable by hand cranks will be provided. Verification of levelled position can be done by an on frame mounted spirit level.
The wheels will be equipped with swivels and brakes.
It will have lifting eyes for crane movement.
Mass of the item: 5700 kg

Design Description
The Vertical Integration Stand is a stabilised platform to support the fully integrated S/C in order to assist integration activities. It consists of a welded box section frame with an interface plate on top.

The overall dimension of the item is driven to give maximum access to the +x side of SVM and PLM and by the stability requirement.
An octagonal shaped frame, welded from carbon steel RHS profiles forms the structure of the item. 8 Columns on the bottom side of the item transforms the load from the I/F to the castors and jacks and provide good access to the inner aperture of the VIS. This aperture has a diameter of 2500 mm.
The threads placed on the standard-PCD for interfacing to the various adapters is incorporated into the framing. The I/F to the adapters is protected by aluminum alloy sheets.
Also on the topside of the frame the spirit level, showing the levelling of two crosswise oriented axis, is placed on one of the edges of the plate, to allow a proper levelling of the item when jacking it up.
Steel sheets, welded to the frame close the other openings in the frame.
An additional adapter with a height of 486 mm is necessary to reach the same working height as the MPT.
On all four sides of the item handles are provided for moving the empty item and to protect the lower part of the SVM from damages caused by other activities nearby. They are made from bent steel tubes with welded on fixation flanges. For transport or AIT, the handles can be detached.
The VIS is equipped with swivelling, brakeable castors to provide mobility and screw down jacks (with integrated gearboxes), to allow levelling during AIT activities. Both features are mounted to the bottom side of the item. The handwheels have to be removed before transport.
Crane handling of the empty VIS within the facilities can be done by incorporated hoisting eyes.
The structural material for the item is carbon steel with an aluminium alloy made interface saver for the adapters. The Handles will be made from stainless steel. The I/F for detachable parts will be made from stainless steel.
Surface treatment will be at least passivating for stainless steel, alodine treatment for aluminium alloy parts and white gloss painting for carbon steel parts.

10.1.6 ADJUSTABLE INTEGRATION PLATFORM (AIP)

Function
The AIP will be able to lift two persons providing full accessibility to the SVM in all the possible integration configurations.

Performance
AAE baseline is to use a commercial standard electrical Manlift, which is capable to lift at least 2 persons up to an working height of 8 m. The Manlift will be specially equipped to comply with cleanroom 100.000 conditions.

The main technical parameters are:
Capacity: 215 kg
Working Height: 8 m
Outreach: 2.6 m
Rotation: 360°
Turning Radius (internal): 0.3 m
Turning Radius (external): 1.85 m
Weight: 2500 kg

Control of movement will be possible from the moving platform.
Movements are controlled by proportional controls.

10.1.7 SVM STIFFENER SET (SSS)

Function

The SSS will be used to support and stiffen the SVM structure or equipment support brackets during the integration activity when the structure is handled without lateral panels.
The first set will be constituted by 4 items, 2 for long length panels and 2 for short length panels.
The second set will be constituted by 6 items, 3 for long length panels and 3 for short length panels.
Only the first set will include 7 dedicated panel mock-ups to allow the electrical integration of the equipment mounted on the lateral panels.

Performance

The stiffeners provide the interfaces with the Flight Hardware.
The attachment bolts comply with Flight Hardware requirements in terms of material and thread tolerance (Titanium bolts with metric thread assessed).
The size of the frames will be in the same size as the lateral panels.
The SSS provides stiffness similar to aluminium alloy composite panels with a thickness of 25 mm.

Design Description

The SSS is designed to give the bare SMV structure the needed stiffness for handling and integration activities.
The SSS is designed for installation similar than Flight Hardware panels.
The weight of the frames does not exceed 40 kg.
Material for the SSS is aluminium alloy.

10.1.8 HORIZONTAL LIFTING ADAPTER

Function

The Horizontal Lifting Adapter will be used for handling and lifting of the SVM in dry configuration with attached Transport and Handling Adapter THA and General Test Adapter GTA.

Performance

The SWL of the item will be 900 kg plus necessary MGSE covering all occurring loadcases during handling, integration and testing.
The mass of the item will be less than 210 kg (tbc)
The I/F to the SVM will be a bolted I/F with 80 bolts M10 on 2600 mm PCD (tbc)

Design Description

The HLA will be an aluminium alloy construction. It will have the typically adapter design with two flanges and a cylindrical body.
The hoisting lugs for hoisting the SVM in horizontal orientation and for hoisting of the adapter himself in horizontal or vertical orientation are welded on the conical part.
The upper flange provides the I/F to the SVM and the lower flange provides the hole pattern for attachment to the MPT.
A softcover for the Flight Hardware I/F will be provided

10.1.9 SCC PANELS STIFFENER DEVICE (SPSD)

Function

The SCC Panels Stiffener Device (SPSD) will be used for hoisting and handling of the SCC SVM Plank S/C Panels which are rigidly linked together maintaining them in vertical position.
The SPSD will also support the SCC panels during transport.

