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, leaded 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 phase C/D is June 2001.
This Issue of the document has been prepared as part of the Data Package of the System Requirement Review with the objective to document the technical Baseline for both the 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 PDR.

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

Acronym	Description
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
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
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
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
CDR	Critical Design Review
CDS2A	CCSDS Day Segmented A
CE	Conducted Emission
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
Co-I	Co-Investigator
COBE	Cosmic Background Explorer
CoC	Certificate of Conformance/Compliance
CoG	Centre of Gravity
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
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
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
MoI	Moment of Inertia
MoI	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
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
RE-E	Radiated Emission E-field
RE-H	Radiated Emission H-field
REBA	Radiometer Electronics Box Assembly (LFI)
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)
SDB	Satellite Data Base
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	Instrument Interface Document, part B: Bolometer Instrument
AD-03	SCI-PT-IIDB/HIFI-02125	Instrument Interface Document, part B: Heterodyne Instrument
AD-04	SCI-PT-IIDB/PACS-02126	Instrument Interface Document, part B: Photoconductor Instrument
AD-05	SCI-PT-IIDB/HFI-04141	Instrument Interface Document, Part B (IID-B): HighFrequency Instrument
AD-06	SCI-PT-IIDB/LFI-04142	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	H-P-4-ASPI-IS-0042	SVM interface specification

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 dated 13-June-2001	SVM Configuration Requirement
AD-43	H-P-4-ASPI-SP-0019 Issue 1.1	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

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-000X	SVM Budget Report

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

3. INSTRUMENTS INTERFACE AND ACCOMMODATION DATA

This chapter provides a brief description of the interfaces with Herschel and Planck Instruments warm units installed on the Service Modules.
A compilation of Instruments interface data is specified in the Instruments Interface Documents, IID-A and IID-B's (AD-01 to AD-06).
At the time of the Report preparation, the valid Issues are the Proposal ones (Issue 1.0). Based on the clarifications exchanged since the beginning of the phase B, some updating are reflected in the present Report. This applies only to the modifications clearly identified without major impacts on SVM design and agreed among all the parties.
This chapter will be updated as result of the SRR process taking into account the agreed set of interfaces. Global resources required from the SVM are stated in the form of budget tables, to be discussed in the reminder of the report.

3.1 INTERFACE DATA

3.1.1 Structure Interface

For the warm modules in the SVM, the mechanical interfaces between the instruments and the satellites are similar to any other avionics modules. Boxes will be bolted on a radiator (Al skins sandwich panel) on the side of the SVM (preferably a panel dedicated to an instrument), according to the scheme proposed in AD(1) which is standard for such equipment.
The main requirements concerning the instrument warm boxes accommodation are to limit the length of the cables and pipes. Cable length must be minimized when large dissipation or signal losses can take place (Planck sorption cooler power cables between PDU and SCE [Sorption Cooler Electronics] and between SCE and SCC [Sorption Cooler Compressor). These constraints are taken into account in the proposed configuration.
Mechanical loads for instrument warm boxes are specified in the IID-A (Ref. AD1). for the limit loads (10 g for SVM units, originated from ISO). These levels will have to be updated according to the analysis results of the proposed solution for the SVM, and the ARIANE 5 Launcher.

3.1.2 Thermal Control Interface

Thermal interfaces of instrument warm units on service module are similar to any other Avionics modules.
Dissipation and required temperature ranges are shown on tables Table 3.1.2-1 for Herschel and Table 3.1.2-2 for Planck. Temperature requirements are not completely similar for warm electronic boxes and will have to be standardised during phased B.

HERSCHEL		TCS Design Temperature Range [°C]					
Project code	Instrument unit	Operating range	Non operating range	Start-up	Switch-off	Stability [°C/100s]	Reference Document
HIFI							
FHWBO	Wide Band Spectrometer, AOS	-10/+40	-25/+55	-25	-30	0.03	SCI-PT-IIDB/HIFI-02125
FHWBI	WBS - IF processor 8	0/+25	-25/+55	-25	-40	0.03	SCI-PT-IIDB/HIFI-02125
FHWBE	WBS - electronics	0/+40	-25/+55	-25	-40	0.14	SCI-PT-IIDB/HIFI-02125
FHICU	Instrument Control Unit	-25/+40	-30/+60	-30	-50	0.14	SCI-PT-IIDB/HIFI-02125
FHFCU	Focal Plane Control Unit	-10/+40	-25/+55	-25	-40	0.14	SCI-PT-IIDB/HIFI-02125
FHHRV	High-Res Spectrom. ACS vertical polarisation	-10/+40	-25/+55	-25	-40	0.03	SCI-PT-IIDB/HIFI-02125
FHHRI	High-Res Spectrom. IF Processor	-10/+40	-25/+55	-25	-40	0.03	SCI-PT-IIDB/HIFI-02125
FHHRH	HRS, ACS horizontal polarization	-10/+40	-25/+55	-25	-40	0.03	SCI-PT-IIDB/HIFI-02125
FHLCU	Local Oscillator Control	-10/+40	-25/+55	-25	-40	0.03	SCI-PT-IIDB/HIFI-02125
FHLSU	Local Oscillator Source Unit	-10/+40	-25/+55	-25	-40	0.03	SCI-PT-IIDB/HIFI-02125
PACS							
FPDPU	Digital Processing Unit	-15/+45	-30/+60	-30	+50	NA	SCI-PT-IIDB/PACS-02126
FPSPU	Signal Processing Unit	-15/+45	-30/+60	-30	+50	NA	SCI-PT-IIDB/PACS-02126
FPDMC	Detector / Mechanism Control	-15/+45	-30/+60	-30	+50	NA	SCI-PT-IIDB/PACS-02126
FPBOLC	Bolometer / Cooler Control	-15/+45	-30/+60	-30	+50	NA	SCI-PT-IIDB/PACS-02126
SPIRE							
FSDRC	Detector Read-out and Control Unit	-15/+45	-35/+80	-30	+50	NA	SCI-PT-IIDB/SPIRE-02124
FSDPU	Digital Processing Unit	-15/+45	-35/+80	-30	+50	NA	SCI-PT-IIDB/SPIRE-02124
CRYO							
CRYOELECT	Cryoelect	-10/+40	-20/+50	-20			SVM IS FP-ASPI-IS-1008

<u>* External interface: [FP-ASPI-IS-1008]</u>

Cryostat interface: the Thermal control of the SVM shall ensure that the heat fluxes from the SVM to the Cryostat via Cryostat support struts are t be lower than 1 Watt, considering a temperature T1 (see fig. page 28) of 65 K at Cryostat I/F. [FP-ASPI-IS-1008]

Table 3.1.2-1 HERSCHEL Instrument Units temperature Range

PLANCK		TCS Design Temperature Range [°C]					
Project code	Instrument unit	Operating range	Non operating range	Start-up	Switch-off	Reference Document	Rem.
HFI	**High Frequency Instrument**						
PHBA	Data Processing Unit (DPU)	-10/+40	-20/+50	TBD	TBD	SCI-PT-IIDB/LFI-04141	**
PHCBA	Pre-Amplifier Unit (PAU)	-20/+30	-20/+50	TBD	TBD	SCI-PT-IIDB/LFI-04141	**
-20 °C < PAU I/F temperature < +30 °C						SVM IS FP-ASPI-IS-1008	**
PHCBC	Readout Electronics (REU)	-20/+30	-20/+50	TBD	TBD	SCI-PT-IIDB/LFI-04141	**
PHDA	4 K Cooler Compressor Unit	-10/+40	-20/+40 TBC	TBD	TBD	SCI-PT-IIDB/LFI-04141	**
PHDB	4 K Cooler Ancillary Unit	-10/+40	-20/+50	TBD	TBD	SCI-PT-IIDB/LFI-04141	**
PHDC	4 K Cooler Electronics Unit	-10/+40	-20/+50	TBD	TBD	SCI-PT-IIDB/LFI-04141	**
PHEAA	0.1 K Dilution Cooler ^{3} He Tank	-10/+40	-20/+50	TBD	TBD	SCI-PT-IIDB/LFI-04141	**
PHEAB	0.1 K Dilution Cooler ^{4} He Tanks	-10/+40	-20/+50	TBD	TBD	SCI-PT-IIDB/LFI-04141	**
PHEC	0.1 K Dilution Cooler Control Unit	-10/+40	-20/+50	TBD	TBD	SCI-PT-IIDB/LFI-04141	**
PHED	0.1 K Filling and Venting Panel	-10/+40	-20/+50	TBD	TBD	SCI-PT-IIDB/LFI-04141	**
LFI	**Low Frequency Instrument**						
PLBEU	Back End Unit (BEU)	-20/+28 *	TBD/TBD			SCI-PT-IIDB/LFI-04142	
20 °C < BEU I/F temperature < +28 °C						SVM IS FP-ASPI-IS-1008	
PLREN	Radiometer Electronics Box Assemply (nominal)	-20/+50	-30/+70			SCI-PT-IIDB/LFI-04142	
PLRER	Radiometer Electronics Box Assemply (redundant)	-20/+50	-30/+70			SCI-PT-IIDB/LFI-04142	
Sorption Coolers							
SCC	Sorption Cooler Compressor	-13/+7	-20TBC/+50	-20 TBC		PL-LFI-PST-ID-002 SCC ICD Annex of IIDB/LFI-04142	
SCE	Sorption Cooler Electronics	-10/+40	-20/+50	-10	+40	" "	

* The main requirement is not the absolute temperature limits but in the temperature stability. In order to avoid any disturbance of the LFI detected signal the temperature variation shall be less than TBD K/hr during normal observation period.
This stability requirement is not yet agreedby.the Project

** In order to avoid any disturbance of HFI detected signal the Pre-Amplifier Unit temperature variation shall be less than 0.1 degree per hour during nominal observation period. A temperature at the lower end of the operational range is preferred to reduce the noise of components.
This stability requirement is not yet agreedby.the Project

External Interface: [FP-ASPI-IS-1008]

The temperatures range at the BEU I/F (T2) and at the PAU I/F (T3) shall be (see fig. page 34): [FP-ASPI-IS-1008]

20°C < BEU I/F temperature (T2) < +28°C

-20°C < PAU I/F temperature (T3) < +30°C

PPLM Interface

\# The maximum temperatures (T1) PPLM Interface shall be lower than 293 K

\# The fluctuation of the temperatures (T1) shall be:

± 325 µK on a time period of 325 s

± 0.25 K on a time period of 2 hours

Inside SVM: [FP-ASPI-IS-1008]

The difference of the temperature between P.Tanks inside the SVM shall.be lower than 5°C

The temperature of the He Tanks I/F is -10°C<T5<40°C

The difference of the temperature between He Tanks inside the SVM shall be lower than 5°C (TBC).

The Thermal control of the SVM shall ensure that the fluctuation of the everage temperatures (T4) at the SCC I/F shall be:

260 K < T4 < 280 K with a nominal temperature at 270 K

The thermal control of the SVM shall ensure that the fluctuaction of the average temperatures of the SCC panels shall be:

± 0.4 K on a 325 s time period.

± 0.5 K on a 2 hours time period.

Table 3.1.2-2 PLANCK Instrument Units temperature Range

The instrument electronics boxes or cooler compressors are attached to a radiator dedicated to an Instrument.
Instrument boxes are attached directly on radiators which will be sized in emissivity/Area. Software controlled heaters will adjust the temperature in the middle of the allowed range, or compensate for the lack of dissipation when the instrument is switched off.
There are some specific requirements concerning the temperature stability for instrument warm units on both satellites:
For the Planck satellite studies performed up to now have shown that the degree of thermal insulation required between the SVM and the PLM is such that a typical temperature fluctuation on the SVM is damped low enough.
The Herschel HIFI electronics, accommodated on the SVM, has a special requirement on temperature stability (0.03°K/100 s, or 1°K/h) on most of the warm units, and a very narrow temperature range on the wide band spectrometer. The stability comes from the fact that the HIFI spectrometers are on the SVM. The IID-A (AD(1)) specifies a SVM bus stability of 0.3 K/h, with a goal of 0.1 K/h.
Temperature lower than ambient should be avoided for the SVM for ground tests. It appears that the requirement of 0 to 10° C for the WBO is related to the lifetime of an internal diode laser. It has been proposed with HIFI to relax this requirement for ground tests, together with the establishment of a budget of the usage duration/temperature of the diode laser (allowing TBD hours at 22° C).
The Stability requirement has to be assessed in more details before PDR for design feasibility and for the impact that it will imply to the CDMS and power architecture with respect to the proposed configuration.

3.1.3 Electrical Interface

The electrical interface between Herschel Instruments and SVM units are given in Figure 3.1.3-1, Figure 3.1.3-2 and Figure 3.1.3-3.

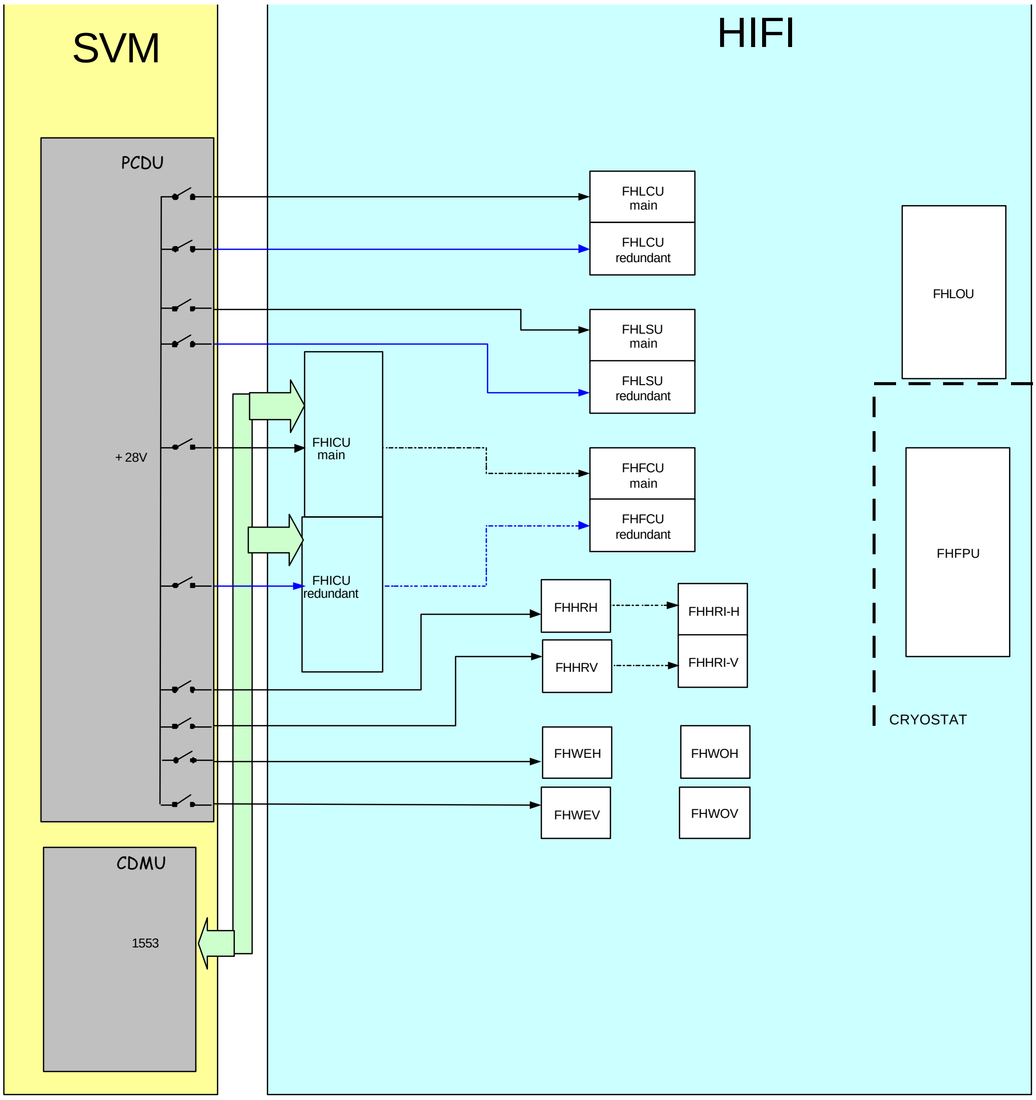


Figure 3.1.3-1 Heterodyne Instrument to SVM Interfaces

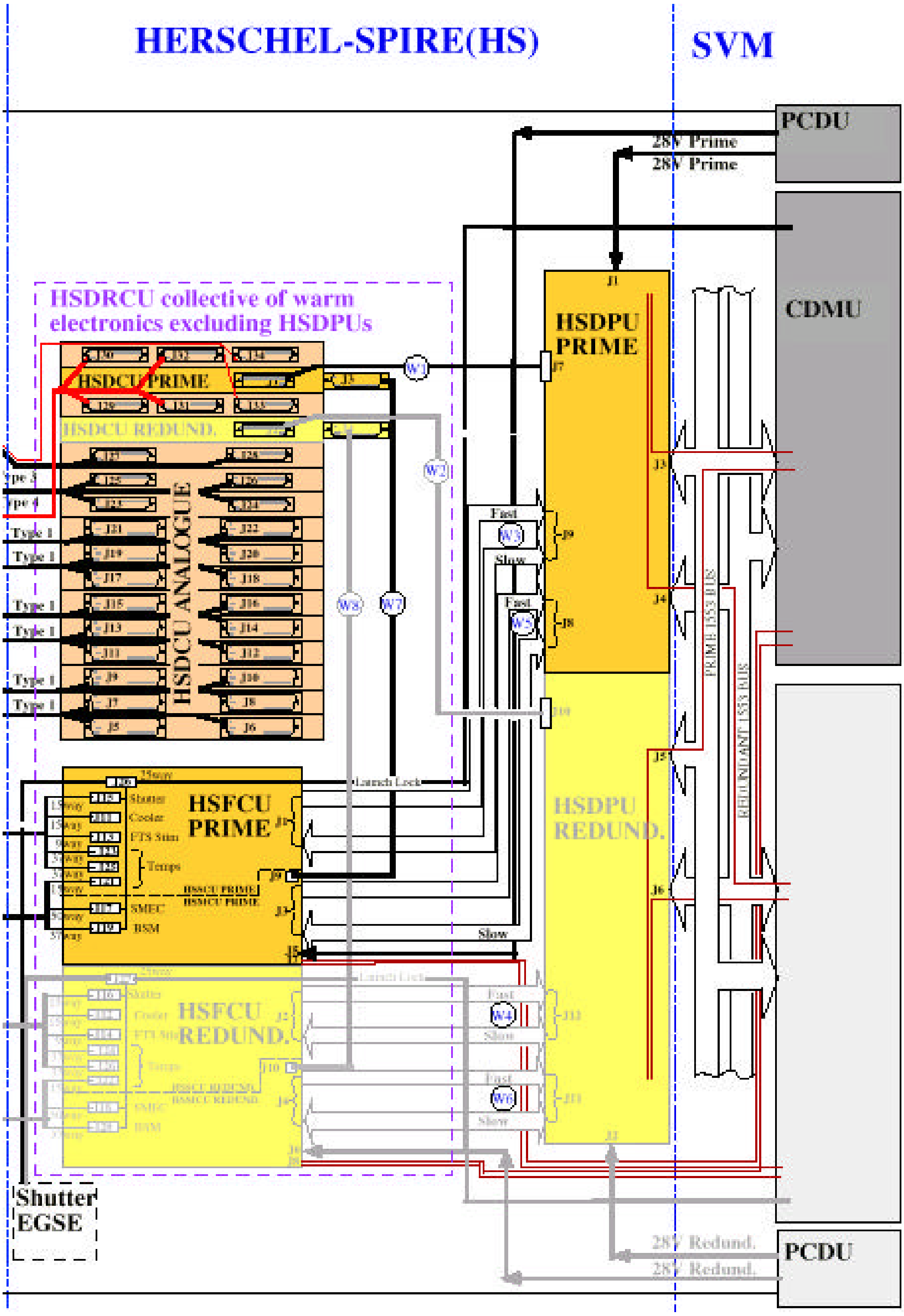


Figure 3.1.3-2 Spectral and Photometric Imaging Receiver to SVM Interfaces

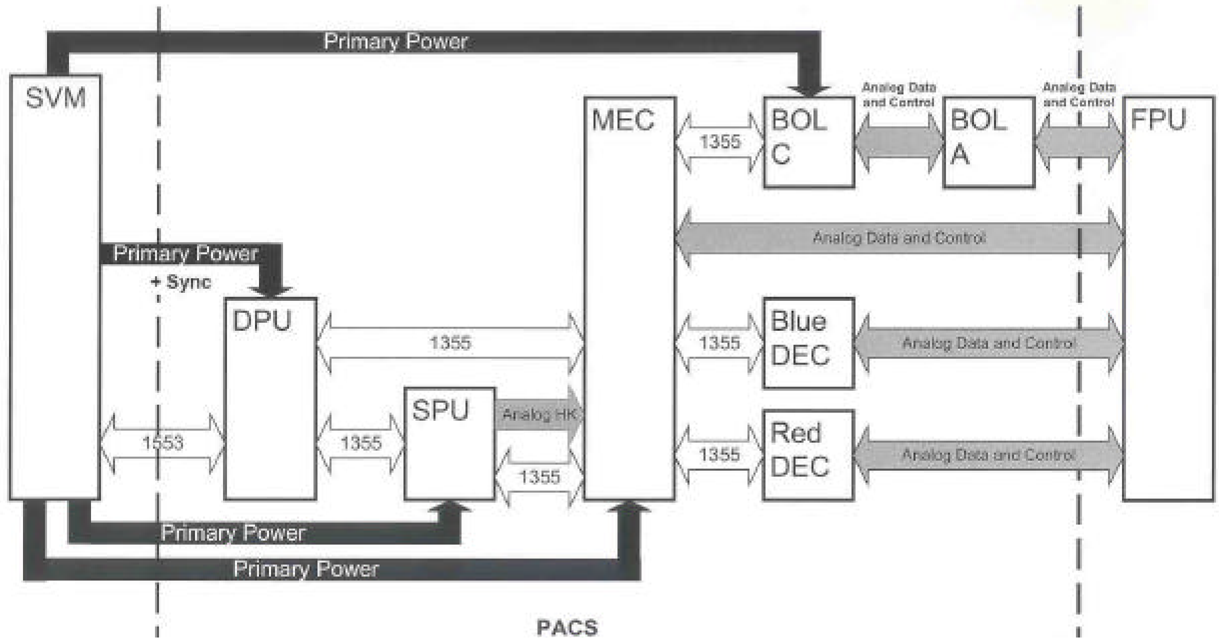


Figure 3.1.3-3 Photoconductor Array Camera and Spectrometer to SVM Interfaces

The electrical interface between Planck Instruments and SVM units are given in Figure 3.1.3-4, Figure 3.1.3-5 and Figure 3.1.3-6.

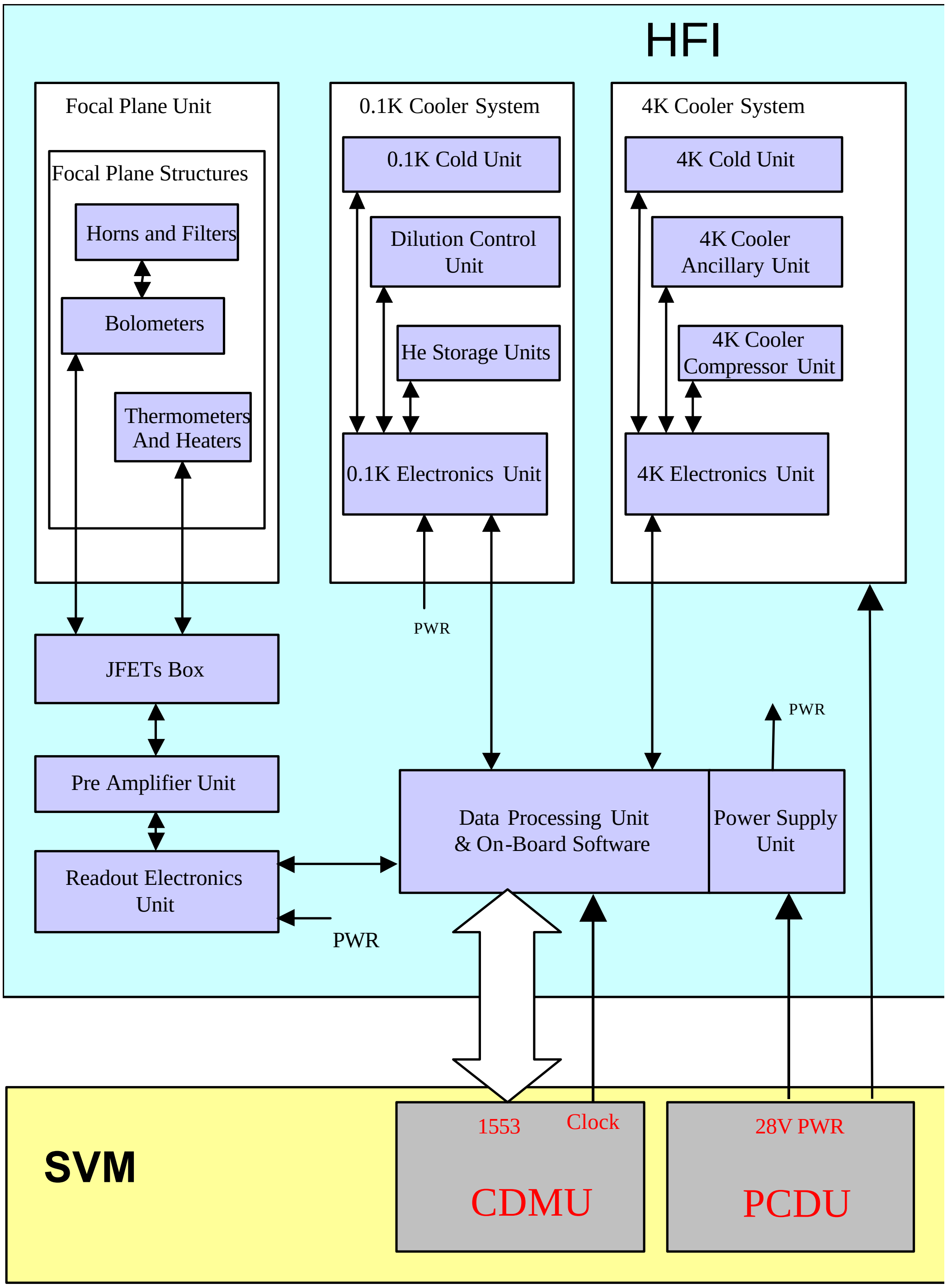


Figure 3.1.3-4 High-Frequency Instrument to SVM Interfaces

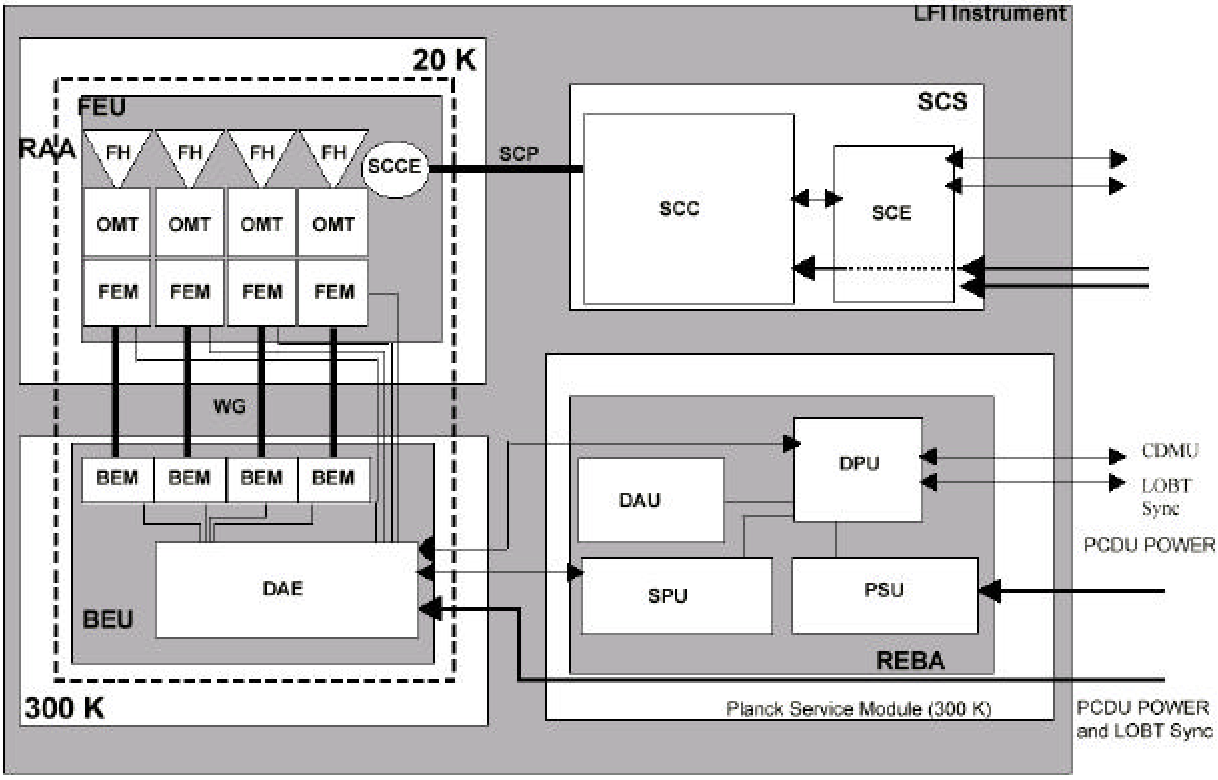


Figure 3.1.3-5 Low Frequency Instrument to SVM Interfaces

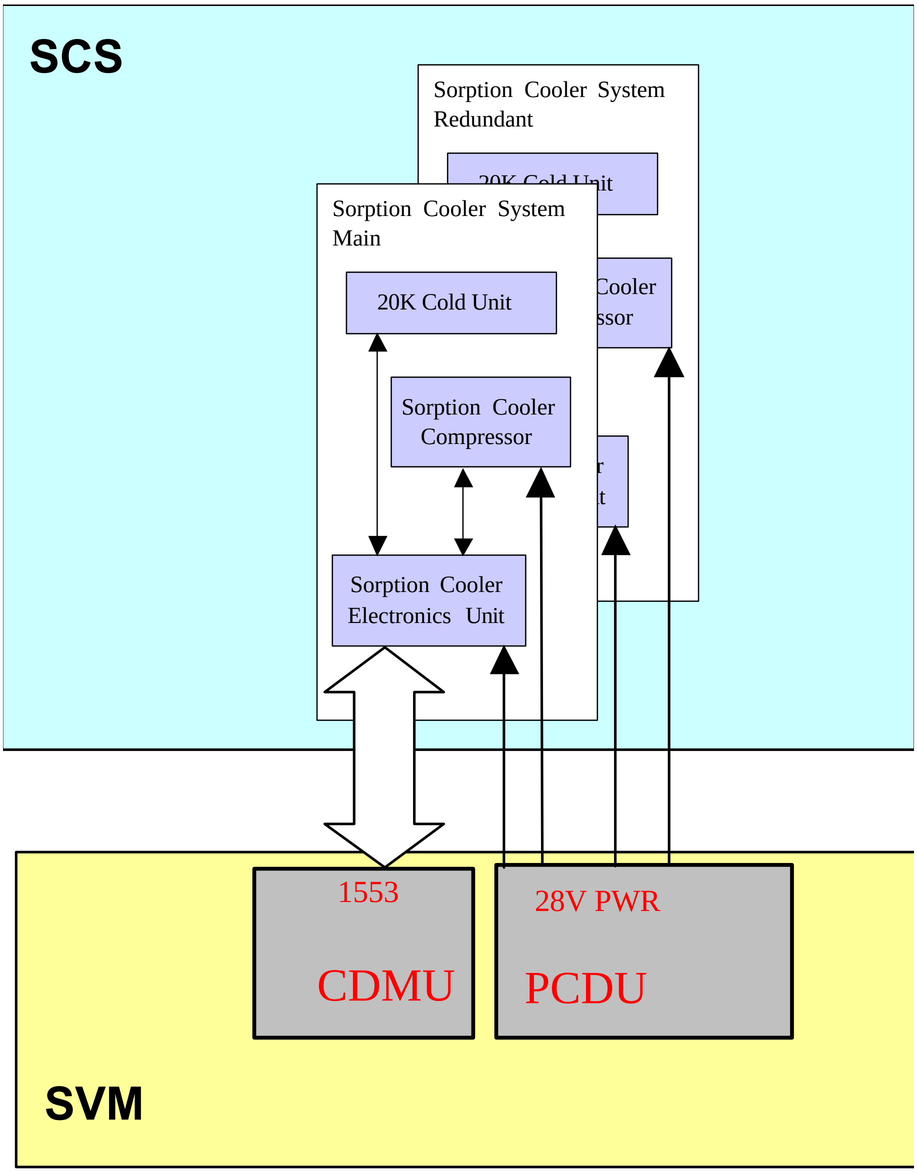


Figure 3.1.3-6 Sorption Cooler System to SVM Interfaces

3.1.4 Data Handling Interface

The data bus for both satellites will be implemented using the specified MIL-1553B bus. It will be used for science and housekeeping data collection and for time broadcasting and specific commanding of the instruments.

Discrete TM acquisitions and TC commands will be of the electrical characteristics specified in GDIR (AD-12). The number of discrete lines will be kept to a minimum since the majority of the TM/TC will be routed via the 1553 bus.
The Herschel instruments require an "On Target Flag". This flag is distributed via the 1553 bus using the Event TC mechanism.
The Planck Instruments require a reference star pulse, originating from the ACMS Star Mapper. This pulse is distributed via the 1553 bus using the Event TC mechanism.

A broadcast pulse will be generated by the Control and Data Management Unit (CDMU) which can be used by each instrument to synchronise their local on-board time to the satellite on-board time which is provided via the 1553 bus broadcasts. The electrical characteristics and timing of this clock will be identical for both Herschel and Planck.

Some instruments requires the CDMU to acquire temperature sensor channels. Quantity and type of these interface channels is not yet clearly defined.

.A Nominal and redundant broadcast pulse will be provided to enable the instrument Local On Board Time to be synchronised with the satellite On Board Time at the transmission of a 1553 broadcast message.

Herschel SPIRE instrument has 3 launch lock status indicators, to provide information to the CDMU when SPIRE is un-powered that it is ready for launch. At the present stage, these channels are allocated at CDMU side, but it still to be confirmed that these status have to be acquired for all the duration of the mission.

All TM/TC, and 1553 busses will be provided as Nominal and Redundant

CDMU interfaces with the Herschel instruments are identified in the following.

HIFI to CDMU Interfaces

1N + 1R 1553 Bus to the Instrument Control Unit (ICU)
TBD Thermistors

SPIRE TM/TC

1N + 1R 1553 Bus to the Digital Processing Unit (HSDPU)
3N + 3R Launch Lock Status (Relay Status) to the HSFCU
TBD Thermistors

PACS TM/TC

1N + 1R 1553 Bus to the DPU

CDMU interfaces with the Planck instruments are identified in the following.

HFI to CDMU Interfaces

1N + 1R 1553 Bus to the Data Processing Unit (DPU)
1N + 1R 131kHz LOBT Sync to DPU
14N + 14R HSK Thermistors

LFI to CDMU Interfaces

1N + 1R 1553 Bus to the Radiometer Electronics Box Assembly (REBA)
1N + 1R 1553 Bus to the Data Acquisition Electronics (DAE)
1N + 1R 131kHz LOBT Sync to REBA
1N + 1R 131kHz LOBT Sync to DAE
3 Thermistors

SCS to CDMU Interfaces

1N + 1R 1553 Bus to the Sorption Cooler Electronics (SCE)

3.1.5 Power Interface

Both satellites will distribute, as required, a regulated +28 V bus with adequate battery. The battery is sized for the launch phase considering possible failure within one battery string; this sizing is also covering the attitude loss failure case and the possible eclipse during transfer phase.
The power control and distribution functions for both Herschel and Planck will be implemented as the same units, although the power demand and distribution will have to be sized for the worst case satellite.
The power to the Herschel and Planck instruments will be supplied from the SVM via Latching Current Limiters (LCL).

PCDU interfaces with the Herschel instruments are identified in the following.

PCDU to HIFI Power Lines

1N + 1R 28V Power Bus to the Instrument Control Unit (ICU), LCL Class II
1N + 1R 28V Power Bus to the Local Oscillator Unit (LCU), LCL Class II
1N + 1R 28V Power Bus to the Local Oscillator Source Unit (LSU), LCL Class II
1 x 28V Power Bus to the WBS Electronics Horizontal polarisation (WEH), LCL Class II
1 x 28V Power Bus to the WBS Electronics Vertical polarisation (WEV), LCL Class II
1 x 28V Power Bus to the HRS Horizontal polarisation (HRH), LCL Class III
1 x 28V Power Bus to the HRS Vertical polarisation (HRV), LCL Class III

PCDU to SPIRE Power Lines

1N + 1R 28V Power Bus to the Digital Processing Unit (HSDPU), LCL Class II
1N + 1R 28V Power Bus to the Focal Plane Control Unit (FCU), LCL Class III

PCDU to PACS Power Lines

1 x 28V Power Bus to the Mechanism Control 1 (MEC1), LCL Class I
1 x 28V Power Bus to the Mechanism Control 2 (MEC2), LCL Class I
1N + 1R 28V Power Bus to the Digital Processing Unit (DPU), LCL Class II
1N + 1R 28V Power Bus to the Bolometer Cooler Control (BOLC), LCL Class II
1N + 1R 28V Power Bus to the Signal Processing Unit (SPU), LCL Class II

PCDU interfaces with the Planck instruments are identified in the following.

PCDU to HFI Power Lines

1N + 1R 28V Power Bus to the Power Supply Unit (PSU), LCL Class II
1N + 1R 28V Power Bus to the 4K Cooler Electronic Unit (CEU), LCL Class II
1N + 1R 28V Power Bus to the 4K CEU for Launch Lock, LCL Class III

PCDU to SCS Power Lines

1N + 1R 28V Power Bus to Sorption Cooler Electronics (SCE), LCL Class III
1N + 1R 28V Power Bus to the SCE for Sorption Cooler Compressor, LCL 20A

PCDU to LFI Power Lines

1N + 1R 28V Power Bus to the Radiometer Electronics Box Assembly (REBA), LCL Class II
1N + 1R 28V Power Bus to the Data Acquisition Electronics (DAE), LCL Class II

4. 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 4.1.1-1, 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.
-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.

5. 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.

5.1 CONFIGURATION OPTIONS AND TRADE-OFFS

5.1.1 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).

5.1.2 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 will be 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.

5.1.3 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 is to **not implement** the Turbo Coding option and to use the R/S concatenated encoding with SRRC-OQPSK modulation.

5.1.4 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 string level, because this battery is made by 24 parallel strings. Under all the aspects, this battery can be considered as a 24 batteries system.

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.

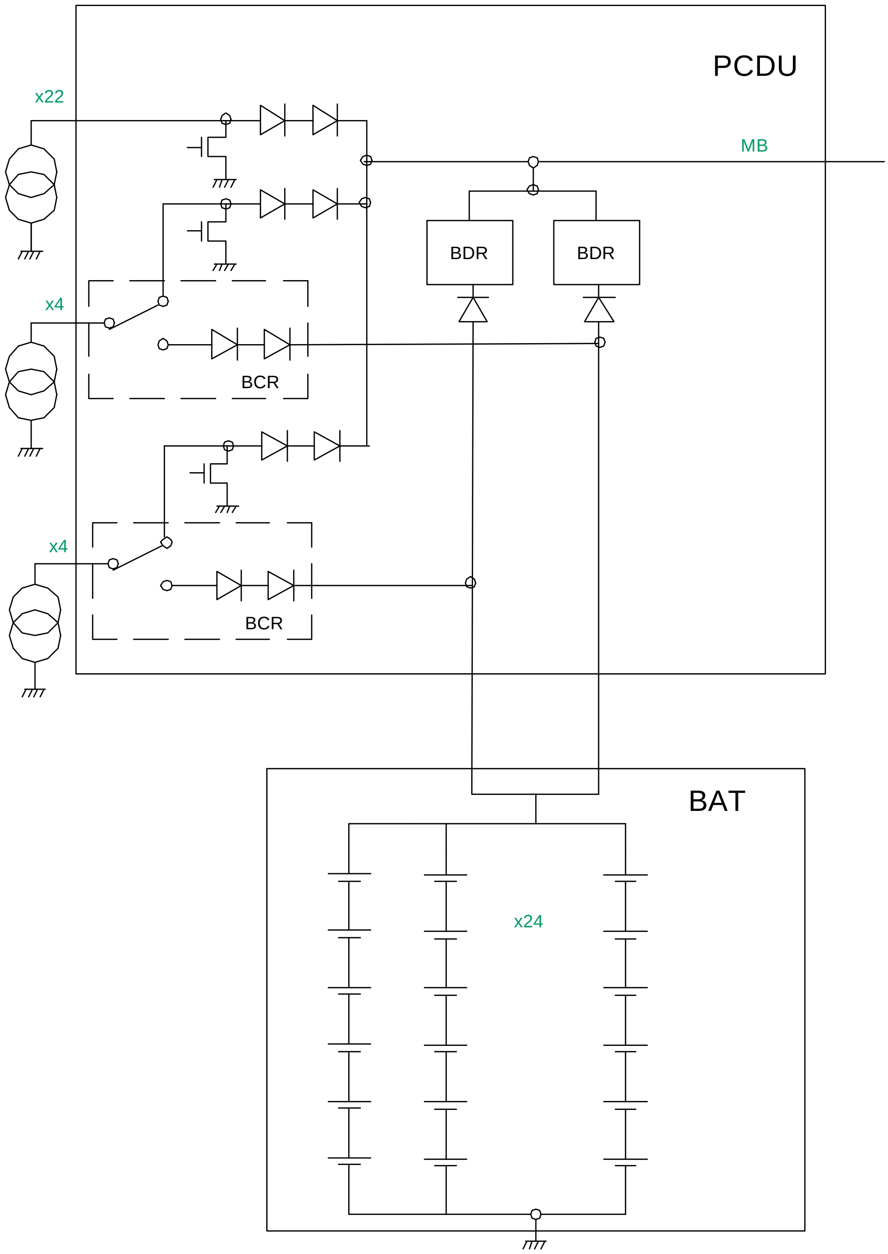


Figure 5.1.4-1 Battery Configuration

6. OPERATIONAL CONCEPT

See HERSCHEL/Planck system design report

7. SVM FUNCTIONAL DESIGN AND PERFORMANCE ANALYSES

7.1 SVM OVERALL DESCRIPTION

7.1.1 Herschel SVM Configuration Overview

7.1.1.1 REFERENCE AXIS SYSTEM

The Herschel satellite reference Axis (**O, Xs, Ys, Zs)** is a right-handed Cartesian system (see figure 7.1.1.1-1)

Its origin **O** is located at the point of intersection of the longitudinal launcher and the Satellite/launcher separation plane. The origin coincides with the centre of the satellite/launcher separation plane.

Xs-axis coincides with the nominal optical axis of Herschel telescope. Positive Xs-axis is oriented towards the target source. The Xs-axis coincides with the launcher longitudinal axis.

Zs is in the plane normal to Xs-axis, such that nominally the Sun will lie in the (Xs, Zs) plane (zero Roll angle with respect to Sun). Positive Zs-axis is oriented towards the Sun.

YS complete the right-handed orthogonal reference frame.

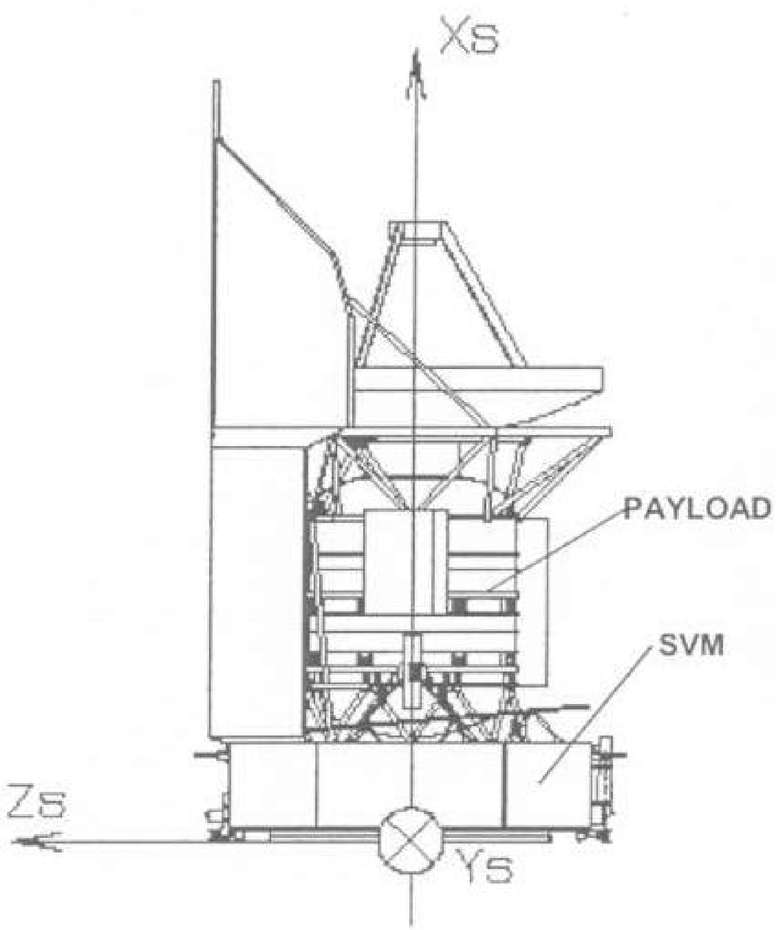


Figure 7.1.1.1-1 Herschel Spacecraft Axes

7.1.1.2 Herschel SVM Configuration

The Herschel SVM is an octagonal box built around a conical tube. Herschel SVM houses all the satellite S/S equipment and the payload "warm Units “.

Herschel SVM houses the equipment of the following functional Subsystem:

Power Control Subsystem (PCS)
Attitude Control Measurement Subsystem (ACMS)
Command and Data Management Subsystem (CDMS)
Telecommunication Subsystem (TTC)
Reaction Control Subsystem (RCS)
Harness Subsystem (HRN)
Payload Warm Units

Two propellant tanks are symmetrically implemented inside the central cone, whereas various sensors and antennae are accommodated on the outside of the SVM structural panels.
The SVM upper cone directly interfaces with the cryostat-supporting truss.

The SVM structure ensures also the mechanical link with the Launcher adapter, and the main load path during launch. Herschel SVM is designed to provide the various equipment and instruments housed in it with suitable mechanical and thermal environments during launch and in orbit phases.
As required the Herschel SVM presents a lot of communality with Planck SVM.
This search for commonality is particularly achieved for Herschel and Planck SVM Structures, which are identical with the exception of some specific structural items as described in Paragraph 9.1

7.1.1.2.1 STRUCTURAL CONCEPT

The main components of the SVM Primary Structure are the Central cone and the SVM box.
These elements are basically constituted of composite parts manufactured in a sandwich form.

CENTRAL TUBE

The Central Tube is a conical tube, built with CFRP sandwich shell. It provides the main load path to the launcher by means of an Aluminium interface ring for the attachment with launcher adapter.
The Central Tube is integrating 8 shear webs to be used for the fixation of SVM box parts as well as some components, harness and lines. The shear webs contribute to the high rigidity of the SVM Structure.
Herschel dictates the geometry (conicity) of the Central Tube, and it is perfectly compliant with Planck needs.
The Central Tube of Herschel and Planck has identical design, and is compatible with the implementation of Herschel and Planck Payloads.
The upper part of the Central Tube interface with the Cryostat Payload by 24-support truss in 12 bipod points adapter brackets. The main function of the support truss is to support the Cryostat payload, and to isolate thermally from the SVM structure. Detailed description of the HPLM – SVM interface is included in paragraph 9.1.
The Central Tube is equipped with inserts and brackets to support Propellant Tanks, some RCS items, the Lower Closing thermal panel and two umbilical connectors on the bottom.

SVM BOX

The SVM box is basically a panels structure with an octagonal shape, enclosing the Central Tube. The SVM box includes the following main parts:
8 lateral panels of 2 different sizes, i.e. long length panels and short length panels with Aluminum face-sheets. They accommodate the S/S units and the PLM "warm units", and provide them with large dissipative surfaces.

It is to be noted that long length panels and short length panels provide in fact the same accommodation surface independently of their length
An Upper and Lower closure panels for the closure of the SVM box. They are segmented in 4 parts for integration easiness and for accessibility to the SVM equipment. They are free from equipment (except FHLSU located below the Upper closure panel), but provide support for the harness and pipe routing when necessary. On the Lower closure panel are accommodated the RCS thrusters brackets.

PAYLOAD SUBPLATFORM
It is used to close and to stiffen the Central cone. It is not used for equipment accommodation on Herschel.

RCS PANEL
It is used to accommodate the piping and relevant valves of the Reaction Control Subsystem.
The SVM structure overall configuration, exploded view, with identification of the primary structure panels, is shown in the figures 7.1.1.2-1 and 7.1.1.2-2.
The SVM primary structure overall dimensions associated with general interface requirements are shown in the drawings of the figure 7.1.1.2-3, 7.1.1.2-4, 7.1.1.2-5, 7.1.1.2-6 and 7.1.1.2-7.

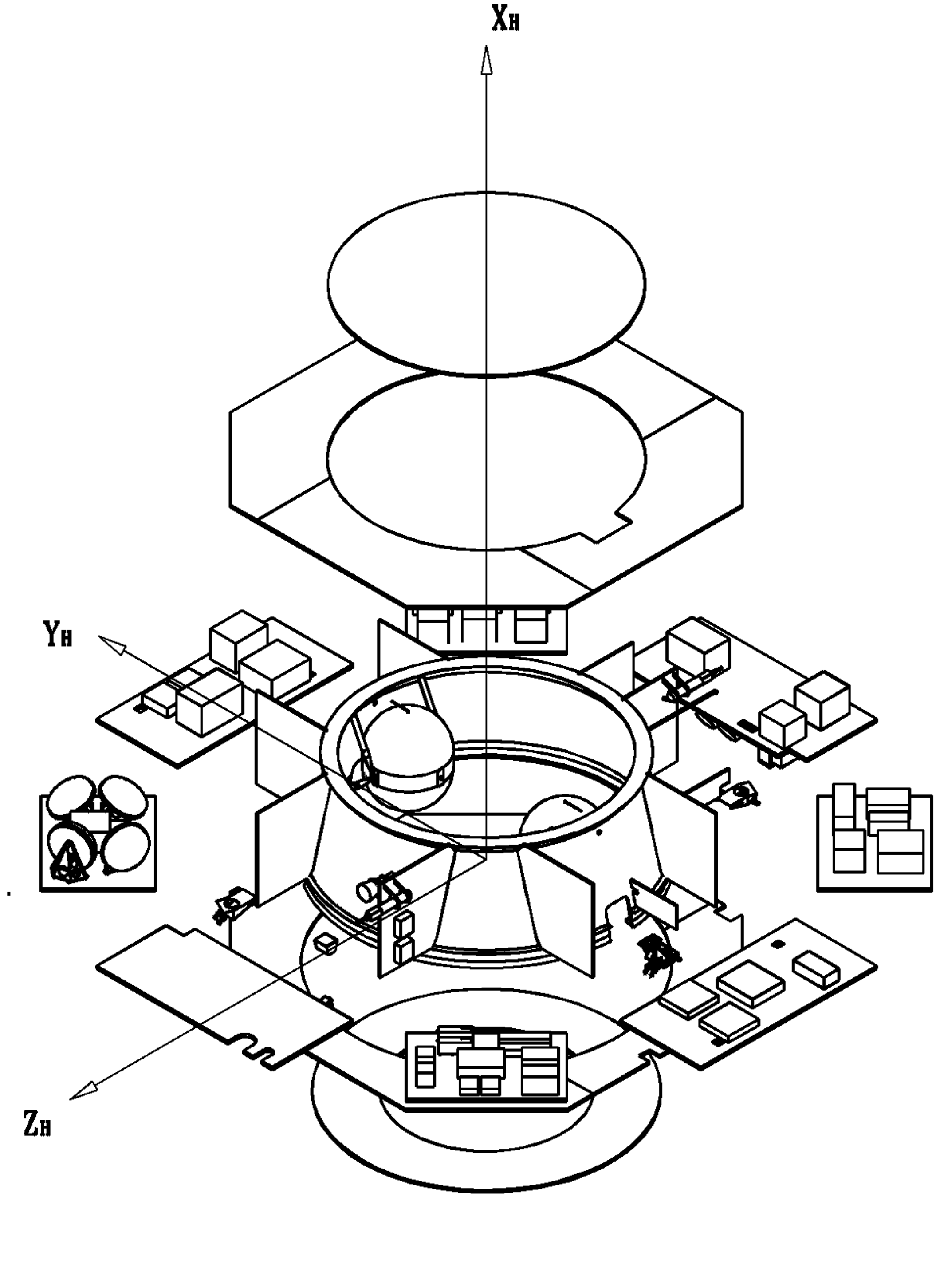


Figure 7.1.1.2-1Herschel SVM Exploded View

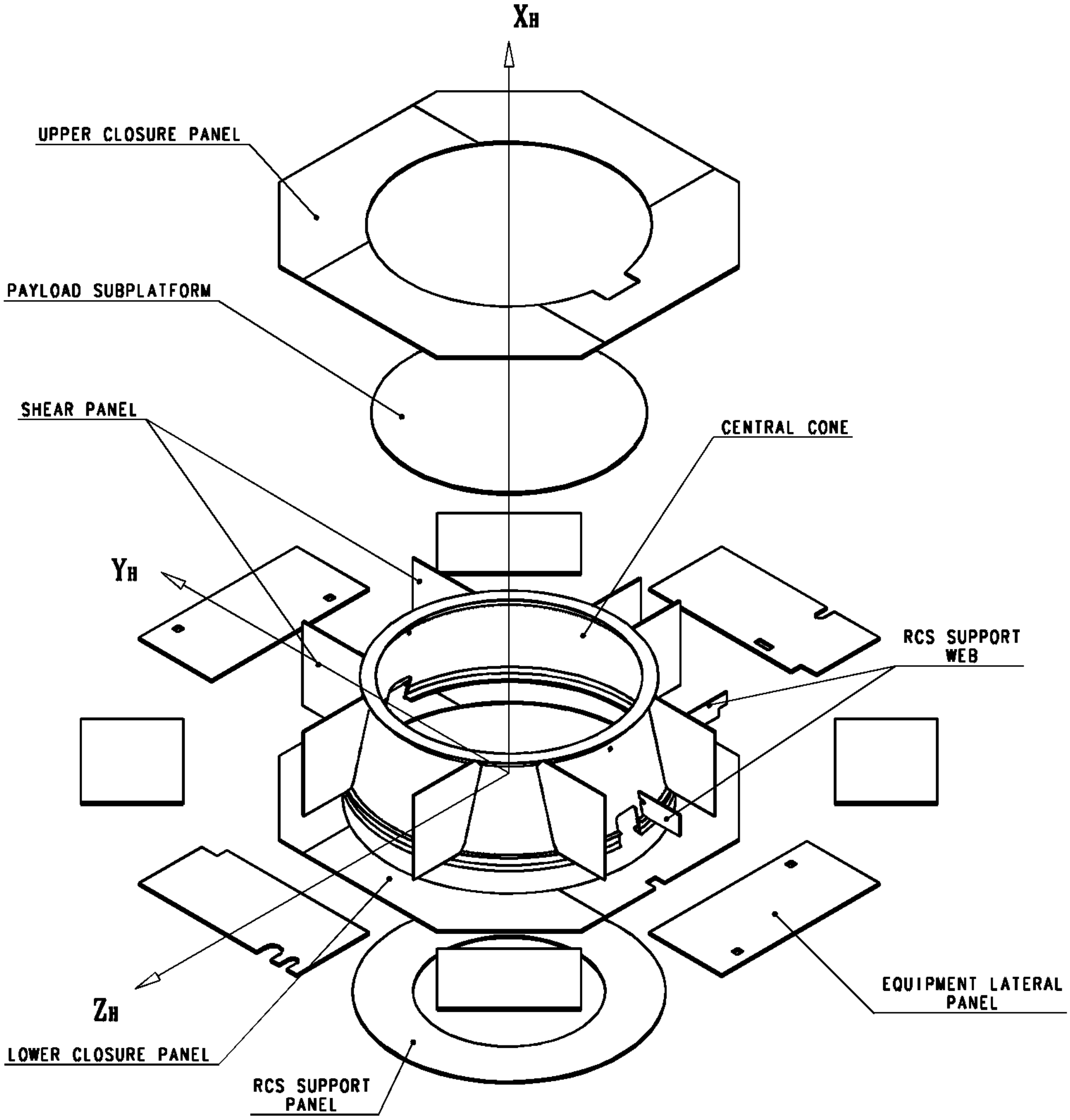


Figure 7.1.1.2-2 Herschel SVM Primary Structure Explode View

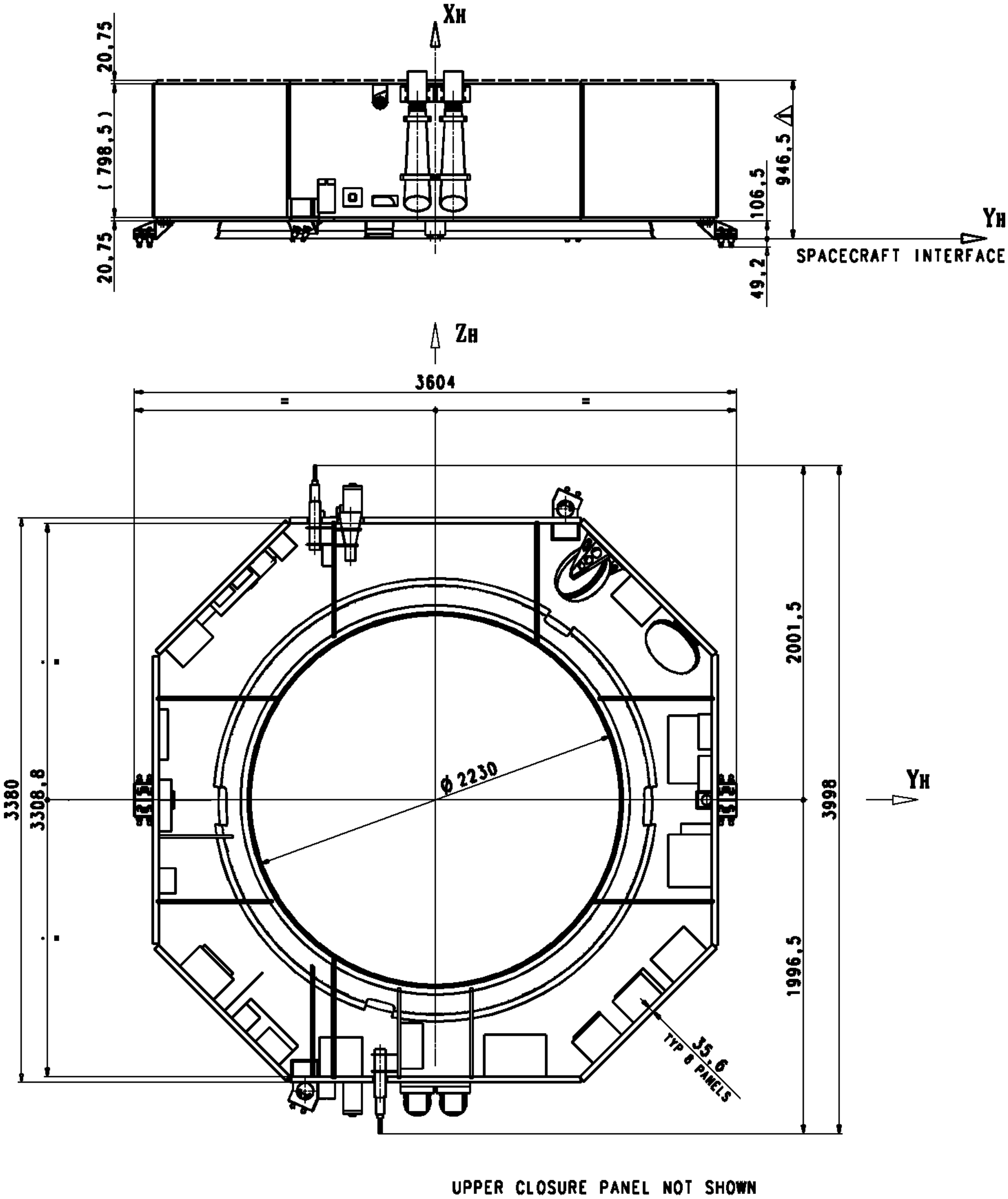


Figure 7.1.1.2-3 Herschel SVM Primary Structure overall dimensions

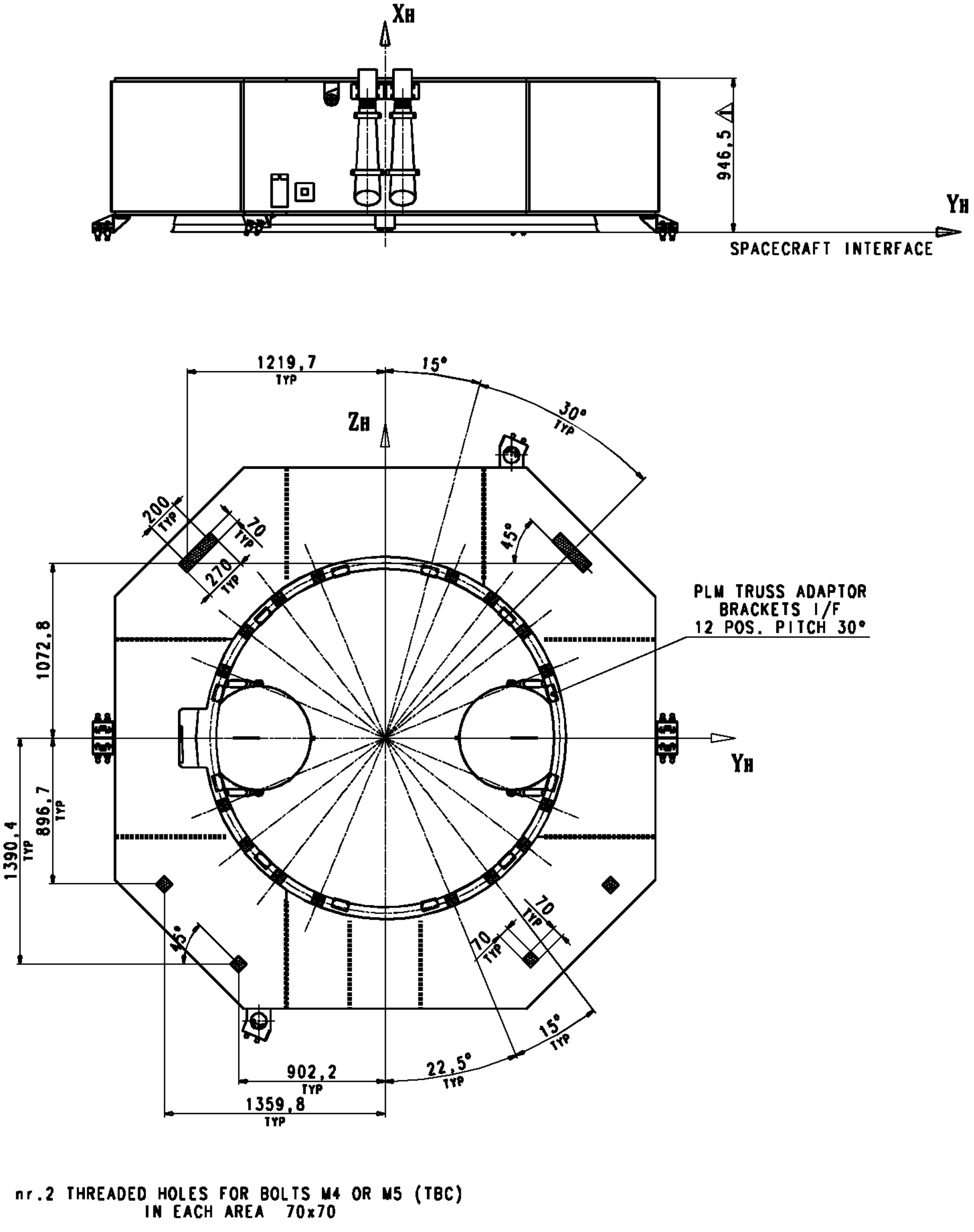


Figure 7.1.1.2-4 Herschel SVM Primary Structure overall dimensions

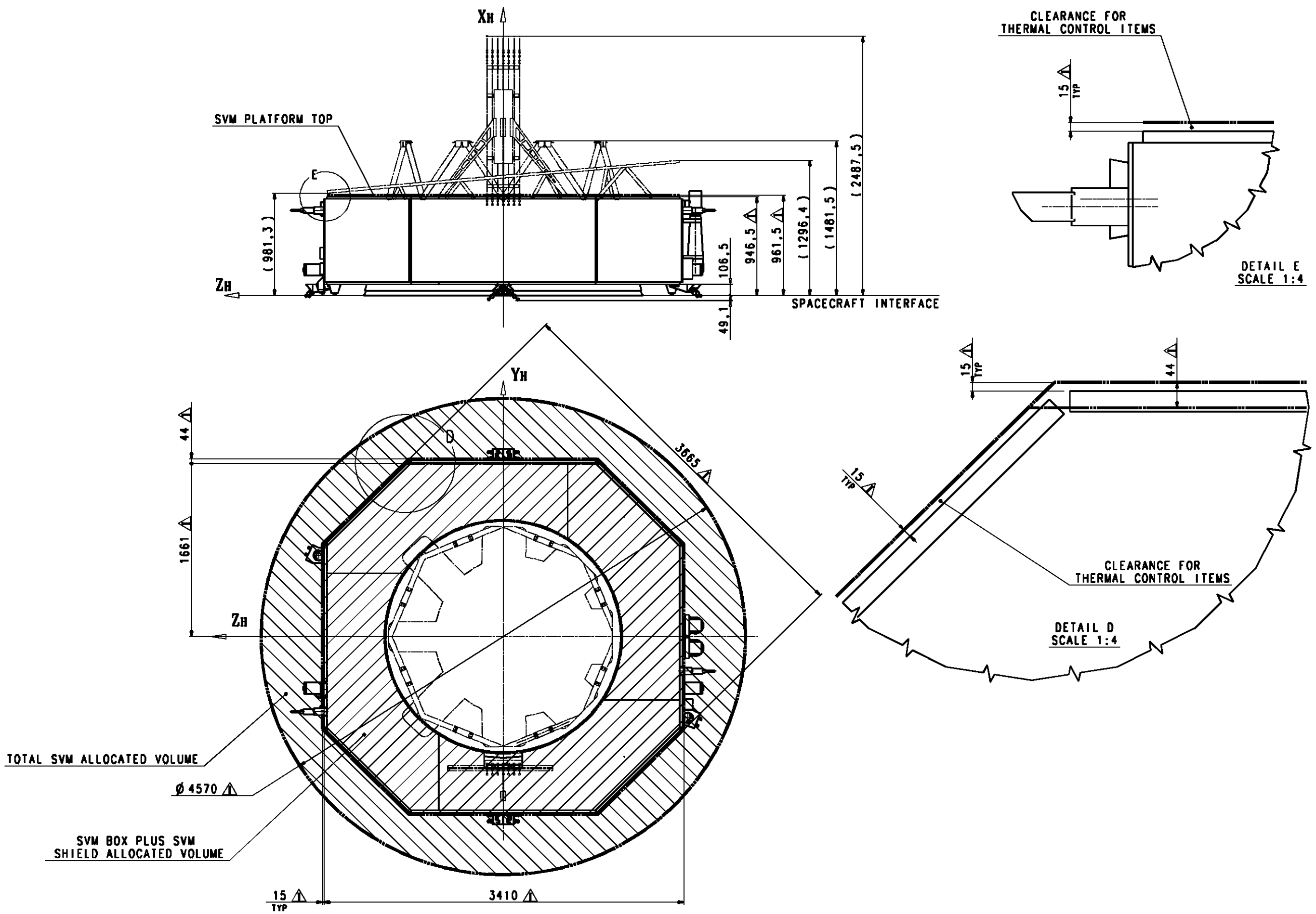


Figure 7.1.1.2-5 Herschel SVM Primary structure overall dimensions

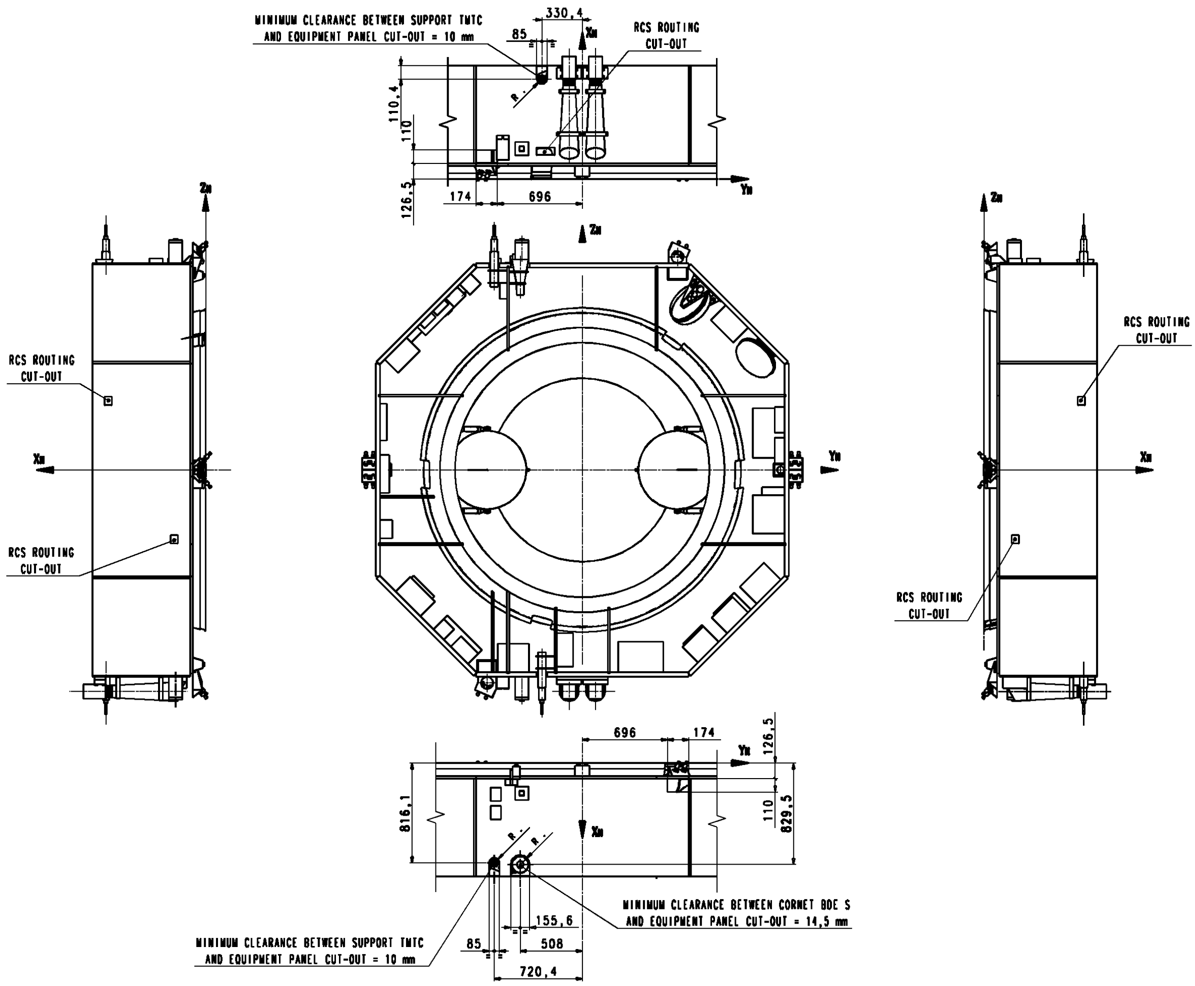


Figure 7.1.1.2-6 Herschel SVM Primary structure Overall dimensions

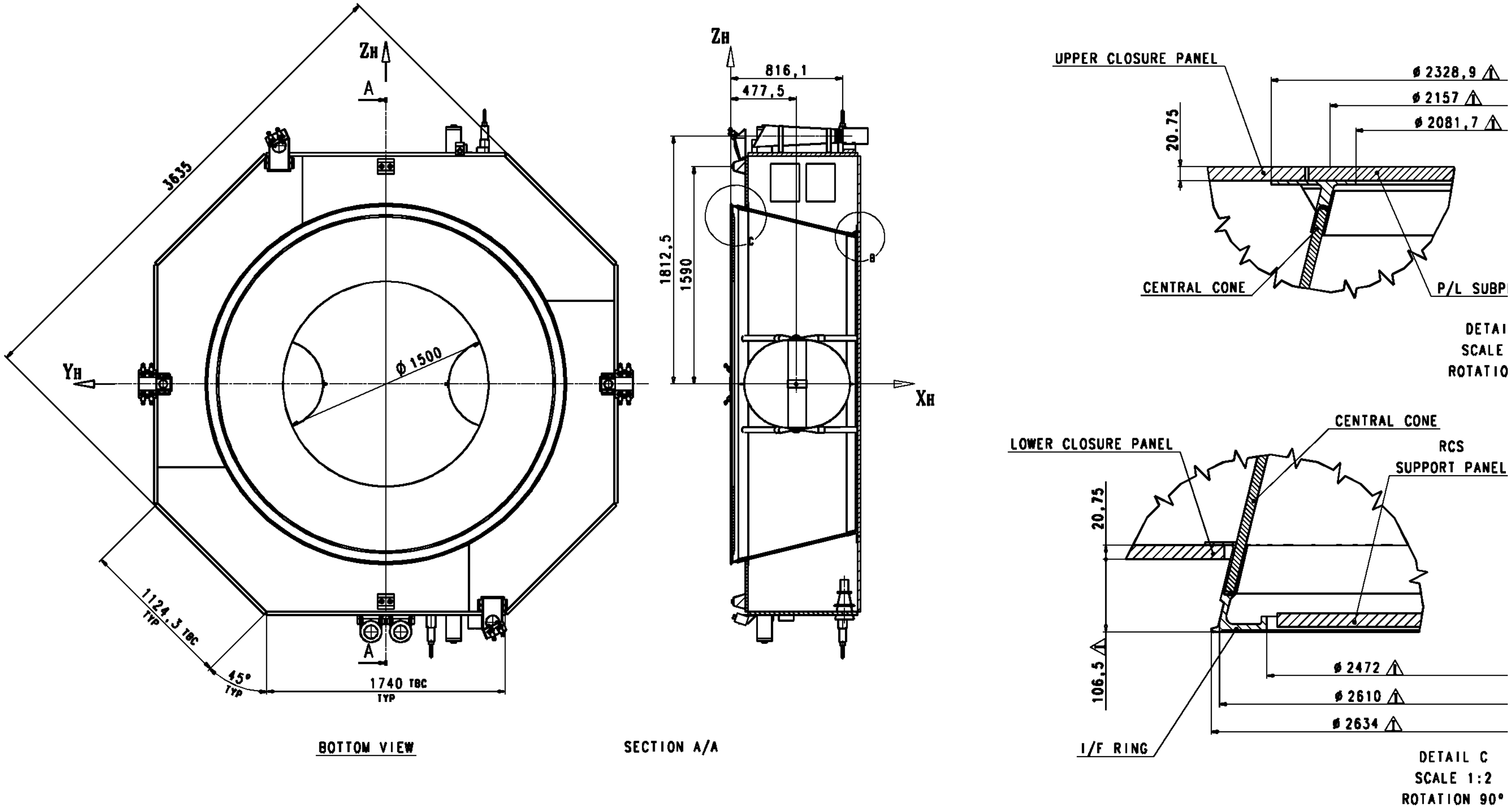


Figure 7.1.1.2-7 Herschel SVM Primary structure overall dimensions

7.1.1.3 Herschel overall SVM Configuration and Architecture

The accommodation of the S/S equipment and PLM "warm units" inside the SVM are dictated by some strong drivers in terms of system functionality which are reflected on the primary structure design.

Modular accommodation
It is requested to respect as far as possible a modular approach for the different units accommodation inside the SVM. This means to accommodate each units group of the same functions or of the same instruments on a dedicated panel

This disposition allows the units integration and functional testing at different level of the S/C integration in independence with the other units integration.
The above defined rule applies to the accommodation of the Avionics functions, and to the accommodation of the instruments (HIFI, PACS, SPIRE).

Herschel and Planck commonality
Herschel and Planck commonality is to be achieved by the extensive selection of common equipment for Herschel and Planck Avionics functions. According to the same logic, it is recommended to have an identical accommodation on SVM panels for the common Avionics units.
The Avionics components on the Herschel panel +Z / -Y are located on identical position on the Planck panel –Y.
The Avionics on the Herschel panel +Y are in identical position in the Planck panel +Z / -Y.

The current units accommodation is shown in the Figure 7.1.1.3-1. It achieves a good level of compliance with the a.m. drivers.
The + Z panel of the SVM panel facing the sun is free from any equipment because it is requested for satellite balancing to compensate PLM un-balance, and because of its low radiative capability.
The overall SVM Subsystems components and Warm Units accommodation, completed of detailed location for each unit on single panel is shown in the figures 7.1.1.3-2, 7.1.1.3-3 and 7.1.1.3-4.
The list of the SVM equipments of the PLM "Warm Units" and Subsystem, associated with dimension and location on SVM, are included in the table 7.1.1.3-1.

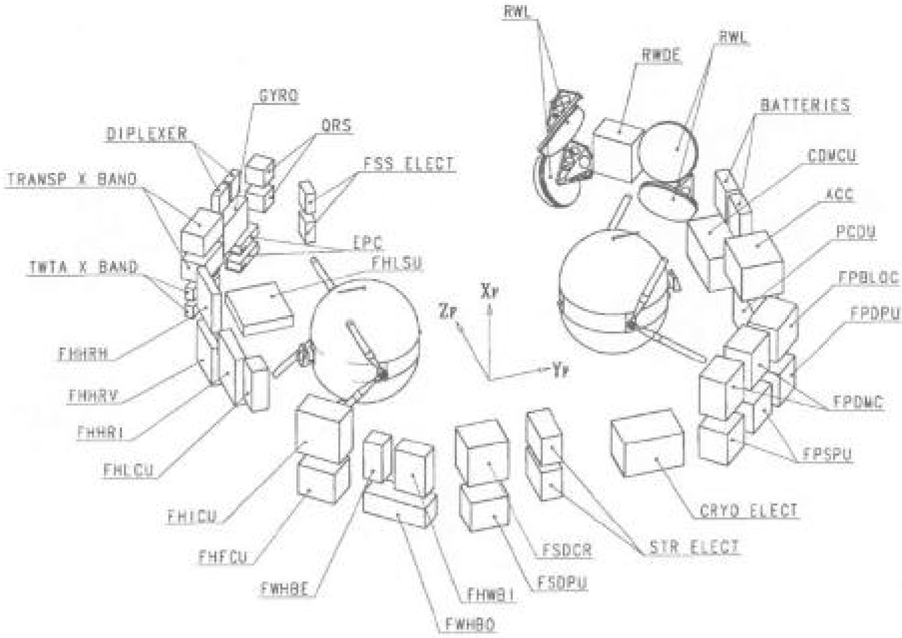


Figure 7.1.1.3-1 Units accommodation on Herschel

ACMS – Attitude Control and Measurement Subsystem

The ACMS units are spread at different location in Herschel SVM:

The 4 Reaction Wheels plus electronics on a dedicated panel +Z / +Y
The Attitude Control Computer, Quartz Rate Sensors and Gyro on 2 other panels
The 2 Star Trackers (STR's) electronics on a shear web closed to the STR's
The STR's are mounted on a dedicated base plate located on the external panel –Z

Sets of 2 SAS's are located on +/- Z panel external side. The FSS is accommodated on +Z panel external side

CDMS & TTC - Command Data Management S/S & Telemetry, Tracking, Command

The SREM is located on –Z panel external side.
The VMC is located on +Z external side.
The CDMU is located on +Y panel.
The 2 LGA's antenna are accommodated on +/- Z side.
The MGA is located on +Z side
The Transponder X/A, TWTA, EPC, Diplexer are located on +Z-Y panel.

POWER

The Battery and PCDU is located on the +Y panel (drawings show 2 batteries but last minute trade off decision is baselining 1 battery only).

HARNESS

The SVM primary structure shall include provision like inserts for the fixation of the Harness cabling.

RCS accommodation

The RCS system comprises 2 Propellant Tanks, pipe work, components as valves and pressure transducers, the Reaction Control Thrusters (RCT).
The 2 Propellant Tanks of Integral type, with an internal bladder for liquid and pressurant gas separation, function in blow-down conditions. They are symmetrically installed inside the Central Tube.
The routing of the RCS components and RCS piping is organised in 2 zones. In a first time, a major part of the RCS piping and RCS components not necessitating a frequent accessibility (filters, latch valves, ...) are routed inside the central cone on a dedicated support ring identified as RCS Panel. This configuration allows to quickly distributing the RCS piping from the P.Tank in the direction of the RCT.
In a second time, radial lines pass through the central cone wall and route (mainly) on the shear webs to feed the RCTs and RCS components requiring accessibility (fill and drain valves, test ports). This configuration allows a clear and decoupled RCS implementation inside the SVM, limiting interfaces and interwovenness with the structure and other SVM subsystems.
An overall RCS line routing associated with Propellant Tanks and valves location is shown in the drawings of figures 7.1.1.3-5 and 7.1.1.3-6.

THERMAL CONTROL

The thermal hardware is mainly composed by Multilayer Insulation Blanket (MLI), Optical Solar Reflectors (OSR), Paints and Fillers.
All these items are directly attached to the primary structure of the SVM.
An overview of the preliminary distribution and location of the thermal hardware is shown in the figure 7.1.1.3-7.

PLM WARM BOXES

HIFI Warm Boxes

The HIFI warm boxes are mainly grouped on 2 dedicated panels, -Y and -Y-Z as the HIFI instruments on the Optical Bench. This position allows to minimize the length of the Cryo harness connecting these instruments to the OB, and to guarantee a stable environment for these instruments, independently of the SAA variations.
Additionally, a last HIFI instrument (FHLSU) is accommodated at the bottom of the Upper Closure platform –Y sector. In this position allows to minimize the length of the wave guides connecting this instrument to the LOU on the Cryostat.

PACS warm Boxes

The PACS warm boxes are grouped on a dedicated panel, located in the panel + Y- Z as the PACS instruments on the OB. This position allows minimising the length of the Cryo harness connecting these instruments to the OB.

SPIRE Warm Boxes

The 2 SPIRE warm boxes are grouped on the – Z panel, as the corresponding instruments on the OB. This position allows minimizing the length of the Cryo harness connecting these instruments to the OB. The SPIRE warm boxes share the -Z panel with the Cryo electronics that preserves the SVM modular approach.

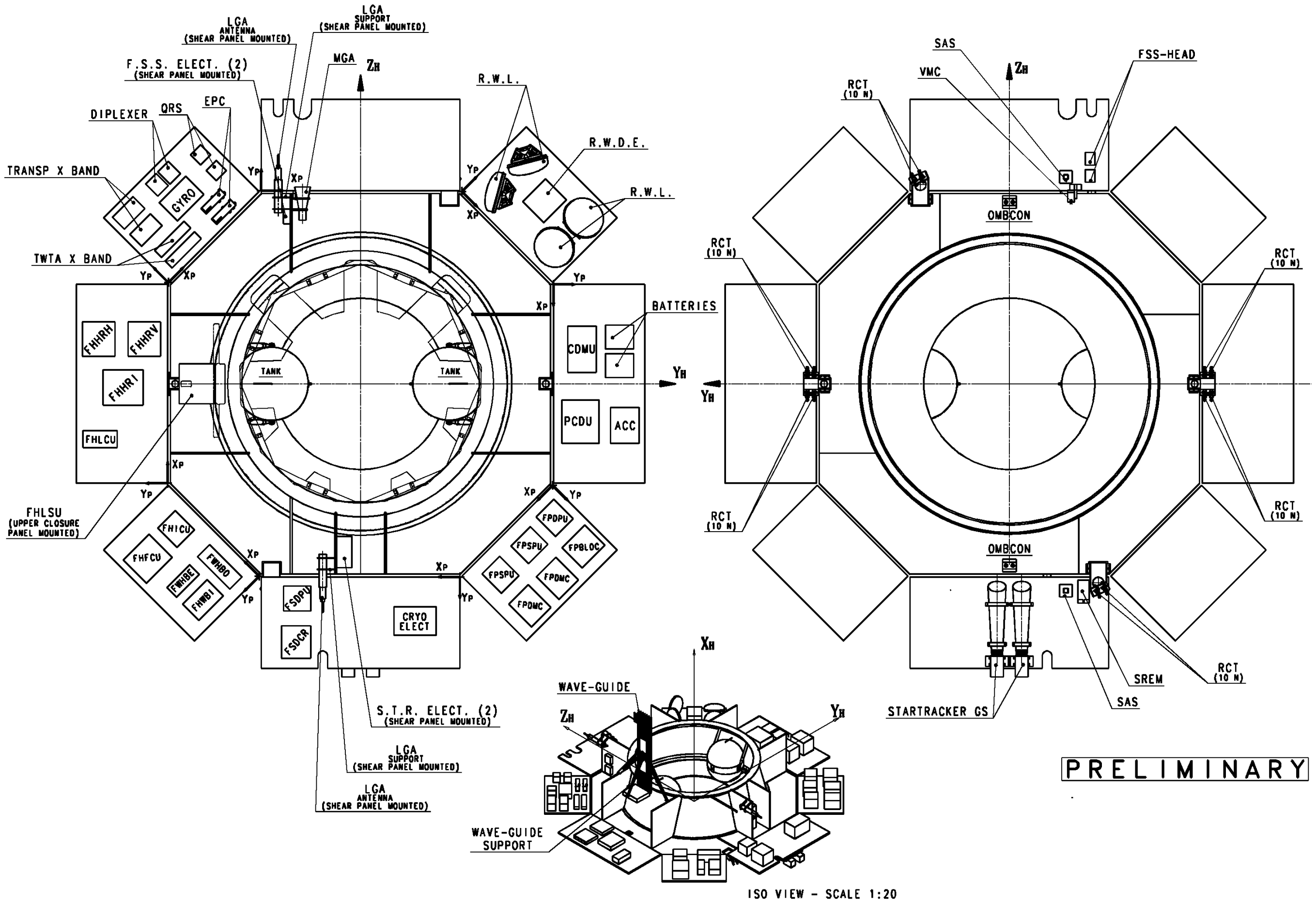


Figure 7.1.1.3-2 Herschel SVM Units Accommodation

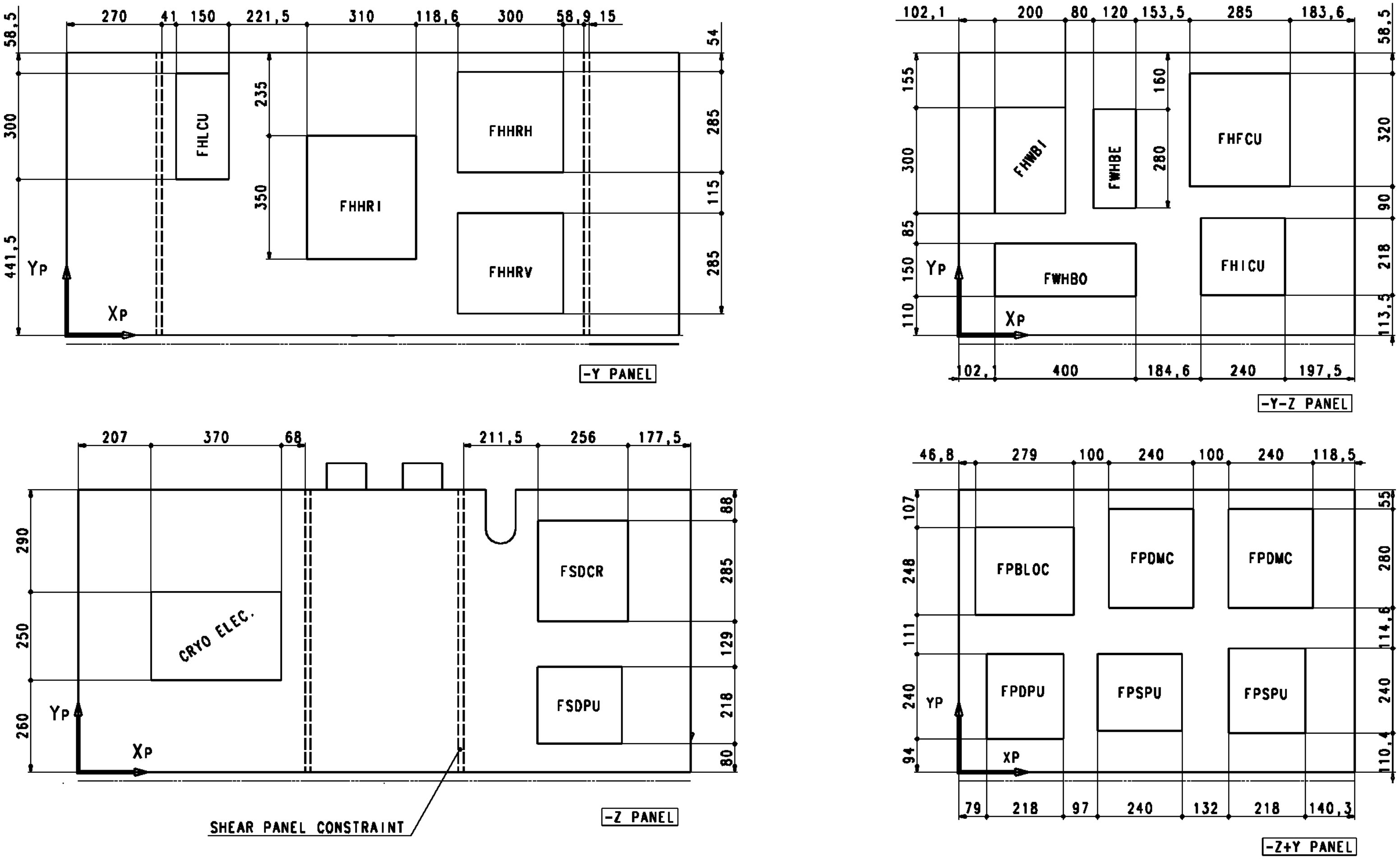


Figure 7.1.1.3-3 Herschel SVM Units Accommodation

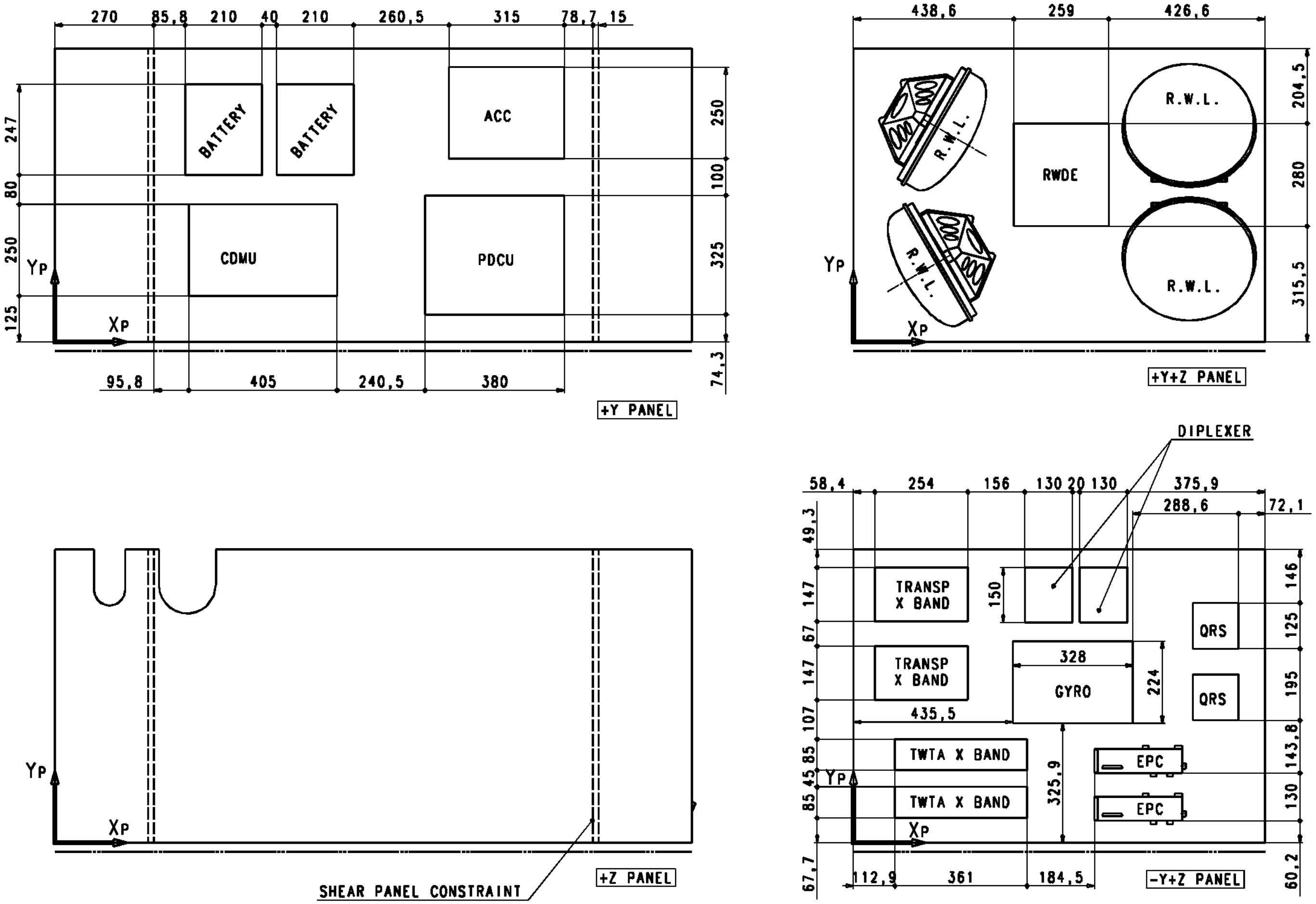


Figure 7.1.1.3-4 Herschel SVM Units Accommodation

		1 o	Unit Dimension (mm)			
HERSCHEL SVM	HERSCHEL SVM	Location	L	W	H	Q.ty
Equipment Acronym	Long Name	Panel				
PLM - WARM UNITS	PLM - WARM UNITS					
HIFI	Heterodyne Instrument for Hershel					
FHFCU	Focal Plane Control Unit	-Z / -Y	320	285	170	1
FHLCU	Local Oscillator Control	-Y	300	150	100	1
FHLSU	Local Oscillator Source Unit	-Y / +X	310	350	75	1
FHHRI	High-Res Spectrom. IF Processor	-Y	310	350	75	1
FHHRH	HRS, ACS horizontal polarization	-Y	285	300	55	1
FHHRV	HRS, ACS vertical polarization	-Y	285	300	135	1
FHWBI	WBS - IF processor 8	-Z / -Y	300	200	120	1
FHWBO	Wide Band Spectrometer, AOS	-Z / -Y	400	150	160	1
FHWBE	WBS - electronics	-Z / -Y	280	120	120	1
FHICU	Instrument Control Unit	-Z / -Y	240	218	194	1
PACS	Photo Conductor Array Camera					
FPDMC	Detector / Mechanism Control 1-2	-Z / +Y	280	240	180	2
FPBOLC	Bolometer/Cooler Control	-Z / +Y	248	279	197	1
FPDPU	Digital Processing Unit	-Z / +Y	240	218	194	1
FPSPU	Signal Processing Unit 1-2	-Z / +Y	240	218	194	2
SPIRE	Spectral Photom. Imaging Recei.					
FSDPU	Digital Processing Unit	-Z	240	218	194	1
FSDCR	Detector Read-out and Control Unit	-Z	285	256	234	1
Cryo elec.	Cryo Electronics	-Z	350	370	250	1

		1 o	Unit Dimension (mm)			
HERSCHEL SVM	HERSCHEL SVM	Location	L	W	H	Q.ty
Equipment Acronym	Long Name	Panel				
SUBSYSTEM						
POWER	POWER					
BATTERY	Lithium-Ion Battery	+Y	210,00	247,00	80,00	1
PCDU	PCDU (Power Conditio.Distr. Unit)	+Y	380,00	325,00	185,00	1
ACMS	ACMS					
STR H	Star Trackers Head	-Z				2
STR E	STR Electronics	-Z shear	274,00	210,00	135,00	1
GYR	GYR	+Z / -Y	328,00	224,00	96,00	1
RWDE	RWD Electronics	+Z /+Y	326,00	247,00	125,00	1
RWS	React wheel	+Z /+Y	D.350x120			4
SAS	Sun Acquisition Sensor	+Z/-Z	110,00	170,00	110,00	2
QRS	Quartz Rate Sensor	+Z / -Y	125,00	125,00	120,00	2
FSS	Fine Sun Sensor	+Z shear	152,00	127,00	61,00	2
ACC	Attitude Control Computer	+Y	315,00	250,00	260,00	1
CDMS						
CDMU	Central Data Management Unit	+Y	405,00	250,00	260,00	1

		1 o	Unit Dimension (mm)			
HERSCHEL SVM	HERSCHEL SVM	Location	L	W	H	Q.ty
Equipment Acronym	Long Name	Panel				
TT&C						
TRANS X/B	Transponder	+Z / -Y	147,00	254,00	153,00	2
TWTA	Travelling Wave Tube Amplifier	+Z / -Y	361,00	85,00	54,00	2
EPC	Electrical Power Conditioner	+Z / -Y	249,00	65,00	103,00	2
RFDN (diplexer)	Radio Frequency Distribution Network	+Z / -Y	150,00	130,00	50,00	2
MGA	Medium Gain antenna	+Z	D.448 h 472			1
X/B LGA	Low Gain antenna	+Z	D.90 h 141			1
X/B LGA	Low Gain antenna	- Z	D.90 h 141			1
SREM	Standard Radiation Monitor	-Z	200,00	100,00	95,00	1
VMC	Visual Monitoring Camera	+ Z	65,00	60,00	88,00	1
RCS Reaction Control Subsystem						
RCT	10 N thrusters	RCS panel	150,00	60,00	60,00	12
Propellant Tank	Propellant Tank	RCS panel				2
LV	Latch valve	RCS panel				2
PT	Pressure transducer	RCS panel				1
FD	Fill/Drain valve	RCS panel				1
FV	Fill/Vent valve	RCS panel				2
TP	Test port	RCS panel				2
LF	Filter	RCS panel				1
Ducting	Ducting	RCS panel				1
Bracketry	Bracketry	RCS panel				1

Table 7.1.1.3-1 Herschel Equipment and items list

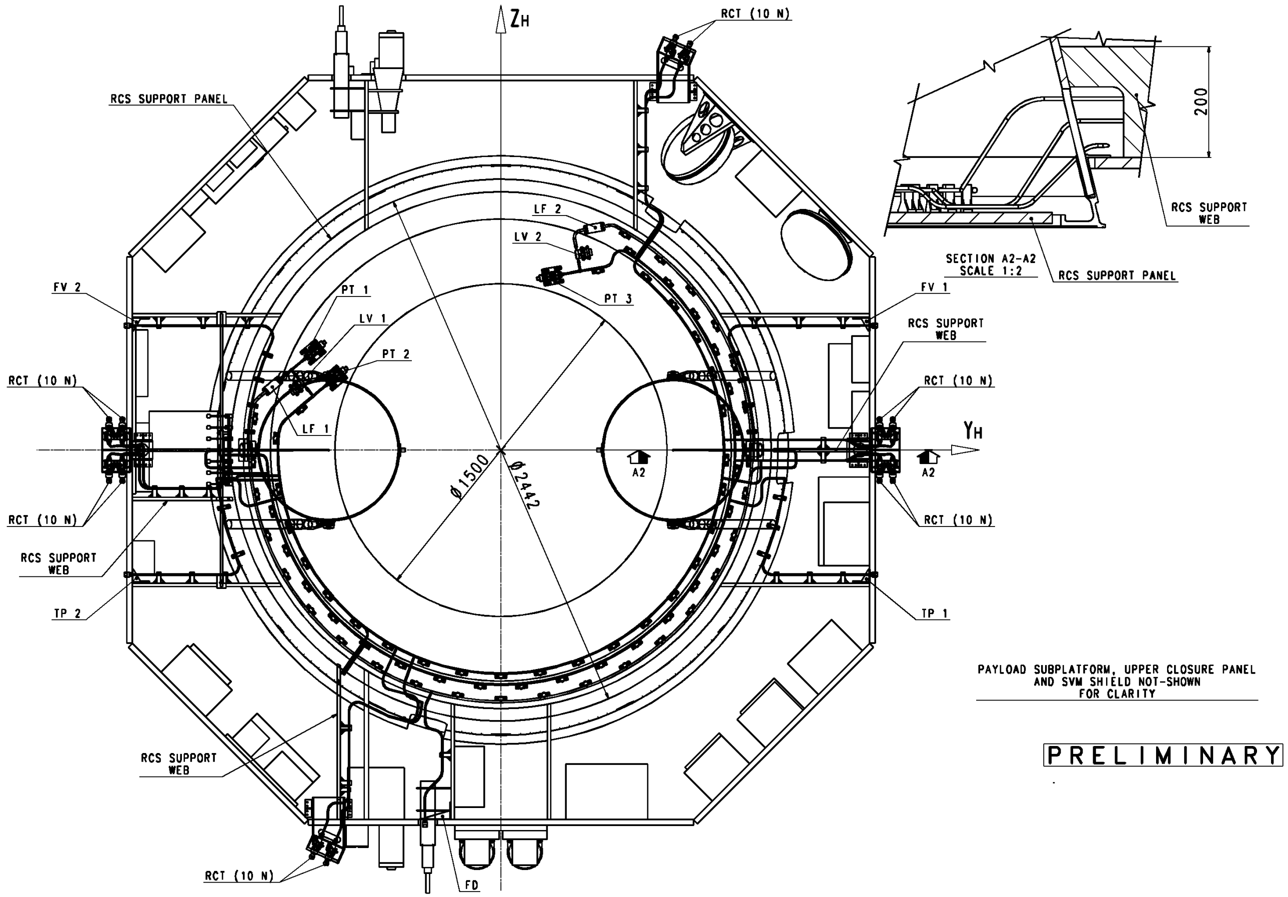


Figure 7.1.1.3-5 Herschel RCS Line routing and items location

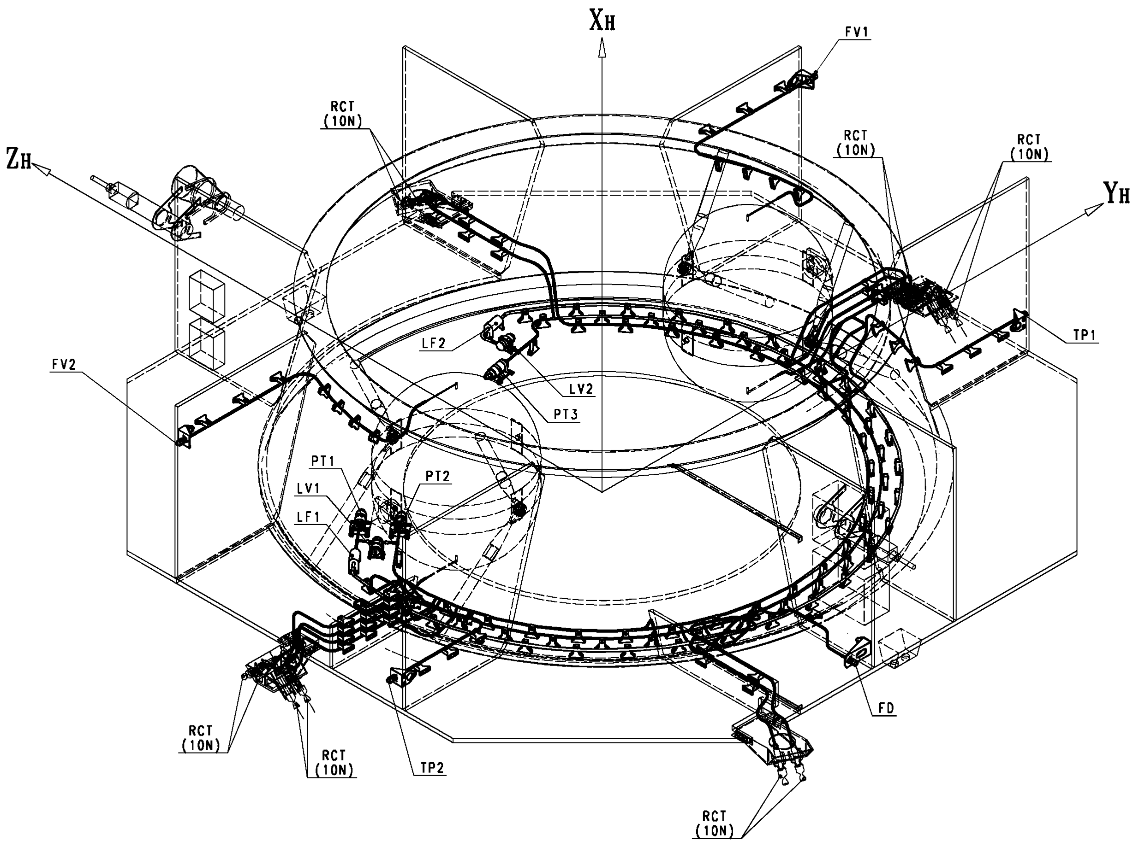


Figure 7.1.1.3-6 Herschel RCS Line routing and items location

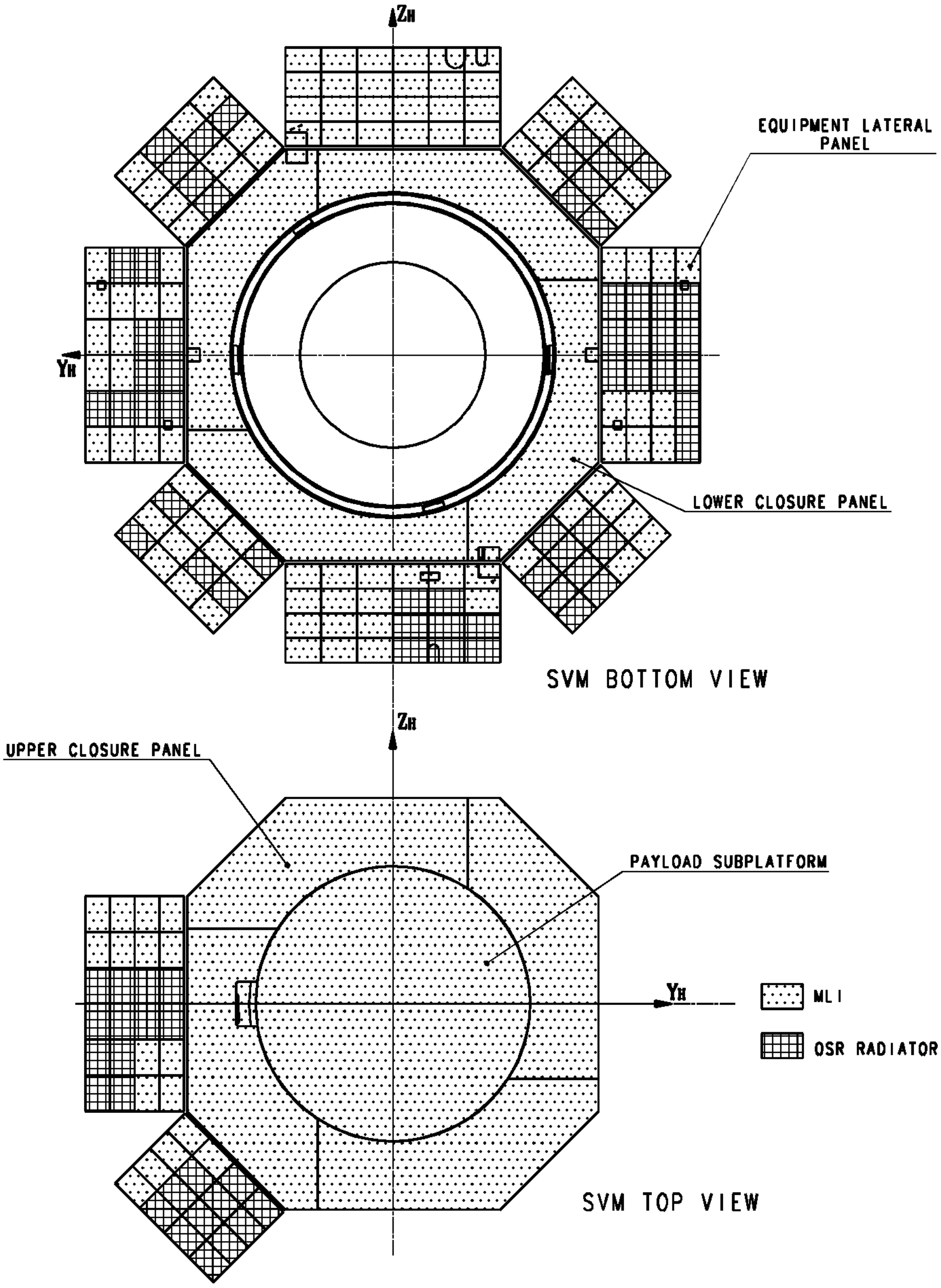


Figure 7.1.1.3-7 Herschel SVM MLI location

7.1.2 Planck SVM Configuration Overview

7.1.2.1 REFERENCE AXIS SYSTEM

The Planck satellite reference frame (**O, Xx, Yx, Zx**) is defined (see Figure 7.1.2.1-1) such that:

Its origin **O** is located at the point of intersection of the longitudinal Launcher and the Satellite /Launcher separation plane. The origin coincides with the centre of the Satellite /Launcher separation plane.

