REPORT

TITLE: SVM DESIGN REPORT

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02	28-07-2002	Updating for System PDR	ALL (no track changes provided)
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TABLE OF CONTENTS

1. INTRODUCTION

HERSCHEL/PLANCK, the 4th cornerstone of the ESA Scientific Programme Horizon 2000 is a challenging mission for the European industry as well as for the European scientific community. Both HERSCHEL and PLANCK spacecraft will represent a major step forward in the knowledge of the Universe and of the mechanisms driving its evolution.
ALENIA Spazio part of the a core team, led by ALCATEL, is responsible for the design of both the SVMs
ALENIA Spazio is a major actor in the scientific programmes of ESA, currently Prime Contractor of the Integral programme and AIT Contractor of the two most recent scientific programmes ROSETTA and MARS EXPRESS.
As part of the Integral programme, ALENIA demonstrated its capability to maintain to the highest possible level the communality of the Integral Service Module design with the XMM bus, while adapting its performance to the requirements of the Integral mission. This approach will serve the HERSCHEL/PLANCK programme to maximise the commonalties between the two satellites and therefore minimise costs and risks.
As part of their involvement in both Integral and the two ROSETTA and MARS EXPRESS programmes, ALENIA has acquired a thorough knowledge of recent ESGSE and testing techniques of current spacecraft design. In addition the stringent launch window of ROSETTA and MARS EXPRESS demonstrates ALENIA flexibility and adaptability to meet challenging milestone schedule.
For the establishment of the HERSCHEL/Planck technical baseline, the following basic objectives were considered:

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

Application of proven and fault tolerant design, re-use of existing hardware were paramount input parameters into the design.
The HERSCHEL/PLANCK project started its phase B on April 2001 and the expected date for its completion and starting of phase C/D is planned on September 2002.
This Issue of the document has been prepared as part of the Data Package of the System Critical Design Review with the objective to document the technical Baseline for both the Herschel and Planck SVM's. It represents an updating of the document presented at the PDR

1.1 PURPOSE

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

1.2 GUIDE TO THE REPORT

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

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

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

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

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

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

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

Chapter 7 presents the SVM Functional design and performance analyses. This chapter is supported by the Chapter 8 (where the road-map of the budgets presented in a dedicated Reports) and together with the Chapter 9 complete the description of SVM Subsystems and Equipment Design.

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

1.3 ACRONYMS AND ABBREVIATIONS

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

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

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

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

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

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

FTP	File Transfer Protocol
FTS	In-flight Testing
FTS	Fourier Transform Spectrometer
G/S	Ground Station
G/T	Gain to Temperature Ratio
GFC	Glass Fibre Compound
GFRP	Glass Fibre Reinforced Plastics
Ghe	Gaseous Helium
GM	Ground Managed
GMM	Geometrical Mathematical Model
GMSK	Gaussian Minimum Shift Keying
GN2	Gaseous Nitrogen
GND	Ground
GPS	Global Positioning System
GRD	Graphical Display
GSE	Ground Support Equipment
GTD	Geometrical Theory of Diffraction
GTO	Geo-stationary Transfer Orbit
GYR	GYRo Blocks
H/W	Hradware
HC	High Speed CMOS
HCM	Angular Momentum Control Mode
He I	Normal Fluid Helium
He II	Helium II (Superfluid Helium)
He3	Helium 3 (Isotrope used in HFI dilution cooler)
He4	Helium 4 (natural isotope of Helium)
HEB	Hot-Electron Bolometer
HEMT	High-Electron Mobility Transistor
HEO	Highly Eccentric Orbit
HEX	Hexadecimal
HFI	High Frequency Instrument (Planck)
HGA	High Gain Antenna
HIFI	Heterodyne Instrument for FIRST
HK	House Keeping
HLC	High Level Command
HOOD	Hierarchical Object Oriented Design
HOT	Helium I Tank
HPA	High Power Amplifier
HPSDB	Herschel Planck System Database
HRS	High Resolution Spectrometer
HSC	Helium System Components
HSIA	Hardware/Software Interaction Analysis
HSK	House Keeping
HST	Helium System Tubing
HTT	Helium II Tank
HW	Hardware
IA	Interactive Analysis (software)
IABG	Industrie Anlagen Betriebsgesellschaft
IAR	Instrument Acceptance Review
IAS	Institut d'Astrophysique Spatiale
IBDR	Instrument Baseline Design Review
ICC	Instrument Control Centre
ICD	Interface Control Document

ICDR	Instrument Critical Design Review
ID	Interface Document
ID	Identifier
IDL	Interactive Data Language
IF	Interface
IF	Intermediate Frequency
IFAR	Instrument Flight Acceptance Review
IFEM	Interface Finite Element Model
IFEM	Instrument Finite Element Model
IFMS	Intermediate Frequency Mass System
IGES	Initial Graphic Exchange Specification
IHDR	Instrument Hardware Design Review
IID	Instrument Interface Document
IIDB	Instrument Interface Document Part B
IIDR	Instrument Intermediate Design Review
ILT	Instrument Level Test
INFT	In-flight Testing
IO	Input/Output
IOB	Instruments Optical Bench
IOCR	In-Orbit Commissioning Review
IOP	Initial Orbit Phase
IPT	Instrument Polling Table
IR	Infrared
IRU	Inertial Reference Unit
ISO	International Standards Organisation
ISO	Infrared Space Observatory
ISS	Integrated Switching System
IST	Integrated Satellite Test
ISV	Independent Software Validation
ISVR	Instrument Science Verification Review
ITT	Invitation To Tender
IVG	Inverted Voltage Gradients
JFET	Junction Field Effect Transistors
JPL	Jet Propulsion Laboratory
JT,J-T	Joule-Thomson
KAL	Keep Alive Line
KIP	Key Inspection Point
L2	Second Lagrangian Point
LAT	Lot Acceptance Test
LCDA	Launcher Coupled Dynamic Analysis
LCL	Latching Current Limiters
LCU	Local Oscillator Control Unit (HIFI)
LEOP	Launch and Early Orbit Phase
LET	Linear Energy Transfer
LFI	Low Frequency Instrument
LGA	Low Gain Antenna
LHC	Left Hand Circular
Lhe	Liquid Helium
LHV	Liquid Helium Valves
LISN	Line Impedance Stabilisation Network
LLI	Long Lead Items
LNA	Low Noise Amplifier
LO	Local Oscillator (HIFI)

LOBT	Local On-Board Time
LoS	Line of Sight
LOU	Local Oscillator Unit (HIFI)
LSB	Least Significant Bit
LSM	Line Scanning Mode
LSU	Local Oscillator Source Unit (HIFI)
LUM	LaUnch Mode
LV	Launch vehicle
LVDE	Low Vibration Drive Electronics (HFI 4K Cooler)
LW	Launch Window
M3	(ESA) Medium Size Mission
MAC	Modal Assurance Criterion
MAIT	Manufacture, Assembly, Integration and Test
MAP	Multiplexed Access Point
MCC	Mission Control Centre
MCM	Monitor and Control Module
MDD	Mimic Display Diagrams
MEA	Main Error Amplifier
MEOP	Maximum Expected Operating Pressure
MGA	Medium Gain Antenna
MGSE	Mechanical Ground Support Equipment
MIP	Mandatory Inspection Point
ML	Memory Load Command (=CS)
MLI	Multi-layer Insulation
MM	Mass Memory
MM	Memory Management
MNEM	Mnemonic
MOC	Mission Operations Centre
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
OS	Operating System
OSR	Optical Solar Reflector
OTF	On Target Flag
P/A	Partially applicable
P/L	Payload
P/ST	Primary Structures
PA	Product Assurance
PACK	Packet (Telecommand or Telemetry)
PACS	Photo-conductor Array Camera Spectrometer (FIRST)
PAD	Parts Approval Document
PAU	Power Amplifier Unit
PCDU	Power Conditioning and Distribution Unit
PCH	PLM Cryostat Harness
PCM	Pulse Code Modulation
PCS	Power Control Subsystem
PCU	Power Control Unit
PDD	Payload Definition Document
PDE	Pointing Drift Error
PDF	(Adobe) Portable Document Format
PDR	Preliminary Design Review
PDU	Power Distribution Unit
PERP	Periodic Reporting
PF	Platform
PFC	Parameter Format Code
PFM	Proto Flight Model
PGSE	Pneumatic Ground Support Equipment (HFI dilution)
PH3HE	Planck HFI 0.1K Dilution Cooler 3He Tank (1)

PH4HE	Planck HFI 0.1K Dilution Cooler 4He Tanks (3)
PHCDU	Planck HFI 0.1K Dilution Cooler Control Unit
PHDPU	Planck HFI Data Processing Unit (DPU)
PHFET	Planck HFI J-FET Box
PHFPU	Planck HFI Instrument Focal Plane Units
PHJCE	Planck HFI 4K Cooler Cold Unit
PHJTA	Planck HFI 4K Cooler Ancillary Unit
PHJTC	Planck HFI 4K Cooler Compressor Unit
PHJTE	Planck HFI 4K Cooler Electronics Unit (4KCDE)
PHPAU	Planck HFI Pre-Amplifier unit (PAU)
PHREU	Planck HFI Readout Electronics Unit (REU)
PI	Principal Investigator
PID	Parameter Identification Number
PID	Proportional, Integral, Derivative (controller)
PLL	Phase Lock Loop
PLM	Payload Module
PM	Processor Module
PM	Project Manager
PM	Phase Modulation
PMD	Propellant Management Device
PND	Passive Nutation Damper
PO	Physical Optic
PPL	Parts and Processes List
PPLM	Planck PayLoad Module
PPS	Pulse Per Second
PPS	Passive Pahse Separator
PR	Primary Reflector
PRE	Pointing Reproducibility Error
PREF	Parameter Reference Number
PROM	Programmable Read Only Memory
PRT	Packet Routing Table
PSEC	Plank Science Evaluation Committee
PSF	Point Spread Function
PSK	Phase Shift Keying
PSS	Procedures, Specifications and Standards
PSVM	Planck Service Module
PT	Product Tree
PTC	Parameter Type Code
PTR	Post Test Review
PtV	Peak to Valley
PTXC	Packet Transmission Control
PUS	Packet Utilisation Standard
PVC	Polyvinyl Chloride
PWM	Pulse Width Modulation
QA	Quality Assurance
QFP	Quad Flat Pack
QLA	Quick Look Analysis (software)
QM	Qualification Model
QMWC	Queen Mary and Westfield College
QR	Qualification Review
QRS	Quartz Rate Sensor
QSL	Quasi-Static Loads
QSO	Quasi Stellar Object

R	Redundant Item
r.m.s.	Root Mean Square
RAA	Radiometer Array Assembly (LFI)
RAM	Random Access Memory
RCA	Radiometer Chain Assembly (LFI)
RCS	Reaction Control Subsystem
RCS	Reaction Control System
RCT	Reaction Control Thrusters
RD	Reference Document
RE	Radiated Emission
REBA	Radiometer Electronics Box Assembly (LFI)
RE-E	Radiated Emission E-field
RE-H	Radiated Emission H-field
REU	Readout Electronics Unit
RF	Radio Frequency
RFA	Request for Approval
RFDM	Radio Frequency Development Model
RFDN	Radio Frequency Distribution Network
RFDU	Radio Frequency Distribution Unit
RFI	Radio Frequency Interference
RFQ	Request For Quotation
RFQM	Radio Frequency Qualification Model
RFW	Request for Waiver
RH	Reference Hole
RH	Relative Humidity
RHC	Right Hand Circular
RHCP	Right Hand Circular Polarisation
RID	Review Item Discrepancy
RM	Reconfiguration Module
RML	Recoverable Mass Loss
RMS	Root Mean Square
ROM	Rough Order of Magnitude
ROM	Read Only Memory
RPE	Relative Pointing Error
RS	Radiated Susceptibility
RS-E	Radiated Susceptibility E-field
RS-H	Radiated Susceptibility H-field
RSP	Reference Star Pulse
RSS	Root Square Sum
RSS	Root Sum Square
RT	Real Time
RTA	Real Time Assessment (software)
RTMM	Reduced Thermal Mathematical Model
RTU	Remote Terminal Unit
RW	Reaction Wheel
RWA	Reaction Wheels Assembly
RWS	Reaction Wheels System
Rx	Receiver
S/C	Spacecraft
S/N	Signal to Noise Ratio
S/S	Subsystem
S/W	Software
S3R	Sequential Switching Shunt Regulator

SA	Solar Array
SAA	Solar Aspect Angle
SADM	Solar Array Drive Motor
SAM	Sun Acquisition Mode
SAS	Sun Acquisition Sensor
SBDL	Standard Balanced Digital Link
SCC	Sorption Cooler Compressor assembly (LFI)
SCC	Stress Corrosion Cracking
SCC	Space Components Co-ordination
SCCE	Sorption Cooler Cold End (LFI)
SCE	Sorption Cooler Electronics (LFI)
SCET	Spacecraft Elapsed Time
SCI	SCIence Mode
SCL	Spacecraft Control Language
SCOE	Special Check Out Equipment
SCOS	Spacecraft Control and Operations System
SCOS	Space Control and Operations Centre
SCOTE	Satellite and Check-Out Terminal Equipment
SCP	Sorption Cooler Piping (LFI)
SCS	Sorption Cooler Subsystem (LFI)
SDASW	Satellite Dependent Application Software
SDBP	Satellite Data Bus Protocol
SDE	Software Development Environment
SDS	System Definition Study
SE	Saab Ericsson Space AB
SECDED	Single Error Correction and Double Error Detection
SEL	Spacecraft Event Log
SEU	Single Event Upset
SF	Safety Factor
SFCG	Space Frequency Co-ordination Group
SFPT	System Requirement Review
SFT	Short Functional Test
SFW	Spatial Framework
SGICD	Space/Ground Interface Requirement Document
SGM	Safe-Guard Memory
SH	Safety Hazard
SHM	Safe and Hold Mode
SID	Structure ID
SIH	Scientific Instrument Harness
SIN	Straylight Induced Noise
SIRD	Science Implementation Requirements Document
SIS	Spacecraft Interface Simulator
SIS	Superconductor-Insulator-Superconductor
SIST	Short Integrated Satellite Test
SIT	System Integration Test
SIUB	Serial Internal User Bus
SIV	Software Independent Validation
SLD	Scrolling Log Display
SLE	Standard Laboratory Equipment
SLT	Static Load Test
SM	Star Mapper
SM	Structural Model
SM	Survival Mode

SOC	Science Operations Centre
SoW	Statement of Work
SP	Sun Pointing
SPC	Science Programme Committee
SPF	Single Point Failure
SPIRE	Spectral Photometer Imaging Receiver (FIRST)
SPL	Split Phase Level
SPT	Specific Performance Test
SPU	Signal Processing Unit
SR	Secondary Reflector
SRD	Software Requirements Document
SREM	Standard Radiation Environment Monitor
SRON	Space Research Organisation Netherlands
SRPE	Spatial Relative Pointing Error
SRR	Software Requirements Review
SRR	System Requirements Review
SRRC	Spare-Root Raised Cosine
SRS	Shock Response Spectrum
SRS	System Requirements Specification
SSAC	Space Science Advisory Committee
SSCE	Sun/SpaceCraft/Earth (Angle)
SSCM	Sun/SpaceCraft/Moon(Angle)
SSM	Second Surface Mirror
SSMM	Solid State Mass Memory
SSR	Solid State Recorder
SST	Stainless Steel
ST	Star Tracker
STC	Station Computer
STD	Standard
STM	STar Mapper
STM	Structural/Thermal Model
STMM	Simplified Thermal Mathematical Model
STR	Star-Tracker
STRP	Statistic Reporting
SUM	Satellite Users Manual
SVC	Service Call
SVF	Software Validation Facility
SVM	Service Module
SVT	System Validation Test
SW	Software
T°	Temperature
TA	Telescope Assembly
TAI	Temps Atomique International
TASW	Test Application Software
TB	Test Bed
TB	Thermal Balance
TBC	To Be Confirmed
TBD	To Be Determined
TC	Telecommand
TC	Tele-Communication mode
TC	Telecommand
TCE	Tele Command Equipment
TCS	Thermal Control Subsystem

TCU	Thermal Control Unit
TCV	Telecommand Verification
TE	Test Equipment (LFI)
TESRE	Istituto di Tecnologie e Studio delle Radiazioni E
TF	Test Factor
TID	Total Integrated Scattering
TIM	Total Integrated Scattering
TIS	Total Integrated Scattering
TM	Telemetry
TM	Telemetry
TML	Total Mass Loss
TMM	Thermal Mathematical Model
TOP	Transfer Orbit Phase
TOT	Thruster On Time
TPN	Telemetry Packet Number
TPT	Tank Pressure Transducer
TRP	Technological Research Programme
TRR	Test Readiness Review
TSF	Tank Support and Spatial Framework
TSMM	Transport Stimuli and Monitoring Unit
TT&C	Telemetry Tracking and Command
TT&C	Telemetry, Tracking and Command
TV	Thermal Vacuum
TWTA	Travelling Wave Tube Amplifier
Tx	Transmitter
UART	Universal Asynchronous Receiver Transmitter
UF	Ultimate Factor of Safety
UFT	Upper and Lower Thermal Shields
ULS	Upper and Lower Thermal Shields
UMOS	Ultimate Margin of Safety
URD	User Requirement Document
URR	User Requirements Review
USF	Ultimate Safety Factor
UTC	Unit Under Test
UUT	Unit Under Test
UV	Ultraviolet
VC	Visual Monitoring System
VCA	Virtual Channel Assembler
VCM	Virtual Channel Multiplexer
VEB	Visual Monitoring System
VHDL	Very High Speed Integrated Circuit Hw Descr Lang
VMC	Visual Monitoring System
VPP	Verification Programme Plan
VSWR	Voltage Standing Wave Ratio
WBS	Work Breakdown Structure
WBS	Wide Band Spectrometer
WC	Worst Case
WCA	Worst Case Analysis
WD	Watch Dog
WFE	Wave Front Error
WG	Wave-guide (LFI)
WP	Work Package
WPD	Work Package Description

WU	Warm Unit
XMM	X-ray Multi Mirror
XPND	Transponder
YF	Yield Factor of Sa
YMOS	Yield Margin of Safety

1.4 DOCUMENTS

1.4.1 Applicable Documents

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

AD-01	SCI-PT-IIDA-04624, Issue 3 Rev.1, October 2003	Instrument Interface Document, part A
AD-02	SCI-PT-IIDB/SPIRE-02124, Issue 3 Rev. 0, September 2003	Instrument Interface Document, part B: Bolometer Instrument
AD-03	SCI-PT-IIDB/HIFI-02125, Issue 3 Rev. 0, October 2003	Instrument Interface Document, part B: Heterodyne Instrument
AD-04	SCI-PT-IIDB/PACS-02126, Issue 3 Rev. 0, July 2003	Instrument Interface Document, part B: Photoconductor Instrument
AD-05	SCI-PT-IIDB/HFI-04141, Issue 3 Rev. 0, October 2003	Instrument Interface Document, Part B (IID-B): HighFrequency Instrument
AD-06	SCI-PT-IIDB/LFI-04142, Issue 2 Rev. 1, July 2002	Instrument Interface Document, Part B (IID-B): LowFrequency Instrument
AD-07	SCI-PT-ICD-07418, Issue 3 Rev. 1, December 2003	Herschel/Planck Space to Ground Interface Document
AD-08	SCI-PT-RS-07360, Issue 2 Rev. 2, September 2003	Herschel/Planck Operations Interface Requirement Document
AD-09	SCI-PT-ICD-07527, Issue 4, November 2003	Herschel/Planck Packet Structure ICD
AD-10	Not Used	Not Used
AD-11	FP-MA-RP-0010	Herschel–Planck Consolidated Report on Mission Analysis (CREMA)
AD-12	H-P-1-ASPI-SP-0027, Issue 4 Rev. 2, November 2003	General Design and Interface Requirements (GDIR)
AD-13	H-P-1-ASPI-SP-0030, Issue 4 Rev. 2, December 2003	Environment and Tests Requirement
AD-14	H-P-1-ASPI-SP-0037, Issue 3 Rev. 1, November 2002	EMC Specification
AD-15	H-P-1-ASPI-SP-0035, Issue 2 Rev. 2, September 2003	Cleanliness Requirements Specification
AD-16	Not Used	Not Used
AD-17	Not Used	Not Used
AD-18	Not Used	Not Used
AD-19	Not Used	Not Used
AD-20	Not Used	Not Used
AD-21	ESA PSS-04-105, Issue 1,December 1989	Radio Frequency and Modulation Standard
AD-22	ESA PSS-04-104, Vol. 1, Issue 2, March 1991	Ranging Standard ESA
AD-23	ESA PSS-04-103, Issue 1, September 1989	Telemetry Channel Coding Standard ESA
AD-24	ESA PSS-04-106, Issue 1, January 1988	Packet Telemetry Standard
AD-25	ESA PSS-04-107, Issue 2, 1991	Packet Telecommand Standard
AD-26	ESA PSS-02-10, Nov 1992	ESA Power Subsystem Standard Specification
AD-27	ECSS-E-30-00 Part 2-3	Space Mechanisms Standard Requirements Specification
AD-28	ECSS-E-40, Issue B	ESA Software Engineering Standards
AD-29	ECSS-Q-80	Software Product Assurance

AD-30	CCSDS 301.0-B-2 issue 2	Time Coded format
AD-31	Issue 3/Rev 0, March 2000	ARIANE 5 Users's Manual
AD-32	Not used	Not Used
AD-33	Not used	Not Used
AD-34	ECSS-E-30-01A	Fracture Control Requirements Specification
AD-35	Not used	Not Used
AD-36	H-P-1-ASPI-SP-0046, Issue 3 Rev. 0, December 2003	Software Requirements Specification
AD-37	H-P-1-ASPI-SP-0044, Issue 4 Rev. 0, May 2003	Mechanical Ground Support Equipment Specification
AD-38	H-P-1-ASPI-PL-0009, Issue 2 Rev. 1, October 2002	Herschel-Planck Design and Development Plan
AD-39	SG-0-01, Issue 3	Ariane Specification
AD-40	H-P-1-ASPI-SP-0045, Issue 3 Rev. 0, June 2002	Electrical Ground Support Equipment Specification
AD-41	H-P-1-ASPI-PL-0038, Issue 3 Rev. 0, May 2002	EMC/ESD Control Plan
AD-42	Not used	Not Used
AD-43	H-P-4-ASPI-SP-0019, Issue 4 Rev. 1, January 2004	Service Module Requirements Specification
AD-44	H-P-1-ASPI-SP-0017, Issue 1 Rev. o, June 2001	Radiation Requirements Specification
AD-45	ESA PSS-04-151	ESA Telecommand Decoder Specification
AD-46	Not used	Not Used
AD-47	H-P-4-ASPI-IS-0042, Issue 5 Rev. 0, November 2003	SVM Interface Specification
AD-48	Not Used	Not Used
AD-49	SG-PR-AI-0264, Issue 1, April 2000	Guidelines to Mathematical Model Preparation Description & Quality Assessment
AD-50	H-P-1-ASPI-SP-0014, Issue 1 Rev. 0, June 2001	Herschel/Planck Mathematical Model Specification
AD-51	Not Used	Not Used
AD-52	H-P-2-ASPI-ID-0621, Issue 2 Rev. 0, April 2004	Herschel PLM Electrical ICD
AD-53	H-P-3-ASPI-ID-0550, Issue 2 Rev. 0, March 2004	Planck PLM Electrical ICD

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	Not used	Not Used
RD-12	H-P-PL-AI-0009, Issue 3,. December 2002	SVM Software Design and Development Plan
RD-13	H-P-SP-AI-0006, Issue 5, February 2004	ACC and CDMU Basic Software Requirements
RD-14	H-P-AI-SP-0031, Issue 5, may 2004	CDMU Application Software Requirements Baseline
RD-15	H-P-4-SES-NT-0076, Issue 5, June 2004 H-P-4-SES-NT-0077, Issue 5, June 2004	CDMU ASW-BSW Software Interface Control Document ACC ASW-BSW Software Interface Control Document
RD-16	H-P-IC-AI-0004, Issue 4 DR, July 2004	SVM SW Interface Control Document
RD-17	H-P-RP-AI-0003, Issue 4, July 2004	SVM Configuration Report
RD-18	Not used	Not Used
RD-19	H-P-4-SES-NT-0022, Issue 5, June 2004	ACC Technical Description
RD-20	Not used	Not Used
RD-21	Not Used	Not Used
RD-22	Not used	Not Used
RD-23	H-P-TN-AI-0015, Issue 4, May 2004	SDE definition
RD-24	Not used	Not Used
RD-25	Not used	Not Used
RD-26	H-P-SP-AI-0001Issue 7, July 2004	SVM Structure Specification
RD-27	H-P-SP-AI-0033, Issue 4 , July 2004	SVM Mecahnical Environment and Test Specification
RD-28	H-P-TN-AI-0019, Issue 1, February 2002	SVM Acceleration Limit Load Factors
RD-29	H-P-TN-AI-0023, Issue 3, July 2004	H & P SVM Normal Mode and Sine response Analyses
RD-30	H-P-TN-AI-0028, Issue 3, July 2004	Herschel Planck Vibro-acoustic Environment and Test Levels Definition
RD-31	H-P-TN-AI-0029, Issue 2, December 2002	Herschel Planck Shock Environment and Test Levels Definition
RD-32	H-P-PL-AI-0005, Issue 2, June 2002	Fracture Control Plan
RD-33	H-P-4-CASA-RP-0013, Issue 4, December 2003	SVM Structure Design Report
RD-34	H-P-4-CASA-RP-0012, Issue 4, December 2003	Performance Analyses Report
RD-35	H-P-4-CASA-RP-0032, Issue 3,	Herschel FEM Description

	January 2004	
RD-36	H-P-4-CASA-RP-0033, Issue 3, December 2003	Planck FEM Description
RD-37	H-P-4-CASA-NT-0029, Issue 4, December 2003	Material and Standard Allowable
RD-38	H-P-4-CASA-RP-00044, Issue 1, May 2004	Planck Alignment Stability Analysis Report
RD-39	H-P-4-CASA-RP-00045, Issue 1, May 2004	Herschel Alignment Stability Analysis Report
RD-40	H-P-4-CASA-NT-0017, Issue 1, December 2003	Joint Verification Assessment
RD-41	H-P-MI-AI-0092	Minute of PM # 8
RD-42	H-P-RP-AI-0023 Issue 1, January 2003	SVM Mechanical Performance Analyses Reports
RD-43	H-P-4-CASA-RP-0036, Issue 02, May 2004	Mass budget report
RD-44	H-P-4-CASA-NT-0015, Issue 01, December 2003	Mass Saving Options Evaluation
RD-45	Not used	Not Used
RD-46	Not used	Not Used
RD-47	Not used	Not Used
RD-48	ACMS Parameter Data Base Issue 3	H-P-SP-AI-0039
RD-49	CDMU SW I/F Req Doc (IRD) Issue 5	H-P-SP-AI-0005
RD-50	X Band Low Gain Antenna Specification Issue 4	H-P-SP-AI-0024
RD-51	X Band Medium Gain Antenna Specification Issue 4	H-P-SP-AI-0025
RD-52	SVM Harness Requirement Specification Issue 4	H-P-SP-AI-0026
RD-53	H-P-SP-AI-0002, Issue 3, December 2003	RCS Requirements Specification
RD-54	H-P-SP-AI-0003, Issue 5, February 2004	CDMU HW Requirements Specification
RD-55	H-P-SP-AI-0008, Issue 5, November 2003	ACC HW Requirements Specification
RD-56	H-P-SP-AI-0011, Issue 5, January 2004	ACMS Specification
RD-57	H-P-SP-AI-0012, Issue 3, July 2003	X-X Band Transponder Specification
RD-58	H-P-SP-AI-0014, Issue 4, January 2004	PCDU Requirements Specification
RD-59	H-P-SP-AI-0015, Issue 4, January 2004	Planck Solar Array Specification
RD-60	H-P-SP-AI-0016, Issue 4, January 2004	X Band TWTAS (TWTA+EPC) Specification
RD-61	H-P-SP-AI-0022, Issue 4, January 2004	Battery Requirement Specification
RD-62	H-P-SP-AI-0023, Issue 3, October 2003	RFDN Specification
RD-63	H-P-TN-AI-0011, Issue 1, December 2001	TCS Design Description
RD-64	H-P-4-ETCA-TN-0010, Issue 5, December 2003	PCDU Technical Description

RD-65	H-P-4-SES-NT-0021, Issue 5, June 2004	CDMU Technical Design Report
RD-66	Not used	Not Used
RD-67	Not used	Not Used
RD-68	Not used	Not Used
RD-69	Not used	Not Used
RD-70	Not used	Not Used
RD-71	Not used	Not Used
RD-72	H-P-TN-AI-0005, Issue 2, June 2002	SVM thermal Analysis report
RD-73	H-P-TN-AI-0004, Issue 1, June 2001	Active Versus Passive Nutation Dumping Trade Off
RD-74	H-P-RP-AI-0002, Issue 1, July 2001	Battery Cell capacity redundancy Trade Off
RD-75	H-P-RP-AI-0001, Issue 3, December 2001	Turbo Codes Implementation Trade Off
RD-76	H-P-MA-AI-0001, Issue 2, July 2004	Module/Subsystem/Unit User Manual
RD-77	H-P-IC-AI-0001, Issue 6, June 2004	SVM Mechanical ICD
RD-78	H-P-ASPI-MN-452	Solar Array Work Group #1 Minutes of Meeting
RD-79	H-P-TN-AI-0076, Issue 1, December 2003	Star Tracker Assembly Definition
RD-80	H-P-TN-AI-0073, Issue 1, December 2003	FEM model history and sensitivity analysis of STR support structure
RD-81	H-P-TN-AI-0074, Issue 1, December 2003	Star Tracker Support Structure FEM Description & Result
RD-82	H-P-TN-AI-0071, Issue 1, February 2004	SOHO failure operational aspects
RD-83	H-P-TN-AI-0070, Issue 3, June 2004	SOHO thermal analysis - Plank Scenario 2
RD-84	H-P-RP-AI-0082, Issue 1, June 2004	Planck SCC panel mechanical design and analyses
RD-85	TBD	Design and qualification status for S/S Equipments
RD-86	H-P-TN-AI-0030, Issue 1, June 2002	STR Positioning Trade-Off
RD-87	H-P-TN-AI-0045, Issue 3, February 2004	Uncertainties Thermal Analysis
RD-88	H-P-4-AAE-RP-2001, Issue 1, March 2003	Herschel / Planck SVM MLI Equipment Design Description
RD-89	H-P-TN-AI-0060, Issue 1, June 2003	Fine Control Law Analysis
RD-90	H-P-4-EHP-RP-001, Issue 1.B, February 2004	Design Report of Heat Pipes Type 1, 2A & 2B
RD-91	H-P-TN-AI-0024, Issue 6, July 2004	SVM FDIR Design Specification
RD-92	H-P-TN-AI-0065, Issue 1, November 2003	Herschel Thermal Analysis results and breakdown
RD-93	H-P-TN-AI-0066, Issue 1, November 2003	Planck Thermal Analysis results and breakdown
RD-94	H-P-TN-AI-0070, Issue 3, June 2004	SOHO thermal analysis - PLANCK scenario 2
RD-95	H-P-TN-AI-0040, Issue 1, October 2002	SVM TCS Thermal Analysis Report
RD-96	H-P-TN-AI-0075, Issue 1, May 2004	Herschel Star Tracker Assembly Thermal Control and Analysis Description
RD-97	H-P-BD-AI-0004, Issue 1, March 2004	Mass & Power Budgets
RD-98	H-P-IC-AI-0002, Issue 3, June 2004	SVM Thermal ICD
RD-99	H-P-DS-TN-0011, Issue 5, July 2004	ACMS Design Report
RD-100	H-P-TN-AI-0053, Issue 2, July 2004	CDMS Functional Design Description
RD-101	H-P-4-SES-NT-0078, Issue 3, June 2004	BSW Design Description
RD-102	H-P-4-SSF-DD-0001, Issue 1 Rev. 3,	H-P-CDMU ASW Design Document

	July 2004	
RD-103	H-P-TN-AI-0079, Issue 1, July 2004	Grounding and bonding concept
RD-104	H-P-BD-AI-0003, Issue 2, July 2004	SVM SW Budgets Report
RD-105	H-P-4-SES-NT-0027, Issue 4, June 2004	Basic Software Timing and Sizing Budgets
RD-106	H-P-4-TASW-AN-0001 Issue 1, November 003	ACC ASW Performance and Schedulability Analysis
RD-107	H-P-4-DS-RP-003, Issue DR, December 2002	ACMS Budget Report
RD-108	H-P-4-SSF-BU-0001, Issue 1.2 DR 3, July 2004	H-P CDMU Software Budget Report
RD-109	H-P-4-SSF-TN-0007, Issue 1.1 DR 2, July 2004	H-P CDMU ASW Schedulability Analyses
RD-110	H-P-4-GAF-BD-0001, Issue 2DR, April 2004	H-ASTR SW CPU and Memory Budgets
RD-111	H-P-4-GAF-BD-0002, Issue 2 DR, April 2004	P-ASTR SW CPU and Memory Budgets
RD-112	H-P-BD-AI-0005, Issue 1, May 2004	Link Budget Report
RD-113	H-P-BD-AI-0006, Issue 3, June 2004	H/P Mass Budget and Properties Report
RD-114	H-P-BD-AI-0007, Issue 1, July 2004	Pointing Budget Report
RD-115	H-P-BD-AI-0008, Issue 1, May 2004	SVM Power budget
RD-116	H-P-TN-AI-0018, Issue 2, June 2002	SVM TM/TC Budget Technical note
RD-117	H-P-BD-AI-0004, Issue 1, March 2004	TCS Budget Report
RD-118	H-P-IC-AI-0003, Issue 4 + DCN 016 & 017, May 2004	SVM Electrical ICD
RD-119	H-P-4-NXH-RP-0002, Issue A1, July 2004	H-P PERFORMANCE & BUDGET ANALYSIS
RD-120	H-P-4-NXH-LI-0017, Issue A1, July 2004	Herschel-Planck MICD
RD-121	H-P-4-NXH-TN-0001, Issue A5, July 2004	Herschel – Planck Dismountability Bracket Connector list
RD 122	H-P-TN-AI-0035, Issue 3, March 2004	ACMS FDIR Issues
RD 123	H-P-4-DS-IC-007, Issue 2 Rev. 3, June 2004	ACMS internal ICD
RD 124	H-P-TN-AI-0089, Issue 1, July 2004	Guide for RCS interfaces for ACMS users
RD 125	H-P-ANA-TN-005, Issue 4, June 2004	Herschel RWS Controller Design Report
RD 126	H-P-4-DS-TN-027, Issue 1, January 2003	Herschel Control Design Report RCS
RD 127	H-P-4-SEN-TN-0002, Issue 2.1, April 2004	Planck Attitude Determination Algorithms Description
RD 128	H-P-4-DS-PL-002, Issue 2 Rev. 3, June 2004	ACMS DD&Q
RD 129	H-P-4-DS-PL-015, Issue 2, December 2003	FDIR verification plan
RD 130	H-P-4-DS-PL-016, Issue 2, December 2003	SE Verification plan
RD131	H-P-4-DS-PL-018, Issue 1 Rev. 1, December 2003	Verification Plan PA
RD 132	H-P-4-DS-PL-019, Issue 1, September 2003	Electrical Verification Plan

RD 133	H-P-4-DS-PL-020, Issue 1, September 2003	RAMS verification plan
RD 134	H-P-4-DS-PL-023, Issue 2, December 2003	Verification Plan Func Design Eng
RD 135	H-P-4-DS-PL-024, Issue 2, December 2003	Verification Plan OPS
RD 136	H-P-4-DS-PL-025, Issue 2, December 2003	Verification Plan for ACMS Unit Communication
RD 137	H-P-4-DS-PL-026, Issue 1, February 2004	Verification Plan Sim Model Val
RD 138	H-P-4-DS-PL-021, Issue 2, December 2003	Verification Plan for Control Design Herschel
RD 139	H-P-4-DS-PL-022, Issue 2, December 2003	Verification Plan Herschel Signature Test
RD 140	H-P-4-SEN-PL-007, Issue 1 Rev. 1, November 2003	Verification Plan for Control Design Planck
RD 141	H-P-4-SEN-PL-008, Issue 1 Rev. 1, November 2003	Verification Plan for Planck Signature Tests
RD 142	H-P-4-DS-SP-0013, Issue 1, September 2003	ACMS Implementation Spec
RD 143	H-P-4-DS-PL-0014, Issue 3, June 2004	Requirement verification responsibility allocation
RD 144	H-P-4-TNO-RP-S004, Issue 3, October 2003	SAS design & analysis report
RD 145	H-P-4-TNO-RP-A004, Issue 3, October 2003	AAD design & analysis report
RD 146	H-P-4-LAB-RP-0001, Issue 2, June 2004	CSR detailed design report
RD 147	H-P-4-GAF-RP-0002, Issue 3, June 2004	STR design report
RD 148	899710, Issue A, February 2004	GYR design report
RD 149	H-P-4-TX-RP-0001, Issue 1, June 2004	RWA design report
RD 150	H-P-4-ANA-TN-001, Issue 4 Rev. 2, June 2004	ACMS Pointing 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 similar for both the spacecraft) 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 and interfaces 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 be in line with the requirement of AD(43) and the relevant applicable documents. In each subsystem chapter (chapters 7 and 9) discussion of applicable requirements is included leaving at System Level the harmonisation with the relevant PLM assessment
This chapter highlights the driving requirements for the Herschel/Planck SVM which are constraining the design in terms of functions to be performed, performance to be obtained, resources to be fulfilled, external interface (both launcher and Instruments) to be respected and overall configuration constraints to be considered.

Resources

The specified SVM **Dry mass** is 600 kg for Herschel and 680 Kg for Planck. It does not include the AR5 2624 Separation System nor the **System Margin**. AGENCY (ESA) and PRIME (ASPI) are managing their respective margin to cover System/SVM Design changes. Further mass requirement is the **maximum amount of fuel** to be embarked. They are expressed in terms of maximum mass to be filled in Fuel tanks. **No Mass Margin is required at launch. With respect to the PDR the allocated mass for the SVM have been increased (was 415 Kg and 485 Kg respectively) in order to cope with the achievable SVM performances (mainly on structure and harness). The discussion of the Mass evolution is reflected in the chapter 8 of this document and on the relevant mass budget document.**
The **Battery and Solar Array** sizing are driven by the allocated power for Payloads operations. Transfer and operational orbits are eclipse free (it is expected some moon shadowing impacting the power availability of about 10% of the maximum) but the battery is included in the design to cover power peak requirement and to supply power in case of emergency situation.

Lifetime

The **lifetime** requirement:

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

drives the design through the provisions needed to meet the extended life
Important considerations include the **reliability** of specific equipment items as well as of the satellite as a whole and hence functional redundancy.
No critical lifetime constraints are imposed to the SVM except to the related thermal requirements especially on Herschel.

Pointing and Attitude

The pointing requirements are fundamental for being satisfied in order to meet the Mission scientific objectives.
For Herschel, very stringent pointing and slew performance requirements combined with the need to guarantee complete autonomy of scientific operations without ground contact impose serious constraints on the selection of ACMS units and their mounting structure. Mission autonomy requirements can only be satisfied using star trackers with autonomous attitude recognition capability which in general provide lower accuracy than non-autonomous

units optimised for very precise measurements of a single star. In particular, STR biases must be kept at levels achieved only by the best autonomous units on the market in order to satisfy the absolute measurement and pointing requirements. The mounting of the STR must guarantee low thermoelastic distortions and a dedicated trade-off has been performed to select the most suitable location and support structure. After several iterations the selected accommodation of the Herschel Star tracker has been found inside the Structure cone and directly connected to the PLM CVV. Discussion and implementation of the selected configuration is provided in RD (79). Requirements on short term pointing stability have led to the selection of a very high quality gyroscope used for short-term propagation of attitude derived from STR data. Additionally, slew efficiency requirements imply the use of reaction wheels with high torque capacities and may lead to simultaneous use of all four reaction wheels in order to satisfy the goals.
For Planck the pointing requirements constrain a wider range of system parameters. The passively stabilised spacecraft has no direct closed loop attitude control but nevertheless requires accurate sensors to satisfy stringent requirements on *post facto* attitude reconstruction. Although not originally foreseen, the capability of autonomous determination of inertial attitude had to be introduced in order to satisfy the pointing drift requirements with worst case solar disturbance torque. This capability is provided by autonomous star trackers similar to the units selected for Herschel but with modifications necessary to allow operation at very high star tracking rates (nearly 6°/s) imposed by the rotation of the spacecraft. The performance characteristics of the STR are driven mainly by the absolute measurement accuracy required for the SVM; however, the requirements on the accuracy of spin axis repointing are also constraining the unit specification. Because of the relatively high accuracy of spin axis control that can be provided by the ACMS, its contribution to the absolute pointing error is small, and the achievement of the required accuracy will be determined mainly by the mass distribution of the spacecraft (deviation of the principal axis of inertia from the desired direction). The Planck SVM will be operated under very stable thermal conditions and the contribution of thermoelastic terms appears to be minor.

Commonality

The Herschel and Planck SVM design must be optimised in order to minimise the needs for changing the design of the SVM Subsystems and or units developed in the frame of the two projects. This implies some over design (especially on box dimensions and relative mass). The verification on EM (AVM) is conceived to minimise the hardware needs. Hardware commonality on the structure is limited to the Central Cone, interface with the launcher and on the Panel dimensions. The original idea to have common lateral and shear panels has been relaxed to meet the accommodation of the Instruments interface requirements evolution.

Instruments Accommodation

The instrument accommodation and operations strongly influence the SVM Configuration, Structural sizing and the thermal design. This because mostly of the Instruments units (Warm part of the Payload) are located on the Panels of the SVM and will constraint the CoG and the thermal design
PLM configuration and lay-out.
Stringent Thermal Stability requirement on mostly of the Warm Units imply the utilisation of dedicated Thermal Control Law.

Autonomy

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

Tables 2-1-1 to 3 summarises the Key requirements and Design Drivers in term of Characteristics and Performance at system and SVM level

Launch characteristics	**HERSCHEL**	**PLANCK**
Launch Vehicle	**ARIANE-V**	
Launch Site	Kourou	
Launch Mode	Dual launch	
Lifetime • Nominal • Including Degradable items	3,5 years (including 6 m to L2) 6 years (including 6 m to L2)	21 mon. (including 6 m to L2) 2,5 years (including 6 m to L2)
Ground Stations	New Norcia (Nominal) Kourou (Back-Up)	New Norcia (Nominal) Kourou (Back-Up)
Ground Station Coverage Time	3 hours per day max	3 hours per day max

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

	HERSCHEL SVM Required Performance	HERSCHEL SVM **Achieved**
SVM COMMONALITY	SVM COMMONALITY REQUIRED AT THE MAXIMUM EXTENT	ACHIEVED AT EQUIPMENT LEVEL BUT **NOT FOR STRUCTURE, HARNESS AND THERMAL CONTROL**
AUTONOMY (no ground contact)	48 hours fully autonomous control and 7 days in survival mode	Achievable with very complex ASW and dedicated FDIR
HK and scientific DATA STORAGE	25 Gbit Solid State Memory	Storage provided in the CDMU
THERMAL STABILITY	High level of thermal stability (1deg over 1 h) and very low flux to PLM	Achievable with dedicated thermal control law and dedicated Star tracker accommodation
Uplink Low/High bit rate Downlink low bit rate (TM) Downlink medium/ high bit rate (TM)	125 bps / 4kbps 500 bps/5 kbps 150 kbps /1,5 Mbps	125 bps / 4kbps 500 bps/5 kbps 150 kbps /1,5 Mbps
SVM Dry Mass at Launch Max Loaded Fuel + Nitrogen Mass Instrument Mass on SVM	600 kg	**648 kg (Nominal CDR Value) 682 max** 200 kg on Fuel tanks 287 kg (312,37 max)
Power Availability (allocation) From Battery (storage) **To SVM (from SA)** To Instruments	 567 Wh for SVM 520 W 550 W	 Achieved Exceeded by 240W but OK at SYS level Achieved
Absolute Pointing Error (APE) Relative Pointing Error (RPE) Pointing Drift Error (PDE) Absolute Measurement Error (AME) Slew duration (Herschel)	2.25”, 1.15”, 0.24” (bias, long and short term) 0.25” over 60 seconds 1.19” for up to 24 hours 1.62”, 1.15”, 0.24” (bias, long and short term) 41 seconds for 8’, goal = 27 seconds	With Sun Aspect Angle (SAA) of +/-30° about Y, +/-1° about X Achieved with: Dedicated AOCS sensors and actuators accommodation Specific Thermal Control design On flight calibration procedure

Table 2-1-2 – Herschel SVM Key Requirements and achieved performance

	Planck SVM Required Performance	PLANCK SVM **Achieved**
SVM COMMONALITY	SVM COMMONALITY REQUIRED AT THE MAXIMUM EXTENT	ACHIEVED AT EQUIPMENT LEVEL BUT **NOT FOR STRUCTURE, HARNESS AND THERMAL CONTROL**
AUTONOMY (no ground contact)	48 hours fully autonomous control and 7 days in survival mode	Achievable with very complex ASW and dedicated FDIR
HK and scientific DATA STORAGE	25 Gbit Solid State Memory	Storage provided in the CDMU
THERMAL STABILITY	High level of thermal stability (1deg over 1 h) and very low flux to PLM	Achievable with dedicated thermal control on SCC Panels and Payload subplatform
Uplink Low/High bit rate Downlink low bit rate (TM) Downlink medium/ high bit rate (TM)	125 bps / 4kbps 500 bps/5 kbps 150 kbps /1,5 Mbps	125 bps / 4kbps 500 bps/5 kbps 150 kbps /1,5 Mbps
SVM Dry Mass at Launch Max Loaded Fuel + Nitrogen Mass Helium Mass on helium tank Instrument Mass on SVM	680 kg kg	**746 kg (Nominal CDR Value)786 max** 402 kg on Fuel tanks 307 kg 356 kg (389max)
Power Availability (allocation) From Battery (storage) From S.A. (generation) To Instruments	 567 Wh for SVM 1900 W 1000 W	 Achieved Achieved Achieved
Absolute Pointing Error (APE) Relative Pointing Error (RPE) Pointing Drift Error (PDE) Absolute Measurement Error (AME) Spin axis repointing (Planck)	33', 1.5' (long and short term) 36.1' around LOS 1.5' over 55 minutes 6.19' over 24 hours 0.2', 0.14', 0.15' (bias, long and short term) 0.4' for displacements up to 3'	With Sun Aspect Angle (SAA) of 10° half-cone centred on –X Achieved with passive AOCS: Dedicated AOCS sensors and actuators accommodation Specific Thermal Control design Periodic On flight calibration procedure

Table 2-1-3 – Planck SVM Key Requirements and achieved performance

3. INSTRUMENTS INTERFACE AND ACCOMMODATION DATA

This chapter provides a brief description of the HERSCHEL and PLANCK Instruments and their scientific performances. A compilation of instruments interface data as specified in the Instrument Interface Documents part B (IID-Bs) for each experiment.

3.1 HERSCHEL INSTRUMENTS DESCRIPTION

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

- **PACS** (**P**hotoconductor **A**rray **C**amera and **S**pectrometer)
- **SPIRE** (**S**pectral **P**hotometer **I**maging **RE**ceiver)
- **HIFI** (**H**eterodyne **I**nstrument for the **F**ar **I**nfrared)

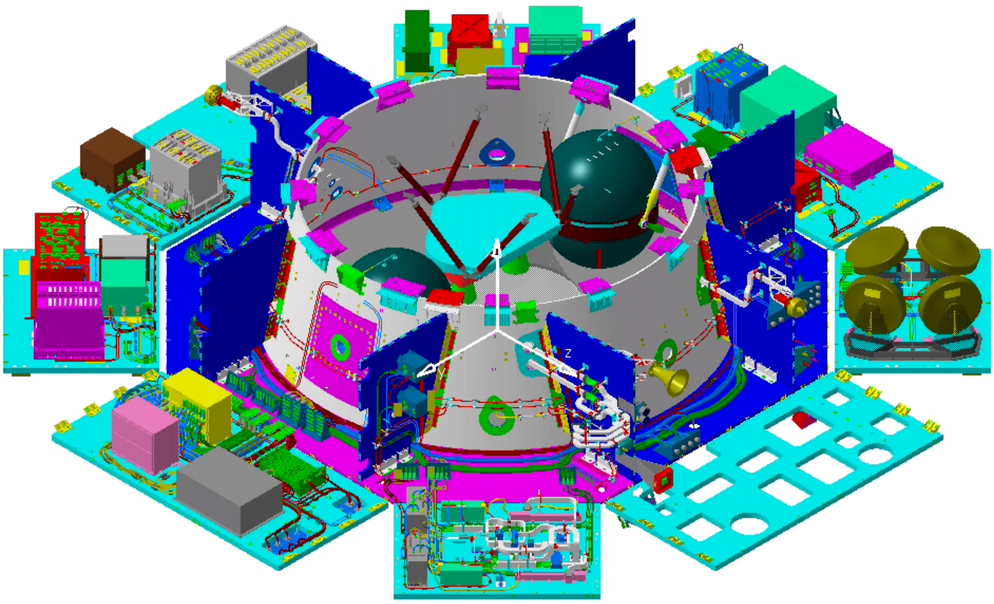


Fig.3.1-1 Herschel SVM layout.

3.1.1 PACS HARDWARE DESCRIPTION

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

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

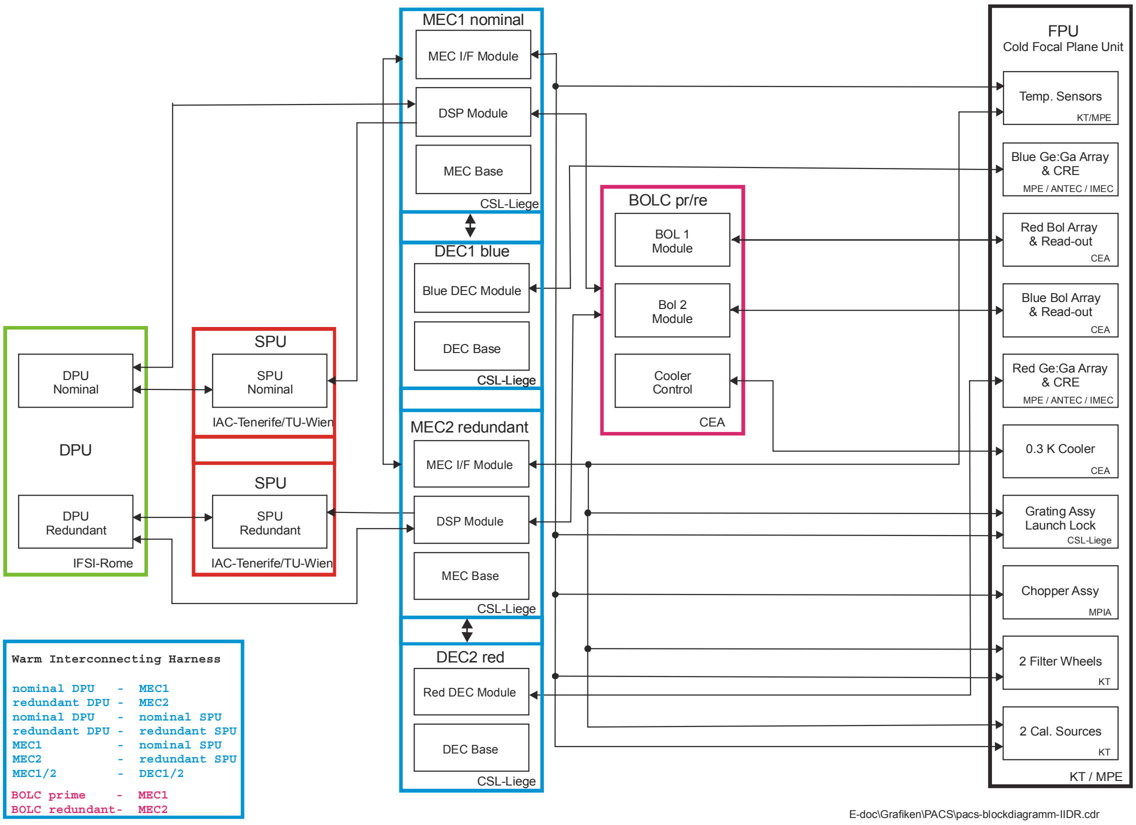


Fig.3.1.1-1 PACS Instruments Block Diagram.

In particular, the PACS instrument consists of:

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

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

- **DPU**, one digital electronics box (prime and redundant sections) for instrument control and telemetry interface to the spacecraft.
- **SPU**, two boxes (one prime and one redundant) stacked together to make a single unit, containing the electronics required for the task of signal processing respectively data compression.
- **DECMEC**, one box, consisting of four analogue electronics blocks: DEC1, MEC1, DEC2, MEC2 (prime and redundant functions), which provide power supply and control of the Ge:Ga detector arrays, transmission of the raw data rate to the signal processing unit SPU, control of all moving mechanisms and calibration sources, control/readout of the temperature sensors inside the FPU, and appropriate interfaces with BOLC.
- **BOLC**, one analogue electronics box (nominal and redundant sections) for control of the 0.3K sorption cooler and for supply and read-out of the two bolometer arrays.

3.1.1.1 PACS OPERATING MODES

The instrument operating modes are defined as subsets of the available observing modes and of auxiliary modes. PACS Operating mode diagram is given by the following figure:

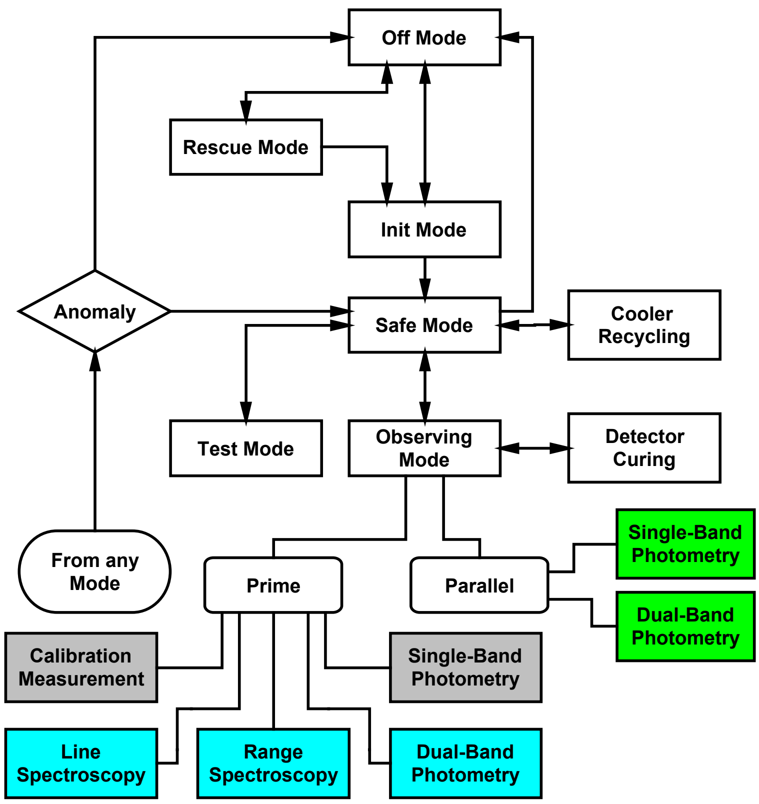


Fig.3.1.1.1-1 PACS Operating mode diagram.

3.1.1.2 PRIMARY OPERATING MODES

3.1.1.2.1 PHOTOMETER OPERATING MODES

These comprise all photometer observing modes. Science and housekeeping data are produced at a rate compatible with the CDMU. During photometer observations, the spectrometer channel and the spectrometer detectors are not operational (switched off).

3.1.1.2.2 SPECTROMETER OPERATING MODES

These comprise all spectrometer observing modes. Science and housekeeping data are produced at a rate compatible with the CDMU. During spectrometer observations, the photometer channel and the photometer detectors are not operational (switched off).

3.1.1.3 PARALLEL MODE

At this moment the parallel mode with SPIRE is going to be implemented. “Parallel mode” means that PACS is operated in its photometer operating mode, in parallel and in a co-ordinated manner, with the SPIRE instrument. This could allow more efficient large-scale multi-band mapping. The parallel mode has an impact on the PACS data reduction, TM rates will be shared between PACS and SPIRE. PACS and SPIRE observe at the same time.

3.1.1.4 RECYCLE MODE

The ^3He sorption cooler should be recycled every 2 days for 2h. This recycling activity is supposed to take place during the earth-spacecraft transmission period, when no instruments can observe. Except for the cooler, all other subsystems are in a state identical to the SAFE mode.

The recycling mode timeline comprise the following phases of heat dissipation into Level-0:

Heating	65 min	42 mW
Cooler Cool Down	45 min	122 mW
Nominal Operation for	2770 min	0.6 mW

3.1.1.5 SAFE MODE

In safe mode the mechanisms are powered down if possible and, if applicable, in their default position, no bias is applied to the detector array, the CRE’s are in their off mode. Only housekeeping data are produced at a rate compatible with the CDMS.

3.1.1.6 INIT. MODE

This mode represent the state the instruments enters after a power on or re-boot. All sub-units (FPDPU,FPSPU,FPDECMEC and BOLC) are powered on. In this mode only a sub-set of software commands may be executed and updates of the respective sub-unit on-board software can be carried out safely.

3.1.1.7 OFF MODE

All power is removed from the instrument. Mechanisms may actually be in any position, depending how the switch-off was done. Even when a nominal switch-off is done via the SAFE mode, the mechanisms (especially the grating) may change its position when the spacecraft moves. No data are transmitted or received through the instrument telemetry interface, but limited temperature data will be available from spacecraft powered sensor. Transition into this mode can be either in a controlled way via the safe mode or in case of more severe anomalies instantaneously. In that case the status of some mechanisms may be unknown.

3.1.1.8 TEST MODES

Test modes will be mainly implemented for investigations of fault conditions. Fixed configurations of the instrument are used to generate known set of data. They will be used during ILT's and during integration and verification for debugging of the interface between PACS sub-units and between the instrument and the spacecraft. Obviously, standard as well as non-standard Instrument Data Configurations will be used while running in these instrument modes. Some test possibilities will be implemented in the OBS.

3.1.1.9 NON PRIME MODE

The Non Prime mode is identical to the Safe mode with a H/K rate reduced to 2 kbit/s.

3.1.2 SPIRE HARDWARE DESCRIPTION

The SPIRE instrument consist of:

- **HSFPU** (Focal Plane Unit): This interfaces to the cryostat optical bench, and the 4-K and 2-K temperature stages provided by the cryostat. Within the unit, further cooling of the detector arrays to a temperature of around 300 mK is provided by a 3He refrigerator which is part of the instrument.
- **HSJFP** (JFET box for the photometer detector): This box is mounted on the optical bench next to the photometer side of the FPU and contains JFET preamplifiers for the detector signals. The JFETs operate at around 120 K, and are thermally isolated inside the enclosure.
- **HSJFS** (JFET box for the spectrometer detector): This box is mounted on the optical bench next to the spectrometer side of the FPU and contains JFET preamplifiers for the detector signals. The JFETs operate at around 120 K, and are thermally isolated inside the enclosure.
- **HSDCU** (Detector Control Unit): This box is mounted on the SVM lateral panel; it's a warm analogue electronics box for detector read-out analogue signal processing, multiplexing, A/D conversion, and array sequencing.
- **HSFCU** (Focal Plane Control Unit): This box is mounted on the SVM lateral panel; it's a warm analogue electronics box for mechanism control, temperature sensing, general housekeeping and 3He refrigerator operation. It conditions secondary power both for itself and for the DCU.
- **HSDPU** (Digital Processing Unit): This box is mounted on the SVM lateral panel; it's a warm digital electronics box for signal processing and instrument commanding and interfacing to the spacecraft telemetry.

3.1.2.1 SPIRE OPERATING MODES

3.1.2.2 OFF MODE

All instrument sub-system will be switched off – including the DPU and there will be no instrument telemetry.

3.1.2.3 INITIALISE (INIT) MODE

This is an intermediate mode between OFF and ON. This will be the mode the instrument enters after a power on or re-boot. In this mode only a limited sub-set of commands may be executed. This mode allows updates of DPU on-board software and/or tables to be carried out safety before they are used for instrument control.

3.1.2.4 ON MODE

The DPU will be switched on and can receive and interpret all instrument commands, but no other sub-system will be switched on (including DRCU, i.e. DCU & FCU). For engineering purposes it will be possible to command the instrument to switch on individual sub-system from this mode. Full DPU housekeeping data will be telemetered.

3.1.2.5 READY (REDY) MODE

The DPU and DRCU are powered on and the on-board software is ready to receive commands. No other sub-system are switched on in this mode. DRCU housekeeping data will be telemetered.

3.1.2.6 STANDBY (STBY) MODE

The spacecraft may be pointed in an arbitrary direction (observing with another instrument for instance). The instrument will telemeter only housekeeping information, and perhaps some degraded science data at a rate very much lower than the full telemetry bandwidth.
This is presently baseline to be the photometer detectors on and at 300 mK i.e. the cooler will have been recycled previous to entering STANDBY. All other sub-system will be switched off.

3.1.2.7 OBSERVE (OBSV) MODE

There are two basic sub-modes for the observe mode Photometer and Spectrometer.

3.1.2.8 COOLER RECYCLE (CREC) MODE

The 3He cooler requires recycling every 46 hours (TBC). During this time the instrument will be switched off except for vital housekeeping and cooler functions (TBC).

3.1.2.9 SAFE MODE

The instrument will be switched to SAFE mode in the event of any anomalous situation occurring whilst in autonomous operation. This will be with the DPU on having been rebooted from a restricted set of software stored in ROM.

3.1.3 HIFI HARDWARE DESCRIPTION

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

1. **The Focal-Plane subsystem** consists of:

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

- relay optics (including the HIFI M3 in the telescope focal plane),

- 7 Mixer assemblies containing:
  - 14 mixers (SIS and HEB) cooled to 2K by a thermal strap to the helium tank,
  - Optical combiners and mechanisms,
  - 14 low-noise IF HEMT pre-amplifiers operated at 15K,

- 14 additional IF amplifiers,
- passive power combiners,
- a chopping mechanism,
- a calibration source.

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

1c. A Focal-Plane Intermediate Frequency Up-converter operating at room temperature, containing a mixer converting the band 6 IF frequency from 3.6 GHz to 6 GHz and a DRO at 10.4 GHz.

2. **The Local Oscillator subsystem** consists of:

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

2b. A local oscillator control unit (FHLCU) located in the service module and operated at room temperature. The FHLCU provides the bias and control signals for the LOU, and secondary power and control signals for the FHLSU.

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

3. **The High-Resolution Spectrometer (HRS)** consists of two identical units, each containing an IF processor, an ACS, HRS controller and the DC/DC converters:

3a. One unit for Horizontal Polarisation (FHHRH)

3b. One unit for Vertical Polarization (FHHRV)

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

4a. Electronics for Horizontal Polarisation (FHWEH)

4b. Electronics for Vertical Polarisation (FHWEV)

4c. Optics for Horizontal Polarisation (FHWOH)

4d. Optics for Vertical Polarisation (FHWOV)

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

6. **The IF up-converter** is a unit of HIFI IF system and is placed between the FPU and the spectrometer. Its primary functions are to frequency up-converter the 2.4 - 4.8 GHz IF from some of the Band 6 Hot Electrom Bolometer mixer to the 5.6 - 8 GHz region and to cross-couple the up-converter signal with the IF signal from the SIS mixer.

The Fig. 3.1.3 is a block diagram of the HIFI showing the relationship between the various units of the instrument.

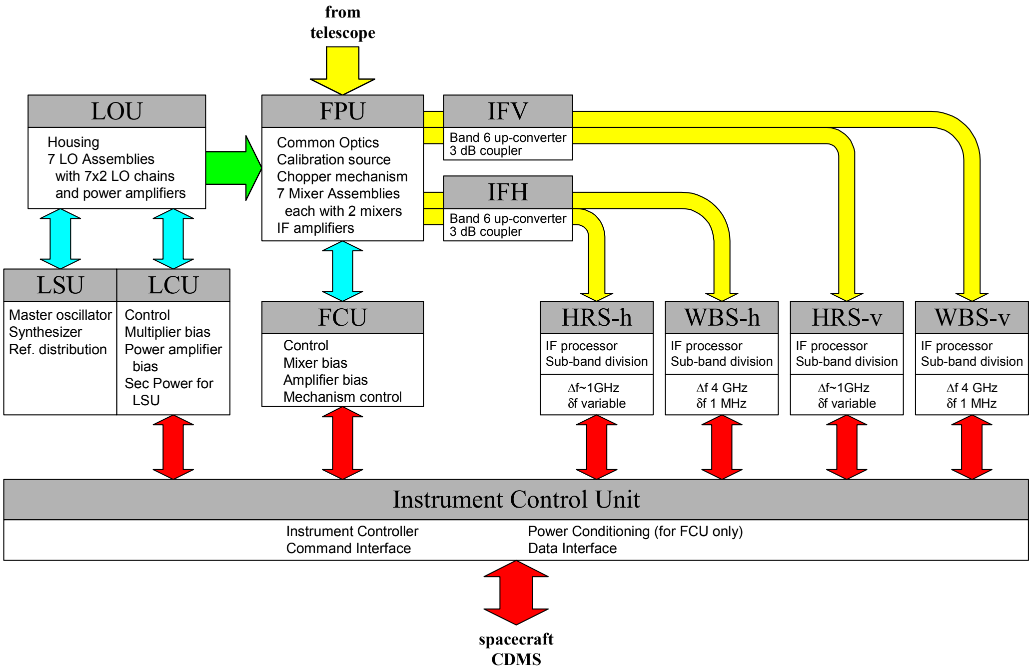


Fig.3.1.3. Block diagram of the HIFI.

3.1.3.1 HIFI INSTRUMENT MODES

HIFI has the following modes:

3.1.3.1.1 OFF MODE

In this mode all power is removed from the instrument.
This mode will be used during emergencies and other critical phases in the Herschel mission (e.g. during launch and orbit insertion).

3.1.3.1.2 STAND-BY MODE

In this mode:

- All units in the SVM are active,
- Only thermal control of the LOU is active,
- The FPU is inactive,
- Housekeeping data will be available,
- No science data are produced.

In this mode other instruments may be active
This mode will be used when HIFI is not primary during normal science operations.

3.1.3.1.3 PRIMARY MODE

In this mode:
- The instrument is operating,
- One mixer band and one LO sub-band are active,
- Scientific data are generated,
- Housekeeping data are generated,
- Pointing corrections may be generated as a result of peak-up procedures,
- The instrument warm-up time, from standby mode, will be less than 1 hour.

The warm up time for the LO-, WBS- and HRS-subsystems from cold (i.e. from OFF mode) will be much more than 1 hour.

3.1.3.1.4 INTERMEDIATE MODE

This mode is entered after successful switch-on of the ICU or during a nominal switch off procedure.

In this mode:
- Only the ICU is active.
- Housekeeping data are generated
- No science data are produced,
- HIFI subsystems powered: ICU, FCU

3.1.3.1.5 RESCUE MODE

This mode is the result of a non-successful switch-on of the ICU.
In this mode:
- Event reports are generated
- Telecommands of service type 6 (memory management) can be received and executed. (without generating acknowledgement reports of service type 1)
- Telecommands of service type 8 (perform activity) can be received to resume loading

This mode can be entered from the intermediate mode for test-purposes.

3.1.3.1.6 HIFI MODE TRANSISIONS

The following mode transitions can be made:

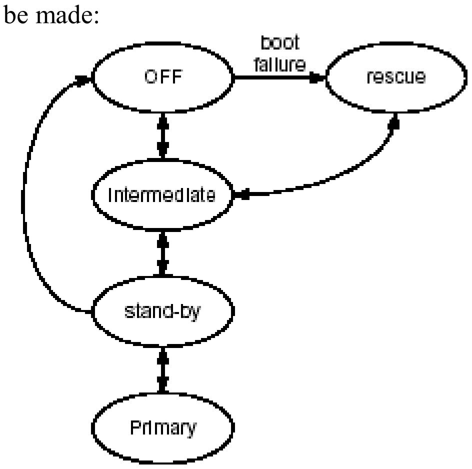


Fig.3.1.3.1.6. HIFI mode transitions.

3.1.3.1.6.1 OFF to INTERMEDIATE

When the ICU is switched on the boot-procedure brings HIFI to the intermediate-mode.
Required commands:
- To PDU: switch on ICU

3.1.3.1.6.2 OFF to RESCUE

In case the boot-procedure fails, the boot-procedure ends in the rescue mode.

3.1.3.1.6.3 INTERMEDIATE to STAND-BY

In the stand-by mode all subsystems are switched on.

For each subsystem to be switched on the following steps shall be taken:
- Notify ICU that subsystem will be switched on in 1 s.
- Switch subsystem on

Required commands:
- To ICU: notify next instrument status.
- To PDU: switch on LCU
- To ICU: notify next instrument status.
- To PDU: switch on WBS-V subsystem
- To ICU: notify next instrument status.
- To PDU: switch on WBS-H subsystem
- To ICU: notify next instrument status.
- To PDU: switch on HRS-V subsystem
- To ICU: notify next instrument status.
- To PDU: switch on HRS-H subsystem

3.1.3.1.6.4 INTERMEDIATE to RESCUE

For test-purpose the instrument can be brought into the rescue mode.

3.1.3.1.6.5 RESCUE to INTERMEDIATE

The resume-loading command brings the instrument from the rescue mode into the intermediate mode.

3.1.3.1.6.6 STAND-BY to PRIMARY

The difference between primary and stand-by is:
- Laser status in the WBS
- LO status
- FP status

The instrument enters the primary mode by turning on the WBS-laser and by activating the LO-subsystem.

Notice:
The instrument must not be switched off from the primary mode.

3.1.3.1.6.7 PRIMARY to STAND-BY

The instrument enters the standby mode from the primary mode by turning off the WBS-laser and by deactivating the FP- and LO-subsystem.

3.1.3.1.6.8 STAND-BY to INTERMEDIATE

For each subunits to be switched off the following steps shall be taken:

- Notify ICU that subsystem will be switched off in 1 s.
- Switch subsystem off

Required commands:

- To ICU: notify next instrument status.
- To PDU: switch off HRS-H subsystem.
- To ICU: notify next instrument status.
- To PDU: switch off HRS-V subsystem.
- To ICU: notify next instrument status.
- To PDU: switch off WBS-H subsystem.
- To ICU: notify next instrument status.
- To PDU: switch off WBS-V subsystem.
- To ICU: notify next instrument status.
- To PDU: switch off LCU.

3.1.3.1.6.9 INTERMEDIATE to OFF

The instrument is off when the ICU is switched off. The ICU should only be switched off when no other subunit is on.

Required commands:

- To PDU: switch off ICU

3.1.3.1.6.10 EMERGENCY OFF

The nominal way to switch off HIFI is through stand-by→intermediate→off.

A less elegant way is from stand-by directly to off.

An undesired (hazardous) way to switch off HIFI is directly from the primary mode. (The LO-subsystem should be de-activated in a proper way)

3.2 PLANCK INSTRUMENTS DESCRIPTION

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

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

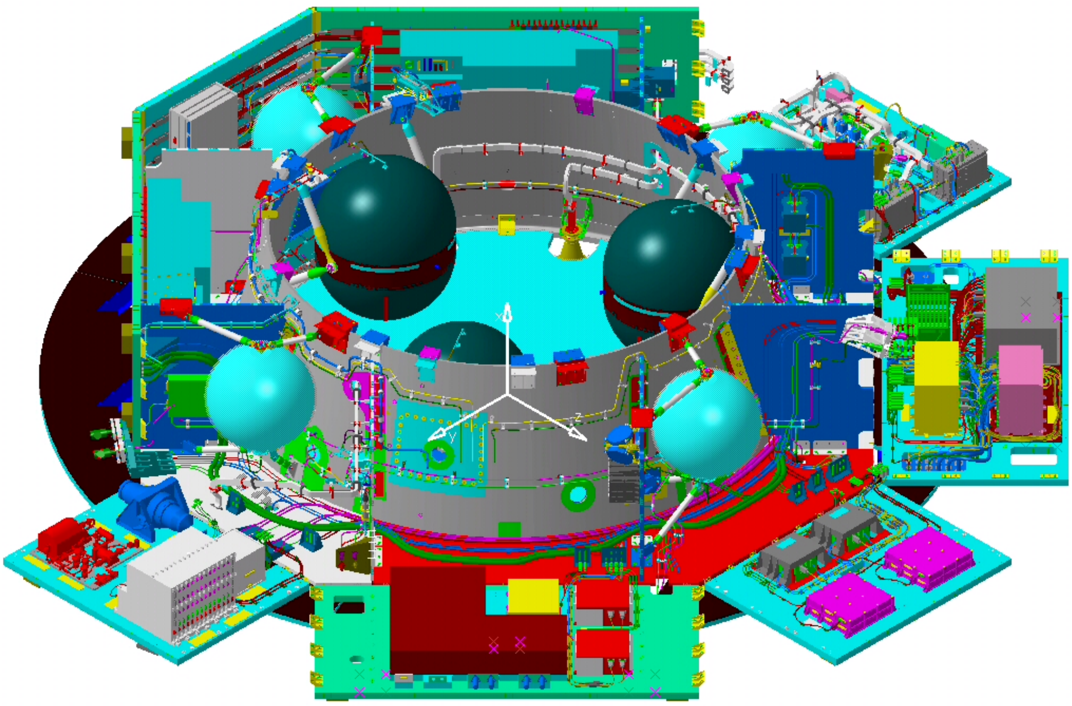


Fig.3.2. Planck SVM layout.

3.2.1 HFI HARDWARE DESCRIPTION

The HFI instrument consists of the following subsystems :

- **HFI Focal Plane Unit (FPU)**: the function of this unit is the detection at 0.1K. It is the most sensitive part of the instrument in terms of thermal radiation and electromagnetic field. The detection subsystem integrates feed-horns, spectral filters, and solid states detectors (bolometers). It also includes the following cold end units of the cooling system: “18K”, “4k”, “1.6K” and “0.1K”.

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

The following unit are located inside the SVM:

- **Readout Electronics Unit (REU)**: the readout electronics of the bolometers and of the cryo-thermometers is based on a system able to cover the frequency range needed for HFI, i.e. 0.016 Hz to about 100Hz. This system uses a differential AC square bias current and has a uniform noise performance: $\sqrt{(5nV/Hz)}$, i.e. less than the Johnson noise of the bolometers, over most of the useful frequency range. This system allows a full control of the current and voltage of the measured resistor, so that in-flight optimisation of the bias voltage is possible. Dedicated thermometers and heaters allow the control of the different FPU stages temperature. For that the Readout Electronics have to manage the 0.1K stage temperature at bolometer and dilution plates, the 1.6K stage temperature and the 4K stage temperature.

- **Data Processing Unit (DPU) nom. & red.**:

  the main functions of this unit are:

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

  The DPU is linked to the spacecraft through the MIL-STD-1553B bus, and to the other HFI sub-systems through home-made synchronous serial lines:

  - An High Speed Link (HSL running at 2 MHz) for REU,
  - And Low Speed Links (LSL running at 100 kHz) for 4KCDE.

  The HFI data flow will contain, in routine operation, all the information necessary for flight observation data reduction: bolometers, dark bolometers, thermometers, etc… In test mode, it will contain data sets from selected channels, in a more verbose format.
  The housekeeping flow will contain all context parameter and event messages, including detectors selected readings, regularly transmitted at low rates.

- <u>4K Cooler Subsystem</u>:

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

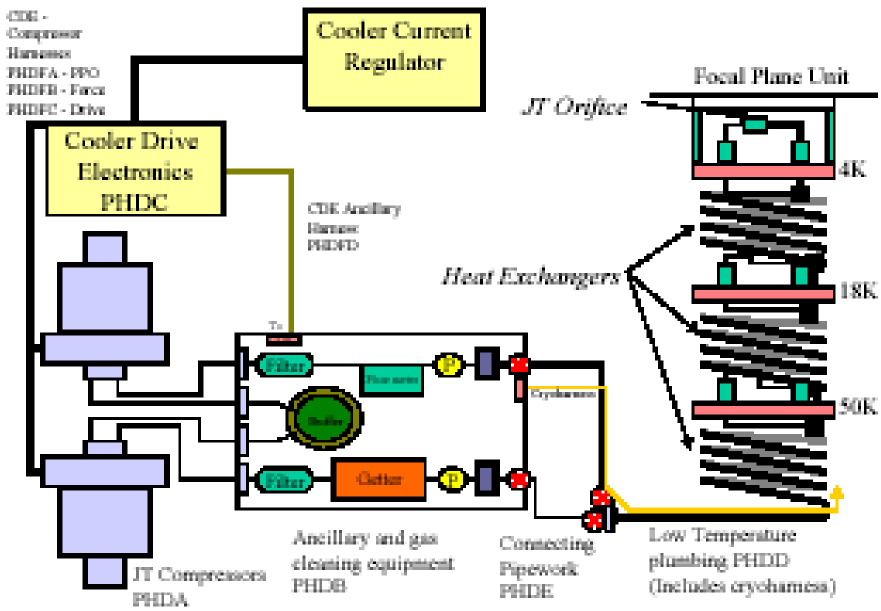


Fig.3.2.1. The major components of the 4K system.

The main components of the 4K system for Planck are:

- **<u>The JT compressors</u>** give two stages of compression from around 1 bar to approximately 9-10bar. The temperature that the cooler can achieve is dependent on the pressure on the effluent side of the JT orifice. The ultimate temperature that can be achieved depends on the overall fill pressure in the system and the stroke on the JT compressors. The compressors are reciprocating devices operating in the frequency region 30-45Hz. There are two compressors in a head to head configuration mounted off force transducers. The head to head configuration provides a degree of momentum compensation. The force transducers are used with the Cooler Drive Electronics (CDE) to provide fine momentum compensation. The CDE senses the out of balance forces and actively feeds back to the mechanisms signals to null the vibration. Residual forces generated by the compressors are between 20 and 80millinewtons at each stroke frequency harmonic (at least up to the 7th one, i.e. about 280Hz). The aim is to keep all harmonics below 40mN.

- **<u>The Ancillary and gas cleaning panel</u>** contains part of the gas purification system, a filter, a flow meter and pressure transducers. The gas purity is maintained by the use of a hot reactive getter. The use of the getter is necessary for several reasons. The components in the JT compressors contain some organic resins that retain moisture over long periods. This moisture needs to be removed from the system. The other major contaminant is Hydrogen. This is evolved from the metal components in a time independent manner and is difficult to remove by cold trapping. The flow meter and pressure transducers provide information on the health of the system and will help to rapidly diagnose any problems as they occur. A filter is incorporated into the hot reactive getter in order to minimise the risk of particle migration. Additional sintered metal filters are used to protect the JT compressor reed valves. The instrumentation on the panel and the cold plumbing is monitored through the Cooler Drive Electronics.

- **The Connecting Pipework** joins the ancillary panel to the cold plumbing and is simply a pair of pipes that run from the lateral panel on which the cooler components are situated, to the start of the cold plumbing near the LFI Back End Unit. These are attached to the SVM and PPLM. The cryo-harness runs along, and is attached to this pipework.

- **The Low Temperature plumbing** incorporates counter-current heat exchangers between the stages and filters and gas purifiers on the stages. The function of the stages are to transfer heat from the circulating gas to that stage. The heat transferred is minimised by the high efficiency heat exchangers. The 4K stage contains a reservoir for the liquid helium. There will also be a small wiring harness with the cold pipe-work that will connect to the housekeeping sensors.

- **The Cooler Drive Electronics** provides drive to the compressors as well as controlling the hot reactive getter and conditioning the housekeeping sensors and thermometers on the 4K system. The unit provides active cancellation of the vibrations from the units over a wide frequency range up to the 7th harmonic of the normal operating frequency. The degree of compensation that can be achieved depends on the amplitude of the mechanisms as the gas spring is highly non-linear. The electronics interfaces to the JT compressors and the ancillary panel. The low temperature wiring harnesses interfaces to the ancillary panel and through that to the Cooler Drive Electronics.

- **The JT compressors, Ancillary panel and Low Vibration Drive Electronics** are all mounted on the SVM lateral panel fairly close to each other. The connecting pipework leads from the panel to the base of the LFI Back End Unit where the cold plumbing starts. The cold plumbing leads from this point into the radiation shields interfacing at the 50K radiation shield, the sorption cooler interface at 18K and the focal plane unit where the cooling occurs at a temperature of around 4.5K.

- **The Current Regulator**: the 4KCDE Current Regulator, also sometimes referred as “Pre-regulator” function is to “smooth” the interface between the 4KCDE compressor drive and its S/C primary power source. Thus protecting the spacecraft power bus from low frequency ripples that might be injected by the cooler in nominal mode and/or from large spikes (with a duration of some hundreds of microsecond) that might be introduced by active clamping of the compressor during launch environment.

- **The Dilution Cooler Subsystem**:

The Dilution Cooler subsystem is mainly composed of two units:

- **the Focal plan structure FPS**: the FPS is an assembly, part of the Focal plan unit FPU, providing the bolometers stage with the required cooling power to achieve 100 mK.

  The 0.1K Cooler uses the dilution of helium3 in helium4 into proper proportions in small capillary tubes in an open cycle. The gas mixture is then re-used in a Joule-Thomson expander providing extra cooling at 1.6K.
  The 0.1 K plate supports the bolometers with horns and attached filters, capacitors, blind bolometers, thermometers, heaters and is fixed at the cold end of the dilution heat exchanger. The mechanical and thermal link is made with Holmium-Yttrium alloy material used as a very low frequency pass thermal filter. A PID regulator cut the high thermal frequencies provided by the dilution phenomenon.

Thermometers (using same readout electronics as the bolometers) and redundant heaters are used to regulate the 0.1 K plate temperature.

In order to decrease the HFI Focal Plane Unit cooling-down duration during ground testing: a specific precooling flyable capillary loop circuit is included in the Dilution Cooler Cold end Unit. This loop is composed of a counter flow heat exchanger coming from the warm parts of the dilution cooler, with thermalisation points on the upper temperature levels.

The 1.6 K stage is cooled by the Joule-Thomson expander in the mixture circuit. It accommodates the 1.6 K filters plate, with heaters and thermometers. This intermediate stage supports and provides positioning for the 100 mK stage.

The 4K stage is the external part of the FPU; the lower part is the interface with the 1.6 K stage supported by struts. It provides the global positioning in between HFI cold optics and LFI FPU. The upper part supports the 4K plate populated with the horns that collect the astronomical signal. This stage is cooled by the cold end of the 4K cooler. It also accommodates the LFI “4K reference loads” radiatively connected to LFI detection systems.

- **the Isotope supply unit ISU**: the ISU is the subsystem providing the FPS with the 3He and 4He isotopes in the proper conditions and conduct the final mixture to space.
  The Isotope supply unit is composed of different units:

  - the gas storage unit GSU: the Gas storage unit is designed to store the volume of isotopes for the whole mission. The nominal set point has been fixed for a flow of 4He four times more than the 3He flow. The storage volumes have been chosen thus close to that proportion.

    Three 51 liters tanks for 4He and one for 3He at the nominal pressure of 295 bars provide the required duration with margin.

    The tanks are fixed on the SVM and connected for purging, filling and feeding the dilution cooler to the DCCU by means of high pressure pipes. These pipes are a part of the GSU.

    The temperature of each tank is precisely measured with an accuracy allowing to perform isotope leak evaluation promptly, and to measure the gas stored volume. The associated harness is routed from the tanks to the DCCU with the pipes.

  - the Dilution Cooler Control Unit DCCU composed of two parts:

    - the Dilution Cooler Pneumatic Unit: The dilution cooler pneumatic unit controls and commands the flow and pressure of isotope supply. It houses the different pneumatic components allowing to permanently flush the cooler at necessary small flow rate and to perform the optimal cooling of the inner stages of the HFI FPU.

    - the Dilution Cooler Electronics: interfacing the spacecraft only for power line, the DCE is linked to the HFI DPU and is in charge of the process of the Dilution cooler. It is connected to the DCPU or more generally to the dilution cooler to insure the proper monitoring and commanding.

    The DCPU and DCE are located on a single panel gathering the pneumatic components and the electronic box dedicated to the control/command of the whole dilution cooler.

- The Dilution cooler piping DCP: The dilution cooler piping is composed of counter-flow heat exchangers transporting the isotopes from the DCCU to the FPS. Thanks to a suitable thermalisation located on the 3rd V-groove and the 18 K stage it is also aimed to cool down to this temperature the isotopes before entering the FPS. It is the same for the pre-cooling loop. Although the management of isotope purity is done to avoid in nominal conditions any clogging due to condensation of pollutants, the part of the pipes located just before the filters can be heat up to a temperature depending on the considered stage, this allows unclogging and obviously the non clogging of the next step of filtering. The thermometers and heaters are monitored by the DCE. This unclogging mode is a degraded temporary mode for the dilution cooler.

  The DCP and the Dilution Cooler Cryo-Harness are routed from the SVM to the FPU on the PPLM through the V-grooves. They are composed of two different segments linking:

  - the DCCU to the SVM panel,
  - the SVM panel to the FPU.

  The second segment is attached to V-grooves 1 & 2. It is thermalised on the 3d one, and includes a filter also accommodated on Planck 3d V-groove.

- **Pre-Amplifier Unit (PAU)**: The PAU preamplifiers the signal coming from the JFET box and provide them to the REU which is located at about 5 meters from the PAU. The PAU provide also the polarisation to the detectors via the JFET box. As the REU, the PAU consists in 12 identical analogue modules.

3.2.1.1 HFI MODES DESCRIPTION

The flow of helium in the dilution system has to be controlled with long time constants, due to the need to control the cleanliness of capillary tubes, and due to the thermal time constant of this cryogenic system.

This system has three modes irrespectively of which Sorption Cooler is active (nominal or redundant):

(1) stop mode: no helium flow,

(2) pre-cooling/maintenance mode: low flow rates,

(3) cooling mode at (selectable) nominal flow rates.

3.2.1.2 HFI "OFF" MODES

In all the following "OFF" modes, no electronics is ON and therefore only an external monitoring can report on the HFI status.

3.2.1.2.1 HFI STORAGE MODE

In Storage Mode HFI is not powered, it cannot receive any command, it generates no data. Instrument dedicated non-op substitution heaters are not powered, neither are so-called "spacecraft powered thermistors" installed on HFI. The instrument can stay safely in this mode without limitation of duration when stored on ground at ambient temperature. Strong limitation in duration exists for storage when in other environment conditions or during flight.

3.2.1.2.2 HFI LAUNCH MODE

HFI Launch Mode is exactly the same as the Storage Mode, except for power being made available to the instrument 4K cooling system. This Launch Power is used to electro-mechanically lock moving parts of the compressors for the duration of the vibrations generated during the propulsion phases of the rocket (note that power dissipation varies with compensated vibration level). The need to provide such power during vibration tests performed on ground is to be confirmed. Necessary power shall be provided directly from the spacecraft Service Module to the instrument 4K cooler electronics or compressor unit through dedicated lines.

3.2.1.2.3 HFI MODE DURING COAST PHASE

During Herschel/Planck, or Planck alone, coast phase HFI is exactly in the same condition as in Storage Mode: no electric power and no commands are received, no data are generated (except for the opening of the 0.1K exhaust,).
During this flight phase HFI temperature may vary quite rapidly, different possible coast scenario impact on instrument thermal behaviour shall be assessed. During coast phase, as in any other phase of flight, spacecraft attitude shall not bring the sun into Planck telescope forbidden volume.

3.2.1.2.4 HFI OFF MODE

OFF Mode difference with Storage Mode is that, thanks to spacecraft power availability, despite instrument is not operating: HFI installed "non-op substitution heaters", directly powered by the Service Module, can maintain the instrument indefinitely within acceptable temperature limits. In this mode, redundant (TBC) spacecraft powered thermistors provide for temperature measurements on the different HFI subsystems. The measurement data will be included into spacecraft housekeeping telemetry packets.

3.1.2.3 HFI "ON" MODES MANAGED by DPU OBSW

Here, DPU, REU processor, DCE and 4KCDE are ON and therefore internal monitoring can report the partial or complete HFI status. All the modes are managed by the DPU OBSW according to following figure:

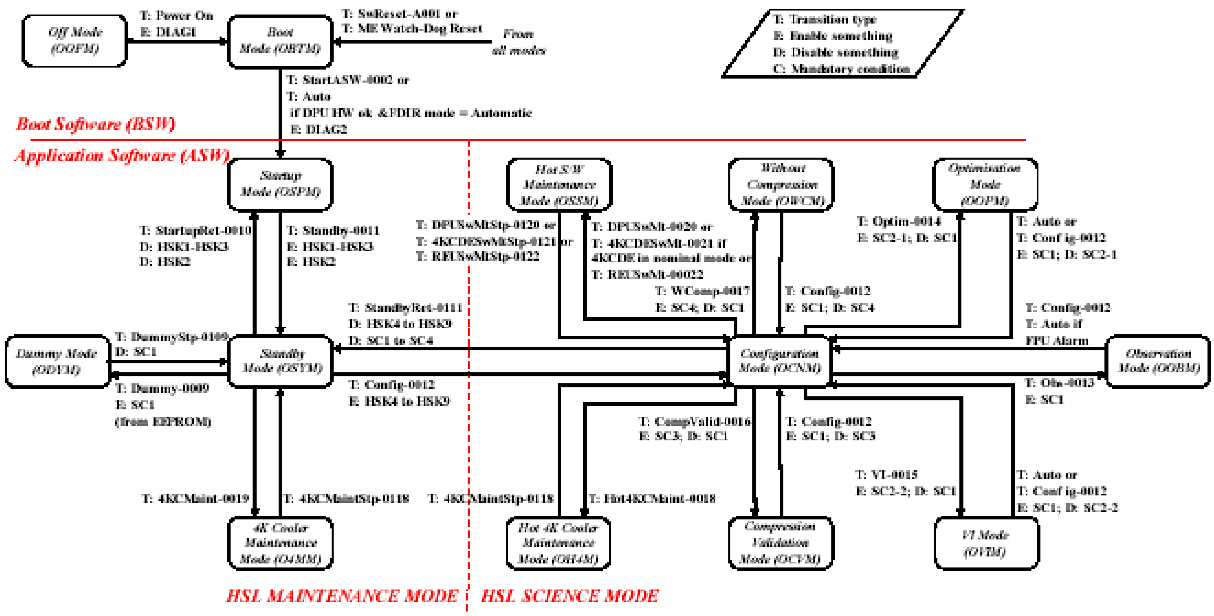


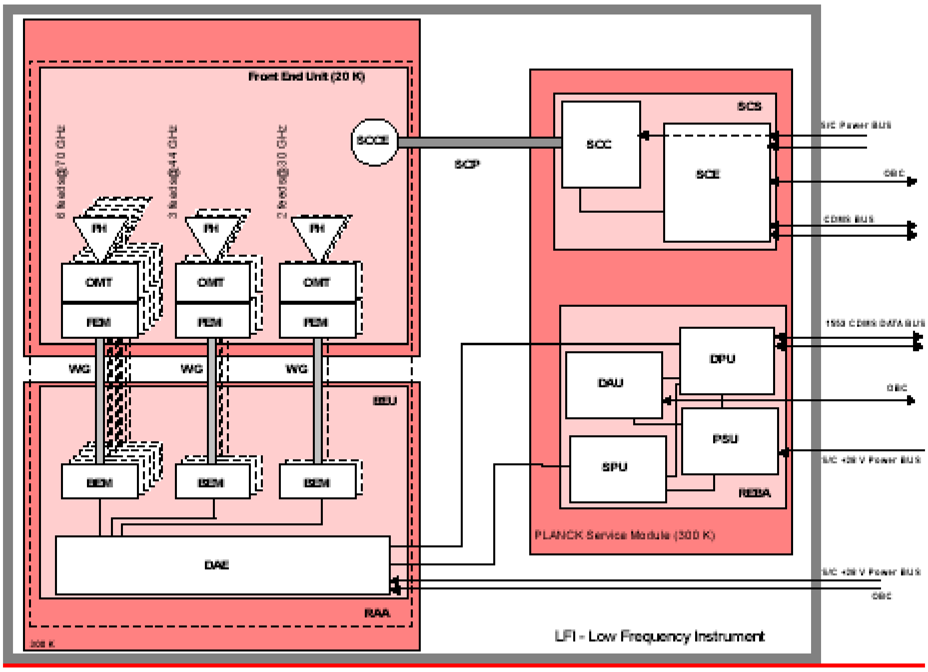
Fig.3.2.1.3. HFI Modes Diagram.

3.2.2 LFI HARDWARE DESCRIPTION

The LFI consists of the following subsystems:

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

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



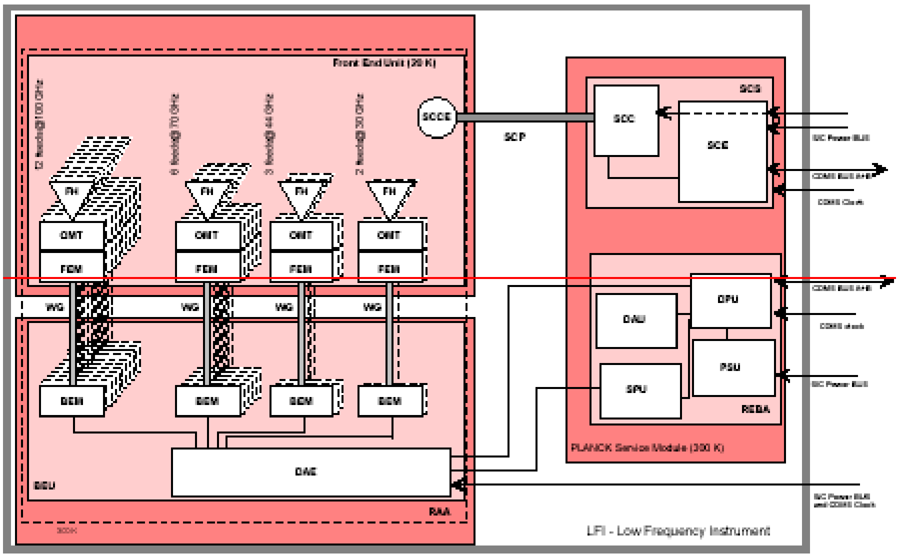


Fig.3.2.2. Block Diagram of LFI; the SCS is shared with HFI.

- **<u>Radiometer Array Assembly (RAA)</u>**:

- <u>Front End Unit (FEU)</u>: the FEU contains the feed array and associated orthomode transducers (OMTs), hybrid couplers, amplifiers, and phase switches, all cooled to 20 K by the sorption cooler.
The FEU comprises 11 modules, each containing one feed horn, one orthomode transducer (OMT), two hybrid couplers, and four cryogenic amplifiers. The modules are mounted on a plate that provides mechanical support and adds thermal inertia.

- <u>Feed Horns and OMTs (FH and OMT)</u>: the radiation focused by the telescope is coupled to the radiometers by double profiled, corrugated feedhorns. The radiation patterns of the horns must be highly symmetric, with very low side lobes and a beam width that matches the telescope edge taper requirement. In addition, the electromagnetic field inside the horn must propagate with low attenuation and low return loss. The OMTs separate the orthogonal polarizations with minimal losses and cross-talk.

- <u>Front End Modules (FEM)</u>: The OMTs are followed by the Front End Modules, which include the first hybrid couplers block, and the amplifiers block with phase switches and output hybrids. This front-end is designed to minimize instabilities in the radiometer while maintaining low thermal noise.
Each Front-end Module (FEM) contains two hybrid couplers for the two channels selected by the OMT. Each hybrid has two inputs, one of which sees the sky, the other of which looks at the reference load through a small horn fabricated into the block.
The low-noise amplifiers use indium phosphide (InP) high electron mobility transistors (HEMTs) in cascaded gain stages. Following amplification the signals are passed through a phase switch. The phase switch adds 90 or 180 deg of phase lag to the signals, thus selecting the input source as either the sky or the reference load at the radiometer output.
The phase lagged pair of signals is then passed into a second hybrid coupler, separating the signals.

- <u>Reference loads</u>: Each front-end hybrid coupler is interfaced with an external reference load which provides a stable blackbody reference signal at approximately 4.5K. The low temperature is obtained by connecting the reference loads to the HFI 4K stage. The radiometric interface is provided by highly absorbing material coupled to a small rectangular waveguide flare produced in the FEM hybrid (70 GHz) or to a small reference horn connected to the FEM hybrid (30 and 44 GHz). The total additional heat power to the HFI 4K stage will not exceed approximately 1 mW.

Two thermo-mechanical solutions are being studied:

- Reference loads attached to the HFI 4K box, and radioactively coupled with the LFI hybrid arms ("HFI mounted" scheme)
- Reference loads mechanically mounted on (but thermally isolated from) the 20K LFI plate, and thermally linked to the HFI 4K box ("LFI mounted" scheme).

The baseline is the "HFI mounted" scheme.

- Waveguides (WG): the front-end and back-end portions of each radiometer are connected with wave-guide sections. Each radiometer will need two wave-guides, for a total of 44 connections.
The main requirement is thermal isolation since wave-guides will link the 20 K front-end to the 300 K back-end. Low-loss performance will not be critical, although desirable. For the baseline radiometer design phase coherence in the wave-guide pairs of each channel is not required.

- Back End Unit (BEU): the BEU comprises the radiometer Back End Modules (BEM) and the Data Acquisition Electronics (DAE), which are connected by an internal harness. The BEU is connected to the FEU by 44 waveguides. Wires for DC biasing of the amplifiers and for switch control signal are also required. A unidirectional, synchronous serial interface is used for transmitting science data to the Signal Processing Unit (SPU).
Communication, timing, and analog housekeeping interfaces are transmitted to the Data Processing Unit (DPU). Internally, each back end analog output is connected, by twisted shielded pairs, to the DAE (see Fig.3.2.2).
As in the FEU, InP HEMTs offer the highest gain, lowest power consumption, and lowest noise. However, GaAs HEMTs may be acceptable.

- Back End Modules (BEM): each receiver Back End Module (BEM) comprises two parallel chains of amplification, filtering, detection.
Post-detection amplifiers are integrated into the BEMs to avoid data transmission problems between the radiometer and the electronics.
Phase match is unimportant in the BEU because the second hybrids for the pseudo-correlation radiometers are in the FEU; only the amplitude of the signals is important in the back end. Each backend module (BEM) will be packaged into a box of a few centimetres on a side, including the biasing circuitry and the input and output connectors.

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

- Communication with the REBA DPU, including simple commands reception and status transmission
- Acquisition, conditioning, and multiplexing of science signals;
- Acquisition and conditioning of the LFI housekeeping;
- Control of the data acquisition chain;
- Transmission of raw data to the REBA SPU;
- Power supply conditioning and distribution to the RAA;
- DC biasing of the FEU and BEU amplifiers;
- Synchronous control of the FEU phase switches;
- ON/OFF control of FEU and BEU amplifiers.
- Time tagging of the science data

The DAE functions are distributed into four different boxes.

DAE BEU Box
This box is in charge of conditioning and acquiring the science data. The analogue outputs of each radiometer are conditioned to provide signal characteristics suitable for AD conversion. The signal coming from each detector (4 per radiometer) is integrated along a predefined period of time, and held during the synchronous sampling and conversion. Science signals are digitised using 16-bit analogue-to-digital converters. There are 11 independent

analogue acquisition chains (one for each RCA). Acquired data are converted into serial streams and automatically transferred to the REBA SPU, through the synchronous serial link, for later processing and compression.

Two DAE lateral trays
These two boxes will contain the circuitry needed to provide the power supply to the radiometer chains. Notice that these power supplies will be independent from each other. The bias of each FEM and the controls for the phase switches will be regulated to selectable voltage levels and filtered to achieve a minimum level of conducted noise. The bias for the BEMs will be provided only filtered at a selected voltage level.

DAE Power box
This box is interfaced with the spacecraft in order to receive the primary power supply. This box is also in charge of generating all the secondary voltages needed to the DAE.

The time at which each sample is acquired must be accurately known so that the corresponding position on the sky may be determined accurately. Consequently the DAE shall tag the acquired data using the information of its on-board time (OBT) to ensure that correlation can be made on ground.

The REBA and the DAE communicate through IEEE 1355 interfaces implemented using SMCS332 circuits, and by means of data flag signals which ensure hardware and software synchronisation.
The DPU interface is responsible for all commanding towards the DAE and DAE housekeeping retrieval, while the SPU interface is responsible for retrieving the fixed format radiometer scientific raw data.
For commanding (FEM/BEM on-off and voltage rail adjustment), the DAE Program Devices Dual Port RAM (DPRAM) is directly addressed by the DPU while for housekeeping the DAE continually refreshes the content of its HK Data Registers DPRAM which is directly addressed for data retrieval by the DPU. It should be noted that this configuration allows variable format and retrieval rates to be set for DAE housekeeping packet production through options in the DPU ASW, and also very flexible commanding and set-up of each FEM/BEM combination.
The DPU also supplies the DAE with a 1 Hz signal generated by the DPU hardware from its OBT synchronised clock enabling the internal time maintained in the DAE to be a replica of the satellite OBT.
For status monitoring purposes the DAE supplies the REBA with ON STATUS generated from the secondary side of it's DC/DC converter.
The REBA, under ground control, can also reset the DAE communication interfaces without requiring switch off/on of the DAE through the DAE RESET command lines (one for each of the two SMCS 332 chips in the DAE).
In the case of retrieval of the raw science data by the SPU, the DAE prepares fixed rate and fixed format samples of radiometer data alternating between two data buffers that are read out by the SPU for further processing. Synchronisation between the DAE and SPU is maintained by the Data Buffer Ready signal generated in the DAE and supplied to the SPU and interrogation of the GPIO port in the DAE by the SPU.

- Internal harness: the RAA internal harness provides all connections between the DAE and the FEMs and BEMs and the DAE internal harness all connections between the DAE BEU Box and the DAE Power Box.

- **Radiometer Electronics Box Assembly (REBA)**:

The REBA consists of one nominal and one redundant unit, one unit of which is shown schematically in Fig.3.2.2-1. Internally the REBA is separated into four sub-units the Data Processing Unit (DPU), the Signal Processing Unit (SPU), the Data Acquisition Unit (DAU), and the Power Supply Unit (PSU) that are here described.

- Digital processing unit (DPU): the DPU performs the following functions:
    - Communication with the spacecraft CDMU via the CDMS bus;
    - Communication with the SPU via a REBA internal IEEE 1355 interface;
    - Communication with the RAA via a REBA internal IEEE 1355 interface;
    - Monitoring and control of the REBA and the RAA;
    - Initialisation and error management;

- Management of operating modes of the instrument;
- Onboard time synchronisation with the CDMS;
- Acquisition of housekeeping data from the DAU and incorporation of this into the REBA housekeeping telemetry packets;
- Control of overall LFI data rate and data volume towards the CDMS

- Signal processing unit (SPU): the SPU performs the following functions:

- Communication with the DPU via a REBA internal IEEE 1355 interface for command receiving from the DPU and science telemetry transmission to the DPU;
- Receipt of raw digital science data from the BEU of the RAA;
- Science data storage, reduction and compression;
- Science telemetry packetisation (TBC);

- Data Acquisition Unit (DAU): the Data Acquisition Unit performs the analogue to digital conversion of the analogue housekeeping data of the REBA itself (temperatures and voltages). It has no interfaces with the RAA.

Three temperature monitoring telemetries are provided by the DAU function, using type NTC thermistor:

- the DPU board temperature
- the SPU board temperature
- the PSU board temperature.

Three secondary voltages monitoring telemetries are provided by the DAU function:

- the VCC voltage (logic supply) and the corresponding current
- the +15V voltage (positive analog supply) and the corresponding current
- the –15V voltage (negative analog supply) and the corresponding current

Each conditioning circuitry includes a filter with fc = 100Hz

In addition the DAU provides

- Nominal and Redundant S/C OBC interface (131.072 KHz clock signal).
- One timing interface (1 Hz signal).to the Back End Unit (BEU)

- Power Supply Unit (PSU): the Power Supply Unit (PSU) consists of a DC/DC converter which converts the primary power received from the spacecraft PDU to the secondary regulated voltages required by the REBA only and provides galvanic isolation towards the spacecraft side of the interface. The PSU distributes the OBC to the DPU through a RS422 interface for use by the DPU in the production of it's copy of the CDMS On-Board Time OBT.

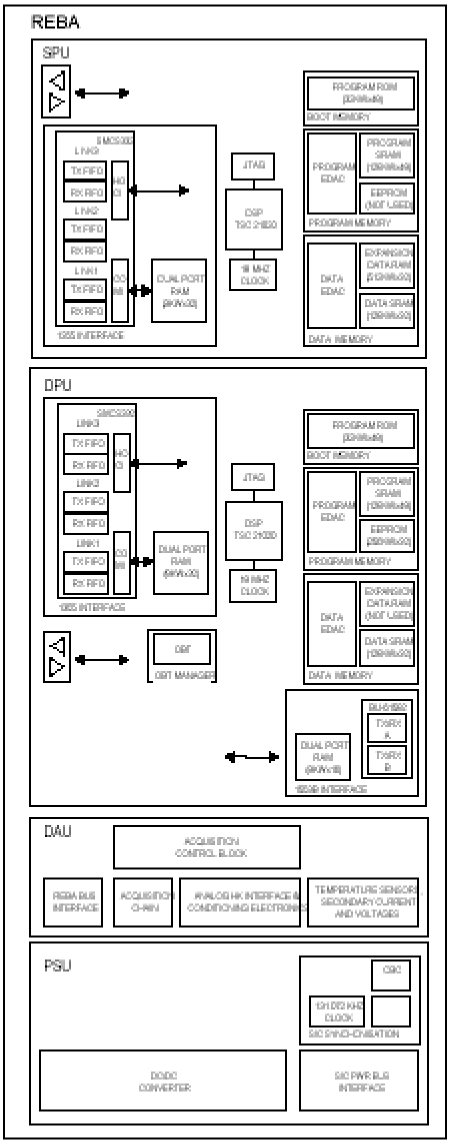


Fig.3.2.2-1.Nominal REBA functional block diagram.

- **<u>Harness</u>**:

The harness provides all connections among the REBA and the two boxes of the DAE on the BEU.

- **<u>Sorption Cooler Subsystem (SCS)</u>**:

The Sorption Cooler Subsystem provides the 20/18 K stage to both LFI and HFI.
The Sorption Cooler is fully redundant.
The FEU is cooled to 20 K by a hydrogen sorption cooler. It is a Joule-Thomson cooler in which 0.0045 g/s of hydrogen expands from 6 MPa to 0.03 MPa through a Joule-Thomson (J-T) expander. The high and low gas pressures are maintained by the fact that the equilibrium pressure of gas above the sorbent bed is a strong function of temperature.
The cooler also provides 18 K precooling to the HFI 4K cooler.

Each sorption cooler subsystem (main and redundant) comprises:

- A Sorption Cooler Compressor assembly
- A Sorption Cooler Cold End
- The Sorption Cooler Pipes, and
- The Sorption Cooler Electronics
- Internal harness

3.2.2.1 LFI MODES DESCRIPTION

Each sky survey will be conducted by the LFI with the instrument in the Normal Operations Mode mode.
No deployable elements, or mechanically moving parts are included in the instrument. The scanning of the sky will be achieved by progressive reappointing of the satellite spin axis, with the Sun direction always within a cone 10 degrees from the spin axis.
Within the Normal Operations Mode the instrument can be configured in order to fit with different science or diagnostic needs without changing the power consumption and thus the temperature in the FPU. Changes in power consumption in the FPU will be minimised and should occur only in the case that failures in the radiometers that could create interference problems require an RCA to be switched off. Power adjustments on the first stage of the HEMT amplifiers which are contemplated, will require extremely small power level variations.
The LFI Operating Modes and theirs nominal transitions are given in Fig.3.2.2.1.

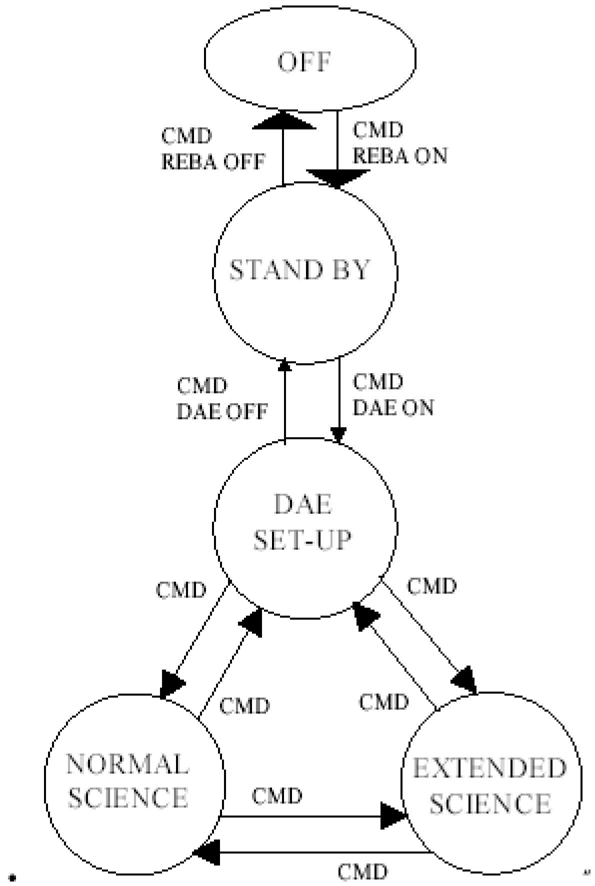


Fig.3.2.2.1.LFI Operating Modes and theirs nominal transitions.

3.2.2.1.1 NORMAL SCIENZE MODE

This is the normal mode of operation of the LFI with the REBA on, DAE and FEM's and BEM's on and the instrument producing scientific and housekeeping data. It should be noted that in this mode single FEM/BEM combinations can be configured separately or in groups not requiring a transition back to DAE Set-Up Mode for configuration changes. This allows continued scientific data acquisition while radiometer calibration adjustments are made in parallel.

3.1.2.3.1 EXTENDED SCIENZE MODE

In Extended Science Mode all the facilities of the Normal Science Mode are present in LFI, but by agreement co-ordinated on the ground and then by command to the instrument and the CDMS, the telemetry allocation to LFI for science telemetry has been increased above the nominal baseline value being used during the mission.

3.2.2.1.3 DAE Set-Up MODE

In DAE Set-Up Mode the DAE has been switched on by ground command to the CDMS, but no BEM's or FEM's in the RAA are switched on.
In this mode communication between REBA and DAE is established under ground command and all settings of FEM/BEM parameters can be loaded into the REBA prior to moving to Normal Science or Extended Science Modes by command from the ground.

3.2.2.1.4 STANDBY MODE

After initial power on of the REBA from the PCS the instrument is in the Standby Mode. During this mode the start-up procedure for the REBA will be performed. It is in this mode that the On board Time would be transmitted from the CDMU to the REBA and will be kept synchronous using the distributed OBC. The housekeeping telemetry is present in this mode even if it will be a sub-set of the total HK amount.

3.2.2.1.5 LAUNCH/OFF MODE

In this mode all of the instrument units are powered off.
The LFI will be in the “off” mode only during launch and for contingency situations and/or to allow diagnostics of HFI or of the spacecraft subsystems.

3.2.3 SCS HARDWARE DESCRIPTION

The LFI FEU is cooled to 20 K by the operating hydrogen sorption cooler (the nominal or the redundant version). The operating cooler also provides 18K precooling to the HFI 4-K cooler.
Each cooler is a Joule-Thomson cooler in which ~0.0065 g/s of hydrogen expands from 5 MPa to ~0.03 MPa through a Joule-Thomson (J-T) expander. The high and low gas pressures are maintained by the fact that the equilibrium pressure of gas above the sorbent bed is a strong function of temperature.
The sorption cooler subsystem comprises the following units both main and redundant:

- a Sorption Cooler Compressor assembly (SCC)
- a Sorption Cooler Cold End (SCCE)
- the Sorption Cooler Pipes (SCP),
- the Sorption Cooler Electronics (SCE).
- The internal harnesses

It should be noted that the SCC, SCCE, and SCP in each of the nominal and redundant coolers form an all-welded, principally stainless steel assembly of fluid loop components which, with associated permanently installed wiring and adapter brackets, is handled and installed as a single, non-separable unit.

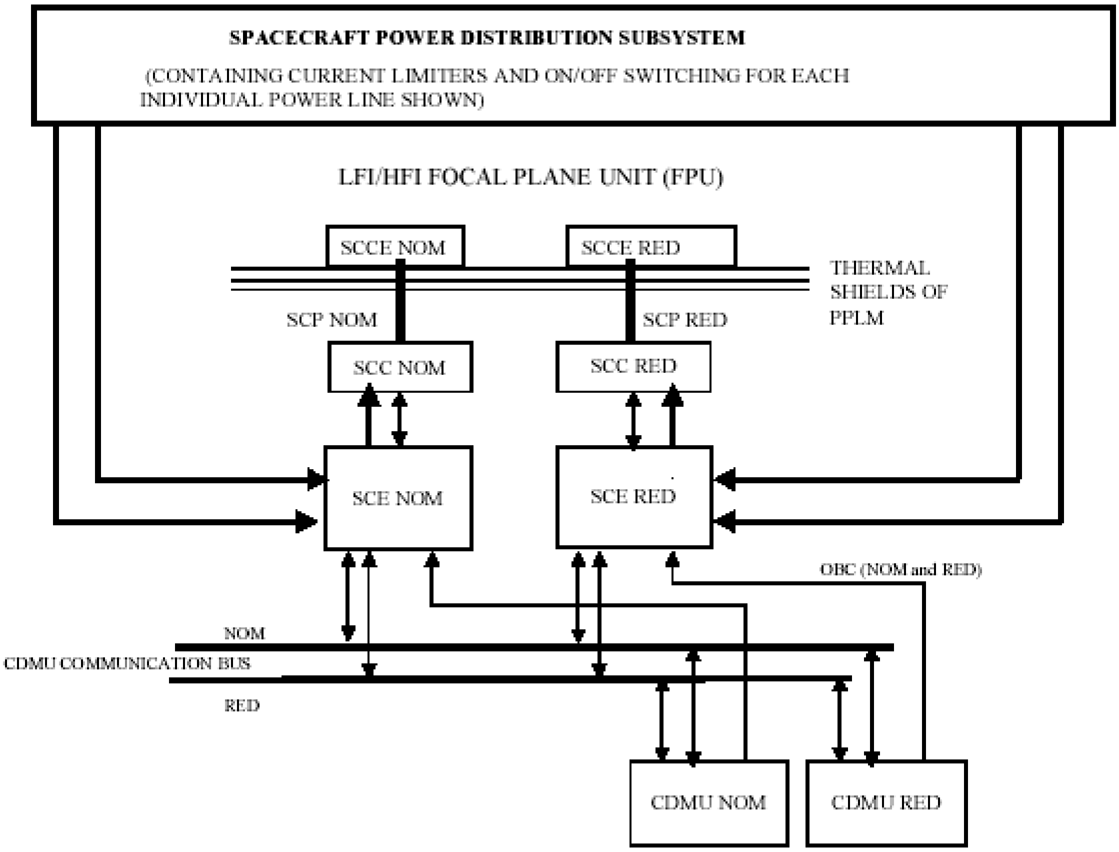


Fig.3.2.3. Functional Block Diagram of the Sorption Cooler Subsystem (SCS) (Full internal harness not shown).

- **Sorption Cooler Compressor assembly (SCC)**

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

- **Sorption Cooler Cold End (SCCE)**

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

- **Sorption Cooler Pipes (SCP)**

The Sorption Cooler Pipes (SCP), connects the SCCE and the Sorption Cooler Compressor (SCC). The SCP are stainless steel tubes of OD 6.35 mm and 3.18 mm, about 9.5 m long.

The heat exchangers are supported by precooler elements attached to each thermal shield. In addition, a charcoal filter is located between the two pre-cooling heat exchangers at ~50 K.

- **Sorption cooler electronics (SCE)**

The functions to be provided by the SCE are :
  - Sense temperature sensors.
  - Time and control of the compressor heaters (including thermal switch actuation).
  - Sense pressure transducers.
  - Read up-link parameters and write downlink parameters through communication with the S/C.
  - Warm-up of the J-T and the coldest filter
  - Convert and condition electrical power to be used by the compressor assembly heater circuits, low-power heater circuits and the electronic circuits
  - Process periodic ground uplink commands or a command table to modify control parameters (switch times, control values such as warning levels, and heater levels) to enable optimisation of cooler performance in the actual flight environment and to accommodate aging of the cooler and the temperature surrounding environmental surfaces on-orbit.
  - Control to maintain constant power during heating and desorption, and to accommodate degradation (end-of-life performance) of the cooler (i.e., compressor assemblies).
  - Provide closed-loop control of the LR3 temperature based on temperature and heater power feedback,
  - Perform internal diagnostics and appropriate responses to protect the sorption cooler from catastrophic failures.
  - Control the compressor assemblies operating in sequence to maintain a constant cold-head temperature.
  - Monitor compressor temperatures, pressures and power.

- **Harness**

The harness of the SCS consists of the following:
  - Harness from SCE to SCCE
  - Harness from SCE to SCC

The harness is separate for both the nominal and redundant SCS.
The harnesses from the SCS (note: defined earlier as both coolers) to both the spacecraft power and communications buses are supplied by ESA.

- Harness SCE to SCCE: the SCE to SCCE harness is separated in to two sections joined by a connector interface on the SCS side of the interface at the coldest V-groove.

- Harness SCE to SCC: the harness from SCE to SCC is made of 2 cable bundles. One bundle of 8 cables representing 72 twisted pairs of wires and one bundle of 2 cables representing 13 twisted pairs of wires.

3.3 WARM UNITS ACCOMODATION LAYOUT

The accommodation warm units on SVM panel will have to hold in consideration the following constraints:
- stay-out areas on SVM panels, namely:
i) 60mm-wide band on each panel-to-panel edge for structural cleats (see Fig.3.3 and Fig.3.3.1)

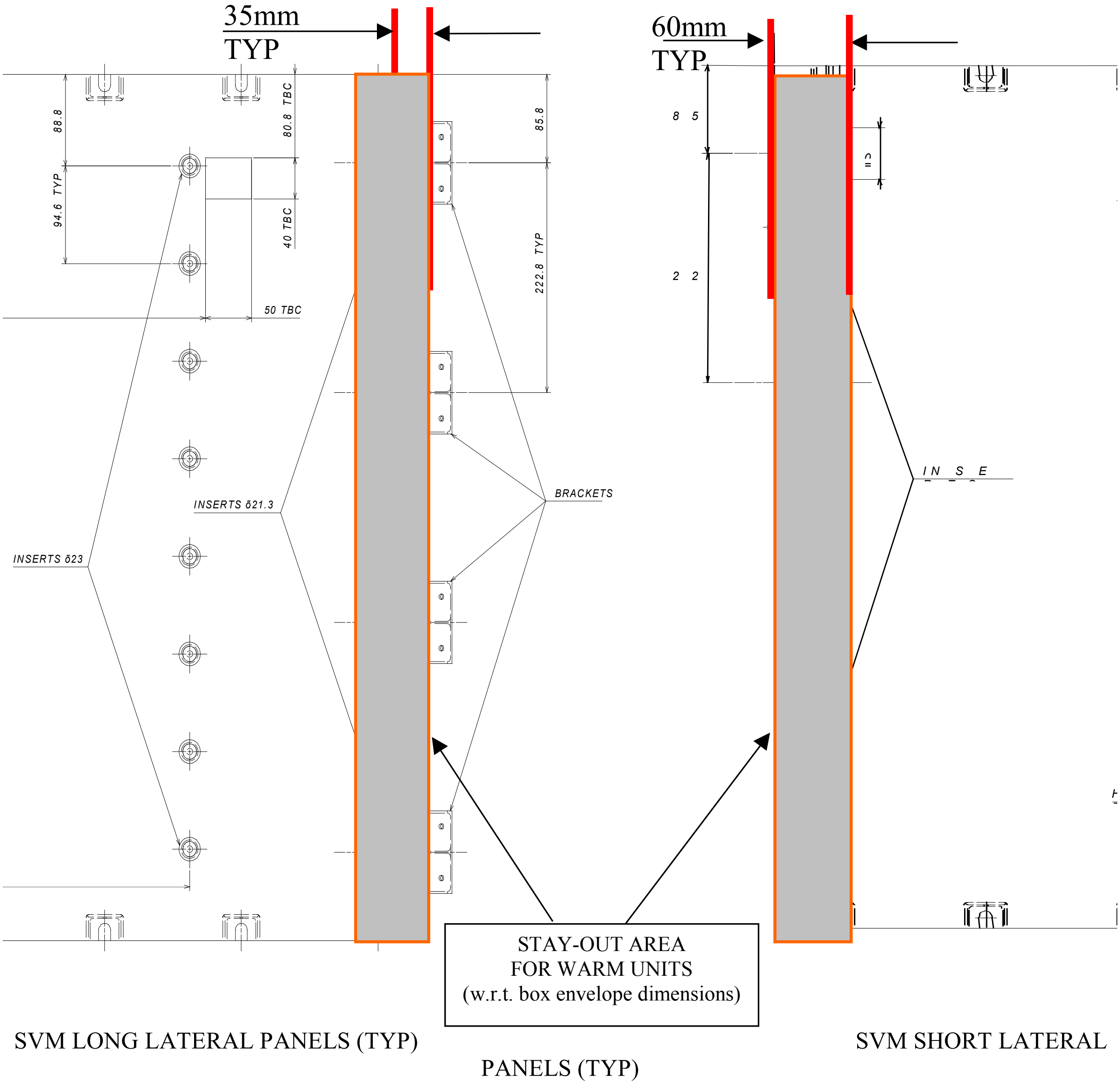


Fig.3.3 Structure Drawings.

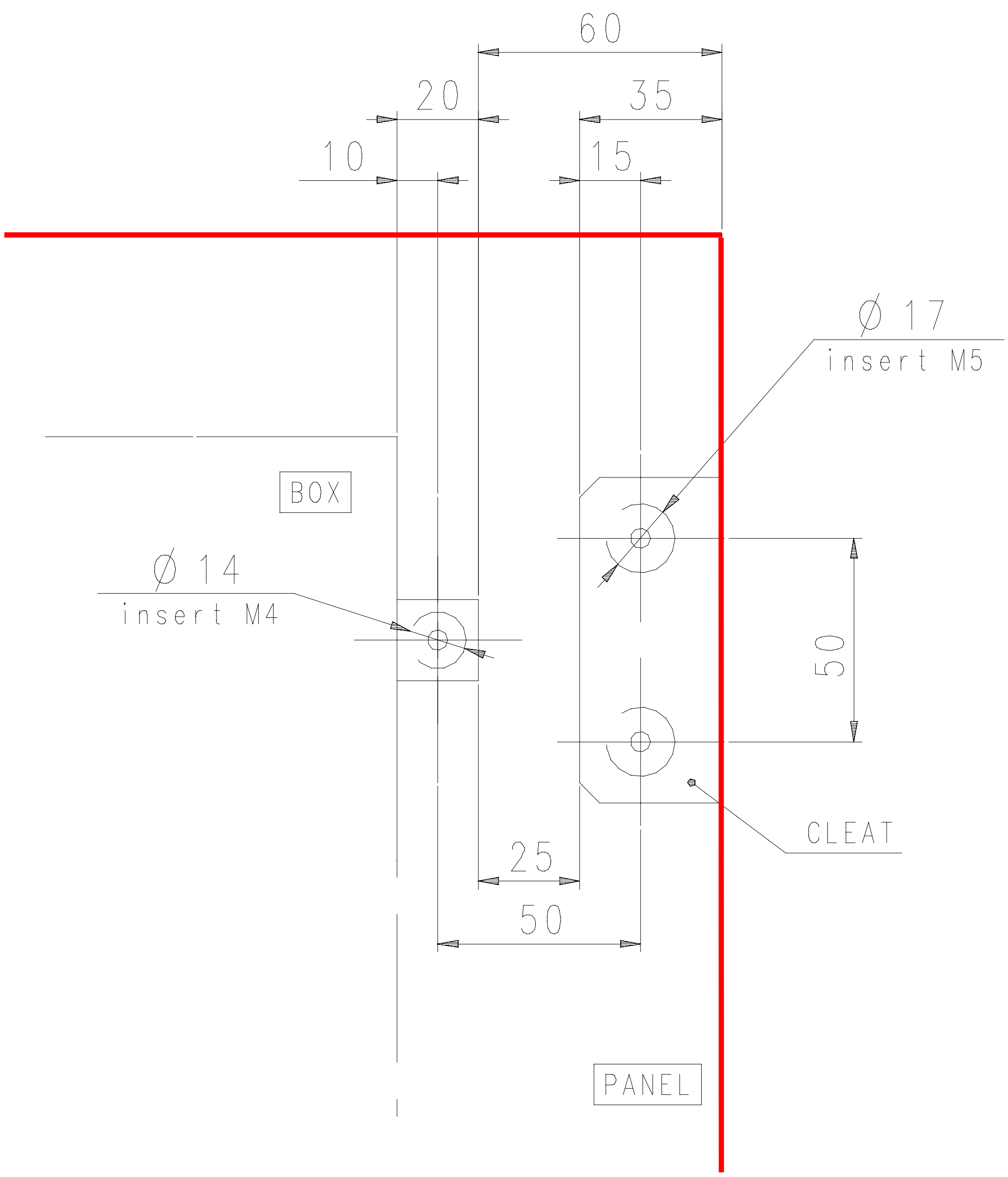
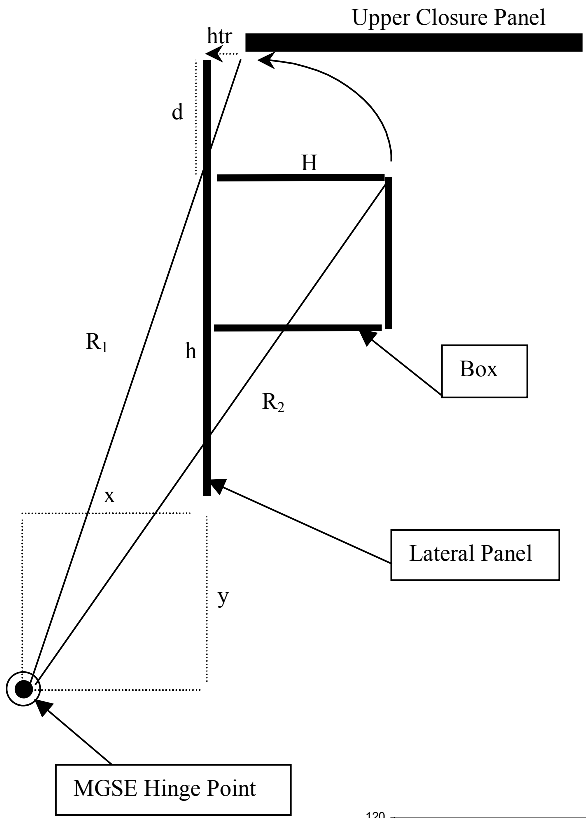


Fig.3.3.1 Structural cleat.

ii) minimum distance of warm units from the upper edge (off the upper closure panel) as a function of the unit height (see Fig.3.3.2);



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

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

h=796.5 (Lateral Panel height)

d = Box to panel edge distance
H = Box height

(x;y) = MGSE Hinge Points location coordinates

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

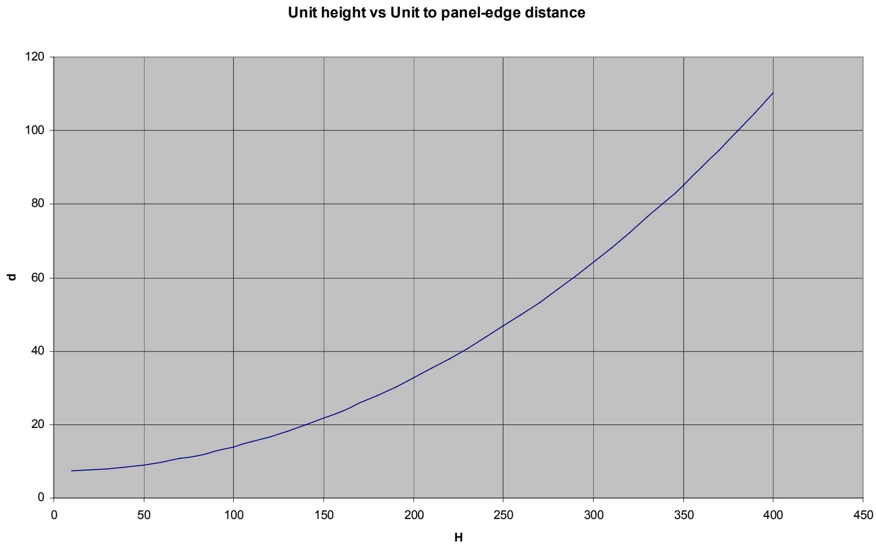


Fig. 3.3.2 Study of panel tilting.

3.4 HERSCHEL WARM UNIT ACCOMODATION

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

3.4.1 HIFI WARM UNITS

The HIFI Warm Units are mainly grouped on two dedicated SVM panels (i.e. the –Y and the –Y-Z lateral panels). In the following table there are the project codes allocated to HIFI warm units:

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

In the following tables below are indicated the dimensions, the masses and the drawings ref. numbers for each HIFI Warm Unit:

Table 3.4.1.: HIFI W.U. dimensions and mass

Project Code	# of	Dimensions (mm)	Mass (kg)
FHFCU	1	326 x 289 x 180	8.3
FHLCU	1	340 x 290 x 260	15.0
FHLSU	1	424 x 286 x 264.9	19.0
FHHRH/V	1+1	390 x 355 x 102	12.3
FHWEH/V	1+1	290 x 240 x 175.7	6.9
FHWOH/V	1+1	400 x 170 x 130	5.7
FHICU	1	274 x 258 x 194	7.6
FHIFV/H	1+1	70 x 70 x 107	0.6
Total			**75.4**

Table 3.4.1-1: HIFI W.U. Reference Drawings.

HIFI unit	Drawing Ref. Number	Drawing issue	Drawing date
FHFCU	324-E-5000	B	07/07/03
FHLCU	SRC/LCU/SP/2001-012	8	12/06/03
FHLSU	ICD-HIF-157704	P2	10/07/03
FHHRH/V	CESR-HRS-MD-3151-103 (sheet 1 & 2, dated 08/11 & 13/11)	3.4	08/11/02
FHWOH/V	FHWOH(V) Configuration (UC 00.00)	4	24/03/03
FHWEH/V	HIFI-MPAE-ID-ES100-001	1 a	14/07/03
FHIFH/V	DR 521-001	1	04/07/03
FHICU	HER H004/02	TBD	10/02/02

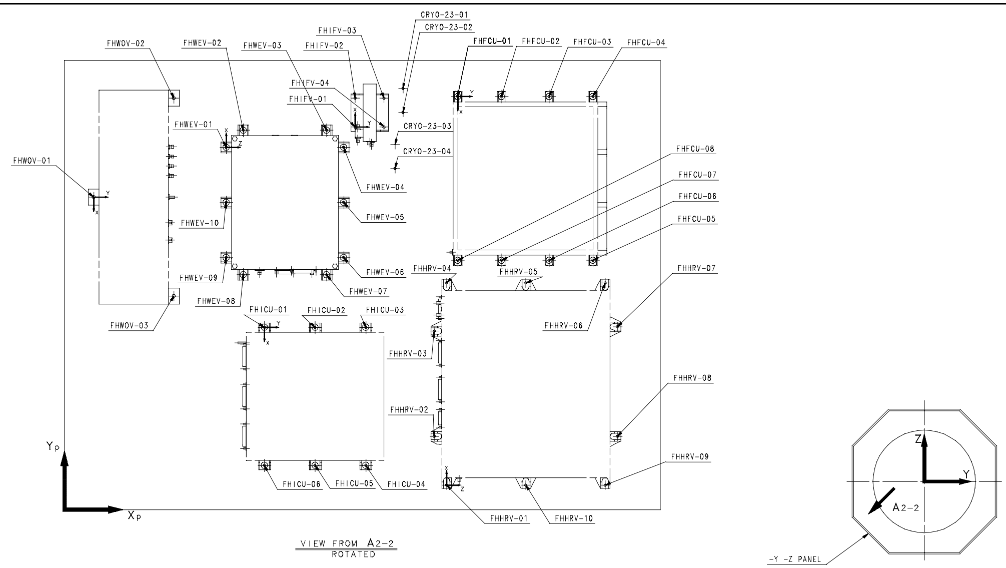
On the –Y Herschel HIFI lateral panel are located the following units:

- FHLSU
- FHLCU
- FHWOH
- FHWEH
- FHHRH
- FHIFH

On the –Y-Z Herschel HIFI lateral panel are located the following units:

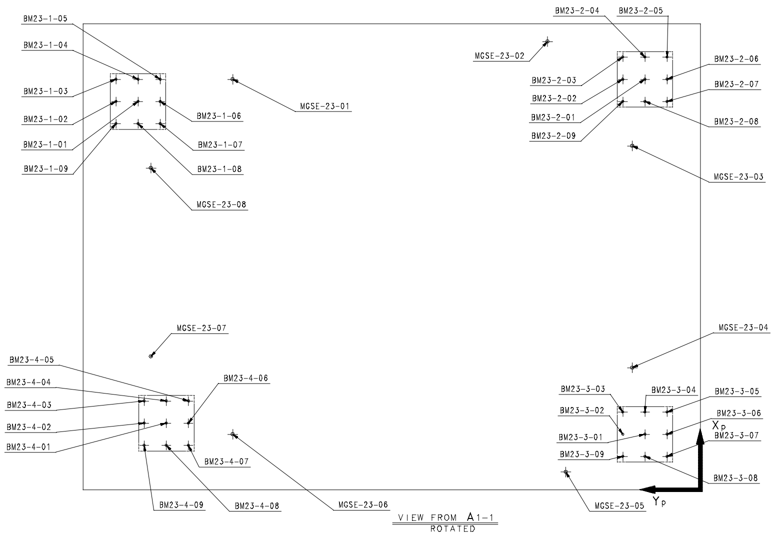
- FHICU
- FHFCU
- FHWOV
- FHWEV
- FHHRV
- FHIFV

The HIFI Warm Units configuration, on board Herschel SVM, is shown in the following figures from ALS Mechanical ICD(H-P-IC-AI-001 Issue 5):



ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
CRYO-23-01	633.95	787.40	M4	Ø0,4	Xp Yp AXIS	HIFI
CRYO-23-02	633.95	742.60	M4	Ø0,3	CRYO-23-01	HIFI
CRYO-23-03	618.95	682.40	M4	Ø0,4	Xp Yp AXIS	HIFI
CRYO-23-04	618.95	637.60	M4	Ø0,3	CRYO-23-01	HIFI
FHIFV-01	544.42	715.20	M4	Ø0,4	Xp Yp AXIS	HIFI
FHIFV-02	544.42	769.20	M4	Ø0,3	FHIFH-01	HIFI
FHIFV-03	598.42	769.20	M4	Ø0,3	FHIFH-01	HIFI
FHIFV-04	598.42	715.20	M4	Ø0,3	FHIFH-01	HIFI
FHFCU-01	736.42	772.20	M4	Ø0,4	Xp Yp AXIS	HIFI
FHFCU-02	818.42	772.20	M4	Ø0,3	FHFCU-01	HIFI
FHFCU-03	907.42	772.20	M4	Ø0,3	FHFCU-01	HIFI
FHFCU-04	989.42	772.20	M4	Ø0,3	FHFCU-01	HIFI
FHFCU-05	989.42	466.20	M4	Ø0,3	FHFCU-01	HIFI
FHFCU-06	907.42	466.20	M4	Ø0,3	FHFCU-01	HIFI
FHFCU-07	818.42	466.20	M4	Ø0,3	FHFCU-01	HIFI
FHFCU-08	736.42	466.20	M4	Ø0,3	FHFCU-01	HIFI
FHHRV-01	715.42	45.80	M4	Ø0,4	Xp Yp AXIS	HIFI
FHHRV-02	692.42	136.80	M4	Ø0,3	FHHRV-01	HIFI
FHHRV-03	692.42	333.80	M4	Ø0,3	FHHRV-01	HIFI
FHHRV-04	715.42	423.80	M4	Ø0,3	FHHRV-01	HIFI
FHHRV-05	863.92	423.80	M4	Ø0,3	FHHRV-01	HIFI
FHHRV-06	1012.42	423.80	M4	Ø0,3	FHHRV-01	HIFI
FHHRV-07	1035.42	341.80	M4	Ø0,3	FHHRV-01	HIFI
FHHRV-08	1035.42	136.80	M4	Ø0,3	FHHRV-01	HIFI
FHHRV-09	1012.42	45.80	M4	Ø0,3	FHHRV-01	HIFI
FHHRV-10	863.92	45.80	M4	Ø0,3	FHHRV-01	HIFI
FHWEV-01	302.92	677.20	M4	Ø0,4	Xp Yp AXIS	HIFI
FHWEV-02	334.92	709.20	M4	Ø0,3	FHWEV-01	HIFI
FHWEV-03	490.92	709.20	M4	Ø0,3	FHWEV-01	HIFI
FHWEV-04	522.92	677.20	M4	Ø0,3	FHWEV-01	HIFI
FHWEV-05	522.92	574.20	M4	Ø0,3	FHWEV-01	HIFI
FHWEV-06	522.92	471.20	M4	Ø0,3	FHWEV-01	HIFI
FHWEV-07	490.92	439.20	M4	Ø0,3	FHWEV-01	HIFI
FHWEV-08	334.92	439.20	M4	Ø0,3	FHWEV-01	HIFI
FHWEV-09	302.92	471.20	M4	Ø0,3	FHWEV-01	HIFI
FHWEV-10	302.92	574.20	M4	Ø0,3	FHWEV-01	HIFI
FHWOV-01	54.92	584.20	M6	Ø0,4	Xp Yp AXIS	HIFI
FHWOV-02	204.92	769.20	M6	Ø0,3	FHWOV-01	HIFI
FHWOV-03	204.92	399.20	M6	Ø0,3	FHWOV-01	HIFI
FHICU-01	374.42	340.80	M4	Ø0,4	Xp Yp AXIS	HIFI
FHICU-02	469.42	340.80	M4	Ø0,3	FHICU-01	HIFI
FHICU-03	564.42	340.80	M4	Ø0,3	FHICU-01	HIFI
FHICU-04	564.42	82.80	M4	Ø0,3	FHICU-01	HIFI
FHICU-05	469.42	82.80	M4	Ø0,3	FHICU-01	HIFI
FHICU-06	374.42	82.80	M4	Ø0,3	FHICU-01	HIFI

Fig. 3.4.1.Herschel HIFI panel –Y-Z.



ITEM	COORDINATES		INSERT TYPE	POSITION TOLERANCE		S/S
	Xp mm	Yp mm		⌖	REFERENCE	
BM23-1-01	1016.00	700.00	M4	Ø0,4	Xp YP AXIS	
BM23-1-02	1056.00	700.00	M4	Ø0,3	BM23-1-01	
BM23-1-03	1056.00	740.00	M4	Ø0,3	BM23-1-01	
BM23-1-04	1016.00	740.00	M4	Ø0,3	BM23-1-01	
BM23-1-05	976.00	740.00	M4	Ø0,3	BM23-1-01	
BM23-1-06	976.00	700.00	M4	Ø0,3	BM23-1-01	
BM23-1-07	976.00	660.00	M4	Ø0,3	BM23-1-01	
BM23-1-08	1016.00	660.00	M4	Ø0,3	BM23-1-01	
BM23-1-09	1056.00	660.00	M4	Ø0,3	BM23-1-01	
BM23-2-01	100.00	740.00	M4	Ø0,4	Xp YP AXIS	
BM23-2-02	140.00	740.00	M4	Ø0,3	BM23-2-01	
BM23-2-03	140.00	780.00	M4	Ø0,3	BM23-2-01	
BM23-2-04	100.00	780.00	M4	Ø0,3	BM23-2-01	
BM23-2-05	60.00	780.00	M4	Ø0,3	BM23-2-01	
BM23-2-06	60.00	740.00	M4	Ø0,3	BM23-2-01	
BM23-2-07	60.00	700.00	M4	Ø0,3	BM23-2-01	
BM23-2-08	100.00	700.00	M4	Ø0,3	BM23-2-01	
BM23-2-09	140.00	700.00	M4	Ø0,3	BM23-2-01	
BM23-3-01	100.00	100.00	M4	Ø0,4	Xp YP AXIS	
BM23-3-02	140.00	100.00	M4	Ø0,3	BM23-3-01	
BM23-3-03	140.00	140.00	M4	Ø0,3	BM23-3-01	
BM23-3-04	100.00	140.00	M4	Ø0,3	BM23-3-01	
BM23-3-05	60.00	140.00	M4	Ø0,3	BM23-3-01	
BM23-3-06	60.00	100.00	M4	Ø0,3	BM23-3-01	
BM23-3-07	60.00	60.00	M4	Ø0,3	BM23-3-01	
BM23-3-08	100.00	60.00	M4	Ø0,3	BM23-3-01	
BM23-3-09	140.00	60.00	M4	Ø0,3	BM23-3-01	

ITEM	COORDINATES		INSERT TYPE	POSITION TOLERANCE		S/S
	Xp mm	Yp mm		⌖	REFERENCE	
BM23-4-01	965.00	120.00	M4	Ø0,4	Xp YP AXIS	
BM23-4-02	1005.00	120.00	M4	Ø0,3	BM23-4-01	
BM23-4-03	1005.00	160.00	M4	Ø0,3	BM23-4-01	
BM23-4-04	965.00	160.00	M4	Ø0,3	BM23-4-01	
BM23-4-05	925.00	160.00	M4	Ø0,3	BM23-4-01	
BM23-4-06	925.00	120.00	M4	Ø0,3	BM23-4-01	
BM23-4-07	925.00	80.00	M4	Ø0,3	BM23-4-01	
BM23-4-08	965.00	80.00	M4	Ø0,3	BM23-4-01	
BM23-4-09	1005.00	80.00	M4	Ø0,3	BM23-4-01	
MGSE-23-01	845.00	740.00	M6	Ø0,3	Xp YP AXIS	MGSE
MGSE-23-02	276.00	808.00	M6	Ø0,3	Xp YP AXIS	MGSE
MGSE-23-03	122.77	620.00	M6	Ø0,3	Xp YP AXIS	MGSE
MGSE-23-04	122.77	220.00	M6	Ø0,3	Xp YP AXIS	MGSE
MGSE-23-05	243.00	32.00	M6	Ø0,3	Xp YP AXIS	MGSE
MGSE-23-06	845.00	100.00	M6	Ø0,3	Xp YP AXIS	MGSE
MGSE-23-07	992.77	240.00	M6	Ø0,3	Xp YP AXIS	MGSE
MGSE-23-08	992.77	580.00	M6	Ø0,3	Xp YP AXIS	MGSE

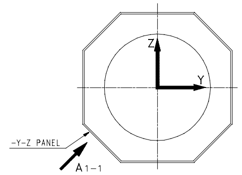
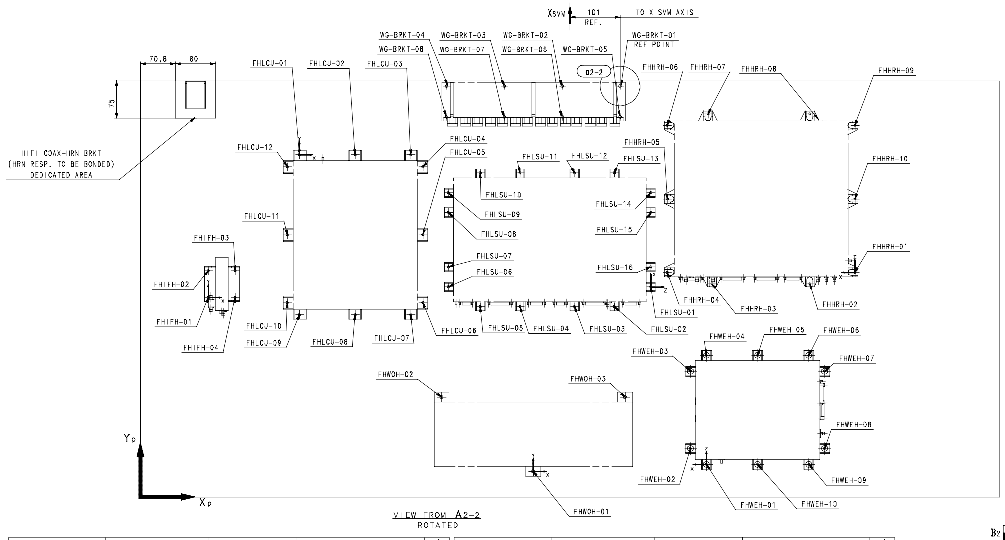


Fig. 3.4 1-1. Herschel HIFI panel –Y-Z (outside of the SVM).



ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
FHIFH-01	136.99	402.80	M4	Ø0,4	Xp Yp AXIS	HIFI
FHIFH-02	136.99	456.80	M4	Ø0,3	FHIFH-01	HIFI
FHIFH-03	190.99	456.80	M4	Ø0,3	FHIFH-01	HIFI
FHIFH-04	190.99	402.80	M4	Ø0,3	FHIFH-01	HIFI
FHHRH-01	1439.59	453.20	M4	Ø0,4	Xp Yp AXIS	HIFI
FHHRH-02	1348.59	430.20	M4	Ø0,3	FHHRH-01	HIFI
FHHRH-03	1151.59	430.20	M4	Ø0,3	FHHRH-01	HIFI
FHHRH-04	1061.59	453.20	M4	Ø0,3	FHHRH-01	HIFI
FHHRH-05	1061.59	601.70	M4	Ø0,3	FHHRH-01	HIFI
FHHRH-06	1061.59	750.20	M4	Ø0,3	FHHRH-01	HIFI
FHHRH-07	1143.59	773.20	M4	Ø0,3	FHHRH-01	HIFI
FHHRH-08	1348.59	773.20	M4	Ø0,3	FHHRH-01	HIFI
FHHRH-09	1439.59	750.20	M4	Ø0,3	FHHRH-01	HIFI
FHHRH-10	1439.59	601.70	M4	Ø0,3	FHHRH-01	HIFI
FHLCU-01	320.59	690.95	M4	Ø0,4	Xp Yp AXIS	HIFI
FHLCU-02	432.59	690.95	M4	Ø0,3	FHLCU-01	HIFI
FHLCU-03	544.59	690.95	M4	Ø0,3	FHLCU-01	HIFI
FHLCU-04	569.09	666.45	M4	Ø0,3	FHLCU-01	HIFI
FHLCU-05	569.09	529.45	M4	Ø0,3	FHLCU-01	HIFI
FHLCU-06	569.09	392.45	M4	Ø0,3	FHLCU-01	HIFI
FHLCU-07	544.59	367.95	M4	Ø0,3	FHLCU-01	HIFI
FHLCU-08	432.59	367.95	M4	Ø0,3	FHLCU-01	HIFI
FHLCU-09	320.59	367.95	M4	Ø0,3	FHLCU-01	HIFI
FHLCU-10	296.09	392.45	M4	Ø0,3	FHLCU-01	HIFI
FHLCU-11	296.09	529.45	M4	Ø0,3	FHLCU-01	HIFI
FHLCU-12	296.09	666.45	M4	Ø0,3	FHLCU-01	HIFI

ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
FHLSU-01	1028.59	424.20	M4	Ø0,4	Xp Yp AXIS	HIFI
FHLSU-02	955.09	384.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-03	875.09	384.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-04	764.79	384.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-05	684.79	384.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-06	620.59	424.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-07	620.59	464.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-08	620.59	574.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-09	620.59	614.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-10	684.79	654.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-11	764.79	654.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-12	875.09	654.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-13	955.09	654.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-14	1028.59	614.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-15	1028.59	574.20	M4	Ø0,3	FHLSU-01	HIFI
FHLSU-16	1028.59	464.20	M4	Ø0,3	FHLSU-01	HIFI
FHWEH-01	1140.59	65.80	M4	Ø0,4	Xp Yp AXIS	HIFI
FHWEH-02	1108.59	97.80	M4	Ø0,3	FHWEH-01	HIFI
FHWEH-03	1108.59	253.80	M4	Ø0,3	FHWEH-01	HIFI
FHWEH-04	1140.59	285.80	M4	Ø0,3	FHWEH-01	HIFI
FHWEH-05	1243.59	285.80	M4	Ø0,3	FHWEH-01	HIFI
FHWEH-06	1346.59	285.80	M4	Ø0,3	FHWEH-01	HIFI
FHWEH-07	1378.59	253.80	M4	Ø0,3	FHWEH-01	HIFI
FHWEH-08	1378.59	97.80	M4	Ø0,3	FHWEH-01	HIFI
FHWEH-09	1346.59	65.80	M4	Ø0,3	FHWEH-01	HIFI
FHWEH-10	1243.59	65.80	M4	Ø0,3	FHWEH-01	HIFI
FHWOH-01	791.59	51.80	M6	Ø0,4	Xp Yp AXIS	HIFI
FHWOH-02	606.59	201.80	M6	Ø0,3	FHWEH-01	HIFI
FHWOH-03	976.59	201.80	M6	Ø0,3	FHWEH-01	HIFI
WG-BRKT-01	966.59	829.60	THROUGH (Det. a2-2)	Ø0,4	Xp Yp AXIS	HIFI
WG-BRKT-02	850.09	829.60	THROUGH (Det. a2-2)	Ø0,3	WG-BRKT-01	HIFI
WG-BRKT-03	733.59	829.60	THROUGH (Det. a2-2)	Ø0,3	WG-BRKT-01	HIFI
WG-BRKT-04	617.09	829.60	THROUGH (Det. a2-2)	Ø0,3	WG-BRKT-01	HIFI
WG-BRKT-05	966.59	767.00	M6	Ø0,3	WG-BRKT-01	HIFI
WG-BRKT-06	850.09	767.00	M6	Ø0,3	WG-BRKT-01	HIFI
WG-BRKT-07	733.59	767.00	M6	Ø0,3	WG-BRKT-01	HIFI
WG-BRKT-08	617.09	767.00	M6	Ø0,3	WG-BRKT-01	HIFI

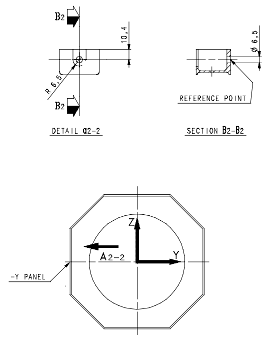
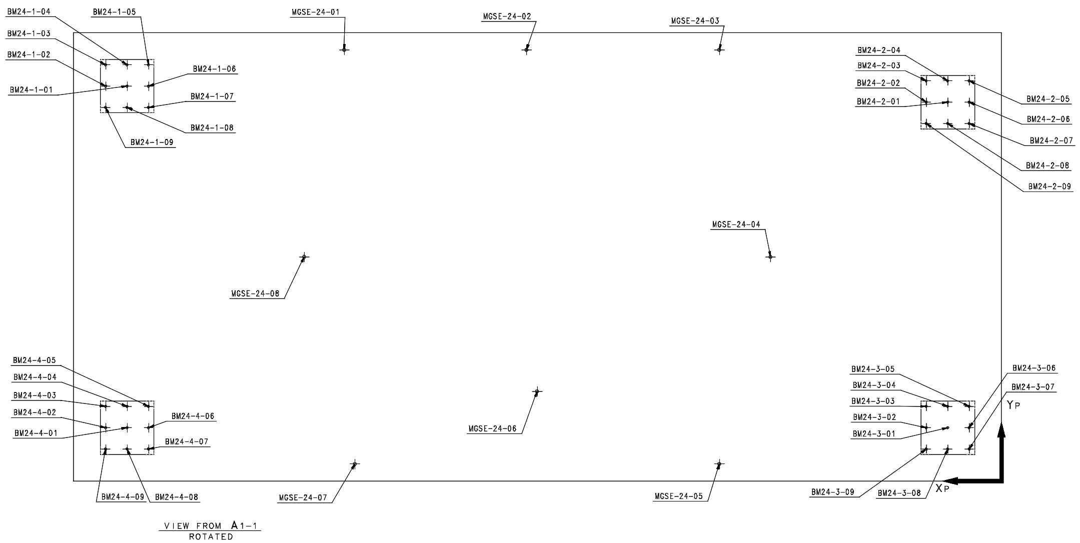


Fig. 3.4.1-2 Herschel HIFI panel –Y.



ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
BM24-1-01	1631.00	740.00	M4	Ø0,4	Xp Yp AXIS	
BM24-1-02	1671.00	740.00	M4	Ø0,3	BM24-1-01	
BM24-1-03	1671.00	780.00	M4	Ø0,3	BM24-1-01	
BM24-1-04	1631.00	780.00	M4	Ø0,3	BM24-1-01	
BM24-1-05	1591.00	780.00	M4	Ø0,3	BM24-1-01	
BM24-1-06	1591.00	740.00	M4	Ø0,3	BM24-1-01	
BM24-1-07	1591.00	700.00	M4	Ø0,3	BM24-1-01	
BM24-1-08	1631.00	700.00	M4	Ø0,3	BM24-1-01	
BM24-1-09	1671.00	700.00	M4	Ø0,3	BM24-1-01	
BM24-2-01	100.00	710.00	M4	Ø0,4	Xp Yp AXIS	
BM24-2-02	140.00	710.00	M4	Ø0,3	BM24-2-01	
BM24-2-03	140.00	750.00	M4	Ø0,3	BM24-2-01	
BM24-2-04	100.00	750.00	M4	Ø0,3	BM24-2-01	
BM24-2-05	60.00	750.00	M4	Ø0,3	BM24-2-01	
BM24-2-06	60.00	710.00	M4	Ø0,3	BM24-2-01	
BM24-2-07	60.00	670.00	M4	Ø0,3	BM24-2-01	
BM24-2-08	100.00	670.00	M4	Ø0,3	BM24-2-01	
BM24-2-09	140.00	670.00	M4	Ø0,3	BM24-2-01	
BM24-3-01	100.00	100.00	M4	Ø0,4	Xp Yp AXIS	
BM24-3-02	140.00	100.00	M4	Ø0,3	BM24-3-01	
BM24-3-03	140.00	140.00	M4	Ø0,3	BM24-3-01	
BM24-3-04	100.00	140.00	M4	Ø0,3	BM24-3-01	
BM24-3-05	60.00	140.00	M4	Ø0,3	BM24-3-01	
BM24-3-06	60.00	100.00	M4	Ø0,3	BM24-3-01	
BM24-3-07	60.00	60.00	M4	Ø0,3	BM24-3-01	
BM24-3-08	100.00	60.00	M4	Ø0,3	BM24-3-01	
BM24-3-09	140.00	60.00	M4	Ø0,3	BM24-3-01	

ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
BM24-4-01	1631.00	100.00	M4	Ø0,4	Xp Yp AXIS	
BM24-4-02	1671.00	100.00	M4	Ø0,3	BM24-4-01	
BM24-4-03	1671.00	140.00	M4	Ø0,3	BM24-4-01	
BM24-4-04	1631.00	140.00	M4	Ø0,3	BM24-4-01	
BM24-4-05	1591.00	140.00	M4	Ø0,3	BM24-4-01	
BM24-4-06	1591.00	100.00	M4	Ø0,3	BM24-4-01	
BM24-4-07	1591.00	60.00	M4	Ø0,3	BM24-4-01	
BM24-4-08	1631.00	60.00	M4	Ø0,3	BM24-4-01	
BM24-4-09	1671.00	60.00	M4	Ø0,3	BM24-4-01	
MGSE-24-01	1225.99	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-02	885.99	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-03	525.99	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-04	430.59	420.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-05	525.99	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-06	865.99	168.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-07	1205.99	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-08	1300.59	420.00	M6	Ø0,3	Xp Yp AXIS	MGSE

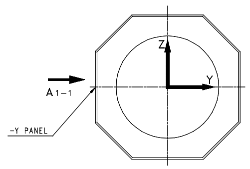


Fig. 3.4.1-3 Herschel HIFI panel –Y (outside of the SVM).

3.4.2 SPIRE WARM UNITS

The SPIRE Warm Units are mainly grouped on one dedicated SVM panels (the -Z lateral panel) with the CCU unit. In the following table there are the project codes allocated to SPIRE warm units:

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

In the following tables below are indicated the dimensions, the masses and the drawings ref. numbers for each SPIRE Warm Unit:

Table 3.4.2.: SPIRE W.U. dimensions and mass.