Performance
The SPSD will support the SCC panels partly or fully equipped. 18 Inserts (TBC) will be used for the panels.
6 additional brackets/frame will be provided. These brackets can be attached to the frame also after final assembly of the frames.
The flatness of the I/F plane for the panels will be =0.3 mm.
Dedicated hoisting points will be provided for levelled lifting of the item with/ without payload The SPSD will have a load capability of 180 (tbc) kg Flight Hardware.
The SPSD will support the SCC panels during transportation.
Mass of the item: 955 kg (tbc)

Design Description
The SPSD is designed to support all handling and AIV activities related to the SCC panels. It is a multiple handling device, which can be operated in several configurations to allow all required integration and handling procedures.
It consist of the following main structural parts:

- Panel frame item
The Panel frame items consist of three panel handling frames similar to LPHs. Each Panel frame is a bolted structure assembled from standard aluminium alloy extrusions. The three panel frames are rigidly linked together.
The I/F to the panels are L-shaped profiles aluminium brackets, which will be bolted to the aluminium extrusions (120 mm clearance between frame and panel). A washer (Mat. Vetronite) bonded to the top of the brackets forms the actual I/F to each panel's surface to avoid damages to the panel's surfaces.
The panels are fixed to the frame via M6 bolts, the number of fixations foreseen is 18 brackets.
Two additional fixation brackets plus fixation hardware for each frame are part of the item.
The brackets can be put on the frame also after final assembly of the frame.
To allow a levelled hoisting of the SPSD in different panel integration variations a counterweight on the opposite side of the central panel frame as well as 2 I/F sets for a dedicated sling set are fixed on the central part of the Panel frame item.
Two Grounding points are provided one internal and one external.
The Panel frame item is equipped with a resetable shock indicator for ±5 g in all three directions.
On the four outer sides of the central part, provisions are made to fix the panel frame item onto the ELD by means of eight catchplates for the self locking latches, attached to the interfacing MGSE items. Additional plates with a hole in the middle mounted in line with the catchplates to the bottom side of the frames complete the I/F to the interfacing MGSE. The distance (510 mm) between the two I/F points and the hole diameter in the plate on each side of the frame is the same for all frames to form a uniform interface for all interfacing MGSE items.
All materials used are aluminium alloy or stainless steel. The surfaces will be anodised or alodined for aluminium alloy parts or passivated for stainless steel parts.

- Trolley item
The design of the Trolley item is similar to the EPT design comprises a simple rectangular bolted box section construction with attached castors and screw jacks at the bottom side of the legs and stainless steel support areas for attachment of the Panel frame item.
The I/F to the panel frame item is composed of the shear/centring pins and 4 self locking latches.
The flatness of the MGSE to MGSE interface areas will be better than 0.5 mm.
Two grounding points will be provided.
The Trolley item can be turned around the vertical axis (180°) and used as support during transport.
Main material used is stainless steel. The surfaces will be passivated for stainless steel parts. The material of the wheels is polyamide.

- Working Platform
The design of the working platform is similar to the EPT design comprises a simple rectangular bolted box section construction with a dedicate Al platform (1600 x 800 mm) steps and handrails on two sides.
Main material used is stainless steel and aluminium. The surfaces will be anodised or alodined for aluminium alloy parts or passivated for stainless steel parts.

- Container
The transport and storage container will allow a transportation of the item in assembled configuration with payload (empty panels) installed. The container will not be equipped with a shock absorbing device nor an active thermal control unit. For humidity control desiccant baskets will be installed. The container will be similar to a standard ISO container with the possibility to load and unload the container via a ramp. The surface finish will be white gloss paint inside and outside

10.1.10 SVM CONTAINER (TSCS)

Function
The TSCS is used for transportation and storage of the Herschel/Planck SVM in the X-axis vertical configuration. The TSCS supports covers and protects the Flight Hardware against adverse environmental conditions. The TSCS is used for road air and ship transportation and long term storage.

Interfaces

MGSE
– THA
Fixation is performed via 36 bolts M16x50 on PCD 2580; quality A2-70; torque 79Nm and
48 washers 17 DIN433; quality A2
– EDU
The Container is equipped on both sides with a special EDU I/F Bracket.

Facilities
facilities cranes with the TSCS Hoisting Device
facilities floors
facility doors

Electrical
380 V-AC, 50Hz; 400 V IEC 309 CEE 32 A
Grounding Points: Bolts M8 xTBD with 2 washers (to avoid electrostatic charging)
Environmental Data Recorder (ACORVITAS / ENDAL)

Transportation
Interfaces with flat-bed truck for road transport are foreseen. For road transport special permissions may be required (depending on national regulations), due to the overall dimensions of the container.
For ship transport it is foreseen, that the same I/F than for road transport can be used.
The TSCS can be transported with an ANTONOV 124 freighter aircraft for air transport. For fixing the TSCS inside the cargo bay a set of tensioning straps will be delivered.

Test Equipment
– Leak Check Test Equipment
The Container is equipped on one side with a panel, which provides the I/F to the Leak Check Test Equipment.

Performance
INTERFACES:
There is no direct physical I/F to Flight Hardware. The TSCS accommodates the envelope of the SVM (dynamic clearance 50 mm, static clearance: min.174 mm).
The TSCS can be transported with the ANTONOV AN124 air freighter.
Interfaces with truck bed for road transport are foreseen. For road transport special permission is required, due to the overall dimensions of the container.
The necessary Height under Hook for opening the TSCS will be max. 6.5 m

PROTECTION AGAINST THERMAL ENVIRONMENT, SHOCK AND VIBRATION:

An air conditioning system is included to keep the internal temperature between 10 °C and +30 °C when the Container is exposed to external temperatures between -40 °C to + 60 °C or 40 °C+ 1000W/m² solar flux
The heating/cooling power of the system is TBD kW.
The Container protects the PLM from shock and vibration inputs by a damping system. It consists of a set of Helicable Dampers (4 off).
The dynamic clearance is always more than 50 mm, considering static and dynamic envelope.

MONITORING:
The Container is equipped with an ACORVITAS or ENDAL Environmental Data Recorder (Industrial Standard) to monitor 3 axis shocks, humidity and temperature.