Xs coincides with the nominal spin axis of Planck. Positive Xs axis is oriented opposite to the Sun in nominal operation. The Xs axis coincides with the launcher longitudinal axis.

Zs is such that the Planck telescope line of sight is in the (Xs, Zs) plane. The telescope is pointing in the +Zs half-plane

Ys complete the right-handed orthogonal reference frame..

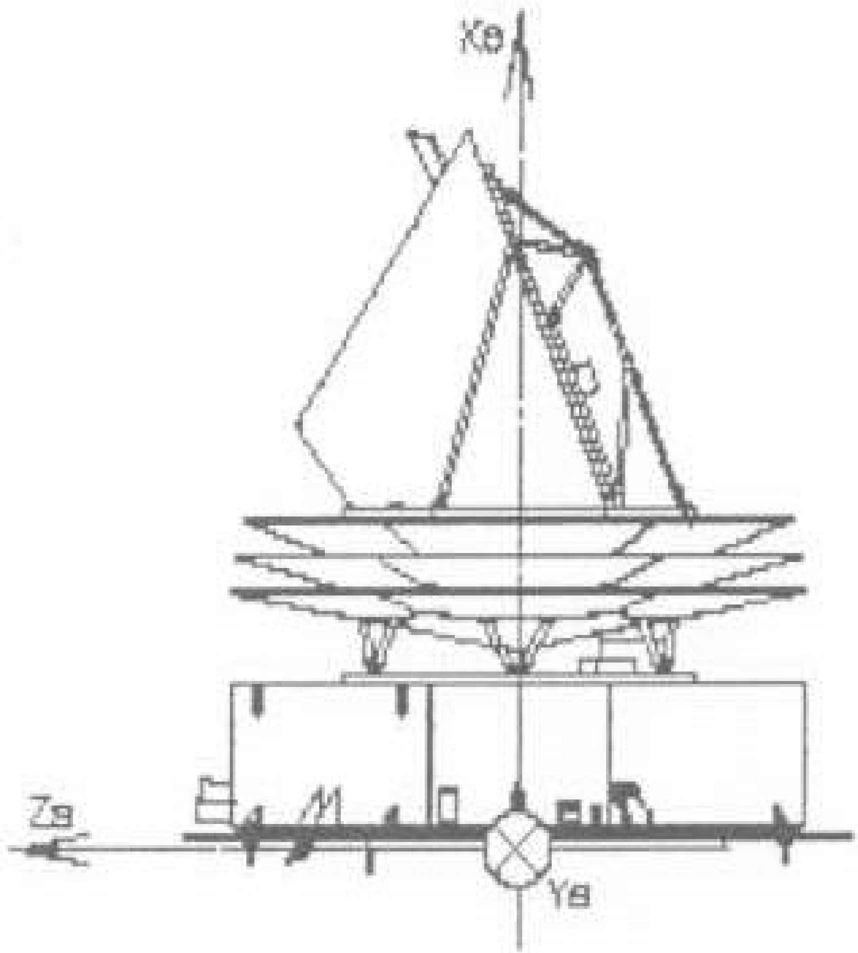


Figure 7.1.2.1-1 Planck Spacecraft Axes

7.1.2.2 Planck SVM Configuration Overview

Planck SVM is an octagonal box built around a conical tube. Planck SVM houses all the satellite S/S equipment and some of the Payload units.

Planck SVM houses the equipment of the following functional Subsystem:

Power Control Subsystem (PCS)
Attitude Control Measurement Subsystem (ACMS)
Command and Data Management Subsystem (CDMS)
Telecommunication Subsystem (TTC)
Reaction Control Subsystem (RCS).
Harness Subsystem
Payload SCC Units

Planck SVM supplies most of the panels for the accommodation of PLM units.
Three propellant tanks are equally implemented inside the central cone, whereas various sensors and antennae are accommodated at the bottom of the SVM structural panel.
The SVM upper cone directly interfaces with the PPLM-supporting truss.
The SVM ensures the mechanical link with the Launcher adapter. It carries also the
Planck Solar Array on its bottom.
Planck SVM presents a lot of communality with Herschel SVM.
This search for commonality is particularly achieved for Herschel and Planck SVM Structures, which are identical with the exception of some specific structural items as described in Paragraph 9.1

7.1.2.2.1 STRUCTURAL CONCEPT

The main components of the SVM structure are the Central cone and the SVM box.
These elements are basically constituted of composite parts manufactured in a sandwich form.

CENTRAL TUBE

The Central Tube is a conical tube, built with CFRP sandwich shell . It provides the main load path to the launcher by means of an Aluminium interface ring for the attachment with launcher adapter.
The Central Tube is integrating 8 shear webs necessary for the fixation of the SVM box parts as well as some components, harness and lines. The shear webs contribute to the high rigidity of the SVM Structure.
The Central Tube geometry is dictated by Herschel and it is perfectly compliant with Planck needs. The Central Tube of Herschel and Planck has identical design, and is compatible with implementation of Herschel and Planck Payloads.
The upper part of the Central Tube interface with the PPLM by 12 support truss in 6 bipod point adapter brackets.
Detailed description of the PPLM – SVM interface is included in paragraph 9.1.
The Central Tube is also compatible with the implementation of 3 Propellant Tanks.
The Central Tube is equipped with inserts and brackets to support: RCS items, 4 He tanks with dedicated tanks support structure, He lines routing and two umbilical connectors.
The inserts or brackets at the bottom of the Central Tube shall be compatible with the attachment of the Solar Array central part of the Planck and the attachment of the thermal lower closing panel.

SVM BOX

The SVM box is basically a panels structure with an octagonal shape, enclosing the
Central Tube. The SVM box includes the following main parts:
8 lateral panels of 2 different sizes, i.e. long length panels and short length panels with Aluminium face-sheets. They accommodate the S/S units and the PLM "warm units", and provide them with large dissipative surfaces.
It is to be noted that long length panels and short length panels provide in fact the same accommodation surface independently of their length.

As a particularity of Planck, 3 of the lateral panels are substituted by the SCC panel. See paragraph 9.1.4.1 for detailed description.

An Upper and Lower closure panels for the closure of the SVM box.
They are segmented in 4 parts for integration easiness and for accessibility to the Service module equipment. The Lower closure panel is free from equipment but provide attachment for Solar Array peripheral part and RCS thrusters brackets Lower panels provide support for the RCS pipe routing and harness.

A Payload subplatform used to close and to stiffen the Central cone.
It is used also to accommodate the Warm Units PAU and BEU on upper side, while the two REBA are accommodated on the lower side.

RCS PANEL

The RCS panel is used to accommodate the piping and relevant valves of the Reaction Control Subsystem.
The SVM structure overall configuration, exploded view, with identification of the primary structure panels, is shown in the figures 7.1.2.2-1 and 7.1.2.2-2.
The SVM primary structure overall dimensions associated with general interface requirements are shown in the drawings of the figure 7.1.2.2-3, 7.1.2.2-4, 7.1.2.2-5, 7.1.2.2-6 7.1.2.2-7 and 7.1.2.2-8.

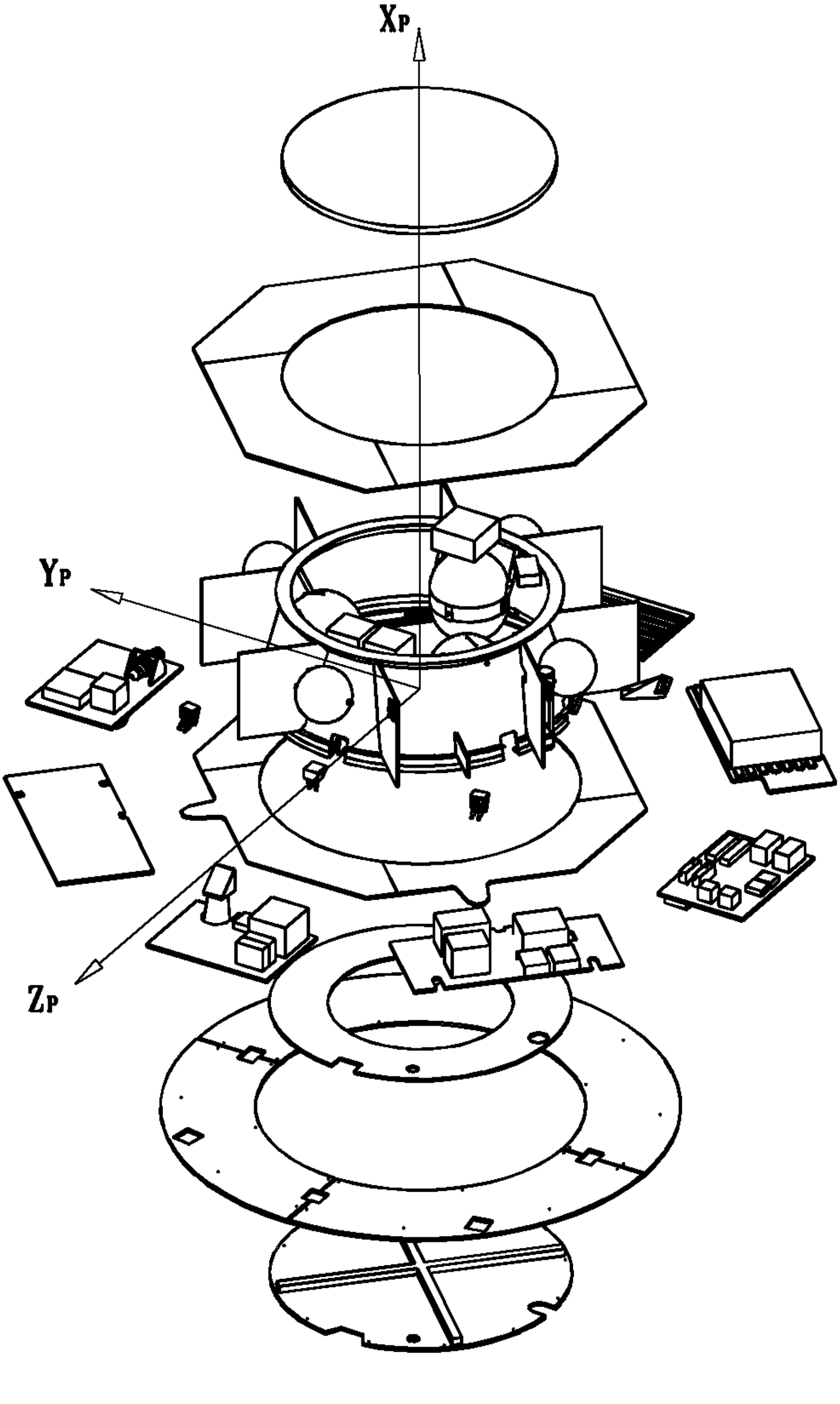


Figure 7.1.2.2-1 Planck SVM Exploded View

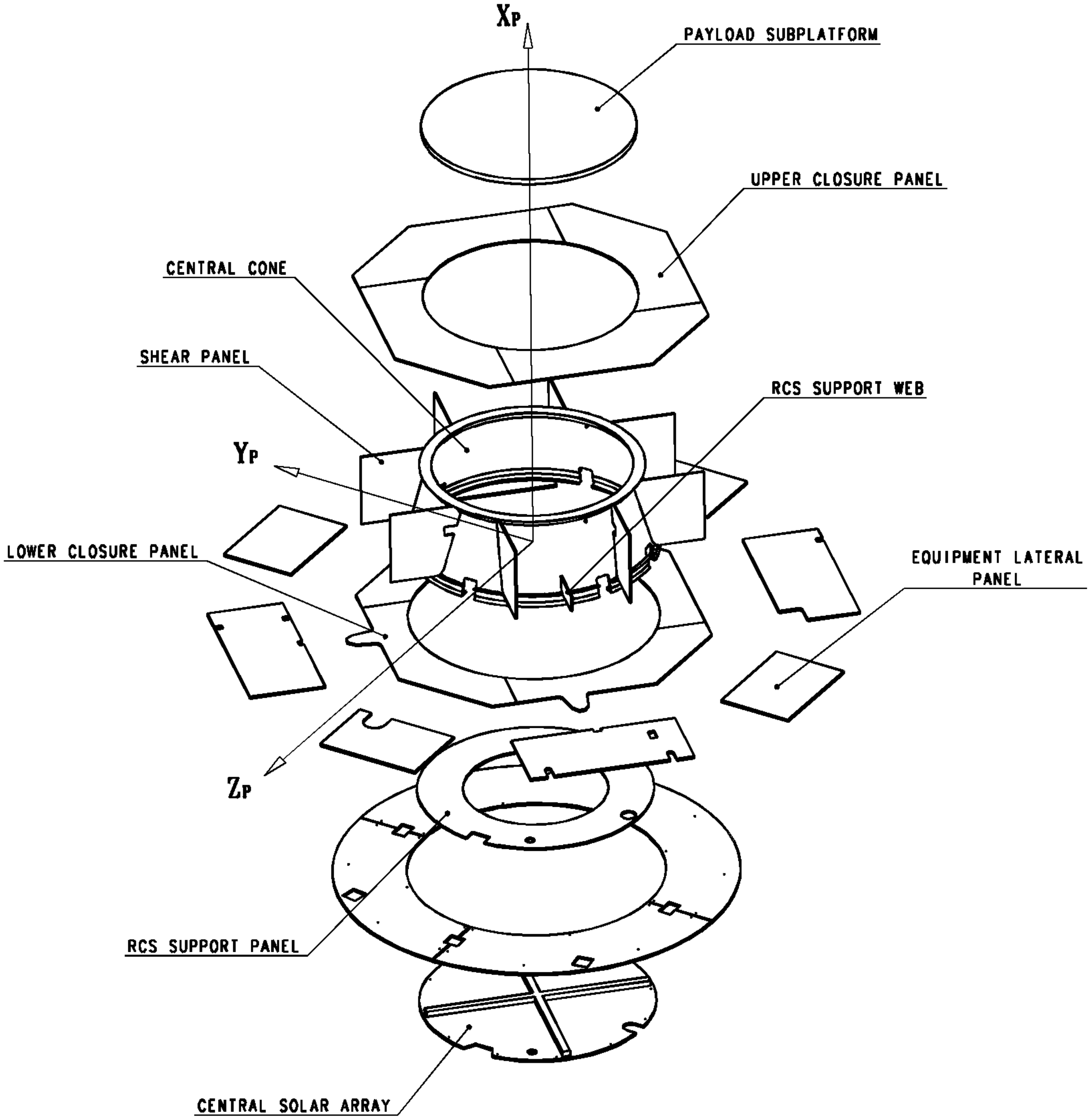


Figure 7.1.2.3-2 Planck SVM Primary structure Exploded View

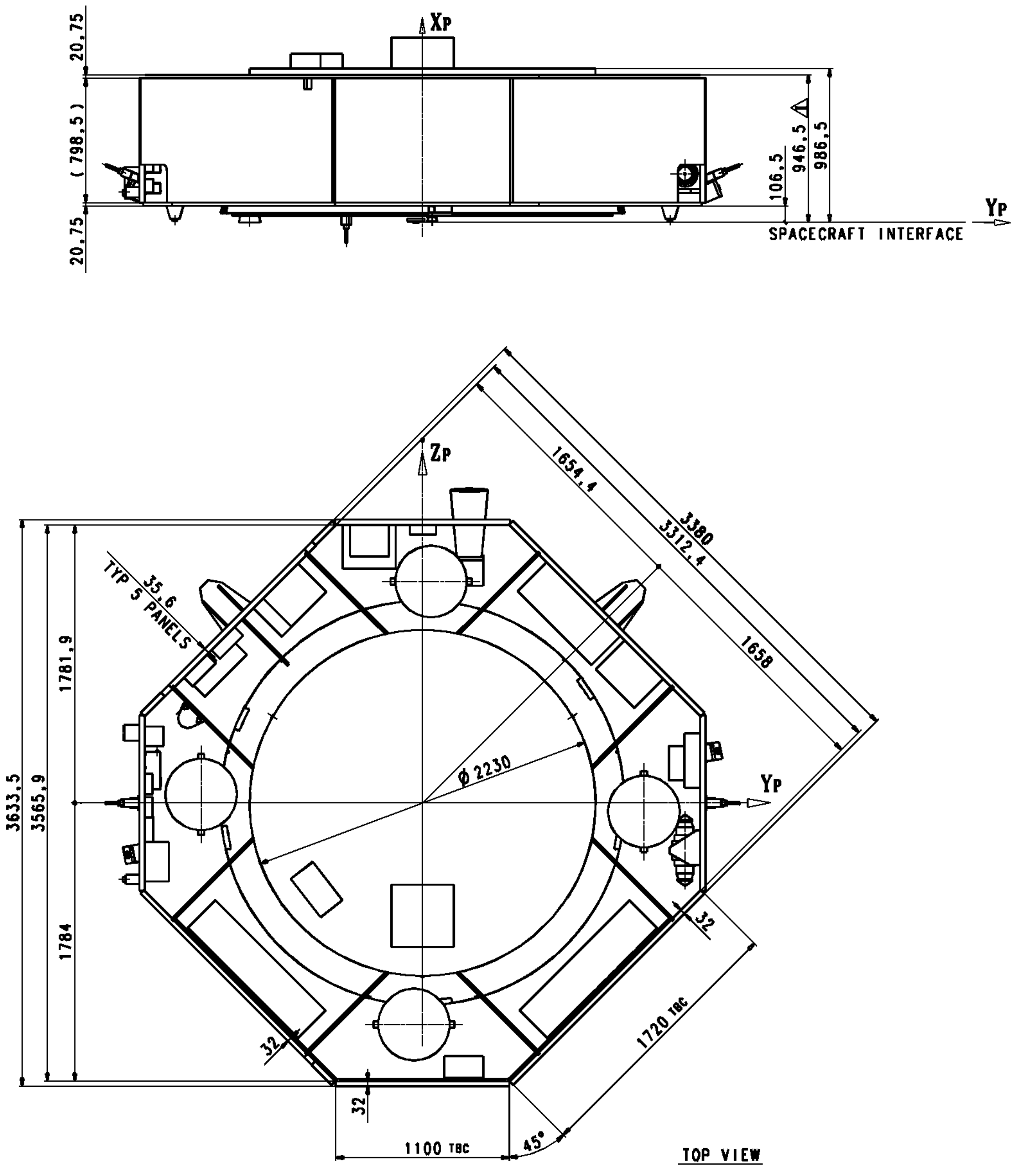


Figure 7.1.2.2-3 Planck SVM Primary structure overall dimension

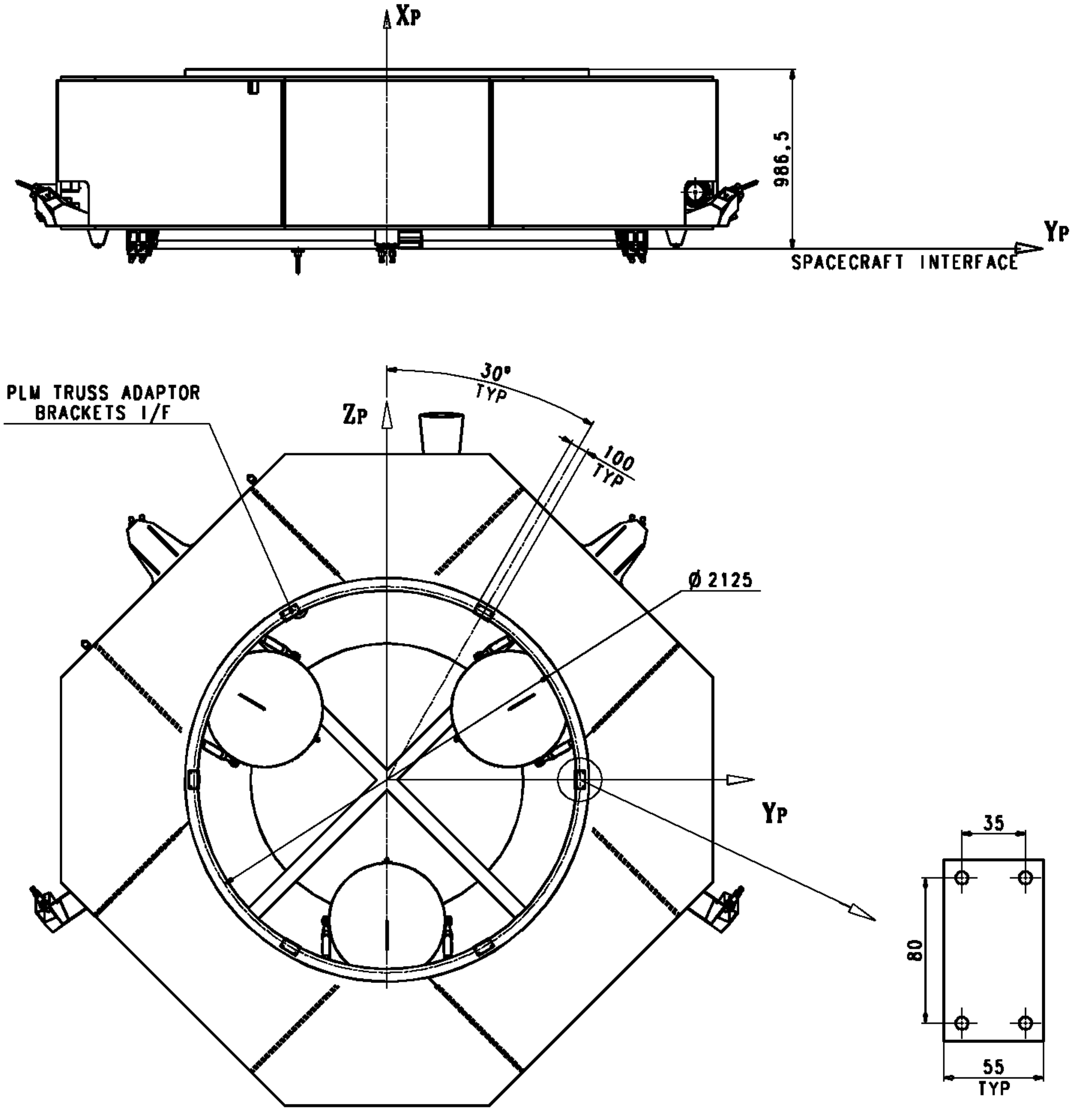


Figure 7.1.2.2-4 Planck SVM Primary structure overall dimension

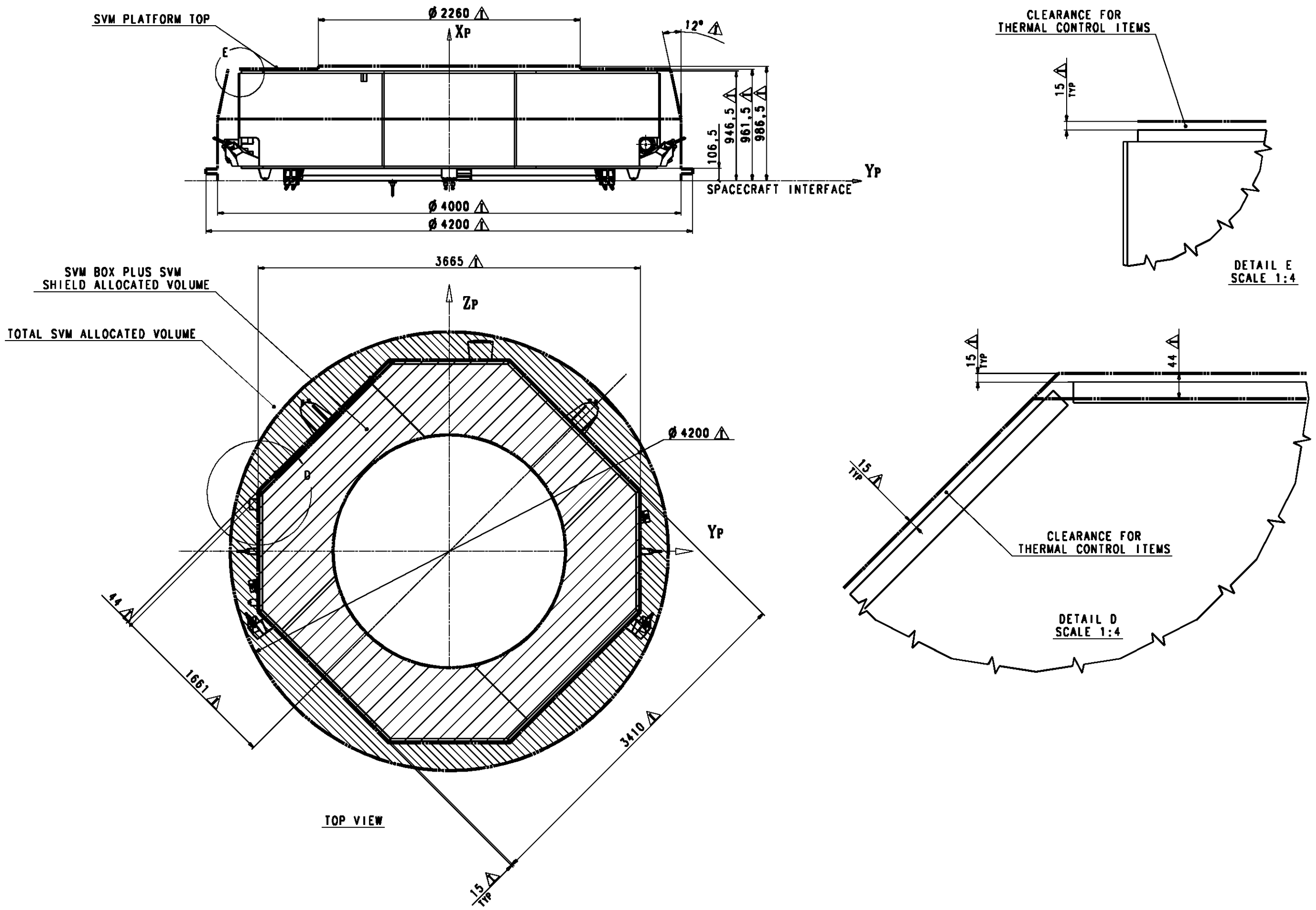


Figure 7.1.2.2-5 Planck SVM Primary Structure overall dimension

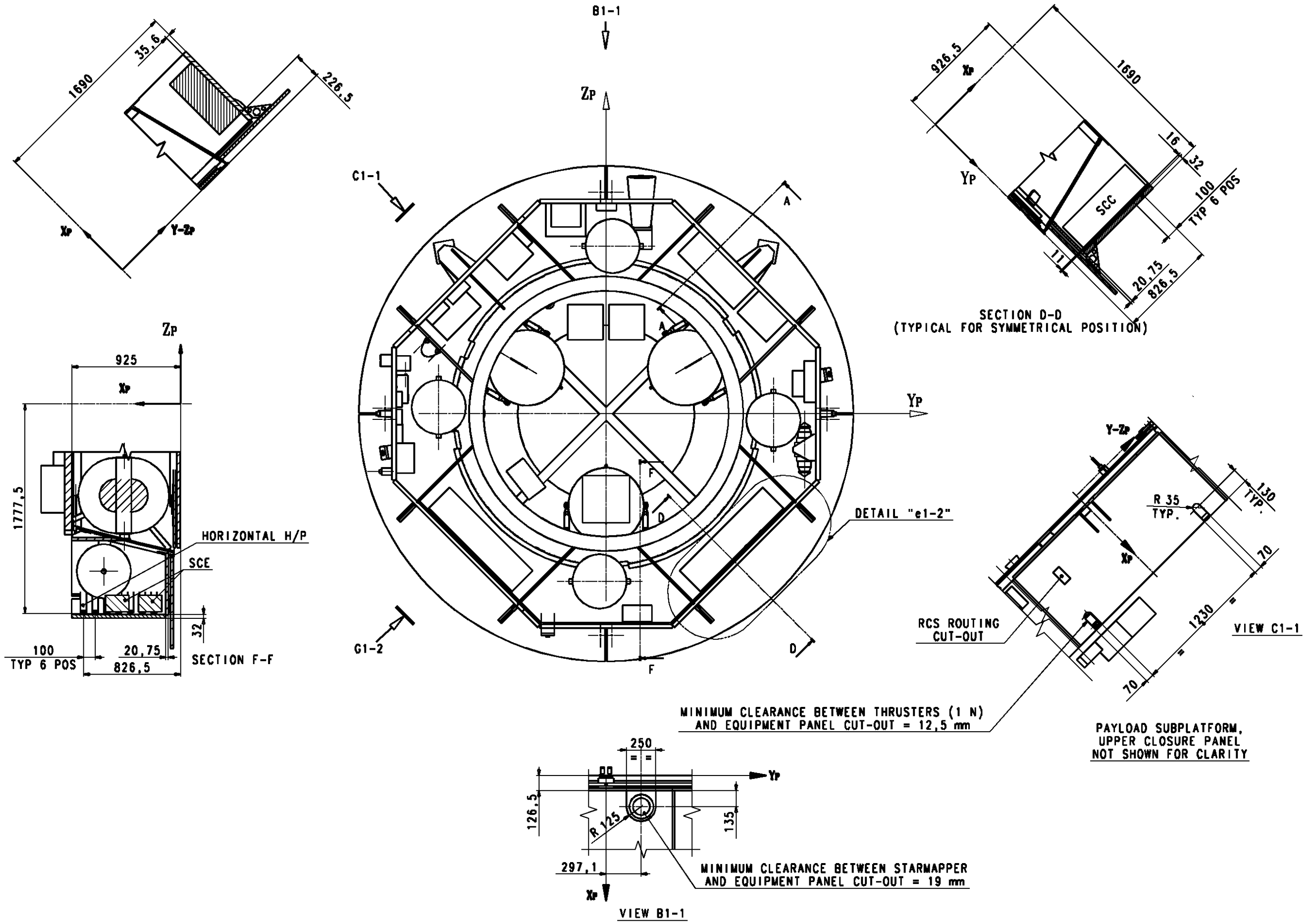


Figure 7.1.2.2-6 Planck SVM Primary structure overall dimension

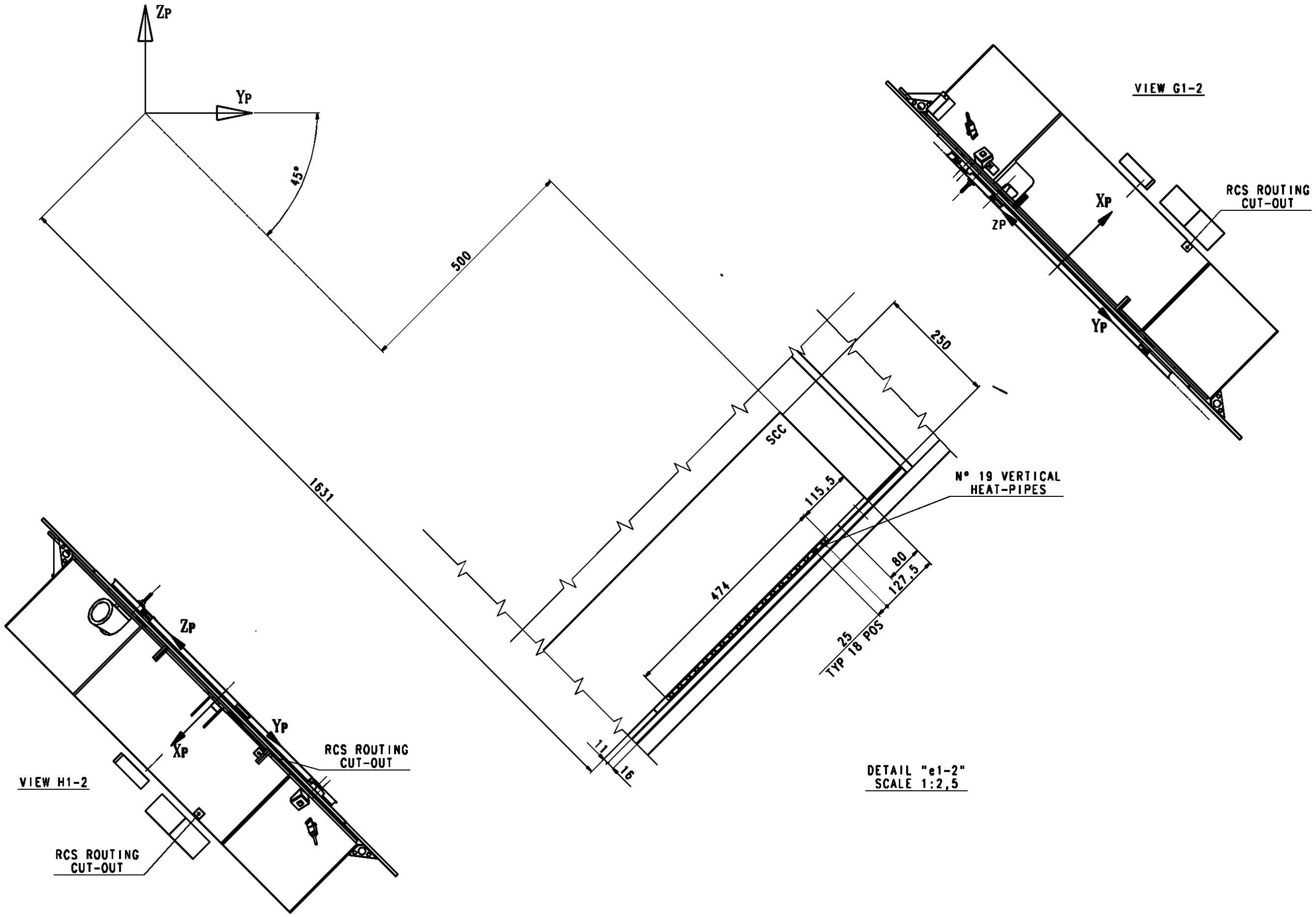


Figure 7.1.2.2-7 Planck SVM Primary structure overall dimension

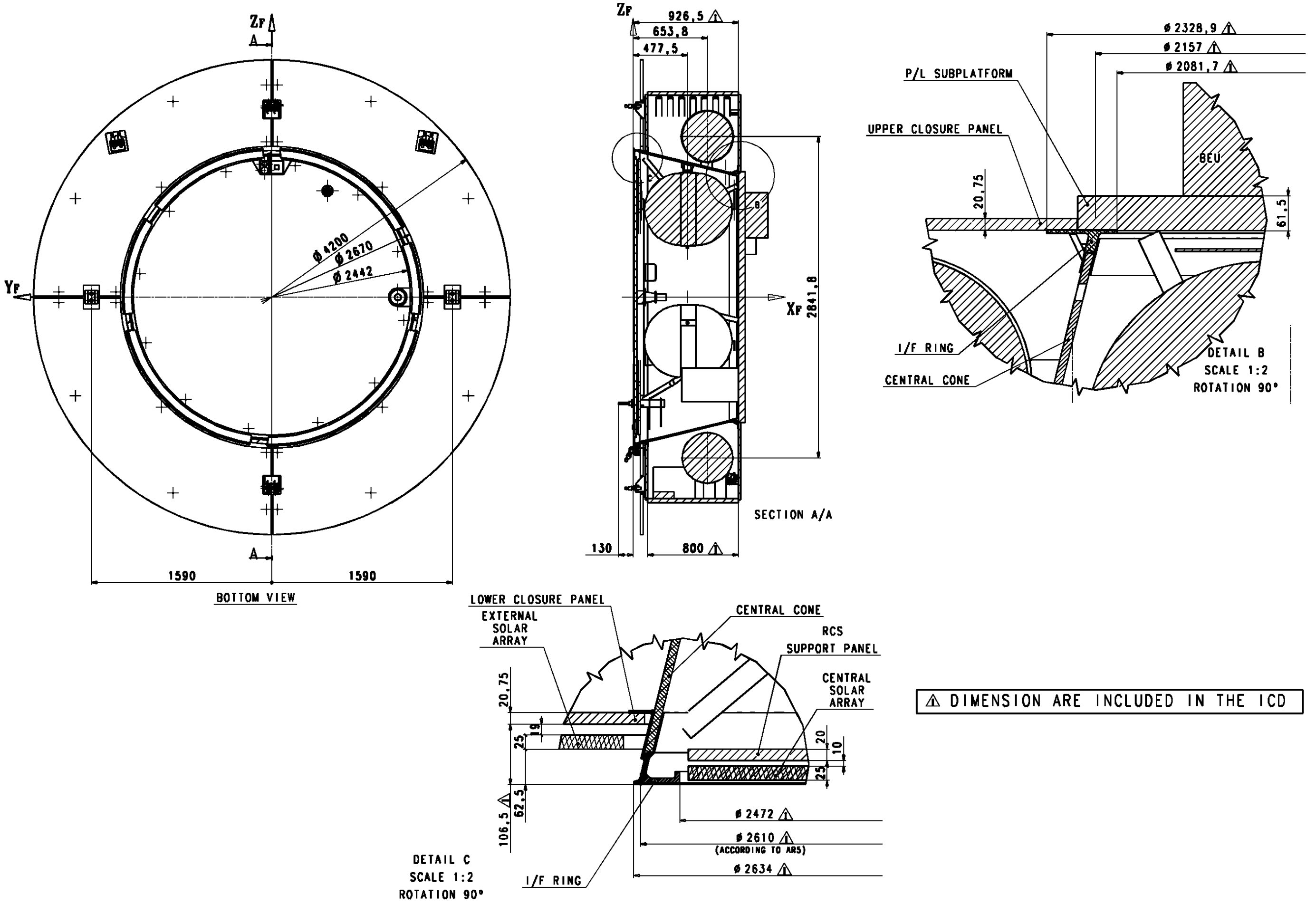


Figure 7.1.2.2-8 Planck SVM Primary structure overall dimension

7.1.2.3 Planck SVM Configuration and Architecture

The accommodation of the S/S equipment and PLM units inside the SVM is dictated by a certain number of strong drivers in terms of system functionality, which are reflected on the primary structure design.

Modular accommodation

First of all, it is requested to respect as far as possible a modular approach for the different units accommodation inside the SVM. This means to accommodate each units group of the same functions or of the same instruments on a dedicated panel. This disposition allows the units integration and functional testing at different level of the S/C integration in independence with the other units integration.

The above defined rule applies to the accommodation of the Avionics functions, and to the accommodation of the instruments (HFI, LFI).

Herschel and Planck communality

Herschel and Planck communality is to be achieved by the extensive selection of common equipment for Herschel and Planck Avionics functions. According to the same logic, it is recommended to have an identical accommodation on SVM panels for the common Avionics units.

The Avionics components on the Herschel panel +Z / -Y are located on identical position on the Planck panel –Y. The Avionics on the Herschel panel +Y are in identical position in the Planck panel +Z / -Y.

The current unit accommodation is shown in the Figure 7.1.2.3-1. It achieves a good level of compliance with the a.m. drivers.

The overall SVM Subsystems components and Warm Units accommodation, completed of detailed location for each unit on single panel is shown in the figure 7.1.2.3-2, 7.1.2.3-3 and 7.1.2.3-4.

The list of the SVM equipments of the PLM "Warm Units" and Subsystem, associated with dimension and location, are included in the table 7.1.2.3-1.

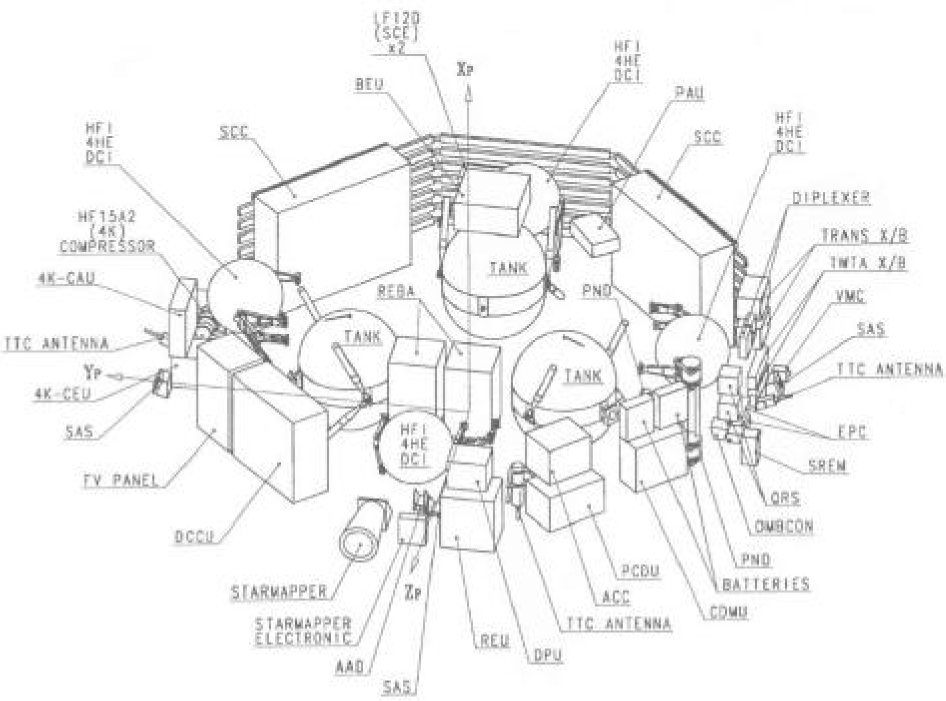


Figure 7.1.2.3-1

ACMS – ATTITUDE CONTROL AND MEASUREMENT SUBSYSTEM

The ACMS units are spread at different location in Planck SVM:
The Quartz Rate Sensors (x2) on a short length panel shared with the TTC units, on –Y side
The Attitude Control Computer on a long length panel shared with the power units, in –Y+Z quadrant
The Star Mappers (STM) electronics closed to the STM on +Z side, on a short length panel shared with 2 warm boxes of the Payload. The ACMS sensors are accommodated on the outside panels of the SVM.

CDMS & TTC COMMAND DATA MANAGEMENT SUBSYSTEM & TELEMETRY, TRACKING, COMMAND

The SREM is located on –Y panel external side.
The VMC is located on -Y external side.
The CDMU is located on -Y+Z panel.
The 3 LGA's antennas are accommodated on side.
The MGA is located on +Z side
The Transponder X/A, TWTA, EPC, RFDN (Diplexer) are located -Y panel.

POWER

The battery and the PCDU units are accommodated together on a long length panel on –Y+Z side (drawings show 2 batteries but last minute trade off decision is baselining 1 battery only.
The Solar Array composed by 2 panels located at the bottom of the SVM box.
The first panel is housed inside the central cone while the second one is located around the circumference of the central cone.

HARNESS

The SVM primary structure shall include provision like inserts , for the fixation of the Harness cabling.

RCS ACCOMMODATION

The RCS system comprises 3 Propellant Tanks (P. Tanks), pipe work, components as valves and pressure transducers, the Reaction Control Thrusters (RCT).
The 3 Propellant Tanks of Integral type, with an internal bladder for liquid and pressurant gas separation, function in blow-down conditions. They are installed at pitch angle of 120° inside the Central Tube.
The routing of the RCS components and RCS piping is organised in 2 zones. In a first time, a major part of the RCS piping and RCS components not necessitating a frequent accessibility (filters, latch valves, ...) are routed inside the central cone on a dedicated support ring identified as RCS Panel. This configuration allows to quickly distributing the RCS piping from the P.Tank in the direction of the RCT.
In a second time, radial lines pass through the central cone wall and route (mainly) on the shear webs to feed the RCTs and RCS components requiring accessibility (fill and drain valves, test ports). This configuration allows a clear and de-coupled RCS implementation inside the SVM, limiting interfaces and interwovenness with the structure and other SVM subsystems.
An overall RCS line routing associated with Propellant Tanks and valves location is shown in the drawings of figures 7.1.2.3-6 and 7.1.2.3-7.

THERMAL CONTROL

The Thermal Control hardware is mainly composed by Multilayer Insulation Blanket (MLI), Optical Solar Reflectors (OSR), Paints and Fillers.
All those items are directly attached to the primary structure of the SVM.
The Thermal Control of the Sorption Cooler Compressor is performed by use of crossed Heat Pipes network installed on the panels: -Z+Y,-Z and –Z-Y.
An overview of the preliminary distribution and location of the thermal hardware is shown in the figure 7.1.2.3-8.

PLM WARM BOXES

HFI warm boxes

The HFI warm boxes are mainly grouped on 3 adjacent and dedicated panels, located in the sector +Y+Z. Two of the panels group respectively the instruments of the 0.1 K and the 4 K cooling stages, when the 3 rd one accommodates electronics for signal and data processing. Additionally, the 0.1 K cooling stage includes 4 He Tanks accommodated around the central cone.
The PAU box is located on top of the Payload Subplatform in the sector –Y-Z.

LFI warm boxes

The 2 REBA are accommodated below the Payload Subplatform towards +Z side. This position of the REBA participates to the good balancing of Planck as the REBA mass acts again the natural PPLM un-balance on –Z side.
The BEU box is located on top of the Payload Subplatform on the axis –Z.

Sorption Cooler Compressors (SCC)

The SCC system belongs to the 20 K cooling stage, and comprises 2 SCC units and 2 associated electronics accommodated on 3 adjacent panels on – Z side. The location of these units on –Z side is required to minimize effect of SCC temperature fluctuation on SIN.
The 2 SCC units are accommodated on 2 opposite long length panels, -Z+Y and –Z-Y, whereas the SCC electronics are accommodated on the central panel –Z.
Each SCC base plate is directly connected with 19 vertical heat pipes 11 mm thick. This assy is connected on 7 longitudinal heat pipes 16 mm thick mounted on the SVM panels.
A preliminary design of the interfaces between SVM panel, Heat pipes and SCC boxes is shown in the figures 7.1.2.3-5a and 7.1.2.3-5b below.

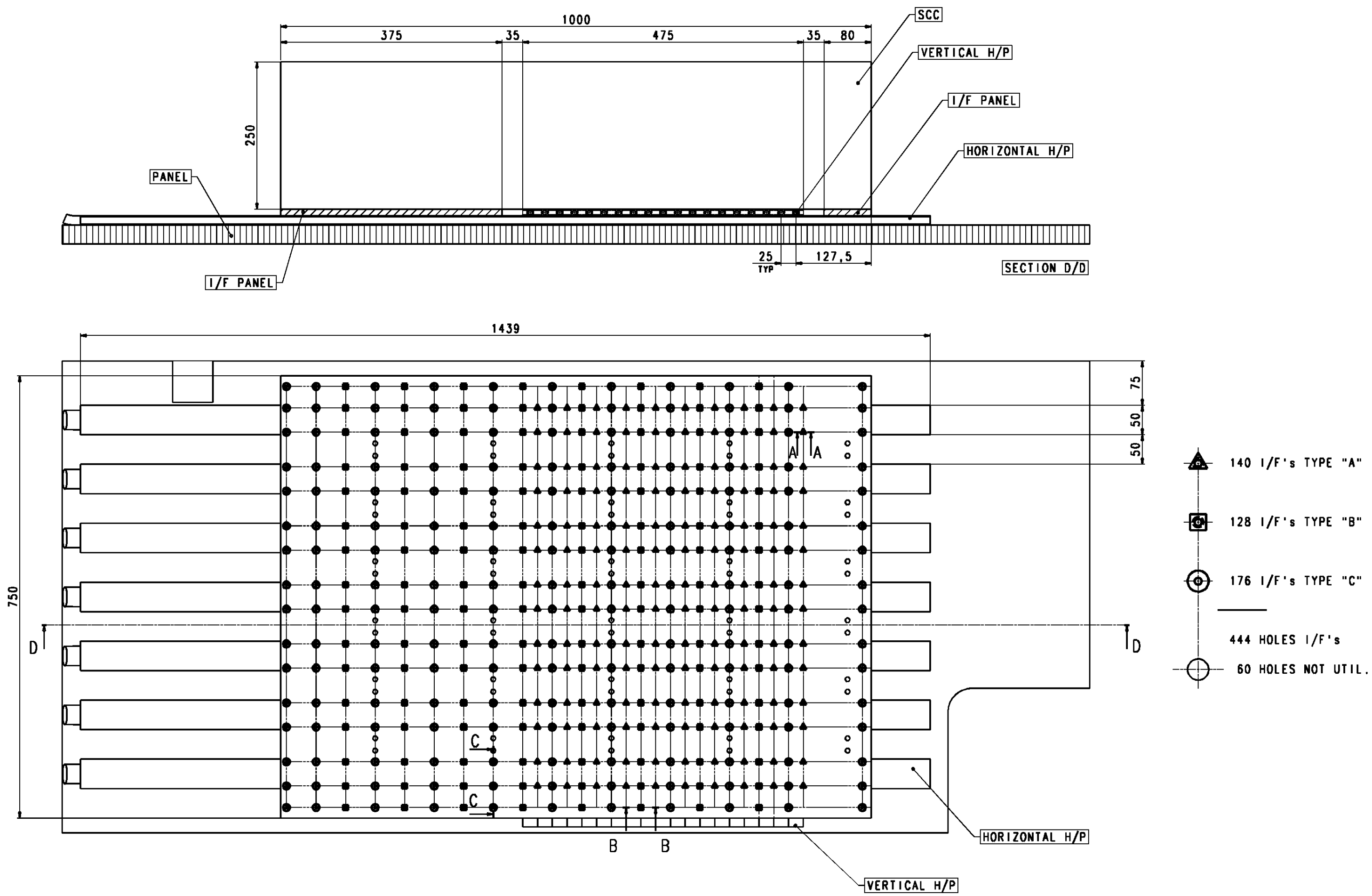


Figure 7.1.2.3-5a Planck SVM panel/Heat pipes/SCC box Interfaces

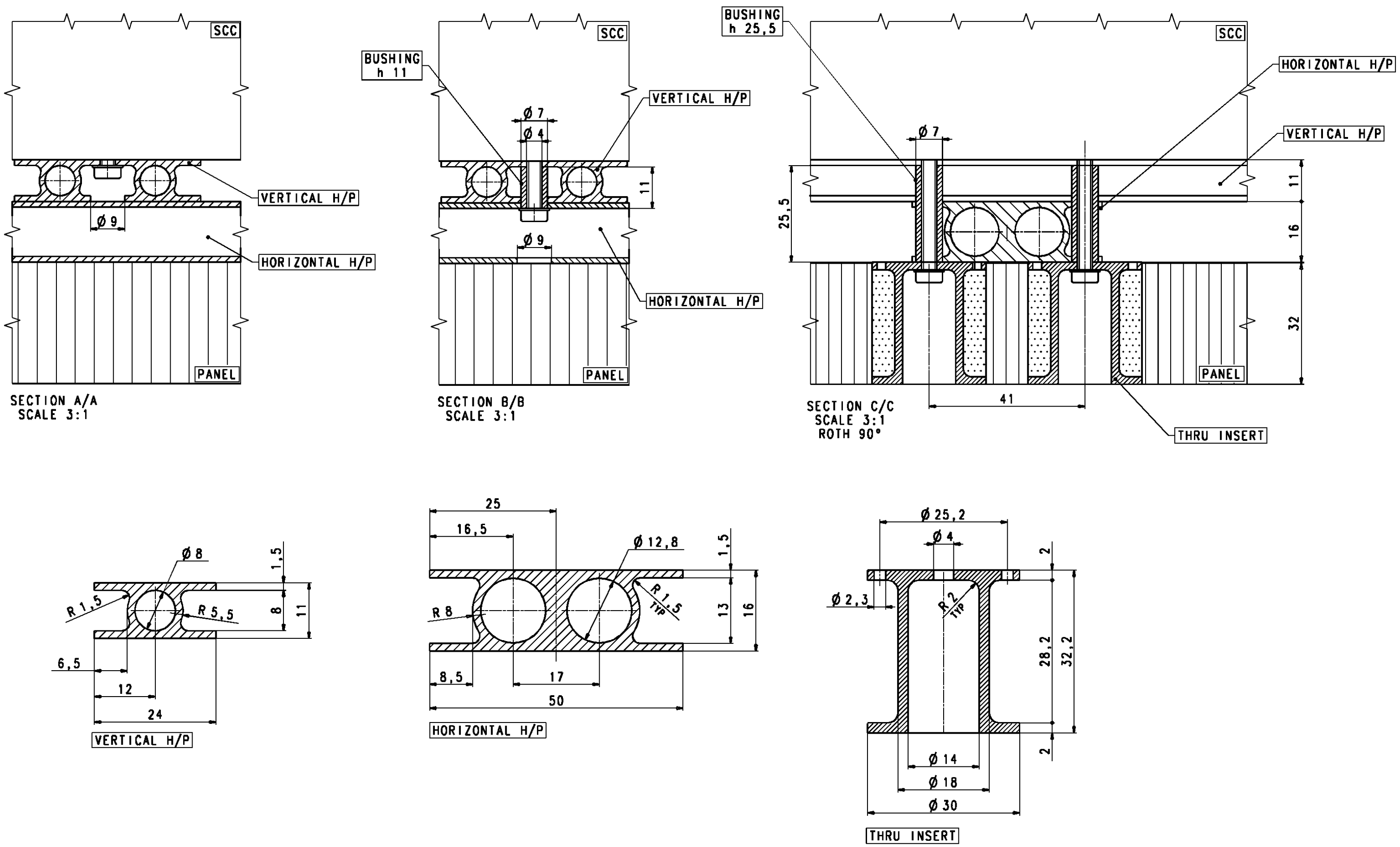


Figure 7.1.2.3-5b Planck SVM panel/Heat pipes/SCC box Interfaces

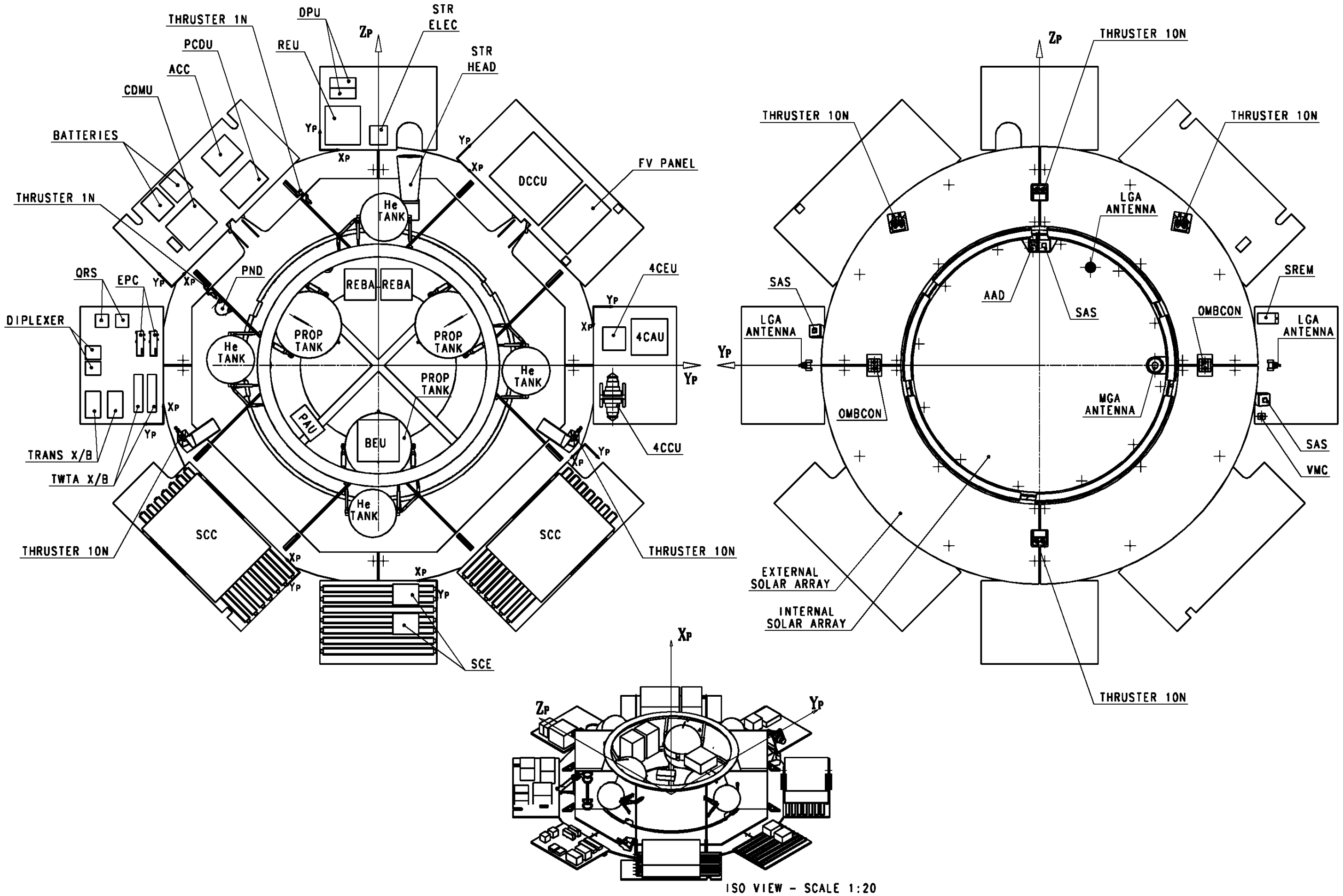

THRUSTER 1N
DPU
STR ELEC
STR HEAD
REU
PCDU
ACC
CDMU
BATTERIES
THRUSTER 1N
DCCU
FV PANEL
He TANK
REBA
REBA
PND
QRS
EPC
DIPLEXER
PROP TANK
PROP TANK
He TANK
He TANK
4CEU
4CAU
PAU
BEU
TRANS X/B
TWTA X/B
4CCU
He TANK
SCC
SCC
THRUSTER 10N
THRUSTER 10N
SCE
THRUSTER 10N
THRUSTER 10N
THRUSTER 10N
LGA ANTENNA
SAS
LGA ANTENNA
AAD
SAS
SREM
OMBCON
LGA ANTENNA
OMBCON
MGA ANTENNA
SAS
VMC
EXTERNAL SOLAR ARRAY
INTERNAL SOLAR ARRAY
THRUSTER 10N
ISO VIEW - SCALE 1:20

Figure 7.1.2.3-2 Planck SVM Units accommodation

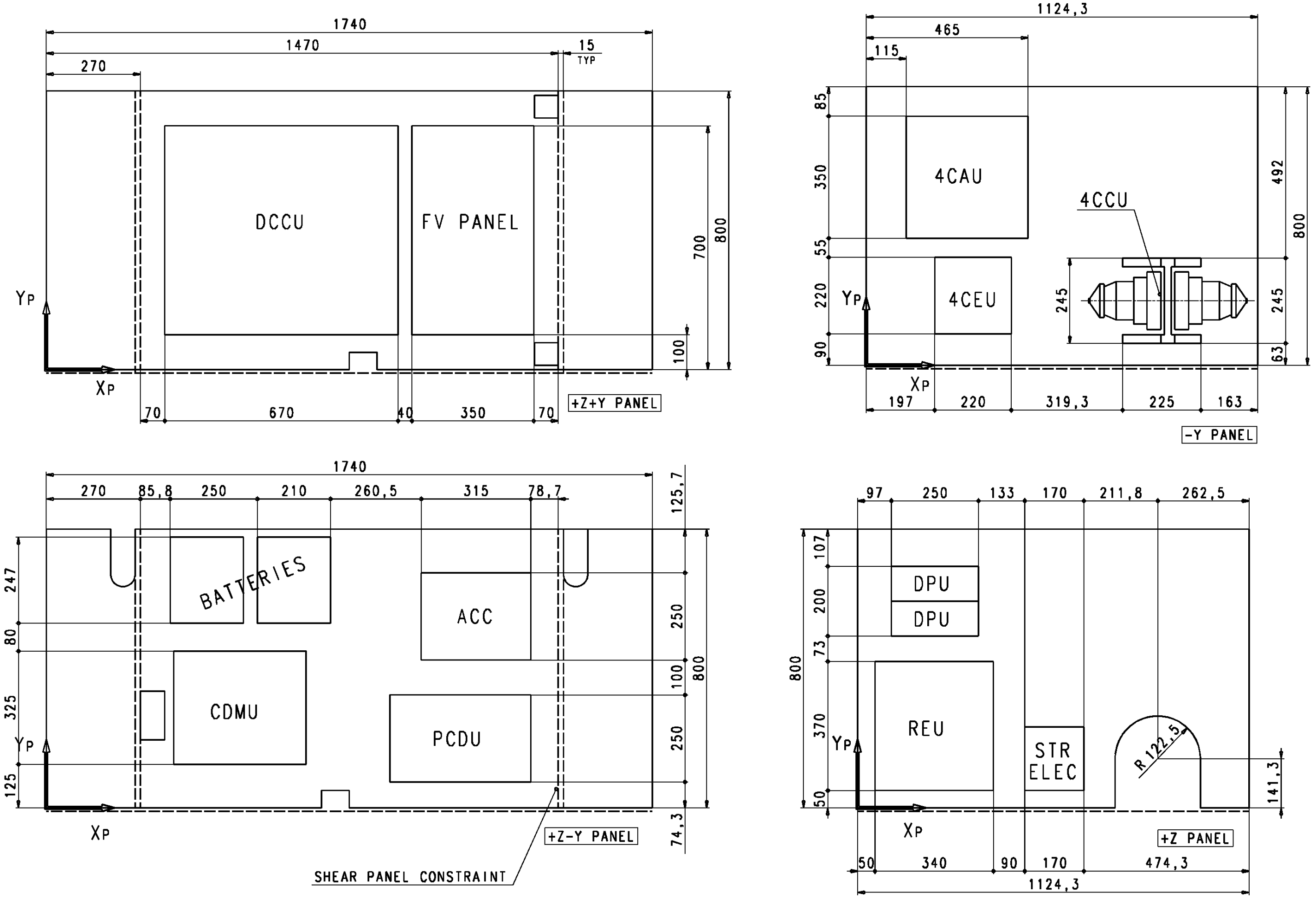


Figure 7.1.2.3-3 Planck SVM Units Accommodation

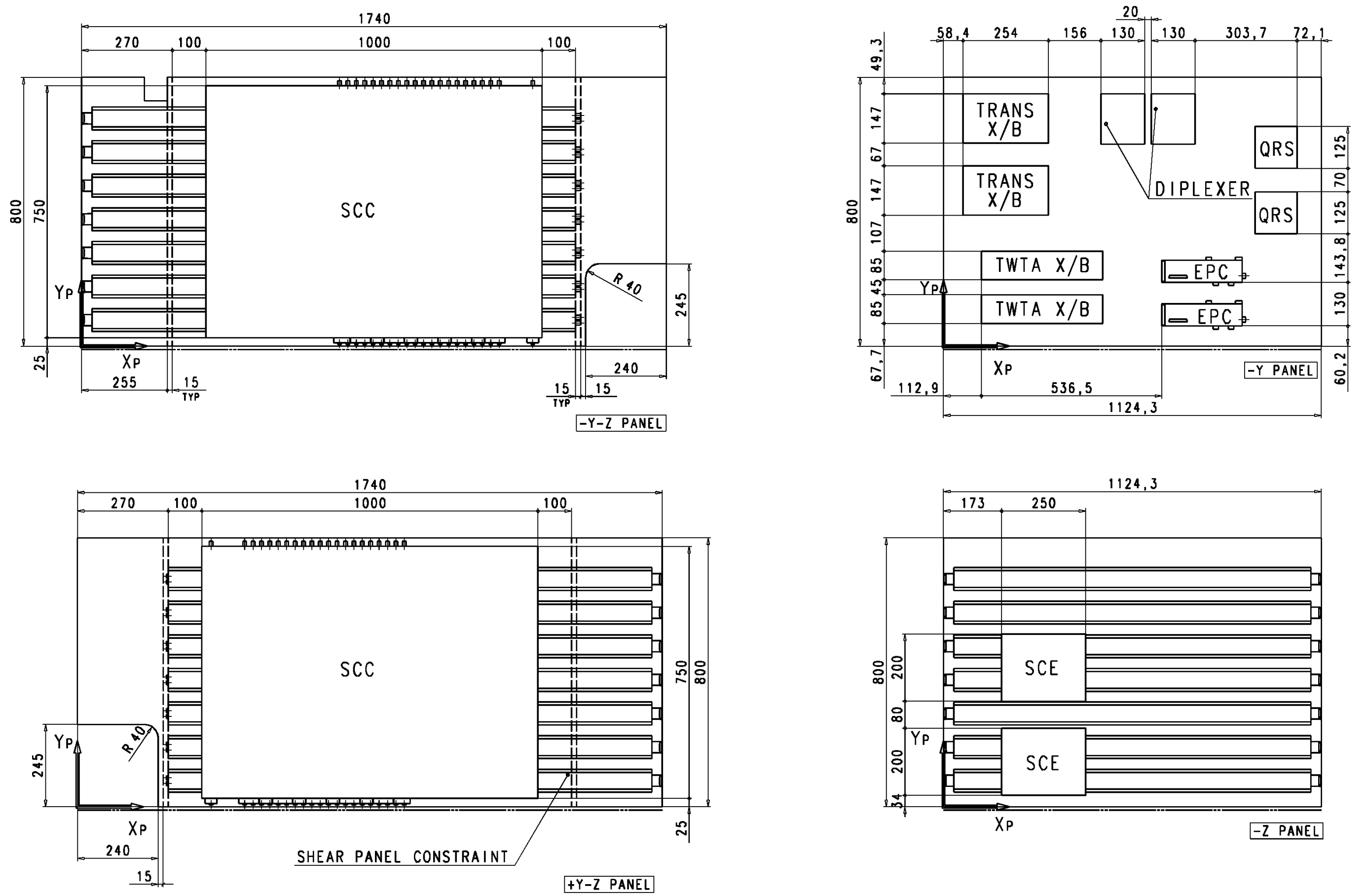


Figure 7.1.2.3-4 Planck SVM Unit accommodation

			Unit Dimension (mm)			
PLANK SVM	PLANK SVM	Location	L	W	H	Q.ty
Equipment Acronym	Long Name	Panel				
PLM - WARM UNIT	PLM - WARM UNIT					
HFI	High Frequency Instrument Planck					
PHBA	Data Processing Unit DPU	+Z	250,0	200,0	200,0	1
PHCBA	Pre-Amplifier Unit PAU	Sub pl.+X	310,0	180,0	95,0	1
PHCBC	Readout Electronic REU	+Z	340,0	370,0	280,0	1
PHDA	4K Cooler Compressor UNIT 4CCU	+Y	456,0	245,0	195,0	1
PHDB	4K Cooler Auxillary Unit 4CAU	+Y	350,0	350,0	100,0	1
PHDC	4K Cooler Electronic Unit 4CEU	+Y	220,0	220,0	200,0	1
PHEAA	0,1 K Dilution Cooler 3He Tank		Diam. 460			1
PHEAB	0,1 K Dilution Cooler 4He Tank		Diam. 460			1
PHEC	Dilution Cooler Contr. Unit DCCU	+Z+Y	670,0	600,0	260,0	1
PHED	0,1 K Filling and Venting Panel	+Z+Y	350,0	600,0	260,0	1
LFI	Low Frequency Unit					
PLBEU	Back End Unit BEU	Sub pl.+X	400,0	400,0	200,0	1
PLREN	REBA nominal	Sub pl.-X	300,0	300,0	500,0	1
PLRER	REBA redundant	Sub pl.-X	300,0	300,0	500,0	1
SORPTION COOLERS	SORPTION COOLERS					
PSM3	Sorption Cooler Compressor SCC	-Z-Y	1000,0	750,0	250,0	1
PSM4	Sorption Cooler Elec. SCE	-Z	250,0	200,0	140,0	1
PSR3	Sorption Cooler Compressor SCC	-Z+Y	1000,0	750,0	250,0	1
PSR4	Sorption Cooler Elec. SCE	-Z	250,0	200,0	140,0	1

Table 7.1.2.3-1 Planck SVM Equipment list (1 of 3)

			Unit Dimension (mm)			
PLANK SVM	PLANK SVM	Location	L	W	H	Q.ty
Equipment Acronym	Long Name	Panel				
POWER						
BATTERY	Lithium-Ion Battery	+Y	210,00	247,00	80,00	1
PCDU	PCDU (Power Conditio.Distr. Unit)	+Y	380,00	325,00	185,00	1
SOLAR ARRAY						
External Array		Cone -Z				1
Internal Array		Cone -Z				1
Electrical Network		Cone -Z				1
ACMS						
STM-H	STM Mapper Head	+Z				1
STM-E	STM Mapper Elec.	+Z	274,0	210,0	130,0	1
SAS-1	Sun Acquisition Sensor	-Y	110,0	110,0	30,0	1
SAS-2	Sun Acquisition Sensor	+Y	110,0	110,0	30,0	1
SAS-3	Sun Acquisition Sensor	Cone -X	110,0	110,0	30,0	1
AAD	Attitude Anomaly detector	Cone -X	110,0	70,0	60,0	1
QRS	Quartz Rate Sensor	-Y	125,0	125,0	120,0	2
ACC	Attitude Control Computer	-Y+Z	315,0	250,0	260,0	1
CDMS						
CDMU	Central Data Management Unit	-Y+Z	405,0	250,0	260,0	1

Table 7.1.2.3-1 Planck SVM Equipmen t list (2 of 3)

			Unit Dimension (mm)			
PLANK SVM	PLANK SVM	Location	L	W	H	Q.ty
Equipment Acronym	Long Name	Panel				
TT&C						
TRANS X/B	Transponder	-Y	250,0	153,0	147,0	2
TWTA	Travelling Wave Tube Amplifier	-Y	360,0	85,0	55,0	2
EPC	Electrical Power Conditioner	-Y	240,0	66,0	100,0	2
RFDN (diplexer)	Radio Frequency Distribution Network	-Y	150,0	130,0	50,0	2
MGA	Medium Gain antenna	-X	D.448 h 472			1
X/B LGA	Low Gain antenna	+Z	D. 90 h 141			1
X/B LGA	Low Gain antenna	-Z	D. 90 h 141			1
X/B LGA	Low Gain antenna	-X	D. 90 h 141			1
SREM	Standard Radiation Monitor	-Y ext.	100,0	200,0	95,0	1
VMC	Visual Monitoring Camera	-Y ext.	65,0	60,0	100,0	1
RCS						
Propellant Tank	Tank					3
RCT 10N	10 N thruster					12
RCT 1N	1 N thruster					4
LV	Latch valve					2
PT	Pressure transducer					1
FD	Fill/Drain valve					1
FV	Fill/Vent valve					3
TP	Test port					2
LF	Filter					1
Ducting	Ducting					1
Bracketry	Bracketry					1

Table 7.1.2.3-1 Planck SVM Equipment list (3 of 3)

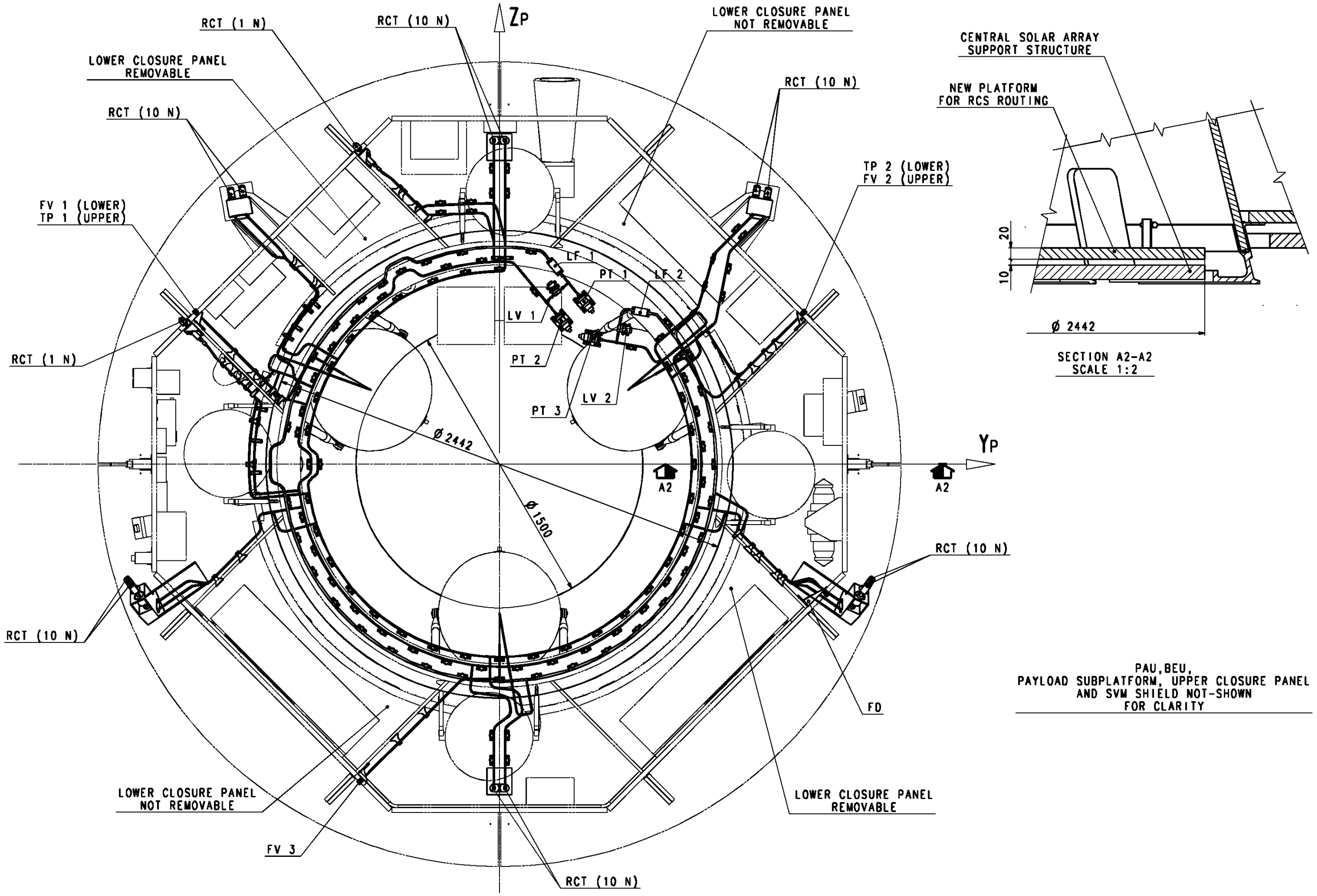


Figure 7.1.2.3-6 Planck SVM RCS line routing and items location

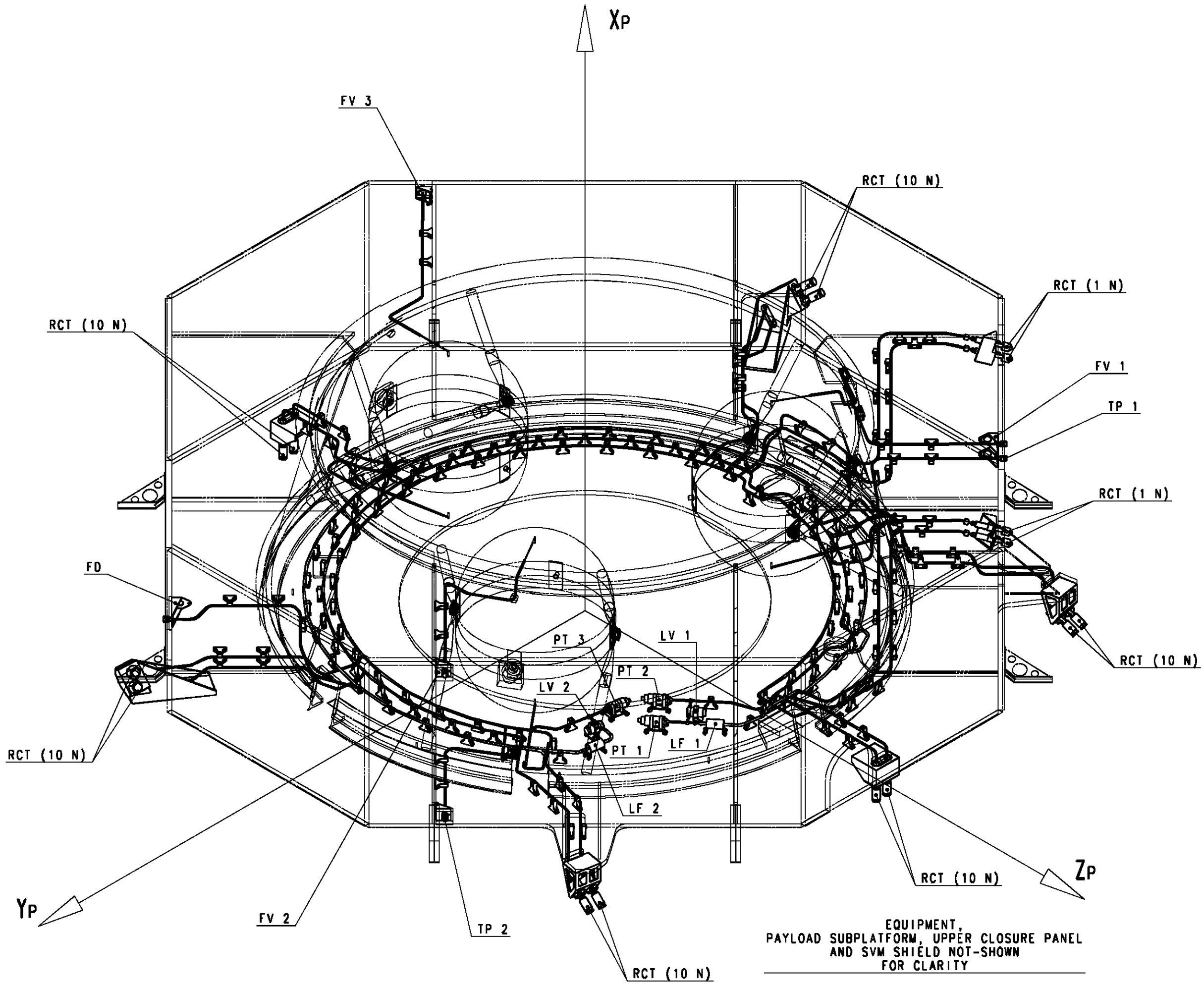


Figure 7.1.2.3-7 Planck SVM RCS line routing and items location

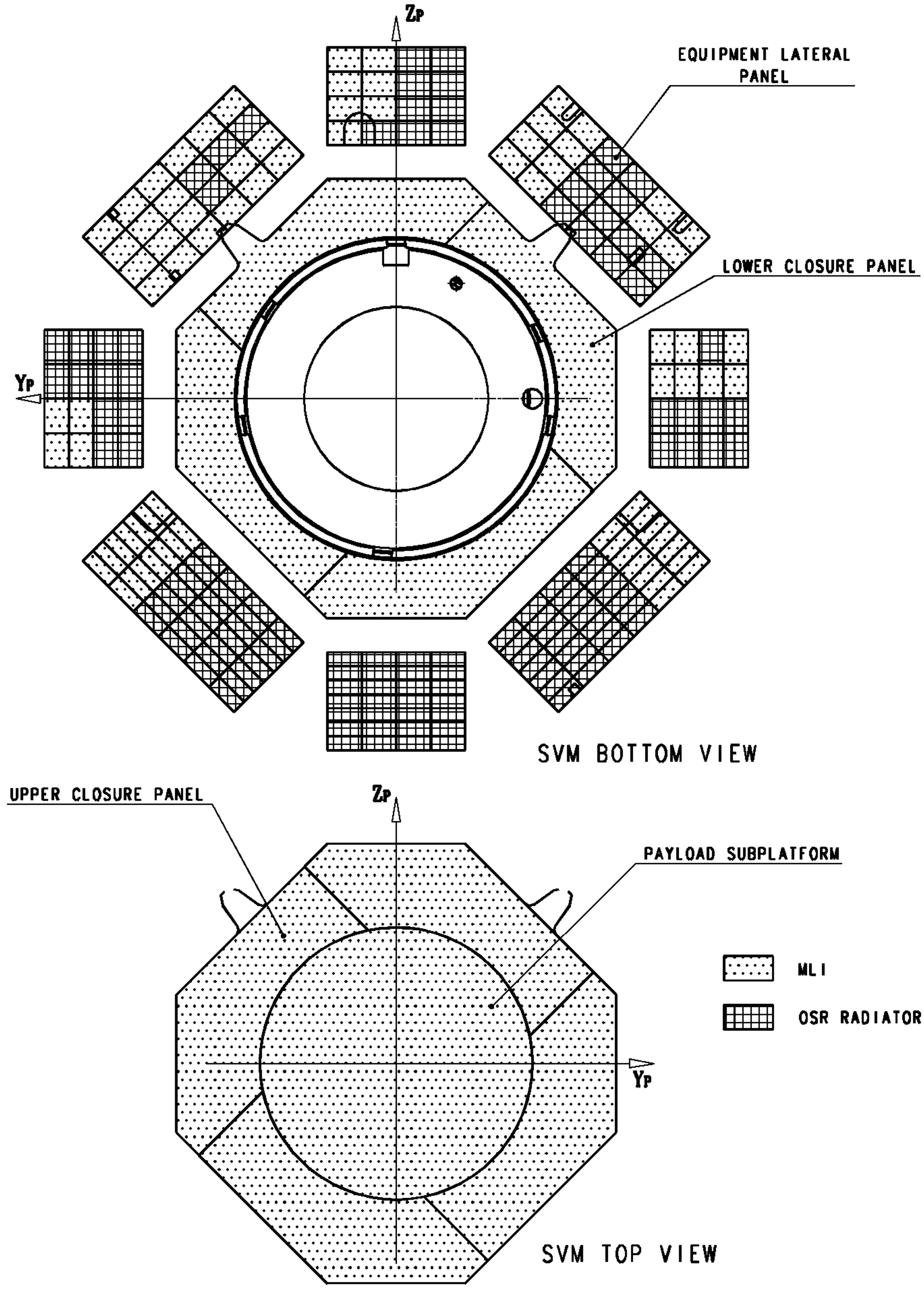


Figure 7.1.2.3-8 Planck SVM MLI location

7.1.3 Service Module to Payload Module Interface

Herschel SVM to PLM Interface

The payload is accommodated in a modular way on the top of the SVM structure. The main interfaces with the SVM are provided by the cryostat, which in turn provides mechanical supports for the other PLM elements as the telescope and the Sunshield/ Sunshade assembly.
The cryostat is accommodated in along the launch axis on the top of the SVM structure. The cryostat support structure is constituted by a set of 24 truss interfacing with the upper cone by 12 adapter brackets at Payload sub-platform level as described in detail in paragraph 9.1. Interface locations shown in the Figure 7.1.3.1-1.

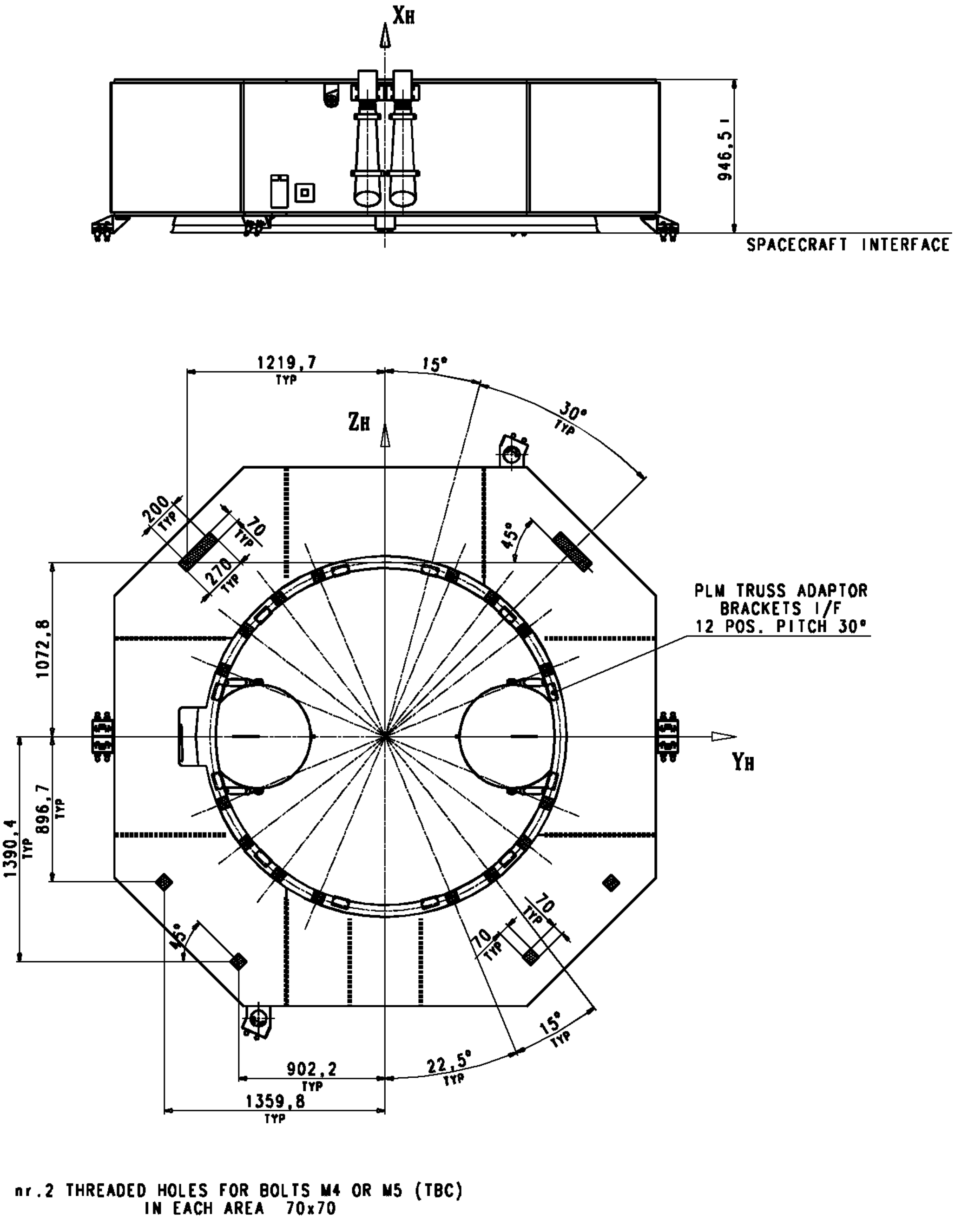


Figure 7.1.3.1-1 Herschel SVM to PLM Interface

Planck SVM to PLM Interface

The Payload is accommodated in a modular way on the top of the SVM Structure.The main interfaces with the SVM are provided by the Cryo structure which in turn provides mechanical supports for the other PLM elements as the Focal Plane Unit FPU and the main baffle.
The PPLM is accommodated on the top of the SVM via the Cryo structure made by a set of 12 struts interfacing on the top area of the Conical Tube by 6 adapter brackets at Payload subplatform level.
The location of the truss adapter brackets on the Conical Tube is shown in the Figure 7.1.3.1-2.

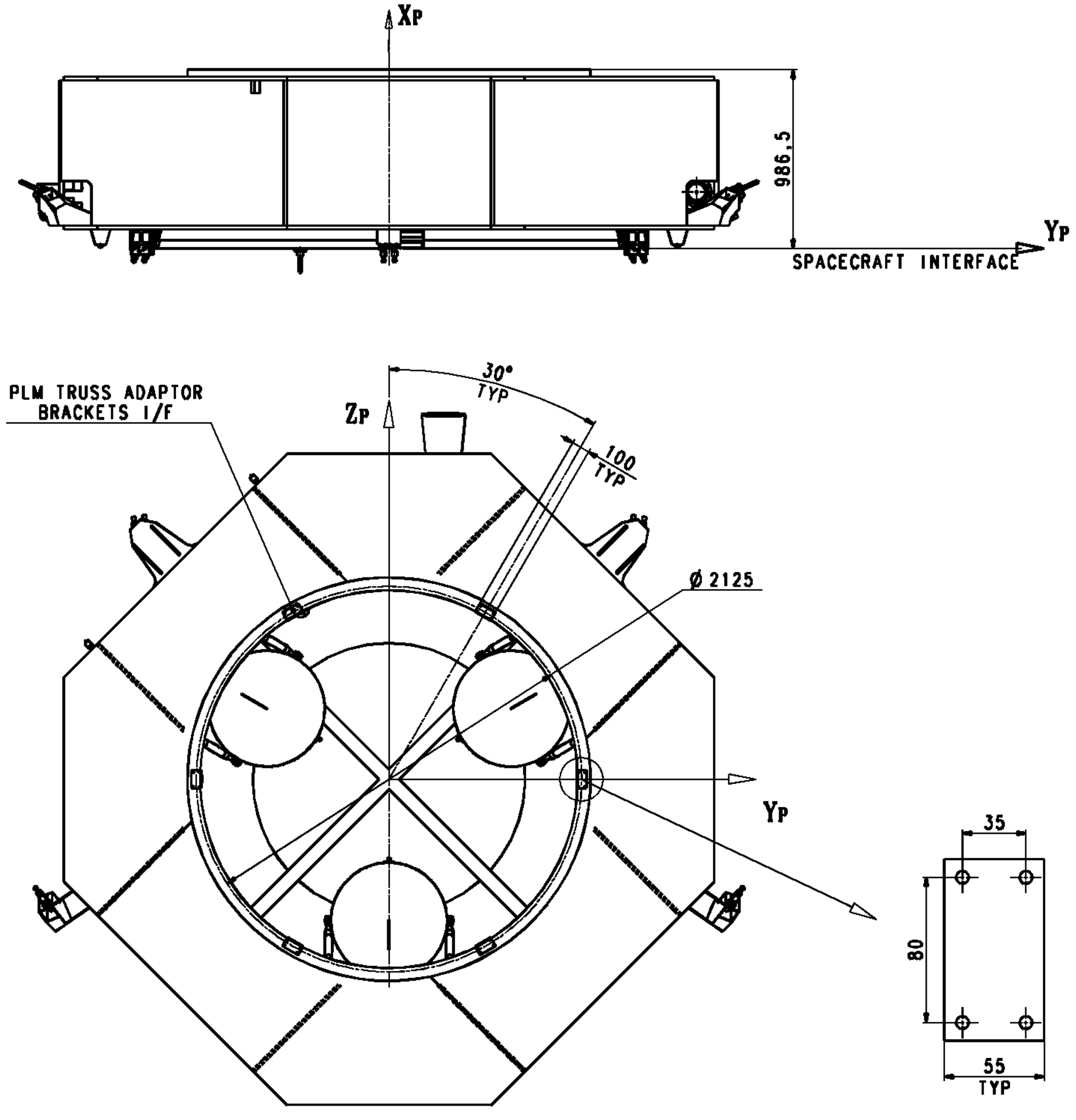


Figure 7.1.3.1-2. Planck SVM to PLM Interface

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)
The interface ring meet the shape and dimension (see figure 7.1.4-3) and the cone angle is presently about 15 degrre.