Project Code	# of	Dimensions (mm)	Mass (kg)
HSDCU	1	490 x 285 x 305	14.4
HSFCU	1	325 x 370 x 335	16.2
HSDPU	1	274 x 274 x 194	7.2
Total			**37.8**

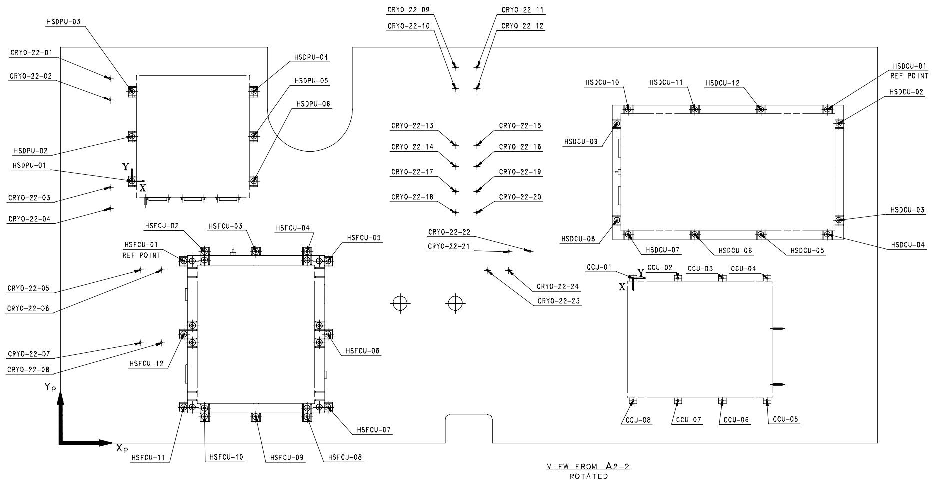
Table 3.4.2-1: SPIRE W.U. Reference Drawings.

SPIRE unit	Drawing Ref. Number	Drawing issue	Drawing date
HSDCU	SPIR-MX-5100 000	E	XX-01-04
HSFCU	SPIR-MX-5200 000	J	XX-01-04
HSDPU	HER S005/03	4	23-02-03

On the –Z Herschel SPIRE lateral panel are located the following units:

- HSDCU
- HSFCU
- HSDPU
- CCU (no SPIRE unit)

The SPIRE Warm Units configuration, on board Herschel SVM, is shown in the following figures from ALS Mechanical ICD (H-P-IC-AI-001 Issue 5):



ITEM	COORDINATES Xp mm	COORDINATES Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	POSITION TOLERANCE REFERENCE	S/S
CCU-01	1213.61	349.55	M4	Ø0.4	Xp Yp AXIS	CRYO
CCU-02	1308.61	349.55	M4	Ø0.3	CCU-01	CRYO
CCU-03	1402.61	349.55	M4	Ø0.3	CCU-01	CRYO
CCU-04	1497.61	349.55	M4	Ø0.3	CCU-01	CRYO
CCU-05	1497.61	89.55	M4	Ø0.3	CCU-01	CRYO
CCU-06	1402.61	89.55	M4	Ø0.3	CCU-01	CRYO
CCU-07	1308.61	89.55	M4	Ø0.3	CCU-01	CRYO
CCU-08	1213.61	89.55	M4	Ø0.3	CCU-01	CRYO
HSDCU-01	1625.50	707.20	M4	Ø0.4	Xp Yp AXIS	SPIRE
HSDCU-02	1649.50	677.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDCU-03	1649.50	472.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDCU-04	1625.50	442.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDCU-05	1484.50	442.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDCU-06	1344.50	442.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDCU-07	1203.50	442.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDCU-08	1179.50	472.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDCU-09	1179.50	677.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDCU-10	1203.50	707.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDCU-11	1344.50	707.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDCU-12	1484.50	707.20	M4	Ø0.3	HSDCU-01	SPIRE
HSDPU-01	151.60	555.20	M4	Ø0.4	Xp Yp AXIS	SPIRE
HSDPU-02	151.60	650.20	M4	Ø0.3	HSDPU-01	SPIRE
HSDPU-03	151.60	745.20	M4	Ø0.3	HSDPU-01	SPIRE
HSDPU-04	409.60	745.20	M4	Ø0.3	HSDPU-01	SPIRE
HSDPU-05	409.60	650.20	M4	Ø0.3	HSDPU-01	SPIRE
HSDPU-06	409.60	555.20	M4	Ø0.3	HSDPU-01	SPIRE

ITEM	COORDINATES Xp mm	COORDINATES Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	POSITION TOLERANCE REFERENCE	S/S
HSFCU-01	261.60	385.80	M5	Ø0.4	Xp Yp AXIS	SPIRE
HSFCU-02	305.60	405.80	M5	Ø0.3	HSFCU-01	SPIRE
HSFCU-03	414.10	405.80	M5	Ø0.3	HSFCU-01	SPIRE
HSFCU-04	522.60	405.80	M5	Ø0.3	HSFCU-01	SPIRE
HSFCU-05	566.60	385.80	M5	Ø0.3	HSFCU-01	SPIRE
HSFCU-06	566.60	230.80	M5	Ø0.3	HSFCU-01	SPIRE
HSFCU-07	566.60	75.80	M5	Ø0.3	HSFCU-01	SPIRE
HSFCU-08	522.60	55.80	M5	Ø0.3	HSFCU-01	SPIRE
HSFCU-09	414.10	55.80	M5	Ø0.3	HSFCU-01	SPIRE
HSFCU-10	305.60	55.80	M5	Ø0.3	HSFCU-01	SPIRE
HSFCU-11	261.60	75.80	M5	Ø0.3	HSFCU-01	SPIRE
HSFCU-12	261.60	230.80	M5	Ø0.3	HSFCU-01	SPIRE
CRYO-22-01	104.87	772.40	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-02	104.87	727.60	M4	Ø0.3	CRYO-22-01	CRYO
CRYO-22-03	104.87	542.40	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-04	104.87	497.60	M4	Ø0.3	CRYO-22-03	CRYO
CRYO-22-05	169.27	367.50	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-06	214.07	367.50	M4	Ø0.3	CRYO-22-05	CRYO
CRYO-22-07	169.27	212.50	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-08	214.07	212.50	M4	Ø0.3	CRYO-22-07	CRYO
CRYO-22-09	837.59	796.60	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-10	837.59	751.80	M4	Ø0.3	CRYO-22-09	CRYO
CRYO-22-11	882.59	796.60	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-12	882.59	751.80	M4	Ø0.3	CRYO-22-11	CRYO
CRYO-22-13	837.59	631.60	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-14	837.59	586.80	M4	Ø0.3	CRYO-22-13	CRYO
CRYO-22-15	882.59	631.60	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-16	882.59	586.80	M4	Ø0.3	CRYO-22-15	CRYO
CRYO-22-17	837.59	533.60	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-18	837.59	488.80	M4	Ø0.3	CRYO-22-17	CRYO
CRYO-22-19	882.59	533.60	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-20	882.59	488.80	M4	Ø0.3	CRYO-22-19	CRYO
CRYO-22-21	950.17	406.20	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-22	994.97	406.20	M4	Ø0.3	CRYO-22-21	CRYO
CRYO-22-23	905.17	366.20	M4	Ø0.4	Xp Yp AXIS	CRYO
CRYO-22-24	949.97	366.20	M4	Ø0.3	CRYO-22-23	CRYO

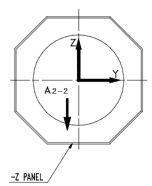
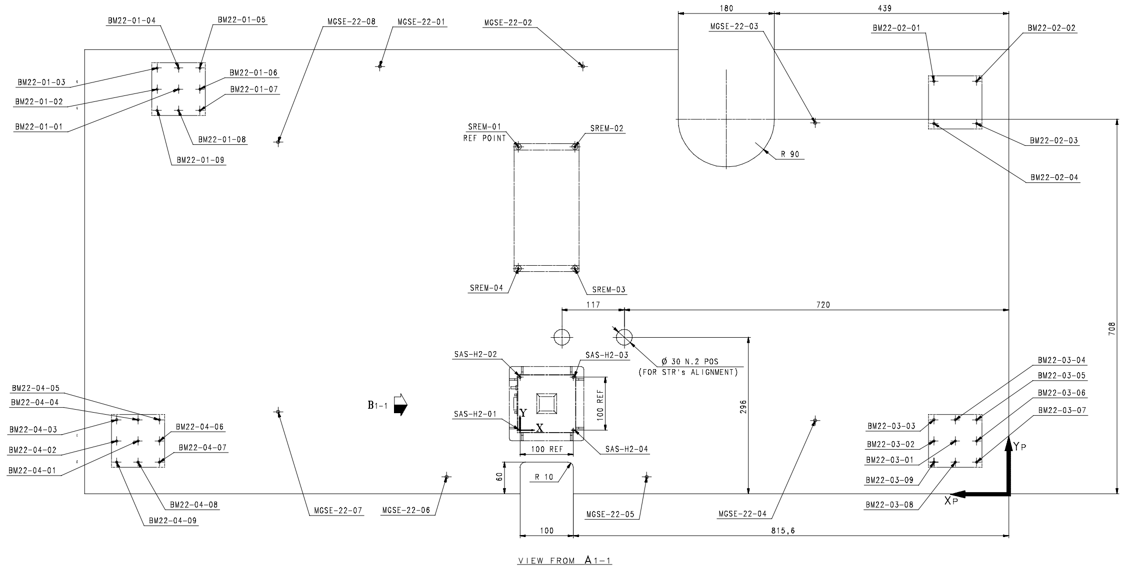


Fig. 3.4.2 Herschel SPIRE panel –Z.



ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
BM22-01-01	1555.09	765.00	M4	Ø0,4	Xp Yp AXIS	
BM22-01-02	1595.09	765.00	M4	Ø0,3	BM22-01-01	
BM22-01-03	1595.09	805.00	M4	Ø0,3	BM22-01-01	
BM22-01-04	1555.09	805.00	M4	Ø0,3	BM22-01-01	
BM22-01-05	1515.09	805.00	M4	Ø0,3	BM22-01-01	
BM22-01-06	1515.09	765.00	M4	Ø0,3	BM22-01-01	
BM22-01-07	1515.09	725.00	M4	Ø0,3	BM22-01-01	
BM22-01-08	1555.09	725.00	M4	Ø0,3	BM22-01-01	
BM22-01-09	1595.09	725.00	M4	Ø0,3	BM22-01-01	
BM22-02-01	140.09	780.00	M4	Ø0,4	Xp Yp AXIS	
BM22-02-02	60.09	780.00	M4	Ø0,3	BM22-02-01	
BM22-02-03	60.09	700.00	M4	Ø0,3	BM22-02-01	
BM22-02-04	140.09	700.00	M4	Ø0,3	BM22-02-01	
BM22-03-01	100.09	100.00	M4	Ø0,4	Xp Yp AXIS	
BM22-03-02	140.09	100.00	M4	Ø0,3	BM22-03-01	
BM22-03-03	140.09	140.00	M4	Ø0,3	BM22-03-01	
BM22-03-04	100.09	140.00	M4	Ø0,3	BM22-03-01	
BM22-03-05	60.09	140.00	M4	Ø0,3	BM22-03-01	
BM22-03-06	60.09	100.00	M4	Ø0,3	BM22-03-01	
BM22-03-07	60.09	60.00	M4	Ø0,3	BM22-03-01	
BM22-03-08	100.09	60.00	M4	Ø0,3	BM22-03-01	
BM22-03-09	140.09	60.00	M4	Ø0,3	BM22-03-01	

ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
BM22-04-01	1631.09	100.00	M4	Ø0,4	Xp Yp AXIS	
BM22-04-02	1671.09	100.00	M4	Ø0,3	BM22-04-01	
BM22-04-03	1671.09	140.00	M4	Ø0,3	BM22-04-01	
BM22-04-04	1631.09	140.00	M4	Ø0,3	BM22-04-01	
BM22-04-05	1591.09	140.00	M4	Ø0,3	BM22-04-01	
BM22-04-06	1591.09	100.00	M4	Ø0,3	BM22-04-01	
BM22-04-07	1591.09	60.00	M4	Ø0,3	BM22-04-01	
BM22-04-08	1631.09	60.00	M4	Ø0,3	BM22-04-01	
BM22-04-09	1671.09	60.00	M4	Ø0,3	BM22-04-01	
MGSE-22-01	1178.10	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-02	797.60	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-03	362.60	701.30	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-04	362.60	138.70	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-05	678.10	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-06	1053.10	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-07	1368.60	155.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-08	1368.60	665.00	M6	Ø0,3	Xp Yp AXIS	MGSE
SREM-01	918.59	656.00	M4	Ø0,4	Xp Yp AXIS	CFE
SREM-02	812.59	656.00	M4	Ø0,3	SREM-01	CFE
SREM-03	812.59	426.00	M4	Ø0,3	SREM-01	CFE
SREM-04	918.59	426.00	M4	Ø0,3	SREM-01	CFE

ITEM	COORDINATES Xp mm	Yp mm	Zp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
SAS-H2-01	915.59	120.50	-170	M4	Ø0,4	Xp Yp Zp AXIS	ACMS
SAS-H2-02	915.59	220.50	-170	M4	Ø0,3	SAS-H2-01	ACMS
SAS-H2-03	815.59	220.50	-170	M4	Ø0,3	SAS-H2-01	ACMS
SAS-H2-04	815.59	120.50	-170	M4	Ø0,3	SAS-H2-01	ACMS

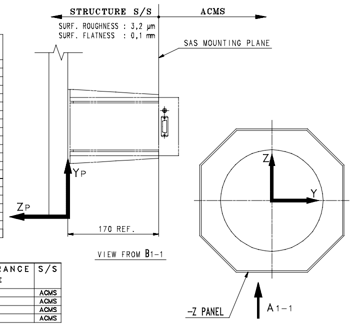


Fig. 3.4.2-1. Herschel SPIRE panel –Z (outside of the SVM).

3.4.3 PACS WARM UNITS

The PACS Warm Units are mainly grouped on one dedicated SVM panels (the +Y-Z lateral panel).
In the following table there are the project codes allocated to PACS warm units:

Project Code	Instrument Unit
FPDECMEC	PACS Detector Control Mechanism Control
FPBOLC	PACS Bolometer/Cooler Control
FPDPU	PACS Digital Processing Unit (DPU nom + red)
FPSPU	PACS Signal Processing Unit (Nom.+Red.)
FPWIH	PACS Warm Interconnect Harness

In the following tables below are indicated the dimensions, the masses and the drawings ref. numbers for each PACS Warm Unit:

Table 3.4.3.: PACS W.U. dimensions and mass.

Project Code	# of	Dimensions (mm)	Mass (kg)
FPDECMEC	1	560 x 320 x 300	23.0
FPBOLC	1	382.5 x 289 x 333.5	15.7
FPDPU	1	274 x 258 x 194	6.6
FPSPU	1	270 x 215 x 194	7.0
Total			**52.3**

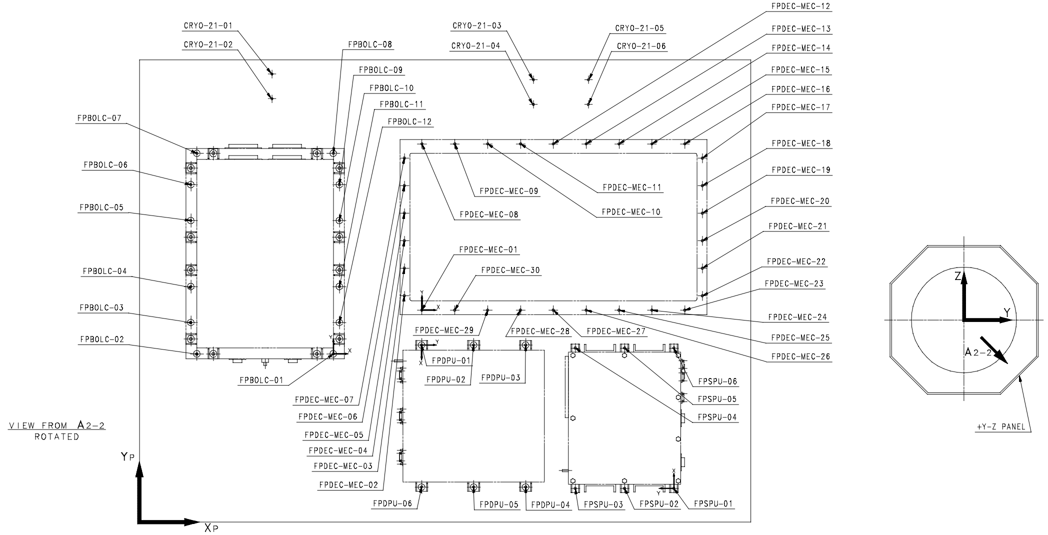
Table 3.4.3-1: PACS W.U. Reference Drawings.

PACS unit	Drawing Ref. Number	Drawing issue	Drawing date
FPDECMEC	ME.HES.114P.S.001SA	B	19-02-04
FPBOLC	PACS-MX-2000 000	G	XX-01-04
FPDPU	HER 005/02	TBD	02-05-02
FPSPU	FPL-ID-SPU-00002-CRS	3	02-04-03

On the +Y–Z Herschel PACS lateral panel are located the following units:

- FPDECMEC
- FPBOLC
- FPDPU
- FPSPU

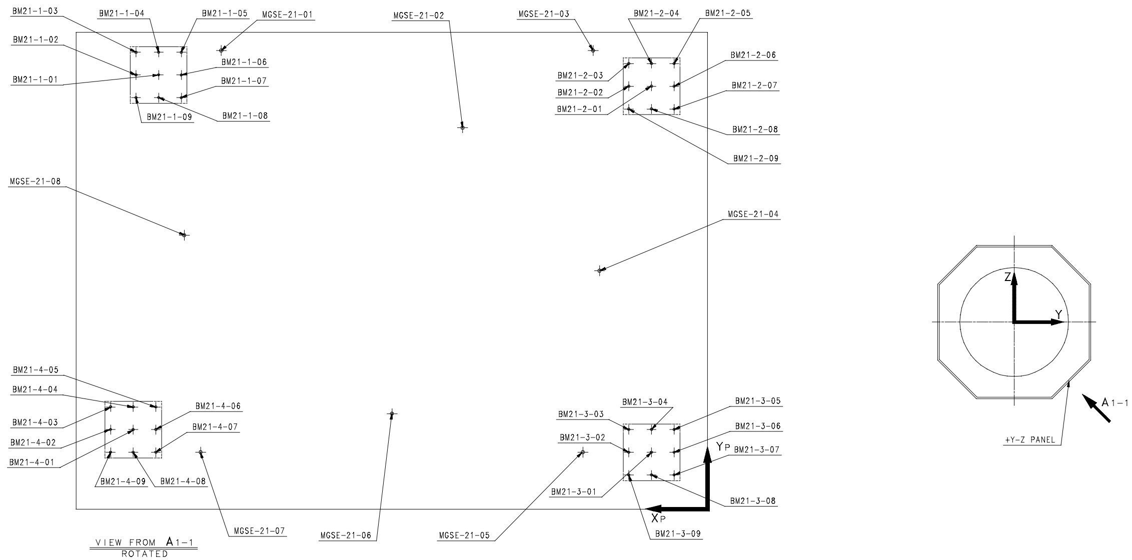
The PACS Warm Units configuration, on board Herschel SVM, is shown in the following figures from ALS Mechanical ICD (H-P-IC-AI-001 Issue 5):



ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
FPDEC-MEC-01	515.47	385.20	M4	Ø0,4	Xp Yp AXIS	PACS
FPDEC-MEC-02	483.47	411.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-03	483.47	461.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-04	483.47	511.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-05	483.47	561.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-06	483.47	611.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-07	483.47	661.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-08	515.47	687.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-09	575.47	687.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-10	635.47	687.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-11	695.47	687.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-12	755.47	687.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-13	815.47	687.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-14	875.47	687.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-15	935.47	687.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-16	995.47	687.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-17	1027.47	661.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-18	1027.47	611.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-19	1027.47	561.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-20	1027.47	511.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-21	1027.47	461.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-22	1027.47	411.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-23	995.47	385.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-24	935.47	385.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-25	875.47	385.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-26	815.47	385.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-27	755.47	385.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-28	695.47	385.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-29	635.47	385.20	M4	Ø0,3	FPDEC-MEC-01	PACS
FPDEC-MEC-30	575.47	385.20	M4	Ø0,3	FPDEC-MEC-01	PACS

ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
FPBOLC-01	353.92	305.70	M4	Ø0,4	Xp Yp AXIS	PACS
FPBOLC-02	104.92	305.70	M4	Ø0,3	FPBOLC-01	PACS
FPBOLC-03	93.92	362.70	M4	Ø0,3	FPBOLC-01	PACS
FPBOLC-04	93.92	427.95	M4	Ø0,3	FPBOLC-01	PACS
FPBOLC-05	93.92	547.95	M4	Ø0,3	FPBOLC-01	PACS
FPBOLC-06	93.92	613.20	M4	Ø0,3	FPBOLC-01	PACS
FPBOLC-07	104.92	670.20	M4	Ø0,3	FPBOLC-01	PACS
FPBOLC-08	353.92	670.20	M4	Ø0,3	FPBOLC-01	PACS
FPBOLC-09	364.92	613.20	M4	Ø0,3	FPBOLC-01	PACS
FPBOLC-10	364.92	547.95	M4	Ø0,3	FPBOLC-01	PACS
FPBOLC-11	364.92	427.95	M4	Ø0,3	FPBOLC-01	PACS
FPBOLC-12	364.92	362.70	M4	Ø0,3	FPBOLC-01	PACS
FPDPU-01	514.92	321.80	M4	Ø0,4	Xp Yp AXIS	PACS
FPDPU-02	609.92	321.80	M4	Ø0,3	FPDPU-01	PACS
FPDPU-03	704.92	321.80	M4	Ø0,3	FPDPU-01	PACS
FPDPU-04	704.92	63.80	M4	Ø0,3	FPDPU-01	PACS
FPDPU-05	609.92	63.80	M4	Ø0,3	FPDPU-01	PACS
FPDPU-06	514.92	63.80	M4	Ø0,3	FPDPU-01	PACS
FPSPU-01	975.42	61.30	M4	Ø0,4	Xp Yp AXIS	PACS
FPSPU-02	885.42	61.30	M4	Ø0,3	FPSPU-01	PACS
FPSPU-03	795.42	61.30	M4	Ø0,3	FPSPU-01	PACS
FPSPU-04	795.42	316.30	M4	Ø0,3	FPSPU-01	PACS
FPSPU-05	885.42	316.30	M4	Ø0,3	FPSPU-01	PACS
FPSPU-06	975.42	316.30	M4	Ø0,3	FPSPU-01	PACS
CRYO-21-01	241.95	814.10	M4	Ø0,4	Xp Yp AXIS	CRYO
CRYO-21-02	241.95	769.30	M4	Ø0,3	CRYO-21-01	CRYO
CRYO-21-03	719.35	803.70	M4	Ø0,4	Xp Yp AXIS	CRYO
CRYO-21-04	719.35	758.90	M4	Ø0,3	CRYO-21-03	CRYO
CRYO-21-05	819.35	803.70	M4	Ø0,4	Xp Yp AXIS	CRYO
CRYO-21-06	819.35	758.90	M4	Ø0,3	CRYO-21-05	CRYO

Fig. 3.4.3 Herschel PACS panel +Y-Z.



ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
BM21-1-01	970.00	765.00	M4	Ø0,4	Xp Yp AXIS	
BM21-1-02	1010.00	765.00	M4	Ø0,3	BM21-1-01	
BM21-1-03	1010.00	805.00	M4	Ø0,3	BM21-1-01	
BM21-1-04	970.00	805.00	M4	Ø0,3	BM21-1-01	
BM21-1-05	930.00	805.00	M4	Ø0,3	BM21-1-01	
BM21-1-06	930.00	765.00	M4	Ø0,3	BM21-1-01	
BM21-1-07	930.00	725.00	M4	Ø0,3	BM21-1-01	
BM21-1-08	970.00	725.00	M4	Ø0,3	BM21-1-01	
BM21-1-09	1010.00	725.00	M4	Ø0,3	BM21-1-01	
BM21-2-01	99.00	745.00	M4	Ø0,4	Xp Yp AXIS	
BM21-2-02	139.00	745.00	M4	Ø0,3	BM21-2-01	
BM21-2-03	139.00	785.00	M4	Ø0,3	BM21-2-01	
BM21-2-04	99.00	785.00	M4	Ø0,3	BM21-2-01	
BM21-2-05	59.00	785.00	M4	Ø0,3	BM21-2-01	
BM21-2-06	59.00	745.00	M4	Ø0,3	BM21-2-01	
BM21-2-07	59.00	705.00	M4	Ø0,3	BM21-2-01	
BM21-2-08	99.00	705.00	M4	Ø0,3	BM21-2-01	
BM21-2-09	139.00	705.00	M4	Ø0,3	BM21-2-01	
BM21-3-01	99.00	100.00	M4	Ø0,4	Xp Yp AXIS	
BM21-3-02	139.00	100.00	M4	Ø0,3	BM21-3-01	
BM21-3-03	139.00	140.00	M4	Ø0,3	BM21-3-01	
BM21-3-04	99.00	140.00	M4	Ø0,3	BM21-3-01	
BM21-3-05	59.00	140.00	M4	Ø0,3	BM21-3-01	
BM21-3-06	59.00	100.00	M4	Ø0,3	BM21-3-01	
BM21-3-07	59.00	60.00	M4	Ø0,3	BM21-3-01	
BM21-3-08	99.00	60.00	M4	Ø0,3	BM21-3-01	
BM21-3-09	139.00	60.00	M4	Ø0,3	BM21-3-01	

ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
BM21-4-01	1015.00	140.00	M4	Ø0,4	Xp Yp AXIS	
BM21-4-02	1055.00	140.00	M4	Ø0,3	BM21-4-01	
BM21-4-03	1055.00	180.00	M4	Ø0,3	BM21-4-01	
BM21-4-04	1015.00	180.00	M4	Ø0,3	BM21-4-01	
BM21-4-05	975.00	180.00	M4	Ø0,3	BM21-4-01	
BM21-4-06	975.00	140.00	M4	Ø0,3	BM21-4-01	
BM21-4-07	975.00	100.00	M4	Ø0,3	BM21-4-01	
BM21-4-08	1015.00	100.00	M4	Ø0,3	BM21-4-01	
BM21-4-09	1055.00	100.00	M4	Ø0,3	BM21-4-01	
MGSE-21-01	859.25	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-02	432.75	672.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-03	202.25	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-04	190.77	420.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-05	220.25	100.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-06	557.75	168.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-07	895.75	100.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-08	924.77	482.50	M6	Ø0,3	Xp Yp AXIS	MGSE

Fig. 3.4.3-1. Herschel PACS panel +Y-Z (outside of the SVM)

3.5 PLANCK WARM UNIT ACCOMODATION

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

3.5.1 HFI WARM UNITS

The HFI Warm Units are mainly grouped on three dedicated SVM panels, while the Pre-Amplifier Unit is located on the P/L sub. PLT and the 4K Current Pre-Regulator is located on a shear panel.
In the following table there are the project codes allocated to HFI warm units:

Project Code	Instrument Unit
PHDA	HFI 4K Cooler Compressor Unit (4KCCU)
PHDB	HFI 4K Cooler Ancillary Unit (4KCAU)
PHDC	HFI 4K Cooler Electronics Unit (4KCDE)
PHBA-N	HFI Data Processing Unit (DPU) Nom.
PHBA-R	HFI Data Processing Unit (DPU) Red.
PHCBC	HFI Readout Electronics (REU)
PHEB	HFI Dilution Cooler Contr. Unit (DCCU)
PHDJ	HFI 4K Current Pre-Regulator
PHCBA	HFI Pre-Amplifier Unit (PAU)

In the following tables below are indicated the dimensions, the masses and the drawings ref. numbers for each HFI Warm Unit:

Table 3.5.1.: HFI W.U. dimensions and mass.

Project Code	# of	Dimensions (mm)	Mass (kg)
PHDA	1	460 x 250 x 200	14.9
PHDB	1	384 x 415 x 127.8	7.1
PHDC	1	220 x 220 x 200	6.4
PHBA-N&R	1+1	316 x 280 x 90	5.0
PHCBC	1	410.5 x 410.4 x 320.3	33.5
PHEB	1	800 x 785.6 x 170	19.1
PHDJ	1	226 x 206 x 55	2.3
PHCBA	1	446 x 261 x 215	13.2
Total			**106.5**

Table 3.5.1-1: HFI W.U. Reference Drawings.

HFI unit	Drawing Ref. Number	Drawing issue	Drawing date
PHDA	CO-65720 Sheet 1 TS-0063-807 TS-0063-830 TS-0063-831	01 C A A	08-03-02 19-11-02 TBD TBD
PHDB	PLS114FS002S A TS-0063-700 TS-0063-701	A TBD B	22-07-03 TBD 19-11-02
PHDC	O-KE-0151-001-E Sheet 1 & 2	E	11-09-02
PHBA-N&R	I592EB003 I591EB002 I591EB004	B A A	02-12-02 05-06-02 29-10-02
PHCBC	PHREUMQENS01	C	29-07-03
PHEB	H0201I001-A H0201I003-A	A1 A1	07-10-03 07-10-03
PHDJ	CDE-ID-1275-00002-CRS	2	02-12-03
PHCBA	PHPAUMQMID01	C	29-07-03

Inside of the SVM the HFI W.U. are located as below:

- +Y Panel: 4KCCU, 4KCAU, 4KCDE and REU
- +Y+Z(+Z) Shear panel: 4K Current Pre-Regulator
- +Z Panel: DPU (nom.+ red.)
- +Y+Z Panel: DCCU
- P\L Sub. PLT +X: PAU
- +Y Panel:

The following figures show the +Y panel with 4KCCU, 4KCAU, 4KCDE and the REU.

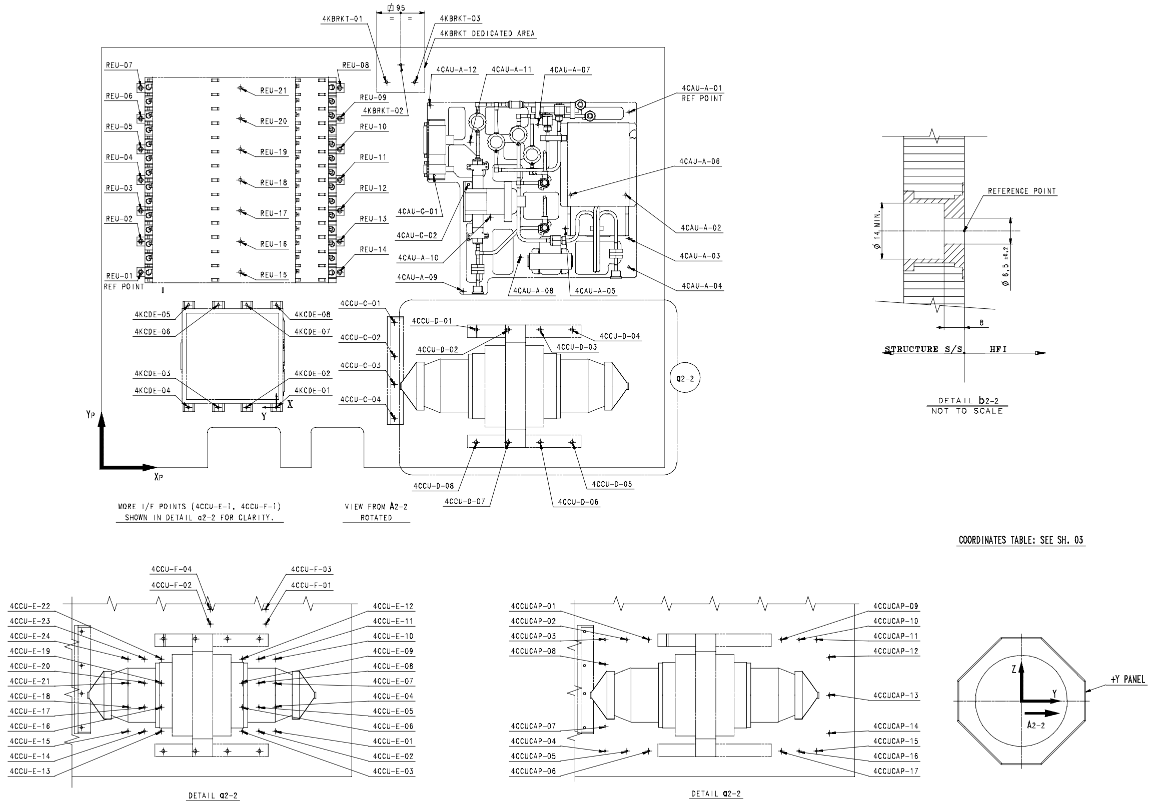
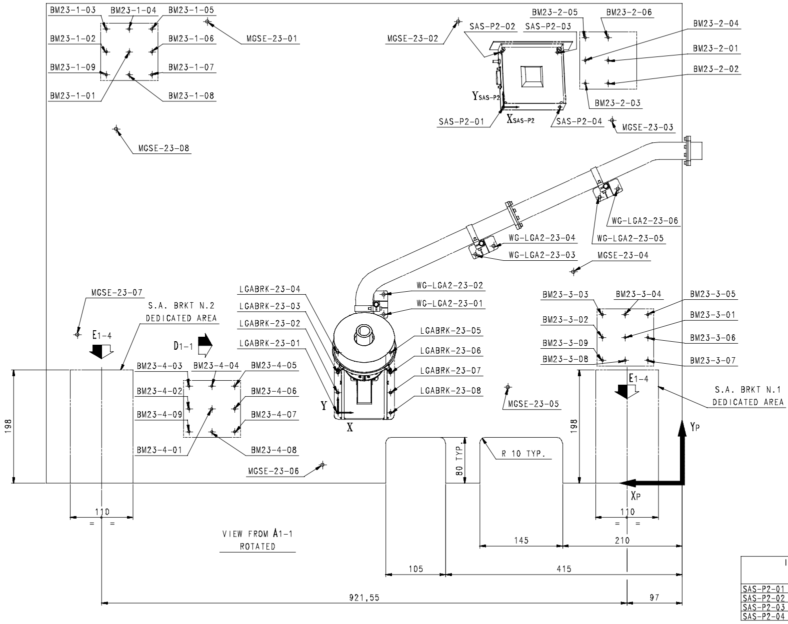
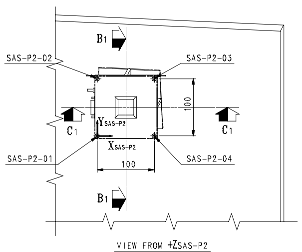


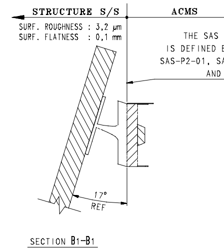
Fig 3.5.1 Planck +Y Lateral Panel REU, 4KCCU, 4KCAU, 4KCDE (HFI).

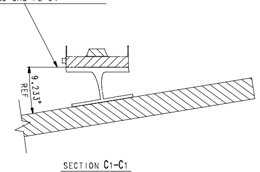


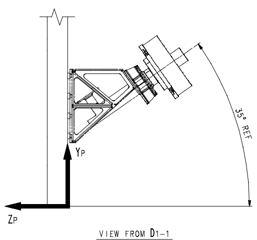
ITEM	COORDINATES		INSERT TYPE	POSITION TOLERANCE		S/S
	Xp mm	Yp mm		⌖	REFERENCE	
BM23-1-01	970.00	755.00	M4	Ø0,4	Xp Yp AXIS	
BM23-1-02	1010.00	755.00	M4	Ø0,3	BM23-1-01	
BM23-1-03	1010.00	795.00	M4	Ø0,3	BM23-1-01	
BM23-1-04	970.00	795.00	M4	Ø0,3	BM23-1-01	
BM23-1-05	930.00	795.00	M4	Ø0,3	BM23-1-01	
BM23-1-06	930.00	755.00	M4	Ø0,3	BM23-1-01	
BM23-1-07	930.00	715.00	M4	Ø0,3	BM23-1-01	
BM23-1-08	970.00	715.00	M4	Ø0,3	BM23-1-01	
BM23-1-09	1010.00	715.00	M4	Ø0,3	BM23-1-01	
BM23-2-01	130.00	740.00	M4	Ø0,4	Xp Yp AXIS	
BM23-2-02	130.00	700.00	M4	Ø0,3	BM23-2-01	
BM23-2-03	170.00	700.00	M4	Ø0,3	BM23-2-01	
BM23-2-04	170.00	740.00	M4	Ø0,3	BM23-2-01	
BM23-2-05	170.00	780.00	M4	Ø0,3	BM23-2-01	
BM23-2-06	130.00	780.00	M4	Ø0,3	BM23-2-01	
BM23-3-01	100.00	255.00	M4	Ø0,4	Xp Yp AXIS	
BM23-3-02	140.00	255.00	M4	Ø0,3	BM23-3-01	
BM23-3-03	140.00	295.00	M4	Ø0,3	BM23-3-01	
BM23-3-04	100.00	295.00	M4	Ø0,3	BM23-3-01	
BM23-3-05	60.00	295.00	M4	Ø0,3	BM23-3-01	
BM23-3-06	60.00	255.00	M4	Ø0,3	BM23-3-01	
BM23-3-07	60.00	215.00	M4	Ø0,3	BM23-3-01	
BM23-3-08	100.00	215.00	M4	Ø0,3	BM23-3-01	
BM23-3-09	140.00	215.00	M4	Ø0,3	BM23-3-01	
BM23-4-01	825.00	130.00	M4	Ø0,4	Xp Yp AXIS	
BM23-4-02	865.00	130.00	M4	Ø0,3	BM23-4-01	
BM23-4-03	865.00	170.00	M4	Ø0,3	BM23-4-01	
BM23-4-04	825.00	170.00	M4	Ø0,3	BM23-4-01	
BM23-4-05	785.00	170.00	M4	Ø0,3	BM23-4-01	
BM23-4-06	785.00	130.00	M4	Ø0,3	BM23-4-01	
BM23-4-07	785.00	90.00	M4	Ø0,3	BM23-4-01	
BM23-4-08	825.00	90.00	M4	Ø0,3	BM23-4-01	
BM23-4-09	865.00	90.00	M4	Ø0,3	BM23-4-01	
LGABRK-23-01	603.90	123.40	M4	Ø0,4	Xp Yp AXIS	TT&C
LGABRK-23-02	603.90	158.40	M4	Ø0,3	LGABRK-23-01	TT&C
LGABRK-23-03	603.90	193.40	M4	Ø0,3	LGABRK-23-01	TT&C
LGABRK-23-04	603.90	228.40	M4	Ø0,3	LGABRK-23-01	TT&C
LGABRK-23-05	511.60	228.40	M4	Ø0,3	LGABRK-23-01	TT&C
LGABRK-23-06	511.60	193.40	M4	Ø0,3	LGABRK-23-01	TT&C
LGABRK-23-07	511.60	158.40	M4	Ø0,3	LGABRK-23-01	TT&C
LGABRK-23-08	511.60	123.40	M4	Ø0,3	LGABRK-23-01	TT&C
MGSE-23-01	832.75	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-23-02	392.75	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-23-03	122.74	635.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-23-04	190.75	370.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-23-05	305.75	168.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-23-06	630.75	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-23-07	1060.75	260.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-23-08	992.74	620.00	M6	Ø0,3	Xp Yp AXIS	MGSE
WG-LGA2-23-01	523.61	295.27	M4	Ø0,3	Xp Yp AXIS	TT&C
WG-LGA2-23-02	523.61	330.27	M4	Ø0,3	Xp Yp AXIS	TT&C
WG-LGA2-23-03	362.38	400.50	M4	Ø0,3	Xp Yp AXIS	TT&C
WG-LGA2-23-04	330.58	415.11	M4	Ø0,3	Xp Yp AXIS	TT&C
WG-LGA2-23-05	144.29	500.67	M4	Ø0,3	Xp Yp AXIS	TT&C
WG-LGA2-23-06	112.48	515.28	M4	Ø0,3	Xp Yp AXIS	TT&C

ITEM	COORDINATES			INSERT TYPE	POSITION TOLERANCE		S/S
	Xp mm	Yp mm	Zp mm		⌖	REFERENCE	
SAS-P2-01	313.130	658.318	-81.537	M4	Ø0,4	Xp Yp Zp AXIS	ACMS
SAS-P2-02	317.621	753.948	-52.647	M4	Ø0,3	SAS-P2-01	ACMS
SAS-P2-03	218.808	753.948	-37.285	M4	Ø0,3	SAS-P2-01	ACMS
SAS-P2-04	214.317	658.318	-66.175	M4	Ø0,3	SAS-P2-01	ACMS









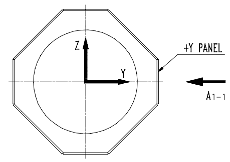


Fig 3.5.1-1 Planck +Y Lateral Panel (outside of the SVM).

REF TO SHEET 02

ITEM	COORDINATES		INSERT TYPE	POSITION TOLERANCE		S/S
	Xp mm	Yp mm		⌖	REFERENCE	
4CAU-A-01	1045.50	710.50	M4	Ø0,4	Xp Yp AXIS	HFI
4CAU-A-02	1039.00	545.00	M4	Ø0,3	4CAU-A-01	HFI
4CAU-A-03	1045.50	457.50	M4	Ø0,3	4CAU-A-01	HFI
4CAU-A-04	1045.50	400.50	M4	Ø0,3	4CAU-A-01	HFI
4CAU-A-05	919.50	477.50	M4	Ø0,3	4CAU-A-01	HFI
4CAU-A-06	930.00	545.00	M4	Ø0,3	4CAU-A-01	HFI
4CAU-A-07	865.50	685.50	M4	Ø0,3	4CAU-A-01	HFI
4CAU-A-08	830.50	420.50	M4	Ø0,3	4CAU-A-01	HFI
4CAU-A-09	716.50	352.50	M4	Ø0,3	4CAU-A-01	HFI
4CAU-A-10	770.50	500.50	M4	Ø0,3	4CAU-A-01	HFI
4CAU-A-11	730.50	650.50	M4	Ø0,3	4CAU-A-01	HFI
4CAU-A-12	651.50	724.50	M4	Ø0,3	4CAU-A-01	HFI
4CAU-G-01	659.50	583.50	M4	Ø0,3	4CAU-A-01	HFI
4CAU-G-02	727.50	566.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-C-01	580.50	290.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-C-02	580.50	222.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-C-03	580.50	166.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-C-04	580.50	98.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-D-01	742.50	275.50	M6	Ø0,3	4CAU-A-01	HFI
4CCU-D-02	806.00	275.50	M6	Ø0,3	4CAU-A-01	HFI
4CCU-D-03	869.50	275.50	M6	Ø0,3	4CAU-A-01	HFI
4CCU-D-04	933.00	275.50	M6	Ø0,3	4CAU-A-01	HFI
4CCU-D-05	933.00	50.50	M6	Ø0,3	4CAU-A-01	HFI
4CCU-D-06	869.50	50.50	M6	Ø0,3	4CAU-A-01	HFI
4CCU-D-07	806.00	50.50	M6	Ø0,3	4CAU-A-01	HFI
4CCU-D-08	742.50	50.50	M6	Ø0,3	4CAU-A-01	HFI
4CCU-E-01	965.00	91.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-02	932.00	91.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-03	899.00	91.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-04	965.00	139.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-05	932.00	139.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-06	899.00	139.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-07	965.00	187.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-08	932.00	187.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-09	899.00	187.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-10	965.00	235.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-11	932.00	235.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-12	899.00	235.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-13	738.00	91.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-14	705.00	91.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-15	672.00	91.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-16	738.00	139.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-17	705.00	139.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-18	672.00	139.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-19	738.00	187.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-20	705.00	187.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-21	672.00	187.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-22	738.00	235.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-23	705.00	235.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-E-24	672.00	235.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-F-01	945.50	305.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-F-02	835.50	305.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-F-03	945.50	335.00	M4	Ø0,3	4CAU-A-01	HFI
4CCU-F-04	835.50	335.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-01	707.50	274.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-02	664.25	274.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-03	621.00	274.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-04	621.00	51.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-05	664.25	51.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-06	707.50	51.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-07	621.00	100.33	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-08	621.00	224.67	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-09	970.50	274.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-10	1005.50	274.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-11	1040.50	274.00	M4	Ø0,3	4CAU-A-01	HFI

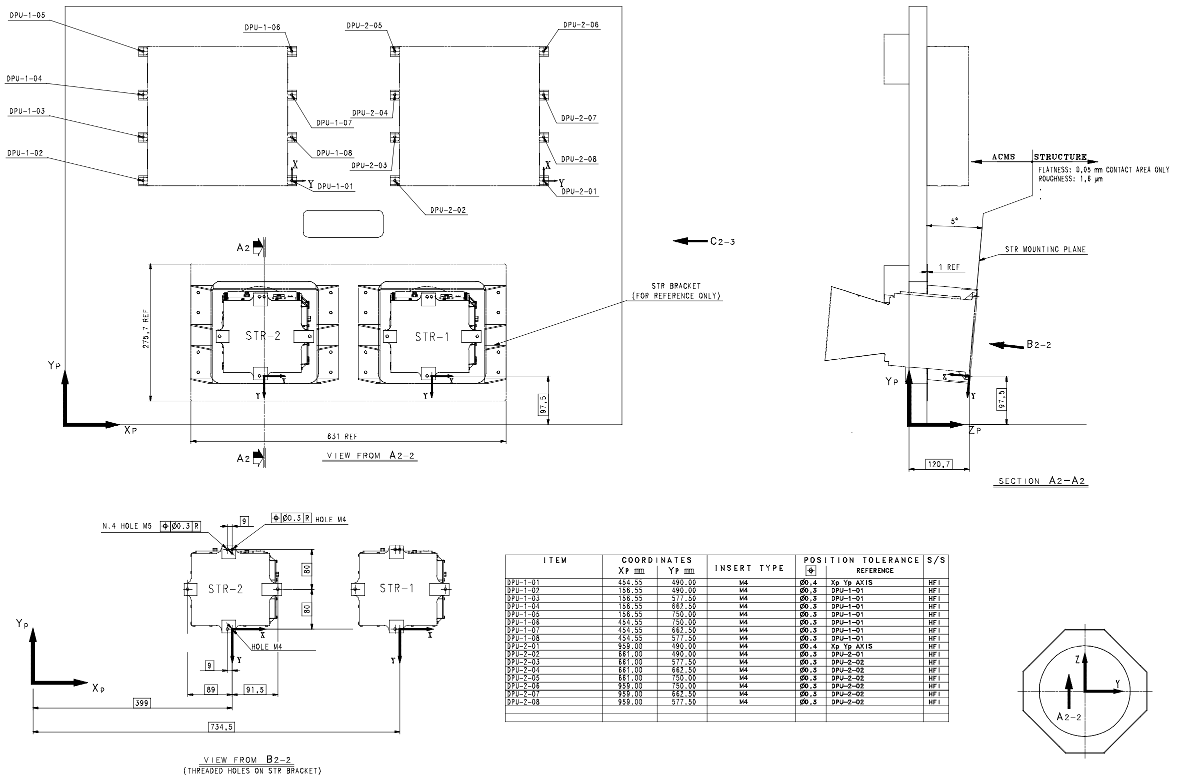
REF TO SHEET 02

ITEM	COORDINATES		INSERT TYPE	POSITION TOLERANCE		S/S
	Xp mm	Yp mm		⌖	REFERENCE	
4CCUCAP-12	1065.50	238.25	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-13	1065.50	162.50	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-14	1065.50	86.75	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-15	1040.50	51.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-16	1005.50	51.00	M4	Ø0,3	4CAU-A-01	HFI
4CCUCAP-17	970.50	51.00	M4	Ø0,3	4CAU-A-01	HFI
4KBRKT-01	565.55	770.00	M5	Ø0,4	Xp Yp AXIS	HFI
4KBRKT-02	593.05	805.00	M5	Ø0,3	4KBRKT-01	HFI
4KBRKT-03	620.55	770.00	M5	Ø0,3	4KBRKT-01	HFI
4KCDE-01	346.50	120.00	M4	Ø0,4	Xp Yp AXIS	HFI
4KCDE-02	287.50	120.00	M4	Ø0,3	4KCDE-01	HFI
4KCDE-03	231.50	120.00	M4	Ø0,3	4KCDE-01	HFI
4KCDE-04	172.50	120.00	M4	Ø0,3	4KCDE-01	HFI
4KCDE-05	172.50	325.00	M4	Ø0,3	4KCDE-01	HFI
4KCDE-06	231.50	325.00	M4	Ø0,3	4KCDE-01	HFI
4KCDE-07	287.50	325.00	M4	Ø0,3	4KCDE-01	HFI
4KCDE-08	346.50	325.00	M4	Ø0,3	4KCDE-01	HFI
REU-01	78.00	390.60	M6	Ø0,4	Xp Yp AXIS	HFI
REU-02	78.00	452.00	M6	Ø0,3	REU-01	HFI
REU-03	78.00	513.40	M6	Ø0,3	REU-01	HFI
REU-04	78.00	574.80	M6	Ø0,3	REU-01	HFI
REU-05	78.00	636.20	M6	Ø0,3	REU-01	HFI
REU-06	78.00	697.60	M6	Ø0,3	REU-01	HFI
REU-07	78.00	759.00	M6	Ø0,3	REU-01	HFI
REU-08	472.56	759.00	M6	Ø0,3	REU-01	HFI
REU-09	472.56	697.60	M6	Ø0,3	REU-01	HFI
REU-10	472.56	636.20	M6	Ø0,3	REU-01	HFI
REU-11	472.56	574.80	M6	Ø0,3	REU-01	HFI
REU-12	472.56	513.40	M6	Ø0,3	REU-01	HFI
REU-13	472.56	452.00	M6	Ø0,3	REU-01	HFI
REU-14	472.56	390.60	M6	Ø0,3	REU-01	HFI
REU-15	275.28	390.60	THROUGH (Det. b2-2)	Ø0,2	REU-01	HFI
REU-16	275.28	452.00	THROUGH (Det. b2-2)	Ø0,2	REU-01	HFI
REU-17	275.28	513.40	THROUGH (Det. b2-2)	Ø0,2	REU-01	HFI
REU-18	275.28	574.80	THROUGH (Det. b2-2)	Ø0,2	REU-01	HFI
REU-19	275.28	636.20	THROUGH (Det. b2-2)	Ø0,2	REU-01	HFI
REU-20	275.28	697.60	THROUGH (Det. b2-2)	Ø0,2	REU-01	HFI
REU-21	275.28	759.00	THROUGH (Det. b2-2)	Ø0,2	REU-01	HFI

Fig 3.5.1-2 Planck +Y Lateral Panel coordinates and type of the HFI boxes inserts.

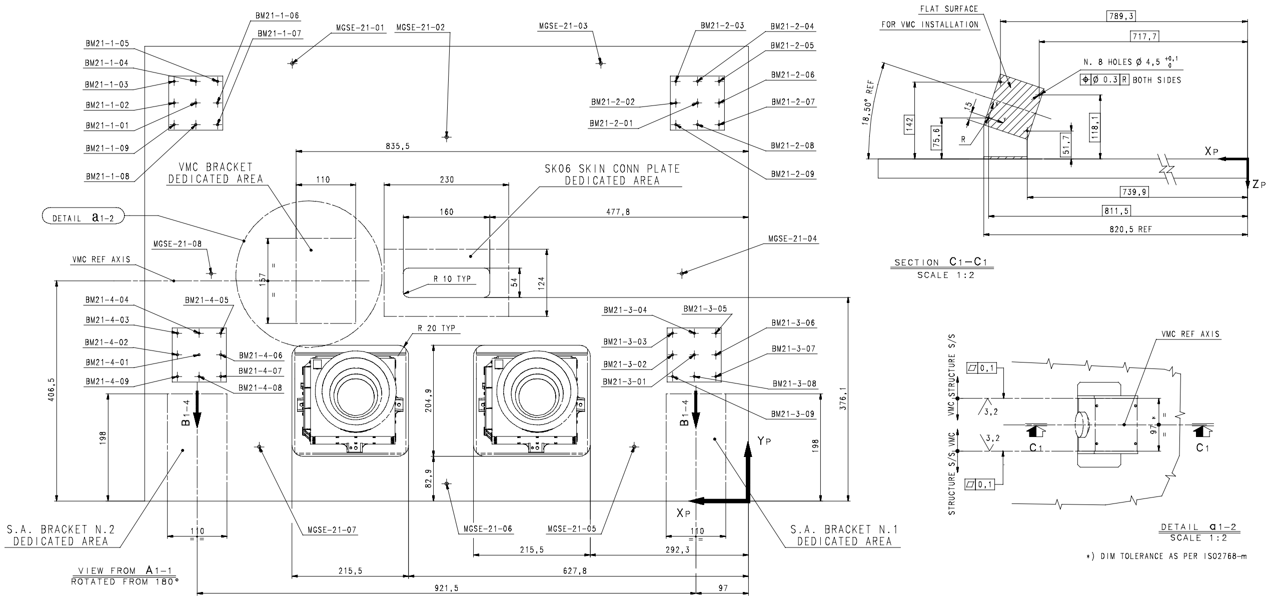
- +Z Panel:

The following figures show the +Z panel with the DPU (nom + red); on this panel are also located the two Star Tracker as indicated in Fig.3.5.1-3.:



ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
DPU-1-01	454.55	490.00	M4	Ø0,4	Xp Yp AXIS	HFI
DPU-1-02	156.55	490.00	M4	Ø0,3	DPU-1-01	HFI
DPU-1-03	156.55	577.50	M4	Ø0,3	DPU-1-01	HFI
DPU-1-04	156.55	662.50	M4	Ø0,3	DPU-1-01	HFI
DPU-1-05	156.55	750.00	M4	Ø0,3	DPU-1-01	HFI
DPU-1-06	454.55	750.00	M4	Ø0,3	DPU-1-01	HFI
DPU-1-07	454.55	662.50	M4	Ø0,3	DPU-1-01	HFI
DPU-1-08	454.55	577.50	M4	Ø0,3	DPU-1-01	HFI
DPU-2-01	959.00	490.00	M4	Ø0,4	Xp Yp AXIS	HFI
DPU-2-02	661.00	490.00	M4	Ø0,3	DPU-2-01	HFI
DPU-2-03	661.00	577.50	M4	Ø0,3	DPU-2-02	HFI
DPU-2-04	661.00	662.50	M4	Ø0,3	DPU-2-02	HFI
DPU-2-05	661.00	750.00	M4	Ø0,3	DPU-2-02	HFI
DPU-2-06	959.00	750.00	M4	Ø0,3	DPU-2-02	HFI
DPU-2-07	959.00	662.50	M4	Ø0,3	DPU-2-02	HFI
DPU-2-08	959.00	577.50	M4	Ø0,3	DPU-2-02	HFI

Fig 3.5.1-3 Planck +Z Lateral Panel DPU (HFI).



ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
BM21-1-01	1021.00	735.00	M4	Ø0,4	Xp Yp AXIS	
BM21-1-02	1061.00	735.00	M4	Ø0,3	BM21-1-01	
BM21-1-03	1061.00	775.00	M4	Ø0,3	BM21-1-01	
BM21-1-04	1021.00	775.00	M4	Ø0,3	BM21-1-01	
BM21-1-05	981.00	775.00	M4	Ø0,4	BM21-1-01	
BM21-1-06	981.00	735.00	M4	Ø0,3	BM21-1-01	
BM21-1-07	981.00	695.00	M4	Ø0,3	BM21-1-01	
BM21-1-08	1021.00	695.00	M4	Ø0,3	BM21-1-01	
BM21-1-09	1061.00	695.00	M4	Ø0,3	BM21-1-01	
BM21-2-01	94.00	735.00	M4	Ø0,4	Xp Yp AXIS	
BM21-2-02	134.00	735.00	M4	Ø0,3	BM21-2-01	
BM21-2-03	134.00	775.00	M4	Ø0,3	BM21-2-01	
BM21-2-04	94.00	775.00	M4	Ø0,3	BM21-2-01	
BM21-2-05	54.00	775.00	M4	Ø0,3	BM21-2-01	
BM21-2-06	54.00	735.00	M4	Ø0,3	BM21-2-01	
BM21-2-07	54.00	695.00	M4	Ø0,3	BM21-2-01	
BM21-2-08	94.00	695.00	M4	Ø0,3	BM21-2-01	
BM21-2-09	134.00	695.00	M4	Ø0,3	BM21-2-01	
BM21-3-01	100.00	270.00	M4	Ø0,4	Xp Yp AXIS	
BM21-3-02	140.00	270.00	M4	Ø0,3	BM21-3-01	
BM21-3-03	140.00	310.00	M4	Ø0,3	BM21-3-01	
BM21-3-04	100.00	310.00	M4	Ø0,3	BM21-3-01	
BM21-3-05	60.00	310.00	M4	Ø0,3	BM21-3-01	
BM21-3-06	60.00	270.00	M4	Ø0,3	BM21-3-01	
BM21-3-07	60.00	230.00	M4	Ø0,3	BM21-3-01	
BM21-3-08	100.00	230.00	M4	Ø0,3	BM21-3-01	
BM21-3-09	140.00	230.00	M4	Ø0,3	BM21-3-01	

ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
BM21-4-01	1015.00	270.00	M4	Ø0,4	Xp Yp AXIS	
BM21-4-02	1055.00	270.00	M4	Ø0,3	BM21-4-01	
BM21-4-03	1055.00	310.00	M4	Ø0,3	BM21-4-01	
BM21-4-04	1015.00	310.00	M4	Ø0,3	BM21-4-01	
BM21-4-05	975.00	310.00	M4	Ø0,3	BM21-4-01	
BM21-4-06	975.00	270.00	M4	Ø0,3	BM21-4-01	
BM21-4-07	975.00	230.00	M4	Ø0,3	BM21-4-01	
BM21-4-08	1015.00	230.00	M4	Ø0,3	BM21-4-01	
BM21-4-09	1055.00	230.00	M4	Ø0,3	BM21-4-01	
MGSE-21-01	842.75	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-02	557.75	672.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-03	272.75	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-04	122.75	420.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-05	211.00	100.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-06	557.75	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-07	904.00	100.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-21-08	992.75	420.00	M6	Ø0,3	Xp Yp AXIS	MGSE

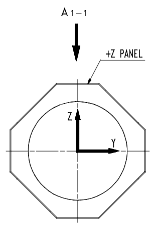


Fig 3.5.1-4 Planck +Z Lateral Panel.(outside of the SVM).

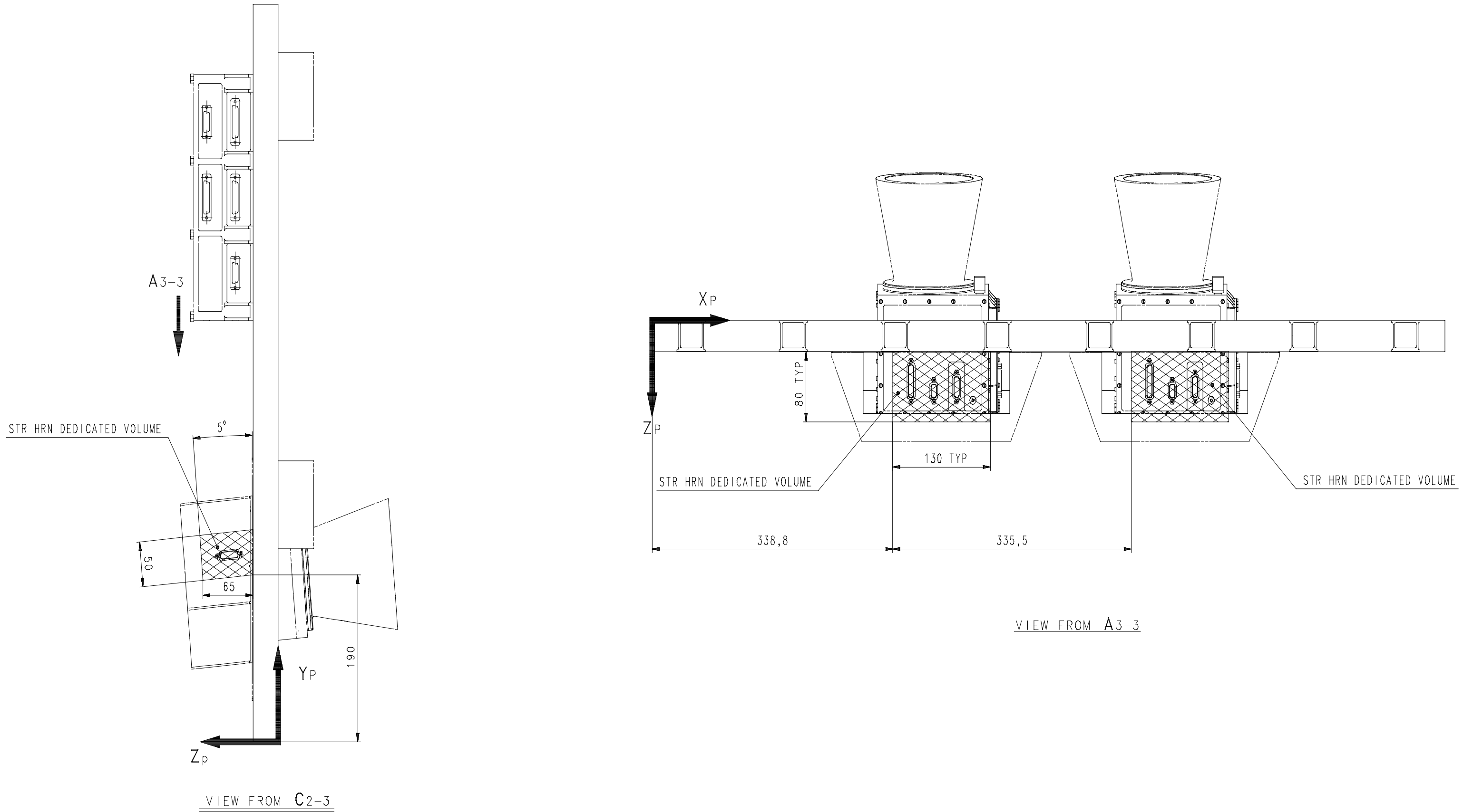
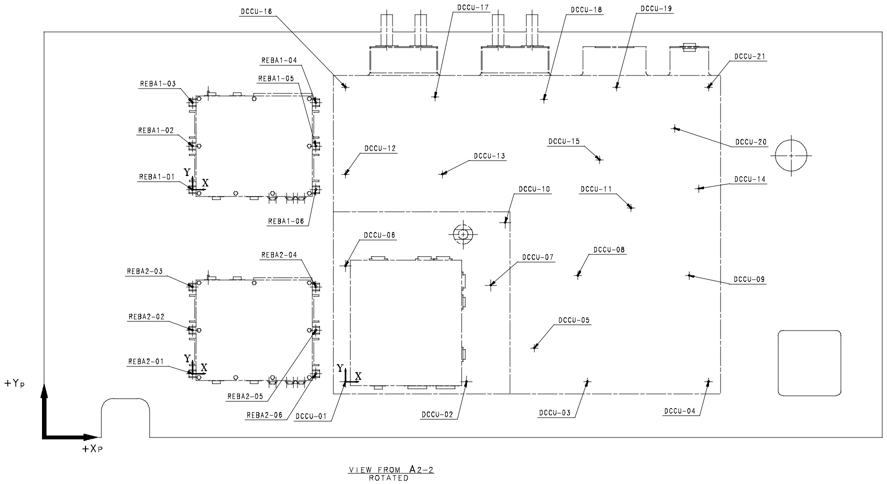


Fig 3.5.1-5 Planck +Z Lateral Panel (sections views).

- +Y+Z Panel:

The following figures show the +Y+Z panel with the DCCU; on this panel, are also located two LFI warm units: the REBA's as indicated in Fig.3.5.1-6.:



ITEM	COORDINATES		INSERT TYPE	POSITION TOLERANCE		S/S
	Xp mm	Yp mm		⌖	REFERENCE	
DCCU-01	622.60	115.00	M4	Ø0,4	Xp Xp AXIS	HFI
DCCU-02	872.60	115.00	M4	Ø0,3	DCCU-01	HFI
DCCU-03	1122.60	115.00	M4	Ø0,3	DCCU-01	HFI
DCCU-04	1372.60	115.00	M4	Ø0,3	DCCU-01	HFI
DCCU-05	1012.60	185.00	M4	Ø0,3	DCCU-01	HFI
DCCU-06	622.60	355.00	M4	Ø0,3	DCCU-01	HFI
DCCU-07	922.60	315.00	M4	Ø0,3	DCCU-01	HFI
DCCU-08	1102.60	335.00	M4	Ø0,3	DCCU-01	HFI
DCCU-09	1332.60	335.00	M4	Ø0,3	DCCU-01	HFI
DCCU-10	952.60	445.00	M4	Ø0,3	DCCU-01	HFI
DCCU-11	1212.60	475.00	M4	Ø0,3	DCCU-01	HFI
DCCU-12	622.60	545.00	M4	Ø0,3	DCCU-01	HFI
DCCU-13	822.60	545.00	M4	Ø0,3	DCCU-01	HFI
DCCU-14	1352.60	515.00	M4	Ø0,3	DCCU-01	HFI
DCCU-15	1147.60	575.00	M4	Ø0,3	DCCU-01	HFI
DCCU-16	622.60	725.00	M4	Ø0,3	DCCU-01	HFI
DCCU-17	807.60	705.00	M4	Ø0,3	DCCU-01	HFI
DCCU-18	1032.60	700.00	M4	Ø0,3	DCCU-01	HFI
DCCU-19	1182.60	725.00	M4	Ø0,3	DCCU-01	HFI
DCCU-20	1302.60	640.00	M4	Ø0,3	DCCU-01	HFI
DCCU-21	1372.60	725.00	M4	Ø0,3	DCCU-01	HFI
REBA1-01	306.35	513.25	M4	Ø0,4	Xp Xp AXIS	LFI
REBA1-02	306.35	603.25	M4	Ø0,3	REBA1-01	LFI
REBA1-03	306.35	693.25	M4	Ø0,3	REBA1-01	LFI
REBA1-04	561.35	693.25	M4	Ø0,3	REBA1-01	LFI
REBA1-05	561.35	603.25	M4	Ø0,3	REBA1-01	LFI
REBA1-06	561.35	513.25	M4	Ø0,3	REBA1-01	LFI
REBA2-01	306.35	131.75	M4	Ø0,4	Xp Xp AXIS	LFI
REBA2-02	306.35	221.75	M4	Ø0,3	REBA2-01	LFI
REBA2-03	306.35	311.75	M4	Ø0,3	REBA2-01	LFI
REBA2-04	561.35	311.75	M4	Ø0,3	REBA2-01	LFI
REBA2-05	561.35	221.75	M4	Ø0,3	REBA2-01	LFI
REBA2-06	561.35	131.75	M4	Ø0,3	REBA2-01	LFI

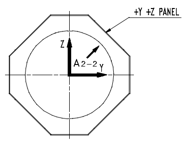
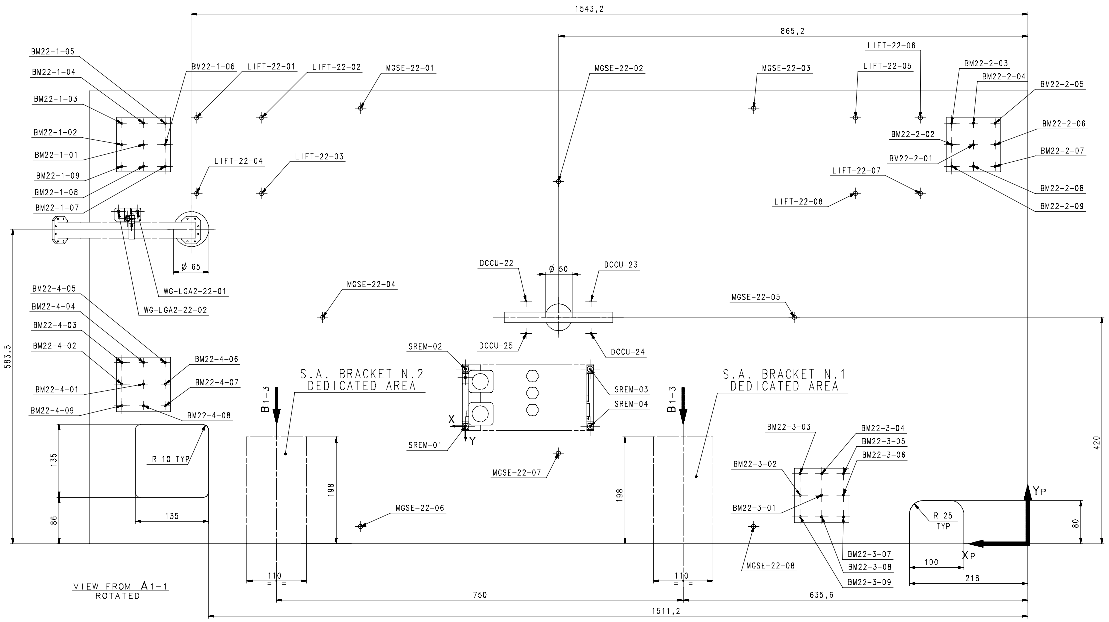


Fig 3.5.1-6 Planck +Y+Z Lateral Panel DCCU (HFI) and REBA (LFI).



ITEM	COORDINATES Xp mm	COORDINATES Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
BM22-1-01	1631.09	740.00	M4	Ø0,4	Xp Yp AXIS	
BM22-1-02	1671.09	740.00	M4	Ø0,3	BM22-1-01	
BM22-1-03	1671.09	780.00	M4	Ø0,3	BM22-1-01	
BM22-1-04	1631.09	780.00	M4	Ø0,3	BM22-1-01	
BM22-1-05	1591.09	780.00	M4	Ø0,3	BM22-1-01	
BM22-1-06	1591.09	740.00	M4	Ø0,3	BM22-1-01	
BM22-1-07	1591.09	700.00	M4	Ø0,3	BM22-1-01	
BM22-1-08	1631.09	700.00	M4	Ø0,3	BM22-1-01	
BM22-1-09	1671.09	700.00	M4	Ø0,3	BM22-1-01	
BM22-2-01	100.09	740.00	M4	Ø0,4	Xp Yp AXIS	
BM22-2-02	140.09	740.00	M4	Ø0,3	BM22-2-01	
BM22-2-03	140.09	780.00	M4	Ø0,3	BM22-2-01	
BM22-2-04	100.09	780.00	M4	Ø0,3	BM22-2-01	
BM22-2-05	60.09	780.00	M4	Ø0,3	BM22-2-01	
BM22-2-06	60.09	740.00	M4	Ø0,3	BM22-2-01	
BM22-2-07	60.09	700.00	M4	Ø0,3	BM22-2-01	
BM22-2-08	100.09	700.00	M4	Ø0,3	BM22-2-01	
BM22-2-09	140.09	700.00	M4	Ø0,3	BM22-2-01	
BM22-3-01	380.00	90.00	M4	Ø0,4	Xp Yp AXIS	
BM22-3-02	420.00	90.00	M4	Ø0,3	BM22-3-01	
BM22-3-03	420.00	130.00	M4	Ø0,3	BM22-3-01	
BM22-3-04	380.00	130.00	M4	Ø0,3	BM22-3-01	
BM22-3-05	340.00	130.00	M4	Ø0,3	BM22-3-01	
BM22-3-06	340.00	90.00	M4	Ø0,3	BM22-3-01	
BM22-3-07	340.00	50.00	M4	Ø0,3	BM22-3-01	
BM22-3-08	380.00	50.00	M4	Ø0,3	BM22-3-01	
BM22-3-09	420.00	50.00	M4	Ø0,3	BM22-3-01	
BM22-4-01	1631.09	296.00	M4	Ø0,4	Xp Yp AXIS	
BM22-4-02	1671.09	296.00	M4	Ø0,3	BM22-4-01	
BM22-4-03	1671.09	336.00	M4	Ø0,3	BM22-4-01	
BM22-4-04	1631.09	336.00	M4	Ø0,3	BM22-4-01	
BM22-4-05	1591.09	336.00	M4	Ø0,3	BM22-4-01	
BM22-4-06	1591.09	296.00	M4	Ø0,3	BM22-4-01	
BM22-4-07	1591.09	256.00	M4	Ø0,3	BM22-4-01	
BM22-4-08	1631.09	256.00	M4	Ø0,3	BM22-4-01	
BM22-4-09	1671.09	256.00	M4	Ø0,3	BM22-4-01	
DCCU-22	925.60	450.00	M4	Ø0,4	Xp Yp AXIS	
DCCU-23	805.60	450.00	M4	Ø0,3	DCCU-22	HFI
DCCU-24	805.60	390.00	M4	Ø0,3	DCCU-22	HFI
DCCU-25	925.60	390.00	M4	Ø0,3	DCCU-22	HFI
LIFT-22-01	1533.11	790.00	M8 TBC	Ø0,4	Xp Yp AXIS	MGSE
LIFT-22-02	1413.11	790.00	M8 TBC	Ø0,3	LIFT-01	MGSE
LIFT-22-03	1413.11	650.00	M8 TBC	Ø0,3	LIFT-01	MGSE
LIFT-22-04	1533.11	650.00	M8 TBC	Ø0,3	LIFT-01	MGSE
LIFT-22-05	318.06	790.00	M8 TBC	Ø0,4	Xp Yp AXIS	MGSE
LIFT-22-06	198.06	790.00	M8 TBC	Ø0,3	LIFT-05	MGSE
LIFT-22-07	198.06	650.00	M8 TBC	Ø0,3	LIFT-05	MGSE
LIFT-22-08	318.06	650.00	M8 TBC	Ø0,3	LIFT-05	MGSE
MGSE-22-01	1230.60	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-02	865.60	672.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-03	505.60	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-04	1300.59	420.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-05	430.59	420.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-06	1230.60	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-07	865.60	168.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-22-08	505.60	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
SREM-01	1037.00	218.00	M4	Ø0,4	Xp Yp AXIS	CFE
SREM-02	1037.00	324.00	M4	Ø0,3	SREM-01	CFE
SREM-03	807.00	324.00	M4	Ø0,3	SREM-01	CFE
SREM-04	807.00	218.00	M4	Ø0,3	SREM-01	CFE
WG-LGA2-22-01	1642.67	615.89	M4	Ø0,3	Xp Yp AXIS	TT&C
WG-LGA2-22-02	1677.67	615.89	M4	Ø0,3	Xp Yp AXIS	TT&C

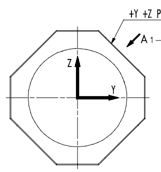
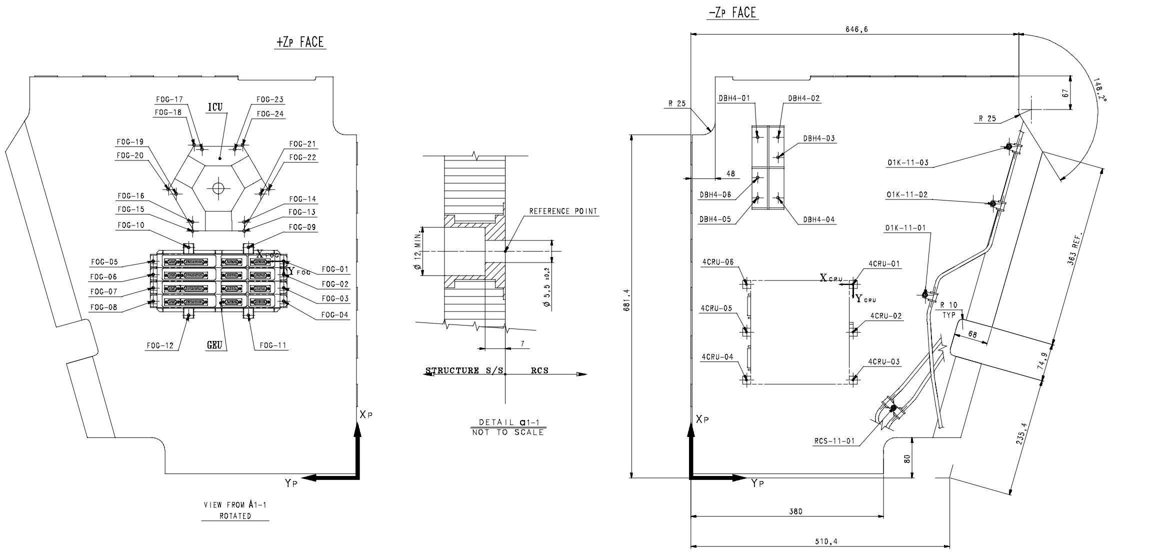


Fig 3.5.1-7 Planck +Y+Z Lateral Panel.(outside of the SVM).

- +Y+Z(+Z) Shear Panel:

The following figure shows the +Y+Z(+Z) shear panel with the 4KCRU:



+Zp FACE

ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POS. TOL. ⌖	SUBSYSTEM
FOG-01	430.20	145.38	M4	Ø0,4 REF TO Xp,Yp AXIS	CFE
FOG-02	403.70	145.38	M4	Ø0,3 REF TO FOG-01	CFE
FOG-03	377.20	145.38	M4	Ø0,3 REF TO FOG-01	CFE
FOG-04	350.70	145.38	M4	Ø0,3 REF TO FOG-01	CFE
FOG-05	430.20	402.98	M4	Ø0,3 REF TO FOG-01	CFE
FOG-06	403.70	402.98	M4	Ø0,3 REF TO FOG-01	CFE
FOG-07	377.20	402.98	M4	Ø0,3 REF TO FOG-01	CFE
FOG-08	350.70	402.98	M4	Ø0,3 REF TO FOG-01	CFE
FOG-09	457.95	215.18	M4	Ø0,3 REF TO FOG-01	CFE
FOG-10	457.95	333.18	M4	Ø0,3 REF TO FOG-01	CFE
FOG-11	322.95	215.18	M4	Ø0,3 REF TO FOG-01	CFE
FOG-12	322.95	333.18	M4	Ø0,3 REF TO FOG-01	CFE
FOG-13	489.95	223.18	M6	Ø0,3 REF TO FOG-01	CFE
FOG-14	507.95	223.18	M6	Ø0,3 REF TO FOG-01	CFE
FOG-15	489.95	325.18	M6	Ø0,3 REF TO FOG-01	CFE
FOG-16	507.95	325.18	M6	Ø0,3 REF TO FOG-01	CFE
FOG-17	652.34	306.54	M6	Ø0,3 REF TO FOG-01	CFE
FOG-18	661.34	322.13	M6	Ø0,3 REF TO FOG-01	CFE
FOG-19	564.01	357.54	M6	Ø0,3 REF TO FOG-01	CFE
FOG-20	573.01	373.13	M6	Ø0,3 REF TO FOG-01	CFE
FOG-21	564.01	190.81	M6	Ø0,3 REF TO FOG-01	CFE
FOG-22	573.01	175.22	M6	Ø0,3 REF TO FOG-01	CFE
FOG-23	652.34	241.81	M6	Ø0,3 REF TO FOG-01	CFE
FOG-24	661.34	226.22	M6	Ø0,3 REF TO FOG-01	CFE

-Zp FACE

ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POS. TOL. ⌖	SUBSYSTEM
01K-11-01	363.33	462.38	M4	Ø0,3 REF TO Xp,Yp AXIS	INSTRUMENT
01K-11-02	544.26	596.51	M4	Ø0,3 REF TO Xp,Yp AXIS	INSTRUMENT
01K-11-03	657.96	628.12	M4	Ø0,3 REF TO Xp,Yp AXIS	INSTRUMENT
RCS-11-01	139.24	400.01	THROUGH (Det. a1-1)	Ø0,2 REF TO Xp,Yp AXIS	RCS
DBH4-01	676.40	132.00	M5	Ø0,4 REF TO Xp,Yp AXIS	HRN
DBH4-02	676.40	172.00	M5	Ø0,3 REF TO DBH4-01	HRN
DBH4-03	636.40	172.00	M5	Ø0,3 REF TO DBH4-01	HRN
DBH4-04	556.40	172.00	M5	Ø0,3 REF TO DBH4-01	HRN
DBH4-05	556.40	132.00	M5	Ø0,3 REF TO DBH4-01	HRN
DBH4-06	596.40	132.00	M5	Ø0,3 REF TO DBH4-01	HRN
4CRU-01	384.40	320.00	M4	Ø0,4 REF TO Xp,Yp AXIS	W.U.
4CRU-02	289.40	320.00	M4	Ø0,3 REF TO 4CRU-01	W.U.
4CRU-03	194.40	320.00	M4	Ø0,3 REF TO 4CRU-01	W.U.
4CRU-04	194.40	110.00	M4	Ø0,3 REF TO 4CRU-01	W.U.
4CRU-05	289.40	110.00	M4	Ø0,3 REF TO 4CRU-01	W.U.
4CRU-06	384.40	110.00	M4	Ø0,3 REF TO 4CRU-01	W.U.

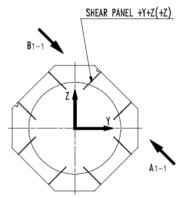


Fig 3.5.1-8 Planck +Y+Z(+Z) Shear Panel 4KCRU (HFI).

- Planck Payload Subplatform:

The following figures show the Planck Payload Subplatform where are located a HFI w.u.(PAU) and two LFI w.u's (BEU and DAE Power Box):

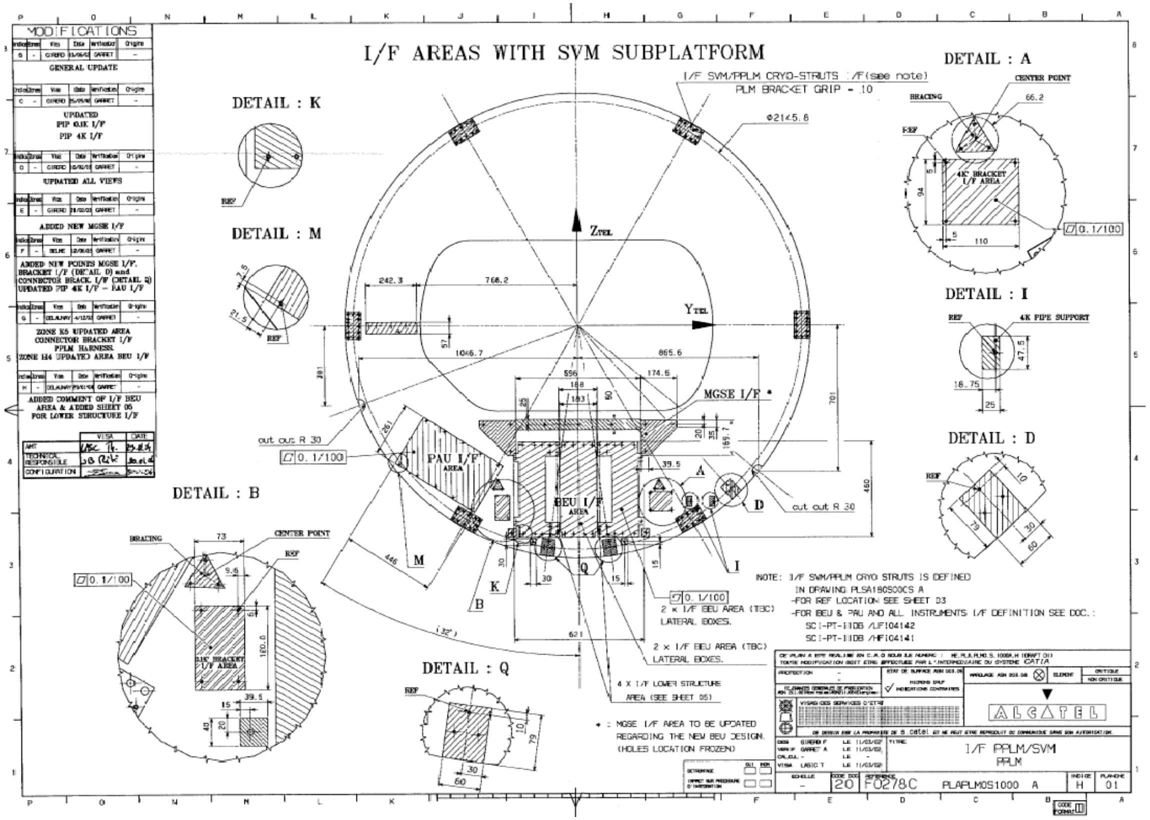


Fig 3.5.1-9 Planck Payload Subplatform BEU(LFI) and PAU (HFI) (on top side).

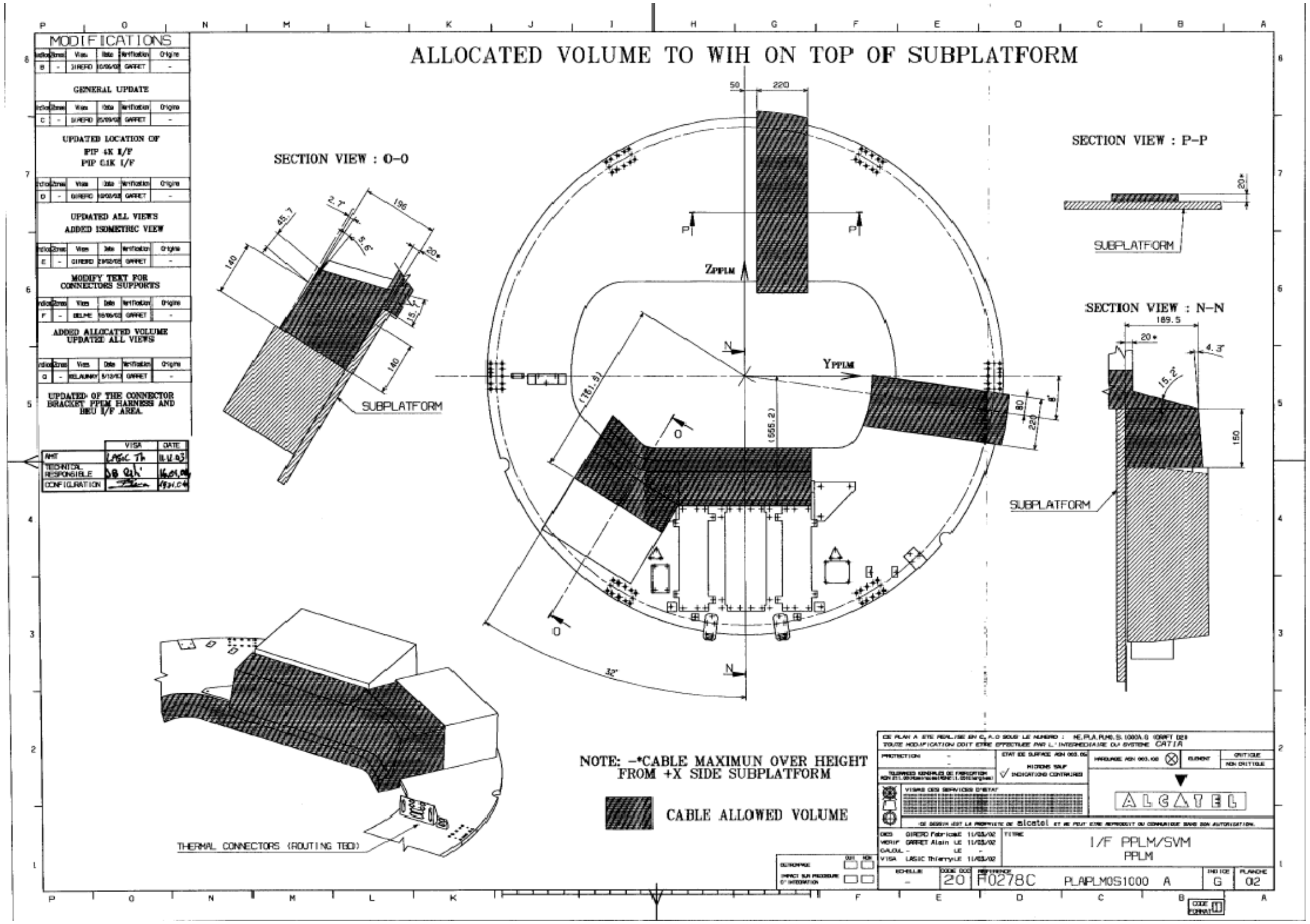


Fig 3.5.1-10 Planck Payload Subplatform allocated volume to WIH on top side.

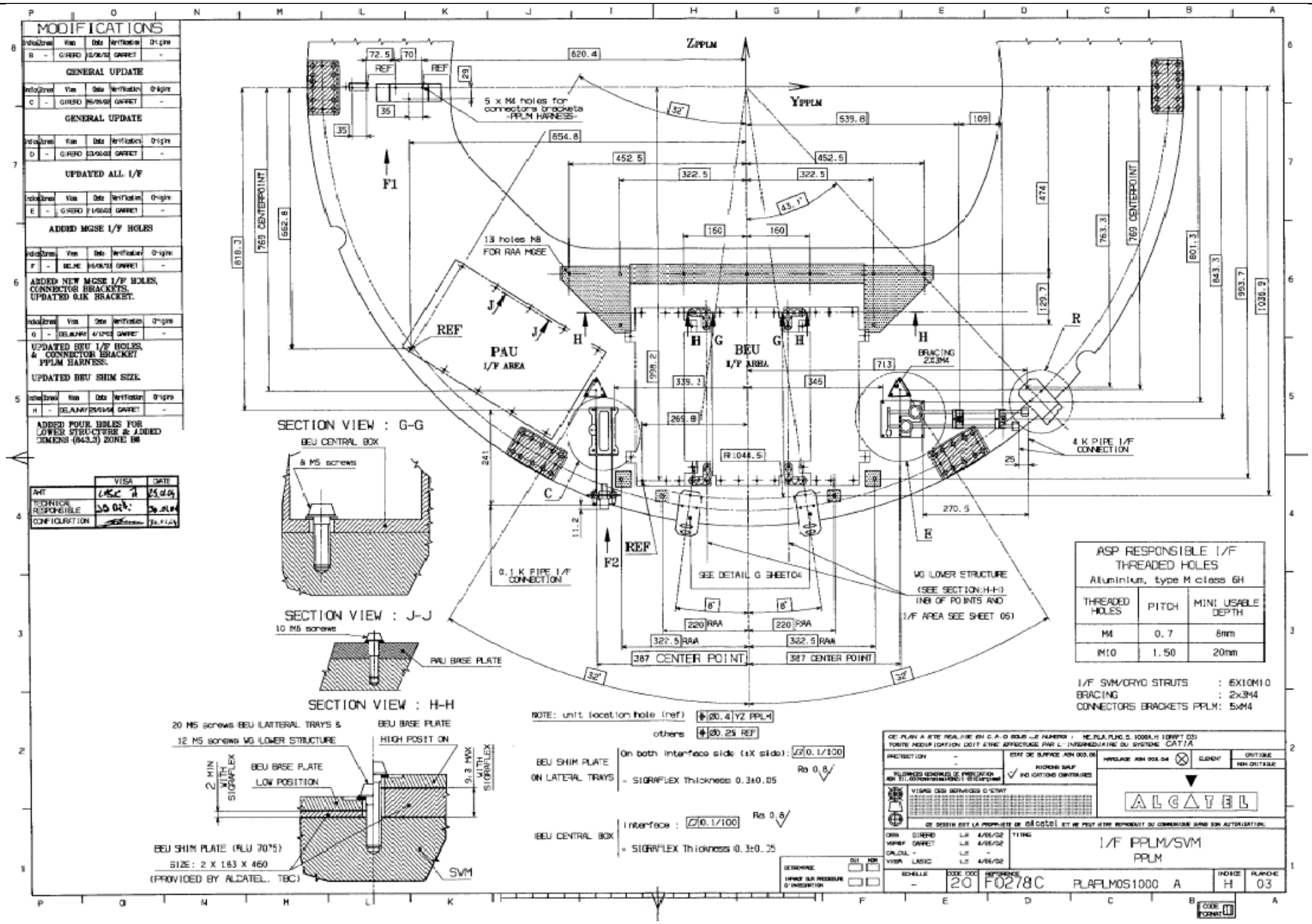


Fig 3.5.1-11 Planck Payload Subplatform Sections views of the mechanical I/F on top side.

3.5.2 LFI WARM UNITS

The LFI Warm Units are grouped on a dedicated SVM panel and on the Planck Payload Subplatform.
In the following table there are the project codes allocated to LFI warm units:

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

In the following tables below are indicated the dimensions, the masses and the drawings ref. numbers for each LFI Warm Unit:

Table 3.5.2.: LFI W.U. dimensions and mass.

Project Code	# of	Dimensions (mm)	Mass (kg)
PLBEU	1	626 x 452 x 200	24.0
PLAEF	1	255 x 216 x 119	5.1
PLREN/R	1+1	270 x 221 x 108	4.2
Total			**37.5**

Table 3.5.2-1: LFI W.U. Reference Drawings.

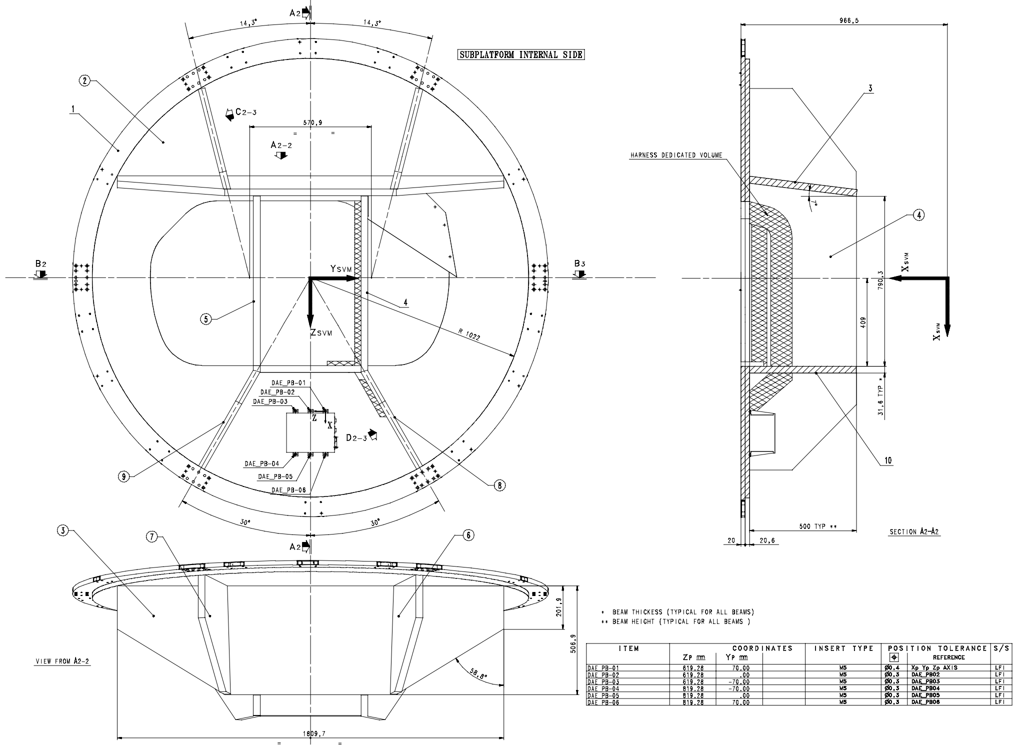
LFI unit	Drawing Ref. Number	Drawing issue	Drawing date
PLBEU	ICD751000102	A	23-01-04
PLAEF	ICD750800115	1	30-01-04
PLREN/R	FPL-ID-REB-0002-CRS	4	23-09-03

Inside of the SVM the LFI W.U. are located as below:

- P\L Sub PLT +X: BEU (see Fig.3.5.1-9, Fig.3.5.1-10 and Fig.3.5.1-11 in HFI section 3.5.1, Planck Payload Subplatform).
- P\L Sub PLT –X: DAE Power Box.
- +Y+Z panel: two REBA (nom. + red.) (see Fig.3.5.1-6 and Fig.3.5.1-7 in HFI section 3.5.1, +Y+Z Lateral Panel)

- Planck Payload Subplatform:

The following figure shows the Planck Payload Subplatform where is located the DAE Power box (LFI warm unit):
(mechanical configuration of the sub-platform not jet frozen)



ITEM	COORDINATES			INSERT TYPE	POSITION TOLERANCE		S/S
	Zp mm	Yp mm			⌖	REFERENCE	
DAE_PB-01	619,28	70,00		M5	Ø0,4	Xp Yp Zp AXIS	LFI
DAE_PB-02	619,28	,00		M5	Ø0,3	DAE_PB02	LFI
DAE_PB-03	619,28	-70,00		M5	Ø0,3	DAE_PB03	LFI
DAE_PB-04	819,28	-70,00		M5	Ø0,3	DAE_PB04	LFI
DAE_PB-05	819,28	,00		M5	Ø0,3	DAE_PB05	LFI
DAE_PB-06	819,28	70,00		M5	Ø0,3	DAE_PB06	LFI

Fig 3.5.2 Planck Payload Subplatform DAE Power Box (LFI) (on bottom side).

3.5.3 SCS WARM UNITS

The Sorption Cooler Subsystem is mainly grouped on three dedicated SVM lateral panels and they are mounted over the Heat Pipes network.
In the following table there are the project codes allocated to SCS warm units:

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

In the following tables below are indicated the dimensions, the masses and the drawings ref. numbers for each SCS Warm Unit:

Table 3.5.3: SCS W.U. dimensions and mass.

Project Code	# of	Dimensions (mm)	Mass (kg)
PSM3/R3	1+1	982 x 720 x 250	44.5
PSM4/R4	1+1	300 x 300 x 137	6.7
Total			**102.4**

Table 3.5.3-1: SCS W.U. Reference Drawings.

SCS unit	Drawing Ref. Number	Drawing issue	Drawing date
PSM3/R3	10203010 (3 sheets)	A	13-05-03
PSM4/R4	PL-ID-SCE-00002-CRS	1	19-12-03

Inside of the SVM the SCS W.U. are located as below:

- -Z panel: two SCE units
- +Y-Z panel: SCC unit
- –Y-Z panel: SCC unit

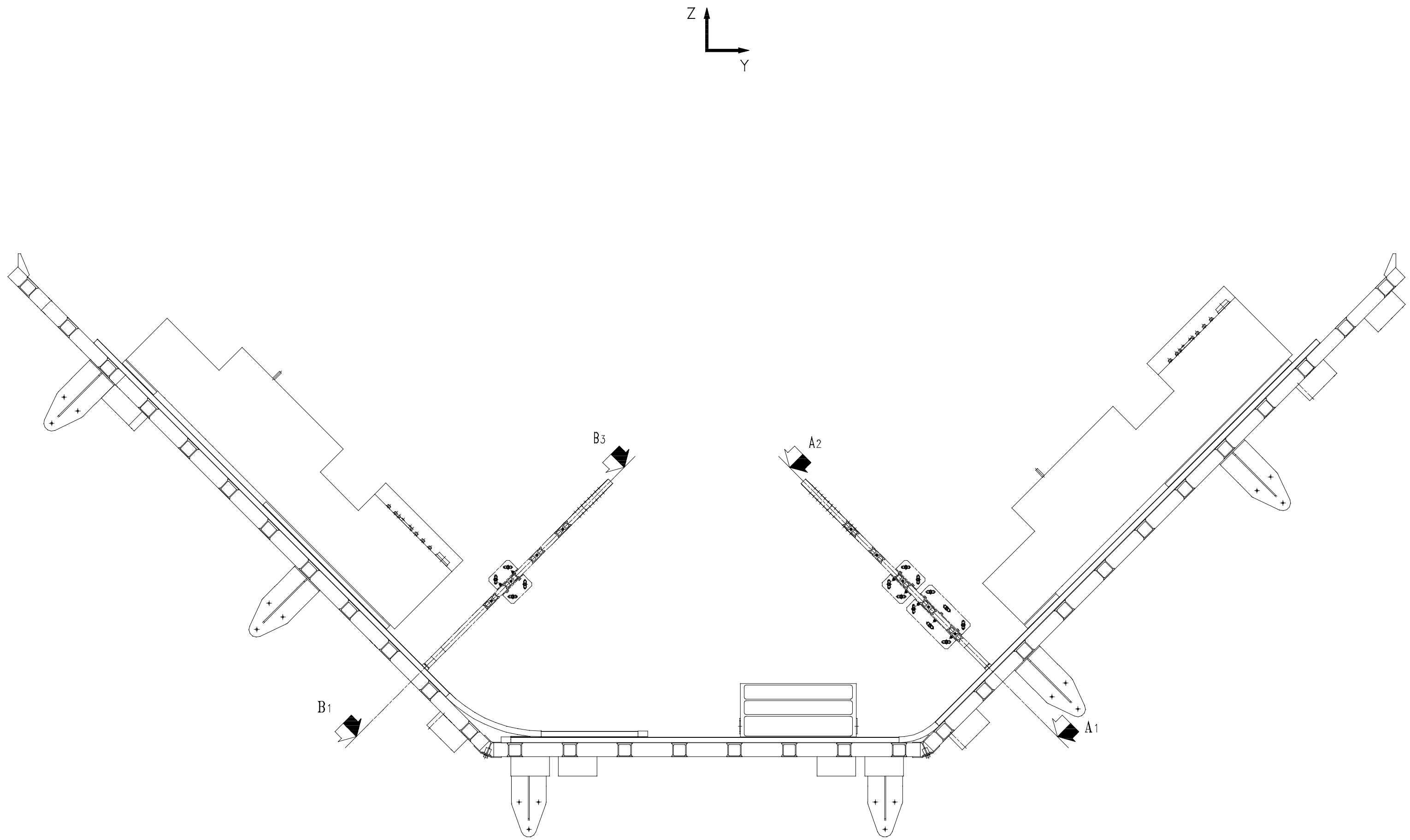
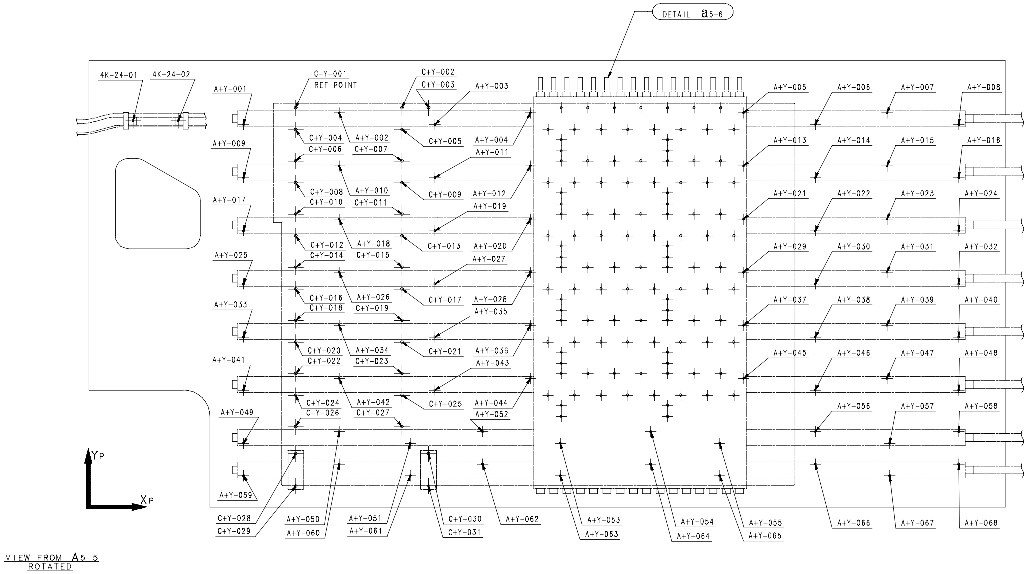


Fig.3.5.3.View of the SCS mounted inside of the SVM.

- +Y-Z Panel & -Y-Z Panel:

The following figures show the +Y-Z & -Y-Z lateral panels with the SCC units mounted:



NOTE: a position tolerance of Ø 0.6 mm applies between the following inserts:

+Y PANEL(SCC1) SH. 05	-Z PANEL(SCE's) SH. 09
A+Y-008	A-Z-001
A+Y-016	A-Z-007
A+Y-024	A-Z-013
A+Y-032	A-Z-019
A+Y-040	A-Z-027
A+Y-048	A-Z-033
A+Y-058	A-Z-039
A+Y-068	A-Z-045

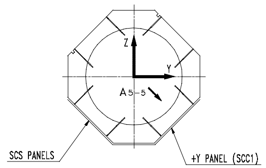
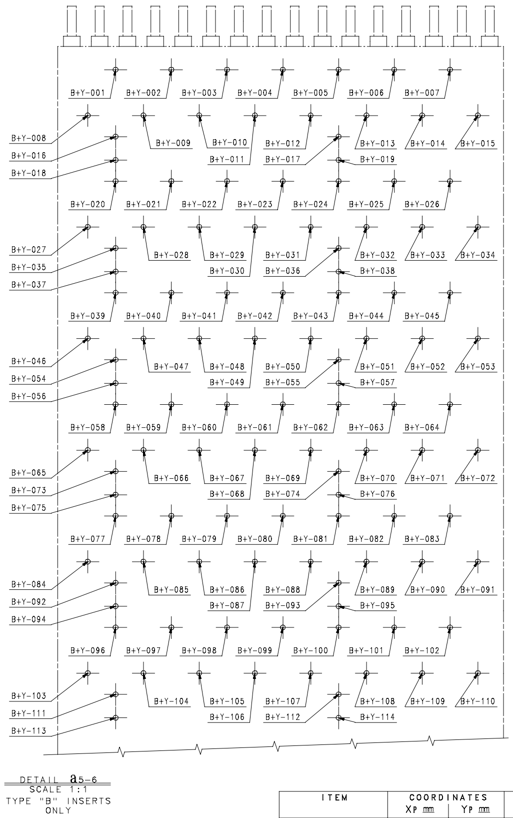
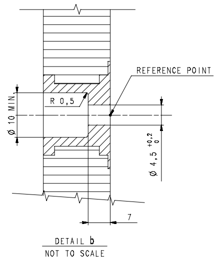


Fig.3.5.3-1. SCC is mounted inside of the SVM on the +Y-Z Lateral Panel.





ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
B+Y-001	890.59	751.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-002	940.59	751.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-003	990.59	751.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-004	1040.59	751.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-005	1090.59	751.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-006	1140.59	751.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-007	1190.59	751.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-008	865.59	710.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-009	915.59	710.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-010	965.59	710.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-011	1015.59	710.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-012	1065.59	710.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-013	1115.59	710.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-014	1165.59	710.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-015	1215.59	710.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-016	890.59	691.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-017	1090.59	691.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-018	890.59	670.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-019	1090.59	670.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-020	890.59	651.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-021	940.59	651.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-022	990.59	651.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-023	1040.59	651.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-024	1090.59	651.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-025	1140.59	651.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-026	1190.59	651.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-027	865.59	610.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-028	915.59	610.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-029	965.59	610.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-030	1015.59	610.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-031	1065.59	610.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-032	1115.59	610.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-033	1165.59	610.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-034	1215.59	610.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-035	890.59	591.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-036	1090.59	591.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-037	890.59	570.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-038	1090.59	570.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-039	890.59	551.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-040	940.59	551.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-041	990.59	551.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-042	1040.59	551.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-043	1090.59	551.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-044	1140.59	551.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-045	1190.59	551.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-046	865.59	510.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-047	915.59	510.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-048	965.59	510.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-049	1015.59	510.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-050	1065.59	510.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-051	1115.59	510.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-052	1165.59	510.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-053	1215.59	510.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-054	890.59	491.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-055	1090.59	491.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-056	890.59	470.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-057	1090.59	470.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-058	890.59	451.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-059	940.59	451.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-060	990.59	451.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-061	1040.59	451.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-062	1090.59	451.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-063	1140.59	451.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-064	1190.59	451.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-065	865.59	410.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-066	915.59	410.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-067	965.59	410.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-068	1015.59	410.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-069	1065.59	410.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-070	1115.59	410.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-071	1165.59	410.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-072	1215.59	410.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-073	890.59	391.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-074	1090.59	391.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-075	890.59	370.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-076	1090.59	370.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-077	890.59	351.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-078	940.59	351.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-079	990.59	351.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-080	1040.59	351.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-081	1090.59	351.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-082	1140.59	351.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-083	1190.59	351.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-084	865.59	310.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-085	915.59	310.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-086	965.59	310.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-087	1015.59	310.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-088	1065.59	310.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-089	1115.59	310.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-090	1165.59	310.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-091	1215.59	310.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-092	890.59	291.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-093	1090.59	291.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-094	890.59	270.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-095	1090.59	270.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-096	890.59	251.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-097	940.59	251.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-098	990.59	251.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-099	1040.59	251.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-100	1090.59	251.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS

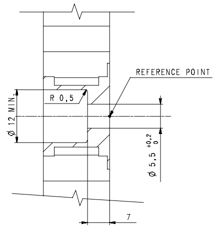
ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
B+Y-101	1140.59	251.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-102	1190.59	251.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-103	865.59	210.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-104	915.59	210.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-105	965.59	210.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-106	1015.59	210.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-107	1065.59	210.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-108	1115.59	210.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-109	1165.59	210.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-110	1215.59	210.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-111	890.59	191.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-112	1090.59	191.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-113	890.59	170.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS
B+Y-114	1090.59	170.30	THROUGH (det. b)	Ø0,1	C+Y-001	SCS

Fig.3.5.3-2. Inserts of the SCC inside of the SVM on the +Y-Z Lateral Panel.

REF INSERT POINT ON SHEET 05

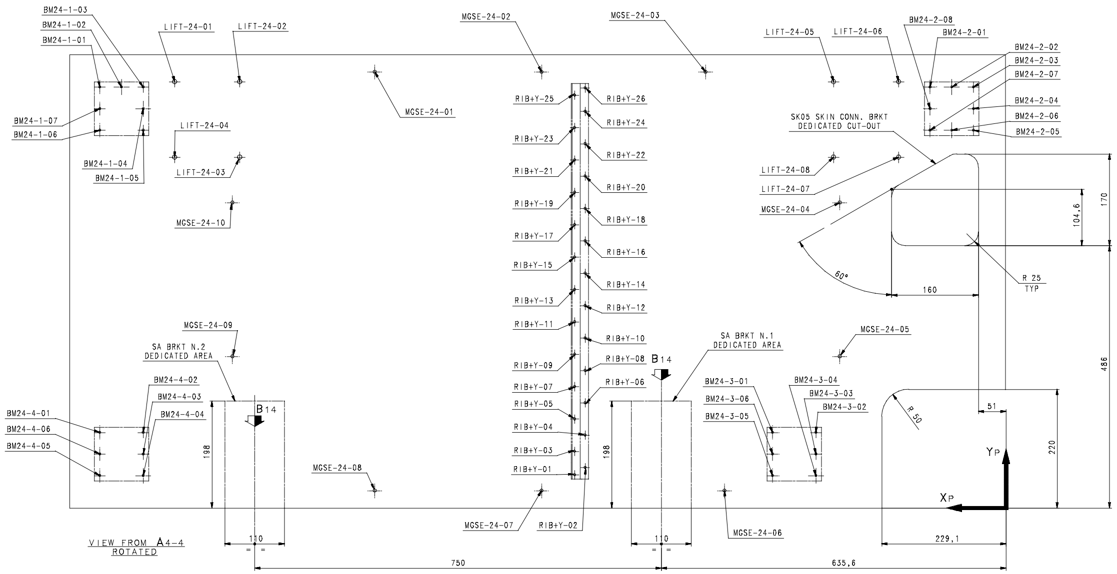
ITEM	COORDINATES Xp mm	COORDINATES Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
4K-24-01	84.55	726.95	M4	Ø0,3	Xp Yp AXIS	INST
4K-24-02	169.55	726.95	M4	Ø0,3	Xp Yp AXIS	INST
A+Y-001	292.39	719.80	M4	Ø0,2	Xp Yp AXIS	SCS
A+Y-002	472.39	741.80	M4	Ø0,1	A+Y-001	SCS
A+Y-003	652.39	719.80	M4	Ø0,1	A+Y-001	SCS
A+Y-004	832.39	741.80	M4	Ø0,1	A+Y-001	SCS
A+Y-005	1233.85	741.80	M4	Ø0,1	A+Y-001	SCS
A+Y-006	1368.85	719.80	M4	Ø0,1	A+Y-001	SCS
A+Y-007	1503.85	741.80	M4	Ø0,1	A+Y-001	SCS
A+Y-008	1638.85	719.80	M4	Ø0,1	A+Y-001	SCS
A+Y-009	292.39	619.80	M4	Ø0,2	Xp Yp AXIS	SCS
A+Y-010	472.39	641.80	M4	Ø0,1	A+Y-009	SCS
A+Y-011	652.39	619.80	M4	Ø0,1	A+Y-009	SCS
A+Y-012	832.39	641.80	M4	Ø0,1	A+Y-009	SCS
A+Y-013	1233.85	641.80	M4	Ø0,1	A+Y-009	SCS
A+Y-014	1368.85	619.80	M4	Ø0,1	A+Y-009	SCS
A+Y-015	1503.85	641.80	M4	Ø0,1	A+Y-009	SCS
A+Y-016	1638.85	619.80	M4	Ø0,1	A+Y-009	SCS
A+Y-017	292.39	519.80	M4	Ø0,2	Xp Yp AXIS	SCS
A+Y-018	472.39	541.80	M4	Ø0,1	A+Y-017	SCS
A+Y-019	652.39	519.80	M4	Ø0,1	A+Y-017	SCS
A+Y-020	832.39	541.80	M4	Ø0,1	A+Y-017	SCS
A+Y-021	1233.85	541.80	M4	Ø0,1	A+Y-017	SCS
A+Y-022	1368.85	519.80	M4	Ø0,1	A+Y-017	SCS
A+Y-023	1503.85	541.80	M4	Ø0,1	A+Y-017	SCS
A+Y-024	1638.85	519.80	M4	Ø0,1	A+Y-017	SCS
A+Y-025	292.39	419.80	M4	Ø0,2	Xp Yp AXIS	SCS
A+Y-026	472.39	441.80	M4	Ø0,1	A+Y-025	SCS
A+Y-027	652.39	419.80	M4	Ø0,1	A+Y-025	SCS
A+Y-028	832.39	441.80	M4	Ø0,1	A+Y-025	SCS
A+Y-029	1233.85	441.80	M4	Ø0,1	A+Y-025	SCS
A+Y-030	1368.85	419.80	M4	Ø0,1	A+Y-025	SCS
A+Y-031	1503.85	441.80	M4	Ø0,1	A+Y-025	SCS
A+Y-032	1638.85	419.80	M4	Ø0,1	A+Y-025	SCS
A+Y-033	292.39	319.80	M4	Ø0,2	Xp Yp AXIS	SCS
A+Y-034	472.39	341.80	M4	Ø0,1	A+Y-033	SCS
A+Y-035	652.39	319.80	M4	Ø0,1	A+Y-033	SCS
A+Y-036	832.39	341.80	M4	Ø0,1	A+Y-033	SCS
A+Y-037	1233.85	341.80	M4	Ø0,1	A+Y-033	SCS
A+Y-038	1368.85	319.80	M4	Ø0,1	A+Y-033	SCS
A+Y-039	1503.85	341.80	M4	Ø0,1	A+Y-033	SCS
A+Y-040	1638.85	319.80	M4	Ø0,1	A+Y-033	SCS
A+Y-041	292.39	219.80	M4	Ø0,2	Xp Yp AXIS	SCS
A+Y-042	472.39	241.80	M4	Ø0,1	A+Y-041	SCS
A+Y-043	652.39	219.80	M4	Ø0,1	A+Y-041	SCS
A+Y-044	832.39	241.80	M4	Ø0,1	A+Y-041	SCS
A+Y-045	1233.85	241.80	M4	Ø0,1	A+Y-041	SCS
A+Y-046	1368.85	219.80	M4	Ø0,1	A+Y-041	SCS
A+Y-047	1503.85	241.80	M4	Ø0,1	A+Y-041	SCS
A+Y-048	1638.85	219.80	M4	Ø0,1	A+Y-041	SCS
A+Y-049	292.39	119.80	M4	Ø0,2	Xp Yp AXIS	SCS
A+Y-050	472.39	141.80	M4	Ø0,1	A+Y-049	SCS
A+Y-051	606.39	119.80	M4	Ø0,1	A+Y-049	SCS
A+Y-052	742.39	141.80	M4	Ø0,1	A+Y-049	SCS
A+Y-053	888.70	119.80	M4	Ø0,1	A+Y-049	SCS
A+Y-054	1058.70	141.80	M4	Ø0,1	A+Y-049	SCS
A+Y-055	1188.70	119.80	M4	Ø0,1	A+Y-049	SCS
A+Y-056	1368.85	141.80	M4	Ø0,1	A+Y-049	SCS
A+Y-057	1508.85	119.80	M4	Ø0,1	A+Y-049	SCS
A+Y-058	1638.85	141.80	M4	Ø0,1	A+Y-049	SCS
A+Y-059	292.39	58.80	M4	Ø0,2	Xp Yp AXIS	SCS
A+Y-060	472.39	80.80	M4	Ø0,1	A+Y-059	SCS
A+Y-061	606.39	58.80	M4	Ø0,1	A+Y-059	SCS
A+Y-062	742.39	80.80	M4	Ø0,1	A+Y-059	SCS
A+Y-063	888.70	58.80	M4	Ø0,1	A+Y-059	SCS

ITEM	COORDINATES Xp mm	COORDINATES Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
A+Y-064	1058.70	80.80	M4	Ø0,1	A+Y-059	SCS
A+Y-065	1188.70	58.80	M4	Ø0,1	A+Y-059	SCS
A+Y-066	1368.85	80.80	M4	Ø0,1	A+Y-059	SCS
A+Y-067	1508.85	58.80	M4	Ø0,1	A+Y-059	SCS
A+Y-068	1638.85	80.80	M4	Ø0,1	A+Y-059	SCS
C+Y-001 (REF POINT)	390.59	751.30	THROUGH (det. c)	Ø0,2	Xp Yp AXIS	SCS
C+Y-002	590.59	751.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-003	640.59	751.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-004	390.59	710.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-005	590.59	710.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-006	390.59	651.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-007	590.59	651.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-008	390.59	610.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-009	590.59	610.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-010	390.59	551.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-011	590.59	551.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-012	390.59	510.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-013	590.59	510.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-014	390.59	451.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-015	590.59	451.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-016	390.59	410.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-017	590.59	410.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-018	390.59	351.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-019	590.59	351.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-020	390.59	310.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-021	590.59	310.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-022	390.59	251.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-023	590.59	251.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-024	390.59	210.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-025	590.59	210.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-026	390.59	151.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-027	590.59	151.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-028	390.59	100.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-029	390.59	39.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-030	640.59	100.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS
C+Y-031	640.59	39.30	THROUGH (det. c)	Ø0,1	C+Y-001	SCS



DETAIL C
NOT TO SCALE

Fig.3.5.3-3. Inserts and coordinates of the SCC inside of the SVM on the +Y-Z Lateral Panel.



ITEM	COORDINATES Xp mm	COORDINATES Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	POSITION TOLERANCE REFERENCE	S/S
BM24-1-01	1671.07	780.00	M4	Ø0,4	Xp Yp AXIS	
BM24-1-02	1631.07	780.00	M4	Ø0,3	BM24-1-01	
BM24-1-03	1591.07	780.00	M4	Ø0,3	BM24-1-01	
BM24-1-04	1591.07	740.00	M4	Ø0,3	BM24-1-01	
BM24-1-05	1591.07	700.00	M4	Ø0,3	BM24-1-01	
BM24-1-06	1671.07	700.00	M4	Ø0,3	BM24-1-01	
BM24-1-07	1671.07	740.00	M4	Ø0,3	BM24-1-01	
BM24-2-01	140.07	780.00	M4	Ø0,4	Xp Yp AXIS	
BM24-2-02	100.07	780.00	M4	Ø0,3	BM24-2-01	
BM24-2-03	60.07	780.00	M4	Ø0,3	BM24-2-01	
BM24-2-04	60.07	740.00	M4	Ø0,3	BM24-2-01	
BM24-2-05	60.07	700.00	M4	Ø0,3	BM24-2-01	
BM24-2-06	100.07	700.00	M4	Ø0,3	BM24-2-01	
BM24-2-07	140.07	700.00	M4	Ø0,3	BM24-2-01	
BM24-2-08	140.07	740.00	M4	Ø0,3	BM24-2-01	
BM24-3-01	430.57	140.00	M4	Ø0,4	Xp Yp AXIS	
BM24-3-02	350.57	140.00	M4	Ø0,3	BM24-3-01	
BM24-3-03	350.57	100.00	M4	Ø0,3	BM24-3-01	
BM24-3-04	350.57	60.00	M4	Ø0,3	BM24-3-01	
BM24-3-05	430.57	60.00	M4	Ø0,3	BM24-3-01	
BM24-3-06	430.57	100.00	M4	Ø0,3	BM24-3-01	
BM24-4-01	1671.07	140.00	M4	Ø0,4	Xp Yp AXIS	
BM24-4-02	1591.07	140.00	M4	Ø0,3	BM24-4-01	
BM24-4-03	1591.07	100.00	M4	Ø0,3	BM24-4-01	
BM24-4-04	1591.07	60.00	M4	Ø0,3	BM24-4-01	
BM24-4-05	1671.07	60.00	M4	Ø0,3	BM24-4-01	
BM24-4-06	1671.07	100.00	M4	Ø0,3	BM24-4-01	
LIFT-24-01	1533.10	790.00	M8 TBC	Ø0,4	Xp Yp AXIS	MGSE
LIFT-24-02	1413.10	790.00	M8 TBC	Ø0,3	LIFT-24-01	MGSE
LIFT-24-03	1413.10	650.00	M8 TBC	Ø0,3	LIFT-24-01	MGSE
LIFT-24-04	1533.10	650.00	M8 TBC	Ø0,3	LIFT-24-01	MGSE
LIFT-24-05	318.05	790.00	M8 TBC	Ø0,4	Xp Yp AXIS	MGSE
LIFT-24-06	198.05	790.00	M8 TBC	Ø0,3	LIFT-24-05	MGSE
LIFT-24-07	198.05	650.00	M8 TBC	Ø0,3	LIFT-24-05	MGSE
LIFT-24-08	318.05	650.00	M8 TBC	Ø0,3	LIFT-24-05	MGSE

ITEM	COORDINATES Xp mm	COORDINATES Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	POSITION TOLERANCE REFERENCE	S/S
MGSE-24-01	1164.09	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-02	856.59	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-03	554.09	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-04	306.59	565.80	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-05	306.59	280.80	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-06	519.09	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-07	856.59	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-08	1164.09	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-09	1426.59	280.80	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-10	1426.59	565.80	M6	Ø0,3	Xp Yp AXIS	MGSE
RIB+Y-01	795.59	61.50	M4	Ø0,4	Xp Yp AXIS	STR
RIB+Y-02	776.09	75.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-03	795.59	105.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-04	776.09	135.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-05	795.59	165.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-06	776.09	195.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-07	795.59	225.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-08	776.09	255.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-09	795.59	285.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-10	776.09	315.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-11	795.59	345.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-12	776.09	375.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-13	795.59	405.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-14	776.09	435.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-15	795.59	465.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-16	776.09	495.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-17	795.59	525.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-18	776.09	555.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-19	795.59	585.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-20	776.09	615.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-21	795.59	645.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-22	776.09	675.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-23	795.59	705.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-24	776.09	735.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-25	795.59	765.00	M4	Ø0,3	RIB+Y-01	STR
RIB+Y-26	776.09	778.50	M4	Ø0,3	RIB+Y-01	STR

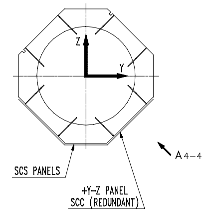
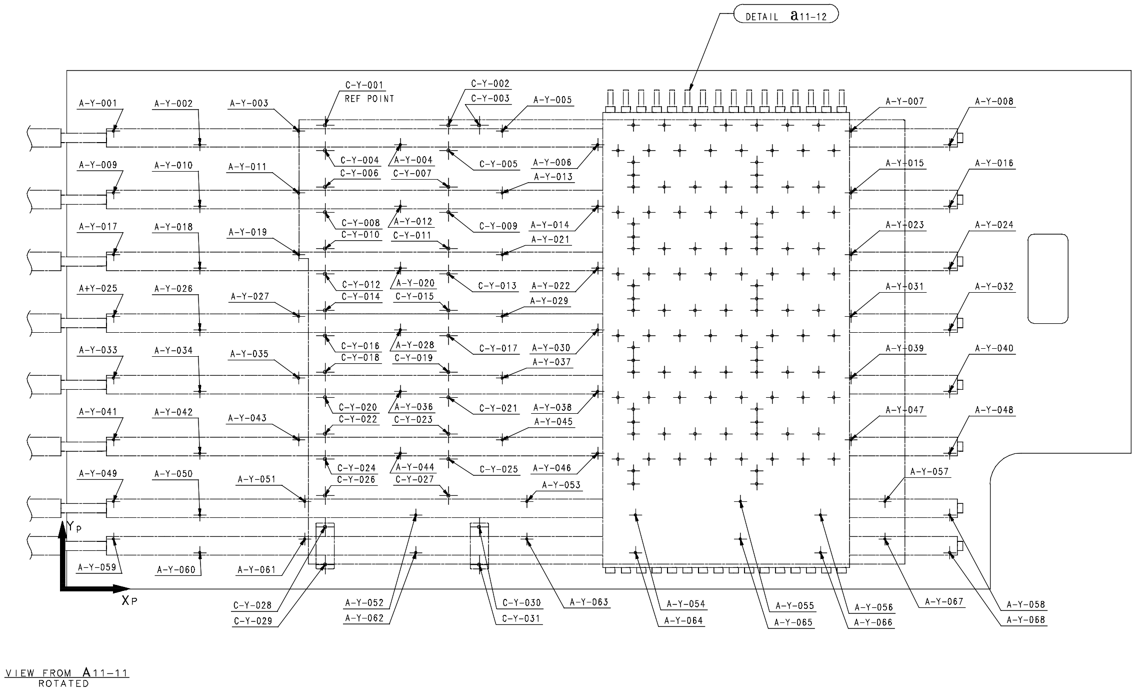


Fig.3.5.3-4.The +Y-Z Lateral Panel outside SVM view.



NOTE: a position tolerance of Ø 0.6 mm applies between the following inserts:

-Z PANEL (SCE's) SH. 09	-Y PANEL (SCC2) SH. 11
A-Z-006	A-Y-001
A-Z-012	A-Y-009
A-Z-018	A-Y-017
A-Z-026	A-Y-025
A-Z-032	A-Y-033
A-Z-038	A-Y-041
A-Z-044	A-Y-049
A-Z-052	A-Y-059

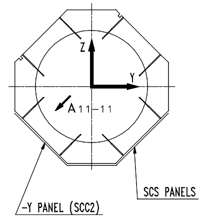
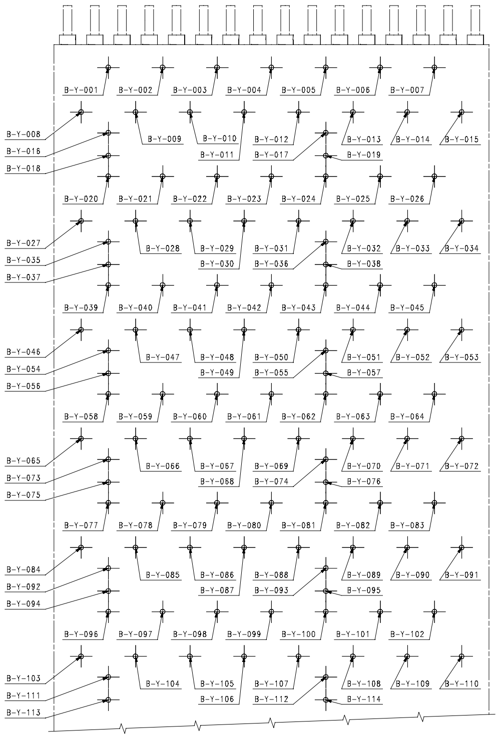
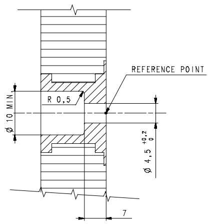


Fig.3.5.3-5. SCC is mounted inside of the SVM on the -Y-Z Lateral Panel.



DETAIL b11-12
SCALE 1:1
TYPE "B" INSERTS
ONLY



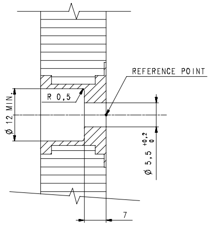
DETAIL b
NOT TO SCALE

ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
B-Y-001	925.59	751.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-002	975.59	751.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-003	1025.59	751.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-004	1075.59	751.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-005	1125.59	751.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-006	1175.59	751.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-007	1225.59	751.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-008	900.59	710.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-009	950.59	710.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-010	1000.59	710.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-011	1050.59	710.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-012	1100.59	710.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-013	1150.59	710.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-014	1200.59	710.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-015	1250.59	710.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-016	925.59	691.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-017	1125.59	691.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-018	925.59	670.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-019	1125.59	670.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-020	925.59	651.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-021	975.59	651.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-022	1025.59	651.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-023	1075.59	651.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-024	1125.59	651.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-025	1175.59	651.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-026	1225.59	651.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-027	900.59	610.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-028	950.59	610.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-029	1000.59	610.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-030	1050.59	610.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-031	1100.59	610.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-032	1150.59	610.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-033	1200.59	610.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-034	1250.59	610.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-035	925.59	591.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-036	1125.59	591.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-037	925.59	570.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-038	1125.59	570.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-039	925.59	551.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-040	975.59	551.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-041	1025.59	551.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-042	1075.59	551.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-043	1125.59	551.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-044	1175.59	551.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-045	1225.59	551.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-046	900.59	510.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-047	950.59	510.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-048	1000.59	510.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-049	1050.59	510.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-050	1100.59	510.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-051	1150.59	510.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-052	1200.59	510.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-053	1250.59	510.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-054	925.59	491.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-055	1125.59	491.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-056	925.59	470.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-057	1125.59	470.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-058	925.59	451.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-059	975.59	451.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-060	1025.59	451.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-061	1075.59	451.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-062	1125.59	451.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-063	1175.59	451.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-064	1225.59	451.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-065	900.59	410.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-066	950.59	410.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-067	1000.59	410.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-068	1050.59	410.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-069	1100.59	410.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-070	1150.59	410.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-071	1200.59	410.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-072	1250.59	410.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-073	925.59	391.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-074	1125.59	391.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-075	925.59	370.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-076	1125.59	370.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-077	925.59	351.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-078	975.59	351.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-079	1025.59	351.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-080	1075.59	351.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-081	1125.59	351.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-082	1175.59	351.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-083	1225.59	351.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-084	900.59	310.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-085	950.59	310.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-086	1000.59	310.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-087	1050.59	310.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-088	1100.59	310.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-089	1150.59	310.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-090	1200.59	310.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-091	1250.59	310.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-092	925.59	291.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-093	1125.59	291.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-094	925.59	270.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-095	1125.59	270.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-096	925.59	251.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-097	975.59	251.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-098	1025.59	251.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-099	1075.59	251.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-100	1125.59	251.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-101	1175.59	251.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-102	1225.59	251.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-103	900.59	210.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-104	950.59	210.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-105	1000.59	210.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-106	1050.59	210.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-107	1100.59	210.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-108	1150.59	210.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-109	1200.59	210.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-110	1250.59	210.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-111	925.59	191.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-112	1125.59	191.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-113	925.59	170.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS
B-Y-114	1125.59	170.30	THROUGH (det. b)	Ø0,1	C-Y-001	SCS

Fig.3.5.3-6. Inserts of the SCC inside of the SVM on the -Y-Z Lateral Panel.

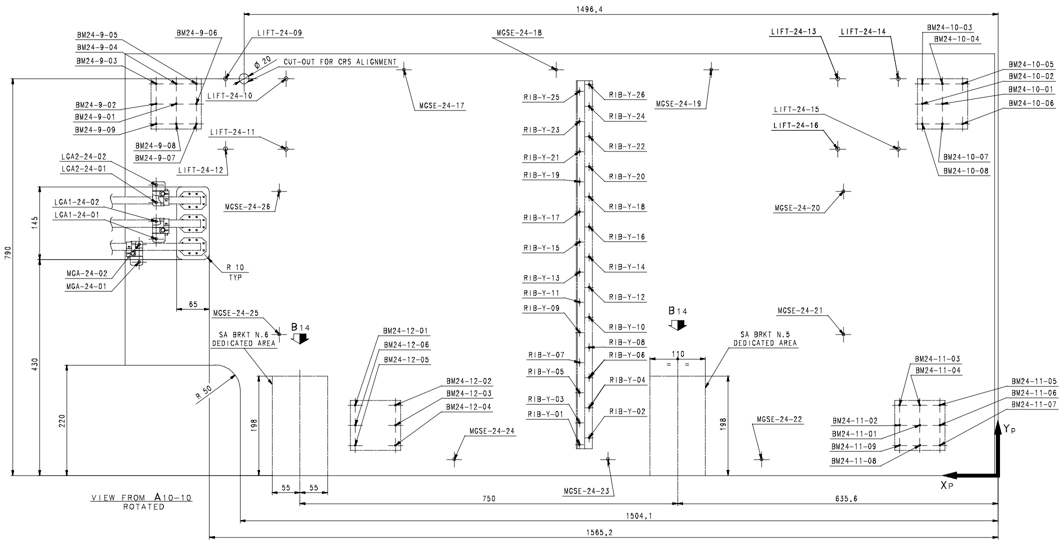
REF INSERT POINT ON SHEET 11

ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
A-Y-001	82.75	741.80	M4	Ø0,2	Xp Yp AXIS	TCS
A-Y-002	222.75	719.80	M4	Ø0,1	A-Y-001	TCS
A-Y-003	382.75	741.80	M4	Ø0,1	A-Y-001	TCS
A-Y-004	547.75	719.80	M4	Ø0,1	A-Y-001	TCS
A-Y-005	712.75	741.80	M4	Ø0,1	A-Y-001	TCS
A-Y-006	867.75	719.80	M4	Ø0,1	A-Y-001	TCS
A-Y-007	1278.28	741.80	M4	Ø0,1	A-Y-001	TCS
A-Y-008	1438.28	719.80	M4	Ø0,1	A-Y-001	TCS
A-Y-009	82.75	641.80	M4	Ø0,2	Xp Yp AXIS	TCS
A-Y-010	222.75	619.80	M4	Ø0,1	A-Y-009	TCS
A-Y-011	382.75	641.80	M4	Ø0,1	A-Y-009	TCS
A-Y-012	547.75	619.80	M4	Ø0,1	A-Y-009	TCS
A-Y-013	712.75	641.80	M4	Ø0,1	A-Y-009	TCS
A-Y-014	867.75	619.80	M4	Ø0,1	A-Y-009	TCS
A-Y-015	1278.28	641.80	M4	Ø0,1	A-Y-009	TCS
A-Y-016	1438.28	619.80	M4	Ø0,1	A-Y-009	TCS
A-Y-017	82.75	541.80	M4	Ø0,2	Xp Yp AXIS	TCS
A-Y-018	222.75	519.80	M4	Ø0,1	A-Y-017	TCS
A-Y-019	382.75	541.80	M4	Ø0,1	A-Y-017	TCS
A-Y-020	547.75	519.80	M4	Ø0,1	A-Y-017	TCS
A-Y-021	712.75	541.80	M4	Ø0,1	A-Y-017	TCS
A-Y-022	867.75	519.80	M4	Ø0,1	A-Y-017	TCS
A-Y-023	1278.28	541.80	M4	Ø0,1	A-Y-017	TCS
A-Y-024	1438.28	519.80	M4	Ø0,1	A-Y-017	TCS
A-Y-025	82.75	441.80	M4	Ø0,2	Xp Yp AXIS	TCS
A-Y-026	222.75	419.80	M4	Ø0,1	A-Y-025	TCS
A-Y-027	382.75	441.80	M4	Ø0,1	A-Y-025	TCS
A-Y-028	547.75	419.80	M4	Ø0,1	A-Y-025	TCS
A-Y-029	712.75	441.80	M4	Ø0,1	A-Y-025	TCS
A-Y-030	867.75	419.80	M4	Ø0,1	A-Y-025	TCS
A-Y-031	1278.28	441.80	M4	Ø0,1	A-Y-025	TCS
A-Y-032	1438.28	419.80	M4	Ø0,1	A-Y-025	TCS
A-Y-033	82.75	341.80	M4	Ø0,2	Xp Yp AXIS	TCS
A-Y-034	222.75	319.80	M4	Ø0,1	A-Y-033	TCS
A-Y-035	382.75	341.80	M4	Ø0,1	A-Y-033	TCS
A-Y-036	547.75	319.80	M4	Ø0,1	A-Y-033	TCS
A-Y-037	712.75	341.80	M4	Ø0,1	A-Y-033	TCS
A-Y-038	867.75	319.80	M4	Ø0,1	A-Y-033	TCS
A-Y-039	1278.28	341.80	M4	Ø0,1	A-Y-033	TCS
A-Y-040	1438.28	319.80	M4	Ø0,1	A-Y-033	TCS
A-Y-041	82.75	241.80	M4	Ø0,2	Xp Yp AXIS	TCS
A-Y-042	222.75	219.80	M4	Ø0,1	A-Y-017	TCS
A-Y-043	382.75	241.80	M4	Ø0,1	A-Y-017	TCS
A-Y-044	547.75	219.80	M4	Ø0,1	A-Y-017	TCS
A-Y-045	712.75	241.80	M4	Ø0,1	A-Y-017	TCS
A-Y-046	867.75	219.80	M4	Ø0,1	A-Y-017	TCS
A-Y-047	1278.28	241.80	M4	Ø0,1	A-Y-017	TCS
A-Y-048	1438.28	219.80	M4	Ø0,1	A-Y-017	TCS
A-Y-049	82.75	141.80	M4	Ø0,2	Xp Yp AXIS	TCS
A-Y-050	222.75	119.80	M4	Ø0,1	A-Y-049	TCS
A-Y-051	392.75	141.80	M4	Ø0,1	A-Y-049	TCS
A-Y-052	572.75	119.80	M4	Ø0,1	A-Y-049	TCS
A-Y-053	752.75	141.80	M4	Ø0,1	A-Y-049	TCS
A-Y-054	928.95	119.80	M4	Ø0,1	A-Y-049	TCS
A-Y-055	1098.95	141.80	M4	Ø0,1	A-Y-049	TCS
A-Y-056	1228.95	119.80	M4	Ø0,1	A-Y-049	TCS
A-Y-057	1333.28	141.80	M4	Ø0,1	A-Y-049	TCS
A-Y-058	1438.28	119.80	M4	Ø0,1	A-Y-049	TCS
A-Y-059	82.75	80.80	M4	Ø0,2	Xp Yp AXIS	TCS
A-Y-060	222.75	58.80	M4	Ø0,1	A-Y-059	TCS
A-Y-061	392.75	80.80	M4	Ø0,1	A-Y-059	TCS
A-Y-062	572.75	58.80	M4	Ø0,1	A-Y-059	TCS
A-Y-063	752.75	80.80	M4	Ø0,1	A-Y-059	TCS
A-Y-064	928.95	58.80	M4	Ø0,1	A-Y-059	TCS
A-Y-065	1098.95	80.80	M4	Ø0,1	A-Y-059	TCS
A-Y-066	1228.95	58.80	M4	Ø0,1	A-Y-059	TCS
A-Y-067	1333.28	80.80	M4	Ø0,1	A-Y-059	TCS
A-Y-068	1438.28	58.80	M4	Ø0,1	A-Y-059	TCS
C-Y-001 (REF POINT)	425.59	751.30	THROUGH (det. c)	Ø0,2	Xp Yp AXIS	SCS
C-Y-002	625.59	751.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-003	675.59	751.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-004	425.59	710.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-005	625.59	710.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-006	425.59	651.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-007	625.59	651.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-008	425.59	610.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-009	625.59	610.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-010	425.59	551.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-011	625.59	551.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-012	425.59	510.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-013	625.59	510.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-014	425.59	451.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-015	625.59	451.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-016	425.59	410.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-017	625.59	410.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-018	425.59	351.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-019	625.59	351.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-020	425.59	310.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-021	625.59	310.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-022	425.59	251.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-023	625.59	251.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-024	425.59	210.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-025	625.59	210.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-026	425.59	151.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-027	625.59	151.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-028	425.59	100.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-029	425.59	39.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-030	675.59	100.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS
C-Y-031	675.59	39.30	THROUGH (det. c)	Ø0,1	C-Y-001	SCS



DETAIL C
NOT TO SCALE

Fig.3.5.3-7. Inserts and coordinates of the SCC inside of the SVM on the -Y-Z Lateral Panel.



ITEM	COORDINATES Xp mm	COORDINATES Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	POSITION TOLERANCE REFERENCE	S/S
BM24-10-01	110.07	740.00	M4	Ø0,4	Xp Yp AXIS	
BM24-10-02	150.07	740.00	M4	Ø0,3	BM24-10-01	
BM24-10-03	150.07	780.00	M4	Ø0,3	BM24-10-01	
BM24-10-04	110.07	780.00	M4	Ø0,3	BM24-10-01	
BM24-10-05	70.07	780.00	M4	Ø0,3	BM24-10-01	
BM24-10-06	70.07	700.00	M4	Ø0,3	BM24-10-01	
BM24-10-07	110.07	700.00	M4	Ø0,3	BM24-10-01	
BM24-10-08	150.07	700.00	M4	Ø0,3	BM24-10-01	
BM24-11-01	155.07	100.00	M4	Ø0,4	Xp Yp AXIS	
BM24-11-02	195.07	100.00	M4	Ø0,3	BM24-11-01	
BM24-11-03	195.07	140.00	M4	Ø0,3	BM24-11-01	
BM24-11-04	155.07	140.00	M4	Ø0,3	BM24-11-01	
BM24-11-05	115.07	140.00	M4	Ø0,3	BM24-11-01	
BM24-11-06	115.07	100.00	M4	Ø0,3	BM24-11-01	
BM24-11-07	115.07	60.00	M4	Ø0,3	BM24-11-01	
BM24-11-08	155.07	60.00	M4	Ø0,3	BM24-11-01	
BM24-11-09	195.07	60.00	M4	Ø0,3	BM24-11-01	
BM24-12-01	1275.57	140.00	M4	Ø0,4	Xp Yp AXIS	
BM24-12-02	1195.57	140.00	M4	Ø0,3	BM24-12-01	
BM24-12-03	1195.57	100.00	M4	Ø0,3	BM24-12-01	
BM24-12-04	1195.57	60.00	M4	Ø0,3	BM24-12-01	
BM24-12-05	1275.57	60.00	M4	Ø0,3	BM24-12-01	
BM24-12-06	1275.57	100.00	M4	Ø0,3	BM24-12-01	
BM24-9-01	1631.07	740.00	M4	Ø0,4	Xp Yp AXIS	
BM24-9-02	1671.07	740.00	M4	Ø0,3	BM24-9-01	
BM24-9-03	1671.07	780.00	M4	Ø0,3	BM24-9-01	
BM24-9-04	1631.07	780.00	M4	Ø0,3	BM24-9-01	
BM24-9-05	1591.07	780.00	M4	Ø0,3	BM24-9-01	
BM24-9-06	1591.07	740.00	M4	Ø0,3	BM24-9-01	
BM24-9-07	1591.07	700.00	M4	Ø0,3	BM24-9-01	
BM24-9-08	1631.07	700.00	M4	Ø0,3	BM24-9-01	
BM24-9-09	1671.07	700.00	M4	Ø0,3	BM24-9-01	
LGA1-24-01	1670.66	471.05	M4	Ø0,3	Xp Yp AXIS	TT&C
LGA1-24-02	1670.66	506.05	M4	Ø0,3	Xp Yp AXIS	TT&C
LGA2-24-01	1670.66	543.46	M4	Ø0,3	Xp Yp AXIS	TT&C
LGA2-24-02	1670.66	578.46	M4	Ø0,3	Xp Yp AXIS	TT&C
LIFT-24-09	1533.10	790.00	M8 TBC	Ø0,4	Xp Yp AXIS	MGSE
LIFT-24-10	1413.10	790.00	M8 TBC	Ø0,3	LIFT-24-09	MGSE
LIFT-24-11	1413.10	650.00	M8 TBC	Ø0,3	LIFT-24-09	MGSE
LIFT-24-12	1533.10	650.00	M8 TBC	Ø0,3	LIFT-24-09	MGSE
LIFT-24-13	318.05	790.00	M8 TBC	Ø0,4	Xp Yp AXIS	MGSE

ITEM	COORDINATES Xp mm	COORDINATES Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	POSITION TOLERANCE REFERENCE	S/S
LIFT-24-14	198.05	790.00	M8 TBC	Ø0,3	LIFT-24-13	MGSE
LIFT-24-15	198.05	650.00	M8 TBC	Ø0,3	LIFT-24-13	MGSE
LIFT-24-16	318.05	650.00	M8 TBC	Ø0,3	LIFT-24-13	MGSE
MGA-24-01	1704.66	425.04	M4	Ø0,3	Xp Yp AXIS	TT&C
MGA-24-02	1704.66	460.04	M4	Ø0,3	Xp Yp AXIS	TT&C
MGSE-24-17	1179.09	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-18	876.59	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-19	569.09	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-20	306.59	565.80	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-21	306.59	280.80	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-22	469.09	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-23	774.09	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-24	1079.09	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-25	1426.59	280.80	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-26	1426.59	565.80	M6	Ø0,3	Xp Yp AXIS	MGSE
RIB-Y-01	830.59	61.50	M4	Ø0,4	Xp Yp AXIS	STR
RIB-Y-02	811.09	75.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-03	830.59	105.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-04	811.09	135.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-05	830.59	165.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-06	811.09	195.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-07	830.59	225.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-08	811.09	255.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-09	830.59	285.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-10	811.09	315.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-11	830.59	345.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-12	811.09	375.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-13	830.59	405.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-14	811.09	435.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-15	830.59	465.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-16	811.09	495.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-17	830.59	525.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-18	811.09	555.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-19	830.59	585.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-20	811.09	615.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-21	830.59	645.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-22	811.09	675.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-23	830.59	705.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-24	811.09	735.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-25	830.59	765.00	M4	Ø0,3	RIB-Y-01	STR
RIB-Y-26	811.09	778.50	M4	Ø0,3	RIB-Y-01	STR

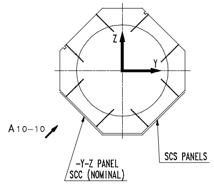
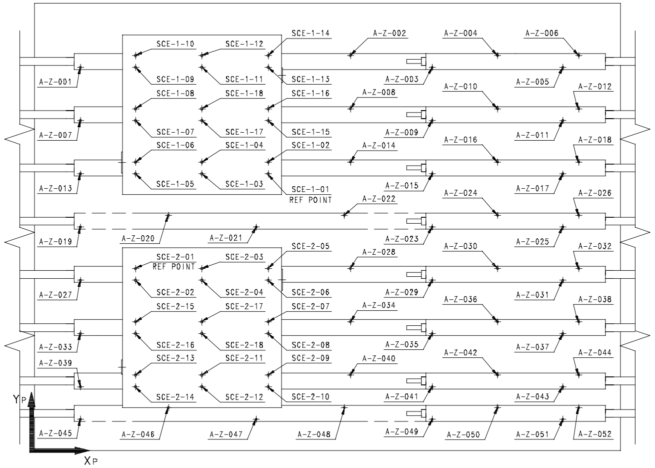


Fig.3.5.3-8.The -Y-Z Lateral Panel outside SVM view.

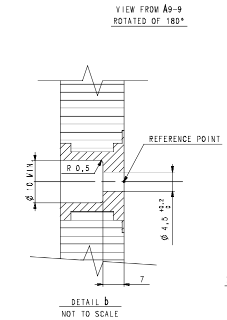
- -Z Panel:

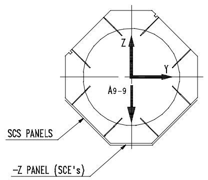
The following figures show the -Z lateral panels with the SCE units mounted:



NOTE: a position tolerance of Ø 0.6 mm applies between the following inserts:

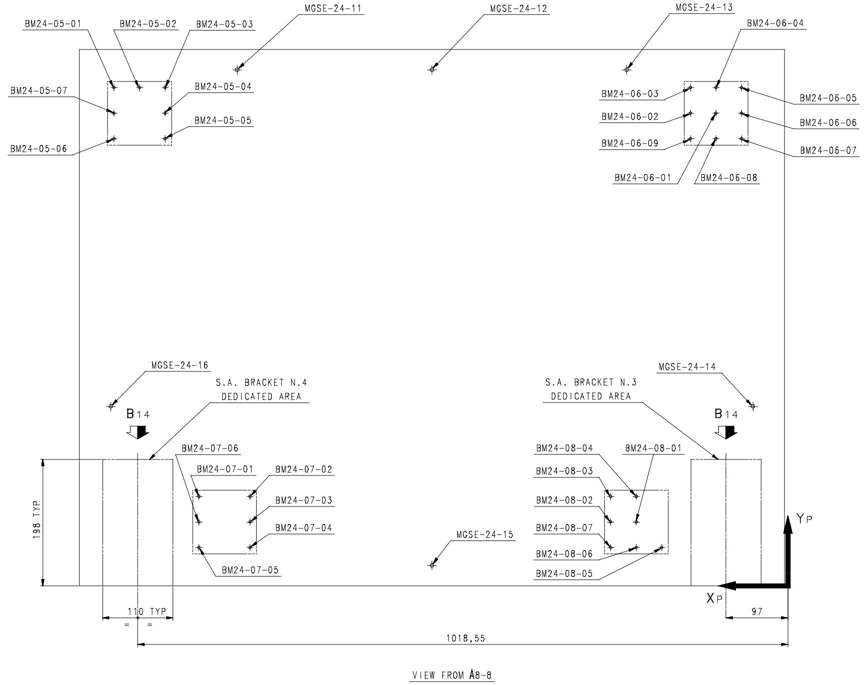
+Y PANEL (SCC1) SH. 05	-Z PANEL (SCE's) SH. 09	-Y PANEL (SCC2) SH. 11
A+Y-008	A-Z-001	
A+Y-016	A-Z-007	
A+Y-024	A-Z-013	
A+Y-032	A-Z-019	
A+Y-040	A-Z-027	
A+Y-048	A-Z-033	
A+Y-058	A-Z-039	
A+Y-068	A-Z-045	
	A-Z-006	A-Y-001
	A-Z-012	A-Y-009
	A-Z-018	A-Y-017
	A-Z-026	A-Y-025
	A-Z-032	A-Y-033
	A-Z-038	A-Y-041
	A-Z-044	A-Y-049
	A-Z-052	A-Y-059





ITEM	COORDINATES		INSERT TYPE	POSITION TOLERANCE		S/S
	Xp mm	Yp mm		⌖	REFERENCE	
A-Z-001	92.30	719.80	M4	Ø0,3	Xp Yp AXIS	TCS
A-Z-002	601.20	741.80	M4	Ø0,2	A-Z-001	TCS
A-Z-003	755.34	719.80	M4	Ø0,2	A-Z-001	TCS
A-Z-004	878.50	741.80	M4	Ø0,2	A-Z-001	TCS
A-Z-005	1001.66	719.80	M4	Ø0,2	A-Z-001	TCS
A-Z-006	1031.66	741.80	M4	Ø0,2	A-Z-001	TCS
A-Z-007	92.30	619.80	M4	Ø0,3	Xp Yp AXIS	TCS
A-Z-008	601.20	641.80	M4	Ø0,2	A-Z-007	TCS
A-Z-009	755.34	619.80	M4	Ø0,2	A-Z-007	TCS
A-Z-010	878.50	641.80	M4	Ø0,2	A-Z-007	TCS
A-Z-011	1001.66	619.80	M4	Ø0,2	A-Z-007	TCS
A-Z-012	1031.66	641.80	M4	Ø0,2	A-Z-007	TCS
A-Z-013	92.30	519.80	M4	Ø0,3	Xp Yp AXIS	TCS
A-Z-014	601.20	541.80	M4	Ø0,2	A-Z-013	TCS
A-Z-015	755.34	519.80	M4	Ø0,2	A-Z-013	TCS
A-Z-016	878.50	541.80	M4	Ø0,2	A-Z-013	TCS
A-Z-017	1001.66	519.80	M4	Ø0,2	A-Z-013	TCS
A-Z-018	1031.66	541.80	M4	Ø0,2	A-Z-013	TCS
A-Z-019	92.30	419.80	M4	Ø0,3	Xp Yp AXIS	TCS
A-Z-020	258.06	441.80	M4	Ø0,2	A-Z-019	TCS
A-Z-021	423.82	419.80	M4	Ø0,2	A-Z-019	TCS
A-Z-022	589.58	441.80	M4	Ø0,2	A-Z-019	TCS
A-Z-023	755.34	419.80	M4	Ø0,2	A-Z-019	TCS
A-Z-024	878.50	441.80	M4	Ø0,2	A-Z-019	TCS
A-Z-025	1001.66	419.80	M4	Ø0,2	A-Z-019	TCS
A-Z-026	1031.66	441.80	M4	Ø0,2	A-Z-019	TCS
A-Z-027	92.30	319.80	M4	Ø0,3	Xp Yp AXIS	TCS
A-Z-028	601.20	341.80	M4	Ø0,2	A-Z-027	TCS
A-Z-029	755.34	319.80	M4	Ø0,2	A-Z-027	TCS
A-Z-030	878.50	341.80	M4	Ø0,2	A-Z-027	TCS
A-Z-031	1001.66	319.80	M4	Ø0,2	A-Z-027	TCS
A-Z-032	1031.66	341.80	M4	Ø0,2	A-Z-027	TCS
A-Z-033	92.30	219.80	M4	Ø0,3	Xp Yp AXIS	TCS
A-Z-034	601.20	241.80	M4	Ø0,2	A-Z-033	TCS
A-Z-035	755.34	219.80	M4	Ø0,2	A-Z-033	TCS
A-Z-036	878.50	241.80	M4	Ø0,2	A-Z-033	TCS
A-Z-037	1001.66	219.80	M4	Ø0,2	A-Z-033	TCS
A-Z-038	1031.66	241.80	M4	Ø0,2	A-Z-033	TCS
A-Z-039	92.30	119.80	M4	Ø0,3	Xp Yp AXIS	TCS
A-Z-040	601.20	141.80	M4	Ø0,2	A-Z-039	TCS
A-Z-041	755.34	119.80	M4	Ø0,2	A-Z-039	TCS
A-Z-042	878.50	141.80	M4	Ø0,2	A-Z-039	TCS
A-Z-043	1001.66	119.80	M4	Ø0,2	A-Z-039	TCS
A-Z-044	1031.66	141.80	M4	Ø0,2	A-Z-039	TCS
A-Z-045	92.30	58.80	M4	Ø0,3	Xp Yp AXIS	TCS
A-Z-046	258.06	80.80	M4	Ø0,2	A-Z-045	TCS
A-Z-047	423.82	58.80	M4	Ø0,2	A-Z-045	TCS
A-Z-048	589.58	80.80	M4	Ø0,2	A-Z-045	TCS
A-Z-049	755.34	58.80	M4	Ø0,2	A-Z-045	TCS
A-Z-050	878.50	80.80	M4	Ø0,2	A-Z-045	TCS
A-Z-051	1001.66	58.80	M4	Ø0,2	A-Z-045	TCS
A-Z-052	1031.66	80.80	M4	Ø0,2	A-Z-045	TCS
SCE-1-01	446.20	519.80	THROUGH (Det. b)	Ø0,3	Xp Yp AXIS	SCS
SCE-1-02	446.20	541.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-03	321.20	519.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-04	321.20	541.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-05	196.20	519.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-06	196.20	541.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-07	196.20	619.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-08	196.20	641.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-09	196.20	719.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-10	196.20	741.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-11	321.20	719.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-12	321.20	741.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-13	446.20	719.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-14	446.20	741.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-15	446.20	619.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-16	446.20	641.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-17	321.20	619.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-1-18	321.20	641.80	THROUGH (Det. b)	Ø0,2	SCE-1-01	SCS
SCE-2-01	196.20	341.80	THROUGH (Det. b)	Ø0,3	Xp Yp AXIS	SCS
SCE-2-02	196.20	319.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-03	321.20	341.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-04	321.20	319.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-05	446.20	341.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-06	446.20	319.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-07	446.20	241.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-08	446.20	219.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-09	446.20	141.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-10	446.20	119.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-11	321.20	141.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-12	321.20	119.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-13	196.20	141.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-14	196.20	119.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-15	196.20	241.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-16	196.20	219.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-17	321.20	241.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS
SCE-2-18	321.20	219.80	THROUGH (Det. b)	Ø0,2	SCE-2-01	SCS

Fig.3.5.3-9. SCE are mounted inside of the SVM on the -Z Lateral Panel.