GASTIGHTNESS:
The container is sealed by a sealing system comprising two stiff flanges and two hollow section sealing profiles. The lid is latched to the base tub to achieve the required pressure on the sealing.
The leakage rate is less than 50 mbar/24 hours so that the internal pressure of 10 mbar can be maintained during:

- 14 days storage, or
- take off and landing including 1 day for flight and flight preparation.
- 14 days road or ship transport

GN2 SYSTEM:
The container incorporates a nitrogen system, which keeps the container environment at an over pressure of 10 mbar. The pressure within the container is regulated by a means of a fully active regulation system.
The container is equipped with 4 GN2-bottles on the container. The GN2-system on the TSCS is equipped with an I/F to the facility nitrogen source.
At an over pressure of more than 15 mbar as well as at an under pressure less than 10 mbar the safety valves (breathing valves) will get operational.

Item Characteristics

Dimensions
TSCS completly equipped (without tow bar)
length: 6352 mm
width: 4582 mm
height: 2265 mm

Weight

Configuration / Single Items	Mass [Kg]
unloaded (ready for use)	6636 +20%
loaded (with SVM max. mass)	7436 + 20%
lid	1950 + 20%
lifting beam	500 + 20%
tow bar	28

Design Description
MAIN ELEMENTS:
Container Base Frame, Base Tub, Container Cover, Container Inner Frame (CIF), Container Hoisting Device (HD), GN2 - System, Active Thermal Control Unit (ATCU), Lifting Slings, Helicable Shock Mounts, Castors, Environmental Recorder (ER) (Shocks, Humidity, Temperature and Pressure).

CONTAINER BASE FRAME:
The Container Base Frame is the main load carrying element of the container. It withstands all introduced handling loads also when the Container Cover is dismounted. It provides the "hard-points" for attaching the Jacks, lifting eyes for lifting the Container, lashing eyes for fixation at transport and the GN2 - system.

The Base Frame is a welded framework, made from carbon steel RHS. The top of the Base Frame forms support for the lower part of the sealing system.

BASE TUB:

The Base Tub is the lower part of the Container "Box". It is welded from stainless steel beaded sheets. (Beading extensions facing inside the TSCS.) Its upper rim comprises the lower flange of the separation line. Insulation Panels are bonded on the outside of the tub to increase stiffness and provide the insulation capability. This assembled tub is bonded and bolted into the Base Frame. All grounding use DINOL Adhesive (Poly Urethane). Throughput for the Nitrogen supply, purge ports and other feedthroughs are welded into the vessel.

CONTAINER COVER:

The Cover is built from a welded vessel using also stainless steel beaded sheets, with its lower rim comprising the upper flange of the separation line. Its wall cross section is built in the same way as the base tub. Insulation Panels are bonded on the outside of the tub, between the framing, to increase stiffness and provide the insulation capability. All Grounding use DINOL Adhesive (Poly Urethane). Throughputs for the Air condition system are welded into the vessel.

The Cover is stiffened by profiles in the edges, forming the ‘wireframe’ of the outer shape of the cover.

The Container Cover is equipped with 4 lifting eyes, which are used for lifting of the Cover alone.

An access door is incorporated (Ø 600 mm).

For protecting the Flight Hardware during opening and closing the LID, guiding rods are provided.

CONSTRUCTION OF THE CONTAINER WALL:

This design of the container box withstands high pressure loads and ensures high thermal insulation capability. The used insulation panels are made from GFRP face sheets and polystyrene foam.

The design of the TSCS Vessel fulfils the IATA Requirement 80/2 (emergency case) by providing 1 burst disc (Ø 900 mm) with an opening pressure of 97mbar ± 25mbar. This burst disc is made from stainless steel sheets with a Teflon liner as a sealing material.

It must be taken into account, that in case of activation of this item, the container will have a large opening! However, this is just in emergency case where the aeroplane is facing a severe damage (e.g. loss of cargo door), and the burst disk is required to avoid further damage or hazard to the flight personnel by a bursting container.

The sealing between Cover and Base tub is performed by a sealing system comprising two hollow section sealing profiles, the upper and the lower flange, stand-offs to provide a defined deformation of the sealings. The fixation of the cover to the lid is done by self locking latches for best clamping performance. To allow an easy closure procedure guiding pins are used.

CONTAINER INNER FRAME (CIF):

The I/F to the THA is a frame welded from aluminium sheets, which is supported by the Helicable Damping System. On its upper face is the I/F for the THA. The I/F’s to the dampers are located on the bottom.

The CIF is equipped with 4 weights, each 100 kg. They are mounted to the legs of the CIF when only the SVM structures are mounted. Each weight is equipped with 3 lifting eyes for movement with facility standard lifting device.

GN2-SYSTEM:

Internal atmosphere of the container during transport / storage is a mixture of air and dry GN2. It is maintained at an over pressure against ambient of 1 kPa (10 mbar) by an automatic control system, so that leakage is always compensated by the GN2-supply.

Due to the large volume of the container the amount of gas to be replaced during aircraft emergency descent is more than the supply system can provide within the given time. In this case the Container sucks up to 45% air from the outside (aircraft cargo bay). This air is filtered. Increase of relative humidity inside the container, due to air sucked in and temperature decrease will be avoided by using desiccants.

Twin vent valves (diaphragm actuated) perform depressurisation / repressurisation during rapid pressure change and are a redundant safety devices in case of complete malfunction of the GN2 system. This will avoid structural collapsing of the container hull due to malfunction.

For pressure relief before opening, a valve is provided.

The GN2 pressurisation system is designed to match the normal transport conditions and to refill the TSCS with GN2-gas during temperature descent and outside pressure rise.