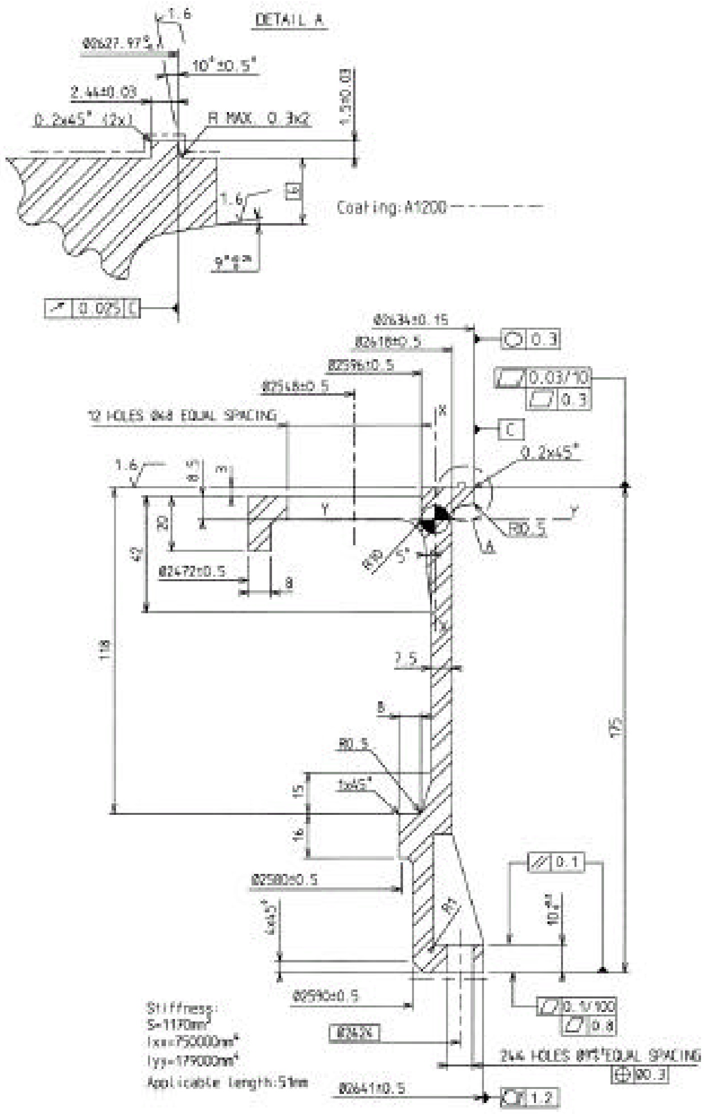


Figure 7.1.4-1 Adaptor 2624 Interface

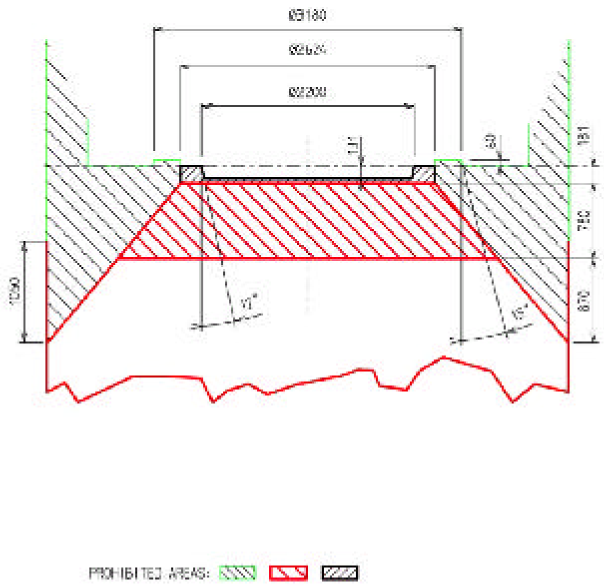


Figure 7.1.4-2 Adaptor 2624 Usable Volume

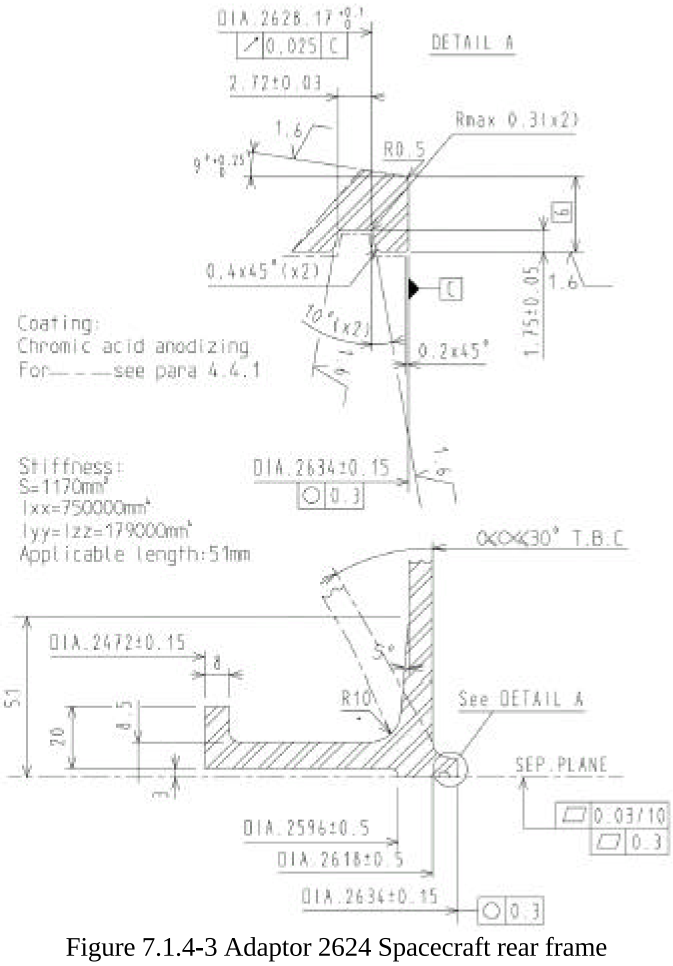


Figure 7.1.4-3 Adaptor 2624 Spacecraft rear frame

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).
SVM Planck Solar Array (diam.4200 mm) violate the static envelope of Sylda 5 (diam. 4000 mm) with respect to the ARIANE V User Manual. However present SVM shape is compliant with the allowable volume identified in the SVM specification
Same problem has been encounterd also on the RCS brackets which violate the Sylda 5 constraint.

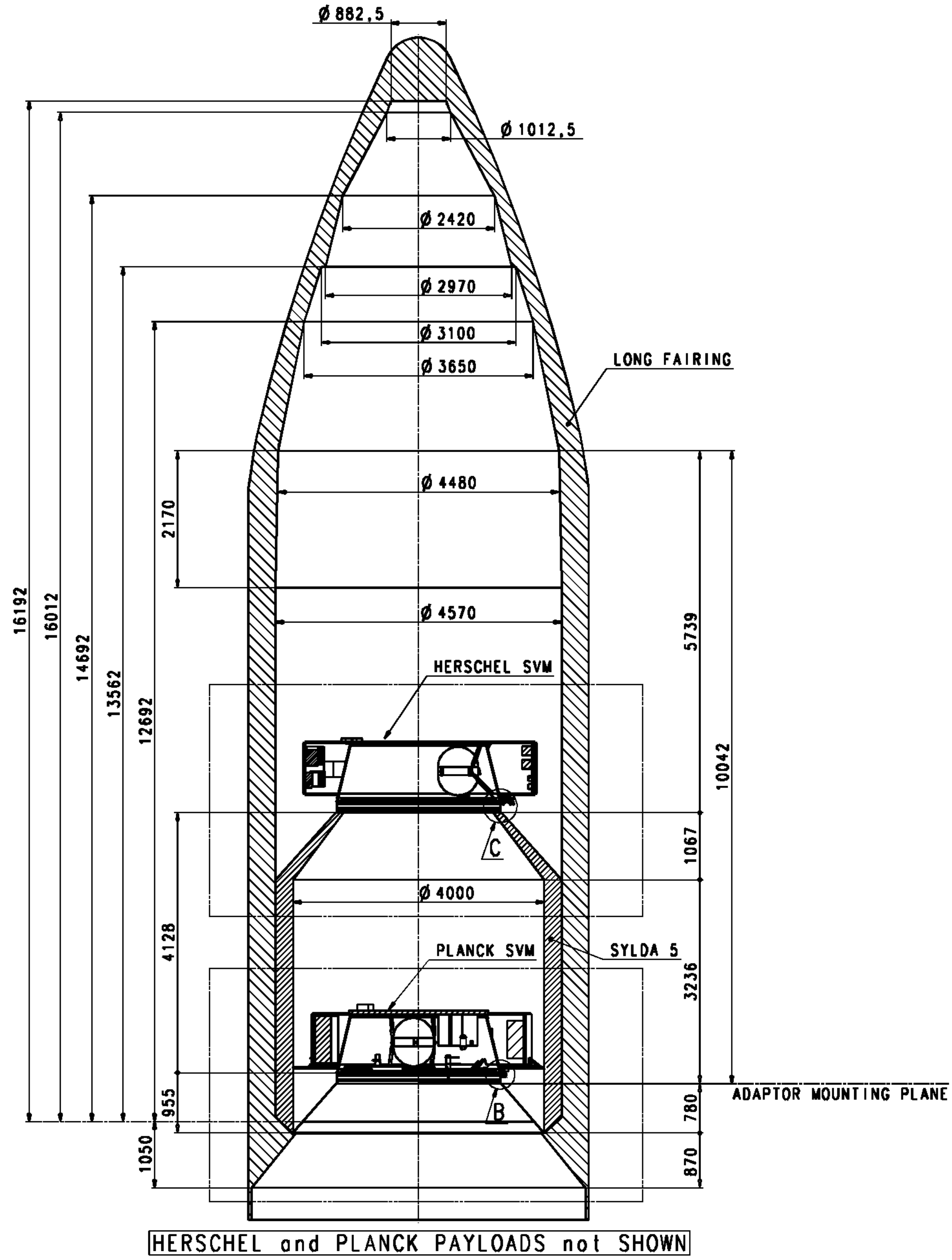


Figure 7.1.4-4 SVM Herschel/ Planck launch configuration

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.

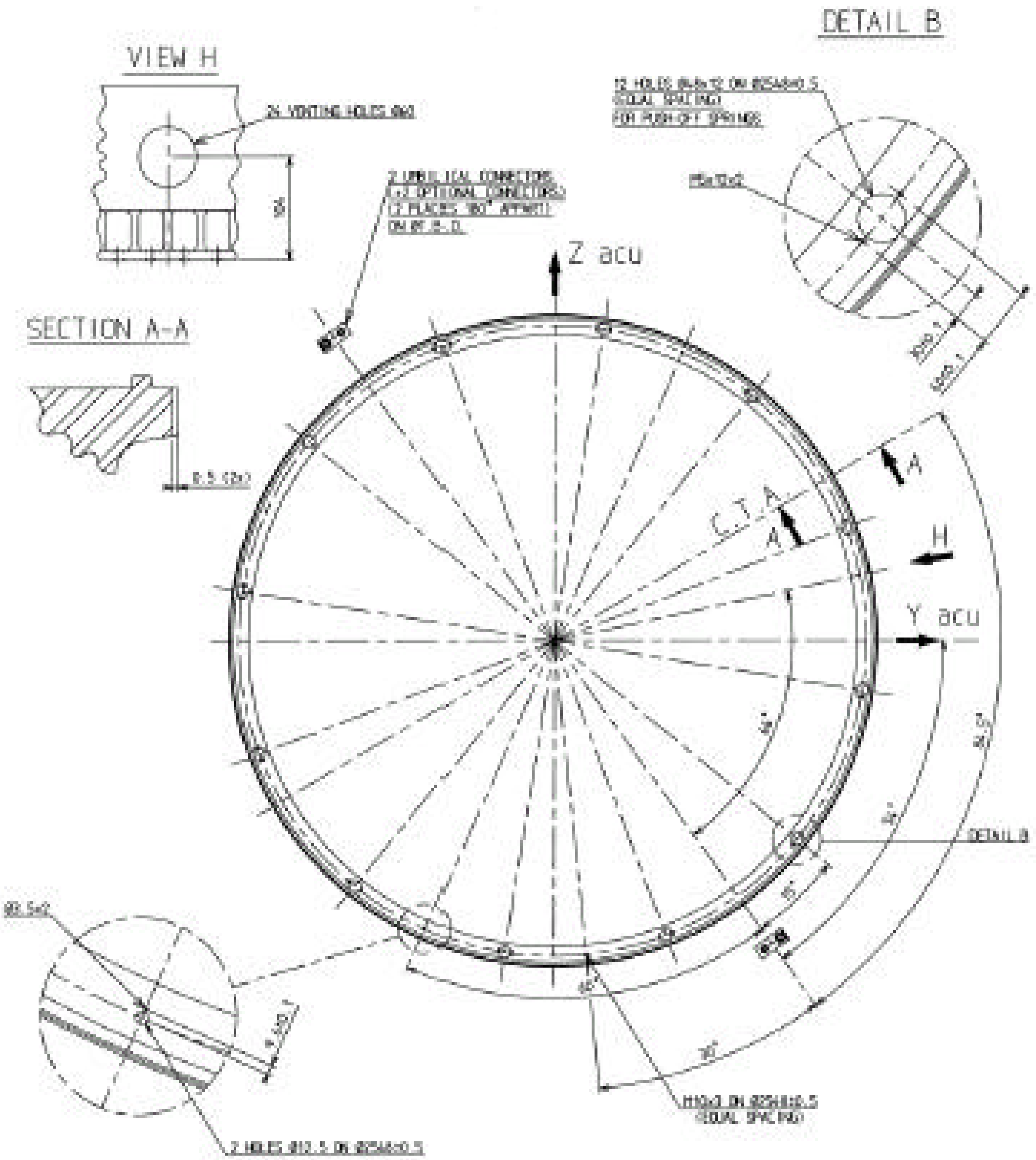


Figure 7.1.4-5 Adaptor 2624 General View with Umbilical connectors location.

7.2 POINTING AND DYNAMICS

The Attitude Control and Measurement Subsystem provides the following services:

To keep the satellite attitude within the limits of its attitude constraints during all mission phases.
To command the RCS in order to generate orbit correction (at injection and for orbit maintenance) according to the mission needs.
To manage the system angular momentum.
To point autonomously the instruments LOS according to the mission operations schedule and achieve the pointing performance requirements during observations.
To provide the attitude information needed for attitude reconstruction by the ground.

Attitude constraints

Both Planck and Herschel payloads are not only highly sensitive to straylight but can be damaged almost immediately in case of direct illumination by the Sun. For this reason, attitude constraints with respect to the Sun shall be satisfied during all mission phases, except transitorily immediately after launcher separation during initial rate damping. In particular, the FDIR and redundancy strategies shall be designed to guarantee that the spacecraft shall remain in a secure attitude even after occurrence of a single equipment failure.

Orbit corrections & angular momentum management

Both satellites have comparable propulsion needs: the large L2 injection .V required for Planck to reach its small Lissajous orbit is balanced by its lower dry mass compared to Herschel. Also, the magnitude of the routine orbit maintenance manoeuvres is similar for both satellites.
The driving requirements for the design of the RCS are the association of the attitude constraints with the capability to produce Delta-V with any solar aspect angle, even though some manoeuvres might be split into two consecutive manoeuvres.
Besides, both satellites shall perform routinely angular momentum control manoeuvres: daily wheel unloading for Herschel, spin axis reorientation for Planck every 45 minutes in average. At L2, propulsion is the only efficient way to generate the needed external torque. Ideally, pure torque should be produced, in order to avoid perturbing the orbit while controlling the angular momentum.
The payloads are highly sensitive to contamination. This induces strong limitation to the accommodation of thrusters and their location and orientation must be traded-off carefully to provide:

acceptable efficiency for the orbit correction manoeuvres
low orbit perturbation while correcting the angular momentum
while avoiding contamination of the payloads.

The RCS shall support orbit manoeuvres for worst case solar aspect angle, i.e. 0 or 180 deg. This requirement only applies to those manoeuvres in the mission plane for which the solar aspect angle is unpredictable. Fuel budget for other manoeuvres shall be derived on the basis of their deterministic SAA.

Scientific pointing modes

Herschel and Planck missions will follow different pointing laws: Herschel is basically switching between inertial pointing or scanning phases for data collection and slew phases for new target acquisition, while Planck is spinning at constant rate and the magnitude and orientation of its angular momentum are corrected hourly. The pointing requirements of both satellites are discussed separately below.

7.2.1 Requirements and Design Drivers

7.2.1.1 Common Requirements

The following high level common requirements can be defined:

- Guarantee operational capability 20 seconds after launcher release achieving attitude constraints in less than 5 minutes.
- Perform orbit correction manoeuvres (at injection and for orbit maintenance) according to the mission needs. The magnitude error of the Delta-V manoeuvre shall not exceed 1% (including the effects of attitude accuracy) of the commanded magnitude at 95% confidence level.
- Point the instruments LOS according to the mission scheduling and achieve the pointing performance requirements during observations. A capability of sensor calibration shall be provided to fulfil those requirements.
- Avoid hazardous operations and protect both spacecraft and payload from unsafe attitude conditions autonomously commanding fall-back to a properly designed survival mode.
- Provide a high level of reactivity and reliability towards contingencies and anomalies through a robust FDIR design.
- Both spacecraft shall be compatible of an eclipse during the transfer orbit.

For both satellites the lifetime of ACMS items which degrade with time or usage shall be dimensioned for 6 years.

7.2.1.2 Herschel Requirements

Angular momentum management

The reaction wheels angular momentum capacity and their geometrical arrangement will be such to allow up to 22 hours without wheel unloading. This requirement is understood to apply to specific observation runs in which the same target is pointed during 22 hours. It is assumed that in this case the whole observation period will be dedicated to a single target and therefore that large slew requirements (90 deg. in 15 min) do not apply.
Specially, if needed, wheel unloading shall be done at the end of the OP before performing a large slew of 90 deg. to reach the attitude desired for the communication phase. In other situations during routine observation, wheel unloading shall only be necessary at daily rate: the satellite shall be able to reach any direction in its FOR without unloading.

Scientific pointing modes

There are 5 pointing performance requirements for Herschel both in pointing and scanning conditions. Goals are not seen as design drivers, but once the ACMS is designed to meet the specified performance in worst case conditions, analyses will be conducted to evaluate in which conditions performance goals could be achieved (for example, a bright star is available in the Star Tracker FOV, multiple stars are available, the guiding star position in the STR FOV guarantees optimum bias performance).
Performance requirements are generally specified for the two main modes of observation used during scientific modes: inertial pointing and scanning mode.
The **absolute pointing error** is an allocation given to the accumulated pointing bias sources constant or variable. The specification for the APE is stringent: 3.7 arcsec (1σ) cannot be achieved and demonstrated by design only. Calibration procedures will be needed in flight during commissioning phase and during routine operation, the observation phase beginning by a brief calibration period.
The **relative pointing error** specification together with the manoeuvrability requirements is driving the sizing of sensor performances. Indeed, in the quiet dynamic environment of L2 (reaction wheels should be the main perturbation source at high frequencies), the RPE could easily be met in constant inertial pointing with moderately accurate sensors and slow control bandwidth.
In raster pointing mode, the pointing direction shall be modified by a few arcmin at regular intervals to allow the payload instruments to survey fields larger than their own field of view.

The **Spatial Relative Pointing Error** (SRPE) is understood as spatial transposition of the pointing drift error, which is a temporal concept. It defines the allocation given to the pointing bias error drift while guiding constantly with the same guiding star (in raster pointing mode). The relative pointing error is not seen as a contribution to the SRPE. The SRPE requirement thus directly translates into a requirement to the Star Tracker internal spatial bias while tracking a unique star.

Specific requirements define the maneuverability of Herschel, i.e.the way the raster pointing, position switching or nodding mode shall be used. The 16 arcmin maximum slew amplitude for which slew duration is defined corresponds to the nodding maximum amplitude. A requirement and a goal for slew duration are defined which are functions of slew angle. This duration shall also include settling time, i.e. the line of sight has stabilized and RPE requirements are met. These requirements put constraints on the actuators sizing (wheels) but also on sensor selection: efficient damping has to be provided to reach the RPE requirements at the end of the slew.

Survival mode

Attitude during survival mode is aimed at maintaining power supply availability and stable thermal conditions, while being within attitude constraints. As attitude might not been known, it is understood that Sun pointing (two axes) must be maintained and angular rate about the Sun vector must be controlled. The survival mode has to be maintained during 7 days, which means that is has to be compatible with the Sun rotation of around 1 deg/day seen from the spacecraft.

7.2.1.3 General requirement

In addition to the common requirements defined in 7.2.1 the Herschel attitude and orbit control subsystem provides the satellite with the following main services:

- Keep the satellite attitude within the limits of its attitude constraints during all mission phases. These constraints specify that the Sun aspect angle is maintained in the range 90° +30°/-30° from the body +X axis and ± 5° from the +Z axis.
- Manage the system angular momentum taking into account both the maximum period of scientific observation (22 hour) without off-loading and the Slew requirements afterwards summarised.
- Provide the attitude information needed for attitude reconstruction by the ground.

Herschel is specified to have a nominal lifetime of 3.5 years from launch till the end of the mission. This duration includes a margin of 6 months for the transfer to the L2 Lissajous orbit. However the propellant for orbit maintenance, attitude control and momentum management has to be dimensioned for 6 year mission.

7.2.1.4 Operational requirements in science

For scientific observation the satellite must be provided with a large number of operative sub-modes allowing fine pointing for prolonged periods (up to 22 hours), pointing for predefined duration on targets equally spaced in a sky map (**raster pointing**) and scanning of tracks in the sky (**line scanning**). Moreover the satellite must be able to accomplish fast slew manoeuvres to rapidly acquire the most favourable telecommunication attitude. Hereafter a survey of the sub-modes is given.

Raster Pointing

The **normal raster pointing** is a series of fine pointing observations of equal duration (in the range from 10 s to 30 minutes), separated by slews, in order that the pointing of the telescope axis moves in a raster pattern as shown in Figure 7.2.1.4-1/A (the spatial distance of the targets is between 2” and 8’). The **raster pointing with OFF-position** is a special form of raster pointing where, after a specified number of raster points (ON positions), the spacecraft slews to a predefined point (the OFF position), after which it resumes its raster pointing where it left the raster before going to the OFF position.

Particular Raster pointing conditions

Two particular raster pointing conditions are represented by the nodding and the position switching. The **nodding** is an observing mode in which the target source is periodically moved between two chops positions (chosen in the range between 2” and 16’). The **Position switching** is an observing mode in which the instrument line of sight is periodically changed between a target source and a position off the source (the associated slew is in the range between 2” and 2°). In both cases the integration time in the two positions is equal and contained in the range between 10 s and 20 minutes.

Line Scanning

The **normal line scanning** is a scanning mode along short parallel lines, such that the telescope axis moves as shown in Figure 7.2.1.4-1/B. Each line corresponds to an angular rotation in the range between 1’ and 20°. The line separation varies between 2” and 8’ and the scan rate can be changed between 0.1”/s and 1’/s. **Line scanning with OFF-position** is a special form of line scanning where, after a specified number of lines, the spacecraft slews to a predefined point (the OFF position), after which it resumes its line scanning where it left the pattern before going to the OFF position.

Tracking of Solar system object

The satellite must be provided with the capability to follow, by ground commanded tables of coefficients of Chebyshev polynoms, objects such as planets, comets, etc. having a maximum speed relative to the tracking star of 10 arcsec/min. Furthermore it is required that the whole raster or scan pattern can be rigidly moved with the solar system object.

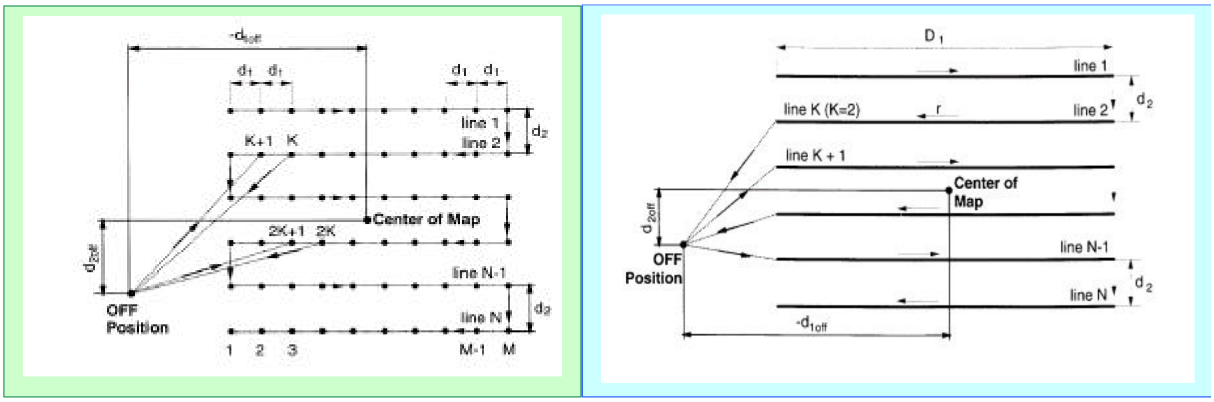


Figure 7.2.1.4-1: Raster Pointing (A) and Line Scanning (B)

Long Slew Manoeuvres

The ACMS shall be dimensioned for operational slews of at least 90 degrees executed twice per day (at the begin and at the end of daily scientific observations. Such slews shall be completed within 15 minutes, including settling.

7.2.1.5 Pointing requirements

During all scientific observation modes requiring periods of stable pointing or scanning, the ACMS shall be able to accomplish the pointing and scanning requirements and goals hereafter listed.

ERROR	*LOS (arcsec)*	*Around LOS (arcmin)*	*Goals for LOS (arcsec)*	*Goals around LOS (arcmin)*
APE pointing	1.8	2.0	1.0	3.0
APE scanning	2.5	n.a.	2.0	n.a.
PDE point (24 h)	0.3	2.0	n.a.	n.a.
PDE scanning(24 h)	0.1	2.0	n.a.	n.a.
RPE pointing (1 min)	0.2	1.0	n.a.	n.a
RPE scanning (1 min)	1.1	1.0	0.7	n.a.
AME pointing	1.9	2.0	n.a.	n.a.
AME scanning	3.1	2.0	1.2	n.a
AME slew	10	3.0	5	3.0

Table 7.2.1.5-1

In consecutive pointing within 4° x 4° spherical area, the SRPE of all pointings following the initial pointing, as referred to the average (barycentre) pointing direction of the first pointing, shall be less than 1 arcsec at 68% probability level. The actual direction of the first pointing will lie within a cone of half angle RPE around this reference direction.

7.2.1.6 Slew requirements

The satellite will be able to change its slew rate between 0.1 arcsec/s and 1 arcmin/s with a resolution of 0.1 arcsec/s in line scanning. Furthermore the maximum slew rate will increase up to 7 degrees/min for slew angles large enough to permit full angular velocity. The Absolute Rate Error about the scan axis is required to be better than 1% of the demanded rate (with a threshold of 0.1 arcsec/s for rates lower than 10”/s).
For slews smaller than 16 arcmin, during any of the observational pointing modes, the total time between initiation of the slew and the moment when the telescope axis has achieved the pointing requirements on the new target is defined to be less than:

Requirement: 10+SQRT (2*φ) seconds
Goal: 5 + SQRT(φ) seconds
being j the slew angle in arcsec.

The system has to be dimensioned for operational slews of at least 90 degrees to be completed in less than 15 minutes including settling. They can be executed twice per day in correspondence of transition from observation periods to telecommunication phases and vice-versa.

7.2.2 PLANCK Requirements

Angular momentum management

The accuracy as well as the time allocation is given for typical amplitude of 3 arcmin and a time interval between two manoeuvres of 45 minutes in average. We understand this requirement to hold only in this specific condition. However, possibility to perform two manoeuvres with a time interval of 30 minutes has also been taken into account.
In addition requirements for specific slew not part of the nominal scanning law will be allowed. Such spin axis re-orientation can be used to re-point the spacecraft to an area of the sky not properly scanned during a previous day.

Pointing Performance Requirements

There are 5 pointing performance requirements (APE, PDE, RPE, AME and PRE). Each of them is specified in two parts: one is relative to the pointing performance of the Line Of Sight (LOS), the second to the pointing performance around the LOS.
Due to the spacecraft spinning motion, the instrument LOS describes a circle on the celestial sphere. The LOS pointing errors relates to the distance between the actual line of sight trajectory on the celestial sphere and the desired one. Possible error in the phase is not taken into account. This is covered by the requirement on spin rate drift or fluctuation over one hour.
The errors around LOS relate to incorrect orientation of the spacecraft spin axis with respect to the detector lines. If the scanning is not properly oriented, the celestial objects will not be properly observed by the various detectors, which should see it.
The RPE requirement sets a limit to the deviation of the optical axis trace from a circle traveled at uniform rate. Two effects can potentially impact the RPE: nutation and fluctuation of the spin rate due to external torques or angular momentum transfer between the satellite body and its moving parts (if any). Besides, since the RPE is specified on a 55 minutes horizon, it also sets a limit to the drift rate of the spin axis direction w.r.t. inertial space due to the effect of solar pressure.
The AME addresses directly the pointing of the telescope optical axis. Its budget contains mainly two parts:
One part relative to the attitude measurement performance, i.e. the accuracy to which the ACMS provides through TM data allowing to reconstruct the attitude history of a well defined body-attached reference frame.
A second part relative to the knowledge of the instrument LOS direction with respect to the body reference frame used by the ACMS.
Misalignment will overcome the total AME allocation if calibration is not performed in flight. The calibration procedure will rely on the opportunity to observe bright point sources such as JUPITER or SATURN with the payload instruments.
Pointing Reproducibility Error (PRE) relates to the possibility to re-point the instruments to a portion of the sky for which incorrect data were obtained previously. The maximum time duration between the 2 pointings is 20 days. This is in line with the Planck SAA constraints: it is only possible to depoint Planck by 20 deg (between + 10 deg. and -10 deg. from Sun). As the Sun is moving at a rate of around 1 deg per day, it not possible to recover a pointing older than 20 days.

7.2.2.1 General Requirements

In addition to the common requirements defined in 7.2.1, the attitude and orbit control subsystem provides the satellite with the following main services:

Keep the satellite attitude within the limits of its attitude constraints during all mission phases. These constraints specify that the Sun aspect angle is maintained inside a cone of 10° half-aperture from the body -X axis (the spin axis).

Control the system angular momentum to avoid large displacement between the spin axis reference location and the Sun direction movement and to compensate for the Sun disturbance torque (This corresponds to a spin axis rotation of about 2.5’ per hour)

Provide the estimation of the spin rate, of the spin axis direction and of the nutation needed for attitude reconstruction by the ground.

Planck is dimensioned to have a nominal lifetime, which allows two full sky surveys (at least 95% of the sky) at operational orbit, with a maximal allocation of 6 months for the transfer to the Lissajous orbit. Propellant for orbit maintenance, attitude control and momentum management shall be dimensioned for 2.5 years.

7.2.2.2 Pointing Requirements

The pointing requirements, during the sky survey mode, are specified in the table below:

ERROR	*LOS (arcmin)*	*Around LOS (arcmin)*	*Goals for LOS (arcmin)*	*Goals around LOS (arcmin)*
APE	5	n.a.	n.a.	n.a.
PDE (24 hours)	1.2	n.a.	n.a.	n.a.
RPE (55 min)	0.1	n.a.	n.a.	n.a.
AME	0.7	n.a.	n.a.	n.a.
PRE (20 days)	0.4	n.a.	n.a.	n.a.

Table 7.2.2.2-1

NOTE: *No active control actions are expected during the periods when RPE is applicable*

The following other pointing requirements apply:
The spin axis motion about the spacecraft X-axis pointing to the Sun shall be at constant rate of 1 rpm (6°/sec).
The spin rate drift or fluctuation over one hour shall be less than 10^{-4} rpm.
The Absolute Rate Error about the satellite spin axis shall be better than 5.4 arcmin/sec

7.2.2.3 Slew Requirements

In Planck, the capability to reorient the Spin-axis every 45 minutes through a manoeuvre of 3 arcmin, with an accuracy of 0.4 arcmin (amplitude and direction, 68% probability level) is required. Furthermore, for spin axis reorientation not part of the Planck scanning law, the rate of reorientation of the spin axis shall be at least 0.5 arcmin/s. Finally the ACMS design shall not require dedicated reorientation manoeuvres to meet Planck APE and PDE. It will utilise a maximum of ±10% tuning of the amplitude of the manoeuvres needed to execute the nominal sky survey.

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 1.3.1 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 entire Satellite.

Interface Requirements

The SVM Structure has to provide the following main functions:

Ensure the compatibility with the common SVM/PLM interfaces
Ensure the compatibility with all Instruments, Equipment and Subsystems.
Ensure the compatibility with the common SVM/PLM interface.
Ensure the compatibility with ARIANE fairing.
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.

7.3.1.1 SVM Structure Requirement

Here below, the main mechanical requirements, applicable to the SVM Primary Structure are recalled. The complete set of requirements, is included in [SVM Structure Spec. H-P-SP-AI-0001]. However, some different values, as included in [ASPI-2001-PM/IA-XXX, 05/06/01] have been used and here reported.

The requirements reported in the following have been utilised for the SVM Structure preliminary design and analysis as reported in § 9.1.

7.3.1.1.1 Frequency and Rigidity Requirements

7.3.1.1.1.1 Herschel Frequency Requirements

A. PLM MAIN HYPOTHESIS
For computation of the global main modes, the main hypotheses of analysis are the following ones.

The circular SVM upper frame is connected to the geometrical centre with a rigid structure
The central geometrical point of the rigid body is connected to a mass element (CONM2 element)
The mass to be taken into account in the mass CONM2 element are :
Herschel mass CONM2 element = 2115 Kg
The central geometrical point of the rigid body is located along X axis
Herschel mass location X = 2.559 m

This location is given from the Launcher / Spacecraft interface location (X=0)

B. HERSCHEL SVM (SATELLITE) GLOBAL MODE
HERSCHEL frequencies of the global main modes should fulfil the following frequency:

- Frequency of the first longitudinal main mode > 58 Hz
- Frequency of the first lateral main mode > 23 Hz

C. HERSCHEL SVM (BOX) GLOBAL MODES
Without Payload mass, HERSCHEL frequencies of the global SVM main modes should fulfil the following requirements:

- Frequency of the first longitudinal mode > 51 Hz
- Frequency of the first lateral main mode >48 Hz

D. PROPELLANT TANKS SUPPORTING:

The PTSS shall fulfil the following frequency requirements

- Frequency of the first longitudinal X main mode > 145 Hz
- Frequency of the first lateral main mode > 80 Hz

E. SVM LATERAL PANELS:
The first frequency of any Lateral panel fixed to rigid body, fully loaded with all carried equipment, shall be greater than 50 Hz, in accordance with the real boundary conditions resulting from the SVM Structure design.

7.3.1.1.1.2 Herschel Rigidity Requirements

A. GLOBAL STIFFNESS:

The global stiffness requirements are included in Table 7.3.1.1.1.1-1.
The central tube stiffness values are limited, in order to be able to comply with the SVM frequency.

	Minimum stiffness	Maximum stiffness
K longitudinal X	3.5.E8 N/m	3.5E8 N/m + 30%
K lateral Y	8.2E7 N/m	8.2E7 N/m + 30%
K lateral Z	8.2E7 N/m	8.2E7 N/m + 30%

Table 7.3.1.1.1.1-1Central tube stiffness

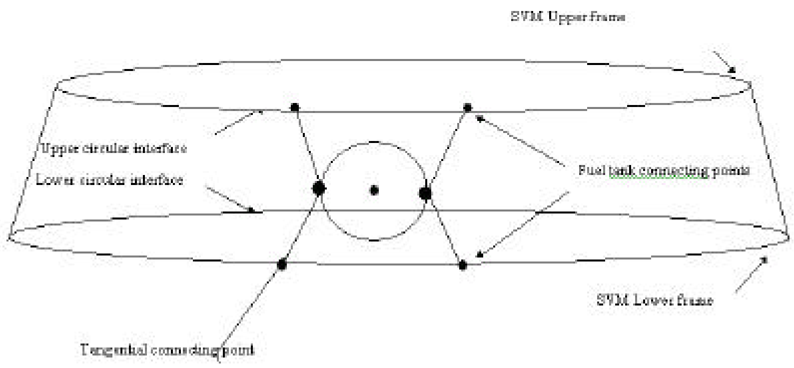
B. LOCAL STIFFNESS:

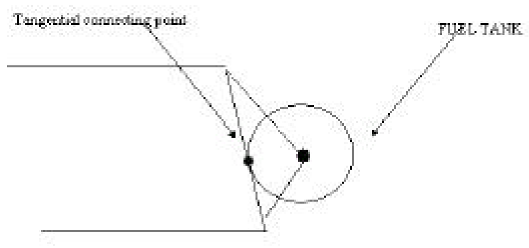
<u>b1. Propellant Tanks support interface:</u>

The local static stiffness of the SVM structure at each Propellant Tanks support interface points shall fulfil the following requirements:

	Upper struts interface	lower struts interface	middle height point
k circumference>	5.4 E 7 N/m	4.5 E 8 N/m	3. E 7 N/m
k radial >	2.5 E 7 N/m	2 E 7 N/m	1. E6 N/m
k longitudinal (X)>	2. E 7 N/m	2 E 8 N/m	1. E 7 N/m

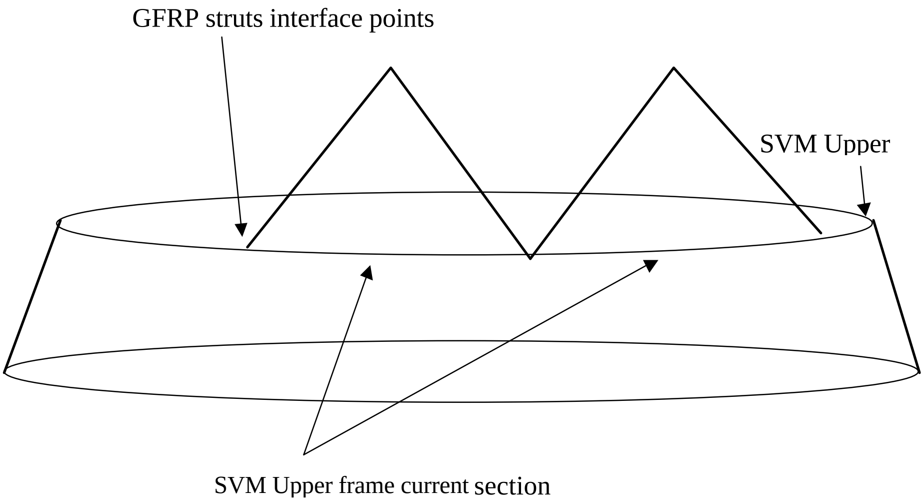
Table 7.3.1.1.1.1-2 Herschel Propellant tanks support local static stiffness





<u>b2. HPLM support interface:</u>
The local static stiffness of the SVM structure at each HPLM support interface points shall fulfil the following requirements:

k circumference	>	5.7 E 7 N/m
k radial	>	2.5 E 7 N/m
k longitudinal (X)	>	5. E 7 N/m
k circumference	>	4.7 E4 Nm/rd
k r radial	>	1. E4 Nm/rd
k x longitudinal	>	1.2 E5 Nm/rd



<u>b3. Herschel SVM Upper Frame</u>

The local static stiffness of the Upper frame, at other points than PLM struts connection points, shall fulfill the following requirements:

k circumference	>	5.4 E 7 N/m
k radial	>	2.5 E 7 N/m
k longitudinal (X)	>	3.4 E 7 N/m
k (circumference)	>	4.7 E4 Nm/rd
k r (radial)	>	1 E4 Nm/rd
k x (longitudinal)	>	1.2 E5 Nm/rd

7.3.1.1.1.3 Planck Frequency Requirements

A. PLM MAIN HYPOTHESIS
For computation of the global main modes, the main hypotheses of analysis are the following ones.

1. The circular SVM upper frame is connected to the geometrical centre with a rigid structure
2. The central geometrical point of the rigid body is connected to a mass element (CONM2 element)
3 The mass to be taken into account in the mass CONM2 element are :
Planck mass conm2 element = 310 Kg
4. The central geometrical point of the rigid body is located along X axis
Herschel mass (telescope+baffle+grooves) location X = 1.83 m

This location is given from the launcher spacecraft interface location (X=0)

B. PLANCK SVM (SATELLITE) GLOBAL MODE
Planck frequencies of the global main modes should fulfil the following requirements:

- Frequency of the first longitudinal main mode > 60 Hz
- Frequency of the first lateral main mode > 35Hz

C. PLANCK SVM (BOX) MODES
Without Payload mass, Planck frequencies of the global SVM main modes should fulfil the following requirements:

- Frequency of the first longitudinal mode > 60 Hz
- Frequency of the first lateral main mode > 50 Hz

In this case are considered main modes those having an effective mass higher than 10% of the total mass of the SVM.

D. PROPELLANT TANKS SUPPORTING:

The PTSS shall fulfil the following frequency requirements

- Frequency of the first longitudinal X main mode > 145 Hz
- Frequency of the first lateral main mode > 80 Hz

E. SVM LATERAL PANELS:
The first frequency of any Lateral panel fixed to rigid body, fully loaded with all carried equipment, shall be higher than 70 Hz, in accordance with the real boundary conditions resulting from the SVM Structure design.

F. PAYLOAD SUB-PLATFORM:
Planck instruments accommodated above and below the Pay-load sub-platform are to be modelled by punctual masses. The first frequency of the Pay-load sub-platform shall be greater than 100 Hz (TBC), in accordance with the real boundary conditions resulting from the SVM Structure design.

7.3.1.1.1.4 Planck Rigidity Requirements

A. GLOBAL STIFFNESS:
The global stiffness requirements are included in Table 1.3-1. They are equal for Herschel and Planck.
The central tube stiffness values are limited, in order to be able to comply with the SVM frequency.

	Minimum stiffness	Maximum stiffness
K longitudinal X	3.5.E8 N/m	3.5E8 N/m + 30%
K lateral Y	8.2E7 N/m	8.2E7 N/m + 30%
K lateral Z	8.2E7 N/m	8.2E7 N/m + 30%

Table 1.3-1 Central tube stiffness

B. LOCAL STIFFNESS:

b1. Propellant Tanks support interface:
The local static stiffness of the SVM structure at each Propellant Tanks support interface points shall fulfil the following requirements:

	Upper struts interface	lower struts interface	middle height point
k circumference>	6.5 E 7 N/m	5.2 E 8 N/m	3. E 7 N/m

k radial >	2.5 E 7 N/m	2 E 7 N/m	1. E6 N/m
k longitudinal (X)>	4.3 E 7 N/m	2 E 8 N/m	1. E 7 N/m

Table 1.3-2 Planck Propellant tanks support local static stiffness

b2. PPLM support interface:
The local static stiffness of the SVM structure at each HPLM support interface points shall fulfil the following requirements:

k circumference > 5.7 E 7 N/m
k radial > 2.5 E 7 N/m
k longitudinal (X) > 5. E 7 N/m
k circumference > 4.7 E4 Nm/rd
k r radial > 1. E4 Nm/rd
k x longitudinal > 1.2 E5 Nm/rd

b3. Planck SVM Upper Frame

The local static stiffness of the Upper frame, at other points than PLM struts connection points, shall fulfill the following requirements:

k circumference > 5.7 E 7 N/m
k radial > 2.5 E 7 N/m
k longitudinal (X) > 3.7 E 7 N/m
k (circumference) > 4.7 E4 Nm/rd
k r (radial) > 1 E4 Nm/rd
k x (longitudinal) > 1.2 E5 Nm/rd

STRENGTH REQUIREMENTS

The SVM Structure shall be compliant with the strength requirements specified 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 preliminary 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: **General Case**: the Qualification Loads are the Limit Loads times 1.25.

Handling Case: the Qualification Loads are the Handling Loads times 2

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 following table 2.1-1 reports the common Herschel and Planck launcher Limit Load cases.

Flight Event	Longitudinal		Lateral	Overflux
	HERSCHEL	PLANCK		
	[g]	[g]	[g]	N/mm
Lift-off	-1.7 +/- 1.5	-1.7 +/- 1.5	+/- 2.0	10
Maximum dynamic pressure	-2.7 +/- 0.5	-2.7 +/- 0.5	+/- 2.0	14
SRB end of flight	-4.55 +/- 1.45	-4.55 +/- 1.45	+/- 1.0	20
Main core Thrust Tail-off	-0.2 +/- 1.4	-0.2 +/- 1.4	+/- 0.25	0
Max tension case: SRB jettisoning	+2.5	+2.5	+/- 0.9	0

Table 2-1 S/C Flight Limit Loads

The minus sign with longitudinal axis values indicates compression
The lateral loads may act in any direction simultaneously with longitudinal loads
The Quasi-Static-Loads apply on center of gravity of the Satellite (SVM+PLM)
The configurations for Herschel and Planck (PLM's masses and locations) are those utilized for the global frequency requirements verification (Point 1.). The PLM's shall be connected to the PLM's struts as in figures reported below.
The uniform Overflux shall be applied to the S/C basis, for the sizing and verification of the LVA ring.

7.3.1.1.1.5 Herschel Strength Requirements (Launch Phase)

The table here below summarises the Herschel Subsystem sizing cases. For each case a dedicated table is provided.

APPLICABILITY	CASE	LOAD TYPE	DEFINITION
HERSCHEL	**1H**	Accelerations	1st case of PLM QSL
HERSCHEL	**2H**	I/F Loads	1st case of Sunshield QSL
HERSCHEL	**3H**	Accelerations	1st case of P.Tank QSL on the Central tube
HERSCHEL	**4H**	Accelerations	QSL due to Lateral panels resonance, except for RWDE panel
HERSCHEL	**5H**	I/F Loads	SVM Shield I/F Forces
HERSCHEL	**6H**	Accelerations	QSL due to RW & RWDE panel resonance (TBD)
HERSCHEL	**7H**	Accelerations	QSL due to local mode of L_GA and M_GA Antennae on ± Z side of the Octagonal box (TBD)
HERSCHEL	**8H**	Accelerations	QSL due to local mode of RCS Thrusters on - X side of the Lower closure panel (TBD)

Table 2.1-1 Herschel Subsystem sizing cases (Limit Load Cases)

Case 1H - Local resonance of HPLM
The HPLM is to be modelled by a punctual mass, connected by rigid bars to the top of the Pay-load support truss. The QSL are to be applied at the location of the HPLM CoG. The specified QSL are strictly valid with a Central tube and Payload sub-platform achieving stiffness requirements specified above.

HPLM support truss geometry, 24 struts (12 points) configuration, is reported in figure 1H-1. The forces at the HPLM struts / SVM interface, resulting from the below accelerations (Tables 1H-1), shall be combined, in the four points where the Sunshield / Sunshade struts are also interfacing, with the forces reported in Tables 1H-2.

Load Cases	X Axis	Y Axis	Z axis
1	+/-10g	/	-/+0.35g
2	/	+/-3g	/
3	/	/	+/-3g

Table 1H-1 Configuration 24 Struts: Acceleration to be applied at the HPLM c.o.g.

Struts	Load Case 1 N	Load Case 2 N	Load Case 3 N
1	+/-3482	-/+741	-/+406
2	+/-2360	+/-704	-/+286
3	+/-4197	+/-5779	-/+1736
4	+/-5202	-/+5757	-/+1983

Table 1H-2 Configuration 24 Struts: forces of the S/S Struts along struts axes direction

The mechanical characteristics of the suspended mass (telescope + cryostat + SSD/SSH) on the struts are the following ones:

Total suspended Mass Mh=2115 Kg
CoG of the suspended Mass M =1.1m from the upper interface plane of the struts, that is 2.559 m from the LVA interface
Number of GFRP struts : 24
Young Modulus E=40 E+9 N/m²
Struts Outer diameter =0.05 m
Thickness=0.006 m (strut configuration 1)
Thickness=0.00205 m (strut configuration 2)
Diameter of the struts interface points on SVM 2133.8 mm
Diameter of the struts interface points on PLM 2133.8 mm

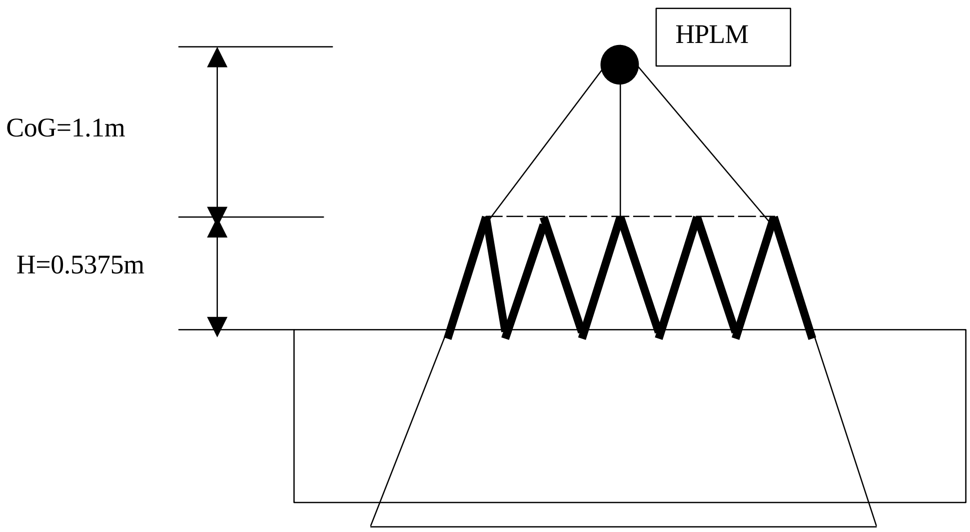


Figure 1H-1 HPLM Support Structure valid for 24 truss

The configuration of the Sunshield / Sunshade struts are reported in figure 2H-1.

Case 2H – Sunshield / Sunshade Local resonance Loads

For local sizing of the Sunshield struts links with SVM, the local forces due to HERSCHEL sunshield local resonance have to be taken into account.
The Sunshield axial (direction along the strut axis) strut forces due to local resonance of sunshield / sunshade structure are presented in the following tables. Each of these load case has an opposite load case (all forces have to be multiplied by –1).

Strut	Load Case 1	Load Case 2	Load case 3
Number	N	N	N
2	5601	-1920	3204
1	5217	1890	3136
4	-13988	-1680	-8448
3	-15444	1800	-7592

Sunshield/Sunshade Struts forces – Case 2H

7.3.1.1.1.6 Sunshield/sunshade struts definition

Four struts supporting the Sunshield structure (Strut number 20048, 20049, 20050 , 20051 in table 4) are connected to the upper interface of the SVM. These struts are defined and presented on figure 5.1.3.2.2-2

For information, the interface nodes of the Sunshield struts support are defined as below:

Sunshield Interface GRIDS

```
GRID  A    3.92697-.754433 .754433
GRID  B    3.92701 .754433 .754433
GRID  C    6.019   1.88749 .940856
GRID  D    6.019  -1.88749 .940856
GRID  E    6.019   .725288 1.75962
GRID  F    6.019  -.725288 1.75962
```

Strut 1: Connecting A and D
Strut 2 : Connecting B and C
Strut 3 : Connecting A and F
Strut 4 : Connecting B and E

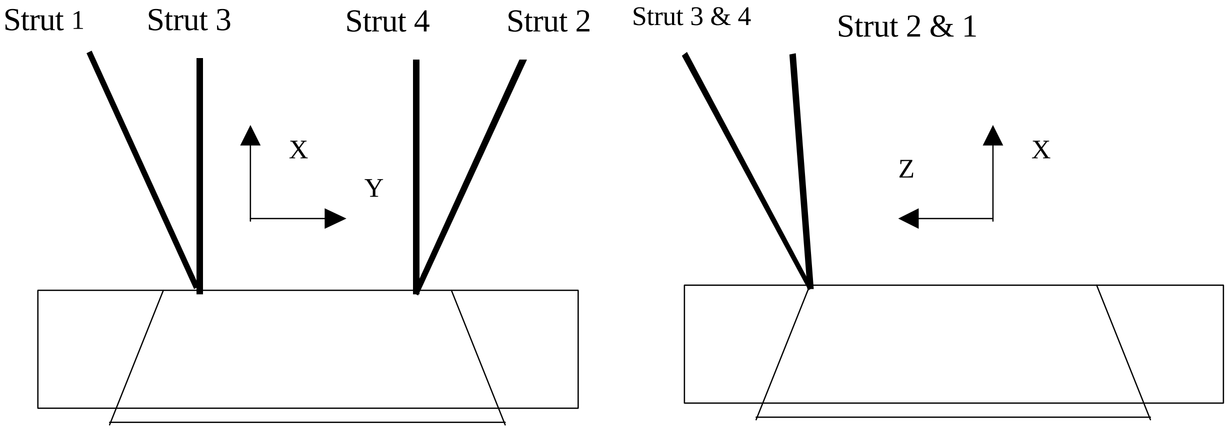


Figure 2H-1 Sunshield /Sunshade Struts Configuration

Case 3H - PTSS local resonance (TBC)
The QSL are to be applied at the theoretical location of the P.Tank CoG. The specified QSL are strictly valid with PTSS achieving stiffness requirements specified in paragraph Point 1, above defined.

Loading case	X longitudinal	Y Z lateral
1	9.6g	
2		±6.4g Y ± 6.4g Z

Case 4H - Local resonance of SVM lateral panels
The units accommodated on SVM panels are to be modelled by distributed masses on the panels.
The specified QSL are strictly valid at the condition that SVM panels comply with stiffness requirements specified in Point 1 above defined.

Loading case	In-plane	Y Z lateral
1	17g	
		32g

Case 5H – SVM Shield Interface Forces
The actual configuration of the SVM shield support is defined with 24 struts.
For SVM shield struts support, the sizing loads are defined from the envelope of the strut axial forces generated by Launcher quasi static and dynamic loads. The maximal axial force in the struts is defined in table below.

Load Case	Max axial force Fx (N)
1	3000

Planck Strength Requirements

The table here below summarises the Planck Subsystems sizing cases. For each case a dedicated table is provided.

APPLICABILITY	**CASE**	LOAD TYPE	DEFINITION

Planck	**1P**	Accelerations (1)	1st case of PPLM QSL
Planck	**2P**	Accelerations (1)	1st case of P.Tank QSL on the Central tube
Planck	**3P**	I/F loads	QSL due to local mode of SA peripheral part on - X side on the Lower closure panels (TBD)
Planck	**4P**	I/F loads	QSL due to local mode of SA central part at the bottom of the Central tube (TBD)
Planck	**5P**	Accelerations	QSL due to Payload sub-platform resonance
Planck	**6P**	Accelerations	QSL due to Lateral panels resonance, except SCC panels
Planck	**7P**	Accelerations	QSL due to SCC panel resonance (TBD)
Planck	**8P**	Accelerations	QSL due to Payload subplatform resonance
Planck	**9P**	Accelerations	QSL due to local mode of L_GA and M_GA Antennae at the bottom of the Central tube (TBD)
Planck	**10P**	Accelerations	QSL due to local mode of RCS Thrusters on the sides of the Octagonal box (TBD)

Table 2.2-1 Planck Subsystems sizing cases (Limit Load Cases)

Case 1P- Local resonance of PPLM
The PPLM is to be modelled by a punctual mass, connected by rigid bars to the top of the Pay-load support truss. The QSL are to be applied at the location of the PPLM CoG. The specified QSL are strictly valid with a Central tube and Payload sub-platform achieving stiffness requirements specified above.
PPLM support truss geometry is reported in figure 1P-1.

Load Cases	X Axis	Y Axis	Z axis
1	23g	/	1g
2	/	15g	/
3	/	/	11g

The mechanical characteristics of the suspended mass on the struts are the following ones:

Total suspended Mass (**telescope + Baffle**) Mp=200 Kg [**the Grooves mass is not considered**]
CoG of the suspended Mass M at 0.532m from the upper interface plane of the struts, that is at 2.35 m from the LVA interface

Number of GFRP struts =12
Young Modulus E=40 E+9 N/m²
Strut Outer diameter=0.05 m
Strut thickness =0.0014 m
Diameter of the struts interface points on SVM 2133.8 mm
Diameter of the struts interface points on PLM 2133.8 mm

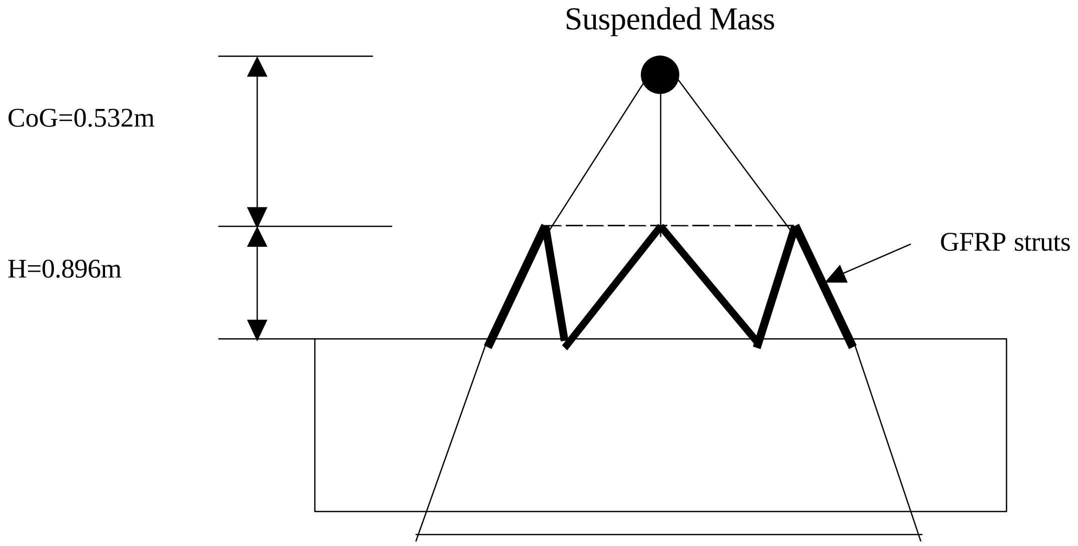


Figure 1P-1 PPLM Support Structure

Case 2P – PTSS local resonance (TBC)
The QSL are to be applied at the theoretical location of the P.Tank CoG. The specified QSL are strictly valid with PTSS achieving stiffness requirements specified in Point 1 above defined.

Loading case	X longitudinal	Y Z lateral
1	9.6g	
2		±6.4g Y ± 6.4g Z

Case 5P – Local resonance of Pay-load sub-platform
The He Tanks accommodated on the Pay-load sub-platform are to be modelled by punctual masses supported by rigid bodies. The BEU is to be modelled by a punctual mass. The QSL are to be applied at units CoG. The specified QSL are strictly valid at the condition that Pay-load sub-platform complies with stiffness requirements specified in Point 1 above defined.

Loading case	X longitudinal	Y Z lateral
1	26g	
2		2g Y ± 2g Z

Case 6P – Local resonance of SVM lateral panels
The units accommodated on SVM panels are to be modelled by distributed masses on the panels.
The specified QSL are strictly valid at the condition that SVM panels comply with stiffness requirements specified in Point 1 above.

Loading case	X longitudinal	Y Z lateral
1	12g	
2		35g

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

7.3.1.2 Mechanical Requirements for Equipment

Here below, the main mechanical requirements applicable to SVM S/S equipment are recalled. They are derived from AD-13.

7.3.1.2.1 Mechanical environment tests

7.3.1.2.1.1 GENERAL

Before and after the Vibration tests (Sinusoidal and random), a resonance search test shall be performed on each axis with the objective to demonstrate that the unit has not degraded. Test parameters are as follows:

- • Acceleration amplitude 0.5 g
- • Frequency 5 Hz to 2000 Hz,
- • Sweep rate 2 octave per minute, one sweep up.

The unit shall be mounted on a rigid vibration adapter.
Functional tests shall be conducted after full level exposure (including low levels) in the three axes.
Electronic units active at launch shall be operating during the tests and limited functional tests shall be conducted during full level exposure.

7.3.1.2.1.2 SINUSOIDAL VIBRATION TEST LEVELS

The level given in Table 7.3.1.2.1-1 shall be used for sinusoidal vibration design qualification.
Notching at any unit vibration frequencies will not be allowed. These levels are preliminary and are still TBC.

Electronic boxes

	Frequency (Hz)	Qualification level	Acceptance level
In box mounting plane	5-100 Hz	25 g	20 g
Perpendicular to box mounting plane	5-100 Hz	30 g	24 g

Fuel Tanks

	Frequency (Hz)	Qualification level	Acceptance level
Longitudinal	5-15 15-100	13.5 mm 12 g	11 mm 9.6 g
Lateral	5-15 15-100	9 mm 8 g	7 mm 6.4 g

Table 7.3.1.2.1-1: Sinusoidal Vibration Levels

RANDOM VIBRATION TEST LEVELS

The levels in Table 7.3.1.2.1-2 shall be used for random vibration design qualification. These levels are preliminary and are still TBC.
The levels apply at the interface with the Structure. The frequency range and levels depend on the mass of the Subsystem or units considered as first order mass system.
If brackets or fixation devices are provided with the equipment, the interface is the bracket/fixation device interface.
For units belonging to the same subsystem, delivered in more than one box but accommodated closely on the same structure part (i.e. panels), the mass to be considered is the total mass of the grouped units.
The lateral axes are in the plane of the mounting plane, the vertical axis is perpendicular to the mounting plane.
The test duration shall be 2 min per axis.
The qualification levels apply on STM, EM, QM or EQM pending on model philosophy.
The acceptance levels applied on FMs are qualification levels divided by a factor 1.5625 for PSD and 1.25 for the global level in g RMS. The test duration shall be 1 min per axis.
Units applying PFM philosophy shall be tested at qualification level and acceptance duration.

Lateral	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	1.0 g^2/Hz
500-700 Hz	0.5 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.1 g^2/Hz
GLOBAL	27.3 g RMS

Axial	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	2.0 g^2/Hz
500-700 Hz	1.0 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.2 g^2/Hz
GLOBAL	38.6 g RMS

Random vibrations for units with mass < 1 kg

Lateral	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	0.5 g^2/Hz
500-700 Hz	0.25 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.05 g^2/Hz
GLOBAL	19.3 g RMS

Axial	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	1.0 g^2/Hz
500-700 Hz	0.5 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.1 g^2/Hz
GLOBAL	27.3 g RMS

Random vibrations for units with mass < 5 kg

Lateral	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	0.2 g^2/Hz
500-700 Hz	0.1 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.02 g^2/Hz
GLOBAL	12.2 g RMS

Axial	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	0.4 g^2/Hz
500-700 Hz	0.2 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.04 g^2/Hz
GLOBAL	17.3 g RMS

Random vibrations for units with mass < 10 kg

Lateral	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	0.14 g^2/Hz
500-700 Hz	0.07 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.014 g^2/Hz
GLOBAL	10.2 g RMS

Axial	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	0.28 g^2/Hz
500-700 Hz	0.14 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.028 g^2/Hz
GLOBAL	14.5 g RMS

Random vibrations for units with mass < 20 kg

Lateral	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	0.1 g^2/Hz
500-700 Hz	0.05 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.01 g^2/Hz
GLOBAL	8.6 g RMS

Axial	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	0.2 g^2/Hz
500-700 Hz	0.1 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.02 g^2/Hz
GLOBAL	12.2 g RMS

Random vibrations for units with mass < 50 kg

Lateral	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	0.07 g^2/Hz
500-700 Hz	0.035 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.007 g^2/Hz
GLOBAL	7.2 g RMS

Axial	
Frequency Range	Qualification Levels
20-100 Hz	+ 3dB/Oct
100-500 Hz	0.14 g^2/Hz
500-700 Hz	0.07 g^2/Hz
700-1200 Hz	-9 dB/Oct
1200-2000 Hz	0.014 g^2/Hz
GLOBAL	10.2 g RMS

Random vibrations for units with mass ≥ 50 kg

Table 7.3.1.2.1-2 RVL for Equipment (test levels)

SHOCK

The level in Table 7.3.1.2-3 shall be used for shock level design qualification.
These levels are preliminary and are still TBC.

	Frequency Hz	Shock Qualification Level (g)
Radial and Longitudinal Direction	200 600 2000 10000	200 1600 2600 4000

Table 7.3.1.2-3 Shock levels

7.3.2 Mechanical Configuration And Design Description

7.3.2.1 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 whenever possible
minimisation of manufacturing / assembly / integration steps and fluxes

7.3.2.2 Mechanical Configuration and Design Description

The Herschel and Planck Mechanical Configuration is described in detail in paragraph 9.1. The design of the SVM Structure, there included, reflects the general configuration and lay-out as described in § 7.1 and the Equipment/Units mass values as included in § 4.

The SVM Structure is composed of a Primary and a Secondary 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. 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 secondary structures consist of:

7.3.2.2.1 HERSCHEL

RCS piping support (circular floor + 3 webs)
Thrusters support (6 brackets supporting 12 10N thrusters)
Sensors supports, namely:
SAS (2)
FSS (2)
Two Star Trackers (STR): only one support for the two STR Heads, that could be broken down in a main plate with isostatic mounting to the main structure, and brackets (if necessary) to interface with the two individual heads. It is thought that this support should be of a higher complexity than the others, at least because of the required alignment stability.
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
Thermal Lower Closing (TLC) (1) support + 12 brackets on the Central tube
Brackets for Umbilical connectors to Launcher (2)

7.3.2.2.2 PLANCK

RCS piping support (circular floor)
Thrusters support (6 brackets supporting 12 10N thrusters and 2 brackets supporting 4 1N thrusters)
Sensors supports, namely:
SAS (3)
AAD (1)
Star Mapper (STM) (1)
Antennae supports, namely:
MGA (1)
LGA (3)
VMC (1) and SREM (1) supports
Thermal Blankets supports
Solar Array supports (8 brackets on the Octagonal box side, 12 brackets on the Central tube)
4 He Tanks supports (struts type supports)
Brackets for Umbilical connectors to Launcher (2)

The main components of the Primary Structures are shown in the following figures. Figure 7.3.2.2-1 shows the Herschel SVM structure layout. Figure 7.3.2.2-2 shows the Planck SVM structure layout

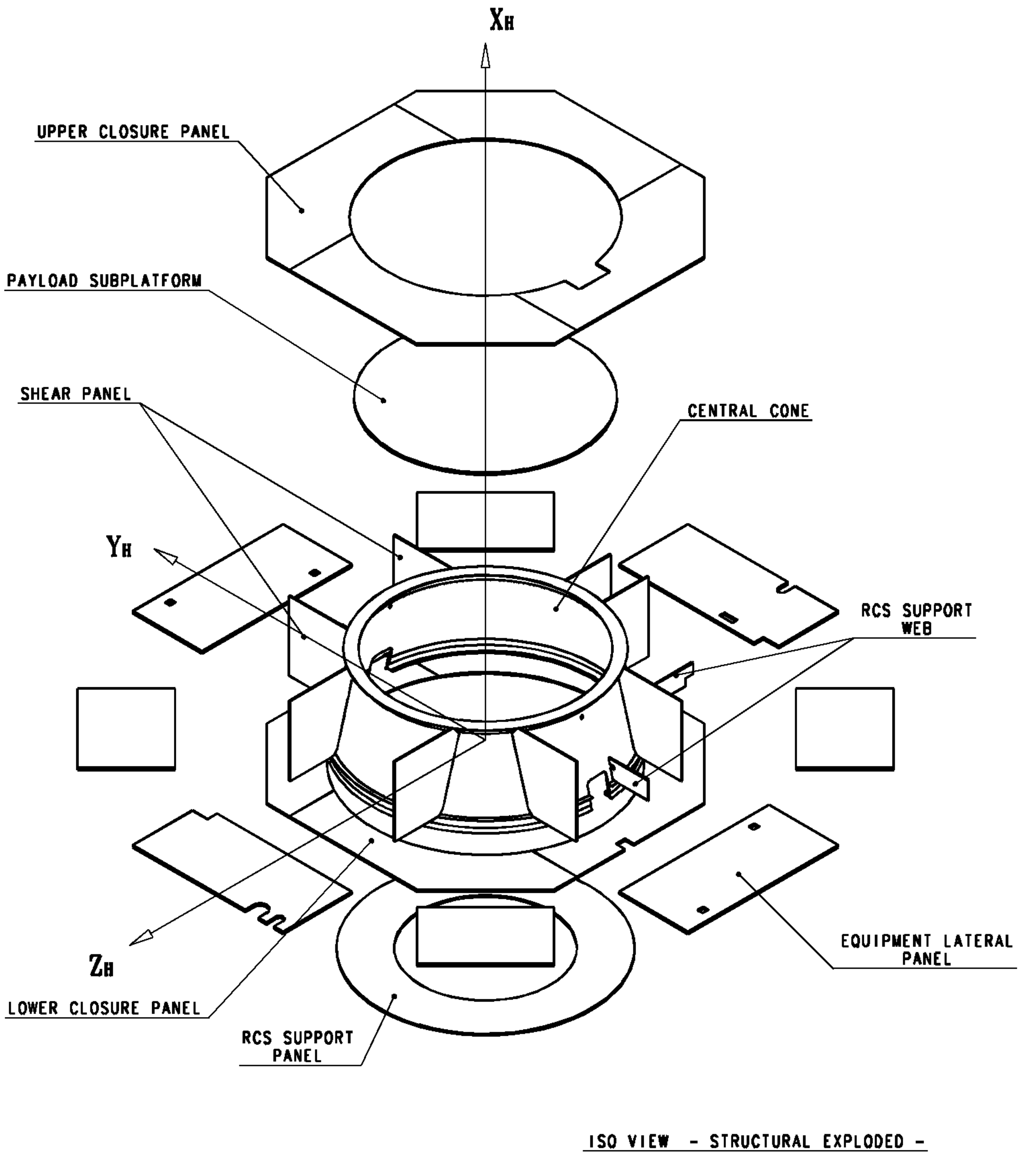


Fig. 7.3.2.2-1 Exploded view of Herschel SVM Structure

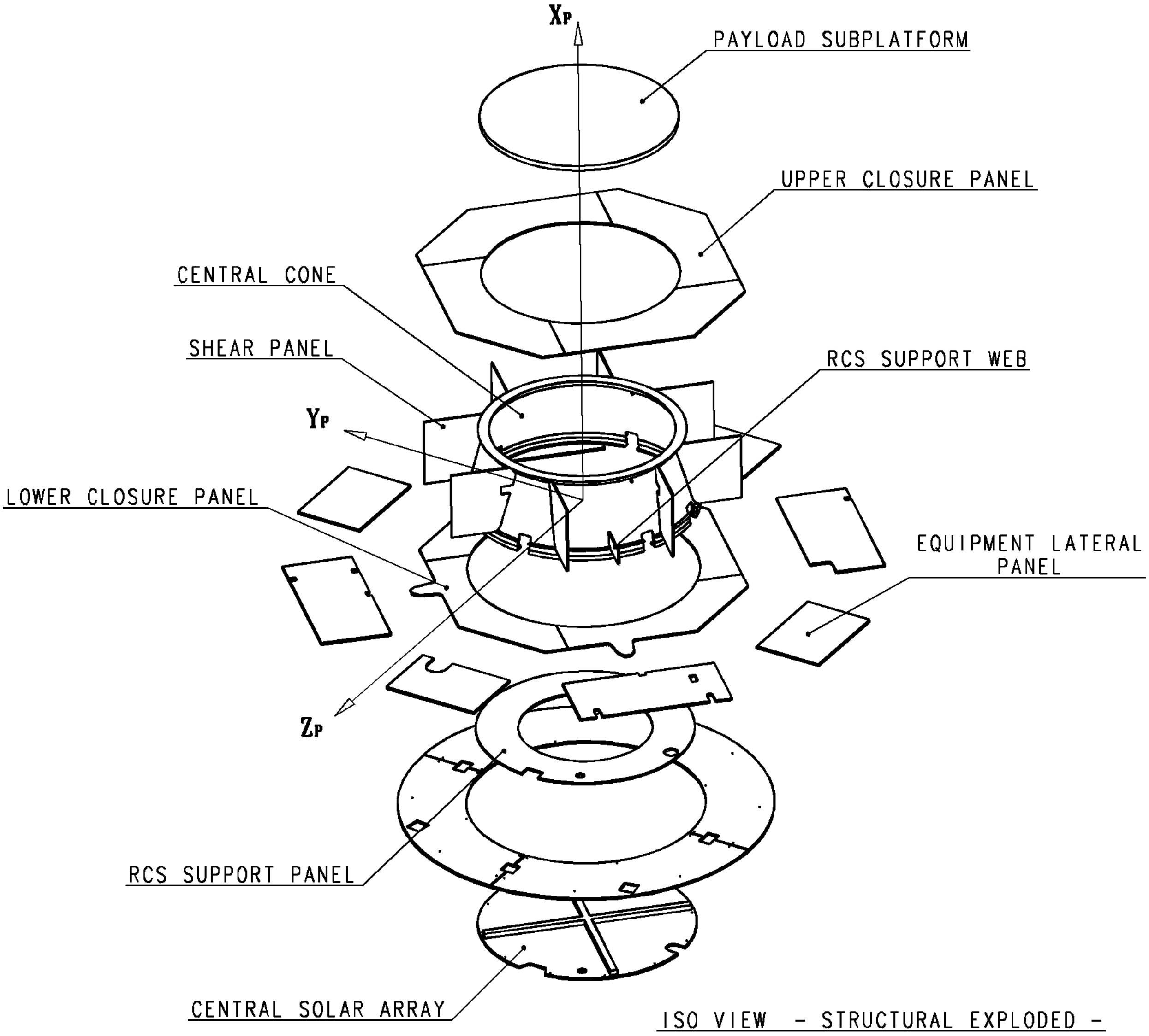


Fig. 7.3.2.2-2 Exploded view of Planck SVM Structure

7.3.3 Design Justification

7.3.3.1 SVM Structure Configuration Design

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 the SVM structure performances are enveloping the two different set of requirements.
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.

7.3.3.2 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 are Aluminum.

7.3.3.3 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 due to:

Local differences between Herschel and Planck at the PLM interfaces (12 points in Herschel, 6 points in Planck)
Presence of three heavier lateral panels (SCC) in Planck
Presence of a thicker P/L sub-platform (for frequency decoupling reasons w.r.t.the PLM)
Different Secondary Structures

7.3.4 Mechanical Performances

The SVM Structure performances are reported in detail in § 9.1.

For the SVM Equipment, a critical analysis of the design requirement, here above reported, have been performed. This is included in [H-P-TN-AI-0003 SVM Equipment Load Factors Assessment]. In this TN a Methodology for reducing the mechanical environment at the Equipment basis is also proposed.

7.3.4.1 SVM FEM Analyses

The analyses are performed using the updated H & P SVM Finite Element Model, including all the mass data reported in § 4. For PLM's the values included in § 7.3.1.1 are used.
For both S/C the following analyses have been carried out:

modal analysis:
- global, including PLM's and
- Box, without PLM's

stress/stiffness analyses

The principal results are included in § 9.1 and details are provided in [H-P-TN-AI-0002 SVM Structural Analysis].

7.3.4.2 SVM Structure Open Areas

The main critical area found so far is the mass.
The budget presented in § 9.1 is a summary of a rather detailed budget, where the several items have been calculated or estimated. In particular, with respect to the values included in the proposal, neglecting the differences due to a better calculation refinement, some increases are shown:

For Herschel and Planck :
Conical shell increases due to the presence of 12 reinforced areas, due to 12 HPLM I/F points instead than the 8 considered for the proposal
For Planck:
SCC panel increase due to the presence of very thick skins (1mm) and a high number of through inserts

In addition, for some other items, as Cone I/F brackets and P/L Sub-platform, a mass variation is expected, always due to the PLM interface (8 to 12).
An increase of the Secondary Structure mass is also expected, due to the consistent number of brackets and supports now defined (see § 71.2.2).

In conclusion, the mass value here presented is indicative and some more precise mass figures are expected by the Subcontractor in charge of the SVM Structure.

However it is clear that, during Phase B the Structure mass shall be kept under control throughout design optimisation and development of dedicated design solutions.

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) or OSR
- Interface fillers and low conductivity stand-offs for mounting equipment and equipment supports
- Aluminium doublers
- Heat pipes (when necessary)

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 will be developed trying to extent to the maximum commonality between them. The commonality will concern mainly the kind of design and the material solutions which will be used, 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 mounting on these panels, in the same picture are shown the respective external MLI/SSM area.

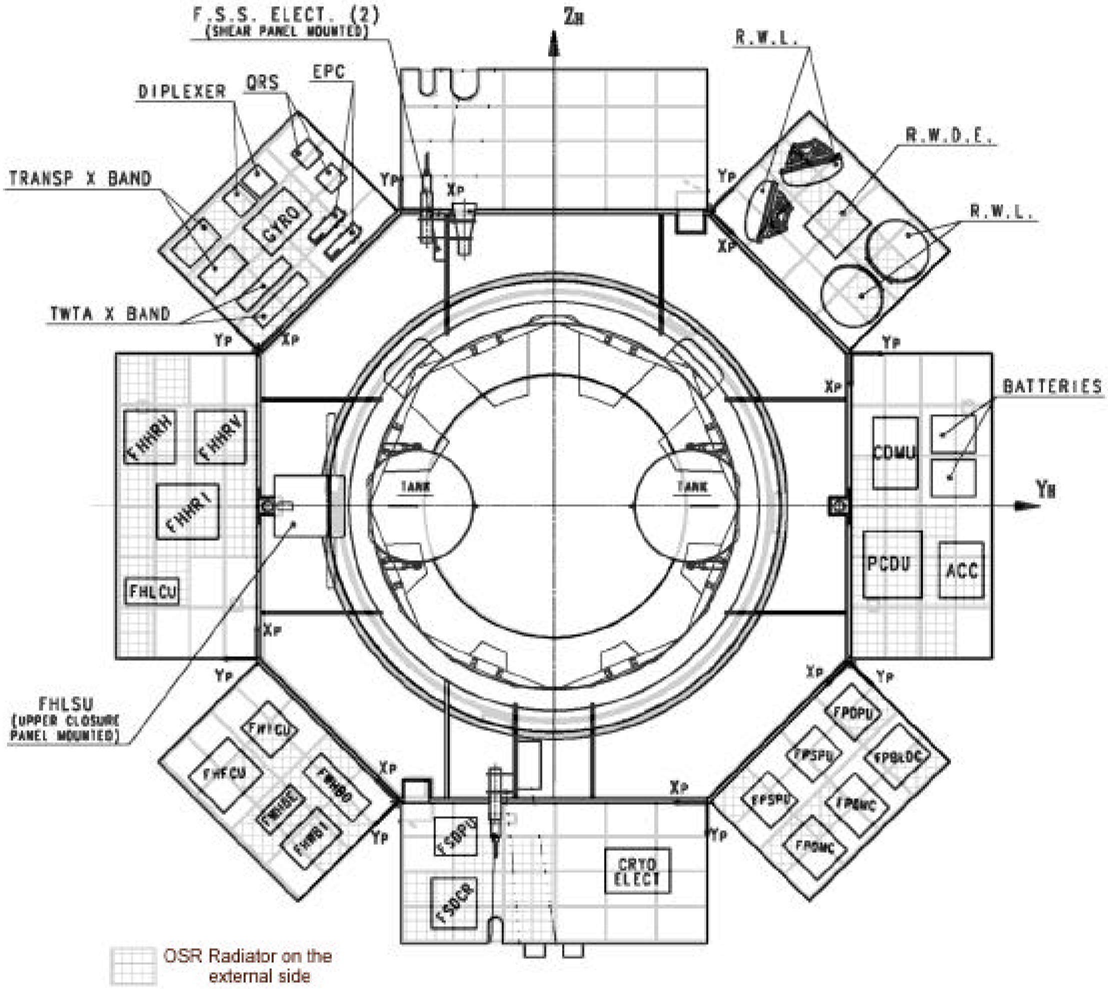


Figure 7.4.2-1 HERSCHEL lateral panels

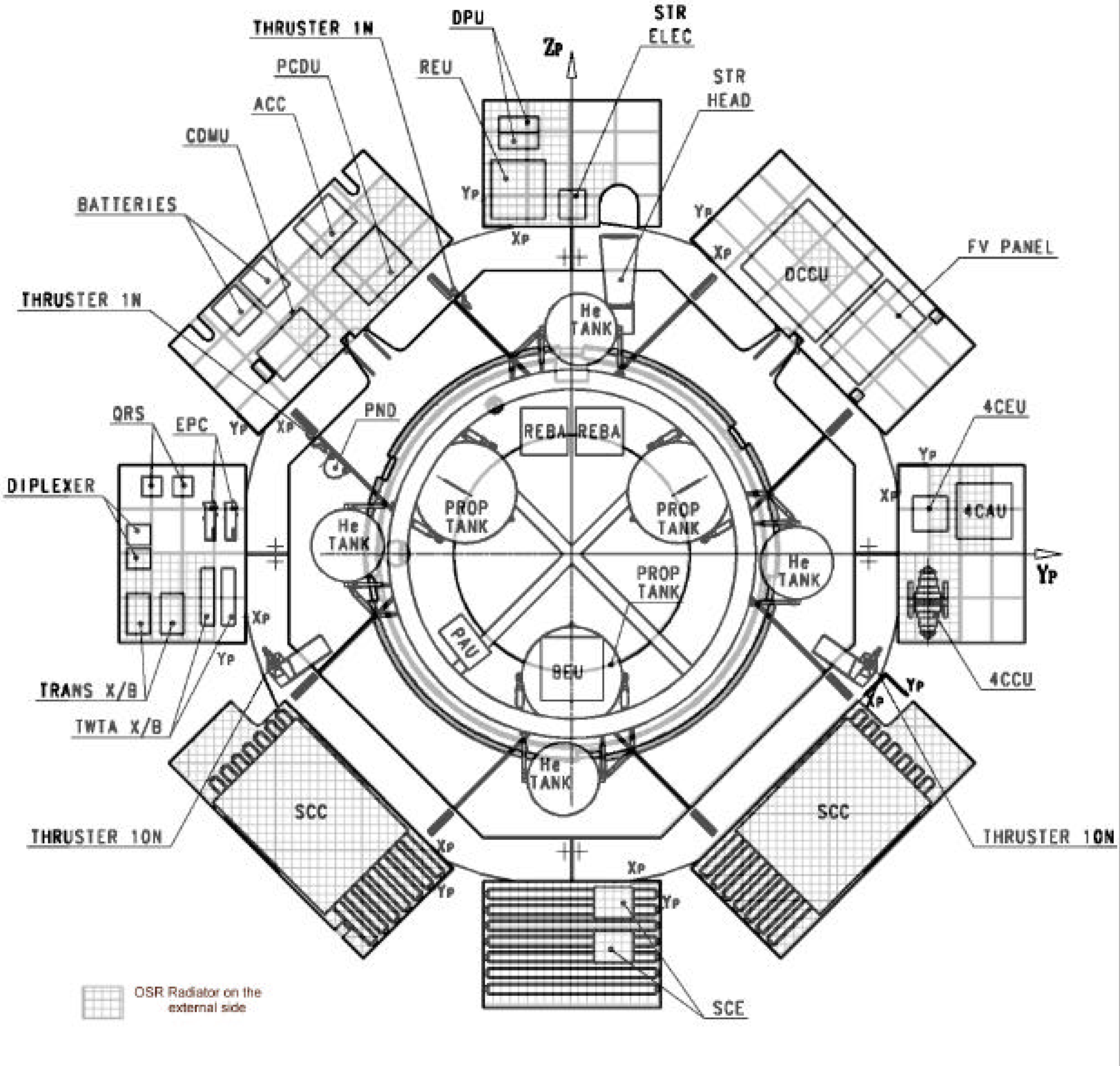


Figure 7.4.2-2 PLANCK Lateral Panels

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.

In addition, the top and the bottom of the SVM are covered with MLI, except for Herschel top panel, where the FHLSU area (300X300mm) is covered by SSM to rejects the heat flux of the units.
For the same reason, all lateral panels are used, when is requested, as radiators; to optimise at heaters power level this area, an accurate trimming between MLI and SSM 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 perform 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.

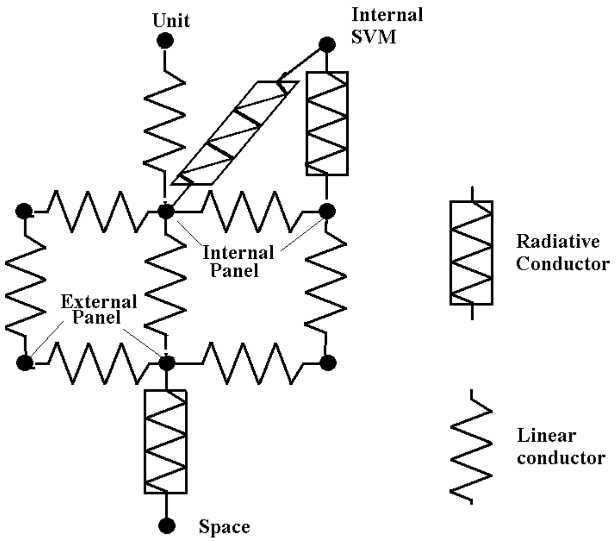
BOL/EOL thermo-optical properties are used for cold/hot cases.

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 only the structural panels, the solar arrays and the tanks, while the electronics boxes were not modeled at geometrical level. Except for certain unit, in order to verify the impact of the radiative environment of the unit.
The lateral panels (1740*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 (1124*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 (1740*800mm) have been modeled with 42 internal and 42 external nodes. The smaller SCC panel (1124*800mm) has been modeled with 28 internal and 28 external nodes.
The lower and upper floors were modeled by 4 internal and 4 external nodes.

After the GMM preparation and the radiative network definition, the linear thermal conductors has been added to complete the total thermal network. At this points the electronics boxes have been included in the TMM, modeling each unit with a single node, connected by a linear conductors to the mounting panel node. It has to be noted that the units are thermally connected (linearly) only to the mounting node, while no radiative conductor (except for some modeled unit) exists between unit node and environment (See figure).



7.4.4.2 Thermal Mathematical Model Description

The TMM has been completed introducing, for each node, thermal capacities and powers.
The unit dissipation has been assigned to the unit node (see Table 7.4.4-1 for HERSCHEL and Table 7.4.4-2 for Planck); In accordance with the system requirements, 10 % dissipation margin are added for computations to the instruments units.
For this study, the external exposed units (RCS thrusters, solar sensors, Star trackers or Star mapper) were not considered in the analysis.
The thermal design of these components will be developed accordingly to works performed for SVM with similar configuration, like INTEGRAL SVM.

The completed and detailed GMM and the TMM results are described in the SVM Thermal Analysis Report (H-P-TN-AI-0005 Is.1)

The design temperatures and dissipation for the units located in the SVM are reported in Table 7.4.4.2-1 for HERSCHEL, in Table 7.4.4.2-2 for Planck.

UNIT	DISSIPATION [Watt]					TCS DESIGN TEMPERATURE RANGE	
	LAUNCH	PRE-OPERATIONAL	SCIENTIFIC OBSERVATION	TELECOM PHASE	SURVIVAL MODE	OPERATING RANGE	NON OPERATING RANGE
Power							
Battery (2 batteries)	2x3=6	0	0	0	2x3=6	0/35 (15 - 20 recommended)	NA
PCDU	23	122	116	116	87	- 10/45	- 20/55
CDMS							
CDMU	20	36	36	36	36	- 10/45	- 20/55
AOCS							
ACC	15	24	24	24	24	- 10/45	- 20/55
RWs	0	20	30	30	10	- 10/50	- 20/60
STRE	0	11.5	11.5	11.5	0	- 20/50	- 30/60
STR	0	3.5	3.5	3.5	0	- 20/50	- 30/60
FSS	TBD	TBD	TBD	TBD	TBD	TBD	TBD
QRS	0	0	0	0	5.5	- 15/45	- 25/55
Gyros	0	15	15	15	0	- 15/45	- 25/55
TTC							
TWTA	0	63	0	63	63	- 15/50	- 25/60
Transponders	25	31	25	31	31	- 15/45	- 25/55
Diplexers	0	3	0	3	3	- 15/45	- 25/55
UPS							
Tanks						0/40	-10/55
HIFI							
FHWBO	0	0	7	7	0	-10/20	- 22/30
FHWBI	0	0	25	25	0	-10/20	- 20/30
FHWBE	0	0	18	18	0	-10/20	- 20/30
FHICU	0	0	22	22	0	- 15/35	- 25/45
FHFCU	0	0	15	15	0	- 15/35	- 25/45
FHHRV	0	0	57	57	0	- 15/35	- 25/45
FHHRI	0	0	29	29	0	- 15/35	- 25/45
FHHRH	0	0	57	57	0	- 15/35	- 25/45
FHLCU	0	0	18	18	0	- 15/35	- 25/45
FHLSU	0	0	20	20	0	- 15/35	- 25/45
PACS							
FPDPU	0	0	15	15	0	- 20/45	- 30/55
FPSPU	0	0	13.65	13.65	0	- 20/45	- 30/55
FPDMC	0	0	40	40	0	- 20/45	- 30/55
FPBOLC	0	0	16.6	16.6	0	- 20/45	- 30/55
SPIRE							
FSDRC	0	0	71	71	0	- 20/45	- 30/55
FSDPU	0	0	15	15	0	- 20/45	- 30/55

Note: The instrument dissipation is the nominal one (without 10 % system margin).

Figure 7.4.4.2-1 HERSCHEL SVM Unit Dissipation and Temperature Requirement

UNIT	DISSIPATION [Watt]					TCS DESIGN TEMPERATURE RANGE	
	LAUNCH	PRE-OPERATIONAL	SCIENTIFIC OBSERVATION	TELECOM PHASE	SURVIVAL MODE	OPERATING RANGE	NON OPERATING RANGE
Power							
Battery (2 batteries)	2x3=6	0	0	0	2x3=6	0/35 (15 - 20 recommended)	
PCDU	27	122	123	123	86	- 10/45	- 20/50
CDMS							
CDMU	20	36	36	36	36	- 10/50	- 20/60
AOCS							
ACC	15	24	24	24	24	- 10/50	- 20/60
STM	0	0.7	0.7	0.7	0	- 20/40	- 30/50
QRS	0	5.5	5.5	5.5	5.5	- 25/50	- 40/70
TTC							
TWTA	0	63	0	63	63	- 10/50	- 20/60
TC receiver	25	25	25	25	25	- 10/50	- 20/60
TM transmitter	0	6	0	6	6	- 10/50	- 20/60
Diplexers	0	3	0	3	3	- 10/50	- 20/60
UPS							
Tanks						+ 5/40	+ 5/40
HFI							
PHDPU	0	0	42	42	0	- 10/40	- 20/50
PHPAU	0	0	10	10	0	- 20/30	- 20/50
PHREU	0	0	90	90	0	- 20/30	- 20/50
PHJTC	0	0	60	60	0	- 10/40	- 20/40
PHJTA	0	0	12	12	0	- 10/40	- 20/50
PHJTE	0	0	30	30	0	- 10/40	- 20/50
PH3HE	0	0	0	0	0	- 10/40	- 20/50
PH4HE	0	0	0	0	0	- 10/40	- 20/50
PHCDU	0	0	10	10	0	- 10/40	- 20/50
LFI							
PLAB0	0	0	45.7	45.7	0	- 20/28	TBD
PLBA	0	0	32.3	32.3	0	- 20/50	- 30/60
SORPTION COOLER							
SCC	0	0	430	430	0	- 13/7	- 50/70
SCE	0	0	135	135	0	- 10/40	- 20/- 50

Note: The dissipation instruments is the nominal ones (without 10 % system margin).

Figure 7.4.4.2-2 PLANCK SVM Unit Dissipation and Temperature Requirements

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. 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/+5 ° (sun on -X/+Y axis); SAA = -30/-5 ° (sun on -X/-Y axis).

The cold case temperatures are obtained considering heaters on Batteries, Tanks, TWTAs, Diplexers, FHWBO, RWL, RWDE, ACC, EPC, QRS and GYRO, as reported in the Heater Power Budget (see Chapter 8.8.).

A summary of the HERSCHEL thermal analysis results for the steady state cases are reported in table 7.4.4.3-1. The reported temperatures are including 7 ºC of uncertainty.

	Temp. Limit [°C]	Cold Case BOL [°C]		Hot case [°C]
UNITS		Survival mode	Scient. Observation	Telecomunication phase

	Operat.		Non Operat.		SAA +30°	SAA +30°	SAA -30°	SAA -30/+5°	SAA -30/-5°
RWL1	-10	50	-20	60	-7.0	-7.0	30.5	32.1	29.6
RWL2	-10	50	-20	60	-5.8	-2.2	40.2	41.3	40.0
RWL3	-10	50	-20	60	-7.0	-7.0	31.7	33.3	30.7
RWL4	-20	60	-30	70	-17.0	-15.8	32.5	32.8	33.0
RWDE	-10	45	-20	55	-7.2	-7.0	34.6	35.8	34.2
PCDU	-10	45	-20	55	-5.1	7.7	40.9	42.7	41.1
CDMU	-10	45	-20	55	-7.0	-3.1	33.4	35.1	33.5
ACC	-10	45	-20	55	-7.3	-7.1	21.8	23.9	21.5
BATT1	0	35	-10	45	2.8	2.8	28.8	30.1	29.0
BATT2	0	35	-10	45	2.8	2.8	29.8	31.0	30.1
FPSPU1	-20	45	-30	55	-27.0	-16.1	24.3	24.8	24.9
FPSPU2	-20	45	-30	55	-27.0	-12.5	27.3	28.1	27.7
FPDPU	-20	45	-30	55	-27.0	-11.1	28.2	29.2	28.6
FPDMC1	-20	45	-30	55	-27.1	-9.4	29.7	30.2	30.3
FPDMC2	-20	45	-30	55	-27.0	-7.6	31.7	32.2	32.2
FPBLOC	-20	45	-30	55	-27.0	-10.6	25.1	26.2	25.4
FSDPU	-20	45	-30	55	-27.0	-12.6	25.0	25.0	25.8
FSDCR	-20	45	-30	55	-27.3	-3.0	32.4	32.4	33.0
STRE1	-20	50	-30	60	-27.0	-14.7	28.5	28.7	29.4
STRE2	-20	50	-30	60	-27.0	-15.4	26.6	26.7	27.5
ELEC.CRYO	-20	50	-30	60	-27.0	-17.0	25.3	25.7	26.1
FHICU	-15	35	-25	45	-22.1	-5.4	32.4	32.0	33.8
FHWBO	-10	20	-20	30	-17.3	-7.2	9.7	9.7	10.2
FHFCU	-15	35	-25	45	-22.1	-12.0	22.1	21.5	23.6
FHWBE	-10	20	-20	30	-17.1	-7.0	11.0	11.0	11.4
FHWBI	-10	20	-20	30	-17.2	-4.6	16.4	16.4	16.9
FHHRV	-15	35	-25	45	-22.3	-8.6	30.4	29.6	33.6
FHHRI	-15	35	-25	45	-22.3	-11.5	26.6	25.4	29.9
FHHRH	-15	35	-25	45	-22.3	-8.2	32.3	30.5	35.0
FHLCU	-15	35	-25	45	-22.2	-12.0	20.7	19.3	23.8
FHLSU	-15	35	-25	45	-22.1	-12.1	30.7	29.8	32.7
EPC1	-15	45	-25	55	-12.0	-12.0	35.2	34.8	36.5
EPC2	-15	45	-25	55	-12.1	-12.0	31.9	30.7	33.7
TWTA1	-15	50	-25	60	-4.6	-12.1	43.2	41.8	45.2
TWTA2	-15	50	-25	60	-6.3	-12.1	42.0	40.4	44.1
QRS1	-15	45	-25	55	-12.0	-12.0	33.6	33.0	35.0
QRS2	-15	45	-25	55	-12.0	-12.0	33.8	33.4	35.2
GYRO	-15	45	-25	55	-16.6	-12.0	33.6	32.1	35.7
TRANSX/B1	-15	45	-25	55	-12.0	-12.0	35.6	34.0	37.9
TRANSX/B2	-15	45	-25	55	-12.0	-12.0	36.8	35.2	39.2
DIPLEXER1	-15	45	-25	55	-12.1	-12.0	33.1	31.9	35.1
DIPLEXER2	-15	45	-25	55	-12.0	-12.0	34.3	33.3	36.1
TANK1 MLI	-100	100	-110	110	-25.5	-17.8	32.0	31.9	33.1
TANK2 MLI	-100	100	-110	110	-23.8	-16.4	32.2	32.5	32.9
TANK1	0	45	-10	55	2.9	2.9	31.9	31.8	33.0
TANK2	0	45	-10	55	2.9	2.9	32.1	32.4	32.8

Table 7.4.4.3-1 HERSCHEL Thermal analysis results

The thermal stability requirement, for the PLM units mounted on the SVM panels has been verified with a transient analysis. Two case of transient analysis have been performed, considering the SAA variation. Each case starts from a cold configuration and ends to a hot configuration.
In the Worst Cold configuration have been considered:

- BOL thermo-optical characteristics
- Sun flux = 1285 W/m^2 (summer solstice)
- Unit power dissipation = Scientific observation mode

In the Worst Hot configuration have been considered:

- EOL thermo-optical characteristics
- Sun flux = 1405 W/m^2 (winter solstice)
- Unit power dissipation = Telecom. Phase.

The first transient analysis (case A) has been performed considering the SAA variation = 0° ± -30°.for a term of ten minutes. The second one (case B) has been performed considering the SAA variation = +30° ± -30° for a term of twenty minutes.
The unit thermal stability has been monitoring for a term of 12 hours for each transient analysis.
The maximum temperature fluctuation for PLM warm units is reported in Table 7.4.4.3-2.

UNIT	Stability Requirement [ÄT/100s]	Case A [ÄT/100s]	Case B [ÄT/100s]
FHICU	0.14	0.038	0.039
FHWBO	0.03	0.020	0.020
FHFCU	0.14	0.035	0.032
FHWBE	0.14	0.017	0.042
FHWBI	0.03	0.019	0.019
FHHRV	0.03	**0.059**	**0.060**
FHHRI	0.03	**0.064**	**0.062**
FHHRH	0.03	**0.095**	**0.089**
FHLCU	0.03	**0.048**	**0.047**
FHLSU	0.03	**0.086**	**0.107**

Table 7.4.4.3-2 HERSCHEL PLM warm units transient thermal analysis results

For the baseline, it is proposed to regulate the temperature of the critical components (HIFI equipment) with a Pulsed Width Modulation, controlled by the CDMU. Whatever the spacecraft orientation, it ensures a strictly constant temperature of the units.

- **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.

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.