ITEM	COORDINATES Xp mm	Yp mm	INSERT TYPE	POSITION TOLERANCE ⌖	REFERENCE	S/S
BM24-05-01	1055.77	780.00	M4	Ø0,4	Xp Yp AXIS	
BM24-05-02	1015.77	780.00	M4	Ø0,3	BM24-05-01	
BM24-05-03	975.77	780.00	M4	Ø0,3	BM24-05-01	
BM24-05-04	975.77	740.00	M4	Ø0,3	BM24-05-01	
BM24-05-05	975.77	700.00	M4	Ø0,3	BM24-05-01	
BM24-05-06	1055.77	700.00	M4	Ø0,3	BM24-05-01	
BM24-05-07	1055.77	740.00	M4	Ø0,3	BM24-05-01	
BM24-06-01	112.77	740.00	M4	Ø0,4	Xp Yp AXIS	
BM24-06-02	152.77	740.00	M4	Ø0,3	BM24-06-01	
BM24-06-03	152.77	780.00	M4	Ø0,3	BM24-06-01	
BM24-06-04	112.77	780.00	M4	Ø0,3	BM24-06-01	
BM24-06-05	72.77	780.00	M4	Ø0,3	BM24-06-01	
BM24-06-06	72.77	740.00	M4	Ø0,3	BM24-06-01	
BM24-06-07	72.77	700.00	M4	Ø0,3	BM24-06-01	
BM24-06-08	112.77	700.00	M4	Ø0,3	BM24-06-01	
BM24-06-09	152.77	700.00	M4	Ø0,3	BM24-06-01	
BM24-07-01	922.77	140.00	M4	Ø0,4	Xp Yp AXIS	
BM24-07-02	842.77	140.00	M4	Ø0,3	BM24-07-01	
BM24-07-03	842.77	100.00	M4	Ø0,3	BM24-07-01	
BM24-07-04	842.77	60.00	M4	Ø0,3	BM24-07-01	
BM24-07-05	922.77	60.00	M4	Ø0,3	BM24-07-01	
BM24-07-06	922.77	100.00	M4	Ø0,3	BM24-07-01	
BM24-08-01	237.77	100.00	M4	Ø0,4	Xp Yp AXIS	
BM24-08-02	277.77	100.00	M4	Ø0,3	BM24-08-01	
BM24-08-03	277.77	140.00	M4	Ø0,3	BM24-08-01	
BM24-08-04	237.77	140.00	M4	Ø0,3	BM24-08-01	
BM24-08-05	197.77	60.00	M4	Ø0,3	BM24-08-01	
BM24-08-06	237.77	60.00	M4	Ø0,3	BM24-08-01	
BM24-08-07	277.77	60.00	M4	Ø0,3	BM24-08-01	
MGSE-24-11	862.75	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-12	557.75	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-13	252.75	808.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-14	54.75	280.80	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-15	557.75	32.00	M6	Ø0,3	Xp Yp AXIS	MGSE
MGSE-24-16	1060.75	280.80	M6	Ø0,3	Xp Yp AXIS	MGSE

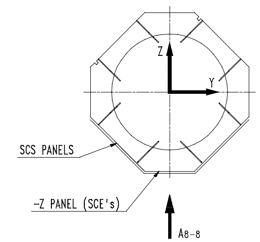


Fig.3.5.3-10.The -Z Lateral Panel outside SVM view.

3.6 THERMAL CONTROL INTERFACES

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

HERSCHEL PACS	**Panel Location**	**Dissipation [Watt]**			**Temperature Range [°C]**			
Project Code		**Safe Mode**	**Spectrosc. Mode**	**Photomet. & Parallel Mode**	**TCS Operating Range**	**TCS Not Operat. Range**	**Start-up**	**Switch-off**
FPDECMEC	+Y-Z	20.9	70.0 (*) 65.0 (**)	28.5 (*) 21.6 (**)	-15/+45	-30/+60	-30	+50
FPBOLC	+Y-Z	6.6	6.6	48.6	-15/+45	-30/+60	-30	+50
FPDPU	+Y-Z	24.0 (18.0 goal)	24.0 (18.0 goal)	24.0 (18.0 goal)	-15/+45	-30/+60	-30	+50
FPSPU	+Y-Z	30.3	30.3	30.3	-15/+45	-30/+60	-30	+50

*) PACS IID-B issue 3.2 Dated 02-03-04 under investigation by ALS TCS.
**) ALS TCS BASELINE from PACS IID-B issue 3.0, used for TCS CDR.

HERSCHEL SPIRE	**Panel Location**	**Dissipation [Watt]**			**Temperature Range [°C]**			
Project Code		**Standby/ Parallel/ Serendip.Mode**	**Spectrosc.Mode**	**Photomet.Mode**	**TCS Operating Range**	**TCS Not Operat. Range**	**Start-up**	**Switch-off**
HSDCU	-Z	37.0	37.0	37.0	-15/+45	-35/+60	-30	+50
HSFCU	-Z	42.9	42.9	42.9	-15/+45	-35/+60	-30	+50
HSDPU	-Z	15.3	15.3	15.3	-15/+45	-35/+60	-30	+50

HERSCHEL HIFI	Panel Location	Dissipation [Watt] *)		Dissipation [Watt] **)		Temperature Range [°C]			
Project Code		Standby	Primary	Standby	Primary	TCS Operating Range	TCS Not Operat. Range	Start-up	Switch-off
FHLCU	-Y	26.0	35.4	37.6	43.7	-10/+40	-25/+55	-25	+40
FHIFH	-Y	0.25	0.25	0	0.4	-10/+40	-25/+55	-25	+40
FHIFV	-Y-Z	0.25	0.25	0	0.4	-10/+40	-25/+55	-25	+40
FHLSU	-Y	45.8	45.8	45.7	50.3	+10/+40	-25/+55	-25	+40
FHHRH	-Y	63.3	63.3	63.3	69.7	-10/+40	-25/+55	-25	+40
FHHRV	-Y-Z	63.3	63.3	63.3	69.7	-10/+40	-25/+55	-25	+40
FHFCU	-Y-Z	13.0	13.0	13.0	14.3	-10/+40	-25/+55	-25	+40
FHWEV	-Y-Z	26.9	26.9	27.0	29.7	0/+30	-25/+55	-25	+40
FHWEH	-Y	26.9	26.9	27.0	29.7	0/+30	-25/+55	-25	+40
FHICU	-Y-Z	29.6	29.6	29.0	34.5	-25/+40	-30/+60	-30	+50
FHWOV	-Y-Z	2.2	2.2	1.5	1.7	+5/+15	-25/+55	-25	+30
FHWOH	-Y	2.2	2.2	1.5	1.7	+5/+15	-25/+55	-25	+30

*) ALS TCS BASELINE from HIFI IID-B issue 3.0 Dated 13-10-03, used for TCS CDR.
**) HIFI CR 54 v.3 (ASP CR 553) is applied to HIFI IID-B issue 3.2 Dated 05-03-04 under investigation by ALS TCS.

PLANCK LFI	Panel Location	Dissipation [Watt] *)		Temperature Range [°C]			
Project Code		Standby (OFF)	Primary (ON)	TCS Operating Range	TCS Not Operat. Range	Start-up	Switch-off
PLBEU (BEU)	Subplt. +X	0	31.7	-20/+40	-30/+50	-30	TBD
PLREN (REBA Nom.)	+Y+Z	0	41.5	-20/+50	-30/+50	-30	TBD
PLRER (REBA Red.)	+Y+Z	0	0	-20/+50	-30/+50	-30	TBD
PLAEF (DAE Power Box)	Subplt. –X	0	13.0	-20/+50	-30/+50	-30	TBD

*) From ASPI CR 519.

PLANCK HFI			Temperature Range [°C]			
Project Code	**Panel Location**	**Power Dissipation [Watt]**	**TCS Operating Range**	**TCS Not Operat. Range**	**Start-up**	**Switch-off**
PHDA (4KCCU)	+Y	60	-10/+40	-20/+50	-20	TBD
PHDB (4KCAU)	+Y	15	-10/+40	-20/+50	-20	TBD
PHDC (4KCDE)	+Y	42.8	-10/+40	-20/+50	-20	TBD
PHBA-N (DPU Nom.)	+Z	22	-10/+40	-20/+50	-20	TBD
PHBA-R (DPU Red.)	+Z	0	-10/+40	-20/+50	-20	TBD
PHCBC (REU)	+Y	92	-10/+40	-20/+50	-20	TBD
PHEB (DCCU)	+Y+Z	16	-10/+40	-20/+50	-20	TBD
PHDJ (4KCRU)	+Y+Z(+Z)	21	-10/+40	-20/+50	-20	TBD
PHCBA (PAU)	Subplt. +X	15	-10/+30	-20/+50	-20	TBD

PLANCK SCS			Temperature Range [°C]			
Project Code	**Panel Location**	**Power Dissipation [Watt]**	**TCS Operating Range**	**TCS Not Operat. Range**	**Start-up**	**Switch-off**
PSM3 (SCC)	-Z+Y	470	-13/+7	-20/+50	-20(*)	TBD
PSR3 (SCC)	-Z-Y	-	-13/+7	-20/+50	-20(*)	TBD
PSM4 (SCE)	-Z	110	-10/+40	-20/+50	-10	TBD
PSR4 (SCE)	-Z	-	-10/+40	-20/+50	-10	TBD

*) The SCC can be switched on at ambient temperature and pressure for 5 minutes maximum per sensor or heater.

3.7 H-P INSTRUMENTS WARM UNITS INTERFACES WITH SVM UNITS

The interfaces of Herschel & Planck instruments warm units with the SVM units (PCDU and CDMU) are reported in the EICD [RD-118] ((it includes Connector Matrix Reports and Pin to Pin Connectivity Reports), where are indicated the name and the type of connector, the pin function and the signal device (i.e. LCL with class, for the power from PCDU, or 1553 bus from CDMU).

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, this point is aligned with the Earth and the Sun and located at 1.5 10^{6} km from the Earth, away from the Sun.

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

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

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

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

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

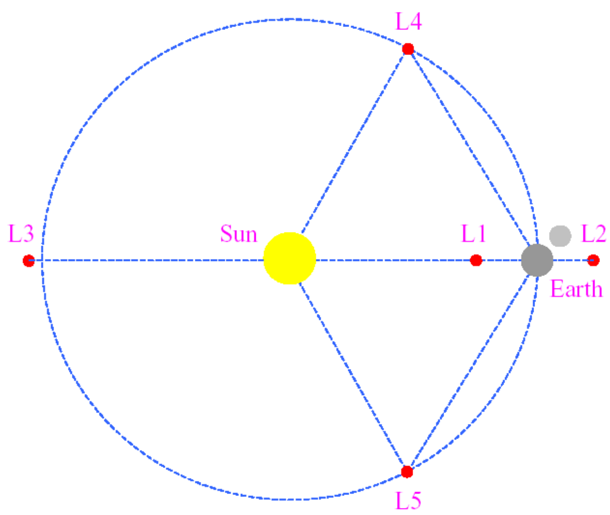


Figure 4-1 - L2 LAGRANGE POINT HERSCHEL ORBIT

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 at the beginnin of phase B between the different approaches to nutation damping depicted in proposal ,namely: (see [RD 73])
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.
Selection has been decided at the SRR and no further option was subsequently analysed
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, it can be concluded 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 and closed at the SRR time.
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 ([RD 74]). 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.

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

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 [RD 75], the gain due to the Turbo Coding does not justify the extra costs so, the current Alenia baseline was to **not implement** the Turbo Coding option and to use the R/S concatenated encoding with SRRC-OQPSK modulation (*). Decision has been taken at the SRR time

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

5.1.4 Battery Redundancy

During the proposal phase, a configuration with two battery set has been presented.
Early in phase B, 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 ([RD 74]) 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 cell trade-off (leading to the choice of low capacity cells), the solution of one battery is the most attractive choice for the redundancy concept
The reliability and the failure tolerance can be easily achieved by adding one or two extra strings at relative low cost.

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

Table 5.1.4-1 Battery Redundancy Trade-Off Summary

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

Based on the above reported data, the solution of one single battery emerges as the baseline solution.
The resulting Charge-Discharge configuration is shown in the following figure and decision on that implementation was decided during the period between SRR and PDR

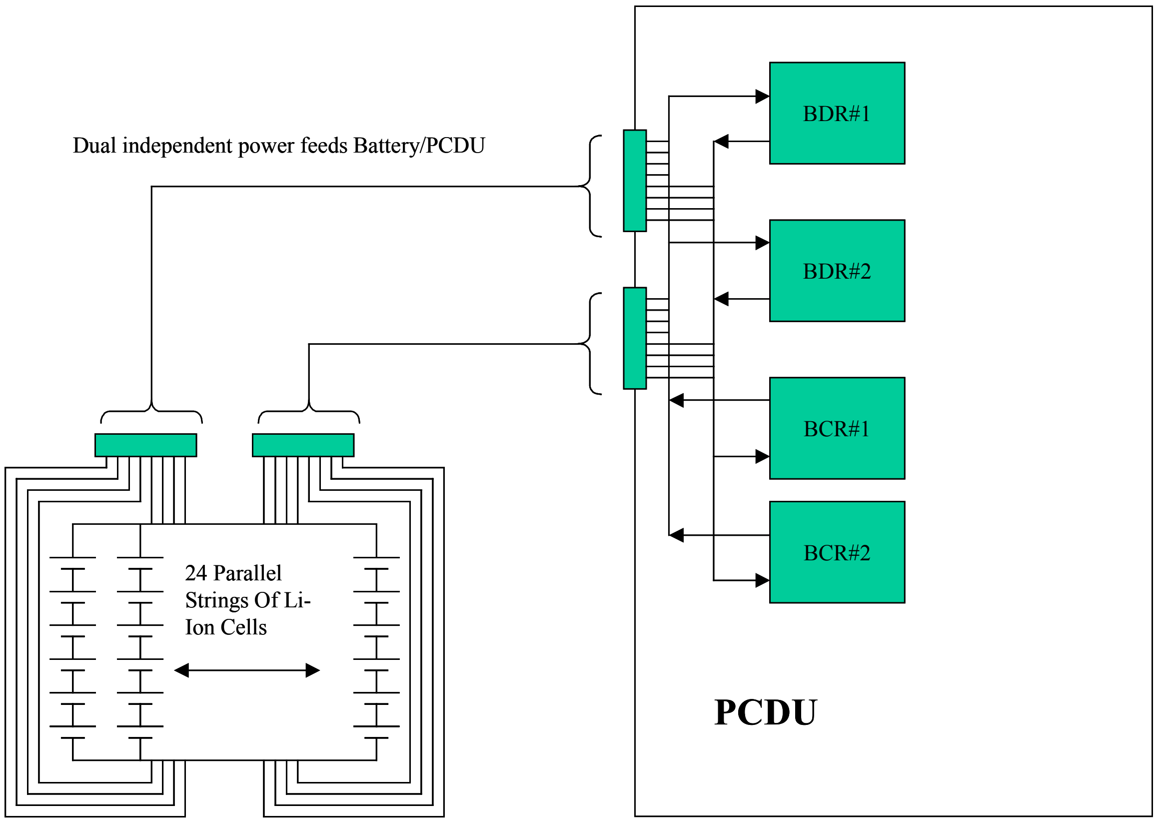


Figure 5.1.4-1 Battery Configuration

5.1.5 Star tracker Accommodation

The STR positioning on the Herschel SVM was considered, since the beginning of the program, extremely critical. After the first thermoelastic analyses loop (run during phase B), the great inconsistency between the requirement and the proposed allocation (on the Planck lateral panel) has became evident. Several checks and trade off to evaluate the stability of the octagonal Box w.r.t the requirements have been performed. The results of such checks and investigations have been reported during PM8 [RD. 41], and are summarised hereafter for clarity:

Comparison between -30 and +30		
	Ry [° 1E-3]	Req. [° 1E-3]
STR1 on Panel -Z	15.3	0.22
STR2 on Panel -Z	14.7	
STR1 on Sh. Panel -Z	12.3	
STR2 on Sh. Panel -Z	12.8	
STR1/2 on PLD Subplatf.	17.7	
STR1/2 on Cone	20.2	
0.22° 1E-3 = 0.8 arcsec		

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

Comparison between -30 and +30 Cone temperature stable within 1 C		
	Ry [° 1E-3]	Req. [° 1E-3]
STR on Panel -Z	0.86	0.22
STR on Sh. Panel -Z	0.77	
STR1/2 on PLD Subplatf.	1.16	

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

Figure shows the original (Phase A and Proposal) STR position:

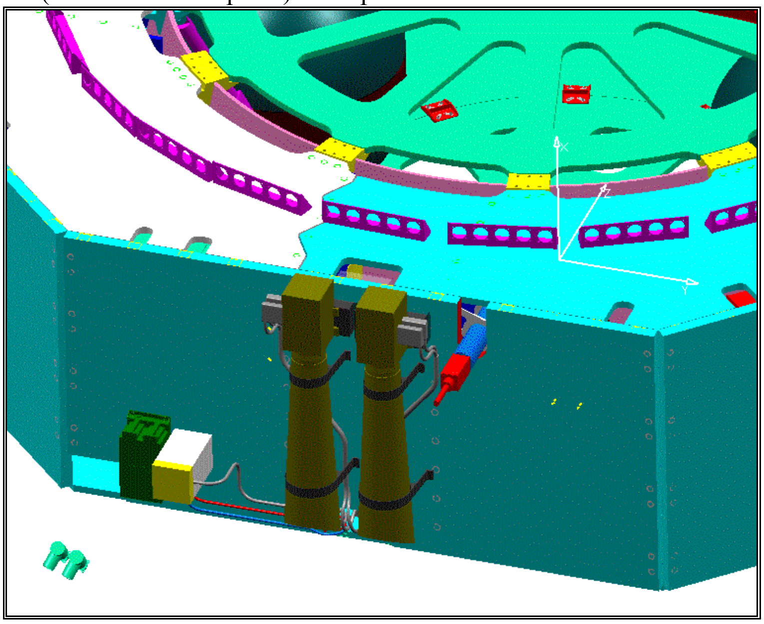


Figure 5.1.5-1 STR baseline position

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

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

According to ESA recommendations, and at that time, Alenia started to verify the feasibility of the Isostatic mounting concept.
Details of the Trade off are reported in [RD 86].
The trade off performed after the SRR till the PDR shows that, the most promising solution that seems feasible even if marginal, is given by a truss beam to be mounted inside the cone, the concept is presented in figure below.

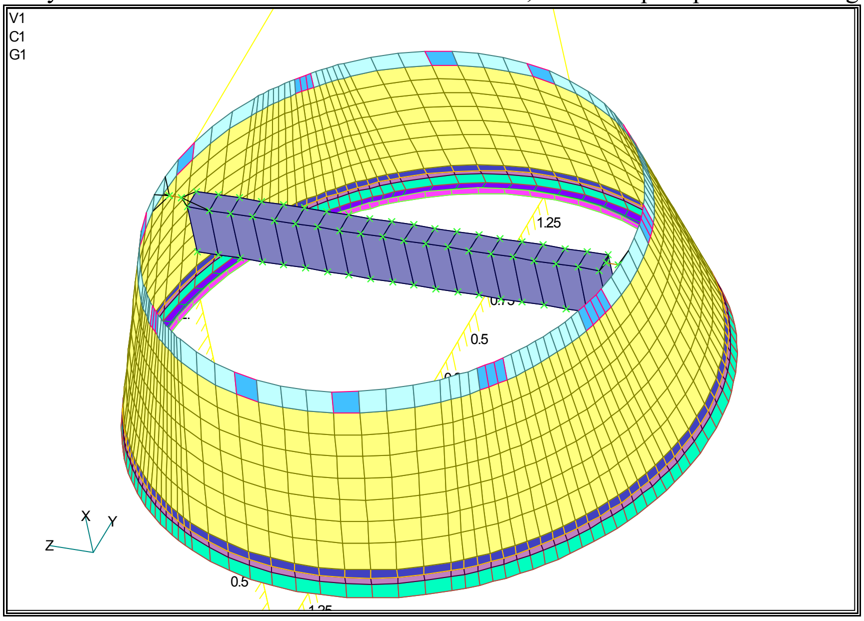


Figure 5.1.5-2 Trade off PDR most promising concept

Detailed analysis performed on the star tracker mounted on a beam in the upper part of the Herschel cone still showed a non compliance for the thermoelastic requirements. Based on that, a new Star Tracker accommodation on a dedicated platform, inside the SVM Cone and attached to the CVV has been studied. This accommodation is based on a dedicated structure, called Star Tracker Assembly (STRA), supporting the two STR units as shown in the following figures.

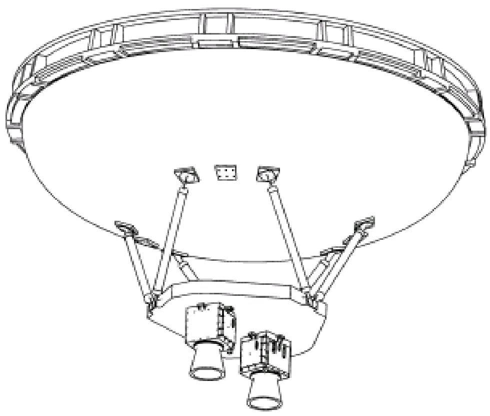


Figure 5.1.5-3 STRA prospective view from below (side +Y/+Z)

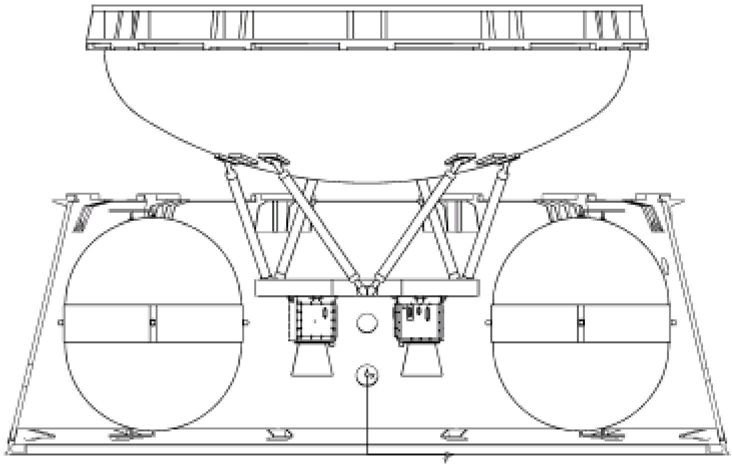


Figure 5.1.5-4 STRA lateral view from +Z

The following driving requirements to be considered for the design of this new assembly have been established.

The thermal conductive leak from the Star Tracker Assembly to Herschel PLM shall not exceed 150 mW.
This requirement is important as every additional mW flowing to the CVV would means a mission lifetime reduction.

Additional thermal conditions to be compliant with the STR Equipment design are:

- STR operative temperature range = -20°C÷ +40°C
- STR temperature stability = 0,25 °C/100sec
- Temperature difference between two STR feet ≤ 0.4°C

For simplicity reasons the current pointing budget (RD.114) allocates a maximum error of 0.8” ($3.9\ 10^{-6}$ rad) to the thermal-elastic distortion of the STR around Y and Z axes (these are the axes orthogonal to the STR Line Of Sight). It is important to recall that, if met, this requirement translates into a de-pointing of the X axis of:

$\vartheta = (\sqrt{\ rot_y^2 + rot_z^2}\ ) = 1.13'' = 5.5\ 10^{-6}$ rad

In reality, different errors around Y and Z are allowed, provided that the de-pointing is met; for example, at the limit, the de-pointing requirement can be met if:

$Rot_y = 1.13''$
$Rot_z = 0$

For Herschel there is also an overall pointing goal to be met that translates into a maximum allowed thermal-elastic distortion of the STR around Y and Z axes of 0.35”.
Also this case may be treated assuming different contributions around Y and Z provided that the following is met:

$\vartheta = (\sqrt{\ rot_y^2 + rot_z^2}\ ) = (\sqrt{\ 0.35^2 + 0.35^2}\ ) = 0.5'' = 2.4\ 10^{-6}$ rad.

A frequency requirement, to dynamically decouple the assembly from the CVV to which it is attached, has been settled. In particular:
The Herscel frequency in hard mounted conditions (at the upper end of the struts) shall be in the range [60;70] Hz or above 95 Hz.

Several iterations have been made to found the optimum solution, also considering the mass impact on the SVM. The final solution chosen is described in RD 79; the resulting configuration is shown in the following figures.

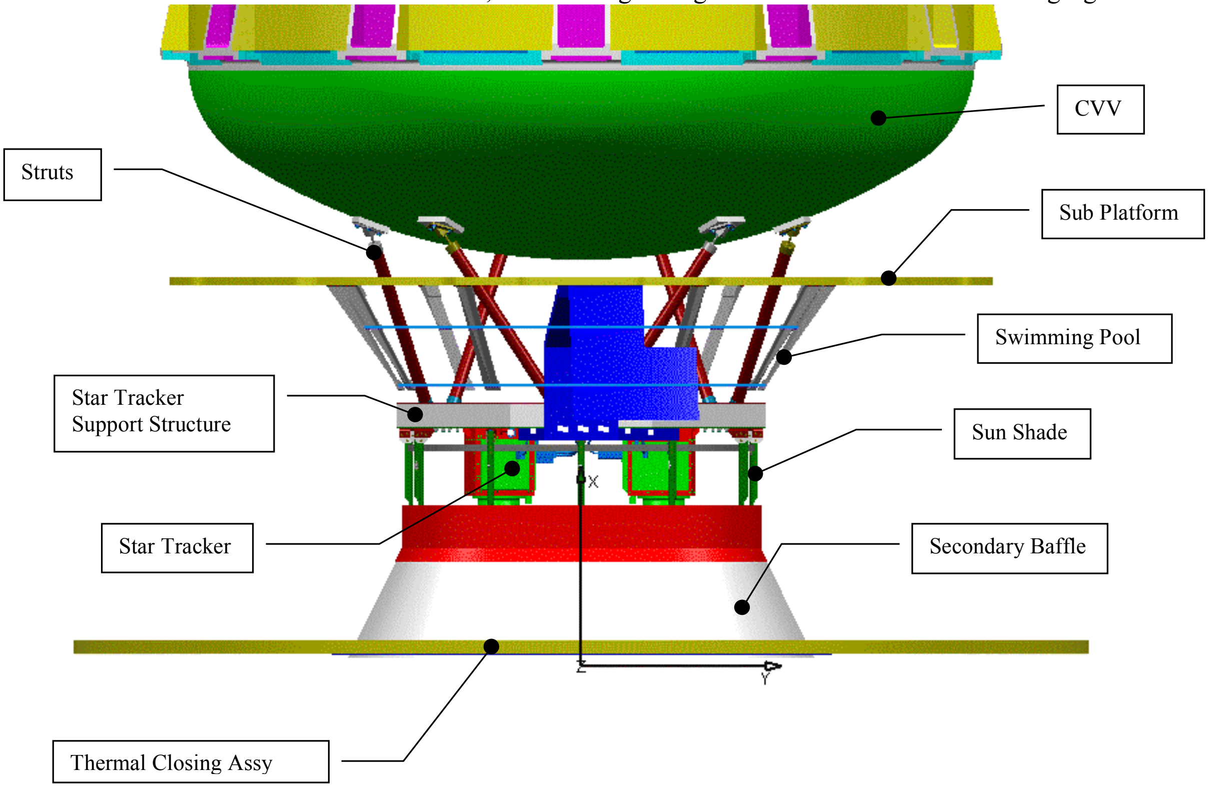


Figure 5.1.5-5 STRA Architecture design

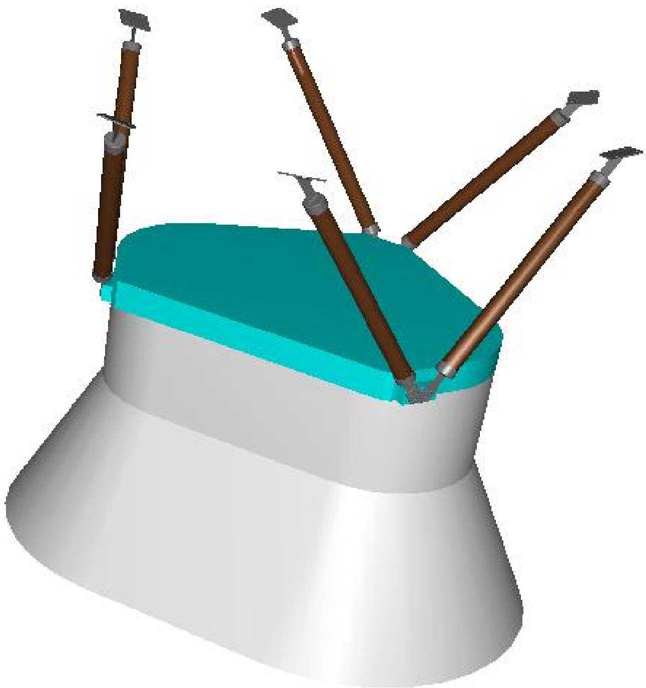


Figure 5.1.5-6 STRA External View

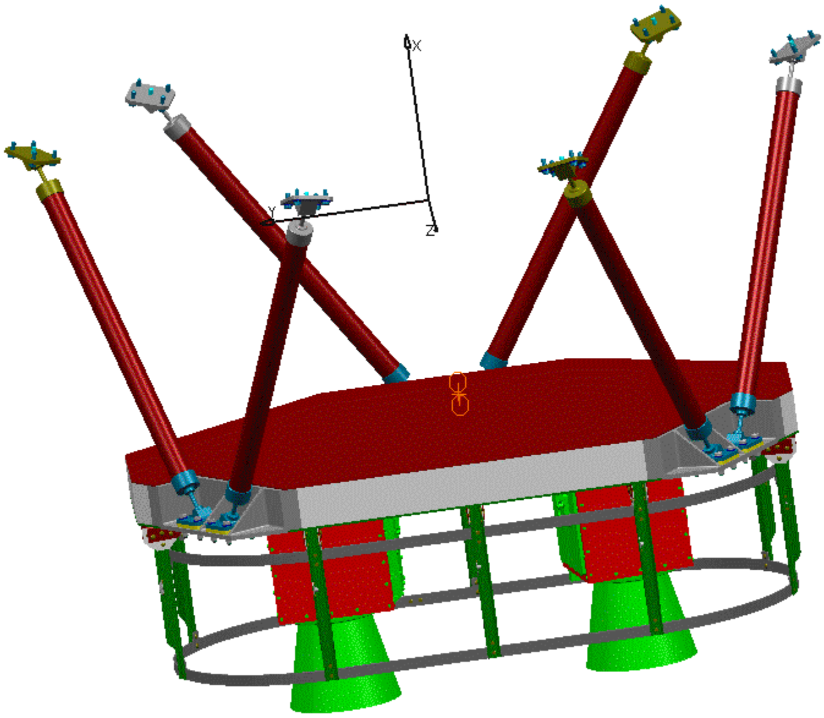


Figure 5.1.5-7 STRA - Swimming pool concept

Dedicated thermoelastic analysis has been performed with the objective to demonstrate the compliance with the main requirement on the maximum thermoelastic distortion. This analysis has been based on the predicted temperature distribution in the SAA worst case (-30° , +30°). Results are reported in the following table.

DIFFERENCE (radiants)

	Rx	Ry	Rz
STR1 sun -30 - sun 0	3,38E-07	1,45E-06	-1,15E-06
STR2 sun -30 - sun 0	3,26E-07	1,44E-06	-1,19E-06
STR1 sun -30 - sun +30	-1,07E-07	2,06E-06	-1,62E-06
STR2 sun -30 - sun +30	-1,26E-07	2,05E-06	-1,61E-06
STR1 sun 0- sun +30	1,58E-07	6,04E-07	8,73E-07
STR2 sun 0 - sun +30	1,51E-07	6,09E-07	9,22E-07

DIFFERENCE (degree)

	Rx	Ry	Rz
STR1 sun -30 - sun 0	1,94E-05	8,31E-05	-6,59E-05
STR2 sun -30 - sun 0	1,87E-05	8,25E-05	-6,82E-05
STR1 sun -30 - sun +30	-6,13E-06	1,18E-04	-9,29E-05
STR2 sun -30 - sun +30	-7,22E-06	1,18E-04	-9,23E-05
STR1 sun 0- sun +30	9,06E-06	3,46E-05	5,00E-05
STR2 sun 0 - sun +30	8,66E-06	3,49E-05	5,29E-05

Tab. 5.1.5-1 Max rotations at STR I/F

The design described in that note meets all the thermal requirements and provides the temperature distribution which allows to meet the thermo-elastic requirements.

The design of the control law for keeping the STR's in the allowed time gradient range will be based on the HIFI control law and therefore it's not expected to raise problems as STR requirements are less tight.
A parametric analysis has also been run, showing that there are some margins on the design assumptions.

From a mechanical p.o.v. a conceptual study has been performed (see [RD-79]). It shows that all mechanical requirements are fulfilled.
The only concern is about the moments at the CVV I/F: this critical point could be due mainly to the preliminary definition of the requirement.
The preliminary stress analysis of the STR support structure shows that it presents a good global behaviour under the loads experienced during all mission phases, as a matter of fact looking at the stress maps we can see that all items exhibit positive margin of safety.
This present analysis has the scope to investigate the rough order of magnitude of stresses for the main parts of the assembly to justify the initial size of the structure.

As far the thermal-elastic stability analysis is concerned the influence of several parameters on the final result has been verified by a sensitivity analysis as reported in [RD-80] and [RD 81].
The scope of that note is to demonstrate that varying the main driving parameters (panel I/F geometry, CTE of strut material and radiator thermal distribution) the order of magnitude of the results is still valid.
It turns out that alignment stability requirements are met with good margins and all over the pointing range.

The main assumptions that were used to verify compliance of the design described in [RD-79] to thermal and mechanical requirements are summarised hereafter.

- Struts are made in GFR (512 mm long splitted in CVV blade 20 mm, titanium strut end fitting 23.5 mm each, glass fiber tube 427 mm, panel blade 18 mm) with Ti end fitting and blades , having the GFR thermal conductivity reported in the range between .30 to 0.75 k [W/m/K](20 % deviation accepted) . The struts are covered with Aluminised MLI. GFR Thickness is 0.8 mm diameter 30 mm The GF struts will be filled with Eccofoam to minimise radiative heat transfer inside the tubes at the cryogenic temperatures.
- Struts will be mounted with flexible titanium blades at the STR support plate and CVV interface
- "Swimming pool" is made of blankets surrounding the 6 Struts, starting from the PLM MLI support panel and ending around the STR support plate. MLI blankets are needed to cover the supporting plate and to create the swim pool and the sunshade. For the time being, it is foreseen to create a light structure (NARMCO or Aluminium) to support the MLI's of the swim pool. This structure may be fixed to the upper thermal closure of the structural cone. For the sun shade it is envisaged to fix a number of stand-offs (NARMCO or Aluminium) to the support plate to allow installation of the MLI's. These MLI's will not be rigidly attached to the secondary baffle; this is to avoid any stress transmission that may develop due to the thermal distortion of the baffle itself.
- STR support plate is made of an Aluminium honeycomb panel of 55 mm thickness with High Conductivity CFRP (K1100) skins. The thickness of the two skins are different (3mm on the –X side and 2 mm on the +X side). The lower skin shows a total of 24 plies and the upper 16 plies in such a way to obtain quasi-isotropic distribution.
- Titanium fittings are embedded into the plate to allow an easier alignment and demountability
- Two Silver Teflon (or OSR) radiator areas (total 35625 mm2) surrounding the two STR's .
- One main and one redundant heater loop each consisting of 8 heaters and 6 (3 per each STR) thermistors. The total heater power will be between 16 and 24 W

All data have to be confirmed by the detailed design phase

5.1.6 Planck Subplatfor Design Evolution

5.1.6.1 Introduction

The Planck Payload Sub-platform, due to the several performance (frequency, mass) but also interface requirement to be met, is one of the most complex structural item inside H-P SVM Structure project.
Along the project evolution it went through several design / analyses iteration, due to the several requirement updating.
In this chapter, the several steps, developed along H-P C/D phase, are described.

5.1.6.2 Requirement evolution – first step

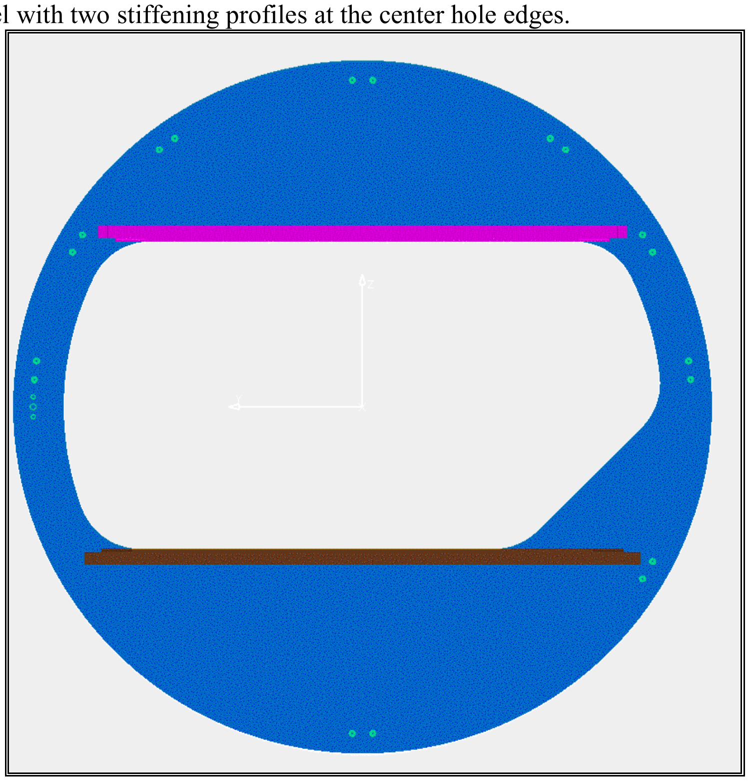
The Planck Sub-platform frequency requirement, has been changed after Structure/ System PDR.

- System PDR: The Sub-platform frequency shall be **f>32 Hz**
- After PDR: The Sub-platform frequency shall be **70< f <76**, the axial dynamic motion at BEU and PAU levels shall be inferior to ±1.5 mm. The BEU/PAU/DAE units must respect Design loads 25 g axial Vs 20 g lateral.

5.1.6.3 Design Concept evolution

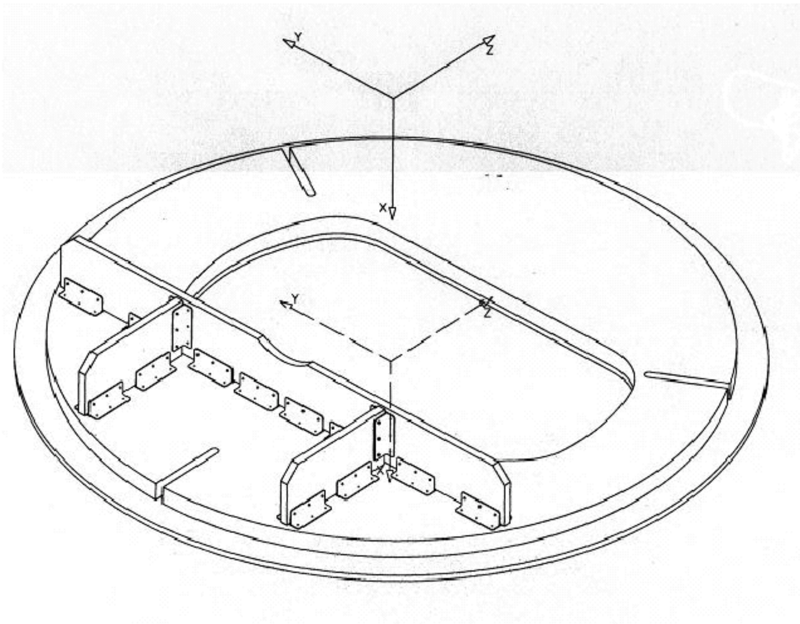
5.1.6.3.1 System PDR Concept

The Sub-platform configuration, meeting the PDR frequency requirement is shown here below.
It was a sandwich panel with two stiffening profiles at the center hole edges.



5.1.6.3.2 Evolution after PDR

The new requirement (frequency, max dynamic displacement and units DLF) could not be entirely verified by CASA, whose tasks do not include verification by sine and vibro-acoustic analysis, devoted to check the max. displacement and unit DLF requirement.
Therefore, ALS started the loop trying to find a configuration meeting the entire requirement, and, in the same time, without affecting the cone, whose design concept was frozen at PDR.
Several trade-offs and a first analysis loop, on the selected concept, were carried out. The analyses included normal mode, sine and vibro-acoustic response. The resulting concept, responding to the requirement, is shown here below. It is a double panel plus stiffening beams underneath the BEU/PAU side.
The double panel is made of two h/c cores 20 mm height, aluminum skins 0.3 / 0.6 (see below) bonded each other. This concept has been conceived to provide the required stiffness in conjunction with the edge interface needs. In fact the Sub-platform shall be mounted on top of the Cone PLM/SVM interface brackets, but without exceeding the total height of 20 mm. Therefore, the total needed thickness for meeting the frequency requirement (35 to 40mm) has been derived inside the panel (inward).



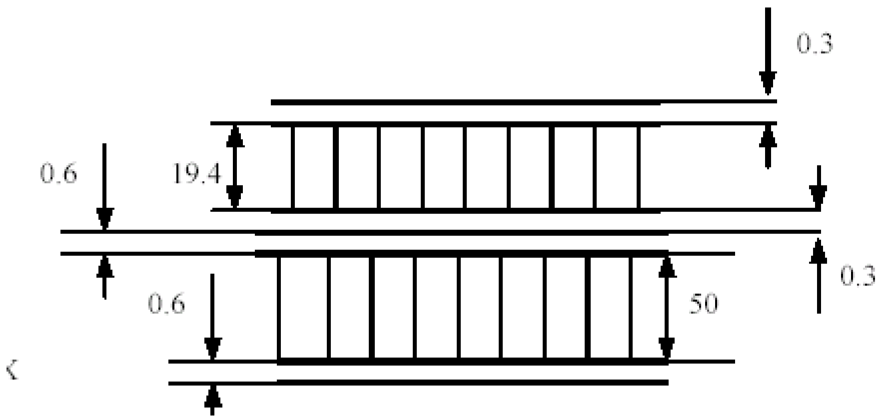


Figure Sub-platform Configuration (May 2003)

At the end of this loop, due to the evolution of the rest of the structure and the resulting coupling with the tanks, additional reinforcements (stiffening beams) were added. Their height has been increased, especially the one underneath the BEU side (0.5 m). Two beams, one of which is removable for Equipment integration reasons, are crossing the center hole, whose transversal size has been decreased to house the beams interfaces.

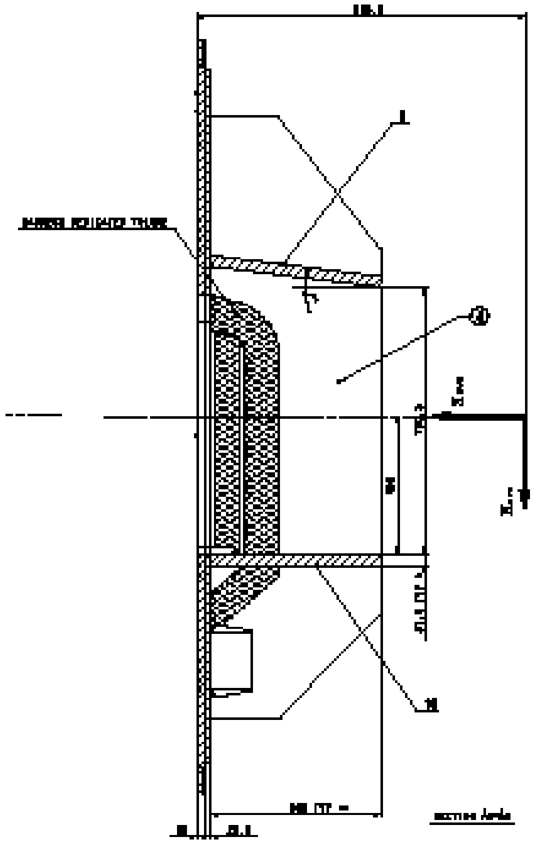


Figure Sub-Platform Configuration (July 2003)

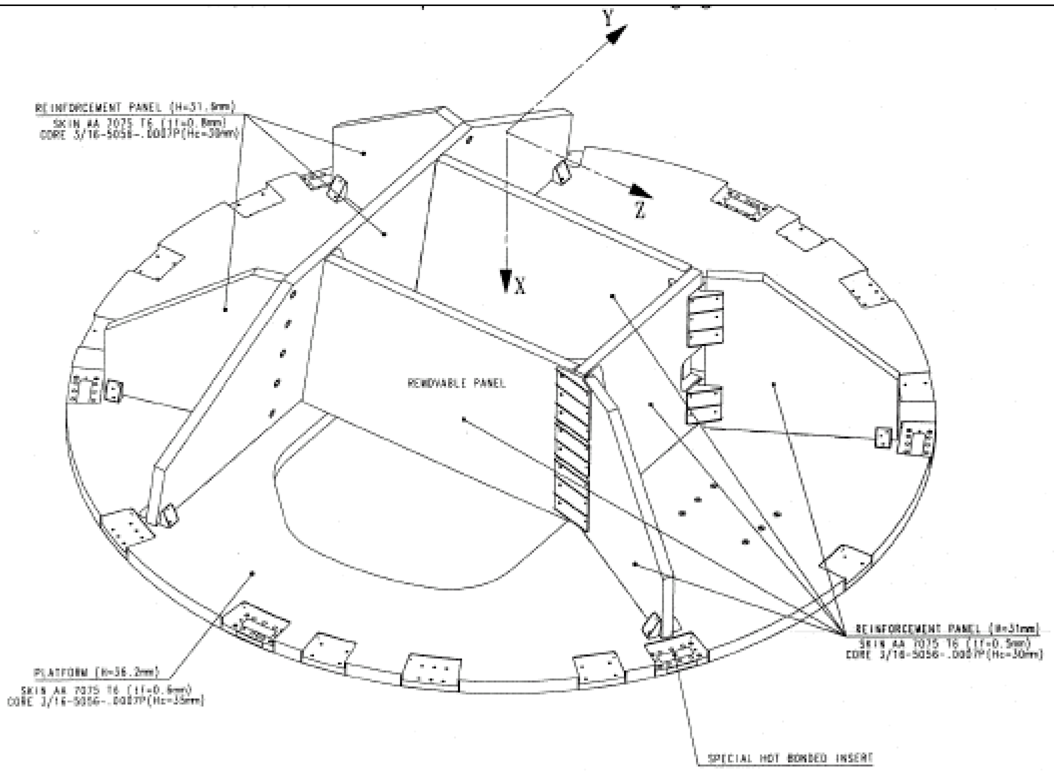


Figure. Sub-platform Configuration October 2003

The concept was transferred to CASA, which, however, was not able to start the definitive design, due to the lack of interface information regarding the mounted units.

Therefore, the item, initially included within the MRR2 items, was then shifted within the MRR3 items (Equipment panels).

During the MRR3 input review, CASA clarified that the double panel concept would have required manufacturing development. The associated schedule problems induced CASA to find alternative solution.
Further, the total SVM Structure mass, increased along the phase c/d development, resulted to be one of the most critical issue of the project. At that point, several main requirements should have been revised, in order to achieve a mass value compatible with the launcher capability. Among them, the frequency requirement of the Sub-platform was revised, focusing the requirement mainly on the BEU/PAU units.

5.1.6.4 Requirement evolution – second step

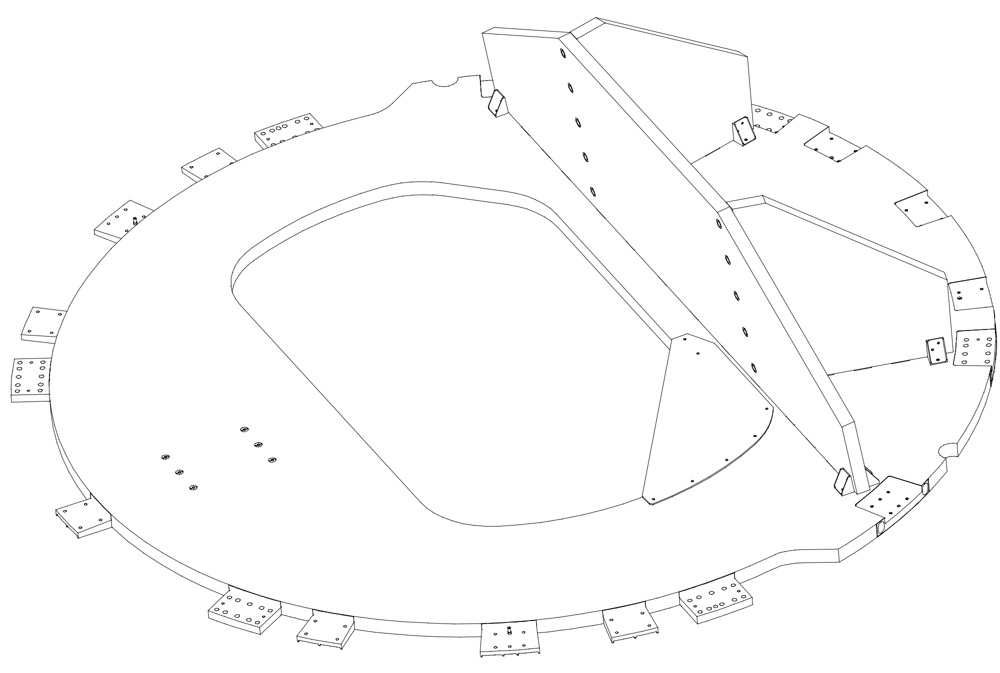
The Planck Sub-platform frequency requirement, has been updated, such to reduce its mass of about 10 Kg.

The Planck payload sub-platform shall ensure:

- an axial dynamic motion at BEU and PAU levels inferior to ±1.5 mm. The BEU/PAU/DAE units must respect Design loads 25 g axial Vs 20 g lateral).
- an axial first frequency in the ranges:
  - 70 Hz <fp< 76 Hz for BEU / PAU side (on SVM)
  - **30 Hz <fp < 38 Hz for DAE side (on SVM)**

5.1.6.5 Present Configuration

The payload sub-platform is made of one sandwich panel with Aluminum skins.
It is fixed on the top of the Central Cone above the upper I/F brackets. It provides the interface to the P-PLM struts as well as to 3 Warm Units (BEU / PAU/ DAE). In addition it also provides interface to several items, as electrical connectors, wave-guides and MGSE devices.
The interface with the Central Cone is made via special inserts on the platform and brackets on the cone. The special insert configuration ("hat like") is a consequence of the relative heights of the cone bracket and the Sub-platform thickness (37.2mm – 35mm H/C, 0.6 x 2-mm facings), necessary to meet the frequency requirement.
The last configuration, whose analysis is in progress, includes one high stiffening beam (sandwich with CFRP facings) underneath the BEU side plus two other shorter stiffening beams. A large number of inserts are required in the BEU side and many of them are located very close to the panel edge where the PLM to cone bracket are located. In order to cope with this layout, a wide hot bonded insert, machined and lightened when possible, has been considered the most efficient solution.



The stress analysis and manufacturing drawing of this concept will be presented at MRR3 review.

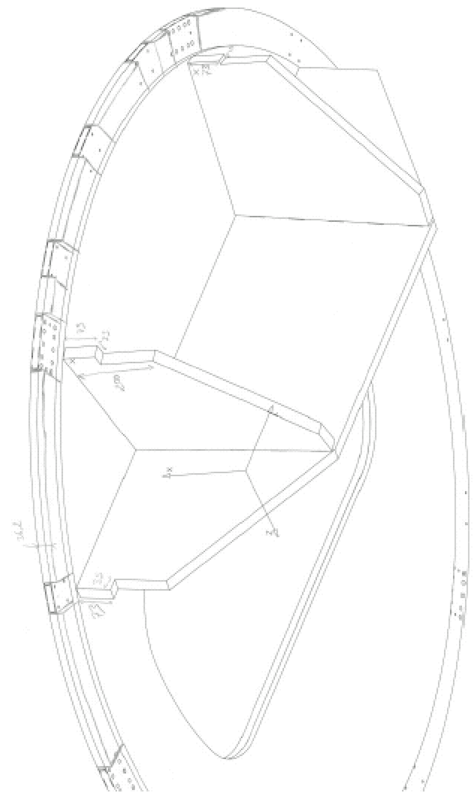
A final check, regarding the dynamic requirement (max displacement and units DLF), will be performed by ALS with the CASA last FEM.
Preliminary ALS analysis checks have been performed showing confidence on meeting frequency, unit DLF and max. displacement requirement.
6. Requirement evolution – third step

On July 19th, a fax from ASP asked for a further requirement modification, due to a problem identified during mating of PLM on SVM. To solve this problem two options shall be investigated.
In both cases a change of requirement shall be specified and implemented by CASA.

Option 1 is to have some cut at the end of the long beam and stiffeners to perform lateral requested lateral translation. These are shown in figure 3 and a better proposition is given in figure 4. We think that these small cuts at the end of the beam and stiffeners shall have negligible impact stiffness and load transfer.
Option 2: basing on the CAD model, the long beam and stiffeners seem to be dismountable, these being fixed by the top of the sub-platform. In that case we think of dismounting them before the mating, and mount them back to the platform after.

- For this we firstly need the confirmation that they are indeed removable and re-mountable without impacting platform integrity.
- We also need confirmation of the mass of long beam and stiffeners to be sure they are handable.
- In addition, as the RAA MGSE is present and weighs 250 kg, we need to know if the sub-platform is able to carry it without the stiffeners and without being damaged under 1g vertical.

In case it is not possible, it could be envisaged to use stiffener tools to enable the sub-platform withstanding the RAA MGSE loads.



6. OPERATIONAL CONCEPT

See [RD-76] MODULE/SUBSYSTEM/EQUIPMENT User Manual where in conjunction with the overall System Concept the SVM considerations are reported.
The document provides all the technical inputs necessary to operate the HERSCHEL and PLANCK SVM. In particular the document content provides information sufficient to control the HERSCHEL and PLANCK SVM from the separation from the launcher until completion of the defined mission. and details high-level mission description as well as providing a breakdown of the HERSCHEL and PLANCK platforms into sub-systems and components (e.g. Sensors and Actuators).
The HERSCHEL and PLANCK SVM User Manual is divided into the following Volumes:

Volume 1: Introduction and System UM
Volume 2: Command and Data Management Subsystem UM
Volume 3: Telemetry, Tracking and Command Subsystem UM
Volume 4: Attitude Control and Measurement Subsystem UM
Volume 5: Reaction Control Subsystem UM
Volume 6: Power Control Subsystem UM
Volume 7: Thermal Control Subsystem UM

Volume 1 will focuses on Mission and System aspects providing a high level description of both the satellites.
Volumes from 2 to 7 will contain a Subsystem overview and references to available Subsystem documentation.
Note that each volume is considered as a document itself and, when necessary, will be updated and re-issued independently from the other Volumes.

7. SVM FUNCTIONAL DESIGN AND PERFORMANCE ANALYSES

7.1 SVM OVERALL DESCRIPTION

Overall SVM (both for Planck and Herschel) in conjunction with the external interfaces are described in the H-P-RP-AI-0003 Issue 4 [RD-17].

7.2 POINTING AND DYNAMICS

As a three-axis-stabilised observatory Herschel follows the tradition of many recent astronomical space missions and presents no new problems in the control of the dynamics of the spacecraft.
The situation is radically different for Planck for which dynamic characteristics of the spacecraft are a major design driver. With passive stabilization Planck has no closed loop attitude control in any of its operating modes, sophisticated algorithms nevertheless had to be developed in order to manage the onboard determination of attitude and accurate positioning of the spin axis. The discussion in this section will therefore be devoted entirely to Planck with the aim to summarise the main aspects of the dynamics of the spacecraft and identify those that have determined the strategy and the major design choices for the ACMS (the most important element of this type is the effect of the solar disturbance torque and the necessity to introduce autonomous inertial attitude determination onboard). The section starts with a summary of the main concepts used in analyzing the dynamics of spinning spacecraft, which are subsequently applied to dynamics problems specific to Planck.

7.2.1 Dynamics of a spinning body

In a non-inertial reference frame formed by a set of three orthogonal axes fixed with respect to the spinning body, the equation of motion takes the form:

$$\dot{\mathbf{H}} = \mathbf{T} - \omega \times \mathbf{H} \tag{1}$$

where **H** represents the angular momentum, ω is the angular velocity and **T** is the torque acting on the body. The reference in which Eq. (1) is usually written for a spinning spacecraft is usually the mechanical frame with respect to which the element of the spacecraft are placed in the process of mechanical design and integration. This frame will be referred to as the **body frame** in the remainder of this section. The desired direction of the effective line of sight of the payload is also defined with respect to this frame.
The symmetric inertia tensor, **I**, links the components of the angular rate and angular momentum vectors through the relationship:

$$\mathbf{H} = \mathbf{I}\ \omega = \begin{bmatrix} I_{XX} & I_{XY} & I_{XZ} \\ I_{XY} & I_{YY} & I_{YZ} \\ I_{XZ} & I_{YZ} & I_{ZZ} \end{bmatrix} \omega \tag{2}$$

Even though the objective of mechanical design is to reduce the mass unbalance in the spacecraft body frame, *i.e.,* to bring the non-diagonal elements of the inertia tensor close to zero, in general the matrix of inertia is not diagonal in body frame (the limits on the mass unbalance of Planck allowed by the required pointing accuracy will be discussed in detail below). The reference frame in which the matrix of inertia is diagonal is defined by the eigenvectors of the matrix which represent the principal axis of inertia of the body. The principal moments of inertia are the eigenvalues of **I**. In the principal frame, Eq. (2) takes the form:

$$\mathbf{H}_P = \mathbf{I}_P\ \omega_p = \begin{bmatrix} I_X & 0 & 0 \\ 0 & I_Y & 0 \\ 0 & 0 & I_Z \end{bmatrix} \omega_P \tag{3}$$

The equations of motion are usually written in the principal axis frame and this convention will be used in the remainder of this section without explicitly adding the subscript to indicate the reference frame. The moments of inertia written with a single subscript, such as I_X, are assumed to be the principal moments, whereas double subscripts will be used to indicate the moments of inertia in body frame.
In the principal axis frame, the equations of motion take the form of Euler's equations:

$$\begin{aligned} I_X\,\dot{\omega}_X - (I_Y - I_Z)\,\omega_Y\,\omega_Z &= T_X \\ I_Y\,\dot{\omega}_Y + (I_X - I_Z)\,\omega_X\,\omega_Z &= T_Y \\ I_Z\,\dot{\omega}_Z - (I_X - I_Y)\,\omega_X\,\omega_Y &= T_Z \end{aligned} \qquad (4)$$

The form of the Euler equations above is based on the assumption that moments of inertia are fixed in time. This is valid for most aspects of the dynamics of Planck, except for the effect of propellant transfer due to temperature differences between fuel tanks.

7.2.1.1 Torque-free motion. Nutation

In the absence of torques, the equations of motion are reduced to the form:

$$\begin{aligned} I_X\,\dot{\omega}_X - (I_Y - I_Z)\,\omega_Y\,\omega_Z &= 0 \\ I_Y\,\dot{\omega}_Y + (I_X - I_Z)\,\omega_X\,\omega_Z &= 0 \\ I_Z\,\dot{\omega}_Z - (I_X - I_Y)\,\omega_X\,\omega_Y &= 0 \end{aligned} \qquad (5)$$

Inertially symmetric body
In the discussion that follows the X axis will always be assumed to be the main symmetry axis of the body. In the special case of a cylindrically symmetric body, when $I_Y = I_Z$, the first of the three Euler equations implies that the X component of the rate is constant:

$$\omega_X = \omega_S = \text{const} \qquad (6)$$

If $\boldsymbol{\omega}$ is not aligned with the axis of symmetry, it will describe a regular circular cone around this axis. This motion is usually referred to as nutation; in the cylindrically symmetrical case, the **H** vector is always coplanar with the symmetry axis and $\boldsymbol{\omega}$ and also describes a circular cone around the main body axis. The rate at which the motion takes place is a function of the spin rate, ω_S, and the moments of inertia of the body:

$$\omega_N = \frac{I_X - I_T}{I_T}\,\omega_S \qquad (7)$$

where I_T represents the moment of inertia in the plane perpendicular to the principal symmetry axis. The motion of the angular rate vector around the principal axis at the rate given by Eq. (7) defines the **body nutation cone**.
In inertial space, both the principal body axis and the angular rate vector trace circular cones around the fixed direction of the angular momentum vector. The rate of this rotation, ω_P, is usually referred as the inertial nutation rate and can be derived easily by observing that the instantaneous motion of the main body axis in the inertial frame

can be expressed both as rotation about the angular momentum vector at the inertial nutation rate and as rotation defined by the instantaneous value of **ω**. This leads to the expression:

$$\omega_P = \frac{I_X}{I_T} \frac{\omega_S}{\cos\theta} \tag{8}$$

The nutation angle, θ, in Eq. (8) is the angle between the angular momentum vector and the principal body axis and its value provides the standard way to characterise the amplitude of nutation. Eq. (8) shows that for an oblate body ($I_X > I_T$), the inertial nutation rate is always higher than the spin rate.

Stability of torque-free motion

For a general case of a body with a triaxial ellipsoid of inertia (no rotational symmetry), only rotation about the axis with the largest and the smallest inertia can be stable. If the initial rate vector is not aligned with one of these two axes, the body will reorient itself until the stable rotation is achieved. The instability occurs even if the initial rate vector is aligned with the intermediate axis of inertia, since any component of the rate on one of the orthogonal axes will grow exponentially.

The stability conditions can be deduced directly from the Euler equations. Assuming $I_X > I_Y > I_Z$, and placing the initial rate vector along the Y axis, $\omega_Y = \Omega$, the solution for the orthogonal components is unstable since it contains a growing exponential term of the form:

$$\omega_i = A_i \, e^{\frac{t}{\tau}}, \quad i = X, Z \tag{9}$$

where the time constant, τ, is given by

$$\frac{1}{\tau} = \Omega \sqrt{\frac{(I_X - I_Y)(I_Y - I_Z)}{I_X \, I_Z}} \tag{10}$$

If the initial rate, Ω, is directed along the X or Z axis, a small rate component will not grow exponentially, but will vary periodically so that the angular rate vector will trace an elliptical cone about the principal axis (this is discussed in detail in Section 7.2.1.2)

In the presence of energy dissipation, which occurs inevitably in fuel tanks, the stability conditions are modified further. In the absence of torques, the angular momentum is conserved whereas dissipation allows the system to settle towards the lowest energy configuration. The kinetic energy of the spinning body is given by:

$$E = \frac{1}{2} \boldsymbol{\omega} \mathbf{I} \boldsymbol{\omega} = \frac{1}{2} \left(\frac{H_X^2}{I_X} + \frac{H_Y^2}{I_Y} + \frac{H_Z^2}{I_Z} \right) \tag{11}$$

For a given value of the angular momentum, the energy is minimised when the angular momentum vector lies along the axis of largest inertia. As a consequence, rotation about any other axis will be unstable and will cause a reorientation until the angular momentum vector is aligned with the main axis of inertia. In cases in which internal energy dissipation allows the system to settle towards the minimum energy, the body will be reoriented with respect to the angular momentum vector until the angular momentum is aligned with the axis of maximum inertia. It follows immediately that in the case of rotational symmetry, only oblate bodies can rotate in a stable way about the axis of rotational symmetry.

7.2.1.2 Small angle nutation

In the general case of a body without rotational symmetry, the solution of the torque-free Euler equations can be expressed in the form of Jacobi elliptical functions (RD ACMS-1). Since, as will be discussed below, the amplitude of nutation is small during normal scientific operations of Planck, the general case of large nutation is of little interest in analysing the performance of the spacecraft.
In the case of small nutation angles, the solution limited to first order terms in nutation angle takes a simple form which allows the kinematics of the nutating spacecraft to be described through straightforward coordinate transformations. The treatment is based with a few minor modifications on that presented in RD ACMS-2. Without loss of generality, the same assumption is made as in the discussion of the stability of motion above: $I_X > I_Y > I_Z$.
The condition of small nutation implies that transverse components of angular momentum and angular momentum are small with respect to the component along the spin axis:

$$\omega_Y , \omega_Z << \omega_X \tag{12}$$

With constant moments of inertia, the first Euler equation (see Eq. 5) implies that the rate about the principal axis is constant and is not affected by nutation:

$$\omega_X = \text{const} = \omega_S \tag{13}$$

The other two Euler equations can be combined to yield:

$$(I_X - I_Y) I_Y \, \omega_Y \, \dot{\omega}_Y + (I_X - I_Z) I_Z \, \omega_Z \, \dot{\omega}_Z = 0 \tag{14}$$

Integration of this equation shows that the projection of **ω** (and **H**) on the Y-Z plane traces an ellipse:

$$(I_X - I_Y) I_Y \, \omega_Y^2 + (I_X - I_Z) I_Z \, \omega_Z^2 = \text{const} \tag{15}$$

For further analysis, it is convenient to define the following two dimensionless indices related to the mass distribution:

$$i_Y = \sqrt{\frac{I_Y}{I_X - I_Y}}, \quad i_Z = \sqrt{\frac{I_Z}{I_X - I_Z}} \tag{16}$$

The solutions for **ω** and **H** in the principal axis frame represent elliptical cones:

$$\vec{\omega} = I_X \; \omega_S \begin{bmatrix} \dfrac{1}{I_X} \\ \gamma \dfrac{i_Y}{I_Y} \cos(\omega_N \, t) \\ \gamma \dfrac{i_Z}{I_Z} \sin(\omega_N \, t) \end{bmatrix} \tag{17}$$

$$\mathbf{H} = I_X\ \omega_S \begin{bmatrix} 1 \\ \gamma i_Y \cos(\omega_N\, t) \\ \gamma i_Z \sin(\omega_N\, t) \end{bmatrix} \tag{18}$$

The rate at which the nutation cones are traversed is given by:

$$\omega_N = \omega_S \sqrt{\frac{(I_X - I_Y)(I_X - I_Z)}{I_Y\, I_Z}} = \frac{\omega_S}{i_Y\, i_Z} \tag{19}$$

The expression in Eq. (20) is a generalisation of Eq. (7) for bodies without rotational symmetry. The ratio of the nutation rate and the spin rate defines a stability parameter, λ, frequently used in the analysis of spinning spacecraft:

$$\lambda = 1 + \frac{\omega_N}{\omega_S} \tag{20}$$

The nutation angle; *i.e.,* the angle between the angular momentum and the main axis of inertia is given by:

$$\theta = \theta_{\max} \sqrt{\frac{1 + \left(\frac{i_Z}{i_Y}\right)^2 + \left[1 - \left(\frac{i_Z}{i_Y}\right)^2\right]\cos(2\,\omega_N\, t)}{2}} \tag{21}$$

With the assumption $I_Y > I_Z$, the nutation angle reaches maximum value when the transverse component of the angular momentum is aligned with the Y axis. Eq. (18) implies that γ can also be expressed in terms of θ_{max}:

$$\gamma \quad \frac{\theta_{max}}{i_Y} \tag{22}$$

The analysis of the kinematics of Planck and evaluation of performance can be carried out conveniently by introducing a target angular momentum frame as inertial reference. The X axis of this frame lies along the direction of the angular momentum vector. Because of the rotation of the spacecraft, there is no clear preference for the choice of the transverse axis, but the discussion below will follow the convention adopted for the target frame in RD ACMS-2 and assume that the Y axis lies in the ecliptic and the Z axis completes a Carthesian triad. This coordinate system will also be referred to as the space frame. The transformation from space frame to the principal body axes can be represented as a superposition of three Euler rotations in accordance with Fig. 7.2.1.2-1 (adapted from RD ACMS-2). The first of the three Euler rotations aligns the Z axis of the space frame with the projection of the main body axis on the Y-Z space plane. The second transformation rotates the space frame about the Y axis by the nutation angle to align the X axis with the main axis of the body frame. The final rotation achieves the alignment of the Y and Z axis. Angle ψ_N represents the phase of body nutation and defines the position of the angular momentum vector on the nutation cone. The other angles are defined by the drawing and linked by the following relationships:

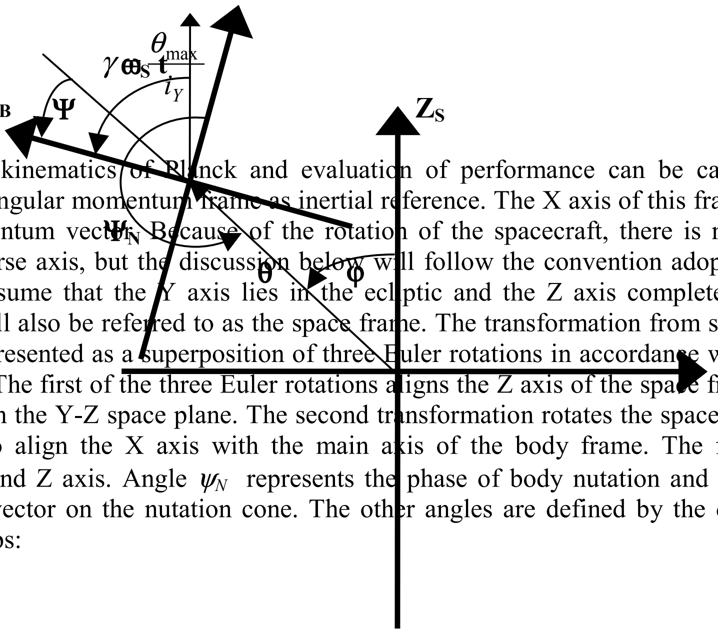


Figure 7.2.1.2-1. *Transformation from angular momentum target frame to principal axis frame for a tri-axial nutating body. See text for the interpretation of the angles indicated in the figure.*

$$\psi = \frac{3}{2}\pi - \psi_N$$
$$\phi = \omega_S\, t - \psi = \omega_S\, t + \omega_N\, t - \frac{3}{2}\pi = \omega_P\, t - \frac{3}{2}\pi \qquad (23)$$

Eq. (22) shows that in the small nutation angle case for a triaxial body, the inertial nutation rate, ω_P, is the sum of the spin rate and the body nutation rate.
With the definitions of the Euler angles given above, the transformation from space to body principal axis can be written as (see RD ACMS-2):

$$\mathbf{M_{SP}} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\psi) & \sin(\psi) \\ 0 & -\sin(\psi) & \cos(\psi) \end{bmatrix} \begin{bmatrix} 1 & 0 & \theta \\ 0 & 1 & 0 \\ -\theta & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & \sin(\phi) \\ 0 & -\sin(\phi) & \cos(\phi) \end{bmatrix}$$
$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\omega_S\, t) & \sin(\omega_S\, t) \\ 0 & -\sin(\omega_S\, t) & \cos(\omega_S\, t) \end{bmatrix} + \begin{bmatrix} 0 & -\theta\sin(\phi) & \theta\cos(\phi) \\ -\theta\sin(\psi) & 0 & 0 \\ -\theta\cos(\psi) & 0 & 0 \end{bmatrix} \qquad (24)$$

For small nutation angles, Eq. (23) provides an accurate solution for the torque-free motion of a tri-axial body and can be used instead of an explicit solution of the Euler equations.
In the small nutation angle approximation, the body nutation is similar to that in the case of bodies with rotational symmetry, but the body nutation cone is elliptical rather than circular. However, in the inertial frame the body axis in the triaxial case does not trace a regular cone and in general the path traced is not closed. This is illustrated in Fig. 7.2.1.2-2, which shows the elliptical trace obtained for the projection of the angular rate on the Y-Z plane of the principal body frame and the irregular path of the transverse components of the principal body axis in the space plane.

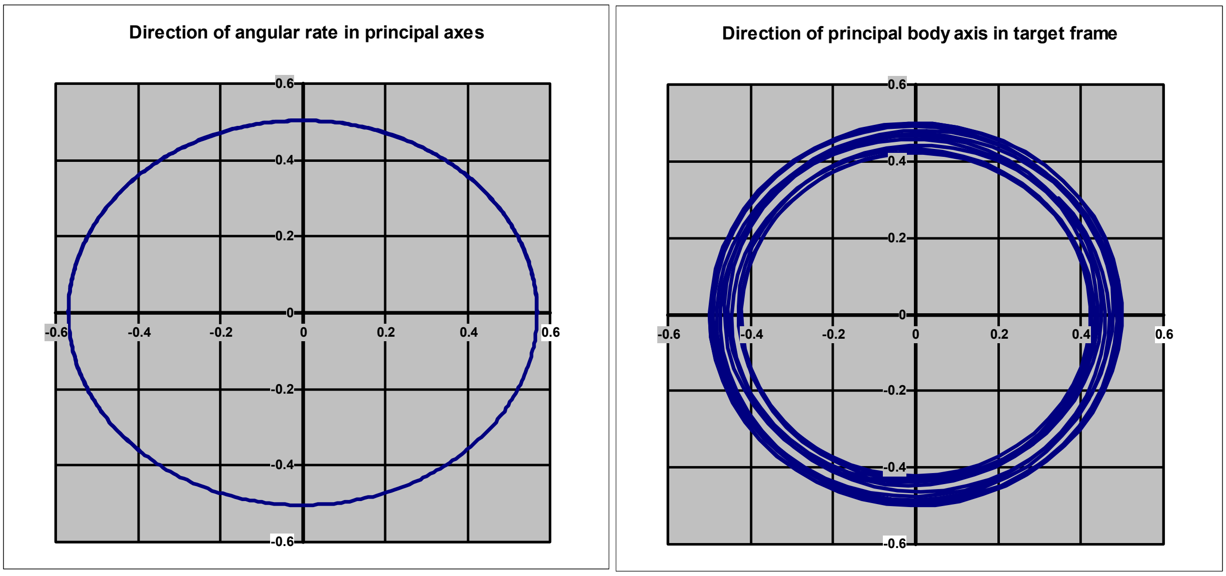


Figure 7.2.1.2-2. *Inertial and body nutation for a tri-axial body. The calculations shown in the graphs have been for Planck at the nominal spin rate of 1 rpm and with the mass properties corresponding approximately to the dry spacecraft. The amplitude of nutation was set to 0.5'. The diagram on the left shows the projection on the Y-Z plane of the principal axis frame of a normalised unit vector directed along the angular rate vector. The diagram on the right shows the irregular path (not closed after every nutation period) traced by a normalised vector aligned with the main body axis in the inertial target frame. The axis of both plots are scaled in arc minutes.*

7.2.1.3 Wobble due to dynamic mass unbalance

The discussion in the previous sections has been carried out using the principal axis system in which the matrix of inertia of the body is diagonal. This simplification is always valid in the analysis of spacecraft dynamics, however, in general the mechanical design of the spacecraft, including crucial pointing directions of the payload or of ACMS instruments is carried out with respect to a mechanical frame in which the matrix of inertia is not diagonal. The offset between the main mechanical body axis and the principal axis of inertia of the body, known as **wobble** must therefore be taken into account in the analysis of the pointing of the line of sight (for Planck wobble outweighs all other contributions to the absolute pointing error) since it causes the actual direction of the line of sight to deviate from the desired path.
In general, the wobble angles which represent the rotations necessary to align the main mechanical body axis with the corresponding principal axis of inertia are defined as rotations about the axes of the body frame. Wobble angles can also be expressed in the principal axes as rotations that align the main axis of inertia with the main axis of the mechanical frame. If the non-diagonal moments of inertia are small with respect to the diagonal terms, the principal wobble angles can be expressed in a first order approximation as:

$$\delta_Y = \frac{I_{XZ}}{I_{XX} - I_{ZZ}} \qquad \delta_Z = -\frac{I_{XY}}{I_{XX} - I_{YY}} \tag{25}$$

The angles in Eq. (25) represent rotations about the principal axis, whereas the moments of inertia are defined in the mechanical body frame.

7.2.2 Characterisation of the pointing performance of Planck

The Planck mission is based on the concept of using passive spin stabilisation to allow the payload line of sight to scan the sky during observation periods with nominal duration up to 55 minutes. Passive observation periods are supposed to be separated by intervals of up to 5 minutes when 1 N thrusters can be fired in order to alter the inertial angular momentum vector of the spacecraft and suppress nutation.
The payload line of sight is defined as a vector lying in the X-Z plane of the spacecraft frame at an angle of 85° with respect to the X axis. The spacecraft frame is assumed to coincide nominally with the SVM and SVM-PLM I/F frames defined in AD-1. The scanning is achieved at the nominal spacecraft spin rate of 1 rpm (6°/sec) with maximum deviation from the nominal value limited by spin rate stability requirements quoted below.
The pointing performance of a spin-stabilised scanning spacecraft must be defined differently from those normally stated for a actively three-axis stabilised spacecraft, such as Herschel. The spacecraft has no active closed loop attitude control at any time during the mission, since stabilisation is passive during observing periods and the repointing of the angular momentum vector requires the excitation of nutation (this is discussed in detail in section **Error! Reference source not found.**) so that thruster torques to be applied to the spacecraft must be calculated in advance for the entire manoeuvre.
The target to be achieved in the pointing of the spacecraft is not defined by a fixed inertial direction, but represents the desired scan path on the sky. For Planck this target is a small circle on the celestial sphere traced when the payload line of sight rotates at an inclination of 85° around the target angular momentum direction. Since stable rotation of the spacecraft is possible only about the principal axis of inertia, **the pointing target can be achieved when the following three conditions are simultaneously satisfied**:

1. The inertial angular momentum vector lies along the desired target direction.
2. There is no nutation.
3. The X axis of the principal inertia frame coincides with the X axis of the spacecraft frame.

The achievement of the first two conditions depends on the accuracy of the angular momentum repointing strategy, whereas the third is determined by the mass distribution of the spacecraft.
The absolute pointing error of the line of sight is defined as the angular distance between its instantaneous direction and the target scan circle. Fig. 7.2.2-1 below shows how this distance can be determined as the angle between the instantaneous inertial LOS direction and the vector on the target circle lying in the plane defined by the LOS and the target angular momentum. The error can also be expressed as the deviation of the actual angle between the LOS and the angular momentum target and the desired value of 85° Denoting by $\mathbf{e_T}^{(I)}$ a unit vector along the direction of the target angular momentum and by $\mathbf{e_{LOS}}^{(I)}$ the instantaneous inertial direction of the line of sight, the absolute pointing error can be calculated as:

$$\varepsilon_{LOS} = \arccos\left(\mathbf{e}_{\mathbf{T}}^{(I)} \cdot \mathbf{e}_{\mathbf{LOS}}^{(I)}\right) - 85^{\circ} \qquad (26)$$

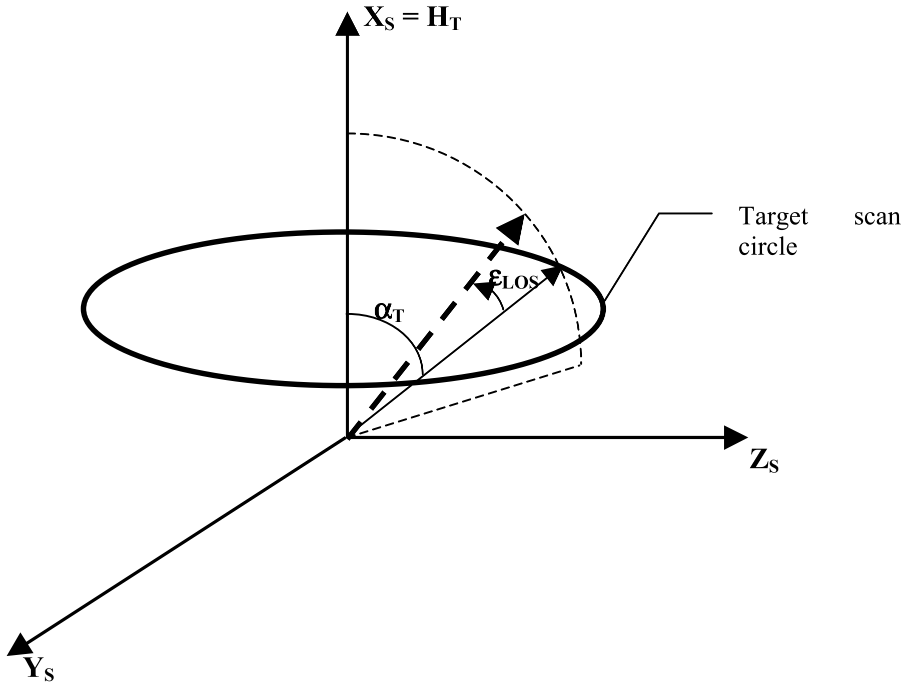


Figure 7.2.2-1. Definition of the absolute pointing error of the Planck line of sight. The aeis shown in the figure are those of the space frame based on the target direction of the angular momentum vector. See text for discussion.

Effects such as nutation and errors in the inertial ponting of the angular momentum vector prevent the LOS from scanning the sky along a circle and lead to a more complex scan path. The individual categories of errors used in characterising the performance of Planck have therefore been defined by introducing the concept of a “jitter strip” defined as the envelope of the actual LOS scan path in the inertial frame over any number of full rotations. With this definition, the usual error categories characterising the performance over different time scales can also be defined. As an example, the relative pointing error (RPE) is defined as the instantaneous angular deviation of the LOS from the jitter strip average calculated over the short term reference interval of 55 minutes. Although there may be some doubts about the exact mathematical definition of the jitter strip average, Eq. (26) suggests how the calculation can be done in practice. Other error categories can be defined in the same vein: the PDE is the deviation between two short term jitter strip averages over an interval of up to 24 hours, the PRE (pointing reproducibility) is the difference between short term averages obtained by commanding the same target at 2 different times separated by up to 20 days. A summary of requirements for the Planck SVM in the individual error categories is given in Table 7.2.2-1 below.

The concepts introduced so far provide no immediate way to define requirements for the pointing accuracy around line of sight. In early phase B discussions, it became apparent that around LOS requirements had been introduced in order to constrain the direction of the passage of the source in the focal plane of the telescope. The need for such constraints was introduced by the science instrument teams in order to make it possible to measure the polarisation of the radiation detected by Planck. The measurements are carried out using detectors polarised at 45° with respect to each other placed at different positions in the focal plane. In order to derive the Stokes parameters of the incoming radiation, the individual detector must observe the same area of the sky (within the limitation of their angular resolution) during a single scan. The detectors are placed by design in positions consistent with the nominal scan direction obtained when the spacecraft rotates without nutation about the X axis of spacecraft frame. If the

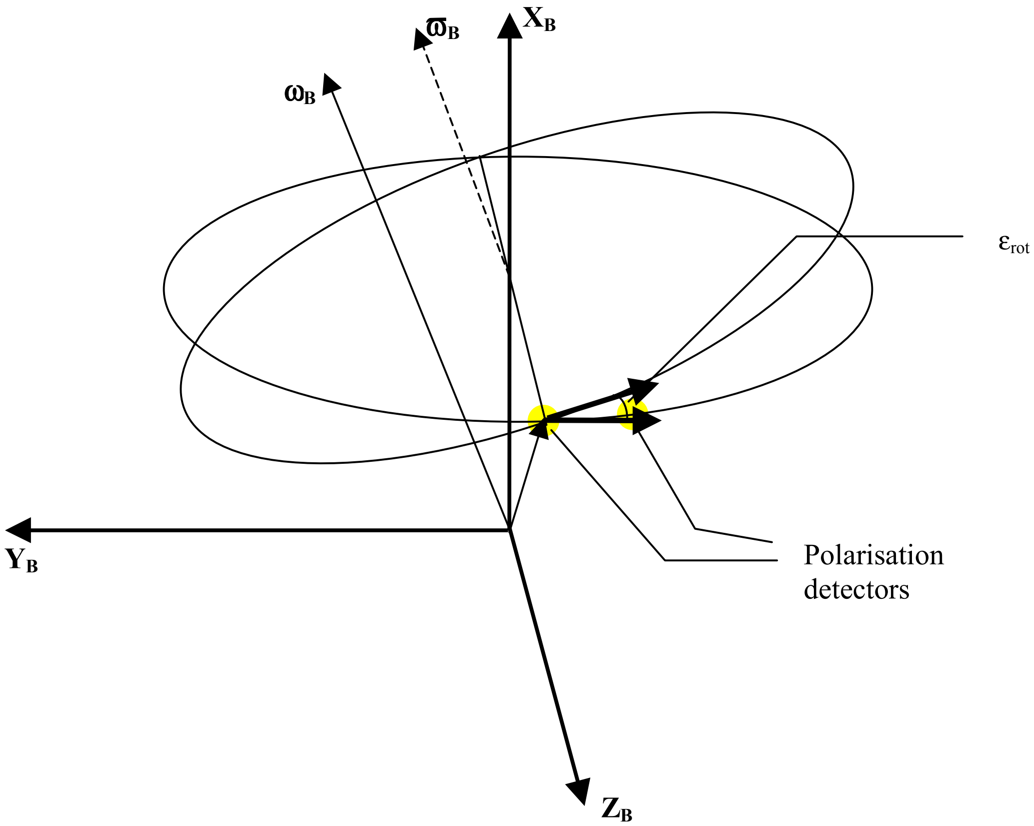


Figure 7.2.2-2. *The concept of absolute pointing errors around LOS. The axis refer to the spacecraft (body) frame. Positions of the polarisation detectors which drives the pointing requirements in this direction are shown schematically (none of the actual detectors is aligned with the payload LOS). See text for further discussion.*

instantaneous spin axis is inclined with respect to the plane defined by the spacecraft X axis and the payload line of sight, the inclination will be reflected in the direction of the scan which will deviate from the nominal direction parallel to the Y-Z plane. If the error exceeds the specified limits, the coherence of different polarisation detectors will not be guaranteed.
The main concepts underlying the definition of absolute pointing accuracy around LOS are illustrated in Fig. 7.2.2-2, where the effect of the passage of a source in different directions with respect to the position of two polarisation detectors is shown schematically. The instantaneous direction in which a vector appears to move in the spacecraft frame is defined by its derivative and this in turn for an inertially fixed vector is given by:

$$\dot{\mathbf{v}} = -\boldsymbol{\omega} \times \mathbf{v} \qquad (27)$$

The vector which defines the scan direction instantaneously coincides with the line of sight. Therefore, if $\mathbf{e_X}^{(B)}$ denotes a unit vector along the X axis of the spacecraft frame, and $\mathbf{e_\omega}^{(B)}$ is a unit vector along the direction of the angular rate in the same frame, the error around LOS can be expressed as:

$$\varepsilon_{rot} = \angle\left(\mathbf{e}_{scan}, \mathbf{e}_{target}\right), \quad \text{where}$$
$$\mathbf{e}_{target} = \frac{\mathbf{e}_X^{(B)} \times \mathbf{e}_{LOS}^{(B)}}{\left|\mathbf{e}_X^{(B)} \times \mathbf{e}_{LOS}^{(B)}\right|} \tag{28}$$
$$\mathbf{e}_{scan} = \frac{\mathbf{e}_\omega^{(B)} \times \mathbf{e}_{LOS}^{(B)}}{\left|\mathbf{e}_\omega^{(B)} \times \mathbf{e}_{LOS}^{(B)}\right|}$$

The sign in front of the vector products has been dropped in Eq. (27) in accordance with the geometry shown in Fig. 7.2.2-2. The sign convention adopted for the errors around LOS in the examples shown in the next section is that the sign is the same as that of the rotation from the target to the actual scan direction.

An immediate consequence of this definition the absolute pointing error around LOS is that the error is not affected by the inertial pointing of the angular momentum, since the scan direction is defined with respect to the spacecraft frame and depointing with respect to the inertial angular momentum target will only affect the area of the sky seen by the detectors but not the coherence of the passage over different locations in the focal plane. Although the APE is the most significant category for around LOS errors, criteria corresponding to RPE and PDE can also be meaningfully defined to constrain, respectively, the short and long term stability of the scan direction.

The approach defined so far is valid for pointing errors, but cannot be applied to errors in attitude determination, for which Planck follows the “traditional” philosophy used also for three axis stabilised spacecraft, since attitude reconstruction in both cases is aimed at determining the instantaneous attitude with respect to the inertial frame. The absolute measurement error for Planck is therefore defined in the same way as for Herschel and the requirement in principle applies to *post facto* attitude reconstruction on the ground. The definition of short and long term time scales, however, is the same as for the other Planck error categories discussed above.

The requirements collected in Table 7.2.2-1 appear to indicate that they were originally defined assuming a specific mission strategy. In particular, the value of the PDE and the accompanying requirement stating APE and PDE requirements must be satisfied without requiring dedicated slews and with no more than 10% adjustment of the amplitude of nominal spin axis repointing manoeuvres both indicate that the mission concept assumed onboard control of only the relative displacements of the inertial angular momentum vector without any determination of inertial attitude onboard. The compatibility of this approach with the properties of Planck is discussed further in Section 7.2.3.1.

The mass properties of the spacecraft provide an essential input for the ACMS and the main constraints for all analysis of the dynamics of the spacecraft. The *SVM Interface Specification* currently defines the following set of inertia properties for the spacecraft:

− Inertia
• 2750 kg.m² > Ix > 2750 kg.m² – 20%
• 1.09 > Iy/Iz > 1.03
• | XY and XZ cross-products| < 0.8 kg.m²
• 5/4 > λ > 8/7

The specification is interpreted assuming that all moments of inertia are referred to the spacecraft frame; however the values of λ are defined in principal inertia axes. The specification of Iyz, which affects the calculation of wobble angles corresponding to the X-Y and X-Z moments of inertia, has not been given explicitly, but a worst case of 150 kg m^2 has been assumed. The examples presented in the previous section have been calculated using a more realistic value of 50 kg m^2.

7.2.3 Sources of pointing errors. Implementation of the spacecraft mission

This section collects a number of examples of the pointing performance of Planck under a set of conditions which illustrate the impact of the various elements of spacecraft dynamics introduced in Section 7.2.1. Starting from simple kinematic cases, the analysis is built up to include factors which turned out to be the main design drivers for the Planck ACMS. All calculations have been carried out assuming mass properties corresponding approximately to those of the dry spacecraft with non-diagonal moments of inertia introduced only in cases which explicitly illustrate the effect of wobble; diagonal inertias were set to [2332, 2050, 1955] in units of kg m^2. The calculation of absolute pointing errors both in direction and rotation around LOS followed in all cases the prescriptions given in Eqs. (26) and (28). The spin rate has been set in all examples to the nominal value.

Table 7.2.2-1. Pointing error requirements specified for the Planck SVM.

	PLANCK SKY SURVEY	
	LOS (‘)	**Around LOS (‘)**
AME		
Required	0.49	2
Goal	*0.17*	-
APE		
Long term	33	36.1 (total)
Short term	1.5	
PDE Required	6.19	6.19
RPE Required	1.5	10
PRE Required	2.4	-
ARE	5.4 arcmin/sec	
Rotation Rate Stability	10^{-4} rpm	
Accuracy of angular momentum repointing (up to 3’)	0.4 arcmin (relative to the previous inertial target)	

7.2.3.1 Effect of disturbance torques

Planck is subjected to two types of disturbance torques that can have significant effects on the dynamics and performance of the spacecraft. The torques are respectively fixed either in the inertial frame or in body coordinates and therefore lead to entirely different effects in the dynamics of the spacecraft.

Helium exhaust
The torque due to helium exhaust is fixed in body frame and is specified to have the following magnitude:

- 4 μNm around X
- 4 μNm in body plane.

The component along the X axis influences the spin rate stability and is the only factor in the dynamics of the spacecraft that has this effect (changes in the diagonal moments of inertia occur over much longer time scales during normal scientific operations). The spin rate is corrected during the angular momentum repointing manoeuvres using the X component of the torque provided by the 1N thrusters. The rate stability requirement therefore applies only to the passive periods between manoeuvres and compliance with it is therefore evaluated over the short term performance interval of 55 minuts. During this interval, the effect of the out-gassing torque amounts to a change of angular momentum along the X axis by 0.0132 Nms. For the lowest value of the I_{XX} quoted in Section 7.2.2, the effect of the accumulated momentum on the rate is 5.7×10^{-5} which is within the 10^{-4} limit stated in the requirements.
The transverse component of the torque causes a small deviation of the angular momentum vector from the principal axis. The magnitude of the effect can be estimated by observing that the angular momentum vector must be tilted by a sufficient amount to allow the gyroscopic torque to match the disturbance. Assuming the spacecraft is axially symmetric, the angle of the tilt can be estimated as:

$$\theta = \frac{T}{\omega_S \, H_S} \frac{1}{\lambda - 1} \tag{29}$$

where T represents the transverse torque and H_S is the angular momentum along the spin axis. With worst case values possible for Planck, the value of θ is below 0.25", which shows that the effect is negligible with respect to the typical magnitude of nutation resulting from residual errors of angular momentum repointing. If the torque is assumed to act indefinitely, the effect is only that of a constant tilt of the angular momentum vector and there is no nutation.

Solar torque
The torque due to the pressure exerted by solar radiation on the solar panel depends on the angle between the Sun and the –X axis of the spacecraft (Sun aspect angle, SAA). A first order approximation can be obtained by assuming that the geometrical centre of the panel lies exactly on the spacecraft X axis. The torque is then zero when the Sun vector is exactly aligned with the X axis. In general, if the Sun vector makes an angle θ_{Sun} with the –X axis, the force exerted by the photons can be decomposed into two components. Specular reflection transfers angular momentum only along the X axis. Diffuse reflection can be assumed to consist of the absorption and then re-emission of a photon. The re-emission process is symmetric around the normal direction and results in a force directed along X. Absorption processed (due both to a total absorption of a photon and to absorption prior to re-emission) result in a force acting along the Sun vector and this component can provide a non-zero torque. The value of the torque is given by:

$$\mathbf{T}_{Sun} = \frac{E_{Sun}}{c} S\left(\varepsilon_a + \varepsilon_d\right) r_X \left(\mathbf{e}_X \times \mathbf{e}_{Sun}\right) \tag{30}$$

where E_{Sun} is the flux of solar radiation, c is the velocity of light, S denotes the surface area of the solar panel, and r_X is the distance along the X axis between the geometrical centre of the panel and the spacecraft centre of mass. Probability of absorption and diffuse reflection is given by the coefficients denoted as ε_a and ε_d and the unit vectors

in the cross product are aligned with the X axis of the spacecraft (**e**$_X$) and the direction of the Sun seen from the spacecraft. The magnitude of the torque is obviously proportional to the sine of the Sun aspect angle.
Assuming the values for all parameters estimated for Planck and an average solar flux, Eq. (30) yields a magnitude of the torque of $\boldsymbol{T_{Sun}}$ **= 7.8 μNm** with the Sun at the edge of the nominal pointing domain; *i.e.*, SAA = 10°. Accounting for the possible errors in the parameters and the simplifications adopted in the calculation of the torque (the centre of the panel perfectly aligned with the X axis of the spacecraft frame), a conservative estimate of the maximum solar torque can be set at **10 μNm**. This value has been passed on in ACMS requirements as a constraint on subsystem design with consequences discussed separately below.
In the case of no nutation and wobble, the direction of the spacecraft X axis in the inertial frame is fixed in the absence of torques. In this case Eq. (30) implies that the spacecraft angular momentum vector should precess about the direction of the Sun vector. The rate of precession can be expressed as:

$$\Omega_P = \frac{T_{Sun}}{H_S \sin SAA} \qquad (31)$$

The resulting precession period is over 10 months for the maximum value of the torque, and the variation of the Sun vector in the inertial frame implies that the motion of the angular momentum vector cannot be described as precession but should be treated as a slow drift over the time scale (24 hours) corresponding to the period of autonomous operation of the spacecraft out of ground visibility.

Impact of solar disturbance torque on the implementation of the Planck mission strategy
The drift implied by the maximum amplityde of the solar disturbance during 1 hour amounts to 0.5' with the principal moment of inertia set to a value appropriate for the scientific mission phase (2400 kg m^2). If this effect is not corrected onboard during the period of autonomous scientific operations, the drift over 24 hours will reach about 12' and will exceed by nearly a factor of 2 the required value of the PDE. As a consequence, a mission strategy based on only relative displacements of the angular momentum vector without autonomous determination of inertial angular momentum cannot be compliant with the essential performance requirements of the spacecraft. **This conclusion renders necessary the introduction of autonomous determination of the spacecraft angular momentum by onboard software so that the effect of drift can be taken into account and corrected during angular momentum repointing manoeuvres.** The implementation of the mission based on this concept has impact both on the configuration of the ACMS and operational control of the spacecraft:

- **Autonomous STR**. Determination of inertial attitude and, consequently, inertial angular momentum is possible using transit sensors, such as the Star Mapper considered in the H-P proposal phase, but it requires relatively complex algorithms and a database of stars which could be seen by the instrument appropriate for each observing period. The introduction of such algorithms in flight software leads to considerable complexity and this provides a strong argument in favour of the introduction of an autonomous Star Tracker capable of providing at any time during the mission a measurement of its inertial attitude. Instruments capable of operating at slew rates of 6°/sec are available and the same STR hardware can even be used for both Herschel and Planck (with differences only in the embedded software) providing overwhelming arguments in favour of the configuration which has been implemented in the Planck ACMS. The amplitude of the solar disturbance torque has therefore turned out to be the main design driver related to spacecraft dynamics.

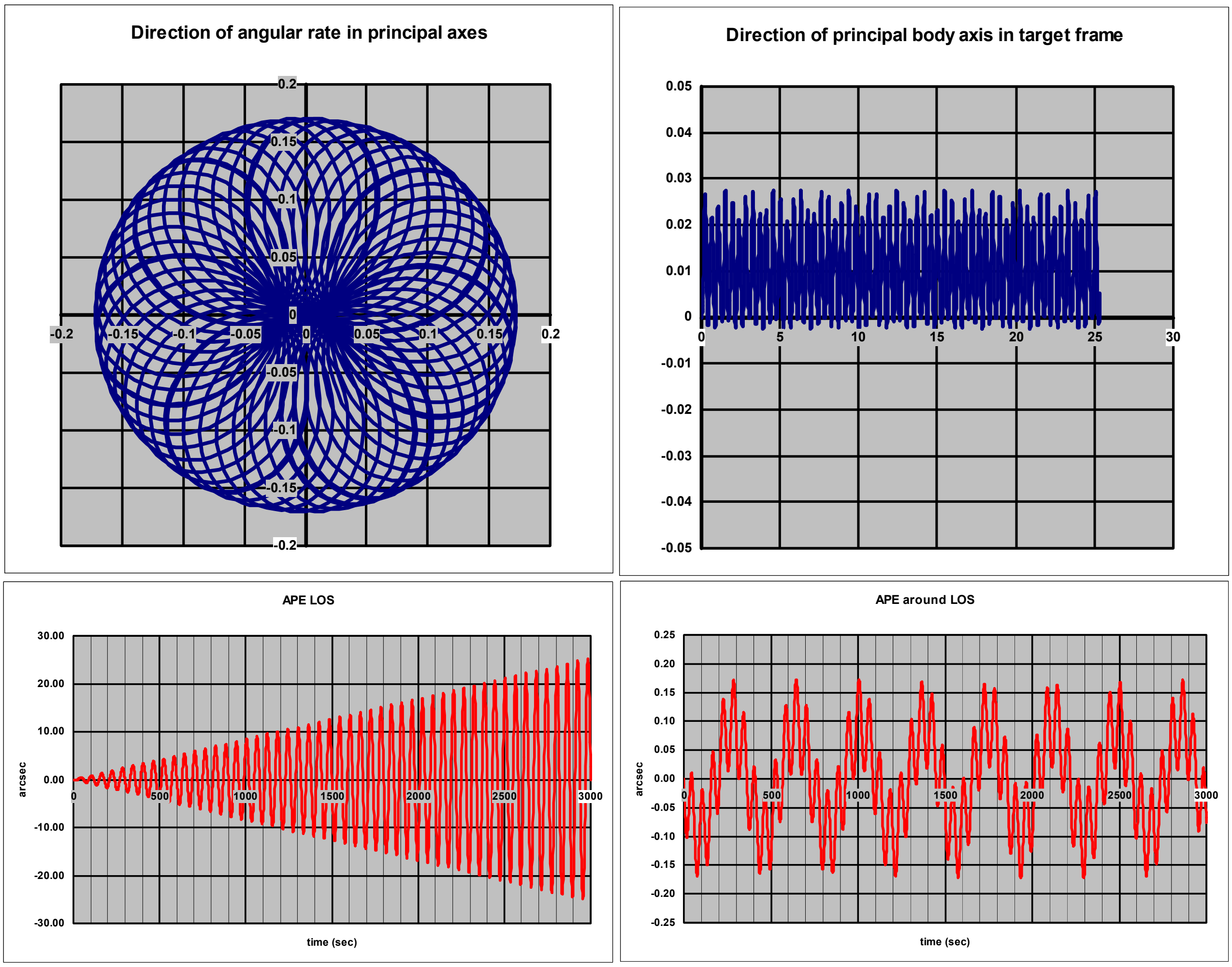


Figure 7.2.3.1-1. Effect of solar disturbance torque on the motion of Planck. The top two diagrams show the transverse components of the angular rate (expressed as angular deviations from the nominal direction) respectively in the spacecraft frame and in the angular momentum target frame (inertially fixed). The axis are scaled in seconds of arc. The diagram on the left shows the torque-driven nutation pattern in the body frame. The angular rate vector in the inertial frame very nearly follows the drift of the angular momentum caused by the solar torque with a small oscillation due to nutation (note the difference in scale between the axes). The botoom diagrams show the directional and rotation components of the absolute pointing error. The line of sight APE reflects the growing inclination of the scan circle on the sky, whereas the error around LOS remains very small and is due only to the nutation shown in the top diagrams. The simulation was carried out assuming a torque of 10 μNm directed along the Y axis of the axis of the angular momentum target frame (in the plane of the ecliptic).

- **Absolute target commanding**. The availability of the inertial attitude measurements onboard implies that angular momentum displacements can be commanded as target vectors in inertial space. Operations are considerably simplified since there is no for compensation of long term drift of angular momentum through offsetting of targets.
- **Performance improvement**. The performance of the spacecraft in all "long term" error categories is much better than the specification since long term drift of attitude is compensated on board and the main contribution comes from errors in the execution of individual manoeuvres which result in the overall directional PDE of less than 1' (RD ACMS-2 makes excessively pessimistic assumptions about the variation of mass properties which increase the error to about 1.7').

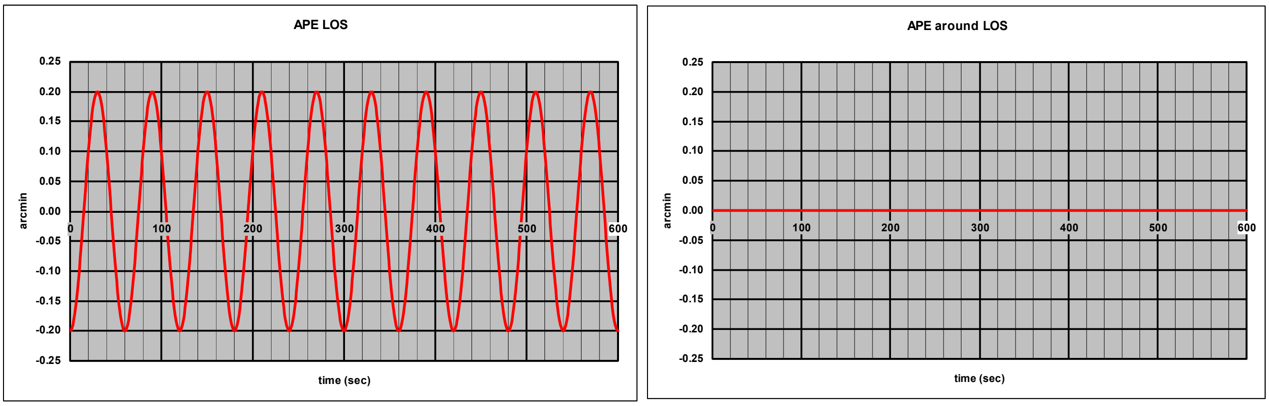


Figure 7.2.3.2-1. *Effect of angular momentum depointing on the directional (LOS) and rotational (around LOS) pointing errors. The simulation has been carried out assuming that the only source of error was a rotation of the inertial angular momentum vector with respect to the commanded target. The amplitude of the rotation was set 0.2 arcmin (the direction of depointing affects only the phase of the absolute pointing error). A graph of the error around LOS has been included to demonstrate that inertial angular momentum depointing has no effect on the error.*

It is important to note that the onboard algorithms does not require accurate knowledge of the inertial pointing direction of the spacecraft line of sight. The onboard state determination algorithms estimate only the inertial angular momentum, angular rate, position of the principal axis of inertia and nutation parameters (all three in body frame) as well as spin phase. The reconstruction of the inertial direction of the LOS is achieved by off-line algorithms executed on ground. Details of both onboard and ground-based state reconstruction can be found in RD ACMS-3.

Spacecraft absolute pointing in the presence of solar disturbance torque
Figure 7.2.3.1-1 shows the result of a simulation of the motion of Planck when the maximum values of the solar disturbance torque is applied. The simulation excluded all other effects (wobble, nutation and helium outgassing torques have all been set to zero). The main effect in the pointing of the spacecraft is the drift of the principal body axis in inertial which remains nearly aligned with the angular momentum vector (the torque rotates at 1 rpm in the body frame and causes only a small amount of nutation, of the same order of magnitude as in the case of the helium outgassing torque).

7.2.3.2 Angular momentum depointing

The simulation presented in Fig. 7.2.3.2-1 is based a set of initial conditions in which the principal axis frame is assumed to coincide with the satellite frame (no wobble) and the amplitude of nutation as well as all disturbance torques are set to zero. The only error introduced is a depointing of the inertial angular momentum error by 0.2' (a value within the range of accuracy estimated at 1σ confidence level in RD ACMS-2). The depointing of the angular momentum vector causes a tilt of the scan circle (the **H** vector was rotated about the Y axis of the target angular momentum frame) which leads to a value of the absolute LOS direction error that oscillates around zero. The rate of variation equals the spacecraft spin rate. The direction in which the **H** is depointed affects only the phase of ε_{LOS}. The depointing has no effect on the error around LOS.

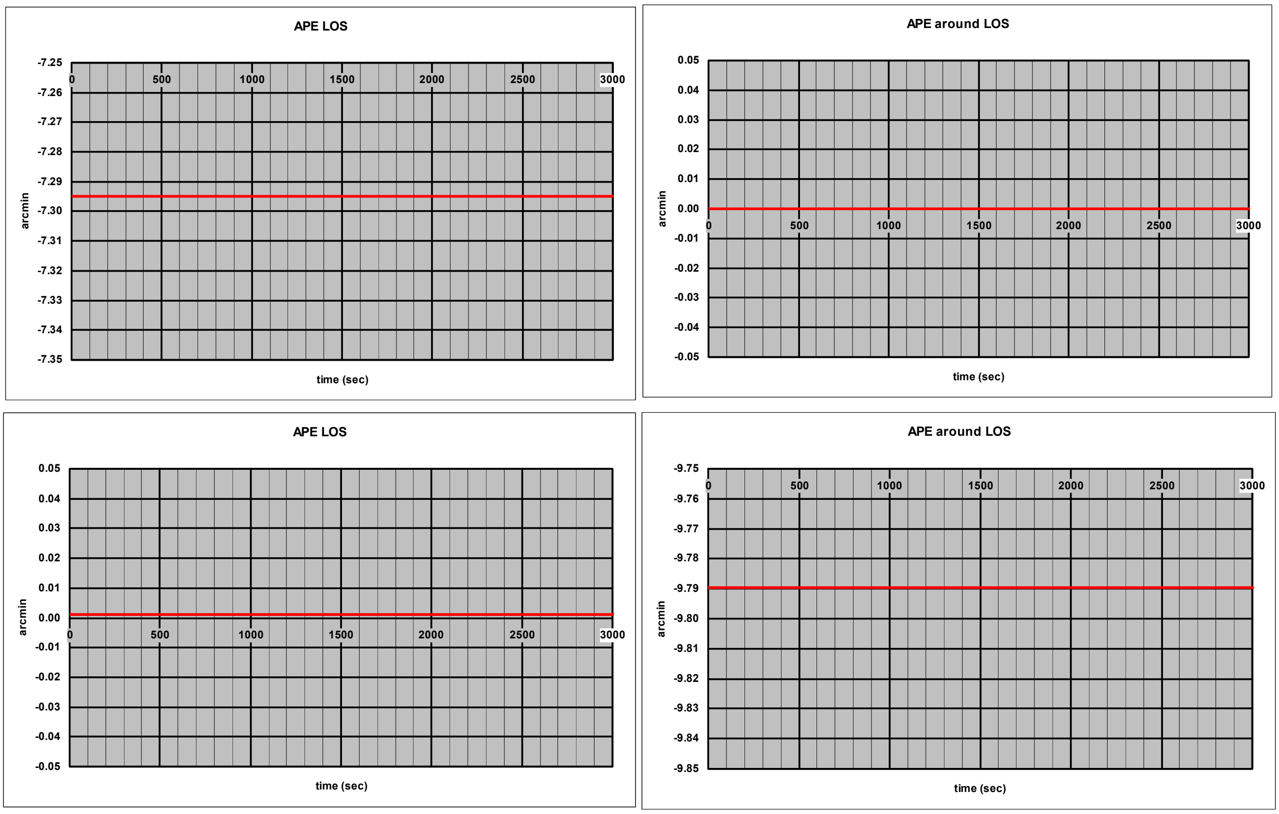


Figure 7.2.3.3-1. *The effect of static wobble on the absolute pointing errors. The top diagrams show simulation results for the case in which the principal axis of inertia was displaced from the X axis of the satellite frame in the X-Z plane which causes only a directional error but has no effect on the pointing around LOS. This is reversed in the case shown in the bottom diagrams, where the simulation was based on a wobble displacement only in X-Y plane. The nutation was set to zero and the scan paths are therefore perfect circles with no short term jitter (RPE is zero for both directional and rotational errors).*

7.2.3.3 Fixed wobble

The simulations shown in this section illustrate the effect of the displacement between the spacecraft frame and the principal axis frame on the motion of the line of sight. Two sets of results have been shown in Fig. 7.2.3.3-1 covering simulation cases with different wobble directions. The graphs show that a displacement of the principal axis in the X-Z affects only the directional pointing errors and causes (in the absence of nutation) a constant offset from the target circle (the scan path on the sky is a circle with no jitter but with the effective radius different from the nominal 85° value). A tilt of the principal axis in the X-Y plane affects the instantaneous direction of the scan and is therefore reflected in the APE around LOS, but the directional LOS error remains unaffected (except for a small second order effect due to the fact that the scanning takes place at 85° rather than 90° from the spin axis).
The two cases shown in the figure have been calculated with the non-diagonal moments of inertia set to the worst case value of 0.8 kg m^2 allowed by the current specification (I_{YZ} was zero in both cases). The fact that the values of the APE, in the absence of other errors, reflect directly those of the principal wobble angles can be used to estimate the maximum values of non-diagonal moments of inertia for which the APE requirements can still be satisfied. Using Eq. (25) with worst case settings of the principal moments of inertia yields the following maximum values compatible with APE requirements:
I_{XY} = 2.1 kg m^2 determined from the total around LOS APE of 36.1’
I_{XZ} = 3.0 kg m^2 determined from the total LOS APE of 34.5’.

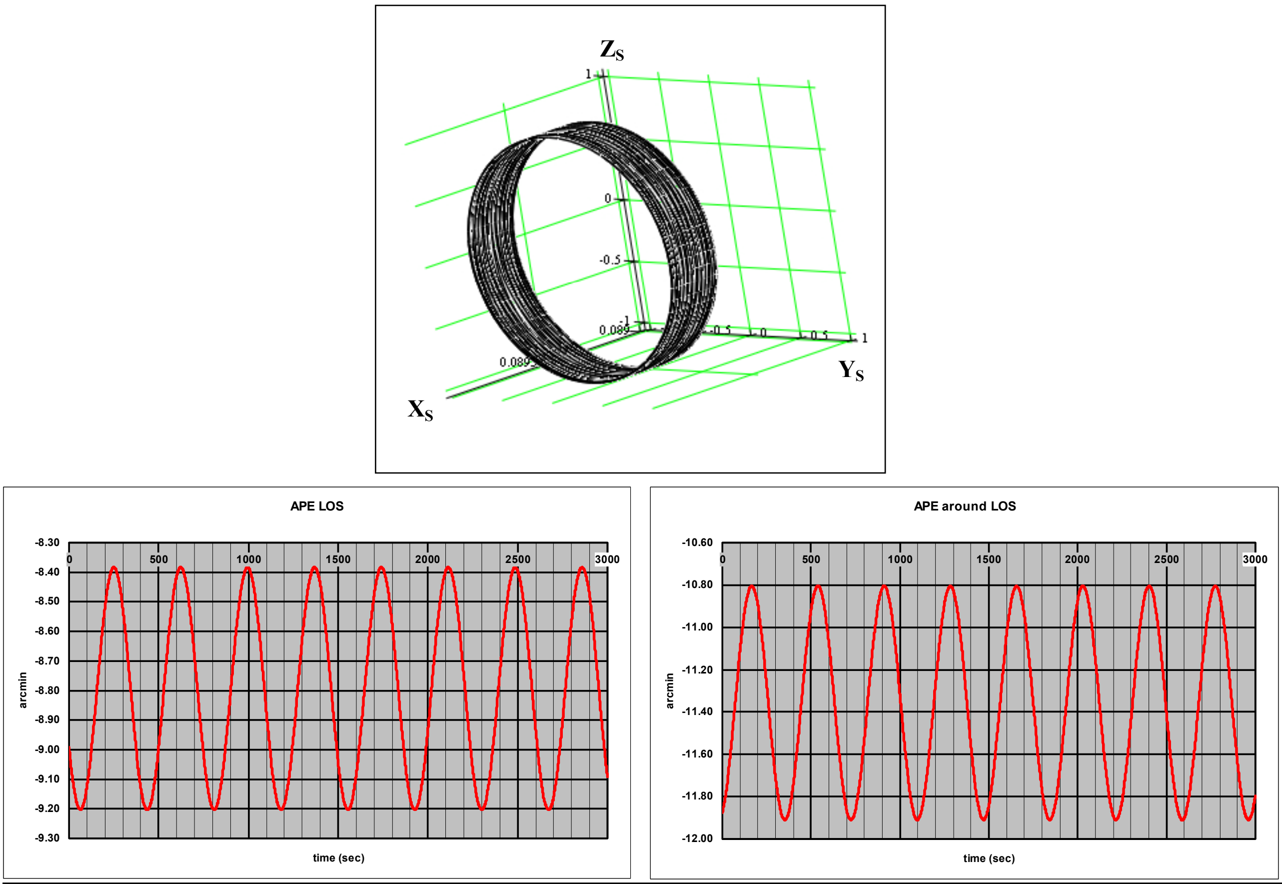


Figure 7.2.3.4-1. *Simulation of the dynamics of Planck including wobble and nutation. The top diagram shows the "jitter strip" traced on the sky by the line of sight. The scale of the X axis has been expanded (the range corresponds to about 3.5') in order to show the dispersion caused by nutation. The lower diagrams show the errors both in LOS pointing and around LOS. See text for further discussion.*

7.2.3.4 Nutation

This section provides a realistic example of the motion Planck by including effects of both nutation and wobble. Amplitude of nutation was set in the simulation to a value of 0.5' and the nutation cone in principal axes is therefore the same as that shown in Fig. 7.2.1.2-2. A static wobble was also introduced in the simulation by setting the following values of the non-diagonal moments of inertia: I_{XY} = 0.8 kg m^2, I_{XZ} = 0.8 kg m^2, I_{YZ} = 50 kg m^2. The three-dimensional plot included in the figure shows the path traced on the sky by the line of sight in order to illustrate the concept of the "jitter strip" introduced in the definitions of pointing errors. The absolute pointing errors both in LOS direction and around LOS show a constant due to wobble and a modulation caused by nutation. The graphs in the figure illustrate several points that must be kept in mind in evaluating the performance of a spinning spacecraft:

- *Principal wobble angles.* The average values of APE of the line of sight and around LOS represent the effect of wobble. These values are different from those shown in Fig. 7.2.3.3-1 even though the values of I_{XY} and I_{XZ} assumed in the simulations are the same. The effect is due to the large Y-Z term in the matrix of inertia assumed in the simulation shown in this section which causes a large rotation of the principal axis frame around the satellite X axis. As a result, the principal wobble angles, which determine the value of the absolute pointing errors, are no longer calculated in the X-Y and X-Z plane of the spacecraft frame and have significantly different values.

- *Errors at 68% confidence level*. The absence of any random jitter in the motion of a passively stabilised spacecraft implies that the error estimates quoted for the 68% confidence level stated in the specification must be interpreted with caution. If the "temporal" interpretation of the error is adopted (the error must remain within the specified limit for 68% of the time), the scaling to other confidence levels depends only on the dynamics underlying the time-dependence of the errors and does not follow the 1σ - $n\ \sigma$ scaling applied to random errors. As an illustration of this effect, the RPE for the direction of LOS equals 0.358' for the case shown in the figure, but the full amplitude of the relative error is 0.411'.

7.2.4 Chapter-specific references

RD ACMS-1 *Spacecraft Attitude Determination and Control,* ed. J. Wertz, ISBN 90-277-0959-9.
RD ACMS-2 = RD 150
RD ACMS-3 *Planck Attitude Determination Algorithm Description*, H-P-4-SEN-TN-0005.

7.3 MECHANICAL DESIGN AND PERFORMANCE

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

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

7.3.1 General Mechanical Requirements and Design Drivers

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

Environmental Requirements

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

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

Functional Requirements

The SVM Structure has to provide the following main functions:

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

Interface Requirements

The SVM Structure has to provide the following main functions:

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

Design Requirements

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

7.3.2 SVM Primary Structure Requirement

The complete set of requirements for the SVM Structure is included in [RD-26] . Thus, for any detail, please, consult this document. This is in agreement with the last issues of the main System Level Specifications, particularly, [AD-43], and [AD-47].
Some mechanical requirements, since PDR, have been refined several times up to the last version, namely [AD-43], is. 4.1 and [AD-47], is 5.0.

The Structure S/S, up to now, has afforded MRR1 (related to H and P cone) and MRR2 (related to H and P Up. & Low. Closures and Shear webs). The design and analyses of these above MRR1 and 2 structural items are compliant with the main structural requirement contained in [AD-43] and [AD-47], last issues, here below summarised.

7.3.2.1 Frequency and Rigidity Requirements

As mentioned above, some summary/comparison tables reports the *System Requirements* used to produce the Structure S/S MRR1 & MRR2 documentation. The same requirements will be used to perform the S/S CDR.

The main System Requirement at PDR have been confirmed for CDR, with the exception of the Planck Sub-platform frequency requirement, which was increased from f>32 Hz to 70< f <76. This new requirement associated to the displacement requirement (< 1.5 mm) of some mounted units (BEU / PAU) leaded to several iterations of the structure design and analysis.
In addition, some other requirements related to interfaces of units or performances have been introduced. The new requirement introduced after PDR leaded to a more complex and heavier structure S/S with respect to that presented at the PDR.

7.3.2.1.1 Frequency Requirements

Item	Herschel	Planck	Remarks
	Minimum Hz	Minimum Hz	
S/C Lateral direction	23	35	H-PLM= 2400Kg, effective mass>20%
S/C Axial direction	65	60	P-PLM=336Kg, effective mass >20%
Octagonal box Lateral direct.	60	50	Effective mass >15% for H and 10% for P (SVM only)
Octagonal box Axial direct.	45	45	Effective mass >5% for H and 5% for P (SVM only)

Table 7.3.2.1.1-1 H-P SVM Frequency requirement

Item	Herschel	Planck	Remarks
	Minimum Hz	Minimum Hz	PTSS i/f real boundary cond. Full tank at C.o.G
Lateral direction	80	80	
Longitudinal direction	100	100	

Table 7.3.2.1.1-2 H-P PTSS Frequency requirement

Item	Herschel	Planck	Remarks
	Minimum Hz	Minimum Hz	Panels hard mounted in the real boundary conditions, lumped masses
Any direction	50	50(target 70)	

Table 7.3.2.1.1-3 H-P SVM Equipment Panels requirement

Item	Herschel	Planck	Remarks
	Minimum Hz	Minimum Hz	On S/C, BEU side
Any direction	NA	70<f<76	

Table 7.3.2.1.1-4 P Sub-platform Frequency requirement

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

7.3.2.1.2 Rigidity Requirements

Items	Herschel		Planck		Remarks
	Min. N/m	Max. N/m	Min. N/m	Max. N/m	Computed at the centre of the rigid plate clamped at PLM interface points only.
Global Longitudinal	5.6E8	6.5 E8	3.1E8	3.7 E8	
Global Lateral	2.2E8	3.0E8	1.5 E8	2.0 E8	

Table 7.3.2.1.2-1 H-P Rigidity requirement

7.3.2.2 Strength Requirements

Also in this case, the complete set of requirement is included in the SVM Structure Spec. [RD-26], is. 6.
The main SVM Structure strength requirements are reported below.

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

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

The acceleration shall be applied to the equipped SVM. The masses of the equipment are defined in [RD-77].

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

The following definitions are applied.

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

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

Qualification Loads: are the Limit Loads times 1.25.

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

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

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

Overflux : defined by the Launcher authorities, induced by ARIANE 5 boosters

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

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

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

7.3.2.2.1 SVM Flight Loads

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

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

Table 7.3.2.2.1-1 S/C Flight Limit Loads

7.3.2.2.2 SVM Structure S/S main resonance loads

In addition to the above A5 defined loads, several load cases are provided both in terms of accelerations as forces. They have been derived considering the responses resonance of the main SVM components, like the H-PLM and P-PLM, Herschel SSH/SSD, Herschel SVM shield as well as the H-P PTSS, H-P Panels, Planck He tanks, Planck Solar Panel.
These load cases are defined for Herschel (cases 1H to 4H) and for Planck (cases 1P to 5P) in paragraphs 5.1.4.7.1.4 for Herschel and 5.1.4.7.2.3 for Planck of the [RD-26], is. 06.

Also in this case some changes have been introduced with respect to the PDR prescribed requirement.

7.3.2.3 Safety Factors

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

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

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

Table 2.3-1 Safety Factors Summary

7.3.2.4 Stability and Alignment Requirement

For Herschel and Planck Structure the stability requirement are included in Table 7.3.2.4-1, the alignment requirement are included in Table 7.3.2.4-2.
For each reported equipment (e.g. STR), the stability / alignment requirement apply to the equipment (e.g. STR) mounting plane in the SVM Structure, with respect to the H-PLM / P-PLM I/F plane.
For the H STR the requirement are defined in Chapter 3.1.5 of this document..

Item	H-P	Reference	Stability (°)		
			Rx	Ry	Rz
STR	P	PLM I/F	1 arcsec	1 arcsec	1 arcsec
Gyroscope	H	PLM I/F	0.02	0.02	0.02
RW	H	PLM I/F	0.02	0.02	0.02
Thrusters	H-P	PLM I/F	0.05	0.05	0.05

Table 7.3.2.4-1 H-P SVM Structure Stability Requirement

Item	H-P	Reference	Alignment (°)		
			Rx	Ry	Rz
STR	P	PLM I/F	-	0.25	0.25
Gyroscope	H	PLM I/F	0.5	0.5	0.5
RW	H	PLM I/F	0.5	0.5	0.5
AAD	H-P	PLM I/F	0.1	0.1	0.1
SAS	H-P	PLM I/F	0.5	0.5	0.5
CRS	H-P	PLM I/F	0.5	0.5	0.5
Thrusters (*)	H-P	PLM I/F	0.1	0.1	0.1

Table 7.3.2.4-2 H-P SVM Structure Alignment Requirement

7.3.3 Mechanical Requirements for Equipment and Secondary Structures

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

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

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

7.3.4 Sorption Cooler Strength Requirement

During the design development of the SCC assembly a new requirement has been introduced.:

"Due to the nature of the mounting scheme of the compressor elements and the SCC base plate, the critical stresses in the tubing are between the compressor elements and the valves mounted on the base plate, as well as the length of tubing extending tram the LPSB.
<u>The maximum design stress shall be inferior to 110 MPa."</u>

Due to this, a dedicated study has been performed. A detailed FEM model of the panel (3D FEM) including also a FEM of the SCC, provided by the Customer, has been developed. See para 9.1 and [RD-84]

7.3.5 SVM Fracture Control Plan

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

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

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

7.3.6 Mechanical Justification

7.3.6.1 Mechanical Design Philosophy

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

<u>Equipment Accommodation Flexibility</u>
The structural design shall be capable to provide 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 have been translated into the following design implementation objectives:

- adoption of clear I/F among structure and equipment
- 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 had been driven by the following objectives:

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

However, the Equipment (Support Subsystem and Experiment) lay-out and interface associated to a high density in terms of unit over available inside volume resulted into a correspondent complexity in structural design solutions. In fact, in order to house units very close each other, including their related harness or pipes with supports, special inserts inside honeycomb panels are very often needed, including also sandwich local reinforcement (h/c and facings) as well as special embedded brackets.
Some example of the complexity of the equipment panels are shown below.
This increased complexity induced a correspondent mass (and cost) increase.

Stability and Alignment Requirement

The more stringent alignment requirement is concerning the H Star Tracker. In order to satisfy these req., after several trade-off and iterations, the selected solution consists of a dedicated support structure, directly interfacing with the H-CVV.

7.3.6.2 Structure Configuration

The Herschel and Planck Structure Configuration is described in detail in paragraph 9.1. The design of the SVM Structure, there included, reflects the general configuration and lay-out and the Equipment/Units mass values as included in MICD, IS. 6

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

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

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

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

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

The H-STR Assy Structure is described in detail in Chapter 3.1.5 STR Accommodation Trade-off.

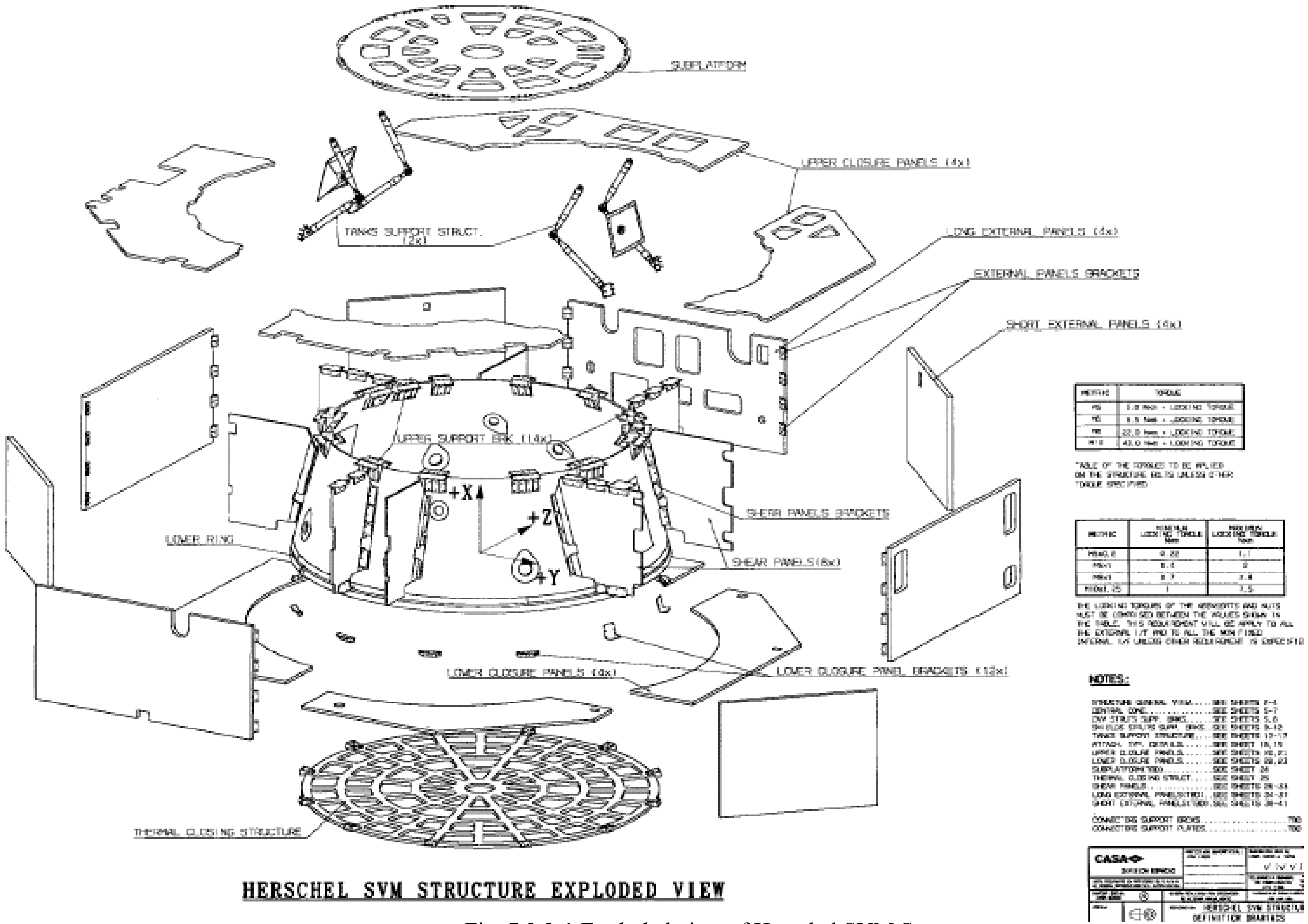


Fig. 7.3.2-1 Exploded view of Herschel SVM Structure

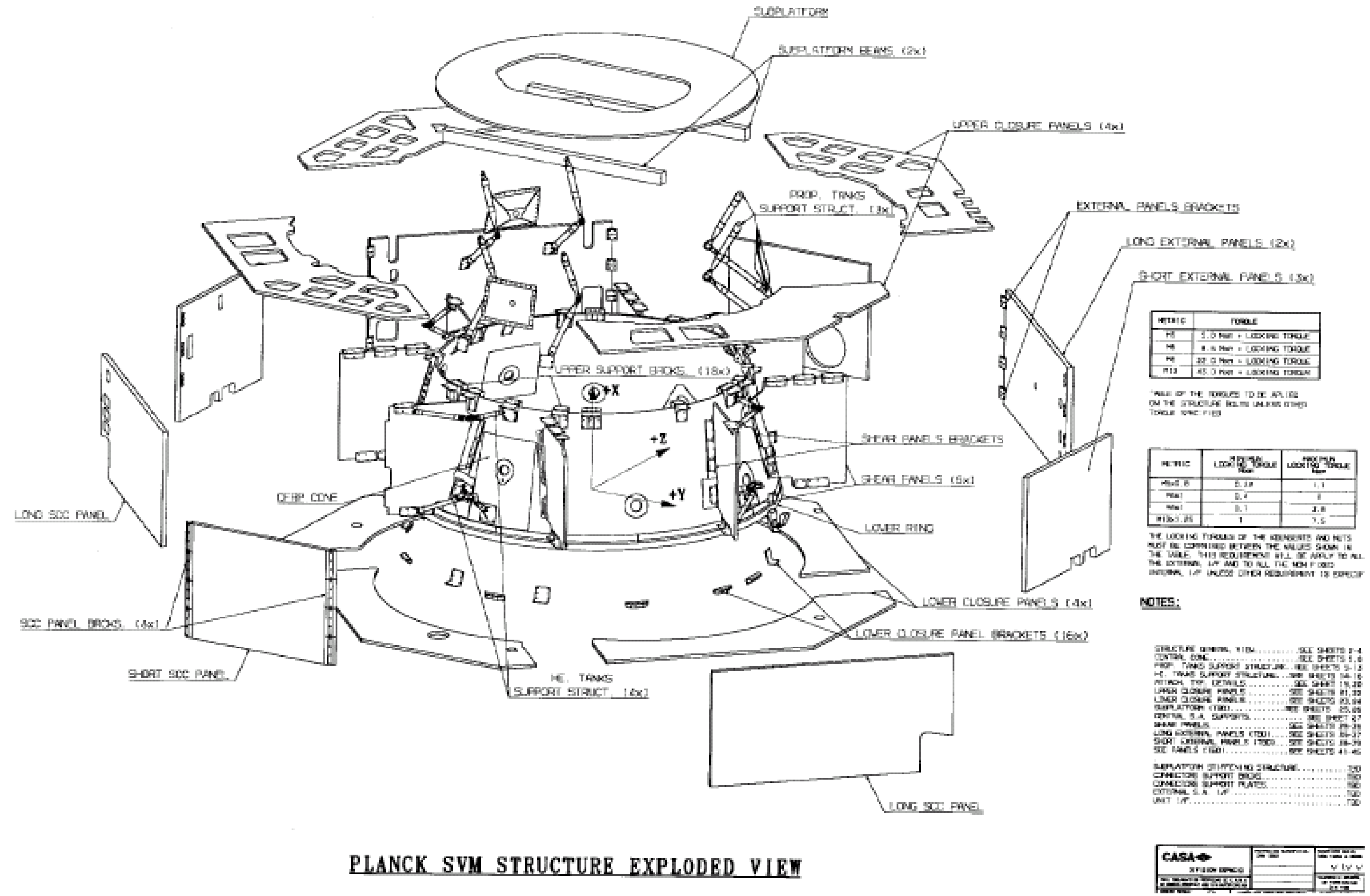


Fig. 7.3.2-2 Exploded view of Planck SVM Structure

7.3.6.2.1 Structure Design Justification

The SVM structure is designed for Herschel and Planck S/C. The commonality approach, has characterised the SVM Structure design since the development beginning such that the SVM structure shall be compliant with the requirements applicable at both Satellites. In particular, when possible, the SVM structure performances are enveloping the two different set of requirement.

However, with the increasing of the design maturity, it became obvious that the great difference in the required performance of the two SVM led to two different structures. The general design and philosophy is still the same, but several parts are widely different, as different are the requirement to be satisfied.
In principle the primary structures are made of the same materials, shape and dimensions.

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

For the H-STR a dedicated structure, directly interfacing with the H-CVV has been developed. This structure is able to meet the instrument stability requirement.

7.3.6.2.1.1 Material Selection

The adopted materials have been selected to meet the requirements for lightweight, high stiffness, low distortions, thermal decoupling properties applied to Herschel and Planck SVM structure. In particular, the octagonal box is in CFRP, whilst the lateral panels and Planck Payload Sub-platform are in Aluminium.
For the STR Support plate, a thermally conductive CFRP is used, such to comply with both thermal and stability requirement.

7.3.6.2.1.2 Mass Justification

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

The major differences between Herschel and Planck are here summarised:

- Different PLM Equipment (WU and S/S units) and related different location between H and P
- Local differences between Herschel and Planck at the PLM interfaces, namely: 12 points in Herschel, 6 points in Planck, where, the Payload Sub-platform is interposed between PLM and Cone I/F brackets
- Interfaces for SSH/SSD on cone and Upper closure for Herschel only
- Interfaces for SVM Shield on cone and Upper closure for Herschel only
- Interfaces for Solar Array Panel for Planck only
- Two propellant tank Support Structure (PTSS) for Herschel and three for Planck
- Different cut-out on the octagonal box panels
- Specific junctions for the 3 Planck SCC panels
- Star Tracker Support: in H the STR are supported by a dedicated structure interfacing with the H-CVV, whilst in Planck they attached to a lateral panel via a dedicated bracket.
- Different Secondary Structures

During the S/S and Experiment development phase, occurred in the period between PDR and CDR, the increase of complexity of the Experiments and S/S themselves leaded to a total SVM mass increase. The increase has been particularly consistent for the Structure S/S, such to jeopardise the Satellites launcheability.
In order to recover the mass out of compliance, a dedicated campaign has been carried out, acting in two directions:
Reduction of the Design Load Factors applicable to the SVM Equipment panels and Equipment. This has been possible considering reduced sine input for both Herschel and Planck and a reduced Vibroacoustic environment for Planck.

Revision of the analytical verification approach, for the panels and supported units, considering the load application in one direction at a time (not contemporarily in the 3 axis).
Revision and sharing of the frequency requirement on the two sides of the Planck Sub-platform, i.e. 70< f < 76 Hz for BEU / PAU side and f> 30 Hz for DAE side.

At the end of this campaign a mass recovery of about 48 Kg (for both H and P) has been agreed.

As a final consideration it is noticed that the first wighed cone (H STM) resulted under the Nominal mass value, namely (see M.I.P. Report H-P-RP-AI-0088):
As built Total Mass: 117.24 Kg
As design Theoretical Mass 121.4 Kg

7.3.7 Mechanical Performances

SVM Structure

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

The Structure design, reported in the Contractor documentation ([RD-33] to [RD-38], [RD-40], [RD-43], [RD-44]) is in line with the System baseline requirement and configuration.

The manufacturing of Cone, Upper and Lower Closures and Shear webs has been authorised on the basis of two dedicated reviews (MRR1 and MRR2).
The detailed design and verification of the remaining panels, namely Equipment panels and Subplatforms and Secondary structures (supporting brackets) are in progress.

In general it can be stated that the entire main requirement are achieved and no big non-compliance are shown.

The structure has been developed in concomitance with the SVM System configuration evolution. For this reason, a final verification of the entire structure, including also the parts already analysed (MRR1 & 2 items) has been recognised necessary. The results will be presented by the end of July. Due to the mass increase, occurred in the period between the first analysis campaign (MRR's) and the S/S CDR analysis campaign, it has been agreed with ESA that, in case of negative margins will occur, reduced Safety Factors (w. r.t. the 1.5) can be used.

As recalled above, the frequency requirement, introduced after PDR, regarding the Planck Subplatform, induced several design and analysis iteration.
Within the mass reduction campaign (see above), it has been agreed to revise the frequency requirement: on the BEU/PAU side the requirement remains the same (70< f < 76 Hz), whilst on the BEU side the frequency can be lower (DAE side f>30 Hz), provided that the DAE mechanical environment remain acceptable for the unit. This requirement revision allowed lightening the Subplatform itself.

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

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

All the above technical notes have been prepared, utilising the two CASA NASTRAN FEM's, (H-SVM and P-SVM) prepared for S/S PDR. This FEM, as already said, reflects the SVM requirement / configuration status of MRR2 configuration. Some upgrading have been introduced in the CASA FEM. They are described in the above document.

Generally, the new results are deemed acceptable, which means compatible with qualification levels used for existing equipment.

A summary showing the status of SVM Support S/S Equipment qualification status is reported in [RD-85].

7.3.7.1 SVM Potential Fracture Critical Item List

On the basis of the Fracture Control Plan, [RD-32] a PFCIL has been included in [RD-34].
The items identified as "Potential fracture critical items" for the SVM structure are listed here below. In addition, the RCS tanks are considered Fracture Critical Item.

PFCI#	SVM	Structural Part	Drawing Number	Type of Construction	Material	Fracture Classification	NDI Method
1	H-P	Rivet Cone – Upper Brackets	TBD	Metallic Part	Titanium	Fail Safe	-
2	H-P	Bolts CFRP Cone - LVA	TBD	Metallic Part	Titanium	Fail Safe	-
3	H-P	Rivets Lower PTSS Bracket – CFRP Cone	TBD	Metallic Part	Titanium	Fail Safe	-
4	H-P	Bolts Upper Brackets – PTSS End-Fitting	TBD	Metallic Part	A-286	Safe Life	-Dye Penetrant -Ultrasonic
5	H-P	Rivets PTSS End-Fitting - Struts	TBD	Metallic Part	A-286	Fail Safe	-
6	H-P	Bolts PTSS Rear Supp. Bracket - Cone	TBD	Metallic Part	Titanium	Fail Safe	
7	H-P	CFRP Cone	TBD	Composite Sandwich	M40 Skin 5056 Core	-	STM Qualification Test FM Acceptance Test
8	H-P	Propellant Tank Struts	TBD	CFRP Parts	M55J	Proof Test	Proof Test
9	H-P	Propellant Tank Struts End-Fittings	TBD	Metallic Part	AA7075T73	Safe Life	Dye Penetrant
10	P	Bolts HeTSS Bracket – Structure	TBD	Metallic Part	Titanium	Fail Safe	
11	P	Bolts HeTSS Brackets – HeTSS End-Fitting	TBD	Metallic Part	A-286	Safe Life	
12	P	Rivets HeTSS End-Fitting - Struts	TBD	Metallic Part	A-286	Fail Safe	
13	P	He Tank Struts	TBD	CFRP Parts	M55J	Proof Test	
14	P	He Tank Struts End-Fittings	TBD	Metallic Part	AA7075T73	Safe Life	
15	H-P	Eq. Panel-Eq. Panel Connection.	TBD	Metallic	AA7075T73	Fail Safe	-

Note:
They have excluded, following the reduced list, the following items:
- Sandwich Inserts :
- Eq. Inserts : Proof Test on 30% of the inserts to 110% load.
- Tank Rear Support Structure Inserts: Proof Test
- Hoisting Inserts: Proof Test
- HeTSS inserts
- Composites Structures : They are not Single Point Failure, except the cone
- LVA Forging: It is inspected by NDI (ultrasonic, Dye Penetrant)

7.3.8 SVM Mechanical Open Areas

7.3.8.1 SVM Structure

A summary of the main open areas found in the SVM Structure is here below included, in the order of criticality.

Structure Performances
Up today, the full Structure S/S level analyses are not yet finished. Issues, if any, will be highlighted as soon as the Subco analysis tasks will be completed. Discussion on Safety Margin could arise but should be solved with the agreement on the reduced safety factors.

Planck Sub-platform design
At the time of writings, the Planck Sub-platform design is still in progress. However, no major issues are expected, thanks to the new frequency specification.

Structure Mass
The H and P SVM Structure mass requirement, since the first months of Structure Contractor activity, has been recognised as the most critical one, such that the major efforts performed during the entire SVM Structure development was, in fact, addressed to design a real mass optimised structure.
The Structure mass evolution is presented in paragraph 9.1.5, where it is clearly shown that after a first mass assessment performed at the phase B beginning, several design iterations have been made.
The last exercise, leading to the present values, has been recognised as the minimum achievable.
The below mass values don't include the STR Assy mass.

<u>Herschel SVM Structure Mass</u>
- Nominal value, including Secondary structure = 331.1 Kg
- Maximum value, including Secondary structure = 343 Kg

<u>Planck SVM Structure Mass</u>
- Nominal value, including Secondary structure = 385.0 Kg
- Maximum value, including Secondary structure = 400 Kg

These values are far from the requirement, but are considered compatible with the entire H and P launchable mass. From the first weighed item (H STM Cone), it results that a value lower than the nominal is achieved.

A RFD will be issued (derived from the Structure Contractor one on this subject).

7.4 THERMAL DESIGN CONCEPT AND PERFORMANCE ANALYSIS

The HERSCHEL/PLANCK thermal design shall maintain all Instruments, equipment and structure temperatures within the specified limits (reported in [AD-02/03/04/05/06]) 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 and thermistors
- Second Surface Mirrors (rigid and/or flexible)
- Interface fillers and low conductivity stand-offs for mounting equipment and equipment supports
- Aluminium doublers
- Heat pipes (limited to the thermal control of Planck SCC)

Thermostats ware previously foreseen to support thermal control in emergency mode (SOHO case). As demonstrated in [RD-82] and [RD-83] the procurement of such a device it is now no more needed.
A detailed description of the SVM Thermal hardware is detailed in section 9.2.

7.4.1 Overall Thermal Design Description and Configuration

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

7.4.2 Design Justification

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

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

A particular attention have been dedicated to stability requirement on HIFI 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.
The nominal operation heaters could be commanded by CDMU/PCDU and operate in Pulsed Width Modulation mode.

7.4.3 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 an ESARAD geometrical mathematical model (GMM) and an 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.
- Different SAA

7.4.3.1 Geometrical Mathematical Model Description

The GMM has been prepared modelling the structural panels, the solar arrays, the tanks and the units. Each electronics units are modelled with a single box.
The lateral panels (1730*800mm) have been modelled with 72 internal nodes representing the structure of the panel, and 72 external nodes representing the external coating of the radiator. The lateral panels (1154*800mm) have been modelled with 48 internal nodes representing the structure of the panel and 48 external nodes representing the external coating of the radiator.
Concerning PLANK SCC radiators, the meshing of the panels have been developed taking into account the presence of the heat pipes on the radiator. The SCC panels (1730*800mm) have been modelled with 45 internal and 45 external nodes. The SCE panel (1154*800mm) has been modelled with 54 internal and 54 external nodes.
The lower and upper floors were modelled by 8 internal and 8 external nodes.

7.4.3.2 Thermal Mathematical Model Description

The TMM has been completed introducing, for each node, thermal capacities and powers.
The completed and detailed GMM and the TMM results are described in the SVM Thermal Analysis Report [RD-72]
The temperature limits and power dissipation for the units located in the SVM are reported in [RD-98]

7.4.3.3 Analysis cases description and results

HERSCHEL Thermal Analysis

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

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

The analysis was carried out for cold and hot case.
The Cold cases are defined by:
- BOL thermal characteristics
- Scientific Observation phase SAA= +30° (sun on +X axis)
- Survival mode: SAA = +30° (sun on +X axis)

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

The following steady state sizing cases have been performed:

CASE	BOL/ EOL	SUN ON PANEL	SAA	ATTITUDE	SOLAR CONSTANT	DISSIPATION MODE
			[deg]		[W/m²]	
A	EOL	+X+Y	30	Rot X = +1 Rot Y = -30	Winter: 1405	TT&C Nominal / MODE1
B	EOL	+X+Y	30	Rot X = +1 Rot Y = -30	Winter: 1405	TT&C Nominal / MODE2 Photometry
C	EOL	+X+Y	30	Rot X = +1 Rot Y = -30	Winter: 1405	TT&C Nominal / MODE2 Spectroscopy
D	EOL	+X-Y	30	Rot X = -1 Rot Y = -30	Winter: 1405	TT&C Nominal / MODE1
E	EOL	+X-Y	30	Rot X = -1 Rot Y = -30	Winter: 1405	TT&C Nominal / MODE2 Photometry
F	EOL	+X-Y	30	Rot X = -1 Rot Y = -30	Winter: 1405	TT&C Nominal / MODE2 Spectroscopy
G	BOL	+X-Y	30	Rot X = -1 Rot Y = +30	Summer: 1285	TT&C Nominal / MODE3
H	BOL	+X-Y	30	Rot X = -1 Rot Y = +30	Summer: 1285	TT&C Nominal / MODE1
I	BOL	+X-Y	5	Rot X = 0 Rot Y = +5	Summer: 1285	Survival BOL

Table 7.4.4.3-1 HERSCHEL – Steady State Orbit Cases description

The temperature results hereafter presented (Tables 7.4.4.3-3/4/5/6) refer to the Sizing Cases reported in this paragraph. The Temperatures values are reported with and without uncertainty for all the Units according to the uncertainty analysis [RD-95].

The Gyro has to be controlled in temperature in way that its temperature not changes more than 1 °C.

Table 7.4.4.3-3 HERSCHEL - Units Temperature results: Sizing Case BOL Nominal G and H.

											TEMPERATURE LIMIT			
		G	G	H	H	UFP	HTR	HTR	G	H	MIN	MAX	MIN	MAX
NODE	LABEL	TEMP	PW	TEMP	PW		NOM	SURV	TEMP -UFP	TEMP- UFP	OPER.	OPER.	N.OPER	N.OPER
		[°C]	[W]	[°C]	[W]	[°C]			[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
4	VMC	**4.5**	0.0	**4.7**	0.0	7.4			-2.9	-2.7	-10	50	-20	60
5	SAS +Z	**19.2**	0.0	**19.2**	0.0	8			11.2	11.2	-70	80	-80	90
16	MGA+Z	**62.7**	0.6	**62.8**	0.6	12.4			50.3	50.4	-150	150	-150	150
21	LGA+Z	**57.1**	0.0	**57.1**	0.0	8			49.1	49.1	-150	120	-150	120
41	LGA-Z	**-65.3**	0.0	**-65.2**	0.0	8			-73.3	-73.2	-150	120	-150	120
45	SAS -Z	**-17.3**	0.0	**-17.1**	0.0	8			-25.3	-25.1	-70	80	-80	90
49	SREM	**5.8**	2.6	**6.1**	2.6	8			-2.2	-1.9	-10	50	-45	90
56	AAD	**30.3**	0.0	**30.3**	0.0	8			22.3	22.3	-70	70	-80	80
70	TANK1	**11.0**	0.0	**11.0**	0.0	8	N	S	11.0h	11.0h	10	50	10	50
71	TANK2	**11.0**	0.0	**11.0**	0.0	8	N	S	11.0h	11.0h	10	50	10	50
81	GYRO	**61.9**	0.0	**61.9**	0.0	0	N	S	61.9	61.9	-15	55	-25	55
101	RFDN	**-3.1**	11.8	**-3.1**	11.8	8			-11.1	-11.1	-25	55	-35	65
102	EPC1	**0.4**	9.0	**0.5**	9.0	8			-7.6	-7.5	-20	60	-30	70
103	EPC2	**-12.8**	0.0	**-12.7**	0.0	8.2			-21.0	-20.9	-20	60	-30	70
104	XPND1	**7.4**	23.0	**7.5**	23.0	7.6	N	S	-0.2	-0.1	-10	45	-20	60
105	XPND2	**-5.2**	10.0	**-5.2**	10.0	8	N	S	-5.2h	-5.2h	-10	45	-20	60
106	TWTA1	**-5.0**	37.0	**-5.0**	37.0	8			-13.0	-13.0	-20	60	-30	70
107	TWTA2	**-14.9**	0.0	**-14.8**	0.0	8.1			-23.0	-22.9	-20	60	-30	70
110	CRS1	**14.9**	8.3	**15.0**	8.3	7.3			7.6	7.7	0	50	-25	55
111	CRS2	**15.6**	8.3	**15.6**	8.3	7.3			8.3	8.3	0	50	-25	55
201	PCDU	**9.4**	76.2	**9.4**	76.2	8			1.4	1.4	-10	45	-20	55
202	CDMU	**8.6**	37.7	**8.7**	37.7	8			0.6	0.7	-10	45	-20	55
203	ACC	**10.6**	32.1	**10.7**	32.1	8			2.6	2.7	-10	45	-20	55
204	BATT	**1.0**	2.3	**1.0**	2.3	8	N	S	1.0h	1.0h	0	35		
301	FPSPU1_2	**10.6**	30.3	**10.7**	30.3	8		S	2.6	2.7	-15	45	-30	60
303	FPDPU	**11.0**	24.0	**11.1**	24.0	8		S	3.0	3.1	-15	45	-30	60
304	FPBOLC	**-8.4**	6.6	**-8.3**	6.6	8	N	S	-8.4h	-8.3h	-15	45	-30	60
305	FPMECDEC	**-3.9**	20.9	**-3.7**	20.9	8		S	-11.9	-11.7	-15	45	-30	60
401	CCU	**2.0**	5.4	**2.4**	5.4	8		S	-6.0	-5.6	-10	40	-20	50
404	HSDCU	**8.6**	37.0	**8.9**	37.0	8		S	0.6	0.9	-15	45	-35	60
405	HSDPU	**5.2**	15.3	**5.3**	15.3	8		S	-2.8	-2.7	-15	45	-35	60
406	HSFCU	**8.1**	42.9	**8.2**	42.9	8		S	0.1	0.2	-15	45	-35	60
501	FHWOV	**9.0**	2.2	**9.0**	2.2	0	N	S	9.0	9.0	5	15	-25	55
502	FHHRV	**19.0**	63.3	**19.4**	63.3	9		S	10.0	10.4	-10	40	-25	55
503	FHICU	**17.2**	29.6	**17.4**	29.6	8.3		S	8.9	9.1	-25	40	-30	60
504	FHFCU	**9.7**	13.0	**10.2**	13.0	8		S	1.7	2.2	-10	40	-25	55
506	FHWEV	**12.4**	27.0	**12.6**	27.0	8		S	4.4	4.6	0	30	-25	55
507	FHIFV	**0.1**	0.25	**0.3**	0.25	8		S	-8.0	-7.7	-10	40	-25	55
508	IFV-HRV	**11.0**	0.00	**11.4**	0.00	9		S	2.0	2.4	-10	40	-25	55
509	IFV-WEV	**11.3**	0.00	**11.6**	0.00	9		S	2.3	2.6	-10	40	-25	55
510	WOV-WEV	**9.7**	0.00	**9.9**	0.00	9		S	0.7	0.9	-10	40	-25	55
511	HRV-HRH	**10.2**	0.00	**12.2**	0.00	9		S	1.2	3.2	-10	40	-25	55
601	FHWOH	**9.0**	2.2	**9.0**	2.2	0	N	S	9.0	9.0	5	15	-25	55
602	FHWEH	**9.2**	27.0	**10.2**	27.0	7.8		S	1.4	2.4	0	30	-25	55
603	FHHRH	**17.2**	63.3	**18.1**	63.3	8.8		S	8.4	9.3	-10	40	-25	55
604	FHLCU	**11.7**	26.0	**19.6**	35.4	8		S	3.7	11.6	-10	40	-25	55
605	FHLSU	**18.9**	44.8	**20.8**	44.8	8		S	10.9	12.8	10	40	-25	55
606	FHIFH	**5.1**	0.25	**9.3**	0.25	8		S	-2.9	1.3	-10	40	-25	55
607	IFH-HRH	**8.7**	0.00	**11.4**	0.00	9		S	-0.3	2.4	-10	40	-25	55
608	IFH-WEH	**8.9**	0.00	**11.5**	0.00	9		S	-0.1	2.5	-10	40	-25	55
609	WEH-W0H	**8.7**	0.00	**10.9**	0.00	9		S	-0.3	1.9	-10	40	-25	55
701	RWL1	**1.5**	5.0	**1.6**	5.0	8	N	S	-6.5	-6.4	0	55	-10	65
702	RWL2	**1.0**	5.0	**1.0**	5.0	8	N	S	-7.0	-7.0	0	55	-10	65

											TEMPERATURE LIMIT			
		G	G	H	H	UFP	HTR	HTR	G	H	MIN	MAX	MIN	MAX
NODE	LABEL	TEMP	PW	TEMP	PW		NOM	SURV	TEMP -UFP	TEMP- UFP	OPER.	OPER.	N.OPER	N.OPER
		[°C]	[W]	[°C]	[W]	[°C]			[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
703	RWL3	**1.0**	5.0	**1.1**	5.0	8	N	S	-7.0	-6.9	0	55	-10	65
704	RWL4	**2.4**	5.0	**2.7**	5.0	8	N	S	-5.6	-5.4	0	55	-10	65
8133	FCV MAIN	**11.0**	OP	**11.0**	OP	8	N	S	11.0h	11.0h	10	65	10	65
8233	FCV MAIN	**11.0**	OP	**11.0**	OP	8	N	S	11.0h	11.0h	10	65	10	65
8333	FCV MAIN	**11.0**	OP	**11.0**	OP	8	N	S	11.0h	11.0h	10	65	10	65
8433	FCV MAIN	**11.0**	OP	**11.0**	OP	8	N	S	11.0h	11.0h	10	65	-20	75
8533	FCV MAIN	**11.0**	OP	**11.4**	OP	8	N	S	11.0h	11.4h	10	65	-20	75
8633	FCV MAIN	**11.0**	OP	**11.0**	OP	8	N	S	11.0h	11.0h	10	65	-20	75
8134	FCV RED	**11.0**	OP	**11.0**	OP	8	N	S	11.0h	11.0h	10	65	-20	75
8234	FCV RED	**11.0**	OP	**11.0**	OP	8	N	S	11.0h	11.0h	10	65	-20	75
8334	FCV RED	**11.0**	OP	**11.0**	OP	8	N	S	11.0h	11.0h	10	65	-20	75
8434	FCV RED	**10.9**	OP	**11.0**	OP	8	N	S	10.9h	11.0h	10	65	-20	75
8534	FCV RED	**12.7**	OP	**13.4**	OP	8	N	S	12.7h	13.4h	10	65	-20	75
8634	FCV RED	**11.0**	OP	**11.0**	OP	8	N	S	11.0h	11.0h	10	65	-20	75
80029	STR1+X FOOT	**0.9**	OP	**0.9**	OP	0	N	S	0.9	0.9	-20	40	-30	50
81029	STR2+X FOOT	**-3.7**	OP	**-3.7**	OP	3.8	N	S	-7.5	-7.5	-20	40	-30	50

(*) Units with dedicated heater control properly sized; their minimum temperature is the analysis temperature without uncertainty.

Table 7.4.4.3-4 HERSCHEL - Units Temperature results: Sizing Case BOL Survival I.