PURGING OF THE CONTAINER:
The TSCS is equipped with an I/F to the facility nitrogen source: A flange size KF25 (TBD) is used for low pressure (max. 40 mbar) GN2 supply, or one of the bottle connectors for high pressure GN2 supply. The container is equipped with a KF40 (TBD) for venting the TSCS during purging. This outlet is gas tight closed, when not used. Instead of GN2 the TSCS can also be purged with dry, clean air. Before every transport the TSCS has to be purged to a rel. humidity of 25 (+3) % at 20°C
During transport the gas (proposed quality 5.0) is taken from the 4 x GN2-Bottles, which stored on the container base frame. All bottle connector lines are equipped with non return valves, which are needed to avoid pressure loss in the container, when one of the supplies is replaced.
The first pressure reduction valve reduces the pressure from 200 bar (or less) to 8 bar, independent of the pressure before the valve. The valve itself is equipped with a safety valve, which opens at 10 bar at malfunction of the main valve.
Pressure reduction to 10 mbar is done by a second pressure reduction valve, which is also equipped with a safety valve.
A manometer with maximum indicator is mounted in the GN2-Box is, which shows the pressure in the container. The GN2-supply can be stopped by a shut off valve.
The container is equipped with breathing valves, opening at an under pressure of more than 10 mbar (redundant valve e.g. when shut off valve is closed and the temperature falls), and venting valves, opening at more than 30 mbar over pressure in the container.
The GN2 System is accommodated in a waterproof box, mounted on the base of the Container.

ACTIVE THERMAL CONTROL UNIT (ATCU):
The evaporator, the ventilators and the electric heaters of the ATCU are mounted inside the Container, a condenser unit and a compressor outside of the container.
The facility or an auxiliary power generator will provide the power necessary for the ATCU (4.4kW).

ENVIRONMENTAL DATA RECORDER:
The Container is equipped with an Environmental Data Recorder (electronic type ACORVITAS Industrial III or ENDAL). It measures accelerations (input through shock mounts) on the suspension system, temperature and humidity inside the container.
This device measures and records the data in an electronic way and the data can be retrieved by means of a PC. The ACORVITAS Industrial III or ENDAL consists of two boxes:
Remote Control Box: It is located outside of the container in the GN2 Box. It provides the I/F to the PC.
Sensor Box: It is located inside the container on the I/F Frame.
Connection between the boxes is performed via PVC-free cables, gas tight connectors and bulkhead feed throughs.

CASTOR-JACKS:
The container will roll on the 4 brakeable, swivel-lock cas tors, which are fitted, to jacks. The castors can be locked in longitudinal direction, which is important when a truck pulls the container. The wheels of the castors are equipped with a revvothane surface for high load capability.

CONTAINER / LID HOISTING DEVICE:
A Container Lifting Device with Hoisting Slings is delivered with the TSCS. It is designed as a set of slings with a foldable main beam. Folding of the beam has been taken into account to allow the transportation of the Lifting Device on the front side of the Container and to allow easy mounting of the beam. The slings are interfacing to the hoisting brackets on the base frame for container lifting and hoisting lugs on the lid for lid lifting. The material of the slings is synthetics, the shackles and the crane ring are made from carbon steel (zinc plated and painted) to comply with the high loads.
The Container Hoisting Device is also used to lift the lid. Therefore the Hoisting Slings for this load case are shorter.

GROUNDING POINTS:
2 grounding points are integrated on the container at the outside. Grounding leads for internal grounding will be used on demand.

HELICABLE DAMPERS:
Helicable dampers are stainless steel cables with aluminium fixations.

OUTER SURFACE TREATMENT:
Surface treatment is white gloss paint and / or Gel coat (panels) for the exterior of the container.
This colour can be cleaned by water and isopropyl alcohol diluted 50 % by water. The solar absorbtivity coefficient of the outer surface treatment is 0.15 to 0.3.

INNER SURFACE TREATMENT:
The material inside is carbon and stainless steel sheets, gas tight welded and painted with white gloss paint or passivated to allow best way for surface cleaning. The inner sheet metal is designed in such a way to avoid any dirt trap.

10.1.11 EQUIPMENT DRIVE UNIT (EDU)

Function
The EDU will be used for short range transportation and manoeuvring of MGSE items heavier than 1000 kg.
It will interface with compressed air main supply with a pressure of 6 bar.

Performance
The item interfaces with MPT, VIS and TSCS
The item interfaces with compressed air main supply via a tbd connector.
The interface with the other MGSE items is a quick connect type and air spring loaded in vertical direction, the main functions, on/off and speed regulation, can be controlled/activated from the handle on the control bar.

Design Description
An item manufactured by Revolving Technologies, Inc., EasyMover Type ARL 500 A, will be provided
The EDU will be equipped with non-marking wheels to comply with cleanroom 100.000 conditions.

10.1.12 SVM LIFITING DEVICE (SLD)

Function
The SLD will be used to hoist the SVM as described below:

- SVM bare structure
- SVM fully (or partially) integrated with Xs axis in vertical position, both in wet and dry configuration
- SVM fully integrated with Xs axis in horizontal position (THA, clamp band and Horizontal Lifting Adapter or TTA) in dry configuration.

Performance
The THA will be compliant to all I/F’s given above.
The item will have a SWL of 1000 kg plus MGSE for lifting with Xs axis vertical as well as horizontal. (MGSE: THA and TTA at lifting with Xs axis in horizontal position.)
A remote control with a position readout on the floor will be provided.
The SLD will be provided with particle and oil shield protection.
Castors for in facility movement will be provided.
The SLD will be attached to the crane hook by means of hydraset. Its configuration will preclude the possibility of slings contacting the Flight Hardware and will minimise the introduction of local moments into the item to be hoisted.

The SLD will be provided with CoG adjustment to centre the crane hook over the CoG of the overall assembly. The adjustment will be operated both electrically (via remote control) and manually along the two axis. The adjustment range will be ± 150 mm (TBC) minimum in both directions (to meet the maximum CoG offset positions) and will be visible by local and remote (digital) position indicators.
The remote switch- board will be equipped with key lock and emergency push button.
Loosen parts will be secured by tether lines. Folding bellows will protect all open spindles.
Slings will be made from synthetics, shackles from stainless steel.
Mechanical stops will be provided on the mechanisms.
The SLD frame will be provided with wheels for cleanroom displacements.
The SLD will be compatible with the 100k cleanliness requirements.