	Temper. Limit [°C]	Cold Case BOL [°C]	Hot Case [°C]

UNITS	Oper.		Non Oper.		Scientific Observation		Surviv Phase	Telecom. Phase
					Sun on +Z 0°	Sun on +Z 10°	Sun on +Z 10°	Sun on +Z 0°
STR ELEC.	-20	50	-30	60	-6.0	-6.1	-27.0	15.7
REU	-20	30	-30	40	8.1	8.0	-27.1	**30.6**
DPU	-10	40	-20	50	-0.3	-0.5	-17.4	22.1
REBA1	-10	40	-20	50	14.7	14.4	-10.3	37.5
REBA2	-10	40	-20	50	4.9	4.6	-11.4	27.2
FV PANEL	-10	40	-20	50	-0.6	-0.8	-16.5	21.5
DCCU	-10	40	-20	50	-3.3	-3.6	-17.2	18.6
4 CCU	-10	40	-20	50	6.4	6.3	-17.4	28.6
4 CEU	-10	40	-20	50	4.7	4.5	-17.2	26.9
4 CAU	-10	40	-20	50	6.3	6.1	-17.0	28.6
SCC1 - Bed1	-13	7	-50	70	-11.1	-11.1	-28.1	**7.7**
SCC1 - Bed2	-13	7	-50	70	-11.1	-11.1	-28.1	**7.7**
SCC1 - Bed3	-13	7	-50	70	-11.1	-11.1	-28.1	**7.7**
SCC1 - Bed4	-13	7	-50	70	-11.1	-11.1	-28.1	**7.7**
SCC1 - Bed5	-13	7	-50	70	-11.1	-11.1	-28.1	**7.7**
SCC1 - Bed6	-13	7	-50	70	-11.1	-11.1	-28.1	**7.7**
SCE1	-10	40	-20	50	-7.3	-7.3	-19.4	10.9
SCE2	-10	40	-20	50	-13.5	-13.5	-19.4	5.1
DAE (BEU/BEM)	-20	28	-30	38	9.5	9.2	-13.3	**31.4**
SCC2 - Bed1	-13	7	-50	70	-13.4	-13.4	-28.1	5.2
SCC2 - Bed2	-13	7	-50	70	-13.4	-13.4	-28.1	5.2
SCC2 - Bed3	-13	7	-50	70	-13.4	-13.4	-28.1	5.2
SCC2 - Bed4	-13	7	-50	70	-13.4	-13.4	-28.1	5.2
SCC2 - Bed5	-13	7	-50	70	-13.4	-13.4	-28.1	5.2
SCC2 - Bed6	-13	7	-50	70	-13.4	-13.4	-28.1	5.2
PAU	-20	30	-30	40	9.0	8.8	-13.2	**31.1**
EPC1	-15	45	-25	55	3.4	3.2	-2.0	27.6
EPC2	-15	45	-25	55	2.1	2.0	-2.0	26.8
TWTA1	-15	50	-25	60	-12.1	-12.1	-0.3	29.8
TWTA2	-15	50	-25	60	-12.2	-12.2	0.9	28.6
QRS1	-15	45	-25	55	6.3	6.2	-2.0	30.0
QRS2	-15	45	-25	55	6.1	5.9	-2.0	29.7
TRANSX/B1	-15	50	-25	60	-12.0	-12.0	-2.1	13.8
TRANSX/B2	-15	50	-25	60	-6.5	-6.6	-2.0	21.6
DIPLEXER1	-15	45	-25	55	-12.0	-12.0	-2.1	11.8

Table 7.4.4.3-3 PLANCK thermal analysis results

UNITS	Temper. Limit [°C]				Cold Case BOL [°C]			Hot Case [°C]
	Oper.		Non Oper.		Scientific Observation		Surviv. Phase	Telecom. Phase
					Sun on +Z 0°	Sun on +Z 10°	Sun on +Z 10°	Sun on +Z 0°
DIPLEXER2	-15	45	-25	55	-2.7	-2.9	-2.0	25.6
PCDU	-10	45	-20	55	20.6	20.5	0.4	43.7
CDMU	-10	45	-20	55	10.3	10.2	-2.0	33.2
ACC	-10	45	-20	55	3.7	3.6	-7.0	26.3
BATT1	0	35	-10	45	4.4	4.2	3.0	27.3
BATT2	0	35	-10	45	4.6	4.4	3.0	27.5
He TANK +Z	0	45	-10	55	3.0	3.0	3.0	23.0
He TANK +Y	0	45	-10	55	3.0	3.0	3.0	22.2
He TANK -Z	0	45	-10	55	3.0	3.0	3.0	17.0
He TANK -Y	0	45	-10	55	3.0	3.0	3.0	24.4
P TANK +Y+Z	0	45	-10	55	5.7	5.4	3.0	27.9
P TANK -Z	0	45	-10	55	3.6	3.4	2.9	26.0
P TANK -Y+Z	0	45	-10	55	7.7	7.4	3.0	30.2

Table 7.4.4.3-3 PLANCK thermal analysis results (continued)

On the other hand 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).
Table 7.4.4.3-4 reports the SCC dissipation (10% system margin is considered), subdivided among the 6 beds for the first 667s period; in the second 667 s period the total power values will be maintained but the single dissipation will redistributed among the 6 beds, and so on for the next 667s period.

TIME [s]	110% BED POWER [W]						
	BED1	BED2	BED3	BED4	BED5	BED6	SCC Total
0.0	51.5	14.6	33.8	48.4	48.4	48.4	245.1
10.0	42.2	14.9	417.8	48.4	48.4	48.4	620.1
20.0	34.9	15.0	635.5	49.5	49.5	49.5	833.8
30.0	28.8	15.1	752.3	49.5	49.5	49.5	944.7
40.0	24.0	15.2	806.7	49.5	49.5	49.5	994.4
50.0	20.0	15.3	823.0	49.5	49.5	49.5	1006.8
60.0	16.9	15.3	816.3	49.5	49.5	49.5	997.0
70.0	14.3	15.4	796.3	49.5	49.5	49.5	974.5
80.0	12.3	15.5	768.6	49.5	49.5	49.5	944.9
90.0	10.7	15.5	737.1	49.5	49.5	49.5	911.8
190.0	5.4	16.0	441.8	48.4	48.4	48.4	608.3
290.0	5.9	16.3	264.8	48.4	48.4	48.4	432.2
390.0	7.3	16.6	163.5	47.3	47.3	47.3	329.2
490.0	8.8	17.1	104.7	46.2	46.2	46.2	269.2
567.0	10.0	17.4	79.4	45.1	45.1	45.1	242.1
577.0	10.2	17.4	78.0	45.1	45.1	45.1	240.9
587.0	10.3	17.4	76.9	45.1	45.1	45.1	239.9
597.0	10.6	17.5	76.0	44.0	44.0	44.0	236.1
607.0	10.7	17.5	75.4	44.0	44.0	44.0	235.5
617.0	10.9	17.6	74.8	44.0	44.0	44.0	235.3
627.0	11.0	17.6	74.3	44.0	44.0	44.0	234.9
637.0	11.2	17.8	73.9	44.0	44.0	44.0	235.0
647.0	11.4	17.7	73.8	42.9	42.9	42.9	231.7
657.0	11.6	11.6	73.8	42.9	42.9	42.9	225.6
667.0	11.8	11.8	73.7	42.9	42.9	42.9	225.9

Table 7.4.4.3-4 Planck SCC Bed dissipation

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 and lateral panels by a limited number of pin; connections to the shear web will be insulated by thermal washers
- MLI will cover the SCC units
- the SVM will be thermally decoupled as much as possible from the SVM PLM I/F: thermal insulating washer will be mounted at the conjunction of the SVM panels.

Transient analysis were performed to evaluate the temperature fluctuation at the PLM-SVM I/F. A summary of these results is reported in Table 7.4.4.3.-5. The Figure 7.4.4.3-1/2 show the temperature fluctuation at the I/F of the 6 dissipation beds and the temperature of the relevant SCC radiative panel nodes.

	Stability requirement		EOL - Telecom phase - Sun +Z 0°	
UNIT	Delta Temp. [K]	Delta Temp. [K]	Temp. Variation [K] / 325 s	Temp. Variation [K]/ 7200 s
	/ 325 s	/ 7200 s	Dtmax	DTmax
I/F SVM - PLM	0.000325	0.25	**0.000399**	0.0074
I/F SVM - PLM	0.000325	0.25	**0.000795**	0.0115
I/F SVM - PLM	0.000325	0.25	**0.001241**	0.0158
I/F SVM - PLM	0.000325	0.25	**0.001146**	0.0139
I/F SVM - PLM	0.000325	0.25	**0.000719**	0.0100
I/F SVM - PLM	0.000325	0.25	**0.000353**	0.0065
Avg. Rad +Y-Z	0.4	0.5	**0.477733**	0.3693
Avg. Rad -Z	0.4	0.5	0.118863	0.1221
Avg. Rad -Y-Z	0.4	0.5	**0.449348**	0.3544

Table 7.4.4.3-5 Planck Stability requirement results

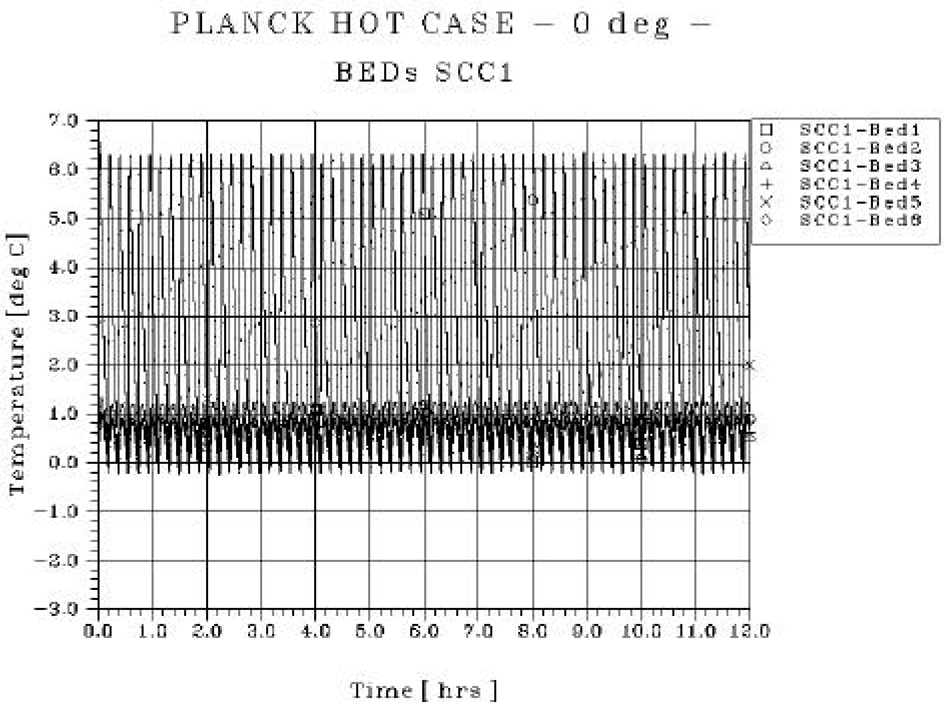


Figure 7.4.4.3-1 Planck I/F BED temperature profile

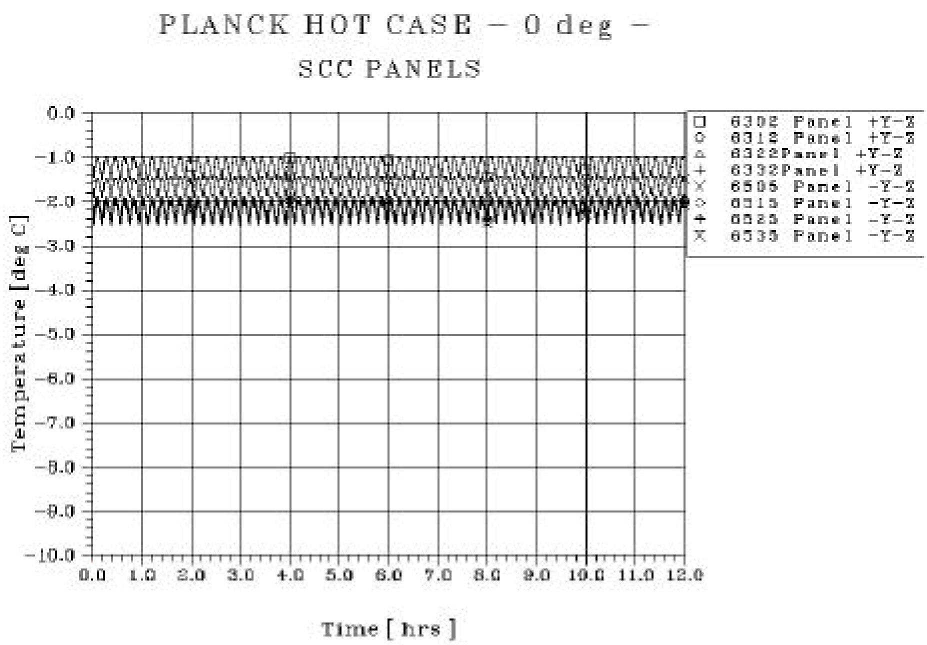


Figure 7.4.4.3-2 SCC panel internal side temperature profile

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:
The analysis results show that all the units are maintained within their temperature limits.
The only out of specification are the temperature fluctuations on the HIFI units mounted on –Y panel during the transient analysis.
The Stability requirement is not met for some units during the attitude variation, but it is reached after 6.6 hours for the case A and after 7.5 hours for the case B.

Actually the –Y HIFI units are covered with an MLI blanket and connected with filler to the panel; trade-off analyses, considering different thermal solutions, have been performed to evaluate the effect on the temperature fluctuation, but the results are not so relevant on the temperature variation and indeed do not allow meeting the stability requirement.

The re-location of the FHLSU, actually mounted on the top floor, to a radiator panel, could be a solution to improve the behaviour of the unit itself and avoid the heat exchange fluxes to Payload Module, but in this case it will be necessary perform new thermal analysis to study the feasibility of this solution.

PLANCK:
The analysis results show that unit/panels out of specification are:

- Solar Array: T=118°C vs 122°C of requirements

- REU T= 31 °C vs 30°C of requirements

Recovery Action: change position (increase distance from PCDU unit)

- BEU: T= 31.4°C vs 28°C of requirements
- PAU: T= 31.1°C vs 30°C of requirements

Recovery Action: 1) Use a dedicate lateral radiative surface
2) Use a aluminium skin instead of carbon fiber
3) Change position

- SCC bed's: T= 7.7 °C vs 7°C of requirements
- SCC panel fluctuation: T= 0.477 K/325s vs 0.4K/325s of requirements
- SVM/PLM I/F fluctuation: T= 1.24 mK/325s vs 0.325mK/325s of requirements

Recovery Action:None

Note: All results including 7°C of uncertatinty

Conclusion:
The analysis of the thermal results shown that, no particulars critical out of specification have been found out.
The relevant aspects is that, especially for Planck, no increased of heat power dissipation on SCC panel is acceptable, unless to change the temperatures limits requirements.

7.5 Avionics Design and Performance Analysis

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

7.5.1 Avionics Requirements and Design Drivers

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

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

- technical compliance, considered as mandatory, including sufficient flexibility to accommodate upgrade of the main requirements;
- Herschel and Planck commonalities
- hardware impact: the selected option 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 figures 7.5.2-1 and 7.5.2-2 respectively.
Detailed drawings showing different functions and their implementation down to equipment level are reported in Annex A of this report.

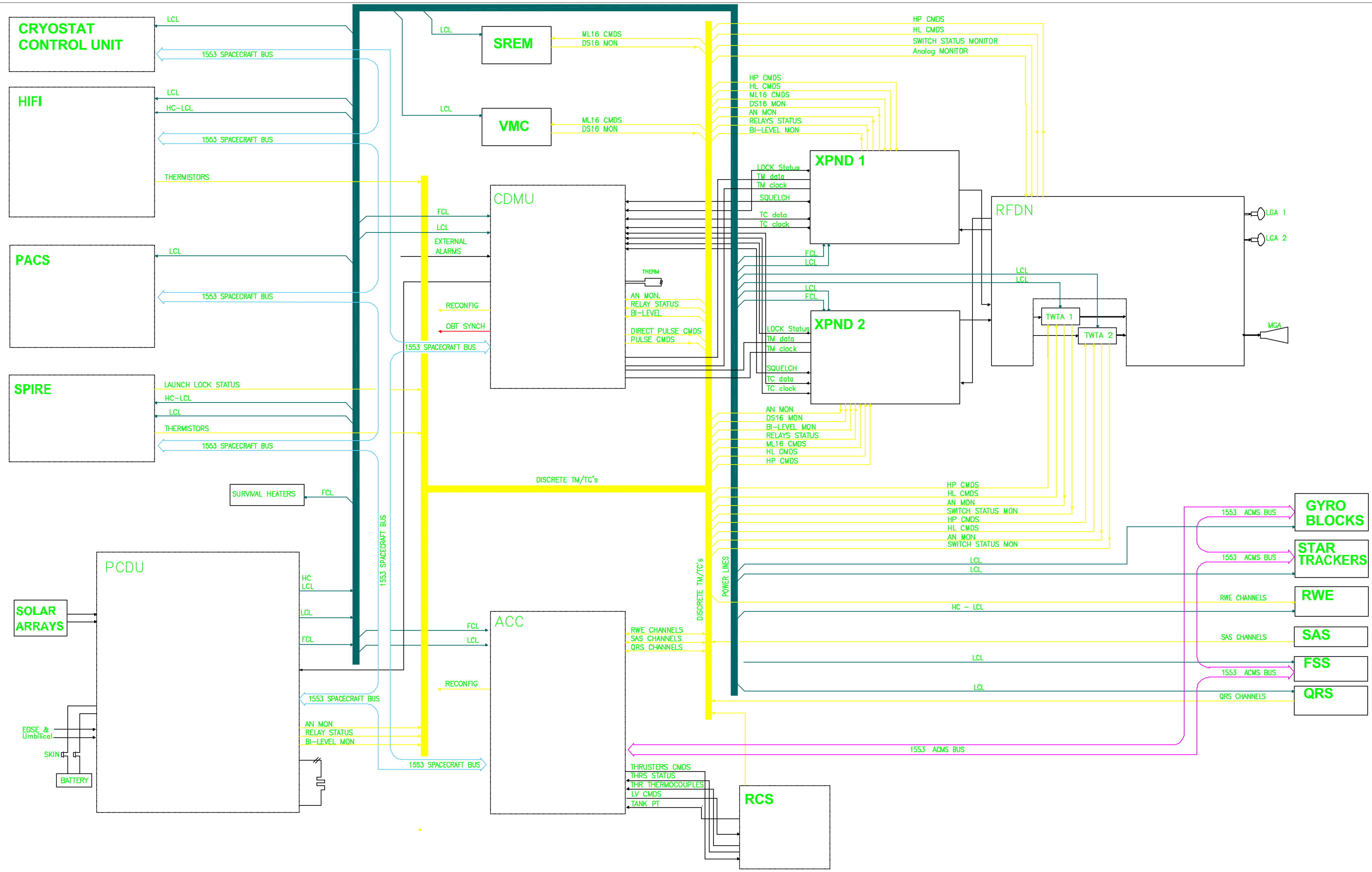


Figure 7.5.2-1 Herschel Block Diagram

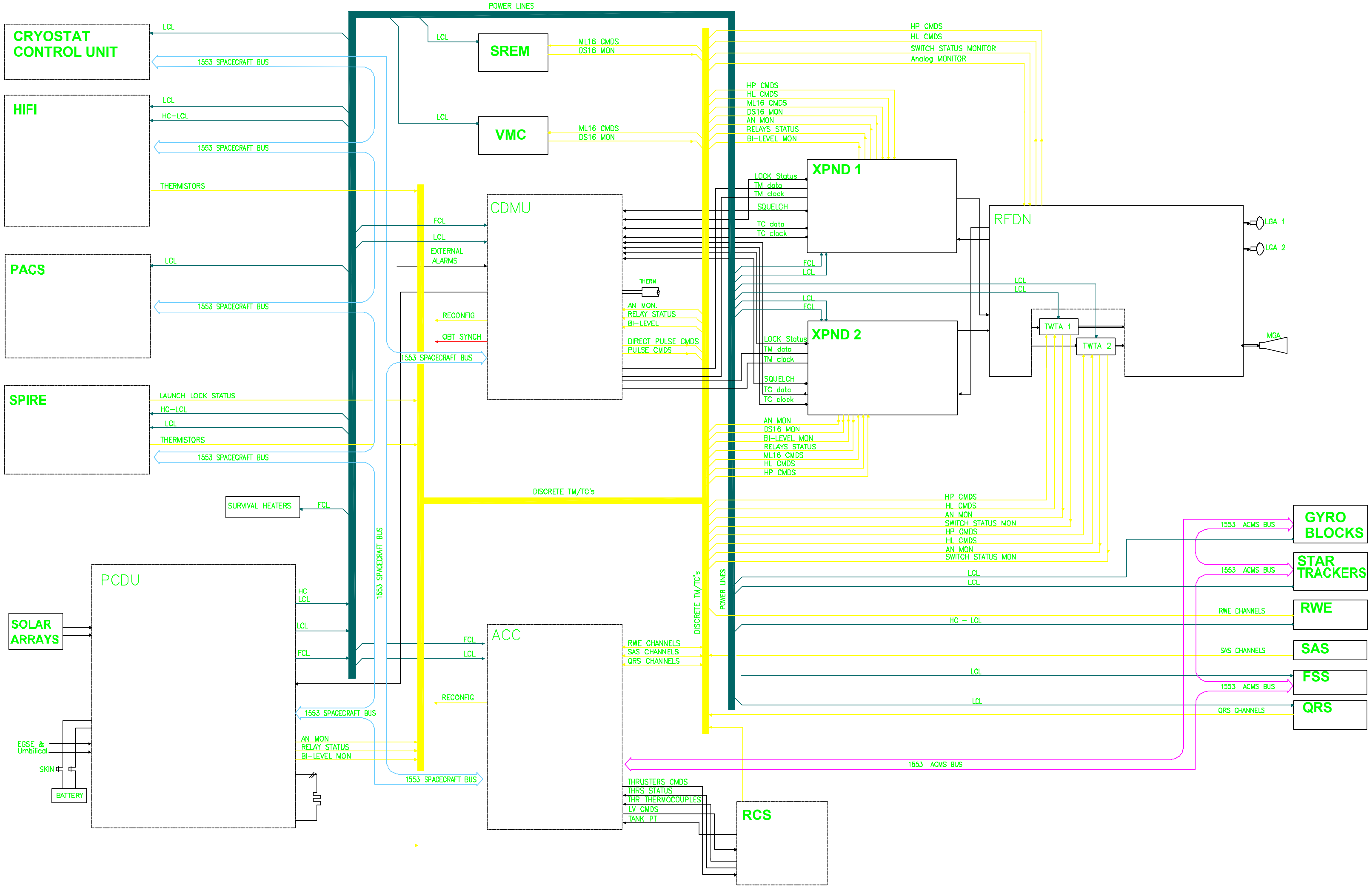


Figure 7.5.2-2 Planck Block Diagram

On Board Data Management

On Board Data Management has been suitably dimensioned to be compatible with both Herschel and Planck satellites, thus providing a high level of commonality.
Subsystem function will be implemented in one CDMU, which includes a Mass Memory of 25 Gbit End Of Life.
The implemented microprocessor is an ERC32SC Processor.
MIL-STD-1553 Bus will be used to transfer data to/from instruments, PCDU, ACC and CDMS.
The CDMU provides condition inputs for a number of discrete telemetry lines which will be used for housekeeping.

A number of discrete telecommand lines are provided for reconfiguration and to users which cannot interface with 1553 bus.

A number of discrete synchronisation lines (On Board Time to Local On Board Time sync, Start of Scan Sync for Herschel and Star Reference Pulse for Planck) are provided to each instrument, these are transmitted via over the MIL-STD-1553 bus and discrete lines.

Radio Frequency Communications

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 range from 500 bps to 1.5 Mbps.
- to receive and demodulate the X-Band telecommand upstream. Uplink rates nominally range from 125 bps to 4 kbps
- to guarantee the satellite accessibility whatever the operating mode over the mission.

The systems comprises two X-band transponders.
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.
The design features two 30 W TWTA (Travelling Wave Tube Assembly).

The telecommunication function uses 2 antenna concepts:

- one MGA
- two LGAs for Herschel and 3 LGAs for Planck

Power Generation, Storage and Distribution

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.

Herschel solar array is composed of three identical panels utilising dual junction GaAs cells.
The lateral panels have an angle of 35° with respect to the central panel.

Planck solar array is composed of a central circular part plus four quarters forming an outer ring, all utilising dual junction GaAs cells common with those used for Herschel.

7.6 Software architecture

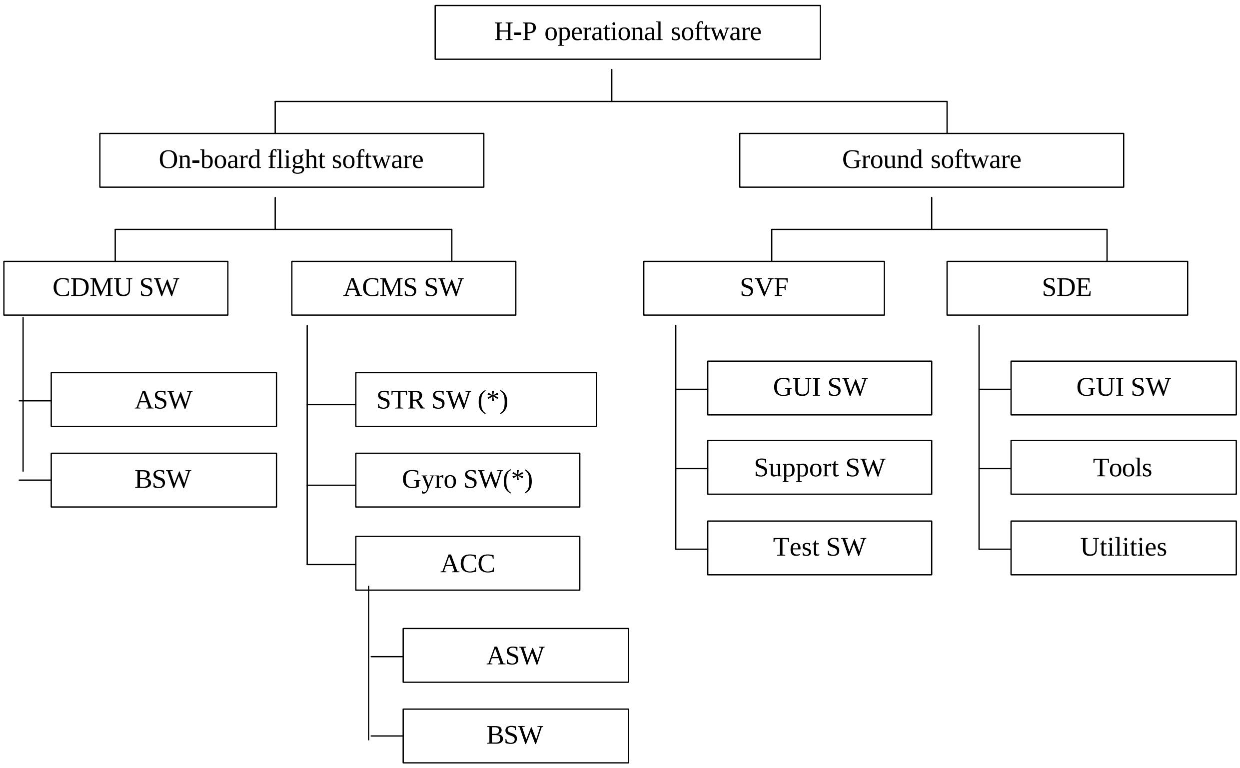
7.6.1 Herschel/Planck software breakdown

The Herschel/Planck software considered in this section is related to the SerVice Module (SVM) of both satellites. All software developed in the frame of the programme but belonging to the PayLoad Module (PLM) is not discussed because out of the scope of this presentation.

The operational software can be conceived as split in two major sections, that is:

On-board flight software
Ground software

The SVM on-board flight software is mainly represented by the CDMS(CDMU) software and ACMS software.
The ground software encloses all software tools and components supporting the flight software design, development, verification and validation activities.



(*) Herschel only

Figure 7.6.1-1 SW Breackdown

In order to identify better the context on which the on-board flight software will run, figure 7.6.1-1 shows the main SW components and their intrinsic relations.

7.6.2 On-board flight software layers

This section is devoted to contain a short description of the relevant on-board SW organisation.

The on-board flight software shall be conceived taking into account the following considerations:

The CDMU and ACC shall use the same type of microprocessor unit

The HW subcontractor shall be in charge of low-level drivers definition and implementation, due to his intrinsic knowledge and experience on the area under discussion

The SW architecture shall be based on various different SW layers

The degree of commonality between the CDMU SW and ACC SW shall be maximised

In the picture is depicted a possible SW layers organisation:

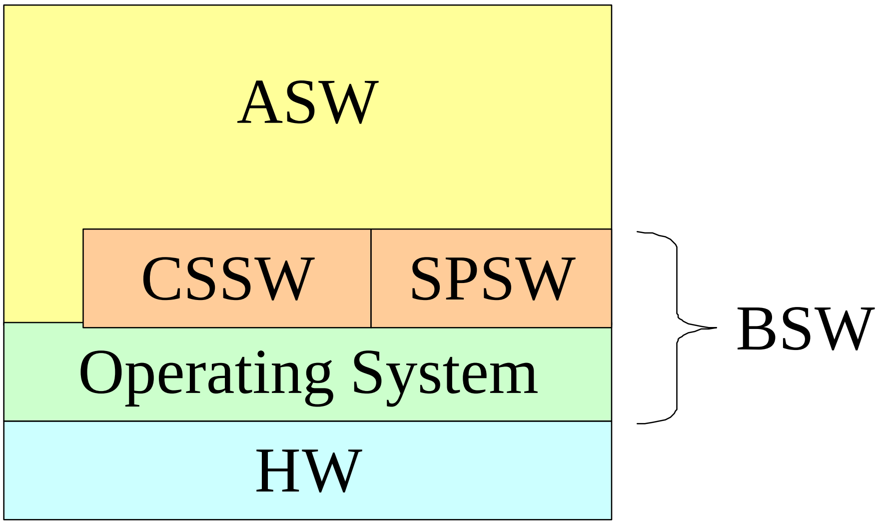


Figure 7.6.2-1 SW Layers Distribution

The HW layer is represented by the physical devices (e.g. 1553 Bus, RTU bus I/F) that must be supported.

The Operating System is the lowest SW layer which directly interfaces the HW and is mainly composed by the following components:

A real-time kernel having basic services as task scheduling, inter-task communication capabilities, delays and events management, etc.
I/O device drivers
Bootstrap module

Notice that the operating system should be a COTS item in order to contain the final cost and to respect the whole developing timing schedule.

The Common Service SW (CSSW) represents the SW core package that can be considered common to Herschel/Planck CDMU and ACC. The following services are included in this layer:

Memory patch/dump
API used to I/F the 1553 device driver
On line self-tests
Other

The SPecialised SW (SPSW) includes a set of custom services specifically related to CDMU or ACC functionality that are part of basic services and cannot be logically incorporated in the higher level (ASW). Examples of such software services, for CDMU, are:

Mass memory API
OBCP basic services
Mission Time Line management services
Other

Viceversa the SPSW of the ACC can be characterised by the following services:

Reaction wheel services
Thruster services
Sun acquisition services
Star Mapper services
Quartz rate sensor services

The highest SW level is represented by the Application software (ASW) that is mainly constituted by mission specific functions, e.g. for CDMU:

Battery Monitoring
Thermal Control
CDMU HK data management
TC analysis and dispatching
Other

The ASW for the CDMU of Herschel and Planck satellites shall be as far as possible the same. Viceversa two different ASW packages shall be developed for the ACMS, one for the ACC of Herschel and one for the ACC of Planck.
Globally, the following services, provided by the lower SW layers, shall be available to the ASW:

TC services
TM services
Time services for OBT management
Reconfiguration Module services
Watch dog services
Safe guard memory services
CPDU services
MIL-1553B bus services
Analogue input services
Thermistor services
Digital input/output services
Mass memory services (CDMU only)

Notice that this configuration is open to further extension or required revision during the development phases. In fact any requested new service could be easily added in the middle layers (represented by the CSSW and the SPSW) without any particular effort and dependence on the current SW development status: each layer can be improved or modified without upsetting the rest of the system.
The commonality between CDMU and ACC is well identified and maximised by the lower SW layers. A reliable and well-settled real time kernel is required in order to avoid the proliferation of its different SW releases.
As a matter of fact this approach will improve the activity performed during the integration and validation phases. Next table summarises the different requested SW packages that would be developed in the frame of the Herschel/Planck programme:

	CDMU Herschel/Planck	ACC Herschel	ACC Planck

ASW	X	X	X
SPSW	X	X	X
O.S. + CSSW		X	

7.6.3 CDMU software

Hereafter a more detailed description of the main CDMU capabilities is reported:

Mission Timeline:

The Mission Timeline (MTL) is defined as a linear sequence of Telecommands, which will be sent to their on-board destinations by the Scheduling Service, when their execution time has arrived. The autonomous operation of Herschel and Planck will also be based on these TC packets, which are uplinked to the MTL during each daily communication period.
The autonomous execution of Telecommands requires that preconditions and execution status of each Telecommand is checked, as part of Flight Procedures that are executed automatically on-board (as opposed to ground control). The Scheduling Service is not specified to check the execution status of Telecommands. However, OBCPs can have capabilities in support of these control functions, like activating a part of the MTL, or skipping (parts of) the MTL up to a point in time, and releasing specific Telecommands for pre-planned recovery activities.

On-board Monitoring

The On-board Monitoring Service provides the capability to monitor on-board parameters with respect to checks defined by the 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 reporting or, in some cases, predefined on-board functions (like nominal OBCPs, or FDIR functions) may be involved, if applicable. In any case the service reports all check status transitions to the ground.
To achieve this, the service maintains a monitoring list, and checks parameter samples according to the information contained therein. If a check results in a positive result, a Monitoring Identifier determines if an activity shall be triggered and if an Event packet shall be generated. This can be evaluated on-board by the Event/ Action Service or on ground in order to initiate related further activities. The Monitoring Service is considered to be a CDMS capability, as far as S/C-related parameters are concerned. For instrument-internal monitoring this service may be implemented as part of the instrument applications.

OBCPs

ESA's requirements, contained in section 2.2.5 of the relevant Herschel/Planck Operations Interface Requirements Document (OIRD, SCI-PT-RS-07360), clearly identify the necessity to design a user-friendly language, devoted to help operations engineers during the definition of the on-board procedures. General requirements provide a short description of the basic characteristics of the proposed languages as well as its on-board utilisation issues. The following basic programming statements and functions are requested:

if ... then ... else
select
repeat
for
while
do

on case
wait
basic mathematical operators (+, - , *, /)

OBCPs shall be controllable in terms of their loading, stopping, running and can concurrently run without any mutual interference.

A reasonable approach to the SCL definition should consider the following items:

The exigency to design and create an operation-oriented control language is a real need of the operation team
The proposed language should be very simple. It should be avoided the definition of a new high level language, containing nonessential statements and/or functionality.
OBCPs on-board execution should not heavily impact the whole system timing and resources allocation

Basing on these considerations the most suitable solution could be centred on a new macro language definition, to be agreed between the software and operation teams. Lexical and syntax analysis of the relevant language should be based on new created SW programs supported by automatic tools (e.g. LEX and YACC). This would greatly improve the design and the maintenance of the language itself in the perspective of syntax/semantic revisions and future extensions. After writing the sequence of operations to execute on-board it shall be necessary to convert them in a format that can be used for on-board up-loading.
Thus the output of the SCL compiling phase should trivially and properly represented by the translation of the operation procedure in a high level language (i.e. C language or Ada) in order to easily generate the necessary binary code to upload on-board.

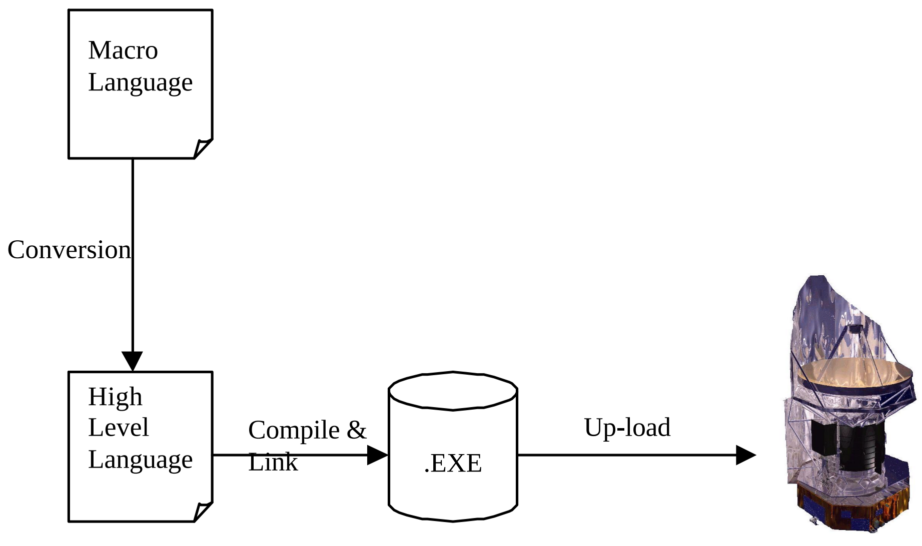


Figure 7.6.3-1 OBCP On Ground life cycle (no On-Board Interpreter)

Once on-board, OBCPs must be considered as tasks that can be managed by means of the relevant Operating System services. They can be activated, stopped, resumed and terminated. It shall be possible to activate as many OBCPs as necessary basing on the fixed O.S. task number limit. It shall not be possible to activate multiple instances of the same OBCP (for safety reasons). Each OBCP shall be independent, being a task, and shall work using its own stack. OBCP's inter-communication can easily implemented through the management of global variables in order to avoid useless resource allocation as, for example, mailboxes or other system queues.
The following steps represent the complete and nominal on-board life cycle of the OBCP:

OBCP activation (task creation)
OBCP execution (task execution)
OBCP termination (task termination)

Notice that OBCPs can be optionally loaded on-board from the beginning of the satellite mission. It means that they can be thought as resident tasks that are activated from ground telecommands as well as on-board specific events or generated commands. Moreover new OBCPs can be created on-ground and up-loaded on-board at any time, during the whole mission, to diagnose and/or recover specific conditions.

It is clear that a language as Ada, running with its proper run-time system, does not represent the best choice to have a flexible environment where task creation and termination represent a major feature of the whole system. This is also one of the reasons that warn and alert us on the usage of Ada itself.

Events management

Three different sub-types of user-initiated event reports are defined for Herschel / Planck, to facilitate routing, on-board processing, and/or ground processing. All reports have the same structure.

Event Report :

This sub-type shall be used for passing on information for any asynchronous event or warning, that has occurred within a unit or subsystem and for which no direct re-action by other units, except recording or transmission, is normally required. The CDMU may decide after reception of a specific Event Packet to initiate a related nominal activity (e.g. releasing a specific Telecommand to other units).

Exception Report:

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 for which on-board procedures are available.

Error/Alarm Report :

An Error/Alarm Report shall be generated for non-nominal events which require intervention from the mission control centre on ground, i.e. no predefined recovery or saving procedures are resident on-board.

Telecommands

Telecommands represent the main capability that shall allow ground to interact with the on-board units/users.

The CDMS SW shall be compliant with the Packet Telecommand Standard, ESA PSS-04-107. No segmentation shall be used for Telecommand packets on Ground to space link .
The CDMU SW shall receive, process and distribute all commands coming from ground, stored on-board and generated on-board. Commands shall be forwarded on-board to the addressed unit according to the packet standard. Only if the addressed unit cannot support the packet standard, raw data can be forwarded.
The CDMS SW shall support the high telecommand rate of 4Kbps.

The destination application process shall validate telecommand packets at the moment of acceptance.
Any telecommand that doesn't conform to the packet telecommand standard and/or is not recognised as a valid telecommand shall be rejected at the earliest possible stage in the on-board acceptance and execution process; the reason of rejection shall be indicated in telemetry.

Telemetry

Telemetry packets will provide science and housekeeping data of the satellite to ground.

The CDMS SW shall be compliant with the Packet Telemetry Standard, ESA PSS-04-106. No segmentation shall be used for Telemetry packets.

The CDMS SW shall acquire the scientific, periodic and non-periodic housekeeping data packets from the scientific instruments as well as all the other HK data coming from intelligent units connected to the CDMS 1553 MIL bus.

Data shall be received on-board from the source according to the packet standard. Only if the source unit cannot support the packet standard, raw data can be received and the packetization is in charge of CDMS SW.

The CDMS SW shall condition, process, format and code the data for on-board storage and for telemetry transmission to Ground and for on-board monitoring and recovery functions.

During the daily Ground contact, the CDMS SW shall support simultaneously the recording of all real time telemetry (only housekeeping or housekeeping + science) and one of the following telemetry mode, for 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

A (small) number of Housekeeping and Diagnostic TM packets may be re-defined by assigning a new definition of a sequence of Parameter Identifiers to an existing packet definition, together with a new Structure Identifier. The rules for construction of the data field and for the timing are the same as for static HK packets.

7.6.4 ACMS software

Analogously, the following ACMS capabilities are presented:

Telemetry acquisition and formatting
Telecommand acquisition, decoding, validation and execution
Tasks and functions management
Memory management
Time management
Autonomy management

Each capability is shortly discussed.

7.6.4.1 Telemetry

The ACMS SW shall be compliant with the Packet Telemetry Standard, ESA PSS-04-107.
The ACC SW shall acquire periodic and non-periodic housekeeping data from all ACMS units and shall format them into telemetry packets, for local usage and routing to the CDMS SW.
For trouble-shooting purposes, the ACMS SW shall support the definition of special diagnostic telemetry packets.
The ACMS SW shall support the dynamic definition of parameters to include in its telemetry packets; the configuration of each packet shall be under ground responsibility (a dump command is acceptable to verify the on board telemetry definitions).
The ACMS SW shall report all events of operational significance using event report packets, to be used locally and routed to the CDMS SW for storing them into the Spacecraft Event Log (SEL). Event reports shall follow the same classification defined in FPOIRD EVRP-1.

7.6.4.2 Telecommand

The ACMS SW shall be compliant with the Packet Telecommand Standard, ESA PSS-04-106.

The ACMS SW shall validate and process the telecommand packets received from the CDMS SW, during the Mission Time Line, or as event/action recovery or directly from ground.
A telemetry packet for successful/unsuccessful acceptance and successful/unsuccessful command execution (if requested) shall be generated by the receiving application. In case of unsuccessful report, the reason of the failed operation is also provided.
The ACMS SW shall support device telecommands (pulse commands and register load commands); usually this service is provided only by the CMDS through the RTU board, but it could be extended to the ACMS with reference to the AIU board.
The ACMS SW shall receive information packets from the CDMS SW.

7.6.4.3 Task and function management

The ACMS SW shall support specific telecommands from ground aimed at modifying the status and the behaviour of on-board software tasks and functions (e.g. start/stop, load/report parameter and so on).
The communication between ground and each task (or function) shall be based on specific telecommand and telemetry source packets.

7.6.4.4 Memory management

The ACMS SW shall support the memory patch and dump of any memory area, including non-volatile memories.
It shall be possible to modify the on-board software, either modifying the image on non-volatile memory or by patching the image in working memory (RAM), while the ACMS is operational.
The ACMS SW shall support memory check requests addressed to a specified on-board memory area, performing a checksum over the requested addresses and reporting the result to ground.

7.6.4.5 Time management Requirements

The ACMS SW shall support time synchronisation and verification respect to the CDMS Master Clock, according to the relevant protocol specified in the Herschel/Planck Packet Structure ICD.
The ACMS SW shall tag all the telemetry packets with the time of initiation of packet data acquisition.

7.6.4.6 Autonomy management

The ACMS SW shall provide an On-Board Monitoring capability to implement the FDIR function. This function shall support the monitoring of same parameters (e.g. sensors) and the association of specified reactions (e.g. mode transition) as result of the monitoring.

7.6.5 SVM SW distribution

This paragraph is devoted to show the logical organisation and the relevant interfaces existing among the SVM S/Ss and units in order to identify better the flight software.

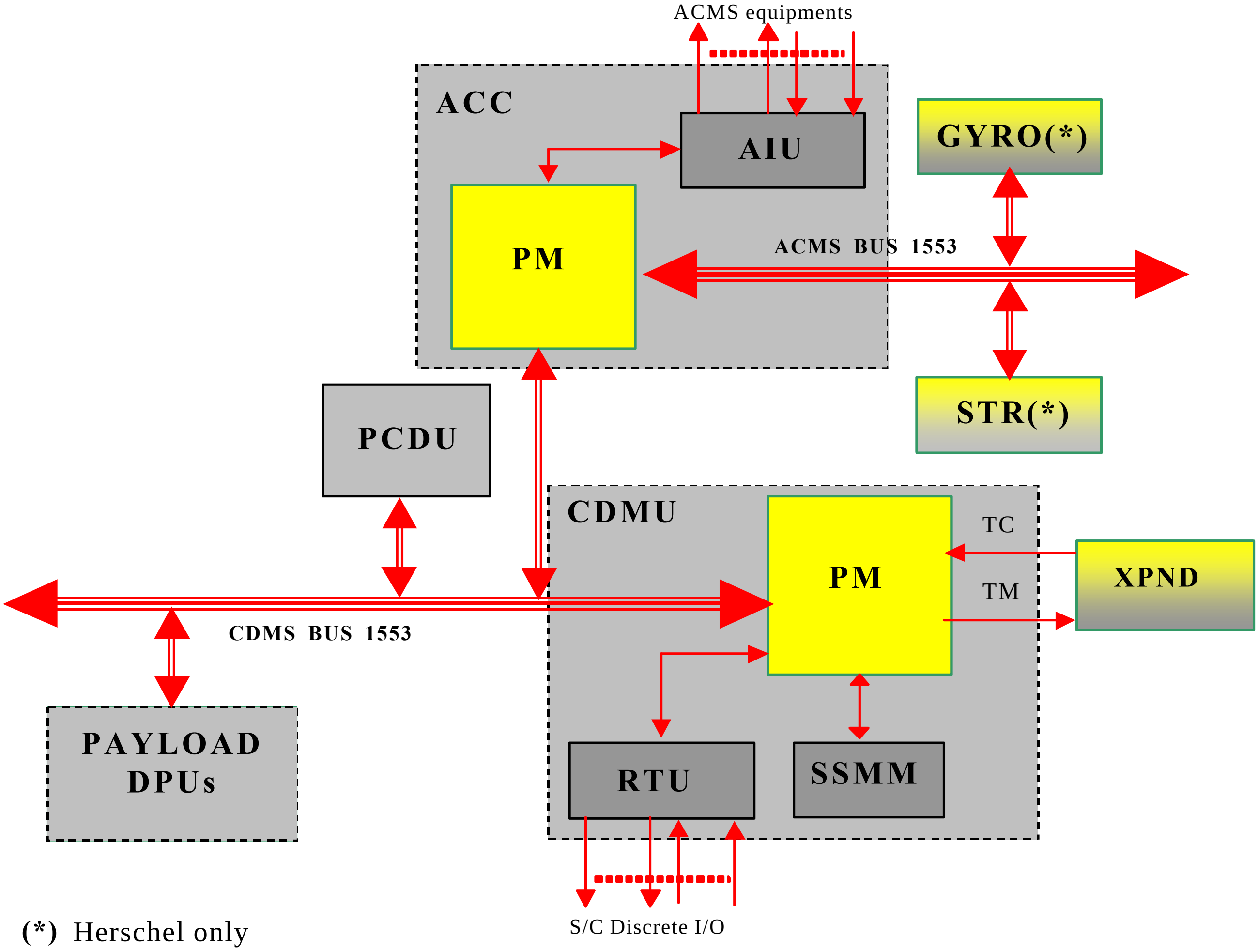


Figure 7.6.5 Herschel/Planck SVM On-Board SW Location

The CDMU Processor Module (PM) shall be in charge to exchange both TM and TC data with the transponder (XPND).

The PM shall interface the Solid State Mass Memory (SSMM) in order to store all the telemetry gathered during the non-contact period and to send it on ground as soon as the RF link is active. The SSMM shall also be used for other functionality as for example the MTL telecommands storage.

A dedicated serial link shall be used to communicate between the PM and the RTU module. This interface shall allow commanding and monitoring all the non-intelligent units through discrete I/O channels.

All the intelligent units shall be interfaced by means of the 1553B bus. Intelligent units have a proper microprocessor permitting them to operate complex tasks. The following terminals shall share the CDMS bus:

CDMU (which acts as the bus controller)
PCDU
Scientific instruments
ACC

The ACC is the other unit of the SVM which uses the same processor type used by the CDMU.

In case Herschel is considered a dedicated 1553B ACMS bus shall be used to communicate with the Gyros as well as the Start tracker unit.

The AIU is used to interface the ACC to all the non-intelligent units foreseen in the relevant ACMS S/S.

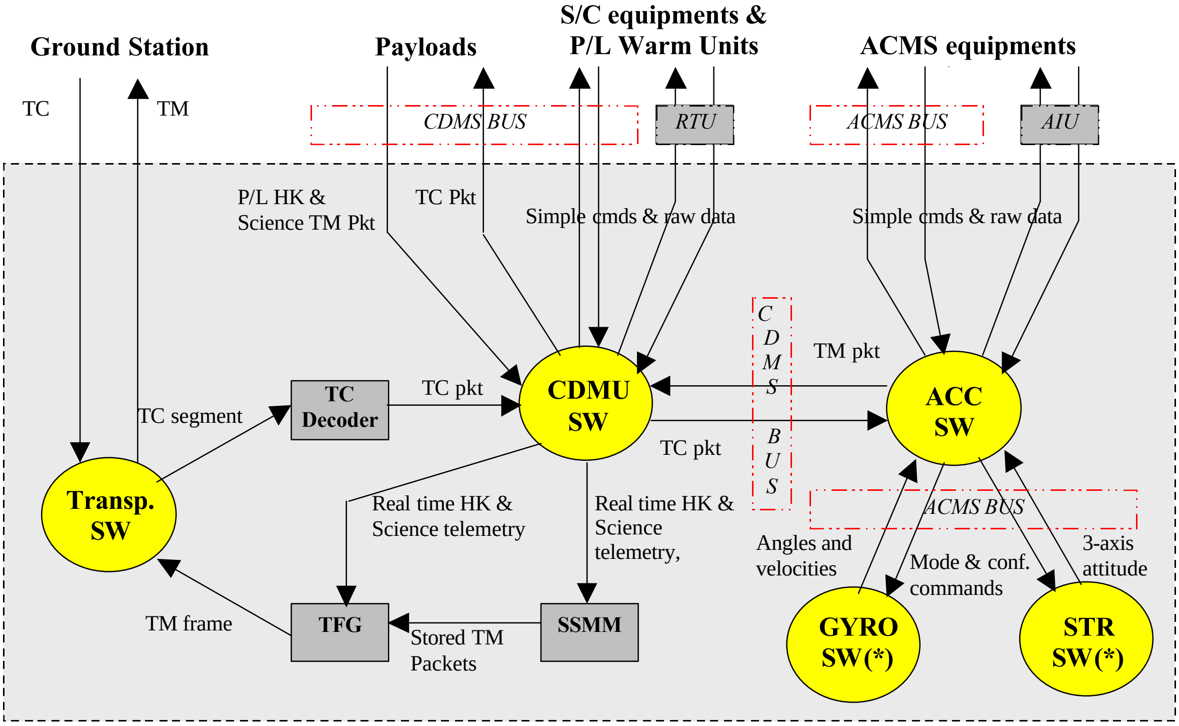


Figure 7.6.5-2 SW Interfaces

7.6.6 Ground software

7.6.6.1 Software Development Environment

The software development environment (SDE) shall allow building up all necessary on-board software by means of standard and reliable SW tools.
The SDE shall include a specific GUI that will allow a full operational management during the design, development and testing phases.
A set of utilities shall be developed in order to perform automatically a certain number of repetitive activities.
The SDE shall be duplicated in each development environment site.
The item list is TBD.

7.6.6.2 Software Validation Facility

TBW

7.7 EMC/ESD

7.7.1 General

This chapter summarise the analysis to be done at SVM level in the EMC/ESD area.

7.7.2 EMC/ESD Specific Aspects

Structural Composition for RF Bonding
One of the important aspects to be implemented into the design of the structure and the equipment attachment points is to maintain a low inductance throughout. To assure this, a verification by RoD and/or by test must be made: contact interfaces shall be made with a low length to width ratio and high conductivity across the junction. Care in assembly of joints is required to ensure conductivity is not compromised and measurement after each piece is assembled is necessary to control the build integrity.
The bonding levels specified in the EMC Design and Requirements Document (AD-12, AD-41), and reflected in the relevant equipment and subsystem specifications, must be in line with the above approach.

Grounding, Isolation and Interfaces
Two point must be verified by analysis and/or by test to demonstrate (AD-12, AD-41):

- isolation of the ground connections at each unit from the primary power feed, to prevent loop currents forming through the power returns and the Spacecraft structure.
- good bonding connections between all RF involved parts (structure, equipment chassis, secondary power connection to chassis), to provide the same voltage potential at all equipment connection points.

Both of these are in place in the Herschel-Planck design.
Another reason for insisting on the good bond connections is the reduction of common mode noise.
All interfaces need to be evaluated by the equipment manufacturers to determine their level of common mode rejection.
Any potential problems will be highlighted and solutions sought.

Coupling Analysis (AD-41)
Using data from the Electrical Design Specification which describes the source and receiver characteristics for the different interfaces types, the analysis must be done.
Firstly, the interfaces will be put into EMC classes (by inspection of their characteristics, power level, frequency content, rise time etc.). This is the basis for the grouping of signal types so that the separation analysis can be performed.
The principle used for the coupling is based on algorithms for a combination of capacitive and inductive coupling between two wires. The model consists of a “culprit” wire with a driving voltage noise level, source and receiver impedances, coupling to a “victim” wire having also source and receiver impedances.
The outcome of the analysis will provide the data for the separation distances, related to parallel lengths of cabling.

Plasma Charging/ESD (AD-12)
The protection against equipment damage or malfunction due to electrostatic discharge will be approached from two sides. Firstly, a verification of the design to highlight the charging mechanism itself and secondly equipment design hardening against possible discharge events will be encouraged through the specification of a test.

7.8 PROTECTION AGAINST RADIATION DAMAGE

Among the various reasons that may induce failures of electronic circuits the radiation damage and the voltage spikes are considered of particular interest because of the induced effects. Indeed these phenomena do not necessarily result in the definitive loss of components but may result in the emission of spurious signals (transients) or bit flips. Due to the high solar activity that is expected in the time period of the mission and the cosmic ray effects on the satellites orbit, the potential damage and related effects due to radiation become of particular significance for the Spacecraft.

For the above reason a suitable policy in the selection of parts will be established by the program to minimise risks due to Single Event Effects (SEE) and Total Radiation Dose damages (AD-44). Protection against Total Dose will be also verified through System and Unit level Sectoring Analysis to assess the shielding effectiveness toward the components (TBC).

7.8.1 Non-Ionising Radiation Effects (AD-44)

The activities summarised in the previous chapters, including SEE sensitivity analysis, is mainly focused on the degradation and damage effects due to ionising mechanisms. This is due to the fact that analogue and digital components are more susceptible to ionising dose damage. However optical components such as opto-couplers are usually sufficiently hardened to ionising effects while suffering considerable degradation because of the non-ionising radiation effects. These effects are dominated by protons from both solar and trapped sources.
The Satellites SVM units using opto-couplers must be analysed to assess their functionality in presence of component degradation due to protons.
Orbit and mission environment predictions is used, in combination with unit and system geometrical sectoring models, to quantify the expected component degradation in orbit.
For each unit the opto-couplers that are mounted on the worst position must be analysed and their degradation must be predicted.

7.9 ALIGNMENT AND ALIGNMENT STABILITY

7.9.1 Requirements

The alignment and Stability Requirements are defined in AD-43. They are here recalled.
For each SVM, an alignment plan and budgets shall be established and maintained.
Optical references shall be used for alignment of the focal plane instruments, telescopes and critical components.
The optical references shall be accessible during module and system AIT operations.
The alignment stability of the spacecraft shall be commensurate with all spacecraft performance requirements (pointing, optical) and 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 stability analysis shall be budgeted according to contributions as specified. Each potential cause of misalignment shall be compliant with its allocation.
The thruster alignment shall be better than 0.5 degree axis perpendicular to the thrust direction.

Herschel equipment alignment shall be better than:

Item	Reference	Alignment (°)		
		X	Y	Z
STR	PLM I/F	-	0.25	0.25
Gyroscope	STR reference frame	0.5	0.5	0.5
RW	STR reference frame	0.5	0.5	0.5

Table -1 Herschel alignment table

Planck equipment alignment shall be better than:

Item	Reference	Alignment		
		X	Y	Z
STM	PLM I/F	-	0.25 °	0.25 °
		absolute	Relative (1)	
P.Tanks	Launcher I/F	Dia.4 mm	Dia.2 mm	

Table -2 Planck alignment table

The thrusters alignment stability shall be better than 0.05 degree axis perpendicular to the thrust direction.

Herschel equipment stability shall be better than:

Item	Stability (°)		
	X	Y	Z
STR	10 arcsec	0.8 arcsec	0.8 arcsec
Gyroscope	0.02	0.02	0.02
RW	0.02	0.02	0.02

Table -3 Herschel stability table

Planck equipment stability shall be better than:

Item	Stability		
	X	Y	Z
STM	NA	TBD	TBD
P.Tanks	Dia.1 mm		

Table -4 Planck stability table

The above requirements shall be confirmed.

Some clarifications are needed about the methodology used for their derivation and their consistency with respect to those given to AOCS and included in paragraph 8.4.
In addition, clarifications are also needed about haw the several causes of misalignment shall be taken into account for both Alignment and for Stability, considering that some errors can be reduced throughout on-orbit calibration and only a residual error will be part of the budget.

8. RESOURCE BUDGETS

See RD11 (SVM Budget Report)

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. In the following paragraphs, the common design solutions are presented first, and then the main design differences are explained.

9.1.2 Commonality Requirements

Herschel and Planck Primary structures has been designed to preserve the maximum of commonality between them, that means that all parts of Herschel and Planck Primary structures shall be exactly of the same design and shall comply conjointly with Herschel and Planck requirements.

As an example, the Central Tube shall comply with the accommodation of:
2 or 3 PTSS, depending of Herschel or Planck
the PPLM or HPLM Interfaces, depending of Herschel or Planck

As an other example, the inserts or brackets at the bottom of the Central tube for the attachment of the Solar Array (central part) for Planck and for the attachment of the Lower closing support for Herschel are compatible with the accommodation of both parts.

Following the same logic, the Central Tube for Herschel and Planck shall be sized to cope with the most severe loading case.

As a last example, PTSS for Herschel and Planck shall be identical in form fit and function, as PTSS shall support the same type of P.Tank for both Satellites.

However, some deviations in the communality requirements are required, detailed paragraphs will define these items for both Herschel and Planck.

General Exploded View o SVM structure is reported in Figure 9.1.2-1 for Herschel and in Figure 9.1.2-2 for Planck.

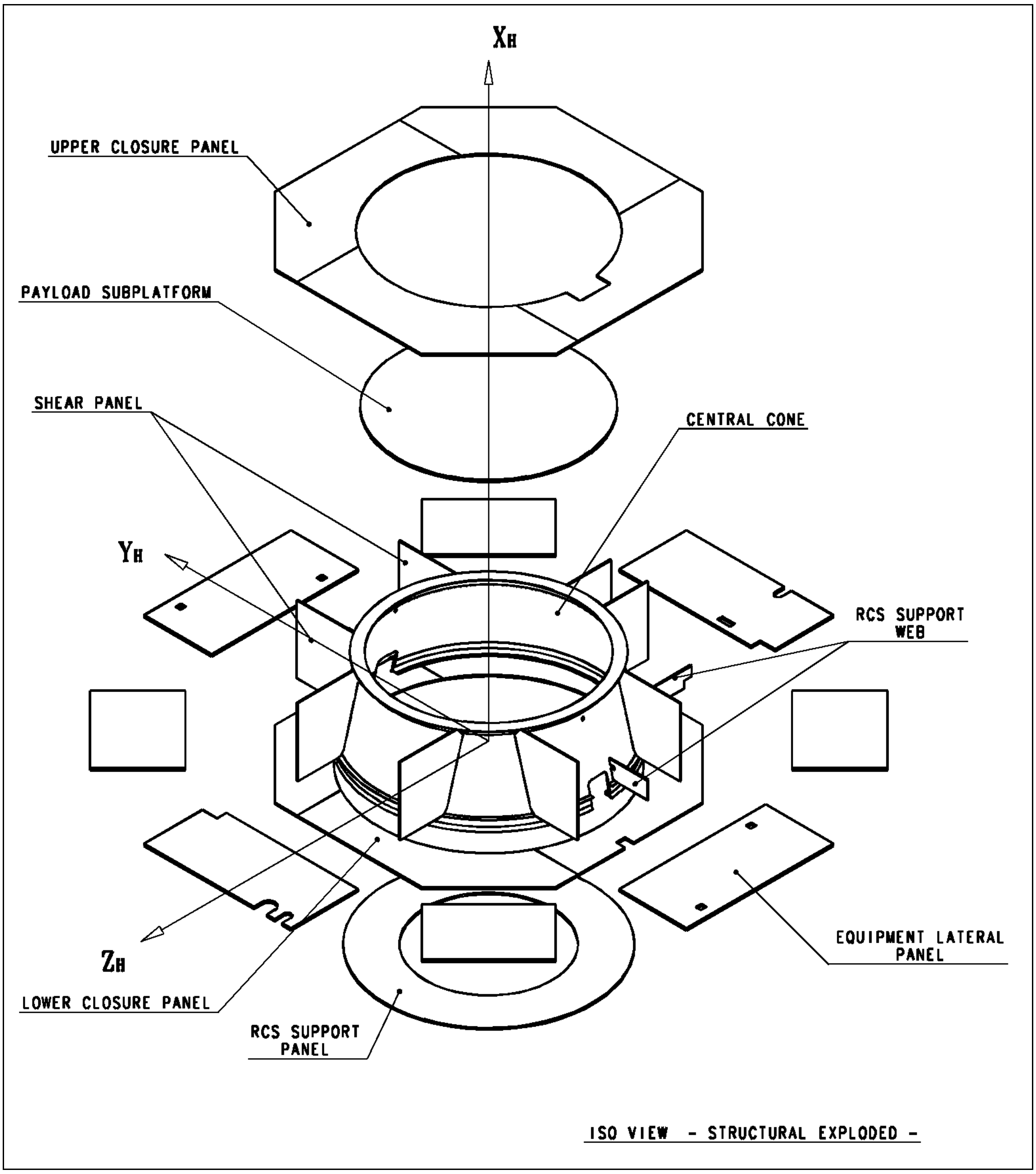

XH
UPPER CLOSURE PANEL
PAYLOAD SUBPLATFORM
SHEAR PANEL
CENTRAL CONE
YH
RCS SUPPORT WEB
ZH
LOWER CLOSURE PANEL
RCS SUPPORT PANEL
EQUIPMENT LATERAL PANEL
ISO VIEW - STRUCTURAL EXPLODED -

Figure 9.1.2-1 General Exploded View of Herschel SVM

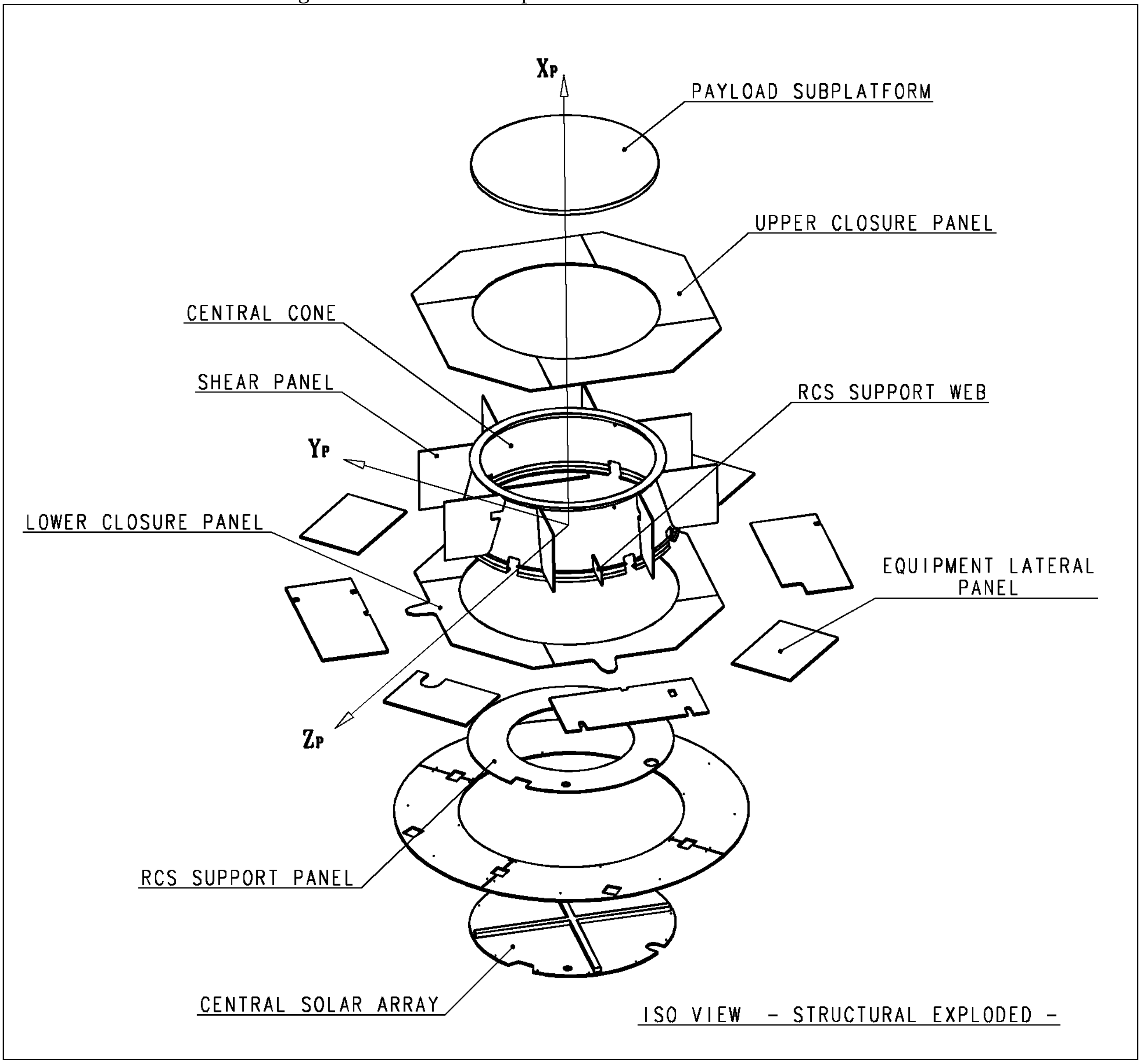


Figure 9.1.2-2 General Exploded View of Planck SVM

Material Summary:

The material summaries of the SVM structure is reported in Table 9.1.4-1 and Table 9.1.4-2 while a brief summary of characteristics, references and allowable for the used materials are reported in Table 9.1.4-3. These characteristics have also been used in the FEM, described in H-P-TN-AI-0002 SVM Structural Analysis.

ITEM	**BASIC MATERIAL**		**THICKNESS**		
	CORE	**SKIN**	Notes	H/C	SKIN
UPPER PLATFORM	3/16-5056-0.001	T300/5208	-	20	0.375
LOWER PLATFORM	3/16-5056-0.001	T300/5208	-	20	0.375
LATERAL PANELS	3/16-5056-0.0007	Al 7075 T6	-	35	0.3
HPLM SUBPLATFORM	3/16-5056-0.001	T300/5208	-	20	0.75
SHEAR PANELS	3/16-5056-0.0007	T300/5208	-	15	0.75
UPPER I/F BRACKETS	Al 7075 PLATE	-	See figure 9.1.4-6	-	-
LOWER RING	Al 7075-T7352 Forged	-	See figure 9.1.4-7	-	-
CFRP CONE	3/16-5056-0.001	T300/5208	See figure 9.1.4-1 to 4	15	0.375

Table 9.1.2-1 HERSCEL SVM Structure Material Summary

ITEM	**BASIC MATERIAL**		**THICKNESS**		
	CORE	**SKIN**	Notes	H/C	SKIN
UPPER PLATFORM	3/16-5056-0.001	T300/5208	-	20	0.375
LOWER PLATFORM	3/16-5056-0.001	T300/5208	-	20	0.375
LATERAL PANELS	3/16-5056-0.0007	Al 7075 T81	-	35	0.3
SCC PANELS	3/16-5056-0.0007	Al 7075 T81	See figure 9.1.4-12 to 14	30	1
PPLM SUBPLATFORM	3/16-.007-5056P	M18/G969	-	60	0.75
SHEAR PANELS	3/16-5056-0.0007	T300/5208	-	15	0.75
UPPER I/F BRACKETS	Al 7075 PLATE	-	See figure 9.1.4-6	-	-
LOWER RING	Al 7075-T7352 Forged	-	See figure 9.1.4-7	-	-
CFRP CONE	3/16-5056-0.001	T300/5208	See figure 9.1.4-1 to 4	15	0.375

Table 9.1.2-2 PLANCK SVM Structure Material Summary

BASIC MATERIAL	**Used**	**Ref.**	E_1 [MPa]	E_2 [MPa]	**n**	**r** [Kg/mm3]	F_{tu} [MPa]	F_{ty} [MPa]	F_{su} [MPa]
Al 7075 T7351 PLATE	Brackets	MIL- HBK -5	71000	-	0.33	$2.8E^{-6}$	448	358	268
Al 7075-T7352 Forged	Lower ring	MIL- HBK -5	70300	-	0.33	$2.8E^{-6}$	441	365	262.
Al 7075 T6 Clad	Lateral panels faces	MIL- HBK -5	71000	-	0.33	$2.8E^{-6}$	489	427	289
Ti 6AL 4V plate	Embedded brackets	MIL- HBK -5	110300	-	0.31	$4.4E^{-6}$	896	827	544
T300/5208 unid.	Octagonal box faces	Bulletin data	181000	10300	0.28	$1.6E^{-6}$	1500	-	68
M18/G969	PPLM Subplatform		257000	15280	0.16	$1.6E^{-6}$	800	-	51
H/C 3/16-5056-0.001	panels H/C	Hexcel TSB 120	-	-	-	$4.966E^{-8}$	-	-	-
H/C 3/16-5056-0.0007	panels H/C	Hexcel TSB 120	-	-	-	$6.2E^{-9}$	-	-	-

Table 9.1.2-3 Material Characteristics and allowable

Analyses Summary:

The main Structural performances of the SVM Structure are reported in H-P-TN-AI-0002 SVM Structural Analysis and summarized in Table 9.1.4-4 and Table 9.1.4-5 and 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, which shall be considered as an integral part of this chapter.

REQUIREMENTS	SPECIFIED VALUES	ACHIEVED VALUES
FREQUENCY		
SVM Global Modes		
Axial (X)	> 58 Hz	63.2 Hz
Lateral	> 23 Hz	30.29 Hz
SVM Box Modes		
Axial (X)	> 51 Hz	57.04 Hz
Lateral	> 48 Hz	50.85 Hz
Propellant Tanks		
Axial (X)	> 145 Hz	188.9 Hz
Lateral	> 80 Hz	84.5 Hz
Lateral Panels	> 50 Hz	64.48 Hz **(1)**
STIFFNESS		
Global Stiffness		
K Longitudinal	$3.5\ 10^8 \div 4.55\ 10^8$ N/m	$\underline{7.19}\ 10^8$ N/m **(2)**
K Axial	$8.2\ 10^7 \div 10.6610^7$ N/m	$\underline{1.21}\ 10^8$ N/m **(2)**
Local: HPLM I/F		
K circumf	$5.7\ 10^7$ N/m	$6.8\ 10^7$ N/m
K radial	$2.5\ 10^7$ N/m	$4.0\ 10^7$ N/m
K longitudinal (X)	$5.0\ 10^7$ N/m	$8.5\ 10^7$ N/m
$K_{\theta\theta}$	$4.7\ 10^4$ Nm/rd	$5.2\ 10^4$ Nm/rd
$K_{\theta r}$	$1.0\ 10^4$ Nm/rd	$1.2\ 10^4$ Nm/rd
$K_{\theta X}$	$1.2\ 10^5$ Nm/rd	$4.3\ 10^5$ Nm/rd

Comments
(1) Minimum achieved value.
(2) The higher than requested global stiffness is due to the Central tube, whose design includes several longitudinal and circumferential reinforcements, necessary to achieve either the local stiffness and strength requirements (PLM interfaces, Fuel Tank interfaces, etc.).The new PLM interface loads and PLM accelerations (used for stress analysis) were derived taking into account the above SVM increased stiffness.

Table 9.1.2-4 HERSCHEL SVM Structure Performance Summary

ITEM	LOAD CASE	FAILURE MODE	MIN. MOS
Lateral panels	SVM panels resonance (case 4H)	Wrinkling	0.13
Platforms/closure panels/shear webs	All cases	All modes	> 1
Panels connection	Envelope	Insert analysis	0.17
Lower platform/cone connection	Envelope	Bracket analysis	0.38
Central cone	All cases	All modes	> 1
Payload struts/cone connection	Local Resonance of HPLM (Case 1H)	Bonding analysis	0.56
Tank support	PTSS local resonance (Case 3H)	Buckling	0.43
LVA	Envelope	Combined stress	0.2
LVA/cone connection	Envelope	Bonding	0.35

Table 9.1.2-5 HERSCHEL SVM Summary of MoS

REQUIREMENTS	SPECIFIED VALUES	ACHIEVED VALUES
FREQUENCY		
SVM Global Modes		
Axial (X)	> 60 Hz	69.35 Hz
Lateral	> 35 Hz	48.48 Hz
SVM Box Modes		
Axial (X)	> 60 Hz	70.3 Hz
Lateral	> 50 Hz	48.41 Hz **(1)**
Propellant Tanks		
Axial (X)	> 145 Hz	220.4 Hz
Lateral	> 80 Hz	98.6 Hz
Lateral Panels	> 70 Hz	73.9 Hz **(2)**
Payload Sub-platform	> 100 Hz	84.7 Hz **(4)**
STIFFNESS		
Global Stiffness		
K Longitudinal	$3.5\ 10^8 \div 4.55\ 10^8$ N/m	$\underline{7.19}\ 10^8$ N/m **(3)**
K Axial	$8.2\ 10^7 \div 10.66 10^7$ N/m	$\underline{1.21}\ 10^8$ N/m **(3)**
Local: HPLM I/F		
K circumf	$5.7\ 10^7$	$7.1\ 10^7$ N/m
K radial	$2.5\ 10^7$	$4.71\ 10^7$ N/m
K longitudinal (X)	$5.0\ 10^7$	$6.7\ 10^7$ N/m
$K_{\theta\theta}$	$4.7\ 10^4$	$6.4\ 10^4$ Nm/rd
$K_{\theta r}$	$1.0\ 10^4$	$6.2\ 10^4$ Nm/rd
$K_{\theta X}$	$1.2\ 10^5$	$1.46\ 10^5$ Nm/rd

Comments

(1) The achieved value should, anyway, avoid potential modal coupling with Payload.

(2) Minimum achieved value.

(3) The higher than requested global stiffness is due to the Central tube, whose design includes several longitudinal and circumferential reinforcements, necessary to achieve either the local stiffness and strength requirements (PLM interfaces, Fuel Tank interfaces, etc.). The new PLM interface loads and PLM accelerations (used for stress analysis) were derived taking into account the above SVM increased stiffness.

(4) This value, which is achieved utilizing a CFRP having higher elastic modulus (as M18), is deemed sufficient to guarantee dynamic de-coupling w.r.t. Planck global modes.

Table 9.1.2-6 PLANCK SVM Structure Performance Summary

ITEM	LOAD CASE	FAILURE MODE	MIN. MOS
Lateral panels	SVM panels resonance (case 6P)	Wrinkling	0.2
Platforms/closure panels/shear webs	All cases	All modes	> 1
Panels connection	Envelope	Insert analysis	0.14
Lower platform/cone connection	Envelope	Bracket analysis	0.54
Central cone	All cases	All modes	0.86
Payload struts/cone connection	Local Resonance of PPLM (Case 1P)	Bonding analysis	> 1
Tank support	PTSS local resonance (Case 2P)	Buckling	0.37
LVA	Envelope	Combined stress	0.71
LVA/cone connection	Envelope	Bonding	0.42

Table 9.1.2-7 PLANCK SVM Summary of M.o.S.

Mass budget summary:

The mass budgets of the SVM Structures are reported in Table 9.1.4-8 and Table 9.1.4-9.
The structural items present different evolution from each other, regarding the mass properties, the typical mass trend w.r.t the proposal values are reported hereafter.
The lateral and closure panels present a mass decrease, this evolution is due to a more mature evaluation of the design that allow to reduce the margin related to uncertainties.
The SCC panels present a mass increase. This is due in particular to the thermal required faces of 1 mm thick and to the great number of through inserts for the Sorption Cooler Compressors fixation. A trade off is in progress to evaluate the possible changes in these two requirements and the consequent mass saving.
The central cone mass is increasing. This result is due in particular to the new requirement to have 12 I/F points instead of 6 and 8 (respectively for Planck and Herschel). Deeper analyses are needed to optimize the local reinforcements and define the real mass of the considered item. A lower increase than that presented could be foreseen.
The actual level of design of secondary structures does not allow a good investigation for the mass trend. A preliminary evaluation, anyway, led to foreseen an increase in the overall mass for both satellites.

PLANCK MASS BUDGET SUMMARY						
	Nominal			15% contingency		
ITEM	ACTUAL	PROPOSED	DELTA	ACTUAL	PROPOSED	DELTA
L.V.A ring	32.8	31.1	1.7	37.7	35.8	2.0
Conical shell	28.1	18.9	9.2	32.3	21.7	10.5
I/F brackets	8.0	8.0	0.0	9.2	9.2	0.0
CENTRAL CONE	**68.9**	**58.0**	**10.9**	**79.2**	**66.7**	**12.5**
equipment panels	18.3	19.0	-0.7	21.0	21.9	-0.8
SCC panels	36.9	23.8	13.1	42.4	27.4	15.1
upper closure panel	7.9	13.6	-5.7	9.0	15.6	-6.6
lower closure panel	9.0	9.4	-0.4	10.4	10.8	-0.4
shear panels	17.7	13.4	4.3	20.3	15.4	4.9
OCTAGONAL BOX	**89.8**	**79.2**	**10.6**	**103.2**	**91.1**	**12.1**
TANK SUPPORT STRUCTURE	**5.4**	**5.2**	**0.2**	**6.2**	**6.0**	**0.2**
P/L SUBPLATFORM	**16.5**	**16.5**	**0.0**	**19.0**	**19.0**	**0.0**
TOTAL MASS	**180.5**	**158.9**	**21.6**	**207.6**	**182.7**	**24.9**
SECONDARY STRUCTURES	**12.6**	**12.6**	**0.0**	**14.5**	**14.5**	**0.0**
TOTAL MASS	**193.1**	**171.5**	**21.6**	**222.1**	**197.2**	**24.9**

Table 9.1.2-8 Planck SVM Structure Mass Budget

HERSCHEL MASS BUDGET SUMMARY						
	Nominal			15% contingency		
ITEM	ACTUAL	PROPOSED	DELTA	ACTUAL	PROPOSED	DELTA
L.V.A ring	32.8	31.1	1.7	37.7	35.8	2.0
Conical shell	28.1	18.9	9.2	32.3	21.7	10.5
I/F brackets	8.0	8.0	0.0	9.2	9.2	0.0
CENTRAL CONE	**68.9**	**58.0**	**10.9**	**79.2**	**66.7**	**12.5**
equipment panels	29.3	30.4	-1.1	33.7	35.0	-1.3
upper closure panel	9.5	13.6	-4.1	11.0	15.6	-4.7
lower closure panel	8.5	9.4	-0.9	9.7	10.8	-1.1
shear panels	18.5	13.4	5.1	21.3	15.4	5.9
OCTAGONAL BOX	**65.8**	**66.8**	**-1.0**	**75.7**	**76.8**	**-1.2**
TANK SUPPORT STRUCTURE	**3.6**	**3.5**	**0.1**	**4.1**	**4.0**	**0.1**
P/L SUBPLATFORM	**13.3**	**13.3**	**0.0**	**15.3**	**15.3**	**0.0**
TOTAL MASS	**151.6**	**141.6**	**10.0**	**174.3**	**162.8**	**11.5**
SECONDARY STRUCTURES	**9.7**	**9.7**	**0.0**	**11.2**	**11.2**	**0.0**
TOTAL MASS	**161.3**	**151.3**	**10.0**	**185.4**	**174.0**	**11.5**

Table 9.1.2-9 HERSCEL SVM Structure Mass Budget

9.1.2.1 Primary Structure

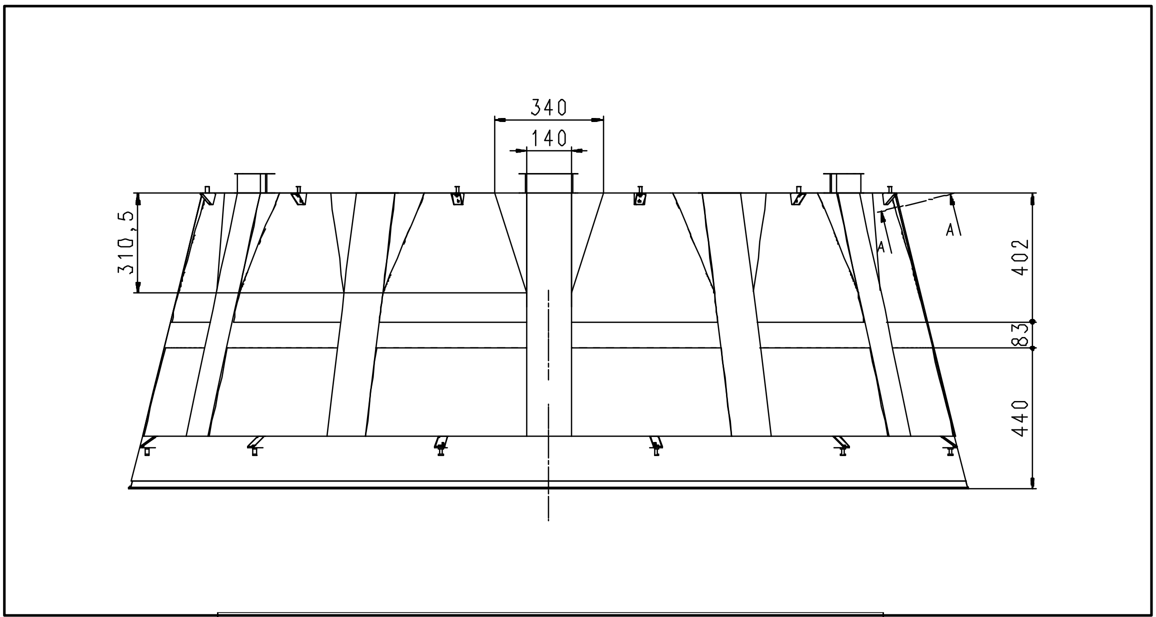
The **Primary Structure** is defined as that part of the structure, which carries the main launch loads and which determines the fundamental frequencies of the satellite.
It is composed of:

- Central tube
- Upper interface
- Lower ring
- Octagonal box
- Payload sub-platforms
- P.Tanks Support Structures (PTSS)
- SCC panels (for Planck only)

Central tube

It is a conical structure providing the interfaces to the launcher and to the Octagonal Box. It is connected to the Launcher Interface ring on the bottom and ensures the main load path to carry SVM and PLM loads to the Launcher.
The conical tube is a composite concept, manufactured in sandwich form with CFRP face-sheets. Longitudinal and circumferential reinforcements are placed in correspondence with the I/F attachment points. The reinforcements are cold bonded on the basic structure.
A built-in interface ring in Aluminium constitutes the interface with the launcher adapter while the interface with the PLM and the PLD subplatform is performed by dedicated embedded inserts in the upper edge of the cone (as will be described in the upper interfaces paragraph).
Central tube concept and main sections of reinforcements and interfaces are shown in figure from 9.1.4-1 to 9.1.4-5.

The material selected for the CFRP skins (for all the items) is T300. This, generally, meets the stiffness and strength requirements. Of course, the final choice will be done, and agreed, by the SVM Structure Subcontractor, also in compliance with the selected manufacturing processes.



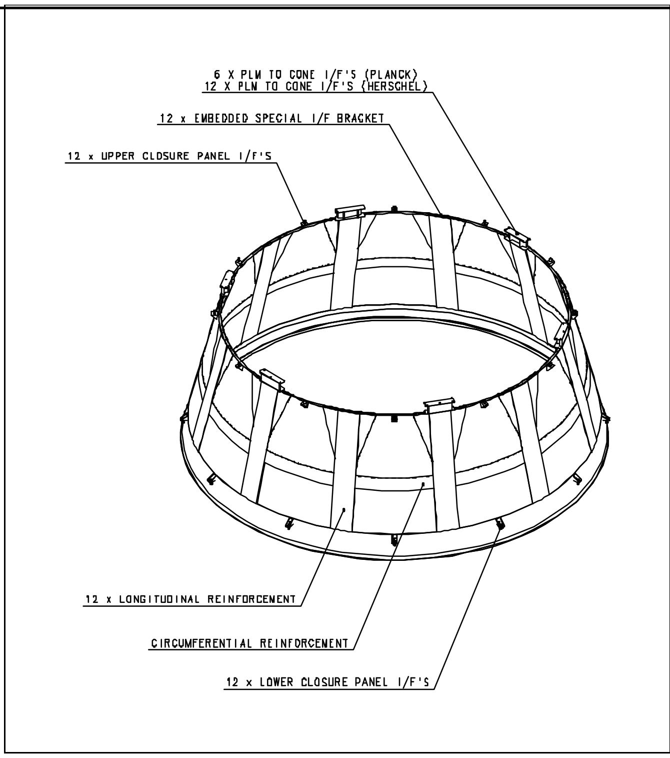


Figure 9.1.2-1 Central Tube overall view (Planck)

Figure 9.1.2-2 Central Tube lateral view (Planck)

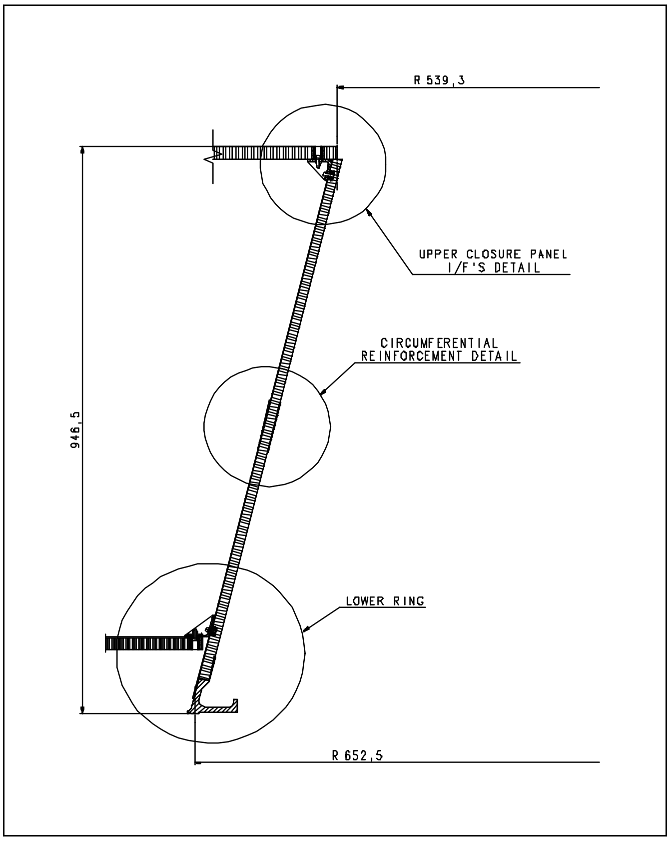


Figure 9.1.2-3 Cone section along closure panels reinforcements

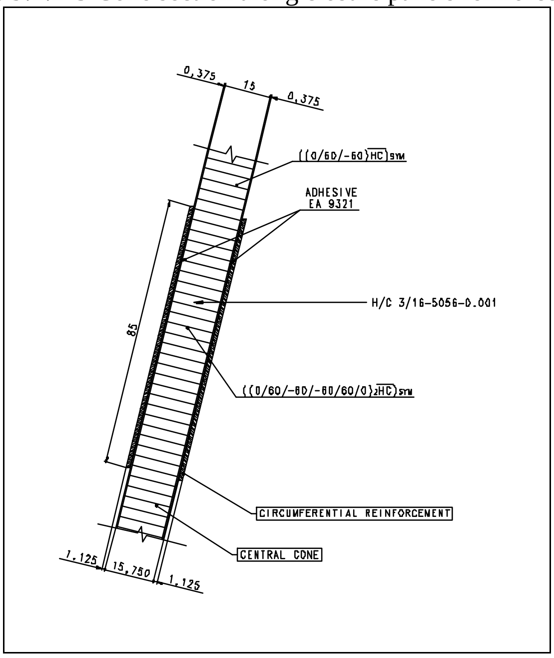


Figure 9.1.2-4 Central cone circumferential reinforcement

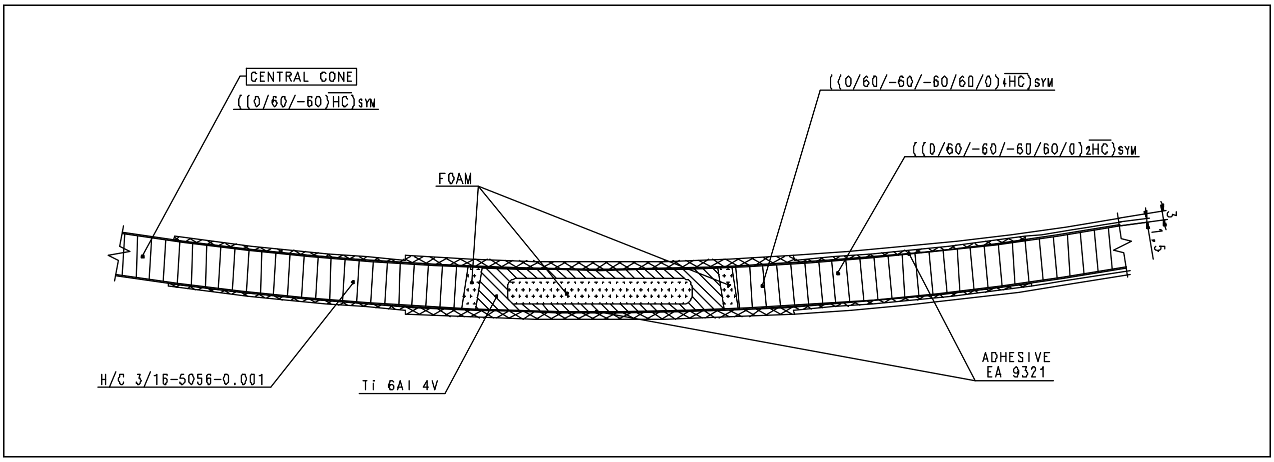


Figure 9.1.2-5 longitudinal reinforcements- circumferential section

The Central Tube is also equipped with various inserts and brackets for:

- Attachment of 2 or 3 P.Tanks via the Tanks Support Structures (PTSS)(see Figure 9.1.4-11)
- Attachment of 4 He Tanks via the He Tanks Support Structures (S/ST's) for Planck
- Accommodation of some parts of the RCS units (components, piping)
- Attachment of the Solar Array (central part) for Planck, or the attachment of the Lower closing support (as support for the Thermal lower closing) for Herschel.
- the umbilical connectors (2) with Launcher

The Central Tube will be identical for Herschel and Planck, with the following minor deviations:

- the cut-out location for Herschel and Planck pipe routing
- the inserts lay-down for Herschel and Planck (pipes and modules plates)

Upper interfaces

The upper interfaces are all those I/F that are located at the upper level of the Central cone.
In this case, mass considerations led to avoid the presence of a continuous ring, whose interface functions are performed by dedicated brackets, whilst the circumferential stiffness is guaranteed by the Upper closure panel and Payload sub-platform.

Two types of upper interfaces are defined:
Interfaces of the cone with the Payload Module (PLM) and the Payload sub-platform (see figure 9.1.4.6).
Interface of the cone with the upper closure panel (see figure 9.1.4.7)..

The first type of interface is obtained via a series of recurrent embedded special insert, these insert (12 for both Herschel and Planck) will carry the attachment bracket that define the Interface plate for the PLM.
In the present baseline, the PLM Struts interface with the I/F bracket located on the PLD Subplatform, via a lug bracket on the PLD subplatform side and ball joint connections on the strut side.
The attachment brackets are also responsible of the connection between the Payload subplatform and the central tube.
Face Reinforcements are defined in correspondence with the I/F point on the central cone.
The interface with upper closure panel is obtained via dedicated brackets and insert positioned along the cone edge.
For the Herschel satellite only, two of the attachment points are also considered as the I/F points for the struts end bracket of the Sunshield /Sunshade structure.

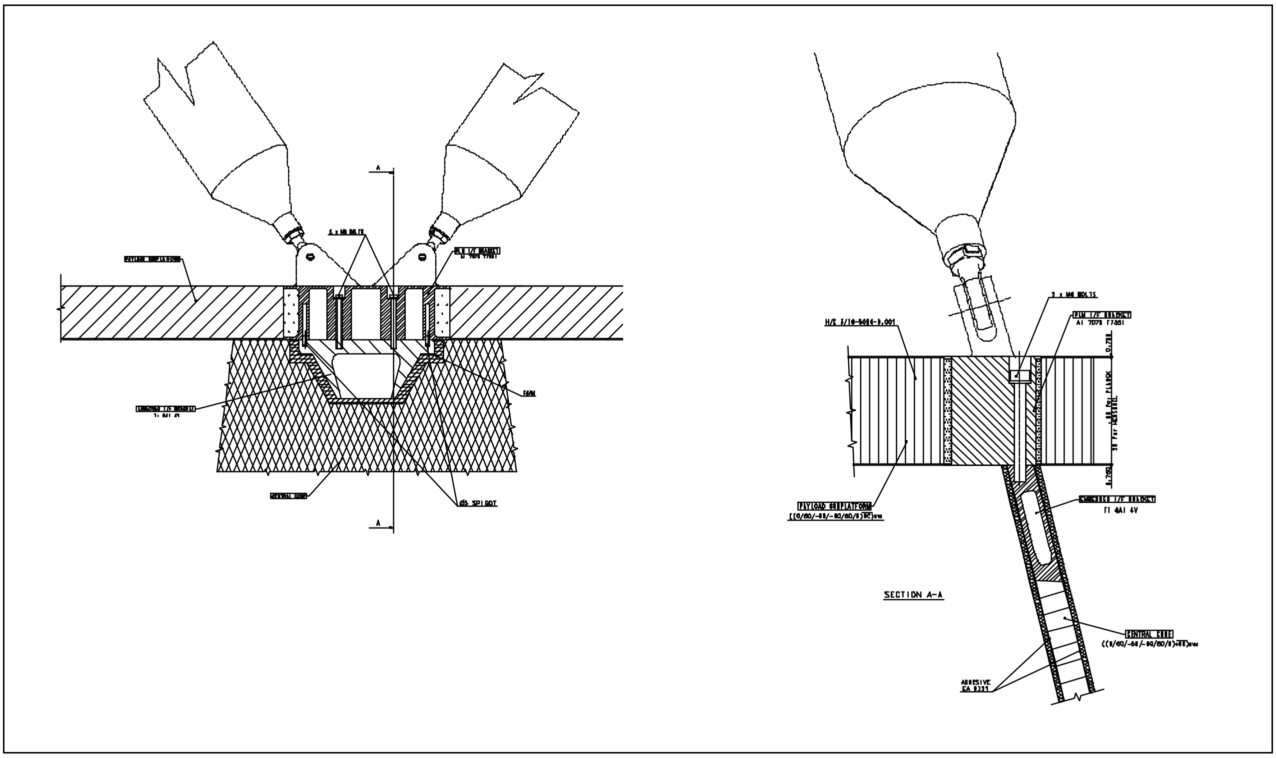


Figure 9.1.2-6 upper cone interfaces with PLM Bracket

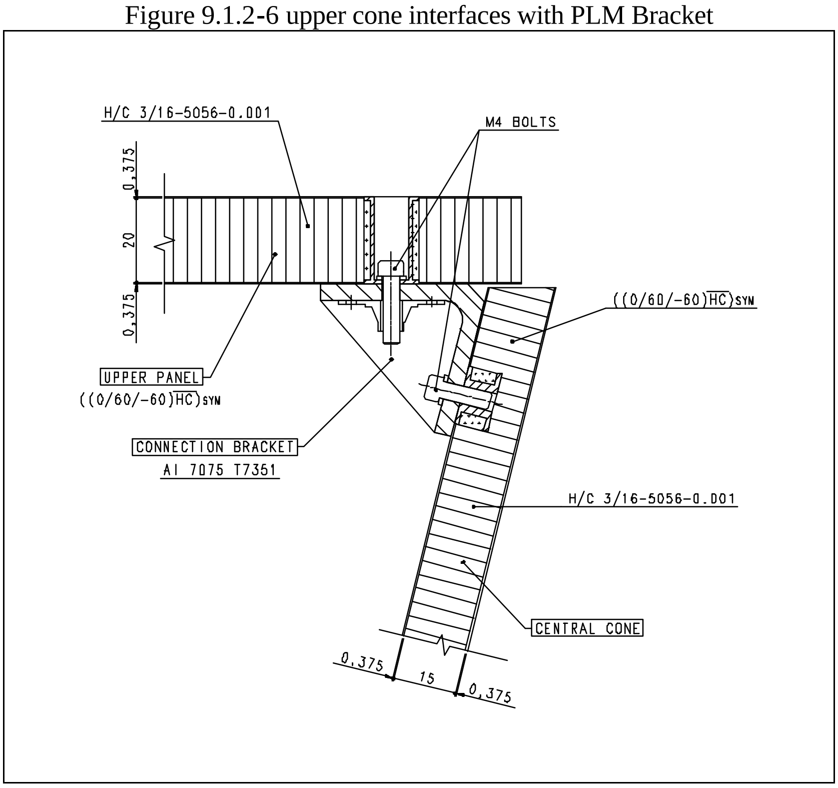


Figure 9.1.2-7 upper cone interfaces with upper closure

Lower Ring

The Lower Ring (see figure 9.1.4-8) provides the interface of the Cone to the launcher.

Also in this case, the solution is conceived to get low mass. In fact, dedicated brackets perform the function of supporting the Lower closure platform and the internal items as internal SA, for Planck, or LCS for Herschel. In addition, the hooping is realized by a separate sheet, bonded to the sandwich Central tube and riveted to the lower ring.
The attachment to the Central tube is made via multipurpose adhesive (structural, shimming and electrical isolation function).
The Aluminum ring will have adequate holes for venting and H/C outgassing.

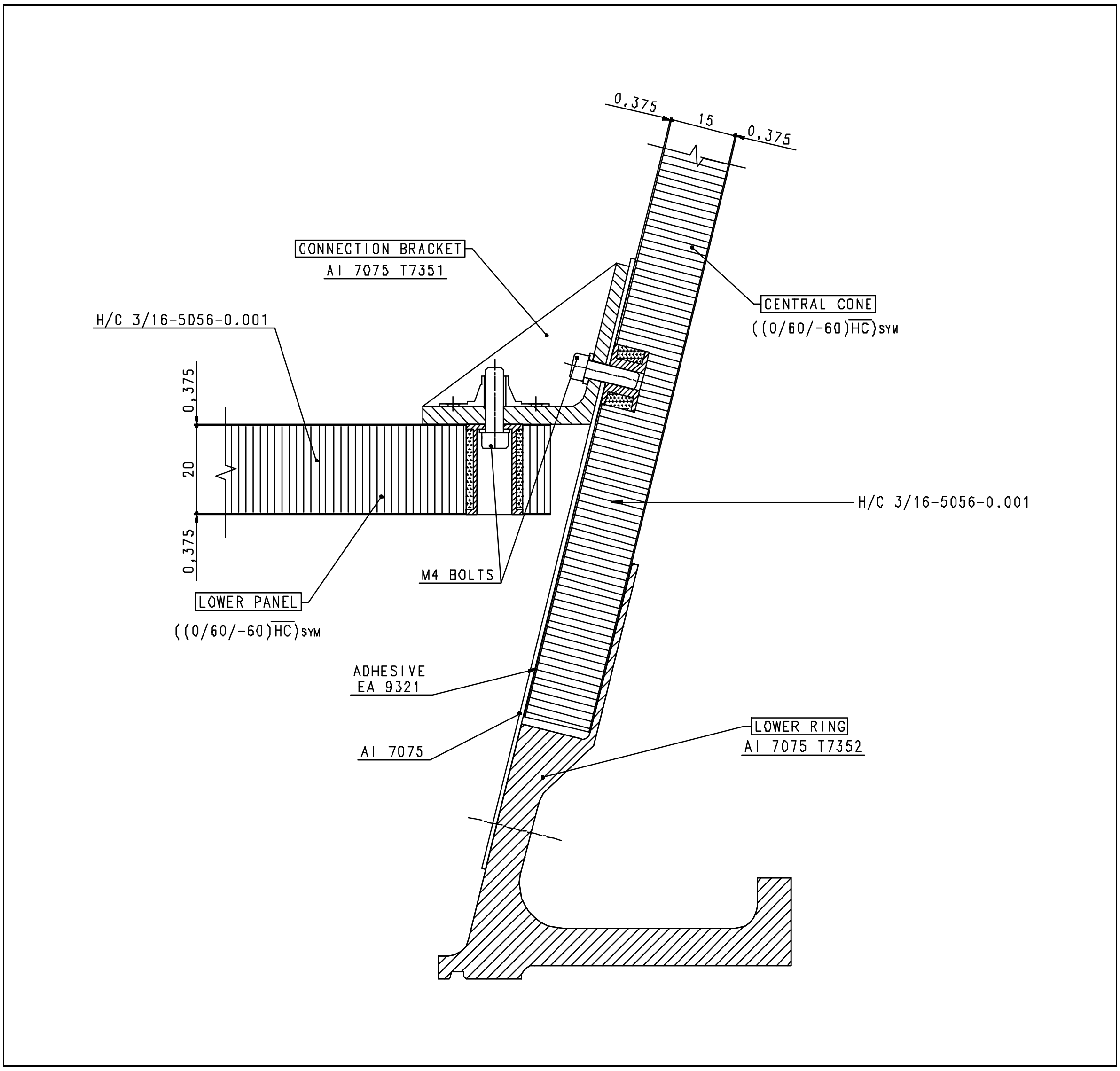


Figure 9.1.2-8 Lower ring

Octagonal box :

The octagonal box is constituted by a set of:

8 lateral panels of 2 different sizes, i.e. long length panels and short length panels, manufactured in sandwich form with Aluminium face-sheets. They accommodate the subsystems units and some of the respective payloads units ("Warm Units") and provide them with large dissipative surfaces.