								TEMPERATURE LIMIT			
		I	I	UFP	HTR	HTR	I	MIN	MAX	MIN	MAX
NODE	LABEL	TEMP	PW		NOM	SURV	TEMP-UFP	OPER.	OPER.	N.OPER	N.OPER
		[°C]	[W]	[°C]			[°C]	[°C]	[°C]	[°C]	[°C]
4	VMC	**3.4**	0.0	8.6			-5.2	-10	50	-20	60
5	SAS +Z	**11.9**	0.0	8.0			3.9	-70	80	-80	90
16	MGA+Z	**67.2**	0.0	12.8			54.4	-150	150	-150	150
21	LGA+Z	**77.5**	0.0	8.0			69.5	-150	120	-150	120
41	LGA-Z	**-43.3**	1.7	8.0			-51.3	-150	120	-150	120
45	SAS -Z	**-36.1**	0.0	8.1			-44.2	-70	80	-80	90
49	SREM	**-25.3**	0.0	8.5			-33.8	-10	50	-45	90
56	AAD	**29.8**	0.0	8.7			21.1	-70	70	-80	80
70	TANK1	**11.0**	0.0	8.5	N	S	11.0h	10	50	10	50
71	TANK2	**11.0**	0.0	8.4	N	S	11.0h	10	50	10	50
81	GYRO	**59.7**	14.3	8.5	N	S	51.2	-15	55	-25	55
101	RFDN	**7.0**	11.8	8.6			-1.6	-25	55	-35	65
102	EPC1	**19.1**	9.0	8.2			10.9	-20	60	-30	70
103	EPC2	**-7.6**	0.0	9.0			-16.6	-20	60	-30	70
104	XPND1	**16.9**	23.0	8.3	N	S	8.6	-10	45	-20	60
105	XPND2	**-0.5**	10.0	8.7	N	S	-9.2	-10	45	-20	60
106	TWTA1	**29.5**	37.0	8.9			20.6	-20	60	-30	70
107	TWTA2	**-9.2**	0.0	9.1			-18.3	-20	60	-30	70
110	CRS1	**15.9**	8.3	8.3			7.6	0	50	-25	55
111	CRS2	**16.6**	8.3	8.3			8.3	0	50	-25	55
201	PCDU	**4.1**	63.2	8.0			-3.9	-10	45	-20	55
202	CDMU	**2.0**	37.7	8.0			-6.0	-10	45	-20	55
203	ACC	**4.3**	32.1	8.0			-3.7	-10	45	-20	55
204	BATT	**1.0**	6.0	8.2	N	S	1.0h	0	35		
301	FPSPU1_2	**-29.5**	0.0	8.2		S	-29.5h	-15	45	-30	60
303	FPDPU	**-27.7**	0.0	8.3		S	-27.7h	-15	45	-30	60
304	FPBOLC	**-26.6**	0.0	8.2	N	S	-26.6h	-15	45	-30	60
305	FPMECDEC	**-29.0**	0.0	8.1		S	-29.0h	-15	45	-30	60
401	CCU	**-19.0**	5.4	8.2		S	-19.0h	-10	40	-20	50
404	HSDCU	**-25.7**	0.0	8.3			-34.0	-15	45	-35	60
405	HSDPU	**-32.6**	0.0	8.2			-32.6h	-15	45	-35	60
406	HSFCU	**-30.0**	0.0	8.2			-30.0h	-15	45	-35	60
501	FHWOV	**-24.3**	0.0	9.2	N	S	-24.3h	5	15	-25	55
502	FHHRV	**-24.2**	0.0	9.5		S	-24.2h	-10	40	-25	55
503	FHICU	**-26.3**	0.0	9.3		S	-26.3h	-25	40	-30	60
504	FHFCU	**-24.0**	0.0	8.4		S	-24.0h	-10	40	-25	55
506	FHWEV	**-24.3**	0.0	8.8		S	-24.3h	0	30	-25	55
507	FHIFV	**-20.7**	0.0	8.0		S	-20.7h	-10	40	-25	55
508	IFV-HRV	**-22.4**	0.0	9.0			-22.4h	-10	40	-25	55
509	IFV-WEV	**-22.7**	0.0	9.0			-22.7h	-10	40	-25	55
510	WOV-WEV	**-22.1**	0.0	9.0			-22.1h	-10	40	-25	55
511	HRV-HRH	**-20.5**	0.0	9.0			-20.5h	-10	40	-25	55
601	FHWOH	**-24.2**	0.0	9.1	N	S	-24.2h	5	15	-25	55
602	FHWEH	**-24.3**	0.0	8.8		S	-24.3h	0	30	-25	55
603	FHHRH	**-24.1**	0.0	9.4		S	-24.1h	-10	40	-25	55
604	FHLCU	**-24.1**	0.0	8.3		S	-24.1h	-10	40	-25	55
605	FHLSU	**-24.1**	-1.0	9.3		S	-24.1h	10	40	-25	55
606	FHIFH	**-18.8**	0.0	8.0		S	-18.8h	-10	40	-25	55
607	IFH-HRH	**-20.9**	0.0	9.0			-20.9h	-10	40	-25	55
608	IFH-WEH	**-21.0**	0.0	9.0			-21.0h	-10	40	-25	55
609	WEH-W0H	**-21.4**	0.0	9.0			-21.4h	-10	40	-25	55
701	RWL1	**1.0**	0.0	8.5	N	S	-7.5	0	55	-10	65
702	RWL2	**3.8**	0.0	8.4	N	S	-4.6	0	55	-10	65
703	RWL3	**1.0**	0.0	8.6	N	S	-7.6	0	55	-10	65
704	RWL4	**1.0**	0.0	8.4	N	S	-7.4	0	55	-10	65
8133	FCV MAIN	**11.0**	OP	8.3	N	S	11.0h	10	65	10	65
8233	FCV MAIN	**21.9**	OP	8.6	N	S	13.3	10	65	10	65
8333	FCV MAIN	**11.0**	OP	8.3	N	S	11.0h	10	65	10	65

								TEMPERATURE LIMIT			
		I	I	UFP	HTR	HTR	I	MIN	MAX	MIN	MAX
NODE	LABEL	TEMP	PW		NOM	SURV	TEMP-UFP	OPER.	OPER.	N.OPER	N.OPER
		[°C]	[W]	[°C]			[°C]	[°C]	[°C]	[°C]	[°C]
8433	FCV MAIN	**11.0**	OP	8.3	N	S	11.0h	10	65	-20	75
8533	FCV MAIN	**11.0**	OP	8.4	N	S	11.0h	10	65	-20	75
8633	FCV MAIN	**15.8**	OP	8.3	N	S	15.8h	10	65	-20	75
8134	FCV RED	**11.0**	OP	8.5	N	S	11.0h	10	65	-20	75
8234	FCV RED	**17.0**	OP	8.6	N	S	17.0h	10	65	-20	75
8334	FCV RED	**11.0**	OP	8.3	N	S	11.0h	10	65	-20	75
8434	FCV RED	**10.9**	OP	8.4	N	S	10.9h	10	65	-20	75
8534	FCV RED	**11.0**	OP	8.4	N	S	11.0h	10	65	-20	75
8634	FCV RED	**11.0**	OP	8.3	N	S	11.0h	10	65	-20	75
80029	STR1+X FOOT	**-29.0**	0.0	8.0	N	S	-29.0h	-20	40	-30	50
81029	STR2+X FOOT	**-29.0**	0.0	8.0	N	S	-29.0h	-20	40	-30	50

(*) Units with dedicated heater control properly sized; their minimum temperature is the switch-on value (minimum threshold) of the heater circuit.

Table 7.4.4.3-5 HERSCHEL - Units Temperature results: Sizing Case EOL Nominal A, B and C.

														TEMPERATURE LIMIT			
		A	A	B	B	C	C	UFP	HTR	HTR	A	B	C	MIN	MAX	MIN	MAX
NODE	LABEL	TEMP	PW	TEMP	PW	TEMP	PW		NOM	SURV	TEMP +UFP	TEMP +UFP	TEMP +UFP	OPER.	OPER.	N.OPER	N.OPER
		[°C]	[W]	[°C]	[W]	[°C]	[W]	[°C]			[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
4	VMC	**42.1**	0.0	**43.0**	0.0	**43.1**	0.0	7.4			49.5	50.4	50.5	-10	50	-20	60
5	SAS +Z	**44.2**	0.0	**44.9**	0.0	**44.9**	0.0	8			52.2	52.9	52.9	-70	80	-80	90
16	MGA+Z	**129.9**	0.6	**130.3**	0.6	**130.3**	0.6	12.4			142.3	142.7	142.7	-150	150	-150	150
21	LGA+Z	**87.2**	0.0	**87.3**	0.0	**87.3**	0.0	8			95.2	95.3	95.3	-150	120	-150	120
41	LGA-Z	**-54.4**	0.0	**-52.6**	0.0	**-52.0**	0.0	8			-46.4	-44.6	-44.0	-150	120	-150	120
45	SAS -Z	**2.9**	0.0	**5.2**	0.0	**5.8**	0.0	8			10.9	13.2	13.8	-70	80	-80	90
49	SREM	**29.7**	2.6	**32.6**	2.6	**33.4**	2.6	8			37.7	40.6	41.4	-10	50	-45	90
56	AAD	**53.9**	0.0	**54.7**	0.0	**54.6**	0.0	8			61.9	62.7	62.6	-70	70	-80	80
70	TANK1	**35.0**	0.0	**36.7**	0.0	**36.8**	0.0	8	N	S	43.0	44.7	44.8	10	50	10	50
71	TANK2	**32.8**	0.0	**35.4**	0.0	**35.4**	0.0	8	N	S	40.8	43.4	43.4	10	50	10	50
81	GYRO	**63.6**	0.0	**63.6**	0.0	**63.6**	0.0	0	N	S	63.6	63.6	63.6	-15	55	-25	55
101	RFDN	**33.8**	11.8	**34.8**	11.8	**34.7**	11.8	8			41.8	42.8	42.7	-25	55	-35	65
102	EPC1	**42.0**	9.0	**42.9**	9.0	**42.8**	9.0	8			50.0	50.9	50.8	-20	60	-30	70
103	EPC2	**19.0**	0.0	**20.0**	0.0	**19.9**	0.0	8.2			27.2	28.2	28.1	-20	60	-30	70
104	XPND1	**39.5**	23.0	**40.6**	23.0	**40.4**	23.0	7.6	N	S	47.1	48.2	48.0	-10	45	-20	60
105	XPND2	**25.0**	10.0	**26.1**	10.0	**26.0**	10.0	8	N	S	33.0	34.1	34.0	-10	45	-20	60
106	TWTA1	**52.4**	37.0	**53.2**	37.0	**53.1**	37.0	7.9			60.3	61.1	61.0	-20	60	-30	70
107	TWTA2	**18.5**	0.0	**19.4**	0.0	**19.3**	0.0	8.1			26.6	27.5	27.4	-20	60	-30	70
110	CRS1	**41.2**	8.3	**43.0**	8.3	**42.7**	8.3	7.3			48.5	50.3	50.0	0	50	-25	55
111	CRS2	**42.0**	8.3	**43.7**	8.3	**43.5**	8.3	7.3			49.3	51.0	50.8	0	50	-25	55
201	PCDU	**29.9**	80.0	**32.2**	80.0	**31.7**	80.0	8			37.9	40.2	39.7	-10	45	-20	55
202	CDMU	**29.7**	37.7	**33.7**	37.7	**32.6**	37.7	8			37.7	41.7	40.6	-10	45	-20	55
203	ACC	**31.3**	32.1	**35.7**	32.1	**34.3**	32.1	8			39.3	43.7	42.3	-10	45	-20	55
204	BATT	**18.1**	2.3	**20.9**	2.3	**20.3**	2.3	8	N	S	26.1	28.9	28.3	0	35		
301	FPSPU1_2	**28.0**	30.3	**32.7**	30.3	**35.0**	30.3	8		S	36.0	40.7	43.0	-15	45	-30	60
303	FPDPU	**28.1**	24.0	**33.3**	24.0	**34.9**	24.0	8		S	36.1	41.3	42.9	-15	45	-30	60
304	FPBOLC	**13.7**	6.6	**31.4**	48.6	**21.1**	6.6	8	N	S	21.7	39.4	29.1	-15	45	-30	60
305	FPMECDEC	**17.0**	20.9	**24.1**	21.6	**33.1**	65.0	8		S	25.0	32.1	41.1	-15	45	-30	60
401	CCU	**26.3**	5.4	**28.1**	5.4	**28.5**	5.4	8		S	34.3	36.1	36.5	-10	40	-20	50
404	HSDCU	**31.2**	37.0	**32.9**	37.0	**33.3**	37.0	8			39.2	40.9	41.3	-15	45	-35	60
405	HSDPU	**23.9**	15.3	**28.0**	15.3	**30.4**	15.3	8			31.9	36.0	38.4	-15	45	-35	60
406	HSFCU	**28.6**	42.9	**32.6**	42.9	**34.2**	42.9	8			36.6	40.6	42.2	-15	45	-35	60
501	FHWOV	**9.0**	2.2	**9.0**	2.2	**9.0**	2.2	0	N	S	9.0	9.0	9.0	5	15	-25	55
502	FHHRV	**27.5**	63.3	**27.7**	63.3	**27.8**	63.3	9		S	36.5	36.7	36.8	-10	40	-25	55
503	FHICU	**24.9**	29.6	**25.2**	29.6	**25.3**	29.6	8.3		S	33.2	33.5	33.6	-25	40	-30	60
504	FHFCU	**18.6**	13.0	**18.7**	13.0	**18.8**	13.0	8		S	26.6	26.7	26.8	-10	40	-25	55
506	FHWEV	**20.8**	27.0	**21.2**	27.0	**21.3**	27.0	8		S	28.8	29.2	29.3	0	30	-25	55
507	FHIFV	**8.4**	0.3	**8.7**	0.3	**8.8**	0.3	8		S	16.4	16.7	16.8	-10	40	-25	55
508	IFV-HRV	**22.3**	0.0	**22.8**	0.0	**22.9**	0.0	9			31.3	31.8	31.9	-10	40	-25	55
509	IFV-WEV	**22.2**	0.0	**22.7**	0.0	**22.8**	0.0	9			31.2	31.7	31.8	-10	40	-25	55
510	WOV-WEV	**21.4**	0.0	**22.0**	0.0	**22.2**	0.0	9			30.4	31.0	31.2	-10	40	-25	55
511	HRV-HRH	**26.2**	0.0	**25.1**	0.0	**25.2**	0.0	9			35.2	34.1	34.2	-10	40	-25	55
601	FHWOH	**9.0**	2.2	**9.0**	2.2	**9.0**	2.2	0	N	S	9.0	9.0	9.0	5	15	-25	55
602	FHWEH	**21.8**	27.0	**21.3**	27.0	**21.3**	27.0	7.8		S	29.6	29.1	29.1	0	30	-25	55
603	FHHRH	**28.3**	63.3	**27.9**	63.3	**27.9**	63.3	8.8		S	37.1	36.7	36.7	-10	40	-25	55
604	FHLCU	**31.0**	35.4	**24.3**	26.0	**24.4**	26.0	8		S	39.0	32.3	32.4	-10	40	-25	55
605	FHLSU	**27.2**	44.8	**25.7**	44.8	**25.7**	44.8	8		S	35.2	33.7	33.7	10	40	-25	55
606	FHIFH	**21.9**	0.3	**18.8**	0.3	**18.9**	0.3	8		S	29.9	26.8	26.9	-10	40	-25	55
607	IFH-HRH	**26.0**	0.0	**24.3**	0.0	**24.4**	0.0	9			35.0	33.3	33.4	-10	40	-25	55
608	IFH-WEH	**25.9**	0.0	**24.2**	0.0	**24.3**	0.0	9			34.9	33.2	33.3	-10	40	-25	55
609	WEH-W0H	**23.7**	0.0	**22.2**	0.0	**22.2**	0.0	9			32.7	31.2	31.2	-10	40	-25	55
701	RWL1	**44.4**	16.0	**45.2**	16.0	**45.2**	16.0	8	N	S	52.4	53.2	53.2	0	55	-10	65
702	RWL2	**43.6**	16.0	**44.4**	16.0	**44.4**	16.0	8	N	S	51.6	52.4	52.4	0	55	-10	65
703	RWL3	**44.9**	16.0	**45.7**	16.0	**45.7**	16.0	8	N	S	52.9	53.7	53.7	0	55	-10	65
704	RWL4	**45.0**	16.0	**45.7**	16.0	**45.8**	16.0	8	N	S	53.0	53.7	53.8	0	55	-10	65
8133	FCV MAIN	**42.3**	OP	**43.1**	OP	**43.1**	OP	8	N	S	50.3	51.1	51.1	10	65	10	65
8233	FCV MAIN	**43.1**	OP	**44.4**	OP	**44.2**	OP	8	N	S	51.1	52.4	52.2	10	65	10	65

														TEMPERATURE LIMIT			
		A	A	B	B	C	C	UFP	HTR	HTR	A	B	C	MIN	MAX	MIN	MAX
NODE	LABEL	TEMP	PW	TEMP	PW	TEMP	PW		NOM	SURV	TEMP +UFP	TEMP +UFP	TEMP +UFP	OPER.	OPER.	N.OPER	N.OPER
		[°C]	[W]	[°C]	[W]	[°C]	[W]	[°C]			[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
8333	FCV MAIN	**34.9**	OP	**41.5**	OP	**39.1**	OP	8	N	S	42.9	49.5	47.1	10	65	10	65
8433	FCV MAIN	**36.9**	OP	**38.2**	OP	**38.4**	OP	8	N	S	44.9	46.2	46.4	10	65	-20	75
8533	FCV MAIN	**41.3**	OP	**41.6**	OP	**41.8**	OP	8	N	S	49.3	49.6	49.8	10	65	-20	75
8633	FCV MAIN	**47.8**	OP	**48.3**	OP	**48.4**	OP	8	N	S	55.8	56.3	56.4	10	65	-20	75
8134	FCV RED	**42.0**	OP	**42.8**	OP	**42.7**	OP	8	N	S	50.0	50.8	50.7	10	65	-20	75
8234	FCV RED	**42.8**	OP	**44.1**	OP	**43.9**	OP	8	N	S	50.8	52.1	51.9	10	65	-20	75
8334	FCV RED	**35.2**	OP	**41.8**	OP	**39.4**	OP	8	N	S	43.2	49.8	47.4	10	65	-20	75
8434	FCV RED	**45.9**	OP	**47.1**	OP	**47.4**	OP	8	N	S	53.9	55.1	55.4	10	65	-20	75
8534	FCV RED	**40.9**	OP	**41.3**	OP	**41.4**	OP	8	N	S	48.9	49.3	49.4	10	65	-20	75
8634	FCV RED	**48.1**	OP	**48.6**	OP	**48.7**	OP	8	N	S	56.1	56.6	56.7	10	65	-20	75
80029	STR1+X FOOT	**1.3**	OP	**1.3**	OP	**1.3**	OP	0	N	S	1.3	1.3	1.3	-20	40	-30	50
81029	STR2+X FOOT	**-3.4**	OP	**-3.4**	OP	**-3.4**	OP	3.8	N	S	0.4	0.4	0.4	-20	40	-30	50

Table 7.4.4.3-6 HERSCHEL - Units Temperature results: Sizing Case EOL Nominal D, E and F.

NODE	LABEL	D TEMP [°C]	D PW [W]	E TEMP [°C]	E PW [W]	F TEMP [°C]	F PW [W]	UFP	HTR NOM	HTR SURV	D TEMP +UFP [°C]	E TEMP +UFP [°C]	F TEMP +UFP [°C]	TEMPERATURE LIMIT MIN OPER. [°C]	TEMPERATURE LIMIT MAX OPER. [°C]	TEMPERATURE LIMIT MIN N.OPER [°C]	TEMPERATURE LIMIT MAX N.OPER [°C]
4	VMC	**42.3**	0.0	**43.2**	0.0	**43.2**	0.0	7.4			49.7	50.6	50.6	-10	50	-20	60
5	SAS +Z	**44.0**	0.0	**44.7**	0.0	**44.7**	0.0	8			52.0	52.7	52.7	-70	80	-80	90
16	MGA+Z	**130.1**	0.6	**130.5**	0.6	**130.5**	0.6	12.4			142.5	142.9	142.9	-150	150	-150	150
21	LGA+Z	**87.6**	0.0	**87.7**	0.0	**87.7**	0.0	8			95.6	95.7	95.7	-150	120	-150	120
41	LGA-Z	**-54.4**	0.0	**-52.6**	0.0	**-52.1**	0.0	8			-46.4	-44.6	-44.1	-150	120	-150	120
45	SAS -Z	**2.9**	0.0	**5.1**	0.0	**5.8**	0.0	8			10.9	13.1	13.8	-70	80	-80	90
49	SREM	**29.7**	2.6	**32.6**	2.6	**33.3**	2.6	8			37.7	40.6	41.3	-10	50	-45	90
56	AAD	**53.8**	0.0	**54.5**	0.0	**54.4**	0.0	8			61.8	62.5	62.4	-70	70	-80	80
70	TANK1	**35.0**	0.0	**36.7**	0.0	**36.9**	0.0	8	N	S	43.0	44.7	44.9	10	50	10	50
71	TANK2	**32.7**	0.0	**35.3**	0.0	**35.3**	0.0	8	N	S	40.7	43.3	43.3	10	50	10	50
81	GYRO	**63.6**	0.0	**63.6**	0.0	**63.6**	0.0	0	N	S	63.6	63.6	63.6	-15	55	-25	55
101	RFDN	**33.3**	11.8	**34.3**	11.8	**34.2**	11.8	8			41.3	42.3	42.2	-25	55	-35	65
102	EPC1	**41.4**	9.0	**42.3**	9.0	**42.2**	9.0	8			49.4	50.3	50.2	-20	60	-30	70
103	EPC2	**18.3**	0.0	**19.3**	0.0	**19.2**	0.0	8.2			26.5	27.5	27.4	-20	60	-30	70
104	XPND1	**38.9**	23.0	**40.0**	23.0	**39.8**	23.0	7.6	N	S	46.5	47.6	47.4	-10	45	-20	60
105	XPND2	**24.4**	10.0	**25.5**	10.0	**25.3**	10.0	8	N	S	32.4	33.5	33.3	-10	45	-20	60
106	TWTA1	**51.9**	37.0	**52.6**	37.0	**52.5**	37.0	7.9			59.8	60.5	60.4	-20	60	-30	70
107	TWTA2	**17.8**	0.0	**18.7**	0.0	**18.6**	0.0	8.1			25.9	26.8	26.7	-20	60	-30	70
110	CRS1	**40.9**	8.3	**42.7**	8.3	**42.4**	8.3	7.3			48.2	50.0	49.7	0	50	-25	55
111	CRS2	**41.7**	8.3	**43.4**	8.3	**43.1**	8.3	7.3			49.0	50.7	50.4	0	50	-25	55
201	PCDU	**29.7**	80.0	**32.0**	80.0	**31.5**	80.0	8			37.7	40.0	39.5	-10	45	-20	55
202	CDMU	**29.5**	37.7	**33.5**	37.7	**32.4**	37.7	8			37.5	41.5	40.4	-10	45	-20	55
203	ACC	**31.2**	32.1	**35.5**	32.1	**34.2**	32.1	8			39.2	43.5	42.2	-10	45	-20	55
204	BATT	**17.9**	2.3	**20.7**	2.3	**20.1**	2.3	8	N	S	25.9	28.7	28.1	0	35		
301	FPSPU1_2	**28.0**	30.3	**32.7**	30.3	**35.0**	30.3	8		S	36.0	40.7	43.0	-15	45	-30	60
303	FPDPU	**28.0**	24.0	**33.2**	24.0	**34.8**	24.0	8		S	36.0	41.2	42.8	-15	45	-30	60
304	FPBOLC	**13.6**	6.6	**31.3**	48.6	**21.0**	6.6	8	N	S	21.6	39.3	29.0	-15	45	-30	60
305	FPMECDEC	**17.0**	20.9	**24.1**	21.6	**33.1**	65.0	8		S	25.0	32.1	41.1	-15	45	-30	60
401	CCU	**26.3**	5.4	**28.1**	5.4	**28.5**	5.4	8		S	34.3	36.1	36.5	-10	40	-20	50
404	HSDCU	**31.3**	37.0	**33.0**	37.0	**33.3**	37.0	8			39.3	41.0	41.3	-15	45	-35	60
405	HSDPU	**23.8**	15.3	**28.0**	15.3	**30.4**	15.3	8			31.8	36.0	38.4	-15	45	-35	60
406	HSFCU	**28.5**	42.9	**32.6**	42.9	**34.1**	42.9	8			36.5	40.6	42.1	-15	45	-35	60
501	FHWOV	**9.0**	2.2	**9.0**	2.2	**9.0**	2.2	0	N	S	9.0	9.0	9.0	5	15	-25	55
502	FHHRV	**27.5**	63.3	**27.7**	63.3	**27.8**	63.3	9		S	36.5	36.7	36.8	-10	40	-25	55
503	FHICU	**24.9**	29.6	**25.2**	29.6	**25.3**	29.6	8.3		S	33.2	33.5	33.6	-25	40	-30	60
504	FHFCU	**18.6**	13.0	**18.8**	13.0	**18.8**	13.0	8		S	26.6	26.8	26.8	-10	40	-25	55
506	FHWEV	**20.8**	27.0	**21.2**	27.0	**21.3**	27.0	8		S	28.8	29.2	29.3	0	30	-25	55
507	FHIFV	**8.4**	0.3	**8.7**	0.3	**8.8**	0.3	8		S	16.4	16.7	16.8	-10	40	-25	55
508	IFV-HRV	**22.3**	0.0	**22.8**	0.0	**22.9**	0.0	9			31.3	31.8	31.9	-10	40	-25	55
509	IFV-WEV	**22.2**	0.0	**22.7**	0.0	**22.8**	0.0	9			31.2	31.7	31.8	-10	40	-25	55
510	WOV-WEV	**21.5**	0.0	**22.1**	0.0	**22.2**	0.0	9			30.5	31.1	31.2	-10	40	-25	55
511	HRV-HRH	**26.2**	0.0	**25.2**	0.0	**25.2**	0.0	9			35.2	34.2	34.2	-10	40	-25	55
601	FHWOH	**9.0**	2.2	**9.0**	2.2	**9.0**	2.2	0	N	S	9.0	9.0	9.0	5	15	-25	55
602	FHWEH	**22.0**	27.0	**21.4**	27.0	**21.5**	27.0	7.8		S	29.8	29.2	29.3	0	30	-25	55
603	FHHRH	**28.5**	63.3	**28.0**	63.3	**28.0**	63.3	8.8		S	37.3	36.8	36.8	-10	40	-25	55
604	FHLCU	**31.1**	35.4	**24.4**	26.0	**24.4**	26.0	8		S	39.1	32.4	32.4	-10	40	-25	55
605	FHLSU	**27.3**	44.8	**25.8**	44.8	**25.8**	44.8	8		S	35.3	33.8	33.8	10	40	-25	55
606	FHIFH	**21.9**	0.3	**18.9**	0.3	**19.0**	0.3	8		S	29.9	26.9	27.0	-10	40	-25	55
607	IFH-HRH	**26.1**	0.0	**24.4**	0.0	**24.5**	0.0	9			35.1	33.4	33.5	-10	40	-25	55
608	IFH-WEH	**26.0**	0.0	**24.3**	0.0	**24.4**	0.0	9			35.0	33.3	33.4	-10	40	-25	55
609	WEH-W0H	**23.7**	0.0	**22.2**	0.0	**22.3**	0.0	9			32.7	31.2	31.3	-10	40	-25	55
701	RWL1	**44.7**	16.0	**45.5**	16.0	**45.5**	16.0	8	N	S	52.7	53.5	53.5	0	55	-10	65
702	RWL2	**44.0**	16.0	**44.7**	16.0	**44.7**	16.0	8	N	S	52.0	52.7	52.7	0	55	-10	65
703	RWL3	**45.2**	16.0	**46.0**	16.0	**46.0**	16.0	8	N	S	53.2	54.0	54.0	0	55	-10	65
704	RWL4	**45.3**	16.0	**46.0**	16.0	**46.1**	16.0	8	N	S	53.3	54.0	54.1	0	55	-10	65
8133	FCV MAIN	**42.3**	OP	**43.1**	OP	**43.0**	OP	8	N	S	50.3	51.1	51.0	10	65	10	65
8233	FCV MAIN	**42.8**	OP	**44.1**	OP	**43.9**	OP	8	N	S	50.8	52.1	51.9	10	65	10	65

														TEMPERATURE LIMIT			
		D	D	E	E	F	F	UFP	HTR	HTR	D	E	F	MIN	MAX	MIN	MAX
NODE	LABEL	TEMP	PW	TEMP	PW	TEMP	PW		NOM	SURV	TEMP +UFP	TEMP +UFP	TEMP +UFP	OPER.	OPER.	N.OPER	N.OPER
		[°C]	[W]	[°C]	[W]	[°C]	[W]				[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[°C]
8333	FCV MAIN	**34.8**	OP	**41.4**	OP	**39.0**	OP	8	N	S	42.8	49.4	47.0	10	65	10	65
8433	FCV MAIN	**36.9**	OP	**38.1**	OP	**38.4**	OP	8	N	S	44.9	46.1	46.4	10	65	-20	75
8533	FCV MAIN	**41.4**	OP	**41.8**	OP	**41.9**	OP	8	N	S	49.4	49.8	49.9	10	65	-20	75
8633	FCV MAIN	**48.1**	OP	**48.6**	OP	**48.6**	OP	8	N	S	56.1	56.6	56.6	10	65	-20	75
8134	FCV RED	**41.8**	OP	**42.6**	OP	**42.5**	OP	8	N	S	49.8	50.6	50.5	10	65	-20	75
8234	FCV RED	**42.4**	OP	**43.7**	OP	**43.5**	OP	8	N	S	50.4	51.7	51.5	10	65	-20	75
8334	FCV RED	**35.1**	OP	**41.7**	OP	**39.3**	OP	8	N	S	43.1	49.7	47.3	10	65	-20	75
8434	FCV RED	**46.0**	OP	**47.3**	OP	**47.5**	OP	8	N	S	54.0	55.3	55.5	10	65	-20	75
8534	FCV RED	**41.0**	OP	**41.4**	OP	**41.6**	OP	8	N	S	49.0	49.4	49.6	10	65	-20	75
8634	FCV RED	**48.4**	OP	**49.0**	OP	**49.0**	OP	8	N	S	56.4	57.0	57.0	10	65	-20	75
80029	STR1+X FOOT	**1.3**	OP	**1.3**	OP	**1.3**	OP	0	N	S	1.3	1.3	1.3	-20	40	-30	50
81029	STR2+X FOOT	**-3.4**	OP	**-3.4**	OP	**-3.4**	OP	3.8	N	S	0.4	0.4	0.4	-20	40	-30	50

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

TRANSIENT

Two Cases with an Attitude Change have been performed with the Warm Units in MODE1: P and Q.
The scope of these transients is to verify the stability requirements. As reported in Requirements paragraph, the stability is reached for all the units that have a requirement.
A fine control law is implemented on the STR, –Y Panel Unit FHWOH and on the -Y-Z Unit FHWOV the units that require a dedicated heater power in nominal conditions.

The analysed cases are:

P: Cold Transient:
- Starting from steady state BOL case with Sun on +X -Y axis, SAA=+30°/-1° in Summer season
- Ending to steady state BOL case with Sun on -X -Y axis, SAA=-30°/-1° in Summer season
- Power units dissipation: constant
- Warm Units in MODE1
- TT&C units: 21 hours Scientific Mode and 3 hours Telecom Mode
- Nominal heater dissipation
- Fine control law on Units: FHWOV, FHWOH, STR.
- GYRO controlled within 1°C at set-point
- Duration of change of attitude (7°/min): 514s

Overall duration of transient case: 130 h

Q: Hot Transient:
- Starting from steady state EOL case with Sun on +X -Y axis, SAA=+30°/-1° in Winter season
- Ending to steady state EOL case with Sun on -X -Y axis, SAA=-30°/-1° in Winter season
- Power units dissipation: constant
- Warm Units in MODE1
- TT&C units: 21 hours Scientific Mode and 3 hours Telecom Mode
- Nominal heater dissipation
- Fine control law on Units: FHWOV, FHWOH, STR.
- GYRO controlled within 1°C at set-point
- Duration of change of attitude (7°/min): 514s
- Overall duration of transient case: 130 h

Transient analysis cases were run to assess the thermal behaviour of the SVM when subjected to attitude change (sun from +30 deg to –30 deg on –X side and vice-versa). Main purpose was to verify the capability of the design to meet the stability requirements. Considerations about the stability are reported in [RD-87]. Purpose of this paragraph is to report the temperature level reach from the units during the attitude change in terms of minimum and maximum temperature (table 7.4.4.3-7). A complete vision of the results is reported in [RD-92] and [RD-95].

Table 7.4.4.3-7 HERSCHEL – Transient cases: Min and Max temperatures (without uncertainty)

		P		Q	
NODE	LABEL	T MIN	T MAX	T MIN	T MAX
		[°C]	[°C]	[°C]	[°C]
4	VMC	4.67	27.38	11	35.78
5	SAS HOUSING +Z	18.21	34.06	24.51	42.14
16	MGA+Z SEPTUM	62.76	121.23	70.17	129.23
21	LGA+Z	57.12	80.01	62.96	86.82
41	LGA-Z	-65.21	-57.2	-64.39	-55.19
45	SAS HOUSING -Z	-17.07	-1.99	-15.71	1.46
49	SREM	6.07	23.72	7.68	27.96
56	AAD HOUSING	30.35	44.26	36.58	52.03
70	TANK1	11	24.93	11.01	31.38
71	TANK2	11	23.63	11.01	30.07
100	GYRO	61.95	63.24	62.09	63.39
101	RFDN	-3.04	20.95	6.56	31.79
102	EPC1	0.48	28.75	7.91	40.29
103	EPC2	-12.73	3.3	0.03	17.03
104	XPND1	7.49	26.37	15.83	37.82
105	XPND2	-5.17	10.31	6.31	23.13
106	TWTA1	-4.95	39.64	4.92	50.76
107	TWTA2	-14.83	2.72	-1.67	16.48
110	CRS1	15.01	31.48	20.31	39.44
111	CRS2	15.65	32.2	20.89	40.17
201	PCDU	9.44	21.71	13.19	28.46
202	CDMU	8.66	23.41	10.87	28.15
203	ACC	10.67	24.91	13.06	29.79
204	BATT	1	10.06	1	16.44
301	FPSPU1_2	10.68	23.6	11.9	26.83
303	FPDPU	11.08	23.71	12.29	26.9
304	FPBOLC	-8.29	7.76	-6.46	12.11
305	FPMECDEC	-3.71	11.64	-2.15	15.58
401	CCU	2.38	20.45	3.91	24.52
404	HSDCU	8.95	25.59	10.5	29.5
405	HSDPU	5.32	19.09	6.61	22.56
406	HSFCU	8.21	23.43	9.62	27.15
501	FHWOV	8.97	10.21	8.98	10.27
502	FHHRV	19.38	25.51	19.84	26.9
503	FHICU	17.42	23.07	17.83	24.35
504	FHFCU	10.16	16.44	10.66	17.91
506	FHWEV	12.58	18.7	13.08	20.2
507	FHIFV	0.35	6.38	0.88	7.81
508	IFV-HRV	11.39	19.5	12.07	21.42
509	IFV-WEV	11.62	19.52	12.27	21.39
510	WOV-WEV	9.94	18.55	10.59	20.58
511	HRV-HRH	12.23	22.14	13.36	24.67
601	FHWOH	8.96	10.21	8.97	10.41
602	FHWEH	10.23	17.62	11.62	20

		P		Q	
NODE	LABEL	T MIN	T MAX	T MIN	T MAX
		[°C]	[°C]	[°C]	[°C]
603	FHHRH	18.14	24.53	19.36	26.68
604	FHLCU	19.61	27.61	20.58	29.71
605	FHLSU	20.78	25.13	21.39	26.34
606	FHIFH	9.32	18.41	10.28	20.65
607	IFH-HRH	11.4	21.63	12.71	24.32
608	IFH-WEH	11.47	21.43	12.81	24.1
609	WEH-W0H	10.94	19.59	12.19	21.97
701	RWL1	1.6	21.13	9.97	30.98
702	RWL2	1	20.86	8.05	30.03
703	RWL3	1.13	21.72	9.29	31.43
704	RWL4	2.65	21.97	9.79	31.01
8133	FCV BODY MAIN	11	32.17	11	40.79
8134	FCV BODY REDUNDANT	11	31.69	11.01	40.29
8233	FCV BODY MAIN	11.01	32.96	14.95	41.62
8234	FCV BODY REDUNDANT	11	32.61	14.92	41.25
8333	FCV BODY MAIN	11.01	28.84	11	33.67
8334	FCV BODY REDUNDANT	11	29.08	11.01	33.92
8433	FCV BODY MAIN	11.01	30.69	11.01	35.4
8434	FCV BODY REDUNDANT	11.02	39.15	11.01	44.61
8533	FCV BODY MAIN	11.44	35.97	12.86	39.9
8534	FCV BODY REDUNDANT	13.41	35.59	15.05	39.51
8633	FCV BODY MAIN	11	32.81	12.95	40.55
8634	FCV BODY REDUNDANT	11	33.15	12.97	40.91
80029	STR1 +X FOOT	1.02	1.32	1.02	1.54
81029	STR2 +X FOOT	-3.69	-3.39	-3.68	-3.16

PLANCK THERMAL ANALYSIS

The nominal analysis have been performed considering transient cases with the S/C operating 21 hours in Scientific mode and 3 hrs in Telecom mode. The analysis takes into account also the cyclic variation of SCC power dissipation on each bed.
The list of the orbital Transient cases analysed is presented in the following table:

CASE	BOL / EOL	SUN ON PANEL	SAA [deg]	ATTITUDE	SOLAR CONSTANT [W/m²]	Remarks
A1	BOL	+Z	10	Rot X = 0 Rot Y = +10	Summer: 1285	Nominal BOL – Dissipation MODE1
A2	BOL	+Z	10	Rot X = 0 Rot Y = +10	Summer: 1285	Nominal BOL – Dissipation MODE2
A3	BOL	+Z	10	Rot X = 0 Rot Y = +10	Summer: 1285	Nominal BOL – Dissipation MODE3
B1	EOL	+Z	0	Rot X = 0 Rot Y = 0	Winter: 1405	Nominal EOL – SCC1 on
B2	EOL	+Z	0	Rot X = 0 Rot Y = 0	Winter: 1405	Nominal EOL – SCC2 on
C	BOL	+Z	10	Rot X = 0 Rot Y = +10	Summer: 1285	Survival BOL

Table 7.4.4.3-8 PLANCK Transient nominal analysis cases

The spin of the satellite around its X-axis (1 round per minute) has a negligible effect on the amount of solar fluxes on the sun-exposed surfaces, so it is not considered in the current analysis.

CHANGE OF ATTITUDE TRANSIENT ANALYSIS

To verify the thermal stability requirement for the SCC Radiative Panels and the SVM/PLM I/F points transient analysis have been performed taking into account the variation of SCC Power dissipation on each bed; moreover a change of attitude of the satellite from SAA=0° to SAA=10° has been considered at time = 86400 sec.
The analysed cases are the following:

Cold Transient (**Case P**):
- Starting from S/S BOL case with Sun on –X and SAA= 0°. Solar constant=1285 W/m^2
- Ending to S/S BOL case with Sun on –X and SAA=+10°. Solar constant=1285 W/m^2
- Duration of change of attitude: 1200s
- Rotation rate: 0.5°/min
- Overall duration of transient case: 348600s (72 hours)
- Dissipation as per nominal case A1

Hot Transient (**Case Q1**):

- Starting from S/S EOL case with Sun on –X and SAA=0°. Solar constant=1405 W/m^2
- Ending to S/S EOL case with Sun on –X and SAA= +10°. Solar constant=1405 W/m^2
- Duration of change of attitude: 1200s
- Rotation rate: 0.5°/min
- Overall duration of transient case: 348600s (72 hours)
- Dissipation as per nominal case B1

Hot Transient (**Case Q2**):

- Starting from S/S EOL case with Sun on –X and SAA=0°. Solar constant=1405 W/m^2
- Ending to S/S EOL case with Sun on –X and SAA= +10°. Solar constant=1405 W/m^2
- Duration of change of attitude: 1200s
- Rotation rate: 0.5°/min
- Overall duration of transient case: 348600s (72 hours)
- Dissipation as per nominal case B2

Table 7.4.4.3-9 PLANCK – Steady State Units Temperature Results

NODE	LABEL	UFP	CASE A1	CASE A2	CASE A3	CASE C	CASE B1	CASE B2	CASE A1	CASE A2	CASE A3	CASE C	CASE B1	CASE B2	**TEMPERATURE LIMIT**			
			Min	Min	Min	Min	Max	Max	Tmin - UFP	Tmin - UFP	Tmin - UFP	Tmin - UFP	Tmax +UFP	Tmax +UFP	**MIN OPER.**	**MAX OPER.**	**MIN N.OPER.**	**MAX N.OPER**
5427	STR_MY -X FOOT	9.2	16.39	15.2	14.1	-29.0	19.7	19.7	7.2	6.0	4.9	-29.0 h	28.9	28.9	**-20.0**	**40.0**	**-30.0**	**50.0**
5428	STR_MY +Y FOOT	9.2	16.44	15.3	14.1	-29.2	19.8	19.8	7.2	6.1	4.9	-29.2 h	29.0	29.0	**-20.0**	**40.0**	**-30.0**	**50.0**
5429	STR_MY +X FOOT	9.2	16.24	15.1	13.9	-29.1	19.6	19.6	7.0	5.9	4.7	-29.1 h	28.8	28.8	**-20.0**	**40.0**	**-30.0**	**50.0**
5430	STR_MY -Y FOOT	9.2	16.31	15.1	14.0	-29.2	19.7	19.7	7.1	5.9	4.8	-29.2 h	28.9	28.9	**-20.0**	**40.0**	**-30.0**	**50.0**
5527	STR_PY -X FOOT	7.3	-15.05	-16.3	-19.1	-29.0	-11.5	-11.5	-22.4	-23.6	-26.4	-29.0 h	-4.2	-4.2	**-20.0**	**40.0**	**-30.0**	**50.0**
5528	STR_PY +Y FOOT	7.3	-15.14	-16.4	-19.2	-29.0	-11.5	-11.5	-22.4	-23.7	-26.5	-29.0 h	-4.2	-4.2	**-20.0**	**40.0**	**-30.0**	**50.0**
5529	STR_PY +X FOOT	7.3	-15.15	-16.4	-19.2	-29.0	-11.6	-11.6	-22.5	-23.7	-26.5	-29.0 h	-4.3	-4.3	**-20.0**	**40.0**	**-30.0**	**50.0**
5530	STR_PY -Y FOOT	7.2	-15.14	-16.4	-19.2	-29.0	-11.5	-11.5	-22.3	-23.6	-26.4	-29.0 h	-4.3	-4.3	**-20.0**	**40.0**	**-30.0**	**50.0**
13	DPU1	8.1	**6.92**	**5.5**	**2.9**	-19.1	**10.7**	**10.7**	-1.2	-2.6	-5.2	-19.1 h	18.8	18.8	**-10.0**	**40.0**	**-20.0**	**50.0**
14	DPU2	7.6	-5.06	-6.7	-8.0	-19.0	-0.9	-0.8	-12.7	-14.3	-15.6	-19.0 h	6.8	6.8	**-10.0**	**40.0**	**-20.0**	**50.0**
101	DCCU	8	**12.82**	**11.1**	**9.7**	-15.7	**17.4**	**17.4**	4.8	3.1	1.7	-23.7	25.4	25.4	**-10.0**	**40.0**	**-20.0**	**50.0**
102	REBA1	8.5	**24**	**22.8**	**19.6**	-27.9	**27.4**	**27.4**	15.5	14.3	11.1	-27.9 h	35.9	35.9	**-20.0**	**50.0**	**-30.0**	**50.0**
103	REBA2	7.8	-4.91	-6.4	-9.1	-29.0	-0.9	-1.0	-12.7	-14.2	-16.9	-29.0 h	6.9	6.9	**-20.0**	**50.0**	**-30.0**	**50.0**
104	FOG (GEU)	8.3	**26.68**	**25.2**	**16.5**	-16.7	**30.6**	**30.6**	18.4	16.9	8.2	-25.0	38.9	38.9	**0.0**	**40.0**	**-40.0**	**70.0**
105	FOG (ICU)	8	10.43	8.7	4.9	-17.9	14.8	14.8	2.4	0.7	-3.1	-25.9	22.8	22.8	**0.0**	**40.0**	**-40.0**	**70.0**
202	4K CAU	8.1	**-3.56**	**-4.7**	**-4.7**	-19.1	**0.0**	**-0.1**	-3.6 h	-4.7 h	-4.7 h	-19.1 h	8.1	8.0	**-10.0**	**40.0**	**-20.0**	**50.0**
203	4K CRU (4K PRE-REG)	8.7	**28.38**	**27.0**	10.1	-17.9	**32.1**	**32.1**	19.7	18.3	1.4	-26.6	40.8	40.8	**-10.0**	**40.0**	**-20.0**	**50.0**
204	CEU	9.3	**27.38**	**26.4**	**26.2**	-17.0	**30.4**	**30.4**	18.1	17.1	16.9	-26.3	39.7	39.7	**-10.0**	**40.0**	**-20.0**	**50.0**
205	REU	9.2	**22.43**	**21.4**	**21.2**	-19.2	**25.6**	**25.5**	13.2	12.2	12.0	-19.2 h	34.8	34.7	**-10.0**	**40.0**	**-20.0**	**50.0**
211	4K CCU Compress.1	11	**48.61**	**47.7**	**47.7**	-5.5	**51.5**	**51.4**	37.6	36.7	36.7	-16.5	62.5	62.4				
212	4K CCU Compress.2	10.5	**42.98**	**42.1**	**42.1**	-6.0	**45.9**	**45.8**	32.5	31.6	31.6	-16.5 h	56.4	56.3				
219	4K CCU I/F Bracket -X	9.1	9.56	8.7	8.7	-16.9	12.6	12.5	0.5	-0.4	-0.4	-16.9 h	21.7	21.6	**-10.0**	**40.0**	**-20.0**	**40.0**

NODE	LABEL	UFP	CASE A1 Min	CASE A2 Min	CASE A3 Min	CASE C Min	CASE B1 Max	CASE B2 Max	CASE A1 Tmin - UFP	CASE A2 Tmin - UFP	CASE A3 Tmin - UFP	CASE C Tmin - UFP	CASE B1 Tmax +UFP	CASE B2 Tmax +UFP	TEMPERATURE LIMIT MIN OPER.	MAX OPER.	MIN N.OPER.	MAX N.OPER
220	4K CCU I/F Bracket +X	8.6	3.28	2.4	2.4	-18.0	6.1	6.1	-5.3	-6.2	-6.2	-18.0 h	14.7	14.7	-10.0	40.0	-20.0	40.0
221	4K CCU I/F Strap -Z	9.9	29.02	28.2	28.2	-9.0	31.8	31.8	19.1	18.3	18.3	-9.0 h	41.7	41.7	-10.0	40.0	-20.0	40.0
222	4K CCU I/F Strap +Z	9.8	27.14	26.3	26.3	-9.5	29.9	29.9	17.3	16.5	16.5	-9.5 h	39.7	39.7	-10.0	40.0	-20.0	40.0
401	SCE1	9.3	**-8.4**	**-8.7**	**-8.7**	-19.9	**-6.6**	-14.4	-8.4 h	-8.7 h	-8.7 h	-19.9 h	2.7	-5.1	-10.0	40.0	-20.0	50.0
402	SCE2	9.3	-13.43	-13.7	-13.7	-19.5	-11.6	**-9.6**	-13.4 h	-13.7 h	-13.7 h	-19.5 h	-2.3	-0.3	-10.0	40.0	-20.0	50.0
519	BEU	9.2	**7.01**	-1.4	**1.5**	-12.8	**21.5**	**21.6**	-2.2	-10.6	-7.7	-22.0	30.7	30.8	-20.0	40.0	-30.0	50.0
520	BEU	9.3	**5.76**	-7.9	**2.4**	-17.9	**16.8**	**16.8**	-3.5	-17.2	-6.9	-27.2	26.1	26.1	-20.0	40.0	-30.0	50.0
521	BEU	9.2	**8.65**	-1.8	**6.0**	-12.1	**23.2**	**23.1**	-0.5	-11.0	-3.2	-21.3	32.4	32.3	-20.0	40.0	-30.0	50.0
522	PAU	8.6	**12.14**	**8.4**	-5.4	-14.2	**20.0**	**20.0**	3.5	-0.2	-14.0	-14.2 h	28.6	28.6	-10.0	30.0	-20.0	50.0
525	DAE POWER BOX	8.1	**23.21**	11.3	**20.7**	-0.8	**29.1**	**29.1**	15.1	3.2	12.6	-8.9	37.2	37.2	-20.0	50.0	-30.0	50.0
551	CRS3	8.5	**21.48**	**19.6**	**19.4**	**19.5**	**29.8**	**30.0**	13.0	11.1	10.9	11.0	38.3	38.5	0.0	50.0	-25.0	55.0
601	XPND_1	8.3	**14.64**	**13.3**	**13.2**	**14.4**	**21.4**	**21.5**	6.3	5.0	4.9	6.1	29.7	29.8	-10.0	45.0	-20.0	60.0
602	XPND_2	7.9	**5.16**	**3.7**	**3.6**	**3.7**	**11.5**	**11.6**	-2.7	-4.2	-4.3	-4.2	19.4	19.5	-10.0	45.0	-20.0	60.0
603	TWTA_1	8.8	-6.81	-8.5	-8.6	**20.7**	27.7	27.8	-15.6	-17.3	-17.4	11.9	36.5	36.6	-20.0	60.0	-30.0	70.0
604	TWTA_2	7.7	-8.2	-9.8	-9.9	-3.7	3.7	3.9	-15.9	-17.5	-17.6	-11.4	11.4	11.6	-20.0	60.0	-30.0	70.0
605	RFDN	7.9	**4.42**	**2.7**	**2.5**	**7.3**	**15.9**	**16.0**	-3.5	-5.2	-5.4	-0.6	23.8	23.9	-25.0	55.0	-35.0	65.0
606	EPC1	8.3	**14.9**	**13.5**	**13.4**	**15.2**	**22.5**	**22.6**	6.6	5.2	5.1	6.9	30.8	30.9	-20.0	60.0	-30.0	70.0
607	EPC2	7.7	1.07	-0.5	-0.6	1.0	8.7	8.8	-6.6	-8.2	-8.3	-6.7	16.4	16.5	-20.0	60.0	-30.0	70.0
701	CDMU	8.1	**15.14**	**13.8**	**13.6**	**7.5**	**19.3**	**19.3**	7.0	5.7	5.5	-0.6	27.4	27.4	-10.0	45.0	-20.0	55.0
702	ACC	8	**8.81**	**7.5**	**7.3**	**0.9**	**12.8**	**12.8**	0.8	-0.5	-0.7	-7.1	20.8	20.8	-10.0	45.0	-20.0	55.0
703	BATT	8	**11.73**	**10.3**	**10.3**	**7.9**	**16.7**	**16.7**	3.7	2.3	2.3	-0.1	24.7	24.7	0.0	35.0	N/A	N/A
704	PCDU	8.7	**27.5**	**26.3**	**26.3**	**16.7**	**32.4**	**32.5**	18.8	17.6	17.6	8.0	41.1	41.2	-10.0	45.0	-20.0	55.0
705	CRS1	8.6	**29.31**	**27.8**	**27.7**	**23.2**	**34.5**	**34.6**	20.7	19.2	19.1	14.6	43.1	43.2	0.0	50.0	-25.0	55.0
706	CRS2	8.7	**32.66**	**31.2**	**31.2**	**27.0**	**37.6**	**37.7**	24.0	22.5	22.5	18.3	46.3	46.4	0.0	50.0	-25.0	55.0

															TEMPERATURE LIMIT			
NODE	LABEL	UFP	CASE A1	CASE A2	CASE A3	CASE C	CASE B1	CASE B2	CASE A1	CASE A2	CASE A3	CASE C	CASE B1	CASE B2	MIN	MAX	MIN	MAX
			Min	Min	Min	Min	Max	Max	Tmin - UFP	Tmin - UFP	Tmin - UFP	Tmin - UFP	Tmax +UFP	Tmax +UFP	OPER.	OPER.	N.OPER.	N.OPER
900	Helium Tank +Z	7.8	7.48	5.6	3.2	-12.2	12.1	12.1	-0.3	-2.2	-4.6	-20.0	19.9	19.9	-10.0	40.0	-20.0	50.0
905	Helium Tank +Y	8.3	11.56	10.0	10.0	-11.0	16.1	16.1	3.3	1.7	1.7	-19.3	24.4	24.4	-10.0	40.0	-20.0	50.0
910	Helium Tank -Z	7.9	8.5	5.9	6.2	-1.9	15.5	15.5	0.6	-2.0	-1.7	-9.8	23.4	23.4	-10.0	40.0	-20.0	50.0
915	Helium Tank -Y	8	10.34	8.5	8.4	7.7	17.8	17.8	2.3	0.5	0.4	-0.3	25.8	25.8	-10.0	40.0	-20.0	50.0
920	Prop. Tank +Y+Z Lower	8	15	14.1	13.5	11.0	21.5	21.4	7.0	14.1 h	13.5 h	11.0 h	29.5	29.4	10.0	50.0	10.0	50.0
925	Prop. Tank -Z Lower	8.1	12.52	11.0	11.0	13.4	20.6	20.6	4.4	11.0 h	11.0 h	13.4 h	28.7	28.7	10.0	50.0	10.0	50.0
930	Prop. Tank -Y+Z Lower	8	14.53	13.8	13.4	17.5	21.3	21.4	6.5	13.8 h	13.4 h	17.5 h	29.3	29.4	10.0	50.0	10.0	50.0
311	SCC1 - Outer shell1	9.9	**-10.3**	**-10.6**	**-10.6**	-19.8	**17.9**	-13.8	-10.3 h	-10.6 h	-10.6 h	-19.8 h	27.8	-3.9				
312	SCC1 - Outer shell2	9.9	**-10.3**	**-10.6**	**-10.6**	-19.8	**18.1**	-13.8	-10.3 h	-10.6 h	-10.6 h	-19.8 h	28.0	-3.9				
313	SCC1 - Outer shell3	9.9	**-10.33**	**-10.6**	**-10.6**	-19.8	**17.8**	-13.8	-10.3 h	-10.6 h	-10.6 h	-19.8 h	27.7	-3.9				
314	SCC1 - Outer shell4	9.9	**-10.33**	**-10.6**	**-10.6**	-19.8	**17.9**	-13.8	-10.3 h	-10.6 h	-10.6 h	-19.8 h	27.8	-3.9				
315	SCC1 - Outer shell5	9.9	**-10.31**	**-10.6**	**-10.6**	-19.8	**18.1**	-13.8	-10.3 h	-10.6 h	-10.6 h	-19.8 h	28.0	-3.9				
316	SCC1 - Outer shell6	9.9	**-10.34**	**-10.6**	**-10.6**	-19.8	**17.9**	-13.8	-10.3 h	-10.6 h	-10.6 h	-19.8 h	27.8	-3.9				
811	HP11 Ver. SCC1	9.7	-10.97	-11.3	-11.2	-19.8	-4.8	-13.8	-11.0 h	-11.3 h	-11.2 h	-19.8 h	5.0	-4.1	-13.0	7.0	-20.0	50.0
812	HP12 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	-13.0	7.0	-20.0	50.0
813	HP13 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	-13.0	7.0	-20.0	50.0
814	HP14 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	-13.0	7.0	-20.0	50.0
815	HP15 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	-13.0	7.0	-20.0	50.0
816	HP16 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	-13.0	7.0	-20.0	50.0
817	HP17 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	-13.0	7.0	-20.0	50.0
818	HP18 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	-13.0	7.0	-20.0	50.0
819	HP19 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	-13.0	7.0	-20.0	50.0
820	HP20 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	-13.0	7.0	-20.0	50.0
821	HP21 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	-13.0	7.0	-20.0	50.0

NODE	LABEL	UFP	CASE A1 Min	CASE A2 Min	CASE A3 Min	CASE C Min	CASE B1 Max	CASE B2 Max	CASE A1 Tmin - UFP	CASE A2 Tmin - UFP	CASE A3 Tmin - UFP	CASE C Tmin - UFP	CASE B1 Tmax +UFP	CASE B2 Tmax +UFP	TEMPERATURE LIMIT MIN OPER.	MAX OPER.	MIN N.OPER.	MAX N.OPER
822	HP22 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	**-13.0**	**7.0**	**-20.0**	**50.0**
823	HP23 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	**-13.0**	**7.0**	**-20.0**	**50.0**
824	HP24 Ver. SCC1	9.7	-10.42	-10.7	-10.7	-19.8	-3.1	-13.8	-10.4 h	-10.7 h	-10.7 h	-19.8 h	6.7	-4.1	**-13.0**	**7.0**	**-20.0**	**50.0**
825	HP25 Ver. SCC1	9.7	-10.97	-11.3	-11.2	-19.8	-4.8	-13.8	-11.0 h	-11.3 h	-11.2 h	-19.8 h	5.0	-4.1	**-13.0**	**7.0**	**-20.0**	**50.0**
801	HP1 Hor. SCC1	9.3	-13.73	-14.0	-14.0	-20.2	-10.3	-13.7	-13.7 h	-14.0 h	-14.0 h	-20.2 h	-1.0	-4.4				
802	HP2 Hor. SCC1	9.3	-11.51	-11.8	-11.8	-19.7	-9.4	-14.1	-11.5 h	-11.8 h	-11.8 h	-19.7 h	0.0	-4.8				
803	HP3 Hor. SCC1	9.3	-12.38	-12.7	-12.6	-20.0	-9.5	-14.4	-12.4 h	-12.7 h	-12.6 h	-20.0 h	-0.2	-5.1				
804	HP4 Hor. SCC1	9.3	-12.51	-12.8	-12.8	-20.3	-9.7	-14.4	-12.5 h	-12.8 h	-12.8 h	-20.3 h	-0.4	-5.1				
805	HP5 Hor. SCC1	9.3	-13.41	-13.7	-13.7	-20.0	-11.1	-14.4	-13.4 h	-13.7 h	-13.7 h	-20.0 h	-1.8	-5.1				
806	HP6 Hor. SCC1	9.3	-14.18	-14.5	-14.4	-19.6	-11.3	-12.9	-14.2 h	-14.5 h	-14.4 h	-19.6 h	-2.0	-3.6				
807	HP7 Hor. SCC1	9.3	-14.16	-14.4	-14.4	-19.8	-11.3	-12.8	-14.2 h	-14.4 h	-14.4 h	-19.8 h	-2.0	-3.5				
808	HP7 Hor. SCC1	9.3	-13.42	-13.7	-13.7	-19.3	-11.3	-12.7	-13.4 h	-13.7 h	-13.7 h	-19.3 h	-2.0	-3.4				
511	SCC2 - Outer shell1	9.1	-14.95	-15.2	-15.2	-18.9	-13.4	**18.2**	-15.0 h	-15.2 h	-15.2 h	-18.9 h	-4.3	27.3				
512	SCC2 - Outer shell2	9.1	-14.95	-15.2	-15.2	-18.9	-13.5	**18.2**	-15.0 h	-15.2 h	-15.2 h	-18.9 h	-4.4	27.3				
513	SCC2 - Outer shell3	9.1	-14.95	-15.2	-15.2	-18.9	-13.5	**18.2**	-15.0 h	-15.2 h	-15.2 h	-18.9 h	-4.4	27.3				
514	SCC2 - Outer shell4	9.1	-14.95	-15.2	-15.2	-18.9	-13.5	**18.2**	-15.0 h	-15.2 h	-15.2 h	-18.9 h	-4.4	27.3				
515	SCC2 - Outer shell5	9.1	-14.95	-15.2	-15.2	-18.9	-13.4	**18.3**	-15.0 h	-15.2 h	-15.2 h	-18.9 h	-4.3	27.4				
516	SCC2 - Outer shell6	9.1	-14.95	-15.2	-15.2	-18.9	-13.4	**18.2**	-15.0 h	-15.2 h	-15.2 h	-18.9 h	-4.3	27.3				
861	HP61 Ver. SCC2	*9.7*	-15.03	-15.3	-15.3	-18.9	-13.5	-4.3	-15.0 h	-15.3 h	-15.3 h	-18.9 h	-3.8	5.4	**-13.0**	**7.0**	**-20.0**	**50.0**
862	HP62 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
863	HP63 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
864	HP64 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
865	HP65 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
866	HP66 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**

NODE	LABEL	UFP	CASE A1 Min	CASE A2 Min	CASE A3 Min	CASE C Min	CASE B1 Max	CASE B2 Max	CASE A1 Tmin - UFP	CASE A2 Tmin - UFP	CASE A3 Tmin - UFP	CASE C Tmin - UFP	CASE B1 Tmax +UFP	CASE B2 Tmax +UFP	TEMPERATURE LIMIT MIN OPER.	MAX OPER.	MIN N.OPER.	MAX N.OPER
867	HP67 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
868	HP68 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
869	HP69 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
870	HP70 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
871	HP71 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
872	HP72 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
873	HP73 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
874	HP74 Ver. SCC2	*9.7*	-14.99	-15.3	-15.2	-18.9	-13.5	-2.7	-15.0 h	-15.3 h	-15.2 h	-18.9 h	-3.8	7.0	**-13.0**	**7.0**	**-20.0**	**50.0**
875	HP75 Ver. SCC2	*9.7*	-15.03	-15.3	-15.3	-18.9	-13.5	-4.3	-15.0 h	-15.3 h	-15.3 h	-18.9 h	-3.8	5.4	**-13.0**	**7.0**	**-20.0**	**50.0**
851	HP51 Hor. SCC2	9.1	-15.1	-15.4	-15.4	-18.1	-13.0	-9.5	-15.1 h	-15.4 h	-15.4 h	-18.1 h	-3.9	-0.4				
852	HP52 Hor. SCC2	9.1	-14.45	-14.7	-14.7	-18.8	-12.9	-9.9	-14.5 h	-14.7 h	-14.7 h	-18.8 h	-3.8	-0.8				
853	HP53 Hor. SCC2	9.1	-14.91	-15.2	-15.2	-19.3	-13.1	-10.1	-14.9 h	-15.2 h	-15.2 h	-19.3 h	-4.0	-1.0				
854	HP54 Hor. SCC2	9.1	-15.03	-15.3	-15.3	-19.5	-13.2	-10.2	-15.0 h	-15.3 h	-15.3 h	-19.5 h	-4.1	-1.1				
855	HP55 Hor. SCC2	9.1	-15.39	-15.7	-15.6	-18.4	-13.8	-10.2	-15.4 h	-15.7 h	-15.6 h	-18.4 h	-4.7	-1.1				
856	HP56 Hor. SCC2	9.1	-15.71	-16.0	-16.0	-20.0	-13.9	-9.6	-15.7 h	-16.0 h	-16.0 h	-20.0 h	-4.8	-0.5				
857	HP57 Hor. SCC2	9.1	-15.7	-16.0	-16.0	-19.1	-13.9	-9.6	-15.7 h	-16.0 h	-16.0 h	-19.1 h	-4.8	-0.5				
858	HP57 Hor. SCC2	9.1	-15.35	-15.6	-15.6	-18.8	-13.8	-9.5	-15.4 h	-15.6 h	-15.6 h	-18.8 h	-4.7	-0.4				
3931	SAS1 HOUSING	9.2	7.78	6.9	6.7	-27.0	10.4	10.4	-1.4	-2.3	-2.5	-36.2	19.6	19.6	**-70.0**	**80.0**	**-80.0**	**90.0**
3951	SAS2 HOUSING	7.5	50.76	49.5	49.1	43.0	59.8	59.8	43.3	42.0	41.6	35.5	67.3	67.3	**-70.0**	**80.0**	**-80.0**	**90.0**
3921	LGA+Y HORN	8.3	-46.54	-47.1	-47.1	**-33.6**	-44.7	-44.7	-54.8	-55.4	-55.4	-41.9	-36.4	-36.4	**-150.0**	**120.0**	**-150.0**	**120.0**
3961	LGA-Y HORN	8.2	-59.83	-60.6	-60.7	**-30.8**	-55.4	-55.3	-68.0	-68.8	-68.9	-39.0	-47.2	-47.1	**-150.0**	**120.0**	**-150.0**	**120.0**
3991	LGA-X HORN	7.2	60.07	59.2	59.2	57.0	67.9	67.9	52.9	52.0	52.0	49.8	75.1	75.1	**-150.0**	**120.0**	**-150.0**	**120.0**
3986	MGA-X SEPTUM	8.5	27.68	25.6	25.4	19.8	47.9	48.0	19.2	17.1	16.9	11.3	56.4	56.5	**-150.0**	**150.0**	**-150.0**	**150.0**
3966	SREM	8.2	**15.95**	**14.4**	**12.9**	-17.4	**20.4**	**20.4**	7.8	6.2	4.7	-25.6	28.6	28.6	**-10.0**	**50.0**	**-45.0**	**90.0**

NODE	LABEL	UFP	CASE A1 Min	CASE A2 Min	CASE A3 Min	CASE C Min	CASE B1 Max	CASE B2 Max	CASE A1 Tmin - UFP	CASE A2 Tmin - UFP	CASE A3 Tmin - UFP	CASE C Tmin - UFP	CASE B1 Tmax +UFP	CASE B2 Tmax +UFP	TEMPERATURE LIMIT MIN OPER.	MAX OPER.	MIN N.OPER.	MAX N.OPER
3970	AAD_HOUSING	8.8	40.28	38.7	38.3	30.7	48.8	48.8	31.5	29.9	29.5	21.9	57.6	57.6	**-70.0**	**70.0**	**-80.0**	**80.0**
8508	1FCV BODY	7.9	11.08	11.0	11.0	11.0	12.6	12.6	3.2	11.0 h	11.0 h	11.0 h	20.5	20.5	**10.0**	**65.0**	**10.0**	**75.0**
8608	1FCV BODY	7.8	11	11.0	11.0	11.0	14.0	14.0	11.0 h	11.0 h	11.0 h	11.0 h	14.0 h	21.8 h	**10.0**	**65.0**	**10.0**	**75.0**
8708	1FCV BODY	8	13.41	11.8	11.8	11.0	19.3	19.3	5.4	3.8	3.8	11.0 h	27.3	27.3	**10.0**	**65.0**	**10.0**	**75.0**
8808	1FCV BODY	8	13.23	11.6	11.6	11.0	19.1	19.2	5.2	3.6	3.6	11.0 h	27.1	27.2	**10.0**	**65.0**	**10.0**	**75.0**
1133	FCV BODY MAIN	7.8	31.88	30.7	29.8	27.2	33.9	33.9	24.1	22.9	22.0	19.4	41.7	41.7	**10.0**	**65.0**	**10.0**	**75.0**
1134	FCV BODY RED.	7.9	31.07	29.9	29.0	22.1	34.0	34.0	23.2	22.0	21.1	14.2	41.9	41.9	**10.0**	**65.0**	**10.0**	**75.0**
1233	FCV BODY MAIN	7.6	29.23	27.5	27.8	29.1	34.9	34.6	21.6	19.9	20.2	21.5	42.5	42.2	**10.0**	**65.0**	**10.0**	**75.0**
1234	FCV BODY RED.	7.7	28.88	27.2	27.5	23.2	35.2	34.9	21.2	19.5	19.8	15.5	42.9	42.6	**10.0**	**65.0**	**10.0**	**75.0**
1333	FCV BODY MAIN	7.9	28.64	27.4	27.4	33.3	33.1	33.2	20.7	19.5	19.5	25.4	41.0	41.1	**10.0**	**65.0**	**10.0**	**75.0**
1334	FCV BODY RED.	8	29.19	28.0	27.9	28.1	33.6	33.6	21.2	20.0	19.9	20.1	41.6	41.6	**10.0**	**65.0**	**10.0**	**75.0**
1433	FCV BODY MAIN	8.1	28.41	27.3	23.5	17.2	32.2	32.2	20.3	19.2	15.4	9.1	40.3	40.3	**10.0**	**65.0**	**10.0**	**75.0**
1434	FCV BODY RED.	7.9	28.15	27.0	23.3	11.0	31.9	31.9	20.3	19.1	15.4	11.0 h	39.8	39.8	**10.0**	**65.0**	**10.0**	**75.0**
1533	FCV BODY MAIN	9.2	20.5	19.5	19.6	22.0	23.7	23.6	11.3	10.3	10.4	12.8	32.9	32.8	**10.0**	**65.0**	**10.0**	**75.0**
1534	FCV BODY RED.	9.3	20.26	19.3	19.3	11.0	23.5	23.4	11.0	10.0	10.0	11.0 h	32.8	32.7	**10.0**	**65.0**	**10.0**	**75.0**
1733	FCV BODY MAIN	8.8	16.9	15.6	15.5	33.5	22.3	22.4	8.1	6.8	6.7	24.7	31.1	31.2	**10.0**	**65.0**	**10.0**	**75.0**
1734	FCV BODY RED.	8.8	17.07	15.8	15.7	20.9	22.5	22.6	8.3	7.0	6.9	12.1	31.3	31.4	**10.0**	**65.0**	**10.0**	**75.0**
8001	Solar Array vs. space -X	8	108.62	108.6	108.6	108.8	118.2	118.2	100.6	100.6	100.6	100.8	126.2	126.2				
8002	Solar Array vs. space-X	7.5	106.96	107.0	107.0	108.7	117.9	117.9	99.5	99.5	99.5	101.2	125.4	125.4				
8003	Solar Array vs. space -X	8.4	107.09	107.1	107.1	108.3	117.8	117.8	98.7	98.7	98.7	99.9	126.2	126.2				
8004	Solar Array vs. space -X	8.1	107.48	107.5	107.5	108.5	117.7	117.7	99.4	99.4	99.4	100.4	125.8	125.8				
8051	Solar Array vs. space +X	8	108.39	108.4	108.4	108.5	117.9	117.9	100.4	100.4	100.4	100.5	125.9	125.9				
8052	Solar Array vs. space +X	7.6	106.72	106.7	106.7	108.5	117.6	117.6	99.1	99.1	99.1	100.9	125.2	125.2				
8053	Solar Array vs. space +X	8.4	106.85	106.8	106.8	108.0	117.5	117.5	98.5	98.4	98.4	99.6	125.9	125.9				

NODE	LABEL	UFP	CASE A1 Min	CASE A2 Min	CASE A3 Min	CASE C Min	CASE B1 Max	CASE B2 Max	CASE A1 Tmin - UFP	CASE A2 Tmin - UFP	CASE A3 Tmin - UFP	CASE C Tmin - UFP	CASE B1 Tmax +UFP	CASE B2 Tmax +UFP	TEMPERATURE LIMIT MIN OPER.	TEMPERATURE LIMIT MAX OPER.	TEMPERATURE LIMIT MIN N.OPER.	TEMPERATURE LIMIT MAX N.OPER
8054	Solar Array vs. space +X	8.1	107.25	107.2	107.2	108.3	117.4	117.5	99.2	99.1	99.1	100.2	125.5	125.6				
8301	Central Solar Array -X	7.9	114.81	114.8	114.8	116.0	121.9	121.9	106.9	106.9	106.9	108.1	129.8	129.8				
8302	Central Solar Array -X	8	114.52	114.5	114.5	115.6	121.4	121.4	106.5	106.5	106.5	107.6	129.4	129.4				
8303	Central Solar Array -X	8.1	113.82	113.8	113.8	115.1	121.0	121.0	105.7	105.7	105.7	107.0	129.1	129.1				
8304	Central Solar Array -X	7.9	114.91	114.9	114.9	115.8	121.8	121.8	107.0	107.0	107.0	107.9	129.7	129.7				
8351	Central Solar Array +X	7.9	114.6	114.6	114.6	115.8	121.6	121.6	106.7	106.7	106.7	107.9	129.5	129.5				
8352	Central Solar Array +X	8	114.31	114.3	114.3	115.3	121.1	121.1	106.3	106.3	106.3	107.3	129.1	129.1				
8353	Central Solar Array +X	8.1	113.62	113.6	113.6	114.9	120.8	120.8	105.5	105.5	105.5	106.8	128.9	128.9				
8354	Central Solar Array +X	7.9	114.7	114.7	114.7	115.6	121.6	121.6	106.8	106.8	106.8	107.7	129.5	129.5				
8101	MLI Solar Array vs. sate	27.7	8.17	8.0	7.9	4.7	11.2	11.2	-19.5	-19.7	-19.8	-23.0	38.9	38.9				
8102	MLI Solar Array vs. sate	26.9	6.27	6.1	6.1	5.8	13.0	12.9	-20.6	-20.8	-20.8	-21.1	39.9	39.8				
8103	MLI Solar Array vs. sate	27.2	5.31	5.1	5.1	5.5	12.1	12.2	-21.9	-22.1	-22.1	-21.8	39.3	39.4				
8104	MLI Solar Array vs. sate	27.3	7.2	7.0	7.0	5.4	10.6	10.6	-20.1	-20.3	-20.3	-21.9	37.9	37.9				

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

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

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

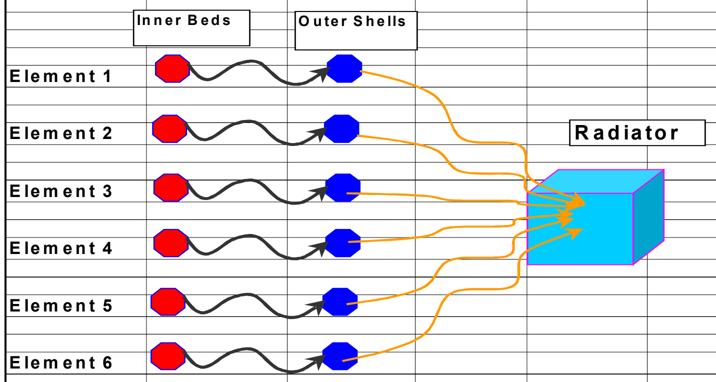
Parameter	Location	Units	Phase 1 Heatup 0-667 s	Phase 2 Desorb 667-1334 s	Phase 3 Cool 1334-2000 s	Phase 4 Absorb 2001-2667 s	Phase 5 Absorb 2668-3333 s	Phase 6 Absorb 3335-4000 s	← Phase ← Cycle Time
Therm. Mass	Inner Bed	MC_p (J/K)	800	3600	930	670	690	710	
	Outer Shell	MC_p (J/K)	720	720	720	720	720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

** see attached table

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

Changed thermal capacitance from last model to get better heat balance

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



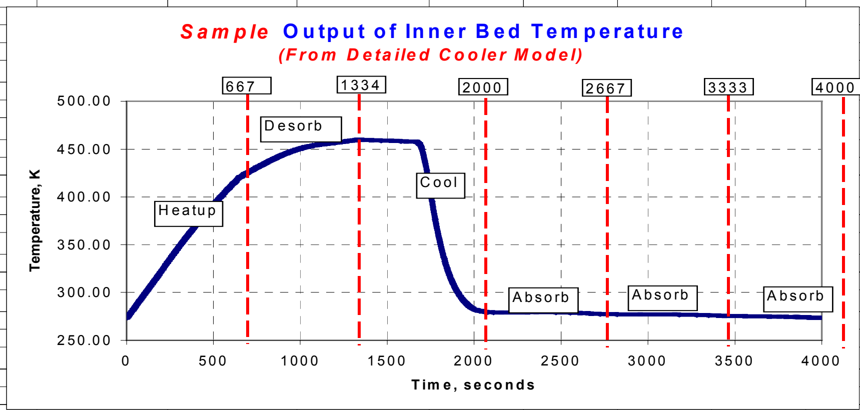


Figure 7.4.4.3-12 Highly Simplified EOL Thermal Model of 20 K Sorption Cooler Compressor Assembly

Highly Simplified BOL Thermal Model of 20 K Sorption Cooler Compressor Assembly										
(To be used by Alcatel to simulate compressor interface with radiator)										
(Pradeep Bhandari, Mauro Prina, 11-15-2001)			(Phone: 818-354-7597)		Modified Model					
			Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6		
Parameter	**Location**	**Units**	**Heatup**	**Desorb**	**Cool**	**Absorb**	**Absorb**	**Absorb**	←	**Phase**
			0-667 s	**667-1334 s**	**1334-2000 s**	**2001-2667 s**	**2668-3333 s**	**3335-4000 s**	←	**Cycle Time**
Therm. Mass	**Inner Bed**	MC_p (J/K)	800	3600	900	670	690	710		
	Outer Shell	MC_p (J/K)	720	720	720	720	720	720		
Conductance	*(Inner Bed to Outer Shell)*	W/K	0.02	0.03	***	6.53	6.53	6.53		
Heat Input	**Inner Bed**	W	201	150	0	36	36	36		
	Outer shell	W	0	0	7	7	7	7		
** see attached table										
(Gas-Gap Conductance Worksheet)						BOL Model				
Notes:										
1) The above values are for beginning of life (excluding margin)										
2) The total cycle time is 667*6 = 4000 seconds.										
3) There are 6 identical beds which are of phase, by one phase width of 667 sec., with respect to each other.										

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

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

Table 7.4.4.3-10 Gas gap Conductance

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

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

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

The spin of the satellite around its X-axis (1.7 round per minute) has a negligible effect on the amount of solar fluxes on the sun-exposed surfaces, so it is not considered in the current analysis.

The analysed cases are the following:

Cold Transient (Case P):
- Starting from S/S BOL case with Sun on –X and SAA= 0°. Solar constant=1285 W/m^2
- Ending to S/S BOL case with Sun on –X and SAA=+10°. Solar constant=1285 W/m^2
- Duration of change of attitude: 1200s
- Rotation rate: 0.5°/min
- Overall duration of transient case: 172800s (48 hours)

Hot Transient (Case Q):
- Starting from S/S EOL case with Sun on –X and SAA=0°. Solar constant=1405 W/m^2
- Ending to S/S EOL case with Sun on –X and SAA= +10°. Solar constant=1285 W/m^2
- Duration of change of attitude: 1200s
- Rotation rate: 0.5°/min
- Overall duration of transient case: 172800s (48 hours)

Transient analysis cases were run to assess the thermal behaviour of the SVM when subjected to attitude change (sun from 0 deg to +10 deg on –X side and vice-versa). Main purpose was to verify the capability of the design to meet the stability requirements. In table 7.4.4.3-11 the min and max temperature during the transient case, for the main units, are shown. The complete data with plots are reported in [RD-95] and [RD-93].

Table 7.4.4.3-11 PLANCK – Transient cases: Min and Max temperatures (without uncertainty)

NODE	LABEL	UFP	CASE P	CASE Q1	CASE Q2
			Tmin -UFP	Tmax +UFP	Tmax +UFP
5427	STR_MY -X FOOT	9.2	7.2	29.0	29.0
5428	STR_MY +Y FOOT	9.2	7.2	29.0	29.0
5429	STR_MY +X FOOT	9.2	7.0	28.8	28.8
5430	STR_MY -Y FOOT	9.2	7.1	28.9	28.9
5527	STR_PY -X FOOT	7.3	-22.4	-4.2	-4.2
5528	STR_PY +Y FOOT	7.3	-22.5	-4.2	-4.2
5529	STR_PY +X FOOT	7.3	-22.5	-4.3	-4.3
5530	STR_PY -Y FOOT	7.2	-22.4	-4.3	-4.4
13	DPU1	8.1	-1.2	18.7	18.7
14	DPU2	7.6	-12.7	6.7	6.7
101	DCCU	8	4.9	25.3	25.2
102	REBA1	8.5	15.6	35.8	35.8
103	REBA2	7.8	-12.6	6.8	6.8
104	FOG (GEU)	8.3	18.4	38.8	38.8
105	FOG (ICU)	8	2.5	22.7	22.7
202	4K CAU	8.1	-11.6	8.0	7.9
203	4K CRU EX 4K PRE-REG	8.7	19.7	40.7	40.7
204	CEU	9.3	18.2	39.6	39.6
205	REU	9.2	13.3	34.7	34.6
211	4K CCU Compress.1	11	37.7	62.4	62.3
212	4K CCU Compress.2	10.5	32.6	56.3	56.2
219	4K CCU I/F Bracket -X	9.1	0.6	21.6	21.5
220	4K CCU I/F Bracket +X	8.6	-5.2	14.6	14.5
221	4K CCU I/F Strap -Z	9.9	19.2	41.6	41.6
222	4K CCU I/F Strap +Z	9.8	17.4	39.6	39.6
401	SCE1	9.3	-17.7	2.7	-5.1
402	SCE2	9.3	-22.7	-2.3	-0.3
519	BEU	9.2	-2.0	30.5	30.5
520	BEU	9.3	-3.4	25.9	25.9
521	BEU	9.2	-0.3	32.2	32.1
522	PAU	8.6	3.6	28.3	28.4
525	DAE POWER BOX	8.1	15.2	37.0	37.0
551	CRS3	8.5	13.0	38.1	38.3
601	XPND_1	8.3	6.4	29.6	29.7
602	XPND_2	7.9	-2.7	19.3	19.4
603	TWTA_1	8.8	-15.6	36.3	36.4
604	TWTA_2	7.7	-15.9	11.3	11.4
605	RFDN	7.9	-3.4	23.6	23.8
606	EPC1	8.3	6.6	30.7	30.8
607	EPC2	7.7	-6.6	16.3	16.3
701	CDMU	8.1	7.1	27.3	27.3

NODE	LABEL	UFP	CASE P	CASE Q1	CASE Q2
			Tmin -UFP	Tmax +UFP	Tmax +UFP
702	ACC	8	0.9	20.7	20.7
703	BATT	8	3.8	24.6	24.6
704	PCDU	8.7	18.8	41.1	41.1
705	CRS1	8.6	20.7	43.0	43.1
706	CRS2	8.7	24.0	46.3	46.3
900	Helium Tank +Z	7.8	-0.3	19.8	19.8
905	Helium Tank +Y	8.3	3.4	24.3	24.2
910	Helium Tank -Z	7.9	0.6	23.2	23.2
915	Helium Tank -Y	8	2.4	25.6	25.7
920	Prop. Tank +Y+Z Lower	8	7.2	29.2	29.2
925	Prop. Tank -Z Lower	8.1	4.7	28.4	28.4
930	Prop. Tank -Y+Z Lower	8	6.7	29.1	29.1
311	SCC1 - Outer shell1	9.9	-20.2	27.8	-3.9
312	SCC1 - Outer shell2	9.9	-20.2	28.0	-3.9
313	SCC1 - Outer shell3	9.9	-20.2	27.7	-3.9
314	SCC1 - Outer shell4	9.9	-20.2	27.8	-3.9
315	SCC1 - Outer shell5	9.9	-20.2	28.0	-3.9
316	SCC1 - Outer shell6	9.9	-20.2	27.8	-3.9
811	HP11 Ver. SCC1	9.7	-20.7	5.0	-4.1
812	HP12 Ver. SCC1	9.7	-20.1	6.7	-4.1
813	HP13 Ver. SCC1	9.7	-20.1	6.7	-4.1
814	HP14 Ver. SCC1	9.7	-20.1	6.7	-4.1
815	HP15 Ver. SCC1	9.7	-20.1	6.7	-4.1
816	HP16 Ver. SCC1	9.7	-20.1	6.7	-4.1
817	HP17 Ver. SCC1	9.7	-20.1	6.7	-4.1
818	HP18 Ver. SCC1	9.7	-20.1	6.7	-4.1
819	HP19 Ver. SCC1	9.7	-20.1	6.7	-4.1
820	HP20 Ver. SCC1	9.7	-20.1	6.7	-4.1
821	HP21 Ver. SCC1	9.7	-20.1	6.7	-4.1
822	HP22 Ver. SCC1	9.7	-20.1	6.7	-4.1
823	HP23 Ver. SCC1	9.7	-20.1	6.7	-4.1
824	HP24 Ver. SCC1	9.7	-20.1	6.7	-4.1
825	HP25 Ver. SCC1	9.7	-20.7	5.0	-4.1
801	HP1 Hor. SCC1	9.3	-23.0	-1.0	-4.4
802	HP2 Hor. SCC1	9.3	-20.8	0.0	-4.8
803	HP3 Hor. SCC1	9.3	-21.7	-0.2	-5.1
804	HP4 Hor. SCC1	9.3	-21.8	-0.4	-5.1
805	HP5 Hor. SCC1	9.3	-22.7	-1.8	-5.1
806	HP6 Hor. SCC1	9.3	-23.5	-2.0	-3.6
807	HP7 Hor. SCC1	9.3	-23.5	-2.0	-3.5
808	HP7 Hor. SCC1	9.3	-22.7	-2.0	-3.4
511	SCC2 - Outer shell1	9.1	-24.1	-4.3	27.3

NODE	LABEL	UFP	CASE P	CASE Q1	CASE Q2
			Tmin -UFP	Tmax +UFP	Tmax +UFP
512	SCC2 - Outer shell2	9.1	-24.1	-4.4	27.3
513	SCC2 - Outer shell3	9.1	-24.1	-4.4	27.3
514	SCC2 - Outer shell4	9.1	-24.1	-4.4	27.3
515	SCC2 - Outer shell5	9.1	-24.1	-4.3	27.3
516	SCC2 - Outer shell6	9.1	-24.1	-4.3	27.3
861	HP61 Ver. SCC2	*9.7*	-24.7	-3.8	5.4
862	HP62 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
863	HP63 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
864	HP64 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
865	HP65 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
866	HP66 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
867	HP67 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
868	HP68 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
869	HP69 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
870	HP70 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
871	HP71 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
872	HP72 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
873	HP73 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
874	HP74 Ver. SCC2	*9.7*	-24.7	-3.8	7.0
875	HP75 Ver. SCC2	*9.7*	-24.7	-3.8	5.4
851	HP51 Hor. SCC2	9.1	-24.2	-3.9	-0.4
852	HP52 Hor. SCC2	9.1	-23.6	-3.8	-0.8
853	HP53 Hor. SCC2	9.1	-24.0	-4.0	-1.0
854	HP54 Hor. SCC2	9.1	-24.1	-4.1	-1.1
855	HP55 Hor. SCC2	9.1	-24.5	-4.7	-1.1
856	HP56 Hor. SCC2	9.1	-24.8	-4.8	-0.5
857	HP57 Hor. SCC2	9.1	-24.8	-4.8	-0.5
858	HP57 Hor. SCC2	9.1	-24.5	-4.7	-0.4
3931	SAS1 HOUSING	9.2	-1.3	19.5	19.5
3951	SAS2 HOUSING	7.5	43.3	67.3	67.3
3921	LGA+Y HORN	8.3	-54.8	-36.4	-36.5
3961	LGA-Y HORN	8.2	-68.0	-47.2	-47.2
3991	LGA-X HORN	7.2	52.9	75.1	75.1
3986	MGA-X SEPTUM	8.5	19.2	56.2	56.2
3966	SREM	8.2	7.9	28.5	28.4
3970	AAD_HOUSING	8.8	31.5	57.4	57.4
8508	1FCV BODY	7.9	3.2	20.5	20.5
8608	1FCV BODY	7.8	3.2	21.8	21.8
8708	1FCV BODY	8	5.4	27.2	27.2
8808	1FCV BODY	8	5.3	27.0	27.0
1133	FCV BODY MAIN	7.8	20.4	45.7	45.7
1134	FCV BODY REDUNDANT	7.9	20.4	44.9	44.9

NODE	LABEL	UFP	CASE P	CASE Q1	CASE Q2
			Tmin -UFP	Tmax +UFP	Tmax +UFP
1233	FCV BODY MAIN	7.6	20.1	44.0	43.7
1234	FCV BODY REDUNDANT	7.7	20.4	44.0	43.7
1333	FCV BODY MAIN	7.9	19.0	42.7	42.8
1334	FCV BODY REDUNDANT	8	19.5	43.6	43.7
1433	FCV BODY MAIN	8.1	18.7	42.0	42.0
1434	FCV BODY REDUNDANT	7.9	18.6	41.4	41.4
1533	FCV BODY MAIN	9.2	11.4	32.8	32.7
1534	FCV BODY REDUNDANT	9.3	11.1	32.6	32.5
1733	FCV BODY MAIN	8.8	8.1	30.9	31.1
1734	FCV BODY REDUNDANT	8.8	8.3	31.1	31.2
8001	Solar Array vs. space -X	8	100.6	126.2	126.2
8002	Solar Array vs. space-X	7.5	99.5	125.5	125.4
8003	Solar Array vs. space -X	8.4	98.7	126.3	126.3
8004	Solar Array vs. space -X	8.1	99.4	125.8	125.8
8051	Solar Array vs. space +X	8	100.4	125.9	125.9
8052	Solar Array vs. space +X	7.6	99.1	125.3	125.3
8053	Solar Array vs. space +X	8.4	98.5	126.0	126.0
8054	Solar Array vs. space +X	8.1	99.1	125.5	125.5
8301	Central Solar Array -X	7.9	106.9	129.7	129.7
8302	Central Solar Array -X	8	106.5	129.4	129.4
8303	Central Solar Array -X	8.1	105.7	129.1	129.1
8304	Central Solar Array -X	7.9	107.0	129.7	129.7
8351	Central Solar Array +X	7.9	106.7	129.5	129.5
8352	Central Solar Array +X	8	106.3	129.1	129.1
8353	Central Solar Array +X	8.1	105.5	128.9	128.9
8354	Central Solar Array +X	7.9	106.8	129.5	129.5
8101	MLI Solar Array vs. sate	27.7	-22.3	41.7	41.7
8102	MLI Solar Array vs. sate	26.9	-20.6	39.9	39.7
8103	MLI Solar Array vs. sate	27.2	-21.9	39.3	39.4
8104	MLI Solar Array vs. sate	27.3	-22.4	40.4	40.4

7.4.3.4 Analysis Results Discussion

The results provided in this documents are not complete and the final ones because at TCS subsystem level the completion of the design is still ongoing.
The final and complete results will be provided in the new issue of the "TCS analysis report" H-P-RP-AI-0040 issue 03.

HERSCHEL

The following interface requirements are not compliance (NC) or partially compliance (PC):
ITP-100-H : NC
RFD has been issued

ITP-120-H : PC and ITP-130-H : PC
After the TMM updating, the radiative area have been optimised in order to save heater power. Consequently we have had an increase of the satellite average temperature. In this condition the requirement on the truss and shield attachment points are not completely met. This requirement could be satisfied decreasing again the average temperature of satellite, but with an important impact on power budget
Due to the limited average out of specification (25.6 °C vs 20°C and 22.6 °C vs 20°C) it is suggested to maintain the current design to avoid impact on the power budget. A RFD will be issued.

ACP-060-H about variation around set-point of STR : PC
Concerning the requirements relevant to the HERSCHEL STR, only the variation around set-point of the STR feet during the HOT CASE (EOL) is not met (0.54 vs 0.5 of requirements).
This out of requirement takes a time of about 4 hours after a S/C change of attitude.
A recovery action is to improve the proportional gain of the regulator to add "reactivity" to the control in order to keep under control the deviation from the set-point.
But this action leads to reduce the dumping effect at the high frequency (telemetry and actuator noises), affecting the temperature stability results.
Before to modify the current design of the control it is suggested to evaluate at system level the possible impacts on the STR performance with the current design.

All the units are maintained within their temperature limits with the exclusion of the following:

HOT CASES (Uncertainty included)

GYRO:	set point	63.0°C vs 55.0°C
CRS:	case B	51.0°C vs 50.0°C
XPND:	case B	48.2°C vs 45.0°C
TWT:	case B	61.1°C vs 60.0°C

RECOVERY ACTIONS:

VMC:
The thermal design has been developed considering this unit working only up to the end of transfer orbit. In this condition the unit works correctly within the requested limits.
Instead if the unit has to work also during the rest of the mission the hot case temperature varies from 51.6 (BOL) to 56.9 (EOL). If necessary the temperature can be reduced adding a lateral radiator (at present the VMC is completely covered by MLI).

GYRO:
RFD has been issued

CRS:

RFD has been issued

XPND:
RFD has been issued

TWT:
RFD has been issued

PLANCK

The following interface requirements are not compliance (NC) or partially compliance (PC):

ITP-150-P: NC
For this interface requirement the considerations reported for the ITP-100-H can be applied.
In this case the average temperature without uncertainty is –62.8 °C, with a margin with respect to requirement of 9.8 °C.

ITP-180-P and ITP-200-P: NC
Same consideration of ITP-100-H can be done for these interface requirements.
The not compliance is due at a high uncertainty value applied at the temperature cause a reduction of emissivity of 40 % for the uncertainty calculation.
For ITP-180-P the max temperature, without uncertainty, is –46.8 °C (req. < –38 °C) with a margin of 8.8 °C.
For ITP-200-P the max temperature, without uncertainty, is 13.3 °C (req. < 26.9 °C) with a margin of 13.6 °C.

ITP-230-P: PC
This out of requirement is relevant to the SCS panel only. This is due to the SCC working cycles and no recovery actions are envisaged. For this reason a Request for Deviation will be issued as anticipated during the Interface Specification revision activity.

SCC Stability (Absorbing beds stability): NC
For this out of requirement, already issued during the past progress meetings, no recovery actions are envisaged. For this reason a Request for Deviation will be issued as anticipated during the Interface Specification revision activity.

All the units are maintained within their temperature limits with the exclusion of the following:

HOT CASES (Uncertainty included)

CRU:	case B1&2	40.8°C vs 40.0°C
CCU I/F:	case B1&2	41.7°C vs 40.0°C

RECOVERY ACTIONS:

COLD CASES (Uncertainty included)

FOG:	case A3	-3.1°C vs 0.0°C

CRU:
RFD has been issued

CCU I/F:
RFD has been issued

FOG:
Possible recovery action is to switch On at 100% the CRU heater. In this case the FOG temperature reaches the 0.1 °C (uncertainty included).

7.5 Avionics Design and Performance

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

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

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

7.5.1 Avionics Requirements and Design Drivers

The requirements are derived from the SVM Requirement Specification [AD-43].

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

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

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

- technical compliance, including sufficient flexibility to accommodate upgrade of the main requirements;
- Herschel and Planck commonalties
- hardware impact: the selected design is such that the hardware is 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 TM/TC flow of Herschel and Planck is depicted in Figure 7.5-1 and Figure 7.5-2.
Detailed drawings showing different functions and their implementation down to equipment level are reported in H-P-DW-AI-0001, SVM Avionics Drawings.

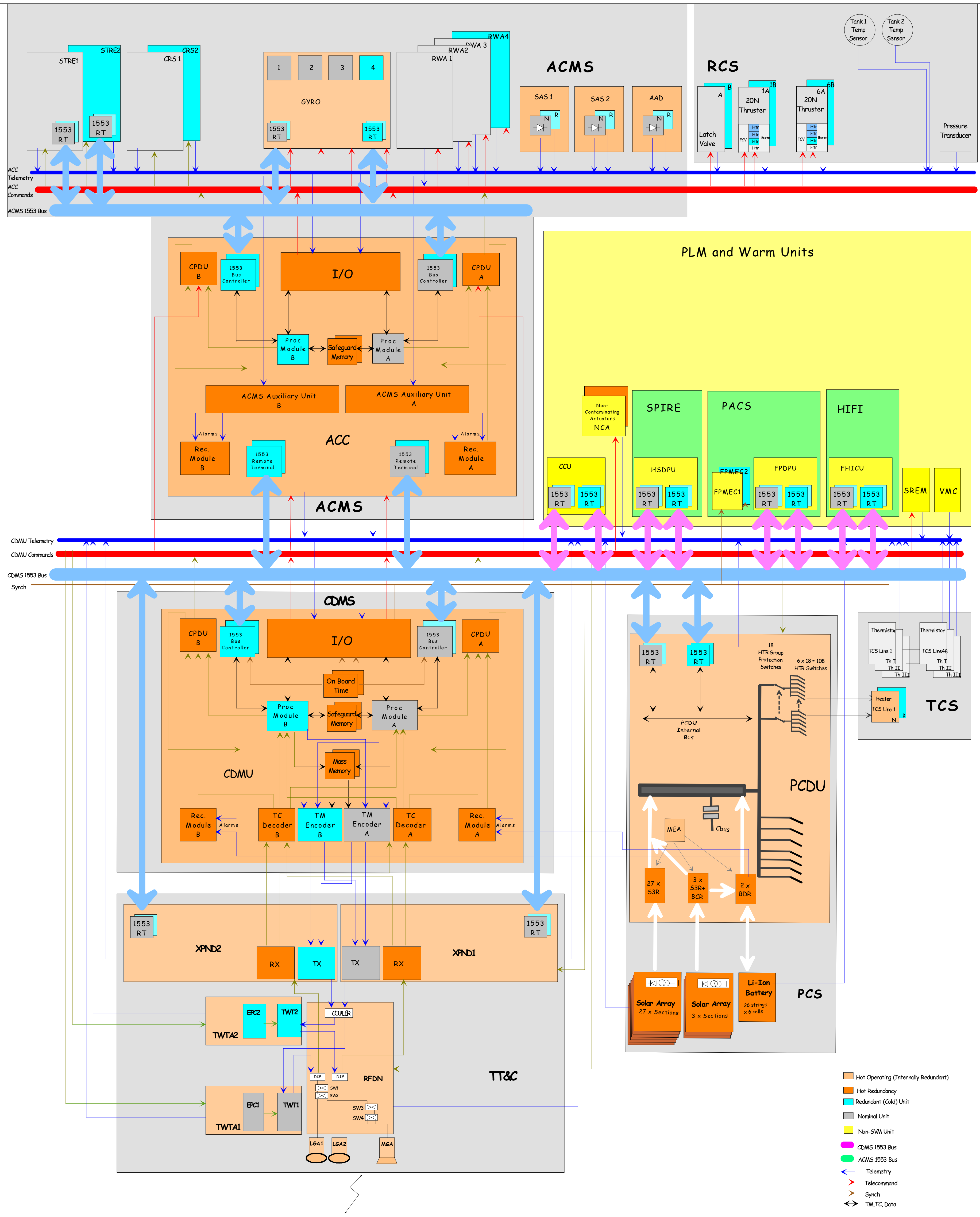


Figure 7.5-1 Herschel TM/TC Flow Block Diagram

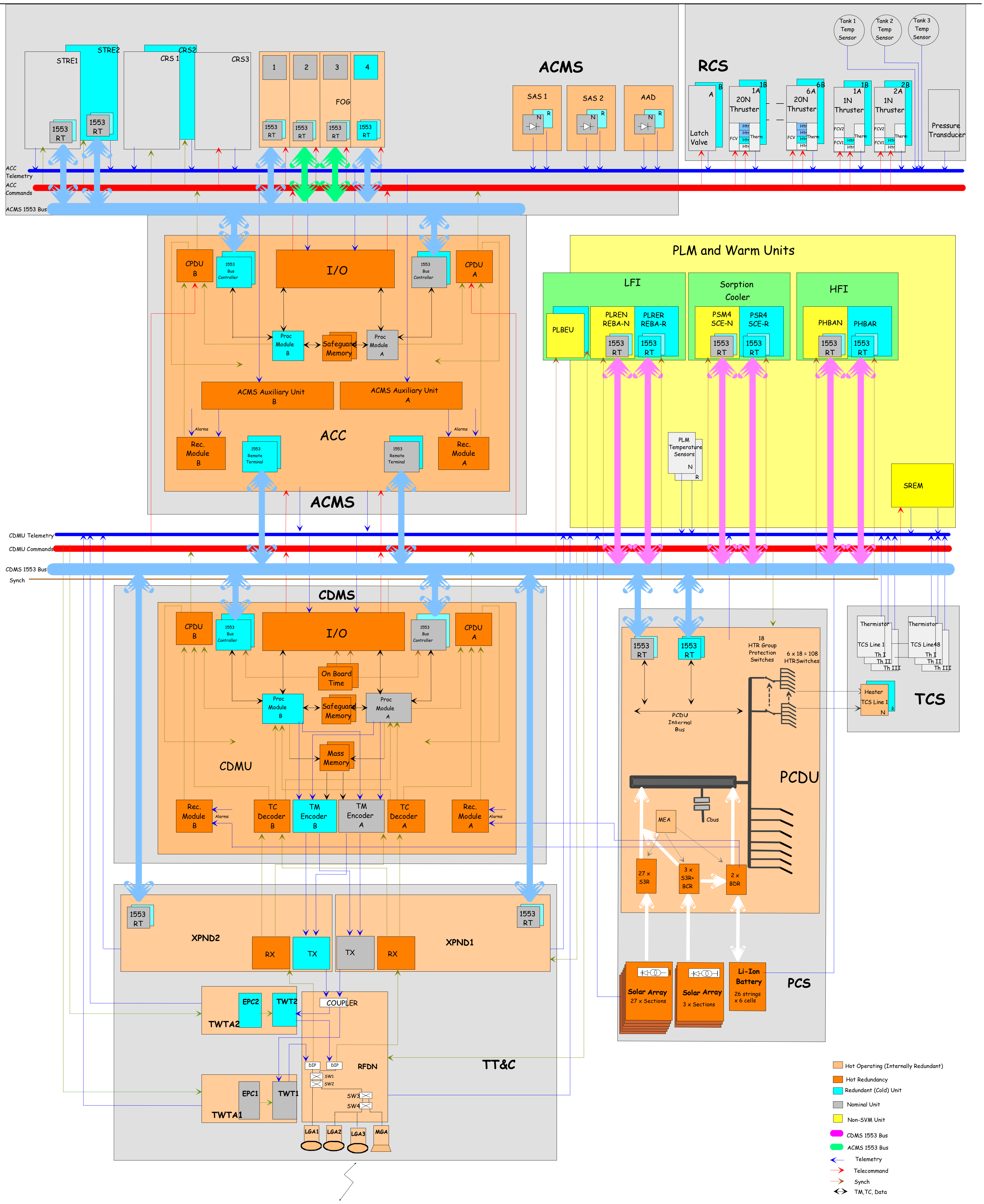


Figure 7.5-2 Planck TM/TC Flow Block Diagram

7.5.2.1 On Board Data Management

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

On Board Data Handling is managed by one CDMU, which is in charge to perform the following functions.
- telemetry acquisition and formatting
- telecommand acquisition, decoding validation and distribution
- data storage
- time distribution and time tagging
- autonomy supervision and management.

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

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

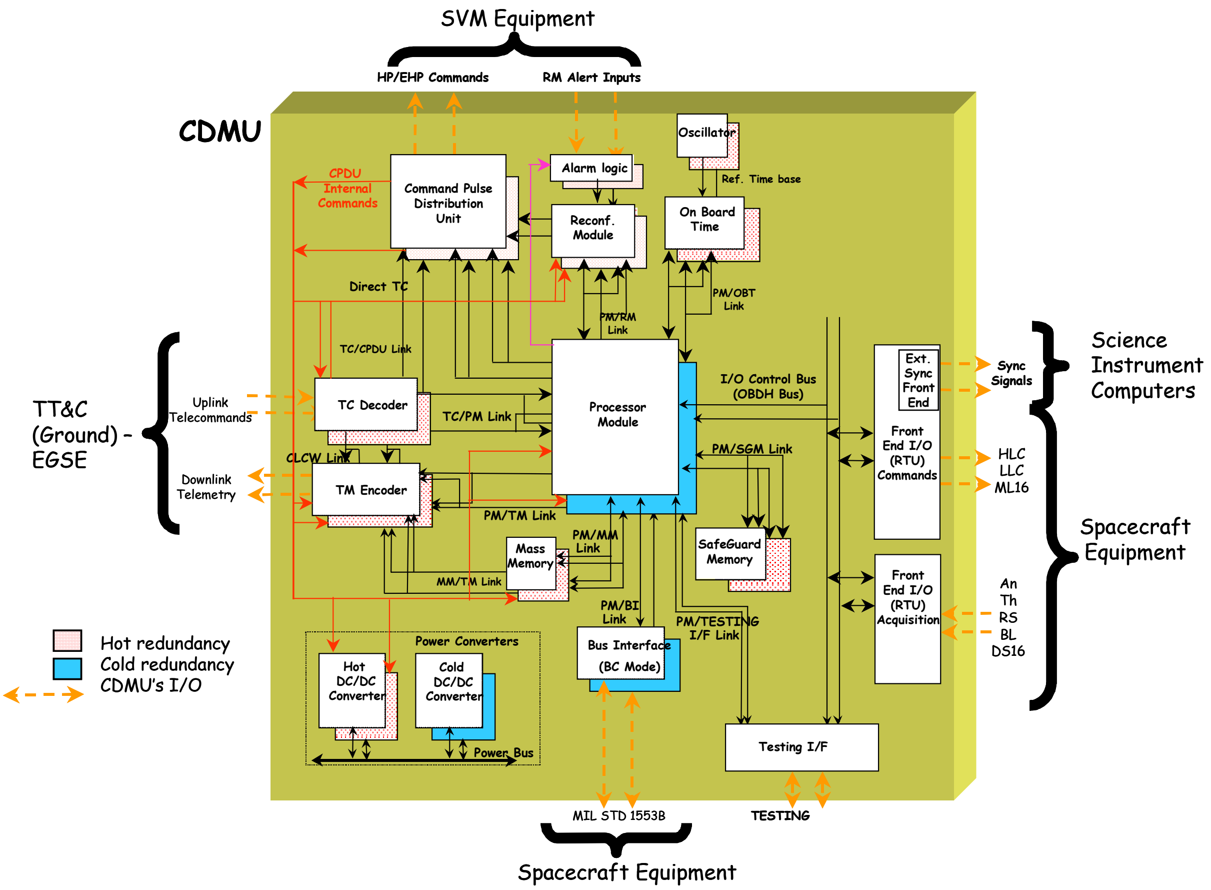


Figure 7.5-3 CDMU Block Diagram

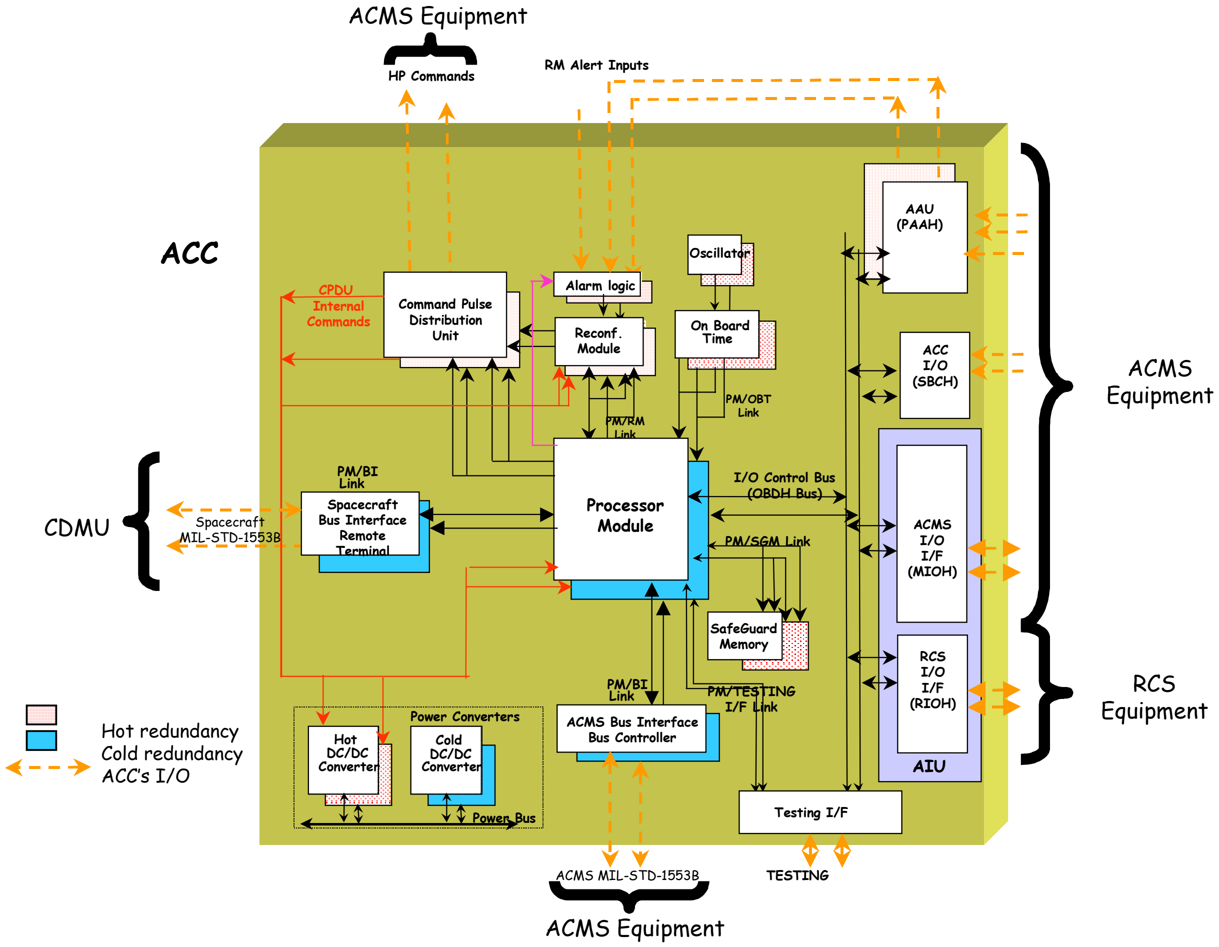


Figure 7.5-4 ACC Block Diagram

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

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

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

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

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

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

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

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

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

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

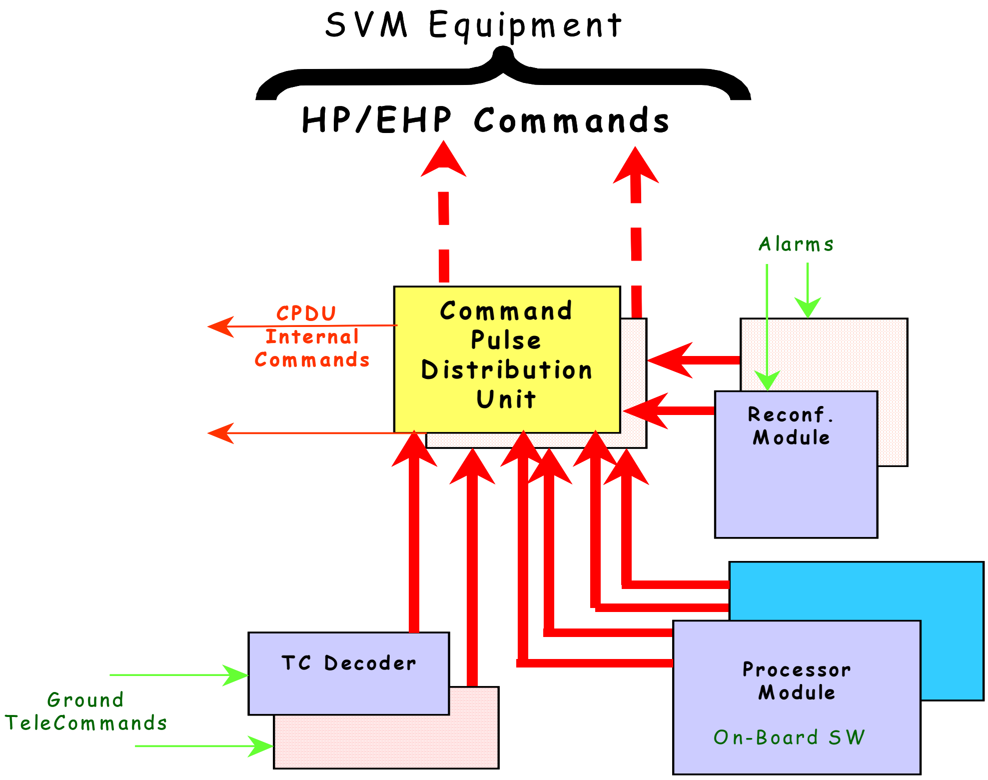


Figure 7.5-5 High Priority Command Generation and distribution

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

CDMU High Priority Commands (external CPDU commands) are sent to:
- TT&C, for RF commanding: TX (Transmitter), TWTA (Traveller Tube Amplifier) and EPC (Electric Power Conditioner) On/Off, RFDN (Radio Frequency Distribution Unit) switches Set.
- ACC, for Reconfiguration Module Enable/Disable
- PCDU, for NCA Arm and Fire and for On/Off of LCL (Latching Current Limiter) Output connected to CDMU and ACC Cold Converters.

It must be taken into account that all the commands for LCL actuation are nominally sent to PCDU through 1553 bus commands. The above-mentioned HP commands have been added in order to give direct access from RM (and from Ground) to critical functions.

CDMU can also send High level Commands and Memory Load Commands generated by On-Board Software through the Front End I/O. These commands are sent to:
- ACC, for Latch Valves Arm/Inhibit and Processor Modules On/Off
- PCDU, for BCR/BDR On/Off, for reconfiguration of 1553 I/F and for direct commands of ACC LCLs.
- SREM

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

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

With the present baseline, Remote Terminals are allocated to:
- Star Trackers
- Gyroscopes (Herschel only)
- Fiber-Optic Gyro (Planck only)

The ACC provides conditioning for analog interfaces for users which cannot interface with 1553 bus:
- Reaction Wheels (Herschel only)
- Sun Acquisition Sensors
- Coarse Rate Sensors
- Attitude Anomaly Detector

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

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

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

Details on CDMU and ACC Command and Telemetry allocation can be found in SVM EICD (H-P-IC-AI-0003) and in SVM TM/TC Budget (H-P-TN-AI-0018). The summary is reported in the following Tables.
In the Tables the following nomenclature is applied:

- TOTAL is the present design need;
- AVAILABILITY is as per relevant CDMU requirements ;
- SPARE is the number of channels still available (Available - Total);

In some case the spare availabilty is zero (0) but it is not considered critical at this stage of the project. The CDMU and the ACC board have been optimised with the objective to save mass and to reduce the overall envelope (criticality on the accomodation on the SVM Power panel. It is not expected the necessity to increment any of the monitoring and/or command Interfaces for the Flight final design.

S/S	Unit	CPDU Int	HP/HL	HP (no SW)	EHP	HL	LLC	ML16	Sync	AN	TH	CR	DR	DB	Status	DS16	Alarm	TC	RFLock	TM	1553
CDMS	CDMU	58	4			4															BC
Power	PCDU		8	16		32				2	1		4				2				2
	BAT										4										
TT&C	XPND1		4			2				5	2		1	1				1	1	1	1
	XPND2		4			2				5	2		1	1				1	1	1	1
	RFDN				16						4		8								
	EPC1		8							2	1			3							
	EPC2		8							2	1			3							
TCS	Control										138										
	Monitoring										6										
ACMS	ACC		12			18				2	5		2	10							2
Solar Array	SA											6									
EGSE	UMB												2				6	2		2	
CFE	VMC															1					
	SREM							1								1					
	CCU																				2
HIFI	FHICU																				2
PACS	FPDPU																				2
	FPDECMEC								2												
SPIRE	HSDPU																				2
PPLM	NCA												2								
Total		58	44	16	16	54	0	1	2	18	164	6	20	18	0	2	8	4	2	4	14
Availability		64	48	16	16	80	8	7	8	48	192	64	80	40	8	7	16	4	2	4	
Spare		6	4	0	0	26	8	6	6	30	28	58	60	22	8	5	8	0	0	0	
Percentage Spare		9%	8%	0%	0%	33%	100%	86%	75%	63%	15%	91%	75%	55%	100%	71%	50%	0%	0%	0%	

Table 7.5-1 – Herschel CDMU I/O

Subsystem	Unit	CPDU Int	HP/HL	HP (no SW)	EHP	HL	LLC	ML16	Sync	AN	TH	CR	DR	DB	Status	DS16	Alarm	TC	RFLock	TM	1553
CDMS	CDMU	58	4			4															BC
Power	PCDU		8	12		40				2	1		4				2				2
	Battery										4										
TT&C	XPND1		4			2				5	2		1	1				1	1	1	1
	XPND2		4			2				5	2		1	1				1	1	1	1
	RFDN				16						4		8								
	EPC1		8							2	1			3							
	EPC2		8							2	1			3							
TCS	Control										114										
	Monitoring										30										
ACMS	ACC		12			18				2	5		2	10							2
Solar Array	SA											6									
EGSE	UMB												2				6	2		2	
CFE	VMC															1					
	SREM							1								1					
HFI	PHBAN								1												1
	PHBAR								1												1
LFI	PLREN								1												1
	PLRER								1												1
	PLBEU								2												
SCS	PSM4								1												1
	PSR4								1												1
PPLM	Cr Temp											56									
Total		58	44	12	16	62	0	1	8	18	164	62	18	18	0	2	8	4	2	4	12
Availability		64	48	16	16	80	8	7	8	48	192	64	80	40	8	7	16	4	2	4	
Spare		6	4	4	0	18	8	6	0	30	28	2	62	22	8	5	8	0	0	0	
Percentage Spare		9%	8%	25%	0%	23%	100%	86%	0%	63%	15%	3%	78%	55%	100%	71%	50%	0%	0%	0%	

Table 7.5-2 – Planck CDMU I/O

Subsystem	Unit	CPDUInt	HP/HL	HP (No SW)	LV Cmd	RWL-T	RWL Td	THR 1N FCV	THR 20N FCV	DR	AAD	CRS C	CRS P	CRS Th	PT Meas	RWL Th	RWL-M	RWL-Psts	RWL-S	RWL Sd	SAS Mnt	Tank Th	THR 1N TS	THR 20N TS	PT Pwr	THR 1N Htr	THR 20N Htr	Alarm	ACMS 1553 Bus
ACMS	ACC	54	12																									8	BC
	STR1		4							1																			1
	STR2		4							1																			1
	CRS1											1	2	1															
	CRS2											1	2	1															
	SAS1																				8								
	SAS2																				8								
	AAD										2																		
	RWL1		4			1	1									1	1	1	1	1									
	RWL2		4			1	1									1	1	1	1	1									
	RWL3		4			1	1									1	1	1	1	1									
	RWL4		4			1	1									1	1	1	1	1									
	GYRE		24																										2
EGSE	UMB									2																		4	
CDMS	CDMU									4																			
RCS	20N THRs								12															12			24		
	LV A				2					2																			
	LV B				2					2																			
	Tanks																					2							
	PT														1										1				
Total		54	60	0	4	4	4	0	12	12	2	2	4	2	1	4	4	4	4	4	16	2	0	12	1	0	24	12	4
Availability		64	64	16	4	4	4	8	12	40	2	3	6	3	1	4	4	4	4	4	16	3	4	12	1	4	24	16	
Spare		10	4	16	0	0	0	8	0	28	0	1	2	1	0	0	0	0	0	0	0	1	4	0	0	4	0	4	
Percentage Spare		16%	6%	100%	0%	0%	0%	100%	0%	70%	0%	33%	33%	33%	0%	0%	0%	0%	0%	0%	0%	33%	100%	0%	0%	100%	0%	25%	

Table 7.5-3 – Herschel ACC I/O

Subsystem	Unit	CPDUInt	HP/HL	HP (No SW)	LV Cmd	RWL-T	RWL Td	THR 1N FCV	THR 20N FCV	DR	AAD	CRS C	CRS P	CRS Th	PT Meas	RWL Th	RWL-M	RWL-Psts	RWL-S	RWL Sd	SAS Mnt	Tank Th	THR 1N TS	THR 20N TS	PT Pwr	THR 1N Htr	THR 20N Htr	Alarm	ACMS 1553 Bus
ACMS	ACC	54	12																									10	BC
	STR1		4							1																			1
	STR2		4							1																			1
	CRS1											1	2	1															
	CRS2											1	2	1															
	CRS3											1	2	1															
	SAS1																				8								
	SAS2																				8								
	AAD										2																		
CFE	FOG		16																										4
EGSE	UMB									2																		4	
CDMS	CDMU									4																			
RCS	20N THRs								12															12			24		
	1N THRs							8															4			4			
	LV A				2					2																			
	LV B				2					2																			
	Tanks																					3							
	PT														1										1				
Total		54	36	0	4	0	0	8	12	12	2	3	6	3	1	0	0	0	0	0	16	3	4	12	1	4	24	14	6
Availability		64	64	16	4	4	4	8	12	40	2	3	6	3	1	4	4	4	4	4	16	3	4	12	1	4	24	16	0
Spare		10	28	16	0	4	4	0	0	28	0	0	0	0	0	4	4	4	4	4	0	0	0	0	0	0	0	2	
Percentage Spare		16%	44%	100%	0%	100%	100%	0%	0%	70%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%	13%	

Table 7.5-4 – Planck ACC I/O

7.5.2.2 Radio Frequency Communications

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

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

The Radio Frequency communications essential functions are:

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

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

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

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

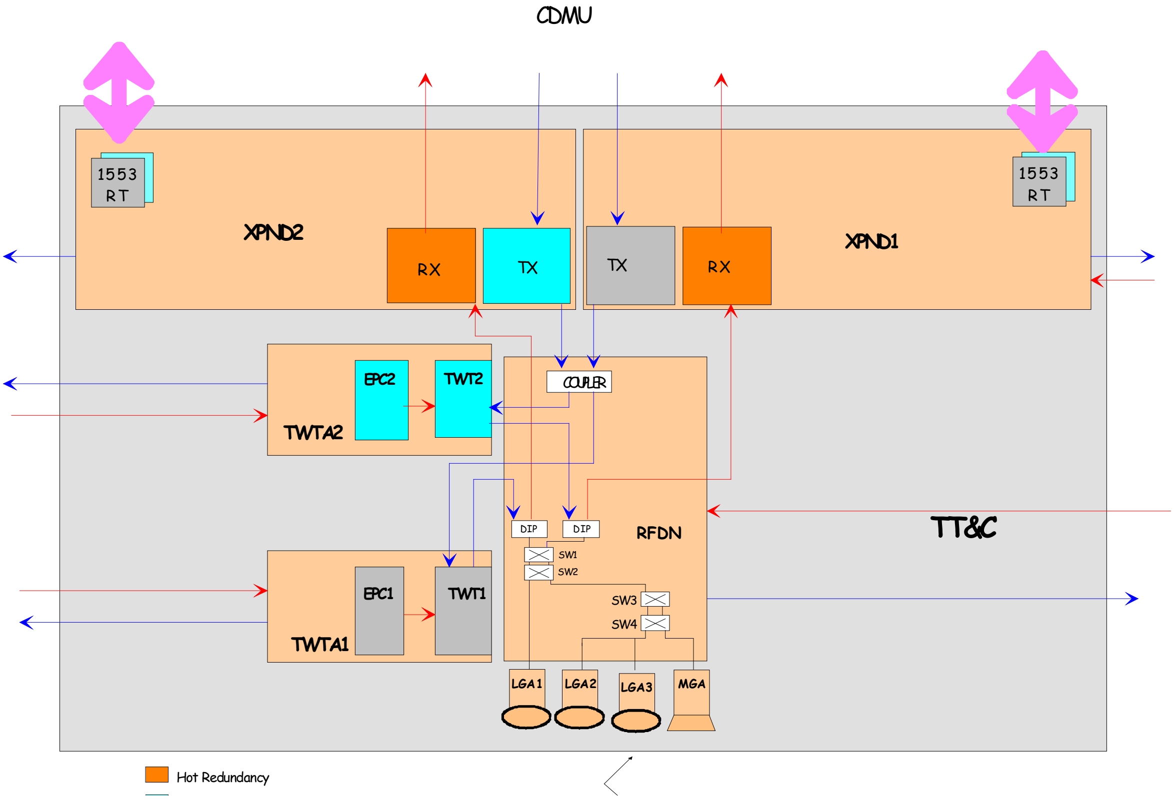


Figure 7.5-6 Telemetry, Tracking & Command system

7.5.2.3 Power Generation, Storage and Distribution

The Power System consists of the following units:

- **Power Control and Distribution Unit, PCDU**, which provides:
  - control of the electrical power generated by the solar array
  - conditions the energy stored in the battery when required
  - controls, monitors and maintains the health of the PCS
  - distributes power to the scientific instruments and spacecraft equipment
  - Protects the power bus from external faults and prevents failure propagation
  - heater switching control in response to 1553 commands
  - interfaces for AIV and Launch support EGSE.
- **Battery,** which provides:
  - a store for the excess solar array energy
  - a source of energy whenever there is insufficient power from the array (e.g. during launch, transient power demands and eclipse periods).
- **Solar Array**, which provides:
  - electrical power from the sun input
  - a thermal shield between the sun and the SVM/PLM.

An overview on the configuration of the power system is given in Figure 7.5.2-7.

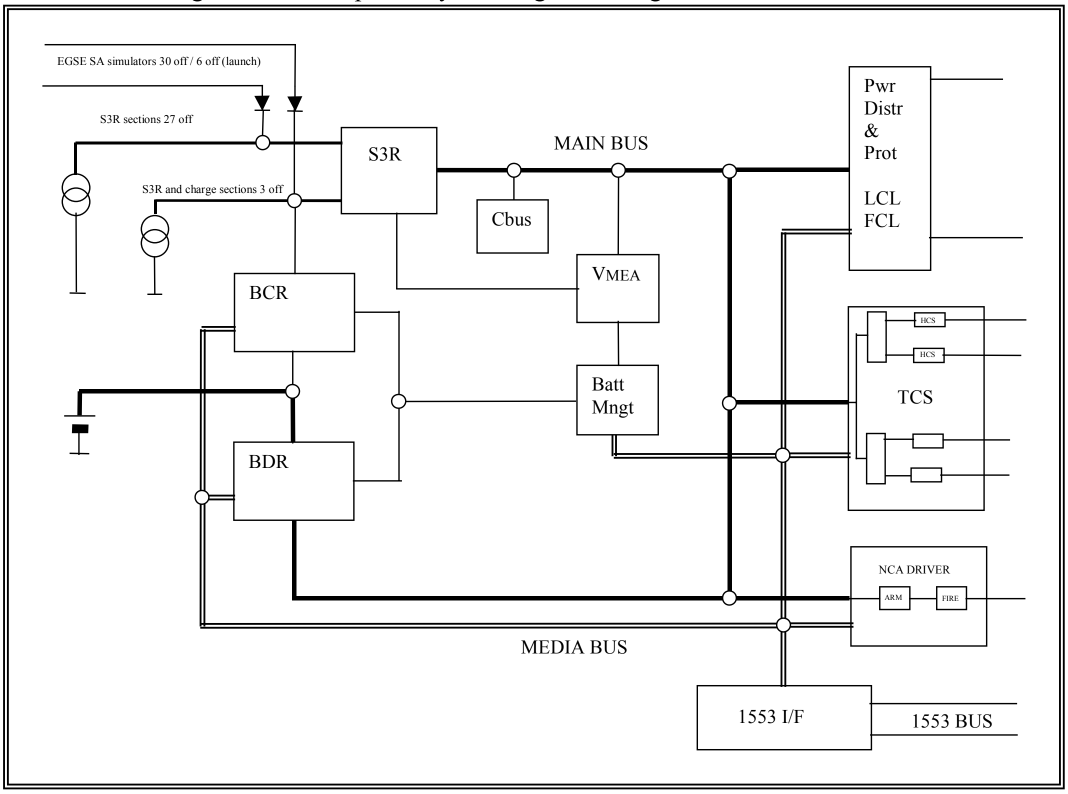


Figure 7.5.2-7 Power Control Subsystem

Details on Power system are given in section 9 of this report.

The Power Distribution and Switching diagrams are presented in Figure 7.5-8 and Figure 7.5-9.

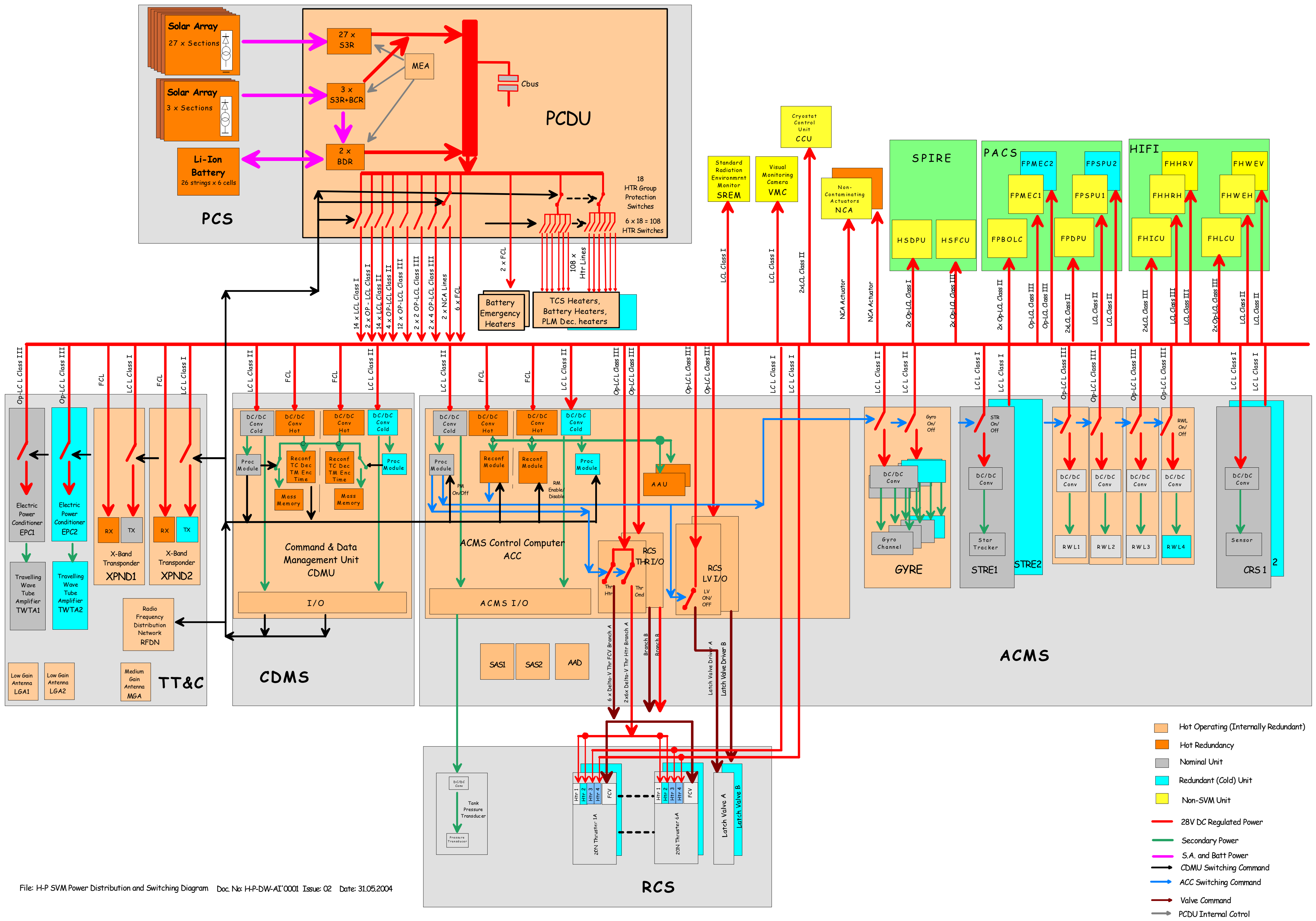


Figure 7.5-8 Herschel Power Distribution and Switching Diagram

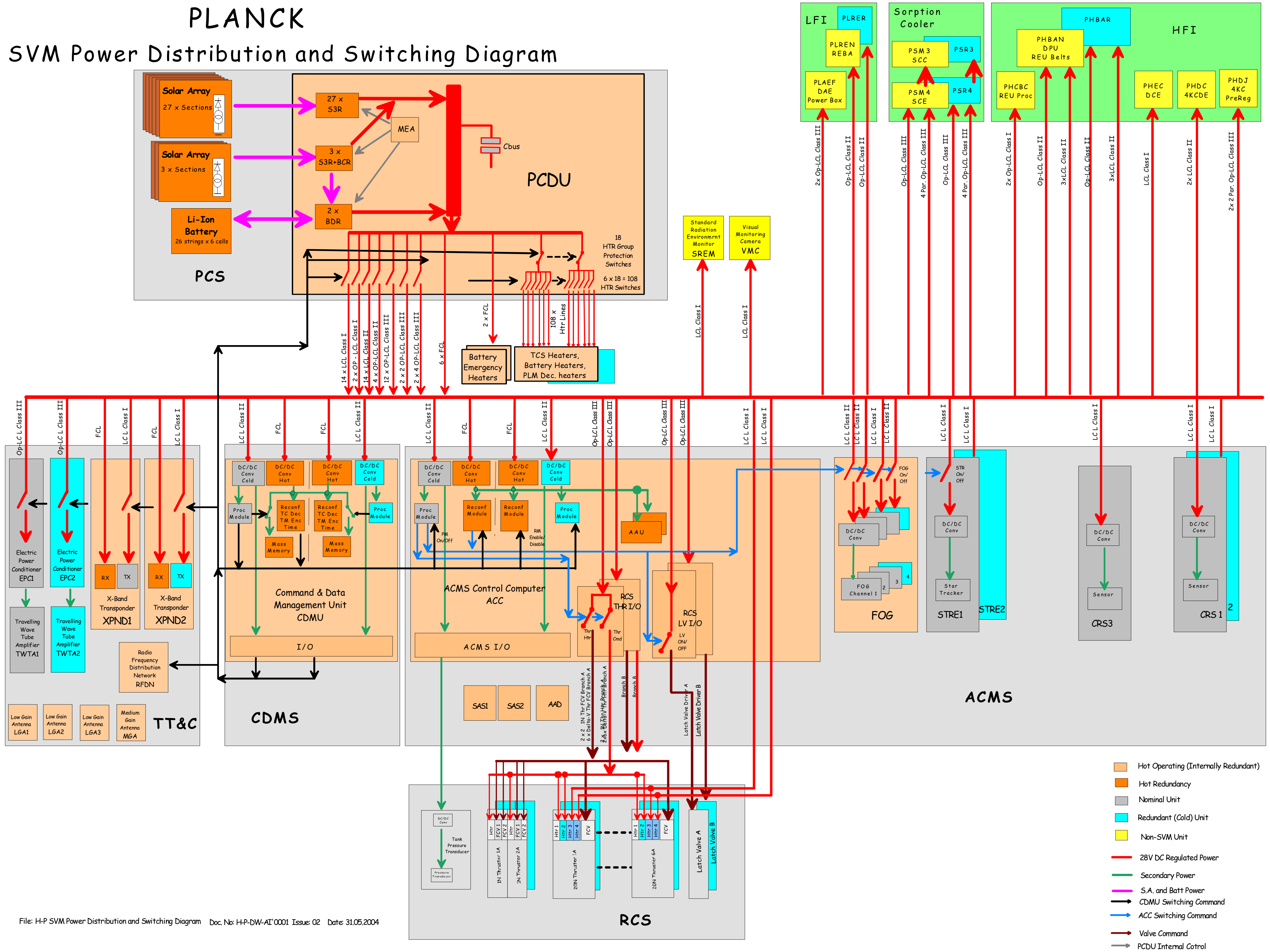


Figure 7.5-9 Planck Power Distribution and Switching Diagram

7.6 Herschel/Planck Software

This section is devoted to present the current software design of the Herschel/Planck Service Modules (SVMs). All the developed software belonging to the Payload Module (PLM) is not herein discussed because out of the scope of this document. The software is procured on the basis of the hereafter listed specification (included in the CDR data Package).

CDMU S/W I/F Req. Doc (IRD) H-P-SP-AI-0005 5 [RD-49]
ACC & CDMU Basic SW Req H-P-SP-AI-0006 5 [RD-13]
CDMU ASW Requirements Specification H-P-SP-AI-0031 5 [RD-14]

The major modification occurred from the PDR (June 2002) are hereafter briefly listed. Any details on the improved design with respect to the one presented at the PDR can be found in the applicable design report at Subsystem level

- VMC, SREM, FOG management
- TC priority management
- SW double image management
- Enhanced ACC Boot sequence in Survival Mode
- Storage of gathered science data in both SSMMs
- Improved S/C bus management (including related FDIR requirements)
- Improvements and changes related to the evolution of the PS-ICD (e.g. Packet transmission control, Abort current dump, User Selectable Data (USD) for HK definition, permanent / transient subschedules in MTL function, etc). See PS-ICD change log for details.
- Mode management logic changed
- SOHO failure case introduced
- Mission continuation concept introduced
- Decontamination heating function introduced
- Changes in various FDIR areas (esp. HW-SW interaction, DoD-triggered level-4 alarm, bus FDIR etc)
- Changes in thermal control function (class-B algorithm, starting delay etc.)

More precisely the following description is focused first on the main capabilities provided by the SVM software and then on the way it will be organised and structured from an architectural point of view. This architecture reflects the design status as fozen in the relevant Design Reviews:

- BSW (CDMU and ACC) PDR
- CDMU ASW PDR
- ACMS ASW V1 PDR

Note therefore that the objectives of the PDR's were considered sufficient to enter the SC CDR phase.
Atually the DDR's for the above SW are planned to take place in parallel to the SC CDR process and the feed-back will be available for incorporation into the system documentation to be updated for CDR close-out.

As far as the Ground software is concerned this document gives a summary of the Software tools and components supporting the Ground activities (e.g. SW development, OBCP generation). Note that the SW Validation Facility is not described as it is outside the activity of the SVM.
As regarding the HP Satellite Data Base, its structure is provide by the Prime Contractor and the SVM task is to populate and use it in accordance to the rules defined by the Prime.

Finally, the contents of this chapter of the DR are integrated by two documents [RD-99] and [RD-100], respectively dedicated to the ACMS and CDMS Design Description.

7.6.1 Software Breakdown

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

- the flight software
- the ground software

Figure 3 shows the main software components.
Contary to the PDR status the SVF environment is now outside the SVM responsibility and is therefore not descibed in this document.

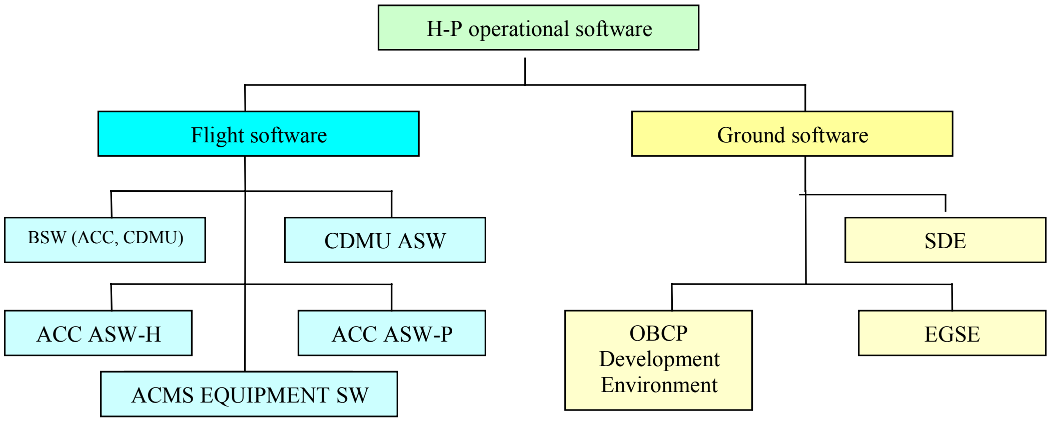


Figure 3 Herschel/Planck SW product tree

7.6.2 Flight Software

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

7.6.2.1 Avionics Architecture

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

The avionics architecture for Herschel and Planck spacecraft is shown in Figure 4 and Figure 5.

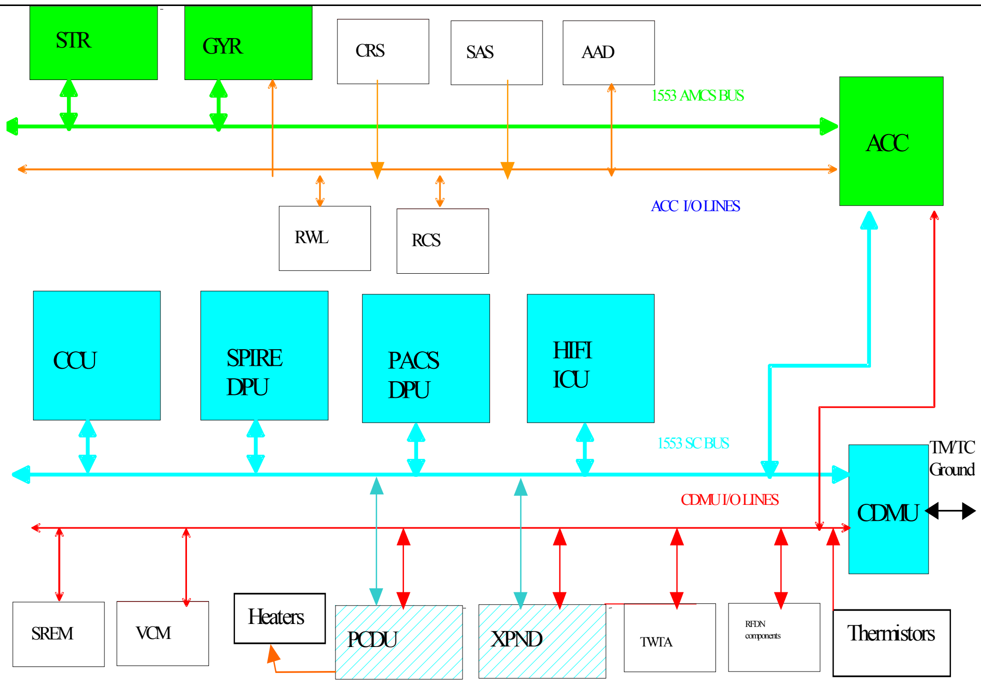


Figure 4- Herschel computers and data exchange block diagram

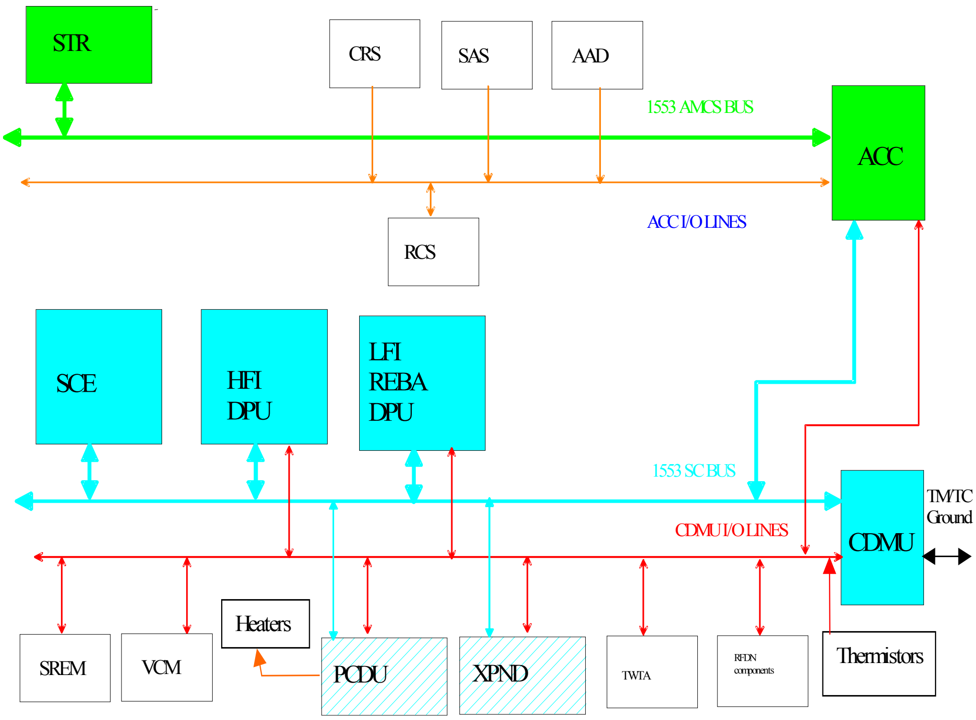


Figure 5 - Planck computers and data exchange block diagram

Basically the Science Instruments and the ACC fully support the Satellite Data Bus Protocol defined in [AD-09] and are therefore defined as Packet Terminals. The other terminals, on the 1553 Spacecraft bus, are the PCDU and the XPND (belonging to the TTC subsystem), referred as non Packet Terminals.

7.6.2.2 Software Layers Breakdown

The whole Herschel/Planck CDMU and ACC OBSW has been conceived in order to maximise the software re-use. Different software layers have been identified according to the SW breakdown depicted in Figure 6.

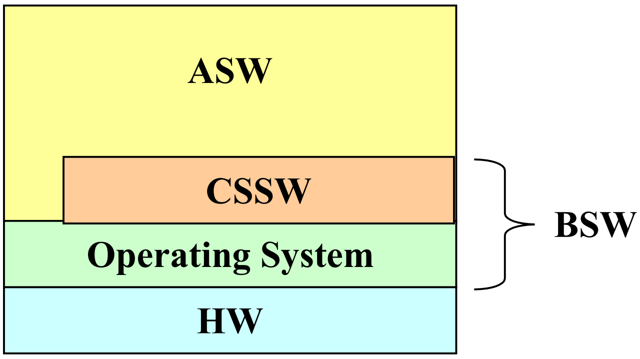


Figure 6 CDMU/ACC Software layers

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

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

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

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

More precisely the BSW allows:

- 1553 management
  - TCs issuing management towards packet terminals and non packet terminals
  - Data gathering from packet terminals and non packet terminals. In this last case the BSW is in charge to properly packetise the data in the standard TM source packet defined in [AD-09]
- I/O channels management
  - command issuing
  - monitor acquisition
  - telemetry data gathering and packetisation in TM source packets for SSMM storing and real-time data downlink

Updating of the data structures (contained in the Data Pool) with the last acquired data to be made available to the ASW for any further processing.

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

- **Mission (Event, MTL, OBCP, Modes)**
- **Payload**
- **Power Control Susbsystem**
- **TTC**
- **Thermal Control**
- **FDIR**

Besides the described functionality the BSW and the ASW fully support the ESA standard packet services specified in [AD-09]. Each software layer is responsible of its own managed packets. The services allocation is shown in Figure 7.

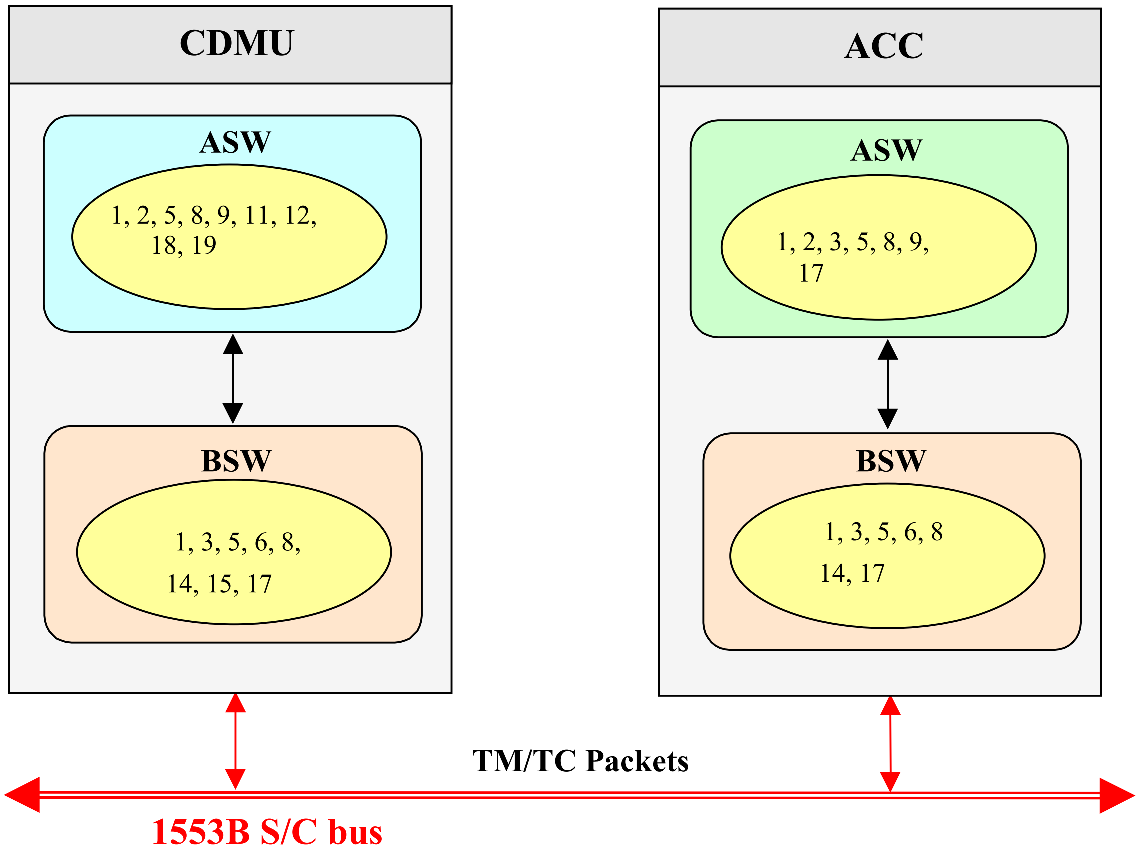


Figure 7 CDMU-ACC Standard Services allocation

Therefore the CDMU and ACC SW's manage a set of almost common services, with the following exceptions:

- **Service 11**, on-board scheduling (mission timeline)
- **Service 12**, on-board monitoring
- **Service 15**, on-board storage and retrieval service, that is only implemented by the CDMU where the SSMM is located.
- **Service 18**, on-board control procedures
- **Service 19**, event action

that are not requested for the ACC.

7.6.2.3 BSW Description

7.6.2.3.1 Components and Modes

The BSW components are stored and executed (on the PM board) as shown in Table 1.

Component	Stored	Executed
Bootstrap	PROM	PROM/RAM
Nominal BSW	EEPROM (two identical images)	RAM

Table 1 Software components

From BSW point of view, the software can execute in one of the following four modes:

Initialisation mode
This mode is entered unconditionally in response to a (hardware) reset being asserted. It constitutes the only entry point to the software. The mode is implemented by means of the Bootstrap component (located in PROM). The purpose of the mode is to determine whether the processor board is reliable or not, by means of running a set of self-tests, and to establish a preliminary set-up of the hardware. After this, a decision is made which of the other modes shall be entered. This decision is based on a number of conditions. Once the initialisation mode has been left, it can then be entered again only as a result of a new reset.

Debug mode
This mode can be entered on ground only and is intended for debugging activities. It presumes that the serial line (test connector) is used for communication. The set of supported commands is identified in the software user manual [SUM]. The debugging mode is implemented by the Bootstrap component, which is physically located in PROM.

Operational mode
After a successful initialisation the operational mode will be entered. In this mode ASW as well as Nominal BSW are running. Only in this mode will the API, as defined in the [CDMU-ICD] and [ACC-ICD], be available.

Shutdown mode
A dedicated RM command (55) will generate a TTR-interrupt (via the CROME). This interrupt can be utilised as a reconfiguration alert. By including this command first in all reconfiguration sequences, the processor is informed that it will be reset or that power is about to disappear. Whenever the reconfiguration alert is recognised by Nominal BSW, it will save context information in the SGM, call ASW to do the same and then stop.

The context information will be useful if ground wants to analyse the state at the time of the reconfiguration.
The modes and possible transitions are summarised in Figure 8 below.
Note that the ACC may be started in the so-called “Survival Mode” (it will be indicated by means of PM relay 0). From BSW’s point of view this only implies that a “quick” Initialisation shall be performed and it is not considered as a separate software mode.

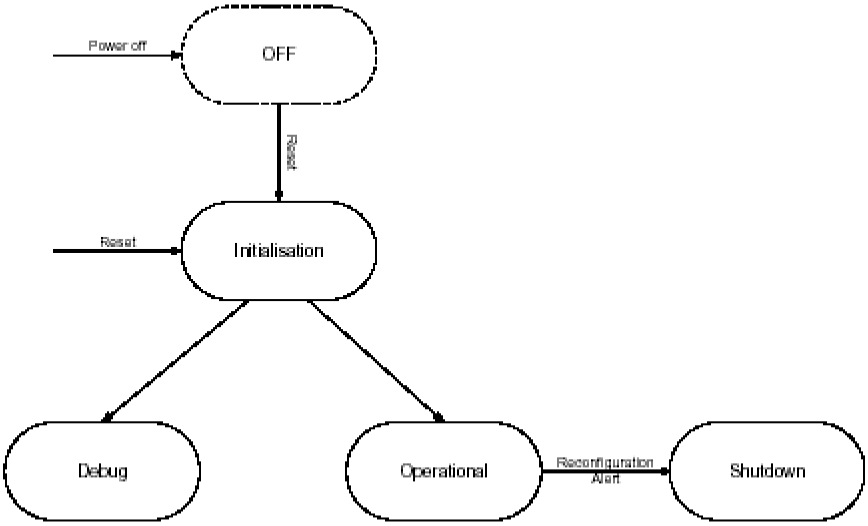


Figure 8 Software Modes

Table 2 shows which component handles each of the modes above.

Mode	Handled by Component
Initialisation	Bootstrap
Debug	Bootstrap
Operational	Nominal BSW
Shutdown	Nominal BSW

Table 2 Mode vs. Component

7.6.2.3.2 Nominal BSW Functions

The following Table 3 lists all BSW functionalities, with reference to both CDMU and ACC.

Functionality	ACC	CDMU
BSW Service Call Handling	X	X
On Board Time	X	X
Telecommands	X	X
Connection Test	X	X
Housekeeping	X	X
Telemetry	X	X
TC and TM Formats	X	X
Checksum Calculations	X	X
Packet Store Contents		X
Mass Memory		X
Cyclic and Asynchronous I/O	X	X
Propulsion and Reaction Wheel	X	
Visual Monitoring Camera		X
Standard Radiation Environment Monitor		X
Memory Handling	X	X
Reconfiguration Management	X	X
Command Pulse Distribution Unit	X	X
Attitude Monitoring	X	
TTR/RM Board	X	X
SpaceWire Link	X	X
ACC Control Bus Management	X	
System Data Bus – Bus Controller		X
System Data Bus – Remote Terminal	X	
1553 Link	X	X
PM Board Setup and Interrupt Routing	X	X
System Initialisation	X	X
Health Status and Monitoring	X	X
Background Activity	X	X

Table 3 Nominal BSW Functionalities

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

The main structure for data exchanging between ASW and BSW is the data pool that is a RAM area where all the I/O acquired data, HK TM data coming from MIL 1553B RTs are stored. This area is maintained by the BSW itself and is present for both the CDMU and ACC.
For the CDMU only, there is an Event queue where all the on-board generated events are stored by the BSW for further ASW processing.

The detail description of the design is provided in the BSW Design Description [RD-19] in terms of packages, where applicable, and otherwise in terms of single object.

That document provides the following elements:
- Object diagram
- Object descriptions
- Related user interfaces
- Related data pool and HPSDB entries
- Functional description.

7.6.2.3.3 Bootstrap BSW Functions

The Bootstrap component contains the code that runs immediately after power-on or reset. The responsibility of the Bootstrap is to:
- Perform start-up HW tests.
- Start the Monitor upon request
- Load and start the Software image stored in EEPROM (containing both ASW + BSW)

The Boot is designed to be stored and run from the PROM without usage of RAM.
There are a few exceptions when the execution is performed in RAM due to optimization of the start-up time. The Monitor is also run from RAM.

Also the Bootstrap component can be described in terms of its objects. This detail can be as well found in the BSW Design Description [RD-101].

7.6.2.4 ASW Description

7.6.2.4.1 CDMU ASW Architecture

The top-level logical model of the CDMU on-board SW is shown in Figure 9.

The ASW uses the BSW and a PUS-library called YATTC. The YATTC contains mission specific and generic parts. The mission specific part is logically considered to be a part of the ASW and the generic part is a separate component like BSW. There will be no interaction between generic YATTC and BSW, but the mission specific part of the YATTC uses BSW services.

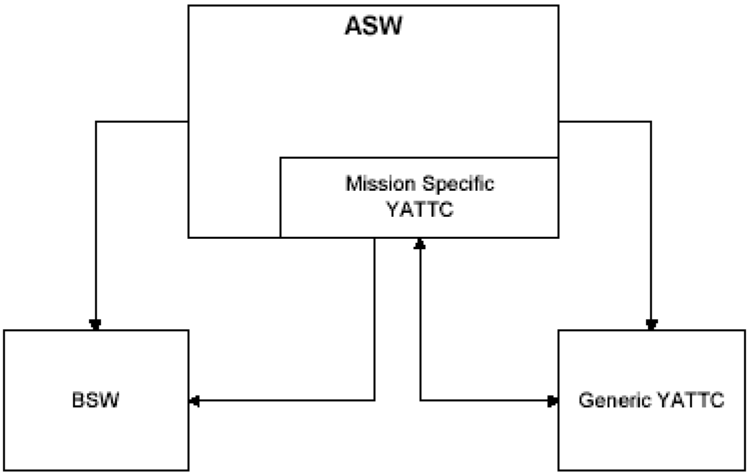


Figure 9 ASW Logical Model

Figure 10 presents the context of the CDMU ASW. The presented external interactors and the information exchange with them are the following:

- **BSW Packet Telecommand Routing:** provides the telecommands relevant to the ASW and routes the telecommands produced by the ASW
- **BSW Telemetry Routing:** routes the telemetry packets produced by the ASW
- **BSW Event Management:** takes care of the event packets produced by the ASW
- **BSW Event Queue Management:** provides event packets relevant to the ASW according to the given event filter
- **BSW Data Pool:** provides values of parameters used for example for on board monitoring and thermal monitoring, and it stores values of ASW parameters
- **Mass Memory:** stores OBCP token code and Mission Time Line
- **Safeguard Memory:** stores information to be saved when data on other memories are lost
- **Discrete I/O:** provides discrete I/O commanding and acquisitions
- **TM Encoder:** is configured according to the spacecraft mode
- **BSW SDB Services:** provides services for handling the Spacecraft Data Bus.