Design Description

To cover all required configurations of hoisting, the shape of the SLD is a rectangular framework with extensions on all four sides and cross beams between the two longer sides of the rectangle. The rectangular shaped frame is welded from carbon steel made RHSs.
The COG adjustment mechanism is formed by crosswise arranged, linear roller bearing sliding units, the electrical powered drive units and the load-carrying structure, which is also made from carbon steel RHSs.
The item will have a drip tray (made from steel sheets), covering almost the entire bottom surface of the frame. During storage of the item inside the facility, all loosen things (shackles, slings...) can be put there in.
Gears and motors drive the drive units of the adjustment mechanism. The gears provide a second input drive shaft that is used to attach the handwheels for the manual adjustment possibility. The motors are chosen to cover also the power needed for adjustment of the COG under max. SWL. The handwheels are facing to the side of the SLD gearbox drives and are placed nearby to ease the access.
The actual position is displayed on two separate display units on the remote control.
Additional scales will be put nearby the sliding units, to allow position supervising during adjustment by hand.
The I/F to the crane is designed as a stainless steel plate providing the necessary opening for the crane hook on the topside. On the bottom side the plate is interfacing to the sliding units for one direction.
On the bottom side of the SLD attachment provisions for the several different hoisting configurations are made. Hoisting eyes welded to the frame makes these provisions.
The sling arrangement is composed from the following parts, listed in the order from the SLD down to the attachment point on the payload:

- Shackle
- Synthetic Sling (with incorporated end fittings)
- Shackle

The electrical switch box is mounted to the top of the item. A line heading from the floor to the SLD hanging on the crane will carry out the power supply. All the other necessary switches and displays are arranged on the remote control, hanging from the SLD. The remote control box is hanging on a so called balancer giving an adjustment range in height of about 6 m to avoid the box lying on the floor. Main switch, fuses and circuit cutters are on or inside the switch box.
The SLD is equipped with 4 castors for in facility ground movement.
Four guiding slings provisions, attached to the outer edges of the frame allow manual stabilising of the item during de- and attaching via facility slings.
Structural Material of the item will be carbon steel due to the high loads occurring. Lifting slings will be made from synthetic material. Attachment hardware between payload, SLD and slings will be stainless steel, between SLD and facilities cranes stainless steel. Surface treatment will be at least alodine 1200 for aluminium alloy, passivating for stainless steel and white gloss painting for carbon steel parts.

10.1.13 TRANSPORT & HANDLING ADAPTER FOR SATELLITES (THA)

Function

The THA will be used to support both SVM and the satellites Herschel and Planck during the integration and transportation activities in any configuration. The THA will support the SVM during Mass, CoG and MoI measurements with the Xs-axis in horizontal and vertical position.

Performance
The THA will be compliant to all I/F's given above.
The height of the item will be 150 mm (tbc) to be compatible with the SVM envelope and PTT/EPT height.
The SWL of the item will comply with the HERSCHEL Satellite in wet configuration (3000 kg - tbc).
Hoisting lugs will be incorporated for the hoisting of the SVM with Xs axis in horizontal position (the TTA or Horizontal Lifting Adapter provides the other I/F's to the SLD). The same lugs will be used for the hoisting of Planck satellite with Xs-axis in horizontal position.
Hoisting points will be incorporated for the levelled hoisting of the adapter alone in horizontal and vertical position.
A removable soft material protection cover will be provided to protect the interface with the Flight Hardware.
Two opposite positioned grounding points will be provided.
The mass of the item will be 110 kg (tbc).
Notches indicating the S/C Y-Z axes will be provided on both I/F flanges of the adapter.
The adapter will be compatible with the class 100k cleanliness requirements.

Design Description
The THA is a welded construction made of aluminium EN AW-6082. It consists of the following parts:

- The I/F flange to the SVM:

The upper flange is build as defined in the ARIANE User Manual.

- Central cone:

A cone, which is fixed on the upper I/F flange by welding.

- The I/F plate to the MGSE:

It is a plate with the needed hole pattern and 3 guiding pins for alignment of the THA on the GTA. Connection between the plate to the central cylinder is also performed by welding.

Wall thickness of plates and central cylinder as well as material EN AW-6082 are selected to be compliant to the maximum load cases during AIT activities.
For Xs-axis horizontal hoisting of the SVM 4 brackets, equally spaced over the circumference, will be welded to the conical part.
For Xs-axis vertical hoisting of the THA 4 brackets, equally spaced over the circumference, will be welded to the conical part.
For periods when not in use, protection rings are fitted to the flanges. For storage and transport, a dedicated MGSE Container is supplied.
Structural material for the THA adapter is aluminium alloy, with stainless steel attachment accessories. Surface treatment is anodised or alodine treatment.

10.1.14 HANDLING CLAMP BAND (HCB)

Function
The Handling Clamp Band will be used to fix the SVM and fully integrated S/L (wet) at its launcher I/F to the relevant adapters during handling activities.

Performance
The HCB will be used to attach the S/C with facility or MGSE equipment for handling and tests.
The HCB will be compliant with cleanliness requirements of class 100 000.
The HCB will allow the fixation for the various S/C configurations on the respective MGSE or facility in either horizontal or vertical position 50 times. The item will be able to withstand min. 10 times the test sequence.

Design Description
The HCB design is based on the concept to have two similar bands segments, bolted together and tensioned by special bolts. This concept provides a better control in terms of band elongation during tensioning than having four segments.
Except the instrumentation with strain gauges the HCB design is similar to the TCB design. It mainly consists of the three major parts:

- The circular band
- The clamp segments
- The tensioning mechanism.