It is to be noted that long length panels and short length panels provide in fact the same accommodation surface independently of their length.
As a particularity, the SCC panel on Planck satellite is a single reinforced sandwich panel of the same geometric envelope of three of the normal lateral panels. For its particularity and strict requirements it will be described later as a dedicated item.

Some of the lateral panels provide cut-out for:

the accommodation of the RCS for **both Satellites**
the accommodation of the Star Mapper (STM) for **Planck Satellite**

The following minor deviations, between Herschel and Planck are also to be considered (TBC):

the Herschel and Planck panels with different Thrusters cut-out
the inserts lay-down for the accommodation of the Support Subsystem units

The lateral panels, but the 3 SCC on Planck, are all equal and their thickness, necessary to meet the high frequency requirement defined for Planck, is 35mm (H/C) + 0.3 mm skins. The equipment mass evolution will be the main design driver; another important design driver will always be the panels' removability and integration easiness

Upper and Lower closure panels manufactured in sandwich form, with CFRP face-sheets for mass saving reason, and for rigidity. The Upper and Lower closure panels close the octagonal box, and are segmented each in 4 parts for integration easiness.
The Upper and Lower closure panels are free from equipment, but provide support for the harness and pipe routing when necessary.

The Lower panel provides supports for:

the accommodation of the RCS equipment (lines, valves) for both Satellites
2 brackets for the umbilical connectors with Launcher (alternative with respect to the mounting on the Central tube)
the attachment of the Solar Array peripheral part, for Planck Satellite

The Upper panel provides supports for:

the attachment for the cryo lines (from He tanks) for Planck
the I/F point for the SVM Shield for Herschel

For Herschel and Planck, the Upper closure panels will be identical, with the following minor deviation (TBC):

the cut-out location for the FPLM and PPLM harness and pipes routing
the interface location for the Herschel SVM shields supports

The Lower closure panels will be identical, with the following minor deviation (TBC):

the cut-out location for Planck SA harness routing
the cut-out location for Herschel and Planck pipe routing
the inserts lay-out for Herschel and Planck
the integrated extensions for thruster support bracket in Planck

8 Shear corner panels (or shear webs) panels manufactured in sandwich form with CFRP face-sheets for mass saving reason, and for rigidity to strengthen the octagonal box.

All Lateral panels of the octagonal box will be identical, with the following deviation:

the SCC panel for Planck, because of the need of a specific mechanical mounting for thermal isolation
the STM panel for Planck, because of the cut-out for the STM

Additionally, the following minor deviations will also be considered:

the Herschel and Planck panels with different Thrusters cut-out
the inserts lay-down (e.g. Shur-lock inserts) for the accommodation of the Support Subsystem units
Specific configuration of Shear panels behind STR on Herschel.

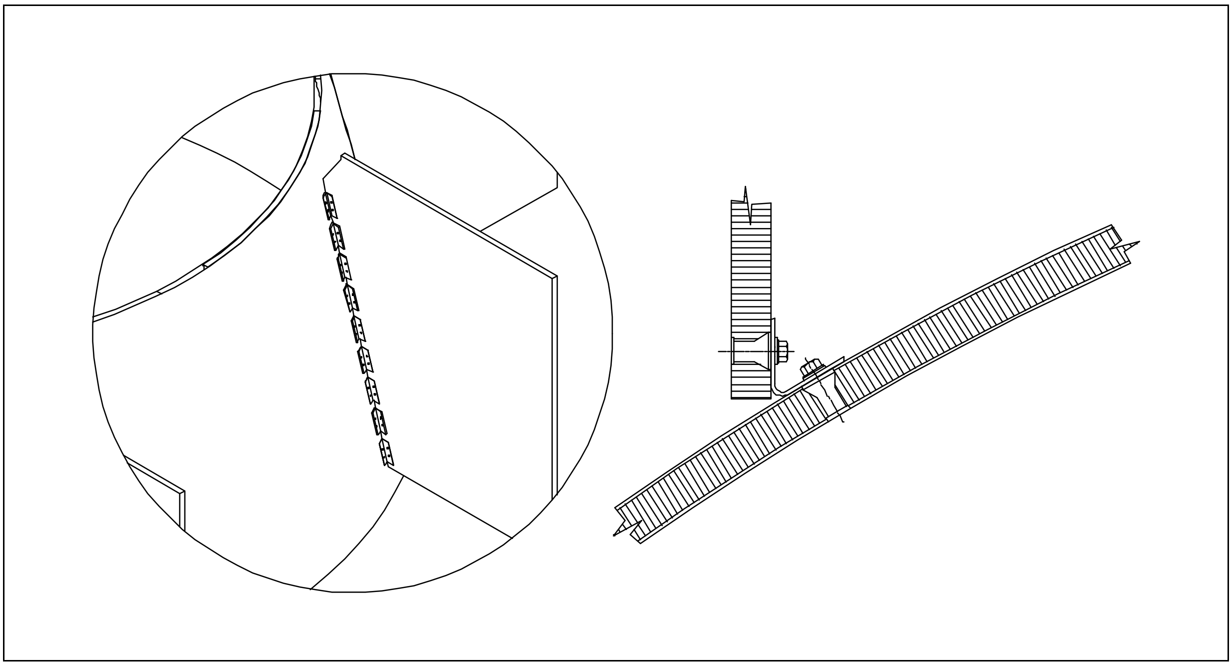


Figure 9.1.2-9 Shear web Vs cone typical I/F

Payloads sub-platforms :

The Payloads sub-platforms are manufactured in sandwich form, with CFRP face-sheets.
For **Herschel and Planck**, the Payload sub-platform is fixed on the top of the Central tube, and is mainly used to rigidify the top of the Central cone when loaded by the Payloads supports truss. The same special insert used to transfer the load from the payload truss to the cone are also used to fix the payload subplatform to the cone. A scheme of the attachment is shown in figure 9.1.4-6 and figure 9.1.4-10.
In addition, and for **Planck** only, the Payloads sub-platform accommodates instruments on its upper and lower face and is then thicker than that mounted on Herschel.

The Payload sub-platforms for Herschel and Planck are basically different because of :
a different thickness (thicker for Planck for rigidity reasons as it supports some PPLM equipment)
different number (6 for Planck and 8 for Herschel) and dimensions (as a result of different thickness) of interface brackets with the Payloads support truss

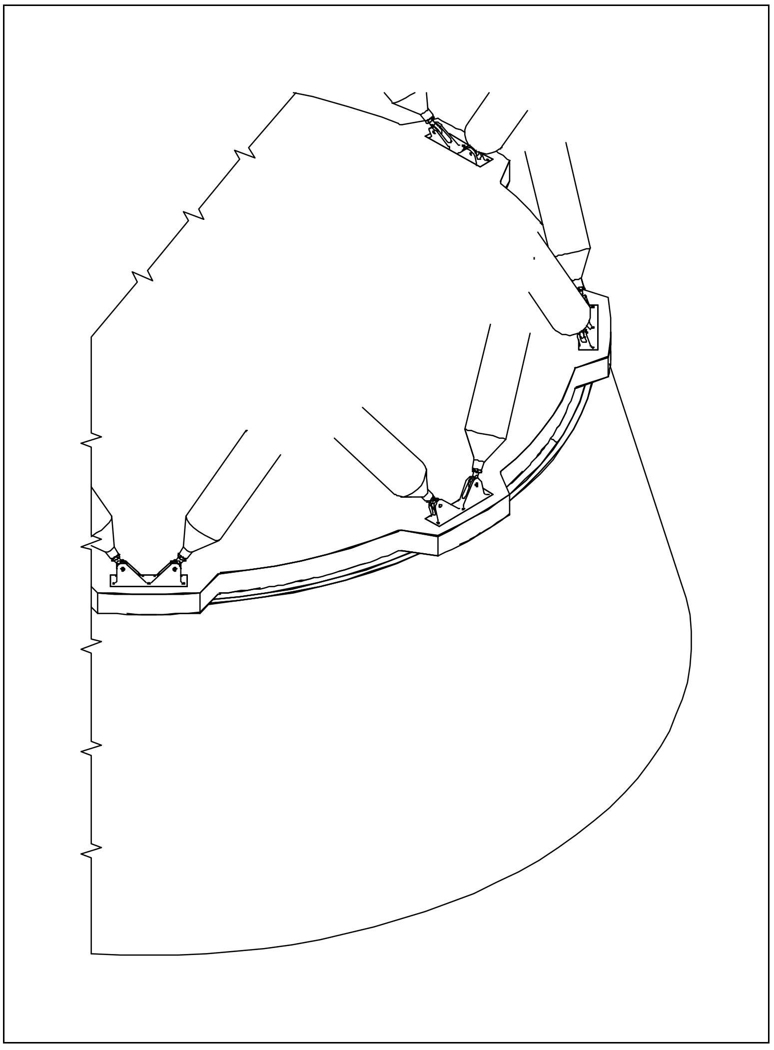


Figure 9.1.2-10 Payload subplatform and PLM I/F concept

P.Tanks Support Structures (PTSS) :

The P.Tanks Support Structures are located inside the Central tube, and are used to connect the P.Tanks to the Central tube. **Herschel** P/ST accommodates 2 PTSS's to support 2 P.Tanks, while 3 PTSS's are required for **Planck** to support 3 P.Tanks.

Each PTSS connect a P.Tank via Ball bearings mounted on 3 of the P.Tanks equatorial trunions, providing the P.Tank with a full isostatic mounting (see figure 9.1.4-11).

The PTSS solution here presented has been derived from other programs (i.e. Integral, Radarsat, etc.)

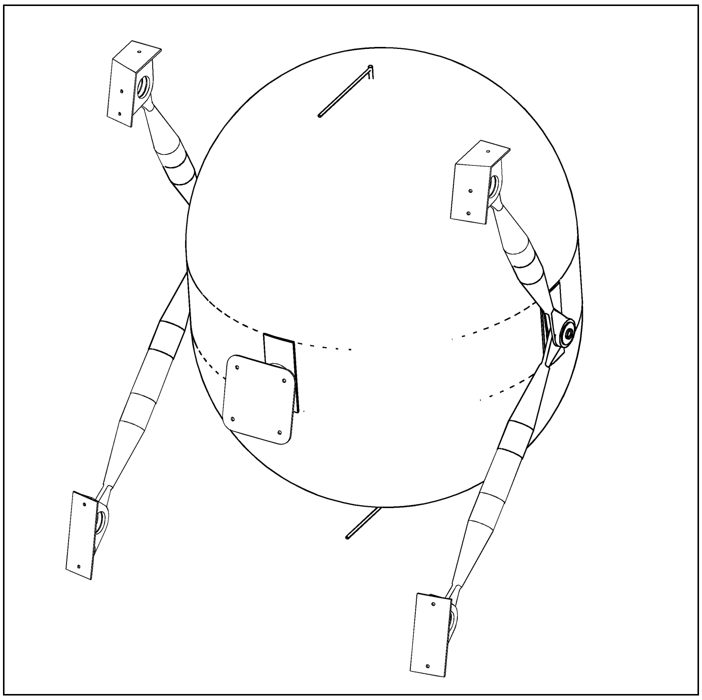


Figure 9.1.2-11 Tank support concept.

SCC Panels:

For Planck, as part of the PPLM units, 2 Sorption Cooler Compressors and 2 associated electronic units are accommodated on the SCC panel, via a Heat pipes network covering the totality of the faces of the panel. Each SCC is mounted to its panel via

- a first layer of horizontal bi-tubes over the SCC panel
- a second layer of vertical tubes, over the SCC beds
- a sandwich plate, for height compensation, outside the SCC beds area

The SCC panel shall have a minimum face-sheets thickness of 1 mm, to ensure an efficient radiator function.

They shall be considered as a unique structural component, including H-pipes layers + SCC units.

The assembly of the SCC + vertical and longitudinal pipes layer to the panels is realised by through inserts.

The interface configuration defined by the 2 SCC boxes, requires that each SCC shall be attached to the heat pipes by a huge (~500) number of fasteners. The presence of such a large number of fixations, to be installed from outside, as well as the thick skins, leads to a high mass value for this structural item. Figure 9.1.4-14 shows the connection concept between panel and equipment

In addition, as the SCC panel shall be thermally de-coupled from the octagonal box, a maximum number of fixation cleats, in Titanium, to the octagonal box, has been considered for the design and analyses, performed in this phase (a fixation scheme is provided in Figure 9.1.4-13).

The considered geometrical/Thermal characteristics of the cleats are sketched in Figure 9.1.4-12.

The validity of the present configuration is confirmed by the Thermal analysis (see § 9.2).

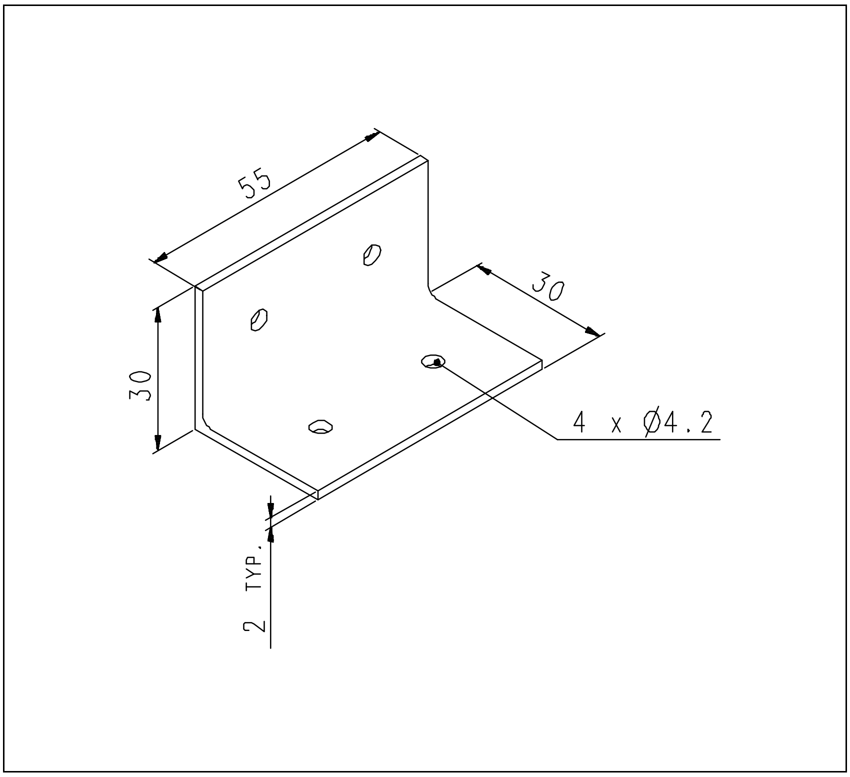


Figure 9.1.2-12 Tipical SCC titanium cleat

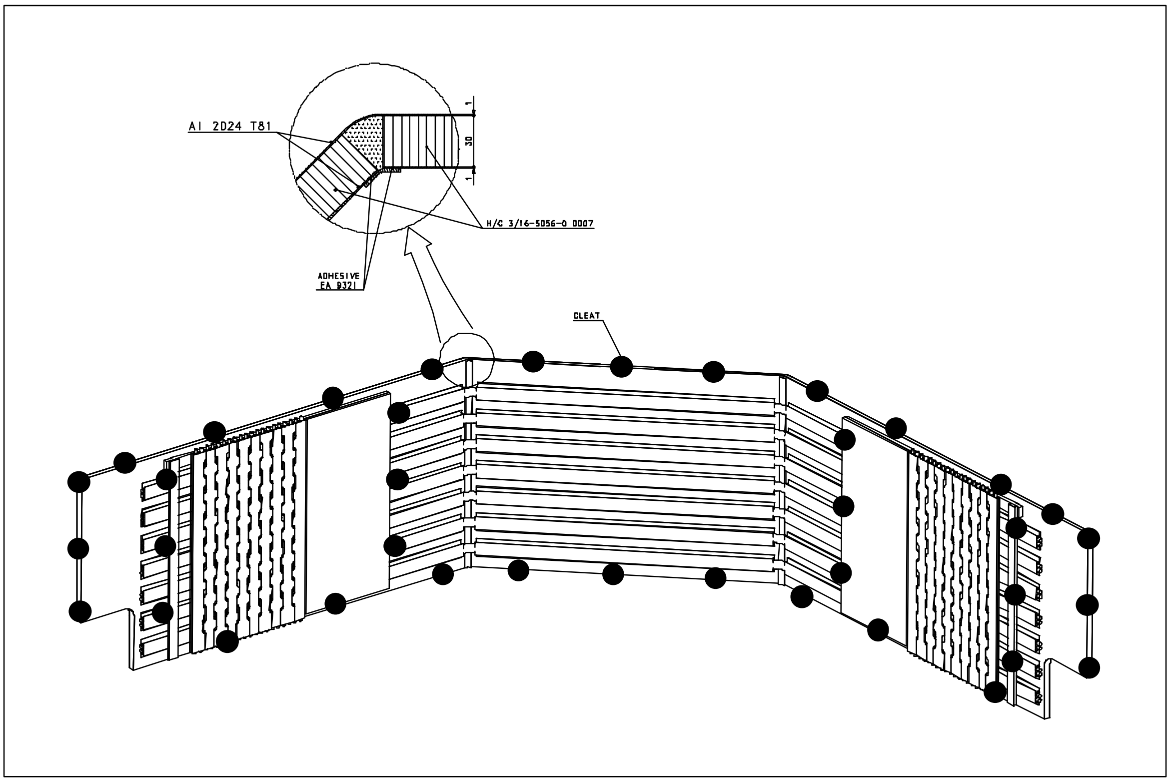


Figure 9.1.2-13 SCC concept and connection scheme

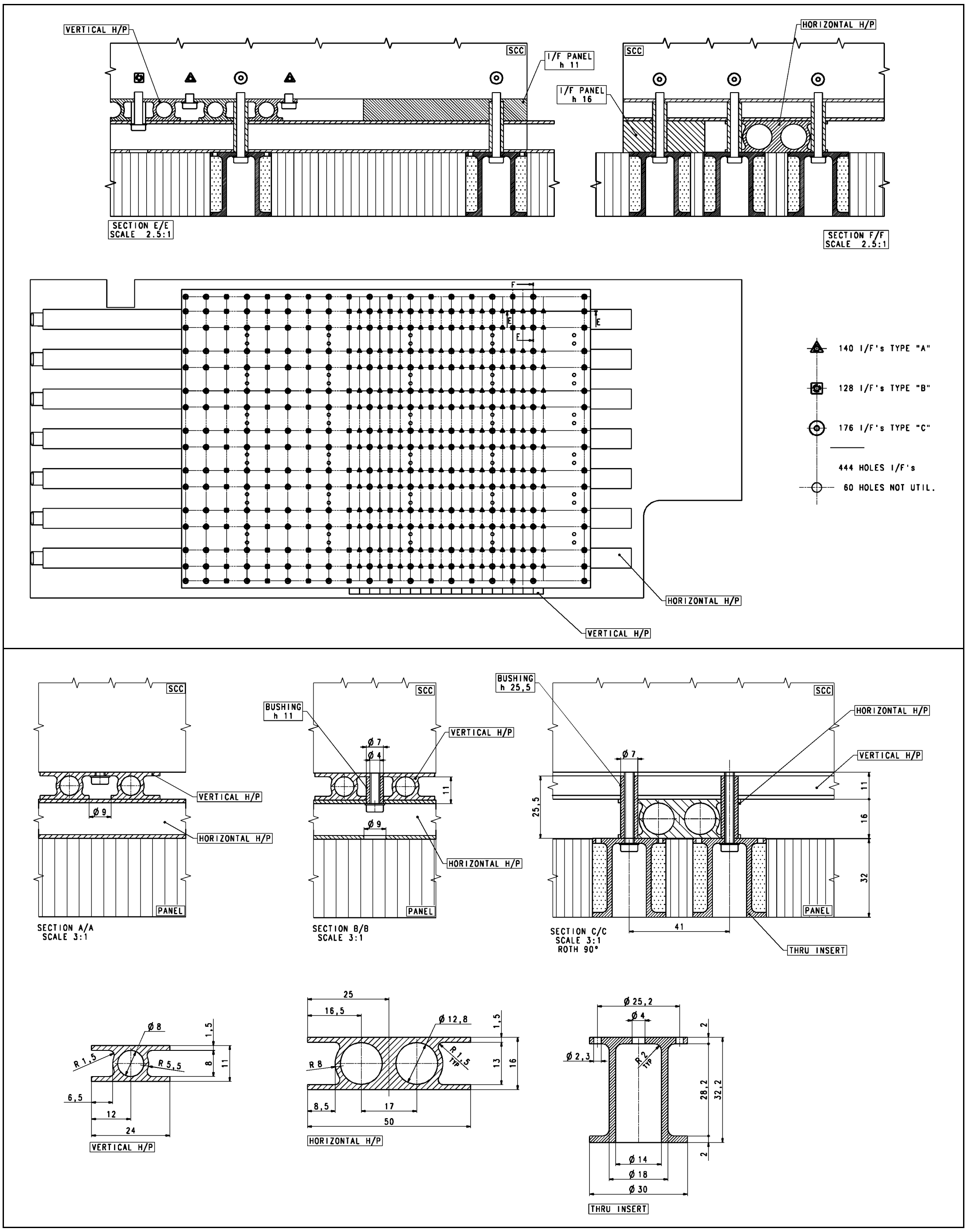


Figure 9.1.2-14 SCC box / panels connection concept

Primary structure design options

For each structural item above described, the here presented solutions are the first step of design iteration, aimed to demonstrate the SVM structure feasibility, with respect to the given requirements.
Large optimization margins could be envisaged. The SVM Structure Subcontractor will perform design optimization with respect to mass, manufacturing, material selection, cost and schedule.

The CFRP selected for the present design iteration (T300) is a widely (low cost) known material. The final selection will be performed by the Subcontractor, also considering the manufacturing process employed. This can lead to a different skins layout and, consequently, skins thickness.

Upper interface
A possible evolution of this interface could be constituted by the deletion of the PLM attachment brackets, directly mounting the PLM truss brackets at the cone embedded inserts. This solution, which might provide some mass saving should anyway face with the need of a new design solution for the fixation of the Payload subplatform and the redesign of the attachment bracket in order to provide enough I/F surface. The mass balance in this activity may be worse than expected.
Another possible solution, could be the use of a continuos ring on the upper I/F. This solution is actually considered undesirable for the mass impact it seems to have.
Another different configuration on this side regards the Herschel satellite only. For this satellite the Sunshield/sunshade I/F is still under evaluation. The modifications to the current baseline should face with the loss of commonality between the central cone structures of the two satellites and/or the mass increase.

Lower ring
A more mature design for the lower ring could be proposed, the cost of such a solution can be the mass increase.

Central tube
An alternative solution could be foreseen in the manufacturing approach. The reinforcements could be co-cured or a both cold bonded (longitudinal) and co-cured (circumferential).
No other main change options are foreseen with the exception of those related to the modifications of I/Fs
If, for the central tube, complete commonality can be abandoned, keeping the same baseline cone for both Herschel and Planck, cold bonded reinforcements at PLM interfaces, could be added only where needed.

Octagonal box
The overall dimensions of the lateral panels (H/C core 35mm - skin thickness 0.3mm) could be modified w.r.t the stiffness requirement, if a lower Planck frequency requirement can be allowed. However, as equipment's mass growth is foreseeable, the present panel size is strongly recommended.

Payload sub-platforms
No main change options are foreseen for these items

P.Tanks Support Structures (PTSS)
No main change options are foreseen for these items

SCC panels
A possible evolution of the SCC panel evolution could be the division of the single huge panel into three parts with corner attachments. This solution should be verified keeping in mind the thermal requirements and manufacturing/integration considerations. Slight modification in mass could be foreseen
A trade off is actually in progress to verify the possibility of reducing the sheet face of the SCC to a thinner value in order to obtain a mass saving.
A dedicated study is also in progress to optimise the fastening path in order to reduce the number of through inserts and the mass accordingly.
A back up solution for fixation of SCC to the rest of octagonal box could be the use of spigots instead of cleats. This solution, described during the proposal phase, could result in slight mass increase and higher manufacturing complexity, but on the other hand thermal de-coupling and integration easiness could be improved.

9.1.2.2 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 main secondary structures consist of:

HERSCHEL

RCS piping support (circular floor + 3 webs)
Thrusters support (6 brackets supporting 12 10N thrusters)
Sensors supports, namely:
SAS (2)
FSS (2)
Two Star Trackers (STR): only one support for the two STR Heads, that could be broken down in a main plate with isostatic mounting to the main structure, and brackets (if necessary) to interface with the two individual heads. It is thought that this support should be of a higher complexity than the others, at least because of the required alignment stability.
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
Thermal Lower Closing (TLC) (1) support + 12 brackets on the Central tube
Brackets for Umbilical connectors to Launcher (2)

PLANCK

RCS piping support (circular floor)
Thrusters support (6 brackets supporting 12 10N thrusters and 2 brackets supporting 4 1N thrusters)
Sensors supports, namely:
SAS (3)
AAD (1)
Star Mapper (STM) (1)
Antennae supports, namely:
MGA (1)
LGA (3)
VMC (1) and SREM (1) supports
Thermal Blankets supports
Solar Array supports (8 brackets on the Octagonal box side, 12 brackets on the Central tube)
4 He Tanks supports (struts type supports)
Brackets for Umbilical connectors to Launcher (2)
The SVM Structure is intended to be anyhow primary and secondary structure together.

Secondary structure design options

The secondary structure design is still very preliminary and it is then really hard to define a baseline and some design option. For almost all the secondary structure, the whole structure consists of a bracket or a set of similar brackets and is then unuseful to define the design in this phase of the program.
There are, anyway, few structures that are more complex and will need a baseline definition. Among those structures we can list TLC structure, the SA stiffening brackets and the RCS piping support panel. For these items a baseline solution has been considered, but further study are needed to clearly define and optimize the design.

9.1.3 Venting

Due to the dimensions of the SVM, a large volume of air needs to be evacuated during launch to avoid overpressure in the structure.

The air contained in the Cone is evacuated through the holes of the cone to the external enclosures and from here to the external of the Satellite through dedicated holes in the octagonal box.
Dedicated venting holes are foreseen in all other items containing an air volume (sandwich panels, struts, etc.)

9.1.4 Electrical Bonding

The design of the SVM Structure will take into account the electrical bonding requirements.

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:

For that 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 request 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.

The main particular thermal requirements for HERSCHEL and Planck SVM are reported hereafter.

HERSCHEL SVM

The total heat fluxes exchanged at the PLM-SVM I/F shall be less than 1 Watt
Some very stringent requirements are those concerning the temperature stability of the warm HIFI payload units:

$\Delta T \leq \pm 0.03$ K on a time period of 100 s, for FHHRV, FHHRH, FHHRI, FHWBI, FHWBO, FHLCU and FHLSU
$\Delta T \leq \pm 0.14$ K on a time period of 100 s, for FHWBE, FHICU and FHFCU
Additional requirements are needed on the temperature difference between Propellant tanks and Helium tanks:

$\Delta T \leq 5$ °C between each Propellant tank

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:

Temperature stability requirements on radiative panels (SCC) :
$\Delta T < \pm 0.4$ K on a 325 s. time period
$\Delta T < \pm 0.5$ K on a 2 hours time period.
Temperature stability requirements at the SVM/PLM interface:
$\leq \pm 0.325$ mK on a 325 s time period
± 0.25 K on a 2 hours time period.
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 (see Table 7.4.4.3-4).
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.
A specification is also put on the temperature difference between the propellant tanks:

$\Delta T \leq 5$ °C between each Propellant tank

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, White 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 [m²]	Blankets [m²]
+Y +Z	0.304	0.730
+Z	0.000	1.461
-Y+Z	0.608	0.364
-Y	0.931	0.548
-Y-Z	0.487	0.608
-Z	0.487	0.974
+Y-Z	0.304	0.669
+Y	0.730	0.730
Total	**3.851**	**6.08**

Table 9.2.4.1-1 HERSCHEL SVM lateral panels - Radiators/MLI areas

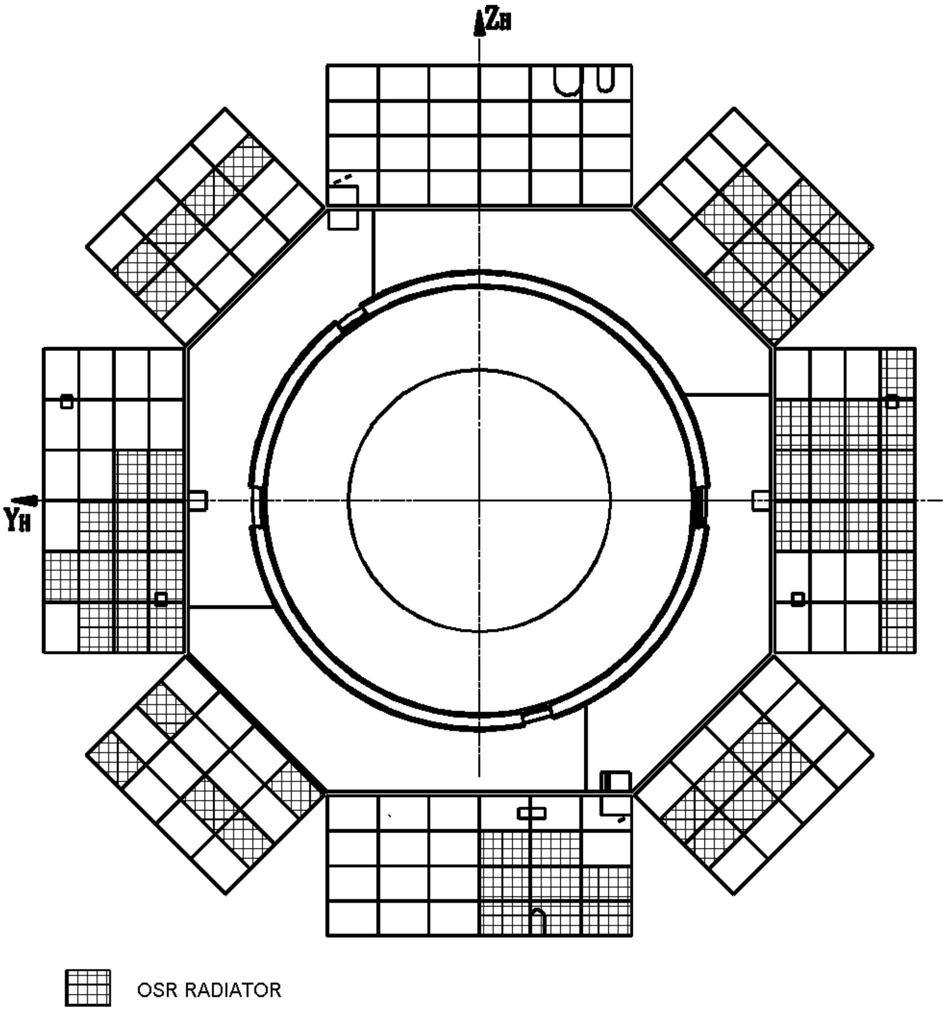


Figure 9.2.4.1-1 HERSCHEL radiator areas

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:

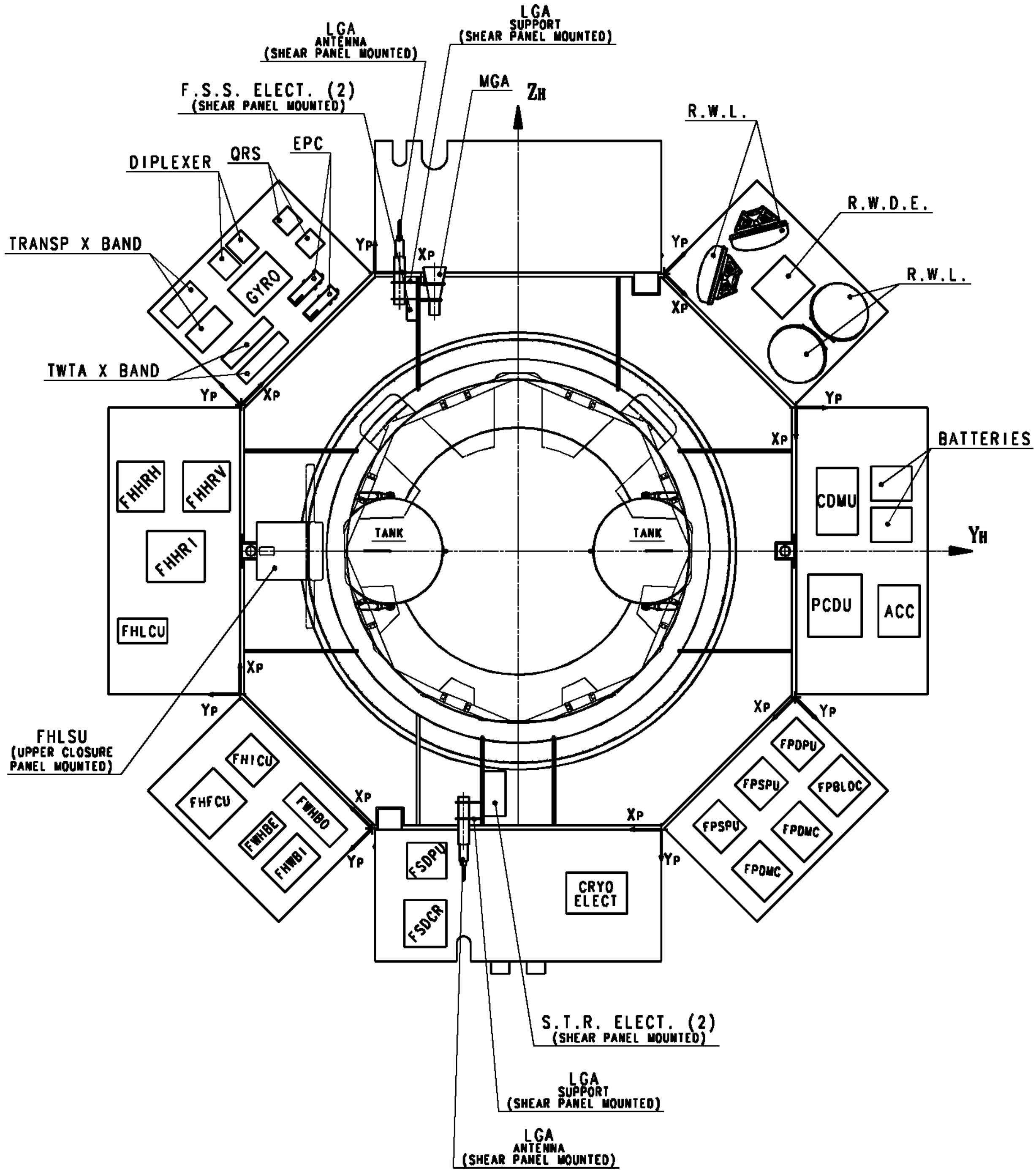


Figure 9.2.4.1-2 HERSCEL internal SVM thermal control components

9.2.4.2 Planck Design

The Planck Thermal Control design is schematically represented in Fig 9.2.4.2-1.

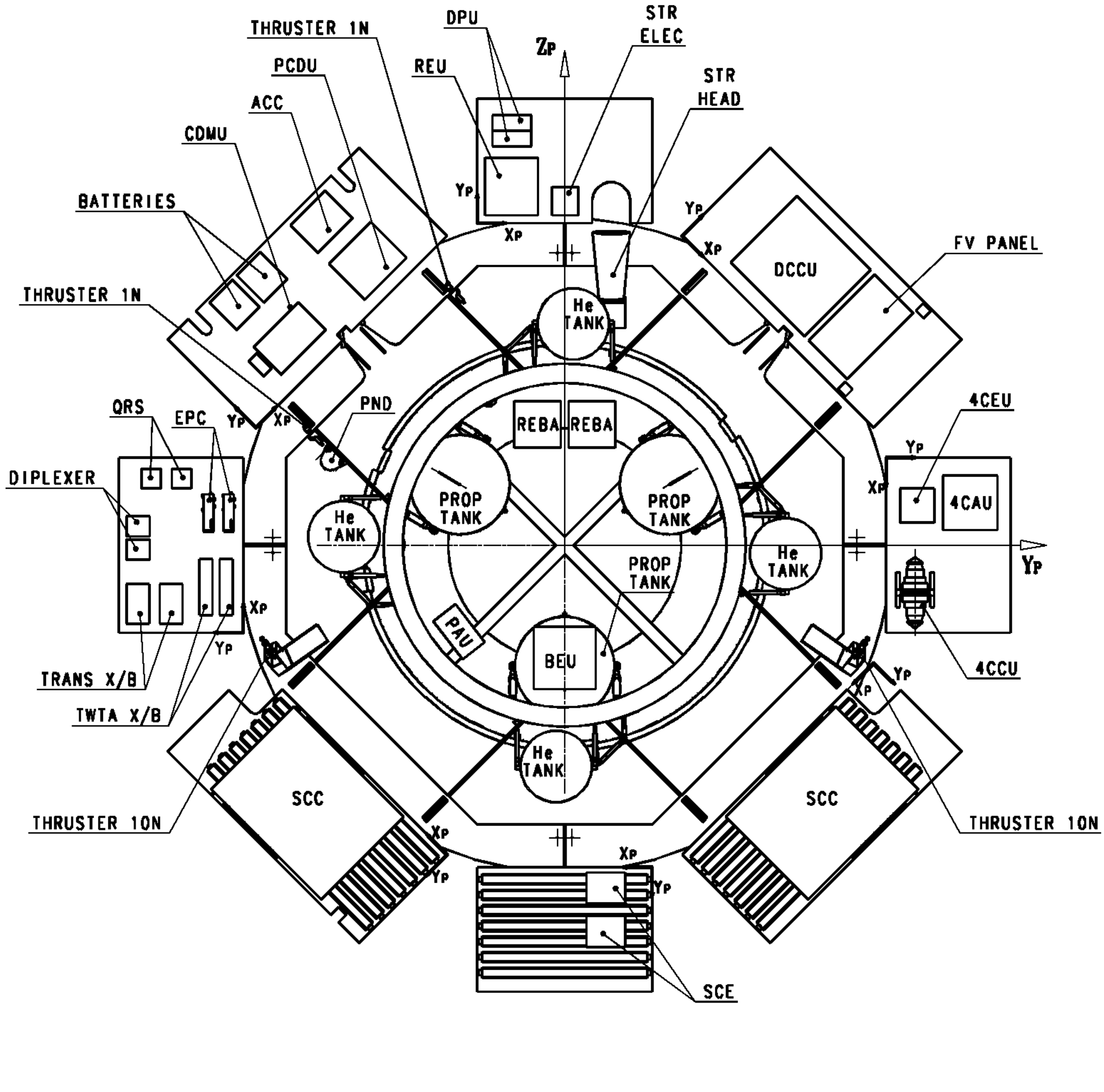


Figure 9.2.4.2-1 PLANCK internal SVM Thermal control components

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.

It is composed by vertical and horizontal HPs. 19 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 (800 mm).

The vertical HPs are mounted on a bench of 7 horizontal double HPs that connected . Each of this double HP works like two combined HPs.

Figure 9.2.4.2-2 and Figure 9.2.4.2-3 show schematically the HP configuration under the SCC beds.

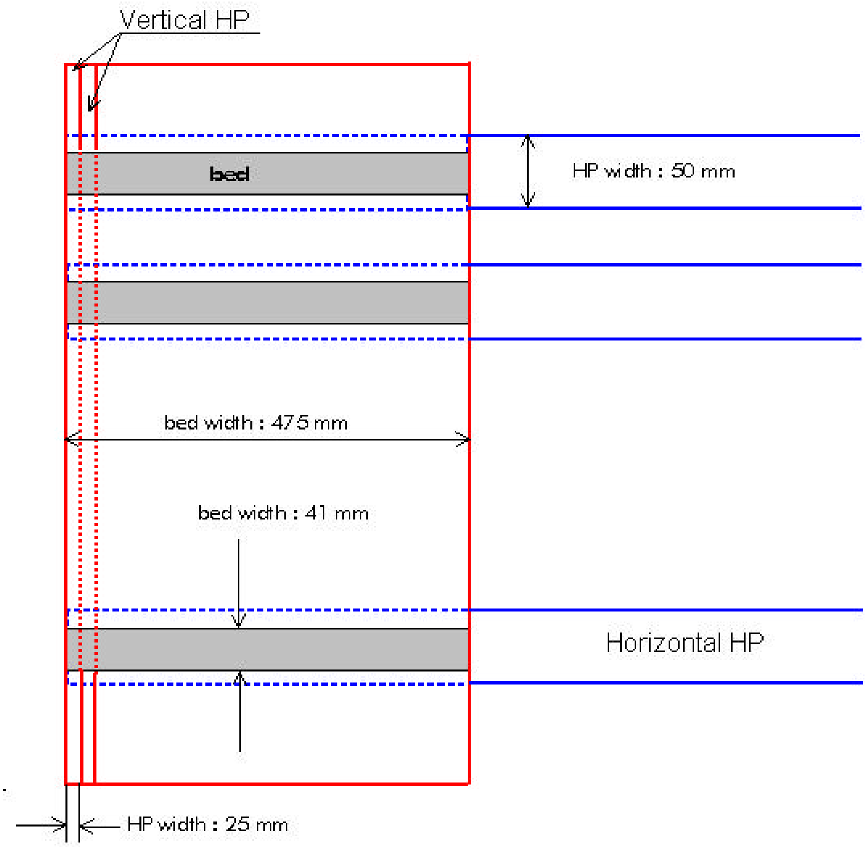


Figure 9.2.4.2-2 Planck Heat Pipe Network

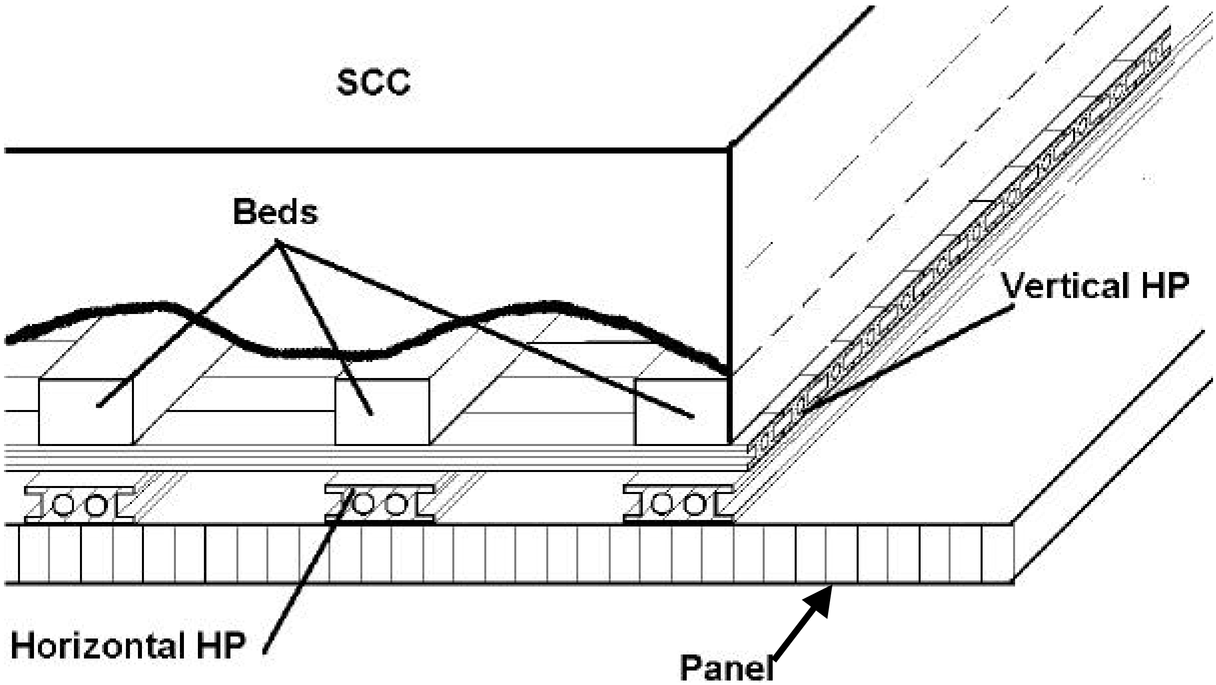


Figure 9.2.4.2-3 Planck Heat Pipe Network

To reject the large SCC dissipation it is necessary a very large radiator area, for this reason the horizontal HP are curved HPs and cover the threeSCC panels, providing 2.5m^2 total radiator area.
The SCC 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).
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	0.354	0.590
+Y +Z	0.124	1.367
+Z	0.708	0.236
-Y+Z	0.683	0.807
-Y	0.472	0.472
-Y-Z	1.385	1.491(*)
-Z	0.944	0.000
+Y-Z	1.385	1.491 (*)
Total	**6.055**	**6.454**

(*) On the internal side

Table 9.2.4.2-1 Planck SVM lateral panel - Radiators/MLI areas

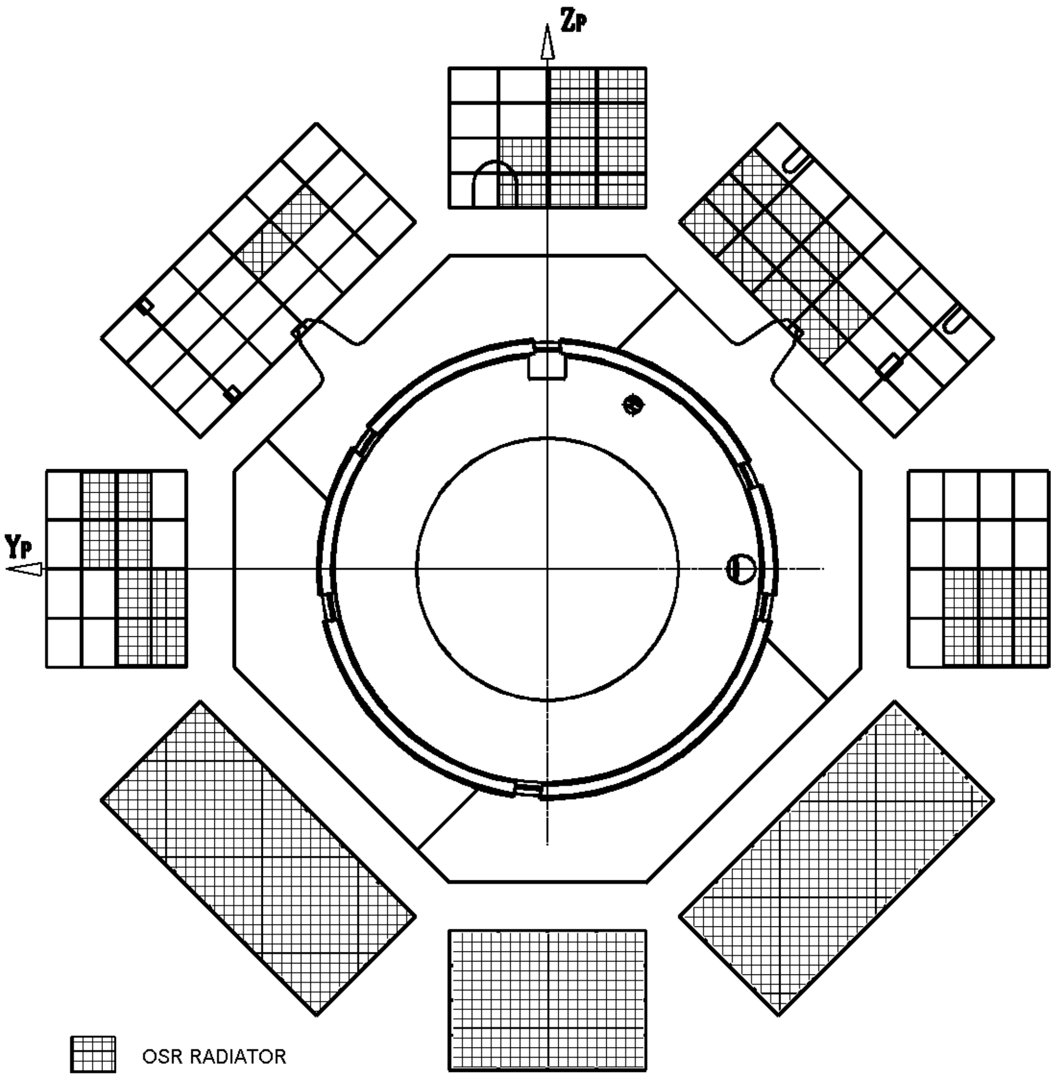


Figure 9.2.4.2-4 Planck Radiators Lay-out

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

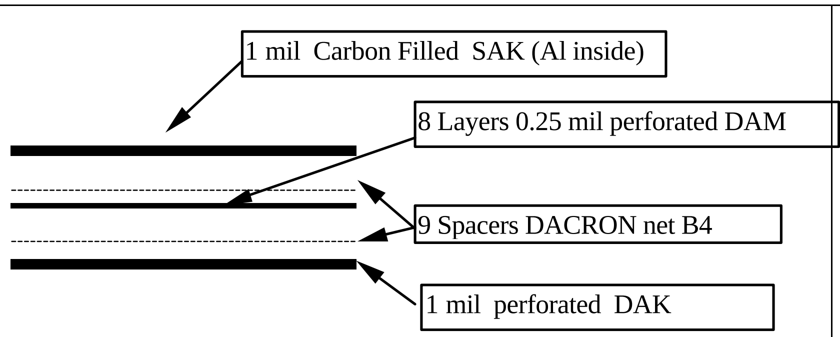
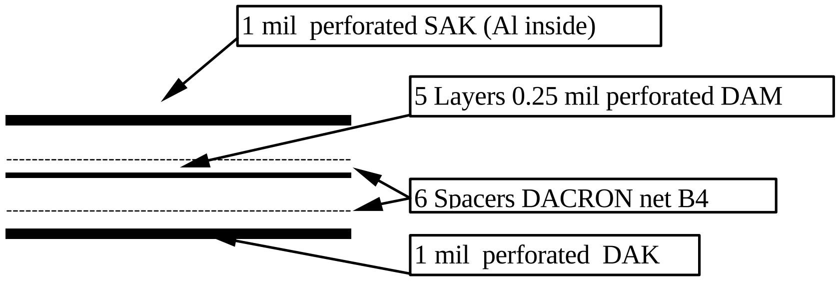
	**MLI TYPE 1** **PANELS**
	**MLI TYPE 2** **INTERNAL SIDE**

Table 9.2.4.3-1 SVM MLI Types

The blankets will be installed taking in to account grounding requirements: Grounding points, see Figure 9.2.4.3-1will 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.

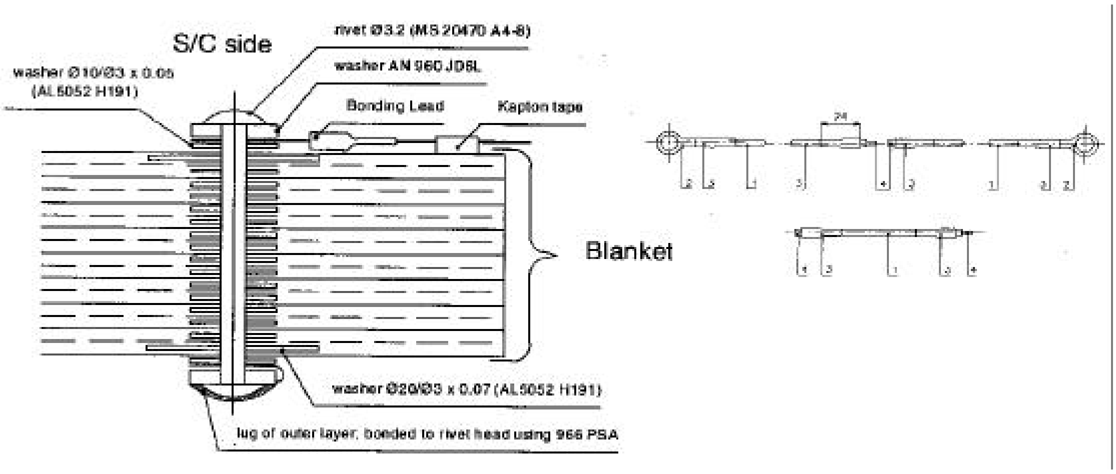


Figure 9.2.4.3-1 PLM MLI Grounding point design

9.2.4.4 Heaters 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 ground command

by a command send by CDMU following temperature sensor measurement

autonomously by thermostat at fixed thresholds

Thermostats are mechanical thermal switches which open/closed an electrical circuit when their temperature reach predefined thresholds. They will be used on survival 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.

<u>Herschel :heaters, thermistors and thermostats</u>

The HERSCHEL heaters can be subdivided in operation and survival ones.
The nominal operation heaters will be used to maintain the minimum operative temperature during the nominal phases. They will be commanded by the CDMU and operate in Pulsed Width Modulation mode. The thermal regulation will follow the reading of 3 thermistors per temperature measurement points, for failure tolerance reason (majority voting).
The nominal operation heaters, commanded by the CDMU in pulse mode, may have also thermostats for safety reason. In this case, thermostats can be mounted in a parallel line.
The required heater power will be calculated by a Proportional-Integral algorithm (see Figure 9.2.4.4-1).

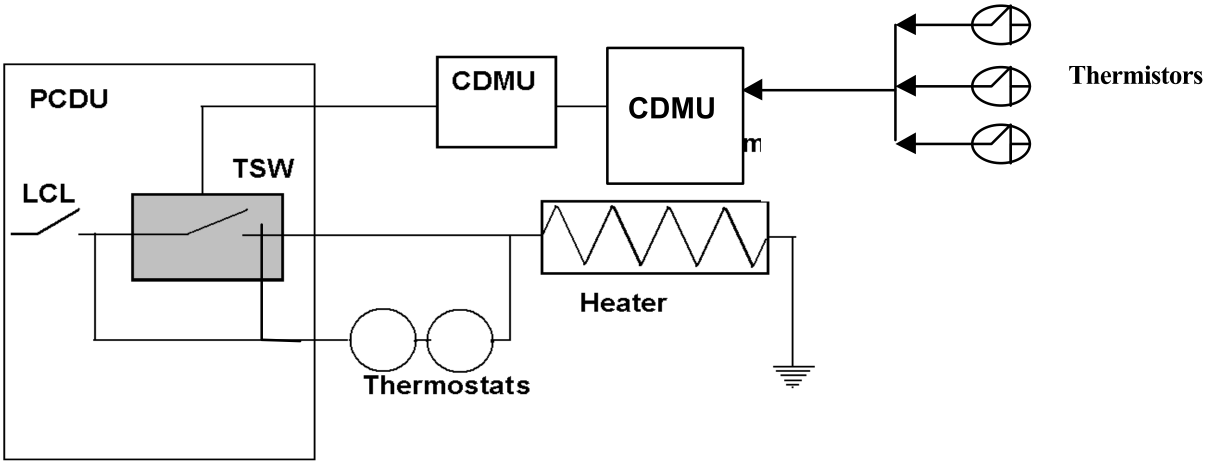


Figure 9.2.4.4-1 Nominal Heaters Electrical scheme

The survival heaters will be used only during the non-operative phases (e.g. commissioning or survival phases).
For safety reason these heaters will command by thermostats; Figure 9.2.4.4-2 shows the electrical scheme.

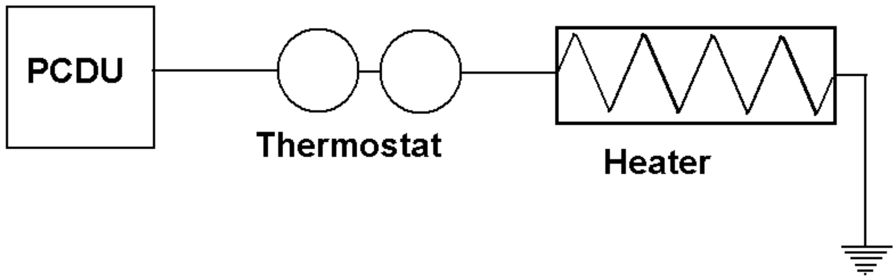


Figure 9.2.4.4-2 Survival Heaters Electrical scheme

PLANCK: heaters, thermistors and thermostats

As for HERSCHEL, Planck heaters can be subdivided in nominal operation heaters and survival heaters.
The first will be used during the pre-operational and scientific observation phases in order to maintain the temperature of the SVM units in their design range; the survival heaters will be used during not-operative phases (commissioning and survival phases).

During the observation mode, the heater switching has to be forbidden in order to avoid temperature variation on the SVM lateral panels and at the SVM/PLM I/F. To overcome this problem, the heaters command is Pulsed Width Modulation type, as for HERSCHEL. The heaters will be switched ON/OFF with a duty cycle which provides the average dissipation to maintain the wished temperature. It is important that the switching frequency is high (~ 1 Hz), which from a thermal point of view gives a resulting constant dissipation (the switch period is much lower than the time constant of the unit). The duty cycle refresh is typically 16 seconds. A PI algorithm is used for the needed power calculation. This kind of regulation is particularly well suited for Planck SVM, as the units will present a stable temperature. Attention will be however paid to limit the errors induced by encoding and measurement chains.

For safety reason, as for HERSCHEL, thermostats will command the survival heaters.

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.

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. No thermal doublers are used for the SRR thermal analysis to fulfill the requirements, they could be used in the relevant PDR issue of the document, if any.

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**
White paint	**.17**	**.55**	**.87**	**Alcatel 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 SRR objective no local thermal analysis has been performed. They will be included in the relevant PDR issue of the document if any.

9.2.4.10 RCS Piping Thermal Control

At SRR no subcontractor has been selected for the RC S/S. It will be included for PDR utilised the data of the selected Subcontractor design.

9.2.4.11 Thruster FCV

At SRR no subcontractor has been selected for the RC S/S. It will be included for PDR utilised the data of the selected Subcontractor design.

9.2.4.12 Heat Pipes

The main component of the Planck SVM TCS is the Heat Pipes (HPs). The Heat Pipes network is installed on the three SCC panels. The network is composed by vertical and horizontal HPs. 19 vertical HPs are mounted directly under each SCC unit, covering the whole bed I/F surface. The vertical HPs are mounted on a bunch of 7 horizontal bi-tube HPs.
Heat pipes network is shown in the Fig 9.2.4.12-1.

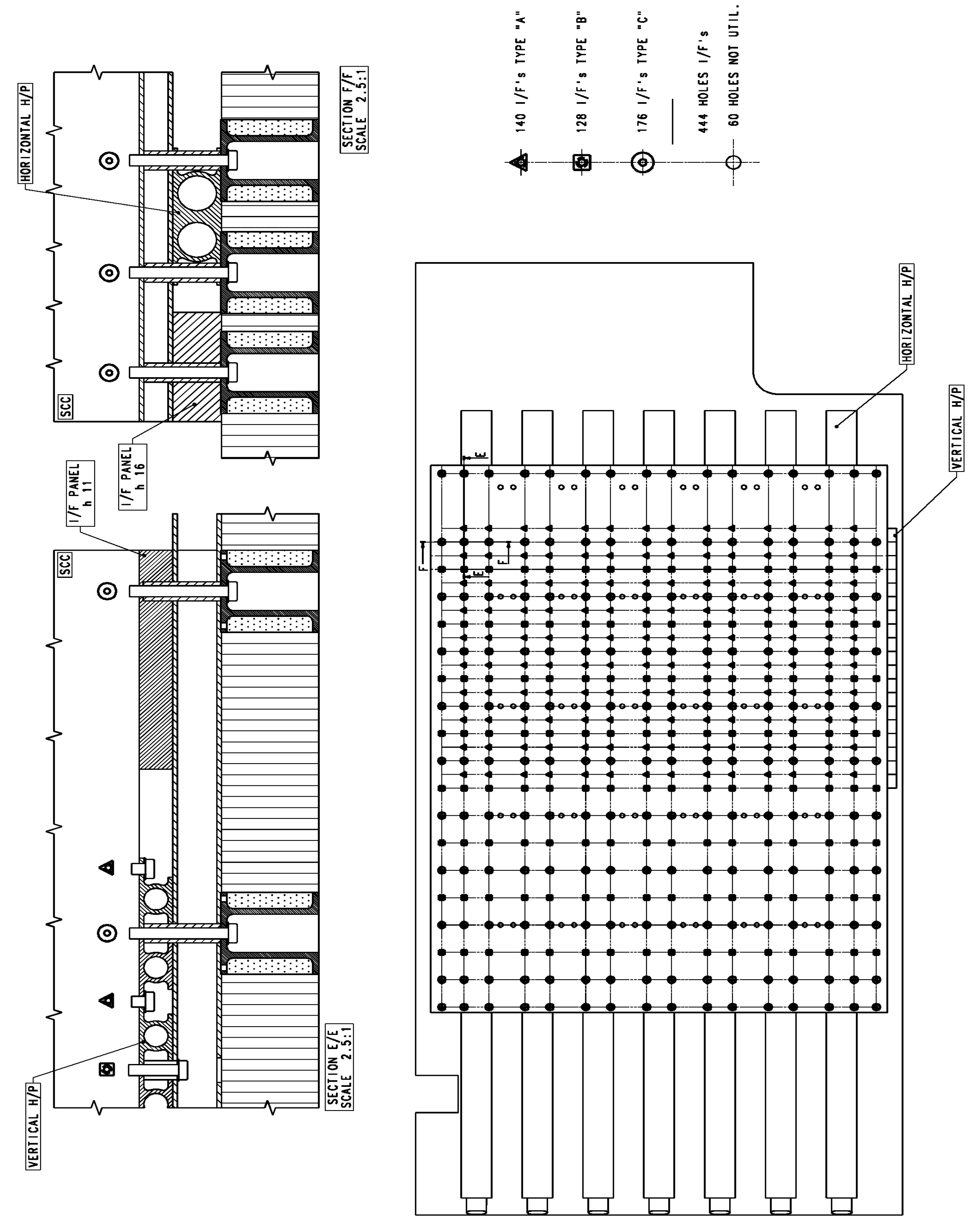


Figure 9.2.4.12-1 Planck Heat Pipe network

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

9.2.6.1 HERSCHEL budget

9.2.6.1.1 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%		8.619		10%		9.481
MLI INTERNAL			100%		1.957		10%		2.152
FILLER			100%		0.759		10%		0.835
RADIATORS			100%		2.685		10%		2.954
BLACK PAINTS			100%		1.19247		10%		1.31172
MISCELLANEOUS			100%		2.149		10%		2.364
TOTAL MASS [kg]					17.362				19.098

Table 9.2.6-1 Herschel TCS Mass Budget (all data TBC)

The table presented above is a preliminary result of the ALENIA internal design not yet supported by the Relevant Subcontractor for detail Design activities. For the SRR purpose the following targhet value will be considered:

Nominal Mass (Status): 15,2 Kg
Uncertanty Mass : 1,6 Kg
Maximum Mass (Current): 16,8 Kg

9.2.6.1.2 Thermistors Budget

To monitoring the status of SVM Thermal Control, 120 (TBC) thermistors will be installed.

9.2.6.1.3 Power Budget

The HERSCHEL heater power budget are reported in following figure

Heater Location	Heater	Heater	Heater	Scient. Obs.	Telecom. Phase	Survival phase
	Power	Lines	Lines	SAA= + 30°	SAA= -30°	SAA = +30°
	[W]	Number	M+R	[W]	[W]	[W]
RWL	37.5	1	1+1	0	0	33.9
ACC	30.5	2	1+1	13.6	0	29.4
CDMU	3.9	2	1+1	0	0	0
BATT1	16.5	3	1+1	13.1	0	15.7
BATT2	16.5	3	1+1	12.7	0	15.2
FPSPU1	8.9	4	1+1	0	0	8
FPSPU2	2	4	1+1	0	0	0
FPDPU	5.1	4	1+1	0	0	4.1
FPDMC1	13.3	4	1+1	0	0	12.2
FPDMC2	2.7	4	1+1	0	0	0
FPBLOC	3.8	4	1+1	0	0	0
FSDPU	9	5	1+1	0	0	8.1
FSDCR	36.5	5	1+1	0	0	35.1
STRE1	3.9	6	1+1	0	0	0
STRE2	6.3	6	1+1	0	0	5.6
ELEC.CRYO	2.5	6	1+1	0	0	0
FHICU	12.5	7	1+1	0	0	11.9
FHWBO	30.6	8	1+1	21.9	0	29.8
FHFCU	15.9	9	1+1	2.2	0	15.1
FHWBE	18.1	10	1+1	2.2	0	17.6
FHWBI	20.4	11	1+1	0	0	19.8
FHHRV	38.1	12	1+1	0	0	37.6
FHHRI	31.9	13	1+1	0	0	31.3
FHHRH	37.6	14	1+1	0	0	37.1
FHLCU	21.8	15	1+1	7.6	0	21
FHLSU	18.9	16	1+1	12.4	0	17.1
EPC1	5.1	17	1+1	0	0	4.4
EPC2	10	17	1+1	2.7	0	9.1
TWTA1	16.9	18	1+1	16.3	0	0
TWTA2	14	18	1+1	13.3	0	0
QRS1	1	19	1+1	0	0	0
QRS2	1.9	19	1+1	0	0	0
GYRO	7.1	19	1+1	0	0	0
TRANSX/B1	3	20	1+1	0	0	0
TRANSX/B2	5.9	20	1+1	0	0	0
DIPLEXER1	10.2	21	1+1	8.4	0	10.1
DIPLEXER2	1.5	21	1+1	0	0	0
TANK1	2.1	22	1+1	1	0	1.6
TANK2	2	23	1+1	1	0	1.5
RCS (*)	24	24-26	3	12	12	12
Thrusters (*)	32	27-38	12+12	16	16	16
TOTAL	581.4	38+38	38+38	156.4	28	460.3

Table 9.2.6-2 Herschel heater power budget

9.2.6.2 PLANCK budget

9.2.6.2.1 Mass budget

Planck TCS mass budget is reported in Table 9.2.6-2:

DESIGNATION	REFERENCE	STATUS				UNCERTAINTY %			CURRENT
		EST.	CALC.	WEIGHT	MASS [kg]	EST.	CALCUL.	WEIGHT	MASS [kg]
MLI EXTERNAL			100%		1.146		10%		1.261
MLI INTERNAL			100%		10.757		10%		11.832
FILLER			100%		0.268		10%		0.295
RADIATORS			100%		4.316		10%		4.747
BLACK PAINTS			100%		1.16914		10%		1.28605
MISCELLANEOUS			100%		2.149		10%		2.364
HEAT PIPE			100%		36.385		10%		40.024
TOTAL MASS [kg]					56.190				61.809

Table 9.2.6-2 Planck TCS Mass Budget

The table presented above is a preliminary result of the ALENIA internal design not yet supported by the Relevant Subcontractor for detail Design activities. For the SRR purpose the following targhet value will be considered:

Nominal Mass (Status): 57,4 Kg
Uncertanty Mass : 5,7 Kg
Maximum Mass (Current): 63,1 Kg

9.2.6.2.2 Thermistors Budget

To monitoring the status of SVM Thermal Control, 120 (TBC) thermistors will be installed.

9.2.6.2.3 Power Budget

The PLANCK power budget are reported in the following table.

Heaters Location	Heaters Power [W]	Heater Lines Numbers	Heater Lines M+R	Scientific Obs. Sun = +Z 10° [W]	Telecom. Phase Sun from +Z 10° [W]	Survival Phase Sun from +Z 10° [W]
STR ELEC.	3.5	1	1+1	0	0	2.3
DPU	36.3	1	1+1	0	0	31.3
REU	7	2	1+1	0	0	0
DCCU	15.1	2	1+1	0	0	0
4 CCU	36.5	3	1+1	0	0	30.5
4 CEU	17.6	4	1+1	0	0	14.1
4 CAU	0.9	4	1+1	0	0	0
SCE1	236.7	5	1+1	0	0	234.1
SCE2	239.5	5	1+1	0	0	236.9
EPC1	2.1	6	1+1	0	0	0
EPC2	1.4	6	1+1	0	0	0
TWTA1	12.8	7	1+1	9.4	0	0
TWTA2	16.2	7	1+1	13.9	0	0
QRS1	1.5	8	1+1	0	0	0
QRS2	2.4	8	1+1	0	0	0
TRANSX/B1	11.4	9	1+1	0	0	0
TRANSX/B2	2.9	9	1+1	0	0	0
DIPLEXER1	6.7	10	1+1	0	0	2.1
DIPLEXER2	0.7	10	1+1	0	0	0
ACC	4.3	11	1+1	0	0	0
BATT1	4	12	1+1	0	0	0.8
BATT2	3.7	13	1+1	0	0	0.5
He TANK +Z	2.8	13	1+1	0	0	1.6
He TANK +Y	2.8	14	1+1	0	0	1.6
He TANK -Z	3.5	15	1+1	0.4	0	2.3
He TANK -Y	1.9	16	1+1	0	0	0.7
P TANK +Y+Z	5.1	17	1+1	0	0	1.5
P TANK -Z	6	18	1+1	0	0	2.5
P TANK -Y+Z	4.6	19	1+1	0	0	0.9
Thrusters	32	20-31	12+12	0	0	32
RCS Lines	12	32-34	3+3	4	12	12
Total	733.9	34-34	27+27	27.7	12	607.7

Table 9.2.6-4 Planck heater power budget

(*) Estimated on the basis of 50% duty cycle

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.

Herschel solar array is composed of three identical panels utilising dual junction GaAs cells.
The lateral panels have an angle of 35° with respect to the central panel.

Planck solar array is composed of a central circular part plus four quarters forming an outer ring, all utilising dual 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 batteries and distribution to the scientific instruments and spacecraft equipment (SMPC-005 ÷ 020, 080)

The subsystem is required to manage the following.

- To provide power from 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 over 80 thermal control and instrument decontamination heaters
- The PCS distributes power over 66 (see Note) individual power lines to the spacecraft equipment.

Note: 64 power lines have been presented in the proposal phase. The ongoing updating in the IID-B could require the increase of this number in order to fit with the Herschel demand. If these data will be confirmed, PCDU design will be different from the present description.

Monitoring and telecommand interfaces 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 shall provide dedicated heater outputs for thermally critical units, directly connected to the batteries such that no other unit must be active to energise them. These lines shall act as additional redundancies and shall be controlled by independent and dedicated thermostats (SPMC-065)

Power Control and Distribution Unit must be active to energise these lines, in order to properly operate the Battery Discharge Regulators.
It is considered too dangerous to connect these heaters directly to the batteries or to the main bus since it could cause potential failure modes where either the battery or bus it short-circuited.
These survival heater lines will be supplied by redundant FCL's in the PCDU.

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 continuous way without main bus voltage variations being outside the specified tolerance. No single component failure shall cause an overvoltage 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). Considering the difference in the bus load due to switch on-off of this user, the required capacitor bank shall be greater than 1mF. Applying adequate margins, the capacitor bank has been sized to 1.5mF.

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) by Fold-back Current Limiters. The other lines will be protected by means of Latching Current Limiters.

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
MISS-035: Both spacecraft shall withstand the transfer trajectory to the operational L-2 orbit , which may include an eclipse of 75 minutes . The transfer trajectory will be defined such that no eclipse will occur during a period of 6 hours starting at separation

AD-11 specifies a time from lift off to S/C separation including delayed ignition of 133.2 min (Table 3.1).

The maximum allowed eclipse duration in transfer orbit has been evaluated as follows.
The transfer eclipse will occur not before 6 hours after separation, therefore there is adequate time for battery re-charging
Considering the power load during transfer orbit and that only one battery have to be capable of supplying the load, then the maximum eclipse time is 1 hour 15 minutes. This is fully compatible with parking orbit transfer strategy except for less than 20 days per year.

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 the proposal phase, the battery shall provide 237W power to the spacecraft during the 133.2 minutes of launch. This means that the Launch energy requirement amounts to 526 Wh.

9.3.2.2 Solar Array

Herschel and Planck solar array provides electrical power to the relevant spacecrafts, out of eclipse phases. **This chapter provides also the description of the HERSCHEL SA even if 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.**
The orbit of both satellites is nominally eclipse free but few eclipses are still possible during transfer orbit.
Solar panels also act as a sunshield and thus provide shielding from Sun illumination to the PLM while heat transfer has to be minimised. This implies that its backside is thermally insulated to avoid thermal loads on the satellite upper part and that heat transfer throughout the fixation points shall be reduced to the minimum.

Based on the power budget presented in the proposal phase, the power required to the solar array is the following.

Herschel solar array is required to deliver:
1338 W at beginning of life (BOL)
1136 W at end of life (EOL).

Planck solar array is required to deliver:
1648 W at beginning of life (BOL)
1481 W at end of life (EOL).

The above power figures include the 100 W of system reserve as per req. SPMC-200 and SMPC-205.

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	1428 W/m^2	1327 W/m^2	1405 W/m^2	30° incidence 1113 W/m^2 0° incidence 1285 W/m^2
	BOL max 0° incidence	BOL min 0° incidence	EOL max 0° incidence	EOL min 10° incidence
Planck solar array	1428 W/m^2	1327 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 30.5 V for both the solar array.
Solar array lifetime is 6 years 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.

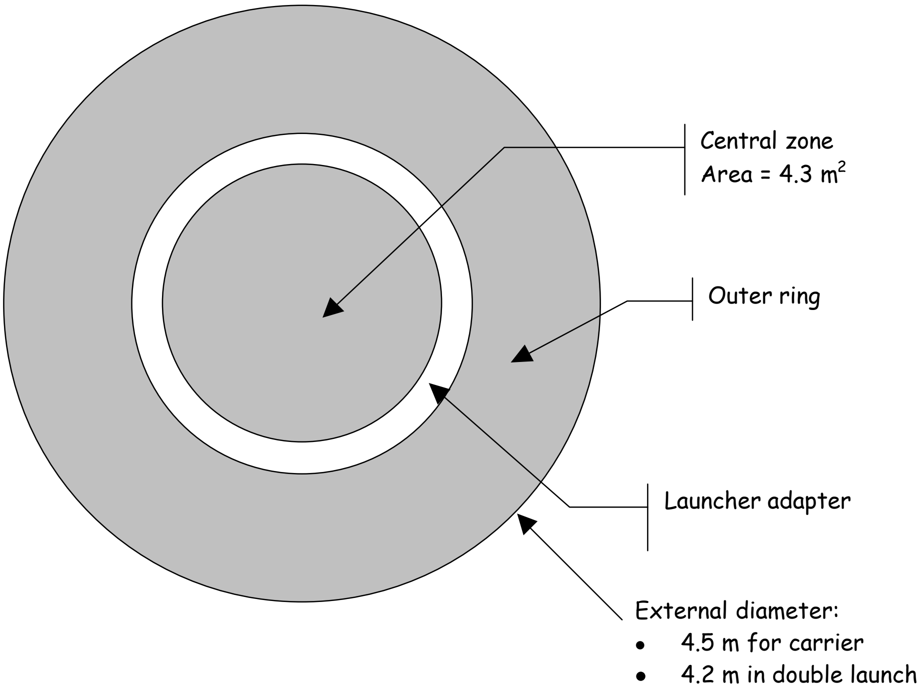


Figure 9.3.2-1 Planck solar array implementation constraints

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.

These requirement can be satisfied by covering the cells surface with ITO and by implementing a grounding network connecting the cells surface and at the end of the string to the substrate.
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.

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 inside the proposed cells type. This 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.

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.

As an optimisation the three Herschel panels are built up identical each with 10 sections.
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.

9.3.3 Functional Description

The PCS consists of the following units:

Power Control and Distribution Unit, PCDU, which provides for:
- control of the electrical power generation and storage
- control of PCS health
- power distribution and power protection to the scientific instruments and spacecraft equipment.

Battery, which provide electrical power to spacecraft equipment during launch and eclipse periods.
Solar Array, which generate the electrical power.

The Solar Array power is conditioned by the PCDU, which is in charge to control and distribute electrical power to the satellite consumer equipment and to manage the charge/discharge of the battery.

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

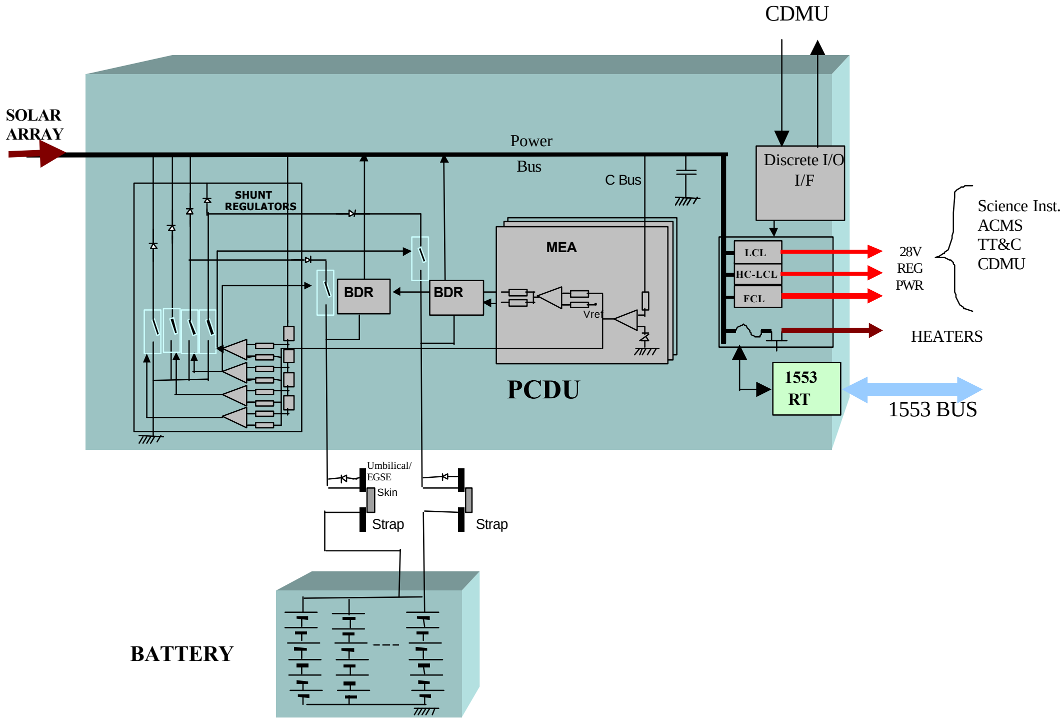


Figure 9.3.3-1 Power Control Subsystem

Herschel solar array has the following features:

- flat and fixed panels: no deployment are foreseen.
  Deployable arrays are not desirable mainly for thermal reasons: the view factor between the cryostat and the back of the solar array is important and would require insulation on solar array back side. This is complex to implement and a fixed array is preferable.

- 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.

9.3.4 Design and Performance

9.3.4.1 PCDU Design Description

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 ($V_{BAT} < V_{BUS}$)

During Sunlight period, the power is delivered by the 30 SA sections, which are connected to the main bus through dedicated electronic switches working under S^3R concept.
In parallel, 8 of these 30 sections are directly connected to the battery, in order to ensure its recharging.

When the SA power is no longer sufficient to satisfy the bus power consumption, the power is delivered by the battery in parallel via two Battery Discharge Regulators (BDR).

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 to optimise the BDR module in terms of mass and electrical performances (mainly the efficiency) due to its single state power cell architecture with Mosfet's referred to the power return.

The BDR module is designed for a maximum power capability of more than 350W (14A @ 28V) in nominal conditions and for an input voltage range from 15V to 27.5V. This power capability satisfies the needs for launch, eclipse and safe mode with battery.
Each BDR module is self-protected against internal short failure to the return or to the bus, it is ON/OFF switchable by telecommands and it includes its own auxiliary supply connected to the battery.
The BDR switch OFF (by TC or by protection activation) means the disconnection (via Power Mosfet) of the battery from the BDR and the main bus. An interlock is foreseen to prevent both BDRs being switched off at the same time when battery power is required
During the launch and AIT phases, the BDR can be switched ON/OFF by direct commands available on a dedicated connector (one per BDR module).

Main Error Amplifier and bus capacitors

The Main Error Amplifier (MEA) is in charge to manage the available energy sources, in order to guarantee a permanent regulated bus. This circuit pilots the 2 BDR's and the 30 SA electronic switches in one of the following modes:

the BDR mode using the limited cycle conductance control (LC's)
the Sunlight mode using the S^3R concept
the 8 first SA sections (when not used on the bus) can be routed individually to the battery via dedicated switches, under the battery management circuit.

The transitions between these modes are automatic and lead to negligible transients to the main bus voltage.

The MEA is fully reliable by utilisation of three parallel MEA channels (working in hot redundancy) associated with reliable majority-minority voters.

A capacitor bank is foreseen at main bus level in order to:
stabilise the bus voltage regulation loop
ensure a low output impedance
filter the switching noise due to the regulation

For reliability reasons, the bus capacitance is made by self-healing capacitors.
The total capacity is 1.5mF.

Battery Charging

Since Lithium-ion battery is used, the most appropriate charging method is "taper charging". In this case the current is regulated to ensure that at end of charge the charging voltage is constant, and just below the maximum permitted cell voltage. This will be achieved by regulating the battery associated solar array shunts, to be either switched to the battery or switched to the main bus or shunted (SR4 principle). The control of this regulation will be implemented exclusively using hardware circuits.

An independent cell voltage monitoring circuit will be used to inhibit the charging should the cell voltage exceed a pre-defined threshold (set between the nominal end of charge voltage and maximum voltage permitted by the cell). This will only be necessary to cover failure cases of the charging circuit and will ensure that the cells are not stressed or damaged due to overcharge. A cell voltage monitoring circuit will also check for cell undervoltage. If the voltage falls below a minimum threshold then a system alarm is generated.

The battery charging circuit will be designed to charge the battery using 8 sections of the Solar Array. Since each section of the Solar Array produces 2A in nominal illumination conditions, this means that the maximum charge current is 16A which corresponds to a charge rate of almost C/2 considering a 36Ah battery. This means that the battery can be recharged relatively quickly, which is not really required for the nominal scenario (the first transfer orbit eclipse is 6 hours after separation), but it does mean that the system can cope with a SOHO type incident (attitude loss) where fast battery recharging is desirable.

Current Limiters

The PCDU distributes the 28V regulated bus through the following types of Current Limiters:

Standard Latching Current Limiter
High Current Latching Current Limiter
Fold-back Current Limiter

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.

The High Current LCL consists of a standard LCL with a series saturated switch. The HC-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.

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.

The protection is based around a current limiter with a limitation value that can be nominally adjusted from 50% to 100% of I_{lim}. The associated control circuit detects an over-current and starts a timer, which latches off the switch after a fixed delay, defined by the thermal capacity of the MOSFET. The latch is reset by a cycling off then on of the command signal.

The current limitation is defined by the value of the sense shunt and an adjustment resistor. There are 3 classes of CL: Class I - 0.5A to 1.0A; Class II - 1.0A to 2.5A; Class III - 2.5A to 5A.
The 20A outputs are created by commanding in parallel 4 of the High Current LCL's.

An output status and current telemetry of each CL is provided on 1553 bus.

Heater Distribution

The 28V regulated bus is also distributed to 80 heater outputs with a double ON/OFF switching. The first one is provided by individual electronic switches in the return lines. The second level is implemented by an electronic fuse (one per 5 outputs) in the positive supply line. This electronic fuse provides a switch-off in the event of over-current detection. Transients on the main bus are avoided, by the very fast reaction time of the EF (< 1µs) and the fact that there is no inrush current associated with the heater outputs.

Status telemetry of each switch is provided. Heater current telemetry of each group of 5 heaters is also supplied.

Interface module

An auxiliary supply converter is implemented in the module and is a standard off-the-shelf hybrid product designed and developed for other space applications.
It provides the low-level supply voltages for 1553 interface and the low-level command and telemetry circuits.

An input under-voltage ensures that the unit is inhibited when the bus voltage is of an insufficient level. An input protection prevents propagation to the main bus in the event of a failure in the converter.

The two supplies that come from the 2 redundant auxiliary converters are summed at the output to provide reliable voltages for all low-level circuitry. The design of the unit functions ensures that there is no possibility of an overload on the reliable supplies.

The baseline foresees a hot redundancy of the auxiliary supplies. However, the redundancy can be defined by external commands that activate a relay in the supply line of the nominal (or redundant) auxiliary supply.

Each auxiliary supply is dedicated to one of the redundant 1553 interfaces.
1553 interface is implemented in hardware.

The interface is compliant to the MIL-STD-1553BV notice 2 standard and is based on commercially available components.

The module also contains interfaces for the discrete commands required by the unit.

Figure 9.3.4-1 shows the Block Diagram of the PCDU with its main functions.

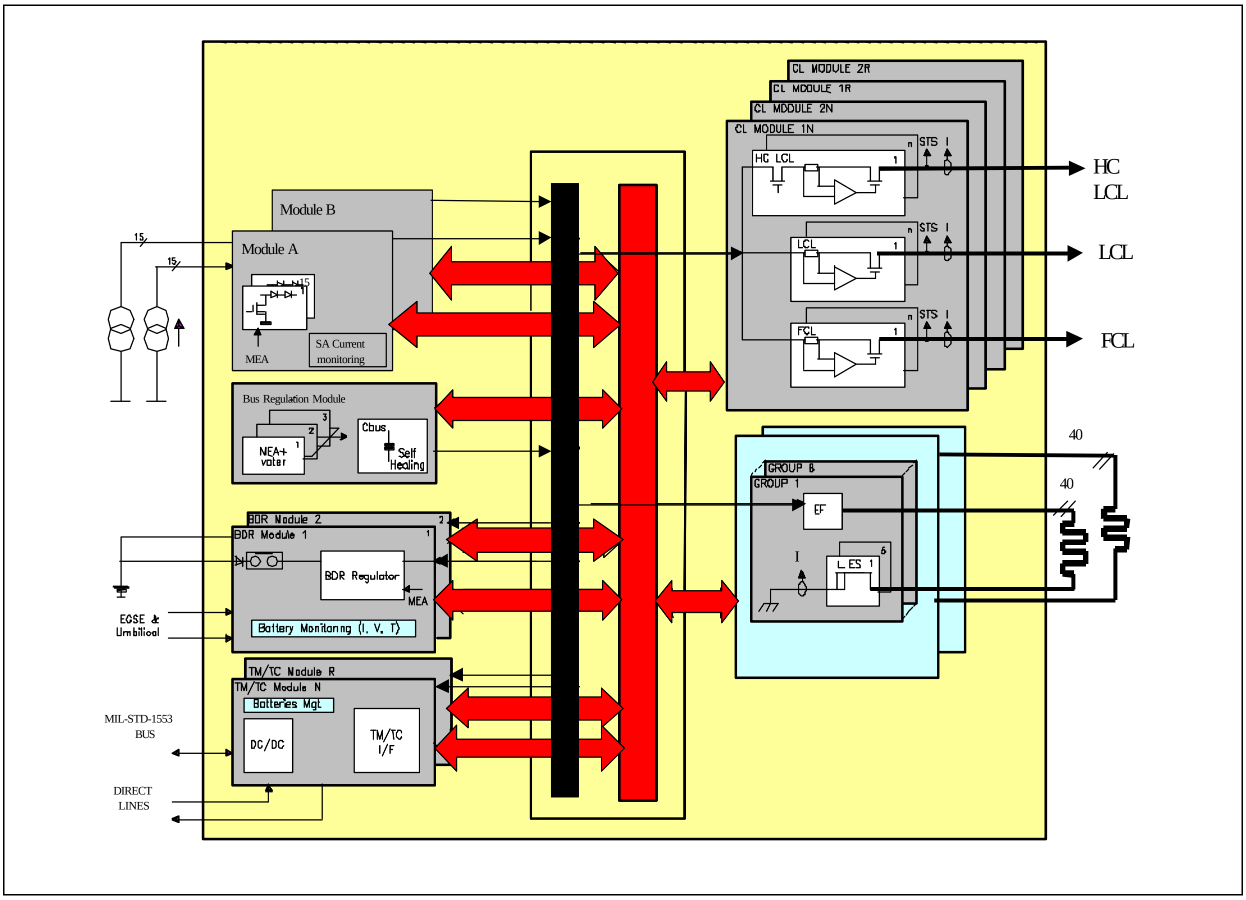


Figure 9.3.4-1 PCDU Block Diagram and Interfaces

PCDU is physically built in several modules, as listed in the following table.

MODULE	QUANTITY	MODULE FUNCTION DESCRIPTION
PCU – S^3R	2	15 non-redundant shunt sections (working with the S^3R concept) 4 of these sections can be re-routed to the battery in order to ensure the recharging SA current monitoring
PCU - BDR	2	Battery discharge regulator including internal protections Battery current, voltage and temperature telemetry
PCU – C_{BUS} and MEA	1	1.5 mF of self-healing capacitors Full reliable Main Error Amplifier (3 MEA + majority/ minority voters)
PDU - TM/TC	2	1553 interface and unit management Low level circuits for discrete interfaces and hardware battery warning
PDU - CL	4	Standard Latching Current Limiters High Current Latching Current Limiters Fold-back Current Limiters Low level circuits far interfacing with motherboard control/data bus
PDU - Heaters	2	Heater outputs Low level circuits for interfacing with motherboard control/data bus

Table 9.3.4-1 PCDU Modules

The typical PCDU design is based on a modular concept with a maximum reuse of existing power modules developed for other programs. All the functionality is implemented as separate modules mechanically plugged into the unit from the front side and electrically plugged into a common backplane.

9.3.4.2 Battery

The battery is designed to provide electrical power during launch.

With the exception of 75 minutes of eclipse during transfer orbit, Herschel and Planck are eclipse free missions. The only case where the battery is used is during launch and in case of attitude loss. Duration of this attitude loss cannot be estimated. It has to be as small as possible as during attitude loss the Sun will illuminate the PLM and thus endanger the scientific mission.

So, the battery is sized to provide power to the spacecraft during the 133.2 minutes of launch. The transfer eclipse is not considered to be a sizing case for the battery. On the contrary, the maximum eclipse time will be determined by the implemented battery.

Table 9.3.4-2 shows the Herschel and Planck power requirements, based on the power budget presented in the proposal, for the phases where battery is used as well as maximum power.

	Herschel	Planck
Power in launch mode	169 W	237 W
Safe Mode on Battery (Attitude loss)	333 W	303 W
Maximum power	1338 W	1648 W

Table 9.3.4-2 Herschel and Planck Power Budget

Including margins, the power need during launch is 169 W for Herschel and 237 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 520Wh for the battery has been derived.
In safe mode, non-essential loads and compensation heating are OFF.

In order to decrease the power in battery mode, it has been considered that, in case of loss of attitude, the payload is switched OFF.

on Herschel, this corresponds to switching OFF all instruments, which is justified by the fact that in case of attitude loss no observation is possible. In order to maintain the HIFI local oscillator operational, it can be envisaged to keep powered the FHLCU and FHLSU, corresponding to 50 W power.

on Planck, in case of attitude loss, the grooves will be illuminated by the Sun. This will lead to an increase of their temperature which is not compatible (and may be dangerous) with proper functioning of the cooling system. It is thus preferable to switch OFF the cooling system as well as the instruments. The consequence is that, after reacquisition of nominal attitude, cooling of the PLM to operational temperature will take a maximum of 4 weeks after which mission can resume. This means that 2x30 deg of longitude of the celestial sphere will be lost which will have to be acquired during the subsequent sky survey.

It is also considered that, in case of attitude loss, compensation heaters will be switched OFF.

This is obviously the case for decontamination heaters during pre-operational phase.

During operational phase, if the payload is switched OFF, compensation heaters should be switched ON to maintain the warm boxes above their start-up temperature.

Herschel safe mode power need is 333W; with a battery of 520Wh (70% DoD), the satellite can be powered for 1.5 hours

Planck safe mode power need is 303W; with the same energy, the satellite can be powered over 1.5 hours

It appears that it is preferable for Herschel and Planck not to switch ON compensation heaters in case of attitude loss. This provides the maximum duration for which the battery can supply the satellite, giving around 3 hours for sun re-acquisition. It is considered that during this short duration the electronic boxes temperature will not change significantly thanks to thermal inertia.

Other design requirements are the following.

- 70% DoD is the maximum allowed
- Voltage: 15 to 27.5 V
- No maintenance (i.e. reconditioning) is foreseen on board
- No trickle charge is required between eclipses
- Number of cycles: 100. Normally the battery only sees one cycle during flight operation. The number of 100 has been introduced to allow for some cycling on ground and loss of attitude in flight. As it appears that the number of 100 cycles, which is oversized, has an impact on cells performance, it would be interesting to reduce it to a more realistic value in order to avoid battery oversizing. The present baseline leads to consider a worst case capacity at the 100^{th} cycle of 5%

The above performances can be satisfied by two types of Li-Ion battery cells: low capacity cells and high capacity cells.

The Trade-off between low capacity and high capacity cells, as well as the selection of redundancy to be applied to the battery system, has been treated in a dedicated document, H-P-RP-AI-0002. A summary is reported in section 5.1.2 and 5.1.4 of this document.

The two trade-offs result in One Battery made by low capacity cells.

Cell Characteristics

Each of these cells has a capacity of 1.5Ah. These are assembled into modules, and a battery may 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.

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	4.2 V
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
The proposed battery configuration foresees 24 parallel strings, each one made by 6 cells in series.

Theoretical Energy (@ 100% DoD) is 777Wh. And 544 Wh with the maximum allowed DoD of 70%

The effects of a single cell failure would lead to have 4.2% less Energy, corresponding to 1 string less, and the same voltage. The resulting energy with one string failed at 70%DoD is 521 Wh.

9.3.4.3 Solar Array

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 dual 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 9.3.4-3 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.

Grounding network

To avoid electrical charges built-up on the ITO (if any) covering the cells, a grounding network shall be implemented on both Herschel and Planck.
The corners of each 4 cells are connected by small metallic pieces bonded to cells surface by means of conductive glue. At the end of the string, the cell surface is connected to substrate with metallic strap.

9.3.4.3.1 Herschel Solar Array

Structure

The Herschel solar array structure has three identical flat panels mounted by struts directly on the payload module body.
The orientation of the central panel is normal to the satellite Z-axis while the two lateral panels are at 35° from the satellite Z-axis.
The configuration of the Herschel solar array is shown in Figure 9.3.4-2.

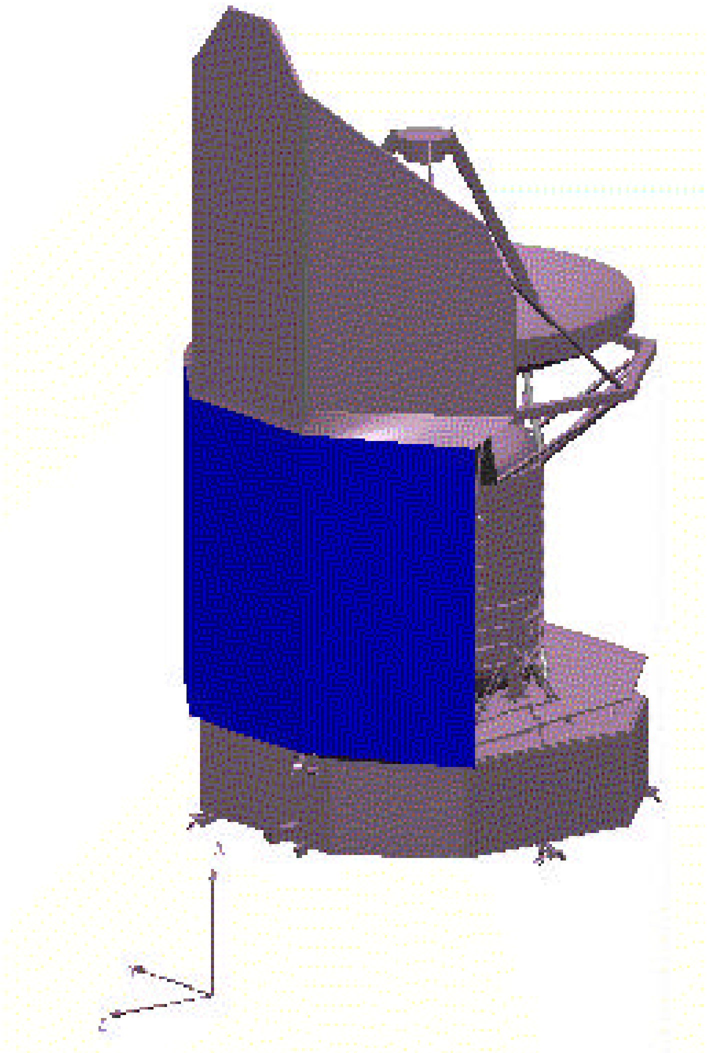


Figure 9.3.4-2 Herschel Solar Array Configuration

Mechanical interface

The mechanical interfaces of the solar array panels to Herschel 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.

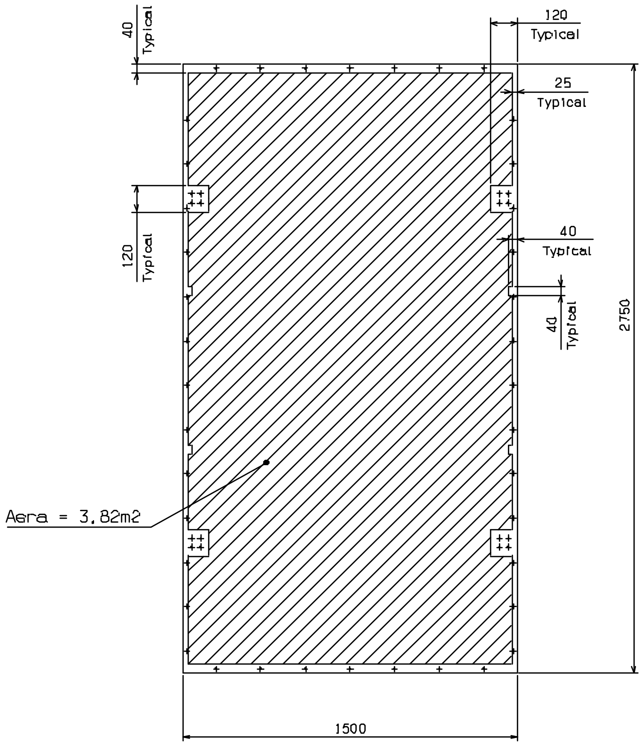


Figure 9.3.4-3 Herschel Mechanical Interface

Electrical network

The solar array is non-deployable and consists in three identical panels fully covered with multijunction GaAs cells.
The size of the usable panel is about **1450** mm **x 2670** mm giving an area of 3.82 m^2
To have identical panels has been decided to have 30 sections of solar array (10 for each panel).

Each panel is equipped with 10 sections,
- 8 sections of 7 strings in parallel
- 2 section of 5 string in parallel

For each string 21 cells in series have been considered, which is enough to ensure a minimum voltage of 30.5 V at the interface connector while compensating the losses on diodes and harness.

Routing and connections 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^2 .

Each individual string is equipped with a blocking diode.
The blocking diodes are mounted on the front side. A detailed thermal analysis will be carried out to demonstrate the adequacy of the technology to the thermal environment of the solar array.

Each string of cells is terminated by a collection bus that is connected via redundant wires to the redundant panel connectors. Positive and return lines are routed in parallel to meet the EMC requirements.
Furthermore each panel is equipped with 2 thermal sensors integrated on the front side and with 2 grounding points each one connected to 2 bleed resistors in parallel.
Connections to the panel connectors are by means of AWG22 (power lines) and AWG26 (signal lines).

Power Prediction

The power prediction is calculated at BOL and at EOL (6 years)
Losses and degradation factors to be taken into account for power prediction are listed hereafter.
The maximum SAA expected is 30° on the Z-X plane resulting in 30° for the central panel and 45° (obtained by the complex angle of 35° structural angle and 30° of SAA) for the lateral panels.

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	0.995	
Coverglass & ESD protection	0.97	
Wiring and diodes losses		2
Central panel		
Temperature	100 °C	100 °C
SAA field of view 30°	0.866	
Lateral panels		
Temperature	82 °C	82 °C
SAA field of view 45°	0.707	

EOL degradation factors	I	V
Sun intensity	1	
Radiation	1.3E+14	4.00E+14
UV and micrometeorites	0.985	
Cell mismatch	0.99	
Calibration	0.98	
Random losses	0.985	
Loss of one string	0.995	
Coverglass & ESD protection	0.97	
Wiring and diodes losses		2
Central panel		
Temperature	102 °C	102 °C
SAA field of view 30°	0.866	
Lateral panels		
Temperature	83 °C	83 °C
SAA field of view 45°	0.707	

Table 9.3.4-4 Herschel Cell Degradation Factors

The power prediction based on the described configuration and taking into account the losses and the array temperature is reported in the following tables.