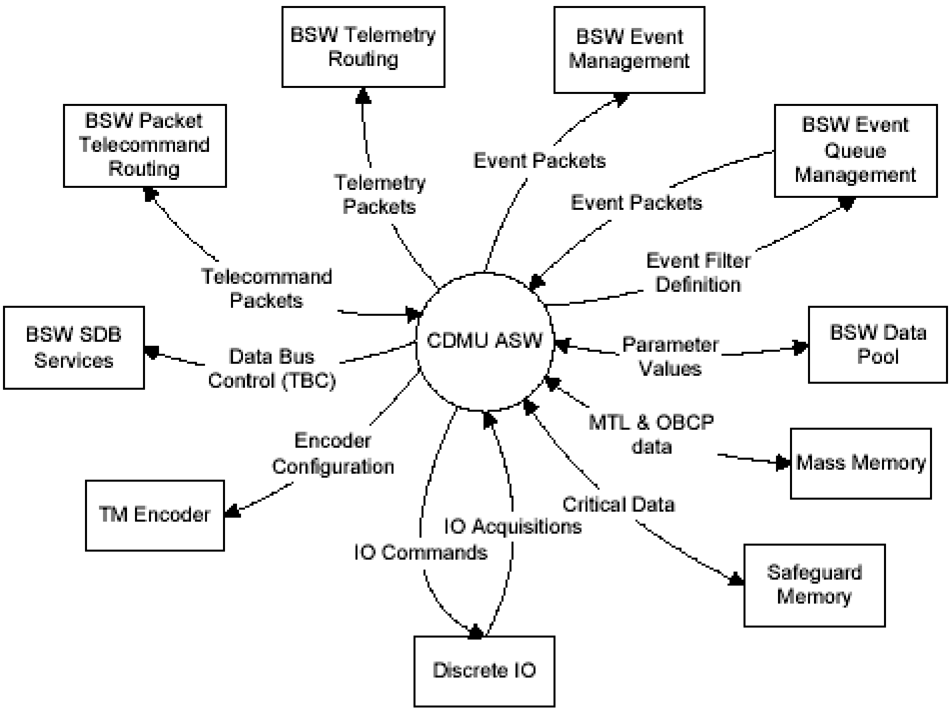


Figure 10CDMU ASW Context

7.6.2.4.2 ASW Functions

The main functional blocks of the CDMU ASW are shortly described herafter.

- **Main:** contains the ASW functions that the BSW is allowed to call: Asw_InitAsw and Asw_SaveContext. Initializes all task class instances. Includes also the Synchro task class.
- **YATTC:** uses BSW services to implement PUS services, which it provides to other software modules
- **TC Receiver:** polls telecommands from the BSW, converts them to YATTC packets and gives the packets to the application process
- **Event/Action Control:** polls events from BSW and uses services of YATTC to implement the Event/Action PUS service
- **Monitoring Control:** polls parameter values stored in the BSW data pool and uses services of YATTC to implement the On Board Monitoring service
- **MTL:** uses services of YATTC to implement On Board Scheduling service
- **OBCP Control:** uses services of On board Control Language and YATTC to perform the management and execution of the On Board Control Procedures.
- **Mode Management:** uses services of BSW to perform the mode transition actions.
- **Payload Management:** uses services of BSW to control payload instruments
- **PCDU Management:** uses services of BSW to control PCDU
- **TTC Management:** uses services of BSW to control equipment belonging to the TTC subsystem
- **Thermal Control:** polls temperature values stored in the BSW data pool and sends commands to heaters via BSW services
- **Decontamination Control:** performs decontamination heating control
- **FDIR:** uses services of YATTC and BSW to perform recovery actions of detected failures.

All ASW packages use services of YATTC at least to send telemetry packets.

7.6.2.4.2.1 ASW Tasks

The CDMU ASW is responsible for several functionalities, from which some are performed cyclically at certain frequencies and others are triggered when some triggering condition is met. The execution of these functionalities is done by several concurrent processing threads, which are called " tasks".
Table 4 presents the tasks of the CDMU ASW, their triggering events and either activation period or minimum activation interval, and a dead-line for one activation.

Task	Description	Task type (cyclic/sporadic)	Triggering event	Period / Minimum activation interval	Dead Line
TC Poller	During one activation polls up to 4 telecommands sent to ASW by calling BswSvc_PTC_PktGet service, verifies them and either executes them or gives them to another task for execution	Cyclic	Cyclic period expires	125 ms	125 ms
Event Poller	Polls events (max 2 per activation) concerning ASW by calling BswSvc_EVQ_GetPkt service and sends the Action telecommand related to them	Cyclic	Cyclic period expires	125 ms	125 ms
Monitor	At the beginning of the task cycle writes ASW parameters to the data pool. Reads monitoring parameter values from Data Pool, checks them against expected limits or values and generates events when values exceed limits or returns within limits	Cyclic	Cyclic period expires	125 ms	125 ms
FDIR Manager	Handles FDIR action telecommands sent from Event/Action service (performs the recovery actions)	sporadic	Reception of Function Management TC containing FDIR recovery action command (TC reference passed by RTEMS message)	1 s (indicative value)	1 s (indicative value)
MTL Manager	Executes MTL managament telecommands	sporadic	Reception of MTL managment telecommand	100 ms (TBC)	100 ms (TBC)
MTL Executer	Executes telecommands stored in MTL	Cyclic	Cyclic period expires	1 s	1 s
OBCP Manager	Performs OBCP control telecommands	Sporadic	Reception of telecommand addressed to OBCP Management	1 s	1 s
Thermal Control	Performs the Thermal Monitoring and control	Cyclic	Cyclic period expires	1 s	1 s
Decontamination Manager	Performs the decontamination management	Cyclic	Cyclic period expires	8 s (Herschel) 10 s (Planck)	8 s (Herschel) 10 s (Planck)
Mode Manager	Performs mode transitions	Sporadic	Reception of Function Management TC triggering a mode change (TC reference passed by RTEMS message)	N/A	N/A
Payload Manager	Performs payload commands	Sporadic	Reception of Function Management TC triggering a payload command	500 ms (indicative value)	500 ms (indicative value)

Device TC Manager	Performs device control commands triggered by telecommands	Sporadic	Reception of Service 2 TC or Function Management TC triggering TTC or PCDU commands	10 s (indicative value)	10 s (indicative value)
OCL Interpreter Threads	16 threads reserved for OBCP execution	Sporadic	OBCP start request	1 s	1 s
Synchro	Task that is synchronised with the BSW tasks and Triggers ASW cyclic tasks with semaphores. Executes the time synchronisation procedure TC(9,3).	Cyclic	BswSvc_Cyc_Synchronise	1 s	100 ms (TBC)

Table 4 ASW Tasks

All cyclic ASW tasks are synchronized to the 1 second BSW cycle by the ASW Synchro task. This task calls a service, provided by the BSW, which in turn keeps the ASW in waiting until the next 1 second cycle starts.
The other cyclic tasks are synchronized to the Synchro task with specific semaphores, which are released by the Synchro task. Because the Synchro task is the only one to release these semaphores the other cyclic tasks need to wait until the Synchro task is activated. As the period of the Synchro task is one second, it can release the semaphores in periods that are multiple of one second (1s, 2s, 3s and so on).

Figure 11 outlines the interaction between tasks and most essential data structures like Monitoring Table, Event/Action Table and Thermal Control Table. Note that some data structures are presented with more than one symbol in order to improve the clarity of the diagram.
The diagram also shows two entities belonging to the BSW, because they are essential for linking information exchange between ASW tasks:

- BSW TC queue
- BSW event queue.

All telecommands generated by the ASW are sent via the BSW TC queue, even if the telecommand is executed by the ASW.
All events are sent via the BSW event queue, even if the ASW performs some actions on it.

The detail description of the CDMU ASW tasks design is provided in the ASW Design Document [RD-102].

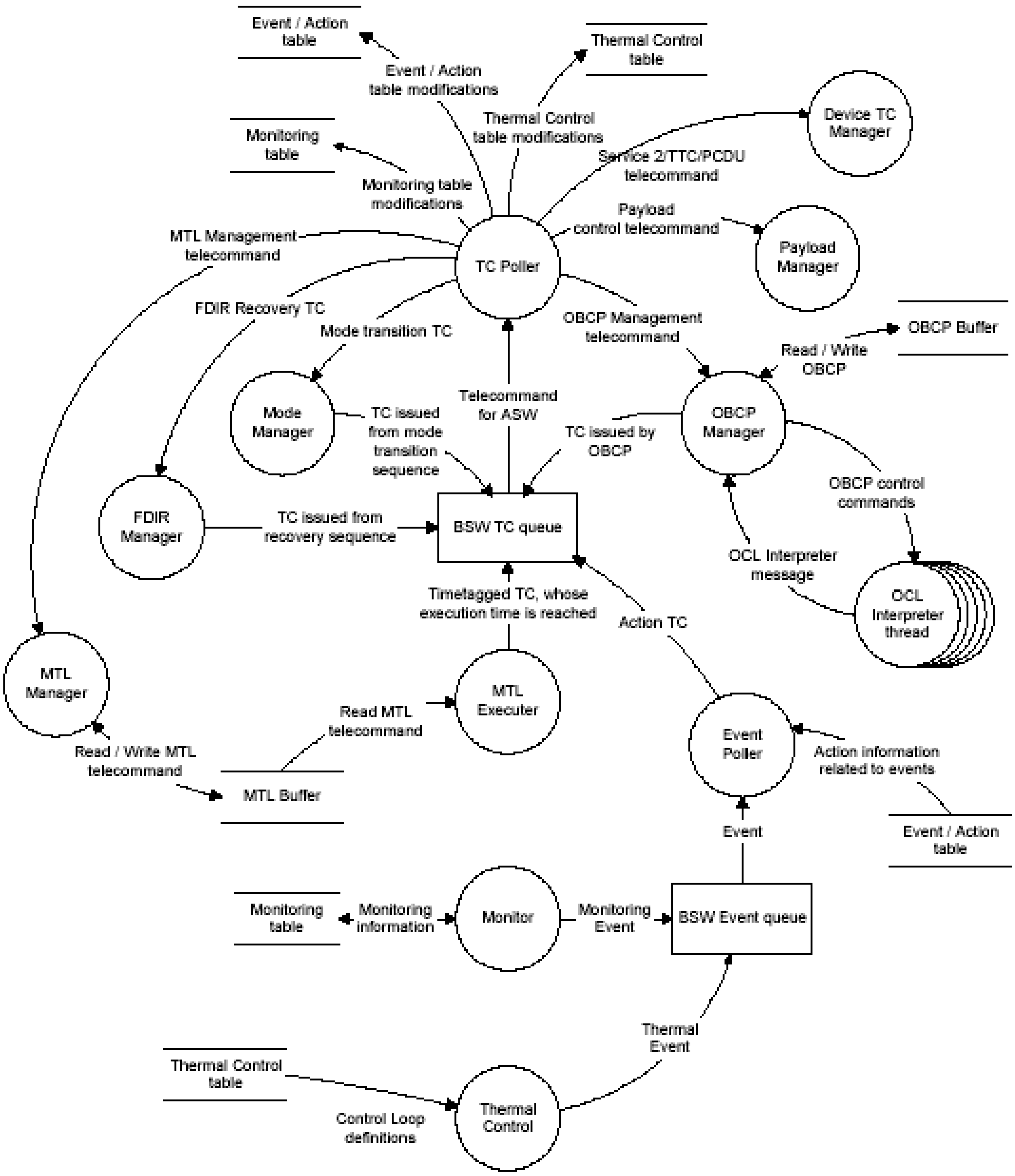


Figure 11 Task Communication

7.6.3 Ground Software

The purpose of the Ground Software is to support all Ground activities foreseen from the Design, Development, Verification and Validation up to the Maintenance phase of the flight software. In this perspective it will be necessary the usage of several Software Tools and Components.

7.6.3.1 Software Development Environment

The Software Development Environment (SDE) essentially includes all the tools and utilities necessary to design, develop and test the on-board software. The trade off, analyses and description of the final SDE configuration are provided in [RD-23]. The SDE that has been identified is fully applicable to all subcontractors in charge to develop any part of the on-board software running on the ACC and CDMU computers of the service module.

The following table gives a summary of the SDE components.

HOST computer	Sun workstation equipped with Solaris 8.0
CASE tool	Rational ROSE Enterprise 2002.05.00 (exception: SAAB will use and deliver Artisan Real Time Studio)
Cross Compilation System	LECCS 1.1.5.3, including: GCC 2.95.2 (compiler) Rdbmon (target debugger) MKPROM (prom builder) gdb (debugger)
Target Simulator	TSIM 1.3
Operating system	RTEMS 4.5.0, OAR distribution
File configuration tool	Rational ClearCase [LT] 2002.05.00
Testing tool	CANTATA++ 3.0 or Cantata 3.4

Software Development Environment Components

Note that most of the products are open source; nevertheless they are the result of many years of work, tests and refinements that has led to reliable and consolidated tools. Products are supported by commercial companies and the source availability gives the final chance for a direct user modification/update. Free detailed documentation is available for any specific tool.

The use of either "Rational ROSE" and "Artisan Real Time Studio" implies the UML design language choice.

7.6.3.2 OBCP Development Environment

The OBCP development environment shall comprise a tool(s) that shall be used to create the OBCPs to run on-board through CDMU ASW supported services. Thus the OBCP tool(s) shall be designed/developed/tested by the CDMU ASW subcontractor. This solution looks like the most reasonable choice due to the strict relationship that will exist between the OBCPs and the used ASW data structures. The relevant tool(s) shall be implemented according to the requirements stated in [RD-14] and shall be used in the SVF, in the EGSE and especially in the Software Maintenance Facility at ESOC premises.

In the process of OBCPs creation an important issue to be taken into account is related to the definition of the Spacecraft Control Language. ESA's requirements, stated in [AD-08], clearly identified the necessity to make use of a user-friendly language devoted to help operations engineers during the definition of the on-board control procedures. It mainly means that the proposed language should be very simple.
Essentially the Spacecraft Control Language will have to foresee the following basic programming statements and functions:

- assignment
- condition
- loop
- delay
- mathematical expressions
- types definition
- logical expressions
- variable declarations

However besides the previous listed grammar elements of the SCL, it will be also an ASW subcontractor task to propose a complete and formal (e.g. BNF) grammar definition.

Depending on the interpreter or compiler solution, Figure 12 OBCP creation process shows the needed activities that must be carried out on ground in order to create an OBCP.

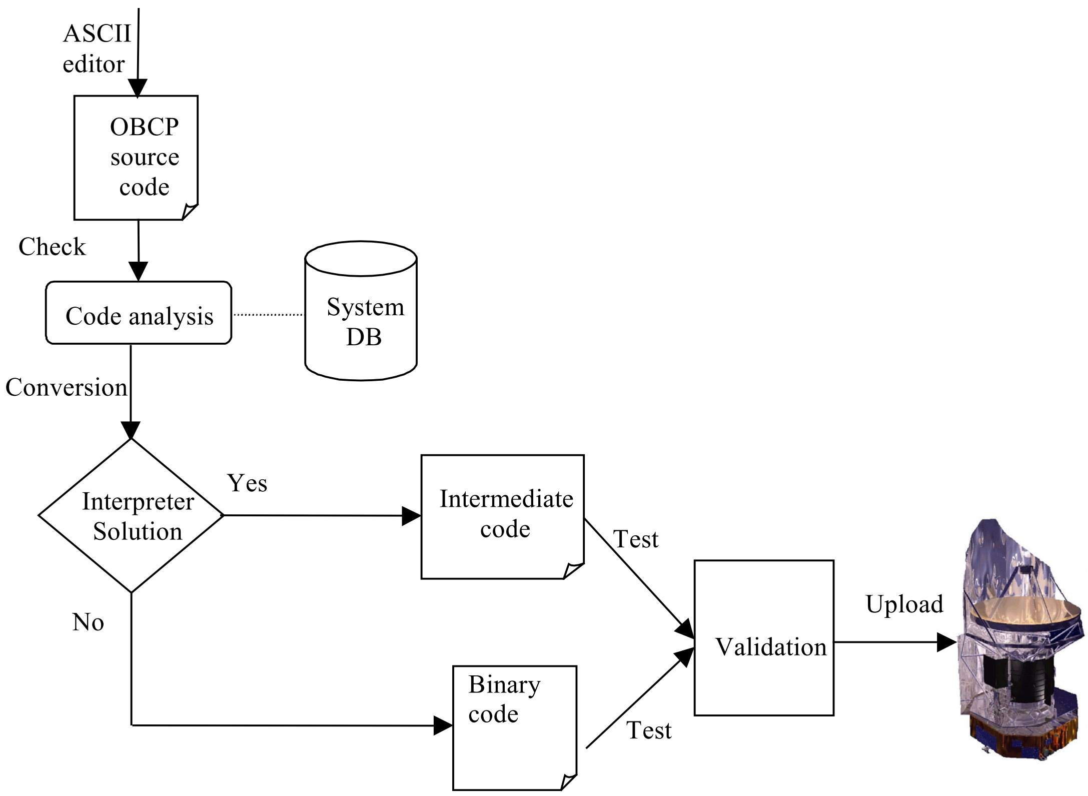


Figure 12 OBCP creation process

Basically ground activities consist of the following steps:

Use a standard ASCII editor to create an OBCP source code written in Spacecraft Control Language.
Perform the lexical and syntactical analysis (code analysis) of an OBCP source code written in SCL by means of a tool developed using LEX and YACC. This approach will give the possibility to easily define and maintain the SCL grammar. In any case if the supplier wants to reuse already existing software, he has to give evidence of the efficiency of the proposed solution that has to be agreed by the customer. At least the following conditions shall be checked:

- Variables initialisation
- Validity of the total needed memory size
- Variables type consistency (applicable to: assignments, conditional statements, parameters, etc)
- Existence of all used identifiers/parameters in the System DB (Event ID, TC , TM, etc)
- Long needed execution time (in case a long sequence of statements is detected and his estimated time exceed the maximum envisaged value)

Conversion of the OBCP source code depending on the chosen interpreter/compiler solution:

- in case of interpreter solution the OBCP source code written in SCL will be translated in a Intermediate Code that will be properly interpreted by the on-board interpreter once it is uploaded on the spacecraft.
- In case of compiler solution the OBCP source code written in SCL will be translated in a high level programming language. A next “Compile & Link” phase will allow the generation of a final binary code that can directly run on-board. For this phase it will be used the same compiler adopted for the development of the ASW.

Test and validate the relevant procedure in the most appropriate test environment (e.g. SVF, SMF)
In order to test and validate the written OBCP code it is, obviously, necessary to carry out specific test sessions in order to certify its behaviour and be confident about the absence of possible system impacts. This is a phase strictly necessary even if the adopted solution, whatever it is, is considered fully reliable.
Upload the OBCP code on-board using the PS-ICD service 18 or include it as a resident part of the on-board flight software (in EEPROM).

7.6.2.5 ACMS Software

All the ACMS Software, but the ACC BSW, is procured by the ACMS subcontractor and it is under his responsibility. The ACMS supplier will provide to Alenia the whole S/S ready to be integrated in the SVM.
The ACMS Software is essentially related to the following units/equipment being part of the S/S:

- ACC
- Star Trackers
- Gyros (for Herschel only)

The relevant software life-cycles must be compliant with the ECSS-E-40B document. Some specific equipment (e.g. Star Tracker) will be supplied with an embedded software, already developed. In these cases the supplier has to provide full access to the SW design, source files and any other document/information needed for its understanding.

The ACC software is essentially conceived to be split in two main parts: BSW and ASW.
As already anticipated, in the CDMU section, the ACC and CDMU BSW will be essentially the same, a part from specific services and needed I/O drivers. The ESA Standard Services implemented in the ACC BSW are shown in Figure 5.
The commonality has been extended to the two satellites. This means that the BSW of Herschel and Planck will be the same (a part from exclusively needed I/O drivers).
Vice versa the ASW of the two ACC's will be different being related to different attitude control laws. However it has been possible to identify a subset of common services in order to re-use as much software as possible.

In the following it will be given a brief description about the ACC software structure, functions and tasks. Such description has been extracted from the 'ACMS Design Report' (H-P-4-DS-TN-011) and from Terma documentation.

7.6.2.5.1 ACC ASW architecture

As above mentioned the ACC ASW of Herschel and Planck are quite different. Anyway despite these differences it is possible to identify a Common Application Software (C-ASW) service layer that implements the functions common to both applications. **Error! Reference source not found.** Figure 25 shows the ACC ASW structure.

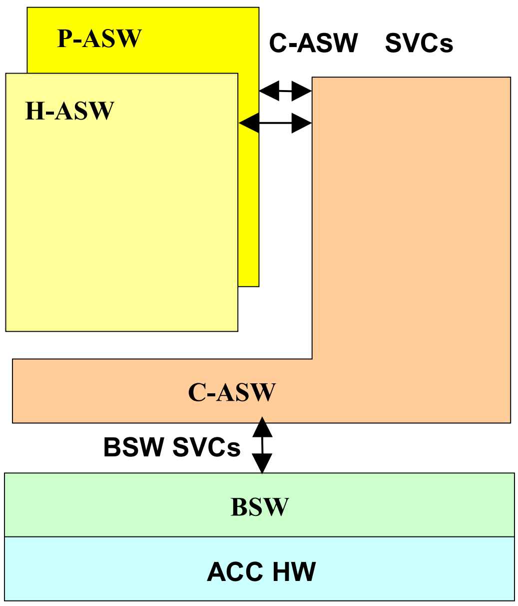


Figure 13 ACC ASW structure

The basic communication with the ACMS units and CDMU, realised through the BSW, is handled by the C-ASW as a single point of contact, and acts as an intermediary for the Satellite Dependent Application Software (H-ASW for Herschel, P-ASW for Planck). However, as much as possible, higher level common functions will be implemented in such a way that they could be used both for H-ASW and for P-ASW.

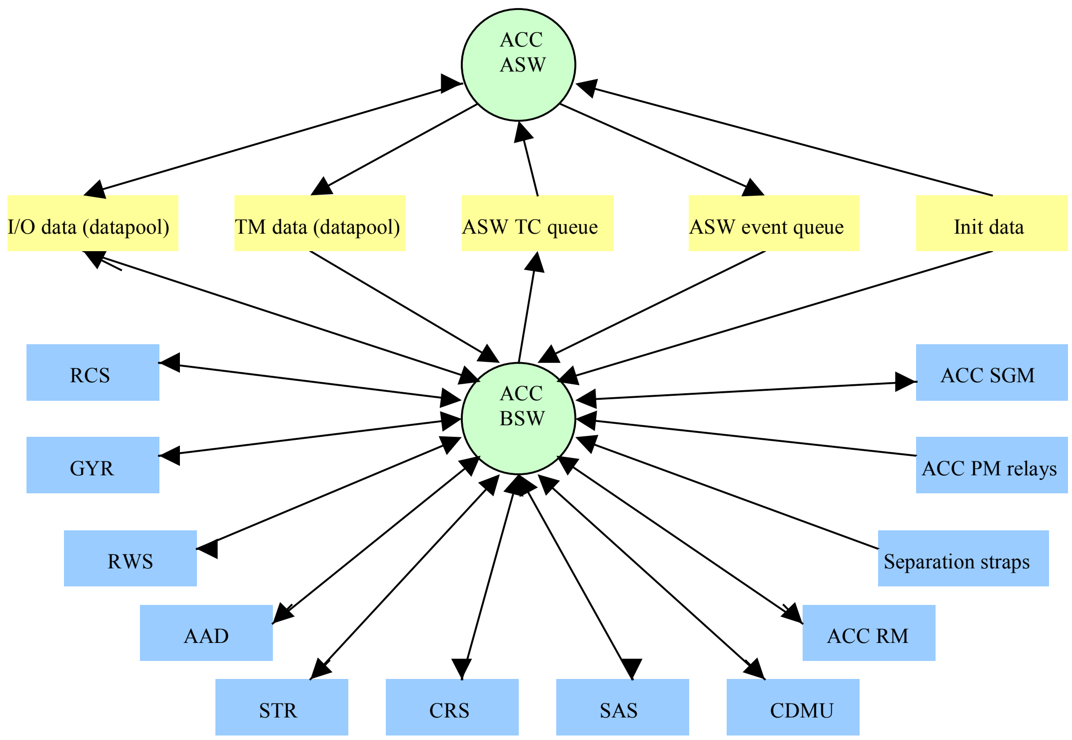
Moreover the C-ASW implements the remaining ESA standard services foreseen for the ACC (see Table 9).

ACC ASW Standard Services		
Service 2	:	Device Command Distribution
Service 8	:	Function Management
Service 9	:	Time Management
Service 12	:	On-board monitoring

Table 9 ACC ASW Standard Services

The main functions of the ASW are
- accept telecommands and data from the CDMU (via the BSW)
- read sensors
- conduct mode transitions based on external commands and internal events
- conduct attitude control for each mode
- command the actuators
- Provide telemetry data to the CDMU (via the BSW)
- conduct FDIR functions

ASW/BSW context diagram
The following figure represents the BSW/ASW context diagram (FOG not shown):



Terminators

RCS
The Reaction Control System (RCS) provides the thrust for orbit control manoeuvres and attitude control for Planck (all but Science Mode) and Herschel (all but Science Mode). For Herschel, the RCS is used in Science Mode for RWS unloading/biasing.

GYR
The gyroscope (GYR) provides the angular velocity measurements for the nominal modes (Herschel only).

RWS
The Reaction Wheel System (RWS) provides the required torque for attitude control during the Science Mode (Herschel only).

AAD
The Attitude Anomaly Detector (AAD) provides for both Herschel and Planck the Sun presence information for the ARAD functionality.

STR
The star tracker (STR) provides for both Herschel (in the science modes) and Planck (Science, Orbit Control and Angular Momentum Control Modes) the spacecraft quaternions.

CRS
The Coarse Rate Sensor (CRS) is an FDIR sensor (as part of the ARAD functionality) and provides for both Herschel and Planck in the Survival Mode, the data to determine the spacecraft angular velocity. The CRS is also used for Planck in Sun Acquisition Mode.

SAS
The Sun Acquisition Sensor (SAS) provides for both Herschel and Planck in Survival Mode and Sun Acquisition Mode, the data to determine the Sun vector.

CDMU
The CDMU provides for the ACMS the telecommands (from ground or generated onboard) and collects the telemetry for subsequent downlinking. In addition, it provides both CIR and SIR signals indicating that the CDMU is in reconfiguration and synchronisation signals to the ACC.
The CDMU uses the AIR signal as provided by the ACMS, to handle ACC reconfiguration.

ACC RM
The Reconfiguration Module (RM) provides switching between the two Processor Modules (A and B) after an ARAD triggering. The ARAD triggering is based on input directly (meaning, without BSW/ASW involvement) from the CRSs and the AAD. Two Reconfiguration Modules acting in hot redundancy are contained in the ACC. In addition, RM registers will be used to securely store configuration data, that is, which ACMS units are to be used in Survival Mode, the separation override flag (to enforce processing in case of separation strap failure), and the post-separation coasting flag (used to check whether the 20 seconds after separation has elapsed in Survival Mode). The latter flag is based on an RM relay status.
The RM registers can be read from the PM at any time, but only written when the CDMU has disabled the RM.

Separation straps
The separation straps provide info on the status of separation from the launcher.

ACC PM relays
Processor Module relays are used to determine which PM (A or B) will be used to execute the software, and whether Nominal Mode or Survival Mode will be executed. The following nomenclature is used:
PMA or PMB On/Off relay indicates which PM will be used to run the software (default is PMA On and PMB Off).
PMA or PMB bit 0 relay indicates whether Nominal Mode or Survival Mode will start (as default, PMA runs the Nominal Mode and PMB the Survival Mode). This relay is also denoted by initialisation path selector.

The relays can be set via the CDMU.

ACC SGM

The SafeGuard Memory (SGM) is a section of memory with specific protection measures. It is used to store critical data.

Datastores and dataflows

I/O data

The datastore *I/O data* contains the data which is provided/used by the ASW and which will be handled by the BSW for transfer/retrieval to/from units. This data is part of the datapool.

TM data

The datastore *TM data* contains the telemetry data as collected by the ASW which is subsequently processed by the BSW for sending to the CDMU. This data is part of the datapool.

TC queue

The datastore *TC queue* contains the telecommands as processed by BSW for execution by the ASW.

Event queue

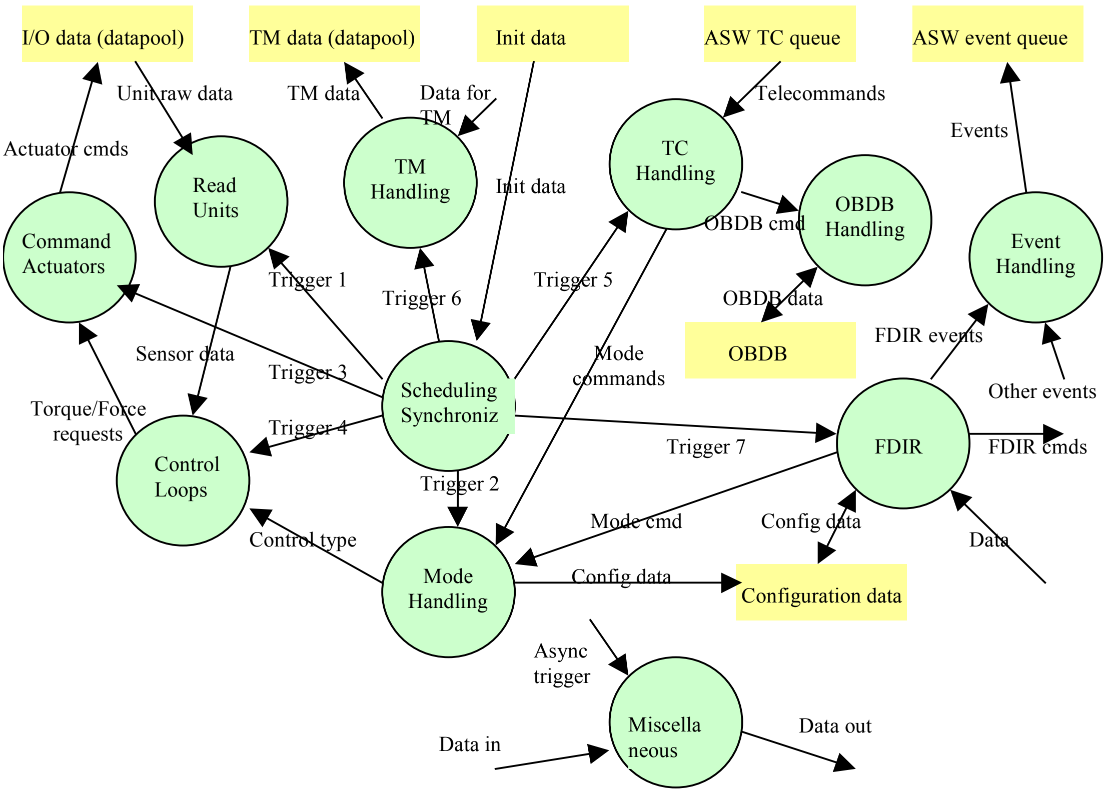
The datastore *event queue* contains the events as generated by the ASW. The events will be processed by the BSW.

Init data

The datastore *init data* contains the initial data required by the ASW.

ASW Level-0 dataflow diagram

The following figure represents the ACC ASW Level-0 DFD (dataflow diagram):



Process descriptions

Scheduling/Synchronisation

The process *Scheduling/Synchronisation* performs the scheduling and synchronisation of the ASW tasks. This process is implemented by the BSW (more precisely, RTEMS).
The control flows *trigger1* to *trigger7* represent the RTEMS calls of ASW tasks.

Mode Handling

The process *Mode Handling* performs the transitions between modes and the main logic within the modes.
The data flow *control type* represents the identification of the specific control law to be applied for the pertinent mode.

FDIR

The process *FDIR* performs the FDIR tasks of the ACMS.
The following data flows have been identified:
Configuration data represents the identification of units to be used, including its health and power status;
Mode cmd represents the mode transition forced by FDIR;
FDIR commands represents the FDIR enforced commands;
FDIR events represents the events raised in the FDIR process;
data represents all data used.

TC handling

The process *TC handling* performs the processing of telecommands as received from the CDMU. The following dataflows are identified:
telecommands from the CDMU (via the BSW) or generated by the ASW;

*mode command*s, telecommands from the CDMU or from FDIR for a mode transition;
*OBDB cm*d, specific onboard database commands.

TM Handling

The process *TM handling* represents the gathering and preparation of ASW data to the BSW. The following data-flows are identified:
data for TM represents the ASW data needed for this process;
TM data represents the data for TM to be processed by the BSW.

OBDB handling

The process *OBDB handling* represents the management of the onboard database, including the CRC. The following dataflows are identified:
*OBDB cm*d, specific onboard database commands;
*OBDB dat*a, data to be stored/retrieved in the database.

Event Handling

The process *Event handling* represents the gathering and preparation of ASW events to the BSW. The following dataflows are identified:
FDIR events represents the events raised in the FDIR process;
other events representsthe events raised in processes other than in the FDIR process;
*event*s, for reporting to the BSW.

Control Loops

The process *Control Loops* executes the Herschel and Planck control laws. The following dataflows are identified:
Sensor data represents data from the units needed for the control calculations; in some cases, processing of these data is necessary;
Torque/Force requests represents the actuator commands for the RWS or RCS;
control type represents the identification of the specific control law to be applied for the pertinent mode.

Miscellaneous

The process *Miscellaneous* contains various minor proceses.

Read units

The process *Read units* performs the reading from the datapool and the basic processing of unit data. The following dataflows are identified:
Sensor data represents data from the units needed for the control calculations; in some cases, processing of these data is necessary;
unit raw data represents the unprocessed data from the units.

Command actuators

The process *Command actuators* performs the basic processing and commanding of the RWS and RCS units. The following dataflows are identified:
Torque/Force requests represents the actuator commands for the RWS or RCS;
Actuator cmds represents the commands to be transferred to the RWS or RCS.

Data stores

The *OBDB* datastore represents the on-board database.
The *Configuration data* datastore represents the identification of units to be used, including the health and power statuses of the units.

On- board ASW database

The On Board ASW Database (OBDB) is a repository for semi-constants in the ACMS, which can be maintained without having to resort to modifications of the executable. A set of default values is located in EEPROM, and is used at each reinitialisation of the ACC. Modifications can only made in the RAM copy of this database, thereby ensuring that an incorrect modification of a parameter does not result in propagation of the error or an infinite loop of resets. As an exception, a copy of some limited essential parameters is maintained in Safeguard Memory, to ensure that these are carried over after a reset. These are unit calibration parameters and target values for essential safing measures (e.g. CIR-SIR signal response). Note that no essential Survival Mode parameters are allowed to be located in SGM.

ASW task allocation

The ACMS ASW must run in a fixed 4 Hz cycle. The BSW synchronises the ACMS cycle with the CDMS time. The BSW also synchronises the operation of the ACMS units with the ACMS cycle with a high accuracy (typically 0,1 ms) to ensure that the control algorithms of the ACMS work properly.
Especially the synchronisation of the STR, GYR and RWL is critical for achieving SCM slew and pointing performance. The units connected on the MIL-STD-1553B bus must be synchronised with a broadcast command, triggered directly by the BSW to achieve the required timing accuracy. The BSW will ensure synchronous data processing of the units connected to the ACC Interface Unit.
The unit data will be read by the BSW, at the start of the cycle and made available to the ASW.
In order to minimise the delays in the control loop, the ASW must be organised so that functions that are part of the dynamic attitude control loop are executed first (primary control functions), followed by secondary functions such as Telecommand and Telemetry handling, ACMS database management, Mode Handling etc..
RCS commanding is a treated in a special way. The timing of RCS firing in the cycle is critical and requires a time resolution of 1 ms synchronised to the ACMS cycle. The delay between attitude determination and the firing of the thrusters is less critical. The firmware will execute RCS on and off commands, with the required time accuracy, in the ACMS cycle after the cycle in which the commands were passed to the firmware
Since Planck does not need the relatively high-bandwidth RWS feedback control of Herschel, there is no need to split control calculations in a primary and a secondary part for Planck, as the only restriction is that these calculations finish within the cycle, in time to send the RCS commands for the next cycle to the BSW. Otherwise, the sequence of functions in the cycle is similar for both satellites.

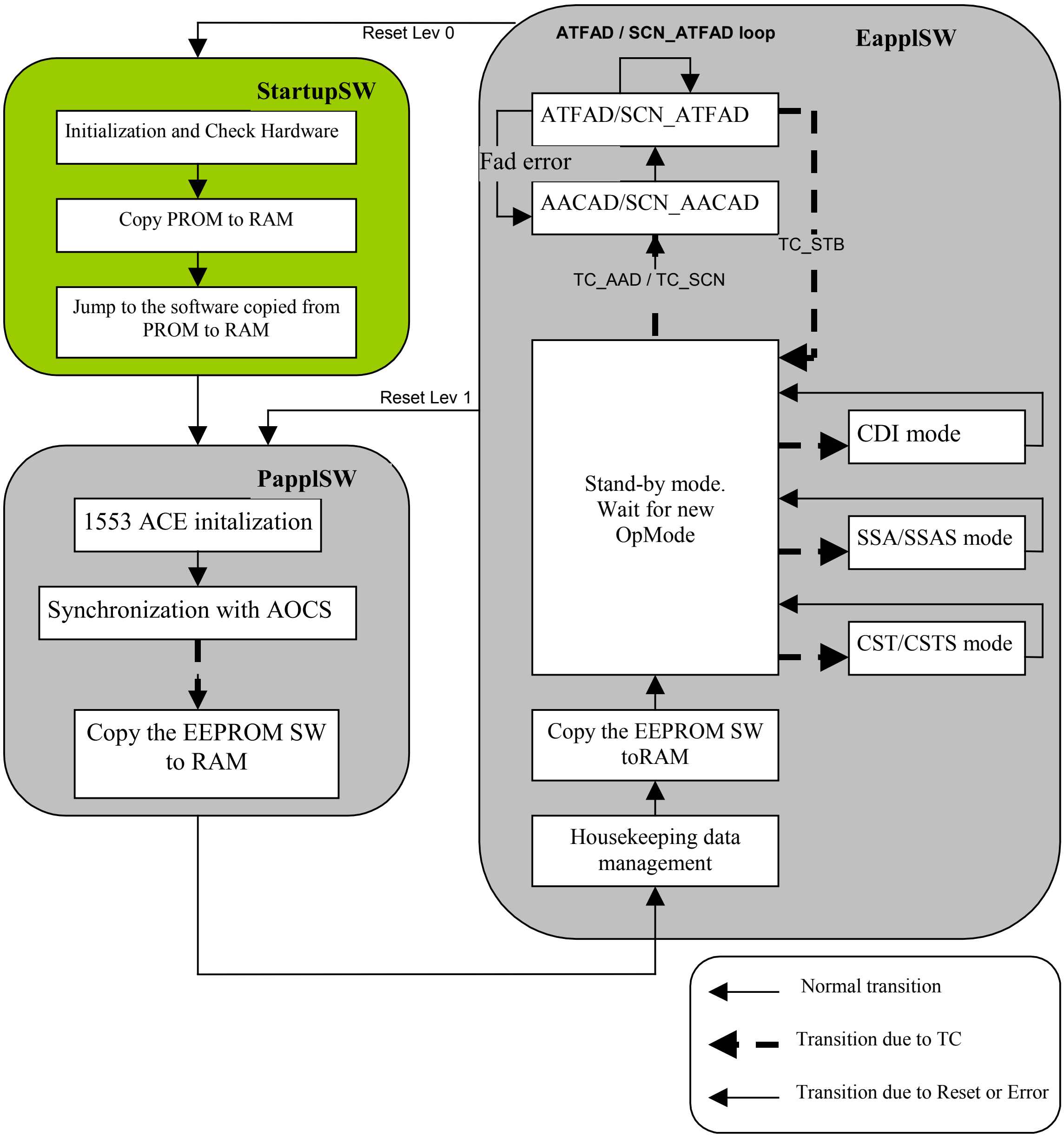
7.6.2.5.2 Equipment Software

Galileo STR for Herschel and Planck

The H/P STR SW is derived from the SW developed for the standard GALILEO AVIONICA ASTR. The SW is designed to run on a CPU board built around an ERC32 single chip RISC microprocessor and a custom ASIC, which has the main function to control the CCD operations. The MIL1553 B interface is used to communicate with the ACC.
Taking into account the similarity with the baseline ASTR SW and in order to minimise the cost of the new development, maximum reuse of existing SW components has been planned.
As the ASTR SW has been designed and verified in accordance to ESA-PSS-05-0 Issue 2, also the H/P SW is produced and verified according to the same standard. Evidence of compliance with ECSS-E-40B and ECSS-Q-80B is given through the Compliance Matrices reported in the Appendices.

In the following it will be given a brief description about the STR dynamic behaviuor as extracted from the Herschel and Planck 'ASTR Desgin Reports' (H-P-4-GAFSD-0001, H-P-4-GAFSD-0002).

The following figure summarizes the general SW dynamic behaviour both for Herschel and for Planck STR.



At startup, the software loaded in PROM (called *STARTUP_SW*) is executed.
The STARTUP_SW has in charge the execution of the following operations:

- Initialization and check of the Hardware.
- Copy from PROM to RAM either of the Monitor software (called *MON_SW*), used for debugging purpose, or of the PROM Application software according to the position of a hardware switch.
- Jump to the software copied from PROM to RAM.

The MON_SW allows to load and debug the PAPPL_SW and/or the EAPPL_SW. It is not treated in this document.

The PROM Application software (called *PAPPL_S*W) is stored into the PROM and copied from PROM to RAM. The PAPPL_SW has in charge the following main tasks:
- 1553 ACE initialization.
- Synchronization with the AOCS.
- Software Maintenance (upload and download data and code).
- Copy, by means of a telecommand from AOCS, of the EEPROM application software (EAPPL_SW) from EEPROM to RAM and jump to it.

The EEPROM Application Software (called *EAPPL_S*W) is stored into the EEPROM and copied from EEPROM to RAM. The EAPPL_SW has in charge the following main tasks:
- Housekeeping data management, devoted to control CCD temperature thanks to a TEC, to check optics temperature and to check 3 secondary voltages.
- Wait for AOCS requests of SW operative mode changing, and switching of ASTR_SW to the requested operative mode.
- Execution of SCN (Scanner Autonomous Attitude Determination) operative mode, subdivided into
    - Execution of AACAD (Autonomous Acquisition and Coarse Attitude Determination) operative submode, which gives information to AOCS about spacecraft attitude starting from a “lost-in-space” condition.
    - Execution of ATFAD (Autonomous Tracking and Fine Attitude Determination) operative submode, which gives information to AOCS about spacecraft attitude starting from the knowledge of previous attitude.

Execution of CST / CSTS (Commanded Star Tracking / Commanded Star Tracking Spinning) operative modes, useful for debug purposes, which gives information to AOCS about position of some stars starting from the knowledge of initial position of the same stars.
Execution of SSA / SSAS (Single Shot Attitude / Single Shot Attitude Spinning) operative mode, useful for debug purposes, which gives information to AOCS about spacecraft attitude starting from a “lost-in-space” condition, and then exits immediately from the operative mode.
Execution of CDI (CCD Image) operative mode, useful for debug purposes, which returns CCD image data requested by AOCS and then exits immediately from the operative mode.

The above figure points out the main execution process up to ATFAD / SCN_ATFAD main loop.
ASTR_SW is an “endless loop” SW, several relevant loop can be highlighted:
- ATFAD / SCN_ATFAD loop.
- ATFAD / SCN_ATFAD – AACAD / SCN_AACAD loop, if errors occur during ATFAD / SCN_ATFAD cycle ASTR_SW returns to AACAD / SCN_AACAD.
- ATFAD / SCN_ATFAD mode to STB mode due to TC_STB telecommand.
- If Reset level 0 signal arises ASTR_SW restarts from Startup software.
- If Reset level 1 signal arises ASTR_SW restarts from PROM Application Software.

7.7 EMC/ESD

7.7.1 Bonding

Electrical Bonding for RF reference purposes is not considered problematic. The majority of the electronic units are located on the structural panels. The structural panels are aluminium faced honeycombed panels and will guarantee the required conductivity. There are a few units that could be mounted on the carbon structure, for these units special grounding arrangements will be planned to carry the zero volt reference back to the aluminium structure. Aluminium strips, forming a Grounding rails network, will be fixed to the carbon face sheets giving a link for the units' bondstraps (that in most of the cases are represented by a semi-rigid aluminium strip) and to provide a pseudo-ground plane for the associated harness routing. Moreover bonding will get a safe path to ground if an electrical fault occurs. Bonds, not associated with the referencing of electronics, will be provided to avoid build up of charge due to electrostatic phenomena.

The above SVM bonding approach is substantially in line with the General Design and interface Requirements Document and an adequate electrical continuity throughout the Satellites structure should be guaranteed even if the Structure Subcontractor foresees 10 mOhm instead of the required 5 mOhm for the bonding resistance between any adjacent metallic structure parts. For more details please to refer to [RD-103], the document explaining the Herschel-Planck SVM Grounding and Bonding concept.

7.7.2 Grounding

The SVM design for the two Spacecraft follows the Distributed Single Point Ground approach: primary power will be grounded to the Satellite Structure inside the PCDU. DC/DC converters will provide galvanic isolation to secondary power for each user.
Signals will be referenced to equipment chassis (i.e. secondary ground) and the use of single ended interfaces at both sides should be avoided to reduce the common-mode coupling.
Generally the unit's electrical interfaces are in accordance with the requirements specified in the [AD-12], and for this reason will follow the DSPG philosophy.

Unfortunately, some devices are off the shelf, and present no standard interfaces. One of the most critical issue is the one relevant to the ACC-RWL electrical interfaces.

Teldix RWAs used for the Herschel ACMS have TM/TC interfaces, which are based on single ended inputs and outputs. In the ACC, most of the interface circuits will be based on single-ended in- and outputs as well. As a consequence, a number of the RWA interfaces do not fit one of the standard interface types defined in [AD-12]. Considering the required performances, the most critical interface should be the torque command interface.

The RWA is an off-the-shelf design. In order to not modify the ACC/RWA present design, following the same solution proposed in previous space programs, including PROTEUS, it has been chosen to keep the internal secondary analog and digital circuits electrically isolated from the RWA chassis, in order to avoid ground loops. The ground to the structure is guaranteed at the control computer.

A set of analyses has been performed, showing potential risks, especially for the torque command interfaces.
In particular, the analyses have highlighted how possible problems can occur due to noise inducted both from the radiated E and H fields to the cables, and the goodness of the recovery solution needs to be verified by test.

Also the TWTA, where the secondary power ground is connected to EPC and TWT structure, is not in line with the applicable requirements. However, as EPC and TWT are close, the small ground loop shouldn't cause any impact at system level.

Particular attention shall be made in the bonding strap design (trying to respect in every case the required length to width ratio lower than 5:1) and in the grounding rails segments design. The aim is to keep limited also at high frequency the impedance of these items.

The Grounding diagrams are included in the H-P-DW-AI-0001.

7.7.3 Coupling

Power and signal lines will be grouped in different EMC category in line with the General Design and interface Requirements Document. To minimise cross-coupling between wires or lines of different classes the separation distances, related to parallel lengths of cabling lines, will be maximised as much as possible relating the available room for the harness paths.

7.7.4 Plasma Charging/ESD

The protection against SVM equipment damage or malfunction due to electrostatic discharge is not considered problematic. The primary risk of spacecraft charging only occurs during the relatively short transfer phase.
If the conductivity requirements are met then no problems are expected from charge build up.
In H-P-TN-AI-0079 issue 1 are shown the solutions implemented for avoiding electrostatic build-up.

For complying with the applicable requirements, all electrically conductive components of the structure including all metallic or carbon fiber items shall be electrically connected. The connector brackets shall be put in contact with the structure ground mainly by direct contact.

The risk of an internal ESD event resulting from the metallic tie bases being isolated from the SVM ground reference is considered to be low. However it is recommended that as a safeguard some provision should be made to connect each of the metallic tie bases into the SVM ground reference. The solution proposed consists of using conductive glue (TBC)

Accordingly to the present baseline, the RCS pipes do not requires to be electrically connected to the satellite reference ground via dedicated bonding straps. The pipes are in direct contact (metal to metal) with the interfacing units, and the interfacing units bonding provisions should guarantee that the RCS piping see a low impedance path with respect to the satellite ground reference. Moreover, considering the Herschel-Planck mission scenarios, the ESD risks are low.
In any case, the pipes are in direct contact with their support brackets and these brackets could be connected to the grounding rail network (a set of inserts is foreseen at lower platform level), by using additional grounding wires.

Herschel Satellite will implement a dedicate structure called Secondary Buffle. This Secondary Buffle is made of Aluminium, and needs to be refereed to the Herschel Satellite reference ground. The connection of the Buffle, will be realised connecting via a grounding wire the Buffle structure with the Sun Shade Structure, by using two dedicated anchor nuts (M4). Finally, the Sun Shade, that foresees another dedicated anchor nut (M4) will be grounded by using one grounding wire to the grounding rails network as illustrated in the following figure.

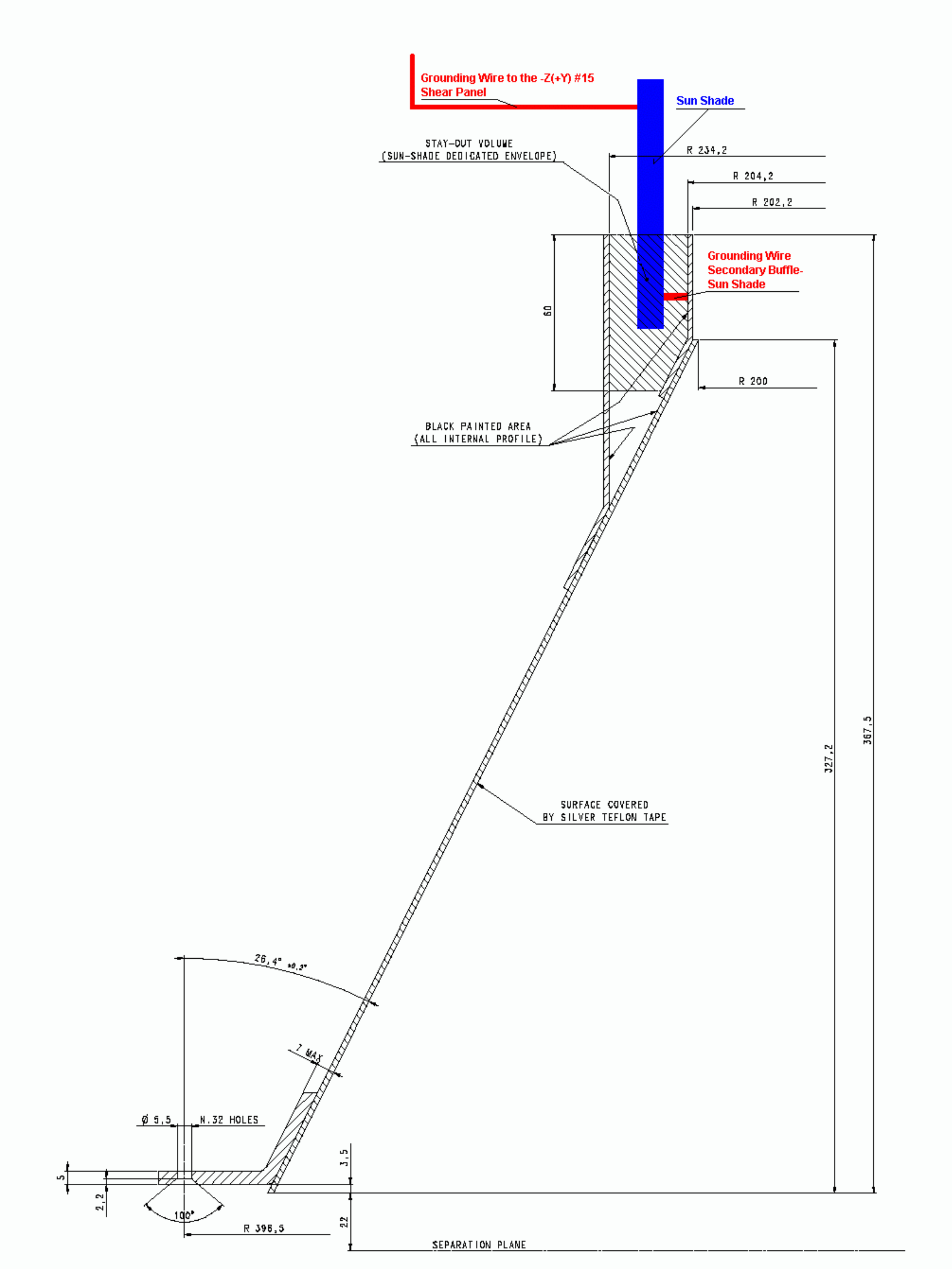


Figure 7.7-1 Secondary Buffle-Sun Shade Bonding Connections

7.7.5 SVM units EMC requirements compliance.

Based on the data available at this time, the compatibility of SVM Equipment to the EMC requirement is almost demonstrated or expected. Most of the units that shall be installed on Herschel/Planck are off-the-shelf units, which in previous programs have just undergone EMC tests. Where the verification by similarity is not possible (new Design, test level more stringent and not enveloped, etc.) additional test have been required. For more details of the SVM unit status with respect to the EMC requirements please to refer to H-P-TN-AI-0079 and to subsystems documentation.

The more relevant open points are represented by the following cases:

ACC & CDMU: both these units have failed the noise rejection test applicable to the 1553 I/F's.
According to the 1553 validation plan the noise shall be band limited, 1 kHz to 4 MHz, white Gaussian noise, with a level of 140mV RMS for Transformer coupled stubs. Several noise sources have been analysed and turned out not to produce Gaussian noise. The repetition of the test by using another noise generator did not support the initial hypothesis of a test set-up problem, but highlighted a design issue.
Acceptance tests were done in the past on COCOS ASIC (prior to integrate ACC or CDMU EQM), that according to SAAB passed successfully the 1553 error rate of 10^{-7}, as per 1553 mil std noise test.
Possibly, there are differences on threshold setting on 1553 transceiver device, which have to be investigated by the customer.

RWA: The RWA is an off-the-shelf design. For not modifying the ACC/RWA present design, it has been chosen to keep the internal secondary analog and digital circuits electrically isolated from the RWA chassis, in order to avoid ground loops. The ground to the structure is guaranteed at the control computer.

A set of analyses has been performed showing potential risks, especially for the torque command interfaces. In particular, the analyses have highlighted how possible problems can occur due to noise inducted both from the radiated E and H fields to the cables.

In order to mitigate the potential risk, conducted EMC measurements on the RWA signal lines will be performed on the EM, which is representative of the flight models.
This will allow early identification of incompatibilities. Furthermore, interface compatibility tests between the ACC and RWA will be performed on the ACMS EM test bench. Finally the P(FM) shall undergone a complete set of tests, also including RE/RS.

XPND: The EQM EMC campaign has not been performed yet, and the design of this device is substantially a "new design".

RFDN: The EQM EMC campaign has not been performed yet. Qualification campaign is expected to be completed by August 2004. However, as stated in the RFD H-P-343000-AEO-RD-0013**,** the unit should not be able to satisfy the requirement EMCEQ-100/110 of [AD-01].
The present baseline foreseen to use Electrodag, at least on the internal flanges. Another possible improvement, consists of add also an aluminium foils in the junctions area. The problem is know and is under investigation.

Without overlooking the other EMC activities, particular attention shall be made on the previous mentioned topics.

7.8 PROTECTION AGAINST RADIATION DAMAGE

7.8.1 Herschel and Planck Missions Radiation Environment Description and Requirements

The Herschel and Planck spacecraft will conduct their scientific missions during their operative lives when orbiting around the L_2 point (second Lagrange's point) of the Earth/Sun system, where they will be substantially exposed only to energetic protons and heavy ions coming with the solar wind (including "flare" phenomena) and the galactic cosmic rays. After launch, however, during their transfer orbits, the spacecraft will be exposed (once only, for a 0.22 day duration) also to Van Allen belts trapped particles (electrons, protons).
Despite the quite benign radiation environment seen by the two satellites, it is anyway necessary to evaluate their degradation and possible damages and failures due to the previous environment, that is: to assess the radiation damage risk and verify the design hardness against it, as represented by radiation related requirements.

In general, radiation related damage mechanisms to which the satellites will be subjected include:
- radiation damage by ionisation due to passage of electrons and protons into electronic devices, expressed as a function of the Total Ionising Dose (TID) left in a Silicon "detector"
- radiation damage due to microscopic displacements (Non Ionising Energy Loss - NIEL), induced mainly by protons, and affecting Solar Cells, CCDs, and optocouplers and bipolar electronics, expressed as a function of the Displacement Damage Equivalent Fluence (DDEF) of particles (equivalent 10 MeV protons in Silicon or in Gallium Arsenide, or, for the solar cells, equivalent 1 MeV electrons)
- effects from Single Event Phenomena (SEP) generated into electronic devices due to the charge left by heavy ions and protons from cosmic rays and solar wind (including "flare" phenomena), and trapped protons, which pass through the devices themselves

In the following, a synthesis is given of the system and subsystem / unit level assessments collected / performed in [SVM RADAN], in order to demonstrate compliance to the Radiation Requirements applicable to Herschel and Planck spacecraft SVM.

In general, the Radiation Requirements applicable to Herschel and Planck spacecraft SVMs are organically displayed and specified by [AD-12] (para. 3.14 – Radiation) and [AD-13] (para. 3.4.4.2.1 - Space Radiation Environment description, and para. 3.4.4.2.2 - Space Radiation Effects) specifications, and by [AD-44], which in turn reflects (or calls) the appropriate qualitative requirements or quantitative figures, tables and curves of [AD-13], and [AD-12] the [AD-44] specification provides the approach and methods to be mandatory followed:
- the **total ionising dose evaluation** and related hardness assurance is dealt in **ch. 7**;
- the **single event phenomena** hardness assurance is dealt in **ch. 8**;
- the **non-ionising effect** of radiation**, as displacement damage,** and related hardness assurance is dealt in **ch. 9.**

In particular, [AD-12] makes it applicable [AD-44], at least for SEEs, equipped with the [AD-13] data and procedures, which are displayed in its para 3.4.4.2.

The radiation requirements are reviewed and analysed in [SVM RADAN] ch. 4, to which the reader is referred for details; however, it is worthwhile to recall explicitly here some of the topmost requirements (in terms of general approach):
as far as Radiation Dose is concerned, be it related to ionising or non-ionising effects:
#----------- Reference **ENVR-010** -----------------------------
- The satellite shall be designed to withstand the doses predicted for a 2 times the nominal lifetime of the spacecraft except for the solar array sizing.

(here it is proper to quote para 3.6 about Lifetime**:**
#----------- Reference **GDGE-210** -----------------------------
- For the **Herschel** mission, the spacecraft shall have a nominal lifetime of 3.5 years. This duration is counted from the launch to end of mission. This duration includes an allocation of 6 months for the transfer to the L-2 Lissajous orbit.

Even though for "hystorical reasons" a value of **4 years** is maintained *de facto.*

#----------- Reference **GDGE-220** -----------------------------
- For the **Planck** mission, the spacecraft shall have a nominal lifetime of at least 21 months. This duration is counted from the launch to end of mission.
- This duration shall allow two full sky surveys (with a coverage of at least 95% of the full sky) at the operational Lissajous orbit around L-2, and includes an allocation of 6 months for the transfer to the L-2 Lissajous orbit.

The photovoltaic assemblies in the Solar Array of Planck (the sole one under Alenia responsibility within SVM) will be designed to survive the space radiation environment nominally during 21 months, actually, with **a margin, to the extended lifetime** of 30 months (instead of 5 years as in general specified by **ENVM-480**).

Since, apart the above mentioned Solar Array of Planck, all the equipment to be considered in the SVM design must comply with both Herschel and Planck configurations and mission profiles (exception made for RWS and GYRO which are present only in Herschel configuration), and since the mission profile is worse for Herschel under radiation point of view (since longer), actually all the environmental boundary conditions concerning radiation will be always (that is to say: for each equipment, but the Solar Array of Planck) selected for Herschel case.

The radiation hardness minimum requirement is anyway the following:
#----------- Reference **ENVM-370** -----------------------------#
- The minimum allowable radiation level for active parts shall be :
- Minimum Total Dose Behaviour : 10 krad (*Si*)
- Minimum Displacement Damage Equivalent Fluence (Si) : $6 \cdot 10^9$ p^+ (*@10 MeV*) /cm²
- Minimum Displacement Damage Equivalent Fluence (GaAs) : $5 \cdot 10^9$ p^+ (*@10 MeV*) /cm²

Concerning SEEs, due to their nature, the concept of "dose / damage integrated over time" is not applicable, and the insensitivity or hardness, as minimisation of event frequency (and consequences at component as well as at equipment level), is requested. (see next para. 7.8.2.3)

To each unit or subsystem, an essentially homogeneous (within limits of single item applicability) conceptual "sift" was devised and used, in order to organically monitor and report about the radiation analyses status, results and design impact, having considered applicable (as far as they indeed are to the individual items, of course), the whole requirements above mentioned. The results are detailedly reported in chapter 6 of [SVM RADAN], and a synthesis is given in the following paragraph 7.8.3.

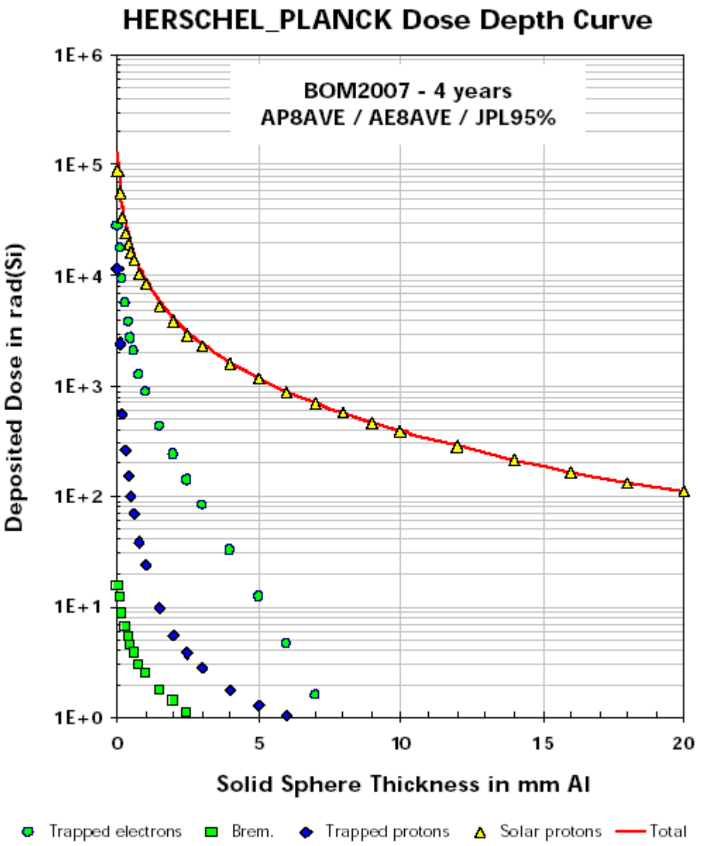
Concretely, the following points have been observed:
- Applicability and presence – as individual document(s) or not – of a radiation analysis, comprehending the following broad areas:
- the ionising effects of the radiation (TID analysis and shielding evaluation by means of the DD curve),
- the non-ionising effects of the radiation (NIEL analysis and shielding evaluation by means of the DDEF curve, or, if applicable, the photovoltaic cell damage and degradation due to radiation),
- the SEP effects, for short: SEEs (analysis of the various types of SEEs and calculation of their rates and consequences).
- Methodology, coherence, completeness, accuracy and correctness (as far as possible, as seen from system level) of the analyses scrutinised
- Coherence of the analytical results facing the environmental requirements
- Coherence of the actual reported qualification status and levels of hardness to radiation of the parts / components w.r.t. the minimum environmental / design requirements and, anyway, vs. the actual radiation level actually seen.
- Acceptability of radiation effects, also as damage / degradation, to unit and to general SVM design, as well as acceptability of design consequences necessary to counter the radiation input (shielding, …) or effects (redundancy, …)

Before synthesising the performed screening of subsystem and units radiation analyses, the next paragraph provides with generally applicable considerations derived by the environmental boundary conditions, that may help assisting / deriving the related merit assessments.

7.8.2 Herschel and Planck Preliminary SVM System-Level Radiation Effects Assessment

7.8.2.1 Total Ionising Dose Damage

In figure 7.8.2.1-1 the Herschel-Planck Total Ionising Dose versus Depth curve is reported from [AD-13], where also there is the related table.
Considering the minimum acceptable TID hardness level of 10 krad (Si) for the active parts and the required Radiation Design Margin of 2 [AD-44], the aluminium solid sphere that guarantees a sufficient shielding has a thickness of 1.86 mm. Also not considering the Payloads shield, the shielding effect of the closure panels, the platforms, and the units' boxes should protect the SVM electronics by the total dose ionisation damage. For the electronic units mounted on the external side of the SVM assembly an adequate box thickness, shielding or proper devices will be used, if needed.



.Figure: 7.8.2.1-1: Total Ionising Dose versus Depth curve

To be noted the "maximum limit" (extrapolated @ shielding = 0 mm(Al)) value of (4 years) TID of ~ 150÷200 krad for a "naked" Silicon detector.

Actually, this curve may help estimating the TID level for 1mission lifetime (to be then multiplied by two), to get a conservative assessment at unit ("equipment box") level, simply entering it with the thickness seen from inside of the box by every face, obtained by summing the constant thickness per face (constant over solid angle) value of 0.8 mm(Al) valid for each side of the 2-meter-sided cube (equivalent satellite for an equipment mounted inside SVM – [AD-44] para 7.3) plus the actual "Al-thickness" of each of the box sides; the resulting 6 doses will be summed after having multiplied them by their solid angle fractions (*id est*: doses apportioned per face will be summed up). Even more conservatively, and if sufficient: the minimum thickness between the box sides ones will be added to the satellite's 0.8 mm(Al), and the corresponding dose extracted from the curve.
This value is to be compared and to result lower than the component minimum TDT of 10 krad, or its possible higher ionising dose hardness.

A first, immediate, assessment valid for any item mounted internally to SVM, in a closed-compartment way, can be derived by the 0.8 mm(Al) "thumb" rule: TID can never exceed 11.7 krad, over 4 years, that is: 23.4 krad over the full RDL. As a matter of fact, [HP RADSHAN], chapter 4, shows that 0.8 mm(Al) are the very minimum value of the actual satellite shielding provided for each face of the equipment inside the SVM, both for Herschel and for Planck.
Even more, in [HP RADSHAN] chapter 5, a 1 mission lifetime dose calculation (preliminarily made assuming a uniform thickness of 0.8 mm(Al) for the all the boxes' wall) shows that the margin of 2 w.r.t. the TDT of 10 krad is always satisfied for all the equipment, , even those mounted outside the satellites, exception made only for the Planck focal plane unit (TID = 10 krad).

7.8.2.2 Non-Ionisation Displacement Damage

In figure 7.8.2.2-1 the Herschel-Planck Displacement Damage (induced from Non Ionising Energy Loss Dose) Equivalent Fluence versus Depth curve is reported from [AD-44], where also there is the related table.
Considering the minimum level of acceptable hardness in terms of DDEF of $6 \cdot 10^{+9}$ $_{10MeV}$ p^+ / cm^2 for Silicon detectors for the active parts, and the required Radiation Design Margin of 2 [AD-44], the aluminium solid sphere that guarantees a sufficient shielding has a thickness of 4.53 mm. For GaAs detectors, the minimum level of acceptable hardness in terms of DDEF is of $5 \cdot 10^{+9}$ $_{10MeV}$ p^+ / cm^2 , and the corresponding aluminium solid sphere shielding has a thickness of 4.63 mm. The shielding effect of the closure panels, the platforms, and the boxes' units should protect the SVM semiconductor by the displacement damage. For the electronic units mounted on the external side of the SVM assembly an adequate box thickness, shielding or proper devices will be used, if needed.

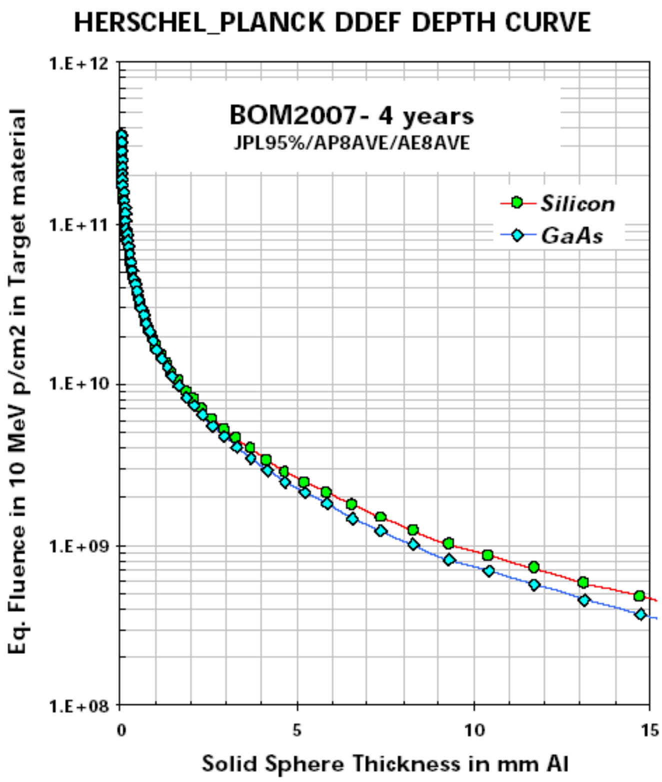


Figure 7.8.2.2-1: Displacement Damage Equivalent Fluence versus Depth curve

To be noted the "maximum limit" (extrapolated @ shielding = 0 mm(Al)) value of (4 years) DDEF of ~ $(5 \div 6) \cdot 10^{+11}$ $_{10MeV}$ p^+ / cm^2 for a "naked" either Si or GaAs detector.

Actually, in a way completely similar to TID case, this curve may help estimating the NIEL-DDEF level for 1mission lifetime (to be then multiplied by two), to get a conservative assessment at unit ("equipment box") level, simply entering it with the overall thickness seen by each of the faces from inside of box, and deriving an overall DDEF value, more or less conservative, as for TIDs.
This value is to be compared and to result lower than the component minimum DDEF of $6 \cdot 10^{+9}$ $_{10MeV}$ p^+ / cm^2 for silicon detectors (or of $5 \cdot 10^{+9}$ $_{10MeV}$ p^+ / cm^2 for Gallium Arsenide detectors), or its possible higher non-ionising dose hardnesses.
A first, immediate, assessment valid for any item mounted internally to SVM, in a closed-compartment way, can be derived by the 0.8 mm(Al) "thumb" rule: DDEF can never exceed, for Silicon items, the value of $2.26 \cdot 10^{+10}$ $_{10MeV}$ p^+ / cm^2, over 4 years, that is: $4.53 \cdot 10^{+10}$ over the full RDL; respectively: the value of $2.21 \cdot 10^{+10}$ $_{10MeV}$ p^+ / cm^2, over 4 years, that is: $4.41 \cdot 10^{+10}$ over the full RDL for Gallium Arsenide detectors.

A similar comfortable consideration in terms of shielding thickness, holds as a matter of fact from [HP RADSHAN] results consideration, also for the radiation non-ionising effects, like for radiation ionising dose, again_both for Herschel and for Planck.

7.8.2.3 Single Event Effects Damages

As baseline [RAD REQ] only parts insensitive to the following destructive events will be used:
- Single Event Latch-up (SEL),
- Single Event Burnout (SEB),
- Single Event Gate Rupture (SEGR),

for which parts a minimum LET_{th} value of 60 MeV/(mg/cm^2) is required to state insensitive; in the opposite case, suitable voltage derating rules (for SEB / SEGR affected Harris & International Rectifier) and/or knowledge of the relevant full device cross section σ (LET) is requested, and risks, impacts, detection and correction analysis, as well (see previously mentioned requirements).
On the contrary, no minimum LET_{th} or maximum σ values are specified for the non destructive events:
- Single Event Upset (SEU),
- Single Event Transient (SET),

however for sensitive devices, frequencies of events and analysis of effects and criticality on design are requested.
In all the cases the resulting analytical data must be compared with the actual design features.

7.8.2.3.1 Single Event Upset (SEU)

In particular, for SEU, determination of **SEU rate τ_{SEU}**, is required, by means of a suitable applicative programme, starting from the environmental boundary conditions of the mission as per [ENVTR], and availing of the device's cross section σ (LET). If no other calculation tools are available, SOCRATE, then OMERE, is to be used, provided by PRIME Contractor.
If the Heavy Ions threshold LET is lower than 15 MeV/(mg/cm^2), the total rate τ_{SEU} is to be calculated adding the effect of (galactic and solar) protons:

$$\tau_{SEU} = \tau_{HI} + \tau_p \ .$$

Even in a conservative way, it is possible to estimate SEU rate(s), instead that from the environment, directly from the curves / tables with provided by [AD-13] for the Herschel-Planck missions environment.
In figure 7.8.2.3.1-1 the [AD-13] Heavy Ions induced SEU rate as a function of the LET threshold of the device is reported.
It may be used, by entering even just the threshold LET and the saturation cross section of the critical device characteristic, the "single upset rate" τ_{HI} in upsets/day related to heavy ions.
In figure 7.8.2.3.1-2 the [AD-13] Protons induced rate curve as a function of the Proton energy threshold A of the part is reported.
It may be used in a similar way, to compute (estimate) a "single upset rate" in upsets/day related to protons.

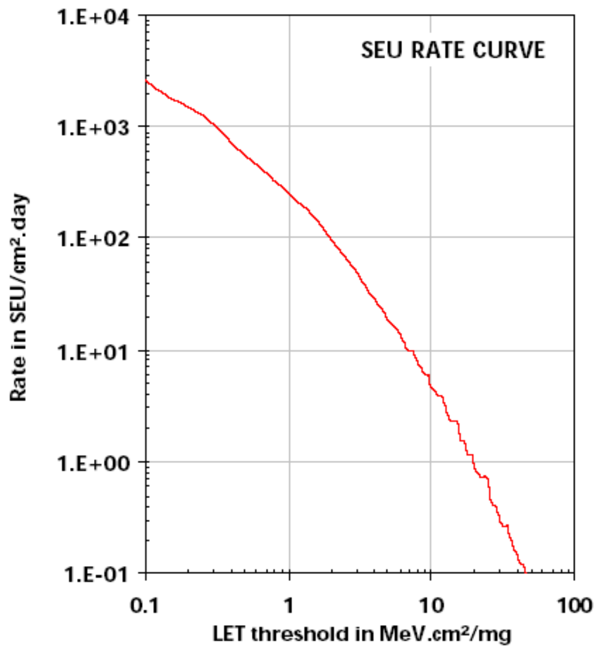


Figure 7.8.2.3.1-1: Heavy Ions Induced SEU Rate

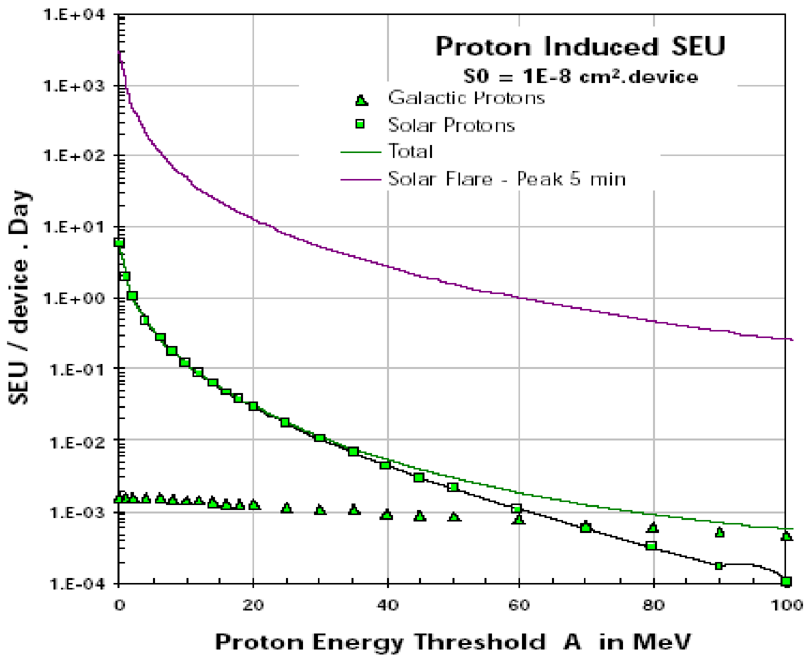


Figure 7.8.2.3.1-2: Protons Induced SEU Rate

7.8.3 SVM SubSystems and hosted units radiation analyses and assessments at system-level

The radiation analyses produced in the course of the design activity of the SVM units and subsystems listed hereafter were screened, and their methods and results evaluated in order to assess their compliance to the relevant requirements directly concerning them, including the acceptability of their impacts on the units design performances; indeed, also the effects of their output into the overall design was evaluated, so that the designs themselves can be considered adequate to the aims of surviving the operational environment of the Herschel and Planck missions.

SubSystems and Units Considered

ACMS, at subsystem level, as well as, at unit level (ACC is shifted by homogeneity to CDMS group):
- AAD
- CRS
- GYR (Herschel only)
- RWA (Herschel only)
- SAS
- STR

CDMS, at unit level:
- ACC
- CDMU

HRN, at subsystem level

PCS, at unit level:
- BATT
- PCDU

SA (Planck only)

RCS, at unit level (only radiation sensitive ones):
- Pressure Transducer
- Latching Valve
- Tank Diaphragm

TCS, at subsystem level

TT&C, at unit level:
- LGA/MGA
- RFDN
- (EPC+) TWTA
- XPND

The activity is detailed in chapter 6 of [SVM RADAN], to which full reference is made, with the exceptions of the further progress achieved in the month passed from the time of writing that document issue, when most of the units/subsystems were under review/revision (mainly under CDR), and the status of the several issues and open points raised about radiation sensitivity was generally **open**, waiting for reply/convergence and consequent updating of documentation/analysis/design; therefore it was not possible to come to a really conclusive assessment of compliance for all the units versus all the radiation environment requirements, also due to outlined areas of radiation design visibility by reporting. This is still certainly valid, but in the meantime the last three CDRs were prepared, so also the last three equipment were evaluated, and RIDs processing and reaction is to come next.
Anyway, it was already possible, also on the basis of the suppletory assessments made by Alenia and reported in the relevant paragraphs of [SVM RADAN] chapter 6, to enlarge the number of units radiation issues that are definitely close to those that can be considered essentially close, even if some answers and clarifications are still awaited.

Hereafter, therefore, the final assessment and summary chapter 7 of [SVM RADAN] will be reported, with last months modifications integrated in order to keep the information up to date.

In the first group, where **no problems at all** are found, we may list units whose situation is considered **closed**:

- LCA/MGA: no sensitivity to radiation at all;
- RFDN: TID hardness demonstrated (and revised by Alenia);
- BATT: TID hardness demonstrated (and revised by Alenia);
- AAD: NIEL hardness demonstrated (and revised by Alenia);
- SAS: NIEL hardness demonstrated (and revised by Alenia);
- TCS: no item sensitive to radiation found.

Much most populated is the group encompassing **units**, whose situation is evidently **open,** units which are characterised by a "mix" of **requirements not clearly matched** or **apparently not matched** and, even more, of **missing or unclear reporting aspects about analytical and/or qualification sides of hardness demonstration** (underlined points are to render immediately a perception of the areas provisionally felt as most critical) – a limited assessment is provided till now for them, since upgrading and amendments are due by CDRs:

CRS: TID analysis questionable (but Alenia assessment covers and closes its open points),
NIEL to be explicitly excluded,
SEE analyses and hardness data above all to completed.

GYR: essentially uncertain under any aspect (generic, too synthetic slides), anyway no danger felt behind TID / NIEL (but explanations necessary, above all NIEL neutrons-to-protons factor);
SEE to be understood and evaluated vs. design.

STR: TID analysis needs explanations and discussions, even on hypotheses, before accepting.
It,furthermore one component hardness is below minimum 9 instead 10 krad;
NIEL analysis missing, hardness of CCD not sufficiently demonstrated;
SEE analysis both in electronics and CCD needs wide explanations, as well as effects on design.

ACC/CDMU: TID analysis poor, despite hardness felt sufficient to actual dose, improvements accepted and awaited;
NIEL analysis not performed as per requirements and uncertain hardness for optocoupler reported;
SEE analysis very limited in basic data, extension, components and design effects.

HRN: TID analysis/statement versus the 10 krad level delayed and missing to-date.

RCS: TID analysis (for PT essentially) still to be provided as per requirements, and results to be compared versus correct hardness levels; reporting on tank diaphragm still missing;
SEE analysis (for PT only) "based on" partly missing LET, cross section data, partly uncorrect requirements and with important lacks.

EPC/TWTA: TID analysis description too synthetic, even on hypotheses (e.g. design lifetime) and actual hardness;
NIEL analysis scarcely reported, even on used design lifetime, perhaps not all items considered;
SEE requirements doubtfully considered, analyses insufficient, and also consequences for design.

XPND: TID analysis insufficiently explained, like hypotheses (e.g. design lifetime); thus unverifiable;
NIEL analysis missing, unmotivatedly;
SEE analyses insufficiently explained, thus unverifiable, some devices not considered for design.

As a result of the last activities it is now possible to upgrade provisional comments for **RWA** (this situation was considered **open**, too, and the judgement is confirmed) since after examining it together all the other ACMS units, was now also scrutinised for the upcoming CDR:

RWA: TID analysis impossible to evaluate, vs hardness statement (even the minimum "10 krad") missing;
NIEL consideration missing;
SEE analysis reporting almost incomprehensible and featuring many aspects at least to be clarified and integrated, as per posed questions.

No longer **"not-yet-evaluated"** are now also PCDU and SA-PVA, which join the group of **units** whose situation is **open** by actual design status:

PCDU: (TID analysis agreed and fulfilling requirements;)

NIEL damage calculations wrong as not considering the correct Radiation Design Lifetime;
SEE used requirements somewhere to be clarified, and analysis often abstract vs. concrete design, to be integrated with SEP rates comparison with actual tolerance in design features and SEP effects functional evaluation.

SA-PVA: NIEL Degradation for solar cells (Planck section considered only) calculation method, hypotheses and results to be discussed and approved w.r.t. the official specifications prescriptions.

Being this the situation, before proceeding further with the SVM system level assessment, it is felt reasonable to wait and receive from SubContractors within a reasonable time span, the reply to open RIDs and/or comments raised, or the missing documentation. After that, the complete evaluation and assessment will be provided.

7.9 ALIGNMENT AND ALIGNMENT STABILITY

7.9.1 SVM Alignment Requirements Assessment

The SVM requirements are herein listed (as they are extracted from the SVM Requirements specification). Reference to the requirement code is maintained. A brief requirement assessment is provided to allow cross check with the applicable design, error allocation and test provision and allocation

***SVM Alignment functional requirements (*Reference ALF-005-C)**
For SVM external or internal units requiring an alignment at satellite level, it shall be possible to perform this alignment without dis- and re-mounting any part of the satellite but MLI blankets.
ASSESSMENT
No equipment mounted on the SVM are requiring alignment at Satellite level. Requirements imposed by the AD-43 are referring to the SVM-PLM Reference frame and will be verified at SVM level. Requirement is considered compliant

Thermal control performance requirements (# Reference **THP-005-C**
Thermo-elastic deformation of the SVM structure shall not cause unacceptable misalignment between reference axes and sensors.
ASSESSMENT
Proper Alignment stability allocation is established for all the equipment/units requested to be stable during the one observation period. The applicability at SVM level is discussed in the assessment of requirement MEV-120-C

Reaction Control performance requirements # Reference **RCP-050-C**
The alignment stability (launch plus in-orbit) of the thrusters direction shall not exceed 0.25°.
ASSESSMENT
The requirement is considered applicable to any Herschel and Planck thruster. The LOS of the thruster firing direction shall be stable in a cone of 0.25° semi-aperture and shall consider the contribution of the launch plus the in orbit stability due to thermo-elastic distortion.
Requirement shall be sub-divided in stability of the thruster firing direction LOS w.r.t. the thruster assembly mechanical Interface (thruster bracket to Primary structure I/F) and Primary structure to PLM Reference frame.

HERSCHEL SVM Alignment performance requirements
Reference **ALP-005-H**
The SVM cube shall allow an orientation knowledge than 10 arcsec in the three directions, and shall be accessible at system level, especially before and after the mating between H-EPLM and SVM.
ASSESSMENT
The SVM Master reference cube has to be procured, mounted and measured with the specified tolerance (i.e. 10 arcsec in any direction). As part of the Alignment error allocation a proper value shall be allocated. Accessibility shall be guarantee

Reference **ALP-010-H**
The in-orbit Star Tracker LOS misalignment shall be lower than 0.25 deg (maximum), with respect to the vector -X of the SVM Interface Frame.

ASSESSMENT
The performance shall be guarantee in-orbit taking into account all the effects including the thermoelastic deformation that will contribute to the Pointing performance.
The following consideration apply.
The requirement shall be partitioned as follow:
1. Ground alignment error due to measurement error and mounting procedures (on-ground bias)
2. Launch and initial in orbit contribution
3. Thermo-elastic Stability contribution

Requirement is imposed as misalignment of the star Tracker LOS w.r.t the vector –X of the SVM reference frame.

The following requirement partitioning will be applicable:

Item	H-P	N°Axis	Reference	Global Alignment Requirement of the Item LOS w.r.t. the Reference		
				X[deg]	Y[deg]	Z[deg]
STR	H	3	PLM I/F	0.1767	0.1767	0.1767

Planck SVM Alignment performance requirements
Reference **ALP-015-P**
The in-orbit Star Tracker LOS shall not deviate of more than 0.5 deg (maximum) with respect to the vector [sin(5°), 0, cos(5°)] in SVM/PLM interface frame. This includes on-ground bias and in-orbit variations.
ASSESSMENT
The performance shall be guarantee in-orbit taking into account all the effects including the thermoelastic deformation that will contribute to the Pointing performance.
The following consideration apply.
The requirement shall be partitioned as follow:
1. Ground alignment error due to measurement error and mounting procedures (on-ground bias)
2. Launch and initial in orbit contribution
3. Thermo-elastic Stability contribution

Requirement is imposed as misalignment of the star Tracker LOS w.r.t the vector –X of the SVM reference frame.
The following requirement partitioning will be applicable:

Item	H-P	N°Axis	Reference	Global Alignment Requirement of the Item LOS w.r.t. the Reference		
				X[deg]	Y[deg]	Z[deg]
STR	P	3	[sin(5°),0,cos(5°)]of PLM I/F	0.3535	0.3535	0.3535

Offset due to STR mounting shall be considered during the measurement

Reference **ALP-020-H**
The knowledge of the SVM frame Y axis direction with respect to the launcher I/F frame shall be better than +/-0.5 arcmin at 68% confidence level.
ASSESSMENT
Requirement shall be considered as a maximum error during the measurement of the alignment of the cube placed on the Launcher Interface and the Master reference cube mounted on the SVM I/F frame. Knowledge shall be less than +/-0.5 arcmin (+/-0.008333 °). No stability nor misalignment due to in-orbit insertion shall be considered. It shall be considered only a on-ground measurement maximum error

Alignment design requirements
Reference **ALD-005-H**
Herschel SVM shall be equipped with at least 2 optical cubes (1N+1R) representing the SVM interface frame. The cubes shall be as defined in the drawing ME.HES.A010.A.001SA specified in AD3-54.
ASSESSMENT
To be procured and location for installation to be specified to Structure S/S contractor. Compliant

Reference **ALD-010-P**
Planck SVM shall be equipped with 2 cubes (1N+1R) and 4 optical balls (3N+1R), visible at satellite level, representing the SVM frame. The cubes shall be as defined in the drawing ME.PLS.A010.A.001SA specified in AD3-54.
ASSESSMENT
To be procured and location for installation to be specified to Structure S/S contractor. HAS TO BE REMINDED THAT NO OPTICAL BALLS ARE DEFINED IN THE MENTIONED DRAWING AND WILL NOT BE PROCURED

Alignment and Stability Requirements
Reference **MEV-105-C**

For each SVM, an alignment plan and budgets shall be established and maintained.

ASSESSMENT

A Plan shall be established (see this plan) listing the requirements to be met, AIT Philosophy, Test approach, description, documentation and organisation. The Alignment allocation shall be included leaving to the Budget (presently see this document on to be replaced latter with a detailed TN or Budget report) the control of the performance achievable and achieved by analysis and test

Reference **MEV-110-C**

Optical references shall be used for alignment of the focal plane instruments, telescopes and critical components

ASSESSMENT

Optical Cube(s) (defined as the master reference cube) shall be provided and installed. They will be used as reference during alignment activities for all the SVM Units needed alignment verification. The Verification of the instruments Focal Plane is out of scope as ALS activity.

Reference **MEV-115-C**

The optical references shall be accessible during SVM and system AIT operations.

ASSESSMENT

Accessibility of the master reference cube shall be guaranteed. ASP agreement and acceptance is needed.

Reference **MEV-120-C (addressed in H-P-SP-AI-0001 chapter 5.1.3.1)**

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 cool-down)
- Ageing
- Creep
- Composite structure deformations due to moisture release and radiation.

ASSESSMENT

Proper allocation shall be considered to take into account all the causes of misalignments as requested by the SVM requirement. The thermal map to allow determination of the deformation caused by orbital extreme condition shall be provided by SVM contractor and agreed with ASP. In particular systematic errors will be caused by:

- Setting due to mounting procedures
- Setting due to launch distortions
- Gravity release
- Composite structure deformations due to moisture release, out-gassing and radiation
- Ageing
- Creep

The thermal-elastic contribution is depending by the S/C attitudes and will be calculated in extreme cases. No random contribution will be take into account.

The effects and combinations of the following shall be considered:

- residual deformation of the Primary Structure after Launch (worst case contribution to consider)
- in-orbit weight distortion (1g to 0 g), considering that Propellant Tanks are full on-ground
- thermo-elastic and hygro-elastic distortion (worst case contribution to consider)

for Herschel : considering that the Cryostat is full on-ground

for Planck : considering that a spin rate of 1 rpm

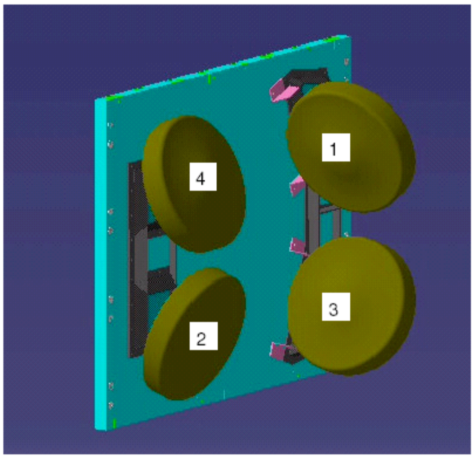
The following requirements extracted from the SVM Requirements, Configuration alignment constraints, maximum error for those item not foreseen calibration and finally from the pointing errors shall be considered: (Alignment Requirements are intended applicable to the identified axis i.e the nominal orientation of the Item (or equipment) axis w.r.t. the SVM/PLM I/F Frame)

Item	H-P	N°Axis	Reference	Global Alignment Requirement of the Item LOS w.r.t. the Reference (Item Alignment including stability shall be less than) absolute value	Uncertainty of alignment knowledge per axis (in case no calibration is foreseen)	Stability of the alignment (from pointing requirements)

				X[deg]	Y[deg]	Z[deg]	[deg]	X[deg]	Y[deg]	Z[deg]
STR	H	2	PLM I/F	0.1767	0.1767	0.1767	+/- 0,01667	0,0002222	0,0002222	0,0002222
STR	P	3	PLM I/F (1)	0.3535	0.3535	0.3535	+/- 0,01667	0,0002777	0,00027	0,00027
Gyroscope (4)	H	3	PLM I/F	0.5	0.5	0.5	+/- 0,01667	0.02	0.02	0.02
RW	H	3	PLM I/F	0.5	0.5	0.5	+/-0,1	0.02	0.02	0.02
AAD	H-P	3	PLM I/F	0.1	0.1	0.1	+/-0,03333	N/A	N/A	N/A
SAS	H-P	2	PLM I/F	0.5	0.5	0.5	+/-0,5	N/A	N/A	N/A
CRS	H-P	3	PLM I/F	0.5	0.5	0.5	+/-0,1	N/A	N/A	N/A
Thrusters (3)	H-P	3	PLM I/F (2)	0,3534	0,3534	0,3534	0,1767	0,050000	0,050000	0,050000

Table 7.9.1-1 Herschel and Planck Alignment and Alignment stability required performances

(1) Inclination of Planck STR shall be considered ([sin(5°), 0, cos(5°)] in SVM/PLM interface frame)
(2) Inclination of each H or P thrusters shall be considered with respect to the SVM/PLM interface frame
(3) Performance are requested between Thruster LOS and PLM I/F
(4) Relevant RW Inclination angle w.r.t.the SVM to PLM I/F interface frame are reported in the following figure and table:



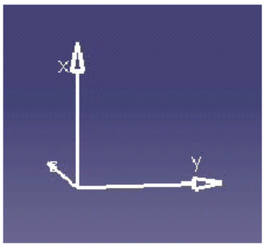


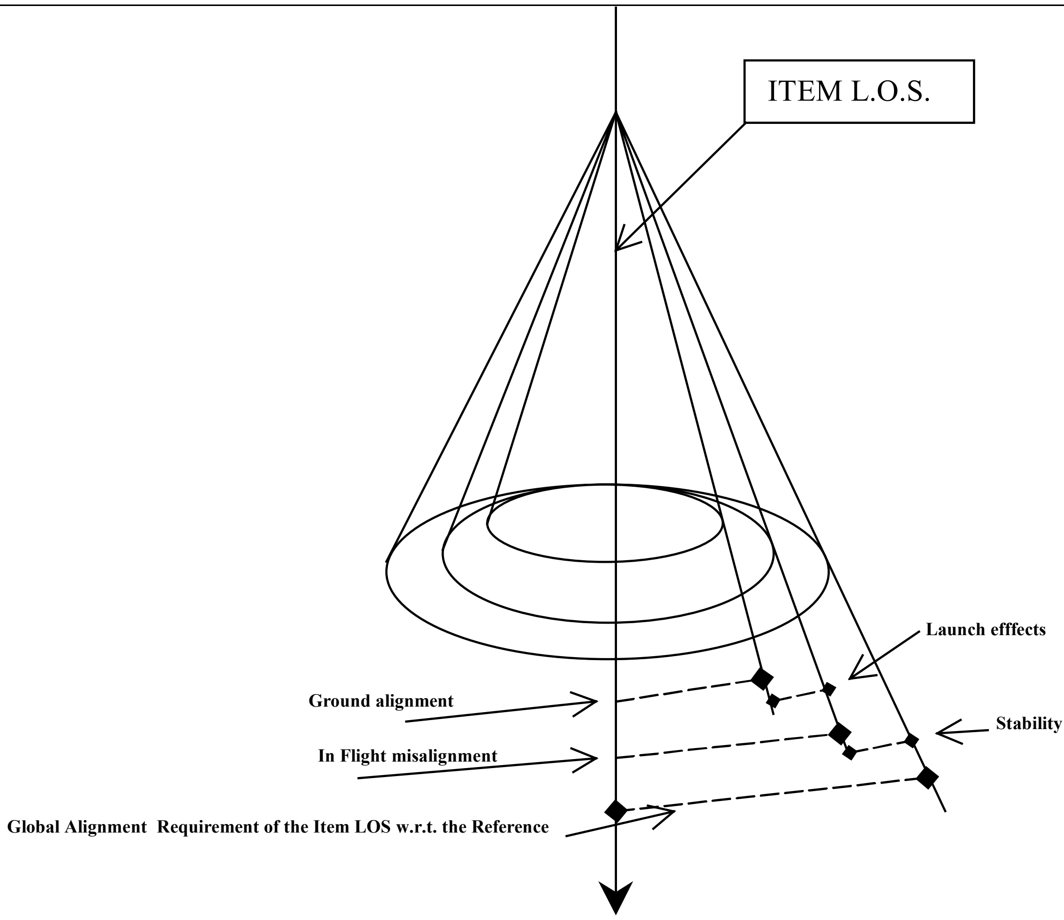
Figure 7.9.1-1 RW numbering system

Axis	RWL1	RWL2	RWL3	RWL4
X	-cos(70°)	-cos(70°)	+cos(70°)	+cos(70°)
Y	-sin(70°)cos(45°)	+sin(70°)cos(45°)	-sin(70°)cos(45°)	+sin(70°)cos(45°)
Z	-sin(70°)sin(45°)	-sin(70°)sin(45°)	-sin(70°)sin(45°)	-sin(70°)sin(45°)

table 7.9.1-2 RW Mounting angles

For each of the installed item the proper local reference axis, nomenclature and orientation are reported in the H-P-SP-AI-0009 Issue 3 (ACMS parameter Data Base) [RD-48]

The following figure with the involved error contribution is applicable:



Partitioning of the above contribution will be discussed in the next chapter

Reference **MEV-125-C (addressed in H-P-SP-AI-0001 chapter 5.1.3.2)**
The stability analysis shall be budgeted according to contributions as specified. Each potential cause of misalignment shall be compliant with its allocation.
ASSESSMENT
Cause of misalignments will be allocated and the Alignment budget will control the achievable performances with the allocated one. It has to be noted that the requirement has been partitioned at SVM level as reported in the next chapter

7.9.2 SVM Requirements

The alignment and Stability Requirements are defined and have been settled to meet the SVM Pointing performance for both the Satellite. Results have been considered in the Satellite Pointing performance evaluation as reported in the Herschel and Planck Pointing Budget [RD –114] H-P-BD-AI-0007 Issue 01
The following causes of misalignments have been 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 Global Alignment requirements reported in the column **Alignment Requirement of the Item LOS w.r.t. the Reference** are the maximum distortion that the Item will be subjected considering all the ground and Flight contribution including thermo-elastic.
The figures given for the **uncertainty of alignment knowledge** include the sum of the measurement errors on ground and all ground-to-orbit effects but exclude and measured mounting misalignment. Permanent effects due to ground to orbit settling may be subject of an in-flight calibration before each observation period. In such a case the residual errors of the calibration will replace the ground to orbit misalignment errors.
This is a set of requirements that if met will allow attitude control an scientific measurement activity as reported in the Pointing Budget. Data are in accordance withH-P-SP-AI-001 issue 6 and H-P-SP-AI-[RD-48]. Modification of the **uncertainty of alignment knowledge** has been made on the GRY Unit to make it compatible with the already imposed stability requirement (in the H-P-AI-0009 issue 3 the identified knowledge is less than the stability requirement on the H-P-SP-AI-0001)

Partitioning will be now done to provide consistent set of data according the following break-down:

Global **Alignment Requirement of the Item LOS w.r.t. the Reference frame** (requirement to be met)
=
Mounting mechanical misalignment (including unit self-misalignment and mounting tolerance) to be imposed to the AIT for shimming provision and/or adjustment
+
Sum of **Ground alignment determination Error** to be met by AIT procedure and measurement instrumentation
+
Launch to Orbit effects to be imposed to the structure subcontractor for structure material selection
+
Stability Performance to be compute considering unit location, structure material and worst case temperature map.
The last three contribution shall be compliant with the **uncertainty of alignment knowledge** requirement.

The following table summarizes the allocation of the Alignment and Stability of the Alignment both for Herschel and for Planck SVM

HERSCHEL: Alignment Requirement of the Item LOS w.r.t. the Reference frame								
Item	**Reference**	**Alignment Requirement of the Item LOS w.r.t. the Reference frame**			**Uncertainty of alignment knowledge**	**Stability of the alignment**		
		X[deg]	Y[deg]	Z[deg]	+/-[deg]	X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,176776	0,176776	0,176776	0,016667	0,000222	0,000222	0,000222
Gyroscope	PLM I/F	0,500000	0,500000	0,500000	0,083333	0,020000	0,020000	0,020000
RW	PLM I/F	0,500000	0,500000	0,500000	0,100000	0,020000	0,020000	0,020000
AAD	PLM I/F	0,100000	0,100000	0,100000	0,033333	N/A	N/A	N/A
SAS	PLM I/F	0,500000	0,500000	0,500000	0,500000	N/A	N/A	N/A
CRS	PLM I/F	0,500000	0,500000	0,500000	0,100000	N/A	N/A	N/A
Thrusters Unit	Thruster BKT	0,141421	0,141421	0,141421	0,070710	0,033000	0,033000	0,033000
Thruster BKT	PLM I/F	0,212132	0,212132	0,212132	0,106066	0,017000	0,017000	0,017000
Thrusters Assy	PLM I/F	0,353553	0,353553	0,353553	0,176776	0,050000	0,050000	0,050000

(2) Inclination of each H or P Thrusters shall be considered with respect to the SVM/PLM interface frame
(3) Performance are requested between Thruster LOS and PLM I/F and will be further partitioned in value for Thruster to bracket and bracket to PLM I/F

Table 7.9.1-3 Herschel Alignment and Alignment stability SVM requirements

PLANCK: Alignment Requirement of the Item LOS w.r.t. the Reference frame								
Item	**Reference**	**Alignment Requirement of the Item LOS w.r.t. the Reference frame**			**Uncertainty of alignment knowledge**	**Stability of the alignment**		
		X[deg]	Y[deg]	Z[deg]	+/-[deg]	X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,353553	0,353553	0,353553	0,016667	0,000278	0,000278	0,000278
AAD	PLM I/F	0,100000	0,100000	0,100000	0,033333	N/A	N/A	N/A
SAS	PLM I/F	0,500000	0,500000	0,500000	0,500000	N/A	N/A	N/A
CRS	PLM I/F	0,500000	0,500000	0,500000	0,100000	N/A	N/A	N/A
Thrusters Unit	Thruster BKT	0,141421	0,141421	0,141421	0,070710	0,033000	0,033000	0,033000
Thruster BKT	PLM I/F	0,212132	0,212132	0,212132	0,106066	0,017000	0,017000	0,017000
Thrusters Assy	PLM I/F	0,353553	0,353553	0,353553	0,176776	0,050000	0,050000	0,050000

(1) Inclination of Planck STR shall be considered ([sin(5°), 0, cos(5°)] in SVM/PLM interface frame)
(2) Inclination of each H or P Thrusters shall be considered with respect to the SVM/PLM interface frame
(3) Performance are requested between Thruster LOS and PLM I/F and will be further partitioned in value for Thruster to bracket and bracket to PLM I/F

Table 7.9.1-4 Planck Alignment and Alignment stability SVM requirements

Additional requirement has been considered for the Planck hydrazine tanks to limit the CoG fluctuation. Alignment and stability specifications apply for each PTSS :
- to the P.Tank interface points (tanks trunnions)
- with respect to the P-PLM mounting plane

Alignment and stability have been specified to be better than specified in Table 7.9.1-5

Item		Reference	Alignment		Stability
			Absolute	Relative (1)	
P.Tanks	P	PLM I/F	Dia.4 mm	Dia.2 mm	Dia.1 mm

Table 7.9.1-5 Planck PTSS Alignment and Stability Requirements

(1) between P Tanks
and will be verified by the Structure Subcontractor by analysis (results are reported in H-P-CASA-RP-0044)

7.9.3 Alignment and Alignment stability Allocation

Starting from the requirements imposed in tables 3.9.1-4 and 5 allocation to the various contributors to the overall Alignment has been performed to the applicable Items. Summary is reported in the following table:

HERSCHEL: STABILITY REQUIREMENT				
Item	Reference	**Stability of the alignment**		
		X[deg]	Y[deg]	Z[de]
STR	PLM I/F	0,000222	0,000222	0,000222
Gyroscope	PLM I/F	0,020000	0,020000	0,020000
RW	PLM I/F	0,020000	0,020000	0,020000
Thrusters Unit	Thruster BKT	0,033000	0,033000	0,033000
Thruster BKT	PLM I/F	0,017000	0,017000	0,017000
Thrusters Assy	PLM I/F	0,050000	0,050000	0,050000

Table 7.9.3-1 Herschel Stability requirement

PLANCK: STABILITY REQUIREMENT				
Item	Reference	**Stability of the alignment**		
		X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,000278	0,000278	0,000278
Thrusters Unit	Thruster BKT	0,033000	0,033000	0,033000
Thruster BKT	PLM I/F	0,017000	0,017000	0,017000
Thrusters Assy	PLM I/F	0,050000	0,050000	0,050000

Table 7.9.3-2 Planck Stability requirement

HERSCHEL: LAUNCH TO ORBIT EFFECTS ALLOCATION REQUIREMENT (including stability)				
Item	Reference	**LAUNCH TO ORBIT EFFECTS**		
		X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,011444	0,011444	0,011444
Gyroscope	PLM I/F	0,058333	0,058333	0,058333
RW	PLM I/F	0,075000	0,075000	0,075000
AAD	PLM I/F	0,028333	0,028333	0,028333
SAS	PLM I/F	0,095000	0,095000	0,095000
CRS	PLM I/F	0,095000	0,095000	0,095000
Thrusters Unit	Thruster BKT	0,032710	0,032710	0,032710
Thruster BKT	PLM I/F	0,084066	0,084066	0,084066
Thrusters Assy	PLM I/F	0,121776	0,121776	0,121776

Table 7.9.3-3 Herschel Launch to Orbit effects allocation

PLANCK: LAUNCH TO ORBIT EFFECTS ALLOCATION REQUIREMENT (including stability)				
Item	Reference	**LAUNCH TO ORBIT EFFECTS**		
		X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,011389	0,011389	0,011389
AAD	PLM I/F	0,028333	0,028333	0,028333
SAS	PLM I/F	0,095000	0,095000	0,095000
CRS	PLM I/F	0,095000	0,095000	0,095000
Thrusters Unit	Thruster BKT	0,032710	0,032710	0,032710
Thruster BKT	PLM I/F	0,084066	0,084066	0,084066
Thrusters Assy	PLM I/F	0,121776	0,121776	0,121776

Table 7.9.3-4 Planck Launch to Orbit effects allocation

The above allocation have been established considering the **uncertainty of alignment knowledge** requirement (Launch to Orbit effects = uncertainties knowledge – Stability – Measurement error)
Accordingly the **Ground alignment determination Error** is:

HERSCHEL: Ground Alignment error determination error				
Item	Reference	**Ground Alignment error determination error**		
		X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,005000	0,005000	0,005000
Gyroscope	PLM I/F	0,005000	0,005000	0,005000
RW	PLM I/F	0,005000	0,005000	0,005000
AAD	PLM I/F	0,005000	0,005000	0,005000
SAS	PLM I/F	0,005000	0,005000	0,005000
CRS	PLM I/F	0,005000	0,005000	0,005000
Thrusters Unit	Thruster BKT	0,005000	0,005000	0,005000
Thruster BKT	PLM I/F	0,005000	0,005000	0,005000
Thrusters Assy	PLM I/F	0,005000	0,005000	0,005000

Table 7.9.3-5 Herschel Ground Alignment determination Error

PLANK: Ground Alignment error determination error				
Item	Reference	**Ground Alignment error determination error**		
		X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,005000	0,005000	0,005000
AAD	PLM I/F	0,005000	0,005000	0,005000
SAS	PLM I/F	0,005000	0,005000	0,005000
CRS	PLM I/F	0,005000	0,005000	0,005000
Thrusters Unit	Thruster BKT	0,005000	0,005000	0,005000
Thruster BKT	PLM I/F	0,005000	0,005000	0,005000
Thrusters Assy	PLM I/F	0,005000	0,005000	0,005000

Table 7.9.3-6 Planck Ground Alignment determination Error

Dedicated allocation has been included in each Item specification to consider the self-misalignment contribution to the overall budget. The following tables report the collection of the requirements.

HERSCHEL: Equipment self-misalignment					
Item	**Reference**	**Unit self-misalignment**			
		X[deg]	Y[deg]	Z[deg]	
STR	Unit O.R.	0,000000	0,004722	0,041940	GA Design Report
Gyroscope	Unit O.R.	0,005555	0,005555	0,005555	H-P-4-DS-SP-0016 (G-6.3.2-04)
RW	Unit O.R.	0,014000	0,014000	0,014000	H-P-4-DS-SP-0014 (W-6.3.2-02)
AAD	Unit O.R.	0,000000	0,000000	0,000000	H-P-4-SEN-SP-0001 (D-3.3-01)
SAS	Unit O.R.	0,100000	0,100000	0,100000	H-P-4-SEN-SP-0003 (S-6.3.3-01)
CRS	Unit O.R.	0,010000	0,010000	0,010000	H-P-4-SEN-SP-0002 (Q-3.3-02)
Thrusters Unit	Unit O.R.	0,070711	0,070711	0,070711	Requirement 4.2.25 of H-P-SP-AI-0002 Issue 3
Thruster BKT	PLM I/F	n/a	n/a	n/a	Included in the allig. Accuracy
Thrusters Assy	PLM I/F	n/a	n/a	n/a	Included in the allig. Accuracy

Table 7.9.3-7 Herschel Unit self-misalignment Error

PLANCK: Equipment self-misalignment					
Item	**Reference**	**Unit self-misalignment**			
		X[deg]	Y[deg]	Z[deg]	
STR	Unit O.R.	0,000000	0,004722	0,041940	GA Design Report
AAD	Unit O.R.	0,000000	0,000000	0,000000	H-P-4-SEN-SP-0001 (D-3.3-01)
SAS	Unit O.R.	0,100000	0,100000	0,100000	H-P-4-SEN-SP-0003 (S-6.3.3-01)
CRS	Unit O.R.	0,010000	0,010000	0,010000	H-P-4-SEN-SP-0002 (Q-3.3-02)
Thrusters Unit	Unit O.R.	0,070711	0,070711	0,070711	Requirement 4.2.25 of H-P-SP-AI-0002 Issue 3
Thruster BKT	PLM I/F	n/a	n/a	n/a	Included in the allig. Accuracy
Thrusters Assy	PLM I/F	n/a	n/a	n/a	Included in the allig. Accuracy

Table 7.9.3-8 Planck Unit self-misalignment Error

To meet the overall Alignment absolute requirement the difference between the above allocated errors will impose the maximum **Mounting mechanical misalignment that** shall be reached during AIT activities or in case no Alignment procedure is planned (i.e. for SAS) the maximum acceptable error on the analytical computation

HERSCHEL: Mounting mechanical misalignment				
Item	**Reference**	**Mounting mechanical misalignment**		
		X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,160109	0,155387	0,118169
Gyroscope	PLM I/F	0,411112	0,411112	0,411112
RW	PLM I/F	0,386000	0,386000	0,386000
AAD	PLM I/F	0,066667	0,066667	0,066667
SAS	PLM I/F	0,300000	0,300000	0,300000
CRS	PLM I/F	0,390000	0,390000	0,390000
Thrusters Unit	Thruster BKT	n/a	n/a	n/a
Thruster BKT	PLM I/F	n/a	n/a	n/a
Thrusters Assy	PLM I/F	0,156066	0,156066	0,156066

Table 7.9.3-9 Herschel Mounting mechanical maximum misalignment

PLANCK: Mounting mechanical misalignment				
Item	**Reference**	**Mounting mechanical misalignment**		
		X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,336886	0,332164	0,294946
AAD	PLM I/F	0,066667	0,066667	0,066667
SAS	PLM I/F	0,300000	0,300000	0,300000
CRS	PLM I/F	0,390000	0,390000	0,390000
Thrusters Unit	Thruster BKT	n/a	n/a	n/a
Thruster BKT	PLM I/F	n/a	n/a	n/a
Thrusters Assy	PLM I/F	0,156066	0,156066	0,156066

Table 7.9.3-10 Planck Mounting mechanical maximum misalignment

7.9.4 Alignment and Alignment Stability performance data

The following four load cases have been studied:
For Herschel

NAME	SEASON	PITCH ANGLE	ROLL ANGLE
CASE 1	Winter solstice	0°	0°
CASE 2	Winter solstice	30°	0°
CASE 3	Winter solstice	-30°	0°
CASE 4	Summer solstice	0°	0°

For Planck

NAME	**SEASON**	**S.A.A**
CASE 1	Winter solstice	0°
CASE 2	Winter solstice	10°

The following tables report the actual performance achieved (or declared) for each error source

HERSCHEL: REQUIREMENT		**STABILITY**			**PERFORMANCE**			
Item	Reference	**Stability of the alignment**						
		X[deg]	Y[deg]	Z[deg]	X[deg]	Y[deg]	Z[deg]	
STR	PLM I/F	0,000222	0,000222	0,000222	0,000019	0,000118	-0,000093	note 1
Gyroscope	PLM I/F	0,020000	0,020000	0,020000	0,005032	0,011480	0,008297	RD 39
RW	PLM I/F	0,020000	0,020000	0,020000	0,015330	0,013307	0,016547	RD 39
Thrusters Unit	Thruster BKT	0,033000	0,033000	0,033000	0,000000	0,000000	0,000000	note 2
Thruster BKT	PLM I/F	0,017000	0,017000	0,017000	0,011344	0,011249	**0,021577**	RD 39
Thrusters Assy	PLM I/F	0,050000	0,050000	0,050000	0,011344	0,011249	0,021577	note 3

Note 1 Chapter 5.1.5 of this document
Note 2 Considered negligible
Note 3 Compliant with the SVM requirement

Table 7.9.4-1 Herschel Stability performance

The only item not meeting the requirement is the Thruster bracket w.r.t the PLM I/F but considering negligible the contribution of the Thruster unit w.r.t its own Bracket the overall Thruster assembly is meeting the requirement.

PLANCK: STABILITY REQUIREMENT					**PERFORMANCE**			
Item	Reference	**Stability of the alignment**						
		X[deg]	Y[deg]	Z[deg]	X[deg]	Y[deg]	Z[deg]	
STR	PLM I/F	0,000278	0,000278	0,000278	0,000120	0,000094	0,000078	RD 38
Thrusters Unit	Thruster BKT	0,033000	0,033000	0,033000	0,000000	0,000000	0,000000	note 1
Thruster BKT	PLM I/F	0,017000	0,017000	0,017000	0,000143	0,000217	0,000123	RD 38
Thrusters Assy	PLM I/F	0,050000	0,050000	0,050000	0,000143	0,000217	0,000123	

Note 1 Considered negligible

Table 7.9.4-2 Planck Stability performance

HERSCHEL: LAUNCH TO ORBIT EFFECTS ALLOCATION REQUIREMENT (including stability)					PERFORMANCE			
Item	Reference	LAUNCH TO ORBIT EFFECTS						
		X[deg]	Y[deg]	Z[deg]	X[deg]	Y[deg]	Z[deg]	
STR	PLM I/F	0,011444	0,011444	0,011444	TBD	TBD	TBD	note 1
Gyroscope	PLM I/F	0,058333	0,058333	0,058333	0,025618	0,025176	0,024452	RD 39
RW	PLM I/F	0,075000	0,075000	0,075000	0,048656	0,044862	0,051429	RD 39
AAD	PLM I/F	0,028333	0,028333	0,028333	0,009997	0,007934	0,014128	RD 39
SAS	PLM I/F	0,095000	0,095000	0,095000	0,018222	0,027029	0,014030	RD 39
CRS	PLM I/F	0,095000	0,095000	0,095000	0,033507	0,018875	0,027541	RD 39
Thrusters Unit	Thruster BKT	0,032710	0,032710	0,032710	0,000000	0,000000	0,000000	note 2
Thruster BKT	PLM I/F	0,084066	0,084066	0,084066	0,023623	0,071676	**0,084177**	RD 39
Thrusters Assy	PLM I/F	0,121776	0,121776	0,121776	0,023623	0,071676	0,084177	note 3

Note 1 To be analyzed jointly with ASP

Note 2 Considered negligible

Note 3 Compliant with the overall requirement

Table 7.9.4-3 Herschel Launch to Orbit effects allocation

The only item not meeting the requirement is the Thruster bracket w.r.t the PLM I/F but considering negligible the contribution of the Thruster unit w.r.t its own Bracket the overall Thruster assembly is meeting the requirement.

PLANCK: LAUNCH TO ORBIT EFFECTS ALLOCATION REQUIREMENT (including stability)					PERFORMANCE			
Item	Reference	LAUNCH TO ORBIT EFFECTS						
		X[deg]	Y[deg]	Z[deg]	X[deg]	Y[deg]	Z[deg]	
STR	PLM I/F	0,011389	0,011389	0,011389	0,008373	**0,078880**	**0,022149**	RD 38
AAD	PLM I/F	0,028333	0,028333	0,028333	0,017770	**0,279490**	**0,032624**	RD 38
SAS	PLM I/F	0,095000	0,095000	0,095000	0,012242	0,007247	0,029244	RD 38
CRS	PLM I/F	0,095000	0,095000	0,095000	0,079563	0,032900	0,053189	RD 38
Thrusters Unit	Thruster BKT	0,032710	0,032710	0,032710	0,000000	0,000000	0,000000	Note 1
Thruster BKT	PLM I/F	0,084066	0,084066	0,084066	0,019771	0,031516	0,016418	RD 38
Thrusters Assy	PLM I/F	0,121776	0,121776	0,121776	0,019771	0,031516	0,016418	Note 2

Note 1 Considered negligible

Note 2 Compliant with the overall requirement

Table 7.9.4-4 Planck Launch to Orbit effects allocation

The above allocation have been established considering the **uncertainty of alignment knowledge** requirement (Launch to Orbit effects = uncertainties knowledge – Stability – Measurement error)

The following items are out of the allocation:
Star Tracker: It will be requested a modification of the uncertainty on the knowledge of 5 armin instead of 1 arcmin.
AAD: It has to be noted that the contributions to the Launch to orbit effects on the analyzed equipment are added considering the absolute value without look on the direction of the deformation. The above calculation is of course the worst case scenario but it is not considering the physics of the problem.
Adding the value with its own sign the out of spec is reduced from 1 order of magnitude to the same order of magnitude. :
The remaining error can be compensated accepting uncertainties on the knowledge of 4 arcmin instead of 1 arcmin This will solve the issue of the Launch to orbit contribution but will decrease the contribution to the Ground

alignment of the same order of magnitude (i.e. 2 arcmin = 0,003333) the allocated Ground error then will become 0,0033 (i.e. 2 arcmin) that is still be acceptable.

AAD	X[deg]	Y[deg]	Z[deg]
Maximum thermal distortion	0,010573	0,102830	0,007714
MOISTURE Contribution	-0,005524	-0,163838	-0,015204
Gravity release Contribution	-0,001661	0,012017	-0,009409
Spin rate Contribution	0,000011	-0,008050	0,000297
Total Align. Contribution	0,003399	-0,057041	-0,016602
Requirement	**0,028333**	**0,028333**	**0,028333**
Out of specification	**Compl**	**0,028708**	**Compl**

Obtained performance for the **Ground alignment determination Errors** are:

HERSCHEL: Ground Alignment error determination error					**PERFORMANCE** Reference Alignment Plan		
Item	Reference	**Ground Alignment determinatio error**					
		X[deg]	Y[deg]	Z[deg]	X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
Gyroscope	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
RW	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
AAD	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
SAS	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
CRS	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
Thrusters Unit	Thruster BKT	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
Thruster BKT	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
Thrusters Assy	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200

Table 7.9.4-5 Herschel Ground Alignment determination Error

PLANK: Ground Alignment error determination error					**PERFORMANCE** Reference Alignment Plan		
Item	Reference	**Ground Alignment determinatio error**					
		X[deg]	Y[deg]	Z[deg]	X[deg]	Y[deg]	Z[deg]
STR	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
AAD	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
SAS	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
CRS	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
Thrusters Unit	Thruster BKT	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
Thruster BKT	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200
Thrusters Assy	PLM I/F	0,005000	0,005000	0,005000	0,002200	0,002200	0,002200

Table 7.9.4-6 Planck Ground Alignment determination Error

Presently no performances have been declared by the units suppliers but statement of compliance on the above is ensured.

HERSCHEL: Equipment self-misalignment					PERFORMANCE			
Item	Reference	Unit self-misalignment						
		X[deg]	Y[deg]	Z[deg]	X[deg]	Y[deg]	Z[deg]	
STR	Unit O.R.	0,000000	0,004722	0,041940	0,000000	0,004722	0,041940	Note 1
Gyroscope	Unit O.R.	0,005555	0,005555	0,005555	0,005555	0,005555	0,005555	Note 2
RW	Unit O.R.	0,014000	0,014000	0,014000	0,014000	0,014000	0,014000	Note 3
AAD	Unit O.R.	0,000000	0,000000	0,000000	0,000000	0,000000	0,000000	Note 4
SAS	Unit O.R.	0,100000	0,100000	0,100000	0,100000	0,100000	0,100000	Note 5
CRS	Unit O.R.	0,010000	0,010000	0,010000	0,010000	0,010000	0,010000	Note 6
Thrusters Unit	Unit O.R.	0,070711	0,070711	0,070711	0,070711	0,070711	0,070711	Note 7
Thruster BKT	PLM I/F	n/a	n/a	n/a	n/a	n/a	n/a	Note 8
Thrusters Assy	PLM I/F	n/a	n/a	n/a	n/a	n/a	n/a	Note 8

Note 1 GA Design Report
Note 2 H-P-4-DS-SP-0016 (G-6.3.2-04)
Note 3 H-P-4-DS-SP-0014 (W-6.3.2-02)
Note 4 H-P-4-SEN-SP-0001 (D-3.3-01)
Note 5 H-P-4-SEN-SP-0003 (S-6.3.3-01)
Note 6 H-P-4-SEN-SP-0002 (Q-3.3-02)
Note 7 Requirement 4.2.25 of H-P-SP-AI-0002 Issue 3
Note 8 Included in the allig. Accuracy

Table 7.9.4-7 Herschel Unit self-misalignment Error

PLANCK: Equipment self-misalignment					PERFORMANCE			
Item	Reference	Unit self-misalignment						
		X[deg]	Y[deg]	Z[deg]	X[deg]	Y[deg]	Z[deg]	
STR	Unit O.R.	0,000000	0,004722	0,041940	0,000000	0,004722	0,041940	Note 1
AAD	Unit O.R.	0,000000	0,000000	0,000000	0,000000	0,000000	0,000000	Note 2
SAS	Unit O.R.	0,100000	0,100000	0,100000	0,100000	0,100000	0,100000	Note 3
CRS	Unit O.R.	0,010000	0,010000	0,010000	0,010000	0,010000	0,010000	Note 4
Thrusters Unit	Unit O.R.	0,070711	0,070711	0,070711	0,070711	0,070711	0,070711	Note 5
Thruster BKT	PLM I/F	n/a	n/a	n/a	n/a	n/a	n/a	Note 6
Thrusters Assy	PLM I/F	n/a	n/a	n/a	n/a	n/a	n/a	Note 6

Note 1 GA Design Report
Note 2 H-P-4-SEN-SP-0001 (D-3.3-01)
Note 3 H-P-4-SEN-SP-0003 (S-6.3.3-01)
Note 4 H-P-4-SEN-SP-0002 (Q-3.3-02)
Note 5 Requirement 4.2.25 of H-P-SP-AI-0002 Issue 3
Note 6 Included in the allig. Accuracy

Table 7.9.4-8 Planck Unit self-misalignment Error

To meet the overall Alignment absolute requirement the difference between the above allocated errors will impose the maximum **Mounting mechanical misalignment that** shall be reached during AIT activities or in case no Alignment procedure is planned (i.e. for SAS) the maximum acceptable error on the analytical computation. Obviously no measurement data are today available but imposed allocation is not impossible to meet.

HERSCHEL: Mounting mechanical misalignment					**PERFORMANCE**			
Item	**Reference**	**Mounting mechanical misalignment**						
		X[deg]	Y[deg]	Z[deg]	X[deg]	Y[deg]	Z[deg]	
STR	PLM I/F	0,160109	0,155387	0,118169	TBD	TBD	TBD	
Gyroscope	PLM I/F	0,411112	0,411112	0,411112	TBD	TBD	TBD	
RW	PLM I/F	0,386000	0,386000	0,386000	TBD	TBD	TBD	
AAD	PLM I/F	0,066667	0,066667	0,066667	TBD	TBD	TBD	
SAS	PLM I/F	0,300000	0,300000	0,300000	TBD	TBD	TBD	
CRS	PLM I/F	0,390000	0,390000	0,390000	TBD	TBD	TBD	
Thrusters Unit	Thruster BKT	n/a	n/a	n/a	n/a	n/a	n/a	Note 1
Thruster BKT	PLM I/F	n/a	n/a	n/a	n/a	n/a	n/a	Note 2
Thrusters Assy	PLM I/F	0,156066	0,156066	0,156066	TBD	TBD	TBD	

Note 1 Internal to Assy
Note 2 Included in the allig. Accuracy

Table 7.9.4-9 Herschel Mounting mechanical maximum misalignment

PLANCK: Mounting mechanical misalignment					**PERFORMANCE**			
Item	**Reference**	**Mounting mechanical misalignment**						
		X[deg]	Y[deg]	Z[deg]	X[deg]	Y[deg]	Z[deg]	
STR	PLM I/F	0,336886	0,332164	0,294946	TBD	TBD	TBD	
AAD	PLM I/F	0,066667	0,066667	0,066667	TBD	TBD	TBD	
SAS	PLM I/F	0,300000	0,300000	0,300000	TBD	TBD	TBD	
CRS	PLM I/F	0,390000	0,390000	0,390000	TBD	TBD	TBD	
Thrusters Unit	Thruster BKT	n/a	n/a	n/a	n/a	n/a	n/a	Note 1
Thruster BKT	PLM I/F	n/a	n/a	n/a	n/a	n/a	n/a	Note 2
Thrusters Assy	PLM I/F	0,156066	0,156066	0,156066	TBD	TBD	TBD	

Note 1 Internal to Assy
Note 2 Included in the allig. Accuracy

7.9.5 SVM Alignment performance vs requirement summary

As shown in the previous table overall alignment requirement can be met (except for the AAD on witch recovery actions should be investigated). It has to be considered that even if the last contribution on the alignment performance can be known only after SVM integration and Alignment activity, the allocation is easy to be met.

8. RESOURCE BUDGETS

8.1 Mass Budget and Mass properties

Overall SVM mass and properties are reported in [RD-113] (H/P Mass Budget and Properties Report) H-P-RP-AI-0061 Issue 03 included in the H-P CDR data package). This summary contains updating not yet reflected in the [RD-113] that will be updated later and includes last information from the Sub-Contractor and a more precise evaluation of the mass properties (mainly Inertia)
A brief summary is here reported.
The mass properties of those items which - although not under the SVM responsibility - are accommodated onboard the SVM of Herschel and Planck (i.e. Warm Units, Warm Units Interconnecting Harness, SREM, VMC(Herschel only), FOG, CCU, Cryo Harness) are not considered for the SVM mass budget purposes.
On the other hand, the mass properties of the aforementioned “non-SVM” items are considered for the SVM mass properties purposes.
Finally, the propellant and the balancing masses are always out of the scope of the present document.

The following table summarises the applicability policy applied throughout the present report.

	SVM Items	Non-SVM Items	Propellant	Balancing Masses
SVM Mass Budget	**Y**	**N**	**N**	**N**
SVM Mass Properties	**Y**	**Y**	**N**	**N**

8.1.1 Herschel Mass Properties data:

A summary of Herschel SVM mass budget is given in Table 8.1-1.
The mass budget figures presented during the PDR are reported in the “Previous Max Mass” for comparison with the current values.

S/S	Nominal Mass [kg]	Max Mass [kg]	S/S Spec. Mass [kg]	Previous Max Mass [kg]	Delta Max Mass [kg]
ACMS	68.9	74.0	72.0	80.7	-6,7
CDMS	13.9	14.7	15.5	16.8	-2,1
HRN	79.6	87.6	85.0	59,4	28,2
PCS	33.5	34.9	36.0	39.4	-4,5
RCS	54.7	57.9	58.0	40.9	17.0
STR	339.9	350.3	287.0	239.8	110,5
TCS	28.9	32.5	23.0	21.6	10.9
TT&C	25.6	26.6	23.0	24.3	2.3
NFH	2.8	3.4	0.0	0	3.4
Grand Total	**647.9**	**681.9**	**599.5**	**522,9**	**+159**

Table 8.1-1-1: Herschel SVM Mass Budget

The location of Herschel SVM Centre of Gravity is given in Table 8.1-1 (w.r.t. the SVM reference frame).

	Mass [kg]	X_{COG} [mm]	Y_{COG} [mm]	Z_{COG} [mm]
Nominal Mass	866.5	489	10	-146
Max Mass	918.6	489	1	-148

Table 8.1.1-2: Herschel SVM C.o.G. location

The components of Herschel SVM inertia tensor - based on the nominal mass values, and referred to satellite C.o.G. - are given in Table 4.2-2.

J_{XX}	1837.4 kg*m^2
J_{YY}	840.7 kg*m^2
J_{ZZ}	1119.2 kg*m^2
J_{XY}	9.2 kg*m^2
J_{YZ}	9.6kg*m^2
J_{XZ}	-6.0 kg*m^2

Table 8.1.1-3: Herschel SVM inertia tensor components

No consolidated data was presented at the PDR due to high uncertainties on the input data and accommodation exercise
The following table summarises the Mass properties data compared with the SVM requirement. A graphics representation of the evolution of the mass for the proposal to the CDR.

Requirement	*Requirement Value*	*Current Value*	*Compliance*	*Remarks*
SVM Mass	< 600 kg	681.9 kg	**N**	Warm units, propellant, pressurant and balancing masses excluded.
C.o.G. Location	+25 mm < Y < +75 mm -150 mm < Z < -80 mm	Y = 10 mm Z = -146 mm	**N** **Y**	SVM dry and equipped with payload warm units.
C.o.G. Accuracy	< 5mm along X axis < 2mm in YZ plane	- -	**Not Yet Evaluated**	SVM dry and equipped with payload units.
Main Inertia	J_{XX} < 1500 kg*m^2 J_{YY} = N/A J_{ZZ} = N/A	J_{XX} = 1837.4 kg*m^2	**N**	SVM dry and equipped with payload units
Inertia Cross Product	$\|J_{XY}\|$ < 100 kg*m^2 $\|J_{XZ}\|$ < 100 kg*m^2	$\|J_{XY}\|$ = 9.2 kg*m^2 $\|J_{XZ}\|$ = 6.0 kg*m^2	**Y** **Y**	SVM dry and equipped with payload units in nominal mass conditions.

Table 8.1.1-4: Herschel SVM compliance vs MCI requirements

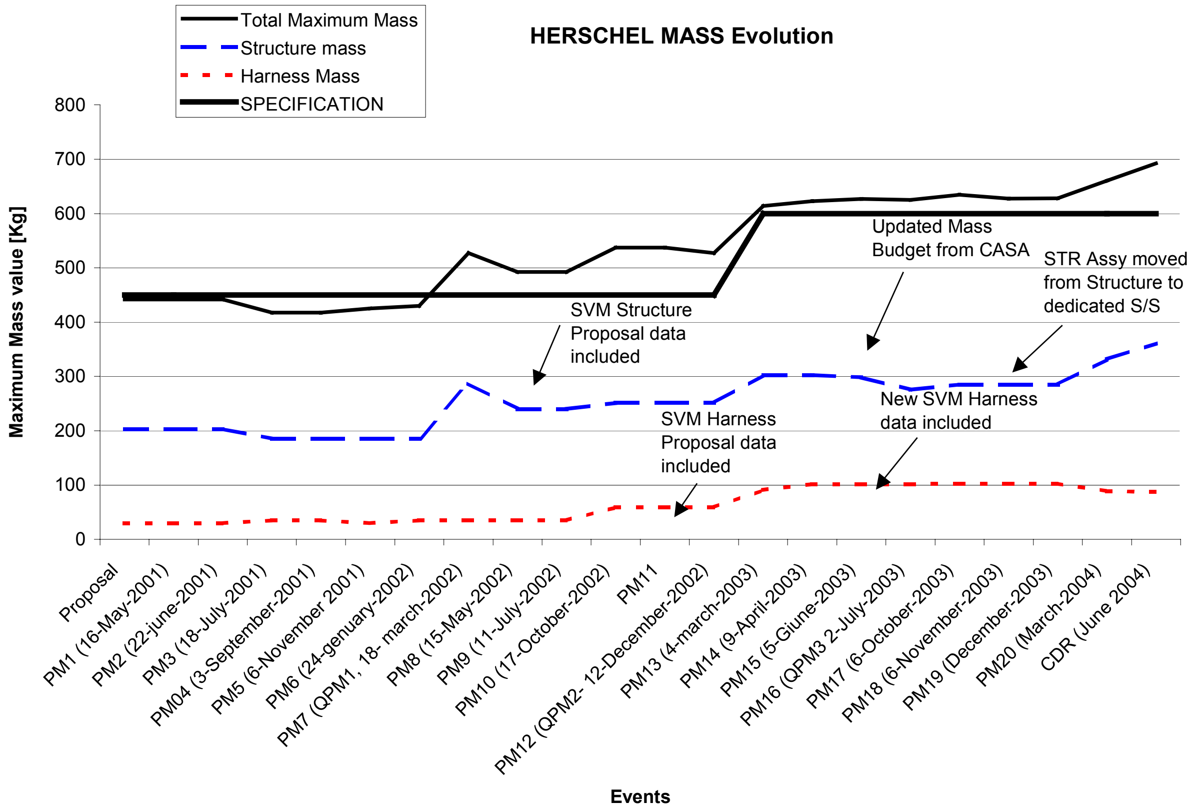


Figure 8.1.1-1 Herschel Mass evolution

8.1.2 Planck Mass Properties data:

A summary of Planck SVM mass budget is given in Table 8.1-1.
The mass budget figures presented during the PDR are reported in the "Previous Max Mass" for comparison with the current values.

S/S	Nominal Mass [kg]	Max Mass [kg]	S/S Spec Mass [kg]	Previous Max Mass [kg]	Delta Max Mass [kg]
ACMS	25.8	27.2	30.0	34,6	-7,4
CDMS	13.9	14.7	15.5	16,8	-2,1
HRN	78.3	86.1	85.0	57,0	29,1
PCS	33.5	34.9	36.0	39,4	-4,5
RCS	72.8	77.1	78.0	57,9	19,2
SA	41.4	42.1	45.0	44,9	-1,2
STR	384.3	400.4	310.0	256	144,4
TCS	54.5	58.7	53.0	53,6	5,1
TT&C	29.1	30.1	24.0	25,6	4,5
NFH	12.7	15.2	0.0	0,0	15,2
Grand Total	**746.3**	**785.2**	**676.5**	**585,8**	**199,4**

Table 8.1.2-1: Planck Mass Budget

The location of Planck SVM Centre of Gravity is given in Table 5.2-1 (w.r.t. the SVM reference frame).

	Mass [kg]	X_{COG} [mm]	Y_{COG} [mm]	Z_{COG} [mm]
Nominal Mass	1109.1	537	37	20
Max Mass	1179.0	538	35	15

Table 8.1.2-2: Planck SVM C.o.G. location

The components of Planck SVM inertia tensor - based on the nominal mass values, and referred to satellite C.o.G. - are given in Table 5.2-2.

J_{XX}	2183.1 kg*m^2
J_{YY}	1125.2 kg*m^2
J_{ZZ}	1240.5 kg*m^2
J_{XY}	-12.2 kg*m^2
J_{YZ}	-45.0 kg*m^2
J_{XZ}	-20.6 kg*m^2
J_1	2183.7 kg*m^2
J_2	1255.3 kg*m^2
J_3	1109.7 kg*m^2

Table 8.1.2-3: Planck SVM inertia tensor components

No consolidated data was presented at the PDR due to high uncertainties on the input data and accommodation exercise. The following table summarises the Mass properties data compared with the SVM requirement. A graphics representation of the evolution of the mass for the proposal to the CDR.

Requirement	*Requirement Value*	*Current Value*	*Compliance*	*Remarks*
SVM Mass	< 680 kg	786.5 kg	**N**	Warm units, propellant, pressurant and balancing masses excluded.
C.o.G. Location	-10 mm < Y < +10 mm +20 mm < Z < +35 mm	Y = 37 mm Z = 20 mm	**N** **N**	SVM dry and equipped with payload warm units.
C.o.G. Accuracy	< 5mm along X axis < 2mm in YZ plane	- -	**Not Yet Evaluated**	SVM dry and equipped with payload units.
Main Inertia	J_{XX} < 2100 kg*m^2 $\lambda^{(1)} > 1.81$	J_{XX} = 2183.1 kg*m^2 $\lambda = 1.85$	**N** **Y**	SVM dry and equipped with payload units
Inertia Cross Product	$\lvert J_{XY}\rvert$ < 25 kg*m^2 $\lvert J_{XZ}\rvert$ < 25 kg*m^2 RSS$^{(2)}$ < 25 kg*m^2	$\lvert J_{XY}\rvert$ = 12.2 kg*m^2 $\lvert J_{XZ}\rvert$ = 20.6 kg*m^2 RSS = 24.0 kg*m^2	**Y** **Y** **Y**	SVM dry and equipped with payload units in nominal mass conditions.

$\lambda = 1 + \text{sqrt}\,[(J_1 / J_2 - 1)*(J_1 / J_3 - 1)]$

λ calculation is performed using **nominal** mass values

RSS = sqrt(J_{XY}^2 + J_{XZ}^2)

Table 8.1.2-4: Planck SVM compliance vs MCI requirements

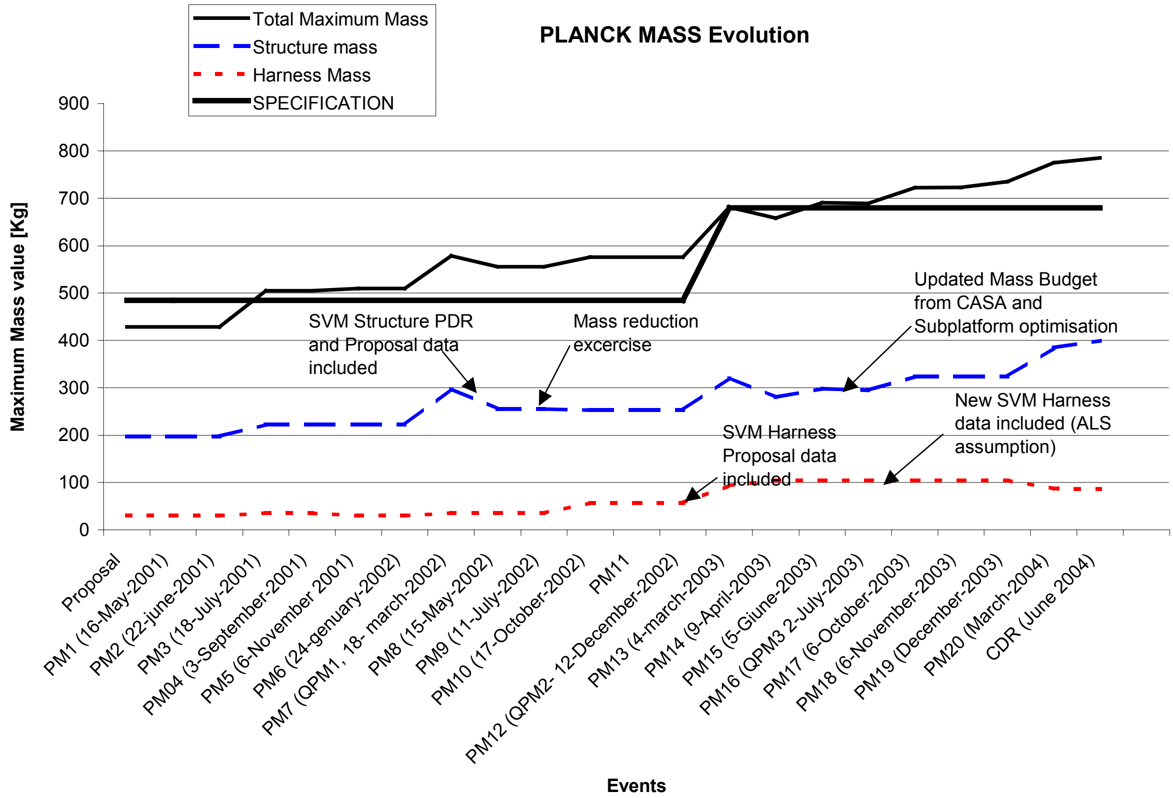


Figure 8.1.2-1 Planck mass evolution

Recovery actions have been started to recover the out of specification highlighted in the previous chapter mainly on the Structure subsystem and on the Harness but it is Alenia intention to issue a dedicated RFD showing the impossibility to meet all the other applicable requirements and the imposed (in the SVM specification) SVM Mass.

8.2 Link Budget

Overall SVM Link Budget is reported See [RD-112] (Link Budget Report) H-P-BD-AI-0005 Issue 01 included in the H-P CDR data package. A brief summary of the are here reported.
The link budgets have been calculated considering the Ground Station characteristics ad data given in the Space to Ground ICD

Kourou
Herschel and Planck nominal configuration

Uplink 125 bps with LGA,
4 kbps via MGA
Downlink 500 bps via LGA and
150 kbps via MGA

New Norcia
Herschel and Planck nominal configuration

Uplink 4 kbps with LGA and MGA,
Downlink 5 kbps via LGA,
150 kbps via MGA
1.5 Mbps via MGA

As a support to the complete set of link budgets provided in the SVM Budget Report, this section summarises the system margins in the same format as the one used during the proposal:

HERSCHEL UPLINK BUDGETS				KOUROU G/S						NEW NORCIA G/S						
			Mode / Antennas	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only
			Antennas	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	MGA
			BIT RATE (kbps)	0.125	0.125	0.125	0.125	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
			S/C ALTITUDE (* 10^6 km)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
PARAMETER	MARGING	ESA Margin dB		calculated margins (dB)						calculated margins (dB)						
Carrier Recovery	Nominal	3		4.69	4.14	4.28	3.72	23.54	22.99	20.72	20.37	20.53	19.95	39.79	39.44	39.73
	mean -3*sigma	0		3.32	2.75	2.90	2.33	21.24	20.67	18.92	18.56	18.65	18.14	36.99	36.64	36.93
	margin - wc RSS	0		3.34	2.78	2.93	2.36	21.94	21.38	19.19	18.83	18.99	18.41	38.03	37.68	37.97
Telecommand Recovery	Nominal	3		5.02	4.47	4.61	4.06	8.83	8.27	6.00	5.65	5.81	5.24	25.08	24.72	25.01
	mean -3*sigma	0		4.18	3.60	3.76	3.18	7.05	6.47	4.63	4.26	4.37	3.84	22.71	22.34	22.64
	margin - wc RSS	0		4.03	3.46	3.62	3.04	7.51	6.95	4.77	4.41	4.58	3.99	23.57	23.21	23.51

PLANCK UPLINK BUDGETS				KOUROU G/S					NEW NORCIA G/S						
			Mode / Antennas	TC only	TC+RNG	TC only	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only
			Antennas	LGA 1	LGA 1	LGA 2&3	MGA	MGA	LGA 1	LGA 1	LGA 2&3	LGA 2&3	MGA	MGA	MGA
			BIT RATE (kbps)	0.125	0.125	0.125	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
			S/C ALTITUDE (* 10^6 km)	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
PARAMETER	MARGING	ESA Margin dB		calculated margins (dB)					calculated margins (dB)						
Carrier Recovery	Nominal	3		5.71	4.02	1.45	24.62	24.07	21.74	20.25	17.65	17.30	37.87	37.52	37.87
	mean -3*sigma	0		4.34	2.63	0.01	22.32	21.75	19.94	18.44	15.72	15.36	35.20	34.84	35.19
	margin - wc RSS	0		4.36	2.66	0.08	23.02	22.46	20.21	18.71	16.10	15.74	36.15	35.79	36.14
Telecommand Recovery	Nominal	3		6.04	5.49	1.78	9.90	9.35	7.02	6.67	2.93	2.58	23.15	22.80	23.15
	mean -3*sigma	0		4.18	4.62	0.87	8.13	7.55	5.65	5.28	1.43	1.07	20.92	20.55	20.91
	margin - wc RSS	0		5.05	4.48	0.77	8.59	8.03	5.79	5.43	1.68	1.32	21.69	21.33	21.69

As identified in the first issue of link budgets, the uplink performances are marginal (on Planck only) with Kourou ground station (identified to be used not as nominal) when using the low gain antennas (LGA2&3 in emergency mode). Though, the telemetry subcarrier recovery margins remain acceptable. The Planck to Kourou link through the two redundant LGAs has been evaluated at the 1,6 10^6 km distance and only in the TC mode as this is an emergency situation.

No criticality identified on the uplink budgets.

HERSCHEL DOWNLINK BUDGETS				KOUROU G/S						NEW NORCIA G/S						
			Mode	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only
			Antennas	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	MGA
			BIT RATE (kbps)	0.5	0.5	0.5	0.5	150.0	150.0	5.0	5.0	5.0	5.0	150.0	150.0	1500.0
			S/C ALTITUDE (* 10^3 km)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
PARAMETER	MARGING	ESA Margin dB		calculated margins (dB)						calculated margins (dB)						
Carrier Recovery	Nominal	3		8.95	8.41	8.80	8.15	21.53	21.48	21.34	20.79	21.41	20.53	34.13	34.08	44.15
	mean -3*sigma	0		7.74	7.10	7.59	6.82	16.35	16.28	19.97	19.22	20.00	18.91	28.74	28.65	42.70
	margin - wc RSS	0		7.67	7.05	7.52	6.77	17.20	17.13	20.07	19.35	20.14	19.05	29.81	29.73	43.12
Telemetry Recovery	Nominal	3		6.19	5.65	6.04	5.38	3.14	3.09	8.57	8.03	8.64	7.76	15.74	15.69	6.04
	mean -3*sigma	0		5.54	5.08	5.39	4.84	2.21	2.18	7.78	7.38	7.82	7.14	14.63	14.60	5.17
	margin - wc RSS	0		5.44	4.97	5.29	4.72	2.38	2.34	7.85	7.44	7.92	7.19	15.01	14.98	5.37

PLANCK DOWNLINK BUDGETS				KOUROU G/S					NEW NORCIA G/S						
			Mode	TM only	TM+RNG	TM only	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only
			Antennas	LGA 1	LGA 1	LGA 2&3	MGA	MGA	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	MGA
			BIT RATE (kbps)	0.5	0.5	0.5	150.0	150.0	5.0	5.0	5.0	5.0	150.0	150.0	1500.0
			S/C ALTITUDE (* 10^3 km)	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
PARAMET	MARGING	ESA Margin dB		calculated margins (dB)					calculated margins (dB)						
Carrier Recovery	Nominal	3		9.97	9.43	5.74	22.55	22.50	22.36	21.81	18.34	18.61	32.15	31.80	42.17
	ean -3*sigr	0		8.76	8.12	4.36	17.37	17.30	20.99	20.21	16.77	17.10	26.86	26.20	40.84
	rgin - wc F	0		8.69	8.07	4.32	18.22	18.15	21.09	20.35	16.93	17.26	27.84	27.23	41.20
Telemetry Recovery	Nominal	3		7.21	6.67	4.06	4.16	4.11	9.59	9.05	6.66	6.39	13.76	13.41	4.06
	ean -3*sigr	0		6.56	6.10	3.46	3.23	3.20	8.80	8.41	5.90	5.61	12.79	12.54	3.34
	rgin - wc F	0		6.46	5.99	3.36	3.40	3.36	8.87	8.47	5.99	5.71	13.12	12.84	3.49

Comfortable margins achieved on all downlinks and here as well no criticality identified.

8.3 Power Budget

Overall SVM Power Budget is reported in [RD-115] (Power Budget Report) H-P-BD-AI-0008 Issue 0 included in the H-P CDR data package. A brief summary of the are here reported.

The allocated power is as instruments power demand Difference between the actual power demand and the allocation, will be added as a virtual load. This virtual load also affects the series losses. Losses on harness between PCDU and PLM unit have been accounted to the SVM. ESA reserve assumed is 30% of the SVM power in pre-launch and LEOP and 100 W for other phases. This reserve also is considered as a further virtual load that affects series losses and PCDU power demand. This reserve is decreased according to the agreements to cope with special cases of power demand. ESA reserve is used to supply ESA units (FOG's) on Planck and part of TCS on Herschel. Design margin has been added to each unit power demand.

Harness losses are related to harness from PCDU SVM/PLM units. Series losses in the PCDU are including also instrument losses. These losses are due to the equivalent resistance of the LCL and other series elements and have been calculated by a model provided by the PCDU manufacturer. These losses are included in the PCDU power demand. Balance is at solar array interface at a voltage of 30 V. Losses on harness between solar array interface point and PCDU are also included

HERSCHEL SUMMARY POWER BUDGET			
		Pre launch	LEOP
PLM total		12.5	12.5
SVM			
	CDMS	37.7	37.7
	TT&C	40.7	40.7
	ACMS	32.38	32.38
	RCS	25.53	25.53
	TCS	0	0
	PCS	43.40	45.10
	Harness	3.21	3.21
Losses SA - PCDU		2.10	
Losses BTR - PCDU			1.30
SVM	total	185.01	185.92
Design margin		10.89	10.89
SVM with design margin		195.91	196.81
ESA reserve		57.18	57.69
ESA margin		0.00	0.00
satellite	TOTAL	265.59	267.00
Energy			200.25
Power from EGSE		450	
Energy from battery			567
Margin		184.41	367.22

Figure 8.4-1 Herschel Nominal Power Budget summary table (1/2)

HERSCHEL SUMMARY POWER BUDGET		BOL				EOL		
		Pr-op	Science	Telecom	Survival	Science	Telecom	Survival
SVM								
	CDMS	37.70	37.70	37.70	37.70	37.70	37.70	37.70
	TT&C	109.50	32.70	109.50	109.50	32.70	109.50	109.50
	ACMS	110.18	149.78	131.62	48.18	149.78	131.62	48.18
	RCS	25.53	25.53	25.53	50.18	25.53	25.53	50.18
	TCS	352.20	183.20	142.00	415.60	161.70	121.30	389.90
	PCS	86.70	72.80	76.20	63.20	76.50	80.00	66.50
	Harness	29.35	20.61	20.99	14.55	19.24	20.96	14.00
Losses SA - PCDU		6.53	6.53	6.53	7.52	6.53	6.53	7.52
Losses BTR - PCDU								
SVM	total	757.69	528.86	550.07	746.42	509.68	533.14	723.47
Design margin		20.26	14.28	21.06	15.69	13.01	21.06	17.19
SVM with design margin		777.95	543.14	571.13	762.12	522.68	554.20	740.65
Requirement SVM	520 W	520.00	520.00	520.00	520.00	520.00	520.00	520.00
Margin		-257.95	-23.14	-51.13	-242.12	-2.68	-34.20	-220.65
ESA reserve		45.00	45.00	45.00	45.00	45.00	45.00	45.00
ESA margin		0.00	0.00	0.00	0.00	121.90	125.26	89.18

Figure 8.4-2 Herschel Nominal Power Budget summary table (2/2)

PLANCK SUMMARY POWER BUDGET		Pre launch	LEOP vibration	LEOP st-by
Instruments				
	HFI	0	0	0
	LFI	0	0	0
	Sorption cooler	0	62.5	19
	Total	0	62.5	19
Dummy load	(margin)	0	0	0
	TOTAL	0	62.5	19
Other units				
	SREM	0	0	0
	VMC	0	0	0
	Decont htr	0	0	0
	TOTAL	0	0	0
ESA units	FOG	0	0	0
	TOTAL	0	0	0
PLM total		0	62.5	19
SVM				
	CDMS	37.7	37.7	37.7
	TT&C	40.7	40.7	40.7
	ACMS	32.38	32.38	32.38
	RCS	17.02	17.02	17.02
	TCS	0	0	0
	PCS	43.20	50.10	45.90
Design margin		10.57	10.47	10.47
	Harness	2.75	5.36	3.16
Losses SA - PCDU		4.20		
Losses BTR - PCDU			1.35	1.13
SVM	total	188.52	195.08	188.46
Dummy load = ESA reserve		56.56	58.52	56.54
Dummy load ESA margin		0.00	0.00	0.00
satellite	TOTAL	245.07	316.10	263.99
Energy Wh			17.56	205.33
Power from EGSE		450		
Energy from battery				567
Margin		204.93		344.58

Figure 8.4-3 Planck Nominal Power Budget summary table (1/2)

PLANCK SUMMARY POWER BUDGET			BOL			EOL	
	Pr-op	Science	Telecom	Survival	Science	Telecom	Survival
Instruments							
HFI	0	0	0	0	0	0	0
LFI	0	0	0	0	0	0	0
Sorption cooler	0	0	0	0	0	0	0
Total	0	943.8	943.8	0	977.8	977.8	0
Dummy load (margin)	0	56.2	56.2	0	22.2	22.2	0
TOTAL	0	1000	1000	0	1000	1000	0
Other units							
SREM	2	2	2	2	2	2	2
VMC	3	0	0	0	0	0	0
Decont htr	300	0	0	0	0	0	0
TOTAL	305	2	2	2	2	2	2
ESA units FOG	24	24	24	0	24	24	0
TOTAL	24	24	24	0	24	24	0
PLM total	329	1026	1026	2	1026	1026	2
SVM							
CDMS	37.7	37.7	37.7	37.70	37.7	37.7	37.7
TT&C	109.50	32.70	109.50	109.50	32.70	109.50	109.50
ACMS	68.08	68.08	68.08	68.08	68.08	68.08	68.08
RCS	26.13	26.13	26.13	47.34	26.13	26.13	47.34
TCS	702.50	179.00	103.00	795.60	78.00	3.20	780.90
PCS	88.00	98.60	99.30	81.20	102.90	102.90	84.10
Design margin	20.09	13.31	20.09	21.15	13.31	20.09	21.15
Harness	27.42	25.89	29.52	27.80	27.74	27.93	22.97
Losses SA - PCDU	18.59	18.59	18.59	18.81	17.66	17.66	17.86
Losses BTR - PCDU							
SVM total	1098.01	500.00	511.91	1207.17	404.22	413.19	1189.60
Dummy load = ESA reserve	76	76	76	100	76	76	100
Dummy load ESA margin	0.00	0.00	0.00	0.00	167.36	168.35	143.51
satellite TOTAL	1503.01	1602.00	1613.91	1309.17	1673.58	1683.55	1435.11
Energy Wh							
Solar array power w sect failure	1918	1918	1918	1940	1836	1836	1857
Margin	415.22	316.22	304.32	631.23	161.94	151.98	421.63
Solar array power if required duriing							
BTR charge - 3 sections w.c.	1904.67	1882.90	1882.90	1904.67	1801.72	1801.72	1822.55
Margin	401.66	280.90	268.99	595.50	128.14	118.17	387.44

Figure 8.4-4 Planck Nominal Power Budget summary table (2/2)

Only in Herschel the power demand of the SVM shows negative margins w.r.t. the allocation of 520 W while Planck satellite shows a positive margin in any phases also considering the worst case of the losses during battery recharge

ESA reserve and margin have been calculated based on reference values for PLM power demand and are reported to be used in the budget at satellite level.

A possible critical area could be the high power demand of TCS in pre-operational phase when also the decontamination of the mirror has to take place. Possible recovery actions shall be taken considering the satellite overall budget.

Also sufficient margin exist during pre-launch and LEOP phases

Special cases (delta V Manoeuvre, Moon Eclipse, Peak Power Consideration) analyses are provided in [RD-115].

8.4 TM/TC Budget

Overall SVM TM/TC Budget is reported in [RD-116] (SVM TM/TC Budget Technical note) H-P-TN-AI-0018 Issue 03 included in the H-P CDR data package

8.5 TCS Budget

Overall TCS Budget is reported in [RD-117] (TCS Budget Report) H-P-RP-AI-0042 Issue 03 included in the H-P CDR data package

8.6 Pointinting Budget

Overall SVM Pointing Budget is reported in [RD-114] (Pointing Budget Report) H-P-BD-AI-0007 Issue 01 included in the H-P CDR data package

8.7 Software Budgets

Overall SVM Software related budgets are reported in the following documents included in the H-P CDR data package

[RD-104] SVM SW Budgets Report H-P-BD-AI-0003 Issue 2
[RD-105] Basic Software Timing and Sizing Budgets P-HPL-NOT-00027 Issue 3
[RD-106] ACC ASW Sizing, Timing and Schedulability Analysis H-P-4-TASW-AN-0005 Issue 2
[RD-107] ACMS Budget Report H-P-4-DS-RP-003 Issue 2/1
[RD-108] H-P CDMU Software Budget Report H-P-4-SSF-BU-0001 Issue1.2 draft 1
[RD-109] H-P CDMU ASW Schedulability Analyses H-P-4-SSF-TN-007 Issue1.1 draft 1
[RD-110] H-ASTR SW CPU and Memory Budgets H-P-4-GAF-BD-0001 Issue 1
[RD-111] P-ASTR SW CPU and Memory Budgets H-P-4-GAF-BD-0002 Issue1

9. SERVICE MODULE

9.1 SERVICE MODULE STRUCTURE

This chapter describe the major Subsystem and/or Equipment design. They are procured on the basis of the hereafter listed specification (included in the CDR data Package).