The circular band is a high strength steel band with a complete Teflon coated surface to allow deflection of the floating shoes relative to the band with low friction.
On each HCB segment there are 13 clamp segments attached. The bolts and distance tubes are connected via slotted holes in the band, so that the shoes can travel a definite length without a physical stop. The bushes have a positive tolerance w.r.t. the band to have no additional compression load on the band due to bolt preload.
The assembly parts will be manufactured completely out of stainless steel.
The Material of the clamps will be a high strength aluminium alloy, the surface treatment will be hard coat anodised.
A loadcell is incorporated into the closing bolts, to check the pretension of the tensioning bolts.
On each end of the band segment a special bracket is attached in order to allow pretensioning the band.
This bracket is a machined part in high strength stainless steel. The surface treatment will be passivation.
The bolt head and nut are supported via spherical washers to assure that there are no bending moments introduced into the bolt shaft during tensioning.

10.1.15 TEST CLAMP BAND (TCB)

Function
The Test Clamp Band will be used to fix the SVM and fully integrated S/L (wet) at its launcher I/F to the relevant adapters during test activities.

Performance
The TCB will be used to attach the S/C with facility or MGSE equipment for handling and tests.
The TCB will be compliant with cleanliness requirements of class 100 000.
The TCB will be compatible with vacuum environment and a working temperature range of – 100°C to +100°C (tbc)
The TCB will allow the fixation for the various S/C configurations on the respective MGSE or facility in either horizontal or vertical position 50 times. The item will be able to withstand min. 10 times the test sequence.

Design Description
The TCB design is based on the concept to have two similar bands segments, bolted together and tensioned by special bolts. This concept provides a better control in terms of band elongation during tensioning than having four segments.
It mainly consists of the three major parts:

- The circular band
- The clamp segments with incorporated keys
- The tensioning mechanism.

The circular band is a high strength steel band with a complete Teflon coated surface to allow deflection of the floating shoes relative to the band with low friction.
On each TCB segment there are 13 clamp segments attached. The bolts and distance tubes are connected via slotted holes in the band, so that the shoes can travel a definite length without a physical stop. The bushes have a positive tolerance w.r.t. the band to have no additional compression load on the band due to bolt preload.

The assembly parts will be manufactured completely out of stainless steel.
The Material of the clamps will be a high strength aluminium alloy, the surface treatment will be hard coat anodised.
A loadcell is incorporated into the closing bolts, to check the pretension of the tensioning bolts. Strain gauges will be placed on the band segments to check the tension in the band segments.
On each end of the band segment a special bracket is attached in order to allow pretensioning the band.
This bracket is a machined part in high strength stainless steel. The surface treatment will be passivation.
The bolt head and nut are supported via spherical washers to assure that there are no bending moments introduced into the bolt shaft during tensioning.

10.1.16 GENERAL TEST ADAPTER (GTA)

Function
The GTA will support the SVM mounted on the THA during Mass Property Measurement

Performance
The GTA upper flange will interface to the THA.
The GTA lower flange will interface to the Mass Property Machine (see above). Therefore also a special centring pin is provided.
The GTA is designed to withstand the maximum load during the AIT activity with the SVM in horizontal and vertical position.
The GTA is equipped with a centring device to the THA I/F. Therefore 3 x alignment pins are used.
When GTA is mated with THA:

- Parallelism between the I/F planes (GTA/Mass Properties Machine and THA/SVM) will not exceed 0,2mm (TBC)
- The THA upper flange and GTA centring pin concentricity will be within ? 0,5 mm (TBC).

The flatness of both I/F planes of the GTA will not exceed 0,2 mm (TBC).
The mass of the item will be 310 kg (TBC).
Hoisting provisions are incorporated for both Xs up/down and Xs horizontal hoisting of the GTA itself.
Two grounding points will be provided.
Engraved marking of the SVM axes (+Y and +Z) shall be present on both flanges of the adapter.
The GTA will be compatible with the class 100k cleanliness requirements.

Design Description
The GTA is a welded construction made of aluminium EN AW-6082. It consists of the following parts:

- The I/F plate to the Mass Property Machine:

It is a plate with the needed hole pattern and a special centring pin for alignment of the GTA on the Mass Property Machine.

- Central cylinder:

A cylinder, which is fixed on the upper surface of the I/F plate to the Mass Property Machine by welding.

- The I/F plate to the THA:

It is a plate with the needed hole pattern and 3 guiding pins for alignment of the THA on the GTA.

Connection between the plate to the central cylinder is also performed by welding.
Wall thickness of plates and central cylinder as well as material EN AW-6082 are selected to be compliant to the maximum load cases during AIT activities.
The item is equipped with 4 x hoisting lugs, for horizontal lifting of the adapter (w/o Flight Hardware) with Xs-axis up and down. For vertical lifting, only one of the four hoisting lugs is used. It is located in the line of the CoG.
Two grounding points are provided on the upper surface of the I/F plate to the Mass Property Machine.
Surface treatment will be alodine treatment.

10.1.17 THERMAL TEST ADAPTER (TTA)

Function
The TTA will be used to support the SVM during the STM Thermal Balance Test. It will form the link between the Chamber Motion of the thermal vacuum chamber and the SVM-PLM I/F. During the Thermal Balance Test the SVM Xs-axis will be in horizontal position with the LVA I/F facing the Sun Simulator.

Performance
Sizing and load capability, under the worst thermal load conditions, will be performed taking into account the physical properties defined in the SVM MGSE Requirements Specification. The relevant design and safety factors will be considered.
The adapter height will be such that the S/C is optimally positioned in the chamber test volume. The height is assumed to be 510 mm.