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 95%.

BOL performances

Central panel @ SAA 30°	633 W
Lateral panel @ SAA 45°	513 W
Lateral panel @ SAA 45°	513 W
Total	**1659 W**

EOL performances

Central panel @ SAA 30°	576 W
Lateral panel @ SAA 45°	467 W
Lateral panel @ SAA 45°	467 W
Total	**1510 W**

Table 9.3.4-5 Herschel Solar Array Performance

9.3.4.3.2 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 9.3.4-4.

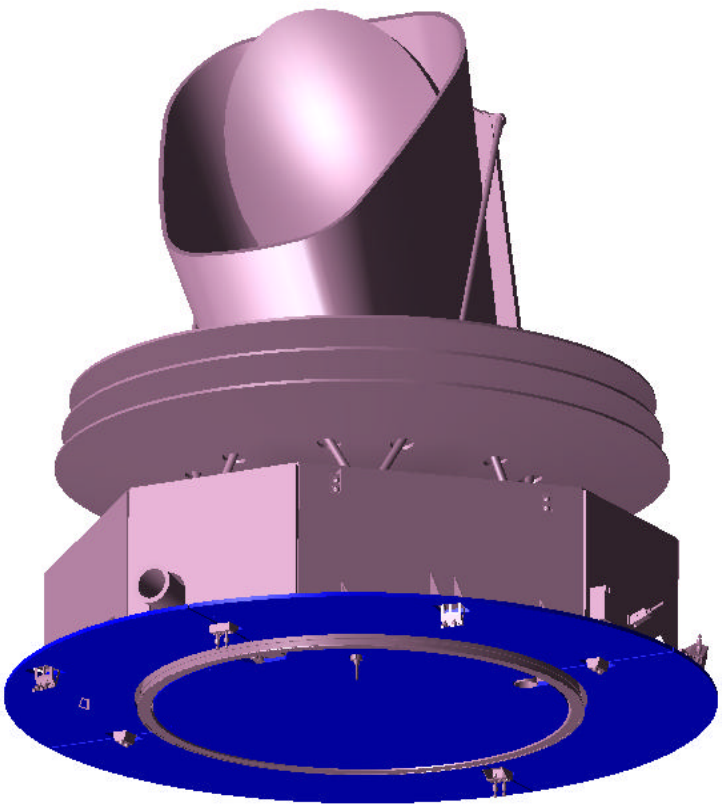


Figure 9.3.4-4 Planck Solar Array Configuration

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 9.3.4-5 shows the mechanical interface

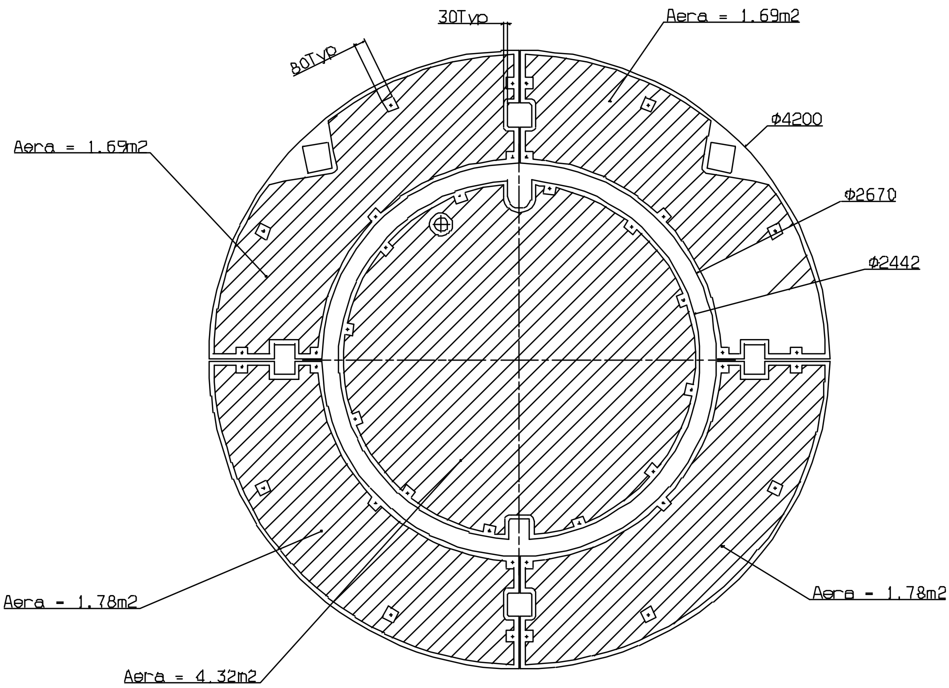


Figure 9.3.4-5 Planck Solar Array Mechanical Interface

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.

The 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 9.3.4-6 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 9.3.4-7 Planck solar array performance

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

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.

Line #	Allocation	Type	Class
1	CDMU Hot Nom	FCL	I
2	CDMU Hot Red	FCL	I
3	XPND1 Rx Nom	FCL	I
4	XPND1 Rx Red	FCL	I
5	XPND2 Rx Nom	FCL	I
6	XPND2 Rx Red	FCL	I
7	ACC Hot Nom	FCL	I
8	ACC Hot Red	FCL	I
9	Survival Heater Line Nom	FCL	I
10	Survival Heater Line Red	FCL	I

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.

Line #	Herschel Allocation	Planck Allocation	Type	Class
11	CDMU Cold Nom	CDMU Cold Nom	LCL	I
12	CDMU Cold Red	CDMU Cold Red	LCL	I
13	XPND1 Tx Nom	XPND1 Tx Nom	LCL	I
14	XPND1 Tx Red	XPND1 Tx Red	LCL	I
15	XPND2 Tx Nom	XPND2 Tx Nom	LCL	I
16	XPND2 Tx Red	XPND2 Tx Red	LCL	I
17	QRS Nom	QRS Nom	LCL	I
18	QRS Red	QRS Red	LCL	I
19	STR Nom	SPARE	LCL	I
20	STR Red	SPARE	LCL	I
21	FSS Nom	SPARE	LCL	I
22	FSS Red	SPARE	LCL	I
23	CCU Nom	SPARE	LCL	I
24	CCU Red	SPARE	LCL	I
25	PACS MEC1	SPARE	LCL	I
26	PACS MEC2	SPARE	LCL	I
27	SREM	SREM	LCL	I
28	VMC	VMC	LCL	I
29	ACC Cold Nom	ACC Cold Nom	LCL	II
30	ACC Cold Red	ACC Cold Red	LCL	II
31	TWTA 1 Nom	TWTA 1 Nom	LCL	II
32	TWTA 1 Red	TWTA 1 Red	LCL	II
33	TWTA 2 Nom	TWTA 2 Nom	LCL	II
34	TWTA 2 Red	TWTA 2 Red	LCL	II
35	GYRO Nom	LFI REBA Nom	LCL	II
36	GYRO Red	LFI REBA Red	LCL	II
37	PACS DPU-Nom	LFI DAE Nom	LCL	II
38	PACS DPU-Red	LFI DAE Red	LCL	II
39	PACS SPU-Nom	HFI PSU Nom	LCL	II
40	PACS SPU-Red	HFI PSU Red	LCL	II
41	PACS BOLC Nom	HFI 4K CEU Nom	LCL	II
42	PACS BOLC Red	HFI 4K CEU Red	LCL	II
43	SPIRE DPU Nom	SPARE	LCL	II
44	SPIRE DPU Red	SPARE	LCL	II
45	HIFI ICU-Nom	SPARE	LCL	II
46	HIFI ICU-Red	SPARE	LCL	II
47	HIFI LCU-Nom	SPARE	LCL	II
48	HIFI LCU-Red	SPARE	LCL	II
49	HIFI LSU-Nom	SPARE	LCL	II
50	HIFI LSU-Red	SPARE	LCL	II
51	HIFI WEH	SPARE	LCL	II
52	HIFI WEV	SPARE	LCL	II
53	HIFI HRH	SCE Nom	HC-LCL	III
54	HIFI HRV	SCE Red	HC-LCL	III
55	SPIRE FCU Nom	HFI 4K CEU Lock Nom	HC-LCL	III
56	SPIRE FCU Red	HFI 4K CEU Lock Red.	HC-LCL	III
57	RWA1 Nom	SPARE	HC-LCL	III
58	RWA1 Red	SPARE	HC-LCL	III
59	RWA2 Nom	SPARE	HC-LCL	III
60	RWA2 Red	SPARE	HC-LCL	III
61	RWA3 Nom	SPARE	HC-LCL	III
62	RWA3 Red	SPARE	HC-LCL	III
63	RWA4 Nom	SPARE	HC-LCL	III
64	RWA4 Red	SPARE	HC-LCL	III
65	SPARE	SCE SCC Nom	20A-LCL	20A
66	SPARE	SCE SCC Red	20A-LCL	20A

Table 9.3.6-2 PCDU LCL Budget

Mass Budget

The PCS mass budget is detailed in the following table.

Unit	Qty	Nominal Mass	Margin	Maximum Mass	Total
PCDU	1	19	15%	22	22
Battery	1	7	10%	7.7	7.7
Total Power Control S/S mass					39 kg

Table 9.3.6-3 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 do not include the thermal hardware for panels thermal insulation and the bolts for fixation.

9.4 SVM Harness

9.4.1 General

SVM Harness provides the interconnections between all electrical and electronic equipment installed on the SVM.
Harness connecting equipment of the SVM to equipment functionally allocated to the PLM but installed on SVM will be part of the SVM harness.
Harness between equipment within the instruments will not be part of the SVM harness.
Coaxial cable connecting the antenna to the Transponders through the TWTA will be part of the TT&C Subsystem.

In addition the harness will provide the electrical connections for all the TCS subsystem items (heater, thermistors and thermostats) mounted on Spacecraft.

Harness S/S provides distribution and separation of power, analogue and digital signal, commands and lines to the different unit and/or interface. The harness will includes the following items:

Cables and connectors required to perform the electrical links
Shielding provisions for the wiring
Connectors accessories and protective caps, edge protections and grommets
Harness fixation devices and associated hardware required to install the cabling on the structure and the connectors bracket mounted

9.4.2 Requirements and Design Drivers

The Herschel/Planck Harness maintain the modularity concept of the Herschel/Planck structure separation. In order to meet this requirements, allowing the module separation, a set of interface connectors are provided between the SVM and PLM modules.

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 minimise 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 are spaced at every 200 mm apart, as far as possible.
Protections will be used in correspondence with sharp edges and cut-outs, taking care to provide sufficient clearance from corners and sharp edges.

A preliminary Harness routing is designed to be compatible with the structure design which provide all the necessary connectors brackets and stand-offs devices.

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.

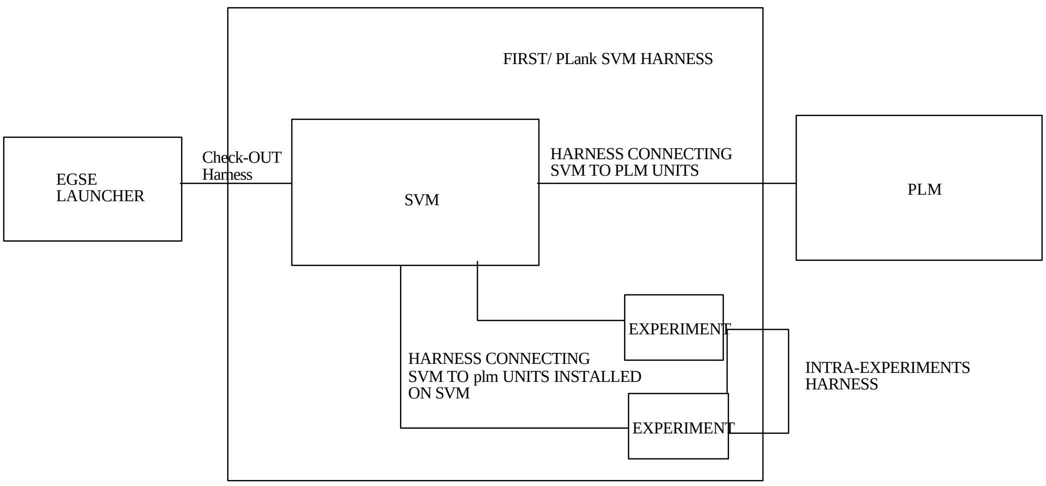
Components are selected according to specifications:

SCC 3401/001	Electrical Connectors Rectangular Coaxial and Power Contact
SCC 3401/002	Electrical Connectors Rectangular Std and High Density Contacts
SCC 3401/022	Accessories for Rectangular Connectors
SCC 3401/008	Electrical Connector Circular DBAS Type
SCC 3901/019	Wire, Cable, Low Frequency, 600V, Detailed Specification
SCC 3902/002	Coaxial, Triaxial and Symmetric Cables, Flexible, -200 to +200°C
MIL-C-85049	Connectors, Accessories, Electrical, General Specification

9.4.3 Functional Description

The Herschel/Planck 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...).

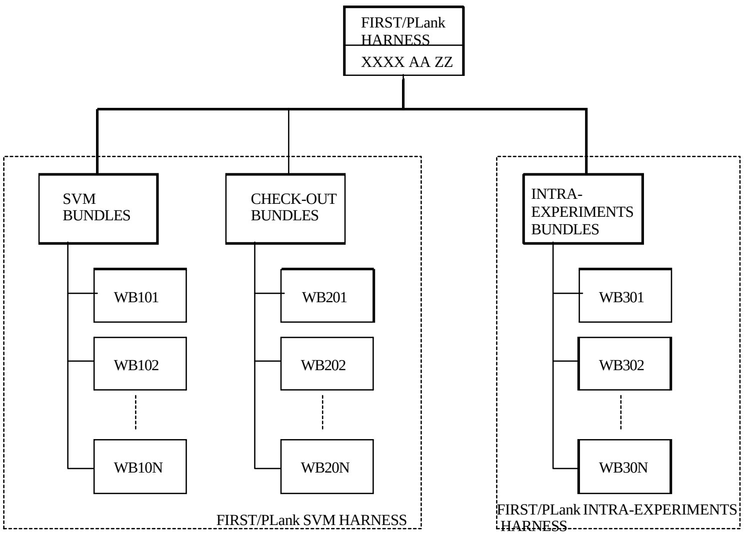


9.4.4 Design and Performance

The major components which constitute the Herschel/Planck Harness are the physically separable manufacturing segments (bundles).
The bundles shall be organised as described in the breakdown of Figure
The electrical characteristics of the bundles (wire/cable arrangement, cable type and size, shielding connection down to connector level...) are designed on the basis of signal characteristics and required performances.
Each bundle will be described and detailed with a manufacturing drawing showing the segment configuration and the associated Part List as applicable to the different models.

Harness S/S is composed by the following parts:

Cable and Wire necessary to allow the electrical connections
Connectors
Back-shells or Grounding Device (Bus-Bar) to connect the cable shields to the ground reference
Supports, clamps, grommets and accessories necessary for the Harness installation (but for connectors support brackets which are a part of Structure S/S)
Harness connectors dust caps and covers
Safe and Arm Connectors
Bonding Straps



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 and equipment location, full commonality (especially on routing) cannot be achieved.
Materials and design methods will however be common.
The following table summarizes the commonalities between the Herschel and Planck on the harness design.

FUNCTION	EQUIPMENT	LEVEL OF COMMONALITY
Launcher Interface	Skin Connector	It is assumed that the interface with the selected Launcher will be the same
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. Minor difference on materials
	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 is 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. Minor Differences on routing is expected. Minor difference on materials for cables has to be considered
	RWS	Equipment used only in Herschel design. Planck harness routing is a Sub-Set of Herschel harness routing
	STR	Equipment used only in Herschel design. Planck harness routing is a Sub-Set of Herschel harness routing
	FSS	Equipment used only in Herschel design. Planck harness routing is a Sub-Set of Herschel harness routing
	GYR	Equipment used only in Herschel design. Planck harness routing is a Sub-Set of Herschel harness routing
	SAS	Commonality achievable
	QRS	Commonality achievable
	AAD	Commonality achievable
	STM	Equipment used only in Planck design. Herschel harness routing is a Sub-Set of Planck harness routing
	PND	Equipment used only in Planck design. Herschel harness routing is a Sub-Set of Planck harness routing
TTC	All equipment	The Herschel/Planck SVM harness does not include the Coaxial Cable. All the other materials are

		considered common.
Thermal Control	Heaters	Both Planck and Herschel will use the same Heater topologies but it is expected minor modification on some location (mainly due to P/L units on SVM constraints). Minor Differences on routing is expected. Minor difference on materials for cables has to be considered
Thermal Control	Thermistors	Both Planck and Herschel will use the same thermistors topologies but it is expected minor modification on some location (mainly due to P/L units on SVM constraints). Minor Differences on routing is expected. Minor difference on materials for cables has to be considered
SOLAR ARRAY	Solar Array	Due to different Panel location the harness routing connecting the S.A. to the PCDU will be completely different

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 realise and install the cabling on the structure.

The preliminary harness mass budget has been performed as estimation in terms of connectors and cables typology and quantity due to the unavailability of a specific EICD (Electrical Interface Control Document) .

The miscellaneous parts include all those items necessary for the Harness manufacturing and installation as :

Ty-bases and Ty-raps
Mounting screws
Metallic Tape and Braid
Heat Shrinkable Tubing and Markers
Bonding Strap

The miscellaneous parts quantity estimation, and the associated equivalent mass, is normally performed on the manufacturing and installation drawings data but, for the purpose of the document and design definition, a quantity evaluation can be defined .

In the miscellaneous items mass are not included all the secondary structure, like connector brackets or dedicated harness stand-off supports, which will be considered as a part of the Structure subsystem mass.

Herschel Harness ITEM	REFERENCE
Rectangular Conn. Mass (g)	9000
Circular Conn. Mass (g)	3000
Bus-Bar and Backshell Mass (g)	3000
Total Cable Mass (g)	35000
Miscellaneous Mass (g)	5000
Herschel Harness Basic Mass (Kg)	55

Planck Harness ITEM	REFERENCE
Rectangular Conn. Mass (g)	8000
Circular Conn. Mass (g)	2000
Bus-Bar and Backshell Mass (g)	2500
Total Cable Mass (g)	35000
Miscellaneous Mass (g)	4500
Planck Harness Basic Mass (Kg)	52

Estimation is based on a very preliminary design and a task of mass optimisation has been planned with the goal to achieve the mass target of 30Kg. Presently as part of the overall MASS estimation 30 Kg will be used.

9.5 AOCS

9.5.1 Herschel – Planck Common Design

From very different missions, the ACMS design aims at the maximum commonality.
The common designed architecture between the two spacecraft foresees full functional redundancy and the use of a central attitude computer (ACC) that interfaces the On Board Data Handling computer and separately all the ACMS units.
Standard interfaces are used between ACC and other units. The control computer is inserted in bus architecture i.e. it has a single interface towards the other Subsystem at Service Module level. In a similar way the ACMS units are interfaced with the ACC using, when possible, a common, standard bus. Dedicated points to point links are used for the units not implementing the standard bus interfaces.
The operational functionality is implemented through the mode logic concept in which the transition between different modes and sub-modes is either autonomously carried out or executed under specific external commands.
A further commonality is pursued at equipment level, FDIR and software in the following way:

- Attitude Control Computer hardware and basic software are common for both satellites, even if the two Application Software are different and some interfaces are used in a single satellite.
- Sun Acquisition Sensors are used on both satellites, even if in different numbers and configurations.
- Quartz Rate Sensors are used on both satellites, even if in different configurations.
- The FDIR function is common to both satellites for what concerns its architecture, based on several levels, even if applied to different units and modes.

9.5.1.1 Herschel ACMS Design Description

The overall Herschel ACMS design description is given through the following paragraphs:

- Mode Transition Logic section in which the entry/exit conditions of each operative mode are identified and described
- Unit Level section where a brief description of the characteristics of the class of identified Computer, Sensor and Actuators is given
- Data Handling Function where the tasks of the Attitude Control Computer are described
- Modes Description section where the main features of each operative mode and the envisaged control strategy are proposed
- Modes Performance Simulations section where the results of the simulation done to assess the obtainable performance are presented.
- FDIR section where the approach to the Failure Detection and Redundancy Management philosophy is described.

9.5.1.1.1 Modes Transition Logic

The Mode Transition Logic is commanded by the occurrence of the following ACMS internal or external events:

- Reception of CDMU commands
- Expiration of Time Tagged Commands
- AAD alarm triggering
- Mode safeguard triggering (including HTOT check)
- Manoeuvre completion (including Sun Acquisition)
- FDIR driven action

For each ACMS mode, the entry condition and the envisaged exit events are described (Figure 9.5.1.1-1). The FDIR actions that remain internal to each mode (i.e. the reconfiguration of hot redounded units) are shown in the figure but considered internal to the mode and not described in the following sections. In Table 9.5.1.1-1 the proposed use of each unit in all operative modes is presented with respect to the use in control and / or in FDIR function.

	SAM	***SHM***	***STAM***	***NOM***	***WUP***	***OCM***
SAS	C-F	C-F	F	F	F	F
QRS	C-F	C-F	F	F	F	F
GYR	---	---	C-F	C-F	C-F	C-F
FSS	---	---	C-F	C-F	C-F	---
STR	---	---	C-F	C-F	C-F	---
RWS	---	C-F	C-F	C-F	C-F	---
THR	C-F	---	---	---	C-F	C-F
	C: unit used in control F: unit used for FDIR function --- unit not used					

Table 9.5.1.1-1: Mode vs Unit Use

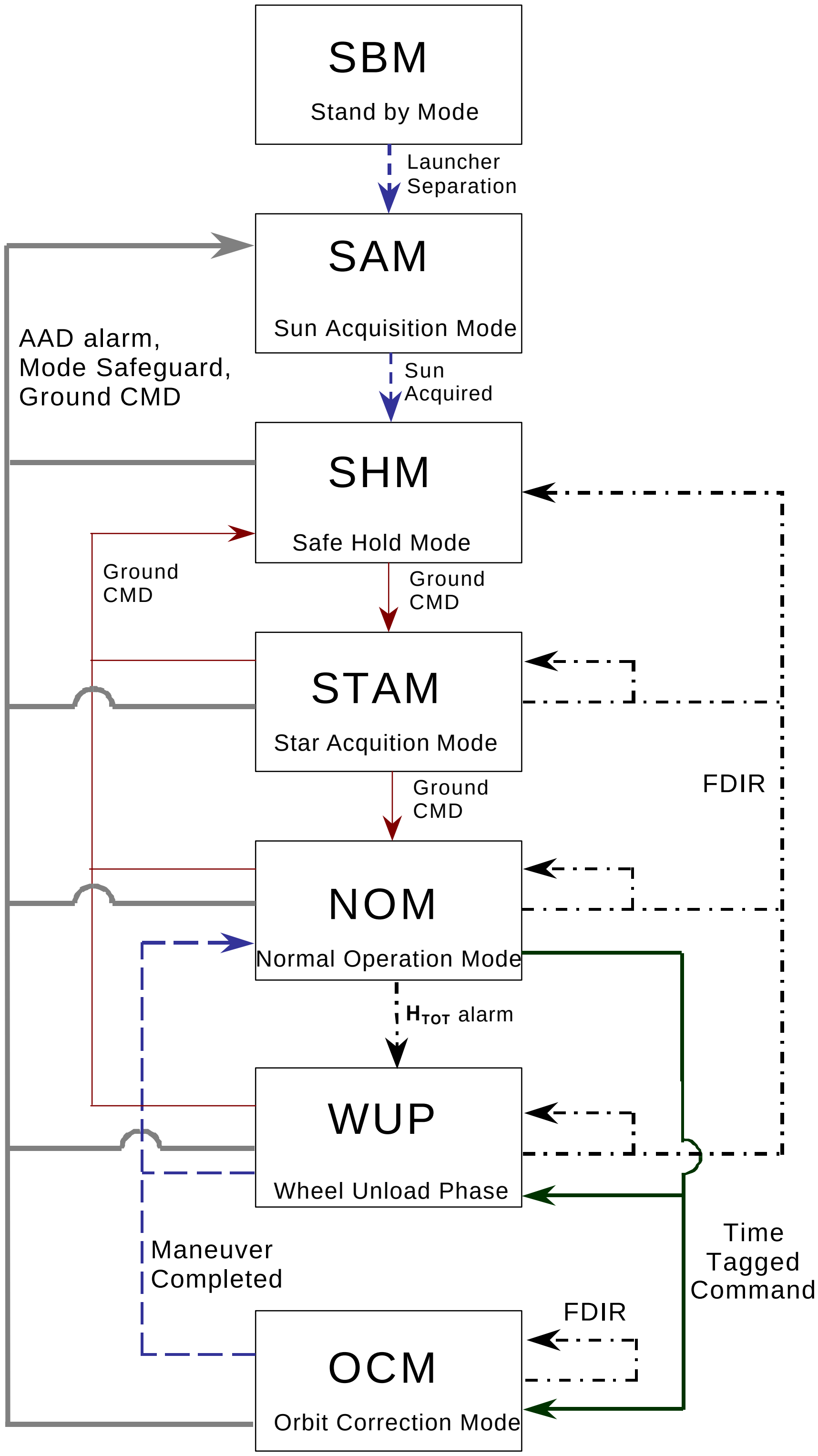


Figure 9.5.1.1-1: Mode Transition Logic

9.5.1.1.1.1 Stand By Mode

The Stand By Mode (SBM) is entered:

on ground and is active during the complete pre-launch and launch phase

The SBM is exited:

with a transition to Sun Acquisition Mode after a delay period of 60 seconds from the reception of the separation signal.

SBM re-entering cannot be executed during the in-flight mission.

9.5.1.1.1.2 Sun Acquisition Mode

The Sun Acquisition Mode (SAM) is the emergency mode entered:

at launcher separation
on ground command
as a consequence of Attitude Anomaly Detector triggering
as a consequence of Mode Safeguard triggering ($\mathbf{H}_{TOT}$ or Attitude violation)

The only exit condition allowed in SAM is:

The transition in Safe Hold Mode that occurs when the mode performance is reached.

9.5.1.1.1.3 Safe Hold Mode

The Safe Hold Mode (SHM) is entered:

as an internal autonomous transition from SAM
on ground command
as a consequence of FDIR action

The exit conditions from SHM are:
towards the higher Star Acquisition Mode (nominal exit condition) upon the reception of a ground command
in SAM in case of attitude loss detected by the mode logic or by the AAD.
in SAM in case of $\mathbf{H}_{TOT}$ check triggering
in SAM upon the reception of a ground command

9.5.1.1.1.4 Star Acquisition Mode

The Star Acquisition Mode (STAM) is entered:

on commanded transition from SHM
as a consequence of FDIR action in case of reconfiguration of hot redounded units

The exit conditions from STAM are:
towards the higher Normal Mode (nominal exit condition) upon the reception of a ground command
in SHM as a consequence of FDIR action in case of reconfiguration of cold redounded units
in SHM upon the reception of a ground command
in SAM in case of attitude loss detected by the mode logic or by the AAD.
in SAM in case of $\mathbf{H}_{TOT}$ check triggering
in SAM upon the reception of a ground command

9.5.1.1.1.5 Normal Mode

The Normal Mode (NOM) is the basic science mode that is entered:

on commanded transition from STAM
at completion of Wheel Unloading Phase
at completion of Orbit Correction Mode

The exit conditions from NOM are:

in SHM as a consequence of FDIR action in case of reconfiguration of cold redounded units
in SHM upon the reception of a ground command
in Wheel Unloading Phase in case of $\mathbf{H}_{TOT}$ check triggering
in Wheel Unloading Phase in case of expiration of a tag tagged command
in Orbit Correction Mode in case of expiration of a tag tagged command
in SAM in case of attitude loss detected by the mode logic or by the AAD.
in SAM upon the reception of a ground command

9.5.1.1.1.6 Wheel Unloading Phase

The Wheel Unloading Phase (WUP) can be considered as a NOM sub mode that is entered:

from NOM in case of $\mathbf{H}_{TOT}$ check triggering
from NOM as a consequence of the expiration of a tag tagged command

The exit conditions from WUP are:

to NOM at completion of the unloading phase
in SHM as a consequence of FDIR action in case of reconfiguration of cold redounded units
in SHM upon the reception of a ground command
in SAM in case of attitude loss detected by the mode logic or by the AAD.
in SAM upon the reception of a ground command

9.5.1.1.1.7 Orbit Correction Mode

The Orbit Correction Mode (OCM) is entered:

from NOM as a consequence of the expiration of a tag tagged command

The exit conditions from OCM are:

to NOM at completion of the orbit correction
in SAM in case of attitude loss detected by the mode logic or by the AAD.
in SAM upon the reception of a ground command

9.5.1.1.2 ACMS Units

Before describing the proposed units, a synthetic overview including their performance class in given in Table 9.5.1.1-2.

In Figure 9.5.1.1-2 possible units mechanical mounting configuration is depicted.

Unit	*Number Of Units*	*Performance Class*
ACC	1	32 bit processor
SAS	2	0.1°
QRS	2	0.01°/s
GYR	1	0.1" noise, ARW< 2 10^{-13} $(rad/s)^2$ / Hz Bias stability < 0.05 °/h (1σ) over 1hr
STR	2	FOV ~4x4deg^2 Bias stability < 1'' 1.3" NEA
FSS	2	1.7" NEA
RWS	4	0.2 Nm, 25 Nms
RCS	2 x 6 THR	10 N

Table 9.5.1.1-2: ACMS Units

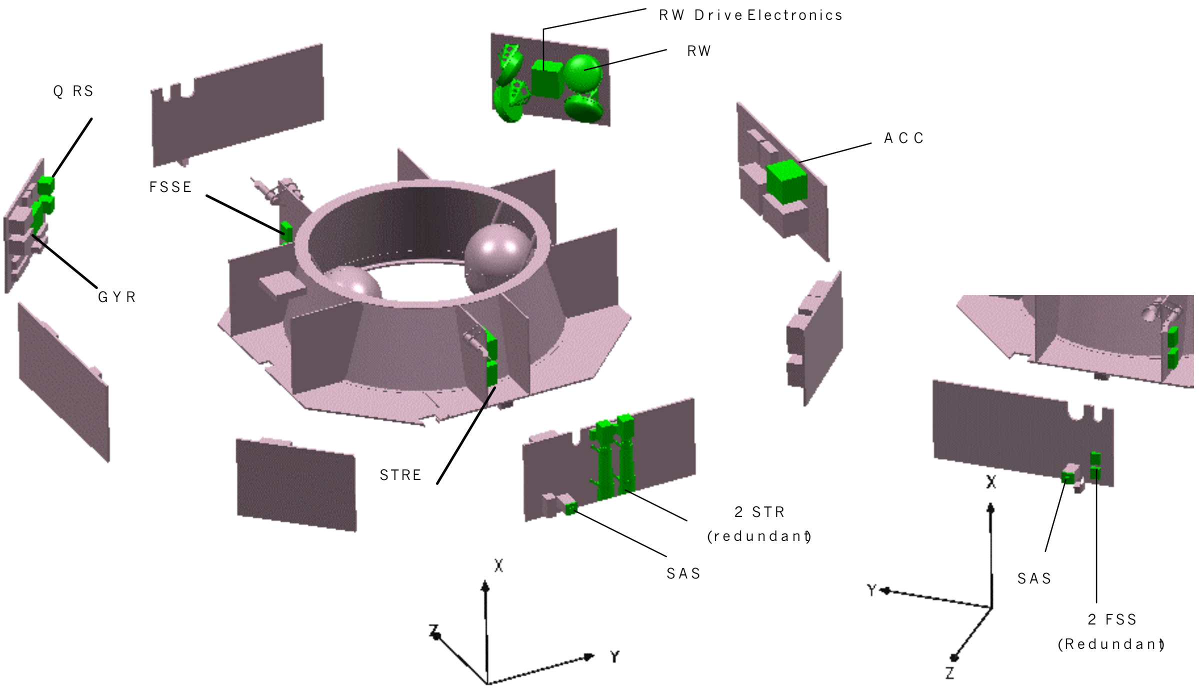


Figure 9.5.1.1-2: ACMS Units Mechanical Configuration

9.5.1.1.2.1 Attitude Control Computer

The Attitude Control Computer (ACC) contains all the hardware and associated software necessary to manage the Attitude and Orbit Control Subsystem (ACMS) units and the Reaction Control Subsystem (RCS) thrusters and valves.
Refer to paragraph 9.5.1.1.3 for the ACC software functional description.

The following functional blocks are identified and are depicted in Figure 9.5.1.1-3 together with the redundancy features:

Central Processing Unit
ACMS interfaces
Reconfiguration Module

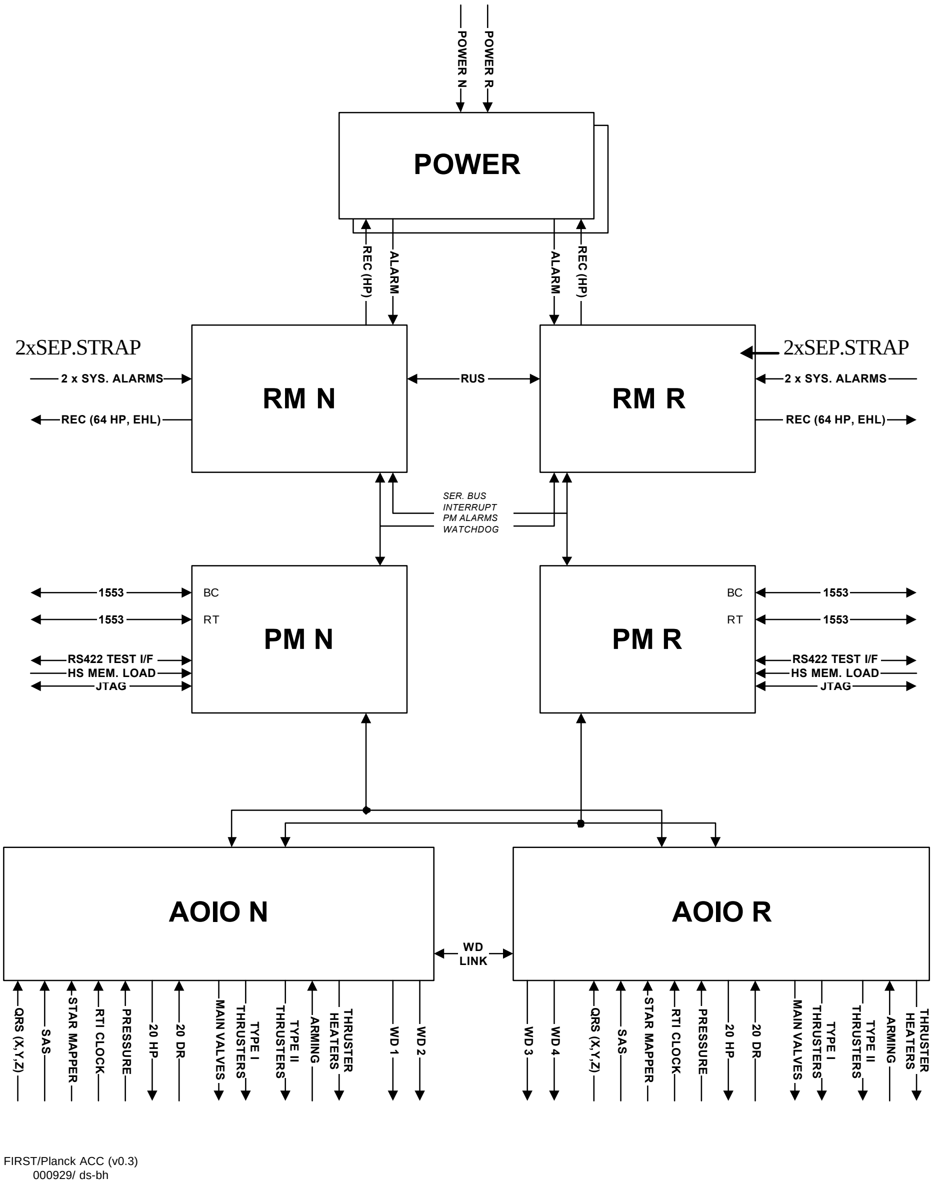


Figure 9.5.1.1-3: ACC Functional Blocks and Redundancy Features

The ACC Processor Module (PM) provides the processing function including PROMs and re-programmable EEPROMs. The PM provides communication on two MIL STD 1553 busses. For ACMS units it acts as a bus controller and for communication with the OBDH it acts as a remote terminal. The PM is also equipped with an RS422 serial link for test purposes and reprogramming of the EEPROMs. It also has an interface for high speed software load (ground use only). The ACC Processor Module is operated in cold redundancy.

The ACC provides two hot redundant Reconfiguration Modules (RM), which are accessible from the two PMs. The RMs will automatically trigger a reconfiguration in case of active alarm input. Two external alarms (AAD, THR On Time) and up to 8 internal CPU alarms (watchdog, EDAC double bit error, illegal access) are foreseen.
A dedicated input for the separation strap status signal is allocated.
The ACC provides a protected resource in the form of two safeguard memories operating in hot redundancy.
The ACC provides also two hot operating, not redundant ACMS units interface modules. (I/F to THR heaters, THR valves, SAS, QRS, RWL)

The ACC uses an internal serial I/O bus for communication between the processor module and the I/O modules. The I/O bus uses the ESA standard OBDH bus protocol. The I/O 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.

9.5.1.1.2.2 Reaction Wheel System

The Reaction Wheel System (RWS) is used in routine operation (science observation, slews and wheel unloading) for the following purpose:

- To provide the desired control torque to the satellite body to correct the attitude and perform slews.
- To store internally the accumulated external perturbing torque between two consecutive wheel unloading.

RWS are also used in Safe Hold mode after successful completion of the Sun acquisition.

The reaction wheels configuration is optimised considering the following requirement:

- During raster pointing modes maximum agility is required about axes Z and Y. Due to attitude restriction, such large slews are performed about an axis rotation close to the Z axis. Performed at constant rate, they require ~10 Nms to be transferred from the RWS to the satellite body's Z axis. Meanwhile, the internally stored momentum is transferred from the Y to the X axis.
- The solar pressure torque is maximum about Y (2. 10^{-4} Nm => 20 Nms daily accumulation), which induces a higher angular momentum storage need on this axis to support long observation runs on a single target.

Leading in an optimised skewed configuration with a skew angle of 70° about the X axis to provide a higher momentum capability in the YZ plane. As the RW are used in cold redundancy, the symmetry of the geometry gives equivalent performances to the four possible wheel configurations.
The wheels are specified to deliver each ± 0.2 Nm and store ± 25 Nms.
The following Figure 9.5.1.1-4 displays a projection of the 3D torque (or momentum) envelop shape:

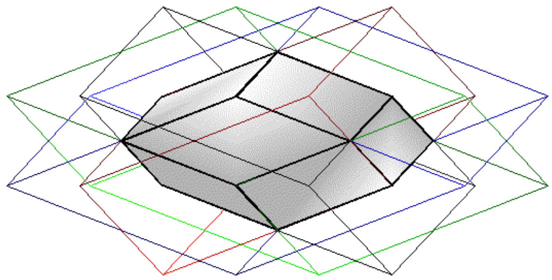


Figure 9.5.1.1-4: RWS 3D Available Torque Envelope: the four coloured volumes are the envelopes of each of the four RWS configurations, the grey polyhedron is their intersection i.e. the envelope available in any configuration.

Such a configuration guarantees the following figures:

The minimum torque available in the YZ plane for raster pointing mode slews, is 0.19 Nm
The minimum torque available in any direction is 0.13 Nm

Combining the contributions of the system's momentum and body momentum during slews, and taking a margin of 20%, the required angular momentum envelope is found to be a cylinder of radius 12 Nms and extension [-12, +12] Nms, parallel to Z axis.
The following Figure 9.5.1.1-5 displays the required angular momentum envelope (grey cylinder, including 20% margin) which fits in the available envelope (polyhedron):

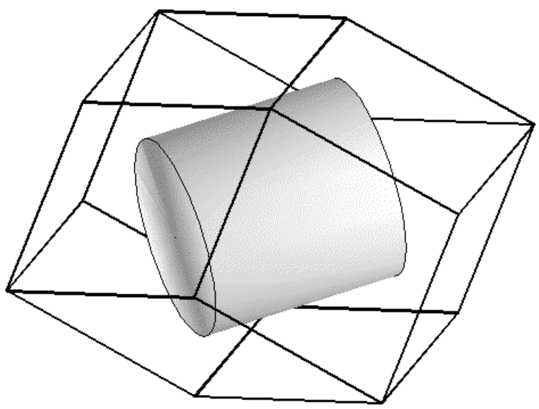


Figure 9.5.1.1-5: Required Angular Momentum envelope vs. available angular momentum envelope

9.5.1.1.2.3 Reaction Control System

The Reaction Control System (RCS) is used in:

Sun Acquisition Mode where the torque actuation on the three axes is commanded
Wheel Unloading Phase where the momentum accumulated on the RWS is properly managed
Orbit Correction Mode when the ΔV manoeuvre is performed

The proposed thruster configuration is shown on in Figure 9.5.1.1-6:

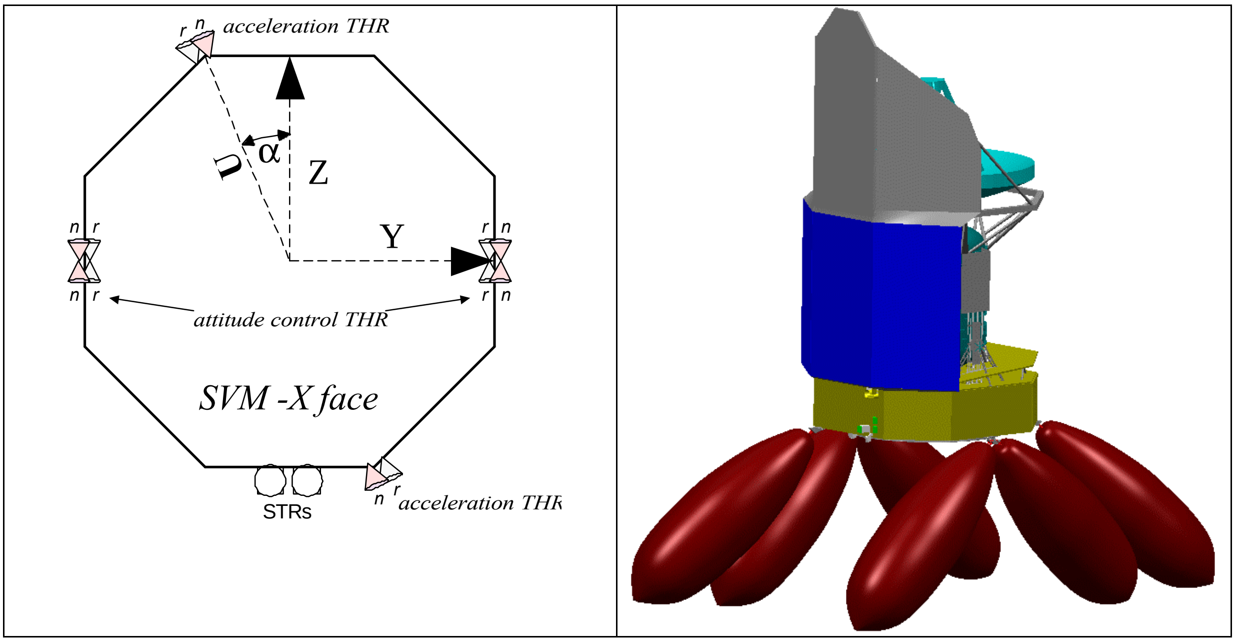


Figure 9.5.1.1-6: Thruster Configuration and Plume

The RCS is implemented in 2 identical branches (nominal and redundant) of 6 thrusters each.
For each branch:

2 thrusters, indicated in figure as Acceleration THR and 22.5° tilted w.r.t. XZ plane, are used to produce the desired acceleration in ΔV mode (one for ΔV with SAA < 90°, the other for ΔV with SAA > 90°)

4 thrusters to produce the control torque both in ΔV mode and in wheel unloading phases. All thrusters are inclined by ~45° towards the –X satellite axis, thus avoiding contamination risks for SVM equipment.

9.5.1.1.2.4 Attitude Anomaly Detector

The AAD function is performed inside the Fine Sun Sensor unit.

9.5.1.1.2.5 Sun Acquisition Sensor

The Sun Acquisition Sensor (SAS) is used in Sun Acquisition and Safe Hold Modes as principal sensors, and in all the other operative modes in the FDIR function. In order to accomplish the required performance, the selected configuration is able to cover the full sky sphere. Two SAS, internally redundant, are mounted in anti-parallel configuration along Z axis. Since each SAS covers a FOV of 2Π srad, the required sky coverage is ensured, as depicted in Figure 9.5.1.1-7.

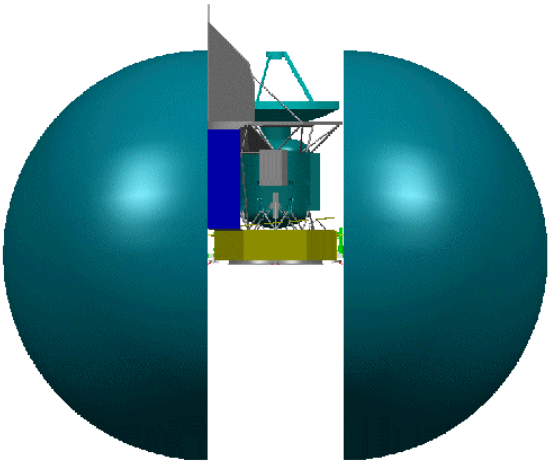


Figure 9.5.1.1-7: Sun Acquisition Sensor Field of View

Due to mission orbit characteristics, eclipse is foreseen only during a transfer orbit phase where the SAS use shall be excluded. Resulting accuracy class is given in Table 9.5.1.1-3. This accuracy prevents the use of SAS in science modes, but fulfils the basic mode requirements.

Parameter	*Range*
Accuracy (bias excluded)	0.1 °

Table 9.5.1.1-3: SAS Characteristics

9.5.1.1.2.6 Quartz Rate Sensor

The Quartz Rate Sensors (QRS) are the main SAM and SHM sensors and used in other modes for FDIR. In addition, QRS are available as sensor rate back up in science modes in replacement of GYR.
The nominal QRS function is to provide the measurement of Z axis rate. An ad-hoc skewed configuration with respect to Z axis is proposed to supply a redundant information of the rate about the Sun vector. The requested measurement is obtained computing the median of the three orthogonal sensor outputs, thus ensuring the measurement reliability. Two QRS units are envisaged, to be operated in cold redundancy for protecting the ACMS from any QRS failure. The 3D angular rate measurement results to be redounded, being available also as a back-up feature. The QRS accuracy class is given in Table 9.5.1.1-4.

Parameter	*Range*
Accuracy	0.01 °/s

Table 9.5.1.1-4: QRS Characteristics

9.5.1.1.2.7 Gyroscope

The gyroscopes (GYR) complete the STR data in Normal Mode during science observation phases and in Wheel Unloading Mode to feed the attitude estimation filter. In Orbit Correction Mode and during long slews, GYR are used as unique sensor, because the induced high thruster perturbing torque prevents the use of STR data. In Star Acquisition Mode GYR are used to control the S/C with the requested accuracy in order to allow the initial star acquisition.
A skewed sensor configuration of four units, with three sensors data used in control is proposed to be operated in hot redundancy; in this way the consistency check at unit level can be computed.

The main GYR characteristics needed to cope with the mission requirements are given in the following Table 9.5.1.1-5.

Parameter	*Range*
Readout noise	< 0.1 arcsec (σ)
Angular Random Walk	< 2 10^{-13} $(rad/s)^2$ / Hz
Bias stability	< 0.05 °/h (σ) over 1hr

Table 9.5.1.1-5: GYR Characteristics

9.5.1.1.2.8 Star Tracker

The **Star tracker (STR)** combined the FSS is used as major sensor for scientific pointing phases, providing a stable absolute reference with respect to the inertial space. The few arcsec accuracy required for the absolute pointing performance leads to select a narrow field sensor (~4 x 4 deg^2) with low spatial bias. With such a FOV the full sky access is ensured if the instrument limit magnitude is Mv = 8. Full measurement accuracy is provided on the transverse directions of the STR line of sight. The STR LOS of both the units is mounted parallel to -X axis and the configuration includes two units in cold redundancy as depicted in Figure 9.5.1.1-8.

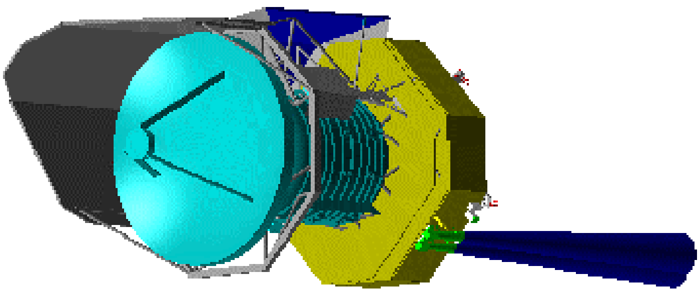


Figure 9.5.1.1-8: Star Tracker Field of View

The units will be equipped with a dedicated baffle able to withstand a Sun Avoidance Angle of at least 60°. With such a baffle, the full performances of the STR is guaranteed during the all observation phases; in addition the instrument is capable, if powered on, to allow the temporary presence of sun inside its FOV.
When high angular rate is required (7 arcmin/sec), STR can't be used to feed the estimation filter, because of its limited tracking capability.
The functionality required to STR involves:

- multiple star tracking capability
- complete FOV mapping

The STR performance, compliant with the mission needs, are presented in the following Table 9.5.1.1-6:

Parameter	*Value*
Limiting magnitude	8
Field of view	4 x 4 deg^2
Acquisition rate	2 Hz
Bias	< 1 arcsec (σ)
Bias spatial variation	< 1 arcsec (σ)
Noise equivalent angle	<1.3 arcsec (σ) at 2 Hz
Cooling system	Electrical (Peltier)

Table 9.5.1.1-6: Star Tracker Characteristics

9.5.1.1.2.9 Fine Sun Sensor

The Fine Sun Sensor (FSS) is used to:

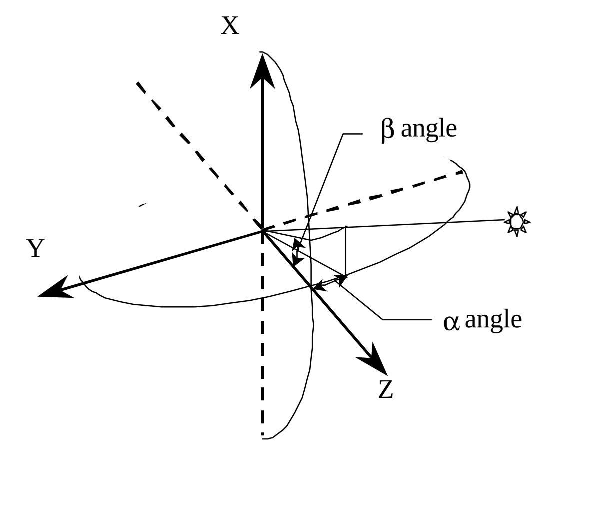
Implement the Attitude Anomaly Detector (AAD) function.

The AAD data is used as an alarm to generate a signal when the ACMS violates the attitude domain with respect to the sun.

Determine the sun vector components in the XY plane.

The FSS data, with STR output and GYR measurements are used to feed the attitude estimator filter in the scientific modes. The proposed configuration envisages the use of two units operated in cold redundancy.

To calculate the sun vector components, the each FSS is charge to measure the angles α and β, where α is the angle between the Z axis and the projection of the Sun Vector onto the YZ plane and β is the angle between the Z axis and the projection of the Sun Vector onto the XZ plane, as depicted in Figure 9.5.1.1-9.



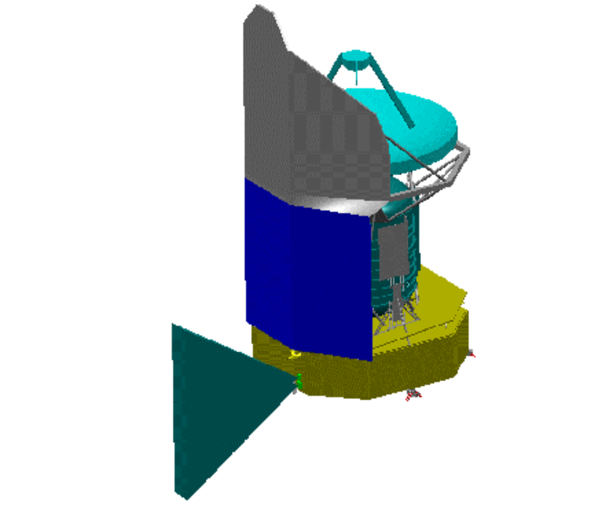


Figure 9.5.1.1-9: FSS Reference Frame vs. Herschel Reference Frame

To cope with the allowed attitude pointing domain, the FSS requested Field of View is at least ±10° about X axis and at least ±35° about Y axis, as depicted in Figure 9.5.1.1-9.

The FSS is able to provide the absolute accuracy as specified in the following Table 9.5.1.1-7.

Altitude	*Slew Rate*	*Bias (3 s)*	*Bias Stability (3 s)*	*NEA (3 s)*
$1.5x10^6$ Km	< 420 "/s	100 "	60 "/hour	5 "

Table 9.5.1.1-7: Fine Sun Sensor Characteristics

9.5.1.1.3 Data Handling Function in Attitude Control Computer

The high level (so called Application) Software running inside the Attitude Control computer must, as principal scope, perform the execution of the algorithm devoted to the spacecraft attitude determination and control. In addition to this main task, several other activities are carried out to provide ancillary functions needed to cover all the requirements applicable to the ACMS.
The most important functions belonging to this category are:

Interface with the On Board Data Handling computer

Synchronisation of the ACMS time with respect to the on board time

Reception, queuing and command integrity check

Command analysis, scheduling and execution

Attitude Operative Plan handling from initial checks to final execution

Packing and reconfiguration of telemetry data

Monitoring of sensors and actuators data

Failure detection and recovery

Data collection from specific functions

Capability to modify the executable SW and database values

Hereafter a brief description of each of the above mentioned item is proposed.

Interface with the On Board Data Handling computer
This piece of SW has in charge the handling of the MIL STD 1553 link between OBDH and ACMS computers. It has a low level section that monitor the correctness of bus transaction (the number of expected word is correct, the command is allowed etc.) whilst a higher level handle the implemented protocol (i.e. Watch- dog, Broadcast transaction re-transmitted to ACC bus in HERSCHEL etc.)

Synchronisation of the ACMS time with respect to the on board time
Another necessary function to implement is the synchronisation between the ACMS time and the on-board time. This is a very important issue because time tagged commands (specially referred at AOP execution) must be in agreement between ACMS operations and Payload configuration. As a consequence the on board time is generated by the OBDH while the ACC must implement a dedicated function transferring the OBDH time in ACC time

Reception, queuing and command integrity check
When a command referred to an ACMS activity (i.e. Unit configuration, Database values collections etc.) is received by the ACC computer, it has to be accepted, queued, in case more than one command per cycle are received, and checked. Syntactic checks are foreseen to verify the consistency of the command structure, the presence and the validity of specific fields and also the CRC correctness (TBC).

Command analysis, and execution
Once the command has been successfully checked, the validity of the command itself is verified. If the command is compatible with the current ACMS mode and the constraints associated to the command are not violated it is activated.

Attitude Operative Plan handling from initial checks to final execution
The Attitude Operative Plan (AOP) is Special commands. They will modify the attitude of the spacecraft and therefore all the above describe checks must be performed. In addition when the command becomes active, the correct manoeuvre is executed. This means that in principle many different attitude have to be computed, planned and executed before having finished the effect of the command. All the SW that, starting from the target quaternion, computes the intermediate attitude and defines the trajectory to follow is part of this module. Also the verification that each portion of manoeuvre does not violate the attitude domain is here contained.

Packing and reconfiguration of telemetry data
Telemetry shall contain unambiguous status information relevant to the fixed data fields. A useful feature in debugging in-flight problems is the capability to reconfigure the telemetry data contents. Assuming fixed the data budget allocated to ACMS, the contents of some telemetry fields can be modified when not-nominal behaviour are autonomously detected on board or a specific command is issued from ground.

Monitoring of sensors and actuators data
A dedicated SW function has been designed to monitor the data coming from the ACMS units, verify their congruence w.r.t. past values and w.r.t other units values. When problem are detected in this frame either change in telemetry data is commanded or the dedicated Recovery action are commanded

Failure detection and recovery
If the previous described function or other specific features detect a failure on a unit or a violation of the mode constraints, this SW module is activated. This module is in charge to perform the mode transition as described in the FDIR paragraph and handle the units (power on and off or reconfigure) depending on the redundancy philosophy adopted.

Data collection from specific functions
Specific commands require the collection of large amount of data mainly referred to different time. An example is the STR mapping that could last more than 60 sec and a lot of data coming from the instrument are to be stored each cycle in the ACC RAM. To be able to handle these data a dedicated SW module has been designed. For each data sample the time in which they have been acquired has to be reported and also the type of data collected since the same module can be used for other collecting functions (for example Event Related Data).

Capability to modify the executable SW and database values
A very important feature that has to be implemented is the capability to modify the running executable SW and the relevant database. Special attention has to be paid to avoid dangerous operations such as unwanted modifications of the low level SW interface driver and/or parameters referred to safeguards. In these latter cases dedicated protection must be handled.

9.5.1.1.4 Modes Description

To fulfil all the requirements the design of HERSCHEL ACMS is logically conceived in the following modes:

Stand By Mode

Sun Acquisition Mode

Safe Hold Mode

Star Acquisition Mode

Normal Operation Mode

Wheel Unloading Phase

Orbit Correction Mode

The logic regulating the transition between the modes have been presented in the above paragraph 9.5.1.1.1 while in the following sections the functional description of each mode is given.

9.5.1.1.4.1 Stand By Mode (SBM)

The mode is active during the pre-launch and launch phase in order to ensure the rapid attitude control activation after the launcher separation; the ACC only is running. This is a passive mode: no control law is implemented.
After separation the ACMS is fully operational within 20 seconds as required. However, the transition to SAM is inhibited for 60 seconds after separation in order to minimise the risks of contaminating PLANCK with the HERSCHEL RCS.

9.5.1.1.4.2 Sun Acquisition Mode (SAM)

The Sun Acquisition Mode is the emergency mode where the control law is based on RCS as actuator and SAS and QRS as sensors.

The SAM objective is:

- acquire the Sun
- reduce the rotation rate about the Sun vector
- unload the angular momentum eventually stored in RWS when the mode is entered from SHM, STAM, NOM, WUP.

The RCS actuators are used for 3-axis control for the following reasons:

- extreme sensitivity of the payload to direct Sun exposition that implies the fastest possible sun re-acquisition.
- the initial (after separation) system angular momentum may be as high as 100 Nms beyond the total RWS capacity
- need of torque capability to unload RWS

Due to the fact that SAM is the emergency mode entered in case of alarms, the following design rules have been considered:

- The Sun acquisition relies on redundant sensors and actuators that are not used in the ACMS mode that caused the fallback transition
- The Sun acquisition can be successfully performed with any initial conditions, i.e. unknown initial attitude and rates. The maximum initial rates considered are the worst case rates at launcher separation
- The ground command forcing the SAM activation has to be considered as emergency operation similar to ACMS power cycling.

The entry in SAM, apart from launcher separation, implies the complete reconfiguration of the units to be used. These features requested a complete RCS branch redundancy.

The used SAS configuration allows detecting the sun position through the complete sky sphere. The control about the sun vector is performed using the QRS output, once the sun is aligned to Z axis. The control of the rate about Z axis is needed to dump the angular rate to reach the correct transition conditions to Safe Hold Mode.

9.5.1.1.4.3 Safe Hold Mode (SHM)

In Safe Hold Mode the control law is based on RWS as actuator and SAS and QRS as sensors.
The SHM function is to ensure:

- the +Z axis is pointed towards the Sun
- a slow angular rate about Z axis (~ 0.5 round per hour) obtained by transferring 5 Nms from the RWS to the +Z

This condition can be maintained indefinitely and will prevent the system angular momentum to diverge due to the accumulation of the solar pressure torque.
The SHM is used also to execute the reconfiguration of the cold redounded unit, in consequence of a problem detected by the FDIR function.
The SHM is in charge of monitoring the angular momentum stored in RWS and in case of overcoming a predefined threshold, the transition to SAM is commanded. This condition could be a consequence of an entry in SHM from higher modes in a critical condition from the $\mathbf{H_{TOT}}$ point of view (for example, a problem occurred during WUP).

9.5.1.1.4.4 Star Acquisition Mode (STAM)

In Star Acquisition Mode the control law is based on RWS as actuator and GYR, FSS and STR as sensors. The SAS and QRS data, even if not used for control, are handled to provide independent data for the mode logic safeguards (Sun pointing domain, stored angular momentum and angular rate about Z axis) and FDIR function.
The STAM function is to ensure the 3-axis inertial attitude determination through:

- +Z axis pointing towards the Sun, using FSS
- the angular rate damping about Z axis (~ $\mathbf{10^{-3}}$ **°/s**), using GYR, in order to allow STR operability
- execution of a set of analysis of stellar fields through STR command:
  - Mapping with the complete FOV scan
  - Searching where a limited area of the FOV is scanned

The chosen angular rate about Sun vector is small enough to allow the star detection with the highest sensitivity (Mv=8) guaranteeing the full sky coverage.
The sequence of STR operations is supported from ground. When the guide stars are acquired in the STR FOV, the S/C remains inertial fixed using FSS and STR, until the transition to science mode is commanded by ground.
This mode is used to handle the possible eclipse condition experienced during transfer orbit. Control relies on GYR sensors only, and FDIR function involving solar detector is disabled.

9.5.1.1.4.5 Normal Operation Mode (NOM)

In Normal Operation Mode the control law is based on RWS as actuator and GYR, FSS and STR as sensors. To reach the required performances in term of pointing errors and manoeuvrability a refined control law is envisaged based on dynamic filtering of data provided by different sensors and allowing fine actuators commanding. The proposed control law is a PD law following a reference profile (with feed-forward torque supplied during acceleration and braking phases) integrated with an automatic gain adaptation module.
The SAS and QRS data, even if not used for control, are handled to provide independent data for the mode logic safeguards (Sun pointing domain, stored angular momentum) and FDIR function.
This mode is devoted to perform the scientific observations. It covers, as a single mode, all the following required types of pointing and manoeuvre:

- Fine pointing
- Raster pointing
- Raster pointing with off position
- Tracking of solar system objects
- Nodding
- Line scanning mode
- Line scanning mode with off position.

The sequence of pointing target directions is autonomously generated following the ground up-linked Attitude Operation Plan.
The attitude estimation is based on a gyro-stellar-sun filter and this mix of sensors allows the fulfilment of all the performance requirements as described hereafter.

During pointing and scanning phases:

- the perpendicular Line of Sight (LOS) of FSS and STR guarantees the maximum accuracy. Nevertheless to meet the stringent requirement on RPE, the use of gyro data is envisaged to reduce the FSS / STR sensor noise.
- the contemporary use of STR and FSS allows the GYR drift calibration
- the star-hopping is envisaged because the maximum length of a line scan (20°) exceeds the STR FOV diameter (5°)

During long slew phases:

- GYR data integration is used because the rate exceeds the STR limits

The characteristics of NOM allow its use for daily ground contact without suspension of observations.
NOM represents also the starting and final state of Wheel Unloading Phase, either in case of nominal transition commanded by ground, or in case of excessive RWS angular momentum storage.
NOM is also used to establish the correct initial attitude for Orbit Correction as well as the return state at manoeuvre completion.

NOM is used to perform the following calibrations:

- GYR mounting matrices and scale factor, through the execution of manoeuvres with slew axis controlled with FSS or STR, and initial and final attitudes based on STR and FSS data only
- GYR drift (inertial pointing maintained only with STR and FSS data)
- FSS / STR misalignment, through inertial pointing maintained only with two stars tracked by the STR and FSS data.
- FSS calibration through a series of inertial pointing maintained only with two stars tracked by the STR and the Sun placed in different position in FSS FOV.
- SAS calibration during the FSS calibration phases
- QRS calibration during the GYR calibration phases

9.5.1.1.4.6 Wheel Unloading Phase (WUP)

Wheel unloading is executed activating RCS to generate a torque needed to compensate the angular momentum stored in the RSW.
The RWS unloading is performed during the daily communication phase, while the scientific observation performance is maintained. Therefore, the WUP does not constitute a specific ACMS mode, but a particular phase of the fine pointing mode; as a consequence of this, WUP uses the NOM safeguards and FDIR function.
WUP consists of a sequence of THR pulses. Since the THR pulse sequence is operated in open loop, THR are not seen in this phase as ACMS actuators, but rather as external perturbations.

The THR pulse sequence is computed on board taking into account:

- the difference between current RWS momentum and the target momentum provided by ground command
- overall sensor constraints (i.e. compatibility with the STR operative conditions)

WUP can also be triggered autonomously from NON, when the onboard stored momentum exceeds a threshold.

9.5.1.1.4.7 Orbit Correction Mode (OCM)

The Orbit Correction Mode uses RCS as actuators and only GYR as sensor. The OCM objective is to ensure:

- the transfer manoeuvre from the launcher to the final operative orbit
- the periodical ΔV manoeuvre to re-adjust the orbit

To successfully perform the orbit correction, an accurate attitude initialisation is performed in NOM, which constitutes the entry point for OCM. The target pointing is constant with respect to inertial space during the whole manoeuvre. At manoeuvre completion the transition to NOM is performed to verify the attitude correctness.

A possible GYR or THR branch reconfiguration can be performed remaining in this mode, whereas the triggering of Sun pointing domain alarms cause a transition to SAM.

9.5.1.1.5 Modes Performance Simulations

9.5.1.1.5.1 Sun Acquisition Mode

The Sun Acquisition Mode strategy has been validated with a MATLAB simulator, implementing all sensors (SAS, QRS) and actuators (THR) used in this mode, with their specified performance (Table 9.5.1.1-2).
The initial conditions, were representative of worst case conditions at launcher separation (attitude error = 1°, angular rate = 1°/sec on Y and 0.6 °/sec on X). The Sun Acquisition Mode is entered 60 seconds after separation.
Figure 9.5.1.1-10 displays the trajectory of the Sun vector in the Satellite Reference Frame from the SAM entrance (t = 60 sec after separation) until t = 1000 sec.

The attitude constraints are met within 300 seconds, according to SMAC-010, as shown on the following figure:

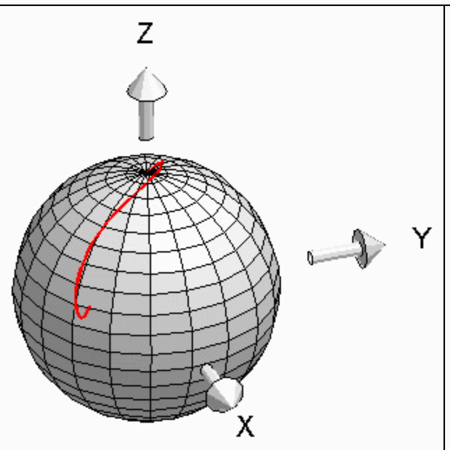


Figure 9.5.1.1-10: Trajectory of sun vector in satellite reference frame during SAM

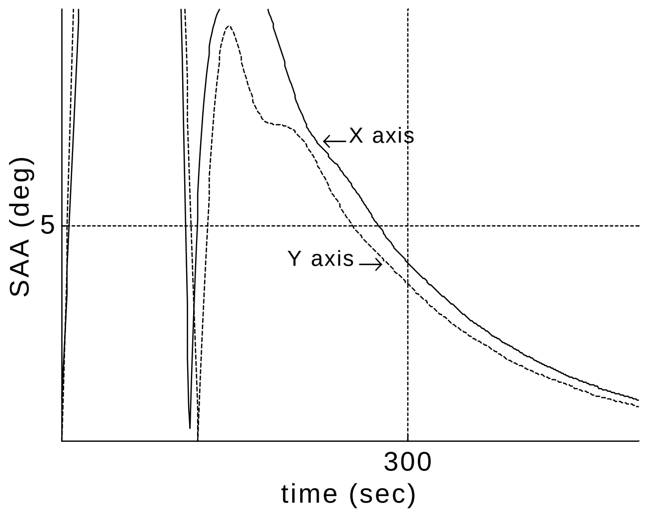


Figure 9.5.1.1-11: SAA during SAM

9.5.1.1.5.2 Safe Hold Mode

The Safe and Hold Mode strategy has been validated with a MATLAB simulator, implementing the full satellite dynamic:

rigid body 3 axes dynamic

RWS with stiction and friction, accuracy and resolution as specified in section 9.5.1.1.2.

drift of Sun direction w.r.t. inertial space due to orbital motion (1 °/day)

Sensors are the same as in SAM.

The simulation starts with a SAM phase (same initial conditions as in previous section). At SAM completion (criterion is: SAA + rate * 0.5 sec < 0.5°), the transition to SHM is prepared continuing to control on THR while an angular momentum is loaded on the wheel, in order to avoid controlling on wheels near 0 rpm.
Transition to SHM is triggered when the RWS reach their target momentum ± 0.2 Nms (an internal loop based on tachometry compensates the friction torque to guarantee the convergence to the target momentum). The solar pressure torque is 2.3 10^{-4} Nm on the Y axis (corresponding to an angular momentum increment rate of 20 Nms / day in inertial pointing). The target rotation rate about Z is 0.5 rounds per hour.

The main results obtained over 4 hours (2 satellite rotations) are displayed on Figure 9.5.1.1-12:

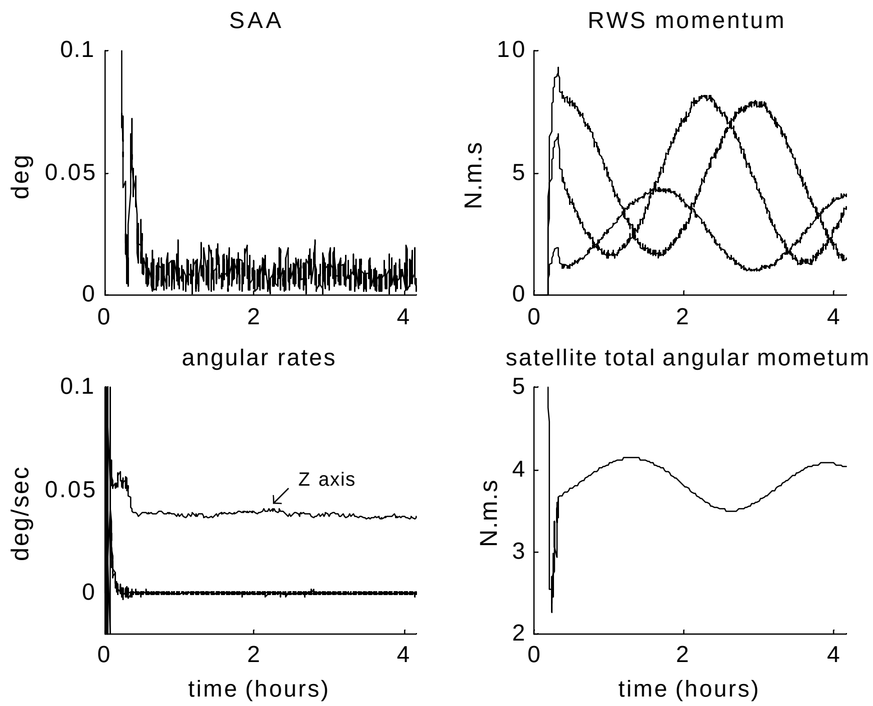


Figure 9.5.1.1-12: SHM main results over 4 hours

The stability of the mode over 7 days (autonomy requirement) has been assessed by running a simulation over 7 days. Results are displayed on Figure 9.5.1.1-13:

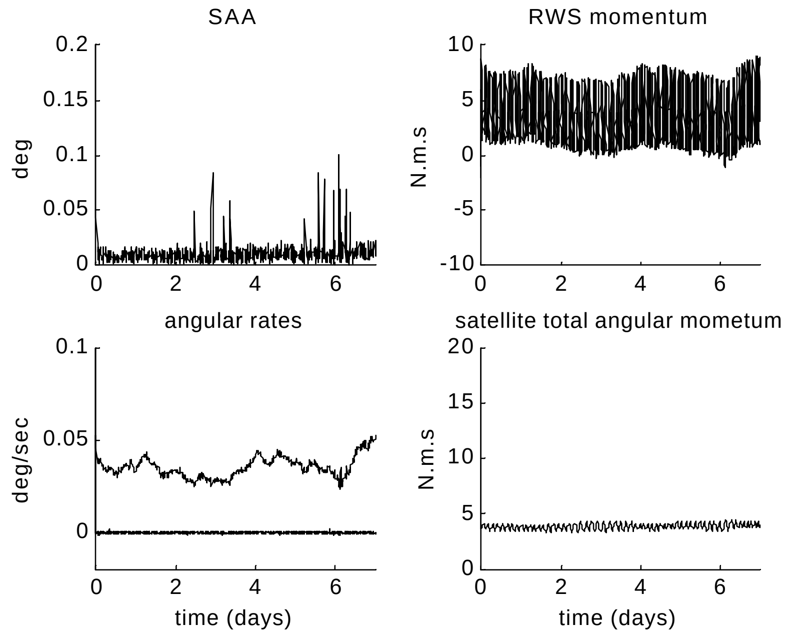


Figure 9.5.1.1-13: SHM results over 7 days

The Z axis remains Sun pointed ± 0.1° during the full 7 days period, and the angular rate about the Sun vector close to the target value (0.5 rph). Variations in the angular rate are due to the QRS bias drift.

The RWS momentum excursion are due to the rotation about the Z axis, which causes the RWS momentum to be counter rotated wrt the satellite body. It is thus alternatively transferred between the 3 operational wheels. During 2 periods (day 3 and day 6), the SAA excursion are higher than on average. During these periods, one of the 3 operational RWS is undergoing wheel speed reversal twice per satellite revolution. Due to stiction, the RWS friction torque shows a sharp discontinuity at wheel speed reversal.

The satellite total angular momentum remains fairly constant during the 7 days, with sine variations at the rotation frequency. The net increment over the 7 days is due to the wind mill torque, which amounts to 0.2 Nms per day (worst case conditions).

9.5.1.1.5.3 Normal Operation Mode

The Normal operative mode has been simulated in several scientific pointing scenarios through a MATRIX-X simulator including the full satellite 3-axes dynamics, the model of the external perturbing torque (solar torque), sensor and actuators features as specified in section 9.5.1.1.2.

Several simulations have been executed to validate the described approach and verify the performance capability. Note that, as at the current stage the implementation of a star change algorithm would be a complex effort not justified in terms of error budget refinement, the slew direction has been chosen to have the star describing the longest possible trajectory from a STR FOV corner to the opposite one. Based on the experience of SAX ESM2 high fidelity simulations, it is expected that star change doesn't introduce too large errors if the control is suspended for few cycles immediately after star change.

The applied control law used a de-coupled algorithm to derive raw errors on Y and Z axes from the STR and the X error from the FSS. This de-coupled algorithm is lighter than the conventional triad composition in terms of computation (two external product instead of seven) and permits a separate handling of the errors so avoiding that the higher noise of the FSS degrades also the estimates on Y and Z axes. These errors, together with the differences between the gyro incremental angle and the expected ones (in body axes), feed three (one for each axis) de-coupled four-state observers. The outputs are the filtered angular and rate errors with respect to the guiding profile, the

estimated external disturbance acceleration and the gyro drift. The estimated disturbance is directly added to PD control term giving an immediate compensation of external disturbance without requiring integrative term (that would decrease the controller reactivity). During slews, this acceleration term includes also the profile acceleration coming from the guiding profile generator. This term corresponds to a feed-forward control that permits to better follow the profile in the acceleration/deceleration phases. The guiding profile generator computes also the expected measurements, to be compared with the actual one, based on slew profile continue in acceleration and exponentially smoothed in the braking phase (for slews longer than 2'). Poles have been constrained to be faster or slower based on the rate in plane X-Z measured by gyros so guaranteeing both very good convergence time at the end of the slews and high noise rejection in the pointing phases.
For the operational slews of 90°, where a maximum rate of about 7°/min is requested to reach the target in less than 15 minutes, the STR cannot be used due to the limited tracking rate. In this case the attitude has been simply propagated through gyro integration.

The simulation results (presented in Figures from 9.5.1.1-14 to -21) have been used to compute the pointing budgets and confirm the compliance of all budget items on the different scientific modes. Required RPE performance is always reached. A summary of the timing performance, directly computed from simulation output is reported in the next table (Table 9.5.1.1-8).

Duration Req	*Requirement (s)*	*Expected Performance (s)*
Slews up to 16', including tranquillisation	$\sqrt{(2\varphi)^{''}}+10$ ($\sqrt{\varphi^{''}}+5$)	$\sqrt{(1.5\varphi)^{''}}$
90° slew, including tranquillisation	900	850

Table 9.5.1.1-8: Expected time performance based on simulation result

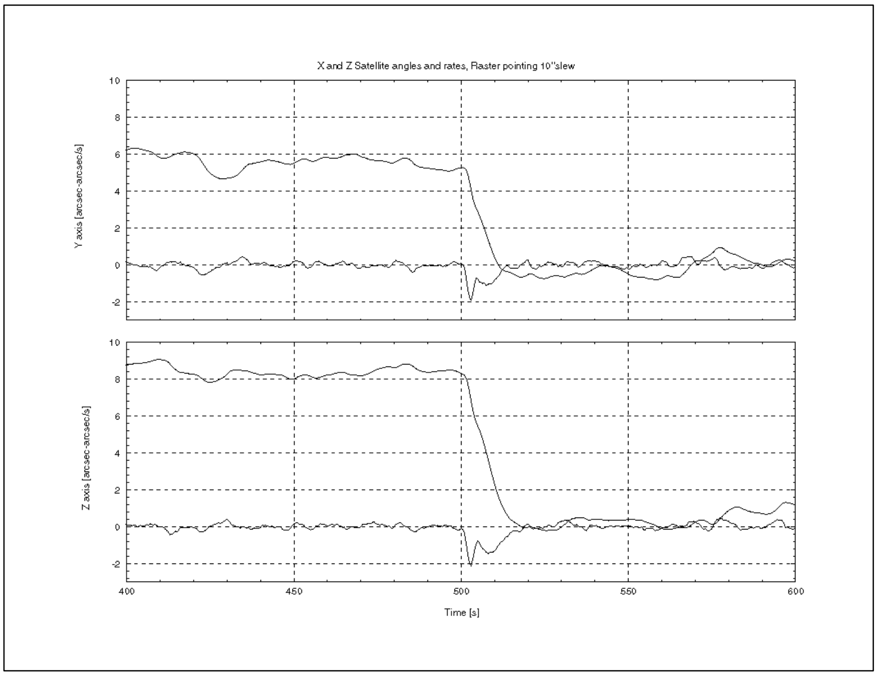


FIG -14 ANGLE AND RATES AROUND Y AND Z AXES DURING A 10" RASTER POINTING SLEW

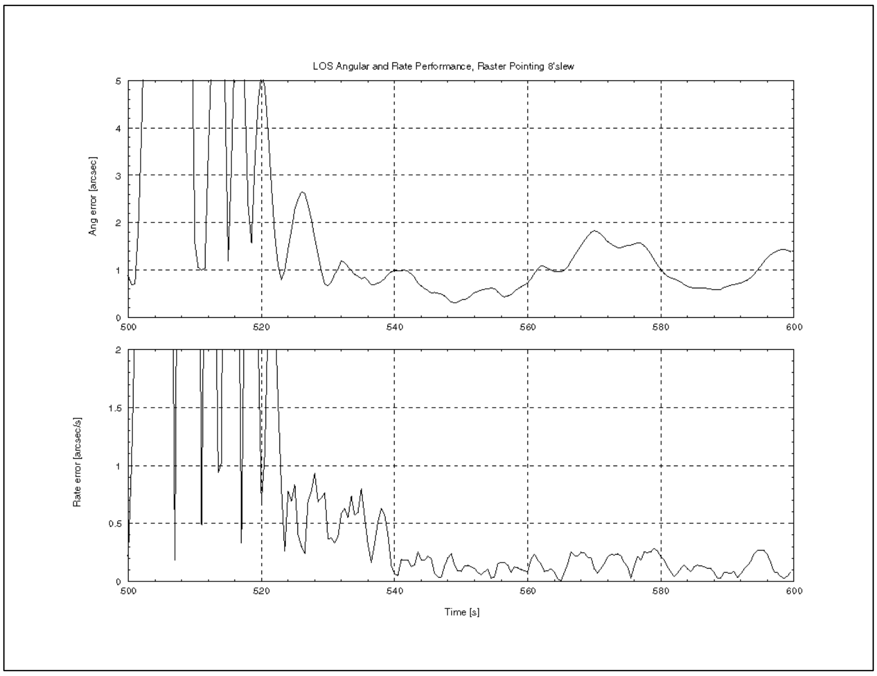


FIG -15 LOS ANGULAR AND RATE ERRORS AFTER A RASTER POINTING SLEW OF 8'

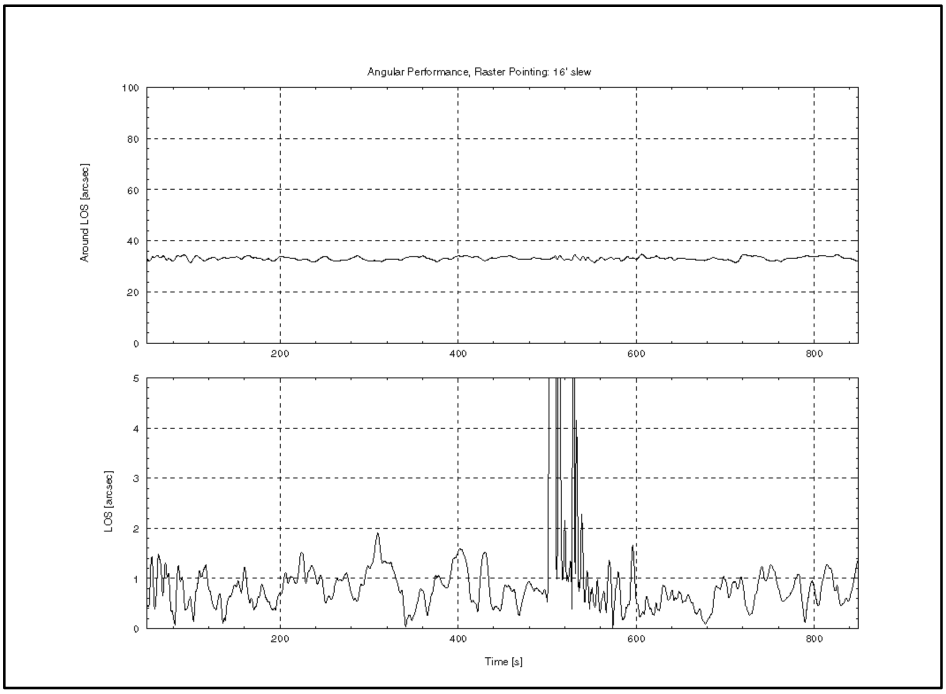


FIG -16 AROUND LOS AND LOS ANGULAR ERRORS AFTER A NODDING SLEW OF 16'

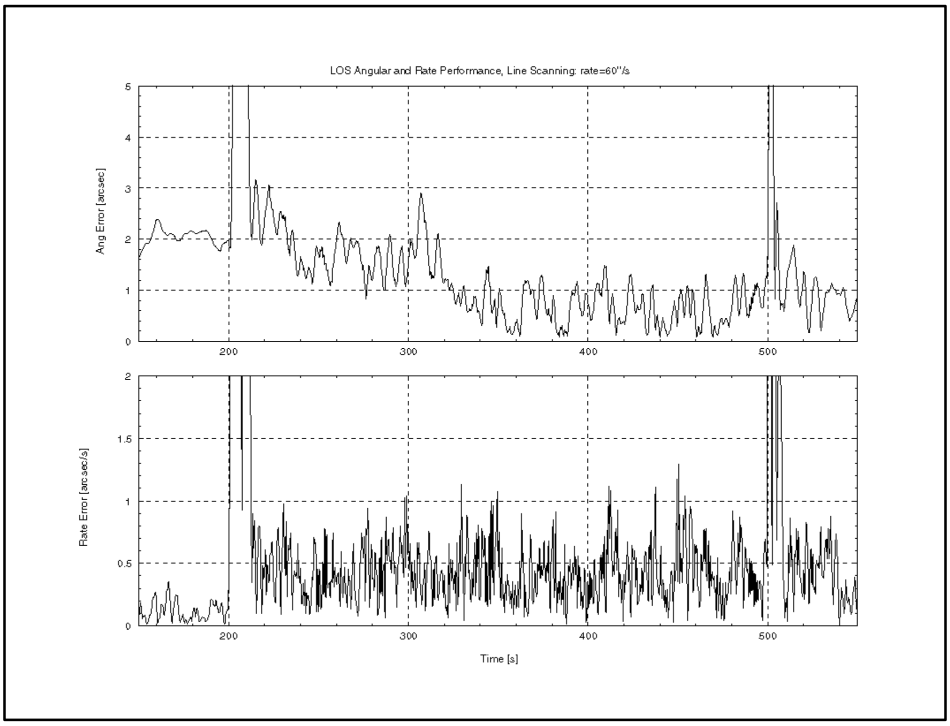


FIG -17 LOS ANGULAR AND RATE ERRORS DURING A LINE SCANNING AT 60"/s

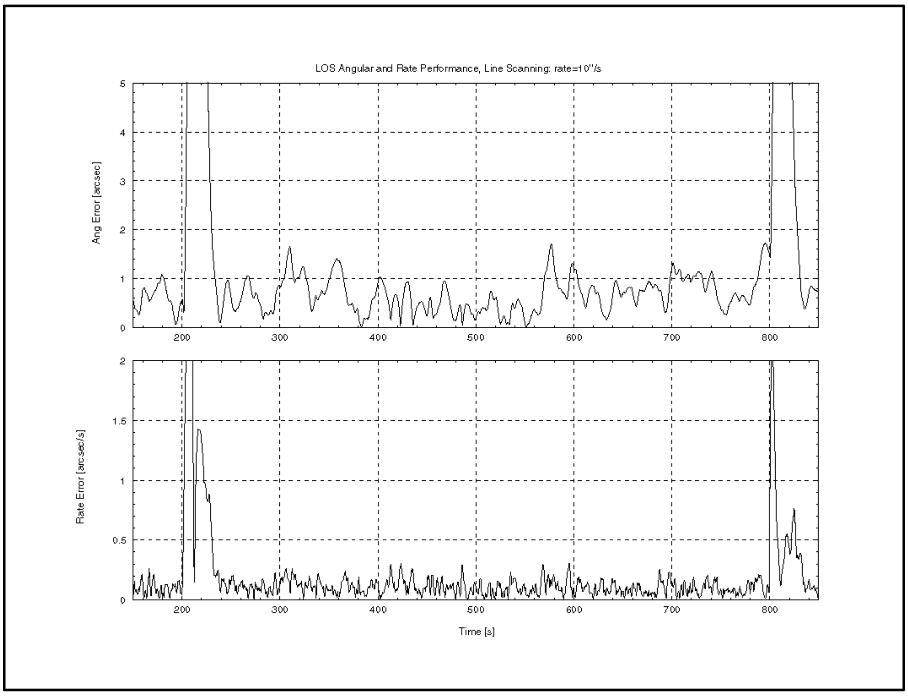


FIG -18 LOS ANGULAR AND RATE ERRORS DURING A LINE SCANNING AT 10''/s

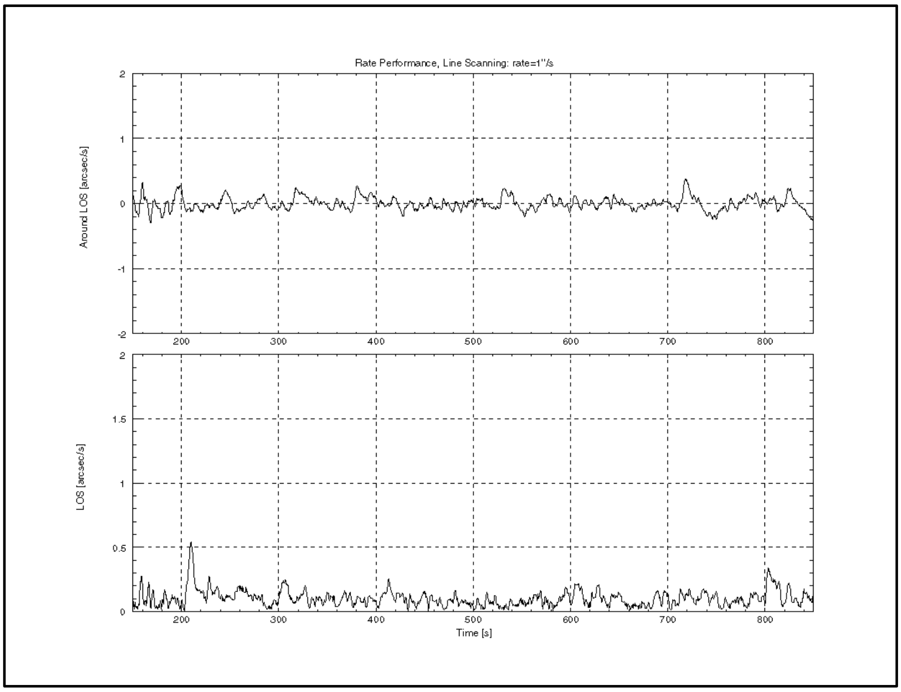


FIG -19 RATE ERRORS AROUND LOS AND LOS DURING A LINE SCANNING AT 1''/s

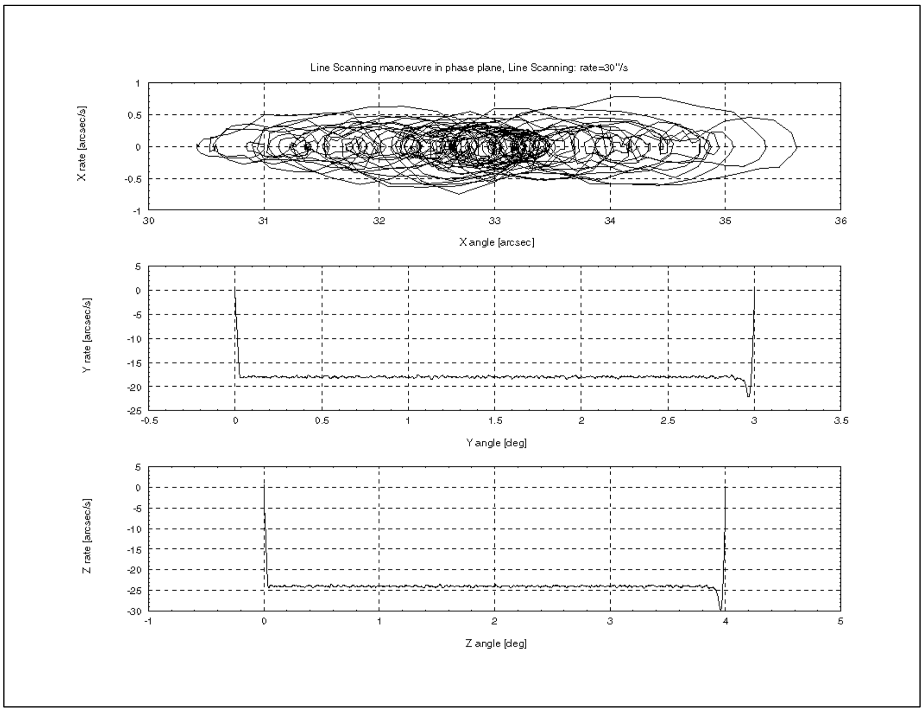


FIG -20 PHASE PLAN DIAGRAM OF THE LINE SCANNING MANOEUVRE AT 30''/s

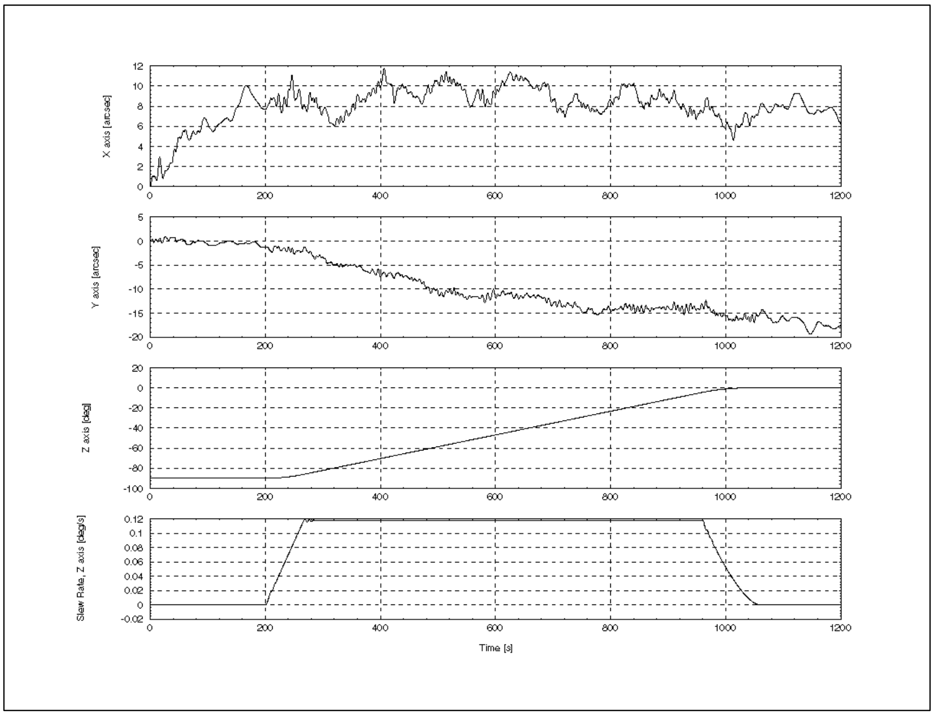


FIG -21 SATELLITE ANGLES TO TARGET AND SLEW RATE DURING A 90º SLEW AROUND Z AXIS

9.5.1.1.6 Failure Detection Isolation and Recovery

9.5.1.1.6.1 Overall Architecture (common to Herschel and Planck)

Both HERSCHEL and PLANCK ACMS FDIR functions have to ensure:

The respect of the severe attitude constraints, due to the high sensitivity of both payloads to direct Sun exposition.
The Autonomous Fail Operation (AFO) mode, necessary to maintain a 48 hours mission autonomy with no major failure but robust to single failures.
The required 7 days autonomy is required for 7 days in survival mode, which is a long period for a THR based mode (safety, propellant budget, orbit perturbation).

The Failure Detection Isolation and Recovery (FDIR) function is able to prevent that any failure occurred at ACMS level can lead to the loss of the satellite.
The FDIR function is implemented at different levels, in such a way that the occurrence of a single failure in an ACMS unit is autonomously detected, isolated and recovered by the ACMS itself or at OBDH level.

FDIR is designed in such a way to prevent the propagation of a failure through the different level in which the function is structured. This means that data from a failing unit are not used for further analysis that could involve other units.
Reporting of detection is designed in such a way to collect the sensor data on the basis of which the violation has been found.
The occurrence of a unit reconfiguration brings the ACMS in a different FDIR status that does not allow further actions on the same unit.

The ACMS FDIR architecture implementation is **hierarchical** as the overall system FDIR. The HERSCHEL and PLANCK ACMS FDIR strategy is adapted to the failure critically level:

Level 0: ACMS high level equipment including software (Star Tracker, Gyrometers unit) have internal FDIR mechanism (EDACS…) enabling equipment level minor failures autonomous reconfiguration.

Level 1: the failure detection relies both on ACMS equipment health status surveillance and on ACMS equipment parameters consistency checks (continuity, output value variation…). High level I/F bus (1553) is also surveyed by health status. Consistency checks between equipment are used to detect anomaly and identify the faulty equipment. Level 1 failures are recovered by the reconfiguration of the failed equipment on the redundant unit.

Level 2: the failure relies on major function observation, which are not identified by unit level check. The detection is based on simple performances thresholds (as pointing accuracy) which anomaly generates a complete system reconfiguration and the maintenance of the current ACMS mode when in AFO and a transition to safe mode when in AFS or GM.

Level 3: these errors are related to the ACC processor module failure detection and are detected by H/W. The failured are detected by the independent **R**econfiguration **M**odule which initiates a complete reconfiguration and the maintenance of the current ACMS mode when in AFO and a transition to safe mode when in AFS or GM.

Level 4: these failures are major system failures, which are not detected by the lower level procedure and could endanger the spacecraft mission life. This ultimate failure detection is ensured by the AAD (Attitude Anomaly Detection) function which detect the loss of the authorized Sun Pointing attitude to the ACC Reconfiguration Module and generate a complete reconfiguration.

This FDIR organization is hierarchic: decisions made at lower level (1, 2 or 3) are overruled by higher level (4).

HERSCHEL and PLANCK are sharing the same overall FDIR architecture:

Level 3 and 4 are common to HERSCHEL and PLANCK, with minor adaptation.

Level 2 implies some specific thresholds and test, which are mission dependent and specific to HERSCHEL and PLANCK.

Level 0 and 1 are specific to the ACMS equipment and modes. Common equipment (AAD, QRS and SAS and RCS) are sharing common functions with adapted parameters tuning.

To ensure the higher safety of the payload, the ultimate level 4 failure detection is handled by a simple independent mechanism, based on the following principles:

The supervision of the system in all modes shall rely on equipment, which are not used in the control loop.
The detection of an anomaly which might lead to a loss of attitude triggers a transition to the Sun Acquisition Mode. The Sun acquisition shall rely on a set of equipment that were not used by the control loop before the failure detection or by the FDIR when the failure was detected. This guarantees a successful Sun acquisition even when a faulty FDIR sensor awkwardly raises the alarm.

This context results in the following level 4 FDIR implementation:

a dedicated sensor, the **A**ttitude **A**nomaly **D**etector, detects the Sun presence in a FOV defined by the attitude restriction.
an alarm raised by this sensor triggers a Sun acquisition, after the system has switch to a complete set of redundant equipment (computer, sensors, and actuators).
the actuators used for the SAM are THR, providing a maximum commandability for high reactivity and enabling to cope with any initial angular momentum.

The general FDIR rules are presented (Table 9.5.1.1-9).

Level	Type of alarm	Conditions	Decision
0		Faulty unit provides internal hot redundancy	faulty unit reconfigures on its own.
1	equipment health status, or consistency check between equipment enabling to identify the faulty unit	A redundant unit is available immediately	Reconfigure unit and resume routine operation
		Reconfiguration to redundant unit takes time	transition to appropriate waiting mode resume routine operations with redundant unit
		Redundant unit already passed away	transition to survival mode
1	Consistency checks between equipment & faulty unit unidentified.	Redundant units to those involved in positive test are available	transition to appropriate waiting mode (if needed) resume routine operations with redundant units
		Suspect units cannot be all replaced	transition to survival mode
2	Attitude / rate threshold		Reconfiguration to redundant units and ACC and transition to survival mode
	No TC applicable		Transition to Stand-by Mode (PLANCK) or Safe Hold Mode (HERSCHEL)
3	ACC alarm		Reconfiguration to redundant units and ACC and transition to survival mode
4	Sun Presence Alarm	Any	Reconfiguration and transition to survival mode

Table 9.5.1.1-9: General ACMS FDIR Rules

9.5.1.1.6.2 FDIR Level 4

Low level alarms are implemented to signal to the OBDH subsystem that the ACMS is not able to control the S/C, in such a way the ACMS can be reconfigured activating its redundant units. Triggering of low level alarms can occur only in case the high level FDIR described in the following is not able to detect a problem, mainly because the ACC is involved in the failure.

The alarm signals are:

AAD trigger
ACC-OBDH watch-dog trigger

AAD trigger
This signal is triggered by the Sun exiting the AAD FOV. This signal is handled by the Reconfiguration Module inside each ACC and its occurrence causes the ACC switch-over (from main to redundant) and also the activation of the redundant branch for the other ACMS units involved in the Sun Acquisition Mode (SAS, QRS) and RCS. During eclipse, possibly experienced during transfer orbit, the AAD triggering shall be disabled.