STRUCTURE SVM Structure Spec. H-P-SP-AI-0001 Issue 6 [RD-26]

The major modification occurred from the PDR (June 2002) are hereafter briefly listed. Any details on the improved design with respect to the one presented at the PDR can be found in the applicable design report at Subsystem and/or Equipment level:

- Herschel STR accommodation, moved from SVM cone (beam) to a dedicated support suspended at CVV
- Planck Sub-platform evolution, due the mechanical requirement updating (frequency)
- Warm units, including SCC, panels design evolution in agreement with IID-B evolution. The interface layouts have often leaded to complex inserts layouts, requiring, in many cases, special inserts.
- Planck handling interface requirement
- He tanks anti-rotation device
- PLM/SVM interface evolution
- Equipment panels DLF updating, in order to reduce the mass Structure mass.

9.1.1 General

The present chapter constitutes the design description for the Service Module (SVM) Structure.
The SVM Structures are designed so as to transfer the inertia loading to the launch vehicle interface and provide adequate stiffness to de-couple the spacecraft's modes from those of the launch vehicle. The structures also provide the mounting area for all equipment and thermal hardware giving protection against the launch and in-orbit environment. The structure also acts as the common electrical return path.
Herschel and Planck SVM are two different structures for which the highest level of commonality was persecuted.

9.1.2 Commonality Requirements

Herschel and Planck Primary structures have been designed to preserve the maximum of commonality between them.
With the increasing of the design maturity, it became obvious that the great difference in the required performance of the two SVM led to two structure which general design and philosophy is still the same, while details are sometimes different as different are the requirement to be satisfied.
In principle the primary structures are made of the same materials, shape and dimensions. ,
The application of this concept is explained in paragraphs below where the main deviation from commonality are also tracked and explained.

General Exploded View o SVM structure is reported in chapter 7.2 Figure 7.3.2-1 for Herschel and in Figure 7.3.2-2 for Planck.

9.1.3 Design description

The structure design has been divided into primary and secondary structure according to the different loading path passing through the structure

9.1.3.1 Primary Structure

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

- Central cone
- Upper interface
- Lower ring
- P.Tanks Support Structures (PTSS)
- Octagonal box
- Payload sub-platforms
- Equipment panels (SCC panels for Planck)
- Upper and lower closures
- Shear Panels

Detailed engineering drawings can be found in [RD-33]

Central Cone

It is a CFRP sandwich with aluminium honeycomb core, which provides the I/F's to the PLM and Octagonal box via the upper brackets and to the Launcher via the lower ring. In order to withstand the flux requirement the skin of the cone has been reinforced locally at the PLM and launcher I/F joints. These reinforcements improve the strength of the skin in membrane and bending stress states.
The Herschel and Planck structures are of the same material, shape and dimensions. Bigger differences are related to the cone holes, PTSS I/F (three on Planck, Two on Herschel) shear panel inserts on Herschel -Z side (Herschel presents a different shear panel configuration for STR Stability requirement), local cut out and equipment inserts, and local reinforcements.
Differences are introduced mainly at upper level ,as well as the two cone share the same I/F philosophy (discrete brackets instead of a continuos ring to save mass), but final results depends on different PLD I/F's and requirements.
The central cones provide also I/F to the:

- Octagonal box
- Payload subplatform
- PTSS
- Helium tank support structure (Planck)
- RCS Piping (inserts)

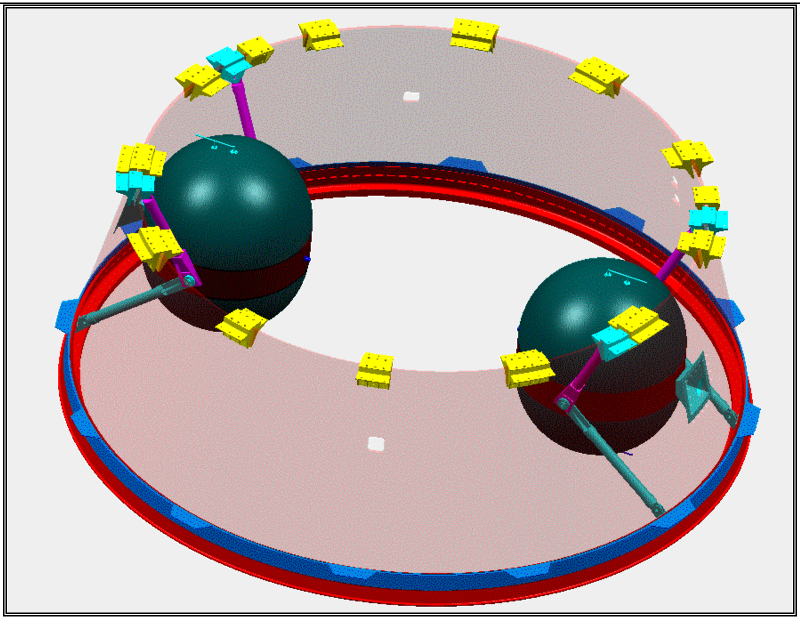


Figure 9.1.3-1 Herschel cone overall view

Upper Brackets

The upper brackets are the interface of the Central Cone with the upper SVM and PLM structure.
These brackets are used to connect different items depending on Herschel and Planck different requirement and configuration:

Herschel
- PLM I/F brackets
- Upper closure (integrated to all other brackets)
- SVM sunshield,
- SSH-SSD
- Payload Subplatform (integrated to all other brackets)
- PTSS. (connected to the PLD Brackets see sketch)

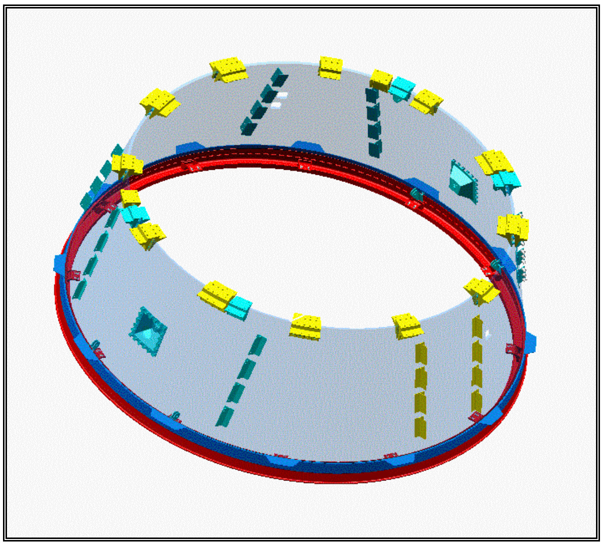


Figure 9.1.3-2 Herschel cone interface overview

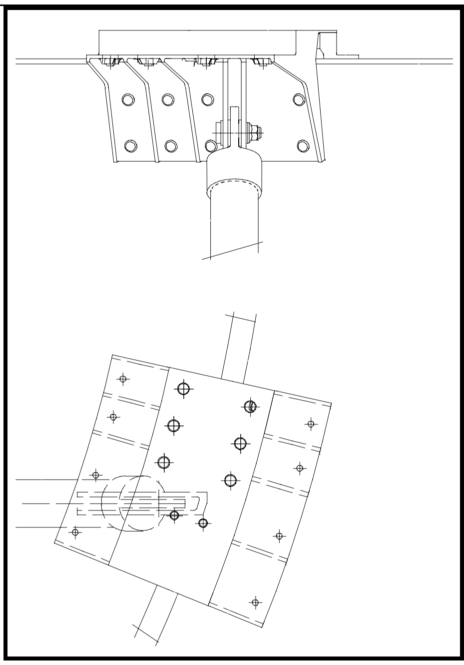


Figure 9.1.3-3 Herschel upper bracket interfacing PLM and PTSS

<u>Planck</u>

- Upper closure (integrated to all other brackets)
- Payload Subplatform (through 6 of these attachments the payload itself is attached)
- PTSS (independent from the PLD Brackets)

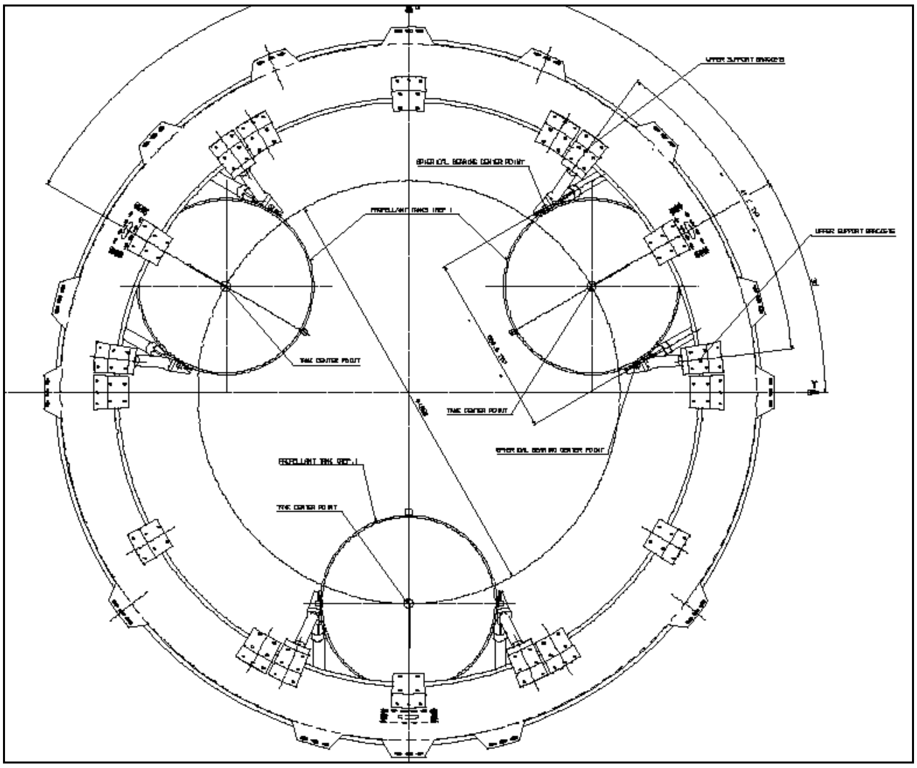


Figure 9.1.3-4 Planck upper bracket I/F

The attachment to the cone is made with rivets type HI-LITE plus structural adhesive that is also used as shimming and electrical isolation.
The attachment to the upper closure and sub-platform is made with Titanium bolts and A-286 anchor nuts. The PLD is attached via dedicated titanium Bolt.

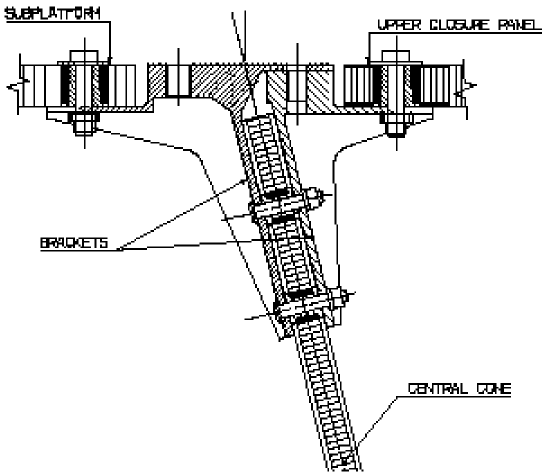


Figure 9.1.3-5 Typical PLM I/F bracket sections (Herschel)

Lower Ring

The Lower Ring provides the interface of the cone to the launcher, lower closure, RCS panel, Solar Array Central panel (Planck) and PTSS. The commonality between Herschel and Planck is complete for this item.
The attachment to the cone is made with titanium bolts, hexagonal self-locking nuts and multimision adhesive (i.e. structural, shimming and electrical isolation function).
The lower part of the ring will be anodised chromically for thermal reasons.

Tanks Supports Structures (PTSS)

The PTSS are located inside the Central cone and are used to connect the P. tanks to the Central cone. In Herschel there are two tanks and in Planck three.
Each PTSS connect a P. tank via spherical bearings mounted on 3 of the P. tanks equatorials trunions , providing the P. Tank with a full isostatic mounting.
The PTSS is composed mainly of a set of CFRP struts with Al end-fitting bonded and riveted.

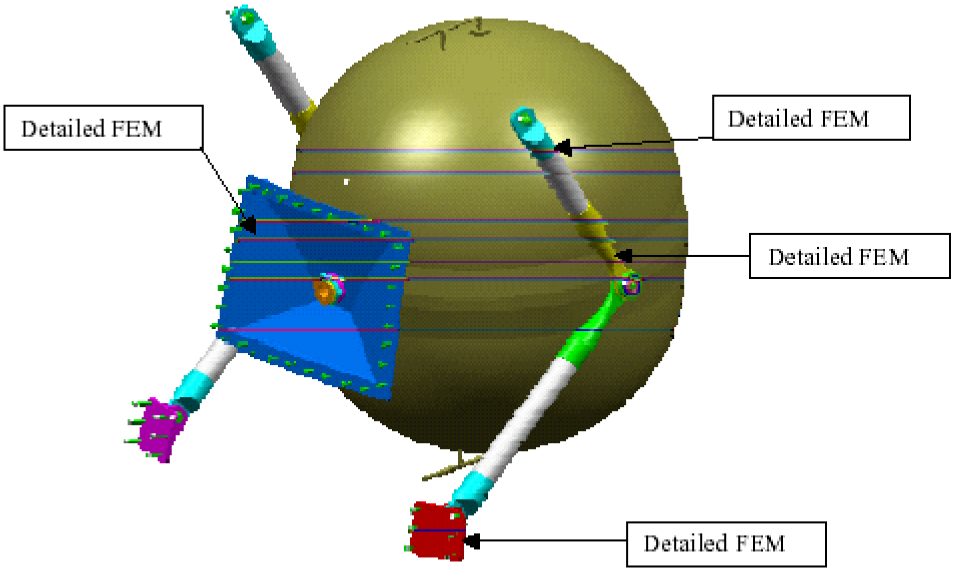


Figure 9.1.3-6 PTSS mechanical interfaces

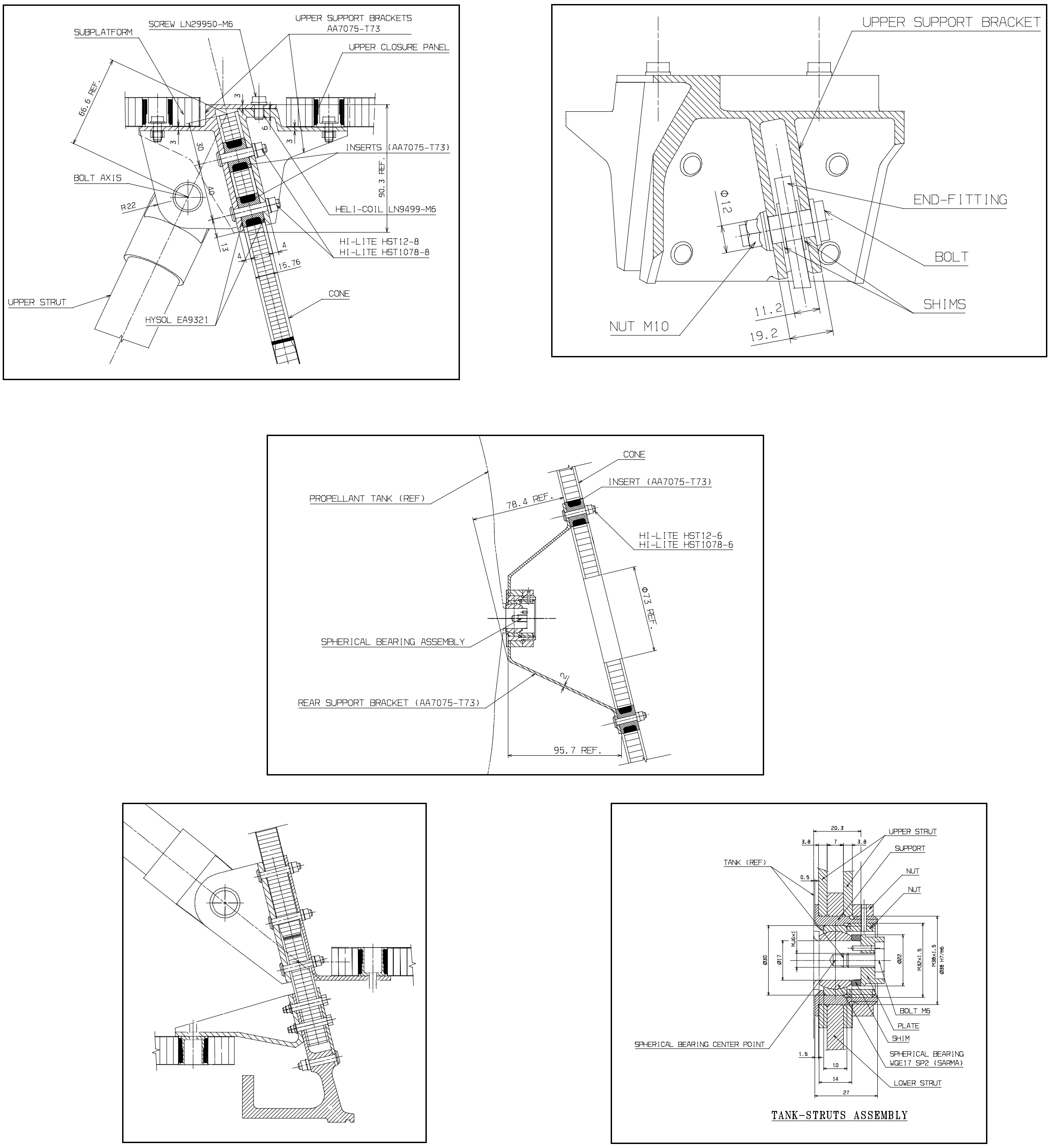


Figure 9.1.3-7 PTSS I/F concepts

Octagonal Box

The octagonal box is constituted by:

- 8 Equipment panels:
  - 4 Long Eq. Panels
  - 4 Short Eq. Panels
- 1 payload subplatform
- 2 closures panels:
  - upper closure
  - lower closure
- 8 shear panels

The main differences between Herschel and Planck can be found in the Payload Subplatform concept and in the SCC panel for Planck while the Shear panels present minor discrepancies due to the Herschel STR stability requirement. Details are explained directly in following sub-paragraphs.

Payload Subplatform

Payload subplatform presents one of the main differences between the two SVM. The two structure are different for scope, shape and material. For this reason they will be presented separately:

Herschel

The payload sub-platform is manufactured in sandwich form with CFRP skins.
It is fixed inside the top of the Central Cone, and it is mainly used to increase radial stiffness of the top of the central cone when loaded by the Payload support struts. It doesn't carry any equipment but provides Interfaces for MLI support. It is holed in order to allow to house the STR Assy Support.
The interface with the Central Cone is made via inserts on the platform and brackets on the cone.

TBD to be filled in as soon as final design from Subco will be available

Figure 9.1.3-8 Herschel PLD subplatform

Planck

The payload sub-platform is manufactured in sandwich with Aluminium skins.
Due to the several performance (frequency, mass) and interface requirement to be met, this panel is extremely complex.
It is fixed on the top of the Central Cone above the upper I/F brackets. It provides the interface to the P-PLM struts as well as to 3 Warm Units (BEU / PAU/ DAE). In addition it also provides interface to several items, as electrical connectors, wave guides and MGSE devices.
The interface with the Central Cone is made via special inserts on the platform and brackets on the cone. The special inserts configuration (“hat like”) is a consequence of the relative heights of the cone bracket and the Sub-platform thickness (37.2mm – 35mm H/C, 0.6 x 2 mm facings), necessary to meet the frequency requirement.
As mentioned above several design / analyses iteration were performed, aimed to meet frequency and mass requirement. The last configuration, whose analysis is in progress, includes a high stiffening beam (sandwich with CFRP facings) underneath the BEU side plus two other shorter stiffening beams. A large number of inserts is required in the BEU side and many of them are located very close to the panel edge where the PLM to cone bracket are located. In order to cope with this lay-out, a wide hot bonded insert, lightened when possible, has been considered the most efficient solution.

TBD To be filled in as soon as final design from Subco will be available

Figure 9.1.3-9 Planck PLD subplatform

Equipment Panels

The Equipment panels are Aluminium sandwich with aluminium honeycomb core. They accommodate the units (subsystem and some warms) and provide them a large dissipative surfaces.
All the external panels are detachable in order to allow the equipment integration or replacement if necessary.
To allow the connection to the closures, these panels have aluminium hot bonded inserts in the upper and lower edges.
As said, the Equipment density, requires to have, in many of them, special inserts to solve the issue of interfaces proximity. In fact, standard inserts cannot be installed at a reciprocal distance lower than 35 mm. Figure 9.1.3-10 shows a configuration very often present in H-P panels.

To be filled in as soon as final design from Subco will be available

Figure 9.1.3-10 H-P Equipment Panels lay-out

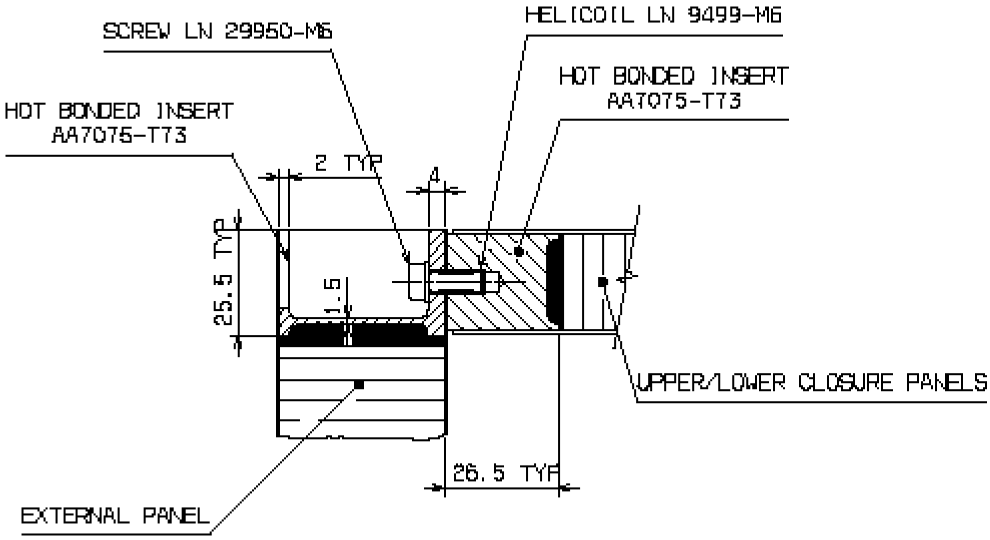


Figure 9.1.3-11 Equipment Panel to Closures typical I/F brackets

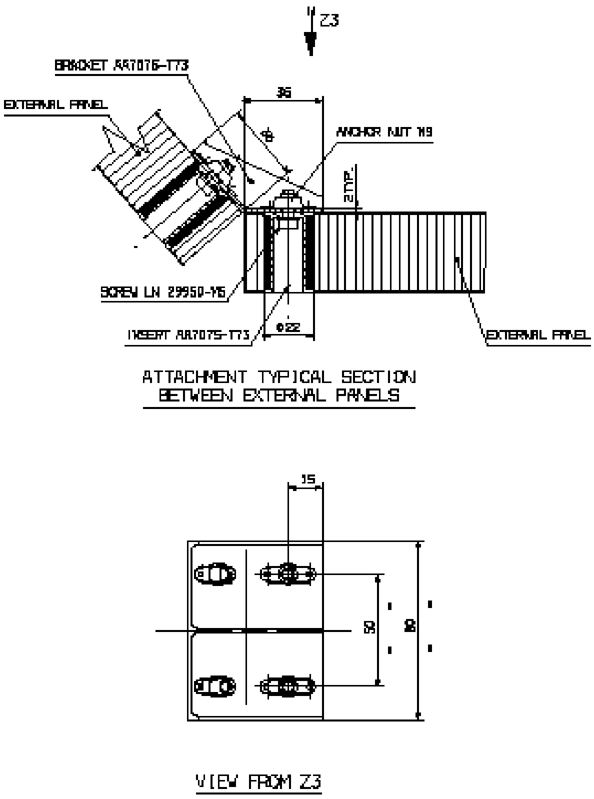


Figure 9.1.3-11 Equipment Panel To Equipment Panel Typical connection

SCC Panels

In the Planck satellite there are 3 equipment panels (namely +Y-Z / -Z /-Y-Z) that, once assembled the first time, form an assembly which has to be manage as a single item. They are called SCC panels.
They are kept togheter by means of a dedicated connecting bracket showed in following figure.

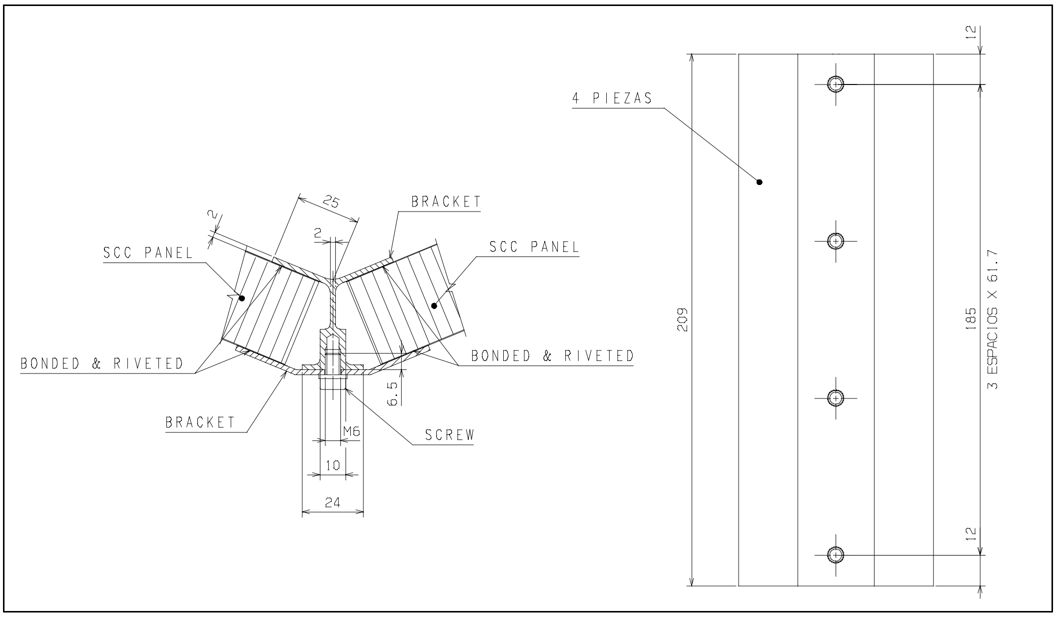


Figure 9.1.3-12 SCC Panel special connecting bracket

The panels are attached by means of Titanium brackets and inserts to the other part of the structure to limit the thermal flux between the attached parts.

This panel carries the Sorption Cooler Compressors and Electronics that are mounted to the SCC panel over the Heat Pipes network.

TBD To be filled in as soon as final design from Subco will be available

Figure 9.1.3-13 SCC Panel Assembly

The attachment of both the network and the equipments to the SCC panel is a demanding target. A dedicated study has been developed in order to reduce the number of I/F points and to de-couple the I/Fs to the SCC. Details are described in [RD-84]

Concerning the panels themselves, to solve the interface proximity issue some continuous beams have been embedded (hot bonded) inside the sandwich panels.

TBD To be filled in as soon as final design from Subco will be available

Figure 9.1.3-14 SCC Panel Assembly

Closure Panels

There are two different closure panels: Upper and Lower.
Both are CFRP sandwich panel with Aluminium Honeycomb core.
The Lower one will be only one-piece panel in both satellite, they will be used for harness routing and will provide I/F for the umbilical connector.
The upper will be in principle 4 pieces in both satellites. In Herschel it carries the Cryo-Harness and related brackets and some of the SVM-Shield and SSH/SSD I/Fs. For this reason it is considered not removable after payload integration.
In Planck the upper closure does not provide any I/F and do not carry equipment or harness as it should be potentially removable until the last moment before flight.
In Both Herschel and Planck several lightening holes on upper closure will be provided to reduce mass.

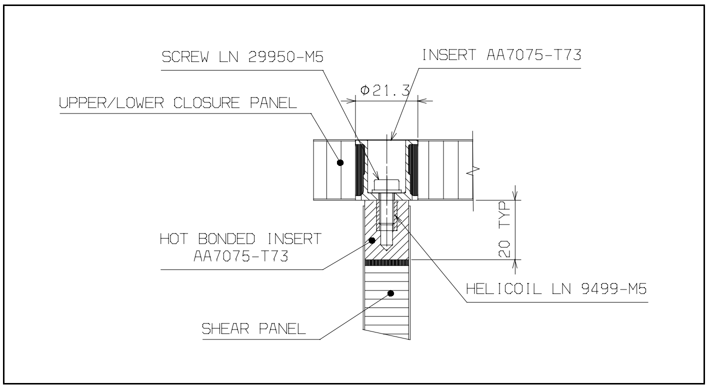


Figure 9.1.3-15 Closure to Shear panel I/F concept

To allow the connections to the Eq-panels, these panels have hot bonded inserts at the edge.

Shear Panels

There are 8 shear panels. There are CFRP sandwiches with aluminium core.
To allow the connections to the Eq. Panels and to the closures they have hot bonded inserts and for the connection to the cone they provide cold bonded inserts.
The -Z shear panels on Herschel are located in a different position for stability requirements and this lead to a different configuration of the described items.
Several cut outs are required along the Shear panel edges for harness, Piping and Wave guide routing.

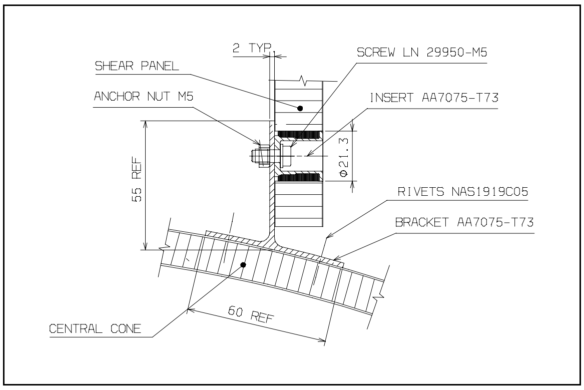


Figure 9.1.3-16 Shear web Vs cone typical I/F

9.1.3.2 Secondary Structure

The **Secondary Structures** are not responsible for the main load transfer. They are fastened to the primary structure and transfer Units loads to the primary structure. The secondary structure is under definition. It will be presented at Structure MRR3.

Thermal Closing Support (For Herschel)
It is a sandwich construction with CFRP face-sheets and aluminium core alloy which has been lightened making holes, being fastened through aluminium alloy brackets to the cone. It provides the support to the STR Secondary Baffle.

He Tanks Support (Planck)
The 4 He tanks are located at the outer side of the Central tube. Each tank will be supported by a tripod interfacing with the lower tank trunnion and a bipod interfacing with the upper tank trunnion. [RD-33] provides more detail on this item.

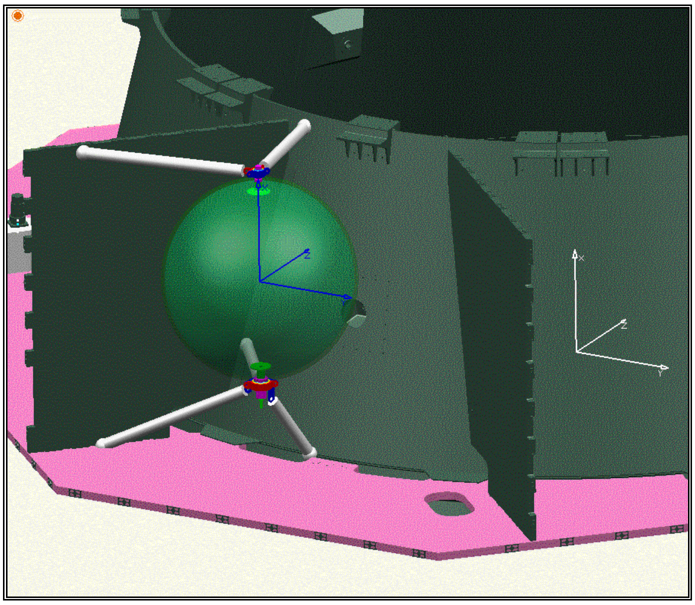


Figure 9.1.3-17 Helium tank support concept

Aluminium brackets supporting some equipment, as Reaction Wheels, P-STR, SAS, AAD, etc. are part of the SVM Structure. They are described in detail in [RD-33] (Issue planned to be provided at subco CDR will be more completed).

9.1.4 Material Summary:

The materials summaries of the SVM structure are reported in Table 9.1.4-1. A detailed list of material characteristics, references and allowable for the used materials are reported [RD-37]. Also the FEM models material properties [RD-35 and 36] are coherent with the referred document [RD-37]

ITEM	PIECE	SANDWICH		
		Core	Skin	Configuration
Upper Bracket	AA7050 T7451	-	-	-
Lower Ring	AA7075 T7351 Die Forging	-	-	-
Central Cone	-	3/16-5056-.001 Hc = 15	M18/M40J th = 0.135	$(35, -35.)_s$ th = 0.54
Equipment Panel	-	3/16-5056-0.001 Hc = 35	AA7075 T6 th = 0.3	-
Payload Subplatform Herschel	-	3/16-5056-0.0007 Hc = 20	M18/G801 th = 0.1	(45, 0, -45) th = 0.3
Payload Subplatform Planck	-	**1.** 3/16-5056-0.0007 Hc = 19.4 **2.** 3/16-5056-0.0007 Hc = 50 **3.** 3/16-5056-0.0007 Hc = 20	AA7075 T6 th = 0.3 AA7075 T6 th = 0.3 AA7075 T6 th = 0.3	- - -
PTSS: Rear Bracket End-Fitting CFRP Struts Spherical Bearing	 Titanium AA7075 T7351 M18/M55J Stainless Steel	 - - - -	 - - - -	 - - - -
Closure Panels	Upper (Herschel)	3/16.0015 (General) 1/8.0015 1/8.002	M18/G801 Th = 0.4 and 1.6	$(45,0,90,-45)_n$
	Lower (Herschel)	3/16.007 (General) 3/16.0015 1/8.002	"	"
	Upper (Planck)	3716.007 (General) 3716.0015	"	"
	Lower Planck)	3/16.007 (General) 3/16.0015 1/8.002	"	"
Shear Panels	-	3/16-5056-.001 Hc = 15	M18/G969 th = 0.19	$(60, -60)_s$ th = 0.76
	Herschel	3/16.001 (General) 3/16.0015 1/8.002		Reinforcement G801 th = 02 08
	Planck	3/16.001 (General) 3/16.0015 1/8.002		Reinforcement G801 th = 02

Table 9.1.4-1 HERSCHEL PLANCK SVM Structure Material Summary

9.1.5 Analyses Summary:

The main Structural performances of the SVM Structure are reported in the Analysis Contractor document.
Due to the SVM Structure complexity and the large amount of analyses performed and still in progress (MRR3 and final re-analyses) for the results summary, please refer to the Contractor document [RD-34] (next issue).

For Alignment and Stability Analyses, please refer to [RD-38] and [RD-39] and Chapter 7.9 of this document.

9.1.6 Mass budget summary:

The mass budgets summary of the SVM Structures (without STR Assy) are reported in Table 9.1.4-8 and Table 9.1.4-9 where SVM Structure masses are presented, contingencies and details are reported in document [RD. 43]. Mass has been considered a critical requirement since the beginning of the program and big effort to reduce the mass have been done. At least the current Requirement cannot be satisfied. The Structure mass budget evolution is presented in [RD-113]

The STR Assy mass is included in the overall SVM Mass Budget Report as a dedicated item.

TBD To be filled in as soon as final design from Subco will be available

Table 9.1.6-1 Planck SVM Structure Mass Budget

TBD To be filled in as soon as final design from Subco will be available

Table 9.1.6-2 HERSCEL SVM Structure Mass Budget

9.1.7 Mountability and Dismountability

At the sight of the SVM proposed design for both satellites the Primary Structure components as well as the Secondary Structure are detachable, even the Shear Panels attached to the Central tube outer skin by special adjusted bolts, being a potentially dismountable items.

To facilitate the mounting / dismounting process, assuring the position repeatability, two centering (guide) pins / holes per item are necessary.

Details related to main items are showed in [RD 33].

9.1.8 Venting

Due to the dimensions of SVM, a large volume of air needs to be evacuated during launch to ensure no damage is caused to any system or component or part of the structure.All the air contained in the Service Module between the panels and the cone will be evacuated through 8 holes to the cone.All the air contained in the cone will be evacuated through the existing holes of the payload subplatform and the thermal lower closing.

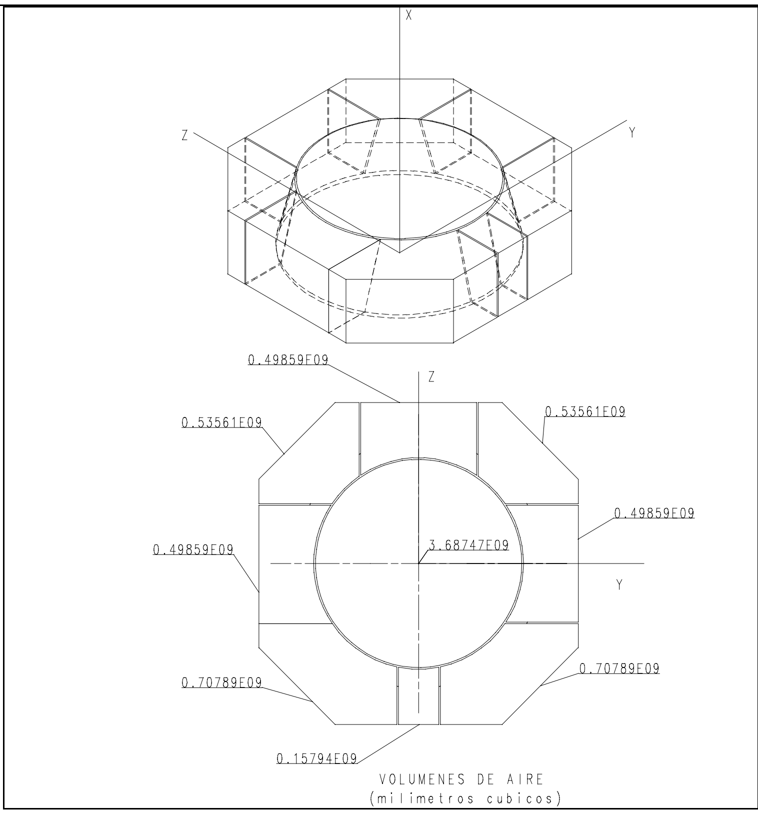
The design of the Service Module Structure will take into account the venting requirements using the solutions as follows:

The air contained in the SVM will pass to the cone box through 8 dedicated holes of the cone and will be evacuated through the holes of the pay-load subplatform and thermal lower closing.

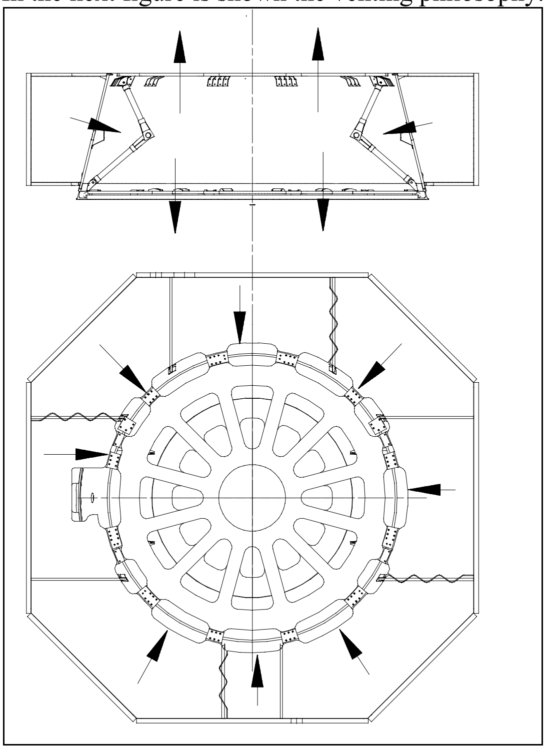
Venting holes around the ring to evacuate the air caught between the CFRP cone and the ring:

- Lower ring: 1 hole of ϕ 3.5 mm
- Venting holes in PTSS struts: 1 x ϕ 2 mm.

In the following figure are included the volumes of air to be vented.



In the next figure is shown the venting philosophy.



The size of the holes, already defined for both Herschel and Planck, will be frozen after RCS pipe routing definition, in order to utilise the same holes for Venting and RCS pipes routing, avoiding additional cut-outs in the cone.

9.1.9 Electrical Bonding

The bonding baseline of the SVM is based on four basic concepts.

Electrical connection between the elements which form a panel

If we consider a typical sandwich, one skin is connected to the other one through the metallic core. This is valid also for CFRP skins.

Connection between equipment insert and panel

The connection will be guaranteed through the unit foot and the bolt by direct contact. In cases it is found that some equipments are using isolation washers or are electrically isolated from the panel for thermal reason, a strap, connecting the requested stud on the unit to the foreseen insert on the panel will be used.

Connection between structural insert and panel

The structural insert is connected to one metallic part by direct contact and through this part to the skin of the sandwich, them we can consider that the insert is connected to the sandwich. Special case of structural inserts are the hot bonded inserts. See below

Connection between Hot Bonded Insert and Sandwich

The connection will be guaranteed riveting the skin to the insert. Details are reported in [RD.33]

9.2 SERVICE MODULE THERMAL CONTROL

9.2.1 General

This chapter describe the major Thermal Control Subsystem and/or Equipment design. They are procured on the basis of the hereafter listed specification (included in the CDR data Package).

SVM Thermal control subsystem spec H-P-SP-AI-0007 5 [RD-63]
SVM TCS Thermal Blankets (MLI) & H/W Spec. H-P-SP-AI-0017 4
Heat Pipers for Herschel-Planck SVM H-P-SP-AI-0018 3

The major modification occurred from the PDR (June 2002) are hereafter briefly listed. Any details on the improved design with respect to the one presented at the PDR can be found in the applicable design report at Subsystem and/or Equipment level:

- BEU-PAU Thermal design. Dedicated radiators has been added.
- HIFI fine control law has been defined and introduced.
- Herschel STR assembly has been introduced changing the original position (from –Z lateral panel to upper cone) in order to meet the ACMS requirements.
- Heaters design configuration changes due to the Uncertainties margin philosophy agreed with ASP and ESA.
- Adaptor ring thermal design has been defined (its different from each to other) in detail for both satellites
- SCC internal MLI layout. New design is improving to avoid secondary structure.
- New MLI composition due to Sun illumination phase and BBQ mode is under investigation

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

- maximum commonality between the two satellites
- use of well proven design solutions
- minimum cost and budget (mass, power)
- fulfil the thermal requirements

Due to the different units/equipment layouts and to the different solar aspect angles, HERSCHEL and Planck SVM are quite different from a thermal point of view and therefore also the two thermal control configurations will be quite different. Consequently, the commonality approach is mainly followed for material procurement and for generic design solutions:

Concerning the procurement, the main components will be procured together for the two satellites, allowing reduction in the spare quantity.

The attitude and orbit constrains are usually important in defining the operative condition for the TCS. The long distance from the earth reduces their effects on the two satellites: albedo and earth-shine fluxes will act only during the launch phase and the LEO time, while on station only the sun fluxes will be considered.

9.2.2 Requirements and Design Drivers

The SVM Thermal Control Subsystem is requested to maintain all the SVM components, within their flight temperature limits, during all the mission phases and in the different operational modes.
The temperature limits shall be guaranteed also for the PLM warm units that are mounted onto the SVM; for some of these units it is also request to limit the temperature fluctuation.
While the temperature requirements of the SVM equipment are the typical ones for scientific satellite, the thermal requirements of the PLM units are much more stringent.
For these reasons, it is mandatory to limit as much as possible the heat transfer at the SVM/PLM interface level.
Goal requirement defines the value over the design requirement which is desired to be obtained. The TCS subsystem shall provide in each case, specified in this document, a detailed assessment of the specific conditions which are to be respected to achieve the required goal and if deemed not achievable, the limit performances with an adequate justification.

The main thermal requirements for HERSCHEL and Planck SVM are given in [RD-98].

9.2.3 Functional Description

The Thermal control of the SVM will maintain the temperature requirements during all the lifetime. For this purpose it will:
Reject the unit dissipation to the deep space (OSR, Black paint).
Insulate the external surfaces of units and module not used for the heat rejection (MLI's, Aluminised tapes).
Increase the linear conductance for the units that need to be cooled via conduction (fillers and thermal doublers).
Conductively insulate the units/items whose sink is too hot or cold (thermal washers).
Provide power dissipation for the units/items/enclosures (heaters, thermostats, thermistors).

The external surfaces of lateral panels, where there are not radiators will be covered by MLI's. The adapter/separation ring will be insulated by MLI as much as possible, except for those surfaces that shall be left free for adapter or Ariane 5 interfaces.

9.2.4 Design and Performance

9.2.4.1 Herschel Design

The main HERSCHEL Thermal Control components are MLI and radiators.
The lateral panels are partially covered with radiators to reject the internal dissipation except for +Z panel (always completely sun-exposed), that are totally cover with MLI.
For the others sun-exposed panels, the radiators will be made of OSRs, (low α and high ε, both at beginning and end of life).

The amounts of radiator/MLI areas for each lateral panel are reported in Table 9.2.4.1-1 while Figure 9.2.4.1-1 shows the radiator area location:

Panel	Total Panel Area [m²]	MLI Area [m²]	OSR Area [m²]	OSR Area / Total panel %
+Z	1.462	1.462	0.000	0 %
+Y +Z	0.974	0.122	0.853	88 %
+Y	1.462	0.914	0.548	38 %
+Y -Z	0.974	0.589	0.386	40 % (black paint)
-Z	1.462	1.198	0.264	18 % (black paint)
-Y –Z	0.974	0.467	0.508	52 % (black paint)
-Y	1.462	0.711	0.751	51 %
-Y +Z	0.974	0.528	0.447	46 %
Total	9.744	5.989	3.756	39 %

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

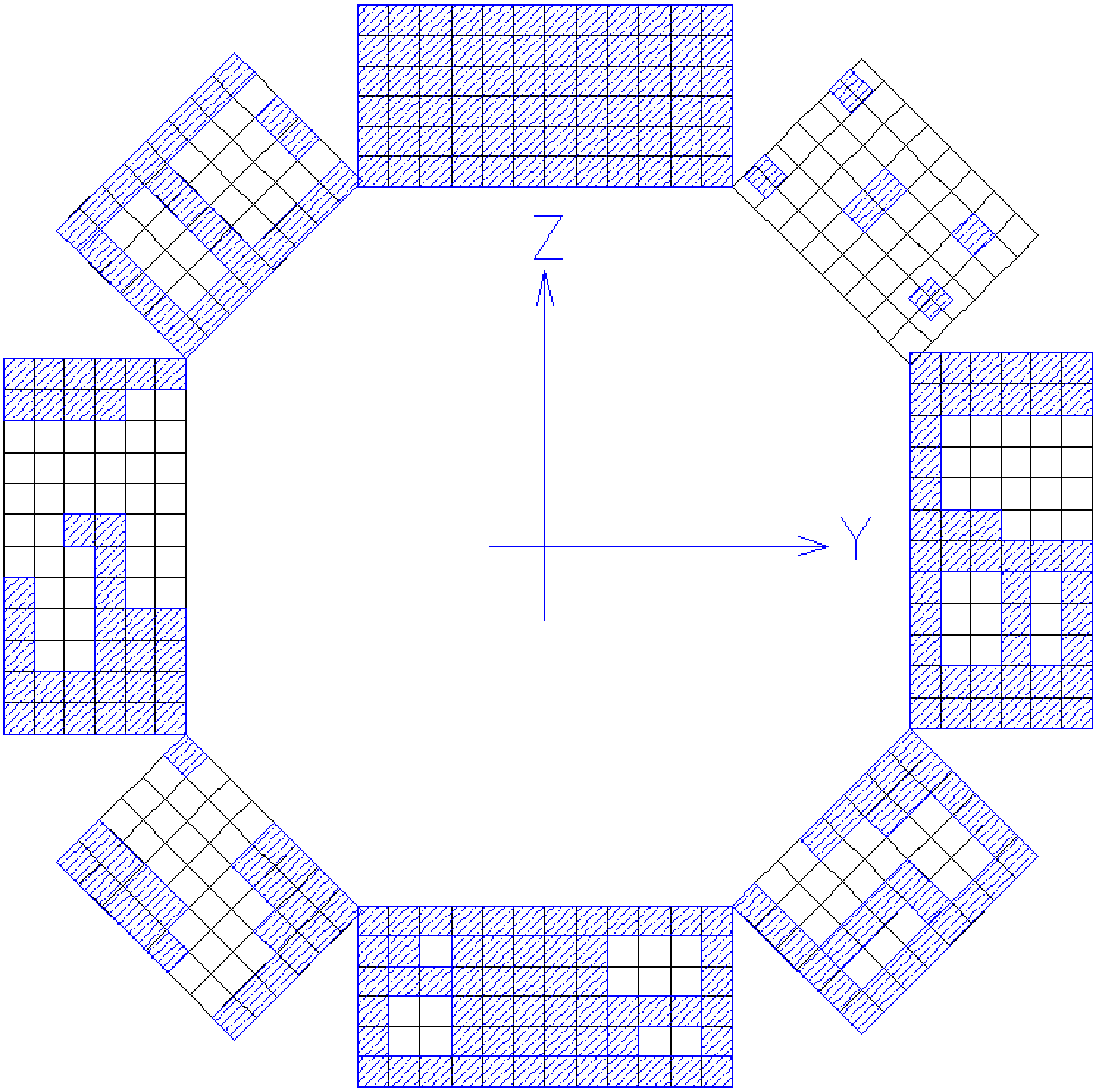


Figure 9.2.4.1-1 HERSCHEL radiator areas

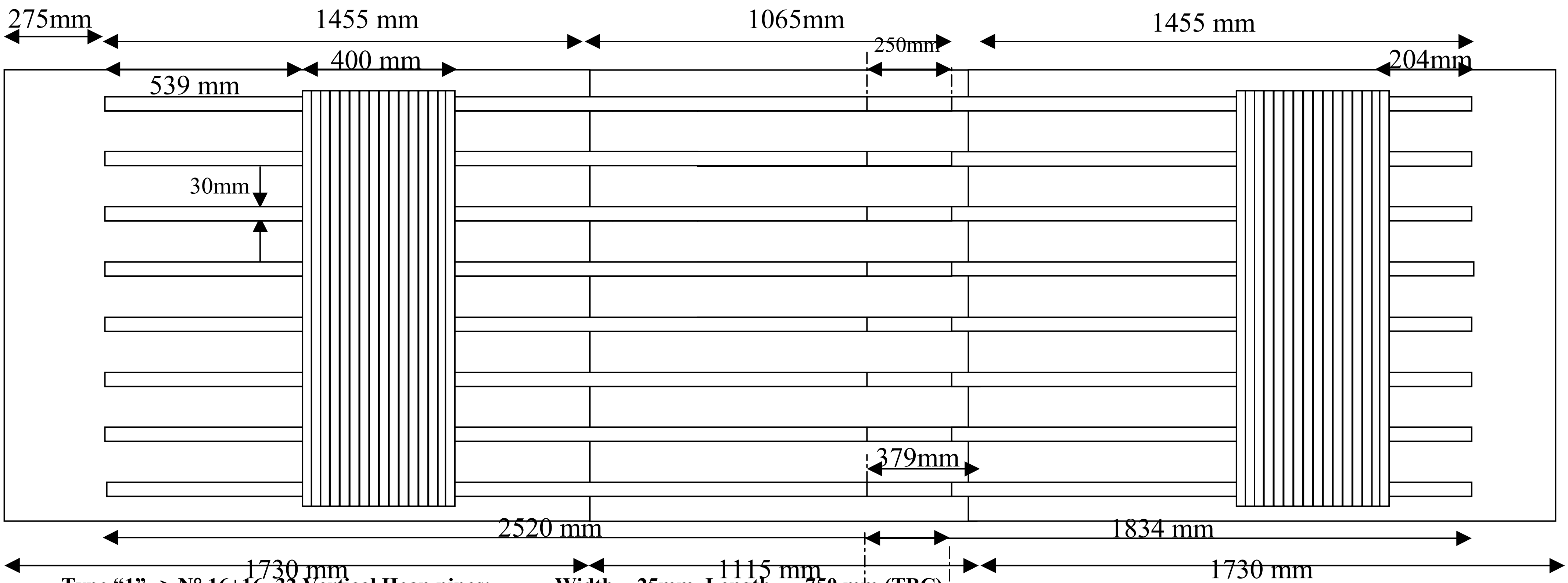
Thermal blankets are also mounted on the two SVM floors, for radiative insulation from the cold environment on –X side, and thermal insulation from the cold PLM.

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 (HIFI) are also covered with MLI to meet the temperature requirement stability. The MLI are directly installed on the units using them as supporting structure.

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

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. 16 vertical HPs are mounted directly under each SCC unit covering the whole bed I/F surface.
The HP width is 25 mm to be compliant with the bed I/F mounting holes. The HP length covers actually all the internal SVM panel height (750 mm).
Each set of vertical HPs are mounted on a bench of 8 horizontal HPs. Figure 9.2.4.2-2 and Figure 9.2.4.2-3 show schematically the HP configuration under the SCC beds.



Type “1”--> N° 16+16=32 Vertical Heap pipes: Width = 25mm, Length = 750 mm (TBC)
Type “2/A”--> N° 8 Horizontal Heap pipes: Width = 30mm, Length = 2520 mm (TBC)
Type “2/B”--> N° 8 Horizontal Heap pipes: Width = 30mm, Length = 1834 mm (TBC)
Note: Drawing not in scale

FIGURE 9.2.4.2-2: HEAT PIPES NETWORK (Frontal view)

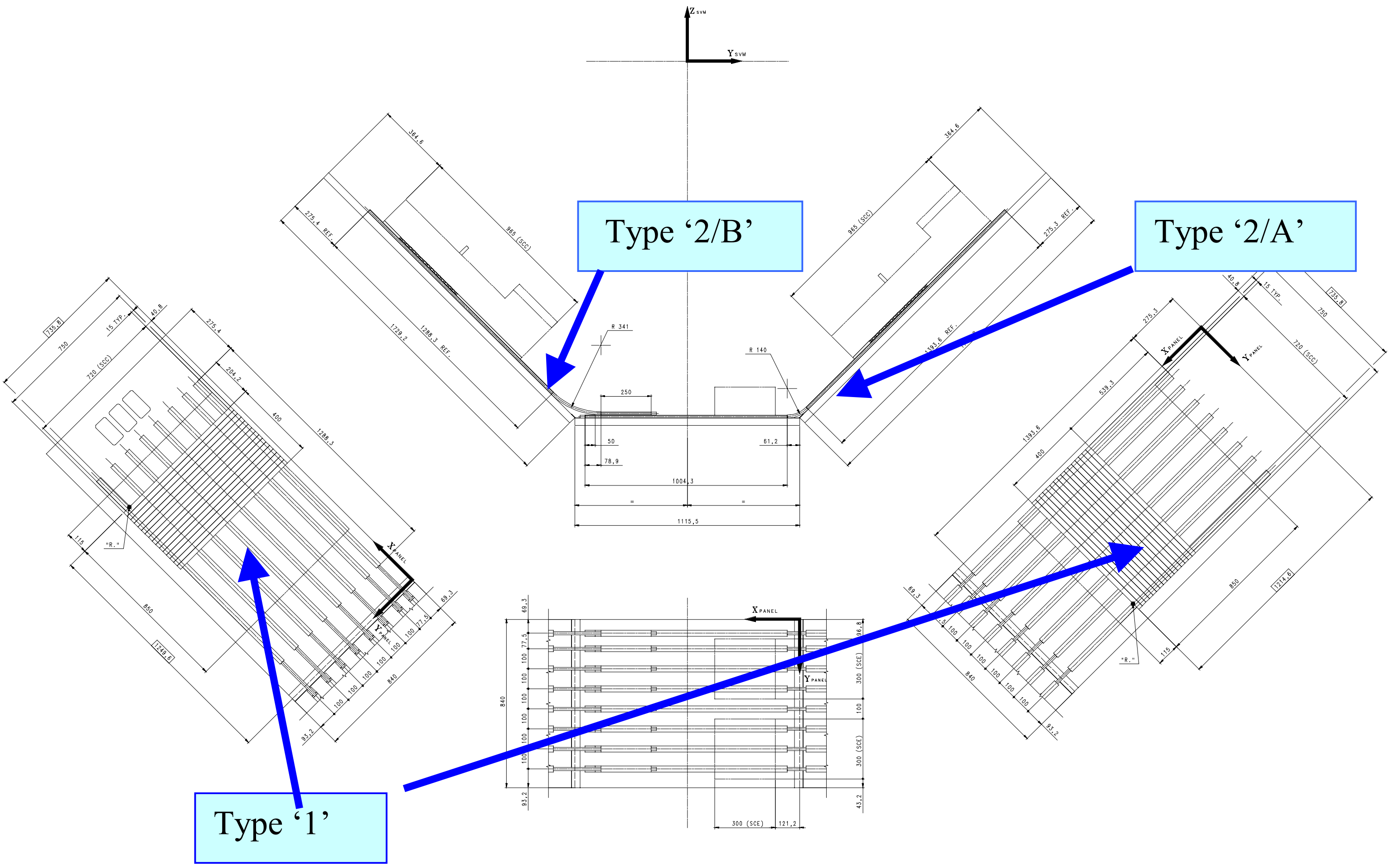


FIGURE 9.2.4.2-3 HEAT PIPES NETWORK (Top view)

The SCC/SCE boxes and panels are covered with MLI blankets in order to avoid the transmission of the temperature fluctuation to the internal SVM.
Also the other SVM lateral panels are partially covered with radiators to reject the internal dissipation. For Planck satellite the radiator material can be chosen among various type of material with high emissivity because in nominal operation no sun impinges on the panels and therefore there is no absorbed solar fluxes.

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 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	Total Panel Area [m²]	MLI Area [m²]	Paint Area [m²]	Paint Area / Total panel %
+Z	0.974	0.771	0.203	21 %
+Y +Z	1.462	1.178	0.284	19 %
+Y	0.974	0.275	0.699	72 %
+Y –Z	1.462	0.269	1.193	82 %
-Z	0.974	0.129	0.845	87 %
-Y –Z	1.462	0.276	1.186	81 %
-Y	0.974	0.629	0.345	35 %
-Y +Z	1.462	0.831	0.631	43 %
Total	9.744	4.358	5.387	55 %

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

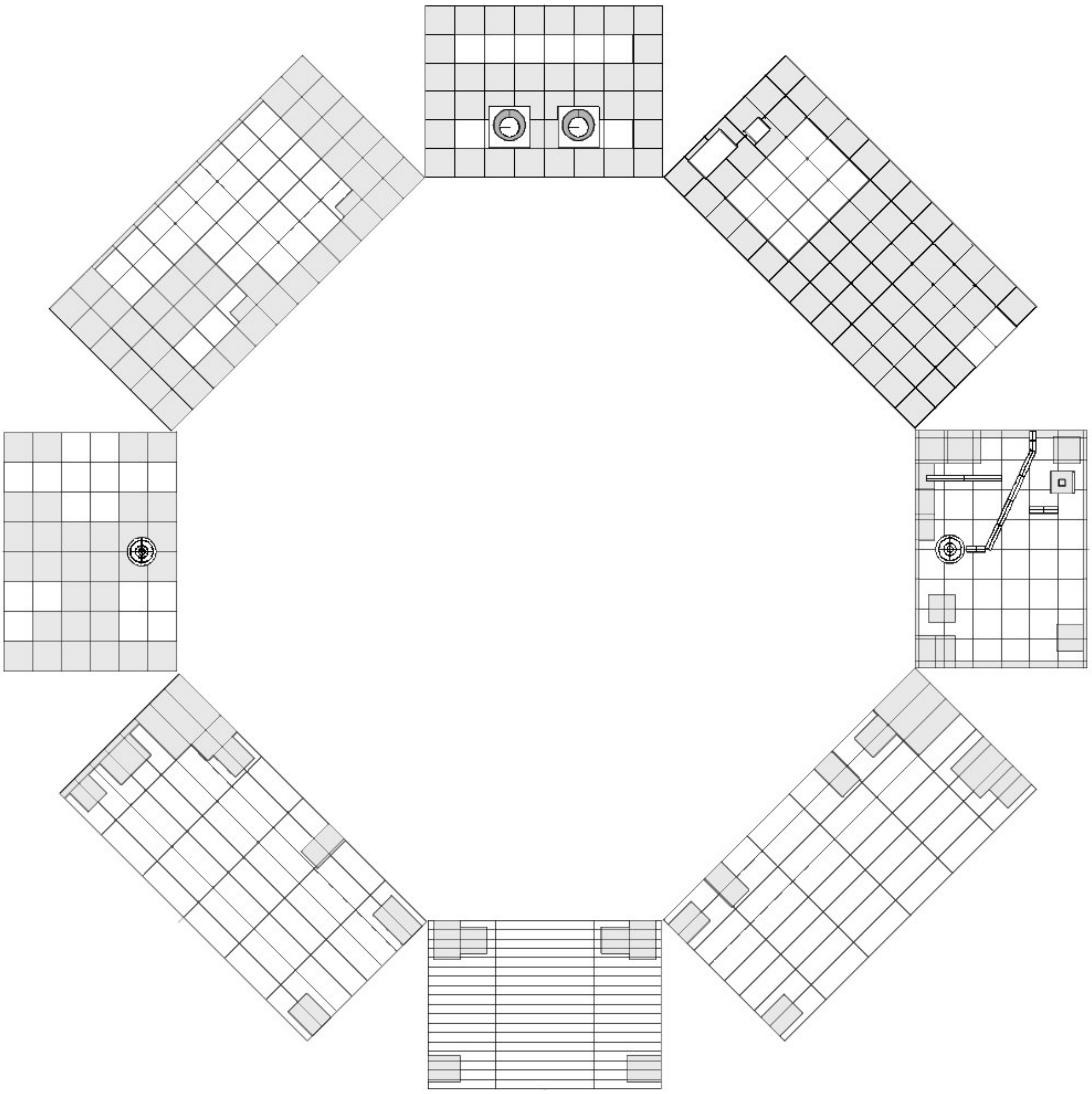


Figure 9.2.4.1-2 Planck Radiators Lay-out

9.2.4.2 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.

The following different types of MLI composition have been defined and are considered as the baseline solution:

BASELINE MLI:

Type B (external)
- 1 outer layer of Carbon Filled Kapton / VDA
- 1 layer Dacron net
- 8 x (1 layer of Double Aluminized Mylar (0.25 mil) perforated; 1 Dacron net layer)
- 1 bottom layer of Double Aluminized Kapton

Type C (external hi-efficiency)
- 1 outer layer of Double Aluminized Kapton
- 1 layer Dacron net
- 18 x (1 layer of Double Aluminized Mylar (0.25 mil) perforated; 1 Dacron net layer)
- 1 bottom layer of Double Aluminized Kapton

Type D (internal)
- 1 outer layer of Double Aluminized Kapton
- 1 layer Dacron net
- x (1 layer of Double Aluminized Mylar (0.25 mil) perforated; 1 Dacron net layer)
- 1 bottom layer of Double Aluminized Kapton

Type E (high temperature)
- 1 outer layer of Carbon Filled Kapton / VDA
- 1 layer Nomex scrim
- 3 x (1 layer of Double Aluminized Kapton (0.3 mil) perforated; 1 Nomex scrim layer)
- 1 bottom layer of Double Aluminized Kapton

APPLICATION:

Use of **Type B** MLI is proposed (Carbon Filled Kapton), both on Herschel and Planck, because CFK is more robust with respect to “Type A” concerning handling and ESD prevention, and for commonality reasons.

In order to provide an optimum insulation level in critical interface areas, such as top and bottom platforms, **Type C** MLI (with a higher number of internal reflector layers) is proposed. For mass saving reasons, use of Type C MLI is limited to critical interface areas only.
Critical Interfaces are assumed to be:
- I/F between PLM and SVM (both SVM’s)
- I/F between Solar Arrays and Planck SVM.

Internal MLI design (**Type D**) accounts for best compromise between mass and insulation performance (lower temperature gradients are to be guaranteed). Its use is foreseen on:
- Herschel tanks,
- Herschel HIFI units and relevant panels
- Planck SCC panels internal side
- Planck tanks.

Type E is foreseen around Thrusters for high temperature application.

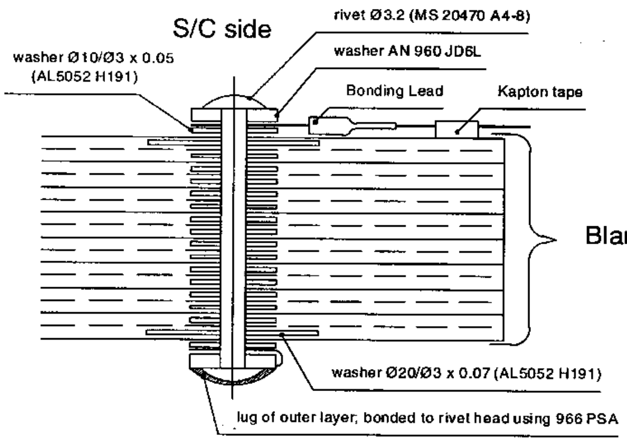
The MLI blankets are installed on the supporting structures by means of fastener studs and/or velcros.
Definition of venting areas will be done according to a dedicated venting analysis.

To be compliant with EMC requirements:

All the internal layers of all the MLI's are aluminised on the two sides.
The external layer of the external MLI's is externally coated by means of ITO which guarantees a surface resistance lower than 20000 Ohm per square or is electrically conductive Carbon Filled Kapton
All the layers of each blanket are electrically bonded together.
All the blankets are grounded to the structure, the number of blanket grounding points to structure is:
- at least 2 points for each blanket;
- on the edges (1 point each 50 cm);

blanket grounding wire will be approximately 15 cm as a goal;
DC resistance between grounding reference point and any metallic face of the blanket shall be less than 10 ohms.

Details of MLI design provisions are given in [RD-88].



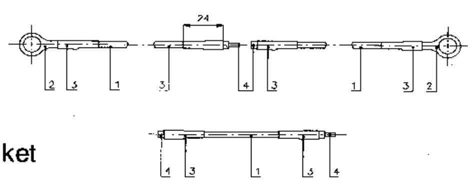


Figure 9.2.4.2-1 SVM MLI Grounding point design

9.2.4.3 Heaters, thermistors and thermostats

Heaters are classified as follows:

Nominal heaters (N): used to maintain the units above their lower operating limits during the nominal phases. They are automatically controlled at the minimum operating temperature threshold.

Survival heaters (S): used to guarantee that the lower non-operating limits are not exceeded during the S/C Survival phase. They are automatically controlled at the minimum not-operating temperature threshold.

They are grouped in two different control loop classes:
- control loop without thermal stability requirements (Class "A")
- control loop with thermal stability requirements (Class "B")

Each control loop is composed of 3 thermistors and 2 heater lines (1 prime and 1 redundant).
The thermal regulation will follow the reading of 3 thermistors; for failure tolerance reason a majority voting policy is applied to the 3 sampled values. The control process acquires the temperature of thermistors and operates consequently on the associated heater lines according to specific control laws. The commanding toward the heater lines is performed managing properly relevant Heater Control Switches (HCS) and Heater Protection Switches (HPS) belonging physically to the PCDU.

The CDMU application software will command all nominal heater lines.

For class "B" a Pulsed Width Modulation mode commanding is carried out with a control loop frequency equal to 10 seconds and the heater command period equal to 1 second.
Viceversa a sample switch ON/OFF is performed for control loop belonging to class 'A" with a control loop frequency equal to 60 seconds.

The temperature regulation, are hereafter showed:

CLASS "A":

Condition	Heater commands
$T_{mon} < T_{min}$	Switch-ON HCS
$T_{mon} > T_{max}$	Switch-OFF HCS
$T_{min} \le T_{mon} \le T_{max}$	No commands

where:
T_{mon}: thermistor value measured according to a majority voting approach.
T_{min}, T_{max}: lower and upper thermistor threshold.

CLASS "B":

- measurement of the temperature every 10 s.
- calculation of the power to be provided by means of a PI algorithm
- switch ON/OFF of the relevant heater line with a frequency of 1 Hz

The heater electrical scheme is given in the following Figure 9.2.4.3-1.

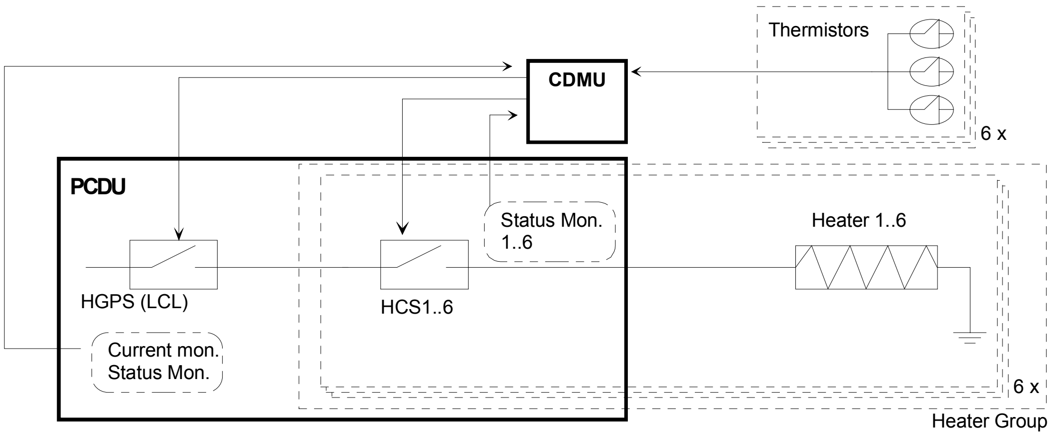


Figure 9.2.4.3-1 Nominal Heaters Electrical scheme

Nominal and Survival heaters are generally controlled with a "ON-OFF logic" between temperature thresholds. For the Herschel HIFI and Star Tracker temperature stability requirement a heater fine control law (PI regulation) has been developed.

Nominal and Survival heater circuits are dedicated to:
- SVM units
- Warm units (instruments)
- RCS pipelines
- Tanks
- External items (Thrusters and Sensors, Star Trackers)

Two types of heaters are foreseen: wire and thermofoil heaters.

Wire Heaters

Wire heaters are used on RCS pipelines only, with a provision of a heater power density in the range between 0.2 and 0.6 w/m.

Main characteristics are hereunder reported.

Characteristics	VALUES
Material :	Kanthal A1
AWG Wire:	AWG 26
Number of wires :	2
Resistivity [Ohm/m]:	11.31 [Ohm/m]
Insulation :	Polymide

Thermofoil Heaters

Foil heaters are double circuits, double layer, thermofoil and internal redundant heater. Inherent magnetic compensation is foreseen.
Heater will be bonded using Y966 PSA tape and AV138 glue-drops on the borders and corners of the heater.

Typologies of the heaters are hereafter given.

HEATER TYPE	Size [mm]	Resistance [ohm]	Power [at 27V]
B	**100x26**	**155**	4.703
C	**137x55**	**47**	15.511
G	**140x40**	**64**	11.391
J	**90x45**	**90**	8.100
D	**320x21**	**945**	0.771
F	**205x28**	**28**	26.036
E	**45x21**	**310**	2.352
L	**145x20**	**276**	2.641

A list of heater circuits and related power and command is given in table 9.2.4.2-2
N.B.: The heater lines dedicated to RCS are under revision.

Table 9.2.4.2-2: HERSCHEL Heater Circuit Breakdown

HERSCHEL Heater line	TCS ID	HEATER's location	Heater line status used spare not-available	Power @27 V [W]	ENABLED in NOMINAL	ENABLED in SURVIVAL	Heater line commanded by THM-	Nominal Threshold [°C]	Survival Threshold [°C]
TCS Line 01	HTR104NS	close to XPND1	used	11.39	YES	YES	49/97/145	-9/-6	-9/-6
TCS Line 02	HTR105NS	close to XPND2	used	11.39	YES	YES	50/98/146	-9/-6	-9/-6
TCS Line 03	HTR204NS	inside BATTERY	used	14.90	YES	YES	51/99/147	1/4	1/4
TCS Line 04		N/A	not-available	N/A	N/A	N/A	N/A	N/A	N/A
TCS Line 05	HTR301S	close to FPSPU, FPDPU	used	31.00	NO	YES	53/101/149	N/A	-29/-26
TCS Line 06	HTR304NS	close to FPBOLC	used	9.40	YES	YES	54/102/150	-14/-11	-29/-26
TCS Line 07			spare						
TCS Line 08	HTR305S	close to FPDECMEC	used	27.48	NO	YES	56/104/152	N/A	-29/-26
TCS Line 09	HTR1533NS	among brck RCS-13-01, RCS-13-02/03, RCS-13-04, RCS- I -33, RCS- I -32, RCS- I -31, RCS- I -21/22	used	3.72	YES	YES	57/105/153	19/22	19/22
TCS Line 10	HTR401S	close to CCU, HSDCU, HSFCU	used	44.50	NO	YES	58/106/154	N/A	-19/-16
TCS Line 11	HTR1501NS	among brck RCS-E-30/31/32/33, RCS- I - 28/28A/29/30, RCS- I - 36/38/35/34	used	2.68	YES	YES	59/107/155	19/22	19/22
TCS Line 12	HTR501NS	close to FHWOV	used	22.80	YES	YES	60/108/156	C.L.	-24/-21
TCS Line 13	HTR502S	close to FHHRV	used	39.00	NO	YES	61/109/157	N/A	-24/-21
TCS Line 14	HTR504S	close to FHFCU	used	20.79	NO	YES	62/110/158	N/A	-24/-21
TCS Line 15	HTR506S	close to FHWEV, FHICU, FHIFV	used	40.40	NO	YES	63/111/159	N/A	-24/-21
TCS Line 16	HTR601NS	close to FHWOH	used	32.40	YES	YES	64/112/160	C.L.	-24/-21
TCS Line 17	HTR602S	close to FHWEH	used	32.40	NO	YES	65/113/161	N/A	-24/-21

HERSCHEL Heater line	TCS ID	HEATER's location	Heater line status used spare not-available	Power @27 V [W]	ENABLED in NOMINAL	ENABLED in SURVIVAL	Heater line commanded by THM-	Nominal Threshold [°C]	Survival Threshold [°C]
TCS Line 18	HTR603S	close to FHHRH	used	39.00	NO	YES	66/114/162	N/A	-24/-21
TCS Line 19	HTR604S	close to FHLCU, FHIFH	used	20.90	NO	YES	67/115/163	N/A	-24/-21
TCS Line 20	HTR605S	close to FHLSU	used	29.00	NO	YES	68/116/164	N/A	-24/-21
TCS Line 21	HTR702NS	on RWL2	used	11.40	YES	YES	69/117/165	1/4	1/4
TCS Line 22	HTR704NS	on RWL4	used	11.40	YES	YES	70/118/166	1/4	1/4
TCS Line 23	HTR701NS	on RWL1	used	11.40	YES	YES	71/119/167	1/4	1/4
TCS Line 24	HTR703NS	on RWL3	used	11.40	YES	YES	72/120/168	1/4	1/4
TCS Line 25	HTR70NS	on TANK +Y	used	6.17	YES	YES	73/121/169	11/14	11/14
TCS Line 26	HTR71NS	on TANK -Y	used	6.17	YES	YES	74/122/170	11/14	11/14
TCS Line 27	HTR20000NS	close to STR's	used	21.10	YES	YES	75/123/171	C.L.	-29/-26
TCS Line 28			spare						
TCS Line 29	HTR8133NS	on FCV A1A	used	2.35	YES	YES	77/125/173	11/14	11/14
TCS Line 30	HTR8233NS	on FCV C2A	used	2.35	YES	YES	78/126/174	11/14	11/14
TCS Line 31	HTR8333NS	on FCV C1A	used	2.35	YES	YES	79/127/175	11/14	11/14
TCS Line 32	HTR8433NS	on FCV A2A	used	2.35	YES	YES	80/128/176	11/14	11/14
TCS Line 33	HTR8533NS	on FCV C4A	used	2.35	YES	YES	81/129/177	11/14	11/14
TCS Line 34	HTR8633NS	on FCV C3A	used	2.35	YES	YES	82/130/178	11/14	11/14
TCS Line 35	HTR1559NS	on brck RCS-15-01, RCS-15-02/04/05, RCS-15-03, RCS-15-03, RCS-15-06, RCS-15-07/08/10, RCS-15-09, RCS-17-01,RCS-17-02/03, RCS-17-04, RCS-E-34/35/36/37/38, RCS-E-01/02/01A/03, RCS-E-	used	14.12	YES	YES	83/131/179	19/22	19/22

HERSCHEL

Heater line	TCS ID	HEATER's location	Heater line status used spare not-available	Power @27 V [W]	ENABLED in NOMINAL	ENABLED in SURVIVAL	Heater line commanded by THM-	Nominal Threshold [°C]	Survival Threshold [°C]
		04/05/06/07/08, RCS- I -16/17/18/19/20, RCS- I -23/24/25/26/27							
TCS Line 36	HTR1506NS	on brck RCS-E-09/10/11/12, RCS-E-13/14/15/16/17/18, RCS- I -09/10/11/12/13/14/15, RCS- I -05/06/07, RCS- I -08, RCS- I -01, RCS- I -02, RCS- I -03/04	used	6.31	YES	YES	84/132/180	19/22	19/22
TCS Line 37	HTR1591NS	on brck RCS-11-05/06, RCS-11-01/02/03/04	used	2.65	YES	YES	85/133/181	19/22	19/22
TCS Line 38	HTR100NS	close to GYRO	used	62.00	YES	YES	86/134/182	62.5/63.0	-14/-11
TCS Line 39	HTR8134NS	on FCV A1B	used	2.35	YES	YES	87/135/183	11/14	11/14
TCS Line 40	HTR8234NS	on FCV C2B	used	2.35	YES	YES	88/136/184	11/14	11/14
TCS Line 41	HTR8334NS	on FCV C1B	used	2.35	YES	YES	89/137/185	11/14	11/14
TCS Line 42	HTR8434NS	on FCV A2B	used	2.35	YES	YES	90/138/186	11/14	11/14
TCS Line 43	HTR8534NS	on FCV C4B	used	2.35	YES	YES	91/139/187	11/14	11/14
TCS Line 44	HTR8634NS	on FCV C3B	used	2.35	YES	YES	92/140/188	11/14	11/14
TCS Line 45	HTR1523NS	on brck RCS-12-08, RCS-12-09, RCS-12-06/07, RCS-12-01/02/03/04/05	used	1.96	YES	YES	93/141/189	19/22	19/22

HERSCHEL Heater line	TCS ID	HEATER's location	Heater line status used spare not-available	Power @27 V [W]	ENABLED in NOMINAL	ENABLED in SURVIVAL	Heater line commanded by THM-	Nominal Threshold [°C]	Survival Threshold [°C]
TCS Line 46	HTR1541NS	on brck RCS-14-01, RCS-14-02/03, RCS-14-04	used	2.47	YES	YES	94/142/190	19/22	19/22
TCS Line 47	HTR1583NS	on brck RCS-18-01, RCS-18-02/03, RCS-18-04	used	2.47	YES	YES	95/143/191	19/22	19/22
TCS Line 48	HTR1550NS	on unit: PT, LF, LV1, LV2	used	9.16	YES	YES	96/144/192	19/22	19/22

Table 9.2.4.2-3: PLANCK Heater Circuit Breakdown

PLANCK Heater line	TCS ID	HEATER's location	Heater line status used spare not-available	Power @27 V [W]	ENABLED in NOMINAL	ENABLED in SURVIVAL	Heater line commanded by THM-	Nominal Threshold [°C]	Survival Threshold [°C]
TCS Line 01	HTR5427S	close to STR 1	used	4.70	NO	YES	49/97/145	N/A	-29/-26
TCS Line 02	HTR5527S	close to STR 2	used	4.70	NO	YES	50/98/146	N/A	-29/-26
TCS Line 03	HTR13S	close to DPU1	used	22.80	NO	YES	51/99/147	N/A	-19/-16
TCS Line 04	HTR14S	close to DPU2	used	22.80	NO	YES	52/100/148	N/A	-19/-16
TCS Line 05	HTR205S	close to REU	used	62.00	NO	YES	53/101/149	N/A	-19/-16
TCS Line 06	HTR220S	close to CEU, CCU	used	52.50	NO	YES	54/102/150	N/A	-18/-15
TCS Line 07	HTRHP7NS	on Heat Pipes	used	78.00	YES	YES	55/103/151	-14/-11 (BOL) -16/-13 (EOL)	-14/-11
TCS Line 08	HTRHP8NS	on Heat Pipes	used	78.00	YES	YES	55/103/151	-15/-12 (BOL) -17/-14 (EOL)	-15/-12
TCS Line 09	HTRHP9S	on Heat Pipes	used	91.00	YES	YES	55/103/151	-16/-13 (BOL) -18/-15 (EOL)	-16/-13
TCS Line 10	HTRHP10S	on Heat Pipes	used	91.00	YES	YES	55/103/151	-17/-14 (BOL) -19/-16 (EOL)	-17/-14
TCS Line 11	HTRHP11S	on Heat Pipes	used	91.00	YES	YES	55/103/151	-18/-15 (BOL) -20/-17 (EOL)	-18/-15
TCS Line 12	HTRHP12S	on Heat Pipes	used	91.00	YES	YES	55/103/151	-19/-16 (BOL) -20/-17 (EOL)	-19/-16
TCS Line 13	HTRHP13S	on Heat Pipes	used	91.00	YES	YES	55/103/151	-20/-17 (BOL) -20/-17 (EOL)	-20/-17
TCS Line 14			spare						
TCS Line 15	HTR522S	PAU	used	8.1			63/111/159		
TCS Line 16	HTR203S	CRU (4K Reg)	used	12.8			64/112/160		

PLANCK

Heater line	TCS ID	HEATER's location	Heater line status used spare not-available	Power @27 V [W]	ENABLED in NOMINAL	ENABLED in SURVIVAL	Heater line commanded by THM-	Nominal Threshold [°C]	Survival Threshold [°C]
TCS Line 17			spare						
TCS Line 18			spare						
TCS Line 19			spare						
TCS Line 20			spare						
TCS Line 21	HTR920NS	on TANK +Z+Y	used	6.17	NO	YES	69/117/165	11/14	11/14
TCS Line 22	HTR925NS	on TANK +Z-Y	used	6.17	NO	YES	70/118/166	11/14	11/14
TCS Line 23	HTR930NS	on TANK -Z	used	6.17	NO	YES	71/119/167	11/14	11/14
TCS Line 24	HTR8508NS	on FCV A1	used	2.35	YES	YES	72/120/168	11/14	11/14
TCS Line 25	HTR8608NS	on FCV A2	used	2.35	YES	YES	73/121/169	11/14	11/14
TCS Line 26	HTR1133NS	on FCV D1A	used	2.35	YES	YES	74/122/170	11/14	11/14
TCS Line 27	HTR1233NS	on FCV D2A	used	2.35	YES	YES	75/123/171	11/14	11/14
TCS Line 28	HTR1333NS	on FCV F1A	used	2.35	YES	YES	76/124/172	11/14	11/14
TCS Line 29	HTR1433NS	on FCV F2A	used	2.35	YES	YES	77/125/173	11/14	11/14
TCS Line 30	HTR1533NS	on FCV U1A	used	2.35	YES	YES	78/126/174	11/14	11/14
TCS Line 31	HTR1633NS	on FCV U2A	used	2.35	YES	YES	79/127/175	11/14	11/14
TCS Line 32	HTR1882NS	among brck RCS-18-03/04, RCS-18-02, RCS-18-01/05	used	2.75	YES	YES	80/128/176	19/22	19/22
TCS Line 33	HTR1809NS	among brck RCS-E-04/05/06/02/34, RCS-E-01, RCS- I -03/04/05/06, RCS- I -02, RCS- I -34, RCS- I -33, RCS- I -32	used	3.39	YES	YES	81/129/177	19/22	19/22

PLANCK

Heater line	TCS ID	HEATER's location	Heater line status used spare not-available	Power @27 V [W]	ENABLED in NOMINAL	ENABLED in SURVIVAL	Heater line commanded by THM-	Nominal Threshold [°C]	Survival Threshold [°C]
TCS Line 34	HTR1814NS	among brck RCS-14-01/02, RCS-E-21/35, RCS-E-23/24/25/26/27,RCS- I -13/14/15/16/17/29, RCS- I -07/08/09/10/11/12/30	used	4.87	YES	YES	82/130/178	19/22	19/22
TCS Line 35	HTR202S	close to CAU	used	39.00	NO	YES	83/131/179	N/A	-19/-16
TCS Line 36	HTR103S	close to REBA1, REBA2	used	22.80	NO	YES	84/132/180	N/A	-29/-26
TCS Line 37	HTR703S	inside BATTERY	used	14.90	NO	YES	85/133/181	1/4	1/4
TCS Line 38	HTR8708NS	on FCV B1	used	2.35	YES	YES	86/134/182	11/14	11/14
TCS Line 39	HTR8808NS	on FCV B2	used	2.35	YES	YES	87/135/183	11/14	11/14
TCS Line 40	HTR1134NS	on FCV D1B	used	2.35	YES	YES	88/136/184	11/14	11/14
TCS Line 41	HTR1234NS	on FCV D2B	used	2.35	YES	YES	89/137/185	11/14	11/14
TCS Line 42	HTR1334NS	on FCV F1B	used	2.35	YES	YES	90/138/186	11/14	11/14
TCS Line 43	HTR1434NS	on FCV F2B	used	2.35	YES	YES	91/139/187	11/14	11/14
TCS Line 44	HTR1534NS	on FCV U1B	used	2.35	YES	YES	92/140/188	11/14	11/14
TCS Line 45	HTR1634NS	on FCV U2B	used	2.35	YES	YES	93/141/189	11/14	11/14
TCS Line 46	HTR1813NS	among brck RCS-16-01, RCS-16-02, RCS-E-16/17/18/19/20, RCS-E-15/32/33, RCS-E-09/10/11/12/36, RCS-E-13/14, RCS- I -18/19/20/21/22/23/24,	used	4.03	YES	YES	94/142/190	19/22	19/22

PLANCK

Heater line	TCS ID	HEATER's location	Heater line status used spare not-available	Power @27 V [W]	ENABLED in NOMINAL	ENABLED in SURVIVAL	Heater line commanded by THM-	Nominal Threshold [°C]	Survival Threshold [°C]
		RCS- I -25/26, RCS- I -27/28, RCS- I -01, RCS- I -40, RCS- I -38/39							
TCS Line 47	HTR1872NS	among brck RCS-17-04, RCS-17-03, RCS-17-02, RCS-17-05/01	used	1.67	YES	YES	95/143/191	19/22	19/22
TCS Line 48	HTR1857NS	among brck RCS-11-01, RCS-12-01/02/03/05, RCS-12-06, RCS-12-04/07/10, RCS-12-09, RCS-12-12/13, RCS-12-08/11, PT, LF, LV1, LV2, RCS-13-01, RCS-13-02, RCS-E-28/29/30/31	used	12.54	YES	YES	96/144/192	19/22	19/22

Thermistors are used for heater control and unit temperature monitoring.
The main characteristics of the thermistors/acquisition chain are hereunder given:

Characteristics	VALUES
Typology:	Betatherm G15K4D393
Resistance in [ohm] at 25°C:	15 Kohms

Thermistors used for heater control are three per circuit according to the “majority voting rule”.
Thermistor breakdown is given in table 9.2.4.2-4/5.
Installation method will make use of AV138 or equivalent adhesive resin.

Table 9.2.4.2-4: HERSCHEL Thermistor's Breakdown

HERSCHEL

MODULE = SIOH1			MODULE = SIOH2			MODULE = SIOH3			
Th. Location		**M/C**	**Th. Location**		**M/C**	**Th. Location**		**M/C**	**Group**
XPND1	THM-49	M+C	XPND1	THM-97	M+C	XPND1	THM-145	M+C	ET0
XPND2	THM-50	M+C	XPND2	THM-98	M+C	XPND2	THM-146	M+C	ET0
BATTERY	THM-51	M+C	BATTERY	THM-99	M+C	BATTERY	THM-147	M+C	ET0
FPDPU	THM-52	M	FPDPU	THM-100	M		THM-148	spare	ET0
FPSPU	THM-53	M+C	FPSPU	THM-101	M+C	FPSPU	THM-149	M+C	ET0
FPBOLC	THM-54	M+C	FPBOLC	THM-102	M+C	FPBOLC	THM-150	M+C	ET0
	THM-55	spare		THM-103	spare		THM-151	spare	ET0
FPMECDEC	THM-56	M+C	FPMECDEC	THM-104	M+C	FPMECDEC	THM-152	M+C	ET0
RCS-13-04 brck	THM-57	M+C	RCS-13-04 brck	THM-105	M+C	RCS-13-04 brck	THM-153	M+C	ET0
CCU	THM-58	M+C	CCU	THM-106	M+C	CCU	THM-154	M+C	ET0
RCS-I-28A brck	THM-59	M+C	RCS-I-28A brck	THM-107	M+C	RCS-I-28A brck	THM-155	M+C	ET0
FHWOV	THM-60	M+C	FHWOV	THM-108	M+C	FHWOV	THM-156	M+C	ET0
FHHRV	THM-61	M+C	FHHRV	THM-109	M+C	FHHRV	THM-157	M+C	ET0
FHFCU	THM-62	M+C	FHFCU	THM-110	M+C	FHFCU	THM-158	M+C	ET0
FHWEV	THM-63	M+C	FHWEV	THM-111	M+C	FHWEV	THM-159	M+C	ET0
FHWOH	THM-64	M+C	FHWOH	THM-112	M+C	FHWOH	THM-160	M+C	ET0
FHWEH	THM-65	M+C	FHWEH	THM-113	M+C	FHWEH	THM-161	M+C	ET1
FHHRH	THM-66	M+C	FHHRH	THM-114	M+C	FHHRH	THM-162	M+C	ET1
FHLCU	THM-67	M+C	FHLCU	THM-115	M+C	FHLCU	THM-163	M+C	ET1
FHLSU	THM-68	M+C	FHLSU	THM-116	M+C	FHLSU	THM-164	M+C	ET1
RWL2	THM-69	M+C	RWL2	THM-117	M+C	RWL2	THM-165	M+C	ET1
RWL4	THM-70	M+C	RWL4	THM-118	M+C	RWL4	THM-166	M+C	ET1
RWL1	THM-71	M+C	RWL1	THM-119	M+C	RWL1	THM-167	M+C	ET1
RWL3	THM-72	M+C	RWL3	THM-120	M+C	RWL3	THM-168	M+C	ET1
TANK +Y	THM-73	M+C	TANK +Y	THM-121	M+C	TANK +Y	THM-169	M+C	ET1

HERSCHEL

MODULE = SIOH1			MODULE = SIOH2			MODULE = SIOH3			
Th. Location		M/C	Th. Location		M/C	Th. Location		M/C	Group
TANK -Y	THM-74	M+C	TANK -Y	THM-122	M+C	TANK -Y	THM-170	M+C	ET1
STR center plate	THM-75	M+C	STR center plate	THM-123	M+C	STR center plate	THM-171	M+C	ET1
	THM-76	spare		THM-124	spare		THM-172	spare	ET1
FCV A1A	THM-77	M+C	FCV A1A	THM-125	M+C	FCV A1A	THM-173	M+C	ET1
FCV C2A	THM-78	M+C	FCV C2A	THM-126	M+C	FCV C2A	THM-174	M+C	ET1
FCV C1A	THM-79	M+C	FCV C1A	THM-127	M+C	FCV C1A	THM-175	M+C	ET1
FCV A2A	THM-80	M+C	FCV A2A	THM-128	M+C	FCV A2A	THM-176	M+C	ET1
FCV C4A	THM-81	M+C	FCV C4A	THM-129	M+C	FCV C4A	THM-177	M+C	ET2
FCV C3A	THM-82	M+C	FCV C3A	THM-130	M+C	FCV C3A	THM-178	M+C	ET2
RCS-15-09 brck	THM-83	M+C	RCS-15-09 brck	THM-131	M+C	RCS-15-09 brck	THM-179	M+C	ET2
RCS-I-12 brck	THM-84	M+C	RCS-I-12 brck	THM-132	M+C	RCS-I-12 brck	THM-180	M+C	ET2
RCS-11-05 brck	THM-85	M+C	RCS-11-05 brck	THM-133	M+C	RCS-11-05 brck	THM-181	M+C	ET2
GYRO	THM-86	M+C	GYRO	THM-134	M+C	GYRO	THM-182	M+C	ET2
FCV A1B	THM-87	M+C	FCV A1B	THM-135	M+C	FCV A1B	THM-183	M+C	ET2
FCV C2B	THM-88	M+C	FCV C2B	THM-136	M+C	FCV C2B	THM-184	M+C	ET2
FCV C1B	THM-89	M+C	FCV C1B	THM-137	M+C	FCV C1B	THM-185	M+C	ET2
FCV A2B	THM-90	M+C	FCV A2B	THM-138	M+C	FCV A2B	THM-186	M+C	ET2
FCV C4B	THM-91	M+C	FCV C4B	THM-139	M+C	FCV C4B	THM-187	M+C	ET2
FCV C3B	THM-92	M+C	FCV C3B	THM-140	M+C	FCV C3B	THM-188	M+C	ET2
RCS-12-07 brck	THM-93	M+C	RCS-12-07 brck	THM-141	M+C	RCS-12-07 brck	THM-189	M+C	ET2
RCS-14-01 brck	THM-94	M+C	RCS-14-01 brck	THM-142	M+C	RCS-14-01 brck	THM-190	M+C	ET2
RCS-18-04 brck	THM-95	M+C	RCS-18-04 brck	THM-143	M+C	RCS-18-04 brck	THM-191	M+C	ET2
PT unit	THM-96	M+C	PT unit	THM-144	M+C	PT unit	THM-192	M+C	ET2

Table 9.2.4.2-5: PLANCK Thermistor's Breakdown

PLANCK

MODULE = SIOH1			MODULE = SIOH2			MODULE = SIOH3			
Th. Location		M/C	Th. Location		M/C	Th. Location		M/C	Group
Star Tracker 1	THM-49	M+C	Star Tracker 1	THM-97	M+C	Star Tracker 1	THM-145	M+C	ET0
Star Tracker 2	THM-50	M+C	Star Tracker 2	THM-98	M+C	Star Tracker 2	THM-146	M+C	ET0
DPU1	THM-51	M+C	DPU1	THM-99	M+C	DPU1	THM-147	M+C	ET0
DPU2	THM-52	M+C	DPU2	THM-100	M+C	DPU2	THM-148	M+C	ET0
REU	THM-53	M+C	REU	THM-101	M+C	REU	THM-149	M+C	ET0
CEU	THM-54	M+C	CEU	THM-102	M+C	CEU	THM-150	M+C	ET0
heat pipe	THM-55	M+C	heat pipe	THM-103	M+C	heat pipe	THM-151	M+C	ET0
DAE	THM-56	M	DAE	THM-104	M	BEU	THM-152	M	ET0
BEU	THM-57	M	He3 tank	THM-105	M	He3 tank	THM-153	M	ET0
DCCU	THM-58	M	DCCU	THM-106	M		THM-154	spare	ET0
He4 tank 3	THM-59	M	He4 tank 3	THM-107	M		THM-155	spare	ET0
CCU	THM-60	M	CCU	THM-108	M	He4 tank 1	THM-156	M	ET0
He4 tank 1	THM-61	M	He4 tank 2	THM-109	M	He4 tank 2	THM-157	M	ET0
	THM-62	spare		THM-110	spare		THM-158	spare	ET0
PAU	THM-63	M+C	PAU	THM-111	M+C	PAU	THM-159	M+C	ET0
CRU(4K Reg)	THM-64	M+C	CRU(4K Reg)	THM-112	M+C	CRU(4K Reg)	THM-160	M+C	ET0
	THM-65	spare		THM-113	spare		THM-161	spare	ET1
	THM-66	spare		THM-114	spare		THM-162	spare	ET1
	THM-67	spare		THM-115	spare		THM-163	spare	ET1
	THM-68	spare		THM-116	spare		THM-164	spare	ET1
TANK +Z+Y	THM-69	M+C	TANK +Z+Y	THM-117	M+C	TANK +Z+Y	THM-165	M+C	ET1
TANK +Z-Y	THM-70	M+C	TANK +Z-Y	THM-118	M+C	TANK +Z-Y	THM-166	M+C	ET1
TANK -Z	THM-71	M+C	TANK -Z	THM-119	M+C	TANK -Z	THM-167	M+C	ET1
1 N FCV A1	THM-72	M+C	1 N FCV A1	THM-120	M+C	1 N FCV A1	THM-168	M+C	ET1
1 N FCV A2	THM-73	M+C	1 N FCV A2	THM-121	M+C	1 N FCV A2	THM-169	M+C	ET1

PLANCK

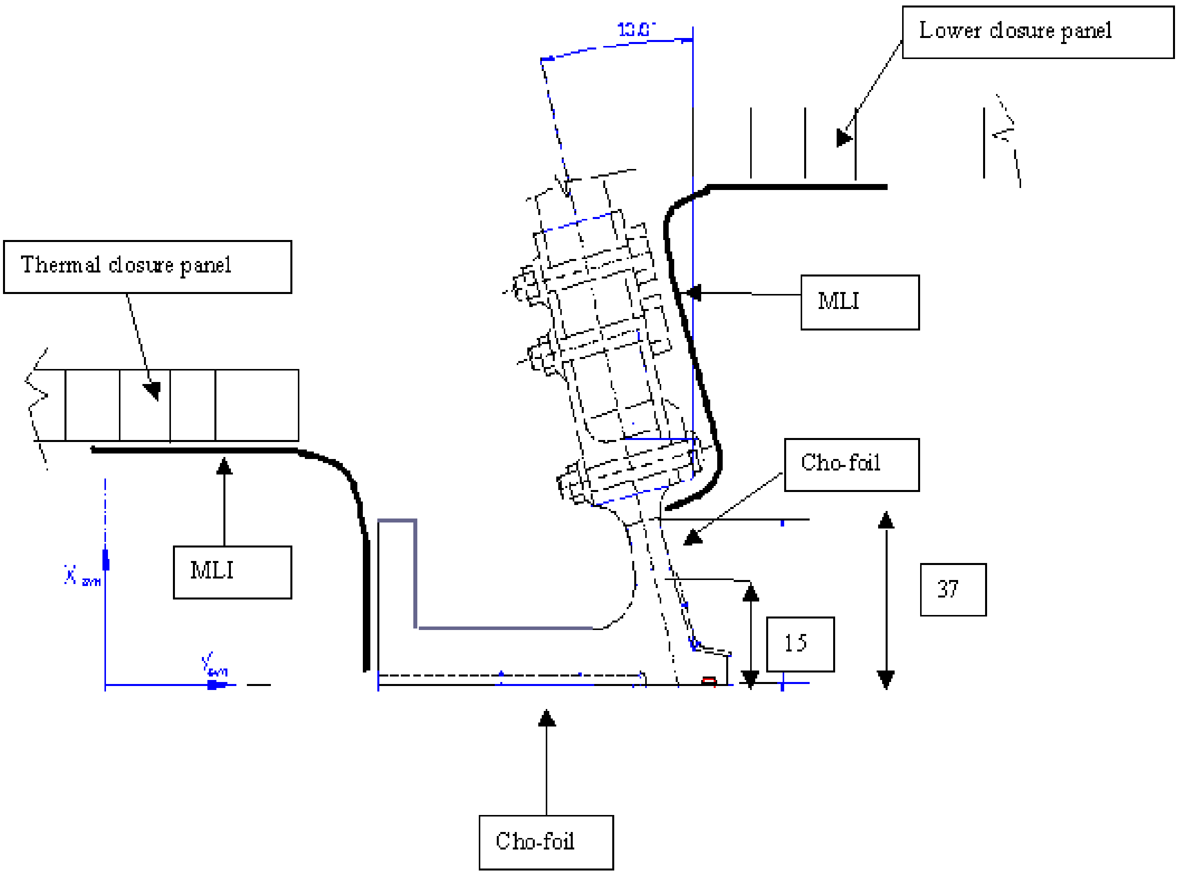
MODULE = SIOH1			MODULE = SIOH2			MODULE = SIOH3			
Th. Location		M/C	Th. Location		M/C	Th. Location		M/C	Group
20N FCV D1A	THM-74	M+C	20N FCV D1A	THM-122	M+C	20N FCV D1A	THM-170	M+C	ET1
20N FCV D2A	THM-75	M+C	20N FCV D2A	THM-123	M+C	20N FCV D2A	THM-171	M+C	ET1
20N FCV F1A	THM-76	M+C	20N FCV F1A	THM-124	M+C	20N FCV F1A	THM-172	M+C	ET1
20N FCV F2A	THM-77	M+C	20N FCV F2A	THM-125	M+C	20N FCV F2A	THM-173	M+C	ET1
20N FCV U1A	THM-78	M+C	20N FCV U1A	THM-126	M+C	20N FCV U1A	THM-174	M+C	ET1
20N FCV U2A	THM-79	M+C	20N FCV U2A	THM-127	M+C	20N FCV U2A	THM-175	M+C	ET1
RCS-18-02 brck	THM-80	M+C	RCS-18-02 brck	THM-128	M+C	RCS-18-02 brck	THM-176	M+C	ET1
RCS-I-32 brck	THM-81	M+C	RCS-I-32 brck	THM-129	M+C	RCS-I-32 brck	THM-177	M+C	ET2
RCS-I-35 brck	THM-82	M+C	RCS-I-35 brck	THM-130	M+C	RCS-I-35 brck	THM-178	M+C	ET2
CAU	THM-83	M+C	CAU	THM-131	M+C	CAU	THM-179	M+C	ET2
REBA 1	THM-84	M+C	REBA 1	THM-132	M+C	REBA 1	THM-180	M+C	ET2
BATTERY	THM-85	M+C	BATTERY	THM-133	M+C	BATTERY	THM-181	M+C	ET2
1 N FCV B1	THM-86	M+C	1 N FCV B1	THM-134	M+C	1 N FCV B1	THM-182	M+C	ET2
1 N FCV B2	THM-87	M+C	1 N FCV B2	THM-135	M+C	1 N FCV B2	THM-183	M+C	ET2
20N FCV D1B	THM-88	M+C	20N FCV D1B	THM-136	M+C	20N FCV D1B	THM-184	M+C	ET2
20N FCV D2B	THM-89	M+C	20N FCV D2B	THM-137	M+C	20N FCV D2B	THM-185	M+C	ET2
20N FCV F1B	THM-90	M+C	20N FCV F1B	THM-138	M+C	20N FCV F1B	THM-186	M+C	ET2
20N FCV F2B	THM-91	M+C	20N FCV F2B	THM-139	M+C	20N FCV F2B	THM-187	M+C	ET2
20N FCV U1B	THM-92	M+C	20N FCV U1B	THM-140	M+C	20N FCV U1B	THM-188	M+C	ET2
20N FCV U2B	THM-93	M+C	20N FCV U2B	THM-141	M+C	20N FCV U2B	THM-189	M+C	ET2
RCS-I-38 brck	THM-94	M+C	RCS-I-38 brck	THM-142	M+C	RCS-I-38 brck	THM-190	M+C	ET2
RCS-17-03 brck	THM-95	M+C	RCS-17-03 brck	THM-143	M+C	RCS-17-03 brck	THM-191	M+C	ET2
RCS-12-09 brck	THM-96	M+C	RCS-12-09 brck	THM-144	M+C	RCS-12-09 brck	THM-192	M+C	ET2

9.2.4.4 Surface Finishes

Internal SVM will be generally high emissivity surfaces in order to minimise temperature gradients inside the SVM as required by the TCS specification.
The black paint "Aeroglaze Z306" having high emissivity (about 0.9) will be used on the lateral panels internal side. The central cone, the shear panels and the two floors have the skins in carbon fibre (emissivity about 0.8) and therefore do not need dedicated painting.
The units shall be black painted.
As already mentioned in par. 4.2, use of electrical conductive black paint (e.g. AEROGLAZE Z307) is foreseen on external radiator panels not directly impinged by solar flux.

HERSCHEL
FHWOH and FHWOV HIFI units are required to have low emissivity external treatment (Aluminum/Alodine).
Even the relevant panels (internal side), mounting the HIFI, units are requested to be with a low emissivity coating (Alodine treatment).

A low emissivity coating, onto the allowable area, (CHOFOIL aluminum tape eps=0.05) on the adapter ring is foreseen. The sketch below shows the design for the Herschel adapter ring.



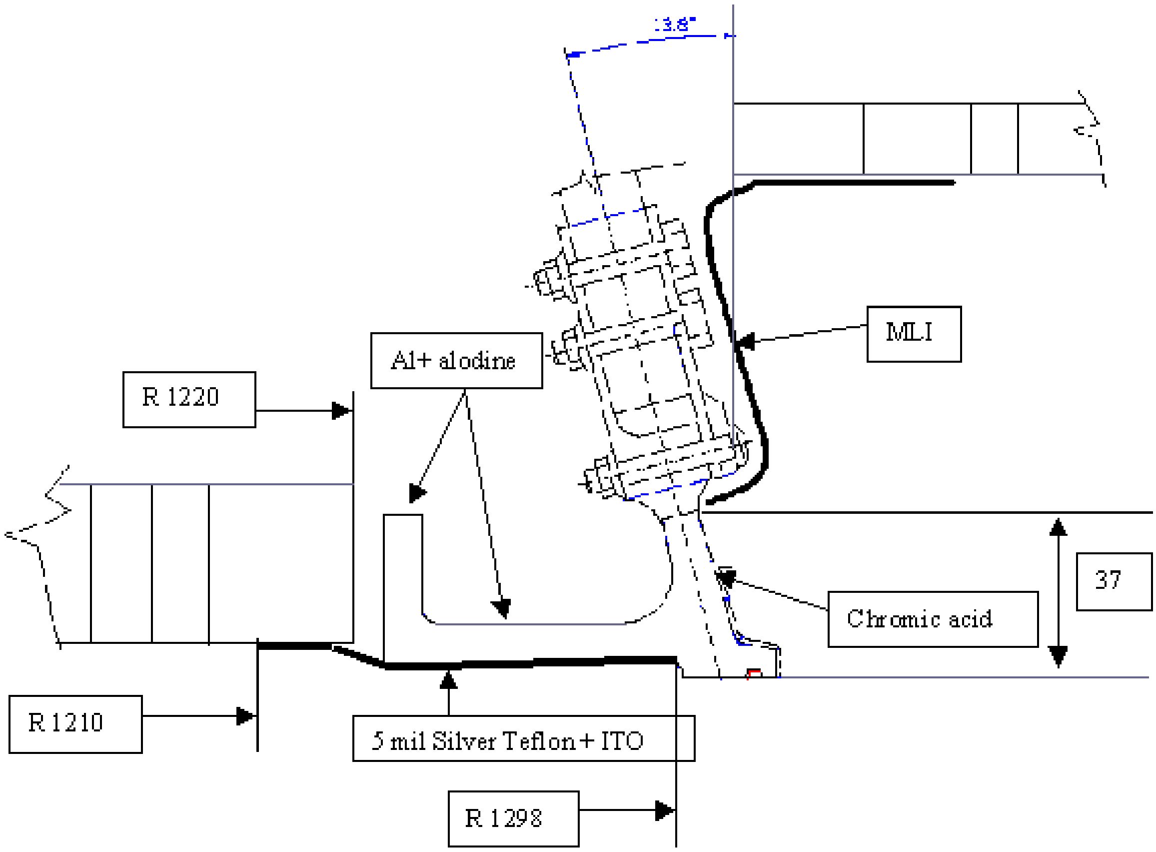
PLANCK

SCC/SCE units and relevant panels/heat pipes are assumed to have low emissivity coating.

SCC panels insulation w.r.t. internal SVM will be further achieved by means of MLI blankets in order to enhance the temperature stability of structural panels and interface truss, otherwise deeply affected by the SCC operation mode.

On SAS –X SSM Silver Teflon Tape is foreseen on the external side of the case unit.

The adapter ring is foreseen to be taped with SSM 5 mil Silver Teflon + ITO on his lower part as shown in the sketch below.


13.8°
MLI
Al+ alodine
R 1220
37
Chromic acid
R 1210
5 mil Silver Teflon+ ITO
R 1298

9.2.4.5 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

UNITS / PANEL INTERFACE:
Thermal interface filler is used to increase the thermal coupling of the dissipating units to the honeycomb structure and to reduce the uncertainty in the evaluation of their contact conductance.
As a baseline design, use of a graphite solid filler type SIGRAFLEX (thickness 0.35 mm) is foreseen.

In principle all dissipating units are assumed to be equipped with thermal interface filler. A list of units equipped with thermal filler is reported in [RD-98].

HEAT PIPES INTERFACE:
Even the interfaces concerning heat pipe installation on Planck make use of this kind of solid thermal filler; heat pipes interfaces include:
- SCC/SCE baseplate to heat pipes junction
- Heat pipe to heat pipe junction (crossing heat pipes)
- Heat Pipes to honeycomb panels' junction.

Selection of graphite foil (Sigraflex) as filler at heat pipe mounting interfaces is justified by the need to guarantee the possible complete dismountability of the heat pipes.

No use of liquid filler is currently foreseen.

In order to provide a suitable thermal control of equipment and/or structural supports requiring to be decoupled by the surrounding environment, use of insulating thermal washers is foreseen.

HERSCHEL & PLANCK

RCS items such as filters, valves and pipelines (not the thrusters) will require to be insulated from the structure. The relevant washers are provided by the RCS supplier.

LGA & MGA antennas at S/C I/F level. The relevant washers are provided by the antennas supplier.

PLANCK

The Planck solar array is requested to be insulated from the structure. The relevant washers are provided by the Solar Array supplier.

Baseline used thermal washers material is GFRP (Torlon /Vespel is taken into account as alternative solution).

9.2.4.6 Thermal Doublers

The structural composition of the radiators is a honeycomb sandwich between two thin aluminum sheets. This structure does not allow a good heat transfer by conduction along the panel. So, thermal doublers in aluminum AL99.5 % (thermal conductivity = 231 W/m/K) are installed under some dissipating units in order to spread the generated heat over larger areas.
The thermal doublers will be installed on the structure by means of AV138 glue or equivalent adhesives.

The following thermal doublers are foreseen:

HERSCHEL

On -Y panel, 1 doubler under FHWEH, approx. dimensions: 290 x 240 x 2 mm
On –Y/-Z panel, 1 doubler under FHWEV, approx. dimensions: 290 x 240 x 2 mm
On –Y/-Z panel, 1 doubler under FHHRV/FHFCU, approx. dimensions: 784 x 446 x 2 mm
On +Y/+Z panel, 1 doubler under TWT1, approx. dimensions: 435 x 144 x 2 mm
On +Y/+Z panel, 1 doubler under TWT2, approx. dimensions: 435 x 144 x 2 mm

PLANCK

On SubPlatform, 1 doubler under BEU, approx. dimensions: 180 x 400 x 2 mm

9.2.4.7 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.

SURFACES	MATERIALS	α	α	ε	Reference
		BOL	EOL		
High Emissivity surfaces (Internal panels & units)	Aeroglaze Z306			0.87	ALS
Lat Panels +Y+Z, +Y, -Y, –Y+Z, STR	OSR	0.1	0.18	0.8	ALS
Others External Lat Panels	Aeroglaze Z307	0.96	=	0.87	Data Sheet
MLI STR Radiator, Units and Baffles	Silver Teflon Tape (ITO)	0.09	0.24	0.75	ALS

Table 9.2.4.8-1 Thermo-optical properties

9.2.4.8 SVM Local Thermal Design

The HERSCHEL Star Trackers have very stringent requirements in terms of thermoelastic stability during the observation phases.
To meet those requirements a dedicated thermal design has been studied.

The main characteristics are the following:

1) A thermally stable support panel on which the STR's are mounted. It is made of Aluminum honeycomb with two thick skin (3mm + 2mm) of high thermal conductive carbon fiber (K1100). Part of the panel is covered with OSR to act as radiator rejecting the STR dissipation.

2) 6 GFRP struts connecting the STR support panel to the CVV. The struts are covered with light MLI and filled with foam to reduce the total flux to the CVV to 150 mW.

3) MLI blankets surrounding the 6 strut set (forming a so called swimming pool) reducing the SVM enclosure effect on the struts.

4) A MLI sun-shade and a secondary baffle (covered with MLI) and with Silver Teflon tape finishes are used to limit the Solar heating effect.

5) 1 heater circuit line (composed of 8 heaters) commanded by means of a fine control law (PI regulation) guarantees temperature stability during hot and cold phases.

A detailed description of the STR assembly design is reported in [RD-96].

9.2.4.9 RCS Thermal Control

The main features are:

PROPELLANT TANK	MLI blankets (type D) both on Herschel and Planck. Both programs are equipped with tank heaters.
VALVES, FILTERS & PRESSURE TRANSDUCERS	Thermofoil heaters and MLI (type D) blankets caps; suitable thermal decoupling from structural panels is required.
PIPELINES	Wire heaters and aluminum tape (such as Chofoil); thermal decoupling of all lines and items from the S/C structure achieved through structural insulating supports and washers is required.
20 N THRUSTERS	Thermofoil heaters on FCV Thermistors on FCV for monitoring and control Filler (SIGRAFLEX) at S/C I/F (bracket – structure) 4 copper multilayer flexible strips (90*12*0.8 mm) between FCV flange and support bracket (INTEGRAL design) No washers between Adjustment Ring and Thruster Bracket MLI type E
1 N THRUSTERS	Thermofoil heaters on FCV Thermistors on FCV for monitoring and control Filler (SIGRAFLEX) at S/C I/F (bracket – structure) MLI type E

The 20N copper strip design is shown in the Figure 9.2.4.9-1.

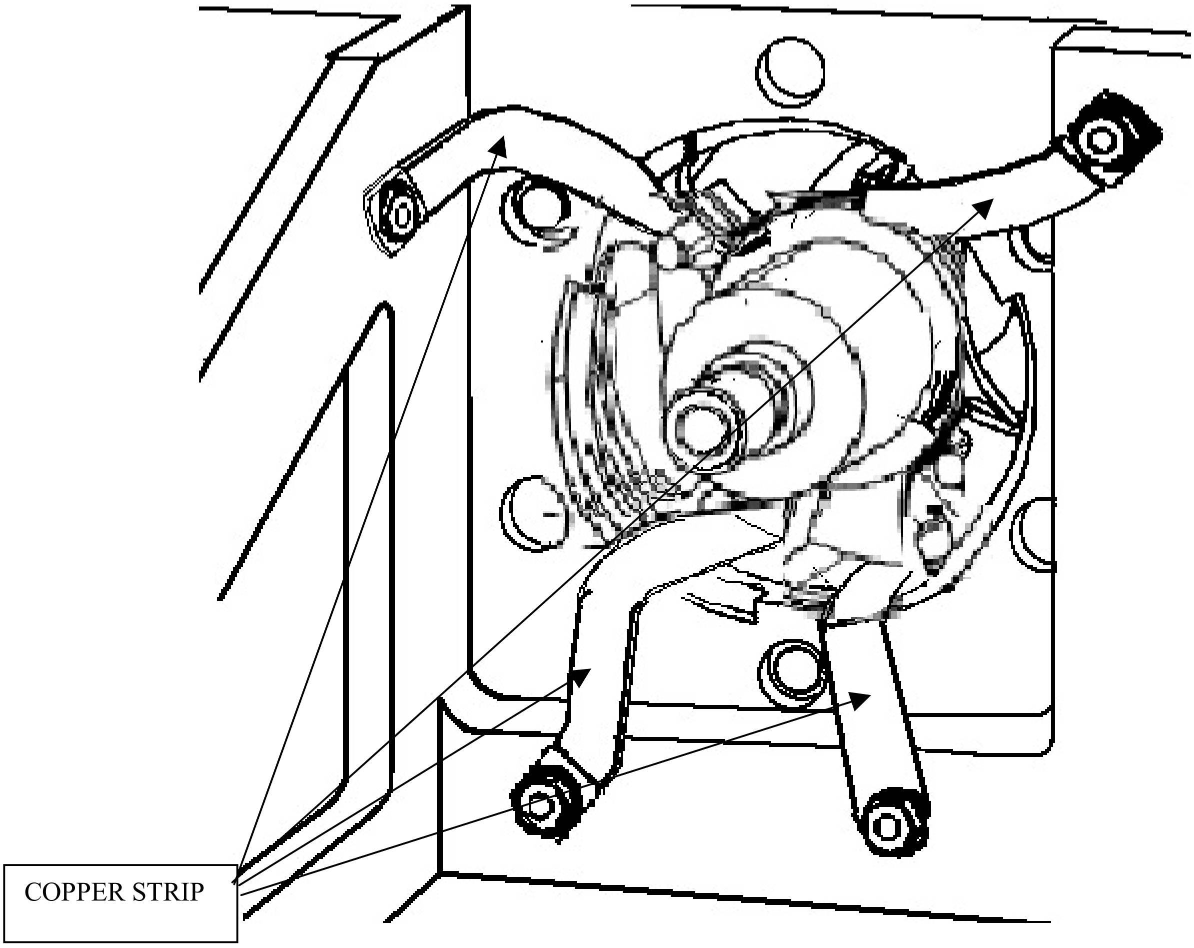


Figure 9.2.4.9-1: 20 N copper strip design

9.2.4.10 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. 16 vertical HPs are mounted directly under each SCC unit, covering the whole bed I/F surface. The vertical HPs are mounted on a bench of 8 horizontal HPs.
Heat pipes network is shown in the Fig 9.2.4.2-3.

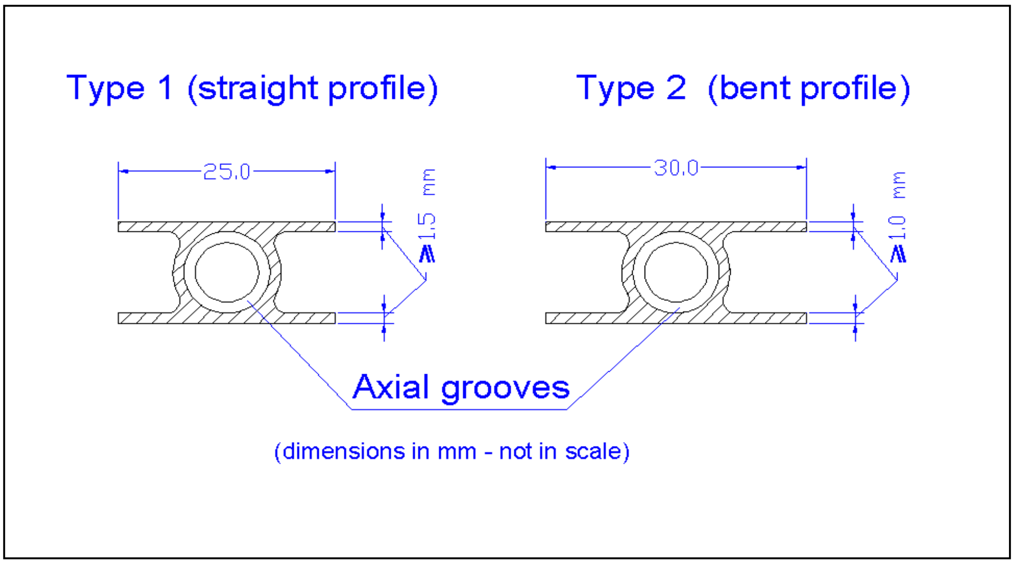
As already discussed a set of heat pipes is foreseen for SCC thermal control on Planck SVM.
Heat Pipes are constant conductance ones using a double T shape (height=15mm) grooved aluminum pipe and ammonia as working fluid.

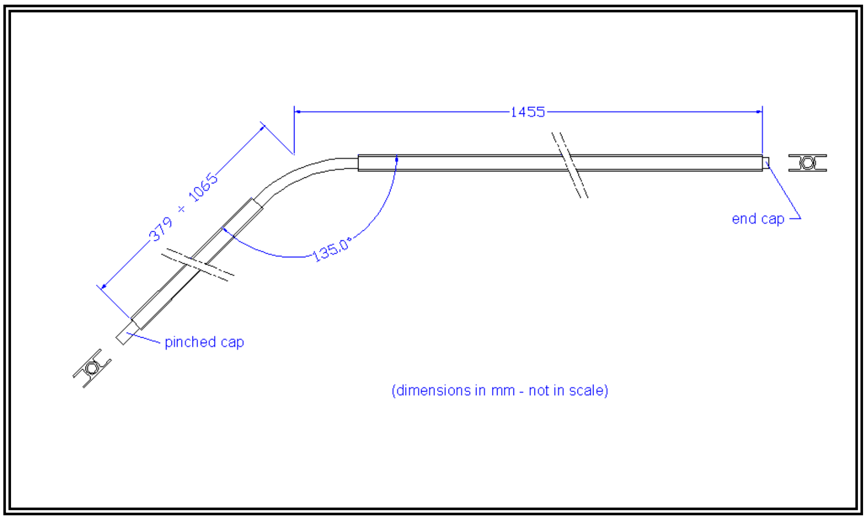
Type, operating length, heat transport capability and shape of the heat pipes are defined as follows:

Type	Length [*]	Heat Transport capability	Shape	Quantity
1	750 mm	150 W*m between -25 and +20 °C	Straight	32
2 /A	2520 mm	150 W*m between -25 and +20 °C	Bent	8
2 /B	1834 mm			8

* The overall length does not include pinch and cap.

Profile sketch is shown in the following figures.




1455
379 ÷ 1065
135.0°
end cap
pinched cap
(dimensions in mm - not in scale)

9.2.4.11 SOFTWARE REQUIREMENTS & HEATER OPERATIONS

The standard heater operation is the ON-OFF logic inside a threshold operated via thermistor.
This thermostat-like control law (Figure 9.2.4.11-1) is characterised by an histeresis cycle between a switching-on temperature and a switching-off temperature.
The thresholds of the heater lines are given in ch.8 together with heater circuit breakdown and power installed.

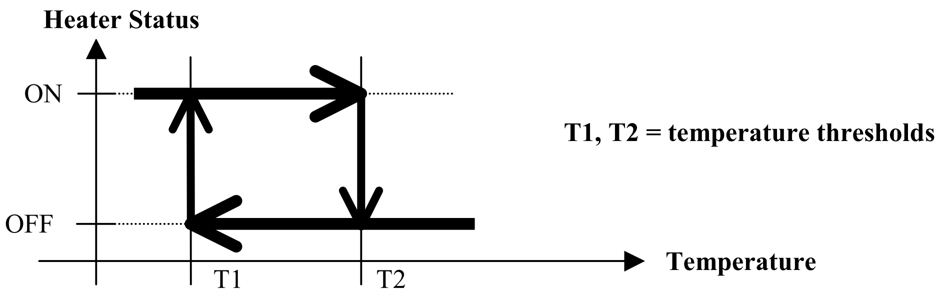


Figure 9.2.4.11-1: Thermostat-like control law

For the Herschel HIFI and Star Tracker temperature stability requirement heaters are operated by means of PWM (Pulse Width Modulation) with a frequency of 1 Hz regulated by a fine control law (PI regulation).

GENERAL APPLICATION (both for Herschel & Planck):
Many heater circuit lines are requested to operate both in NOMINAL Configuration and in SURVIVAL Configuration. This means that there is the possibility that the same heater circuit line works with different temperature threshold settings (e.g. HERSCHEL HTR304NS Nominal threshold is –14/-11 °C and Survival threshold is –29/-26 °C).
For this reason is requested to the Application Software to be able to manage different temperature thresholds for different S/C operating mode (e.g. loading, during nominal operation, a “Nominal Threshold Table” in which are reported the temperature for the Nominal condition and a “Survival Threshold Table” in which are reported the temperature for the Survival condition).
The heater protection and control system comprises two identical halves (P=Prime, R=Redundant). Each half consists of 9 Heater Protection Switches (HPS) and 54 Heater Control Switches (HCS), 6 per HPS.
ON/OFF control over the HPSs and the HCSs is via the system 1553 data bus. Each HPS, prime or redundant, can be controlled indipendently via the data bus.
For each of the 54 P and 54 R HCS a status TM is provided, the telemetry data provided for the 9P + 9R HPS are status, latch status and current. Details are given in [RD-91].
At software level the TCS shall be opearted by-means of a Thermal Control Table (TCT).
The TCT shall be structured and sized in order to allow controlling of 108 control loops.
Each entry of the TCT shall contain at least the following parameters:

- control loop index
- control loop status (enabled, disabled)
- monitored parameter_id’s (3)
- class of the control loop
- temperature monitoring frequency
- class-A threshold values (two pairs of value based on unit status [T_{min-on}, T_{max-on}] and [$T_{min-off}$, $T_{max-off}$]
- thermistor values
- Heater id’s
- Class-B coefficients

Temperature monitoring shall always be enabled regardless of control loop status.
The CDMU ASW shall nominally use the default TCT that will be loaded from EEPROM to RAM.
It shall be possible to modify all parameters of a TCT entry by means of a dedicated TC.

HERSCHEL:

To meet the stability requirement an active thermal control logic (algorithm) has been developed. Details, results and description of the control are provided in [RD-89].

Actually, the required control law major parameters are:

- the temperature acquisition time occurs every 10 sec. with an overall resolution of the monitoring chain of 0.05°C (BIT amplitude over a range of –40/+80 °C)
- active control commands are provided every 10 sec. with a quantization of the heater operation command equal to 10 (1 ON/OFF pulse per 1 sec.).
- the regulation cycle requires the processing of commands/temperature provided/acquired during 10 previous steps, that shall be properly recorded.

PLANCK:

The COMPENSATION HEATER Operations dedicated to the TWTA 1&2 is no more requested.

Concerning the Propellant Tanks on Planck, due to the stability requirement, particular software care is needed.
Hereafter a brief description is given:
the thermal control components installed on each tank are:

- 1 nominal heater line (NHi)
- 1 redundant heater line (RHi)
- 3 therrmistors (TAi,TBi,TCi)

The heaters will be activated following the thermistor measurement, according to the following procedure:

for each tank the three thermistors provide an average temperature value (Ti = Average Ti_A,Ti_B,Ti_C)
Tank 1 temperature T_1
Tank 2 temperature T_2
Tank 3 temperature T_3

Then one selected value (for instance T_1) will be used to be compared to a fixed threshold (T_{ON})
If T1 is colder than Ton the three nominal heater line will be activated at the same time:
$T_1 < T_{ON}$ then NH_1 = ON
then NH_2 = ON
then NH_3 = ON

After a while the tank temperature will increase above a threshold (T_{OFF}) in this case we have

$T_1 > T_{OFF}$ then NH_1 = OFF
then NH_2 = OFF
then NH_3 = OFF

The above procedure will be implemented on the CDMU software, as routine operation (no modification foreseen).

The above procedure will allow to maintain an equivalent environment for the three Tanks, and therefore the temperature variations will be similar for the three Tanks. This procedure is completely automatic and will work correctly even in case of loss of ground contact.

In case of failure (for instance the loss of one heater line) the recovery action will be based on the redundant heaters commanded by the same thermistors but with a different threshold (T_{RON}). In this case the procedure will be the following:

$T_1 < T_{RON}$ then RH_1 = ON
$T_2 < T_{RON}$ then RH_2 = ON
$T_3 < T_{RON}$ then RH_3 = ON

After a while the tank temperature will increase above a threshold (T_{OFF}) in this case we have:

$T_1 > T_{ROFF}$ then RH_1 = OFF
$T_2 > T_{ROFF}$ then RH_2 = OFF
T3 $> T_{ROFF}$ then RH_3 = OFF

Also this procedure is completely automatic and does not require any ground command. Nevertheless this recovery procedure does not guarantee that the stabilisation requirement will be met. In fact it will be necessary to separate the two switching thresholds and therefore in case of failure the temperature of the tank associated to the failed heater line will continue to decrease while the other two tanks start to increase their temperature.

Finally the Command table will be updated substituting the failed heater line with its redundant heater line.
For instance assuming that the Nominal Heater 2 fails the table will change as follows:

$T_1 < T_{ON}$ then NH_1 = ON
then RH_2 = ON
then NH_3 = ON

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 that will be used, while the sizing (radiator areas, heater powers etc.) will be different for the two satellites.
The common design solutions for the two S/Ls will be based on the same Thermal Hardware components:

Multi Layers Insulation
Heaters, thermistors, thermostats
Paints and coatings
Filler and washers

9.2.6 Budget Summary

HERSCHEL budget

Mass budget

HERSCHEL TCS mass budget is reported in Table 9.2.6-1:

SUMMARY								
DESIGNATION	STATUS			BASIC	UNCERTAINTY %			CURRENT
	EST.	CALC.	WEIGHT	MASS [kg]	EST.	CALCUL.	WEIGHT	MASS [kg]
MLI		100%		16.643		15%		19.139
(incl. STR MLI not AAE responsibility)								
FILLER		100%		0.458		10%		0.503
RADIATORS (OSR)		100%		1.819		10%		2.001
BLACK PAINTS		100%		0.762		10%		0.838
MISCELLANEOUS		100%		8.810		10%		9.691
TOTAL MASS [kg]				28.5				32.2

Table 9.2.6-1 Herschel TCS Mass Budget

Thermistors Budget

For monitoring the status of SVM Thermal Control, 144 thermistors will be installed.

Power Budget

The HERSCHEL heater power budget is reported in Table 9.2.6-2.
Updating of the power budget is ongoing and will be reflected in the updated [RD-97].

Line	Unit	Enabled	Heater Power Installed	A Scientific BOL	B Scientific BOL +	C Scientific EOL	D Scientific EOL + 1.5 RMS	E Telecom BOL	F Telecom BOL + 1.5 RMS	G Telecom EOL	H Telecom EOL + 1.5 RMS	I RMS	L Survival BOL	M Survival BOL + 1.5 RMS	N Survival EOL	O Survival EOL + 1.5 RMS	P RMS
1	XPND 1	NS	11.39	0		0		0		0			0		0		
2	XPND 2	NS	11.39	0		0		0		0			0		0		
3	BATTERY	NS	14.9	9.39		6.14		5.98		2.6			9.43		5.96		
5	FPSPU, FPDPU	S	31	0		0		0		0			25.94		25.03		
6	FPBOLC	NS	9.4	0		0		0		0			0		0		
8	FMECDEC	S	26.9	0		0		0		0			12.88		11.01		
9	RCS 1	NS	3.7	1.06		0.99		0.77		0.46			1.02		0.65		
10	CCU, DCU, FCU	S	44.5	0		0		0		0			11.61		9.22		
11	RCS 2	NS	2.7	0.79		0.6		0.6		0.4			1.16		0.97		
12	FHWOV	NS	22.8	14.37		13.97		14.09		13.64			14.34		14.27		
13	FHHRV	S	39	0		0		0		0			31.86		31.5		
14	FHFCU	S	16.2	0		0		0		0			9.29		9.25		
15	FHWEV, ICU,IFV	S	40.4	0		0		0		0			32.63		32.66		
16	FHWOH	NS	32.4	21.44		20.74		21.14		20.33			16.74		16.67		
17	FHWEH	S	32.4	0		0		0		0			25.88		25.36		
18	FHHRH	S	39	0		0		0		0			31.24		30.64		
19	FHLCU, FHIFH	S	20.9	0		0		0		0			15.62		14.9		
20	FHLSU	S	29	0		0		0		0			23.9		23.92		
21	RWL 2	NS	8.1	1.98		0		0		0			11.39		5.95		
22	RWL 4	NS	8.1	0		0		0		0			7.52		3.8		
23	RWL 1	NS	8.1	0		0		0		0			6.39		0		
24	RWL 3	NS	8.1	0.7		0		0		0			7.25		2.05		
25	TANK +Y	NS	6.17	1.6		1.21		1.35		1.03			2.48		2.15		
26	TANK -Y	NS	6.17	1.4		1.18		1.19		0.89			2.08		1.9		
27	STR	NS	21.1	9.47		9.42		9.43		9.37			13.92		13.81		
29	FCV A1A	NS	2.35	0.64		0.35		0.29		0			0.21		0		
30	FCV C2A	NS	2.35	0.19		0		0		0			0		0		
31	FCV C1A	NS	2.35	0.58		0.5		0.5		0.41			0.29		0.23		
32	FCV A2A	NS	2.35	0.89		0.82		0.84		0.77			1.82		1.79		
33	FCV C4A	NS	2.35	0.09		0		0		0			0.39		0.36		
34	FCV C3A	NS	2.35	0.27		0.02		0.24		0			0		0		
35	RCS 3	NS	14.1	2.39		2.07		2.1		1.75			9.15		9.05		
36	RCS 4	NS	6.3	1.83		1.45		1.6		1.19			3.08		2.83		
37	RCS 5	NS	2.7	0.57		0.25		0.42		0			0.64		0.46		
38	GYRO	NS	62	52.93		48.1		46.51		41.47			0		0		
39	FCV A1B	NS	2.35	0.66		0.37		0.31		0			0.24		0		
40	FCV C2B	NS	2.35	0.19		0		0		0			0		0		
41	FCV C1B	NS	2.35	0.58		0.5		0.5		0.41			0.8		0.75		
42	FCV A2B	NS	2.35	0.93		0.87		0.88		0.81			1.91		1.89		
43	FCV C4B	NS	2.35	0		0		0		0			0.9		0.87		
44	FCV C3B	NS	2.35	0.27		0		0.24		0			0.05		0		
45	RCS 6	NS	2	0.59		0.21		0.15		0			0.54		0.08		
46	RCS 7	NS	2.5	0.52		0.43		0.43		0.35			1.01		0.94		
47	RCS 8	NS	2.5	0.56		0.41		0.54		0.35			0.81		0.76		
48	RCS unit	NS	9.2	2.4		2.19		2.21		1.99			4.69		4.59		
				129.3	**176.7**	**112.8**	**154.2**	**112.3**	**153.5**	**98.2**	**134.1**	**31.6**	**341.1**	**418.8**	**306.3**	**376.1**	**51.8**

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

Table 9.2.6-2 Herschel heater line power budget

PLANCK budget

Mass budget

Planck TCS mass budget is reported in Table 9.2.6-3:

SUMMARY								
DESIGNATION	STATUS			BASIC	UNCERTAINTY %			CURRENT
	EST.	CALC.	WEIGHT	MASS [kg]	EST.	CALCUL.	WEIGHT	MASS [kg]
MLI EXTERNAL		100%		21.910		15%		25.197
FILLER		100%		1.543		10%		1.697
HEAT PIPES		100%		22.94		0%		22.940
BLACK PAINTS		100%		1.002		10%		1.102
MISCELLANEOUS		100%		6.845		10%		7.529
TOTAL MASS [kg]				54.239				58.465

Table 9.2.6-3 Planck TCS Mass Budget

Thermistors Budget

For monitoring the status of SVM Thermal Control, 144 thermistors will be installed.

Power Budget

The PLANCK power budget is reported in para 9.2.6-4.
Updating of the power budget is ongoing and will be reflected in the updated [RD-97]

Line	Unit	enabled	Heater Power Installed	A	B	C	D	E	F	G	H	I	L	M	N	O	P
				Scientific BOL	Scientific BOL + 1.5 RMS	Scientific EOL	Scientific EOL + 1.5 RMS	Telecom BOL	Telecom BOL + 1.5 RMS	Telecom EOL	Telecom EOL + 1.5 RMS	RMS	Survival BOL	Survival BOL + 1.5 RMS	Survival EOL	Survival EOL + 1.5 RMS	RMS
1	STR –Y	S	4.7	-		-		-		-			0.72		0.42		
2	STR +Y	S	4.7	-		-		-		-			0.72		0.42		
3	DPU 1	S	22.8	-		-		-		-			15.01		13.71		
4	DPU 2	S	22.8	-		-		-		-			4.15		2.17		
5	REU	S	62	-		-		-		-			44.8		41.89		
6	CEU, CCU	S	51.9	-		-		-		-			45.3		43.77		
7	Heat pipes	NS	78	78		0		78		0			78		78		
8	Heat pipes	NS	78	0		0		0		0			78		78		
9	Heat pipes	S	91	-		-		-		-			91		91		
10	Heat pipes	S	91	-		-		-		-			91		91		
11	Heat pipes	S	91	-		-		-		-			91		91		
12	Heat pipes	S	91	-		-		-		-			91		91		
13	Heat pipes	S	91	-		-		-		-			28.35		21.88		
15	PAU	S	8.1	-		-		-		-			0		0		
16	CRU	S	12.8	-		-		-		-			0		0		
21	TANK +Z+Y	NS	6.17	0.64		0		0.74		0			3.11		2.57		
22	TANK +Z-Y	NS	6.17	0.64		0		0.74		0			3.11		2.57		
23	TANK –Z	NS	6.17	0.64		0		0.74		0			3.11		2.57		
24	FCV A –Y+Z (+Z side)	NS	2.35	0.5		0		0.66		0.11			1.86		1.73		
25	FCV A –Y+Z (-Z side)	NS	2.35	0.83		0.93		0.86		1.02			1.87		1.74		
26	FCV D1A	NS	2.35	0		0		0		0			0		0		
27	FCV D2A	NS	2.35	0		0		0		0			0		0		
28	FCV F1A	NS	2.35	0		0		0		0			0		0		
29	FCV F2A	NS	2.35	0		0		0		0			0		0		
30	FCV U1A	NS	2.35	0		0		0		0			0		0		
31	FCV U2A	NS	2.35	0		0		0		0			0		0		
32	RCS 1	NS	2.8	1.37		1.19		1.45		1.27			2.33		2.19		
33	RCS 2	NS	3.4	0.79		0.6		0.94		0.75			2.49		2.33		
34	RCS 3	NS	4.9	2.35		1.97		2.41		2.04			3.71		3.29		
35	CAU	S	39	-		-		-		-			27.24		26.05		
36	REBA 1 & 2	S	22.8	-		-		-		-			13.13		10.32		
37	BATTERY	S	14.9	-		-		-		-			0		0		
38	FCV B -Y+Z (+Z side)	NS	2.35	0		0		0		0			0.57		0.37		
39	FCV B -Y+Z (-Z side)	NS	2.35	0		0		0		0			0.57		0.37		
40	FCV D1B	NS	2.35	0		0		0		0			0		0		
41	FCV D2B	NS	2.35	0		0		0		0			0		0		
42	FCV F1B	NS	2.35	0		0		0		0			0		0		
43	FCV F2B	NS	2.35	0		0		0		0			0.13		0.07		
44	FCV U1B	NS	2.35	0		0		0		0			0.12		0.08		
45	FCV U2B	NS	2.35	0		0		0		0			0		0		
46	RCS 4	NS	4	1.31		0.92		1.25		0.89			2.64		2.29		
47	RCS 5	NS	1.7	0.83		0.63		0.59		0.41			1.08		0.89		
48	RCS 6	NS	12.5	1.97		1.52		2.33		1.89			9.12		8.87		
				89.9	**163.1**	**7.7**	**14.0**	**90.7**	**164.5**	**8.4**	**15.2**	**48.8**	**735.3**	**825.3**	**712.5**	**799.7**	**60.0**

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

Table 9.2.6-4 Planck heater line power budget

9.3 POWER CONDITIONING AND DISTRIBUTION

This chapter describe the major Subsystem and/or Equipment design. They are procured on the basis of the hereafter listed specification (included in the CDR data Package).

PCDU Requirement Specification H-P-SP-AI-0014 4 [RD-64]
BATTERY Requirement Specification H-P-SP-AI-0022 4 [RD-61]
PLANCK SOLAR ARRAY requirement Specification H-P-SP-AI-0015 4 [RD-59]

The major modification occurred from the PDR (June 2002) are hereafter briefly listed. Any details on the improved design with respect to the one presented at the PDR can be found in the applicable design report at Subsystem and/or Equipment level:

PCDU
- Introduction of DOD Alarm based on the Battery Voltage
- Review of the Battery Charge concept, from S4R to BCR
- Change of NCA actuation concept, introduction of "Disarm" command.
- BDR concept based on super-boost instead of on push-pull regulator to avoid possible transformer saturation
- Review of the trip-off control of LCL to maintain the function active also during switch between main and redundant command chain

BATTERY
No major change occurred but only minor modification typical of phase C/D

PLANCK SOLAR ARRAY
- New cut out definition after thrusters bracket re-design
- Outer panels anti-diffraction edge re-definition
- Increase number of inserts on external panels' outer radius

9.3.1 General

The Power Control Subsystem is in charge to condition, control and distribute the electric power to all payload instruments and spacecraft equipment during all mission phases and for all operation modes including ground testing and pre-launch operations and contingencies.

PCS is suitably dimensioned to be compatible with both Herschel and Planck satellites, thus providing a high level of commonality.

Power Control Subsystem will be implemented as one PCDU and one Battery.

Power Generation is provided by Solar Array. SVM will procure S.A. only for Planck. Herschel S.A. will be part of the Herschel PLM and is not described in this document except for those interface issue affecting the Herschel SVM.

Planck solar array is composed of a internal circular panel and four external panels forming an outer ring, all utilising high efficiency triple 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

The main requirements of SVM Requirement specification [AD-43] have been traced in the following for reference purpose.
The Power Control Subsystem is in charge to provide for the following functions.

- Power conditioning, control and storage of the electrical power coming from the Solar Array and Battery.
- Power bus protection and power distribution to the scientific instruments and spacecraft equipment
- The subsystem is required to manage the following.
  - To provide power from approximately 100W up to 1.5 kW (average) or 1.9 kW (peak)
  - Power is generated by 30 solar array sections
  - Energy is stored in one battery
  - The s/s distributes power via 108 thermal control switches to the SVM units, instruments and decontamination heaters
  - The PCS distributes power via 72 individually controlled and protected power lines to the spacecraft equipment (10 of these lines are permanently ON for essential SVM units). If necessary two or more output lines can be connected in parallel externally to the PCDU in order to increase the output capability.

- Monitoring and telecommand interfaces are provided as necessary to operate the subsystem, to determine its status and performance, to determine the state of charge of the batteries, to meet power users switching, reconfiguration and autonomy requirements, to select between redundant equipment and to override the autonomous and protection functions by ground command
  - The PCDU gets its command and report its status or monitoring results using a redundant MIL-STD-1553 Remote Terminal interface or via direct discrete commands and monitors.

- The subsystem provides dedicated heater outputs for thermally critical units, directly connected to the power bus via Fold-back Current Limiters (FCLs) such that no other unit apart from the PCDU and Battery must be active to energise them. These lines act as additional redundancy. The heaters are controlled by independent and dedicated thermostats.
  - The Power Control and Distribution Unit is self starting and will therefore automatically be active to energise these lines.
  - Over discharging Li-Ion battery technology causes irreversible damage therefore it is considered too dangerous to connect these heaters directly to the battery.
  - One main and one redundant NCA (Non Contaminating Actuator) are foreseen for Herscel only therefore the PCDU architecture includes driver and control for these devices based on requirements. The correspondent lines for Planck can be used as normal power output lines if necessary.

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.
A regulated 28 VDC bus shall be provided to the users in accordance with the requirements of ESA Power Standard PSS-02-10. Ripple voltage and transient voltage, including spikes, shall be compatible with the overall EMC requirements and the science instrument requirements. Transition and sharing between Solar Array mode and battery mode shall be performed in a continuous way without the main bus voltage variations being outside the specified tolerance. No single component failure shall cause an over-voltage or permit short circuit on the main bus.
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 takes into account an allocation for Planck instruments of 1000 W and for Herschel instruments of 550 W.
For Herschel it is required that the SVM has a power demand limited to 520 W. This is a very stringent requirement and cannot be met due to peak power demand of thermal control and AMCS.
GaAs multi junction cell technology is known to have higher junction capacity that silicon solar cell technology.
A maximum value of 2 µF has been taken into account in the design of the S3R and in the sizing of the capacitor bank that has a value of 3.29 mF.
The power available from Solar Array exceeding the system demand shall be left in Solar Array. Large circulating currents between Solar Array and the spacecraft shall be avoided .
A three domain S3R has been implemented therefore when the available SA power exceeds the total bus power demand, including battery recharge parts of SA sections are short-circuited.
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 10 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.
The baseline is to protect output lines to essential loads (transponder receiver, telecommand decoder, reconfiguration module, and emergency heaters) by Fold-back Current Limiters (FCL). The other lines will be protected by means of Latching Current Limiters (LCL).

Latching Current Limiters (LCLs) are designed initially to limit the current demanded by any load to a predefined level, then to disconnect the load if the current limit action persists for more than nominally 10 ms.

Similar protection is provided for the heater control systems but, since heater load characteristics are essentially resistive (minimal inrush current) and the amplitude of the limiting current is higher than the LCL, the time out function is set to a lower level of typically 3 ms.

The energy required by the Battery is derived by the following requirements.

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.
Battery selection and design shall ensure fulfilment of the satellite power requirements to be compliant with the battery depth of discharge requirements.
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 baseline injection scenario (from lift-off to separation of the satellites) with an Ariane 5 ECA launcher has a total duration of 50 minutes.
During the launch phase, both spacecraft shall be in a minimum power mode using on-board batteries
[AD-11] specifies a time from lift off to S/C separation of 45 min, for Herschel and 50 min. for Planck including 7 min. on internal battery during pre-launch.
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.
The battery is required to be able to provide a mean power of 256 W for 133.2 minutes this means that the energy requirement amounts to 568 Wh compatible with the today requested performance at System and SVM Level (50 minutes).

This requirement includes the ALS power margins associated with unit development maturity and the ESA margin applied to the combined PLM and SVM equipment consumption. Both these margins appear as an additional load at the output of the PCDU.

9.3.2.2 Solar Array

Herschel and Planck solar array provides electrical power to the relevant spacecraft in sunlight.
This chapter only provides the description of the PLANCK SA since HERSCHEL SA it is not part of the HERSCHEL SVM Configuration and procurement
Solar panels also act as a sunshield and thus provide shielding from Sun illumination to the PLM while heat transfer has to be minimised. The backside is thermally insulated to avoid thermal loads on the satellite upper part and the heat transfer through the fixation points to the spacecraft shall be reduced to the minimum.
The Planck solar array consists of 5 panels, 1 circular shaped panel called "Internal Solar Array" and 4 segments composing the "External Solar Array" which are quadrant-shaped panels.
The sandwich panels have aluminium core and M55 CFRP face sheets.
The internal solar array is fixed to the S/C by means of 12 brackets. Special titanium brackets are mounted on the panel edge to ensure radial flexibility.
Bolts head and treads are insulated by means of vetronite to ensure electrical and thermal insulstion
The complete solar array has 30 power sections. Each section consists of 4 or 5 strings. The total number of strings is 135. Each string has 21 cells in series to provide power at 30 V at interface point.
The RWE GAGET2 ID2/160-8040 ID ™ triple junction Gallium Arsenide solar cells with 2 junction integrated diode have been selected. Cells are supplied by RWE Solar GmbH.
The cell has silverplated invar interconnectors and a silver diode tab. A Thales CMO micro sheet coverglass with a thickness of 100 µm will be used to protect the active area of the solar cell from radiation.
All panels are electrically insulated from the S/C structure and mutually insulated to limit the impact on power in case of an insulation failure between PVA and solar panel structure. Bleed resistors are implemented to avoid high charge cumulation on the panels.
Each panel has one thermistors (two on the central panel) bonded on the rearside to allow temperature monitoring.

To cope with the power demand increase the solar array capability has been increased wrt what presented in phase B by chosing the option of 1900 W minimum that became then baseline.

Therefore the Planck solar array is required to deliver as a minimum:

- 1900 W at beginning of life (BOL) and at the end of nominal life
- 1810 W at end of extended mission life (EOL).

The above power figures shall be provided assuming one string in failure.

Voltage at the solar array Interface connector shall be above 30.0 V for both the satellites.

The electrical power calculation for each case shall use 1353 $W/m^2 \pm 5\ W/m^2$ WMO solar spectrum and the appropriate degradation factors.

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 4.22 m is acceptable. Figures 9.3.2.2-1 and 9.3.2.2-2 and 9.3.2.2-3 shows the Planck solar array configuration

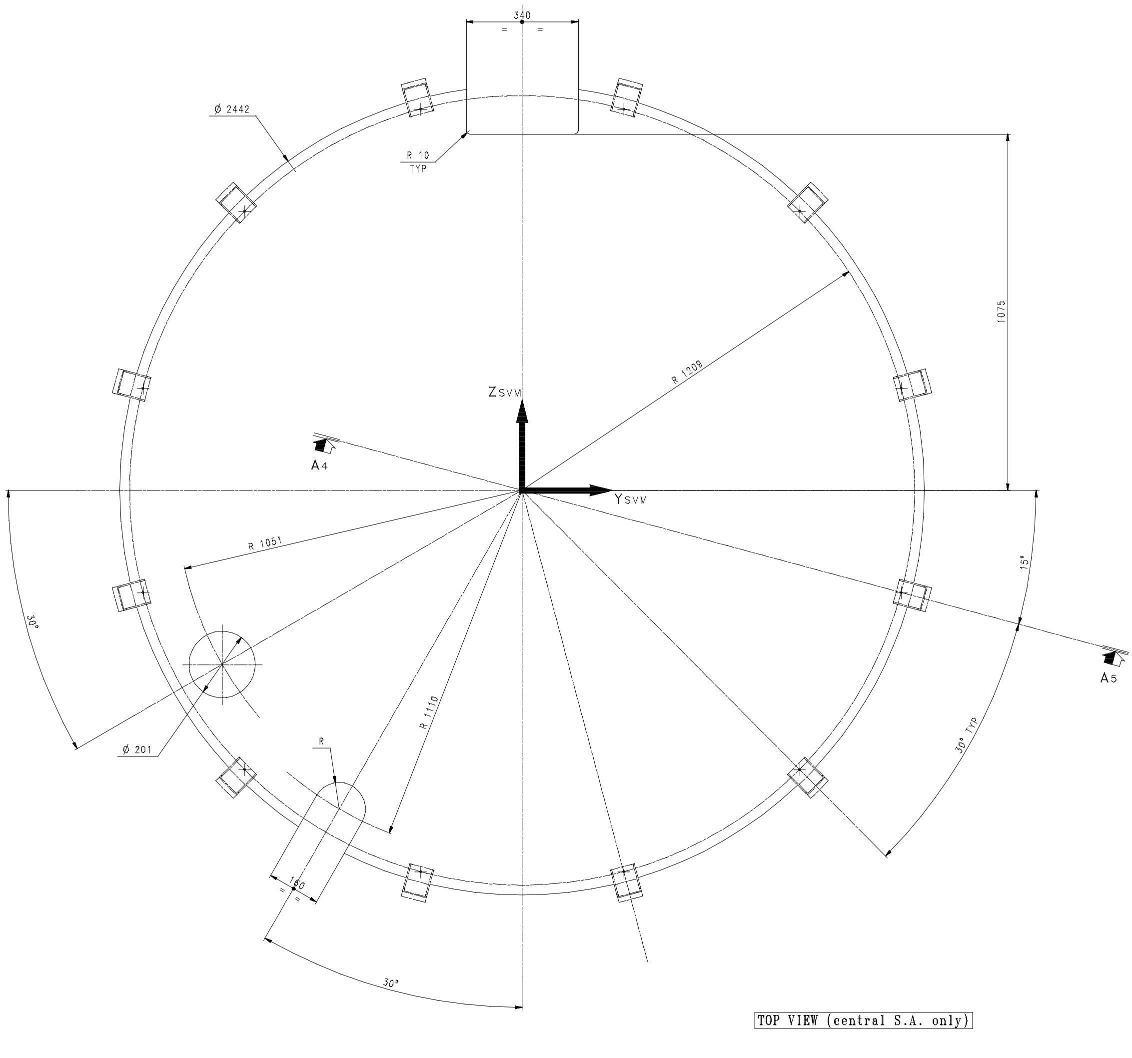


Figure 9.3.2.2-1 Planck solar array central panel configuration

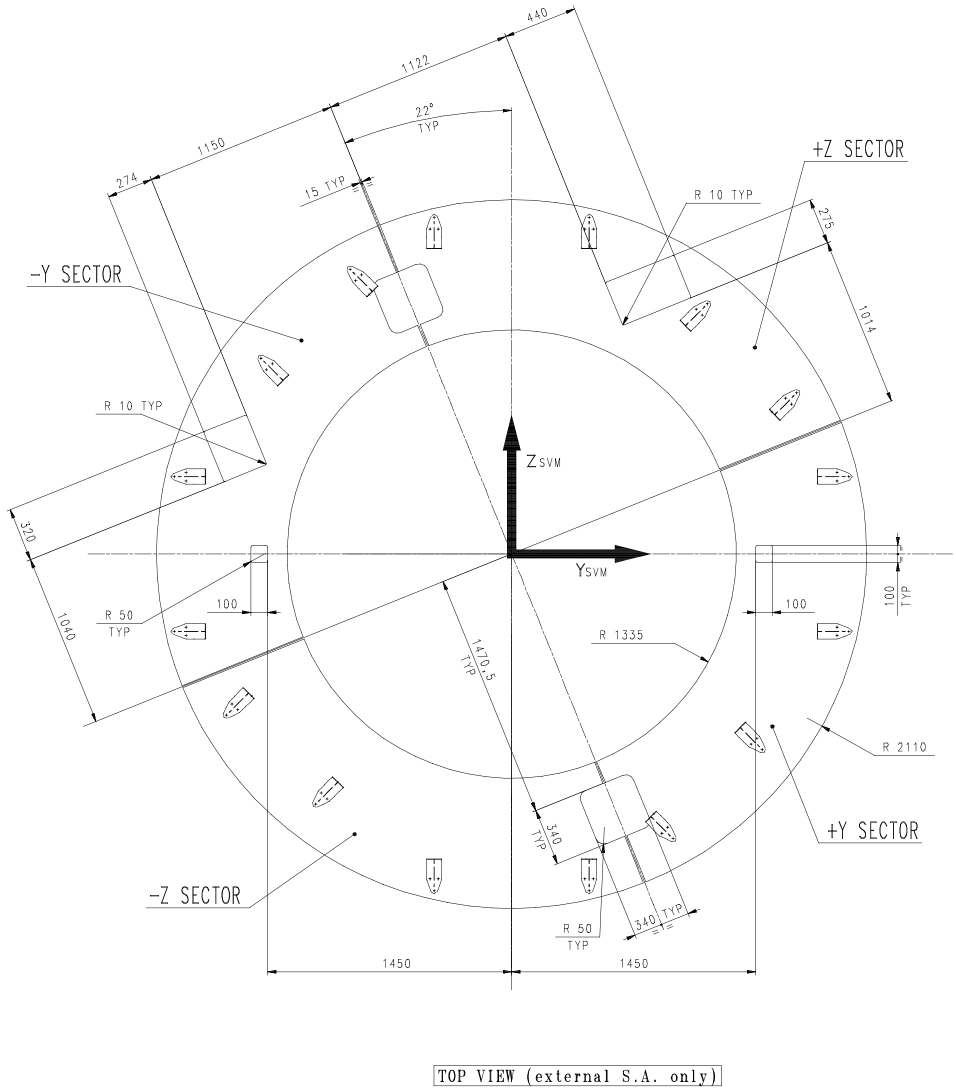


Figure 9.3.2.2-2 Planck solar array external panel configuration

The following requirements from the [AD-43] apply to the solar array:

- 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.

- All spacecraft surfaces exposed to the plasma environment shall be conductive and grounded to the spacecraft structure.
  - The last revision of [RD-01] gives an exception to this requirement for Solar Array. Also, it was agreed during the first Solar Array Working Group [RD-78] (ref HP-ASPI-MN-452) that for the Herschel and Planck mission orbits, ITO covering would not be required.

- All solar array cell strings shall have individual blocking diodes and shunt diodes where required
  - Blocking diodes are implemented at the end of each string, Individual shunt diode against shadowing are integrated onto the cell substrates (to protect the next cell in the string). These diodes in effect are protecting the preceding cell of the string therefore external diode shall be implemented at the end of the string. Cell placement will be implemented to avoid as much as possible spot shadowing on Planck solar array caused by antennas, thrusters or other appendices protruding over the solar array.

- The solar array shall be designed to be one string failure tolerant.
  - The power prediction used in the power budget calculation takes into account one string loss. Additionally, the power budget accounts for the loss of an entire section (1/30th of the panel power output).

- 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.