The TTA will provide notches on both I/F sides indicating the Ys – Zs axes of the S/L The TTA will be provided with hoisting points interfacing the SLD for horizontal lifting and handling and handling the test article inside the Thermal Chamber. During this operation the THA will provide the other two hoisting points.
The TTA will be provided with hoisting points for the levelled lifting of the adapter (alone) in horizontal and vertical position.
The TTA surface finishing will be black anodising
The TTA will allow the fixation of heaters at the SVM I/F and will isolate the S/C from direct heat conductance through the adapter via thermal washers (Vetronite, thickness 10mm)
The TTA will provide access holes for the connection of the test instrumentation to the facility connectors.
The TTA will allow the fixation of MLI via standoffs or sunshield with a similar method.
Soft protective cover will be foreseen for the SVM I/F during transportation and storage.
The TTA mass will be compatible with the maximum allowable load capacity of the test facility.
The TTA will be made of stress corrosion resisting material.
The TTA will be compatible with the class 100k cleanliness requirements.

Design Description
The TTA is a welded construction made of aluminium EN AW-6082 (tbc). It consists of the following parts:

- The I/F flange to the PLM I/F's of Herschel and Planck SVM:
- Central cone:

A cone, which is fixed on the upper I/F flange by welding.

- The I/F plate to the Thermal Test Facility Yoke:

It is a plate with the hole pattern: 24 x ? 21 on PCD 870 Lower I/F plate.

Connection between the plate to the central cylinder is also performed by welding.
Wall thickness of plates and central cylinder as well as material EN AW-6082 are selected to be compliant to the maximum load cases during AIT activities.
The adapter has a height of 500 mm (TBC).
For Xs-axis horizontal hoisting of the SVM 4 brackets, equally spaced over the circumference, will be welded to the conical part.
For Xs-axis vertical hoisting of the TTA 4 brackets, equally spaced over the circumference, will be welded to the conical part.
For periods when not in use, protection rings are fitted to the flanges. For storage and transport, a dedicated MGSE Container is supplied.
Structural material for the TTA adapter is aluminium alloy EN AW 6082, with stainless steel attachment accessories. Surface treatment is black anodising (TBC).
The TTA mass will be 250 kg.
The TTA will provide 4 access holes with a diameter of ? 200 TBC mm on the central cone.
Thermal decoupling will be performed with the use of Vetronite washers between the I/F planes of the TTA to the SVM's and the Facility Yoke.

10.1.18 SPACECRAFT MASS DUMMY (SMD)

For the design of the SMD a maximum mass for the SVM of 1000 kg and a maximum mass for the PLM of 2200 kg is assumed.
In addition the mass of the HLA and HLD for Planck satellite will be simulated (HLA 600 kg, COG offset 300 mm; HLD 3000 kg; COG offset 1400mm)
The COG of the SVM is assumed to be centred 400 mm above the yz-Plane, the COG of the Herschel Spacecraft is assumed.
For the design of the panel mass dummy a COG position in z-Direction of 200 mm is presumed. A drill pattern of the panels is assumed as shown in the drawing.

Function
The SMD will be used to accomplish the acceptance of the various MGSE's as well as certification during the AIT phases.
The SMD will be used for the proof tests and the functional performance tests of the MGSE items.

Performance

The SMD is capable to simulate the mass, centre of gravity and I/F of the Flight Hardware in all test configurations simulating one time the maximum mass, 1.5 times the maximum mass or twice the maximum mass for:

- Each SVM Panel HERSCHEL
- Each SVM Panel PLANK
- Complete SVM HERSCHEL
- Complete SVM PLANK
- Complete PLM HERSCHEL
- Complete Satellite HERSCHEL

As the characteristic values for the Plank-PLM are smaller than the characteristic values for the Herschel-PLM the following loads are covered by simulating the Herschel-PLM:

- Complete PLM PLANK
- Complete Satellite PLANK

The Panel Dummy represents the geometrical and physical properties as necessary for testing the relevant MGSE

Design Description

- Panel Mass Dummy

The following configurations have been taken into account:

To comply with the various sizes, masses and COG positions, the dummy comprises of an I/F-plate, an adjustable box made of thin sheets and mass plates.

The I/F plate shows the same drill pattern as the panels. In addition drilling holes are incorporated to give the possibility to use the I/F plate as a measuring tool for the panel support frames of the EPD I/Fs to the other MGSE parts.

The box is made of thin aluminium alloy sheets and is adjustable in height via slots and fixation bolts.

On top of the box the mass plates will be arranged depending on the needed configuration.

Materials for the Dummy are carbon steel (mass plates) and aluminium alloy.

- SVM Mass Dummy

The SVM Mass Dummy provides the I/F to the PLM Mass Dummy.

It provides I/Fs to the PLM and the THA as on the SVMs.

The mating I/F between the SVM Mass Dummy and the PLM Mass Dummy provides the same drill pattern as the Flight Hardware.

The mass of the dummy represents the specified values of mass and COG position. By attaching mass plates the SVM Mass Dummy can be configured to 1.5 times the specified mass and twice the specified mass maintaining the COG on the requested position.

Materials for the Dummy are carbon steel and aluminium alloy.

- PLM Mass Dummy

The PLM Mass Dummy provides the I/F to the SVM Mass Dummy.

It provides an attachment I/F to the SVM as on the PLMs.

The mating I/F between the SVM Mass Dummy and the PLM Mass Dummy provides the same drill pattern as the Flight Hardware.

The mass of the dummy represents the specified values of mass and COG position. By inserting masses the PLM Mass Dummy can be configured to 1.5 times the specified mass and twice the specified mass maintaining the COG on the requested position.

Materials for the Dummy are carbon steel and aluminium alloy.

10.2 EGSE

Detailed information about CCS design is provided in the [RD-79] (SW Design) [RD-80] (HW Design) Approach to the test is provided in. [RD-81] (CCS Test Plan)

Different test activities are foreseen to be performed on AVM / SVM, in particular:

- HERSCHEL/PLANCK AVM Integration and Functional test
- FM HERSCHEL SVM test activities
- FM PLANCK SVM test activities.

Regardless the ongoing activities, the EGSE configuration will be always the same and it is shown in figure 6-2.