ACC-OBDH watch-dog trigger
This signal is handled by the Reconfiguration Module inside each ACC in case the ACC is not correctly answering to the watch-dog protocol running on the ACC-OBDH bus. Considering the high probability that this failure in induced by ACC SW, this trigger causes the ACC switch-over (from main to redundant).

9.5.1.1.6.3 FDIR Level 3

Hardware and Software errors detection mechanism are implemented at ACC level:

EDAC double error

PM bus time-out

Memory protection violation

H/W watchdog

CPU errors.

The recovery is performed by H/W via the ACC_RM.

9.5.1.1.6.4 FDIR Level 2

Some Level 2 performance checks are implemented, pointing performances are compared to non ambiguous thresholds. The ACC and Mode reconfiguration is started in case of failure detection.

9.5.1.1.6.5 FDIR Level 1

Most of the ACMS FDIR functions are implemented at level 1, and based on different type of parameters observation:

Units level where each unit is in charge of evaluating its health status. The communication bus between ACMS units is also checked.
Consistency Check level where the ACC is analysing different data produced by the same unit
Units Cross checks where the ACC combines pieces of information coming from different units
Total Angular Momentum Check

Unit Level Check

At this level a single unit is in charge of self checking its status and reports it to the ACC through the communication bus or dedicated interface. On the basis of the unit status the ACC can perform the relevant actions (spike filtering, reconfiguration)
In the following Table 9.5.1.1-10 for each ACMS unit the available health-checks are listed:

Unit	*Unit Health Check*
THR	N/A
RWS	OverSpeed, OverTemperature, OverCurrent
SAS	N/A
QRS	Temperature
GYR	Complete Health Status
STR	Single lines power status, Optics and Detector temperature, SW status
FSS	N/A

Table 9.5.1.1-10: Unit Health Checks

Consistency Checks

The consistency checks apply to all units except THR. The checks are carried out only when the operative range of the sensor/actuator is ensured by the mode logic. This means that the fine sensors (STR and FSS) data are not valid during OCM, SHM and SAM.
Hereafter for each unit a description of the consistency checks functionality is proposed.

SAS is operated in hot redundancy and covers the entire sky sphere. These conditions allow performing the following consistency checks in all the ACMS modes.

- Continuity check on the single sensor unit. It is a comparison between successive measurement and a threshold mode dependent.
- Frozen output on the single sensor unit. It is the verification that the output data is not stuck.
- Agreement between measurements provided by the main and redundant chains.

Because of the QRS skewed configuration a redounded Z axis rate measurement is obtained. This allows the execution of the following consistency checks in all ACMS modes.

- Continuity check on the single sensor unit. It is a comparison between successive measurement and a threshold mode dependent.
- Frozen output on the single sensor unit. It is the verification that the output data is not stuck.
- Agreement between the three measurements provided by the units with respect to the Z axis component.

GYR is operated in hot redundancy. Sensors in skewed configuration allow the execution of the following consistency checks in STAM, NOM, WUP, and OCM.

- Continuity check on the single sensor unit. It is a comparison between successive measurement and a threshold mode dependent.
- Frozen output on the single sensor unit. It is the verification that the output data is not stuck.
- Sum check on all the four sensors. It is a verification, due to geometrical mounting properties, that the output sensor are congruent each other. Due to the intrinsic nature of this check, the isolation of the failing unit is not always ensured.

STR is operated in cold redundancy. The execution of the following consistency checks is allowed in STAM, NOM and WUP.
Continuity check on the single star during tracking phase. It is a comparison between successive star co-ordinates and a threshold mode dependent.
Frozen output on the single star during tracking phase. It is the verification that the output co-ordinates are not stuck.
Star Data Validity. It checks that the output star co-ordinates and magnitude remain inside the sensor range.

FSS is operated in cold redundancy. This implies that the comparison between the main and redundant unit is not possible. The execution of the following consistency checks is allowed in STAM, NOM and WUP.

- Continuity check on the single sensor unit. It is a comparison between successive measurement and a threshold mode dependent.
- Frozen output on the single sensor unit. It is the verification that the output data is not stuck.
- Sun Data Validity. It checks that the output sun co-ordinates remain inside the sensor range.

RWS is operated in cold redundancy. The consistency checks on the single unit are allowed in STAM, NOM, and WUP.

- Continuity check on the tachometer. It is a comparison between successive measurement and a threshold.
- Frozen output on the tachometer. It is the verification that the output data is not stuck.
- Consistency Torque Vs. Speed increment. It is the verification that the wheel speed change is in accordance to the commanded torque.

Units Cross Checks

The unit cross checks apply to all units. The checks use data from different units to verify their compatibility. The selection of the units to be used depends on the current mode. Due to the intrinsic nature of the checks, the isolation of the failing unit is not always ensured. In case of unresolved ambiguity both the unit involved in the cross check are reconfigured leaving to ground analysis further investigation. Hereafter in Table 9.5.1.1-11, a list of identified cross checks is proposed, with a reference to the applicable ACMS mode.

	SAM	*SHM*	*STAM*	*NOM*	*WUP*	*OCM*
SAS / QRS	X	X	X	X	X	X
SAS / THR	X					X
QRS / THR	X					X
RWS / QRS		X				
RWS / SAS		X				
SAS / FSS			X	X	X	
GYR / FSS			X	X	X	
GYR / STR			X	X	X	
GYR / RWS			X	X	X	
GYR / THR					X	X

Table 9.5.1.1-11: Unit Cross Checks

Total Angular Momentum Check
This check is done by the ACC that compares the total angular momentum (H_{TOT}) stored in the RWS with a predefined threshold. In case of threshold overcoming:

in NOM a mode transition to WUP without unit reconfiguration is autonomously executed
in all the other modes, where the threshold are set at safeguard level, a transition to SAM is commanded to activate the use of RCS

Mode Analysis
With reference to the above described Unit (U), Consistency (C), Cross (X) checks, their effects and applicability depend on the current ACMS mode.
In fact, in each ACMS mode, the unhealthy unit detection produces different actions according to the current use of the unit that could result used for control, or simply powered on. In any case a unit classified as failing is reconfigured, even if currently not used for control.
In some cases the fallback to a lower mode is commanded, typically when a cold redundancy approach is used.
In the following Table 9.5.1.1-12 for each ACMS mode the action performed by FDIR due to the unit failure detection is listed:

Mode	*Unit Used For Control*	*Unit NOT Used for Control*	*Reconfiguration*	*Mode Transition*
SAM	SAS		C + X	-
	QRS		C +X+U	-
	THR		X	-
		GYR	-	-
		FSS	-	-
		STR	U	-
		RWS	U	-
SHM	SAS		C + X	-
	QRS		C + X + U	-
	RWS		C + X +U	SAM
		GYR	-	-
		FSS	-	-
		STR	U	-
		THR	-	-
STAM	STR		C + X + U	no NOM
	FSS		C + X	SHM
	GYR		C + X + U	-
	RWS		C + X+ U	SHM
		SAS	C + X	-
		QRS	C + X +U	-
		THR	-	-
NOM	STR		C + X + U	SHM
	FSS		C + X	SHM
	GYR		C + X + U	-
	RWS		C + X+ U	SHM
		SAS	C + X	-
		QRS	C + X +U	-
		THR	-	-
WUP	STR		C + X + U	SHM
	FSS		C + X	SHM
	GYR		C + X + U	-
	THR		X	-
	RWS		C + X +U	SHM
		SAS	C + X	-
		QRS	C + X +U	-
OCM	GYR		C + X + U	-
	THR		X	-
		SAS	C + X	-
		QRS	C + X + U	-
		STR	U	-
		FSS	-	-
		RWS	U	-

Table 9.5.1.1-12: FDIR Actions vs ACMS Modes

U: Unit level check; C: unit Consistency check; X: units Cross check

9.5.1.2 Planck ACMS Design Description

The overall Planck ACMS design description is given through the following paragraphs:

- Mode Transition Logic section in which the entry/exit conditions of each operative mode are identified and described
- Unit Level section where a brief description of the characteristics of the class of identified Computer, Sensor and Actuators is given
- Data Handling Function where the tasks of the Attitude Control Computer are described
- Modes Description section where the main features of each operative mode and the envisaged control strategy are proposed
- Mode Performance Simulations section where the results of the simulation done to assess the obtainable performance are presented.
- FDIR section where the approach to the Failure Detection and Redundancy Management philosophy is described.

9.5.1.2.1 Modes Transition Logic

The Modes Transition Logic is commanded by the occurrence of the following ACMS internal or external events:

- Reception of commands from Ground
- Expiration of Time Tagged Commands
- AAD alarm triggering
- Mode safeguard triggering
- Manoeuvre completion (including Sun Acquisition)
- FDIR driven action

For each ACMS mode, the entry condition and the envisaged exit events are described.
In Figure 9.5.1.2-1 a schematic representation of the mode transition logic is depicted. The FDIR actions that remain internal to each mode (i.e. the reconfiguration of hot redounded units) are shown in the figure but considered internal to the mode and not described in the following sections.

In Table 9.5.1.2-1 the proposed use of each unit in all operative modes is presented with respect to the use in control and / or in FDIR function.

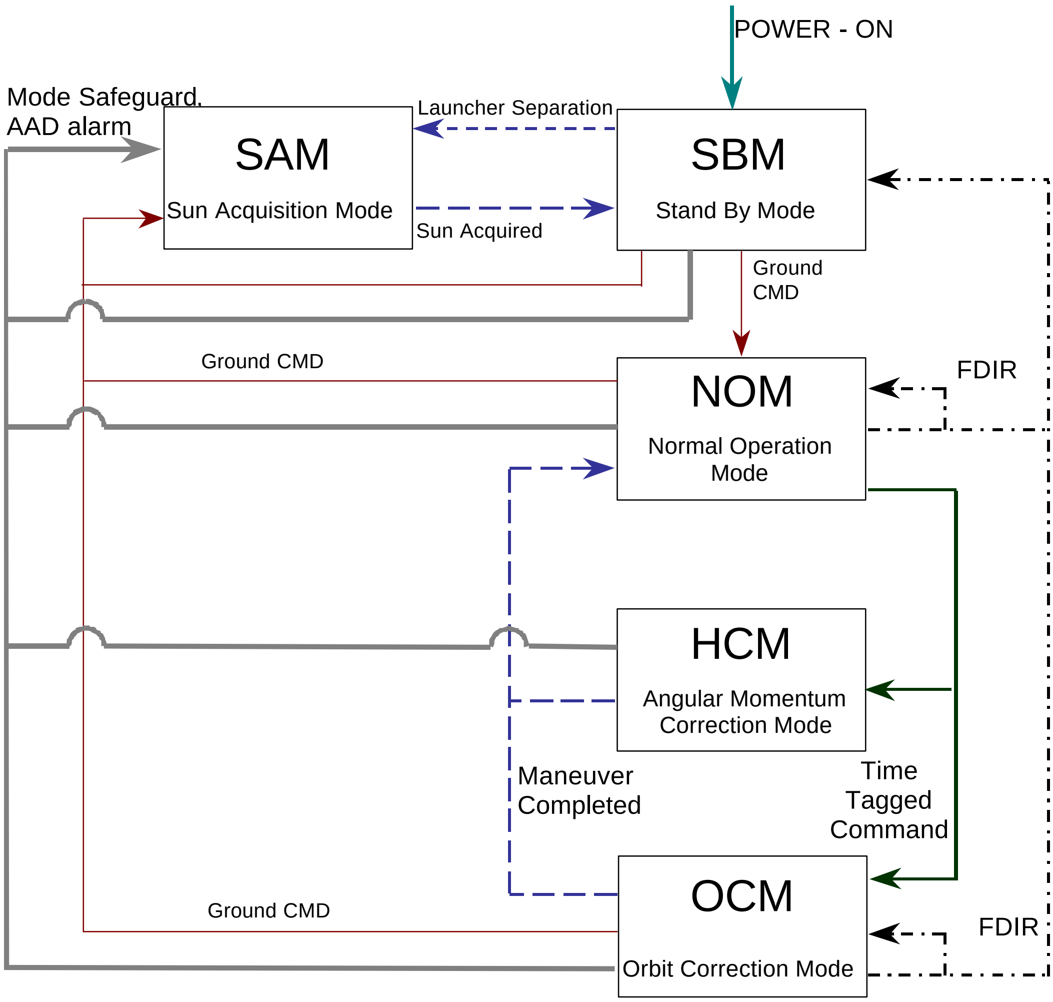


Figure 9.5.1.2-1: Modes Transition Logic

	SBM	*SAM*	*NOM*	*HCM*	*OCM*
SAS	F	C-F	F	---	C-F
QRS	F	C-F	F	---	C-F
STM	---	---	M-F	---	C-F
THR1N	---	---	F(1)	C	---
THR10N	---	C-F	---	---	C-F
	C: unit used in control M unit used for measurement F: unit used for FDIR function --- unit not used				

Table 9.5.1.2-1: Mode vs Unit Use

(1) In NOM, at HCM completion, it is checked the success of the manoeuvre. In case of failure the 1N THR assembly is reconfigured.

9.5.1.2.1.1 Stand By Mode

The Stand By Mode (SBM) is entered:

on ground and it is active during the complete pre-launch and launch phase
from Sun Acquisition Mode at manoeuvre completion
to withstand the possible eclipse condition during transfer orbit. In this case the SAS output data shall be filtered out in order to prevent unwanted mode transition and FDIR actions
as a consequence of FDIR action for cold redundant unit configuration

The SBM is exited:

with a transition to Sun Acquisition Mode after a delay period of 20 seconds from the reception of the separation signal.
in Sun Acquisition Mode as a consequence of Attitude Anomaly Detector triggering
in Sun Acquisition Mode as a consequence of spin rate anomaly
in Sun Acquisition Mode upon the reception of a ground command
in Normal Mode upon the reception of a ground command (nominal condition)

9.5.1.2.1.2 Sun Acquisition Mode

The Sun Acquisition Mode (SAM) is the emergency mode entered:

from SBM after launcher separation
on ground command
as a consequence of Attitude Anomaly Detector triggering
as a consequence of Mode Safeguard triggering (including spin rate anomaly)
The only exit condition allowed in SAM is the transition in SBM hat occurs when the mode performance is reached.

9.5.1.2.1.3 Normal Mode

The Normal Mode (NOM) is the basic science mode that is entered:

on commanded transition from SBM

at completion of Angular Momentum (H) Correction Mode

at completion of Orbit Correction Mode

The exit conditions from NOM are:

in SBM as a consequence of FDIR action in case of reconfiguration of cold redounded units

in Angular Momentum (H) Correction Mode in case of expiration of a tag tagged command

in Orbit Correction Mode in case of expiration of a tag tagged command

in SAM in case of attitude loss detected by the mode logic or by the AAD.

in SAM upon the reception of a ground command

9.5.1.2.1.4 Angular Momentum Correction Mode

The Angular Momentum (H) Correction Mode (HCM) is entered:

from NOM as a consequence of the expiration of a tag tagged command

The exit conditions from HCM:

to NOM at completion of the open loop manoeuvre

in SAM in case of attitude loss detected by the AAD.

9.5.1.2.1.5 Orbit Correction Mode

The Orbit Correction Mode (OCM) is entered:

from NOM as a consequence of the expiration of a tag tagged command

The exit conditions from OCM are:

to NOM at completion of the orbit correction

in SBM as a consequence of FDIR action in case of reconfiguration of cold redounded units

in SAM in case of attitude loss detected by the mode logic or by the AAD.

in SAM upon the reception of a ground command

9.5.1.2.2 ACMS Units

Before describing the proposed units, a synthetic overview including their performance class in given in Table 9.5.1.2-2.

In Figure 9.5.1.2-2 a possible units mechanical mounting configuration is depicted.

Unit	*Number Of Units*	*Performance Class*
ACC	1	32 bit processor
AAD	2	10° FOV
SAS	3	0.1°
QRS	2	0.01°/s
STM	1	9.2° FOV 60” NEA 5” Bias
RCS	2 x 2 THR 2 x 6 THR	1 N 10 N

Table 9.5.1.2-2: ACMS Units

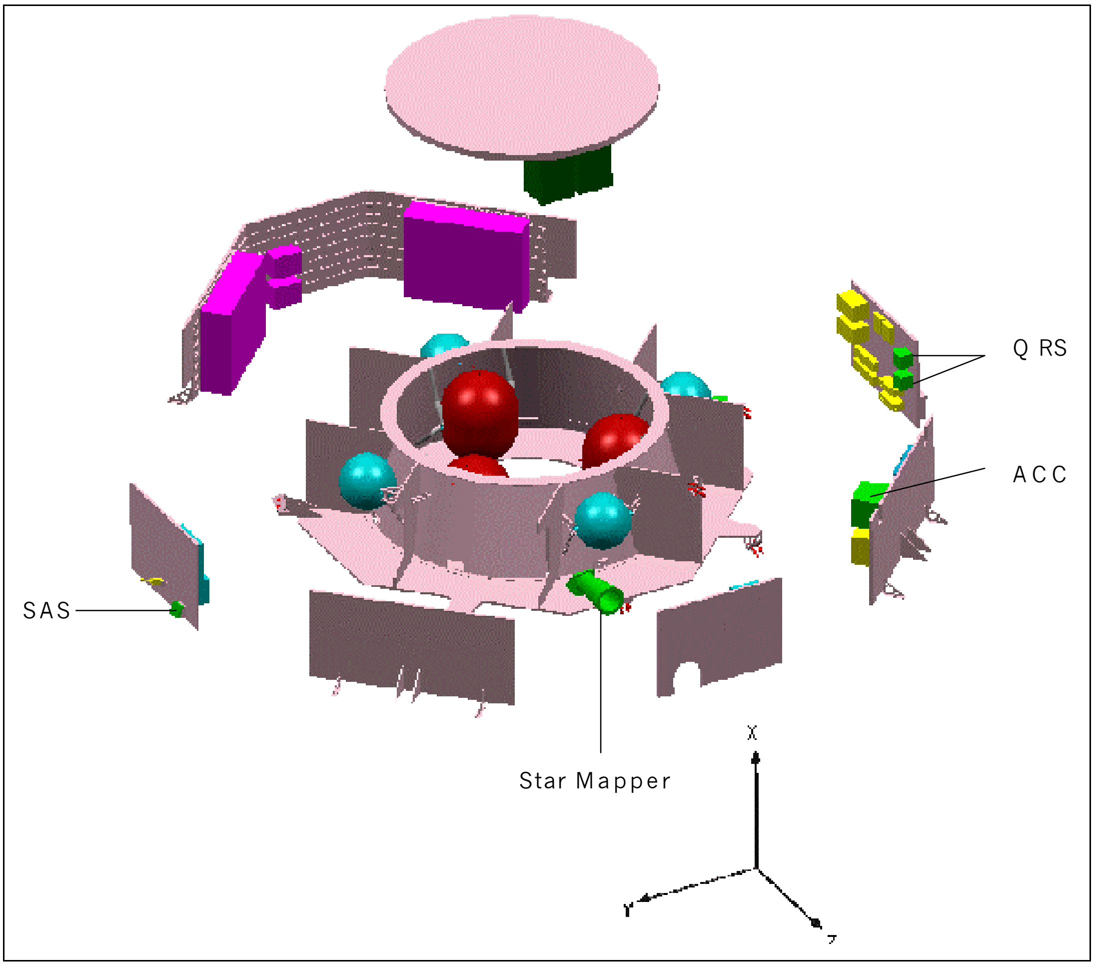


Figure 9.5.1.2-2: ACMS Units Mechanical Configuration

9.5.1.2.2.1 Attitude Control Computer

ACMS design commonality between Herschel and Planck imposes the use of identical units for the Attitude Control Computer (ACC).
The main difference is due to the fact that in Planck the MIL-STD-1553 communication bus between ACC and ACMS units is not used.
Refer to paragraph 9.5.1.1.2.1 for the ACC description, and to 9.5.1.1.3 for the software functional description.

9.5.1.2.2.2 Reaction Control System

The Reaction Control System (RCS) shall be used for orbit correction manoeuvres and for angular momentum correction.
It shall be implemented in 2 branches (nominal and redundant), containing each:

3 pairs of 10N thusters for Delta-V corrections considering the need of 3 axis control during the manoeuvre:
1 pair directed towards the +X hemisphere ("up thrusters")
1 pair directed downwards ("down thrusters")
1 intermediate pair ("flat thrusters")

1 pair of 1N thrusters for angular momentum correction.

The proposed thruster configuration (Figure 9.5.1.2-3) leads to the efficiency reported in Table 9.5.1.2-3:

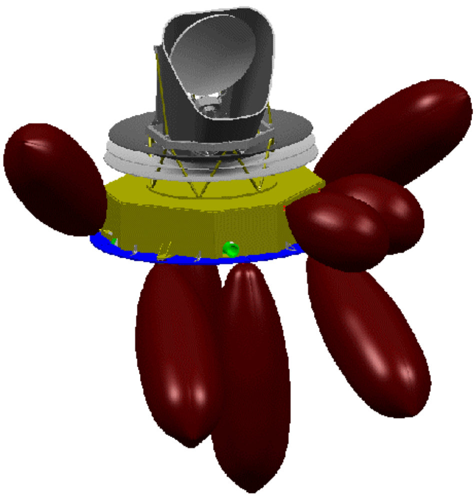


Figure 9.5.1.2-3: THR Configuration and Plume

	Up	*Flat*	*Down*
Pair efficiency	86.6 %	100%	100%

Table 9.5.1.2-3: The 10n Thrusters Efficiency

9.5.1.2.2.3 Nutation Damping

At the beginning of Phase-B a trade-off between Active and Passive Nutation Damping (AND and PND) has been performed. See the specific technical note for details.

9.5.1.2.2.4 Attitude Anomaly Detector

The Attitude Anomaly Detector (AAD) is used as an alarm sensor to inform the OBDH that the ACMS is not able to maintain a safe attitude with respect to the sun. AAD is in charge to detect the Sun presence in a FOV of ±10° from –X axis, corresponding to the allowed attitude domain. The AAD function could be performed by specific solar cells mounted parallel to the solar panels and equipped by proper baffles.

9.5.1.2.2.5 Sun Acquisition Sensor

The Sun Acquisition Sensor (SAS) is used:

- as a principal sensor in all the ACMS modes
- to feed the attitude estimator in Sun Acquisition and in Orbit Correction Modes
- in support to the FDIR function in all the ACMS modes

In order to accomplish the required performance, the selected configuration is able to cover the full sky sphere. Because of the presence of the P/L in the +X hemisphere, the SAS configuration envisages the use of three internally redundant units each of which has a FOV of 2Π srad. One SAS is mounted parallel to -X axis, nominally pointing to the Sun, the other two SAS units are mounted in such a way to ensure the coverage of the +X hemisphere without interfering with the P/L envelope, as depicted in Figure 9.5.1.2-4.

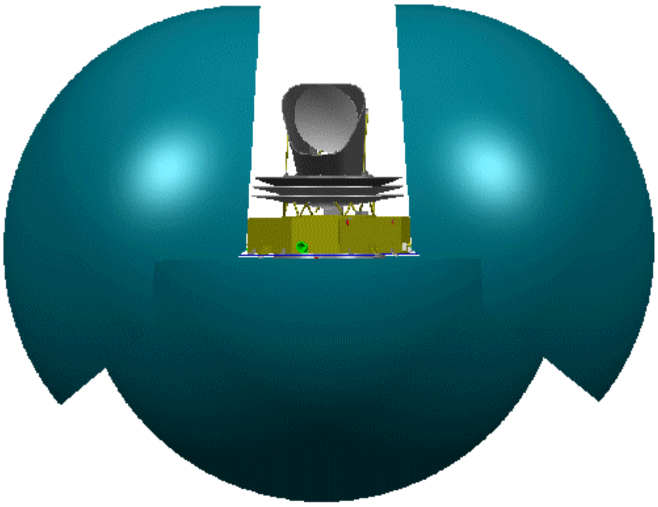


Figure 9.5.1.2-4: Sun Acquisition Sensor Field of View

Due to mission orbit characteristics, eclipse is foreseen only during a transfer orbit phase where the SAS use shall be excluded. Resulting accuracy class is given in Table 9.5.1.2-4. This accuracy prevents the use of SAS in science modes, but fulfils the basic mode requirements.

Parameter	*Range*
Accuracy (bias excluded)	0.1 °

Table 9.5.1.2-4: SAS Characteristics

9.5.1.2.2.6 Quartz Rate Sensor

The Quartz Rate Sensor (QRS) is the same than the Herschel:

as a principal sensor in all the ACMS modes

to feed the attitude estimator in Sun Acquisition and in Orbit Correction Modes

in support to the FDIR function in all the ACMS modes

Two QRS in cold redundant configuration are proposed.

The QRS accuracy class is given in Table 9.5.1.2-5.

Parameter	*Range*
Accuracy	0.01 °/s

Table 9.5.1.2-5: QRS Characteristics

9.5.1.2.2.7 Star Mapper

The Star Mapper (STM) is intended to be used in:

Normal Operation Mode to:

- complement P/L data for on ground attitude reconstruction
- derive the nutation parameters
- determine the direction of the spin-axis w.r.t the inertial reference
- calibrate the QRS drift

Orbit Correction Mode

- calibrate the QRS drift

STM is able to determine both the star relative azimuth angle in the YZ plane and the star elevation with respect to the STM mounting cant angle. The STM FOV is depicted in Figure 9.5.1.2-5.

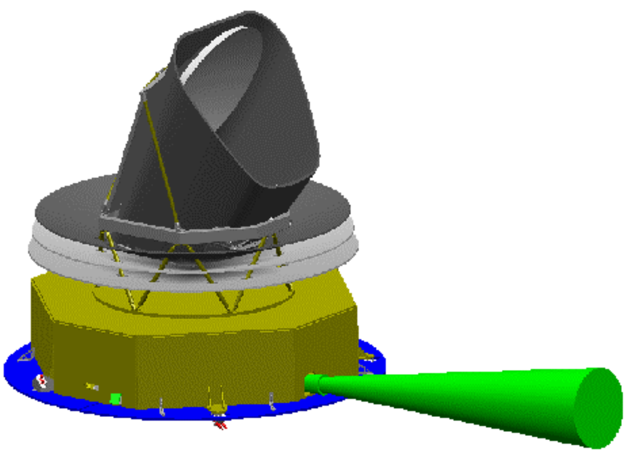


Figure 9.5.1.2-5: Star Mapper Field of View

The unit is equipped with two slit silicon detectors in the form of two (redundant) V-patterns. The STM is able to detect the transition of stars through both the slits. These events must be referred to a specific datation system (clock reference) in order to derive the absolute angle measurements.

The performance requirements for the STM are summarised in the following Table 9.5.1.2-6:

Parameter	*Value*
FOV along meridian	9.2°
azimut angle bias	< 5 arcsec (σ)
aspect angle bias	< 1.5 arcsec (σ)
noise equivalent angle	< 60 arcsec (σ)

Table 9.5.1.2-6: Star Mapper Characteristics

9.5.1.2.3 Data Handling Function in Attitude Control Computer

The same functions described in 9.5.1.1.3 apply to Plank ACC.

9.5.1.2.4 Modes Description

To fulfil all the requirements the design of Planck ACMS is logically conceived in the following modes:

- Stand By Mode
- Sun Acquisition Mode
- Normal Operation Mode
- Angular Momentum Correction Mode
- Orbit Correction Mode

The logic regulating the transition between the modes have been presented in the above paragraph 9.5.1.2.1 while in the following sections the functional description of each mode is given.

9.5.1.2.4.1 Stand By Mode (SBM)

This is the mode activated:

- during the pre-launch and launch phase, where a configuration with the minimum power consumption is selected which implies that at least the ACC must be powered-on to ensure quick operability after the separation
- as a consequence of FDIR action to allow the QRS reconfiguration
- after Sun Acquisition waiting for ground command to enter in Normal Operation Mode

SBM is a passive mode: no control law is implemented. After separation, the monitoring of the Sun Aspect Angle and spin rate are carried out using SAS and QRS.

In case of Sun exiting the allowed domain or spin rate overcoming a predefined range, the transition to Sun Acquisition Mode is autonomously commanded.

9.5.1.2.4.2 Sun Acquisition Mode (SAM)

The Sun Acquisition Mode is used for initial Sun Acquisition, then as emergency mode. The control law is based on RCS 10N thrusters as actuator and SAS and QRS as sensors, independent of the other modes to ensure the highest robustness. When entered on FDIR configuration, the redundant RCS branch is used.
The SAM ensures from any entry conditions both the Sun acquisition with a defined SAA and the stabilisation of the spin rate within a defined range. The SAS provide the Sun vector from any attitude and the QRS the 3-axis spacecraft rate.

9.5.1.2.4.3 Normal Operation Mode (NOM)

The Normal Operation Mode is the routine mode for scientific operations. It is a passive mode in which the attitude stabilisation is based on the satellite gyroscopic stiffness (~240 Nms).
Accurate inertial attitude measurements are provided through the processing of the star mapper measurement, which consequently also provides the estimation of the nutation. This value is used to schedule the next angular momentum correction manoeuvre to be performed with hourly frequency in HCM.
The sequence of pointing target directions is autonomously generated following the ground up-linked Attitude Operation Plan combined to the measurement of the spin axis direction.
SAS and QRS are used to provide independent data for FDIR purpose.

9.5.1.2.4.4 Angular Momentum Correction Mode (HCM)

The Angular Momentum Correction Mode is used at hourly frequency to correct the direction and magnitude of the angular momentum.
The manoeuvre is performed in open loop by commanding three pulses to one of the operating 1N control THR. The three pulses are scheduled to obtain the desired angular momentum rotation (~3 arcmin) without inducing nutation.
The operating 1N THR configuration contains 2 THR. Both of them provide the same transverse torque but the roll torque they generate are opposite.
For each NAM, one THR is selected according to the sign of its roll torque and to the current spin rate.
This allows a coarse spin rate control, in compliance with the requirement for the absolute spin rate accuracy (1.5%).
The capability of performing the nutation damping manoeuvre shall be ensured, in case the active approach is implemented.
Due to the open loop characteristic of this mode, no FDIR function is implemented. Only the low level safeguards are active.

9.5.1.2.4.5 Orbit Correction Mode (OCM)

The Orbit Correction Mode uses 10N THR as actuators and SAS, QRS and STM as sensors.
The OCM objective is to ensure:

- the transfer manoeuvre from the launcher to the final operative orbit (up to 250m/s)
- the monthly ΔV manoeuvre to re-adjust the orbit (magnitude of $V \sim 20$ cm/s)

The stabilisation of the satellite in this mode does not rely on its gyroscopic stiffness because the 10N thrusters induce too high perturbing torque. A 3-axes control loop based on SAS for the SAA measurement and for the rate measurement, on the QRS, whose drift are calibrated by the STM, is implemented. The actuation is performed by the 10 N RCS.
The possible SAS, STM or THR branch reconfiguration can be performed remaining in this mode, whereas the QRS reconfiguration implies a SBM transition and the triggering of Sun pointing domain alarm causes a transition to SAM.

9.5.1.2.5 Mode Performance Simulations

9.5.1.2.5.1 Angular Momentum Correction Mode

The Angular Momentum Correction Mode (HCM) has been simulated with a MATRIXX simulator including environmental disturbance (maximum Solar Torque $\sim 1.e^{-5}$) sensors and actuators errors as described in section 9.5.1.2.2. The actual Sun location in the body reference, purged from the nutation estimation, is computed complementing the SAS information with the star mapper measurements. The needed rotation angle of the spin axis is computed from the external product of the measured Sun vector by the reference Sun vector defined from an ephemerides generator. When the time to correct the angular momentum has come, an internal timer counts the number of cycles necessary to fire exactly in the right plane.

As described in the trade-off section, the NAM consists in three pulses separated by two rounds (as $1.2<\lambda<1.3$). Once the first fire has been executed, a number of 240 timer cycles must be waited before firing second pulse and so on.
The amplitude of the pulses is linked to the total angular momentum to be supplied and to the ratio between the first/third and the second pulses. The manoeuvre is performed activating the 1 N thruster.
Simulations demonstrated the efficiency of the reorientation manoeuvres and its low impact on the nutation (See Figure 9.5.1.2.5.1-6,7).

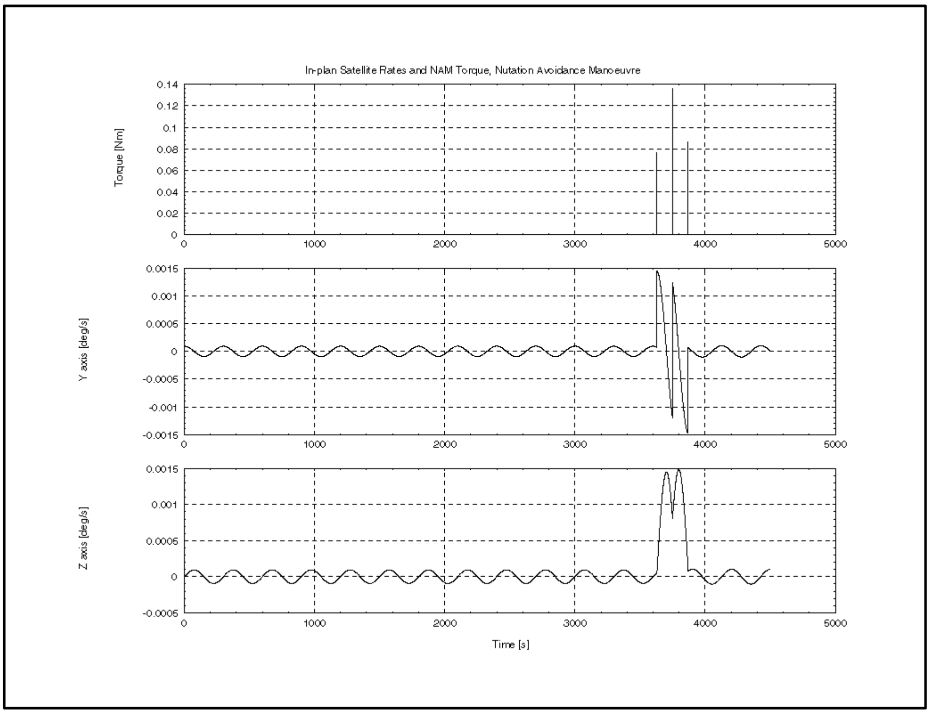


FIG -7: PULSES AND IN-PLANE ANGULAR RATES DURING NAM

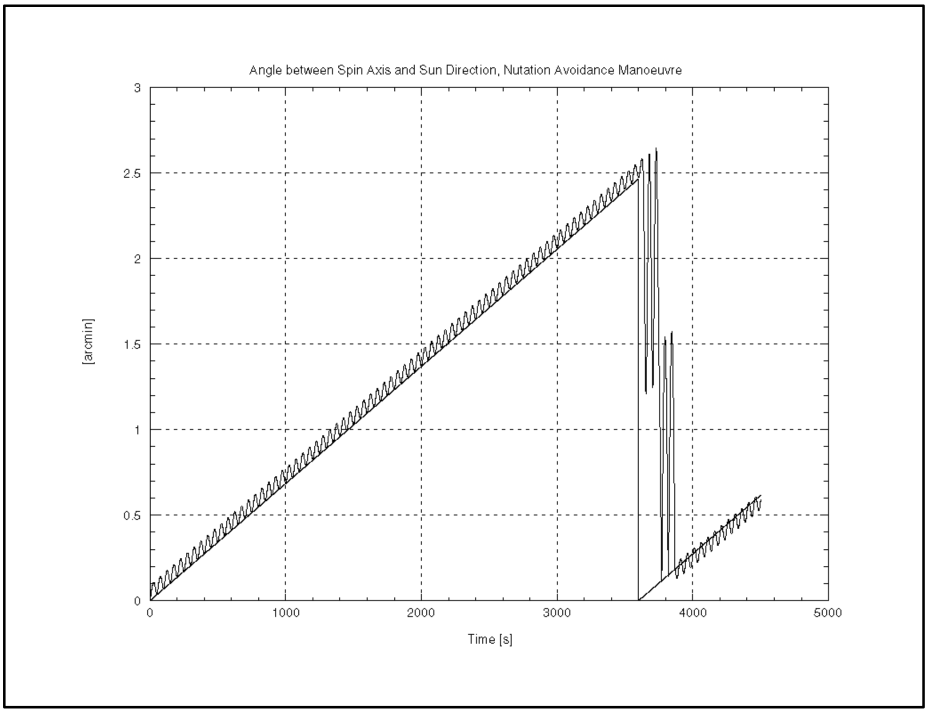


FIG -6: ACTUAL AND REFERENCE ANGLE BETWEEN THE SPIN AXIS AND THE SUN VECTOR. REFERENCE IS MANTEINED CLOSE TO O°

9.5.1.2.5.2 Normal Operative Mode

In NOM the satellite is not actively controlled and stabilised by the spin. In case the Active Nutation Damping approach is implemented, in NOM the sensor output, possibly the STM data are collected for nutation estimation to be performed at the end of each observation period.

9.5.1.2.6 Failure Detection Isolation and Recovery

9.5.1.2.6.1 Overall architecture (common to Herschel and Planck)

See paragraph 9.5.1.1.6.1.

9.5.1.2.6.2 FDIR Level 4

See paragraph 9.5.1.1.6.2

9.5.1.2.6.3 FDIR Level 3

See paragraph 9.5.1.1.6.4

9.5.1.2.6.4 FDIR Level 2

See paragraph 9.5.1.1.6.4

9.5.1.2.6.5 FDIR Level 1

Unit Level Check

At this level a single unit is in charge of self checking its status and reports it to the ACC through dedicated interface. On the basis of the unit status the ACC can perform the relevant actions (spike filtering, reconfiguration)

In the following Table 9.5.1.2-7 for each ACMS unit the available health-checks are listed:

Unit	*Unit Health Check*
THR 1N	N/A
THR 10 N	N/A
SAS	N/A
QRS	Temperature
STM	N/A

Table 9.5.1.2-7: Unit Heath Checks

Consistency Checks

The consistency checks apply to QRS and SAS units. The checks are always carried out.

Hereafter for each unit a description of the consistency checks functionality is proposed.

SAS is operated in hot redundancy and covers the entire sky sphere. These conditions allow performing the following consistency checks in all the ACMS modes.

- Continuity check on the single sensor unit. It is a comparison between successive measurement and a threshold mode dependent.
- Frozen output on the single sensor unit. It is the verification that the output data is not stuck.
- Agreement between measurements provided by the main and redundant chains.

QRS is operated in cold redundancy. Each sensor is in charge to supply a three axis measurement. This allows the execution of the following consistency checks in all ACMS modes.

Continuity check on the single sensor unit. It is a comparison between successive measurement and a threshold mode dependent.

Frozen output on the single sensor unit. It is the verification that the output data is not stuck.

STM is operated in cold redundancy, being internally electrically redounded. The execution of the following consistency checks is allowed in NOM and OCM.

Continuity check on the presence of stars. It is an evaluation based on successive star detection. It relies on several cycles accumulation period and takes into account data from different stars, if any.

Units Cross Checks

The unit cross checks apply to all units. The checks use data from different units to verify their compatibility. The selection of the units to be used depends on the current mode. Due to the intrinsic nature of the checks, the isolation of the failing unit is not always ensured. In case of unresolved ambiguity both the unit involved in the cross check are reconfigured leaving to ground analysis further investigation. Hereafter, in Table 9.5.1.2-8 a list of identified cross checks is proposed, with a reference to the applicable ACMS mode.

	SBM	*SAM*	*NOM*	*HCM*	*OCM*
SAS / QRS	X	X	X		X
SAS / THR 10N		X			X
QRS / THR 10N		X			X
SAS / STM			X		X
QRS / STM			X		X

Table 9.5.1.2-8:Cross Checks

Mode Analysis

With reference to the above described Unit (U), Consistency (C), Cross (X) checks, their effects and applicability depend on the current ACMS mode.

In fact, in each ACMS mode, the unhealthy unit detection produces different actions according to the current use of the unit and the mode functionality. In any case, a unit classified as failing is reconfigured, even if its data are not used for control.

When QRS needs to be reconfigured, the fallback to a lower mode could be commanded.

In the following Table 9.5.1.2-9 for each ACMS mode the action performed by FDIR due to the unit failure detection is listed:

Mode	Unit Used for Control or for Measurement	Unit NOT Used	Reconfiguration	Mode Transition
SBM	SAS		C + X	-
	QRS		C +X+U	-
		STM	-	-
		THR 1N	-	-
		THR 10N	-	-
SAM	SAS		C + X	-
	QRS		C +X+U	-
	THR 10N		X	-
		STM	-	-
		THR 1N	-	-
NOM	SAS		C + X	-
	QRS		C +X+U	SBM
	STM		C + X	-
		THR 1N	-	-
		THR 10N	-	-
HCM	THR 1N		-	-
		SAS	-	-
		QRS	-	-
		STM	-	-
		THR 10N	-	-
OCM	SAS		C + X	-
	QRS		C +X+U	SBM
	STM		C + X	-
	THR 10N		X	-
		THR 1N	-	-

Table 9.5.1.2-9: FDIR Actions vs ACMS Modes

U: Unit level check; C: unit Consistency check; X: units Cross check

As reported in Table 9.5.1.2-9 the FDIR in HCM is practically suspended. This because the mode is operated in open loop. As a consequence the mode itself is in charge to verify the correct completion of the maneuver and in case of not correct attitude to initiate the recovery actions with eventually unit reconfiguration and fallback to SBM.

9.5.1.3 Subsystem Budgets

In the following sections a preliminary Power and Mass budgets are given for both satellites. Due to the fact that the class of the unit has been selected, but the supplier has not been identified, the following figures have to be considered as indicative values.

9.5.1.3.1 HERSCHEL Budget

Power Budget

Unit	*Single Unit (W)*	*Powered Unit*	*Total Power (W)*
ACC	22	1	22
RWS	15	3	45
STR	15	1	15
FSS	2	1	2
GYR	5.5	4	22
SAS	-	2	-
QRS	8.5	1	8.5
Total	-	-	114.5

Table 9.5.1.3-1

Mass Budget

Unit	*Single Unit (Kg)*	*Qty*	*Contingency*	*Total Mass (Kg)*
ACC	9	1	20 %	10.8
RWS	8.5	4	5 %	35.7
STR	8.5	2	5 %	17.8
FSS	1.5	2	5 %	3.1
GYR	5.2	1	5 %	5.5
SAS	0.2	2	5 %	0.4
QRS	1.4	2	5 %	3
Total	-		-	76.3

Table 9.5.1.3-2

Telemetry and Telecommands Budget

	16bit_words/cycle	*KBit/sec*
Telemetry	200	**6.4**
Telecommand	100	**3.2**
Patch TC	**500**	16

Table 9.5.1.3-3

9.5.1.3.2 PLANCK Budget

Power Budget

Unit	*Single Unit (W)*	*Powered Unit*	*Total Power (W)*
ACC	22	1	22
STM	0.5	1	0.5
SAS	-	3	-
QRS	8.5	1	8.5
AAD	-	2	-
Total	-	-	31

Table 9.5.1.3-4

Mass Budget

Unit	*Single Unit (Kg)*	*Qty*	*Contingency*	*Total Mass (Kg)*
ACC	9	1	20 %	10.8
STM	4.1	1	5 %	4.3
SAS	0.2	3	5 %	0.6
QRS	1.4	2	5 %	3
AAD	0.2	1	5 %	0.2
Total	-	-		18.9

Table 9.5.1.3-5

Telemetry and Telecommands Budget

	16bit_words/cycle	*KBit/sec*
Telemetry	40	**1.2**
Telecommand	10	**0.3**
Patch TC	**500**	16

Table 9.5.1.3-6

9.5.1.4 Subsystem Design Summary

9.5.1.4.1 HERSCHEL ACMS Summary

To reach the requested performances the ACMS is designed in a structured way and evolves between its modes either under ground control or autonomously.
Logically the modes are separated into:

Stand By Mode (SBM)

Sun Acquisition Mode (SAM)

Safe Hold Mode (SHM)

Star Acquisition Mode (STAM)

Normal Operation Mode (NOM)

Wheel Unloading Phase (WUP)

Orbit Correction Mode (OCM)

The design is based on the use of these units:

1x Attitude Control Computer (ACC) internally full redundant

Sensors:

2x Sun Acquisition Sensor (SAS) internally redundant
2x Quartz Rate Sensor (QRS) three-axis unit
1x Gyroscope (GYR) skewed hot redundant
2x Star Tracker (STR) cold redundant
2x Fine Sun Sensor (FSS) cold redundant implementing also the Attitude Anomaly Detector (AAD)

Actuators:

4x Reaction Wheel System (RWS) skewed cold redundant
Reaction Control System (RCS) 2 cold redundant branches based on 6x 10N Thrusters each

The sensor / actuators use in each mode is summarised in the following
Table 9.5.1.4-1.

Mode	*Sensors*	*Actuators*
SBM	-	-
SAM	SAS, QRS	RCS
SHM	SAS, QRS	RWS
STAM	GYR, FSS, STR	RWS
NOM	GYR, FSS, STR	RWS
WUP	GYR, FSS, STR	RWS, RCS
OCM	GYR	RCS

Table 9.5.1.4-1: Unit Use vs ACMS Modes

9.5.1.4.2 PLANCK ACMS Summary

To meet the requested performances the ACMS is designed in a robust structured way and evolves between its modes either under ground control or autonomously.
Logically the modes are separated into:

Stand By Mode (SBM)

Sun Acquisition Mode (SAM)

Normal Operation Mode (NOM)

Angular Momentum Control Mode (HCM)

Orbit Correction Mode (OCM)

The design is based on the use of these units:

1x Attitude Control Computer (ACC) internally full redundant

Sensors:

2x Attitude Anomaly Detector (AAD) internally redundant
3x Sun Acquisition Sensor (SAS) internally redundant
2x Quartz Rate Sensor (QRS) three-axis unit
1x Star Mapper (STM) internally redundant

Actuators:
Reaction Control System (RCS) 2 cold redundant branches, each branch based on:
6x 10N Thrusters
2x 1N Thrusters

The sensor / actuators use in each mode is summarised in the following Table 9.5.1.4-2

Mode	*Sensors*	*Actuators*
SBM	-	PND
SAM	SAS, QRS	10N-THR
NOM	SAS, QRS, STM	PND
HCM	-	1N THR
OCM	SAS, QRS, STM	10N-THR

Table 9.5.1.4-2: Unit Use vs ACMS Modes

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 shall be dimensioned for 6 years (GLP-090-H).
For Planck, propellant for orbit maintenance, attitude control and momentum management shall be dimensioned for 2.5 years (GLP-095-P).
Table 9.6.2.1-1 shows the Δ-V requirements for both Herschel and Planck, coming from the AD-11 H-P Consolidated Report on Mission Analysis (CREMA), together with the specified margins (RCF-035-C) to be used when doing the propellant budget (see Chapter 8.3).

MANOEUVRE	Herschel Delta-V [m/s]	Planck Delta-V [m/s]	MARGINS (%)
Removal of launcher dispersion	105	72	10
Manoeuvre 2 on day 12 from Perigee	4	4	10
Mid-course correction	3	3	10
Orbit injection and eclipse avoidance	0	250	10
Correction for injection	0	5	10
Orbit maintenance for mission lifetime	12	6	50
Attitude Control	10	9	50
Active Nutation Damping (TBC)	0	*actuation in pulse mode of 1N thruster for 30 ms to recovery from 1 arcmin nominal nutation each 45 minutes*	50

Figure 9.6.2.1-1 Δ-V Requirements for Herschel and Planck

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
at least equal to the amount of propellant required for three months of operational life.

The budgets for the propellant plus the pressurant are the following:

Herschel 224 kg (RCP-030-H);
Planck 272 kg (RCP-035-P).

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).

9.6.2.3 Design Requirements

Both Herschel and Planck RCS' s shall be based on hydrazine propulsion system (RCD-005-C).

The feeding of propellant shall be in blow down mode (RCD-010-C) and nitrogen shall be used to pressurize the propellant (RCD-015-C).

The RCS shall include two redundant thruster branches each of one capable to perform the complete mission and use of both branches simultaneously shall be possible (RCD-040-C).

Isolation of each branch from the fuel tanks shall be possible to prevent inadvertent firings (RCD-045-C).

The RCS shall provide 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.

10N thruster monopropellant hydrazine type are used for both Delta-V manoeuvres and Attitude Control purposes.

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 6.9 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. The pressure in the tanks is monitored by a high precision Pressure Transducer.

Two Latch valves isolate the two thruster branches. A filter, downstream the Latch Valves prevent the branches from any contamination.

The RCS layout is shown in Figure 9.6.3.1-2.

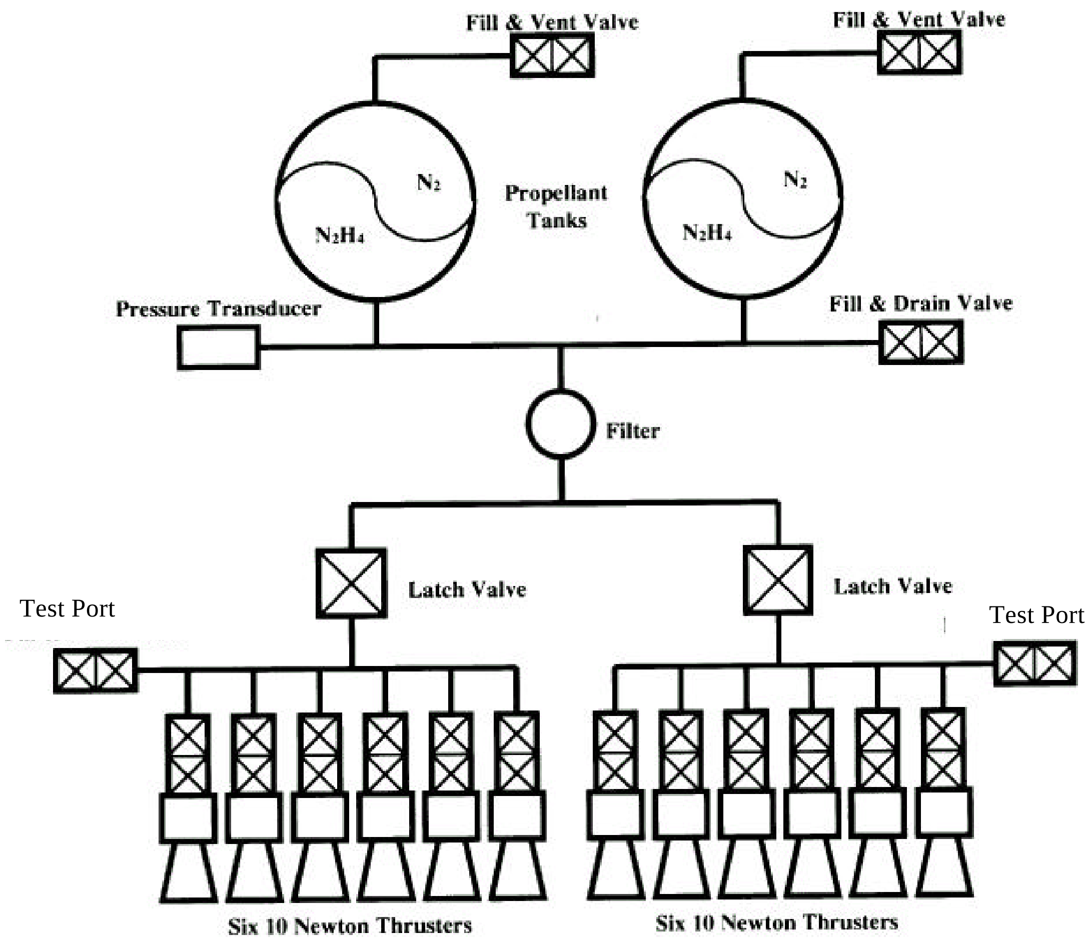


FIGURE 9.6.3.1-1 HERSCHEL RCS FUNCTIONAL DIAGRAM

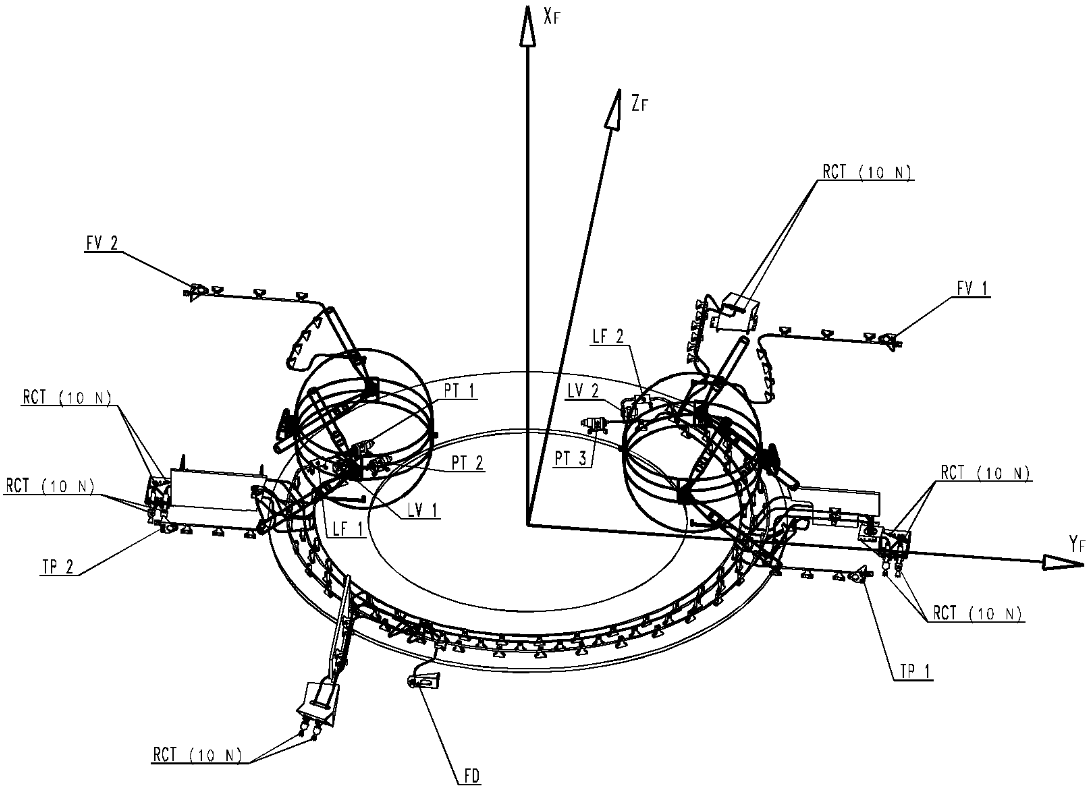
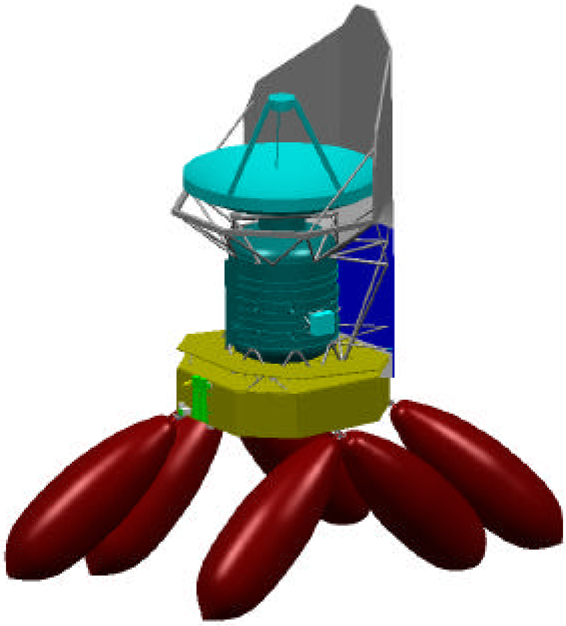


FIGURE 9.6.3.1-3 HERSCHEL THRUSTER LAYOUT

The Herschel thruster configuration is shown in the following Figure 9.6.3.1-3. The configuration and the chosen angles are such that plume impingement on other S/C parts is avoided.



Two 10N 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 9.6.3.1-4.
The thruster redundant branch is identical to the nominal one.

	HERSCHEL 10 N Thrusters					
	Position			Direction		
	X	Y	Z	X	Y	Z
Acceleration thrusters						
ThrA1	0.100 m	0.729 m	1.761 m	- 0.671	0.284	0.685
ThrA2	0.100 m	- 0.729 m	- 1.761 m	- 0.671	- 0.284	- 0.685
Control Thrusters						
ThrC1	0.100 m	1.690 m	0.000 m	- 0.707	0.000	- 0.707
ThrC2	0.100 m	1.690 m	0.000 m	- 0.707	0.000	0.707
ThrC3	0.100 m	- 1.690 m	0.000 m	- 0.707	0.000	0.707
ThrC4	0.100 m	- 1.690 m	0.000 m	- 0.707	0.000	- 0.707

Table 9.6.3.1-4 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, with a blow-down ratio of 2.5. This leads to a thrust variation from 11 N to 5.3 N.

The Planck RCS functional diagram is shown in Figure 9.6.3.2-1.

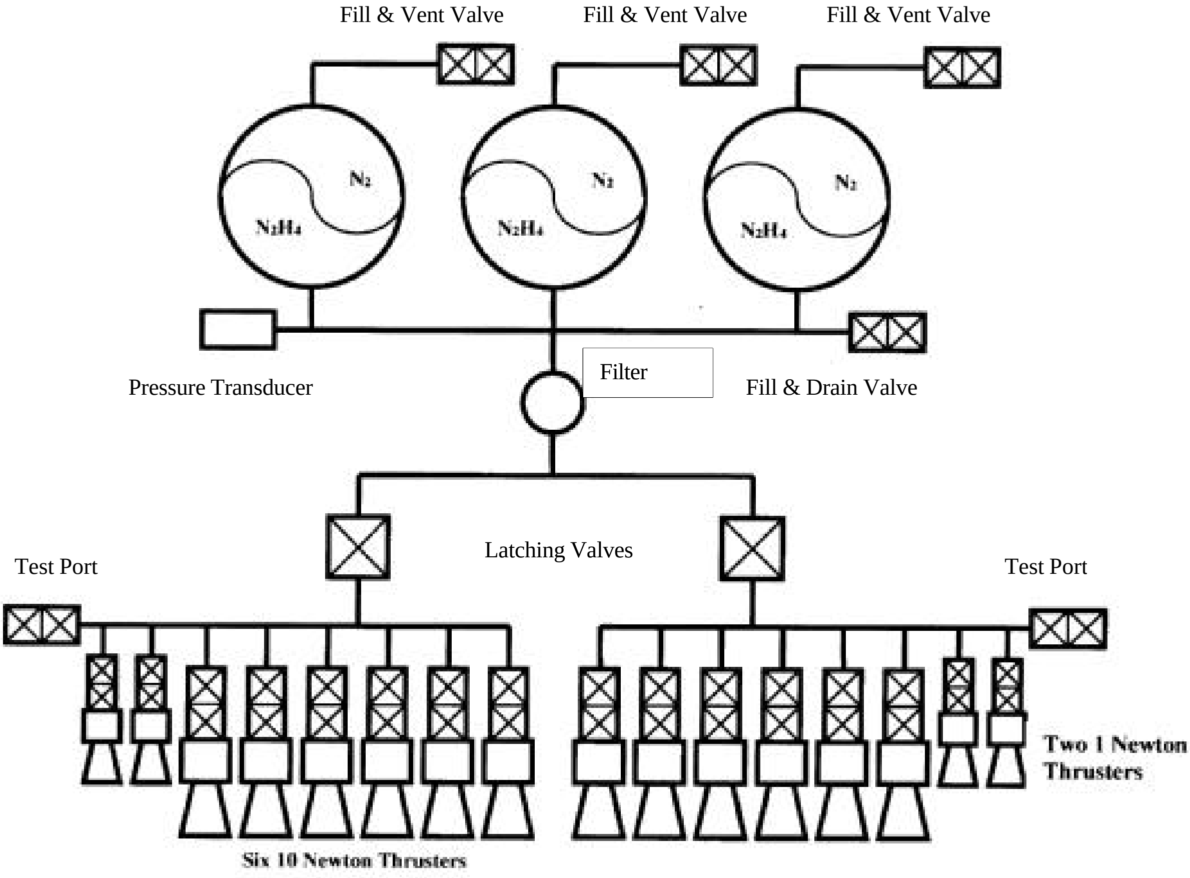


figure 9.6.3.2-2 Planck rcs layout

Two thruster branches, main and redundant constitute the Planck RCS. The thrusters are the 10N 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 9.6 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 high precision Pressure Transducer. A filter, downstream the Latch Valves prevent the branches from any contamination.

The RCS layout is shown in Figure 9.6.3.2-2.

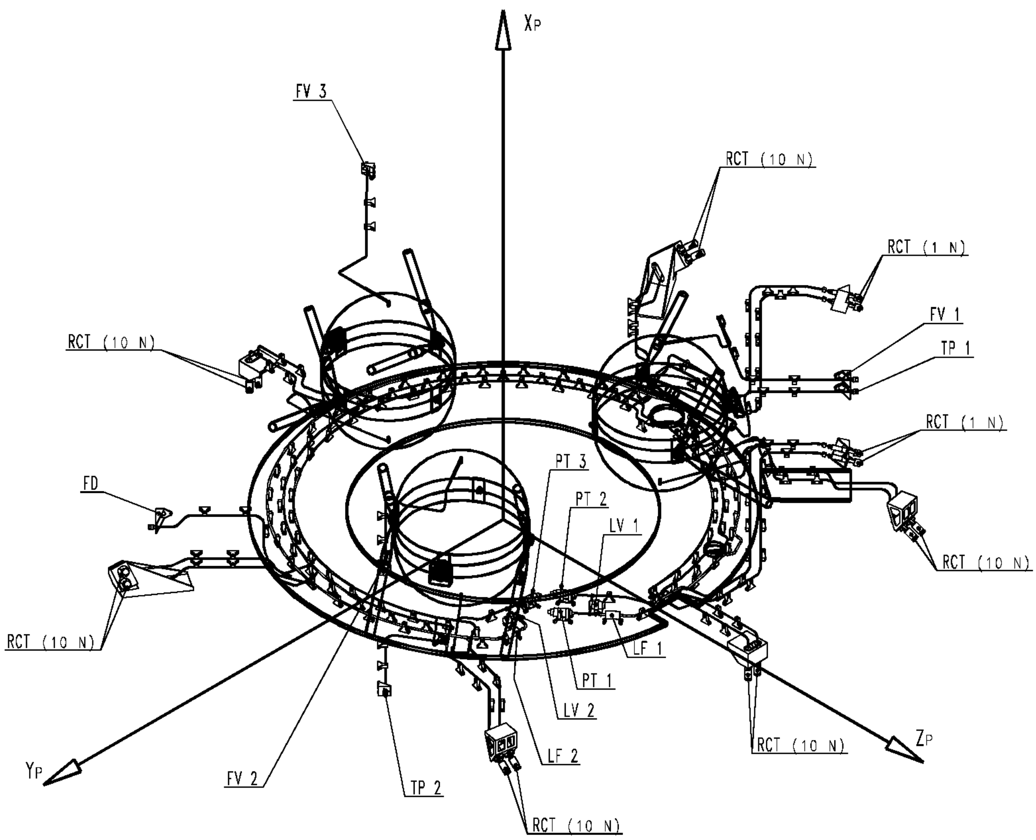


Figure 9.6.3.2-3 Planck thruster configuration

There are two different types of thrusters, 10N and 1N for, arranged in the following configuration:

3 pairs of 10N thusters for ΔV corrections:

1 pair directed towards the +X hemisphere ("up thrusters") for manoeuvres with a SAA below 90 deg;

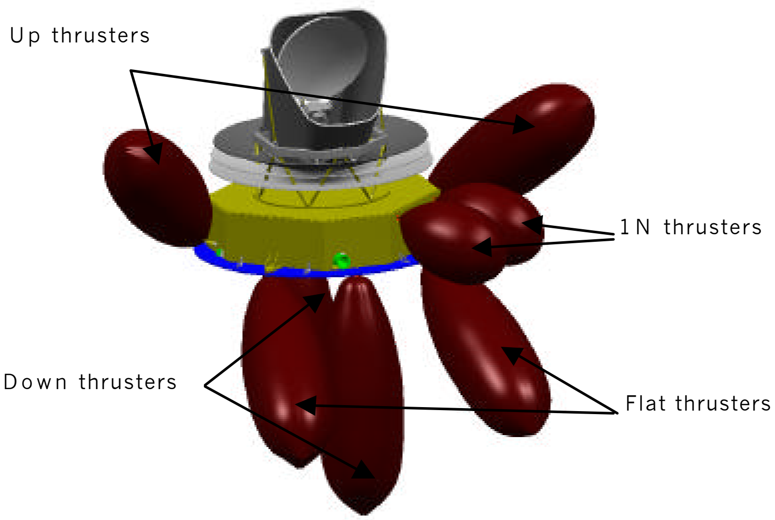
1 pair directed downwards ("down thrusters") with its thrust direction along –X;

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.

Figure 9.6.3.2-3 depicts the thruster configuration for Planck. The configuration and angles chosen do not cause plume impingement problems on the S/C.



The thruster layout for Planck is reported in Table 9.6.3.2-4.

	PLANCK 1 N Thrusters					
	Position			Direction		
	X	Y	Z	X	Y	Z
ThrA1	0.841 m	- 0.760 m	1.671 m	- 0.336	- 0.666	0.666
ThrA2	0.786 m	- 0.760 m	1.671 m	- 0.336	- 0.666	0.666
ThrB1	0.841 m	- 1.671 m	0.760 m	- 0.336	- 0.666	0.666
ThrB2	0.786 m	- 1.671 m	0.760 m	- 0.336	- 0.666	0.666

		PLANCK 10 N Thrusters, Branch A					
		"UP"		"FLAT"		"DOWN"	
		a	B	a	b	a	B
Position	X	0.000 m	0.000 m	0.000 m	0.000 m	0.000 m	0.000 m
	Y	1.690 m	- 1.690 m	- 1.382 m	1.382 m	0.000 m	0.000 m
	Z	- 0.880 m	- 0.880 m	1.188 m	1.188 m	1.649 m	- 1.649 m
Direction	X	0.562	0.562	- 0.534	- 0.534	-1.000	- 1.000
	Y	0.500	- 0.500	0.000	0.000	0.000	0.000
	Z	0.659	0.659	0.846	0.846	0.000	0.000

		PLANCK 10 N Thrusters, Branch B					
		"UP"		"FLAT"		"DOWN"	
		a	B	a	b	A	B
Position	X	0.000 m	0.000 m	0.000 m	0.000 m	0.000 m	0.000 m
	Y	- 1.690 m	1.690 m	1.382 m	- 1.382 m	0.000 m	0.000 m
	Z	- 0.880 m	- 0.880 m	1.188 m	1.188 m	1.690 m	- 1.690 m
Direction	X	0.562	0.562	- 0.534	- 0.534	- 1.000	- 1.000
	Y	- 0.500	0.500	0.000	0.000	0.000	0.000
	Z	0.659	0.659	0.846	0.846	0.000	0.000

Table 9.6.3.2-4 Planck Thruster Layout

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 anhydrous hydrazine in blow-down mode. The baseline pressurant is gaseous Nitrogen.

The tank internal volume is defined to allow a propellant growth of 20 %.

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, 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 will be dedicated to the propellant gauging method and devices.

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 tank internal volume is defined to allow a propellant growth of 20 %.

The above tank has been used on INTEGRAL RCS.

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	99.5 % minimum
Mass	14.86 kg

TABLE 9.6.4.2.1-1 TANK CHARACTERISTICS

At the time being, based on the environmental requirements of AD 13 the following activities are to be considered (as a minimum) for the qualification of the existing tank:

Delta Random Vibration Qualification;
Delta Sinusoidal Vibration Qualification;
Delta Shock Qualification.

No assessment of design changes, i.e. fixation trunnion or other structural items, can be done by the moment.

9.6.4.2.2 10 N Thrusters

The 10 N thrusters are used on both Herschel and Planck RCS's. The proposed ones have been qualified on Meteosat and SAX.

The main characteristics of the 10 N thruster are reported in the following Table 9.6.4.2.2-1.

FUNCTIONAL PARAMETER	QUALIFICATION
Operating	23 bar to 5 bar
Steady state thrust	11 N @ 23 bar to 3 N @ 5 bar
Steady state specific impulse	2228 m/s @ 23 bar to 2147 m/s @ 5 bar
Flow control valve	Dual seat, single coil, monostable

Table 9.6.4.2.2-1 10 N Thruster Characteristics

The following modification on the already qualified 10 N thruster are planned:

modification of the inlet interface of the Thruster Flow Control valve;
change of the heater on the catalyst bed, since the original one is no longer available.

As far as the 10 N Thruster qualification status is concerned the following has to be considered:

total amount of pulses and total accumulated firing duration have to be better investigated to verify compliance to the Herschel and Planck specific requirements;
At the time being, based on the environmental requirements of AD 13 the following activities are to be considered (as a minimum) for the qualification of the existing 10 N thruster:

- Delta Random Vibration Qualification;
- Delta Sinusoidal Vibration Qualification;
- Delta Shock Qualification.
  No assessment of design changes from structural point of view can be done by the moment.

9.6.4.2.3 1 N Thrusters

The 1 N thrusters are used on Planck RCS' s only. The proposed ones have been qualified on Globalstar satellite.

The main characteristics of the 1 N thruster are reported in the following Table 9.6.4.2.3-1.

FUNCTIONAL PARAMETER	QUALIFICATION
Operating	23 bar to 5 bar
Steady state thrust	1 N @ 23 bar to 0.3 N @ 5 bar
Steady state specific impulse	2197 m/s @ 23 bar to 2050 m/s @ 5 bar
Flow control valve	Dual seat, single coil, monostable

Table 9.6.4.2.3-1 1 N Thruster Characteristics

The following modification on the already qualified 1 N thruster is planned:

inclusion of a dedicated catalyst bed temperature sensor (TBC).

As far as the 1 N Thruster qualification status is concerned the following has to be considered:

At the time being, based on the environmental requirements of AD 13 the following activities are to be considered (as a minimum) for the qualification of the existing 1 N thruster:

- Delta Random Vibration Qualification;
- Delta Sinusoidal Vibration Qualification;
- Delta Shock Qualification.
  No assessment of design changes from structural point of view can be done by the moment.

9.6.4.2.4 Latch Valve

The same Latch Valve is used on both Herschel and Planck RCS' s.

The Latch Valve has a solenoid actuation device to open and close position. This is implemented through two different driving coils.
The propellant is filtered through a 40 microns filter located at the inlet of the valve and it flows axially.

The latch Valve implements position status micro-switches to monitor the open and close position.

As far as the Latch Valve qualification status is concerned the following has to be considered:

At the time being, based on the environmental requirements of AD 13 the following activities are to be considered (as a minimum) for the qualification of the existing Latch Valve:

- Delta Random Vibration Qualification;
- Delta Sinusoidal Vibration Qualification;
- Delta Shock Qualification.
  No assessment of design changes from structural point of view can be done by the moment.

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 same valve is used as test port for leak check.

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.

9.6.4.2.6 Pressure Transducer

The pressure transducer provides telemetry information on actual propellant supply conditions to the thrusters. The sensor output is a 0 to 5 VDC signal and the power supply source is 28 VDC.

9.6.4.2.7 Propellant Filter

The included filter traps the remaining particles carried by the propellant. The filtration rate is 15 micron absolute and the pressure drop is 0.4 bar @ 10 g Hydrazine flow at 22 bar.

9.6.5 RCS Commonality Assessment

Both Herschel and Planck RCS' s are designed to use the same following equipment:

Propellant Tanks;
10 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 N thrusters	METEOSAT/ SAX	0.295	12	3.54	5 %	3.7
Latch valve	VBS 100,000	0.42	2	0.84	5 %	0.88
Pressure transducer	Various	0.14	1	0.14	5 %	0.147
Fill/Drain valve	Integral	0.048	1	0.048	5 %	0.05
Fill/Vent valve	Integral	0.048	2	0.096	5 %	0.1
Test port	Integral	0.048	2	0.096	5 %	0.1
Filter	Integral	0.167	1	0.167	5 %	0.17
Ducting	2	2	1	2	20 %	2.4
Bracketry	1.5	1.5	1	1.5	20 %	1.8
TOTAL				**38.1**		**40.5**

TABLE 9.6.6.1.1-1 HERSCHEL RCS MASS BUDGET

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 N thruster	METEOSAT/ SAX	0.295	12	3.54	5 %	3.7
1 N thruster	GLOBALSTAR	0.285	4	1.14	5 %	1.2
Latch valve	VBS 100,000	0.42	2	0.84	5 %	0.88
Pressure transducer	Various	0.14	1	0.14	5 %	0.147
Fill/Drain valve	Integral	0.048	1	0.048	5 %	0.05
Fill/Vent valve	Integral	0.048	3	0.144	5 %	0.15
Test port	Integral	0.048	2	0.096	5 %	0.1
Filter	Integral	0.167	1	0.167	5 %	0.17
Ducting	2	2	1	2	20 %	2.4
Bracketry	1.5	1.5	1	1.5	20 %	1.8
TOTAL				**54.2**		**57.4**

TABLE 9.6.6.1.2-1 PLANCK RCS MASS BUDGET

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
10 N thruster	METEOSAT/SAX		12	
FCV		5		When activated
CBH		7.6		for preheating purposes only (2 hr)
Latch valve	VBS 100,000	33.5	2	for 40 ms only
Pressure transducer	Various	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
10 N thruster	METEOSAT/SAX		12	
FCV		5		when activated
CBH		7.6		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	VBS 100,000	33.5	2	for 40 ms only
Pressure transducer	Various	0.33	1	continuously ON

TABLE 9.6.6.2.2-1 PLANCK

9.6.6.3 Fuel Budget

9.6.6.3.1 Herschel Fuel Budget

The propellant budget for Herschel, inclusive of the required margins, is reported in the following Table 9.6.6.3-1.

A specific impulse of 210 s has been used and a Herschel satellite dry mass of 2743 kg inclusive of all the margins has been considered.

Manoeuvre	Propellant Mass [Kg]
Removal of launcher dispersion	162.5
Manoeuvre 2 on day 12 from perigee	5.9
Mid-course correction	4.5
Orbit Maintenance for mission lifetime	24.2
Attitude Control	20
Remaining propellant mass for three months operation life	1.9
Total Propellant Mass Consumption	217.1
Total Propellant Mass (including residual)	219
Total Fuel Loaded	220
Pressurant Mass (GN2)	5.2

Table 9.6.6.3-1Herschel Propellant Budget

9.6.6.3.2 Planck Fuel Budget

The propellant budget for Planck is reported in the following Table 9.6.6.3.2-1.

A specific impulse of 210 s, while for very short pulses considered in the manoeuvres for Active Nutation Damping a 1000 [Ns/kg] specific impulse has been used.

A Planck satellite dry mass of 1200 kg inclusive of all the margins has been considered.

Manoeuvre	Propellant Mass [kg]
Removal of launcher dispersion	55.5
Manoeuvre 2 on day 12 from perigee	3
Mid-course correction	2.2
Orbit Injection and eclipse avoidance	177.6
Correction for injection	3.3
Orbit Maintenance for mission lifetime	5.4
Attitude Control	8.0
Active Nutation Damping (TBC): actuation in pulse mode of 1N thruster for 30 ms to recovery from 1 arcmin nominal nutation each 45 minutes	2.8 (TBC)
Remaining propellant mass for three months operation life	1.80
Total Propellant Mass Consumption	255
Total Propellant Mass (including residual)	256.8 + 2.8 (TBC)
Total Fuel Loaded	260
Pressurant Mass (GN2)	7.8

Table 9.6.6.3.2--1 Planck Delta-V Budget

9.7 Control and Data Management

9.7.1 General

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

Subsystem function will be implemented in one Control and Data Management Unit, which includes a Mass Memory of 25 Gbit End Of Life.

The implemented microprocessor is an ERC32SC Processor.

MIL-STD-1553 Bus will be used to transfer data to/from instruments, PCDU, ACC and CDMS.

The CDMU provides condition inputs for a number of discrete telemetry lines which will be used for housekeeping.

A number of discrete telecommand lines are provided for reconfiguration and to users which cannot interface with 1553 bus.

A number of synchronisation lines (On Board Time to Local On Board Time sync, Start of Scan Sync for Herschel and Star Reference Pulse for Planck) are provided to each instrument, these are transmitted via over the MIL-STD-1553 bus and discrete lines.

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: 107 kbps
- 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-4.2), 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 100 kbps (SINT-040, SINT-045).

Taking into account a 5 kbps average rate for satellite housekeeping, the required storage is 18.1Gb. A mass memory of 25 Gb End of Life is planned on Herschel and Planck thus providing a margin of more than 30 %.

The instrument data rate over 48 hours compatible with the mass memory sizing is 140 kbps.

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 Functional Description

The Control and Data Management functions are combined in a single **Control and Data Management Unit, CDMU**.

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
Processor Module
Telemetry Encoder
Mass Memory Module
Standard I/O interfaces
Reconfiguration Module.

Time reference pulses are also distributed by the CDMU to the Science Instruments.

A Block Diagram of the CDMU is shown in the following figure.

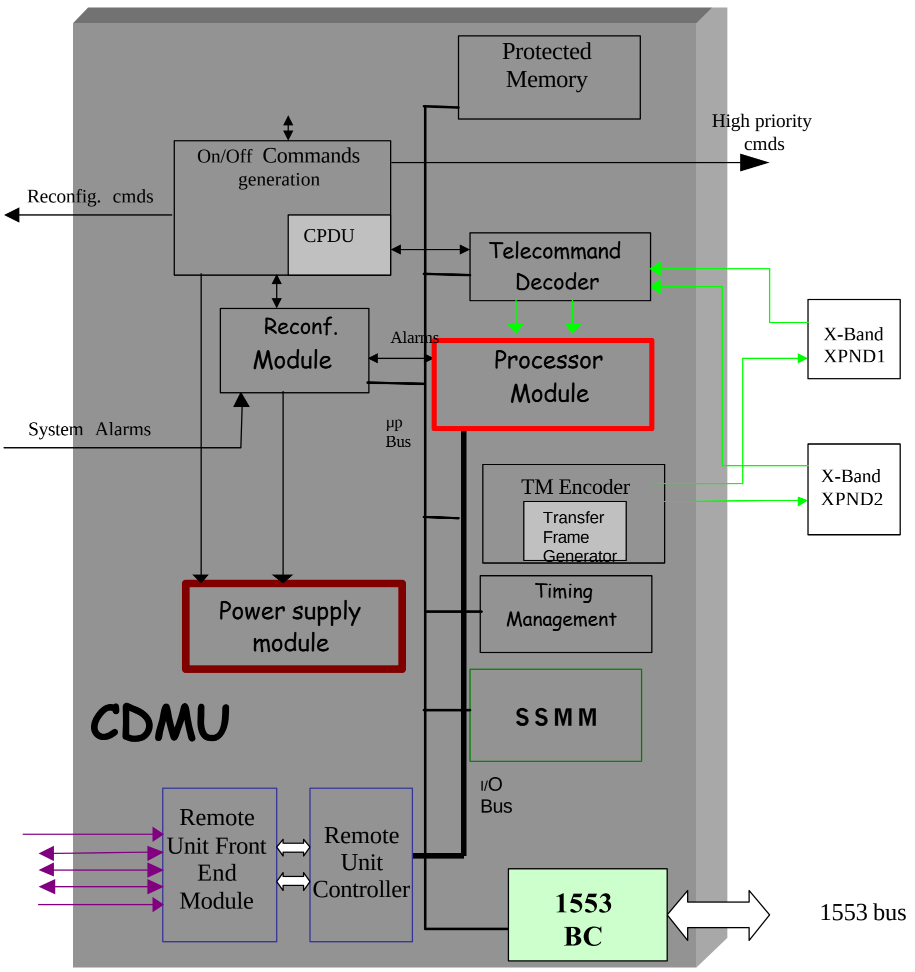


Figure 9.7.3-1 CDMU Functional Block Diagram

9.7.4 Design and Performance

The CDMU consists of the following redundancy blocks:

Blocks operating in hot redundancy. There is no power cross strapping:
TM/TC N and Hot Power Converter N
TM/TC R and Hot Power Converter R.

Blocks operating in cold redundancy. There is no power cross strapping:
PM N, MMC N and Cold Power Converter N
PM R, MMC R and Cold Power Converter R.

Hot operating, non-redundant blocks. They are supplied from Cold Power Converter N or R. The redundancy achieved depends on how they are connected to the users:
Standard Configuration I/O 1
Standard Configuration I/O 2
Standard Configuration I/O 3
MM Banks 1
MM Banks 2.

The CDMU receives demodulated digital telecommand signals from the two Transponder receivers. Each Command Decoder receives data streams from the two receivers. 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]. Two types of commands are possible:

high priority commands, that are directly output as pulse commands from the TC decoder
telecommands, that are distributed to the CDMU Processor Module.

The decoder supports Authentication of telecommands in accordance with ESA TC Decoder Spec [AD-45]. The CDMU decoders are operating in hot redundancy.

The CDMU Processor Module (PM) provides the processing function of the CDMU, including PROMs and reprogrammable EEPROMs. The PM provides communication with Science Instruments on a MIL-STD-1553 bus. The PM is also equipped with a serial link for test purposes and reprogramming of the EEPROMs. It also has an interface for high-speed software load (ground use only). The CDMU Processor Module is operated in cold redundancy.

The Mass Memory systems of the CDMU consist of two redundant Mass Memory Controllers in cold redundancy and Mass Memory Banks operating in hot redundancy. The Mass Memory stores TM data and housekeeping. Both PMs have full access to all Mass Memory Banks. The Mass Memory Controller, implemented in hardware, provides low level mass memory control including memory scrubbing, memory address management and control of the in and outgoing data links. The Mass Memory File Management is handled by the CDMS software as part of the overall CDMS software operating system.

The telemetry is formatted in accordance with ESA Packet Telemetry Standard [AD-24]. The virtual channel concept is implemented using the VCA/VCM functionality. Each TM Encoder provides a virtual channel from each Mass Memory Controller. The telemetry data streams are encoded using Reed-Solomon, convolutional and NRZ-L encoding. The TM interfaces of the CDMU work in hot redundancy.

The CDMU provides two hot redundant Reconfiguration Modules (RM), which are accessible from the two PMs. The RMs will automatically trigger a reconfiguration in case of active alarm input. External alarms and internal CPU alarms (watchdog, EDAC double bit error, illegal access…) are foreseen.

The CDMU provides a protected resource in the form of two safeguard memories operating in hot redundancy.

On-board time keeping is implemented as two OBT functions operating in hot redundancy. The OBT provides CCSDS Unsegmented Time Code. The OBT may be set to use the TAI epoch. The OBT also includes a number of pulse generators which provides the required 131 kHz sync pulses.

The CDMU uses an internal serial I/O bus for communication between the processor module and the I/O modules. The I/O 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.

9.7.4.1 TM/TC Functional Block

There are two TM/TC Blocks operating in hot redundancy.
Each TM/TC block is built IN the TTR board, which houses the following functions:

Command Decoder
Packet Telemetry Encoder
Command Pulse Distribution Module
Reconfiguration Module
On Board Time
Clock Generator
Internal Control Bus Remote Terminal
Memory Interface.

Some of the tasks to be performed are listed below:

Telecommand reception, decoding and handling according to ESA Packet Telecommand standard
Telemetry Transfer Frame generation, coding and modulation according to ESA Packet Telemetry Standard
Timing and Synchronisation management, providing a stable time reference that can be synchronised to external events
Autonomy, in form of a Reconfiguration Unit that change the current configuration in case of errors detected, and a safeguard Memory that is used to store context for later reuse in another configuration
Control Bus for communication with the PM.

Basically all functional modules in the TTR board comprise a digital core within the ASIC and the associated interface circuits (buffers, driver, filters, protections).

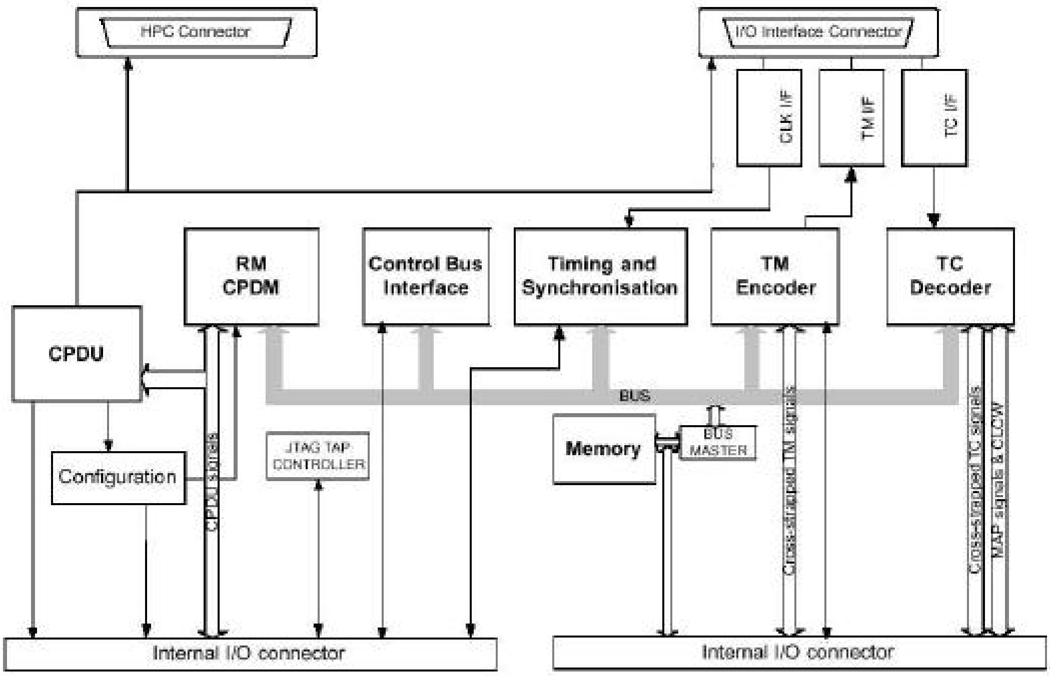


Figure 9.7.4-1 TM/TC Block Diagram

The modules in the TM/TC block are described in the following.

9.7.4.1.1 Command Decoder

The Command Decoder (PTD) implements the Packet Telecommand Protocol in compliance with AD-25.

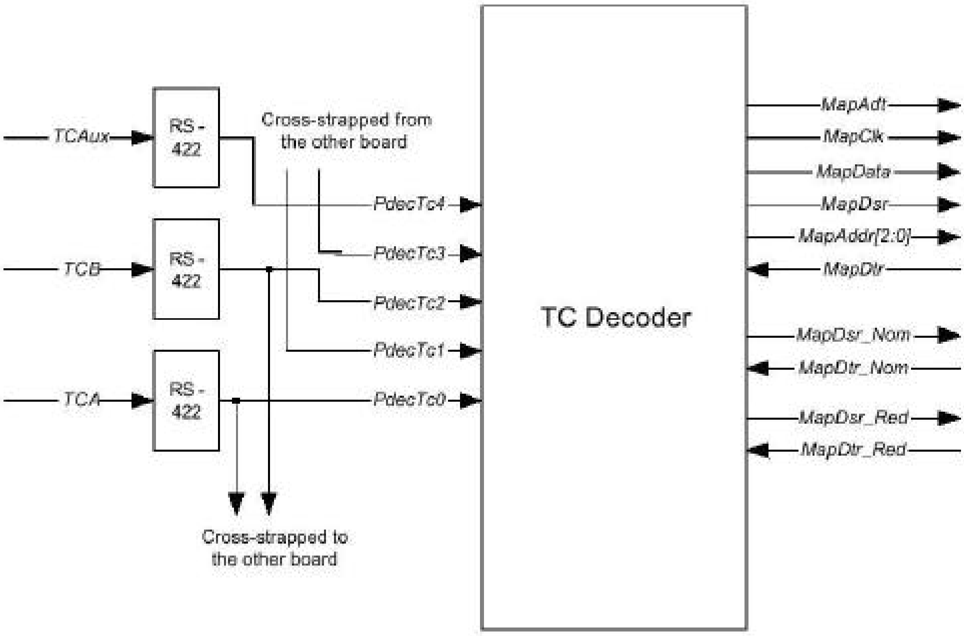


Figure 9.7.4-2 Command Decoder Interfaces

The Command Decoder is built using the following blocks:

- Serial Input Block (SIB)
- AUhentication Block (AUB)
- Segmentation Layer and Router Block (SLRB)
- TeleMetry Block (TMB).

The Serial Input Block handles all serial processing, which covers the entire Coding Layer and Transfer Layer. Headers, frame status and the AU Control Command Identifier are put in registers available to the other blocks. Decoding and execution of BC control commands are also performed here. The frame (AD or BD type) is put in a RAM frame buffer. BC frames are not buffered and thus do not use the RAM.

The Authentication Block uses the AuEnable signal, the Segment Header, and the AU Control Command Identifier provided from the Serial Input Block to decide if authentication shall be performed and which key that shall be used. The keys are fetched from RAM or Mission PROM when needed. The Authentication Block handles AU Control Commands without activating the Segmentation Layer and Router Block.

The Segmentation Layer and Router Block identifies CPDU packets and hands them over to the Command Pulse Distribution Module (CPDM). Other segments are read from RAM and routed to the correct destinations. It uses the MAP address to look in the Mission PROM to find where to send them.

Each block with telemetry is responsible for putting its parts of the required TM in registers that are assembled to telemetry reports by the Telemetry Block.

As per SGICD (AD-07), uplink bit rates are **125 bps** and **4 kbps**.

9.7.4.1.2 Telemetry Encoder

The TM Encoder receives TeleMetry data on a variable number of separate serial input interfaces, each connected to a Virtual Channel. The Encoder then generates complete Transfer Frames. The transfer frames can be Reed-Solomon and/or convolutionally encoded. Before being output, the data is stored in an external memory buffer, which is shared by the Virtual Channels.

The TM Encoder module is functionally compatible with the now obsolete chip-set for Packet TeleMetry (TM) previously developed by the ESA.

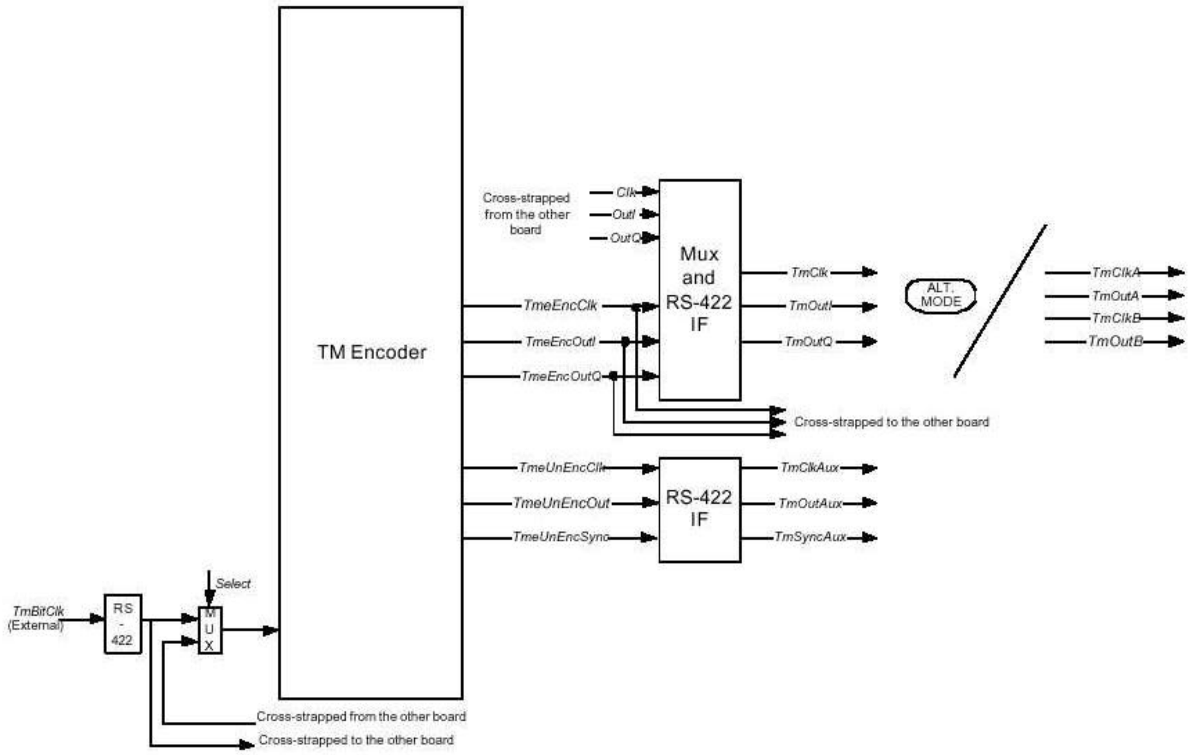


Figure 9.7.4-3 Telemetry Encoder Interfaces

The TM Encoder has the following functions:

- 1 to 8 VCA Interfaces for telemetry data
- retrieval of the CLCW using a TTC-B-01 [RD-01] type interface
- output of the generated frame from three stages: unencoded, encoded, and modulated, all as a serial bit stream
- a strobe to allow the on-board time to be sampled synchronously with the generated transfer frames
- four clock inputs with a frequency being a multiple of the bit rate used for clocking out the serial bit-stream
- DMA Read and Write channels are used to access an external memory buffer for temporary storage of the Telemetry Data.

It is 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.

As per SGICD [AD-07], the required bit rates are the following:

low bit rate: **500 bps**, **5 kbps**; medium rate: **107 kbps**; high rate: **1.5 Mbps**

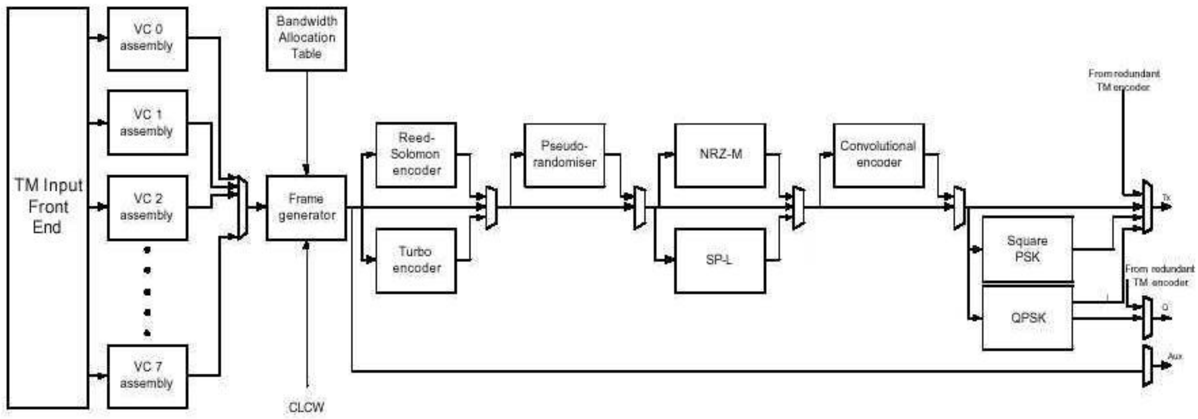


Figure 9.7.4-4 Telemetry Encoder Block Diagram

The TM Encoder is built according to ESA Packet Telemetry standard.
A system is built of two TM/TC Block boards, where one of the two TM encoders is enabled and the other one is disabled.

Modulation:
The following waveforms can be selected:
- NRZ-L
- NRZ-M
- SP-L

If no coding, randomisation or modulation is selected at all, the output is in NRZ-L form.

The selection options for the modulations are:
- no modulation
- Quadrate Phase Shift Keying (QPSK)
- Square PSK.

Output waveforms:
The generated Transfer Frames can be output from three stages of the TM encoder:
- unencoded
- encoded
- modulated.

The unencoded signals are connected to the Auxiliary line and used for test purpose only.

The TTR board is equipped with the following output interfaces:

- Two (Clock and Data) outputs OR
- One Clock, I and Q outputs

The selection of two (Clock and Data) outputs or one Clock, I and Q is selectable by straps on the TTR board.

All serial TM outputs are cross-strapped between the two TTR boards.
The serial TM outputs can be synchronised with an external clock, which also is cross-strapped between the nominal and redundant boards.
At the end of the encoding process it is possible to select which of the TM encoders, nominal or redundant, that will generate data to the transmitters. The selected TM encoder always drives all serial TM outputs (on both TTR boards).
The unselected TM encoder is disabled, placed in a reset state, and is not operating although it is continuously powered.
The foreseen interface between CMDU Telemetry Encoder and Transponder is RS422.

9.7.4.1.3 Timing and Synchronisation

On-Board Time

The On-Board Time function resides in the hot redundant TM/TC block. The OBT is in this way a protected resource, as required.

The OBT is based on a hardware counter following the CCSDS Unsegmented Time Code (UTC) format, as is required by the ESA Packet Telemetry standard [AD-24].
It provides reference time in the system. It is possible to synchronise the OBT to an external master reference time. The OBT may also be used as a master reference time function, and distribute synchronise pulses to slave reference time functions in the systems.
There are four main functions in the OBT module. They are:

- OBT counter
- Numerical Controlled Oscillator, NCO
- Sampling of OBT counter
- Pulse generation

The OBT counter is a pre-settable 56-bit counter where the 24 least significant bits represent sub seconds and the 32 most significant bits represent seconds. This implies that the OBT counter needs an input frequency of 2^{24} Hz to use the full resolution.
Lower frequencies are possible to use, at the cost of lower resolution in the OBT Counter. The OBT counter can be synchronised to an external source and can also act as the synchronisation source. Pre-setting can be done by software or synchronised to an external event.
The OBT also includes a programmable OBT synchronous pulse generator. This will be used for generating the 131072 Hz synchronisation signals.
The OBT counter can be sampled through an external hardware triggered signal or by software generated event. The sampled value can then be read by software. Three such sample registers are available and are allocated as:

REG1 Samples the OBT upon occurrence of software write operation
REG2 Samples the OBT upon occurrence of the ASM pulse from the Transfer Frame Generator
REG3 Samples the OBT upon occurrence of an external signal

The OBT is used for time stamping of on board events.

Clock Generator

In addition to the OBT function, the TM/TC block contains separately programmable pulse generators that can be used to generate different output frequencies from any of two clock sources. The clock sources may be either the OBT clock or the clock that drives the Reconfiguration Module (typically a 1 MHz clock).
The Clock Generator module can generate several divided clocks from one common clock source. For every clock generated the clock waveform is defined by:

Clock Period:	Number of clock cycles of the source clock
Clock Assert edge	Number of clock cycles of the source clock from period start
Clock Deassert edge	Number of clock cycles of the source clock from period start

The polarity of each clock is also possible to program. The generated clocks in one Clock Generator module may be started synchronously on an external event, thus making it possible to generate clocks which are synchronous to each other and have a know phase difference.

Oscillator:
An oscillator with a frequency of 2^{24} Hz is used as system clock.
The On Board Time Clock generated may be temperature controlled using a thermistor, which senses the surrounding temperature of the oscillator. The thermistor resistance is A-to-D converted which is used as an input to an EEPROM. The data of the EEPROM feeds a function, which create a synthesised clock signal. The exact data for the EEPROM of each individual oscillator is defined during board level test.

9.7.4.1.4 Reconfiguration Module

The reconfiguration function in the CDMU system is handled by two hot redundant Reconfiguration Modules that process incoming alarms and generates CPDU packets for execution by the CPDU.
The figure below shows the reconfiguration function, which consists of alarm sensors, two identical Reconfiguration Modules (RM) and command relays.
The Reconfiguration Modules communicate to ensure that only one RM at a time can drive the Command Relays.

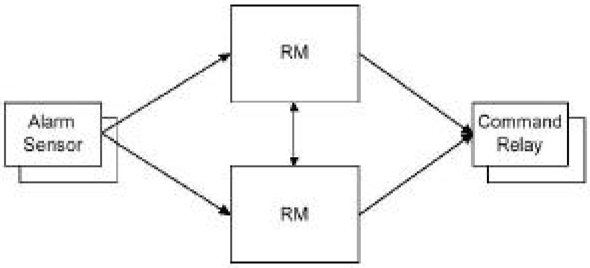


Figure 9.7.4-5 Reconfiguration Function

The RM has the following main features:

implemented in hardware
detects alarm patterns
Voting on alarm triplets (e.g. separation and umbilical straps)
Mission Mode Sensitive Operation
reconfiguration sequences selected according to alarm pattern
automatic retry with different reconfiguration sequence
glitch filter on alarm inputs
programmable delay
programmable retry delay
programmable temporization on all inputs
patterns and sequences stored in PROM or RAM
log of executed reconfigurations to RAM
enable/disable on individual alarm inputs.