- The electrical network shall be composed of identical electrical sections. It shall minimise the resulting magnetic moment and ensure the insulation of solar network with respect to the solar array structure.

  - Planck solar array will be composed by 30 sections. Due to different shapes, the four sectors of the external solar array cannot have identical lay-out. As a goal, the Planck sections have a requirement to not to deviate by more than 1 string between section designs.

9.3.3 Functional Description

The PCS consists of the following units:

- **Power Control and Distribution Unit, PCDU**, which provides:
  - control of the electrical power generated by the solar array
  - conditions the energy stored in the battery when required
  - controls, monitors and maintains the health of the PCS
  - distributes power to the scientific instruments and spacecraft equipment
  - Protects the power bus from external faults and prevents failure propogation
  - heater switching control in response to 1553 commands
  - Interfaces for AIV and Launch support EGSE.
- **Battery,** which provides:
  - a store for the excess solar array energy
  - a source of energy whenever there is insufficient power from the array.
- **Solar Array**, which provides:
  - electrical power from the sun input
  - A thermal shield between the sun and the SVM/PLM.

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

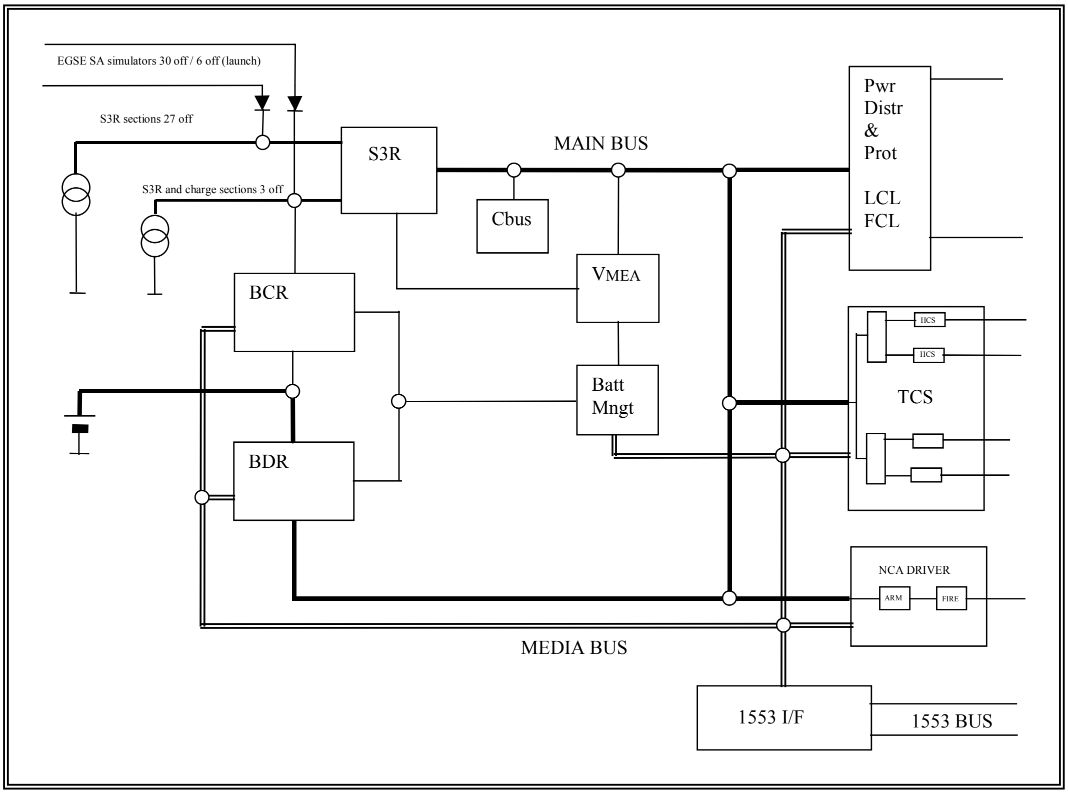


Figure 9.3.3-1 Power Control Subsystem

9.3.4 Design and Performance

9.3.4.1 PCDU Design Description

The PCDU described in this document has been specifically designed to meet the needs of Herschel and Planck ESA satellites, with an important consequence: the PCDU design is suitable for both satellites The electrical design is based on strong heritage from previous projects for:

- BDR design
- S3R topology
- MEA design
- LCL design
- Bus capacitance

However some new features have been implemented

- Forward phase shift, to deal with the high value of the Solar Array parasitic capacitor
- High speed internal data bus, to deal with the hundreds of telecommands and telemetries necessary for the ON/OFF switching of the distribution lines and for the house-keeping data
- A BCR tailored to the needs of the mission

9.3.4.1.1 Power Bus Regulation

The main functions of the PCDU are to generate and distribute a single and fully regulated bus of 28 V providing the necessary power (1.9 kW peak) to the satellite for its specific mission.

Two types of energy sources are used to supply this regulated bus:

- 30 GaAs Solar Array sections.
- 1 Li-Ion battery ($V_{BAT} < V_{BUS}$).

The bus regulation is based on a three-domain concept.
During Sunlight periods, the power is thus delivered by the 30 SA sections, which are connected to the main bus through dedicated electronic shunt switches (one per section) working under S3R concept.
Three of these 30 sections can be directly connected to the battery, in order to ensure its recharging (3 SA sections allow a maximum charge current capability of 3 x 3 A = 9 A).
A reliable electronic circuit controls the connection / disconnection of the SA sections to/from the battery. The battery is charged smoothly; no charge current transient is applied to it.
When the SA power is no longer sufficient to satisfy the bus power consumption, the power is delivered by one Lithium Ion battery via two BDR’s.
The bus regulation is controlled by a Main Error Amplifier (MEA).
The function of the Main Error Amplifier is to manage the available energy sources, in order to guarantee a permanent regulated bus.
The Main Error Amplifier senses the bus voltage at the regulation point and pilots the S3R sections and BDR’s to ensure the bus regulation.
The BCR’s also use the MEA signal to force the end of the battery charge when the BDR’s are working.
The MEA circuitry is one failure tolerant. Its reliability is obtained by using three channels in hot redundancy followed by minority-majority voters. Each channel has its own voltage reference made by a temperature compensated zener and compares it with an adjusted bus divider bridge. An amplifier ensures a proportional - integral action in the regulation loop.
The reliable reference ladder is used to provide a reference voltage to each S3R sections. It is constituted by a resistor bridge supplied by the bus.
This circuit, pilots the 2 BDR's and the 30 SA electronic switches in one of the following modes:

- the BDR mode : the BDR operates at fixed frequency using PWM control to regulate its output current ;
- the Sunlight mode using the S3R concept
- The 3 last SA sections, when they are not used on the bus, instead of being short circuited, can be routed individually to the battery through independent battery charge regulators (BCR).

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

A capacitor bank is foreseen at main bus level in order to:

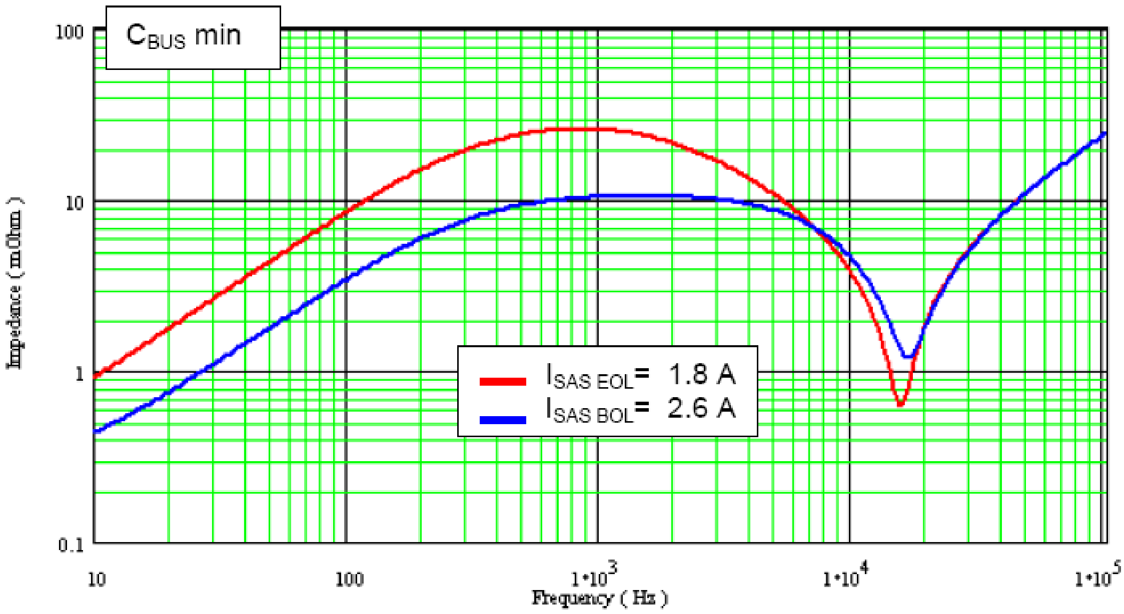
- stabilise the bus voltage regulation loop,
- ensure a low output impedance
- filter the switching noises due to the regulation.

The bus capacitor bank is composed of 702 x 47µF 50V self-healing PM90S capacitors.
The bus capacitance is thus 3.29mF.
The bus capacitor bank is implemented to ensure good bus impedance at high frequencies and is part of the S3R and BDR regulation loop.
The resonance frequency of the capacitors (including their connections) is higher than 200 kHz.
Moreover, the energy on the bus is sufficient to ensure self healing of these capacitors (E> 15µJ). In case of failure of one capacitor, a negligible voltage transient on the bus appears due to the self healing process.
The value of the bus capacitance depends on a few design constraints taking into account the main characteristics of the modules and the SA sections characteristics.
These constraints are:

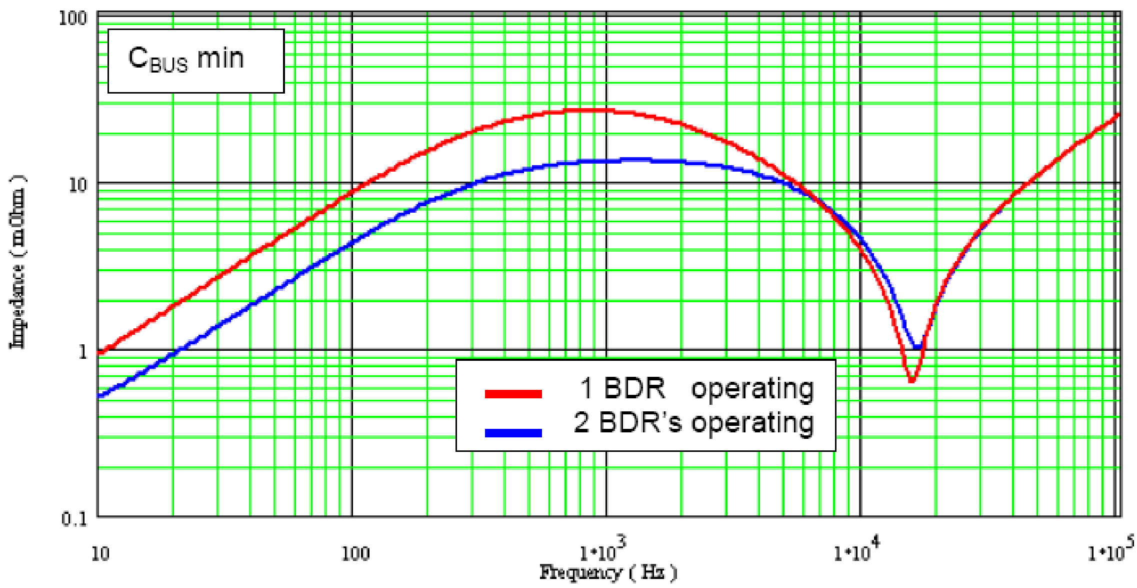
- The bus ripple during load step transient
- The voltage loop stability in BDR mode
- The double sectioning functioning in S3R mode
- The heat dissipation into S3R transistor
- The maximum energy into the bus capacitor

To cope with the above constraints avoiding the use of very large capacitor bank enhanced S3R design has been introduced.
In this enhanced S3R design, we introduced the concept of “forward phase shift advance”. The improvement consists in its concept to anticipate the decision of connecting a SA section to the bus (section previously shunted). That anticipation allows compensating the delay due to the connection time and so keeping margins wrt the double sectioning risks.
The anticipation must also be function of the variation rate of the MEA signal. The PWM MEA signal varies thus in frequency and duty cycle according to the bus load.
Besides the MEA circuit and the capacitor bank the S3R includes 30 S3R cells. Each cell controls the current delivered to the bus by one solar array section through its harness.
Depending on the MEA voltage, each S3R cell either short-circuits its section or let the current flow to the bus. By convention a S3R cell connected to the bus will also be called “section ON” and a S3R cell that short-circuits the SA section will be called “section shunted, or OFF”.
A number of S3R cells are therefore open (connected to the bus), the remaining ones are shorted to ground.
In order to match the current demanded and supplied one cell actually is switched on and off in a ripple mode (also called PWM) to provide the bus with a current whose mean value corresponds to the one of the load. The instantaneous shortage or excess of charge is delivered or absorbed by the bus capacitance.

The Main Bus output impedance includes the internal impedance (100 nH) and the minimum bus capacitance value of 2.916 mF. Typical plots in S3R mode and in BDR modes are provided.



Output impedance in shunt mode



Output impedance in BDR mode

9.3.4.1.2 Battery control

When no or too low solar power is available, the bus regulation is performed by two Battery Discharge Regulators, in hot redundancy that are part of the PCDU.
Each BDR is composed of an input filter, an input switch and a power regulator, switching at 100 kHz (without synchronization).
An isolated driver commands the power MOSFETS. The output current being controlled by the MEA, a correct sharing of the BDR current is automatically ensured.
Protections are provided against any single failure which would cause an overload or a short-circuit either at bus level or at batteries level.
A duty cycle limiter is implemented to avoid the converter to go into uncontrolled mode.
A dedicated bus undervoltage protection is implemented to reset the protection latches (input switch and output overcurrent / overvoltage and APS LCL). Note that these latches are protected against parasitic activation by SEU.
In order to obtain a fully autonomous module, the BDR includes its own auxiliary supply.
The first design proposed for the BDR of the Herschel-Planck PCDU was based on a push-pull topology, with a conductance control. This design had a lot of advantages (good efficiency, good dynamic behaviour), but also a drawback: it was necessary to implement an electronic to avoid the saturation of the transformer.
To overcome this problem the design has been changed to a super boost topology. With this topology, the saturation problem does not exist any more. Its disadvantages (lower efficiency, complexity etc. are considered less severe than the saturation problem of the former topology.
Each BDR consists in:

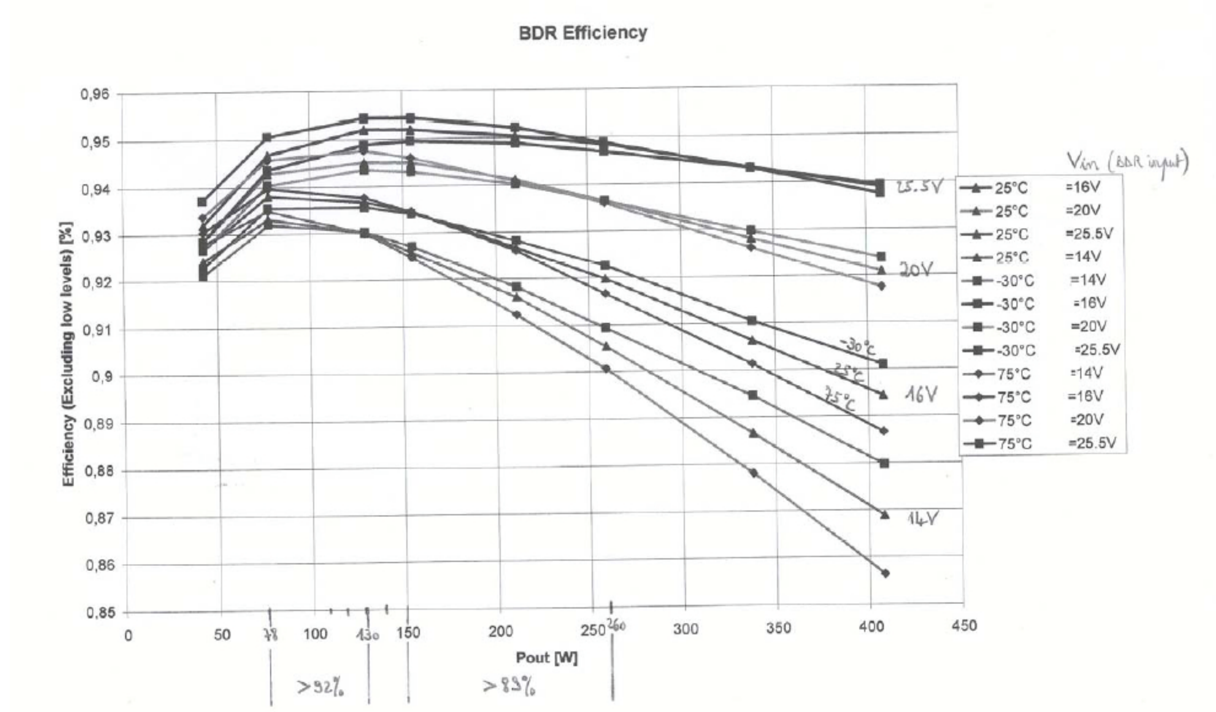
- An input switch, the aim of which is :
  - To protect the battery against any overload caused by internal failures inside the BDR module (overcurrent protection)
  - To protect the battery against over-discharge by battery undervoltage detection
  - To isolate the battery for AIT operations by means of HLC ON/OFF telecommand and in case of over-discharge detection.
  - To control the charge of the BDR input filter and of the main bus capacitor at system start-up (LCL behaviour, with trip-off time detection and latch)
- An input filter which, combined with the battery / harness impedance, controls the conducted emissions to the battery
- a superboost regulator for which the main functions is the output current regulation. This module includes, among other parts :
  - the power FET's, diode, inductances and capacitors of the power converter,
  - an isolated pulse FET driver,
  - a clock, a sawtooth generator and a duty cycle limiter
  - a current sensor in the positive line.
- A MEA interface which ensures a good BDR current sharing, and a BDR output current limitation ($I_{limitation}$ = 15.6 A minimum).
- A protection circuit, with the following functions :
  - Output overcurrent protection to prevent BDR overheating in case of output current limitation failure
  - Bus overvoltage protection detects on the MEA if the system is in BDR mode (eclipse of bus support); if not, the overcurrent protection threshold is set to a low value (below the minimum bus consumption) in order to detect a BDR which has lost its regulation or which is delivering current in sunlight mode.
- A latch, which also switches OFF the input switch
- A bus undervoltage protection which resets the protection, the input switch and the internal APS LCL latches

The protection activation and reset is summarized in the following table

Protection	Effect	Activation	Reset
Input switch over-current protection	Switch OFF of the input switch	If the input current reaches 71 A for more than 3.1 ms	By switch OFF and then ON of the input switch by HLC. By bus undervoltage protection
Battery undervoltage protection	Switch OFF of the APS Switch OFF of the input switch	When V_{BAT} falls below 16 V When V_{BAT} falls below 15 V	When V_{BAT} reaches 18 V When V_{BAT} reaches 18 V
Output overcurrent protection	Switch OFF of the input switch	If the BDR output current reaches 18.6 A while the MEA voltage is within the BDR domain	By bus undervoltage protection By switch OFF and then ON of the APS (by 1553 commands or battery undervoltage protection)
Bus over voltage protection	Switch OFF of the input switch	If the BDR output current reaches 1.5 A while the MEA voltage is within the SUN domain	By bus undervoltage protection By switch OFF and then ON of the APS (by 1553 commands or battery undervoltage protection)
Bus undervoltage protection	Reset of the input switch overcurrent protection latch Reset of the output overcurrent/bus overvoltage protection latch Reset of the APS LCL overcurrent latch	When Vbus falls below 25.7 V	When Vbus reaches 26.22 V
APS LCL overcurrent protection	Switch OFF of the APS	If the current through the APS LCL reaches 265 mA for more than 15 ms.	By switch OFF and then ON of the APS (by 1553 commands or battery undervoltage protection) By bus undervoltage protection

- An auxiliary supply converter providing the supply voltages necessary for the BDR low level circuits. Its main functions are :
  - an input LCL (I_{lim} =350 mA max) with trip-off and latch functions
  - a buck converter
  - a battery undervoltage protection which switches the BDR OFF by its auxiliary converter when the battery voltage goes below 16V. The switch ON threshold has been fixed at 18V
  - An ON/OFF interface (through the TM/TC 1553 bus) : the BDR is switched OFF by its auxiliary supply converter in order to reduce the OFF consumption of the BDR module.
  - Input and output current telemetries and an ON/OFF status.
  - An interface for the charge current, with two independent charge current telemetries.
  - AIT interfaces for the bus and the battery.

The power cell is based on a superboost topology, which allows to regulate the output voltage (28 V) when the battery voltage is in the range 16 V – 26 V (at PCDU connector level).
The output voltage is regulated via the control of the output current. The max. output current value is 17.0 A which gives a max. output power of 480 W.
The switching frequency is 100 kHz.
The following table shows the efficiecy of each BDR module as function of temperature and load



The following telemetries are available

- BDR1 output current
- BDR2 output current
- Battery discharge current via BDR1
- Battery discharge current via BDR2
- Battery voltage via BDR1 sensor
- Battery voltage via BDR2 sensor
- BDR1 APS status
- BDR2 APS status
- Read back of BDR1 1553 command
- Read back of BDR2 1553 command
- DOD level selected (3 bits)
- BDR1 input switch status
- BDR2 input switch status

Three solar array sections (28, 29 and 30) besides that to supply the power bus can be used to recharge the battery through three Battery Charge Regulators
The BCR's perform battery charging in a smooth way (linear control) and ensure taper charging. The BCR's are basically controlled by the battery voltage that is compared with an EOC threshold.
Although very closed three separated EOC thresholds are available for BCR1 BCR2 and BCR3
As far as the battery voltage is lower than the EOC threshold the current of the relevant solar array section is used to recharge the battery.
When an EOC voltage is reached the current flowing into the battery is linearly decreased to zero and made available to the main bus under the classical S3R concept..
At end of charge, only a small amount of power is taken from BCR3 to maintain the battery in tapering mode.
Two different set of EOC voltages are available. HIGH EOC voltage (set by default) and LOW EOC voltage selectable via 1553 command.

When the battery is not fully charged, 3 SA sections are not available on the bus. The number of SA sections available on the bus is reduced to 27 (26 in failure case).
In case of large power demand, the battery, through the BDR's, supplies the necessary additional power.
In order to recover on the bus the power from the SA sections which are charging the battery, a BCR disconnection mechanism is foreseen. This mechanism is driven by the MEA voltage, which is a picture of the PCDU power state. Disconnection levels are defined for each BCR.
BCR1 is the first one to turn OFF under increasing power demand, followed by BCR2 and finally BCR3.
Reconnection of BCR's under decreasing power demand is performed in the opposite order: first BCR3, then BCR2 and finally BCR1.
A case of power demand is still possible during the battery charge in which more than the power available from 27 sections is requested but the delta power is not big enough to trigger the BCR disconnection mechanism. In this case the power from the last three solar array sections is provided via the BDR's.
This situation causes a loss of power as shown hereafter

Power delivered to the bus by 3 SA sections:
$3 \times I_{SA} \times V_{BUS}$
Power delivered to the bus by 3 SA sections through the BDR's
$3 \times I_{SA} \times V_{BAT} \times \eta_{BDR}$
The power loss is then:
$3 \times I_{SA} \times V_{BUS} - 3 \times I_{SA} \times V_{BAT} \times \eta_{BDR}$ or $3 \times I_{SA} \times (V_{BUS} - V_{BAT} \times \eta_{BDR})$

The above loss is considered in the power budget.

The BCR is constituted by:
- Two identical error amplifiers (regulators), controlling the EOC voltage,
- One controlled current limiter,
- One protection against permanent connection of one SA to the battery (to avoid overcharge), action through the S3R,
- One interface with the MEA that can force OFF the BCR under low value of the MEA voltage,
- One Battery undervoltage protection (UVP), avoids overdissipation in the event of false operation during AIT operations (battery to zero).
- One ON_OFF Reset IF: enable/disable command for the BCR.
- One BCR OVP, overvoltage protection against the loss in open of one S3R diode.

The following telemetries are available

- Battery charge current 1 (sum of the charge current)
- Battery charge current 2 (sum of the charge current)
- BCR1 current limitation status
- BCR2 current limitation status
- BCR3 current limitation status
- BCR1 over-charge protection status
- BCR2 over-charge protection status
- BCR3 over-charge protection status

Each BCR can be enabled/disabled via telecommand.
These commands can be used into two different modes:

Static way:	when the BCR is disabled the relevant solar section is permanently available to the bus under S3R control. Battery charge is not anymore performed
Cyclic way:	a cyclic command from enable to disable and to enable again resets the BCR overcharge protection allowing recovery in case of unwanted lock-up.

9.3.4.1.3 PCDU Power Distribution and Bus Protection

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

- Standard Latching Current Limiter (LCL)
- Output Protected Latching Current limiters (OP-LCL)
- Fold-back Current Limiter (FCL)
- Heater Protection Switches (HPS)
- Heater Control switches (HCS)
- NCA Drivers.

The Standard LCL is commanded by a bi-level command; output status signal and output current telemetry are provided. The bi-level command is generated by addressable latches controlled by the 1553 interface. In the event of an overload, the LCL protects the bus by current limiting. After a 10ms nominal trip time, the LCL latches OFF, isolating the fault from the power bus.
Some LCLs can also be commanded ON and OFF by high level commands via optocouplers.
Each LCL provides a current limiter. The associated control circuit detects an over-current and starts a timer, which latches OFF the switch after a fixed delay. The latch is reset by a cycling OFF then ON of the command signals.
When the current (measured through a shunt resistor) reaches its limit the LCL acts on the Mosfet gate. The Mosfet gets in linear mode and limits the current.
To detect an over-current we measure the LCL voltage drop. When it is greater than a diode forward voltage, the LCL is in linear mode. This means that the LCL is limiting the current.
In this case a timer (located in a micro slave terminal µST) is started. If the LCL limits the current during more than 10,2 ms (trip-off time), the µST sends an OFF command to the LCL. If the limitation stops before the trip-off time, the timer starts to count down but 16 times slower. This time integration ensures that the Mosfet will stay inside its rating temperature in case of intermittent failure.
Further an analog timer is started at the same time as the µST timer. This analog trip-off function is always active, i.e. it does not rely on the TM/TC APS or the µST. This trip-off delay is a bit longer than the µST timer one. It is set to 14,1 ms (min 10,8 ms / max 18,5 ms) at 28V. It is a bit longer for lower bus voltages. The worst case maximum trip-off time is 27,3 ms at 21 V (minimum bus voltage for a LCL). The analog timer counts down about 30 times slower than it counts up. If the µST timer is not active and if the LCL limits during more than the analog trip-off time the LCL is switched off.
Note that when a LCL is turned ON by HLC it relies on the analog trip-off only. The trip-off located in the µST is not activated in this case.
The current limiter limitation value will be set between 120% to 150% of the nominal LCL protection rating.
There are 2 classes of standard LCL:

- Class I - has a maximum rating of 1.0A then (Ilim from 1.2 A to 1.5 A);
- Class II - has a maximum rating of 2.5A; then (Ilim from 3A to 3.75 A);

At start-up of the bus LCLs are in OFF state.

The OP-PCL consists of a standard LCL with upstream a series saturated switch (without over-current protection).
The LCL and the switch are commanded by separate ON and OFF signals. They have their own latch. That ensures that even after a single failure it will always be possible to switch OFF the line.
The over-current is detected by measuring the voltage drop across the all OP-LCL. This permits also to detect a drain-gate short circuit failure of one of the two Mosfets.
Whenever the voltage drop across the OP-LCL is greater than 2 diode voltages during more than the trip-off time both the LCL and the switch are switched OFF. It can occur when:

- The LCL is in limitation
- One Mosfet has a D-G short-circuit failure
- One of the 2 functions (the LCL or the switch) is OFF.

So it is important to send simultaneous (in less than 1 ms) ON commands to the LCL and to the switch.

This device is used wherever simultaneous operation of main and redundant units is not allowed or where PCDU dissipation limits prevents the linear failure of the LCL from remaining.

There are 3 classes of OP-LCL:

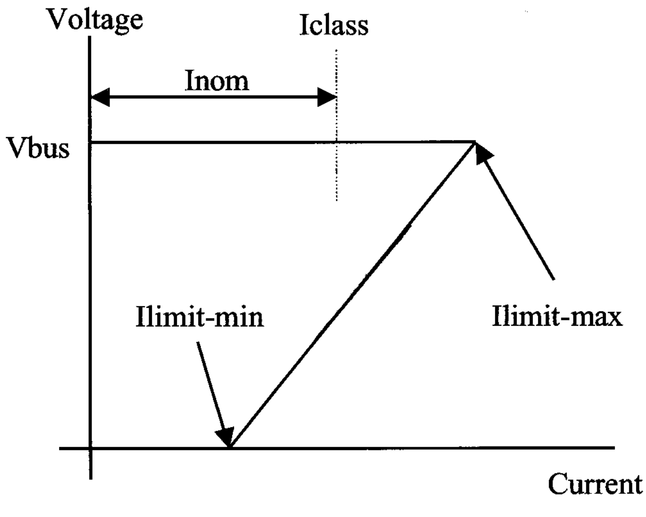
- Class I - has a maximum rating of 1.0A then (Ilim from 1.2 A to 1.5 A);
- Class II - has a maximum rating of 2.5A then (Ilim from 3 A to 3.75 A);
- Class III - has a maximum rating of 5A then (Ilim from 6 A to 7.5 A).

LCLs can be connected in parallel to create higher value LCL, for example, 4 class III OP-LCL can be used to provide a 20A LCL. Configuration of the multiple LCL group is done outside the PCDU by the spacecraft harness. Control of the parallel LCL is done by ensuring that all 4 LCLs are turned on via a single 1553 command containing instructions for all 4 LCLs. Failure to send all 4 commands will not harm any one of the LCLs in the group because each LCL is capable of surviving any over load.

LCLs are further divided into 2 groups, essetial and non essential. The PCDU provides two bus undervoltage detection thresholds. Bus users connected to non-essential LCLs will be disconnected if the power bus falls below the NE threshold (23 to 26 volts) for more then 50 µS.. Essential bus users will be disconnected if the bus voltage falls below the ES level (21 to 23 volts) for more then 50 µS.

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

The Fold-back Current Limiter cannot be switched off by command. It will guarantee the uninterrupted supply of the relevant line and the automatic restore of the nominal conditions after the downstream fault has been removed. It is designed to withstand the maximum power dissipation due to continuous limitation condition. This is achieved by reducing the current supplied by the CL once the limitation condition is triggered, thus reducing the power dissipation on the power stage.



The FCL have been implemented as class I current limiters therefore the Ilim max is between 1.2 and 1.5 A and the Ilim min is around 0.25 A

Heater Distribution

The 28V regulated bus is also distributed to 2 x 54 heaters lines.
Heater lines are grouped in 2 x 9 Heater-groups. A group is made up of 1 Heaters Protection Switch (HPS), 6 Heater Control Switches (HCS) and a thermistor.
Each HPS provides power to 6 HCS
Each HCS controls one heater line and is based on a Mosfet in the return line.
The HPS has a similar characteristic to the Standard LCL.
Each HPS is nominally rated at 10Amps (Ilim is between 12 and 15A) and each HCS is rated at 3.75 Amps. except for one line per group for which it is 4.1 A.
The current flowing through an HPS is provided in telemetry and the ON/OFF status of any HCS is also provided via the 1553 data bus.
At start-up of the bus, all HPS are ON and all HCS are OFF.

Figure 9.3.4.1.5-2 Heater Switching configuration:

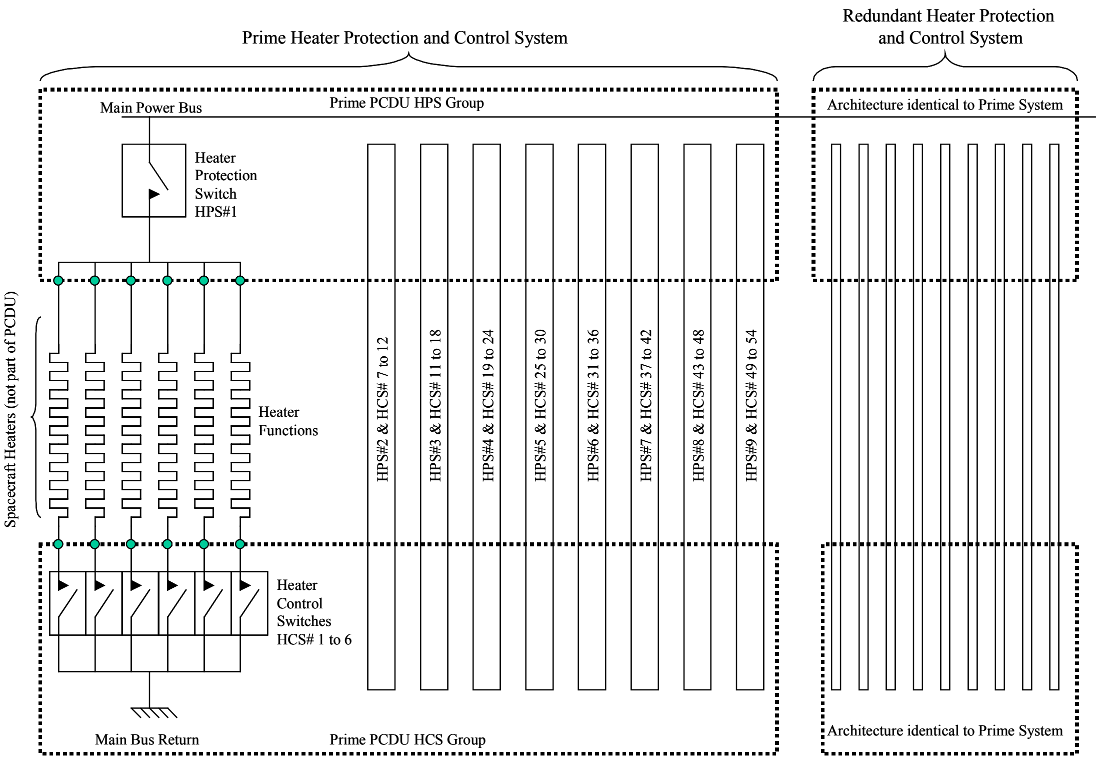


Figure 9.3.4.1.5-2 HPS and HCS configuration

Heater lines are protected against risk of Mosfet drain-gate short circuit failure via an internal protection that switches OFF heater protection switches and heater control switches. If it concerns an HCS Mosfet, the failure is detected via a thermistor placed near all the HCS of the group.
One temperature telemetry per group is provided.
In the heaters lines allocation it must be taken into account that an entire group can be lost even with a single failure.

NCA DRIVER
The Non-Contaminating Actuator device is only required for the Herschel mission.
This driver is made up of:
- 1 OP-LCL that is switched ON by a 1553 command. It is also possible to use this OP-LCL as a conventional class III OP-LCL (as it is used for Planck;
- relays in parallel (each relay has 2 contacts);
- output resistors (R_NCA);
- 1 timer (300 ms ± 20%).

It is located in a thermally sensitive location and special cables are provided to reduce the conducted heat loss. The nominal resistance of the NCA is 0.9 Ohms and is only used once for less than 500ms at the beginning of the mission. The PLM harness is nominally 3.1 Ohms. A maximum firing current of 5.2 Amps is required; consequently the interface voltage at the SVM is 5.2 x 4 Ohms = 20.8 volts. The NCA driver is foreseen to be a Protected LCL and an internal PCDU ballast resistor to drop the remaining 8 volts.

The two series switching element i.e. the OP-LCL and the relay will be used to ARM then FIRE the NCA according to the following sequence:

- NCA is armed via HLC ON that closes the relays.
- NCA is fired via a 1553 command that turns ON the OP-LCL.
- The NCA driver produces a 300 ms ± 20% firing pulse. Then the OP-LCL is automatically turned OFF.
- NCA is “disarmed” via HLC OFF that opens the relays.

Note that the same HLC arms both NCA (nominal and redundant). Further both HLCs (Nominal and redundant) are activated at the same time.
If a failure prevents the OP-LCL from getting open after 300 ms ± 20 % (for instance a failure of the timer), an internal protection turns the OP-LCL off in less than 800 ms.

9.3.4.1.4 Command and monitoring

The PCDU gets its commands and reports its status and monitoring results to the OBC via redundant Remote Terminal Interfaces (1553 protocol), each one has a full view over all the PCDU functions.
The PCDU answers to a set of commands and reports a reduced set of status, through direct lines interface. These commands act on several PCDU functions in order to allow specific reconfiguration combination. The reported statuses are mainly read-back and alarm signals.

The communication between the satellite and the PCDU is performed by two TM/TC interface modules.
Each TM/TC module can communicate with both 1553 data busses, and internally through the MEDIA bus, with the different modules of the PCDU, through the backplane.
The TM/TC interface module of the Herschel-Planck PCDU
- controls the I/F of the PCDU with the OBC via redundant Remote Terminal Interfaces (1553 protocol);
- answers to a set of commands and reports a reduced set of status through direct lines interfaces;
- ensures the interpretation and generation of discrete commands and the storage and reading of the discrete and analogue telemetry signals;

Furthermore the TM/TC module includes the following functions
- generates auxiliary power supplies necessary for PCDU needs
- Battery DOD alarm
- BUS undervoltage protection
- DNEL function

The TM/TC modules are fully redundant; all the functions described hereafter are present in nominal TM/TC module and in redundant TM/TC module.
The two modules are in cold redundancy with a complete separation of nominal and redundant parts.

Only a reliable +14 V and -14 V are made up from main and redundant Auxiliary Power Supply via redundant diodes.
The redundancy configuration is defined by external commands that activate a relay in the supply line of the nominal (or redundant) APS. Two relays are implemented (one per TM/TC module) to avoid loss of both interfaces with one single failure.
If reconfiguration is needed (after an internal failure), the following sequence is requested:

- Switch OFF the APS of the failed TM/TC module (e.g. Main).
- Switch ON the APS of the other TM/TC module (e.g. Redundant).
- Redundant FPGA automatically memorises distribution lines configuration (ON and OFF state).
- Use the 1553 address of the module now switched ON (e.g. the Redundant) to communicate. This shall be done by the OBC

This sequence guarantees that distribution configuration remains unchanged in case of TM/TC reconfiguration.

The auxiliary supply provides the low-level supply voltages to:

- The 1553 interface and the MEDIA bus
- Decentralised TM/TC interface located in distribution modules,
- SA and battery TM sensing (in hot redundancy with redundant auxiliary supply).
- Protection circuits

The following functions can be identified:

- Power cell (flyback topology),
- EMI input filter,
- PWM control circuit (based on an integrated PWM controller, including current limitation loop),
- Start-up circuit (including input under-voltage detection),
- Input protections (LCL type) that prevent propagation to the main bus in case of a failure in the converter.
- Output current limitation and an output overvoltage trip OFF.

The TM/TC module connects the PCDU to a 1553 serial link, compliant with MIL-STD-1553V notice 2 standard. The 1553 remote terminal is able to dialog with both 1553 serial busses (A and B). The physical connection to the busses is made through separated transformers and transceivers.

The FPGA of the TM/TC module performs the following functions:

- It interfaces, via buffers, with the 1553 remote terminal.
- It ensures the interpretation and generation of discrete commands via both 1553 busses (A and B).
- It ensures the reading plus storage of the discrete and analogue telemetry signals.
- It receives direct commands and processes them.
- It provides a reduced set of status through direct lines interface.
- It manages all these information and dialogs with other modules via :
    - an internal digital bus (data and address) ; TC's and digital statuses are sent and gathered via that mean,
    - an analogue acquisition chain, made of analogue to digital converters controlled by the FPGA and analogue multiplexers.
- At start-up or bus recovery, it automatically configures PCDU in a deterministic state (all LCLs, and HCS are OFF and all HPS and FCL are ON).

The following table summarises the telemetry, status and commands managed by each TM/TC interface module.

Description	Type	Number	Remark
Commands			
Main TM/TC interface ON	HLC	1	
Main TM/TC interface OFF	HLC	1	
BDR ON	HLC	2	1 per BDR
BDR OFF	HLC	2	1 per BDR
BDR AIT ON	HLC	1	BDR 1 or BDR 2
BDR AIT OFF	HLC	1	BDR 1 or BDR 2
OP-LCL ON	HLC	8	
OP-LCL OFF	HLC	8	
20 A line ON	HCL	2	4 paralleled OP-LCL's ON at the same time
20 A line OFF	HCL	2	4 paralleled OP-LCL's OFF at the same time
DNEL arm	HCL	1	
DNEL fire	HCL	1	
NCA arm	HCL	1	Both NCA (2x2 relays) armed by the same command
NCA Reset	HCL	1	Both NCA (2x2 relays) reset by the same command
Heater control switch ON	1553	108	1 per heater line
Heater control switch OFF	1553	108	1 per heater line
Heater protection switch ON/OFF	1553	18	1 per heater protection switch
(OP-)LCL ON/OFF	1553	60	1 per (OP-)LCL
NCA firing	1553	1	1 command for both the NCA drivers
EoC selection	1553	1	1 bit
EoD selection	1553	1	8 levels coded on 3 bit
BDR ON/OFF	1553	2	1 per BDR
BCR ON/OFF	1553	3	1 per BCR
DNEL STS RESET	1553	1	
DNEL ARM RESET	1553	1	

Telemetries and statuses			
Main TM/TC I/f Status	RS	2	1 per TM/TC interface
Battery DOD status	RS	1	
BDR input switch status	AN	2	1 per BDR
SA thermistors (SUN2)	AN	1	On Nominal Module only
SAS current	1553	3	1 per sunlight module
BDR output current	1553	2	1 per BDR
Battery charge current	1553	1	N. Battery monitoring are routed to the OBC via N. TM/TC I/F; R. one via the R. TM/TC I/F (without cross-strapping).
Battery discharge current per BDR	1553	2	1 per BDR
Battery voltage	1553	2	
Bus voltage	1553	2	
MEA voltage	1553	2	
FCL current	1553	10	1 per FCL
LCL current	1553	60	1 per LCL
Heater group current	1553	18	1 per heater protection switch
NCA driver current	1553	2	1 per NCA driver
NCA arm status	1553	2	1 per NCA driver
DOD setting	1553	1	8 levels coded in 3 bits
BDR 1553 CMD status	1553	2	1 per BDR
BDR ON/OFF staus	1553	2	1 per BDR (EOD status)
LCL output status	1553	60	1 per LCL
FCL output voltage	1553	10	1 per FCL
Heaters ON/OFF latch status	1553	108	1 per heater line
HPS output status	1553	18	1 per heater group LCL
Heater group thermistors	1553	18	1 per heater group
NCA firing LCL status	1553	2	1 per NCA LCL
BCR limitation status	1553	3	1 per BCR
BCR overcharge protection status	1553	3	1 per BCR
DNEL status	1553	1	
DNEL arm status	1553	1	

9.3.4.1.5 EGSE Interfaces

The PCDU provides the following interfaces for operating the spacecraft during AIV and at the launch site.

Parameter	Herschel/Planck Limit (at PCDU interface)
Battery support	- 0 to 28 Volts - 0 to 25 Amps - PCDU to provide protection from external s/c or supply reversal.
Power bus Support in AIT configuration	- 0 to 31 Volts - 0 to 90 Amps - PCDU to provide protection from external s/c or supply reversal.
Power bus support in launch configuration	- 0 to 31 Volts - 0 to 18Amps
Battery monitor lines	- 2 voltage monitor lines 0 to 28 volts and 2 returns - 100kΩ ±0.1% line protection resistors in series with the positive lines.
Bus monitor lines	- 2 voltage monitor lines 0 to 28 volts and 2 returns - 10kΩ ±0.1% line protection resistors in series with the positive lines.

BATTERY SUPPORT MODES

There are 2 battery support modes:

- AIV support: This mode is used during AIV acivities to power the spacecraft in the absence of a real battery. The battery simulator will be used. Access to the BDR input is provided via the battery safe and arm plug (PCDU side). In the launch configuration this acces is prevented by the safe and arm plug which links the battery to the PCDU.
- Launch configuration: In the launch configuration the battery will be present and the accass is still via the safe and arm plug (Battery side) in this case the battery is separated from the S/C. Once the safe and arm plug is is inserted the battery is connected to the PCDU and can be charge via solar array section simulators from the umbilical connector.

MAIN BUS SUPPORT MODES

To provide power to the satellite during the AIT activities the EGSE solar array simulator is connected to the real harness interface instead of the solar array.
When the solar array are mounted and connected only six sections are available via the umbilical connectors. These six sections include the three that can also be used for battery recharge.
Protection diodes are included in the PCDU to avoid interference between the solar array and the EGSE.
To avoid leakage current flowing into the battery from the sections used for charging, when the battery is connected to the PCDU via the safe and arm plug the EGSE sections shall be switched OFF and the nominal solar array sections shall be shortcircuited. This latter operation is possible through umbilical connectors

9.3.4.2 Battery

The Common Herschel and Planck battery (one for each satellite) is designed to provide electrical power during launch, during partial moon shadowing, in the event of an attitude loss in support of bus transient and to supply peaks if necessary. Details on the capability to provide electrical power in all the above mentioned phases can be found in the H-P-BD-AI-0008 “SVM Power Budget”. In case of attitude loss (SOHO failure scenario) document H-P-TN-AI-0071 “SOW Failure Operational Aspects” shows capability to recover the SVM nominal operations and battery are fully recharged.

The Herschel and Planck battery configuration (see figure 9.3.3.2-1) foresees 24 parallel strings, each one made by 6 Li-ion US18650 manufactured by Sony cells in series. The battery comprises two cell blocks plus structure to provide rigidity and mechanical interface points. Heaters and thermostats provide thermal control, while thermistors provide thermal monitoring.
Theoretical Energy (@ 100% DoD) is 777Wh. The maximum discharge rate for the battery will be 256 W giving a battery energy requirement of 568 Whrs. At this discharge rate the battery efficiency is typically 95% giving an available energy of 738 Whrs before a failure. The DOD is therefore 76% before a failure and 80% after a string failure. The minimum end of discharge voltage is 15 V. The maximum end of charge voltage is 25.5 V

Major details on the battery design can be found in the HP4-AEA-RP-0016 “Battery Design Specification and Description”.

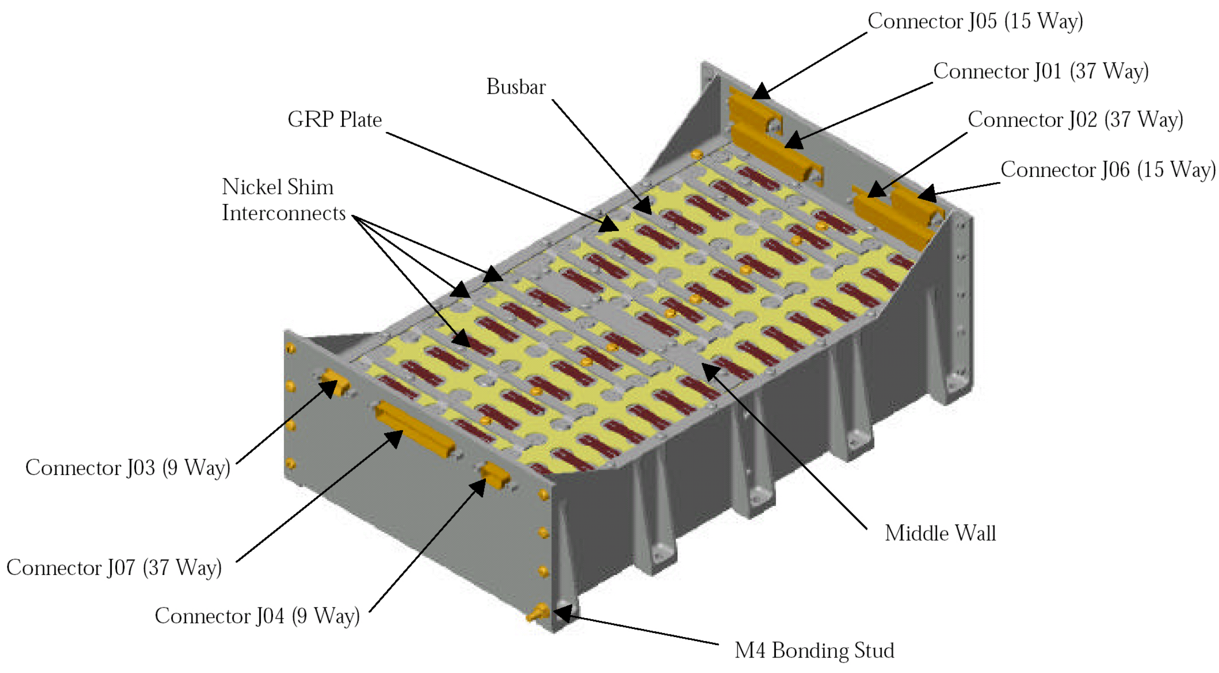


Figure 9.3.3.2-1 Herschel-Planck Battery arrangement

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.

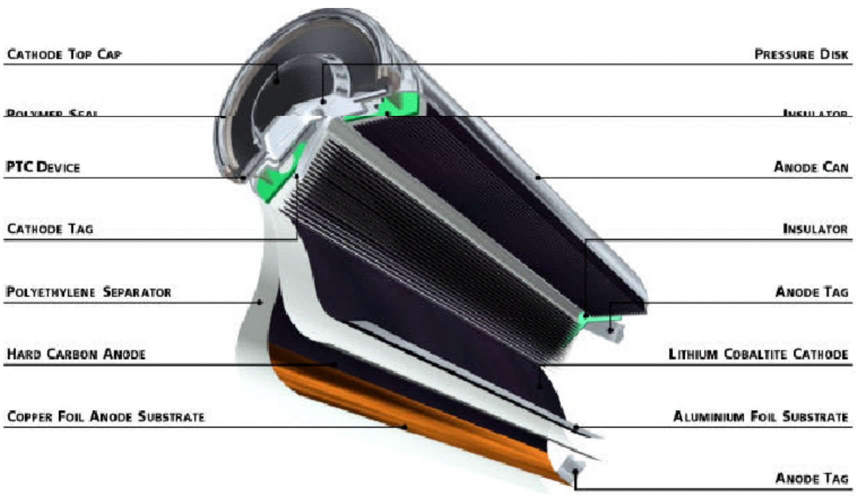
The main features are the following.

- 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	42 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	129 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. Cell architecture is provided in the following picture



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, which reduces battery capacity by 1/p, where "p" (24 in H/P) is the number of battery strings.
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 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.

Embedded Heaters
There are two heaters systems on the battery:
- mission heaters
- emergency heaters

To ensure that heat is evenly distributed over the battery, the heaters are thin-film types attached to the thermal plane on the underside of the battery, split in series to provide heating on both blocks at the same time.
Two (1 Nominal and 1 Redundant) mission heaters are controlled by the Thermal Control via heaters switches located in PCDU and provide 16W power at the nominal bus voltage of 28V, refer H-P-IC-AI-0003 "EICD".
Two emergency heaters are connected to the power bus via FCL located in the PCDU and are controlled by redundant thermostats (located in the battery) arranged in series to avoid a failure case where the heaters are powered continually.
Each emergency heater provides 10W at the nominal bus voltage of 28V.
The thermostats are selected to switch "ON" at -5°C and switch "OFF" at 0°C, giving a nominal-operating environment for the battery during emergency condition.

The mass of the battery is 7.227 kg (refer EM Battery End Item Data Package document: Battery ICD HP4-AEA-ID-0022 issue 3/A).

9.3.4.3 Solar Array

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 has to be insulated to avoid heat transfer on Planck PLM.
- Area limitation: Planck solar array is located at the bottom of the spacecraft.
- Solar array diameter is limited by the launcher fairing diameter and surface available for cells is reduced by the cut outs needed by thrusters, ACMS sensors and antennas. Furthermore the plume impingement due to thrusters firing shall be considered.
- Also, the circular shape of the array has an impact on the filling factor.

The solar array for Planck is composed by structure and electrical network.

Panel structure

The panel structure of Plank solar array 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.

The Planck solar array structure is a disk surface shared into two concentric areas at the launcher interface ring. The part inside the launcher interface ring is called “internal solar array” and the part outside the launcher interface ring is called “external solar array”.
The internal solar array is a unique panel whereas the external solar array is formed by four separated sectors.
The configuration of the Planck solar array is shown in Figure 9.3.4-1.

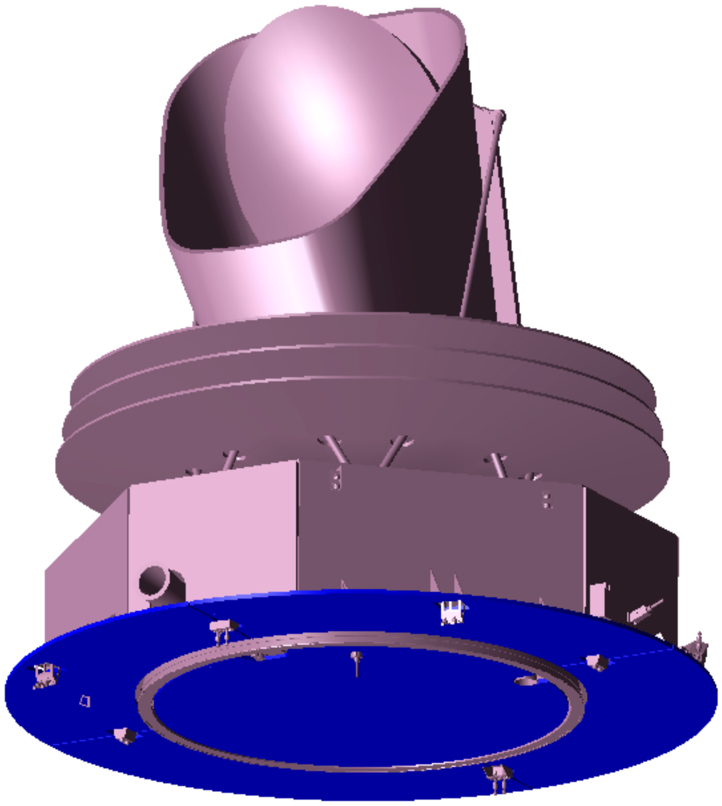


Figure 9.3.4-1 Planck Solar Array Configuration

Mechanical interface

The mechanical interfaces of the solar array panels to Planck spacecraft corresponds to the hard points provided by the spacecraft structure.
Panels shall be fixed with M5 bolts. Adequate cut outs are provided to avoid interference with thrusters.
Figure 9.3.4-2 shows the mechanical interface

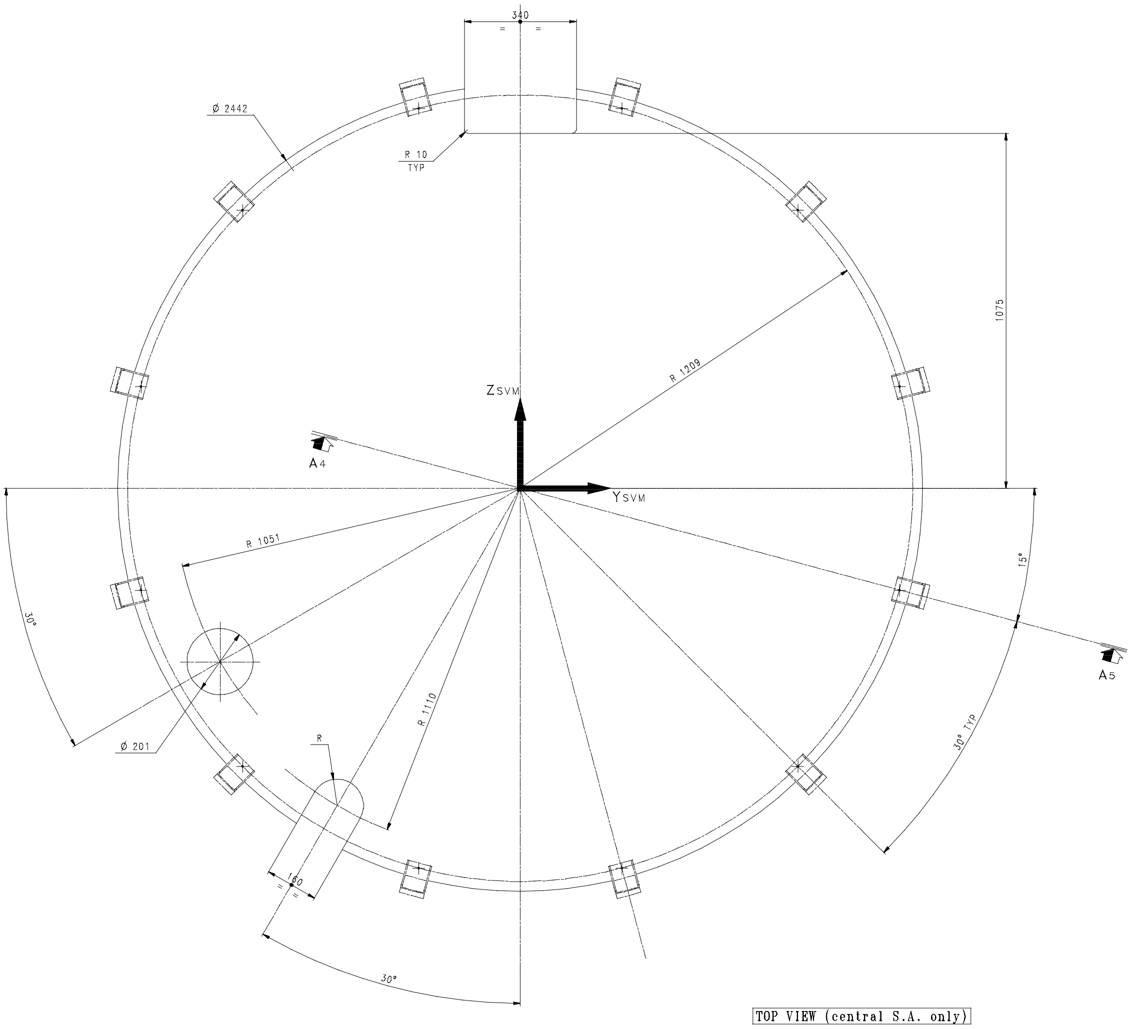
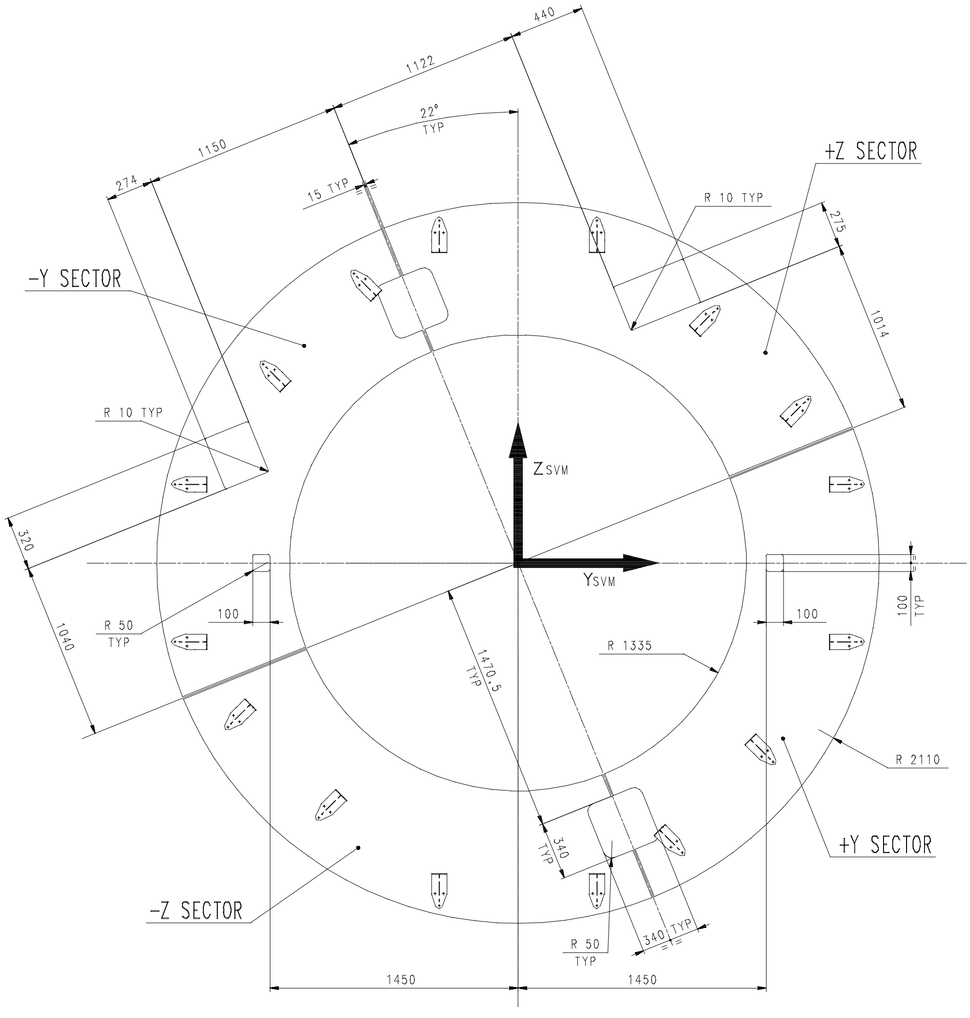


Figure 9.3.4-2 Planck Solar Array Mechanical Interface



TOP VIEW (external S.A. only)

Electrical network

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	GAGET2 –ID2
Dimensions	$40*80m^2$
Thickness	150 µm
Electrical Characteristics Conditions	AM0 28C
Isc	16.5 mA/cm^2
Voc	2570 mV
Imp	15.9 mA/cm^2
Vmp	2275 mA/cm^2
Efficiency	23 %

Table 9.3.4-1 solar cells characteristics

Cells are covered with CMG 100 micron thick coverglass.
A shunt diode is already included in the cell assembly to cope with shadow that was proven possible in survival mode.

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 a 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 4220 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.

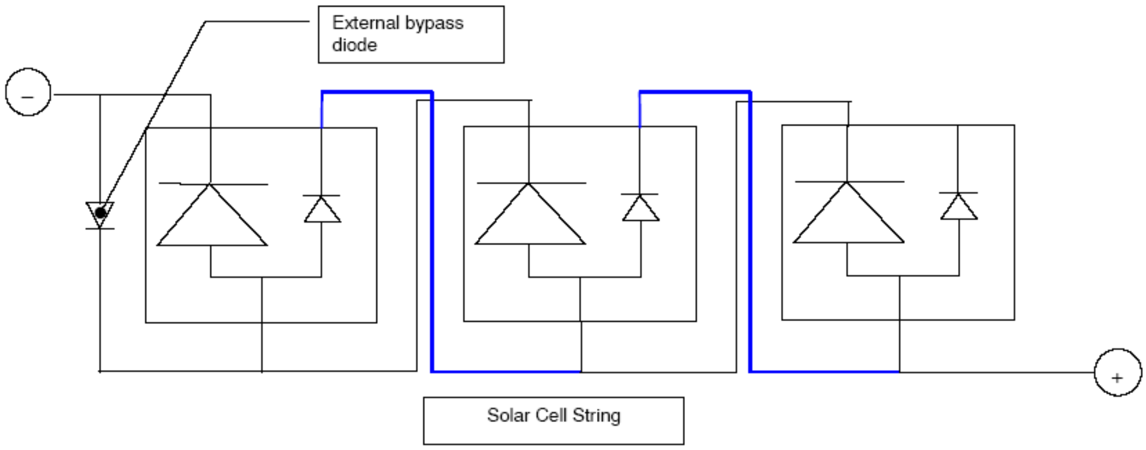
- Internal solar array
  - 6 section formed by 5 strings in parallel
  - 6 sections formed by 4 strings in parallel

- External solar array
  - +Z sector: 1 section with 4 strings and 3 sections with 5 strings
  - +Y sector: 4 sections with 4 strings and 1 section with 5 strings
  - –Z sector: 3 sections with 4 strings and 2 sections with 5 strings
  - –Y sector: 1 section with 4 strings and 3 sections with 5 strings

For each string 21 cells in series have been considered enough to ensure a minimum voltage of 30 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 terminated with a blocking diode mounted on the rear side

Integrated diodes are connected as per the following diagram to protect the cells in case of shadow.



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 back 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 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.
The maximum SAA expected is 10° resulting from a conical rotation around X axis

Complete Solar Array Output characteristics – BOL cases							
		I_{SC} [A]	V_{OC} [V]	P_{MAX} [W]	I_{OP} [A]	V_{OP} [V]	P_{OP} [A]
BOL Acceptance	**Np =** 4 × 15 (A) + 5 × 15 (B) = **135**	*67.31*	*54.46*	*3070*	*66.61*	*45.1*	*3004*
BOL SS 10°		67.87	42.57	2155	66.40	30	**1992**
BOL WS 0°		77.51	42.03	2462	76.55	30	2296
Requirement							**1900**

Complete Solar Array Output characteristics – EOL cases							
		I_{SC} [A]	V_{OC} [V]	P_{MAX} [W]	I_{OP} [A]	V_{OP} [V]	P_{OP} [W]
EOL 21 m. SS 0°	**Np =** 4 × 16 (A) + 5 × 14 (B) = **134**	65.92	39.31	1983	64.45	30	1933
EOL 21 m. SS 10°		64.94	39.40	1960	63.58	30	**1908**
EOL 21 m. WS 0°		71.98	38.35	2087	69.18	30	2075
EOL 21 m. WS 10°		70.91	38.44	2065	68.33	30	2050
Requirement							**1900**
EOL 30 m. SS 0°	**Np =** 4 × 16 (A) + 5 × 14 (B) = **134**	65.72	38.83	1950	63.90	30	1917
EOL 30 m. SS 10°		64.74	38.93	1931	63.07	30	**1892**
EOL 30 m. WS 0°		71.75	37.86	2055	68.32	30	2050
EOL 30 m. WS 10°		70.69	37.96	2031	67.50	30	2025
Requirement							**1810**

Table 9.3.4-2 Planck Power prediction

The power value is given at the interface point already considering the losses on diodes and wiring at a minimum voltage of 30 V.

The mass of the array is 43.2 kg and 44.7 Kg including contingency.

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.
- Due to the specificity of the Science Instruments needing, customisation on distribution lines is performed at harness level thus not affecting the 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.

9.3.6 Budget Summary

9.3.6.1 FCL and LCL Budget

The PCDU power lines connected to Fold-Back Current Limiters are listed in the following table. This configuration is valid for both Herschel and Planck.
Blank rows are spare

	Herschel Allocation	To	Planck Allocation	To	Type	Class
1	CDMU Hot A	CDMU	CDMU Hot A	CDMU	FCL	I
2	CDMU Hot B	CDMU	CDMU Hot B	CDMU	FCL	I
3	XPND1 Rx	XPND1	XPND1 Rx	XPND1	FCL	I
4	XPND2 Rx	XPND2	XPND2 Rx	XPND2	FCL	I
5	ACC Hot A	ACC	ACC Hot A	ACC	FCL	I
6	ACC Hot B	ACC	ACC Hot B	ACC	FCL	I
7	Emergency Heater Line 1 Nom	Batt	Emergency Heater Line 1 Nom	Batt	FCL	I
8	Emergency Heater Line 1 Red	Batt	Emergency Heater Line 1 Red	Batt	FCL	I
9					FCL	I
10					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 and Table 9.3.6-3.
Information on Protected Lines and Direct Commands (in addition of 1553) is also given.

11	SPIRE HSDPU Nom	HSDPU	HFI REU Proc Nom	PHCBC	LCL	I	YES		NE
12	SPIRE HSDPU Red	HSDPU	HFI REU Proc Red	PHCBC	LCL	I	YES		NE
13	GYRO A	GYRE	FOG Channel 1	FOG1	LCL	II			E
14	GYRO B	GYRE	FOG Channel 2	FOG2	LCL	II			E
15	CRS1	CRS1	CRS1	CRS1	LCL	I			E
16	XPND2 Tx	XPND2	XPND2 Tx	XPND2	LCL	I			E
17	Cat Bed Heaters Nom	THR20Ns	Cat Bed Heaters Nom	THR20Ns	LCL	I			NE
18	Cat Bed Heaters Red	THR20Ns	Cat Bed Heaters Red	THR20Ns	LCL	I			NE
19	SREM	SREM	SREM	SREM	LCL	I			NE
20	VMC	VMC	VMC	VMC	LCL	I			NE
21	STR 1	STRE1	STR 1	STRE1	LCL	I			E
22	STR 2	STRE2	STR 2	STRE2	LCL	I			E
23	XPND1 Tx	XPND1	XPND1 Tx	XPND1	LCL	I			E
24	CRS2	CRS2	CRS2	CRS2	LCL	I			E
25			CRS3	CRS3	LCL	I			E
26			FOG Channel 3	FOG3	LCL	I			E
27	PACS BOLC Nom	FPBOLC	LFI REBA Nom	PLREN	LCL	II	YES		NE
28	PACS BOLC Red	FPBOLC	LFI REBA Red	PLRER	LCL	II	YES		NE
29			HFI DPU Nom (PHBA-N)	PHBAN	LCL	II	YES		NE
30			HFI DPU Red (PHBA-R)	PHBAR	LCL	II	YES		NE
31	CDMU Cold A	CDMU	CDMU Cold A	CDMU	LCL	II		YES	E
32	CDMU Cold B	CDMU	CDMU Cold B	CDMU	LCL	II		YES	E
33	ACC Cold A	ACC	ACC Cold A	ACC	LCL	II		YES	E
34	ACC Cold B	ACC	ACC Cold B	ACC	LCL	II		YES	E
35	PACS SPU Nom	FPSPU1	FOG Channel 4	FOG4	LCL	II			NE
36	PACS SPU Red	FPSPU2	HFI DCE	PHEC	LCL	II			NE
37	CCU A	CCU	HFI 4KCDE Nom (PHDC)	PHDC	LCL	II			E
38	CCU B	CCU	HFI 4KCDE Red (PHDC)	PHDC	LCL	II			E
39			HFI REU belts 0 & 1	PHBAR	LCL	II			NE
40			HFI REU belts 2 & 3	PHBAR	LCL	II			NE
41	PACS DPU Nom	FPDPU	HFI REU belts 4 & 5	PHBAR	LCL	II			NE
42	PACS DPU Red	FPDPU	HFI REU belts 6 & 7	PHBAN	LCL	II			NE
43	HIFI WEH	FHWEH	HFI REU belts 8 & 9	PHBAN	LCL	II			NE
44	HIFI WEV	FHWEV	HFI REU belts 10 & 11	PHBAN	LCL	II			NE

Table 9.3.6-2 PCDU LCL Budget – Class I and II

45	ACC RCS Thrusters A	ACC	ACC RCS Thrusters A	ACC	LCL	III	YES	YES	E
46	ACC RCS Thrusters B	ACC	ACC RCS Thrusters B	ACC	LCL	III	YES	YES	E
47	ACC RCS LV A	ACC	ACC RCS LV A	ACC	LCL	III	YES	YES	E
48	ACC RCS LV B	ACC	ACC RCS LV B	ACC	LCL	III	YES	YES	E
49	TWTA 1	EPC1	TWTA 1	EPC1	LCL	III	YES		E
50	TWTA 2	EPC2	TWTA 2	EPC2	LCL	III	YES		E
51	SPIRE HSFCU Nom	HSFCU	LFI DAE Power Box Nom	PLAEF	LCL	III	YES		NE
52	SPIRE HSFCU Red	HSFCU	LFI DAE Power Box Red	PLAEF	LCL	III	YES		NE
53	HIFI LCU Nom	FHLCU	Sorption Cooler Electronics Nom	PSM4	LCL	III	YES		NE
54	HIFI LCU Red	FHLCU	Sorption Cooler Electronics Red	PSR4	LCL	III	YES		NE
55	Reaction Wheel 1	RWE			LCL	III	YES		E
56	Reaction Wheel 2	RWE			LCL	III	YES		E
57	Reaction Wheel 3	RWE			LCL	III	YES		E
58	Reaction Wheel 4	RWE			LCL	III	YES		E
59			HFI 4KC Drive bus Nom	PHDJ	Par-LCL	III	YES		E
60			HFI 4KC Drive bus Nom	PHDJ	Par-LCL	III	YES		E
61			HFI 4KC Drive bus Red	PHDJ	Par-LCL	III	YES		E
62			HFI 4KC Drive bus Red	PHDJ	Par-LCL	III	YES		E
63	HIFI HRH	FHHRH	Sorption Cooler Compressor A 1	PSM4	Par-LCL	III	YES	YES	NE
64	HIFI ICU Nom	FHICU	Sorption Cooler Compressor A 2	PSM4	Par-LCL	III	YES		NE
65	PACS DEC/MEC1	FPMEC1	Sorption Cooler Compressor A 3	PSM4	Par-LCL	III	YES		NE
66			Sorption Cooler Compressor A 4	PSM4	Par-LCL	III	YES		NE
67	HIFI HRV	FHHRV	Sorption Cooler Compressor B 1	PSR4	Par-LCL	III	YES	YES	NE
68	HIFI ICU Red	FHICU	Sorption Cooler Compressor B 2	PSR4	Par-LCL	III	YES		NE
69	PACS DEC/MEC2	FPMEC2	Sorption Cooler Compressor B 3	PSR4	Par-LCL	III	YES		NE
70			Sorption Cooler Compressor B 4	PSR4	Par-LCL	III	YES		NE
71	PLM NCA Actuators Nom	CBPLM1A			NCA act	NCA		YES	NE
72	PLM NCA Actuators Red	CBPLM1A			NCA act	NCA			NE

Table 9.3.6-3 PCDU LCL Budget – Class III

9.3.6.2 Heater Lines Budget

The following tables list the allocation of Heater switch lines and Heater Group Protection Switches.

		HERSCHEL		PLANCK	
HTR Grp #	HTR #	Pwr @28V	Location Unit	Pwr @28V	Location Unit
1	1	100.0	Decontamination 1	60.0	Primary Reflector 1N
1	2	21.0	XPND2	49.0	4KAU
1	3	3.4	FCV A1B	3.4	1 N FCV A1 on -Y+Z (+Z side)
1	4	3.4	FCV C2B	3.4	1 N FCV A2 on -Y+Z (-Z side)
1	5	2.1	RCS piping #2	41.2	PHDA (4KCU/CEU)
1	6	21.0	XPND1	17.4	PHBA-N (HFI DPU1)
2	1	100.0	Decontamination 3	60.0	Primary Reflector 2N
2	2	3.4	FCV C1B	55.9	SCE2
2	3	3.4	FCV A2B	3.4	FCV D2A
2	4	3.4	FCV C4B	3.4	FCV F1A
2	5	33.4	FPDPU/FPSPU	3.4	FCV F2A
2	6		spare	55.9	SCE2
3	1	10.1	FPBOLC	55.9	SCE1
3	2		spare	55.9	SCE1
3	3	28.9	FPMECDEC	10.1	PLREN (REBA)
3	4	3.0	RCS piping #1	16.0	BATTERY Conn.
3	5	31.9	CCU	3.4	1 N FCV B on -Y+Z (+Z side)
3	6	66.7	GYRO	83.9	SCE1
4	1	100.0	Decontamination 5	60.0	Secondary Reflector N
4	2	28.9	FHWOV	46.2	EPC2/TWT2/XPND2
4	3	1.0	RCS brck 12	3.4	1 N FCV B on -Y+Z panel (-Z side)
4	4	3.4	FCV A1A	3.4	FCV D1B
4	5	3.4	FCV C2A	3.4	FCV D2B
4	6	0.8	RCS piping #7	46.2	EPC1/TWT1/XPND1
5	1		spare	3.4	FCV F1B
5	2	41.9	FHHRH	3.4	FCV F2B
5	3	47.0	FHWEV/FHICU	83.9	SCE2
5	4	3.4	FCV C3B	83.9	SCE2
5	5	1.0	RCS piping #8	8.7	STR1
5	6	7.9	PT/LF/LV1/LV2	8.7	STR2
6	1	100.0	Decontamination 7	60.0	Focal Plane HFI 1 N
6	2	8.7	RWA4	83.9	SCE1
6	3	8.7	RWA1	17.4	PHBA-R (HFI DPU2)
6	4	8.7	RWA3	3.4	FCV U1B
6	5	12.3	STR +Y	3.4	FCV U2B
6	6	8.7	RWA2	3.4	FCV D1A
7	1	12.3	STR -Y	83.9	SCE2
7	2	16.0	BATTERY Conn.	83.9	SCE2
7	3	27.5	FHWOH	1.4	RCS piping #1
7	4	34.8	FHWEH	2.7	RCS piping #2
7	5	3.4	FCV C1A	3.2	RCS piping #3
7	6	3.4	FCV A2A	3.7	RCS piping #4
8	1	41.9	FHHRV	60.0	Focal Plane LFI 2 N
8	2	3.4	FCV C3A	0.4	RCS piping #5
8	3	10.0	RCS piping #3	6.6	TANK +Z+Y
8	4	5.4	RCS piping #4	6.6	TANK +Z-Y
8	5	1.1	RCS piping #5	6.6	TANK -Z
8	6	21.0	FHLCU	66.7	PHCBC (REU)
9	1	25.0	Decontamination 8	83.9	SCE1
9	2	6.6	Tank -Y	83.9	SCE1
9	3	3.4	FCV C4A	8.4	RCS piping #6
9	4	100.1	FHLSU		spare
9	5	17.4	FHFCU	3.4	FCV U1A
9	6	6.6	Tank +Y	3.4	FCV U2A
18	1	100.0	Decontamination 2	60.0	Primary Reflector 1R
18	2	21.0	XPND2	49.0	4KAU
18	3	3.4	FCV A1B	3.4	1 N FCV A1 on -Y+Z (+Z side)
18	4	3.4	FCV C2B	3.4	1 N FCV A2 on -Y+Z (-Z side)
18	5	2.1	RCS piping #2	41.2	PHDA (4KCU/CEU)
18	6	21.0	XPND1	17.4	PHBA-N (HFI DPU1)
17	1	100.0	Decontamination 4		
17	2	3.4	FCV C1B	55.9	SCE2
17	3	3.4	FCV A2B	3.4	FCV D2A
17	4	3.4	FCV C4B	3.4	FCV F1A
17	5	33.4	FPDPU/FPSPU	3.4	FCV F2A
17	6	0.0	spare	55.9	SCE2
16	1	10.1	FPBOLC	55.9	SCE1
16	2	0.0	spare	55.9	SCE1
16	3	28.9	FPMECDEC	10.1	PLREN (REBA)
16	4	3.0	RCS piping #1	16.0	BATTERY Conn.
16	5	31.9	CCU	3.4	1 N FCV B on -Y+Z (+Z side)
16	6	66.7	GYRO	83.9	SCE1
15	1	100.0	Decontamination 6	60.0	Secondary Reflector R
15	2	28.9	FHWOV	46.2	EPC2/TWT2/XPND2
15	3	1.0	RCS brck 12	3.4	1 N FCV B on -Y+Z panel (-Z side)
15	4	3.4	FCV A1A	3.4	FCV D1B
15	5	3.4	FCV C2A	3.4	FCV D2B
15	6	0.8	RCS piping #7	46.2	EPC1/TWT1/XPND1
14	1	0.0	spare	3.4	FCV F1B
14	2	41.9	FHHRH	3.4	FCV F2B
14	3	47.0	FHWEV/FHICU	83.9	SCE2
14	4	3.4	FCV C3B	83.9	SCE2
14	5	1.0	RCS piping #8	8.7	STR1
14	6	7.9	PT/LF/LV1/LV2	8.7	STR2
13	1			60.0	Focal Plane HFI 1 R
13	2	8.7	RWA4	83.9	SCE1
13	3	8.7	RWA1	17.4	PHBA-R (HFI DPU2)
13	4	8.7	RWA3	3.4	FCV U1B
13	5	12.3	STR +Y	3.4	FCV U2B
13	6	8.7	RWA2	3.4	FCV D1A
12	1	12.3	STR -Y	83.9	SCE2
12	2	16.0	BATTERY Conn.	83.9	SCE2
12	3	27.5	FHWOH	1.4	RCS piping #1
12	4	34.8	FHWEH	2.7	RCS piping #2
12	5	3.4	FCV C1A	3.2	RCS piping #3
12	6	3.4	FCV A2A	3.7	RCS piping #4
11	1	41.9	FHHRV	60.0	Focal Plane LFI 2 R
11	2	3.4	FCV C3A	0.4	RCS piping #5
11	3	10.0	RCS piping #3	6.6	TANK +Z+Y
11	4	5.4	RCS piping #4	6.6	TANK +Z-Y
11	5	1.1	RCS piping #5	6.6	TANK -Z
11	6	21.0	FHLCU	66.7	PHCBC (REU)
10	1	25.0	Decontamination 9	83.9	SCE1
10	2	6.6	Tank -Y	83.9	SCE1
10	3	3.4	FCV C4A	8.4	RCS piping #6
10	4	100.1	FHLSU	0.0	spare
10	5	17.4	FHFCU	3.4	FCV U1A
10	6	6.6	Tank +Y	3.4	FCV U2A

Table 9.3.6-4 PCDU Heater Lines

9.3.6.3 Mass Budget

The PCS mass budget is detailed in the following table.

Unit	Qty	Nominal Mass	Margin	Maximum Mass
PCDU	1	25.8	10%	28.4
Battery	1	7	15%	8.1
Total		32,8		36,5

Table 9.3.6-5 Power Control Subsystem Mass Budget

9.4 SVM Harness

This chapter describe the major Harness Subsystem and/or Equipment design. They are procured on the basis of the hereafter listed specification (included in the CDR data Package).

SVM HARNESS REQUIREMENT SPEC. H-P-SP-AI-0026 4 [RD-52]

The major modification occurred from the PDR (June 2002) are hereafter briefly listed. Any details on the improved design with respect to the one presented at the PDR can be found in the applicable design report at Subsystem and/or Equipment level:

- The definition of electrical detailed connection lead to a increased design complexity of the SVM harness.
- Lateral panel Demountability connector brackets implemented
- Definition of needed external SKIN connector interface to EGSE
- Implementation of PLM External interface following the PL evolution
- Grounding Rail implementation also for 0V GND reference (not only for harness ground plane)
- WU Harness routing definition assigned to same subcontractor of the SVM Harness

9.4.1 General

The Herschel/Planck SVM Harness provides the interconnections between all electrical and electronic equipment installed on SVM Platform and Panels.
The Harness connecting equipment of the SVM to equipment functionally allocated to the PLM but installed on SVM WU Panels will be part of the SVM harness (up to the first WU unit interface) as well as the SVM part of the cabling up to the dedicate interface connector brackets as defined in the [RD-118] (SVM electrical ICD).

The Harness between WU equipment within the instruments and the Cryo Harness will not be part of the SVM Harness. The electrical and mechanical/routing design responsibility of this WU Interconnecting Harness and Cryo Harness shall be of the relevant supplier.

The SVM Harness shall include the following items:

- Cables, connectors and contacts/screws required to perform the electrical connections
- In Line Couplers (ILC) necessary to implement the MIL-Bus-1553B connections of DMS Bus and ACMS Bus
- MIL-Bus-1553B Termination (in-line and/or with termination loads assembled in a connectors)
- Shielding provisions for the wiring (overall shields/conductive tape, straps to ground)
- Connectors accessories to allow shield termination (RFI backshell included)
- SVM Harness fixation devices and associated hardware required to install the cabling on the structure
- Connector protective caps, edge protections and grommets/tape
- All the Connector Bracket necessary to install the receptacle connectors with the relevant fixation screws
- All the structural support as stand- off, spacers, necessary to perform the harness routing with relevant fixation devices
- Harness Grounding Rail necessary to distribute the grounding plane along the harness routing with relevant fixation devices/media
- Grounding Rail necessary to connect the SVM/WU Unit bonding stud to the relevant insert to distribute the 0V ground reference on Carbon Fibre structures with associated fixation devices/media
- Splice and/or connecting devices necessary to connect devices having flying leads
- Connector Severs

In addition the SVM Harness shall provide the electrical connections for :

- All TCS subsystem items (heaters, thermistors and thermostats) mounted on SVM up to the component and up to CB interface connectors for those dedicated to PLM
- All RCS subsystem items (Thrusters/sensors) mounted on spacecraft up to the component
- All Temperature Sensors of RFDN in the TTC subsystem up to the components

The following cabling will not be part of SVM Harness

- The Coaxial cable connecting the antenna to the Transponders through the TWTA will be part of the TT&C Subsystem.
- The TWTA to EPC HV cables will be part of the TT&C Subsystem.
- The RWL cabling up to the interfrace connector bracket located on the ACMS Panel of Herschel

9.4.2 Requirements and Design Drivers

The Herschel/Planck Harness maintain the modularity concept of the Herschel/Planck structure separation.
Due to the different Configuration constraints and approach the SVM to PLM module separation will be implemented in different manner in between the two S/C.

On Herschel a limited set of interface connectors are provided between the SVM and PLM modules in order to provide the requested interface (Cryo Temperature Monitors, Heaters and NCA lines). Also the Solar Array Interface connectors will be at this level.

In addition to the above interface all there will be the interface connectors belongs mainly to the PLM Cryo Harness and other segments of the Instrument WU Harness (not under ALS responsibility).

All these connectors will be place on the Upper Platform which shall remain fixed to the main structure.

On Planck the Upper platform is requested to be removable for accessibility purpose. Therefore the SVM/PLM interface connectors shall be place on the Shear Panel or on the PLM Sub Platform.

In addition the SVM Harness shall maintain the Lateral Panel Tilting requirements by means of a dedicated connector brackets (Dismountability Connector brackets -DBXX) which are placed on the Lower Platform as much as possible close to the panel hinging point.

The definition of harness routing on the structure will be performed using a System Configuration Model generated on 3-D CAD Model . This model will be representative of all the mechanical data and interface requirements, as well as of constraints, that have to be considered in routing definition.

Routing will be designed in order to guarantee easy access to connectors for insertion and removal from equipment, and to provide sufficient slack in the harness in order to enable termination and mate/demate operation at connector level.
Routing will be, as far as possible, the most direct, in order to minimize cable length, maintaining the cables close to the primary structure.

The bending radius of harness will be maintained greater than 3 times the outside bundle diameter.
Ty-bases, ty-raps are planned to be used to fix the cables to the structure, in order to allow for easy replacement of cables and bundles.
Fixing points shall be adequately spaced to provide safe harness mounting and relief to the structure.
Protections will be used in correspondence of sharp edges, cut-outs and on the harness slacks.

Looms of different EMC classes that run close to each other on the same side of the panel, are separated as much as possible.
As a general rule, the harness looms are routed as close to each unit connector front face as possible without interfering with the unit mounting feet and maintaining the requirement for unit/structure removal.

9.4.3 Functional Description

The Herschel/Planck SVM Harness design will be carried out taking as input the applicable Electrical and Mechanical Interface Information collecting all the electrical interconnections, defined down to equipment level, and mechanical requirements for the harness.
On this basis, the harness will be defined considering the following design requirements:

- separation of SVM/PLM and interface to Launcher/Check-Out (i.e.EGSE) through a Skin connector
- maximum modularity (each bundle was defined with the aim of keeping to a minimum the number relevant connectors);
- EMC class separation, as far as possible with reference to the interface signal assignment on each connector;
- NOM/Red Signal Separation
- performance requirements (length, voltage drop, mass,...).

The following Figure 9.4.3-1 shown the SVM Harness architecture and relevant harness segment responsibility.

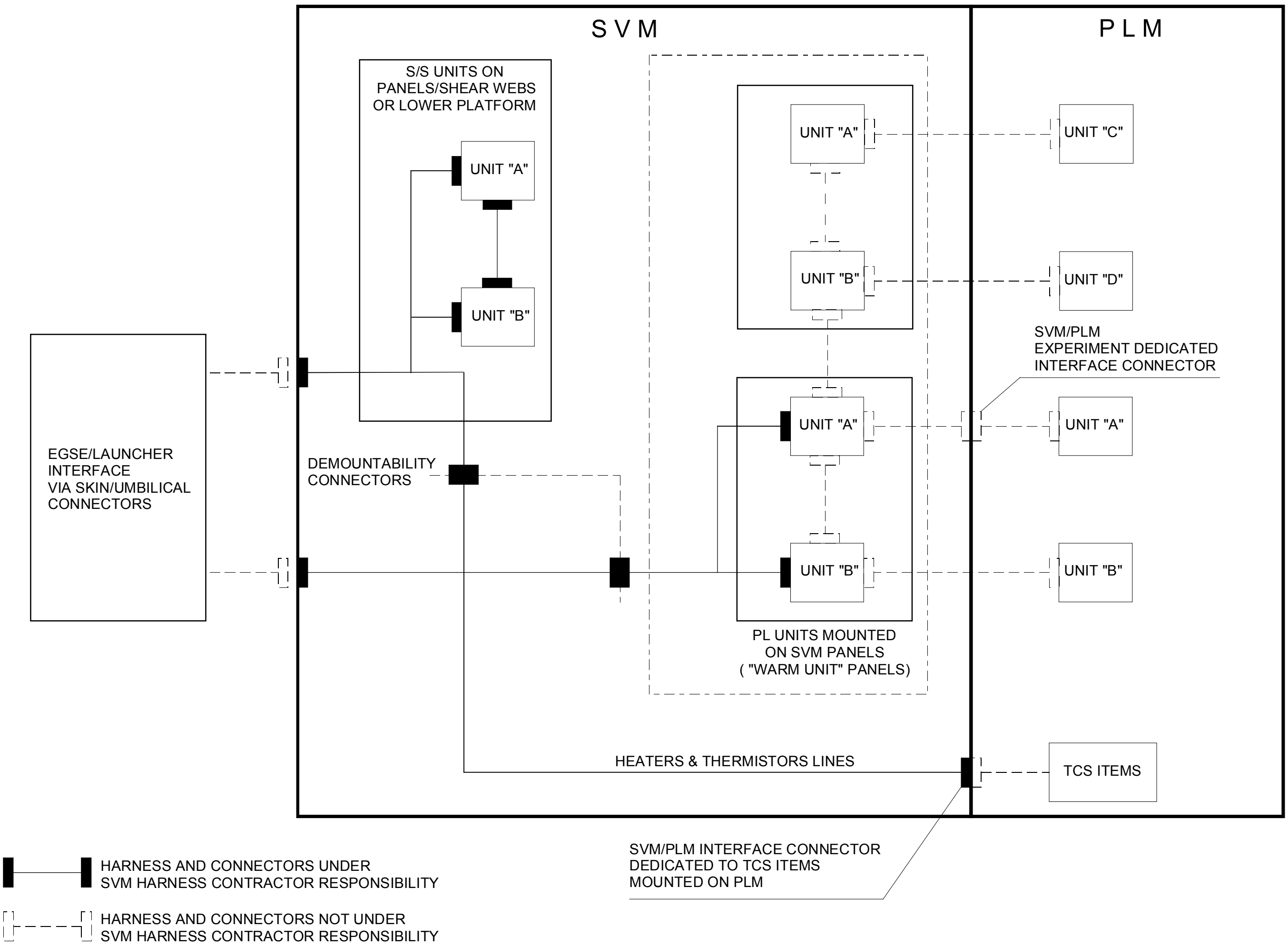


Figure 9.4-3-1 SVM Harness architecture

9.4.4 Design and Performance

The SVM Harness Electrical Items is subdivided in groups which shall be identified in accordance with the module configuration (lateral panels and platform/cone).

Each group shall be composed by the relevant cable and wiring, connectors and associated installation hardware necessary to mount the harness on relevant structures

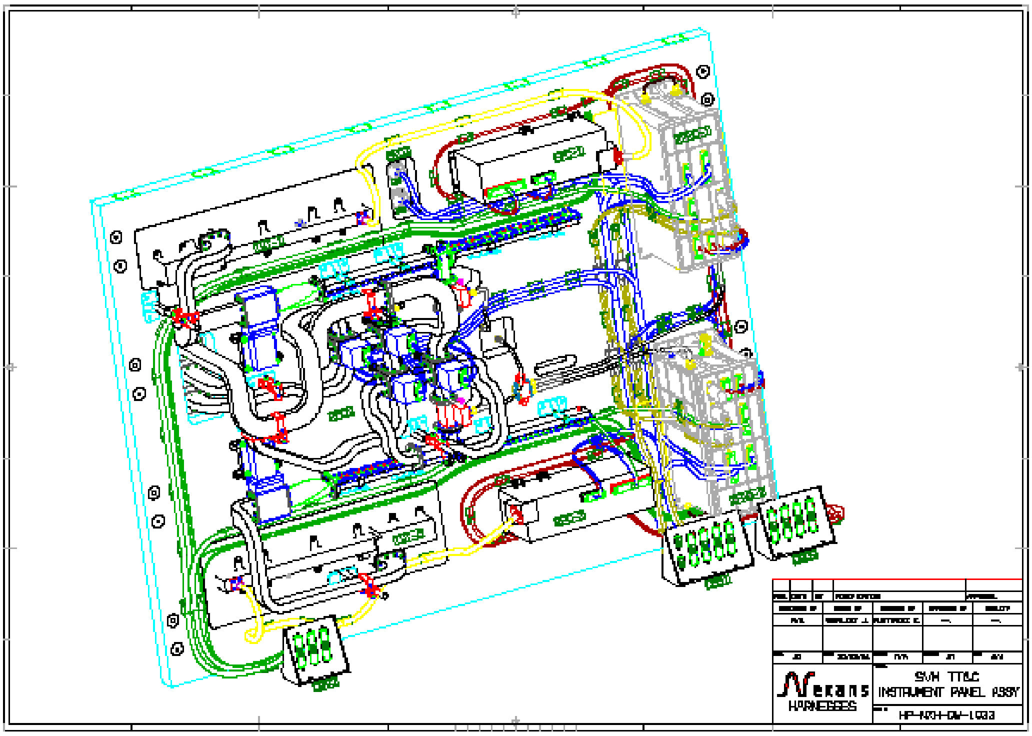
The SVM Harness Mechanical Items shall include all the non-electrical components of harness as Connector Brackets, Stand-off and Support, Grounding Rails and all the hardware necessary to mount these items on SVM.

The details of the harness routing are currently reported in the [RD-119] and [RD-120] documents.
ere below a summary of the drawing are shown of the lateral panels and the Lower platforms of the two configuration.

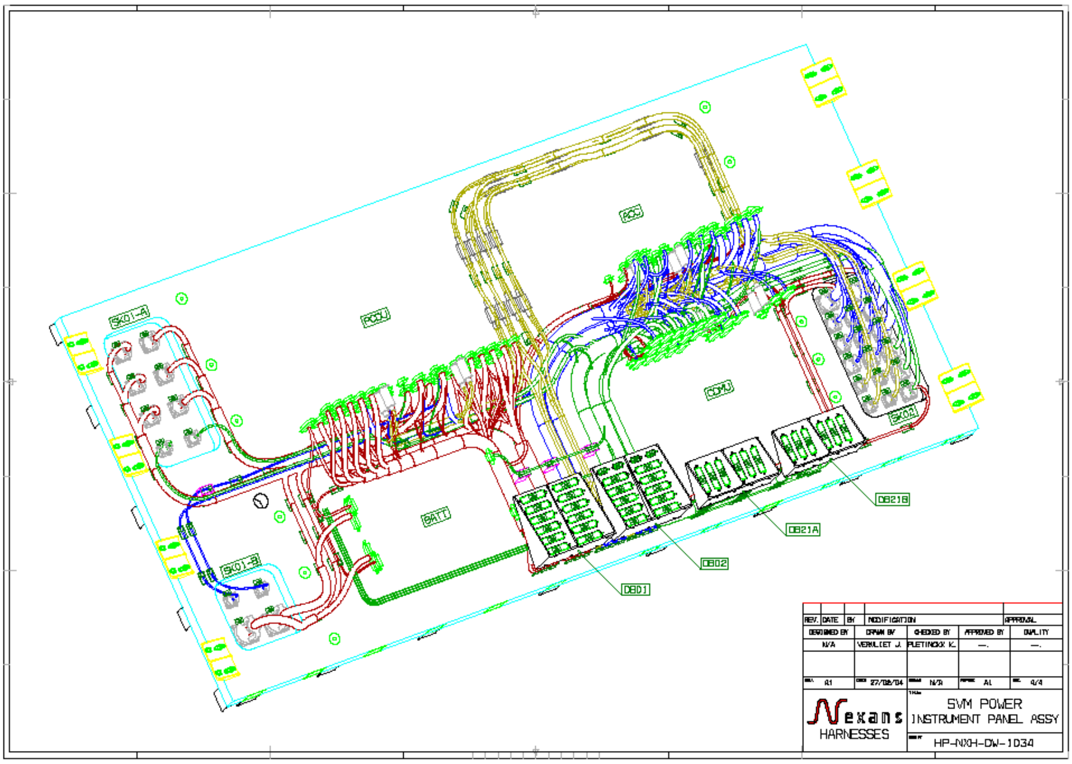
The different loom colours indicate the various EMC classes as follows :

- RED : Power Class 1
- GREEN : Sensitive Analog Class 4
- BLU : Digital/Serial Claee 2
- Dark Yellow : MIL BUS Class 2

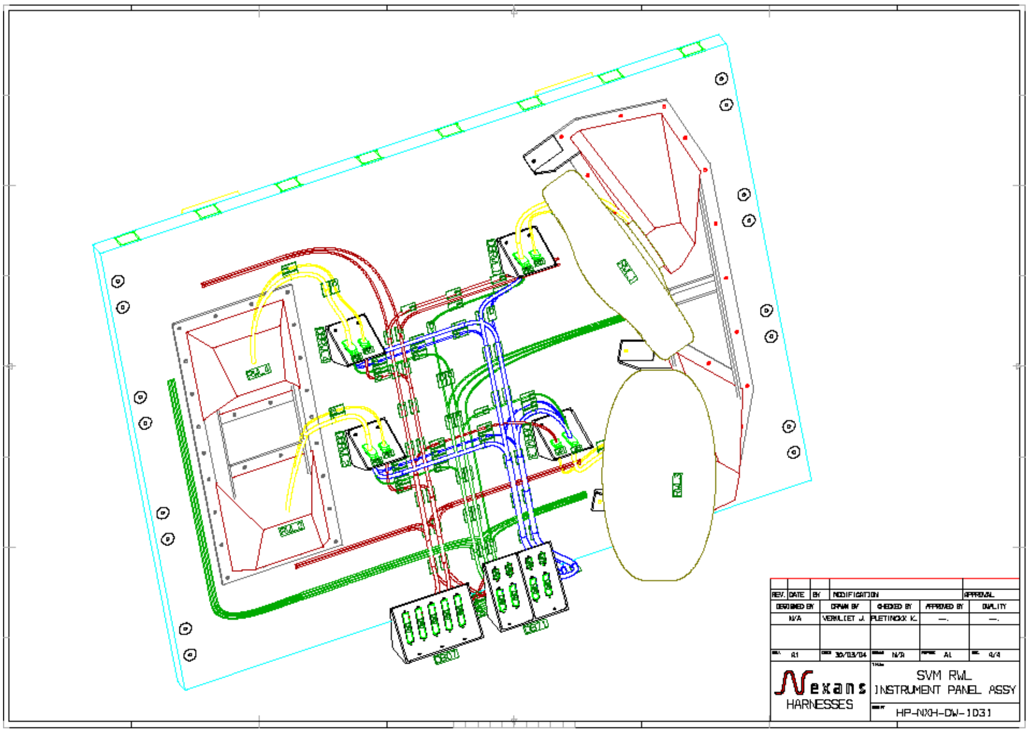
Herschel
TTC Panel



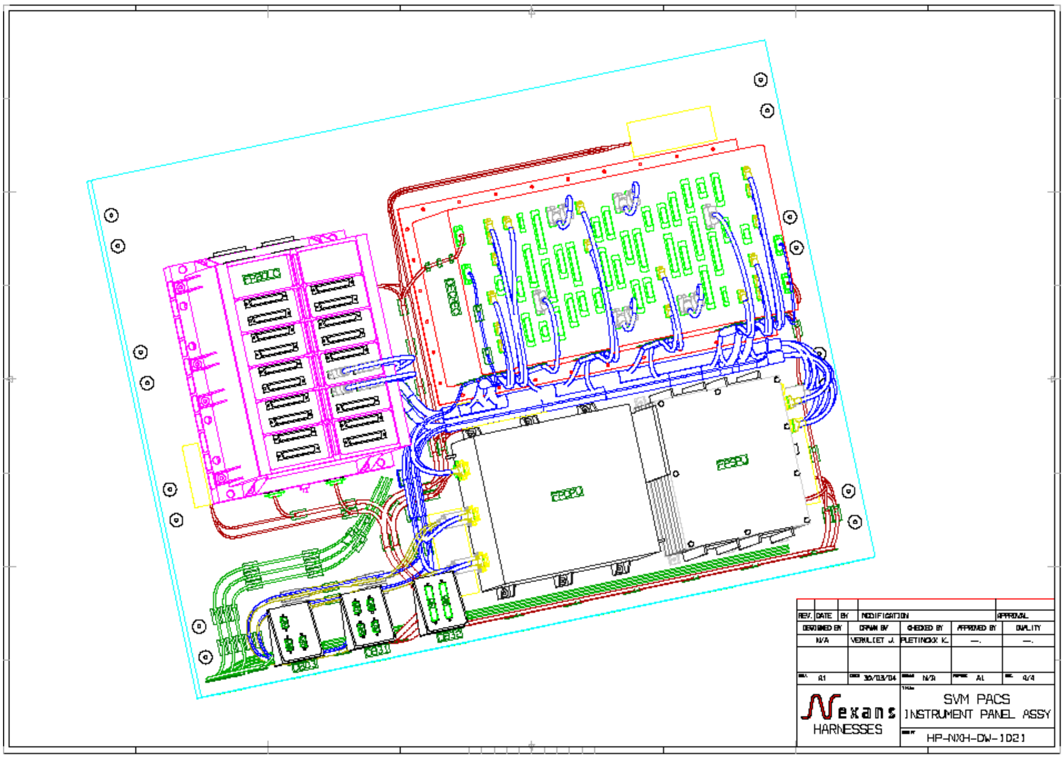
Power Panel (PCDU-ACC-CDMU omitted for clarity)



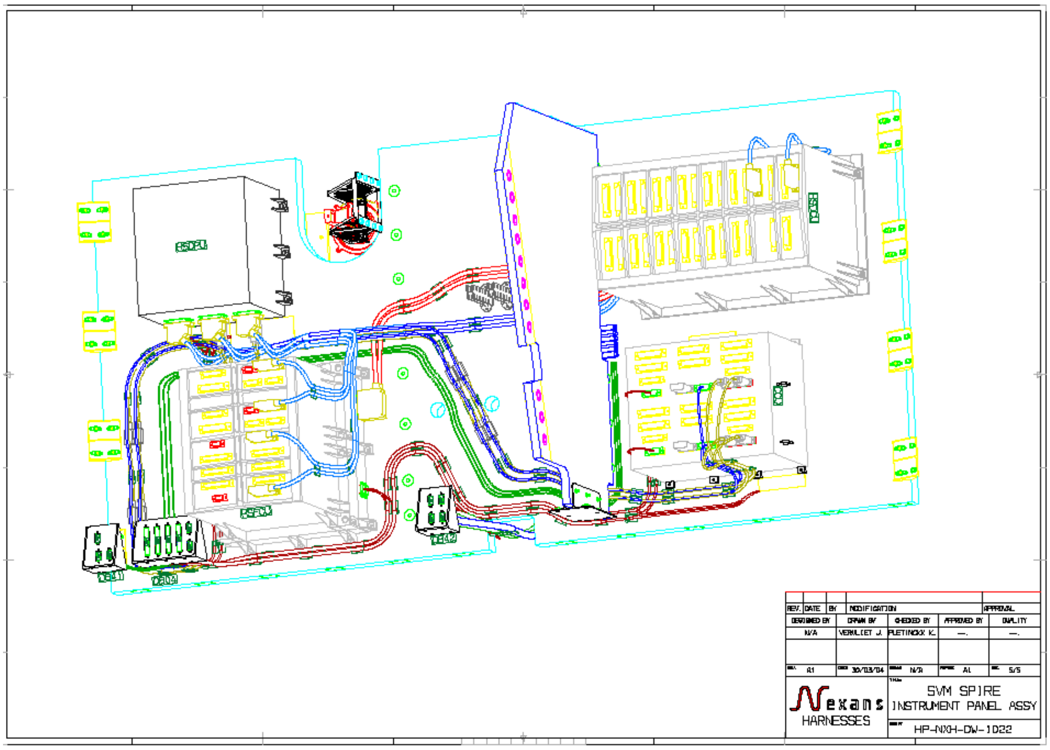
ACMS Panel



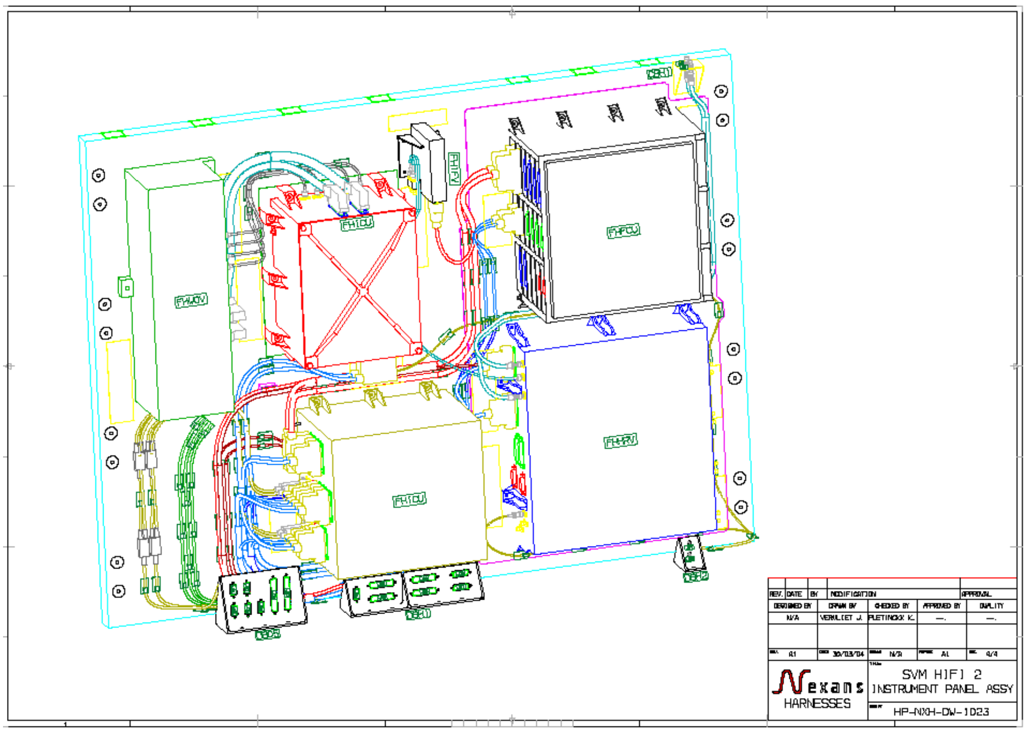
PACS Panel



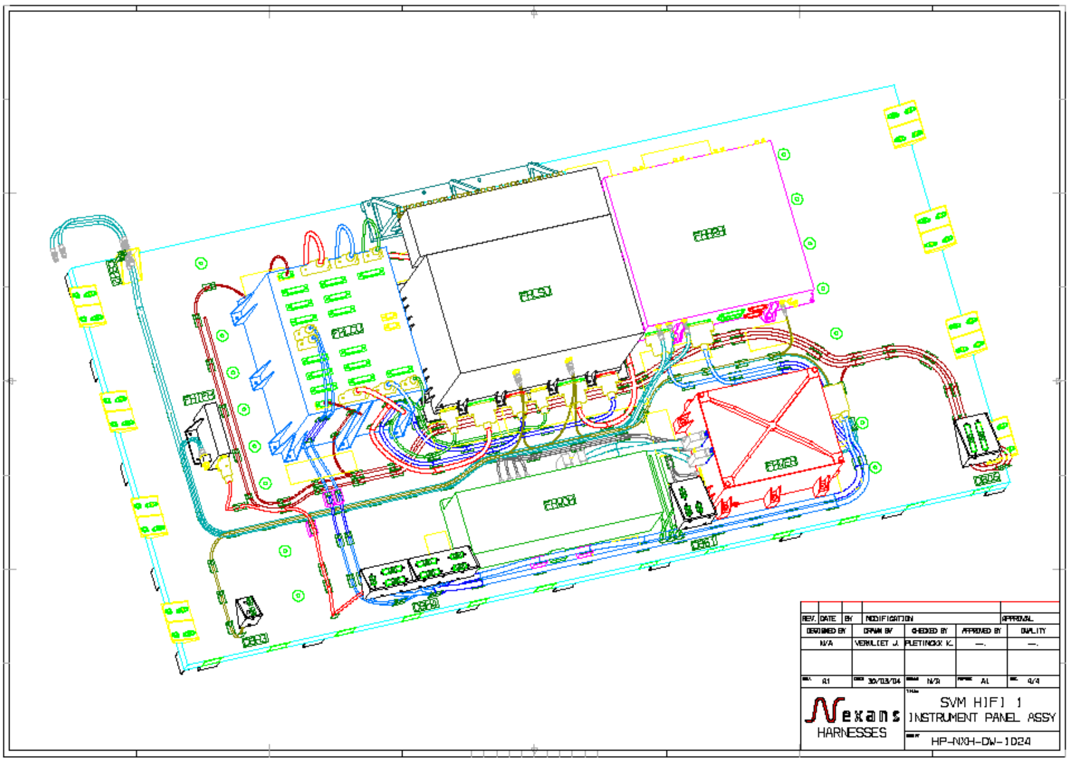
SPIRE Panel



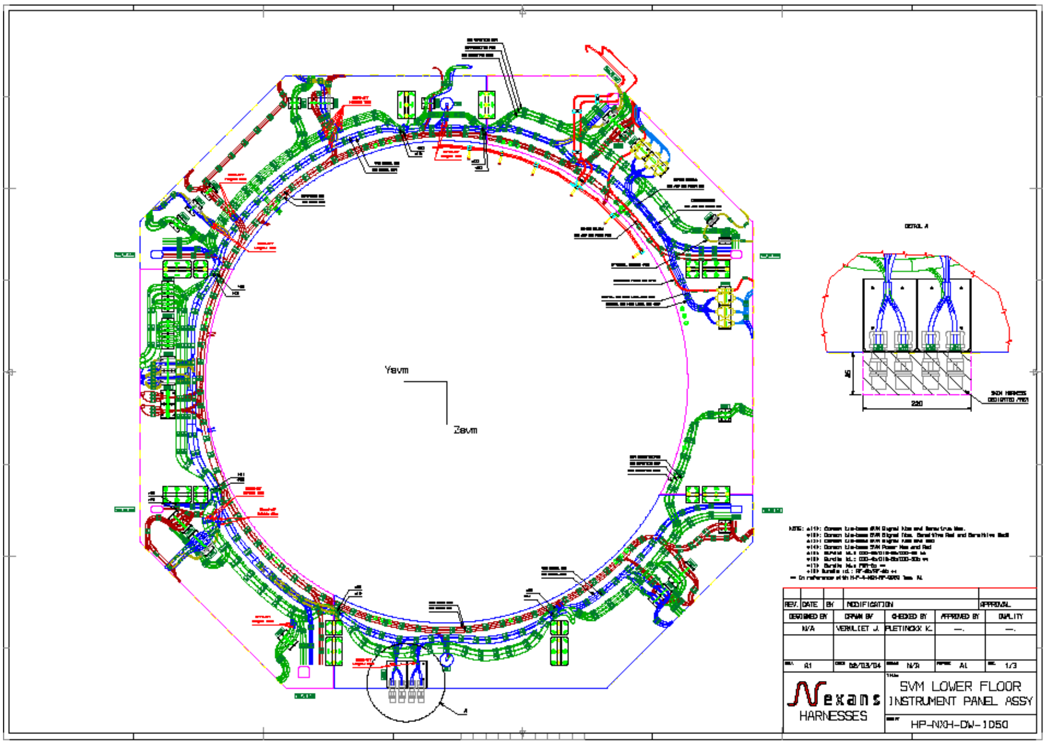
HIFI 2 Panel



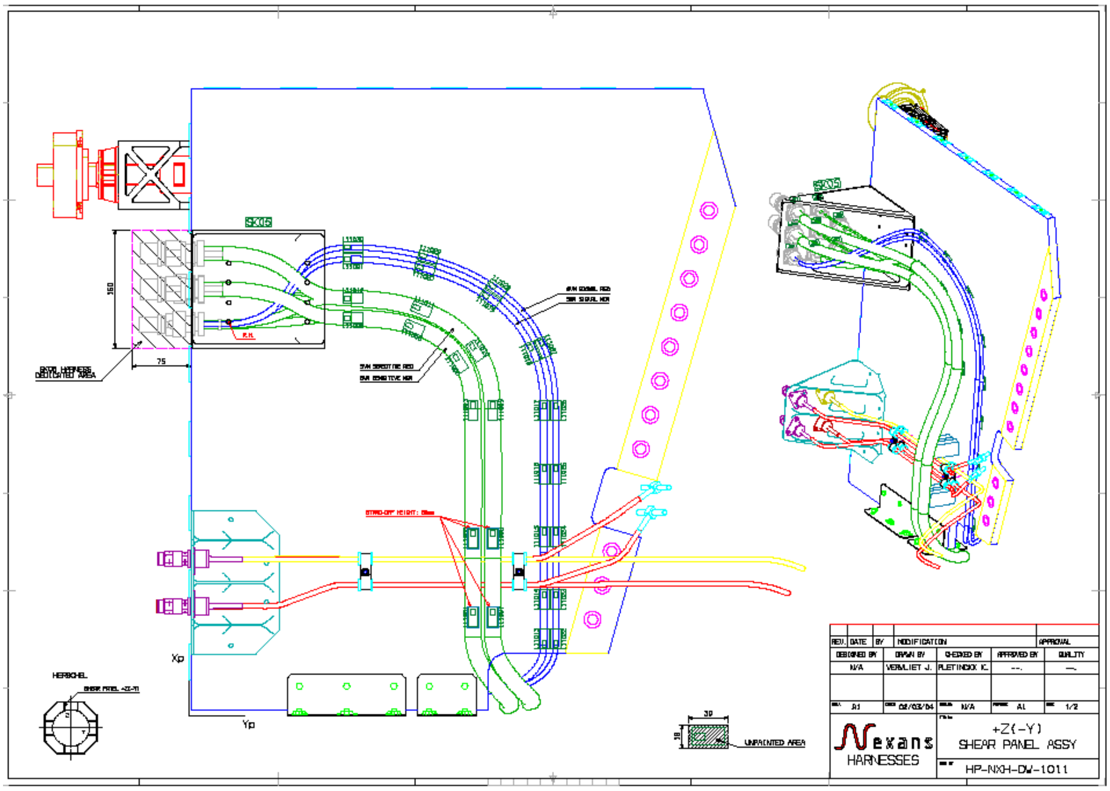
HIFI 1 Panel



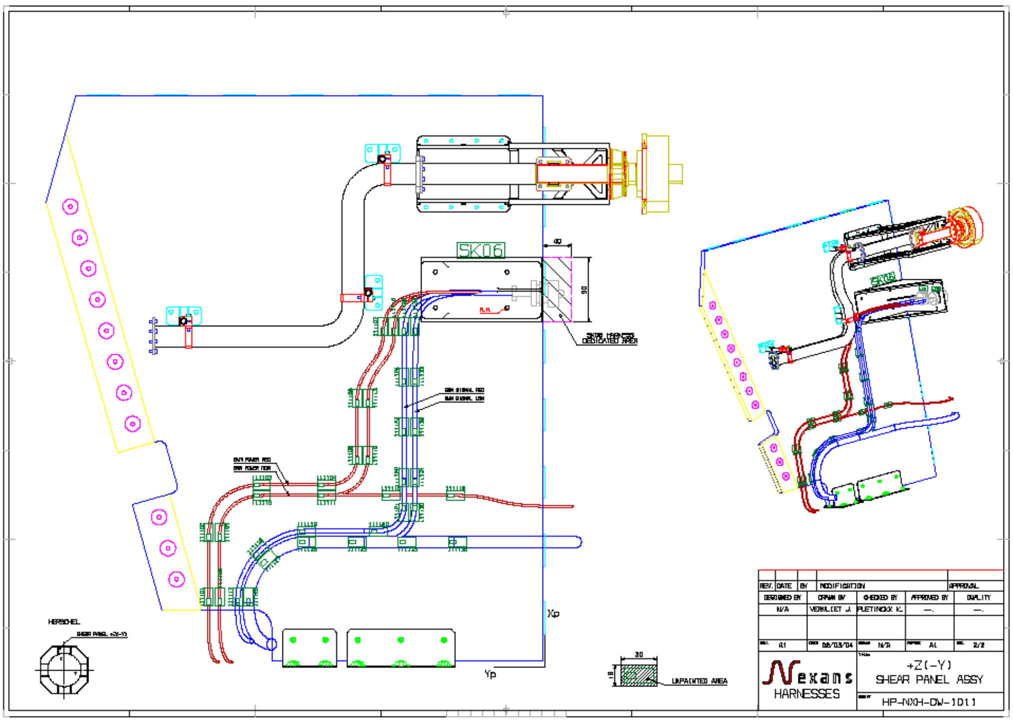
Lower Platform



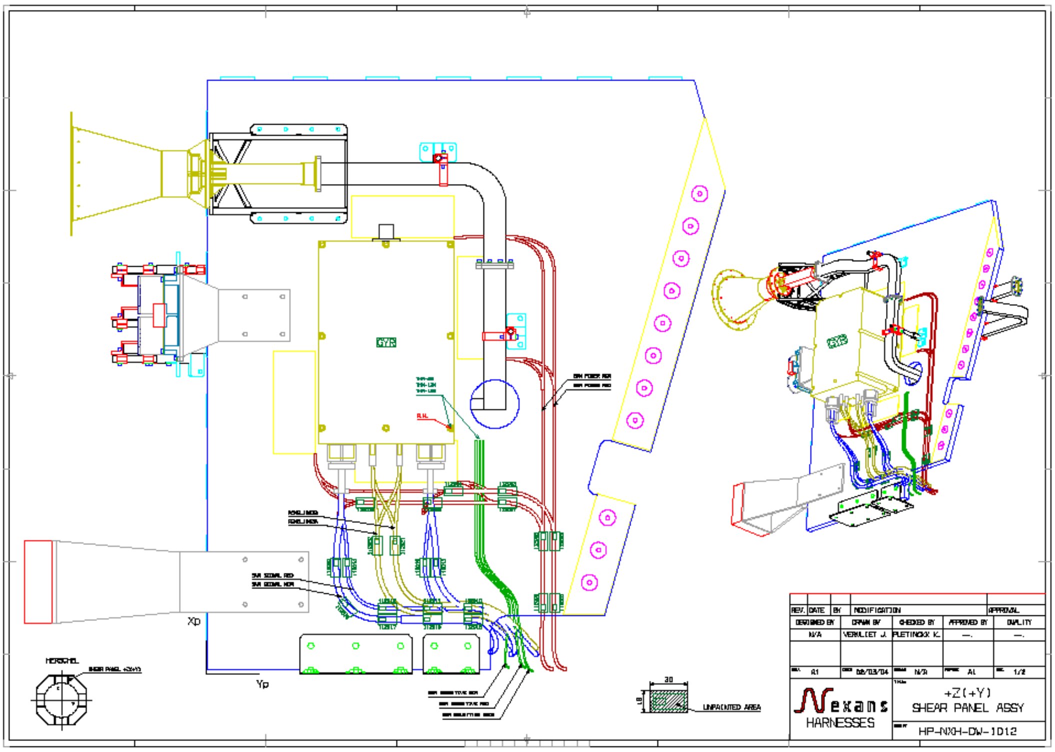
SK05 Detail



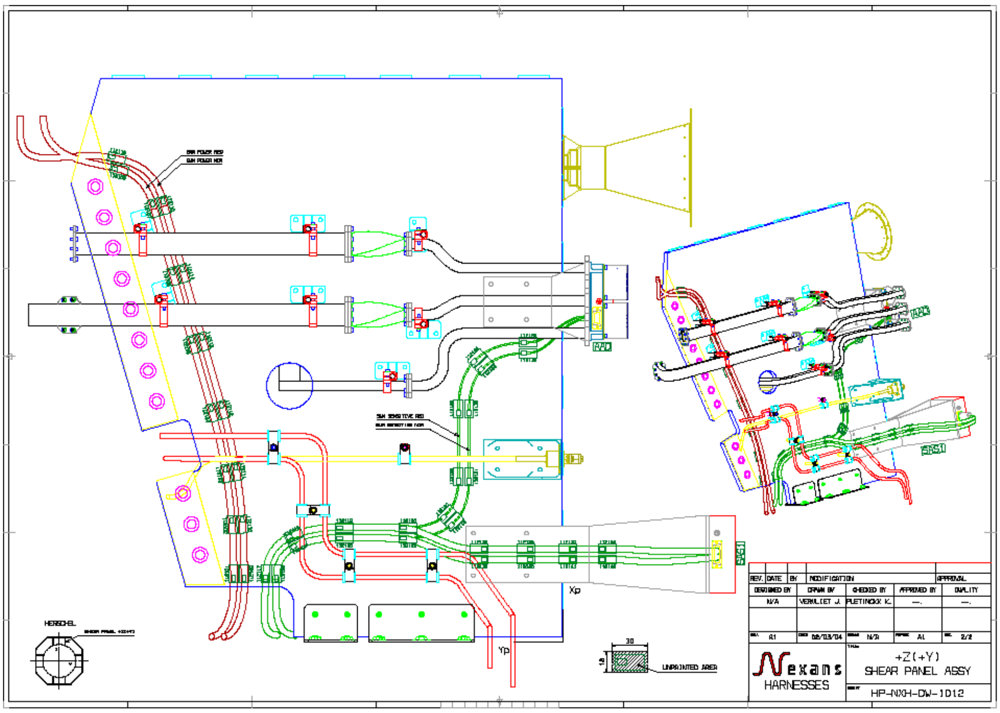
SK06 Detail



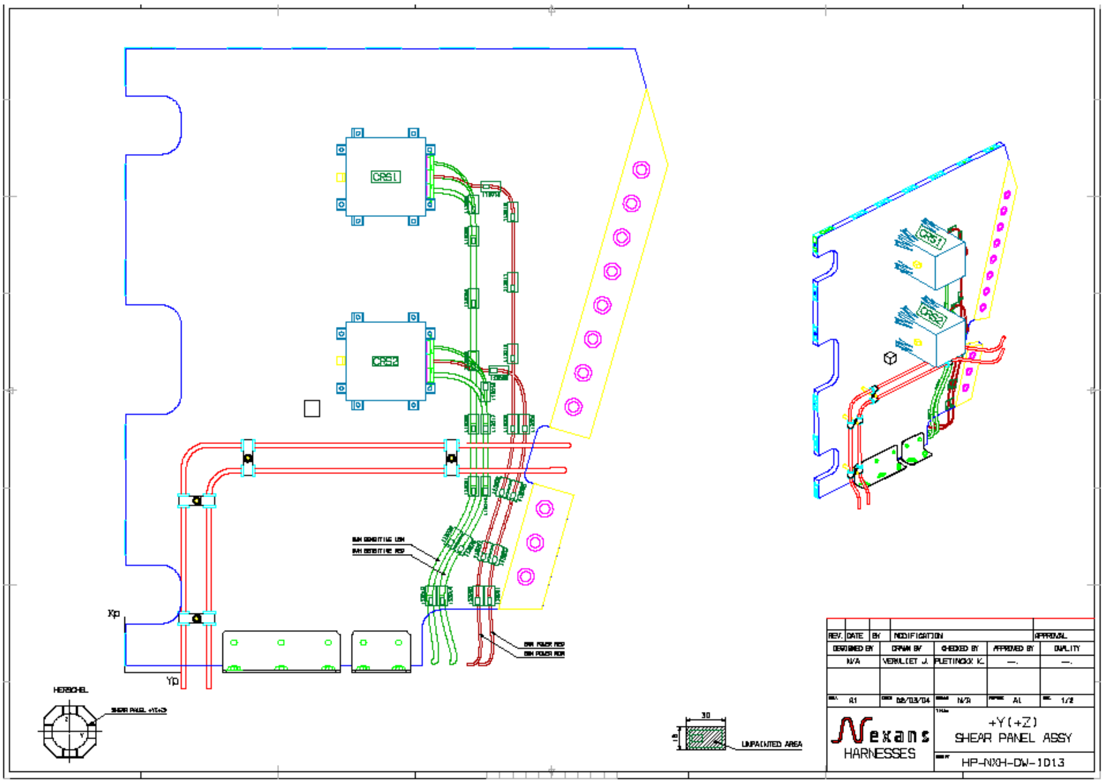
GYR Detail



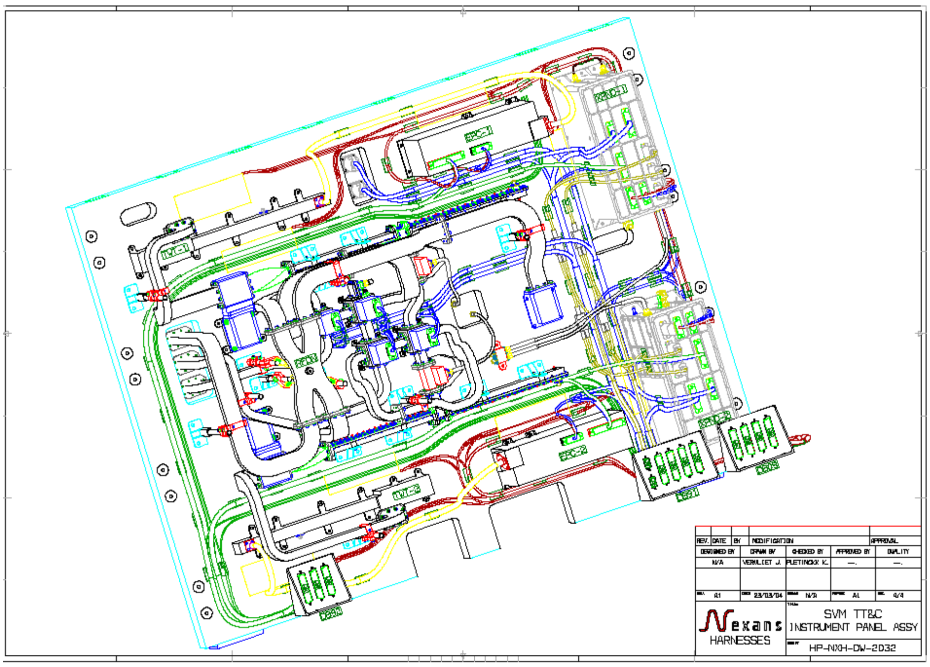
AAD/SA1 Details



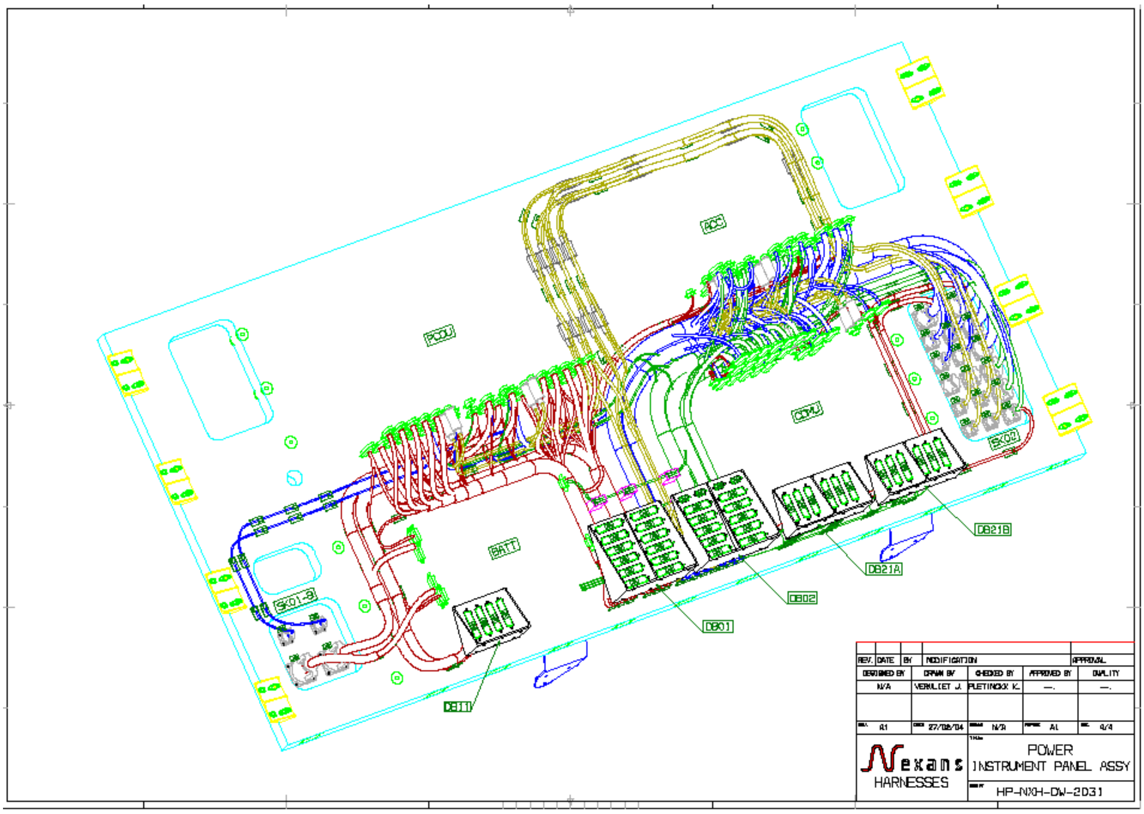
CRS Details



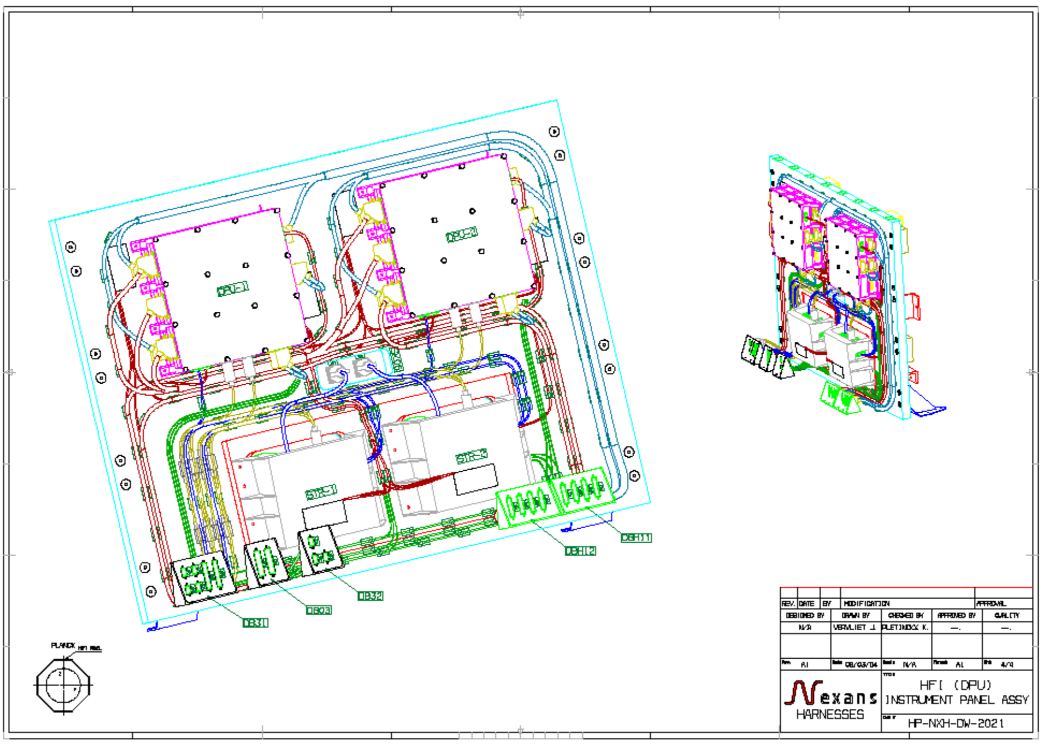
Planck Configuration
TTC Panel



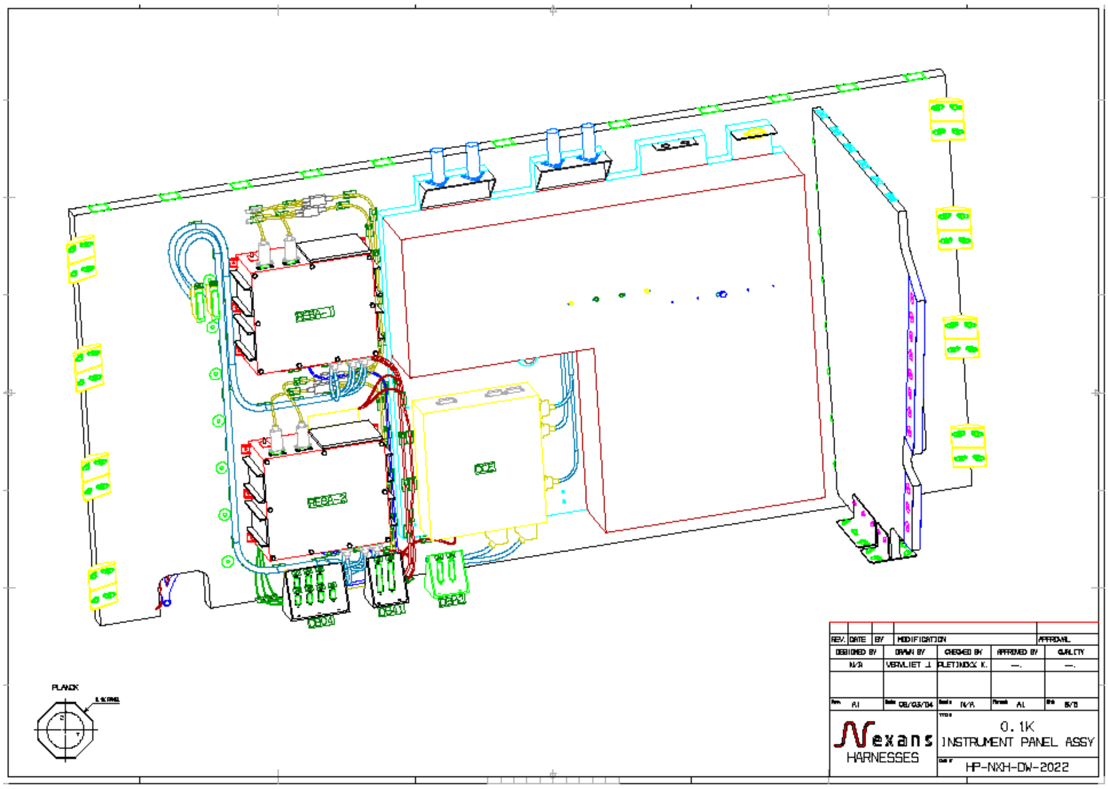
PWR Panel



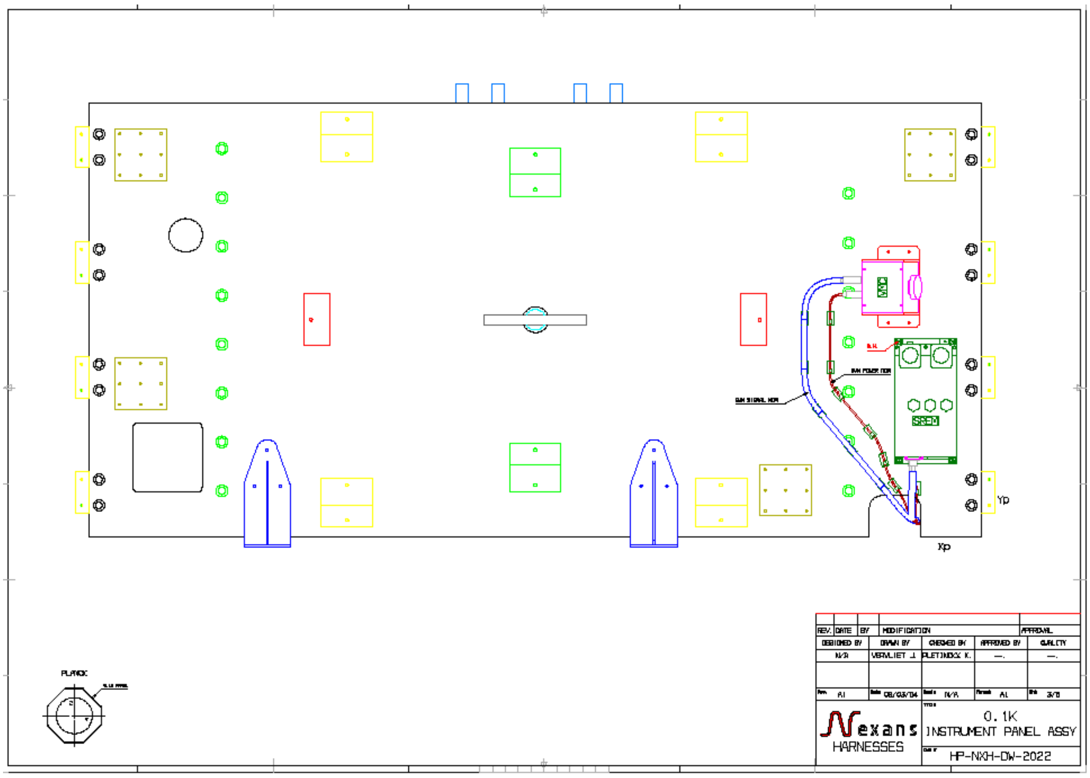
HFI Panel (DPU)



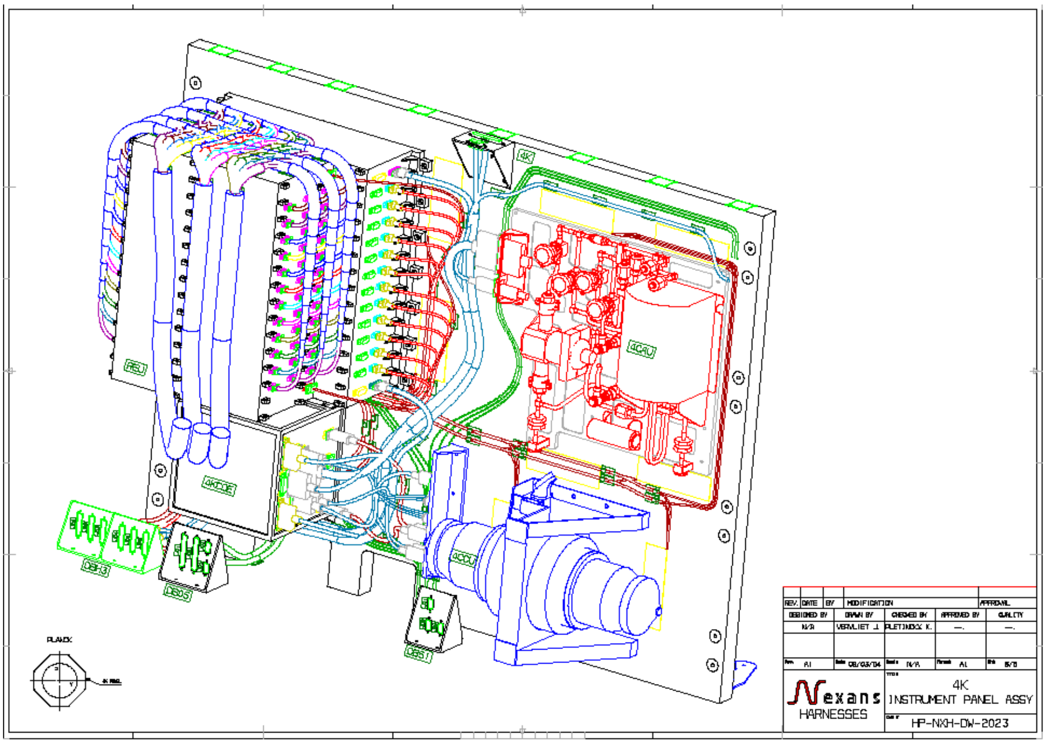
0.1K panel (Internal)



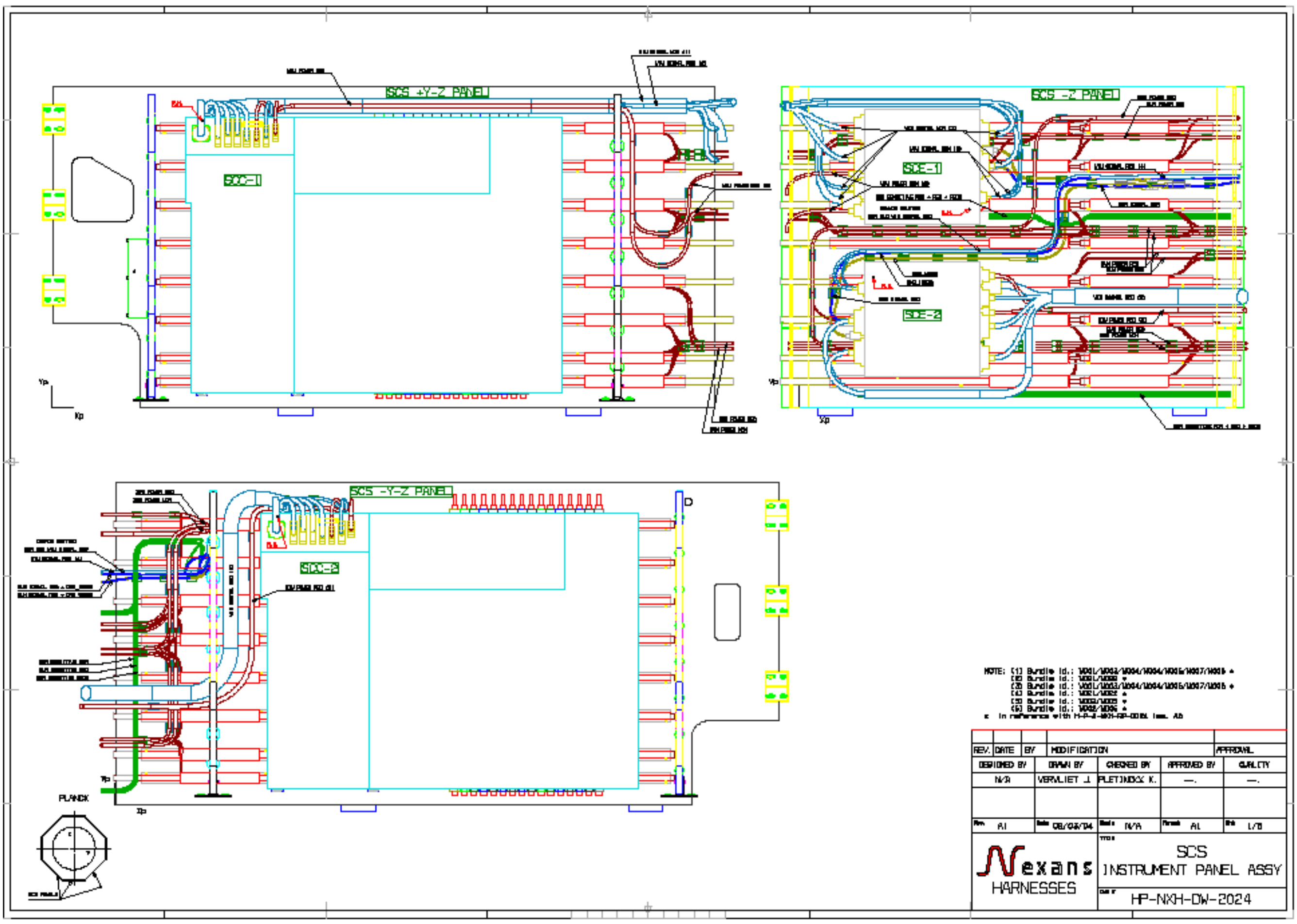
0.1K panel (External)



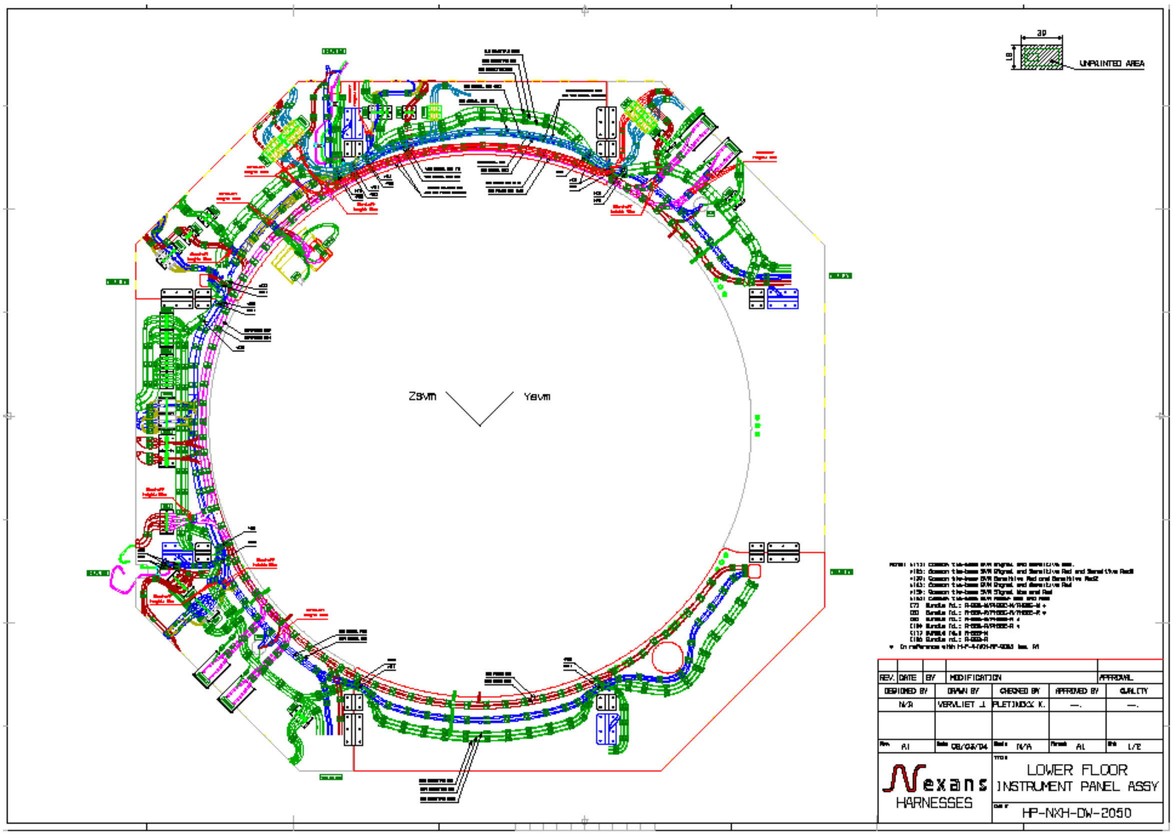
4K Panel



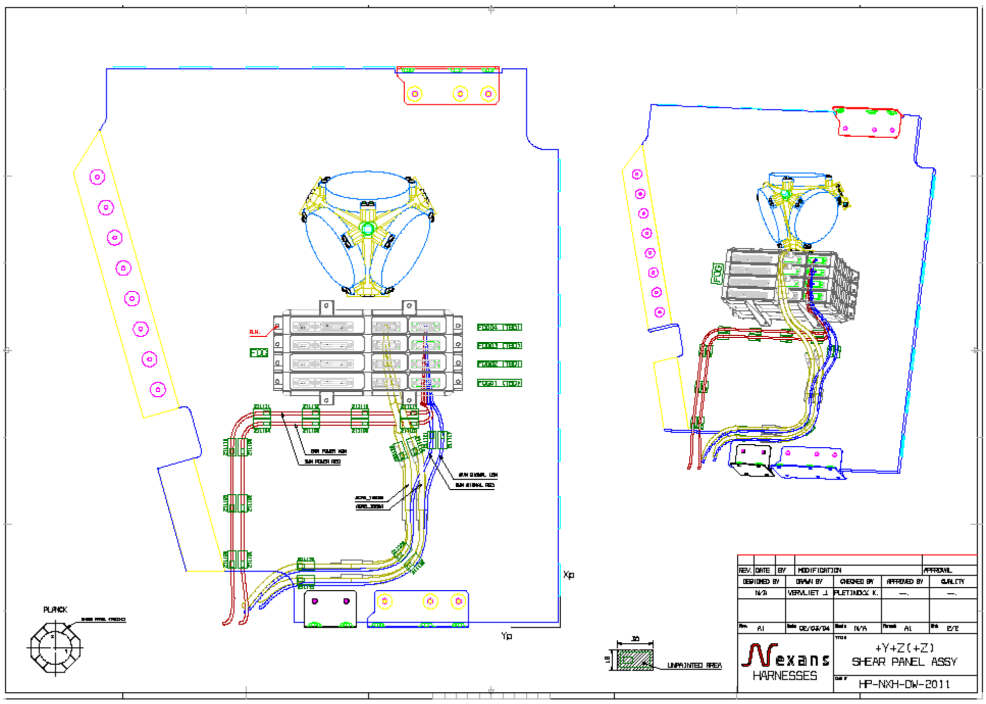
SCS Panels



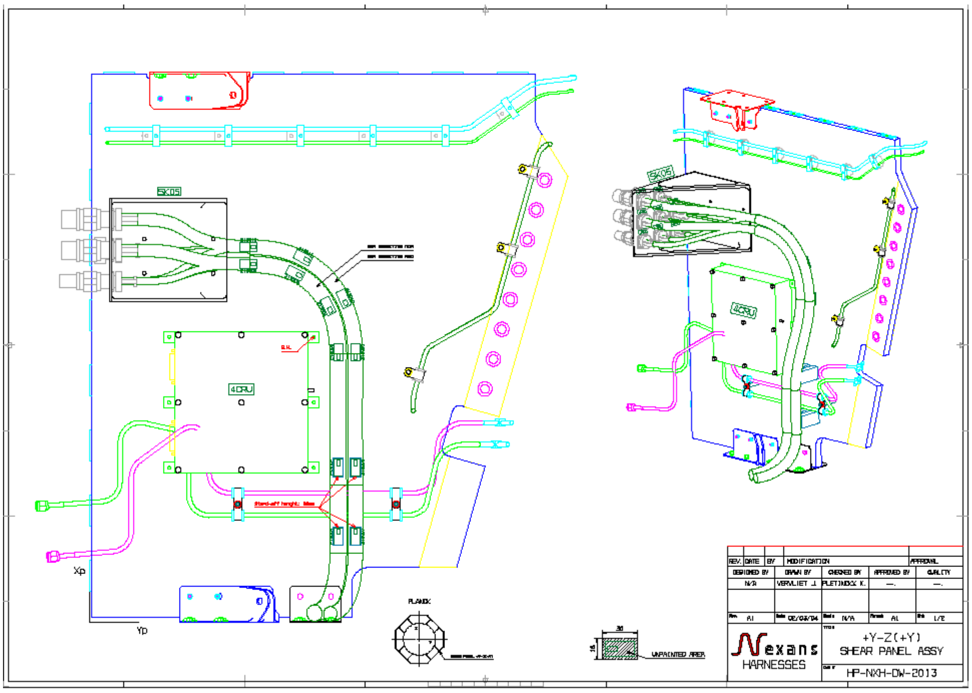
Lower Platform



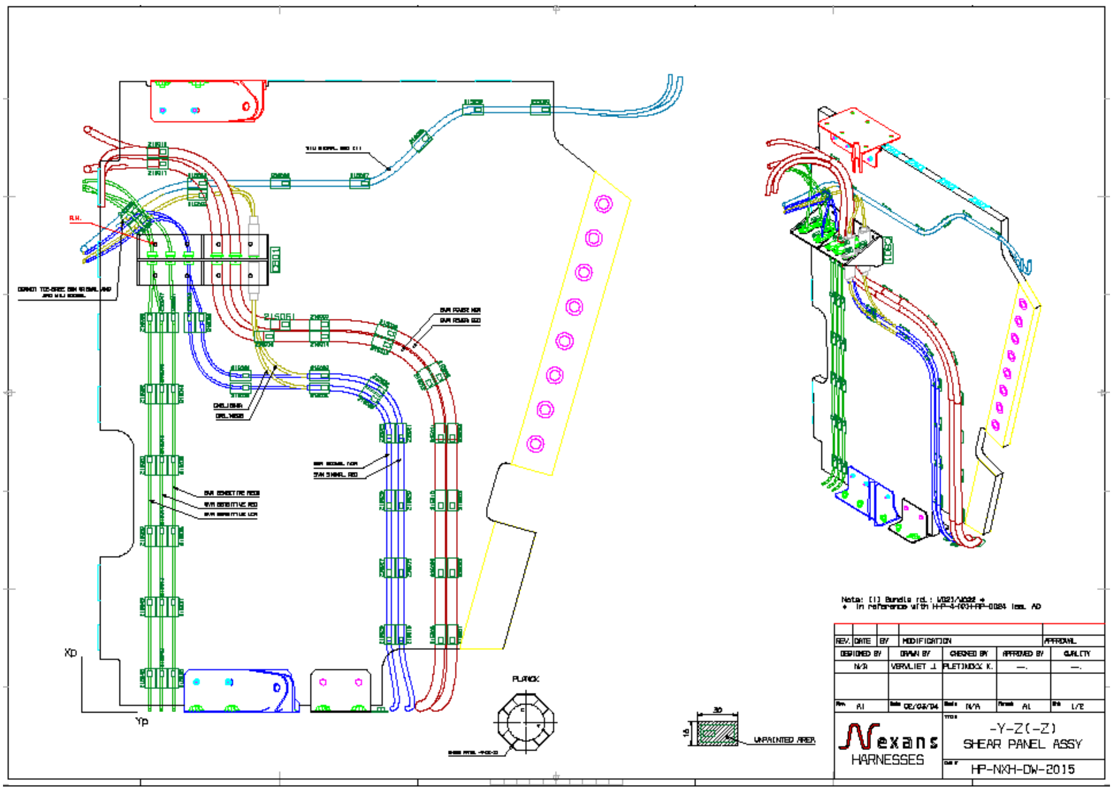
FOG Detail



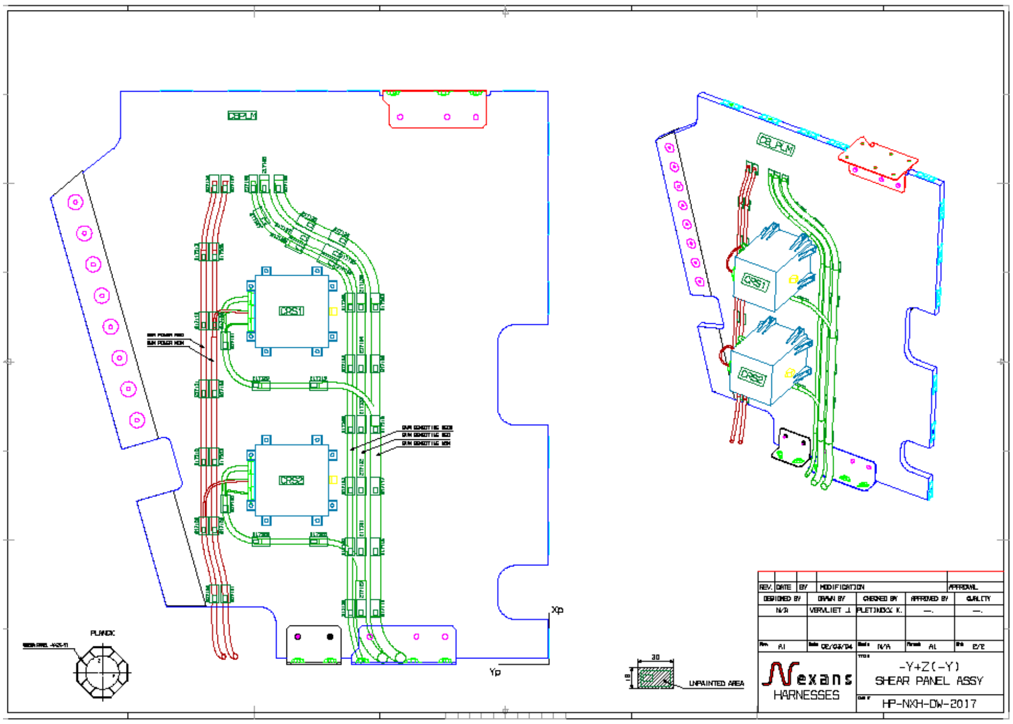
SH05 Details



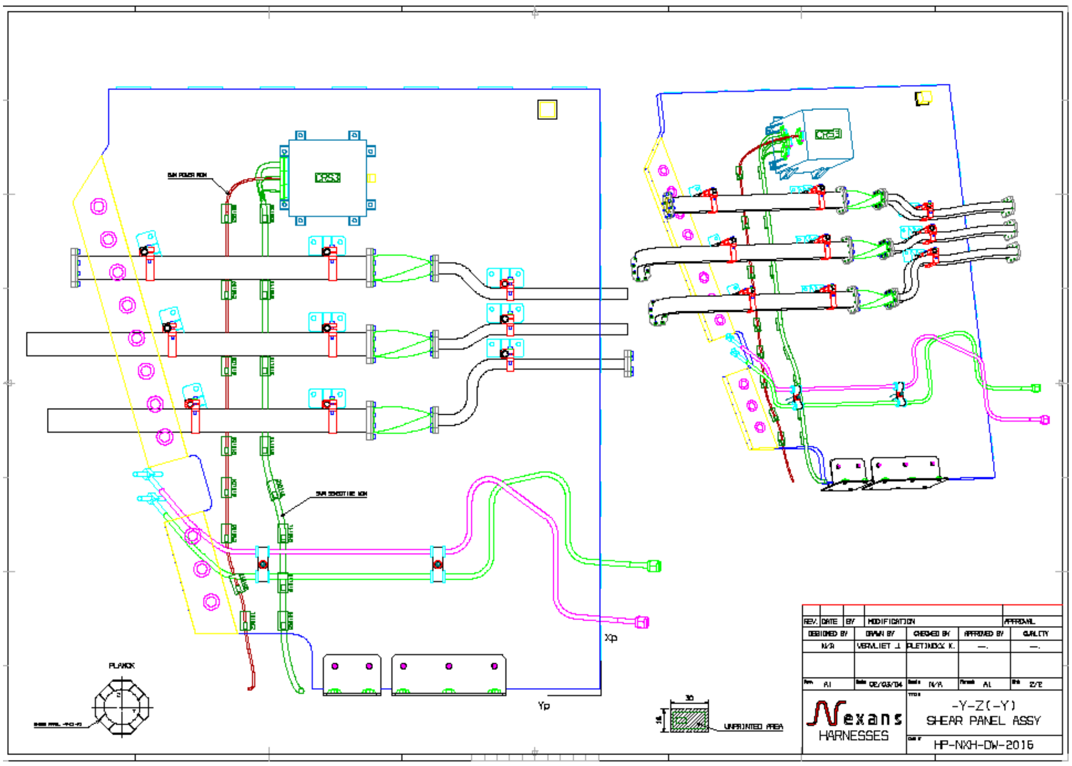
CB01 Details (SCS Panel I/F)



CSR 1/2 Details



CSR 3 Details



9.4.5 Connector Bracket Definition

Herschel
As shown in the drawings the following connector brackets are defined for Dismountability purposes (ref. to [RD-121]):

- DB01 – PWR PANEL Power Nom/Red
- DB02 – PWR PANEL Signal Nom/Red- DMS/ACMS BUS N/R
- DB21A – PWR PANEL Sens Signal N
- DB21B - PWR PANEL Sens Signal R
- DB03 – PACS PANEL Sensitive Nom/Red
- DB31 – PACS PANEL Signal Nom/Red
- DB32 – PACS PANEL Power Nom/Red
- DB04 – SPIRE PANEL Power N/R- Signal & DMS N/R
- DB41 – SPIRE PANEL Sensitive N/R
- DB42 – SPIRE PANEL Sensitive-Signal & Power N/R
- DB05 – HIFI 2 PANEL PWR-Sensitive & DMS BUS N/R
- DB06 – HIFI 1 PANEL PWR N/R
- DB61 – HIFI 1 PANEL Sensitive N/R
- DB07 – ACMS PANEL PWR-Sensitive N/R
- DB71 – ACMS PANEL RWL Interface
- DB09 – TT&C PANEL PWR N/R
- DB91 – TT&C PANEL Signal &DMS N/R
- DB92 – TT&C PANEL Sensitive N/R

- In addition to the above connector brackets a set of Skin connector brackets are foreseen to interface the EGSE during AIT activities. The following are defined :

- SK01-A S.A Interface (PWR Panel)
- SK01-B Battery & PDCU S Interface (PWR Panel)
- SK02 DMS/ACMS Busses- ACC-CDMU-RCS Interface (PWR Panel)
- SK03 TTC Interface (TTC Panel)
- SK04 RWL interface (Lower PLT)
- SK05 ACMS unit interface (Lower PLT-Shear +Z-Y)
- SK06 STR interface (Lower PLT-Shear +Z-Y)

Planck
As shown in the drawings the following connector brackets are defined for Dismountability purposes (ref. to [RD-121]):

- DB01 – PWR PANEL Power Nom/Red
- DB11 – PWR Panel S.A Interface N/R
- DB02 – PWR PANEL Signal Nom/Red- DMS/ACMS BUS N/R
- DB21A – PWR PANEL Sens Signal N
- DB21B - PWR PANEL Sens Signal R
- DB03 – HFI/DPU Panel Power Nom/Red
- DB31 – HFI /DPU Panel Signal-DMS/ACMS Bus N/R
- DB32 – HFI/DPU Panel Sensitive N/R
- DB04 – 0.1K Panel Signal-DMS Bus N/R
- DB41 – 0.1K Panel Power Nom/Red
- DB05 – 4K Panel Power Nom/Red- Sensitive N/R
- DB51 – 4K Panel Sensitive N/R
- CB01 – LFI/SCS Panel Power- Sensitive-Signal-DMS Bus N/R
- DB09 – TT&C PANEL PWR N/R
- DB91 – TT&C PANEL Signal &DMS N/R
- DB92 – TT&C PANEL Sensitive N/R

In addition to the above a set of connector brackets dedicated to the S.A. Interface are defined on the Lower Platform, these brackets are identified :

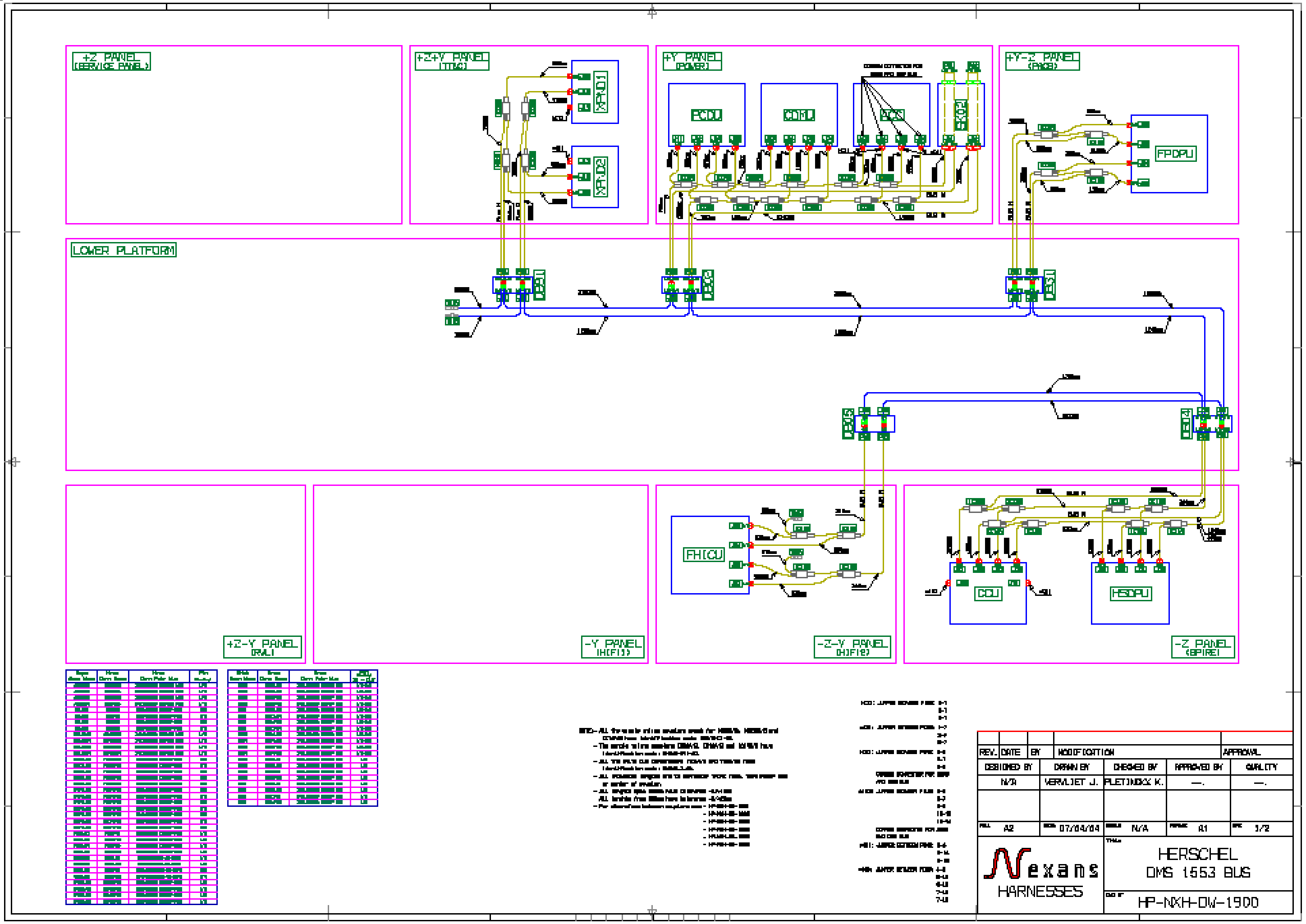
- CB SA11
- CB SA12
- CB SA13
- CB SA14
- CB SA20 (Part of the AAD/SAS units bracket mounted internally to the Cone)

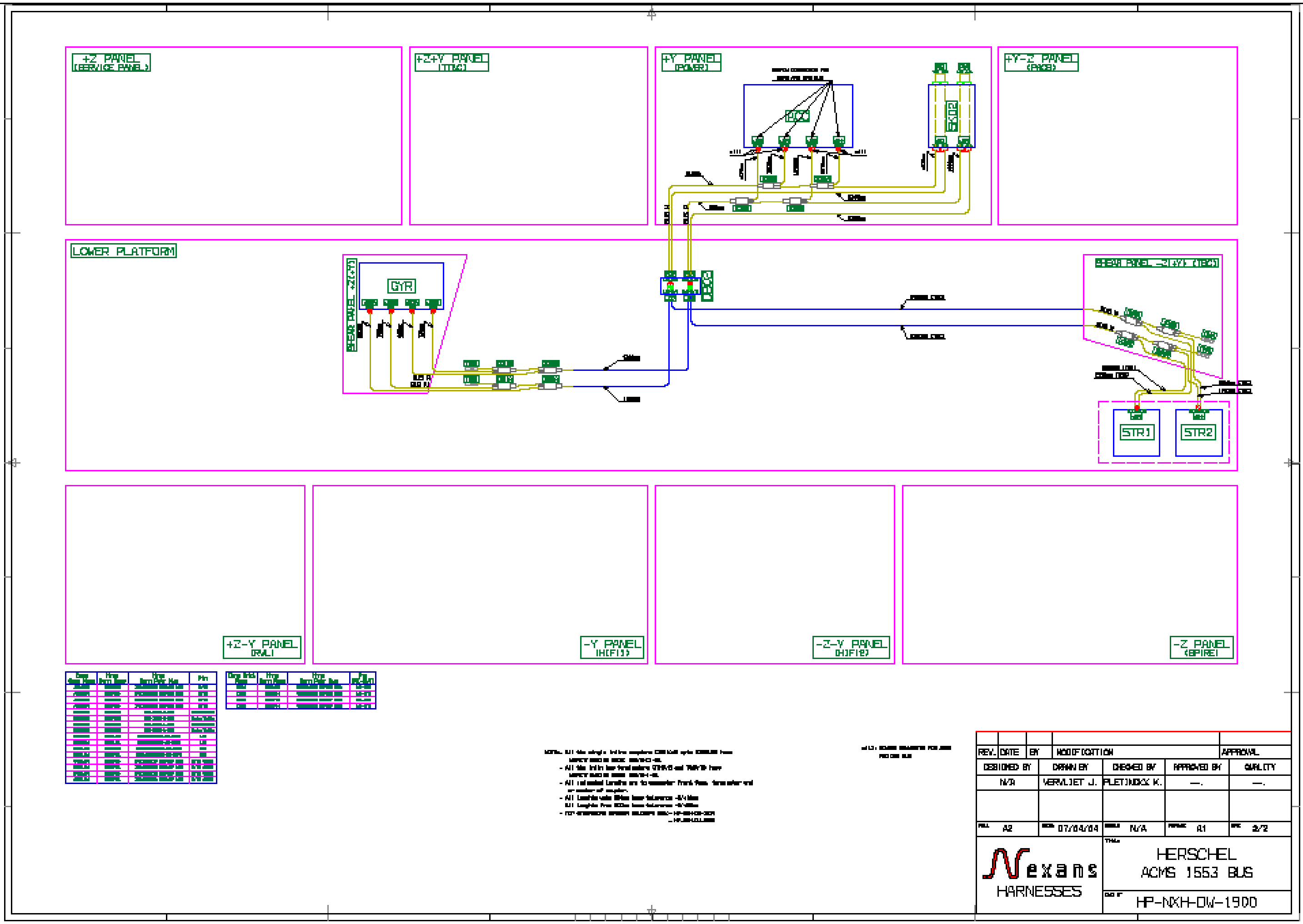
As for Herschel also in the Planck configuration a set of Skin connector brackets are foreseen to interface the EGSE during AIT activities. The following are defined :

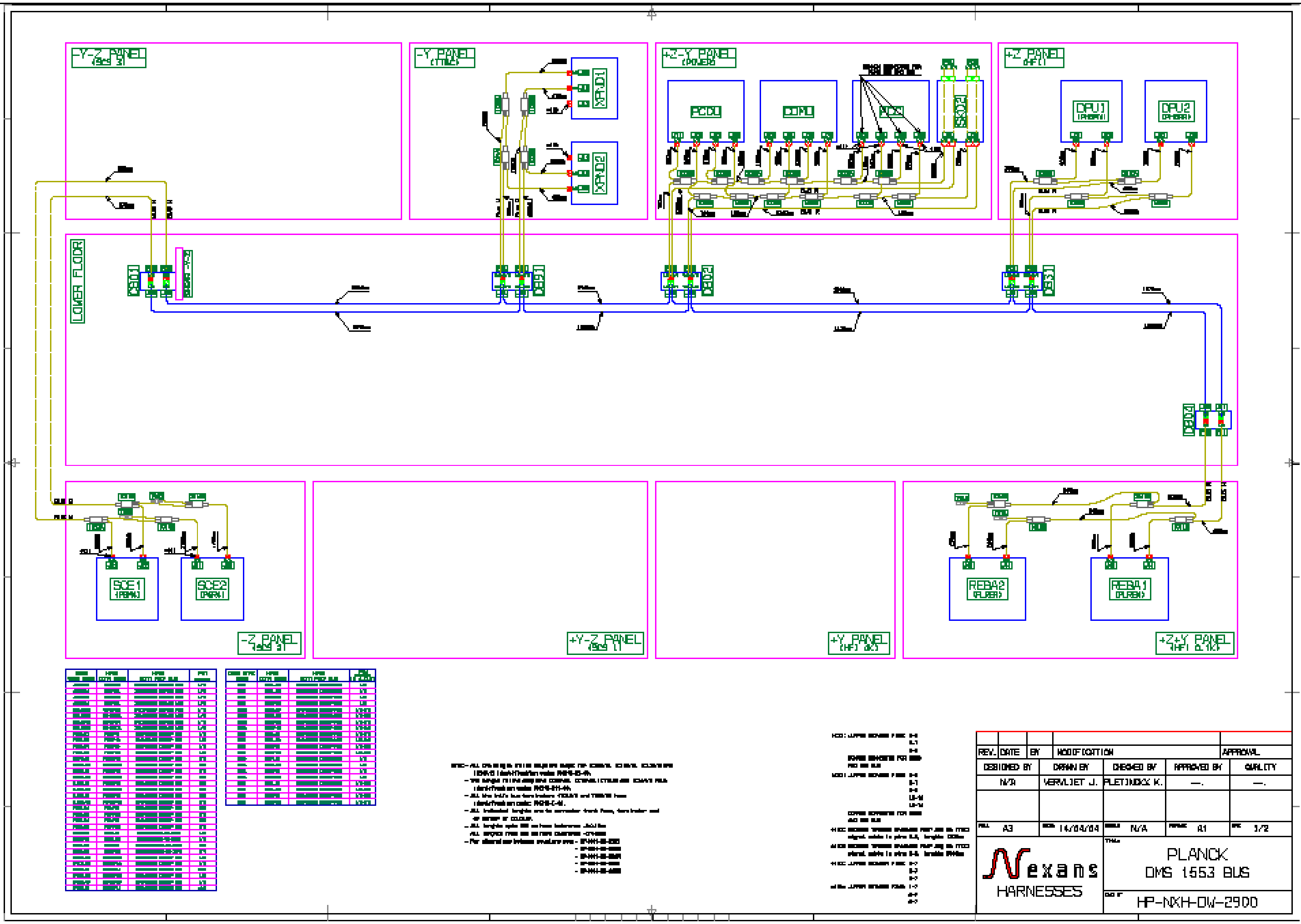
- SK01-B Battery & PDCU S Interface (PWR Panel)
- SK02 DMS/ACMS Busses- ACC-CDMU-RCS Interface (PWR Panel)
- SK03 TTC Interface (TTC Panel)
- SK05 ACMS/FOG unit interface (Lower PLT-Shear +Z-Y)
- SK06 STR interface (HFI/DPU Panel)

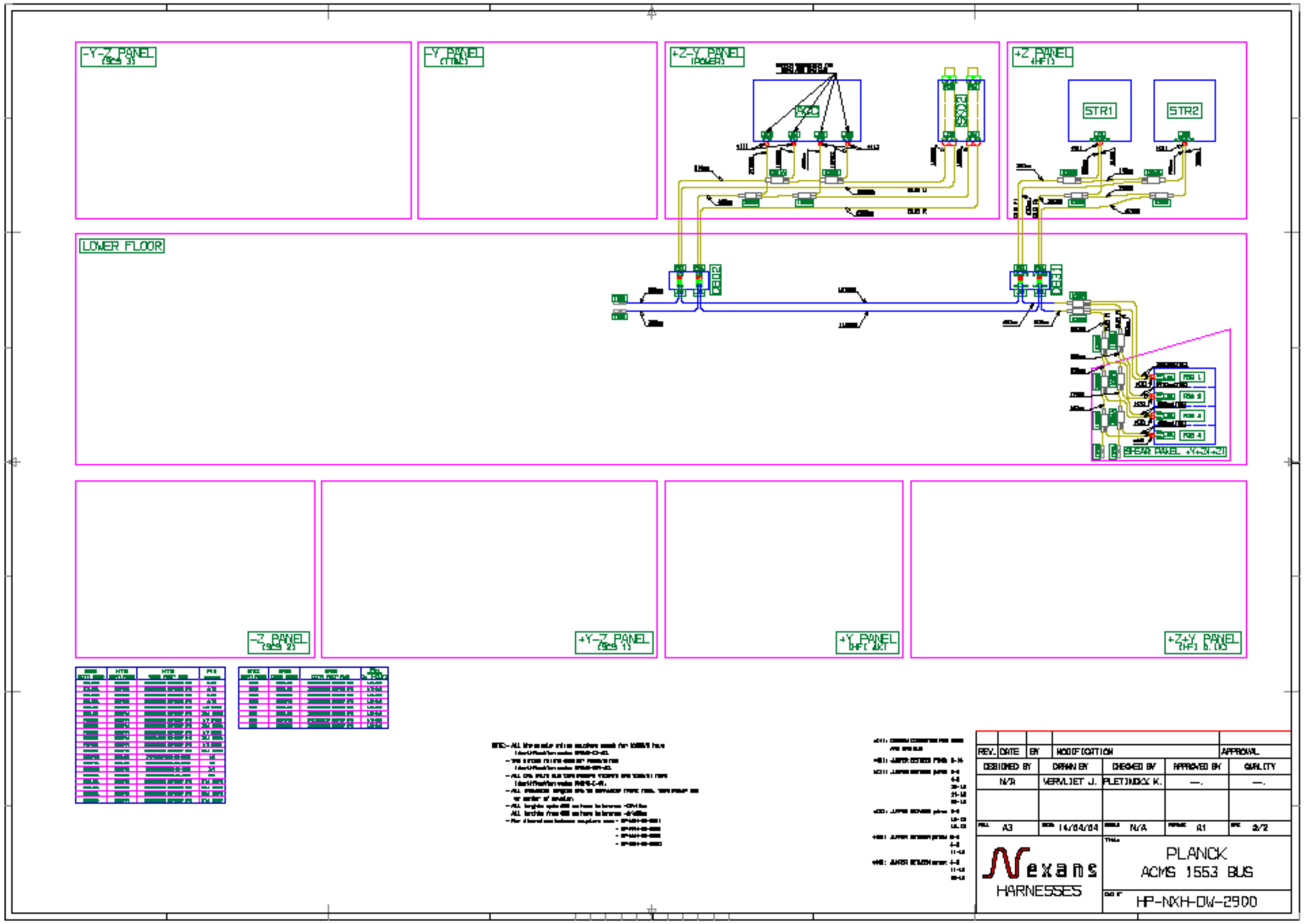
9.4.6 DMS and ACMS MIL 1553 Bus Configuration

The DMS and ACMS MIL 1553 Bus Configuration is reported in the [RD-120]. The interconnection scheme of the two busses are hereunder reported .