The AVM / SVM Herschel/Planck EGSE will be built with the following equipment:

- Central Check Out System (CCS)
- The Power Control Subsystem SCOE (Power SCOE)
- The Telemetry, Tracking and Command SCOE (TT&C SCOE)
- The Telemetry and Telecommand Data Front End Equipment (TM/TC DFE)
- The Attitude and Control Measurement Subsystem SCOE (ACMS SCOE)
- The Central Data management Unit SCOE (CDMU SCOE).

All the above items are interconnected through an Ethernet Local Area Network (LAN) used to exchange both data and command & control information.

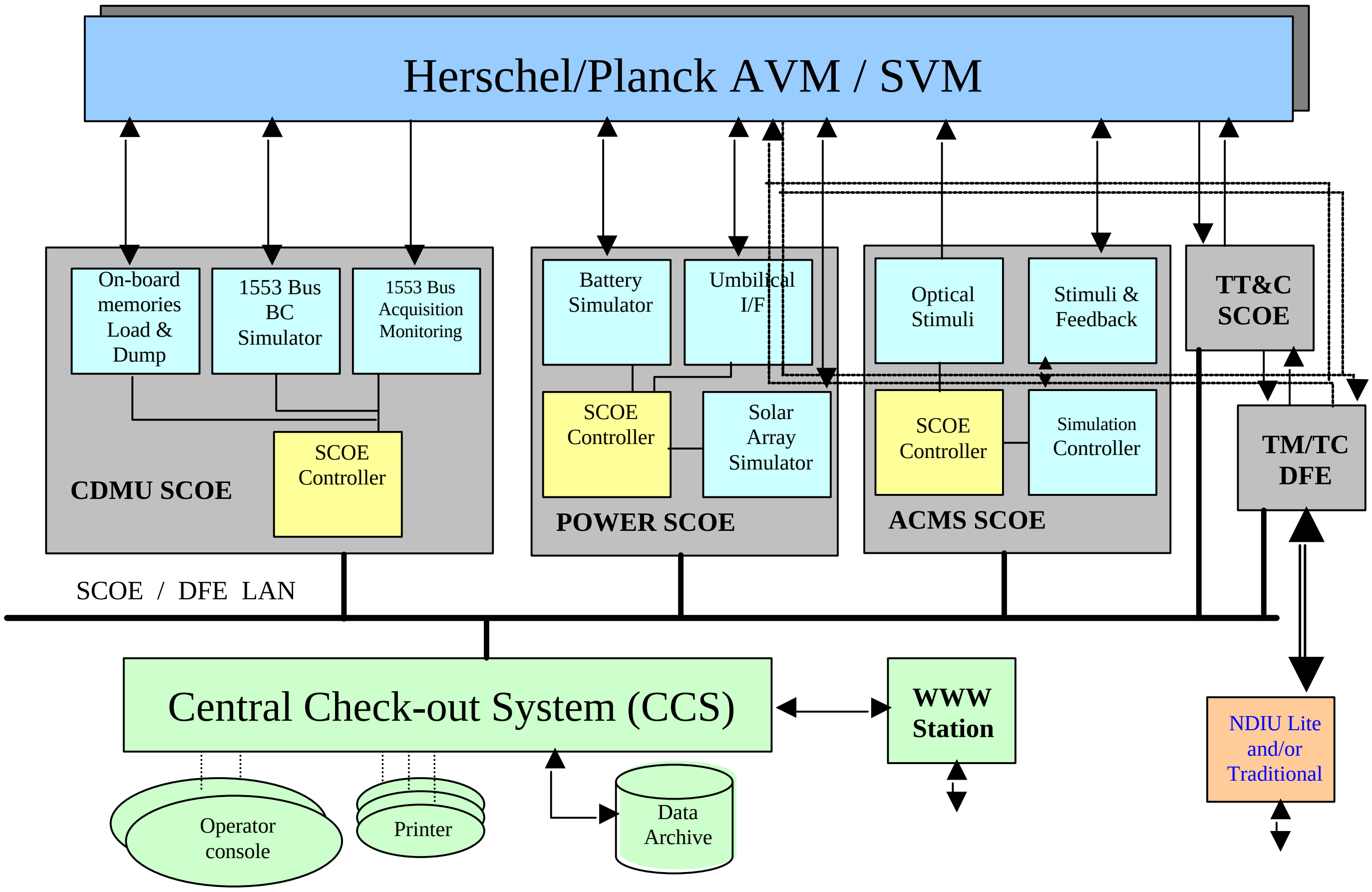


Figure 10.2 -1 Herschel/Planck AVM/SVM EGSE functional architecture

10.3 EGSE USER S/W

During testing activities the Herschel/Planck AIV Team will be able to develop all the required “USER S/W” in order to automate the execution of the functional and performance verifications of the Satellite.
Most of the Test Software will be developed on the CCS and it will consists mainly of:

- Test Sequences
- Synoptic Displays
- Data Evaluation and Test Analysis Software
- Simulation Software Master sequences (mainly for ACMS S/S).

On the contrary, on the SCOE’s/DFE only a very peculiar type of software will be developed; it will mainly consist of:

- Configuration/set-up files for SCOE’s/DFE instrumentation
- Sequence of commands
- Simulation files for Dynamic control and ACMS Sensors simulation
- Telemetry Simulation file for Missing Unit (Experiments).

10.4 AIT TOOLS TEST AID AND BREAK OUT BOXES

A complete series of tool, test Aid and break out boxes (with the relevant interface cables) will be defined and procured as part of early phase B.
The activity of test H/W definition shall consist in:

- Analysis of special need for integration purposes: signal, monitor, power interface etc… to be verified for nominal activity and for troubleshooting purposes.
- Analysis of connectors where a need of an interface arise (skin connectors, etc…)
- Analysis of module accessibility during the defined test