The architecture of the RM allows for selecting which features that shall be enabled. In the CDMU application only one reconfiguration sequence will be triggered by each alarm.

The RM is fail silent.

The RM is controlled from a memory structure typically residing in a mission PROM area. Here are all predefined Alarm Patterns and Reconfiguration Sequences stored, as well as other parameters controlling the RM operation.

Protected Resource

The RAM memory located in the hot redundant TM/TC Blocks will be used for the Protected Resource Storage (E.g. SW Configuration Data, Event Logs, and Time Tag Command Queue).

The reconfiguration safeguard memory will be implemented as 2 x 1 Mbytes.

9.7.4.1.5 Command Pulse Distribution Unit

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 CPDU can be commanded from three sources, the Command Decoder, The Processor Modules via the Serial Link and the Reconfiguration Module. Arbitration and priority between these sources is handled by an input selector.

A total of 88 HPC, 64 external and 24 internal, outputs are available on the 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.

The following internal CPDU commands are used:

Authentication Unit enable
Authentication Unit disable
Use Telemetry EncoderA and ObtA
Use Telemetry EncoderB and ObtB
Use PMA as active PM
Use PMB as active PM
Watchdog enable
Watchdog disable
Enable nominal Reconfiguration Module
Disable nominal Reconfiguration Module
Enable redundant Reconfiguration Module
Disable redundant Reconfiguration Module
Set processor status bit 1
Reset processor status bit 1
Set processor status bit 2
Reset processor status bit 2
Set processor status bit 3
Reset processor status bit 3
PM A on, to Power Converter
PM A off, to Power Converter
PM B on, to Power Converter
PM B off, to Power Converter
Processor Module A reset
Processor Module B reset

9.7.4.1.6 Communication with the Processor Modules

The hot redundant TM/TC block communicates with the two cold redundant Processor Modules using an Internal Control Bus. The Internal Control Bus is used for controlling the TM/TC Blocks as well as for fetching received TC Segments and Sending TM Source Packets.

There is also a number of discrete signals:

PM Interrupt
Clock Synchronisation Signal
PM Alarms to the RM
PM Watchdog to the RM.

9.7.4.1.7 Communication with the Mass Memory

Each TM/TC Block Receives TM Source Packets from the Mass Memory over two discrete Packet Wire links.

9.7.4.2 Processor Module

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
Boot PROM
EEPROM
RAM
Oscillator
Serial I/O Bus (to SCIO)
Mil-STD-1553B Interface
Internal Control Bus Interfaces (for TM/TC)
Test Interfaces.

The Block Diagram of the Processor Board is shown in Figure .

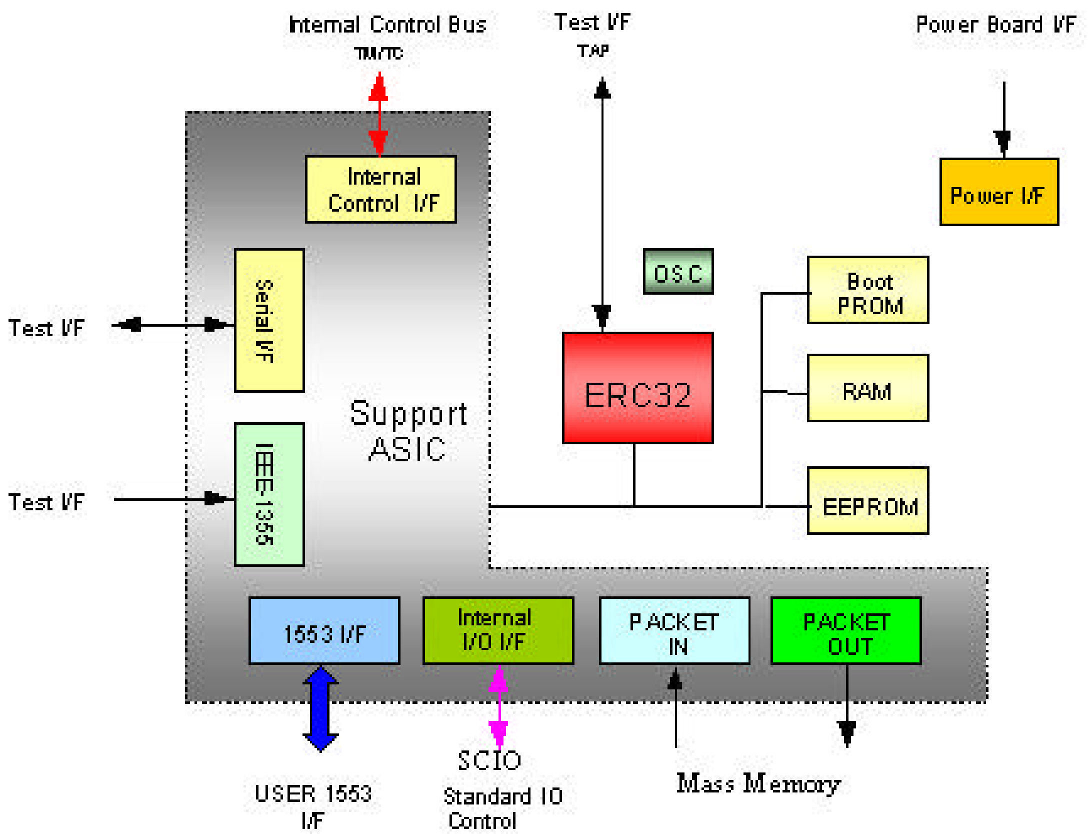


Figure 9.7.4-6 Reconfiguration Function

Processor

The Processor Board will include the ERC 32 radiation tolerant single chip microprocessor (TSC695E) as the baseline. The processor will be clocked with an oscillator running at 24 MHz resulting in an operating frequency of 12 MHz. This is nearly the maximum possible speed when using the RAM devices discussed in the following.

Memories

For booting of the processor, using 32k x 8 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. The use of EEPROMs makes it possible to easily reprogramme the PM during on-ground operations without the need to open the box. In order to improve the Single Event Upset tolerance of the devices further, the EEPROMs are power switched.

The RAM devices foreseen for the baseline are 512k x 8 devices. The RAM memory will be protected by the EDAC available in the ERC32SC, thus minimizing the impact of Single Event Upsets.

The exact amount of memory needed for the Processor Board will be consolidated during Phase B. For the baseline design the following memory types and sizes (excluding check bits) are foreseen:

64 kbyte PROM
1 Mbyte EEPROM
6 Mbyte RAM.

MIL-STD-1553B

A dual redundant MIL-STD-1553B Bus Controller is implemented on each PM.

In addition to the M1553 module in the ASIC a transceiver and two transformers are required.

Power Board Interface (Supply Voltages)

The baseline design of the Processor Board uses 5 V and 3.3 V.

Test Interface

A test interface is provided on the Processor Board allowing communication with the S/W. The test interface uses the ERC32 on-chip UART serial link with RS-422 electrical interface. The bit rate for this interface is 19200 bps.

The high-speed interface for the quick software loading uses one of the UARTs in the ASIC, which is capable of up to 307200 bps.

The ERC32 has a JTAG TAP, which may be used during CDMS testing and SW debugging in complement to the UART serial link.

9.7.4.3 Mass Memory

The baselined Mass Memory is based on the following key features:

256 Mbit SDRAM based solution
convenient file system management
powerful multiple error detection and correction
high fault coverage built-in self tests
file system software running in the controlling processor.

Other technical key features are the following:

record data rate at up to 6 * 10 Mbps
playback data rate at up to 6 * 10 Mbps
powerful file system management handled by the controlling processor
simultaneous record and replay capability
excellent BER even in case of DRAM permanent failures thanks to the Reed Solomon Codec and the DRAM scrubbing
easily expandable memory capacity
very attractive mass due to a high density memory approach
fault tolerant architecture
low power consumption
powerful diagnostic mode and built-in self test.

The Mass Memory architecture is based on a redundant back-plane bus, called the Internal Mass Memory Bus (IMMB), which connects nominal and redundant Memory Controller (MMCTRL) with Memory Boards (MMBANKS).

The advantages of this architecture are many:

simple bus architecture
modularity, providing easy configuration
expandable, both regarding storage capacity and bit rates.

The Memory Controller handles all internal and external interfaces, and receives commands and sends telemetry over two dedicated high-speed links. The MMCTRL function is entirely realised in hardware, with no software involved.

9.7.4.4 External Interfaces

The CDMU I/O interconnections are shown in Figure 9.7.4-7. The entire I/O system is controlled from the active Processor Module.

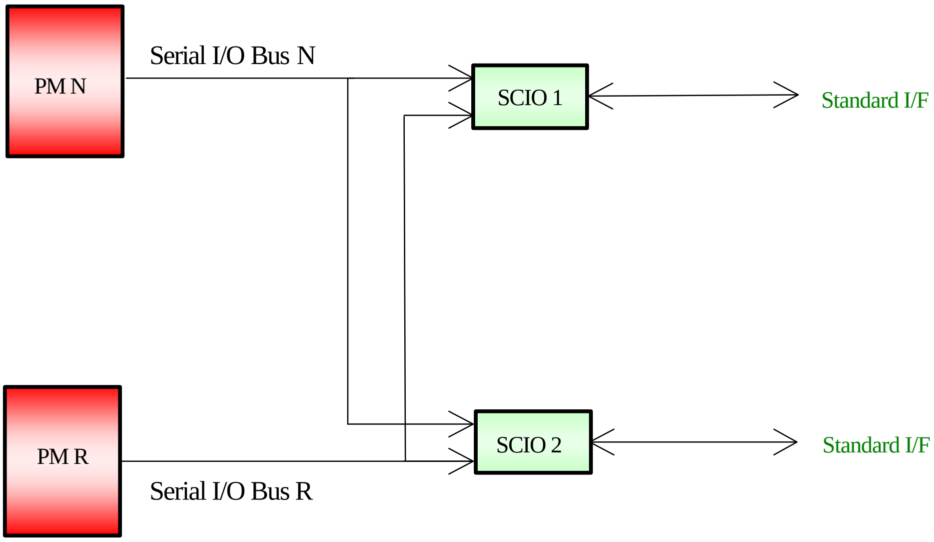


Figure 9.7.4-7 CDMU I/O Organisation

The SCIO boards provide standard I/O functions.

Standard I/O is implemented using a serial bus concept. The I/O channels are connected to independent failure isolated I/O groups, slices, all connected to two redundant internal serial I/O buses, one for each PM, the electrical interface is CMOS type. Each slice has a unique address.

The core of the slice is a mixed Analog/Digital ASIC (M2). Its functions are the following:

redundant I/O bus interface
12 bit ADC for AN and TH
multiplexer and conditioning for TH or DR inputs
control of external multiplexers for AN and DB inputs
control of HL, EHL or LLC commands
control of ML and DS channels
control of general port
pulse counter inputs.

This M2 is designed to give fail silence on the response bus and the pulse command outputs.

The slice is supplied from continuous supply voltages and contains current limiters for all supply lines.

Standard I/O Channels

The Standard I/O channels are implemented using a Standard Reconfigurable I/O board (SCIO). Each board contains two independent non-redundant I/O slices.

The electrical design and layout of the slice admits the following capacity:

48 High Level/Extended High Level Commands
8 Low Level Commands
64 Thermistor/Digital Relay Channels
64 Analog/Digital Bilevel Channels
7 Memory Load Channels
8 Digital Serial Channels.

The slice is fail silent on the response bus and the pulse command outputs.

High Level/Extended High Level Commands are implemented using control signals from the M2 to the Output Command Driver ASIC (OCD) which can handle 16 outputs each. The 28 V supply passes a group switch which is controlled by the M2 to ensure fail silence.

Low Level Commands are implemented in a similar way but with low voltage differential drivers.

Thermistor and Digital Relay inputs are connected to the M2 with external components for each channel conditioning.

Analogue and Digital Bi-level inputs are connected to external analogue multiplexers followed by a differential amplifier. The 12 bit A/D conversion is performed inside the M2.

Memory Load and Digital Series channels are connected to the M2 via external RS422 driver and receiver circuits.

With the budget of channels presently foreseen, this function requires four slices on two boards.

9.7.4.5 Power Converter and Cross-Coupling Board

The main function of the power and cross coupling board is to supply the CDMU with regulated secondary voltages. The board consists of one hot converter, which will be permanently powered on, and one cold converter, which is on/off switchable by means of high level telecommands. The hot and cold converter will share some design blocks (CM-filter, start-up supply etc.) in order to reduce the parts count.

Redundancy is achieved by the use of two boards within the CDMU. The power and cross-coupling board consists of the following blocks.

Hot converter:
The hot converter provides 5 output voltages: + 3 V, + 5 V, + 15 V, **-** 15 V and + 28 V. It supplies the TC Decoder, the TM Encoder, the Protected Resources, the direct command pulse generation and the reconfiguration module. The converter will be able to deliver 15 W peak.
The hot converter is based on an established current mode topology operating at fixed frequency.

Cold converter

The cold converter provides 6 output voltages: + 2.5 V, + 3 V, + 5 V, + 15 V, **-** 15 V and + 28 V. It supplies the processor module, the Mass Memory Controllers and the I/O functions. The converter is able to deliver 45 W peak.
The cold converter, which requires a considerably higher power capability, is based on a current fed dual switch topology.

Cold cross coupling, including:
generation of continuous (CONT) voltages. The CONT voltages are automatically configured to the active supply when the ON or OFF command of the cold converters are received. The design is failure safe meaning that a single part failure cannot lead to that both processors will be powered simultaneously. Nor can any nominal and redundant power line be interconnected. CONT Power is used to supply the Mass Memory Banks.

Telemetry

A thermistor telemeters the board temperature at a location of thermal interest.

Analogue voltage monitoring of some secondary supply rails will be generated in the motherboard and routed internally to the I/O blocks.

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 20 % contingency	12 kg 14.4 kg
Unit Dimensions (excl. Attachment feet)	405 mm x 250 m x 260 mm (WxDxH)
Board size	233 x 160 mm 13 boards
Power Dissipation Nom average	 44 W
Performance CPU performance RAM memory EPROM memory PROM memory Mass Memory Safeguard memory	 10 MIPS 6 Mbyte 1 Mbyte 64 kbyte 34 Gbit BOL; 25 Gbit EOL 2 x 1 Mbyte

Table 9.7.6-1 CDMU Budget Summary

Standard I/O channels budget:

High Prior. Cmds	Ext. High Prior. Cmds	High Level Cmds	Ext. High Level Cmds	Low Level Cmds	ML16	An Mn	Therm	PT Sens	Relay Status	Bi-level	SBDL Status Lines	DS16	RM Alert Inputs	131 kHz LOBT Sync
64	**16**	**80**	**16**	**16**	**14**	**80**	**192**	**64**	**80**	**64**	**40**	**14**	**16**	**16**

Table 9.7.6-2 CDMU I/O Budget Summary

9.8 RF

9.8.1 General

It addresses 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 System Requirements Specification, driving the TT&C, providing consideration and discussion on their indented implementation.
Herschel and Planck missions are essentially characterised by the following features:

- both use X-Band for up and downlinks. Frequencies 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: 10° maximum for Planck and 0° for HERSCHEL
- the uplink and downlink data rates requirements, mainly driven by the science data, are very much comparable between the 2 spacecraft.

Which calls for an obvious hardware commonality between HERSCHEL and Planck TTC subsystems.

9.8.2.1 General Requirements

TEP-nnn-C [SMTT-05]
The TT&C Subsystem shall be able to receive and demodulate telecommands, modulate and transmit the telemetry, and transpond the ranging signal, simultaneously.

TEP-nnn-C [SMTT-010]
The TT&C Subsystem shall interface with the ground segment according to the requirements of the Space to Ground ICD.

TEP-nnn-C [SMTT-015]
The Links shall make use of X-band for both up link and downlink

TEP-nnn-C [SMTT-020]
The TT&C shall follow the ESA ranging and modulation standards
- Ranging Standard, ESA PSS-04-104
- Radio Frequency and Modulation Standard, ESA PSS-04-105

TEP-nnn-C [SMTT-025]
The spacecraft shall have no requirements for telecommand and telemetry operation during the launch phase via its RF links.

TEP-nnn-C [SMTT-030/035]
The following modes shall be supported:

<u>Uplink :</u>	Carrier only, Telecommand, Ranging, Simultaneous Telecommand and ranging
<u>Downlink:</u>	Carrier only, Telemetry, Ranging, Simultaneous telemetry and Ranging, Doppler

TEP-nnn-C [SMTT-040]
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.

TEP-nnn-C [SMTT-045]

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.

TEP-nnn-C [SMTT-050]
The TT&C subsystem shall provide a range and/or range rate measurement capability. For ranging, it shall be capable to demodulate ranging tones from the uplink carrier and modulate the downlink carrier with them.

9.8.2.2 ANTENNA CONFIGURATION AND COVERAGE

TEP-nnn-C [SMTT-075]
The antenna configuration shall ensure sufficient coverage and up-and downlink rate capability for all mission phases.

TEP-nnn-C [SMTT-085]
Telecommands shall be via the LGA's and the subsystem shall provide the required telecommand capabilities at maximum distance from the Earth and in any S/C attitude

TEP-nnn-C [SMTT-090]
The possibility to command via the MGA shall be investigated.

TEP-nnn-C [SMTT-105]
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.

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.

A preliminary analysis for utilization of MGA also for commanding has been performed and the optional 256Kbit TC uplink will be not implemented but, the MGA will be used for the low rate TC uplink.

9.8.2.3 REDUNDANCY AND RF SWITCHING

TEP-nnn-C [SMTT-055]
The receive function shall be in hot redundancy while the transmit function shall be in cold redundancy

TEP-nnn-C [SMTT-060/065]
The receiver outputs shall be cross coupled with the CDMS command decoder allowing that each receiver can receive and each decoder can decode simultaneoulsy

TEP-nnn-C [SMTT-070]
The Trasmitter shall be able to receive telemetry stream from both parts of redundant CDMS

TEP-nnn-C [SMTT-080]
When switching between antennas it shall not be necessary to switch off the transmitter.

TEP-nnn-C [SMTT-160]
The TT&C subsystem shall not have any single point failure except for the radiating elements of the antennas and their associated cabling. Its hall 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.

TEP-nnn-C [SMTT-175]
The radio frequency switching between antenna and transponders shall be done without single point failure.

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

TEP-nnn-C [SGEN-005]
Both spacecraft shall optimise as much as possible the commonality between the HERSCHEL and Planck components and interfaces in order to reduce the costs.

TEP-nnn-C [SMTT-110]
The uplink/downlink signals shall be in the range
- 7190-7235 MHz for telecommands and
- 8450-8500 MHz for telemetry.

Separate frequencies will be allocated by ESA for HERSCHEL and Planck respectively.

[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> different frequency setup will be possible at transponder level

9.8.2.5 LINK BUDGETS AND DATA RATE

TEP-nnn-C [SMTT-120]
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. For optional TURBO coding at rate ¼ the equivalent Eb/No is 0.3 dB.

Telecommand :

Under all conditions specified by the mission Telecommand Bit Error Rate of 10^{-5} corresponding to Eb/No = 9.6 dB (theoretical),

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

TEP-nnn-C [SMTT-125]
Link budgets for all mission phases shall be computed as defined in ESA PSS-04-105, RF and Modulation Standard.

TEP-nnn-C [SMTT-130]
The minimum values of those margins shall be:
- nominal margin : 3dB
- RSS worst case margin : 0dB
- mean - 3 s margin : 0dB

The applicable ground station characteristics are defined in the corresponding interface specification.
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.

TEP-nnn-C [SMTT-135]
The probability of frame loss on the downlink shall be < 10^{-6}

TEP-nnn-C [SMTT-140]
The LGA's shall support the downlink of real time housekeeping data (spacecraft and payload) telemetry using the 35 m station at Perth and 500 bps (TBC) using 15 m station at Kourou up to a distance of 1.8 x 10^6 km from Earth.

TEP-nnn-C [SMTT-145]
LGA's down link of realtime housekeeping data using New Norcia (Perth) 35 m station and 500 bps using Kourou 15 m station

TEP-nnn-C [SMTT-155]
The MGA shall allow for the telemetry downlink with the Perth 35 m station and with the 15 m station at Kourou up to a distance of 1.8 x 10 6 km from the Earth during the telecommunication period at 10°elevation.

ESA recommended margins are satisfied both for the Up and Downlink, except for minor deviation, only for the Planck Receiver carrier recovery (Kourou GS), in case of simultaneous use of the 2 redundant Antennae beyond 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) or 80324.000 Hz (sine)
Low	5 kbps	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine) or 80324.000 Hz (sine)
Medium	107 kbps	PCM(SP-L)/PM	Not applicable
High	1.5 Mbps	SRRC-OQPSK or GMSK	Not applicable

NOTE:
High rate modulation scheme: SRRC OQPSK or GMSK

[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.

NOTE: optional commanding via MGA is still required but at low rate (256k is no more required).

For the High Rate TM link budgets the calculations are based on QPSK modulation that can be preliminary considered as a worst case wrt. SRRC-OQPSK or GMSK.

9.8.2.6.1

9.8.3 Functional Description

The TT&C subsystem 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.

As far as TTC is concerned, the HERSCHEL and Planck missions are essentially characterised by the following features:

.both use X-Band for up and downlinks. Frequencies 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: 10° maximum for Planck and 0° for HERSCHEL

.the uplink and downlink data rates requirements, mainly driven by the science data, are very much comparable between the 2 spacecraft.

Which calls for an obvious hardware commonality between HERSCHEL and Planck TTC subsystems.

It thus comprises:

two X-Band transponders, 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, Herschel case being the envelope of both with:

500 bps, 5 kbps, 107 kbps and 1.5 Mbps for the downlink rates depending on the ground station and the transmitting on-board antenna

125 bps and 4 kbps for the uplink rates depending on the ground station and the receiving on-board antenna.

In addition, the data is transmitted by the CDMU to the transponder under a non modulated format, BPSK, SP/L, GMSK or SRRC OQPSK coded depending upon the actual data rate. It is received by the CDMU from the transponders under 2 digital chains format.

2 cold redundant 30W TWTA amplifying stages, to guarantee the above downlink rates.

One single frequency X-Band Medium Gain Antenna, to perform the high data rate downlink during the planned telecommunication sessions. The use of the MGA in receiving mode to increase the overall spacecraft commanding capability is considered as an option.

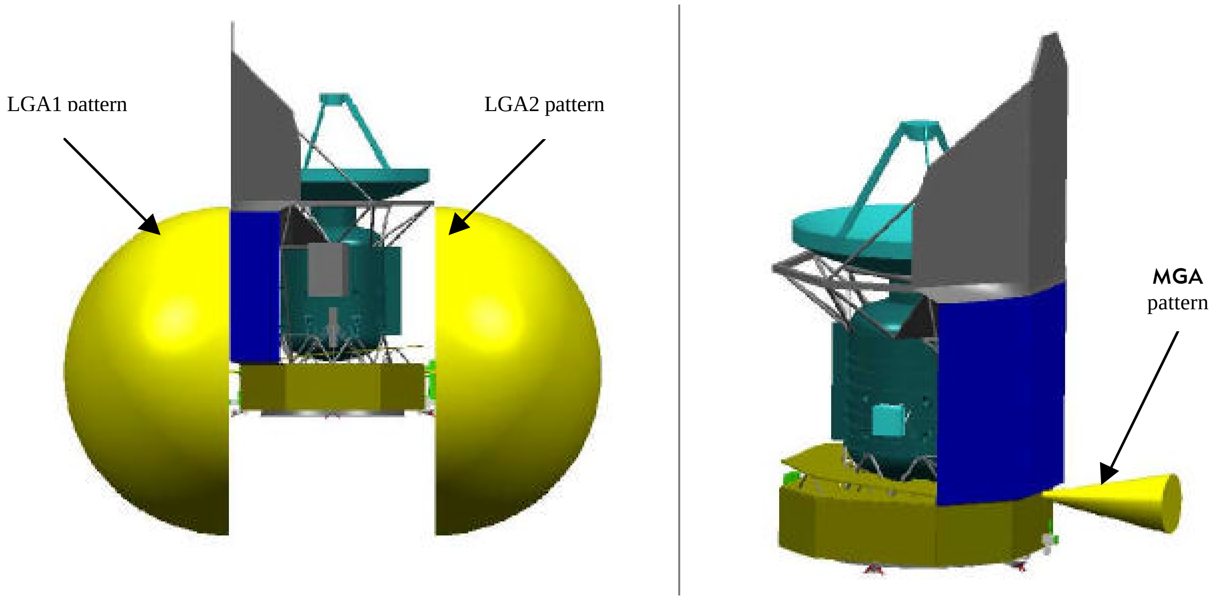
Identical Dual band Rx/Tx Low Gain antennae, to perform the low rate downlink, mainly at start of the missions and in emergency cases, and to receive the telecommand uplink streams. The antennae are accommodated, for each satellite, in order to guarantee a quasi omnidirectional coverage in both TM and 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 define 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, such as to reduce to a minimum the number of commands to send in case of change in the TTC configuration.

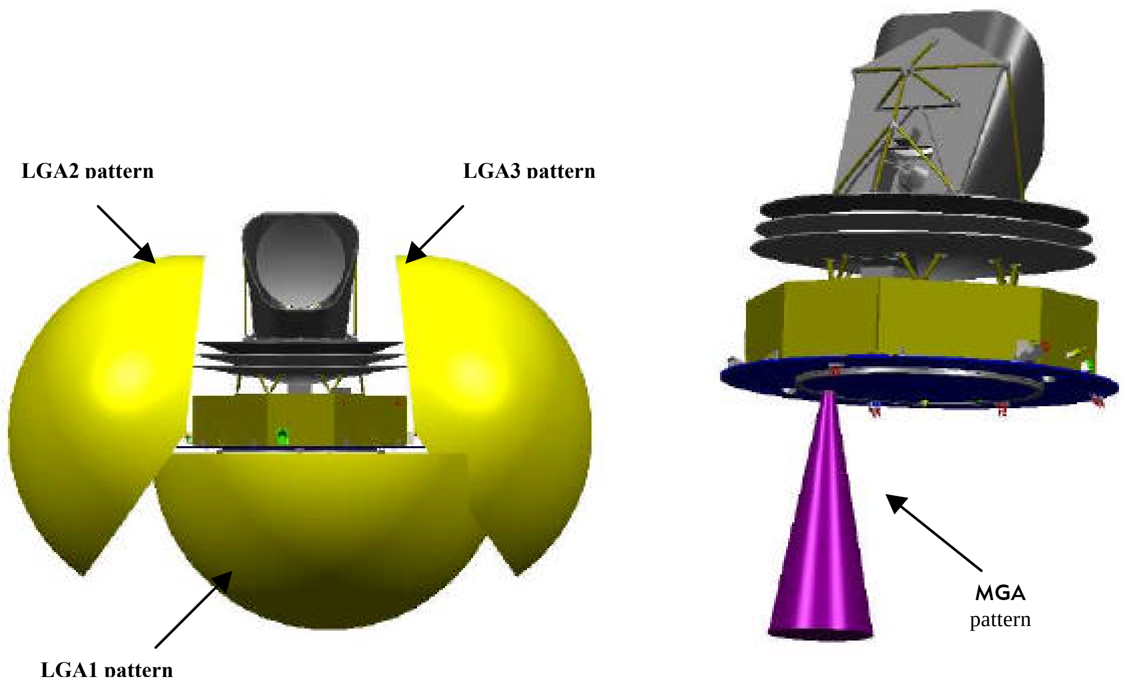
The Herschel and Planck satellites TT&C subsystems will be derived from the previous experience on the Rosetta and MarExpress programs. In both cases in-fact the same radio bands are used and the required performance are very similar.

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 radiofrequency 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 one Medium Gain Antenna. In particular:

HERSCHEL configuration:

Up and Down link with 2 LGAs (LGA 1 nominal - LGA 2 redundant) and
Up and Down link with MGA

PLANCK configuration:

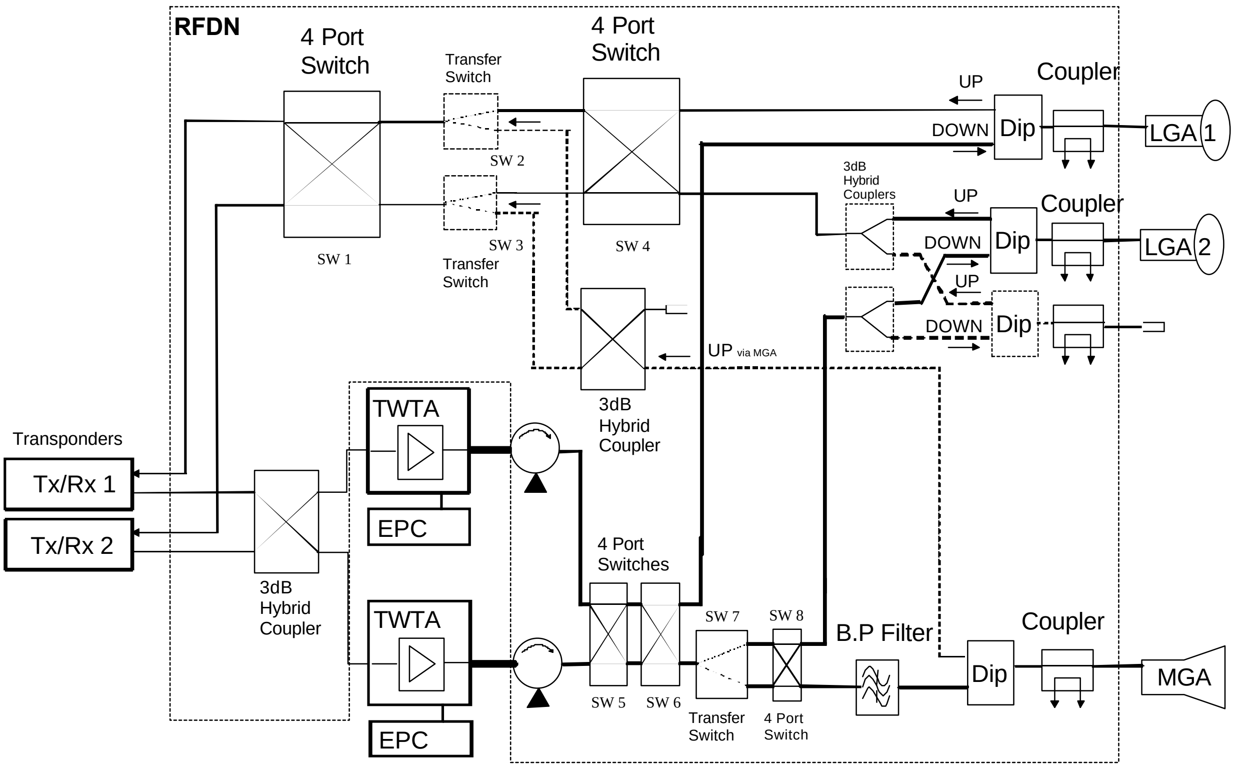
Up - Down link with 3 LGAs (LGA 1 nominal - LGA 2 & 3 redundant and used simultaneously) and
Up and Down link with MGA

The use of the LGA antennas assures an almost complete coverage independently on the spacecraft attitude and operational phases of the mission.
The radiofrequency output power from the transponder is raised through a TWTA up to 30 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) in accordance with the ESA requirements.
Particular emphasis during the proposal definition has been given on the RFDN. In the downlink distribution network, characterised by high RF power, between the output of two TWTAs and the different antennae, the use of waveguide technology is foreseen. The low power downlink distribution network between the outputs of the transponders and the TWTAs and the uplink path will use coaxial technology.
Each LGA antenna is equipped with a diplexer filter in charge to separate the uplink and downlink frequencies.
Directional couplers are connected before the diplexer in downlink path and used to measure the RF output transmitted to the antenna chosen by the switches.

9.8.4.1.1

9.8.4.2 Subsystem Design

The above figure shows the block diagram of the HERSCHEL TTC Nominal configuration.
In uplink the received signal from the two LGAs passes through 4 Port Switch towards the two transponders.
The usage of two 4 Port Switch assures that the configuration chosen is single point failure tolerant. In particular the 4 PS operational mode is described in the figure here below:



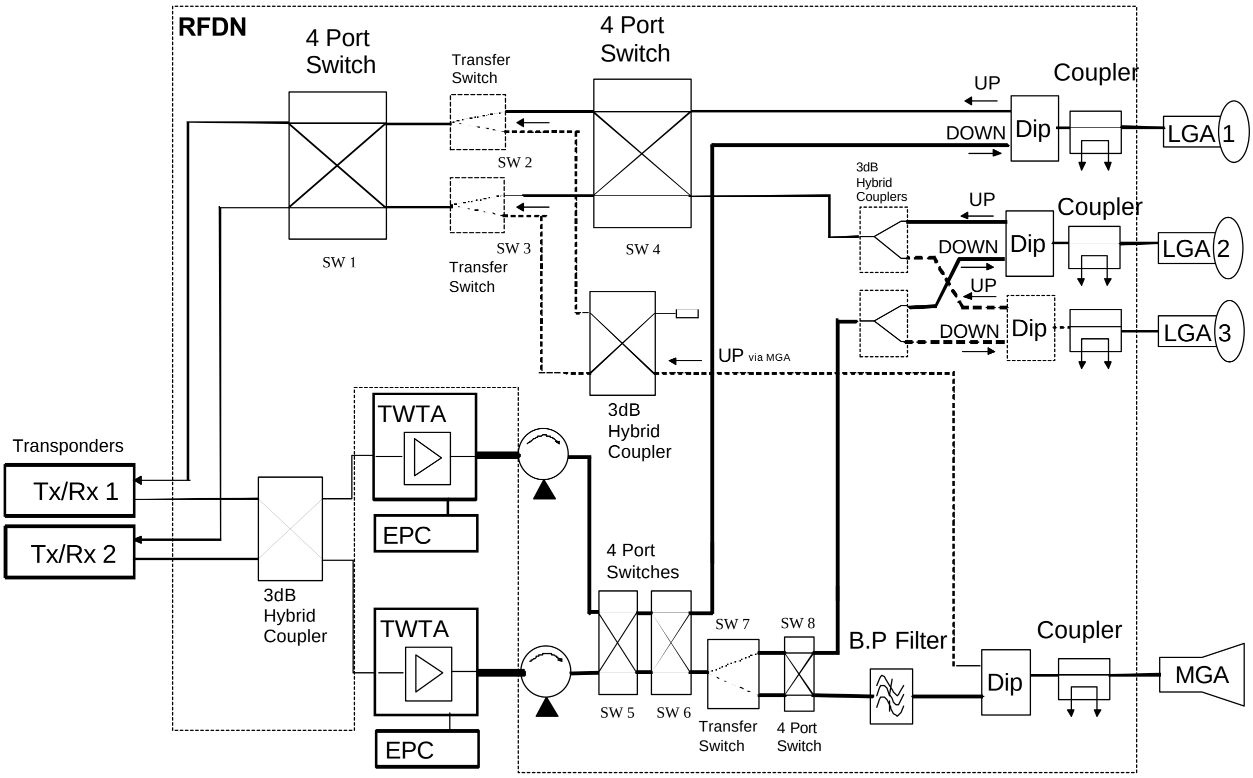
HERSCHEL RFDN configuration

File: Herschel_RFDN.dsf - 23-07-2001

In downlink the output from one of the two transponders feed a 3 dB Hybrid Coupler that supply contemporarily the two TWTA. This solution seems 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 are negligible because the RF signal will be amplified by the TWTA. From each TWTA an RF signal output close to 30 W is obtainable. The TWTAs are in cold redundancy: this means that only one is powered on at the same time. Each TWTA output supplies a 4 PS. From this 4PS, that could be doubled to increase further the reliability of the RFDN it is possible to feed directly the LGA1 or another Transfer Switch and 4 Port switch that route the RF output signal toward LGA2 or the MGA.

For what concerns the downlink, a 3 dB Hybrid Coupler connected to the diplexer of the MGA. In this way it is possible to connect toward the different receivers the uplink signals received. The two transfer switches connected between the transponder and the 4 PS allow to switch the uplink signal from LGA1 and LGA2&3 or MGA.
A Band Pass filter is also foreseen in the MGA path do avoid interferences to other satellites.
The extra output port terminated with a load is foreseen to use the same RFDN both in Planck and in Herschel TT&C subsystem or in the HERSCHEL RFDN will be removed the 2 hybrid coupler to avoid the 3dB extra loss.

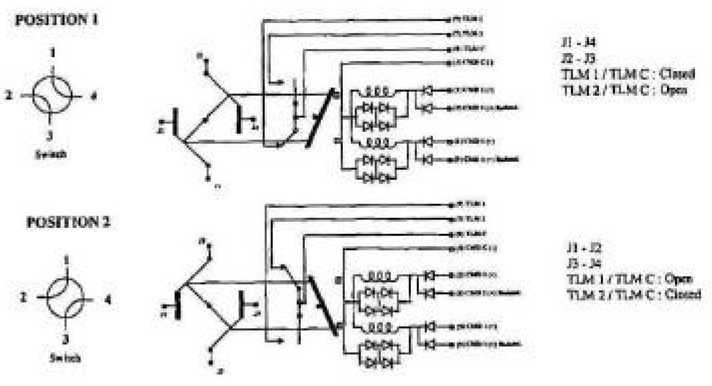
The common approach RF layout proposed is used on the HERSCHEL spacecraft whereas the Planck layout is the same proposed for HERSCHEL with a further 3dB Hybrid Coupler between LGA2 and LGA3 for both Uplinks and Downlinks. It is described in more detail in the figure above.

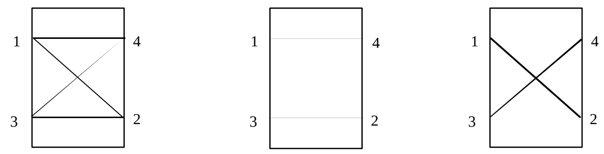


PLANCK RFDN configuration

File: Planck_RFDN.dsf - 23-07-2001

Here is presented a summary of the possible status of the 4 Port Switches:





In the table here below are summarised the operational modes available in the PLANCK configuration:

Uplink:
LGA1 toward Rx1 4PS position 1 4PS position 1 Transf. SW1 pos1 Transf. SW2 pos1
LGA1 toward Rx1 4PS position 2 4PS position 2 Transf. SW1 pos1 Transf. SW2 pos1
LGA1 toward Rx2 4PS position 1 4PS position 2 Transf. SW1 pos1 Transf. SW2 pos1
LGA1 toward Rx2 4PS position 2 4PS position 1 Transf. SW1 pos1 Transf. SW2 pos1

LGA2 toward Rx1 4PS position 1 4PS position 2 Transf. SW1 pos1 Transf. SW2 pos1
LGA2 toward Rx1 4PS position 2 4PS position 1 Transf. SW1 pos1 Transf. SW2 pos1
LGA2 toward Rx2 4PS position 1 4PS position 1 Transf. SW1 pos1 Transf. SW2 pos1
LGA2 toward Rx2 4PS position 2 4PS position 2 Transf. SW1 pos1 Transf. SW2 pos1

The Optional configuration providing the capability of uplink via MGA also for High rate uplink (4 Kbps) is also foreseen.

MGA toward Rx1 4PS position NA 4PS position NA Transf. SW1 pos2 Transf. SW2 pos2
MGA toward Rx1 4PS position NA 4PS position NA Transf. SW1 pos2 Transf. SW2 pos2

Downlink:
Main TWTA toward LGA1 4PS position 1 4PS position 1
Main TWTA toward LGA1 4PS position 2 4PS position 2
Main TWTA toward LGA2 4PS position 1 4PS position 2 3PS pos. 1 4PS position 1
Main TWTA toward LGA2 4PS position 2 4PS position 1 3PS pos. 1 4PS position 1
Main TWTA toward LGA2 4PS position 1 4PS position 2 3PS pos. 1 4PS position 1
Main TWTA toward LGA2 4PS position 2 4PS position 1 3PS pos. 2 4PS position 2
Main TWTA toward LGA3 4PS position 1 4PS position 2 3PS pos. 1 4PS position 2
Main TWTA toward LGA3 4PS position 2 4PS position 1 3PS pos. 1 4PS position 2
Main TWTA toward LGA3 4PS position 1 4PS position 2 3PS pos. 2 4PS position 1
Main TWTA toward LGA3 4PS position 2 4PS position 1 3PS pos. 1 4PS position 2
Red. TWTA toward LGA1 4PS position 1 4PS position 2
Red. TWTA toward LGA1 4PS position 2 4PS position 1
Red. TWTA toward LGA2 4PS position 1 4PS position 1 3PS pos. 1 4PS position 1
Red. TWTA toward LGA2 4PS position 2 4PS position 2 3PS pos. 1 4PS position 1
Red. TWTA toward LGA2 4PS position 1 4PS position 1 3PS pos. 1 4PS position 1
Red. TWTA toward LGA2 4PS position 2 4PS position 2 3PS pos. 2 4PS position 2
Red. TWTA toward LGA3 4PS position 1 4PS position 1 3PS pos. 1 4PS position 2
Red. TWTA toward LGA3 4PS position 2 4PS position 2 3PS pos. 1 4PS position 2
Red. TWTA toward LGA3 4PS position 1 4PS position 1 3PS pos. 2 4PS position 1
Red. TWTA toward LGA3 4PS position 2 4PS position 2 3PS pos. 1 4PS position 2

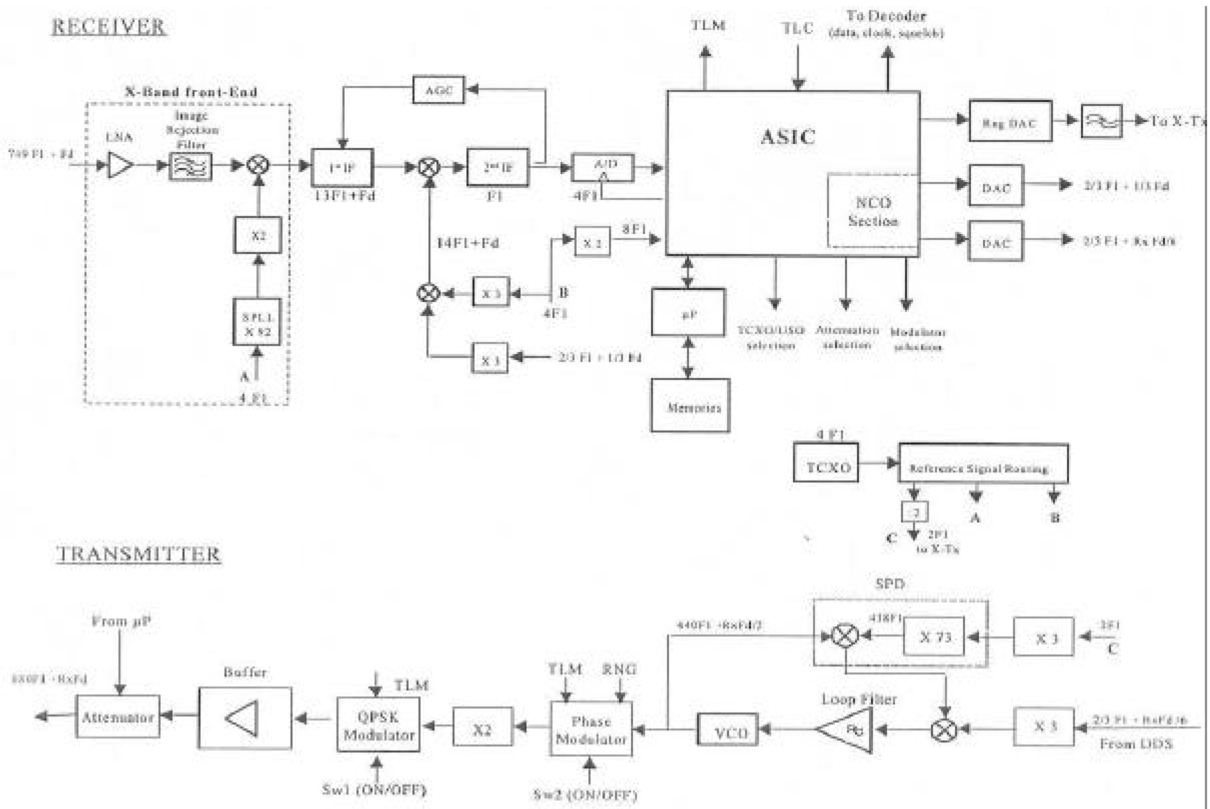
9.8.4.3 Equipment Design

In the following pages the major equipment or components are described in detail.

9.8.4.3.1 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 to classically analog problems. 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 will be placed on each satellite, the main and the redundant. In figure below two typical transponders architecture are shown.



H/P Transponder block diagram

For what concern the TM/TC interfaces the transponder is connected to the CDMU through redundant RS422 interfaces with Data, Clock, Sample signals.

9.8.4.3.1.1 Receiver

The receiver section is based on a digital architecture; this solution allows to meet the HERSCHEL/PLANCK functional requirements with the following advantages with respect to a fully analog solution:
Receiver reconfigurability (for carrier loop BW) according to the recorded signal input power;
Easy implementation of narrow loop bandwidths;
Inclusion of data demodulation capability;
Data rate flexibility with easy matched filtering implementation;
Interface optimisation based on the extensive use of command and telemetry housekeeping in digital format;
Design flexibility with transponder tuning based on software constants (i.e.: signal tracking loops, detection thresholds).

The receiver analog section performs the signal low noise amplification, double down-conversion, filtering and amplification in order to provide the proper interface level to the A/D. An analog wide-band AGC is required to keep constant the signal plus noise power at the A/D input, thus avoiding clipping occurrence.
The receiver RF/analog section performs the following tasks:

Low-noise amplification and down-conversion of the received X-band signal to intermediate frequency capable of being sampled by the A/D and processed by the receiver.
Wide-band AGC function for controlling the receiver gain in a wide dynamic range and setting the operating point for the A/D converter operation.
Removal of carrier frequency Doppler (phase locked loop tracking of the up-link carrier) by means the receiver DDS under the control of µP.
RF filtering of the signal to reject spurious interfering signals.

The architecture chosen for the receiver RF section is based upon two-conversion super-heterodyne configuration. The synthesizer frequency reference is carried out by a VCXO circuit. The signal after low noise amplification and image band rejection is down-converted to an intermediate frequency. At the Herschel intermediate frequency further amplification and filtering is performed before the last conversion at the second fixed intermediate frequency (F1) is accomplished.

The signal plus noise power level is controlled by an analog non-coherent 2nd order AGC which avoids saturation along the receiver chain and clipping in the A/D converter process. The wide-band detector detects the amplitude variations of the incoming signal, the resulting signal after having been integrated is DC amplified and routed to both 1st IF and a 2nd IF chain. For typical input signal level, the signal to noise ratio in the AGC bandwidth is negative and the AGC is essentially based on the noise power.

The receiver analog section is basically a front end which receive and low noise amplifies the received signal, generates the LO signals for the two frequency down-conversions, amplifies and filters the signal in the IF chains (1st and 2nd IF).
The LO signal generation is based on sampling phase lock loop technology and analog frequency multipliers. The master reference oscillator generates the 4F1 while the signal coming from the DDS sections is properly mixed to realise the required frequency plan. The carrier tracking is implemented using the Direct Digital Synthesizer (DDS) technique, which is based on the use of the Numerically Controlled Oscillator (NCO) and Digital to Analog Converter (DAC). The loop filter is software implemented inside the microprocessor (µP). The architecture removes the doppler contribution at the intermediate frequency, allowing the application of the coherent sampling technique.
The digital section is built around the CMOS Receiver ASIC (high rate signal processing and NCOs) and the microprocessor for low rate DSP tasks, transponder management and Data Handling functions.

The receiver outputs shall be cross-coupled with the inputs of the CDMS command decoders to guarantee redundancy.

9.8.4.3.1.2 Transmitter

The selection of the down-link frequency source is done by means of the TCXO/External Oscillator switching circuit driven by the microprocessor. The external USO reference frequency shall be the CDMU USO clock frequency (2^{24} MHz TBC) so, a programmable divider or PLL shall be implemented in the transponder to derive the necessary frequencies.
The **X-band transmitter section** is composed by the following main blocks: SPLL and frequency multiplier, Modulators, X band Amplifier and variable attenuator.
Two different modulation schemes are envisaged: Linear Phase Modulation and QPSK Modulation to support the three different kind of modulation required: PM, SP-L and SRRC-OQPSK.
The Linear Phase Modulator is foreseen to include circuits for modulation index selection, RNG ON/OFF, TLM ON/OFF.
Direct QPSK modulation of the RF carrier is foreseen for high telemetry data rate (1.5 Mbps) without ranging.
The shaping of digital stream of data shall be realised in digital way either for SP-L and SRRC. In the same way shall be realised the offset required by the OQPSK scheme.
The down-link modulation scheme as well as the variable attenuator setting are selected according to the required operating mode. The output level is controlled in the range from –7 dBm to +1 dBm, step 1 dB.

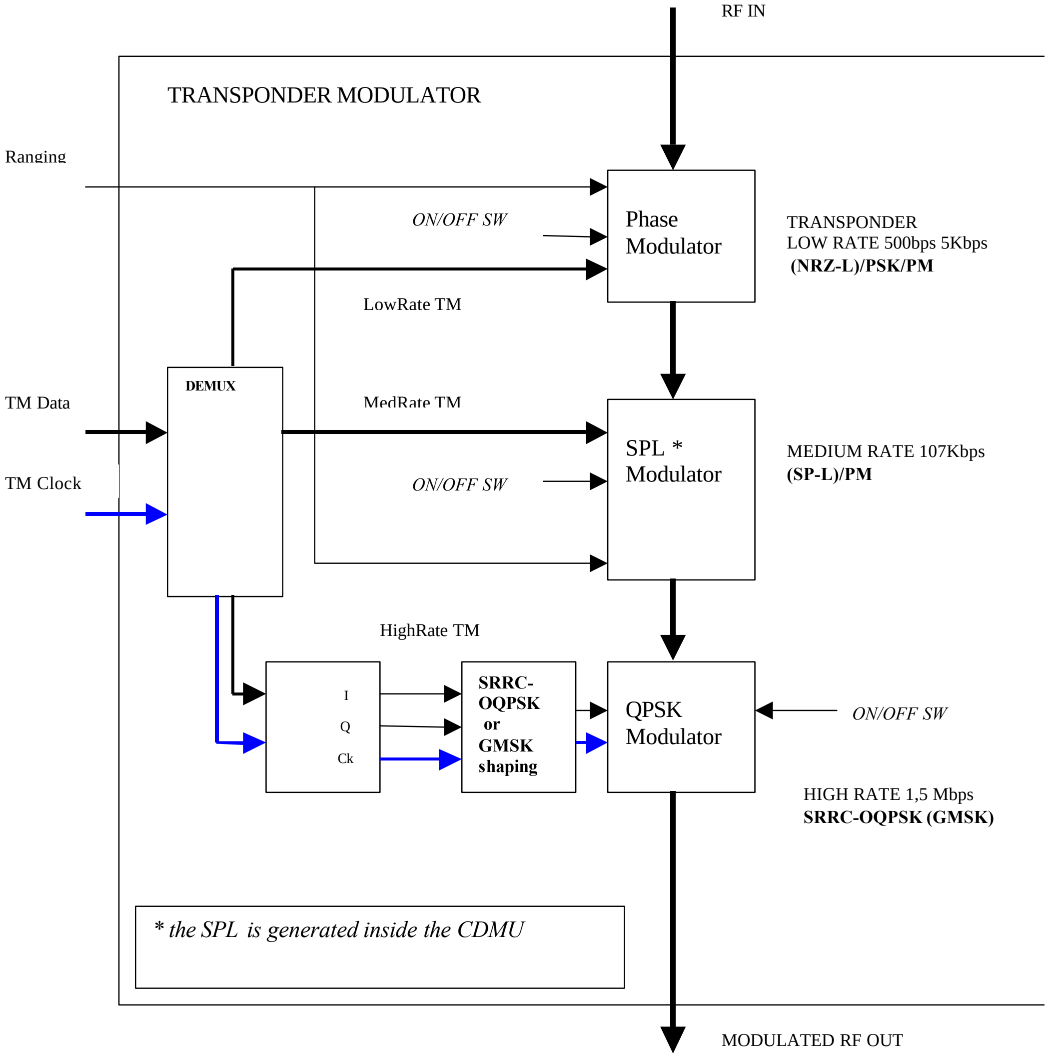


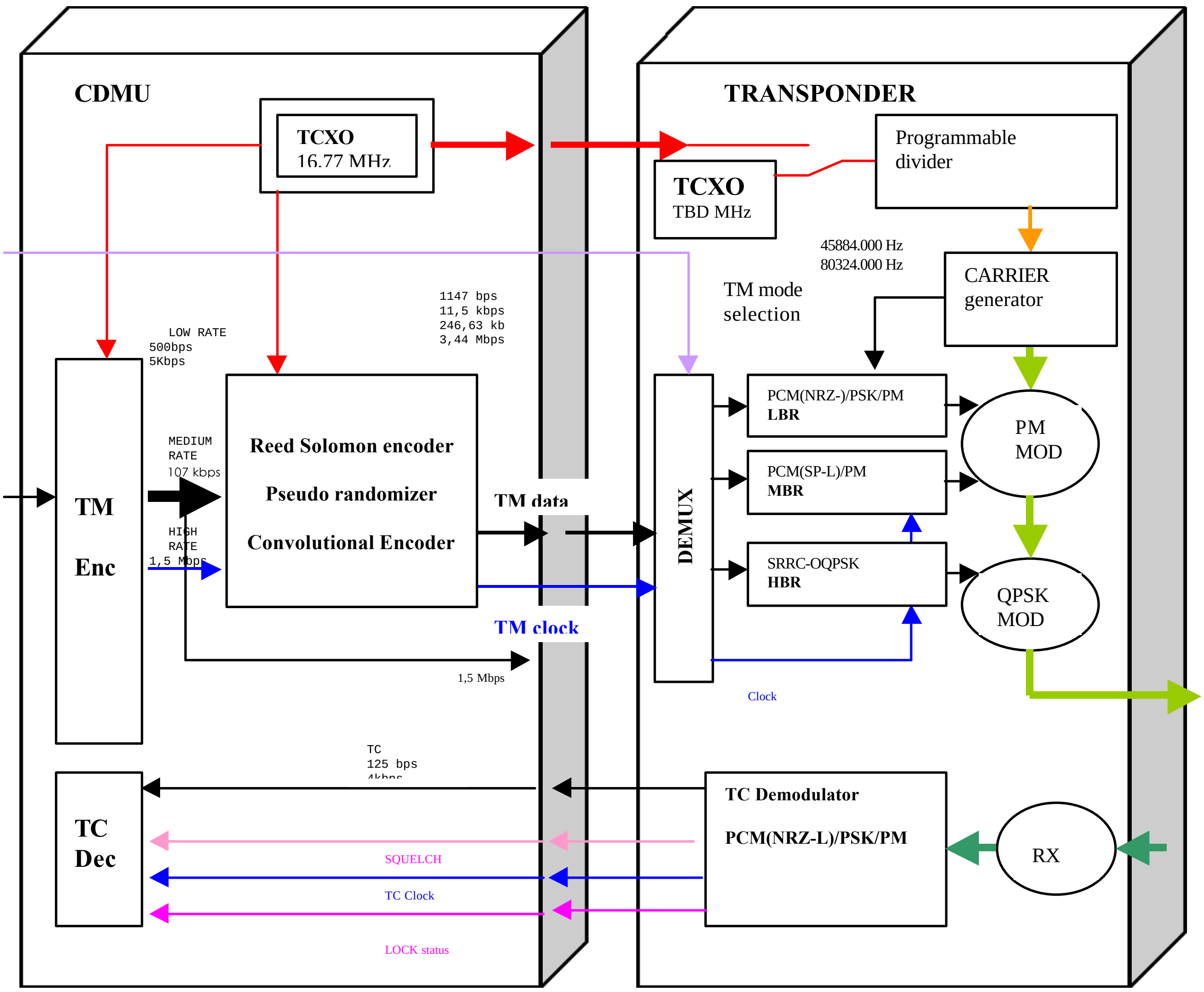
Figure -9-8 ; Transponder modulator block diagram.

9.8.4.3.2 TRANSPONDER – CDMU Interface.

As stated in the H/P requirements the transponder-CDMU interface shall be a digital one while usually, in other projects, it was an analog VIDEO one.
This mean that the modulation is completely performed inside the transponder. For this reason it is important that the digital modulation section will be synchronised to the CDMU TM generator.
The foreseen interface between the two units is RS422 either for data and clock signals.

According to the TC a different TM bit rate shall be selected and, according to the requirements, the correspondent modulation scheme. (TBC)

In the figure above a block diagram of these interfaces is presented.



9.8.4.3.3 TWTA

The equipment is an X band TWTA consisting in a Travelling Wave Tube (TWT) and an Electronic Power Conditioning unit for use onboard a spacecraft. The TWT shall be Periodic Permanent Magnet focused, conduction cooled and shall operate with multiple depressed collector stages. The main characteristics are listed below:

Operating frequency range	8450 - 8500	MHz
Saturated output power	30	W
Input power to achieve saturation	-8 to -3	dBm
Small signal gain, relative to saturation gain	< 8	dB
Gain stability over the mission life time		
Short-term variation of saturated output power over operating temperature	0.1	dB(pp)
Variation of saturated output power including all effects of temperature, ageing, EPC voltage, drift, time etc	0.15	dB(pp)
Variation of small signal gain over 10K temperature change within operating temperature range (with fixed drive level)	0.2	dB(pp)
Variation of small signal gain over full operating temperature range	1.0	dB(pp)
Gain flatness over operating frequency range (from 15 dB below to 3 dB above saturation drive)	0.2	dB(pp)
Gain slope with fixed drive from 15 dB below to 3 dB above saturation	0.01	dB/MHz
Noise figure	< 33	dB
AM/PM conversion (from 15 dB below to 3 dB above saturation drive)	< 6	°/dB
Insertion loss in non-operating condition (OFF) over operational frequency	> 80	dB
Input return loss, cold/hot	14 / 9,5	dB
Output return loss, cold/hot	14 / 7,5	dB
Output load return loss:		
Equipment meets full performance for RL (Return Loss) =	23	dB
No damage for RL =	0 dB / 50 ms	
Overdrive capability (no subsequent degradation of life or performance)	20 dB beyond sat.	
No-drive capability (no damage)	no drive for 24 h while ON	

Radiated emission		< 80	dBµV/m
Spurious outputs shall be below the mask defined by:			
	< = 20 kHz	-65	dBc
	40 kHz	-60	dBc
	> = 80 kHz	-70	dBc
DC bus voltage (regulated)		28	V
DC power consumption (when driven at saturation)		< 65	W

Protection circuits				
Helix overcorrent protection			details TBD	
Undervoltage protection			details TBD	
Automatic restart			details TBD	
Telecommands	digital:	TWTA ON/OFF Automatic restart ON/OFF		
Telemetry	dig. status TM:	TWTA status Automatic restart status		
	analog TM:	Anode voltage Helix current		
Mission lifetime			4.5	years
Operating temperature range		TWT:	-20/+50	°C
		EPC:	-20/+50	°C
Mass (incl. 100 cm HV cable)			< 2500	g

AM/AM response : RF output versus input drive shall be provided from saturation –20dB to saturation +3dB.

9.8.4.3.4 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 antennae shall 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.
Both uplink and downlink are in X-Band.
The uplink frequencies are:

HERSCHEL:	7207.8483 MHz (TBC)
Planck:	7196.3580 (TBC)

The emission bandwidth is 3 MHz.

The downlink frequencies are:

HERSCHEL:	8468.5 MHz (TBC)
Planck:	8455.0 (TBC)

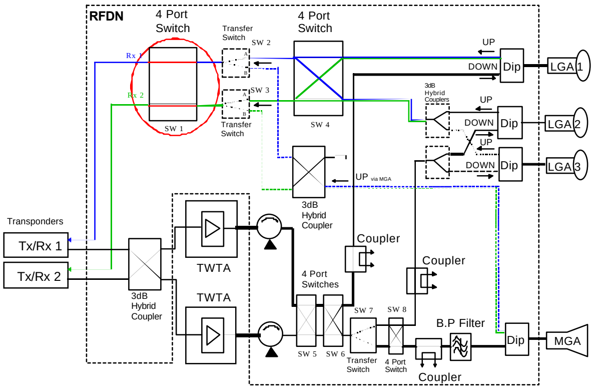
The emission bandwidth is 7 MHz

The downlink hardware, in particular the switches interfacing with the TWTAs power handling, shall guarantee at least 3 dB of margin with respect to the TWTAs RF output power of 30 W.
The switches design is different from 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. This direct coupled actuactor is small in size and more reliable than older designs using motor/gears, rotary or linear solenoids. Typical insertion loss is 0.08 with a maximum up to 0.10 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 Level command lines will be used from 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 shall be completely single point failure tolerant:

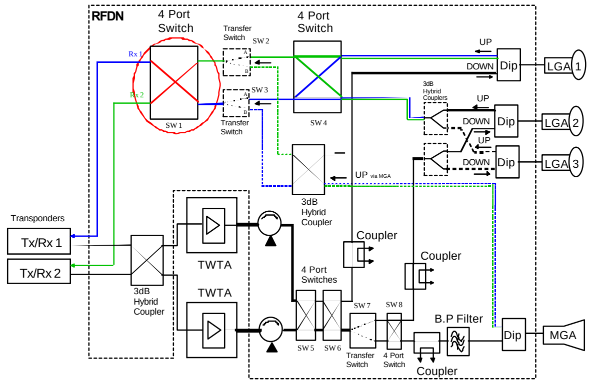
- considering an approach that use a redundant switches configuration foreseeing Time Tagged TCommand approach to recover from an unlikely switch neutral (midpoint) position .
- having the possibility to command the switches both by RTU and Dec.
- Implementing an on-board software routine that is able (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 RFDN has been designed to support and recover a single switch failure using redundant cascading switches.
In the following pictures has the failures of each switch been simulated showing the paths of the two TX and RX signals between transponders, TWTAs and antennas.



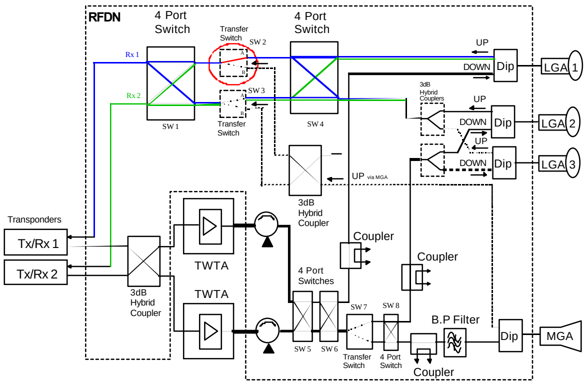
PLANCK RFDN configuration

File: Planck_RFDN.dsf - 18-07-2001



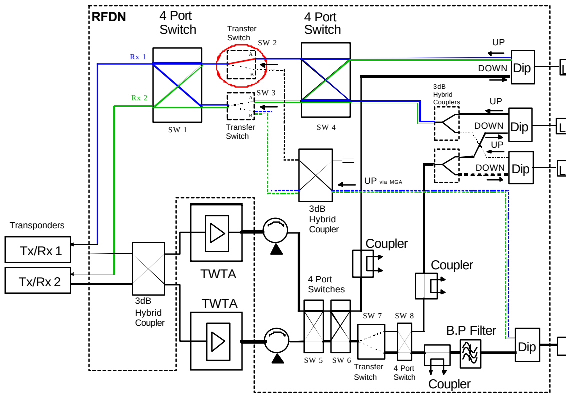
PLANCK RFDN configuration

File: Planck_RFDN.dsf - 18-07-2001



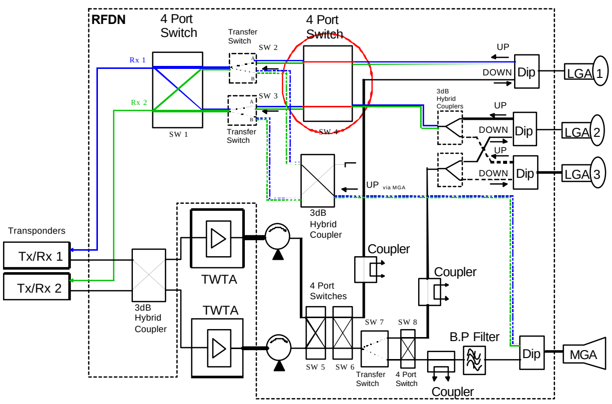
PLANCK RFDN configuration

File: Planck_RFDN.dsf - 18-07-2001



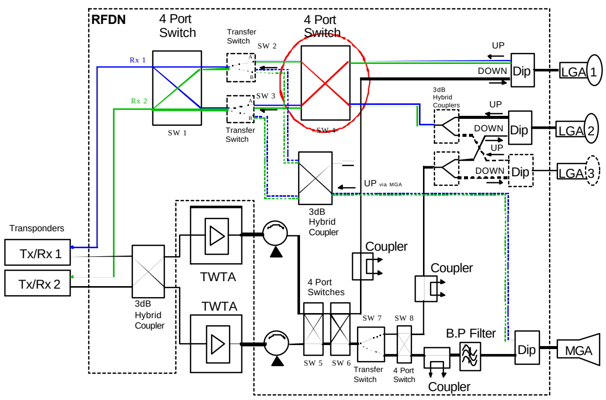
PLANCK RFDN configuration

File: Planck_RFDN.dsf - 18-07-2001



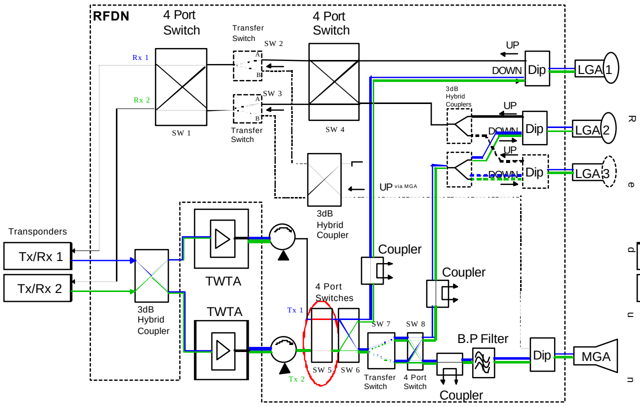
PLANCK RFDN configuration

File: Planck_RFDN.dsf - 18-07-2001

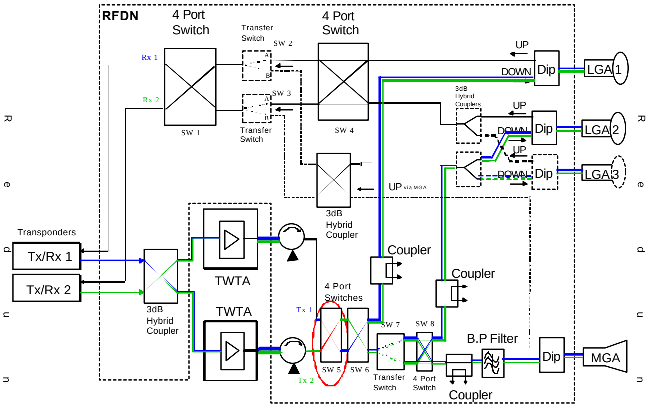


PLANCK RFDN configuration

File: Planck_RFDN.dsf - 18-07-2001

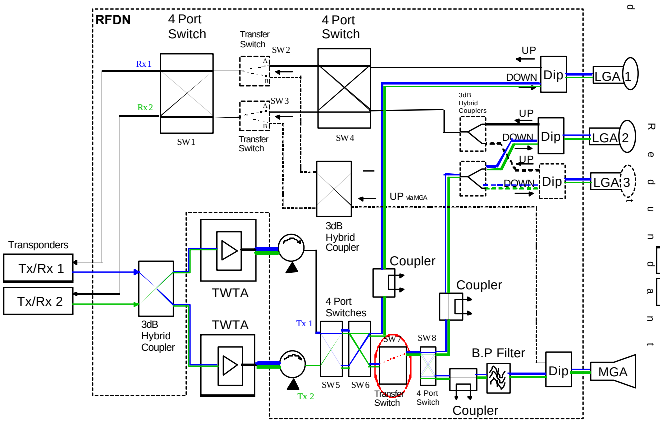


File: Planck_RFDN.dsf - 18-07-2001



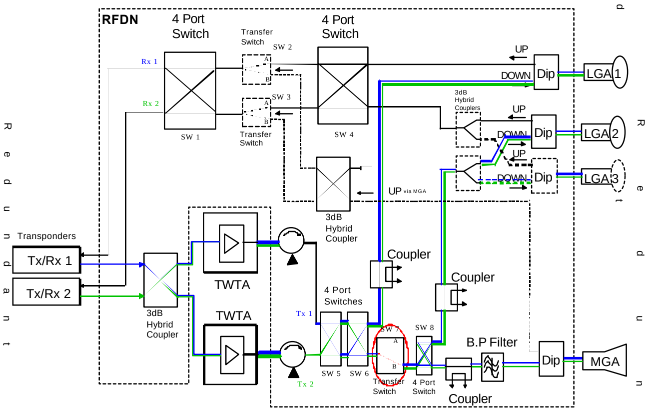
PLANCK RFDN configuration

File: Planck_RFDN.dsf - 18-07-2001



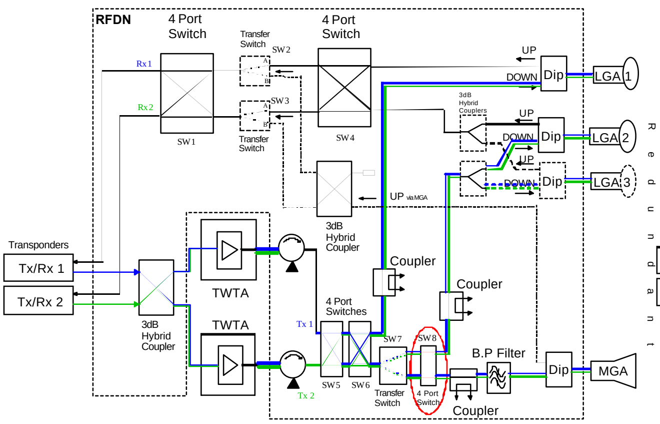
PLANCK RFDN configuration

File: Planck_RFDN.dsf - 18-07-2001

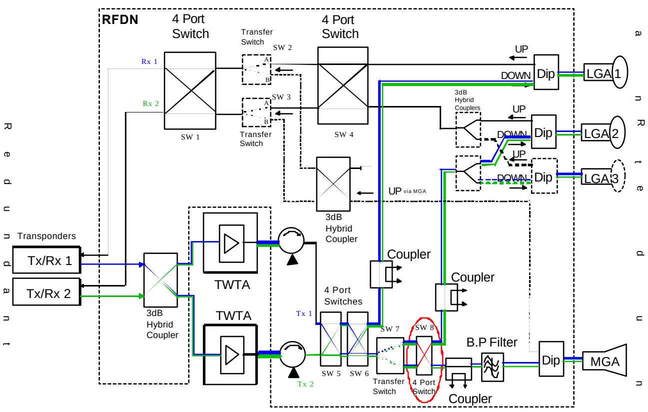


PLANCK RFDN configuration

File: Planck_RFDN.dsf - 18-07-2001



File: Planck_RFDN.dsf - 18-07-2001



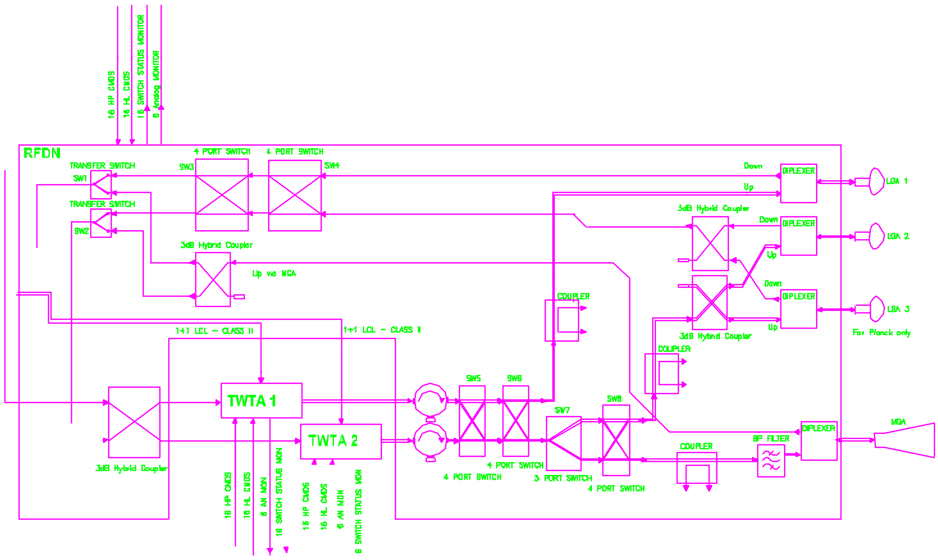
PLANCK RFDN configuration

File: Planck_RFDN.dsf - 18-07-2001

The SW3 and SW6 failures are not showed as they are similar to SW2 and SW5 ones.

The RFDN single point failure has been analized only considering a switch failure because they are the only mechanical moving part of the RFDN. The power splitter, isolators, couplers and diplexer are not considered critical because they are passive components without moving parts.

Considering the drawings above, a failure of one switch can be recovered changing the RDFN configuration using and alternative path both for Transmission and Receiving signals.



The foreseen RFDN interfaces are:

Telemetry:

- 8 Switch position A status (nominal)
- 8 Switch position A status (redundant)
- 8 Switch position B status (nominal)
- 8 Switch position B status (redundant)

- 2 High Power Isolator temperature.
- 1 RFDN temperature

Telecommand:

- 8 Switch position A status (nominal)
- 8 Switch position A status (redundant)
- 8 Switch position B status (nominal)
- 8 Switch position B status (redundant)

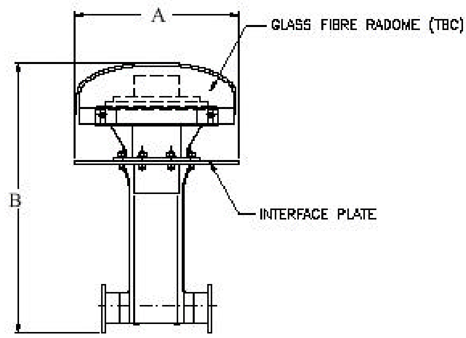
In the RFDN it is also present a band pass filter between the directional coupler and MGA diplexer to avoid interferences to other satellites operating in the same band also considering the number of mission that in the future will use the L2 position.

Preliminary TX Band Pass filter characteristics are presented below:

Centre frequency, fc	8425 MHz
Allocated transmit frequency band	8450 - 8500 MHz
Insertion loss within allocated Tx frequency band	< 0,4 dB
Group delay stability over accept. temp. range, at any frequency within alloc. Tx band	< 1 ns
Return loss within alloc. Tx band	> 23 dB
Rejection at +/-60 MHz from fc	> 22 dB
Rejection at +/-200 MHz from fc	> 30 dB
Rejection at +/-400 MHz from fc	> 50 dB
Rejection within frequency band from 1.6 to 3 GHz	TBD dB
Rejection within frequency band from 4 to 8GHz	TBD dB
Rejection within frequency band from 27 to 33 GHz	TBD dB
Rejection within frequency band from 39.6 to 48.4 GHz	TBD dB
Rejection within frequency band from 63 to 77 GHz	TBD dB
Rejection within frequency band from 99 to 110 GHz	TBD dB
Rated transmit power	40 W
RF interfaces (input & output ports) Waveguide	WR112
Flange	TBD
Radiated emission, when rated transmit power is applied	< 80 dBuV/m
Mass	< 185 g

9.8.4.3.5 Low Gain Antenna (LGA)

The LGAs antennas proposed in X band will be obtained scaling existing ones at C and Ku bands. In particular the radiator has the same configuration, that is corrugated horn, but exact geometry have to be modified to look for the required pattern. The septum polarizer is instead escalated from the previous developed ones. In particular this septum polarizer allows to use two independent ports (LHCP and RHCP). because the Tx and RX signals are separated the system design requires one single Rx/Tx antenna plus one diplexer to include in the RFDN. This antenna is fully designed in waveguide like designs for Ku-band. the diplexer insertion are better than 0.15 dB with a rejection between ports around 45-50 dB.
A drawing of the antenna is showed in the figure below.



X–BAND ANTENNA PROPOSED CONFIGURATION (WG RF INTERFACE)

9.8.4.3.6 Medium Gain Antenna (MGA)

The MGA proposed 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 by the following main blocks:
transition to WR 112 waveguide
- 2 step septum polarizer
- waveguide load
- square to circular transition
- dual flared conical horn

The minimum antenna gain has been assured close to 16 dBi. In particular it withstands up to 70 W RF in input.

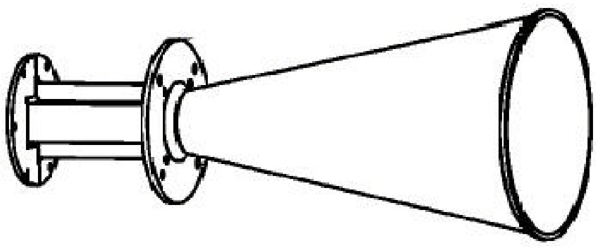


Figure 9.8.4.3.6 : H/P X Band Medium Gain Antenna.

In the RFDN are also present diplexers at each antenna port to split the TX signal from the RX one.

Here below is presented a preliminary detail of the antennas diplexer.

Requirements
Receive Path (from common antenna port to Rx port):

Allocated receive frequency band	7190 - 7215 MHz
RX Centre frequency,	7202 MHz
Insertion loss within allocated Rx band	< 0,4 dB
Insertion loss slope within allocated Rx band	< 0,1 dB/MHz
Group delay stability over accept. temp. range, at any frequency within allocated Rx band	7 ns(pp)
Return loss within allocated Rx band	> 23 dB
Rejection at +/-25 MHz outside allocated Rx band	> 30 dB
Rejection at +/-75 MHz outside allocated Rx band	> 50 dB

Transmit path (from Tx port to common antenna port)

TX Centre frequency, fc	8460 MHz
Allocated transmit frequency band	8445 - 8475 MHz
Insertion loss within allocated Tx frequency band	< 0,4 dB
Group delay stability over accept. temp. range, at any frequency within alloc. Tx band	< 1 ns
Return loss within alloc. Tx band	> 23 dB
Rejection at +/-60 MHz from fc	> 22 dB
Rejection at +/-200 MHz from fc	> 30 dB
Rejection at +/-400 MHz from fc	> 50 dB
Rejection within frequency band from 1.6 to 3 GHz	TBD dB

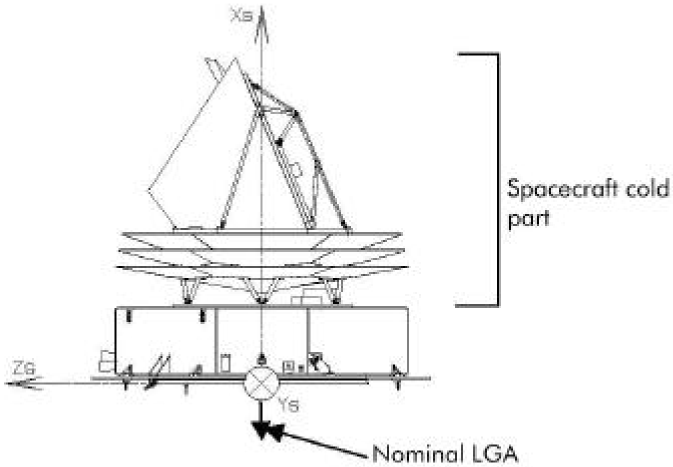
9.8.5 Commonality Assessment

For both Herschel and Planck satellite, omni-directional coverage of the low gain antennas is specified in order to cover cases such as:

beginning of mission: at separation from launcher, the Sun/SC/Earth angle is above 90 deg during around 20 minutes.
in 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 Sunshield. This leads to an accommodation in a narrow space below the grooves, almost like a cavity and this results in a distorted pattern of the LGA as the structural environment generates multipaths and therefore some phase interference phenomenons within the antenna field of view.

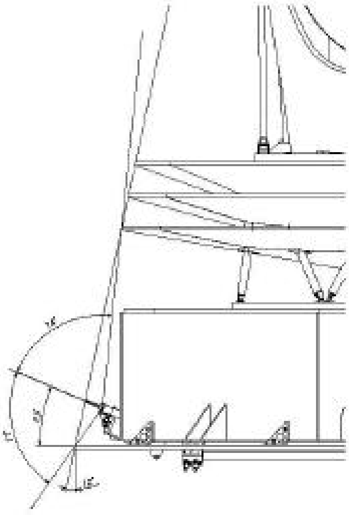


Figure 9-9: Planck redundant LGA position.

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 two possible different solutions:

a LGA antenna characterised by wide coverage with a gain of -3 dBi with a field of view of 95° (helix);
a LGA with higher lobe gain 10 dBi with a field of view of 15° (horn).

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.

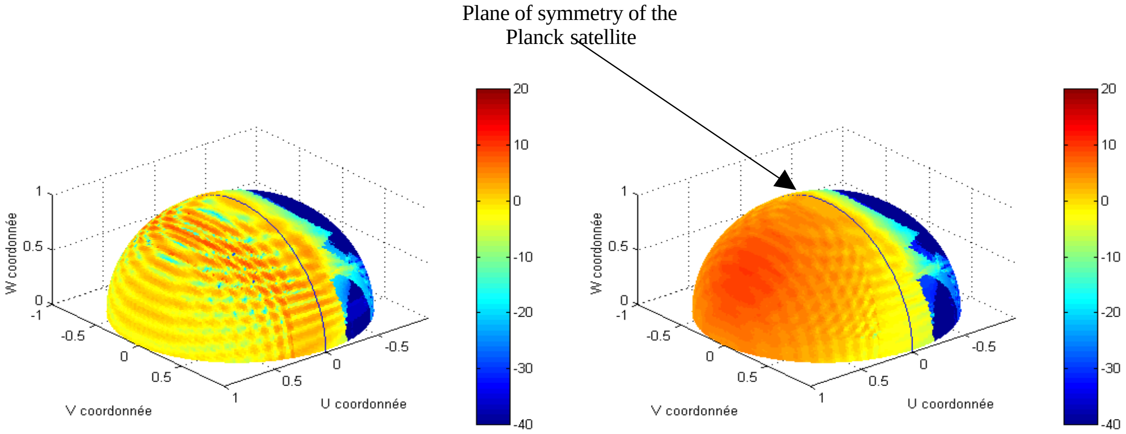
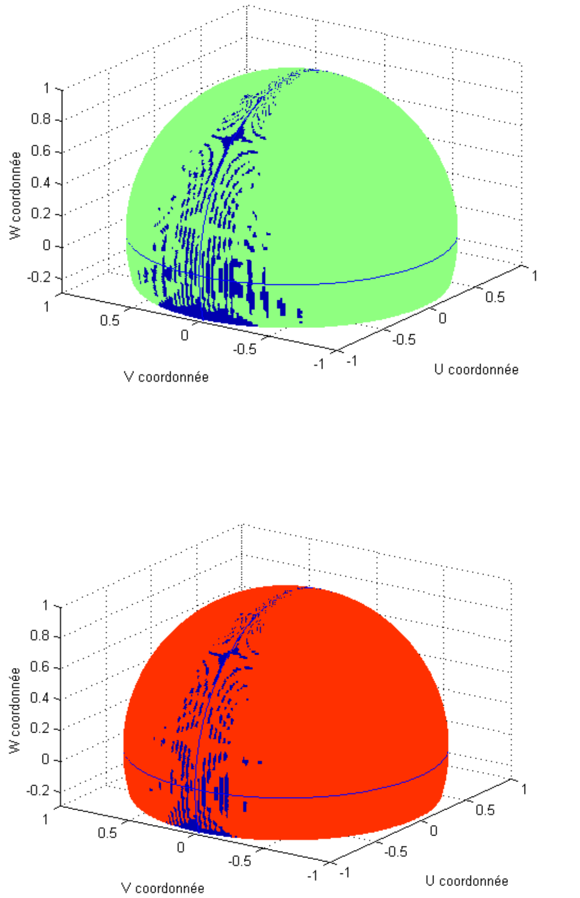


Figure 9-10: PLANCK GTD analysis with two different LGAs.

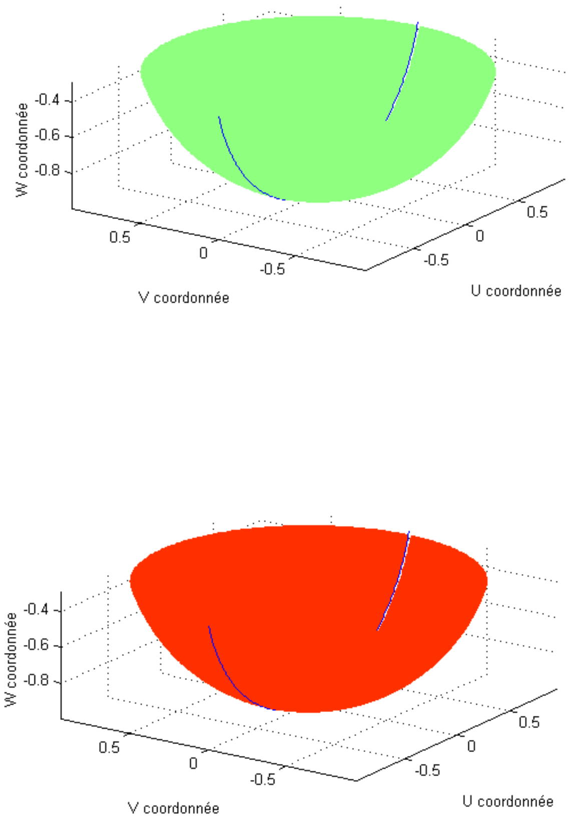
Using an elementary antenna with a narrower pattern than the conical helix type antenna, like a choked horn concept would limitate the side and backward radiations, and thus the phase interferences within the pattern. However, the omni-directionality of the antenna is difficult to predict and must be measured on a mock-up model and the resulting final pattern may demonstrate a more restrictive useful field of view for the emergency mission.

The foreseen solution will permits to use all the LGA type, like the Type2 dual horn, 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 and a 97.31% at - 5 dBi.



GTD analysis -5dBi LGA2 & LGA3 coverage.



GTD analysis -5dBi LGA1 coverage.

The use of three LGA antennas complicates the RFDN with a 3 dB Hybrid Coupler 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 these 3 dB Hybrid Couplers the RFDN is the same proposed for HERSCHEL. To maximize the commonality, the same RFDN could be used in the two satellites terminating the not used port (in HERSCHEL) with a waveguide load or, in order to avoid the 3dB loss on the HERSCHEL LGA2 antenna signal, a RDFN without the 2 Hybrid Coupler could be used in the HERSCHEL design.

9.8.6 Budget Summary

9.8.6.1 HERSCHEL Mass budget

In the table below the mass budget estimated for the Herschel TTC configuration is presented.

Mass Budget	*Unit*	*Mass* (gr)	*Total*	*Remark*
Transponder X/X band	2	3200	6400	
TWTA	2	2500	5000	
RFDN	1	3000	3000	
LGA	2	300	600	
MGA	1	800	800	
TOTAL			**15800**	

9.8.6.2 HERSCHEL Power budget

In the table below the power budget of the Herschel TTC config. is presented. It has been assumed that only one Tx is powered on during the visibility window and two receivers are always powered on.

Power Budget	*Unit*	*Power* (W)		*Remark*
Transponder X/X band	2			
Rx		12	24	
Tx		6	6	
TWTA	1	65	65	
RFDN	1	TBD		
LGA	2	--		
MGA	1	--		
TOTAL			**95**	

If Tx is active the power consumption is 95 W

9.8.6.3 Planck Mass budget

In the table below the mass budget of the Planck TTC config. is presented.

Mass Budget	*Unit*	*Mass*	*Total*	*Remark*
		(gr)		
Transponder X/X band	2	3200	6400	
TWTA	2	2500	5000	
RFDN	1	3000	3000	
LGA	3	300	900	
MGA	1	800	800	
TOTAL			**16100**	

9.8.6.4 Planck Power budget

In the table below the power budget of the Planck TTC config. is presented. It has been assumed that only one Tx is powered on during the visibility window and two receivers are always powered on.

Power Budget	*Unit*	*Power*		*Remark*
		(W)		
Transponder X/X band	2			
Rx		12	24	
Tx		6	6	
TWTA	1	65	65	
RFDN	1	TBD		
LGA	3	--		
MGA	1	--		
TOTAL			**95**	

If Tx is active the power consumption is 95 W.

9.8.6.5 RF link budgets

The link budgets have been calculated considering the Ground Station characteristics given in the Space to Ground ICD and the same (For Herschel & Planck) max. Uplink / Downlink bit rates for commonality optimisation:

Kourou
Herschel and Planck nominal configuration

Uplink	125 bps with LGA,
	4 kbps via MGA
Downlink	500 bps via LGA and
	107 Kbps SP-L via MGA

Herschel and Planck optional configuration using the MGA also for uplink (125bps)

New Norcia (Perth)
Herschel and Planck nominal configuration

Uplink	4 kbps with LGA,
Downlink	5 kbps via LGA and
	1.5 Mbps SRRC-OQPSK via MGA

Herschel and Planck optional configuration using the MGA also for uplink (4Kbps)

All the cases have been calculated both in Ranging and No Ranging modes and with different kind of antennas.

The available data used correspond to two different antenna types

TYPE 1:LGA: 3dB lobe ~90° and a peak gain of 4 dB,
MGA 3dB lobe ~20° and a peak gain of 19 dB

TYPE 2:LGA: .3dB lobe = 30° and a peak gain of 8dB
MGA no data available but similar to MGA type 1.

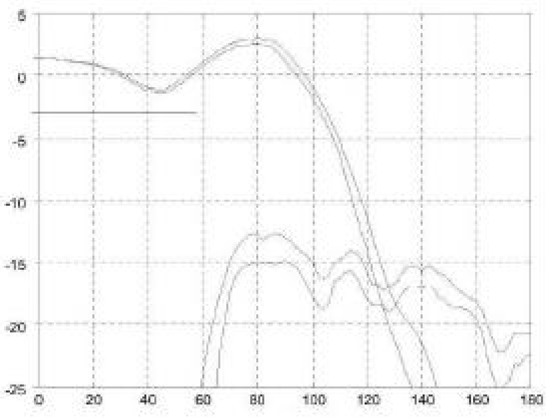


Figure -1: LGA type 1 pattern

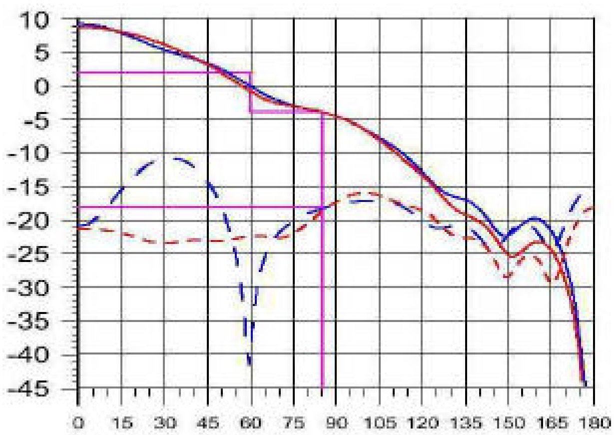


Figure -60: LGA type 2 pattern.

As a support to the complete set of link budgets provided in the SVM Design Report, this section summarises the system margins in the same format as the one used during the proposal:

The Type 2 antenna gain data have been used here to refine the system link budgets, considering the outcomes of the GTD analisys.

UPLINK BUDGETS				KOUROU G/S				NEW NORCIA (PERTH) G/S			
			Mode	TC + RNG	TC only	TC + RNG	TC + RNG	TC + RNG	TC only	TC + RNG	TC + RNG
			Antennas								
			H/P nominal LGA	x				x			
			PLANCK redundant LGAs		x				x		
			H/P MGA			x	x			x	x
			BIT RATE (kbps)	0.125	0.125	0.125	4	4	4	4	4
			S/C ALTITUDE (* 10^6 km)	1.80	1.60	1.80	1.80	1.80	1.80	1.80	1.80
PARAMETER	MARGING	ESA Margin dB		calculated margins (dB)				calculated margins (dB)			
Signal Recovery	Nominal	3		4.50	4.42	21.40	21.40	20.55	19.45	37.45	37.45
	mean -3*sigma	0		0.48	0.50	19.00	19.00	16.73	15.73	35.19	35.19
	margin - wc RSS	0		2.29	2.22	20.01	20.01	18.34	17.25	36.06	36.06
Carrier Recovery	Nominal	3		4.20	4.66	19.87	19.87	20.35	19.16	35.83	36.01
	mean -3*sigma	0		0.02	0.68	17.34	17.34	16.37	15.37	33.46	33.65
	margin - wc RSS	0		1.79	2.25	18.16	18.16	17.94	16.74	34.12	34.30
Telecommand Recovery	Nominal	3		7.60	5.33	22.64	7.59	8.69	5.90	24.68	23.74
	mean -3*sigma	0		3.52	1.46	20.37	5.32	4.82	2.22	22.57	21.61
	margin - wc RSS	0		5.31	3.04	21.17	6.11	6.40	3.61	23.21	22.26

As identified in the first issue of link budgets, the uplink peformances are marginal with Kourou ground station when using the low gain antennas (LGA). Though, the telemetry subcarrier recovery margins remain largely 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.

DOWNLINK BUDGETS				KOUROU G/S					NEW NORCIA G/S					
			Mode	TM only	TM+RNG+ TC echo	TM only	TM only	TM+RNG+ TC echo	TM only	TM+RNG+ TC echo	TM only	TM+RNG+ TC echo	TM only	TM+RNG+ TC echo
			Antennas											
			H/P nominal LGA	x	x				x	x				
			PLANCK redundant LGAs			x					x	x		
			H/P MGA				x	x					x	x
			BIT RATE (kbps)	0.5	0.5	0.5	107	107	5	5	5	5	1500	1500
			S/C ALTITUDE (* 10^6 km)	1.80	1.80	1.60	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
PARAMETER	MARGING	ESA Margin dB		calculated margins (dB)					calculated margins (dB)					
Carrier Recovery	Nominal	3		5.20	5.20	3.12	18.77	18.84	19.91	20.37	17.47	17.51	33.63	33.95
	mean -3*sigma	0		2.08	2.08	0.10	13.21	13.23	17.43	17.52	15.16	15.19	28.07	28.25
	margin - wc RSS	0		2.70	2.70	0.71	14.19	14.22	18.01	18.12	15.72	15.74	29.06	29.24
Telemetry Recovery	Nominal	3		5.54	5.55	3.46	4.95	5.02	7.25	7.41	4.81	4.84	5.33	5.65
	mean -3*sigma	0		2.71	2.71	0.73	3.30	3.27	5.45	5.62	2.98	3.02	3.72	4.01
	margin - wc RSS	0		3.43	3.44	1.36	3.77	3.84	6.00	6.17	3.52	3.56	4.15	4.48

Comfortable margins achieved on all downlinks except when using the redundant LGA (emergency mode) whith Kourou ground station however this scenario remains a very worst case and the require link budgets margins are still justified.
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		
PANELS HANDLING MGSE		
EQUIPMENT PANEL TROLLEY (EPT)	3 sets	
PANEL TILTING TROLLEY (PTT)	6	
EQUIPMENT PANEL LIFTING DEVICE (ELD)	4	
MULTI-PURPOSE TROLLEY (MPT)	4	
VERTICAL INTEGRATION STAND (VIS)	6	
SVM LIFTING DEVICE (SLD)	3	
TRANSPORT & HANDLING ADAPTER (THA)	5	
HANDLING & TEST CLAMP BAND (HTCB)	7	
ADJUSTABLE INTEGRATION PLATFORM (AIP)	1	
SVM STIFFENER SET (SSS) (TBC)	3	
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	
RCS OPERATION		Provided 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 SA PROTECTION COVER		
FIRST SA PROTECTION COVER		
SENSORS PROTECTION COVERS		
THRUSTERS PROTECTORS		
OSR COVERS (TBC)		
MISCELLANEOUS		
EQUIPMENT DRIVE UNIT (EDU)	3	
SVM MASS DUMMY (SMD)	1	
ALIGNMENT TEST EQUIPMENT		

Figure 10.1-1

10.2 EGSE

The SVM EGSE configuration is shown in figure 6-2.
The SVM FIRST/Planck EGSE will be organized around the main functional block:

Central Check Out System (CCS)
the following SVM SCOE, namely:
- the Power Control Subsystem SCOE (Power SCOE)
- the Telemetry, Tracking and Command SCOE (TT&C SCOE)
- the Telemetry and Telecommand Front End Equipment (TM/TC FEE)
- 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), using the industry standard TCP/IP protocol (EGSE network).

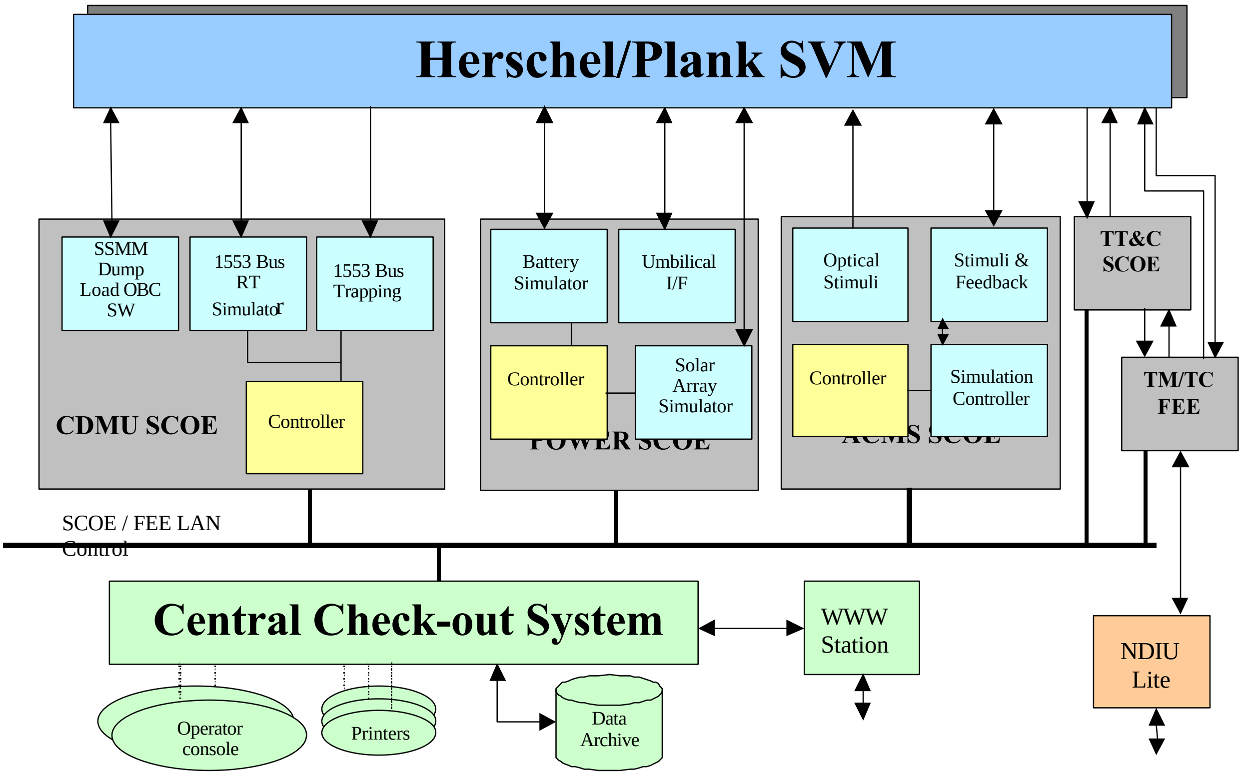


Figure 10.2-1

10.3 EGSE USER S/W

User EGSE USER S/W will be developed in order to automate the execution of the functional and performance verification of the Satellite. In particular, it will consist of :

Test Sequences
Synoptic Displays
Simulation Software (Dynamic control, Accelerometers simulation, etc…)
Data Evaluation and Test Analysis Software

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

ANNEX A

SEE DRAWING 3000PK 500/01
PLANCK Avionics Schematics

SEE DRAWING 3000HR 500/01
HERSCHEL Avionics Schematics