+Z PANEL (SERVICE PANEL)
+Z+Y PANEL (TTC)
XPND1
XPND2
+Y PANEL (POWER)
PCDU
CDMU
ACC
+Y-Z PANEL (PACS)
FPDPU
LOWER PLATFORM
+Z-Y PANEL (RVL)
-Y PANEL (HIFI)
-Z-Y PANEL (HIFI2)
FHICU
-Z PANEL (SPIRE)
DCU
HSDPU
REV. DATE BY MODIFICATION APPROVAL
DESIGNED BY DRAWN BY CHECKED BY APPROVED BY QUALITY
N/A VERVLIET J. PLETINCKX K.
A2 07/04/04 N/A A1 1/2
nexans
HARNESSES
HERSCHEL
DMS 1553 BUS
HP-NXH-DW-1900


+Z PANEL (SERVICE PANEL)
+Z+Y PANEL (TTC)
+Y PANEL (POWER)
+Y-Z PANEL (PACE)
LOWER PLATFORM
GYR
STR1
STR2
+Z-Y PANEL (RWL)
-Y PANEL (HIFI)
-Z-Y PANEL (HIFI)
-Z PANEL (SPIRE)
REV. DATE BY MODIFICATION APPROVAL
DESIGNED BY DRAWN BY CHECKED BY APPROVED BY QUALITY
N/A VERVLIET J. PLETINCKX K.
A2 07/04/04 N/A A1 2/2
Nexans HARNESSES
HERSCHEL ACMS 1553 BUS
HP-NXH-DW-1900


-Y-Z PANEL
-Y PANEL
XPND1
XPND2
+Z-Y PANEL
PCDU
CDMU
ACC
SCSD2
+Z PANEL
DPU1
DPU2
LOWER FLOOR
-Z PANEL
SCE1
SCE2
+Y-Z PANEL
+Y PANEL
+Z+Y PANEL
REBA2
REBA1
REV.
DATE
BY
MODIFICATION
APPROVAL
DESIGNED BY
DRAWN BY
CHECKED BY
APPROVED BY
QUALITY
N/A
VERVLIET J.
PLETINCKX K.
A3
14/04/04
N/A
A1
1/2
Nexans
HARNESSES
PLANCK
DMS 1553 BUS
HP-NXH-DW-2900



The detailed routing of the busses is shown in the [RD120].

9.4.7 Commonality Assessment

The Herschel/Planck SVM harness will be conceived to reach to the maximum extent commonality between the two projects.
Only the TTC panel can be considered common to the two configuration.
On the other panels (PWR and WU) and on the Lower Platform the differences between the Herschel and Planck architecture, connectivity and equipment location the commonality (especially on routing design) cannot be achieved.
Materials, materials and design methods will however be common.
The following table summarizes the commonality between the Herschel and Planck on the harness design.

FUNCTION	EQUIPMENT	LEVEL OF COMMONALITY
Launcher Interface	Umbilical Connector	The interface with the Launcher are same connector type but placed on different location with respect to the reference frame
EGSE Interface	Skin Connectors	Commonality not fully achievable. Skin connectors accessible from EGSE when the panel are closed are placed on the same panel . Location of this Skin interface are also optimised with respect to the unit location specific of each configuration. The relevant routing on is not common.
Power	Power Conditioning and Distribution Unit	Both Planck and Herschel will use the same PCDU (same connector) but some outputs are not connected to the same users. Different routing is expected on the relevant panel . Minor difference on materials
	Solar Array Interface	Due to the different SA location on the two S/C the relevant harness to the PCDU on Power panel as well as on Lower PLT shall be completely different.
	Battery	Full commonality on material and routing can be achievable.
CDMS	CDMU	Both Planck and Herschel will use the same PCDU (same connector) but some I/O lines are not connected to the same users. Minor Differences on routing and wiring arrangement are expected. Minor difference on materials for cables has to be considered
AOCS	ACC	Both Planck and Herschel will use the same ACC (same connector) but some I/O lines are not connected to the same users on Planck due to the reduced s/s configuration. Minor differences on routing and wiring arrangement are expected. Minor difference on materials for cables has to be considered
	RWL	Equipment used only in Herschel design.
	STR	Equipment used on both S/C but located on different place. Routing is not common
	GYR	Equipment used only in Herschel design.
	SAS	Equipment used on both S/C but located on different place. Routing on Lower Platform is not common
	CRS	Equipment used on both S/C but located on different place. Routing is not common (also only 2 units (CRS1/2) are on Herschel, while one additional unit is used on Planck design.
	AAD	Equipment used on both S/C but located on different place. Routing is not common
	SREM	Equipment used on both S/C but located on different place. Routing is not common
	VCM	Equipment used only in Herschel design.
	FOG	Equipment used only in Planck design.
TTC	All equipment	Commonality on routing can be achievable on relevant panels.
Thermal Control	Heaters/ Thermistors	Full dedicated set of harness connecting the TCS items specific for Herschel and Plack design.
RCS	All equipment	Full dedicated set of harness connecting the RCS items specific for Herschel and Plack design.

9.4.8 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 are those available and presented at the time of SVM Harness PDR review and today available from the harness supplier as defined in the [RD-119].
The achieved mass figures are reported in the following tables for Herschel and Planck.

Herschel Weight

5.1.1 Harness weight : Cables Identification n Mass (gr.)
PWR Hrns 8430
SIGN Hrns 13010
SENS Hrns 12170

5.1.2 Harness weight : Connectors Identification Mass (gr.)
Connectors 7969
Contact weight not included

5.1.3 Harness weight : Mounting accessories Identification Mass (gr.)
Tie-bases 1796
Stand-off's and Tie-raps not included.

5.1.4 Harness weight : Brackets Identification Mass (gr.)
Brackets 6378

5.1.5 Harness weight : TOTAL Identification Mass (gr.)

SVM HARNESS 49753

Remarks:
- Grounding rail not included
- Contacts not included
- Bracket weights based on current preliminary design
- Tie-raps not included
- Bundle weight base on density, not on actual wires

Planck Weight

5.2.1 Harness weight : Cables Identification Mass (gr.)
PWR Hrns 10460
SIGN Hrns 10415
SENS Hrns 12560

5.2.2 Harness weight : Connectors Identification Mass (gr.)
Connectors 7499
(Contact weight not included)

5.2.3 Harness weight : Mounting accessories Identification Mass (gr.)
Tie-bases 1530
(Stand-off's and Tie-raps not included)

5.2.4 Harness weight : Brackets Identification Mass (gr.)
Brackets 5420

5.2.5 Harness weight : TOTAL Identification Mass (gr.)

SVM HARNESS 47884

Remarks:
- Grounding rail not included
- Contacts not included
- Bracket weights based on current preliminary design
- Tie-raps not included
- Bundle weight base on density, not on actual wires
- Inline couplers not included

9.5 ACMS

This chapter describe the major ACM Subsystem and/or Equipment design. They are procured on the basis of the hereafter listed specification (included in the CDR data Package).

Attitude Control and Measurement Subsystem Requirement Spec.	H-P-SP-AI-0011	5 [RD-56]
ACMS Parameter Database	H-P-SP-AI-0039	3 [RD-48]
ACC hardware requirement specification	H-P-SP-AI-0008	5 [RD-55]
Herschel-Plank ACMS Star Tracker Requirements Spec	H-P-4-DS-SP-0015	3,1
Gyroscope Assembly Req. Spec.	H-P-4-DS-SP-0016	2
Reaction Wheel Req. Spec.	H-P-4-DS-SP-0014	3,1
Sun Acquisition Sensor Spec.	H-P-4-SEN-SP-0003	3
AAD Unit Spec.	H-P-4-SEN-SP-0001	3,1
Coarse Rate Sensor Assy Spec.	H-P-4-SEN-SP-0002	2,2
ACMS ACC Application SW Req. Spec.	H-P-4-DS-SP-018	3,1
HERSCHEL RWS controller req.spec of the RWS controller	H-P-4-ANA-SP-001	3,2

The major modification occurred from the PDR (June 2002) are hereafter briefly listed. Any details on the improved design with respect to the one presented at the PDR can be found in the applicable design report at Subsystem and/or Equipment level:

- Path planner modification to prevent possible attitude domain violation during slew execution
- Introduction of Star Tracker interlacing feature at equipment level and relevant handling at subsystem level to increase attitude determination accuracy
- Increased complexity of FDIR through introduction of specific unit crosschecks.
- Modification of Herschel design to allow attitude propagation in case of temporary unavailability of Gyro or Star Tracker data.
- Introduction of handling of launcher-induced sun eclipse after separation on Planck
- Introduction of enable/disable of checks on received commands
- Switching-off of ACMS equipment not used in the sun-acquisition and survival modes.
- Introduction of write-protection mechanism for ACC-RM registers
- Introduction of direct RCS latch-valve control through ACC-CPDU commands
- Modification of the separation logic with the implementation of three independent RCS firing barriers up to separation.
- Introduction of alternative sun acquisition strategies on Planck to allow the use of two different sets of rate anomaly thresholds
- Modification of Planck ACC CRS interface to increase the range of rate measurements allowing attitude recovery starting from non-nominal conditions.

The "*ACMS Design Report*" (H-P-4-DS-TN-011) produced by the subcontractors and the technical note titled "*ACMS FDIR Issues*" (HP-TN-AI-0035) are included as part of SVM CDR data package to cover the following aspects:

- ACMS Configuration
- FDIR Design
- Functional Design
- Control Design
- Operations Design
- External Interfaces
- Resource Budgets

The above mentioned points are summarized from the referenced document in the following chapters.

In addition to what is presented in the above mentioned documents, some drawings and references to other documents are provided:

- The power control and monitoring interfaces for the ACMS units are presented in Figure ACMS-01 for Herschel and ACMS-02 for Planck. The drawings have been extracted from "*ACMS internal ICD*" (H-P-4-DS-IC-007).
- Functional block diagrams provided in Figure ACMS-03 for Herschel and ACMS-04 for Planck show the ACMS subsystem internal data interfaces between the ACC and the ACMS sensors/actuators. The drawings have been extracted from "*ACMS internal ICD*" (H-P-4-DS-IC-007).
- The ACMS external interface towards the RCS is presented in Figure ACMS-05 for Herschel and in Figure ACMS-06 for Planck. For the functional description of the interface between ACMS and the RCS refers to the document "*Guide for RCS interfaces for ACMS users*" (H-P-TN-AI-0089)
- The ACMS external interfaces with CDMU and PCDU not described in the figures are available in the document "*SVM Electrical ICD*" (H-P-IC-AI-0003).
- The control logic of the Herschel Subsystem is described in the documents "*Herschel RWS Controller Design Report*" (H-P-ANA-TN-005) and "*Control report RCS*" (H-P-4-DS-TN-027). The equivalent description for Planck is provided in the annexes included in the "*ACMS Design Report*" (H-P-4-DS-TN-011), whereas the attitude determination algorithm are documented in "*Planck Attitude Determination Algorithms Description*" (H-P-4-SEN-TN-0002)
- The Herschel and Planck modes and mode-transition logic are presented in "ACMS Design Report" (H-P-4-DS-TN-011) and summarized in following chapters.

The ACMS design and development concept has been identified in the frame of the subsystem specification and has been presented for the CDR of the ACMS subcontractor in the document "*ACMS DD&Q*" (H-P-4-DS-PL-002).

The ACMS verification approach for the various disciplines is described in the following documents issued by the subcontractor for the Subsystem CDR:

- *FDIR verification plan* (H-P-4-DS-PL-015)
- *SE Verification plan* (H-P-4-DS-PL-016)
- *Verification Plan PA* (H-P-4-DS-PL-018)
- *Electrical Verification Plan* (H-P-4-DS-PL-019)
- *RAMS verification plan* (H-P-4-DS-PL-020)
- *Verification Plan Func Design Eng* (H-P-4-DS-PL-023)
- *Verification Plan OPS* (H-P-4-DS-PL-024)
- *Verification Plan for ACMS Unit Communication* (H-P-4-DS-PL-025)
- *Verification Plan Sim Model Val* (H-P-4-DS-PL-026)
- *Verification PLan for Control Design Herschel* (H-P-4-DS-PL-021)
- *Verification Plan Herschel Signature Test* (H-P-4-DS-PL-022)
- *Verification Plan for Control Design Planck* (H-P-4-SEN-PL-007)
- *Verification Plan for Planck Signature Tests* (H-P-4-SEN-PL-008)

The ACMS verification is defined with respect to the "*ACMS Implementation Spec*" (H-P-4-DS-SP-0013) and the "*Requirement verification responsibility allocation*" (H-P-4-DS-PL-0014). These documents identify various verification levels to be defined by different parties and to be executed in different set-ups. In fact, in addition to the typical case where the verification plans are defined by the ACMS subcontractor and tests are performed at subsystem level, some requirements are covered by test defined by the SVM responsible and performed at subsystem level. For this reason a verification plan has to be prepared by the SVM responsible to cover aspects such as the detection of attitude control failures, the ACMS/RCS initialization and reconfiguration during the transition to and from Survival Mode. Inputs for this verification plan are available in "*ACMS FDIR Issues*" (H-P-TN-AI-0035) where the design of the ACMS initialization, reaction to separation, and reconfiguration is presented. Furthermore the AVM test environment is selected to complete the verification of ACMS requirements involving the interfaces with PCDU and CDMU.

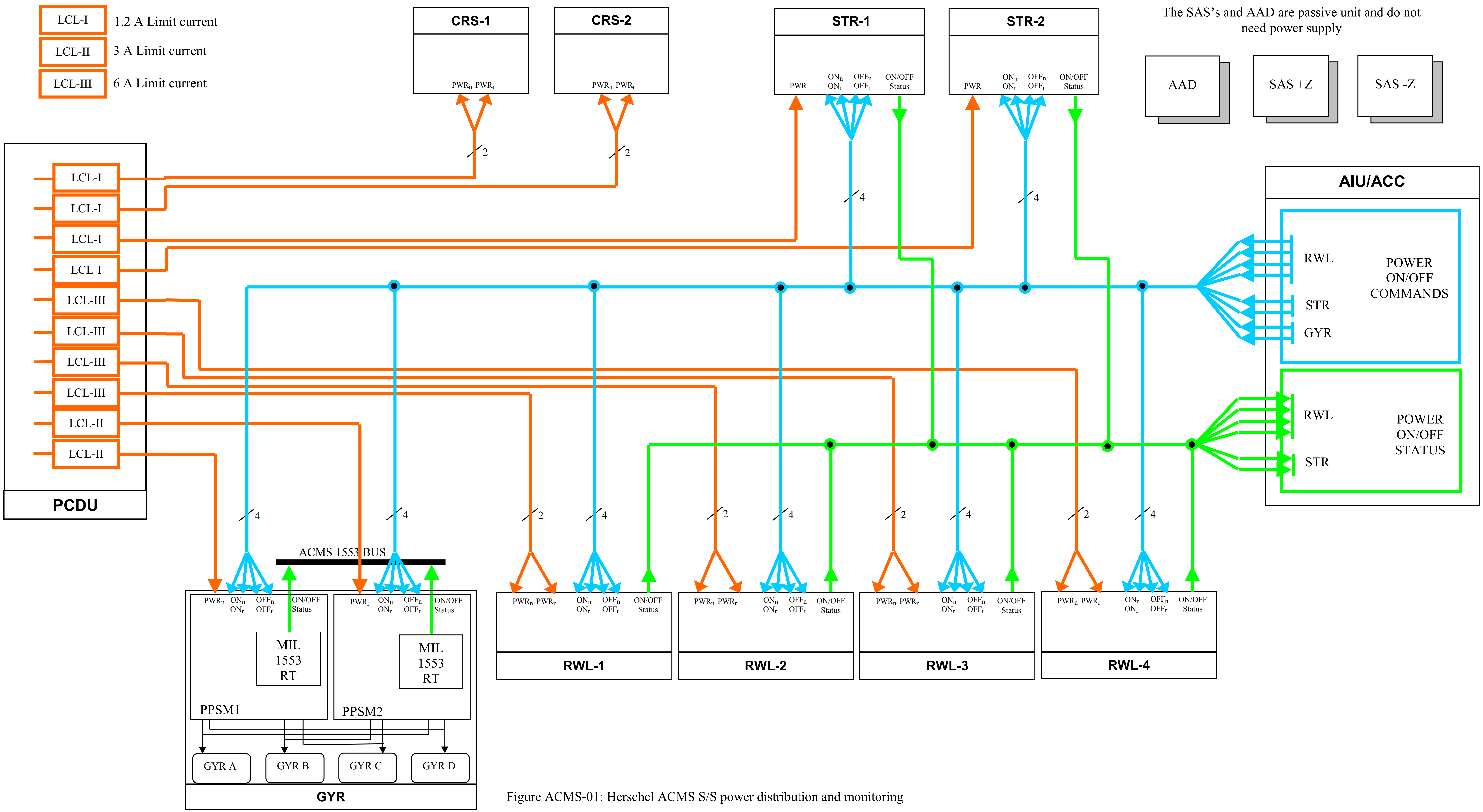


Figure ACMS-01: Herschel ACMS S/S power distribution and monitoring

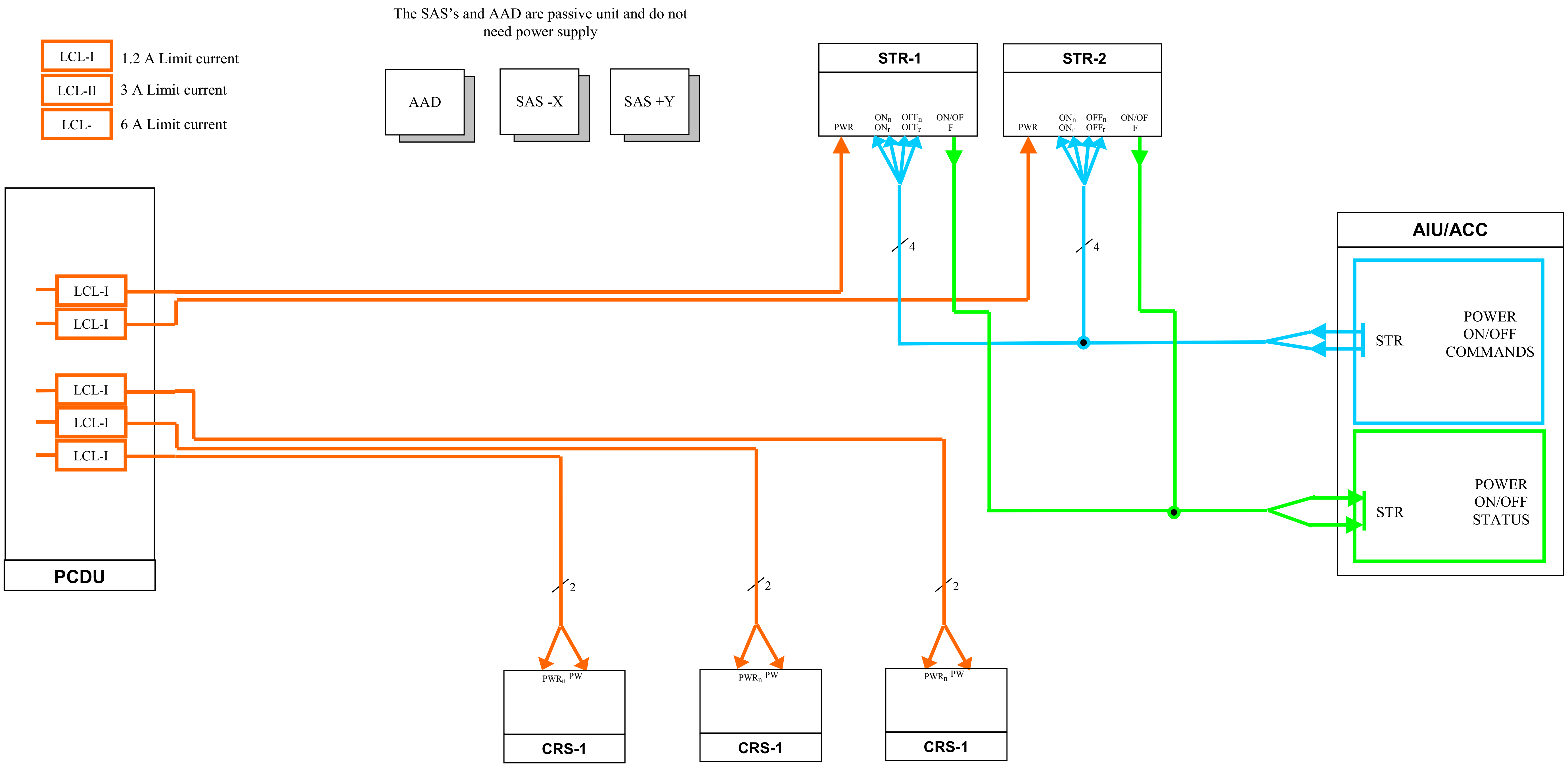


Figure ACMS-02: Planck ACMS S/S power distribution and monitoring

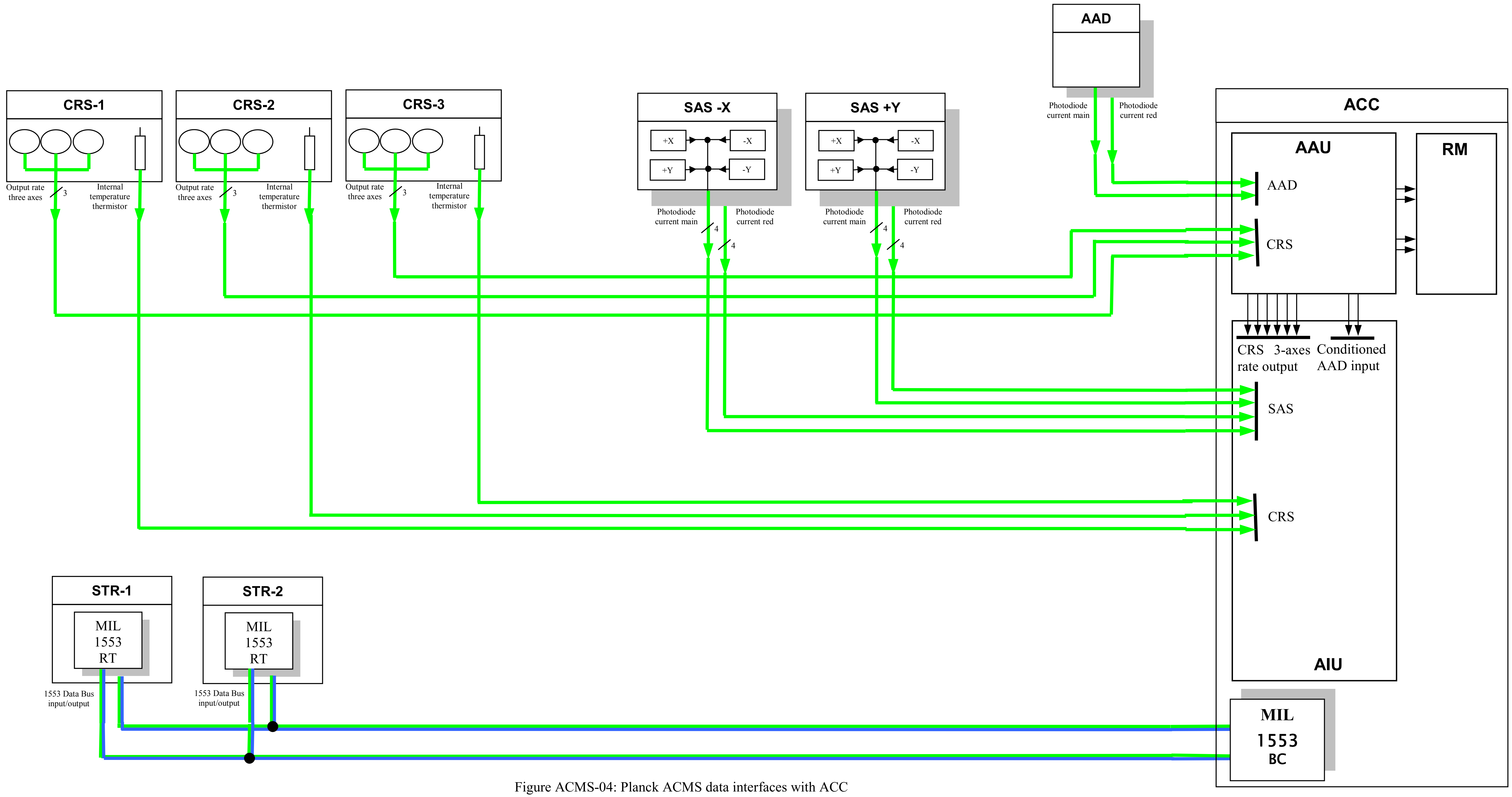
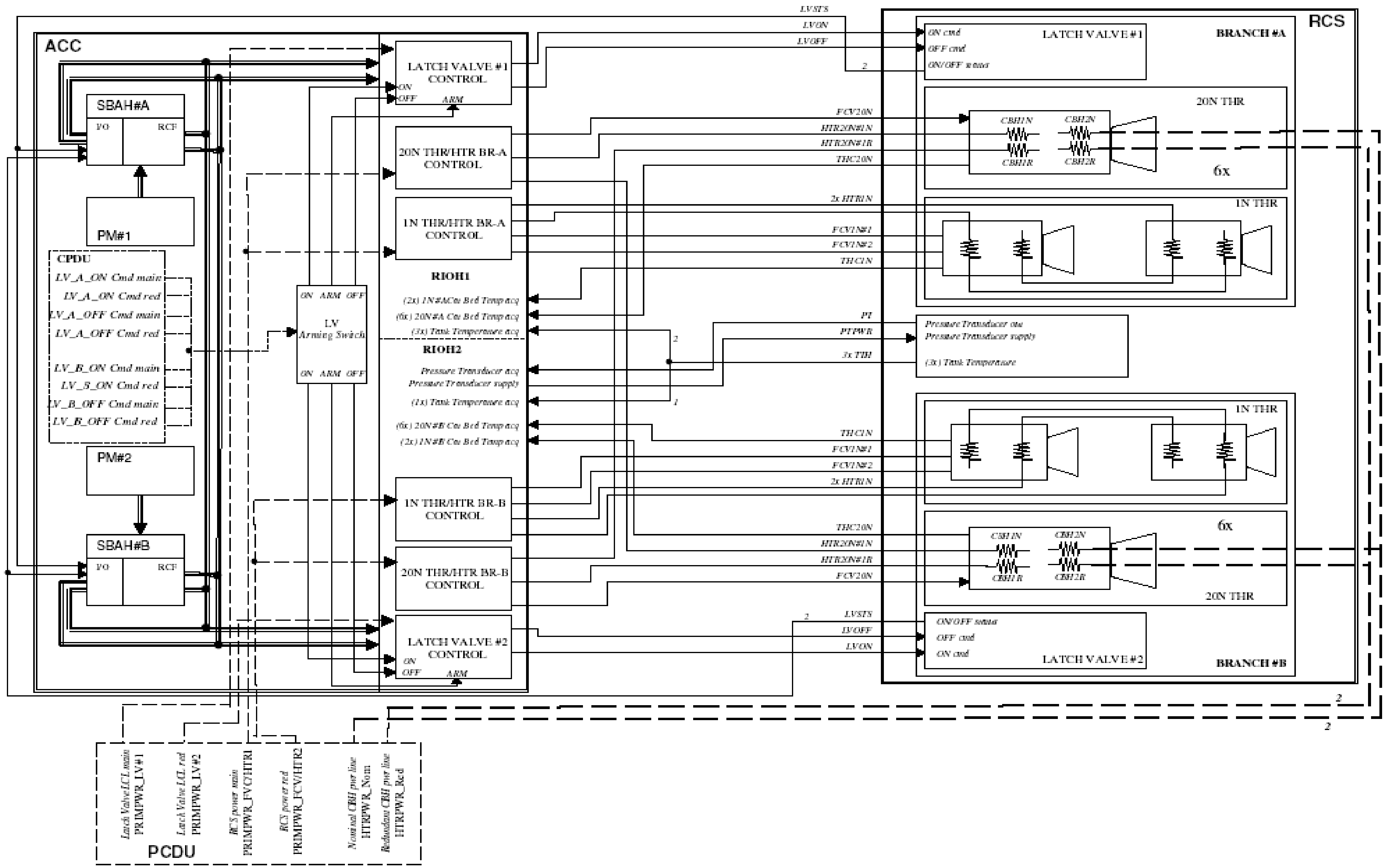


Figure ACMS-04: Planck ACMS data interfaces with ACC


ACC
RCS
SBAH#A
SBAH#B
PM#1
PM#2
CPDU
LV_A_ON Cmd main
LV_A_ON Cmd red
LV_A_OFF Cmd main
LV_A_OFF Cmd red
LV_B_ON Cmd main
LV_B_ON Cmd red
LV_B_OFF Cmd main
LV_B_OFF Cmd red
LV Arming Switch
LATCH VALVE #1 CONTROL
20N THR/HTR BR-A CONTROL
1N THR/HTR BR-A CONTROL
RIOH1
RIOH2
1N THR/HTR BR-B CONTROL
20N THR/HTR BR-B CONTROL
LATCH VALVE #2 CONTROL
LATCH VALVE #1
LATCH VALVE #2
BRANCH #A
BRANCH #B
20N THR
1N THR
6x
Pressure Transducer out
Pressure Transducer supply
(3x) Tank Temperature
PCDU
Latch Valve LCL main PRIMPWR_LV#1
Latch Valve LCL red PRIMPWR_LV#2
RCS power main PRIMPWR_FVC/HTR1
RCS power red PRIMPWR_FCV/HTR2
Nominal CBH pwr line HTRPWR_Nom
Redundant CBH pwr line HTRPWR_Red

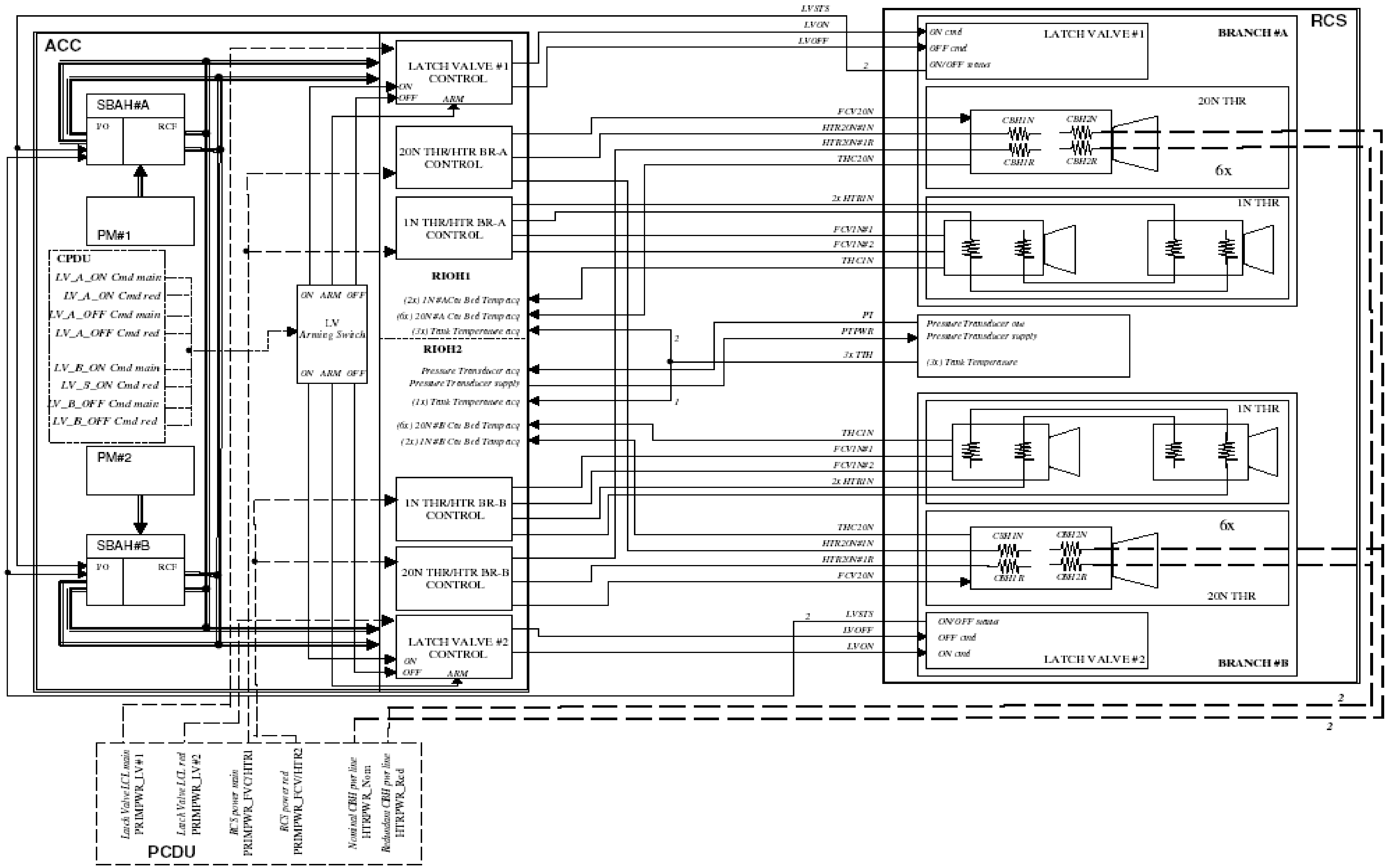


Figure ACMS-06: Planck ACMS to RCS interfaces

9.5.1 ACMS Configuration

The scope of this chapter is to illustrate the configuration of hardware used for Herschel and Planck.

The configuration of sensors and actuators used for each S/C and the informations of type of interface is presented in table CONF-01 below.

Unit	Herschel	Planck	Communication I/F
AAD	X	X	Analogue
CRS	X	X	Analogue
GYR	X		1553B
RWS	X		Analogue
SAS	X	X	Analogue
STR	X	X	1553B

Table CONF-01: Hardware used in Herschel Planck

In the following chapters are described in details the ACMS units.

9.5.1.1 Sun Acquisition Sensor (SAS)

For detailed description of the SAS refers to the document "SAS design & analysis report" (H-P-4-TNO-RP-S004).

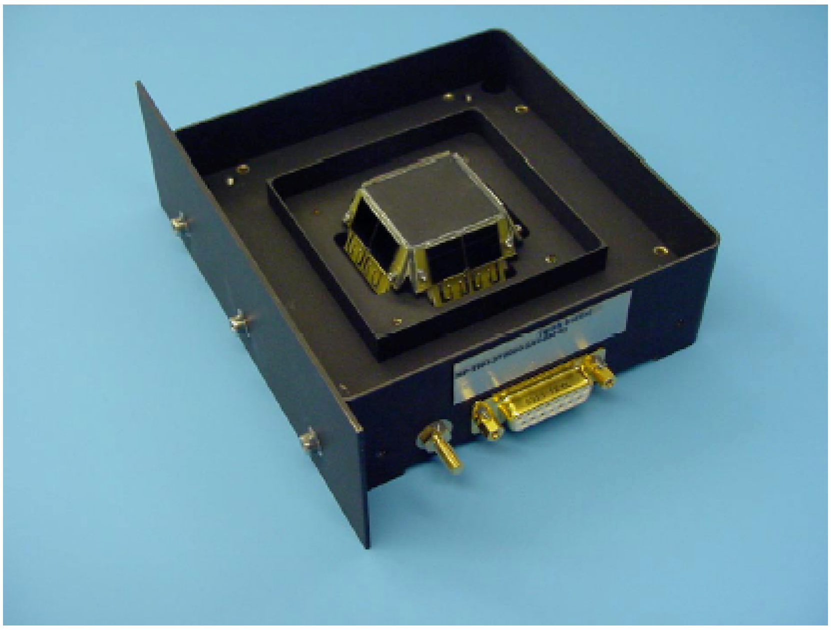


Figure CONF-02: SAS

9.5.1.1.1 General description

A unit consists of a mechanical structure with square symmetry, made from a single piece of duraluminum alloy, which carries sunlight-sensitive detectors, surrounded by knife-edge rims, which define the field of view.
The light detectors are silicon photodiodes with a nominal active area of 10 mm x 10 mm, which are in size, appearance and performance familiar to solar cells, but produced to customised specifications. These Sun-position detectors are mechanically grouped to redundant pairs, bonded to a substrate to form so-called dual-chip devices.
Four of such dual-chip devices are attached to the four sides of a truncated pyramid, located at the center frontside of the structure. The SAS functionality is obtained from outputs of four detectors, one per face of the pyramid.
The redundant chips of the dual devices serve the main and redundant SAS functions.
The H-P requirements for the size of the enhanced accuracy FOV are 30ºx30º. So the tilt angle of the pyramid must be larger than 15º. The design with an angle of 22º, applied before in Artemis, Rosetta, Mars Express and Smart-1 is a good compromise between offset-angle measurement capabilities and null accuracy stability over the mission lifetime.

<u>Herschel</u>
Herschel ACMS implements two internally redundant Sun Acquisition Sensors mounted on SVM such that the first points towards the nominal direction of the Sun and the other towards the opposite one.

<u>Planck</u>
Planck ACMS implements two internally redundant Sun Acquisition Sensors, with a relative orientation such that Sun acquisition is ensured after one spacecraft rotation around its nominal spin axis, assuming that both sensors have a hemispherical field of view.
The SAS that has its boresigth pointed towards tha S/C +Y axis is equipped with a baffle which protects the SAS cells from the Sun reflections on other SVM equipment.

9.5.1.1.2 Key performance requirements

The Sun Acquisition Sensor (SAS) is used for Sun Acquisition and Hold in SAM and SASM. The limit-cycle requirements (Herschel: keep the Sun in a 3,5°x5° (SAM) or 5°x5° box from the spacecraft +Z axis; Planck: keep the solar aspect angle lower than 4° with respect to the direction of the XSCA axis) result in the following key performance requirements:

- The field of view shall be at least 2 sterad.
- The acuracy of the SAS within a region of 30°x30° from its boresight shall be better then 1° in its measured angle (half-cone Sun-vector error). All error sources, like biases, drifts, and noises, shall be included in this figure.
- The error stability during a one-minute interval shall be better than 0,02° with a rate of temperature change of 5 K/hr.
- The SAS shall allow operation of all its channels in hot redundancy.
- The SAS shall be able to operate for angular velocities between 0°/s and 6,6°/s along the center of the field-of-view axis.
- The accuracy specified above shall be independent from the position of the Earth.

9.5.1.2 Attitude Anomaly Detector (AAD)

For detailed description of the AAD refers to the document “AAD design & analysis report” (H-P-4-TNO-RP-A004).

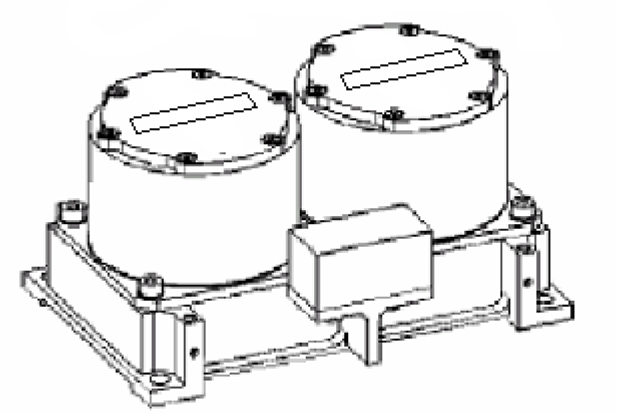


Figure CONF-03: Herschel AAD

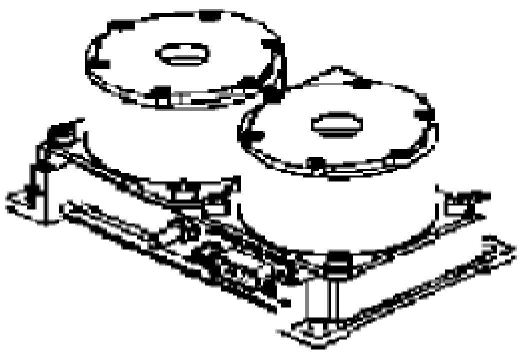


Figure CONF-04: Planck AAD

9.5.1.2.1 General description

The existing layout of the AAD has two detection modules on a common interface bracket. Each detection module consists of an optical head and a single-chip photovoltaic light detector. The latter is a silicon photodiode with a nominal active area of 10 mm x 10 mm, which in size, appearance and performance is identical to the chips of the dual-chip detector in the SAS.
The AAD has two optical heads, which can be designed with identical or different fields of view. In the case of the Herschel-Planck program, the fields of view will be identical for the two modules on one bracket, but will be made different for Herschel and Planck. In both cases, AAD is an internally redundant unit.
By its construction, an optical head completely defines the characteristics of the field of view. The head has a cylindrical shape with a closed bottom in which a small aperture hole is created in the center. The photodiode, on a glass-fiber reinforced substrate, is mechanically attached closely behind that lower aperture hole, so that sunlight penetrating through the hole hits the active area of the device. A second baffle aperture (upper aperture) is located at the top face of the cylinder portion of the optical head and defines the required field of view.
This approach ensures a maximum of modularity, because the optical head cylinders, the lower aperture hole and the sensor brackets can be made the same for Herschel and Planck. Only the top baffle plate with the field-of-view aperture will be different for Herschel and Planck.
The field of view cut-off behavior of the AAD is determined by the (small) angular interval, around the nominal field-of-view cut-off angle, in which the shadow of the rim of the upper aperture shifts across the area of the bottom aperture.

Herschel
An internally redundant Attitude Anomaly Detector aligned with the Z direction of the spacecraft is used to determine with full confidence when the spacecraft attitude is out of the safe attitude domain. The AAD will trigger when the solar aspect angle is larger than the operational domain.
The Herschel AAD field of view shall be determined by the following:
- The projection of the Sun direction (pointing to the center of the Sun disk) on the Z-X plane shall have an angle with respect to Z-axis within [30,33º, +30,33º].
- The projection of the Sun direction on the Z-Y plane shall have an angle with respect to Z-axis within [4.28º, +4.28º].

Planck
The Herschel AAD field of view shall be determined by the following:
The AAD FOV shall be 10,24º on half-cone angle.
An internally redundant Attitude Anomaly Detector located on the X side of the spacecraft and aligned with the X_{SCA} direction is used to determine with full confidence when the spacecraft attitude is out of the safe attitude domain. Provided that no eclipse condition exists, the AAD will only trigger when the solar aspect angle is larger than the operational domain.
This concept is common to Herschel but with a different field of view.

9.5.1.2.2 Key performance requirements

The requirement specification demands for a minimum photo current for the condition that the full Sun is in the field of view and for end of life conditions of responsivity, not less than 0,2 mA.

Herschel
The Attitude Anomaly Detector is used to detect the Sun leaving the safe domain. The main accuracy requirements are listed below.
The Field Of View variation at constant temperature for Herschel shall be:

- At the edge of the 5° field of view, the variation due to the position of the Sun about the Y-axis (±30°) shall not be more than 0,20°.
- At the edge of the 30° field of view, the variation due to the position of the Sun about the X-axis (±5°) shall not be more than 0,01°.
- The AAD for Herschel shall be able to operate for angular velocities between 0°/s and 0,5º/s along the center of the field-of-view axis (Z-axis).
- The total accuracy of the AAD shall be better than 0,15º.

Planck
The Attitude Anomaly Detector is used to detect the Sun leaving the safe domain. The main accuracy requirements are listed below.

- The total AAD sensor error for a temperature variation of 20 °C (range) shall be less than 0,04° in the period of one month of lifetime.
- The AAD shall be able to operate for angular velocities between 0°/s and 6,6°/2 along the center of the field of view axis (S/C X-axis).
- The AAD sensor indication shall be irrespective of Earth position.

9.5.1.3 Coarse Rate Sensor (CRS)

For detailed description of the CRS refers to the document "CSR detailed design report" (H-P-4-LAB-RP-0001).

Figure CONF-05: CRS

9.5.1.3.1 General description

The unit configuration represents the best compromise between the need to have the simplest and lightest hardware and at the same time to grant to its active devices (which are *Coriolis Vibrating Gyroscopes* (CVG), that is, the QRS11® Low Noise Angular Rate Sensor, COTS devices built by the US company Systron Donner Inertial Division), a housing able to protect them from the environmental conditions during the space flight.

Herschel
The CRS units are used in the Attitude and Rate Anomaly Detection (ARAD) function due to the need of detecting anomalies in angular velocity leading to potential excursions out of the safe attitude domain, which could be created by anomalous asymmetric actuation/behavior of the thrusters. Two CRS units are used on Herschel spacecraft.

Planck
A Coarse Rate Sensor (CRS) has been selected as a suitable sensor for dynamic monitoring, and can provide a rough estimation (for SAM and SASM, where the star tracker is not going to be used) of nutation within the

mission. The nutation estimation needs very little time to be estimated (just with one measurement) and it is a way to provide a safe mechanism of angular velocity determination.
In addition, the CRS units are used in the Attitude and Rate Anomaly Detection (ARAD) function due to the need of detecting anomalies in angular velocity leading to potential excursions out of the safe attitude domain, which could be created by anomalous asymmetric actuation/behavior of the thrusters.
Three Coarse Rate Sensors will be implemented on. One of these units will be reserved for angular velocity measurement during Survival Mode. Taking into the account the time this unit requires to provide a valid output, it is continuously switched on, in order to avoid attitude excursions above the contingency attitude domain.
Two CRS units are used in the ARAD logic in order to trigger angular rate anomalies. As an exception, one of these units reserved for ARAD is used in the SAM mode for providing angular velocity measurement for control purposes.

9.5.1.3.2 Key performance requirements

The performance requirements are driven by the accuracy requirements for the ARAD, which must neither trigger too early, nor too late:

- The CRS shall be able to measure rates of up to ±10°/s.
- For rates between 0°/s and 0,5°/s, the total error of the sensor shall be no greater than 0,02°/s. Such error is related to the value provided by each sensor axis measurement with respect to the true angular velocity present at the sensor sensitive axis (that is, without including any sensor axis misalignment, which is covered in a separate requirement), but it must include all kind of bias, bias drift, switch-on to switch-on, noise, nonlinearity effect, scale factor error, etcetera, which are not internally calibrated.This error does not include latency effect (bandwidth and delay is covered in a separate requirement).
- The sensitive axis misalignment with respect to the alignment aids must be less than 0,5°.
- The sensitive axis alignment with respect to the alignment aids must be provided with accuracy of 0,01° or better.
- The stability of the accuracy over one minute interval shall be better than 0,01°/sec. This should include temperature effects due to temperature changes at the mechanical interface of less than 5 °C per hour.
- For Planck, the alignment of the input axis with respect to the alignment aids must be provided with an accuracy of 0,01° or better.
- For rates in the ±[0,5, 10]°/s range, the measurement accuracy shall be better than 1%, all sources of error included.
- For Planck, the CRS shall have a bandwidth of at least 5 Hz.

9.5.1.4 Star Tracker (STR)

For detailed description of the STR refers to the document “STR design report” (H-P-4-GAF-RP-0002).

Figure CONF-06: STR

9.5.1.4.1 General description

Herschel
Two cold-redundant autonomous star trackers are mounted on Herschel oriented with the same direction as the line of sight of the telescope but in opposite versus.
The STR is fully autonomous and is capable of finding the attitude quaternion corresponding to its boresight quickly and with high accuracy. Very stable thermal conditions are thought to be necessary.
To improve the accuracy of the attitude quaternion towards bias variation, a modification has been implemented in the STR software, which combines the data from one cycle with those from the next cycle, where different stars can be used ("interlacing").

Planck
Two cold-redundant autonomous star trackers are mounted with the same direction as the line of sight of the telescope in order to improve the calibration with the telescope, apart from providing good spin phase observation.
The angle between the line of sight of the STR and the spin axis has a direct impact on STR performance as far as the angular motion of the stars in the STR field of view is concerned, leading to reduced integration times.
The STR is the main sensor in science (SCM), angular momentum control (HCM) and orbit control (OCM) modes.
The STR requirements for Planck are mainly driven by the accuracy in the estimation of the spin axis attitude, the angular velocity and the spin phase. This usage of a conventional STR in a spinning satellite is an innovative aspect of the subsystem, and in principle could even work with some sensors without the TDI technique (taking advantage of its relatively slow angular velocity (6°/s)). However, the TDI technique reduces the risk of the sensor usage with very minor modifications.

9.5.1.4.2 Key performance requirements

Herschel
The Herschel main performance requirements for the STR can be found below:

The noise equivalent angle during pointing (0°/s angular rate) shall be:
- Pitch and yaw: 1 arcsec
- Roll: 10 arcsec

The noise equivalent angle during constant slew rate up to 60 arcsec/s shall be:
- Pitch and yaw: 1 arcsec
- Roll: 10 arcsec

The noise equivalent angle during constant slew rate between 60 arcsec/s and 200 arcsec/s shall be:
- Pitch and yaw: 1,5 arcsec
- Roll: 15 arcsec

The noise equivalent angle during constant slew rate between 200 arcsec/s and 10°/min shall be:
- Pitch and yaw: 4 arcsec
- Roll: 30 arcsec

The STR bias stability shall be:
- Pitch and yaw: 0,2 arcsec
- Roll: 6 arcsec

The STR bias stability shall be:
- Pitch and yaw: 0,1 arcsec
- Roll: 4 arcsec

The maximum bias error in the attitude measurement (quaternion) shall be:
- Pitch and yaw: 0,8 arcsec
- Roll: 10 arcsec

This error includes spatial errors such as the (residue) interpolation error.

Relative bias error:
The change in bias in the measured attitude (quaternion) when slewing from one attitude to another attitude, for the worst case attitude within operational range, shall be less than 0,6 arcsec for any motion within a 4°x4° area, and a rate not exceeding 1°/min.
If the previous requirement can not be met, the supplier shall specify under which (slew angle) conditions the pitch and yaw relative bias errors are less than 0,6 arcsec.
This error includes spatial errors such as the (residue) interpolation error.

The probability of successful attitude acquisition (defined as the first valid attitude quaternion output) within 5 s after every transition to acquisition mode for random orientations in the celestial sphere shall be greater than 99,9% (for body rates up to 10°/min).
The STR shall be able to successfully track a star pattern (for body rates up to 10°/min) during the entire mission lifetime.

Planck
The main performance requirements for the Planck STR are listed below:

The STR must be able to track stars and provide attitude information while the spacecraft is rotating at an angular velocity of up to 6,6°/s. Angular velocity nominally (deviations ±1°) around a direction included in XSTR-YSTR deviated 85° from XSTR towards YSTR.

The noise equivalent angle at nominal constant spin rate equal to 6°/s and at a spin rate between 5,9°/s and 6,1°/s, for 99% of the possible attitudes in the celestial sphere, shall be:
- Pitch and yaw: 20 arcsec
- Roll: 100 arcsec

- The noise equivalent angle at a spin rate between 5,4°/s and 6,6°/s (out of the previous range) shall be:
  - Pitch and yaw: 40 arcsec
  - Roll: 200 arcsec

The error contribution due to temperature changes inside the STR and other measurement drift sources shall be within the following limits:

- Bias change after periods smaller than 60 s (by comparing the mean of subsequent 60 s measurement intervals) shall be less than:
  - Pitch and yaw: 1 arcsec
  - Roll: 5 arcsec
- Bias change with frequencies between 1 hr 1 and 1 min 1 shall be less than:
  - Pitch and yaw: 2 arcsec
  - Roll: 2 arcsec
- Bias change with frequencies between 1 hr 1 and 7 days 1:
  - Pitch and yaw: 3 arcsec
  - Roll: 3 arcsec
- The overall bias stability, excluding variations shorter than 60 s and field of view effects and for a temperature range of ±20°C, shall be less than:
  - Pitch and yaw: 5 arcsec
  - Roll: 5 arcsec
- Bias error over the full operational range at 6°/s shall be:
  - Pitch and yaw: 4 arcsec
  - Roll: 20 arcsec
- Total bias error during nominal operation at 6°/s and within a temperature variation of ±10 °C shall be less than (excluding NEA):
  - Pitch and yaw: 6 arcsec
  - Roll: 6 arcsec

9.5.1.5 Gyroscope (GYR)

For detailed description of the GYR refers to the document “GYR design report” (E-1 899710_B).

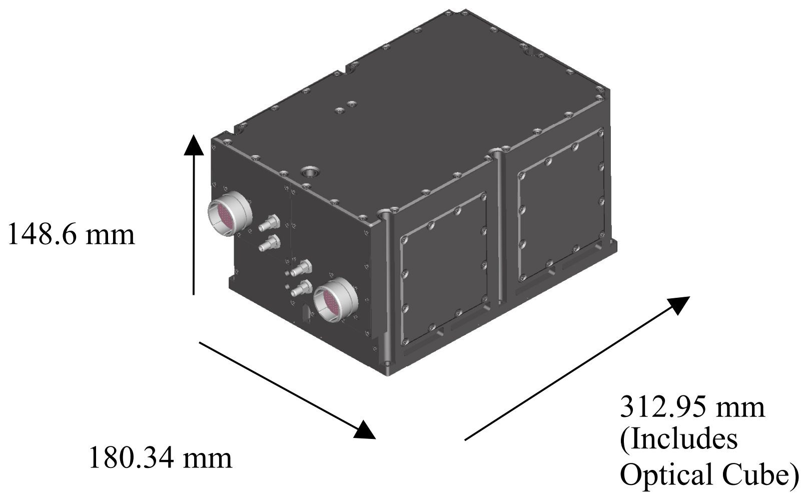


Figure CONF-07: GYR

9.5.1.5.1 General description

The selected GYR is the Northrop-Grumman (Litton) Scalable SIRU hemispherical resonating GYR. The GYR package is used for velocity measurements in science modes. The includes four gyroscopes mounted in a tetrahedral configuration. The four gyroscopes are hot- redundant, and each of the four can replace any of the others. The fourth gyroscope is not used for control, but serves to detect an inconsistency in the output of the other three, through the GYR sum check.

9.5.1.5.2 Key performance requirements

The main performance requirements for the GYR can be found below:

- Each gyro shall be able to measure angular rate up to at least 10°/min, positive as well as negative.
- Above the full rate range up to a rate of 70°/min, the unit shall be able to measure angular rate or indicate saturation.
- The bias error of the gyro shall be less than 2°/hr. This shall be achieved within 6 hours after switch-on.
- The gyro bias stability shall be less than 0,0016°/hr in one hour.
- The error due to angle random walk shall be less than 0,0001°/ hr.
- The standard deviation of noise on the angular increment outputs, sampled at 4 Hz, over a period of 60 s, shall be less than 0,003 arcsec. This is including quantisation noise.
- The error in the scale factor shall be less than 1%. Error is defined as deviation with respect to ground characterisation test value.
- The scale factor non-linearity shall be less than 0,002%.
- The scale factor stability for period up to 48 hours and the specified thermal interface conditions shall be less than 0,01%.

9.5.1.6 Reaction Wheel Assembly (RWA)

For detailed description of the RWA refers to the document “RWA design report” (H-P-4-TX-RP-0001).

Figure CONF-08: Herschel RWL

9.5.1.6.1 General description

The Reaction Wheel System consists of four wheels in a skewed configuration as in figure CONF-09. The skew angle of 70° has been optimised to achieve equal acceleration capabilities about the major satellite axes.
In the control baseline, all four wheels are powered and used for actuation. This gives optimum slew performance and momentum storage capacity. To meet the single point of failure tolerance requirements, the ACMS must also be capable of meeting the requirements with only three wheels powered.
The wheels provide actuation during the science modes and in the survival mode after stable Sun acquisition. The maximum torque each wheel can deliver has been dimensioned to meet the slew control needs with three wheels powered. With the current levels of disturbance torques, a worst case momentum storage capacity of 23,5 Nms (including temporary storage capacity during large slews) is needed per wheel if three wheels are powered. This is within the capacity of the selected wheels when four wheels are powered, although some wheel biasing is required each day. When three wheels are powered, the momentum capacity may not be sufficient to avoid zero crossings without having to unload the RWS once per day. This is allowed by the current ACMS specification. For the four-wheel configuration, a torque distribution algorithm has been designed which optimises for momentum storage and zero crossings.

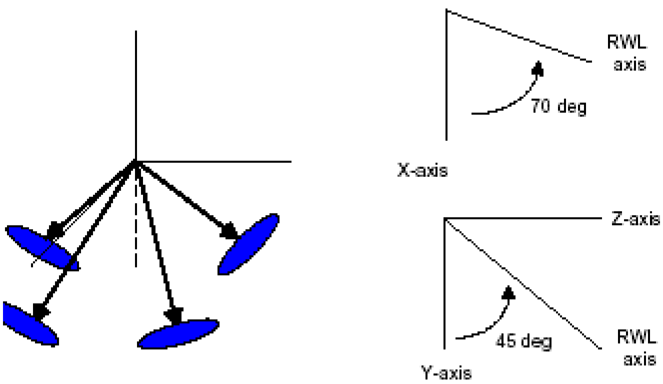


Figure CONF-09: Skewed configuration for Herschel RWL’s

9.5.1.6.2 Key performance requirements

The RWL's are the main actuators used in Science Mode. The main performance requirements for the RWL are as follows:

- Each wheel shall be able to store an angular momentum of at least 30 Nms, positive as well as negative.
- The wheel shall be able to deliver the maximum reaction torque for an angular momentum range up to at least 20 Nms.
- The maximum delivered reaction torque in positive as well as in negative direction shall be at least 0,2 Nm.
- After receiving a torque request, the change of delivered torque shall settle to within 10% of the change in required torque within 250 ms.
- During a constant torque setpoint, the RMS value of the undesired torque variations with frequencies between 0 Hz and 4 Hz shall be less than 0,001 Nm.
- The maximum stiction torque shall be less than 0,01 Nm.
- The total friction shall be less than 0,015 Nm.
- The number of pulses per revolution from the tacho shall be at least 24.

Each RWL shall be able to support the following zero-crossing conditions, without degradation:

- One rapid (torque request more than 0,1 Nm) zero crossing per day.
- One prolonged stay with attitude-hold torque requests around zero per day, compatible with a constant disturbance torque of 80 Nm acting on the satellite in the RWA frame of reference, taking into account at least four passes through stiction of the RWA due to control torques.

9.5.2 Modes design description

9.5.2.1 HERSCHEL

Modes structure the operational control objective of the ACMS. They define the use of sensors and actuators, and the configuration of control functions and supporting functions to achieve this operational control objective.
Modes are divided into states. At any time, the ACMS is in exactly one state of exactly one mode. Autonomous transitions between modes, or between the states in a mode, serve to properly initialise the ACMS and acquire and maintain a stable and safe attitude. All other transitions between modes and/or states are triggered by telecommands.
Figure Modes-01 below shows a simplified mode-transition diagram.

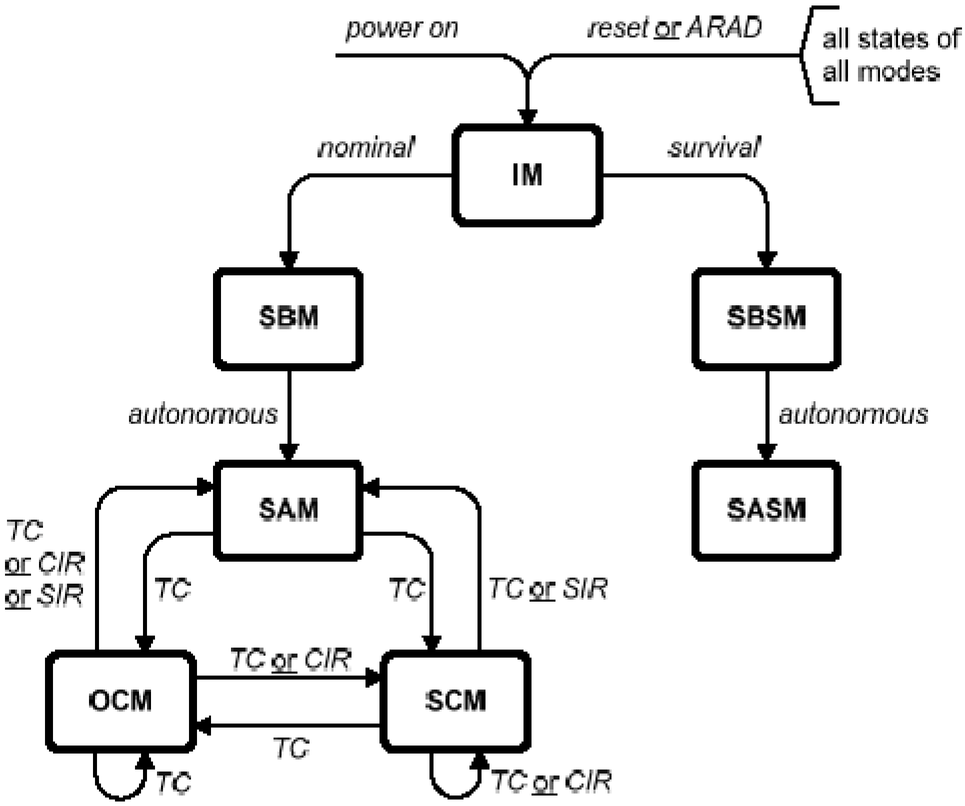


Figure Modes-01: Simplified mode-transition diagram

The full mode and state transition diagram is shown in figure Modes-02.

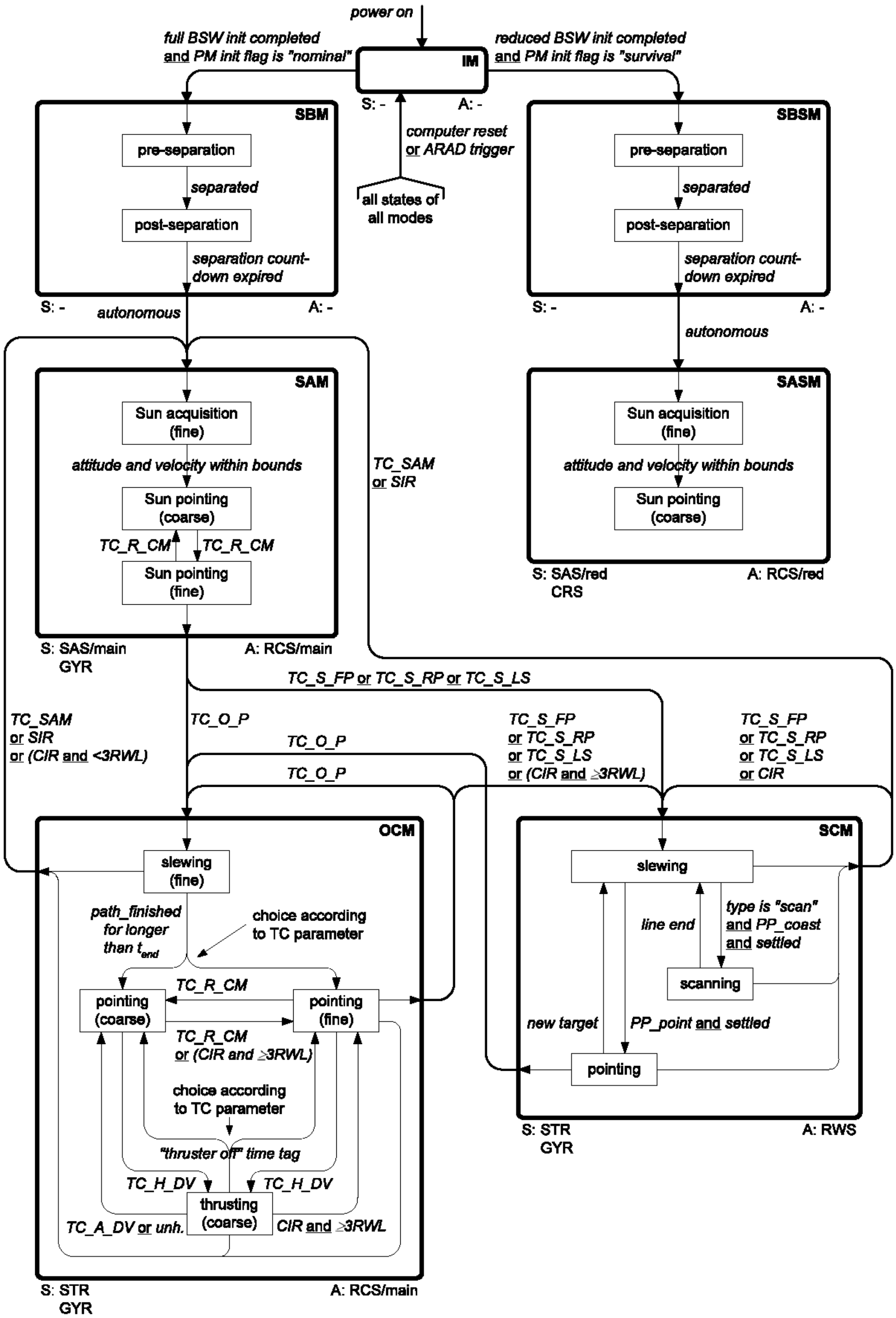


Figure Modes-02 Full mode-transition diagram

A Survival Mode provides safe, redundant attitude control in the presence of a failure. The Survival Mode consists of the modes SBSM and SASM; these modes are detailed in the following chapters.
Under nominal conditions, the ACMS operates in the so-called nominal modes. These nominal modes are entered via the Standby Mode (SBM). The Nominal Modes consist of SBM, SAM, OCM and SCM.
The ACC PM can have either a cold start or a hot start. A cold start occurs when the ACC is switched on, or when a switch of processor module occurs. A hot start occurs at a reset triggered by the Reconfiguration Module.
The main difference between a cold start and a hot start is the initialisation: only after a cold start, the BSW will load the ASW from EEPROM into RAM.
After the (hot or cold) start, the BSW activates the ASW. The ASW enters either Nominal Mode or Survival mode. Which of the two modes is entered depends on relay data which the ASW reads from the BSW. Each ACC processor module has such a relay, which can be set from the CMDU.
When entering Survival Mode, the BSW keeps the initialisation time as short as possible by not performing the RAM memory check. When entering Nominal Mode, the BSW does perform the RAM memory check.

9.5.2.1.1 Initialisation Mode (IM)

Initialisation Mode is entered after power-on and after a computer reset or an ARAD triggering. The goal of Initialisation Mode is to initialise the ACMS. Initialisation Mode also decides whether to enter Nominal Mode or Survival Mode.
Upon entry into Initialisation Mode, the basic software takes control. In case of a hot start, the basic software fills the entire SGM with the value 0xA5A5; in case of a cold start, the basic software does not modify the contents of the SGM.
The basic software also checks the PM init flag. If this flag indicates that Survival Mode is to be started, the BSW performs only limited initialisation. This ensures that the application software is started with as little delay as possible, which is a Good Thing because the very fact that Survival Mode must be started indicates a possibly dangerous situation.
If the PM init flag indicates that Nominal Mode is to be started, the BSW assumes that there is sufficient time to perform full initialisation.
The basic software then transfers control to the application software.
The application software inspects a dedicated location in SGM to see whether it is performing a cold start or a hot start: If the contents of the dedicated SGM location read 0xA5A5, the application software assumes a cold start.
The software initialises all SGM data with default values. This includes the initialisation of the dedicated SGM location to a value that is different from 0xA5A5. If the contents of the SGM location read anything else, the application software assumes a hot start. It does not modify the contents of the SGM, as these are still valid.
Finally, when all initialisation has completed, the ASW starts either Nominal Mode or Survival Mode, depending on the value of the PM init flag.

9.5.2.1.2 Standby Mode (SBM)

Standby Mode has two flavours, one for the Nominal and one for the Survival branch:
<u>Nominal branch</u>
The Standby Mode for the Nominal branch is simply called Standby Mode, or SBM. SBM is described in the current chapter.
<u>Survival branch</u>
The Standby Mode for the Survival branch is called Standby Survival Mode, or SBSM. SBSM is described in following chapter.

Standby Mode (SBM) is entered when the ASW is started by the Initialisation Mode (IM) while the PM init flag indicates that Nominal Mode is to be started.
- SBM has the following states:
- Pre-separation: provides basic communication with the CDMU and monitors the separation status.

Post-separation: initialises the ACMS for SAM and handles the twenty-second separation delay.

Note that, if the ACMS detects separation directly after mode entry, the ASW executes Standby Mode without delay; this allows the fastest possible entry into SAM.

9.5.2.1.3 Standby Survival Mode (SBSM)

Standby Survival Mode (SBSM) is entered when the ASW is started by the Initialisation Mode (IM) while the PM init flag indicates that Survival Mode is to be started:

- Pre-separation: provides basic communication with the CDMU and monitors the separation status.
- Post-separation: initialises the ACMS for SASM and handles the twenty-second separation delay.

Note that, if the ACMS detects separation directly after mode entry, the ASW executes Standby Survival Mode without delay; this allows the fastest possible entry into SASM.

SBSM cannot use the SGM parameters. Since at initialisation all the OBDB is lost, SBSM would read all the OBDB parameters as the default EEPROM values. These values are hardcoded, and therefore they cannot be changed in flight, but with a memory patch (not allowed for nominal operations).
In SBSM, information of the thrust level is used by the controller. In order to assure stability in all mission phases (BOL, EOL and everything in between), the design of SBSM is as follows: SBSM read a value from the RM which acts as a pointer to one of several control sets in EEPROM. Therefore, SBSM will use different control parameters for different mission phases, ensuring stability in all circumstances.
Ground shall update the RM register several times in the mission lifetime, changing the pointer and therefore the control parameters to be used (RM registers are not lost at initialisation).

9.5.2.1.4 Sun Acquisition Mode (SAM)

The Sun Acquisition Mode (SAM) is an RCS-based nominal safe mode. It is entered autonomously after completion of SBM, after receiving a SIR signal, or after a loss of sync. After separation, the Sun Acquisition Mode quickly achieves a safe attitude. The ACMS uses the RCS to remove angular velocities which may have been introduced during separation from the launcher. The satellite is then controlled to attain an attitude where the +Z axis points to the Sun. During the required maneuver, SAM calculates artificial Sun vectors to achieve a slew path that is safe in the sense that it keeps the satellite +X axis as far away from the Sun as possible.
When SAM has reached the safe attitude, it uses the RCS to maintain that attitude. Nominally, SAM is left only by ground command.

9.5.2.1.4.1 SAM states

Sun Acquisition Mode consists of three states:
<u>Sun acquisition</u>
This is the initial state of SAM. The goal is to attain a safe attitude as quickly as possible. The +Z axis is pointed to the Sun in such a way that the +X axis never approaches the Sun.
<u>Sun pointing (coarse)</u>
This state is reached when the +Z axis is close enough to the Sun and the angular rate about the Z azis is low enough, in other words, when the satellite is Sun pointing. The RCS is operating in coarse mode, which means that angular rates vary in a relatively large band, but fuel consumption is low.
<u>Sun pointing (fine)</u>
This state is reached from the Sun pointing (coarse) state upon ground command. The only difference with the Sun pointing (coarse) state is that the RCS is operating in fine mode, which means that angular rates very in a relatively narrow band, but fuel consumption is higher.

Figure Modes-03 shows the flow logic of Sun Acquisition Mode:

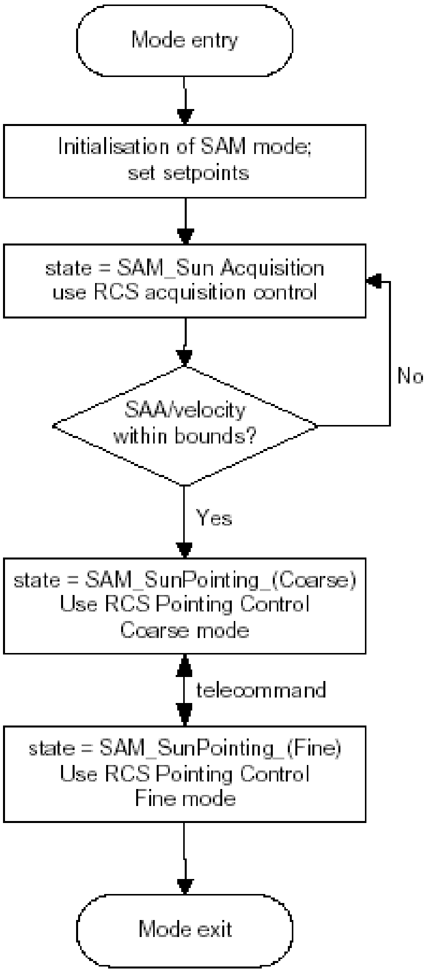


Figure Modes-03: SAM logic flow diagram

9.5.2.1.4.2 SAM sensors and actuators

The sensors used by SAM are the SAS/main and the GYR.
The actuators used by SAM are the RCS/main.

9.5.2.1.4.3 SAM entry/exit modes and conditions

SAM can be entered from the following modes:
- From SBM: autonomously when SBM finishes.
- From OCM: by TC, if a SIR is detected, or if a CIR is detected and less than three wheels are available.
- From SCM: by TC, or if a SIR is detected.

SAM can be exited to the following modes:
- To OCM: by TC.
- To SCM: by TC.

9.5.2.1.4.4 Reaction to the SIR signal

The SIR signal will trigger a transition to the Sun Acquisition Mode. As the SAM design has no knowledge of the reason for the entry, the pointing control algorithm will simply be executed.

9.5.2.1.5 Sun Acquisition Survival Mode (SASM)

The Sun Acquisition Survival Mode (SASM) is an RCS-based survival mode. It is entered autonomously after completion of SBSM.
Sun Acquisition Survival Mode is very similar to Sun Acquisition Mode. For safety, Sun Acquisition Survival Mode uses different sensors and actuators than Sun Acquisition Mode: instead of the GYR, it uses the CRS as a rate sensor, and instead of the main branch of the RCS, it uses the redundant branch of the RCS for actuation.
An important difference between the state transition diagrams of SASM and SAM is that there is only a Sun pointing (coarse) state for SASM, whereas SAM also possesses a Sun pointing (fine) state. The reason is that this Sun pointing in fine mode consumes more fuel than Sun pointing in coarse mode. SAM does have a fine mode because it must be possible to exit SAM to OCM or SCM; SASM is never left, so there is no need for a fine mode.
The objective of SASM is to align the satellite +Z axis with the measured Sun vector and to stabilise the attitude (near-zero angular rates, also about the Sun vector). The ACMS uses the SAS to measure the Sun vector in body coordinates; attitude errors about the X and Y axes are derived from this information. The rate errors are measured with the CRS.

Figure Modes-04 shows the flow logic of Sun Acquisition Survival Mode:

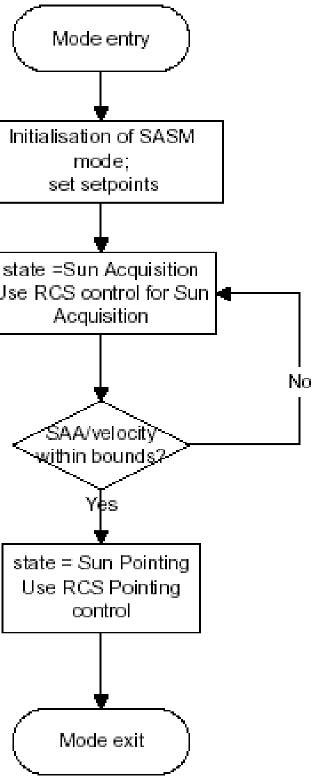


Figure Modes-04: SASM logic flow diagram

9.5.2.1.5.1 SASM control logic

Most important is the fact that the Contingency Zone must be avoided at all costs and the Safe zone re-entered within one minute. If the logic of Sun Acquisition Mode is used, the path will not be optimal.
In order to achieve this optimum SASM slew path, it is necessary to extend the determination of the Sun quaternion such that the target Sun vector is not located on the Z axis, but at the normal between the initial Sun vector and the Safe Zone. In order to avoid premature deceleration, the target Sun vector should be placed somewhat within the Safe Zone, in a region proportional to it.

9.5.2.1.5.2 Survival for seven days

Survival for prolonged periods is in principle limited due to the following factors:
- Need for Periodic Unit Calibration
- The Sensors and actuators used in SM (CRS, SAS, RCS) do not need maintenance on the time scales of a week. The CRS bias and scale factors will deteriorate slightly, but this does not affect SM control.
- Need for updates in the ASW parameters.
- The SM only uses default parameters outside the OBDB.
- Need for updates in the environmental parameters. This is not relevant for Herschel. The position of the Sun is the only important factor, and the absence of eclipses removes the need for maintaining an inertial Sun vector.
- Numerical errors. No integration-type calculations are done. All data is collected anew each cycle, and control decisions taken on that basis.

Conclusion: There is nothing in the design of Survival Mode which limits the autonomy period.

9.5.2.1.6 Orbit Control Mode (OCM)

The primary goal of Orbit Control Mode (OCM) is to perform delta-V maneuvers.
OCM uses the RCS for attitude control. Note that there are separate RCS branches for attitude control and for orbit control:

- The attitude-control thrusters are used for attitude control. These thrusters are used in SAM, SASM, and OCM.
- The orbit-control thrusters are used for orbit control, that is, to perform the actual delta-V action. These thrusters are used exclusively in OCM.

The attitude-control thrusters are always commanded in on-modulation mode. These thrusters are only used to achieve or maintain the commanded attitude; they do not deliver any thrust for the delta-V.
The orbit-control thrusters, when used, are fired continuously for the commanded duration. The delivered thrust is the sole source of propulsion for the delta-V maneuver.
Possible misalignments of the orbit-control thrusters, or differences in thrust level between the orbit-control thrusters, are perceived as a disturbance torque. The ACMS uses the attitude-control thrusters to compensate for this disturbance torque.

The nominal sequence to perform a delta-V is then as follows:

- Enter OCM. OCM enters the slewing state to reach the commanded attitude.
- When the commanded attitude is reached, OCM automatically proceeds to either pointing (coarse) or pointing (fine), depending on a parameter that was given in the OCM telecommand. Normally, this parameter will instruct the system to enter pointing (coarse): using coarse mode uses less fuel, and there is no need to use fine mode.
- Another telecommand, TC_H_START_DELTAV, instructs OCM to enter the thrusting state.
- When the commanded duration of firing of the orbit-control thrusters has expired, OCM automatically goes to either the pointing (coarse) or the pointing (fine) state, again depending on a parameter that was given in the delta-V telecommand. When the ground foresees another delta-V phase, or when the system is expected to remain in OCM for some time, this parameter will tell the system to go to the pointing (coarse) state to reduce fuel consumption. When the ground foresees an exit of OCM (probably to SCM), this parameter will tell the system to go to the pointing (fine) state to reduce the residual angular momentum.
- Steps 3 and 4 may be repeated any number of times.
- When OCM is in the pointing (fine) state, the ground may give a command to go to SCM.

During the delta-V maneuver, OCM performs bookkeeping of the firing of the attitude-control thrusters. The reason for this is, that the attitude-control thrusters, though only intended for attitude control, could contribute to the delta-V (from the point of view of the delta-V maneuver, the actions of the attitude-control thrusters form a disturbance).
While in OCM, the software biases the wheels to a commanded total angular wheel momentum. This allows entering SCM with a known total wheel momentum.
Figure Modes-05 shows the flow logic of Orbit Control Mode:

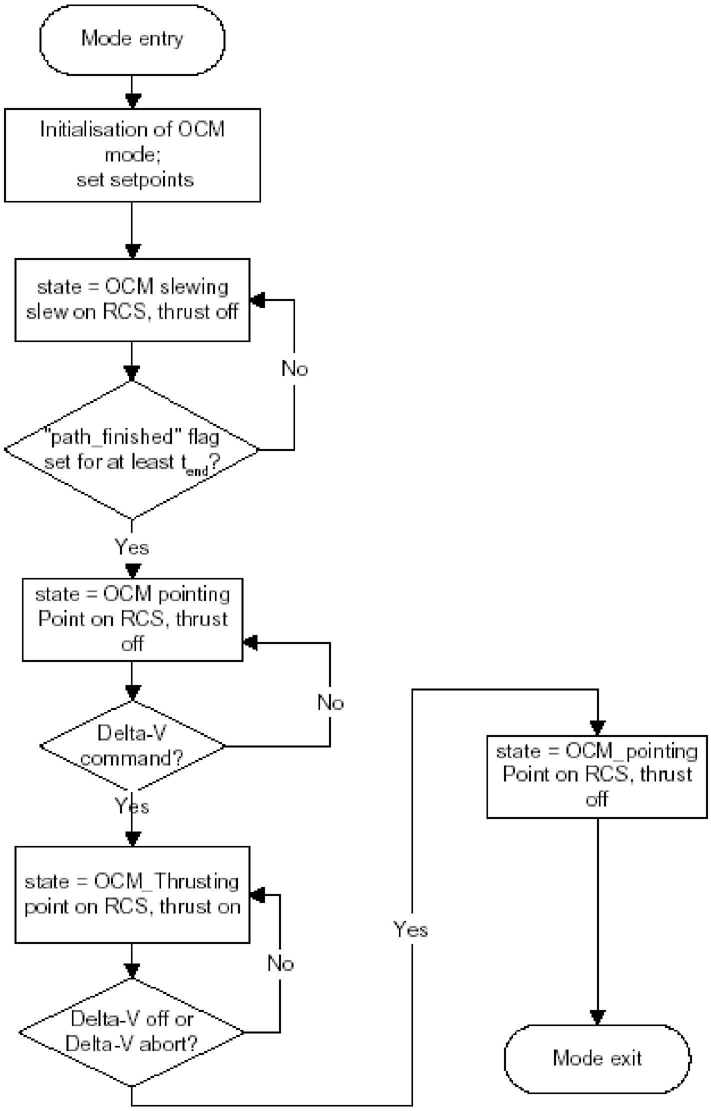


Figure Modes-05: OCM logic flow diagram

9.5.2.1.6.1 OCM states

<u>OCM Slewing</u>

OCM Slewing is the initial state of OCM. It can be entered by telecommand only, from SAM, SCM, or from a previous OCM.

In the Slewing state, a Sun-safe path planner is used to slew to the commanded attitude. This avoids excursions outside the safe domain, which might occur if no path planner were used, or if a path planner were used based on Euler rotations.

OCM Slewing is automatically left to OCM Pointing when the commanded attitude is reached. A parameter in the OCM telecommand determines whether the RCS mode remains fine in OCM Pointing, as it was in OCM Slewing, or whether the RCS mode goes to coarse in OCM Pointing.

OCM Pointing

In OCM Pointing, the satellite is kept in the commanded attitude, which was provided as an attitude quaternion in the OCM telecommand. The satellite remains in OCM Pointing until the ground commands the ACMS to OCM Thrusting, or to a different mode (SAM, SCM, or a new OCM).

There are two "flavours" of OCM Pointing: using either coarse or fine mode for the RCS. A telecommand allows the ground to switch between these two flavours. Coarse mode reduces fuel consumption, but the attitude excursions and the angular rates are higher than when using fine mode. Fine mode provides better control (smaller attitude excursions and lower angular rates), at the expense of higher fuel consumption.

In order to go to SCM, the angular rates must be sufficiently low; even for entering a new OCM, the angular rates must be sufficiently low. Here, the term "sufficiently low" means: lower than those that occur when the RCS is in coarse mode.

Therefore, the RCS must be commanded to fine mode before a transition can be made to SCM or to a new OCM.

As OCM Pointing needs some time to reduce the angular rate and the attitude excursion after a transition from coarse mode to fine mode, the "state" changes from coarse to fine only some time after the ACMS has received the telecommand. This time is a database parameter.

9.5.2.1.6.2 OCM Thrusting

For attitude control, OCM Thrusting is identical to OCM Pointing with the RCS in coarse mode. In addition, the orbit-control thrusters are fired continuously in OCM Thrusting, for a time that is given in the delta-V telecommand.

When the delta-V time has expired, the ACMS automatically returns to OCM Pointing. A parameter in the delta-V telecommand determines whether the RCS mode remains coarse in OCM Pointing, as it was in OCM Thrusting, or whether the RCS mode goes to fine in OCM Pointing.

9.5.2.1.7 Science Mode (SCM)

Science Mode (SCM) provides the control functions needed to perform science operations:

- fine pointing
- raster pointing (optionally with off-position pointings)
- line scanning (optionally with off-position pointings)
- solar system object tracking
- small attitude adjustments (peak-up)

In addition, Science Mode provides control functions needed for momentum management, and maneuvers to support ground commands.

Science Mode has the following states:

- Slewing: A rotation from the current attitude to the target attitude. This is also the first state of SCM, as the attitude at mode entry could be any attitude within the operational domain.
- Pointing: Full-accuracy, stable pointing at a fixed attitude.
- Scanning: Rotation at a constant velocity.

The ASW processes the SCM telecommand to derive a timeline of target attitude quaternions, which governs the state transitions within the mode. The calculation of the target attitude must take the following into account:

Corrections for solar system object tracking.

A peak-up telecommand received prior to the SCM telecommand. This telecommand specifies a correction quaternion that must be applied to the target quaternion of a consecutive SCM (only in case of a fine pointing command or a raster pointing command). The peak-up telecommand imposes a small attitude adjustment.

The SCM telecommand allows the start and the duration of each SCM part to be specified to an accuracy of one ACMS cycle (0,25 s).

Figure Modes-06 shows the SCM flow chart:

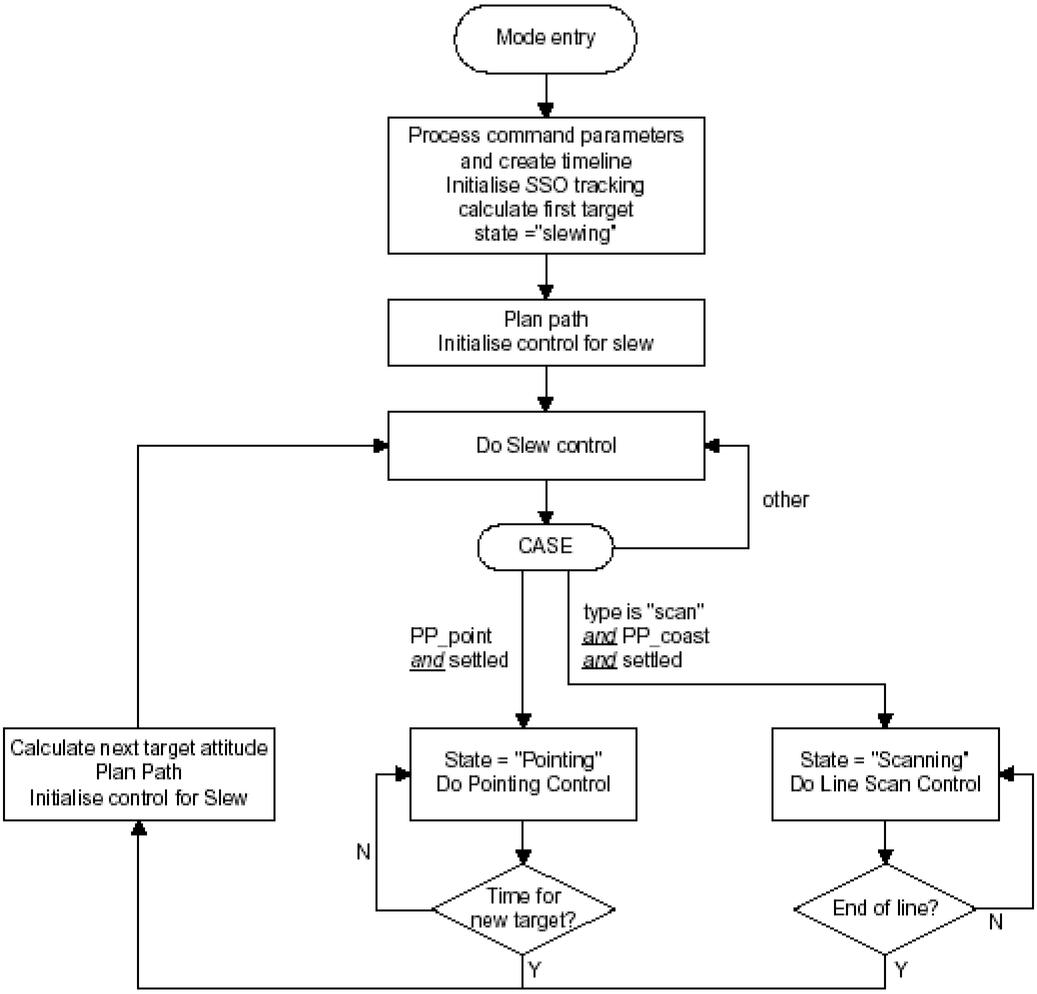


Figure Modes-06: SCM Logic flow diagram

9.5.2.1.7.1 SCM states

<u>Fine Pointing</u>
The simplest type of SCM command is a Fine Pointing. When a Fine Pointing command arrives, the ACMS slews to the target attitude and maintains that attitude until the next command arrives.
The required slew time must be estimated by Ground when the command is prepared; it must be specified in the Fine Pointing telecommand.
<u>Raster Pointing</u>
The Raster Pointing command specifies a sequence of pointings in a predefined pattern, using predefined timing.
This allows the CDMU to synchronise commands to the scientific instruments with the maneuvers of the ACMS.
To allow this timing, the telecommand contains timing parameters that allow the ACMS to calculate the start and end time of each pointing. The ACMS calculates the start time of each intermediate slew to meet the required start time of the next pointing.
During a Raster Pointing, the axis of the telescope moves in a raster pattern as defined in figure Modes-07. In this figure, the following notations are used:

- M is the number of pointings per line.
- N is the number of lines.
- d1 is the spherical angular distance between successive steps.
- d2 is the spherical angular distance between successive lines.

In addition, the inertial attitude of the pattern is defined by the quaternion qrast of the 1st raster point and an angle defining the rotation of the pattern axes with respect to local instrument axes, i.e. a rotation about the X axis of the body frame. More precisely, is the angle between the spacecraft XZ plane and the first line of the pattern.

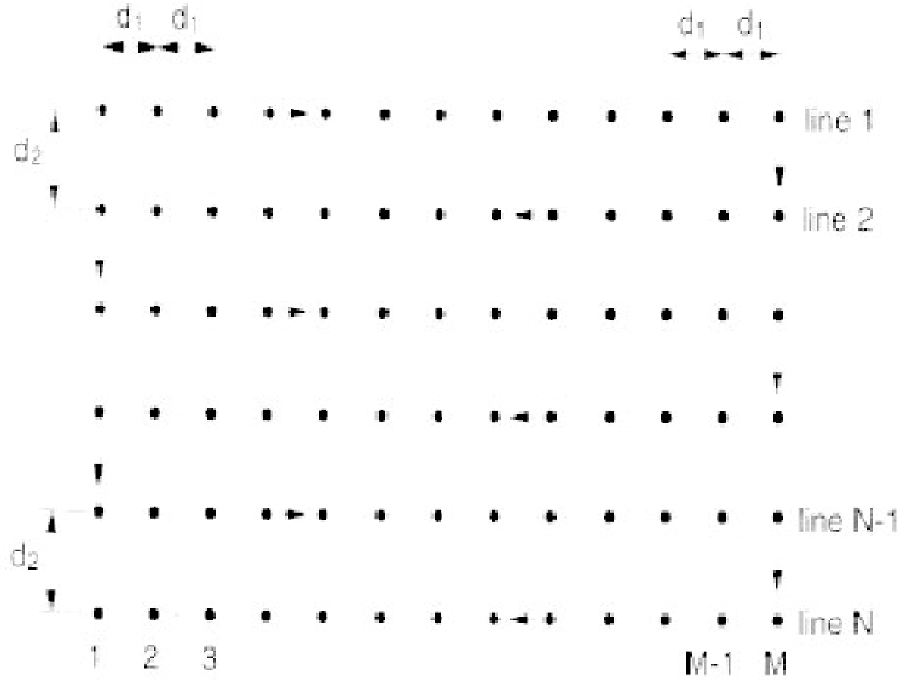


Figure Modes-07: Raster pointing

Line Scanning

A Line Scanning command instructs the ACMS to scan along a number of evenly spaced lines, dubbed the scan lines. Each scan line is traversed at a constant angular velocity.

Before starting a scan of a line, the ACMS must of course accelerate to attain the required angular velocity. To this end, the ACMS plans the acceleration such that it reaches the scan rate before the start of the scan line is reached. This allows the controller to settle before the start of the scan line. The acceleration starts from an intermediate attitude that allows sufficient time and angular separation before the start of the scanline is reached.

The times allocated for the slew, and the intermediate attitude, are parameters in the Line Scanning telecommand.

The path of the instrument axis over the celestial sphere during a line scan is a great-circle; this is similar to what happens during a raster pointing. Figure Modes-08 shows subsequent scan lines.

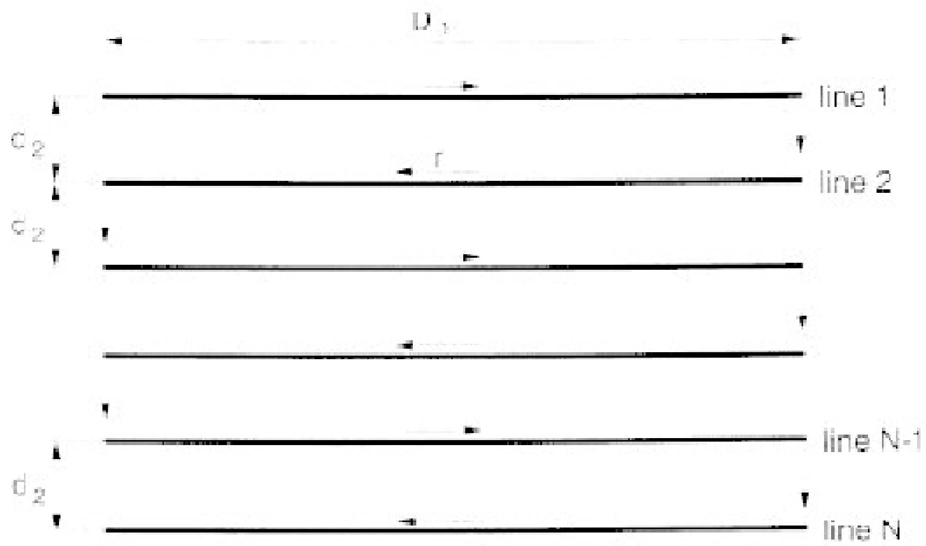


Figure Modes-08: Line scanning

9.5.2.2 PLANCK

Modes structure the operational control objective of the ACMS. They define the use of sensors and actuators, and the configuration of control functions and supporting functions to achieve this operational control objective.
Modes are divided into states. At any time, the ACMS is in exactly one state of exactly one mode. Autonomous transitions between modes, or between the states in a mode, serve to properly initialise the ACMS, acquire and maintain a stable and safe attitude, and resume science operations after slew maneuvers. All other transitions between modes are triggered by telecommands.
Under nominal conditions, the ACMS operates in the so-called nominal modes. These nominal modes are entered via the Standby Mode (SBM). The Nominal Modes consist of SBM, SAM, OCM, HCM and SCM.
The Planck mode transition logic depends on whether the ARAD thresholds for the CRS Y and Z channels (transversal angular velocity) are high or low. Planck has two different sets of values for the ARAD thresholds, depending on the phase of the mission. The phase of the mission is registered in a relay in the Reconfiguration Module, in order to have a reliable reading at the ASW. Therefore, Planck will have two different thresholds for the transversal angular velocity. Planck high threshold phase is the phase where the transversal angular velocity thresholds are set to a high value. Planck low threshold phase is the phase where the transversal angular velocity thresholds are set to a low value. The threshold indicator put into the RM register is changed by ground when changing the threshold values in the ARAD.
Depending on whether the threshold is "low" or "high", some mode transitions are forbidden or allowed. All the modes cannot have the same CRS transversal angular velocity threshold for the ARAD.
On one side, HCM and SCM have to have a low threshold or otherwise may not recover from a worst case thruster left-open failure at the edges of the operational domain. The main consequence of this impossibility to stay within the contingency domain is the need to push down the excursion as much as possible. Since the smaller the triggering value for the ARAD CRS transversal angular velocity is, the smaller the excursion is, a small triggering value is needed.
On the other side, SAM has to have a high threshold, or otherwise would trigger Survival Mode in nominal operational conditions. The nominal operation of SAM is driven by the errors in the CRS, the SAS and the RCS, and in the uncertainty in the inertia and center of gravity, that cannot assure small transversal angular velocity after or during the maneuver.
Finally, the transversal angular velocity excited during the delta-V pulses in OCM can be tuned by changing the duty cycle. Therefore, OCM may have either high or low thresholds for the delta-V maneuvers safely, depending on the typical mode of origin and destination. The consequence is that changing the duty cycle changes as well the duration of the delta-V maneuver, and its efficiency (but the latter only slightly, almost negligibly). The longer the duty cycle is, the faster the delta-V maneuvers are done, but the higher the transversal angular velocity excited during them is. In the early phases, the transitions SAM OCM SAM would be needed, and therefore OCM would work with the threshold equal to the threshold in SAM. In this phase, the duration of the maneuver is important because maneuvers are very long. In science operations, the transitions SCM OCM HCM SCM would be needed, and therefore OCM would work with the threshold equal to the threshold in SCM and HCM. In this phase, the duration of the maneuver is not that critical, because a 10 cm/s maneuver would take some 3 minutes instead of the some 2 minutes that it would last if the high threshold was used for OCM.
Mode transitions that imply thresholding changes should be minimised in order to simplify ground operations and avoid unnecessary risks. When going from a mode with low threshold (like SCM) to a mode with high threshold (like SAM), the thresholds have to be changed before the transition, or otherwise the SAM manoeuvre itself may trigger the ARAD. When going from a mode with high thresholds (like SAM) to a mode with low thresholds (like HCM), the residual nutation from SAM should be damped in HCM before changing the thresholds, or again the ARAD may be triggered. These operation concerns will be described in the Operations Manual.
A sketch of the tresholding phase and the transitions allowed in both high and low thresholding phases are presented in figure Modes-09.

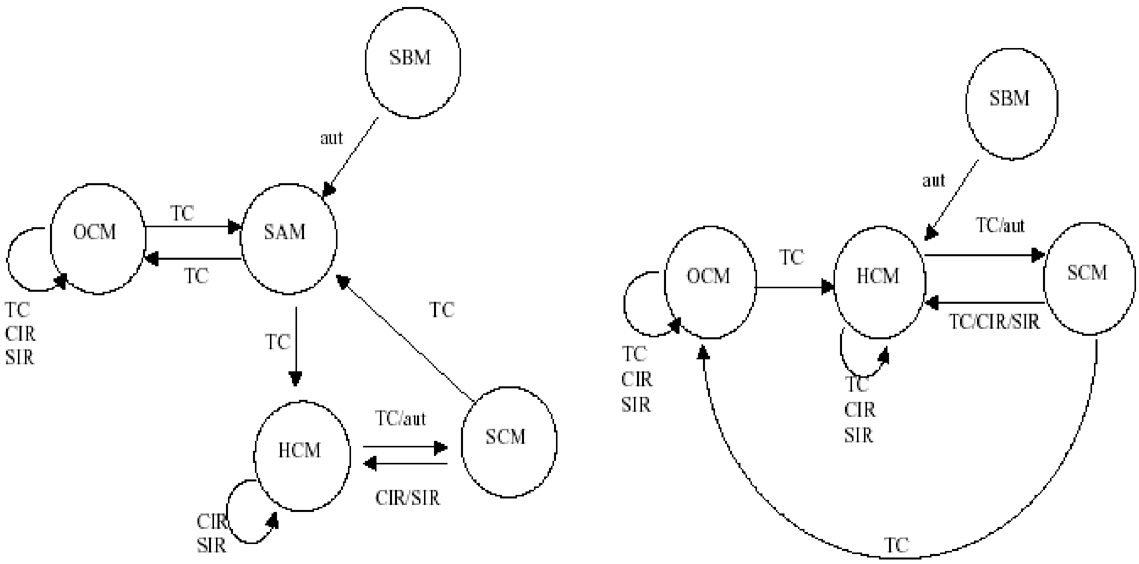
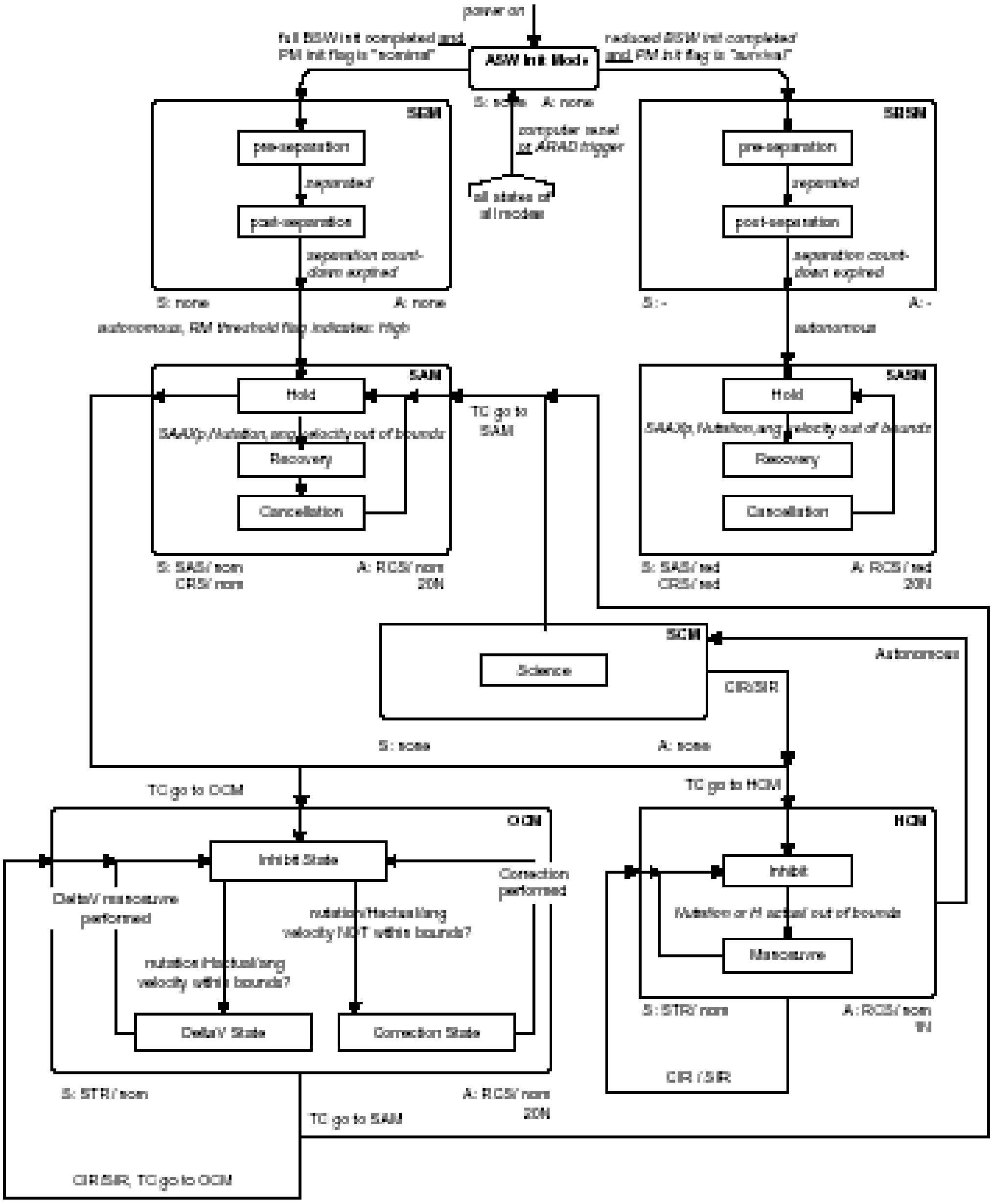


Figure Modes-09: Planck mode-transition logic for high (left) and low (right) threshold

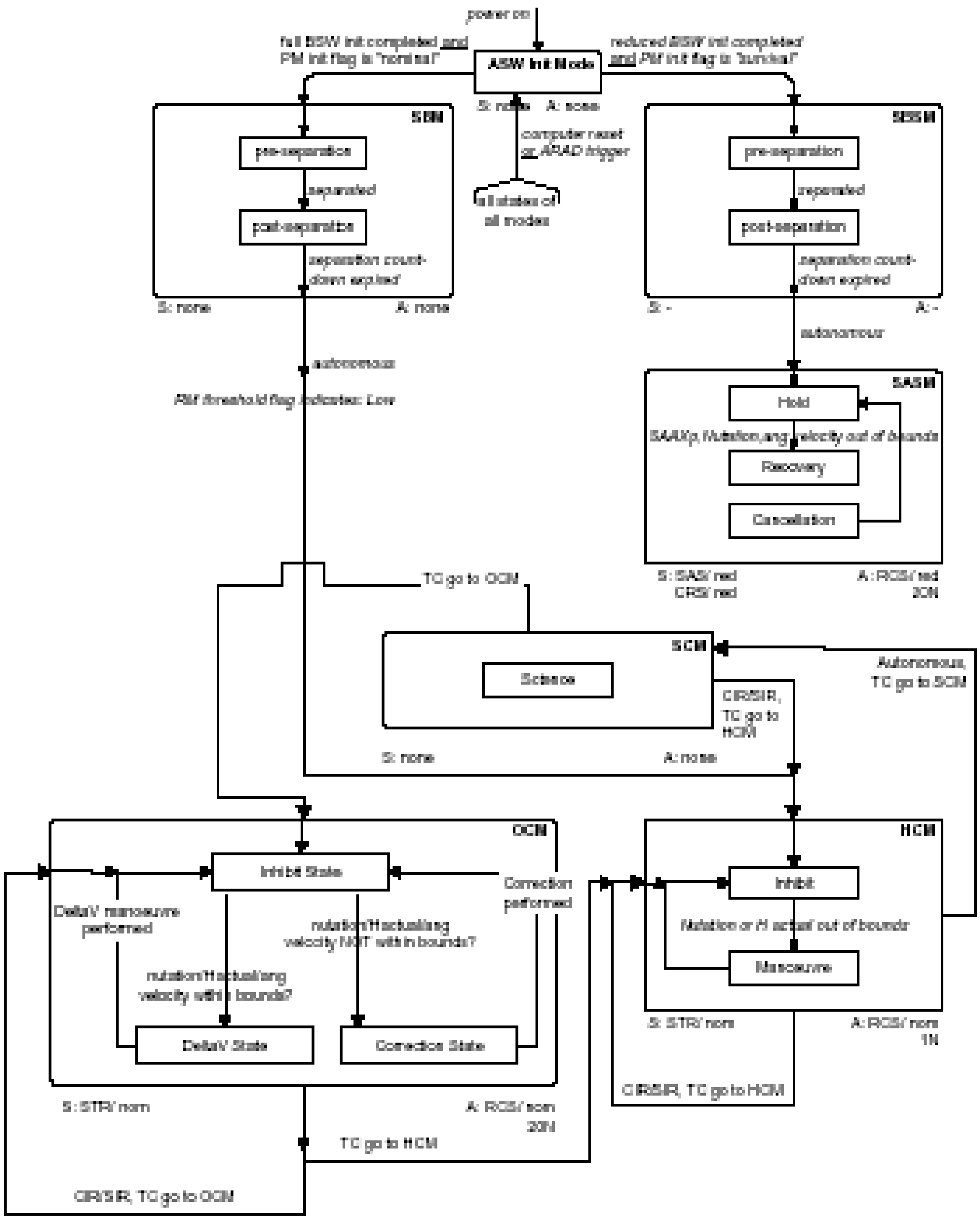
The detailed mode architecture is presented in figures Modes-10 and Modes-11.



Planck, High Threshold mode transitions

Notes:
S: Active sensors on control
A: Active actuators on control
Exit from all modes is possible in all states with the exception of SAM, the exit state is hold.

Figure Modes-10: Planck detailed mode-transition logig for high threshold



Planck, Low Threshold mode transitions

Notes:
S: Active sensors on control
A: Active actuators on control
Exit from all modes is possible in all states.

Figure Modes-11: Planck detailed mode-transition logic for low threshold

9.5.2.2.1 Non-nominal mode transitions

A Survival Mode provides safe, redundant attitude control in the presence of a failure.
The ACC PM can have either a cold start or a hot start. A cold start occurs when the ACC is switched on, or when a switch of processor module occurs. A hot start occurs at a reset triggered by the Reconfiguration Module.
The main difference between a cold start and a hot start is the initialisation: only after a cold start, the BSW will load the ASW from EEPROM into RAM.
After the (hot or cold) start, the BSW activates the ASW. The ASW enters either Nominal Mode or Survival mode. Which of the two modes is entered depends on relay data which the ASW reads from the BSW. Each ACC processor module has such a relay, which can be set from the CMDU. When entering Survival Mode, the BSW keeps the initialisation time as short as possible by not performing the RAM memory check. When entering Nominal Mode, the BSW does perform the RAM memory check.
A transition from Nominal Modes to Survival Modes will be done by switching to the redundant Processor Module through the ACC Reconfiguration Module, followed by the initialisation above. Such a reconfiguration is a possible consequence of a failure of the ACC, a Sun-out-of-limits or a rate-out-of-limits condition detected by hardware, or a High Priority Command from the CDMU. This transition is therefore not controlled by the ASW.
A transition from Survival Modes to Nominal Modes must be commanded from ground, by proper setting of the relay status and initiation of a reset, both via the CDMU. This transition is therefore also not controlled by the ASW. Note that such a transition does not require a switch of Processor Module. The ASW initialises, through the BSW, the software which implements the Nominal Modes.
Other non-nominal situations are the response of the spacecraft to CIR and SIR signals, and to FDIR level 3a failures. The CDMU can generate SIR and CIR signals, which will lead to the activation of Sun acquisition and (Earth) pointing, respectively.
In these cases, the spacecraft is requested to make certain autonomous mode transitions and acquire certain default attitudes. The modification of the ARAD thresholds cannot be done autonomously by the spacecraft (ground needed), and it is not wanted to be in an ACMS mode with the ARAD threshold not tuned for it (mainly applicable on a transition to SAM with the threshold set to low, that may trigger the ARAD due to the SAM maneuvers themselves).
The strategy to cope with SIR, CIS and FDIR 3a alarms without forcing mode transitions that would need threshold changes (autonomous thresholds changes are not permitted) is presented hereafter.
<u>For the SIR signal:</u>
When the Planck ACMS is in OCM and the SIR signal changes to "SIR in progress", the ACMS ASW commands an auto-transition to OCM and initiates a manoeuvre with null target delta-V and pointing towards a predefined anti-Sun pointing attitude, defined by the Angular Momentum direction Hsir stored in the SGM.
The ARAD threshold value does not need to change.
When the Planck ACMS is in HCM or SCM and the SIR signal changes to "SIR in progress", the ACMS ASW commands a transition to HCM and initiates a slew manoeuvre towards a predefined anti-Sun pointing attitude, defined by the Angular Momentum direction Hsir stored in the SGM.
When the Planck ACMS is in SAM and the SIR signal changes to "SIR in progress", the ACMS ASW ignores the SIR status.
Note that Hsir is supposed to be coincident with the anti-Sun pointing.
<u>For the CIR signal:</u>
When the Planck ACMS is in OCM and the CIR signal changes to "CIR in progress", the ACMS ASW commands an auto-transition to OCM and initiates a manoeuvre with null target delta-V and pointing towards a predefined attitude, defined by the Angular Momentum direction Hcir stored in the SGM.
When the Planck ACMS is in HCM or SCM and the CIR signal changes to "CIR in progress", the ACMS ASW commands a transition to HCM and initiates a slew manoeuvre towards a default attitude, defined by the Angular Momentum direction Hcir stored in the SGM.
When the Planck ACMS is in SAM and the CIR signal changes to "CIR in progress", the ACMS ASW ignores the CIR status.
<u>For an FDIR 3a reset:</u>
When the PM selection delay indicates "nominal" and the RM flag reads high threshold phase, the ACMS autonomously enters SAM (from SBM after restart).

When the selection delay indicates "nominal" and the RM flag reads low threshold phase, the ACMS autonomously enters HCM (from SBM after restart) and initiates a slew manoeuvre towards a predefined anti-Sun pointing attitude, defined by the Angular Momentum direction Hsir stored in the SGM.
With this strategy, no ARAD threshold adjustment is needed after an autonomous mode transition caused by CIR/SIR/level 3a.

9.5.2.2.2 Sun Acquisition Mode (SAM)

The Sun Acquisition Mode is the ACMS mode that the spacecraft uses to acquire the Sun and to maintain an anti-Sun pointing for the spacecraft X axis. It is used to start maneuvering after separation from the last stage of the launcher, and to stay safely in non-science phases of the mission. The attitude of the spacecraft in SAM is Sun pointing, with nominal spin rate and small nutation.
SAM has been designed to provide the spacecraft with the capability to quickly make a Sun acquisition, and to keep this pointing by just needing a new manoeuvre every two or three days.
The strategy designed consists of two pulses per acquisition, the first one being called "Recovery pulse" and the second one "Cancellation pulse". Each pulse is executed with one thruster of each of the three 20 N thruster pairs, therefore with three thrusters actuating at the same time. The combination of one individual thruster of each pair can provide any torque direction in the spacecraft frame by means of smartly tuning the on-times.
From any kinematic conditions at the start of the Sun acquisition manoeuvre, the aim of the manoeuvre is to put the spacecraft with its angular momentum (H) direction pointing in the anti-Sun direction, and with no nutation, that is, with the angular velocity vector in the same direction as H. Each pulse applies a torque to the spacecraft that changes the direction of its angular momentum vector by adding a delta-H to it. With a pulse, made with three thrusters, the spacecraft is able to modify its current H vector to any value. Whatever the initial conditions
are, if a manoeuvre is to be done, the first pulse, or "Recovery", brings the H vector to the mid point between the Sun Vector and the X principal axis. In addition, the pulse is designed in a way that the H norm remains the desired one, not to change the spin rate of the spacecraft. This is possible because three thrusters can generate any delta-H targeted (but with the limitations of their own thrust level).
The typical motion of the vectors, according to the mechanics of the rotation is as follows: H stays fixed in the inertial frame (unless external torques are applied). The Sun vector stays as well fixed in the inertial frame. The X principal axis (XP) rotates around H at a rate slightly higher than the spin rate (some 7°/s). Since the aim of the manoeuvre is to put the three vectors together, and after the "Recovery" pulse H is between XP and the Sun, XP starts turning around H, and 180° later (some 25 s) it arrives to the position of Sun. In that very same moment, the "Cancellation" pulse is executed, bringing H where the Sun and XP are, grouping them altogether.
After this second pulse the manoeuvre is finished, the spacecraft stays safely in its spinning state that gives it gyroscopic stiffness.
In SAM, the ACMS performs a manoeuvre every time that the maximum bounds of nutation, Sun Aspect Angle of the X principal axis, or spin rate, are exceeded. Once the manoeuvre is executed, the spacecraft keeps quiet until the bounds are exceeded again. Therefore, the "Recovery" pulses, and the subsequent "Cancellation" pulses, can be triggered by three means:

1. Spin rate out of bounds. The tuneable bounds depend very much on the CRS errors. The baseline is to command maneuvering when the spin rate exceeds a delta of 0,25°/s (positive or negative) from its nominal value of 6°/s. It is not foreseen that during nominal operations in SAM, the manoeuvre would be triggered by this reason, but it may be the triggering reason at separation from the launcher or at mode entry if the entry condition is with non-nominal spin rate.
2. Nutation out of bounds. High nutation is not desired, since it means that there is a high transversal angular velocity. The baseline is to command maneuvering when nutation exceeds 3° (tuneable). It is not foreseen that during nominal operations in SAM, the manoeuvre would be triggered by this reason, but it may be the triggering reason at separation from the launcher or at mode entry if the entry condition are with high nutation.
3. Sun Aspect Angle of XP. When the Sun has drifted outside some tuneable bounds, the manoeuvre is commanded.

The baseline is to command maneuvering when the SAA-XP exceeds 5° (tuneable). It is foreseen that this would be the typical triggering reason when normal operations of the mode, since the Sun drifts one degree per day from H and XP. The Sun Sensor errors and CRS errors would probably not allow the spacecraft to wait five days before a new manoeuvre, but maneuvers every two or three days are foreseen.

The total time for the manoeuvre, including the two pulses, is some 30 s.
With critical initial conditions well outside the nominal operational domain and nominal separation conditions, for example with large Sun Aspect Angles, one manoeuvre composed of one "Recovery" and one "Cancellation" pulse may not be enough to acquire the Sun pointing state. The final conditions at the end of the "Cancellation" would probably not be already within the actuation bounds. This is mainly because the larger the angles are, the worse the linearisation of the algorithms works. In this case, a new manoeuvre, again with one "Recovery" and one "Cancellation" pulses, would be executed in the same way as described in this section, and so on until the Sun is acquired.
Sun Acquisition Mode consists of three states:

- Recovery state. It is the state where the first pulse of the manoeuvre, the so-called "Recovery" pulse, is computed and executed.
- Cancellation state. It is the state where the second pulse of the manoeuvre, the so-called "Cancellation" pulse, is computed and executed. In order to have some tranquilisation period, and to let the CRS measurements be actualised before checking again whether the attitude is within bounds or not, the Cancellation state does not finish immediately after the Cancellation pulse is being performed, but waits some 1,5 s.
- SAM Hold. It is the state active when stable anti-Sun pointing attitude has been acquired, with reduced nutation and nominal spin rate. This state is active until the conditions of the spacecraft imply that a new manoeuvre is needed.

Figure Modes-12 presents these states in the context of the SAM logic:

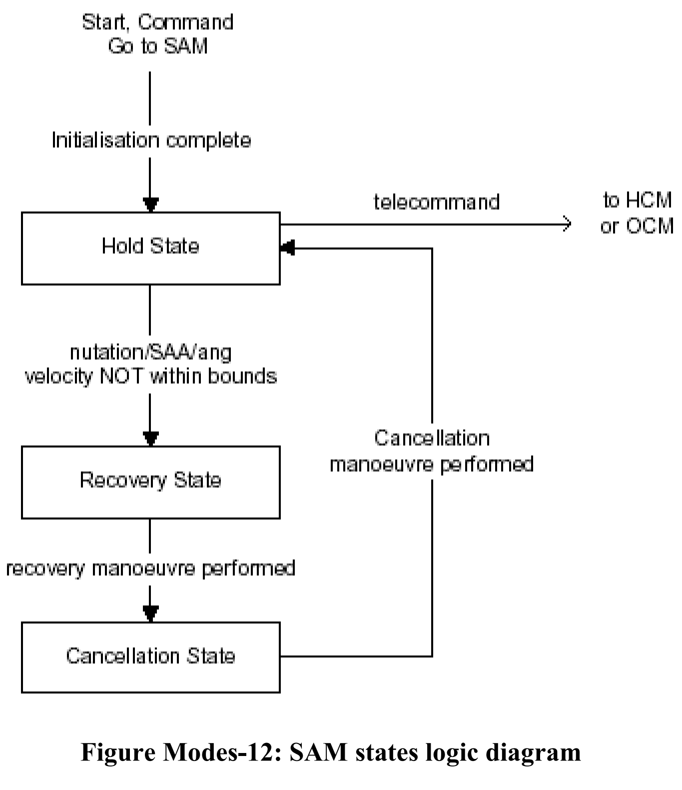


Figure Modes-12: SAM states logic diagram

9.5.2.2.2.1 SAM sensors and actuators

The sensors used for the SAM maneuvers are one CRS, the SAS X and the SAS+Y.
The actuators used for the SAM maneuvers are the six 20 N thrusters, namely two UP thrusters, two FLAT thrusters, and two DOWN thrusters. The six torque directions of these six thrusters make an algebraic base where any torque vector has positive (or zero) components in three of the axes. Any torque direction and magnitude in the body frame can be obtained by smartly combining one thruster of each pair and tuning their on-times.

9.5.2.2.2.2 SAM entry/exit modes and conditions

SAM can only happen with the RM thresholds phase set to high.
The possible mode transitions are:

- Entry Mode:
  - From SBM: autonomously when SBM has completed.
  - From SCM: by TC.
  - From OCM: by TC.
- Exit Mode:
  - To OCM: by TC.
  - To HCM: by TC.

Before entry into SAM, the spacecraft checks if the following conditions are met:

- At least one RCS branch is healthy.
- The SAS in the configuration in use is healthy.
- The CRS in the configuration in use is healthy.
- The ACMS mode of origin is OCM or SCM.
- The direction of the actual angular momentum (Hactual) is within the allowed domain (with respect to the Sun vector) for a SAM transition.
- No CIR nor SIR signals are present.

If any of these conditions is not met, the mode transition command is rejected.

9.5.2.2.3 Survival Mode (SM)

The Survival Mode is the ACMS mode where the spacecraft goes as a consequence of the following reasons: a severe failure has occurred, or the Sun Aspect Angle safe domain is violated, or the nutation threshold is exceeded, or the spin rate thresholds are exceeded. SM is a critical ACMS mode, because it must protect the loss of the whole mission in the case of attitude emergency. It ensures quick return to the safe attitude and its stable maintenance.
The drivers for the design of this mode are the capability to react as soon as possible after mode initialisation, in order not to exceed the contingency domain (if a transition to SM has taken place, it may mean that the safe domain limit has been exceeded) and the time to get back inside the safe domain (the ACMS shall not allow a transient outside the safe domain for more than one minute). With SM, the ACMS guarantees that Planck does not make unacceptable excursions out of the contingency domain in contingency situations, and that it recovers the safe domain in less than one minute.
The attitude determination scheme and the control logic scheme are identical to the ones described for SAM.
Both SAM and SM make the same maneuvers in the same way. At transition to SM, a quick Sun acquisition manoeuvre is executed if needed. It is composed by two pulses, the "Recovery" pulse and the "Cancellation" pulse. With the manoeuvre, the Planck X axis is pointed in the anti-Sun direction, being the spacecraft with nominal spin rate and small nutation. In the same way as in SAM, keeping this pointing needs a new manoeuvre every two or three days.
Like in SAM, the "Recovery" pulses, and the subsequent "Cancellation" pulses, can be triggered by three means: spin rate, nutation, or SAAXp. The triggering values for actuation are the same as in SAM (0,25°/s of spin around 6°/s, 3° of nutation, 5° of Sun Aspect Angle of the X principal axis).
SM can be exited only by ground command, once the failure has been analysed and solved

9.5.2.2.3.1 SM states

Planck implements three different states in SM:

- SM Recovery state. It is the state where the first pulse of the manoeuvre, the so-called "Recovery" pulse, is computed and executed.
- SM Cancellation state. It is the state where the second pulse of the manoeuvre, the so-called "Cancellation" pulse, is computed and executed. In order to have some tranquillisation period, and to let the CRS measurements be actualised before checking again whether the attitude is within bounds or not, the Cancellation state does not finish immediately after the Cancellation pulse is being performed, but waits some 1,5 s.
- SM Hold. It is the state active when stable anti-Sun pointing attitude has been acquired, with reduced nutation and nominal spin rate. This state is active until the conditions of the spacecraft imply that a new manoeuvre is needed.

Figure Modes-13 presents the different states in the context of the SM logic.

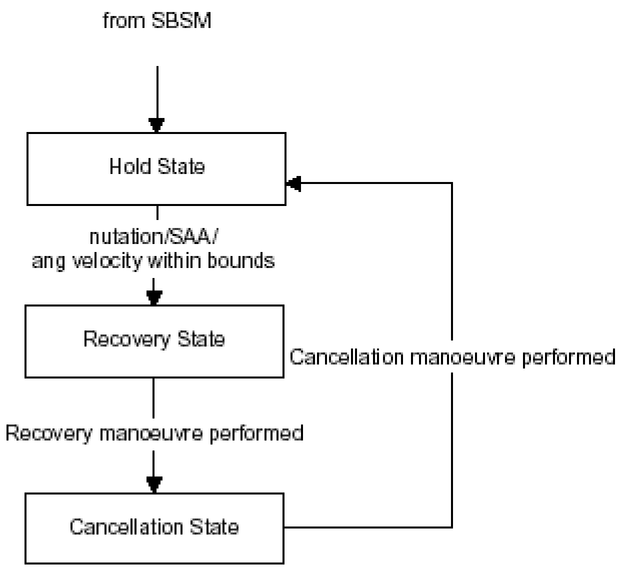


Figure Modes-13: SM state diagram

9.5.2.2.3.2 SM sensors and actuators

The sensors used for the SM maneuvers are one CRS, the SAS X and the SAS+Y.
The actuators used for the SM maneuvers are the six 20 N thrusters, namely two UP thrusters, two FLAT thrusters, and two DOWN thrusters. The six torque directions of these six thrusters make an algebraic base where any torque vector has positive (or zero) components in three of the axes. Any torque direction and magnitude in body frame can be obtained by smartly combining one thruster of each pair, and tuning their on-times.

9.5.2.2.3.3 SM entry/exit modes and conditions

The possible mode transitions are:
Entry Mode
From SBMSM: This transition takes place autonomously when SBMSM has completed. SBMSM can be entered:
From SAM: This transition takes place by initialisation of the ACC in Survival modes.
From SCM: This transition takes place by initialisation of the ACC in Survival modes.
From OCM: This transition takes place by initialisation of the ACC in Survival modes.
From HCM: This transition takes place by initialisation of the ACC in Survival modes.
From SBM: This transition takes place by initialisation of the ACC in Survival modes.
Exit Mode
To SBM: This transition takes place by initialisation of the ACC in Nominal modes.
SM cannot be entered by software, it needs a hardware reset of the PM and start in SBMSM.
SM cannot be exited by software, it needs a hardware reset of the PM and start in SBM.

No entry conditions are checked at transition to SM.

9.5.2.2.4 Science Control Mode (SCM)

The Science Mode is the ACMS mode that the spacecraft uses to gather the science data by the payload.
Planck is a spinning satellite. The telescope is fixed to the body axes, and the rotation of the satellite is used to scan the sky. For every period of observation, the angular momentum vector is fixed in the inertial frame since no external torques are applied. The spacecraft and, therefore, the LOS of the payload, rotates around the angular velocity vector at the nominal rate of 1 rpm (6°/s).
The typical period of data gathering between maneuvers is foreseen to be 45 minutes. Within one spin cycle, the scientific instrument sweeps a ring in the celestial sphere with a scan angle of 85°. Throughout the 45 minutes, the instruments point 45 times to each point of the ring. To go to the following target attitude, the spacecraft leaves SCM and enters HCM, where a nominal manoeuvre of about 3 arcmin is performed, and comes back to SCM to collect the science data in the new pointing. In this way, the spacecraft follows a predefined scanning law, observing the full sky sphere throughout the year. The celestial sphere is fully covered by the whole envelope of different orientations of the spin axis.
The pointing performances specified for the mission, although obtained with maneuvers in HCM, are computed in the science periods, therefore in SCM.
Since no maneuvers are performed in SCM, it is a fully passive mode, where the thrusters are disabled.

9.5.2.2.4.1 SCM states

Science Mode is not subdivided into states.

9.5.2.2.4.2 SCM sensors and actuators

The sensor used for the SCM maneuvers is the STR. No actuators are used in SCM.

9.5.2.2.4.3 SCM entry/exit modes and conditions

The possible mode transitions that involve SCM are:
Entry mode:
From HCM: This transition can take place autonomously or by CDMU telecommand.
Exit mode:
To HCM: This transition takes place by TC.
To OCM: This transition takes place by TC.
To SAM: This transition takes place by TC.

Before entry into SCM, the spacecraft checks if the following conditions are met:
- At least one STR is in the communication configuration and if this STR is healthy or (data temporarily) unavailable (no STR reconfiguration is being done).
- The ACMS mode of origin is HCM.
- No CIR nor SIR signals are present.

If any of these conditions is not met, the mode transition command is rejected.

9.5.2.2.5 Orbit Control Mode (OCM)

The Orbit Control Mode is the ACMS mode that the spacecraft uses to perform all the foreseen delta-V maneuvers, namely dispersion correction maneuvers (after separation from the launcher and during the transfer to L2), injection into L2 orbit manoeuvre, and periodic station keeping maneuvers at L2.
The OCM has been designed to provide the spacecraft with the capability to perform, autonomously without ground intervention, from very small to very large orbit maneuvers.
The strategy designed consists in an on-board delta-V bookkeeping function. This function estimates on-board, in each ACMS cycle, the delta-V that is being executed. It does this by means of integrating the thrust commanded to the thrusters over the thrust-on time in the STR measured spacecraft attitude and with the estimated thrust level and spacecraft mass. Once computed, the estimated executed delta-V is subtracted from the total delta-V to be obtained. In this way, the spacecraft can keep track of the ongoing manoeuvre (note that there are no accelerometers on board), deciding when it is accomplished.
This strategy is needed due to the stringent delta-V requirements and the length of some of the maneuvers (up to 325 m/s in the case of injection into L2, leading to some tens of hours, and up to 10 m/s in the case of dispersion correction, leading to about one hour and a half, in the worst dispersion correction scenario).
Since Planck is a spinning spacecraft, the classical way of executing orbit maneuvers in rotating spacecraft is used. The pulses are executed within a certain duty cycle of the spin period. A (tunable) duty cycle of 10% of each complete revolution of 360°, i.e. thrusting during 36°, is chosen as a compromise solution after a trade-off between duration and efficiency of the manoeuvre. In this way, the spacecraft waits until it is approaching the desired thrust direction in its rotation, then makes a set of pulses for about 36°, and waits almost one full revolution until the following thrust window appears. By means of thrusting, waiting, thrusting, waiting, , the spacecraft is slowly completing the desired delta-V.
Three pairs of thrusters are mounted on the spacecraft for orbit control. Each pair of thrusters provides force in one direction in the spacecraft frame. By appropriately combining pairs of thrusters, any direction in the spacecraft body frame can be achieved. By means of waiting to the desired spin phase, any inertial direction can be obtained.
In addition, the OCM has to make compensation of attitude deviations during the pulses. The combination of pure delta-V thrustings results in an undesired torque to the spacecraft every spin revolution. This torque is precomputed, and on-modulation of certain thrusters is fed-forward to the thrusters to compensate this effect.
Nominally, using this strategy, the spacecraft would not deviate from its attitude during the delta-V manoeuvre.
The reality is that uncertainties in the sensor measurements, thrusting pulses, on-board knowledge of the inertia tensor and the centre of gravity, etc., lead to a random attitude deviation after every set of pulses. To cope with this fact, the OCM checks the attitude after every delta-V thrusting. If the attitude deviates more than a predefined value with respect to the ideal attitude for the maneuvers, the ACMS stops the delta-V maneuvers, corrects the attitude, and resumes the delta-V maneuvers afterwards. This may imply that one delta-V window is lost when the attitude correction manoeuvre is needed, and therefore one spin cycle does not have delta-V pulses.

It may happen as well that no delta-V window is lost, and the next delta-V pulse can be executed in the same spin cycle as the correction pulse. It depends on the direction of the deviation of the attitude.
The attitude correction, both the precomputed compensation of the torques of the delta-V pulses themselves, and the correction of random residual attitude deviations after the pulses, are obtained by a combination of one individual thruster of each pair. Different combinations can provide any torque direction in spacecraft frame, by means of smartly tuning the on-times. Therefore the orbit control thrusters are used as well for attitude control.
Figure Modes-14 shows the high level OCM logic design.

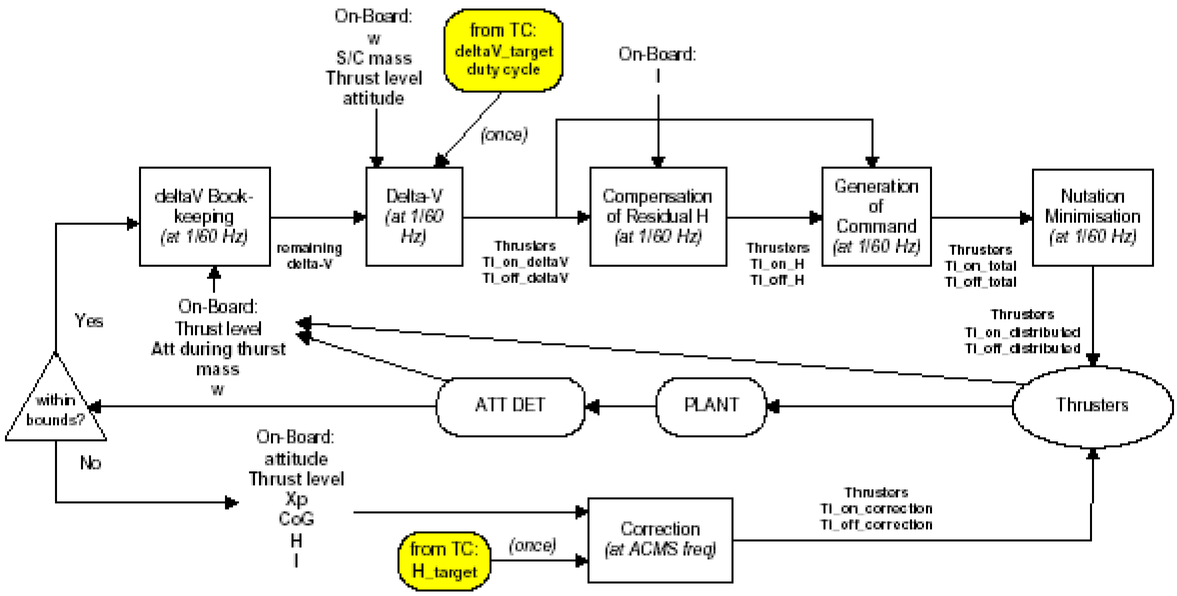


Figure Modes-14: OCM logic design flow chart

The on-board execution of the manoeuvre can be summarised as follows:

1. Inertial delta-V is fed as input to the control algorithms. The on-board software computes the actuation times for each thruster.
2. A feed-forward torque is commanded to cancel the residual torque induced by the delta-V maneuvers.
3. A decomposition into several pulses of the pulses that may excite high nutation during the thrusting transient is done.
4. Bookkeeping strategy before performing the next delta-V manoeuvre is done:
   - On-board computation of the cumulated inertial thrust using the thrust-on times, the actual attitude during thrusting, the thrust level, and the spacecraft mass.
   - Next delta-V command computed by comparison between target and on-board estimation of the delta-V.
5. Attitude correction is performed if necessary.

To give a feeling, simulations show that typically one attitude correction dedicated manoeuvre is needed every five to ten delta-V pulses, that is, every five to ten minutes. But this is very dependent on the delta-V direction in the body frame, on on-board inertia tensor and centre of gravity estimations, and on RCS errors.

9.5.2.2.5.1 OCM states

Planck implements four different states in OCM:

- Delta-V. It is the state where the delta-V pulses, together with the precomputed compensation of the torques, are computed and executed.
- Correction. It is the state where the attitude correction pulses, are computed and executed.
- Inhibit. It is the entering state of the mode. In addition, inhibit is the state of the spacecraft after any thrusters pulse. It is used to wait until the attitude determination algorithms converge to a value that can be used by the control. This operation takes about ten seconds due to initialisation of the attitude determination functions after mode transition or pulse execution. This state provides tranquilisation of the spacecraft after the pulses.
- Post delta-V. It is the state obtained after the spacecraft estimates that the delta-V pulse has been already executed. The spacecraft compares the cumulated delta-V executed by any pulse (both delta-V pulses and correction pulses) to the target delta-V, and goes to this state if the difference is below a predefined value. In addition, this mode is used when the Abort OCM telecommand is received or when the timeout for the manoeuvre is exceeded.

The following figure Modes-15 presents the different states in the context of the OCM logic.

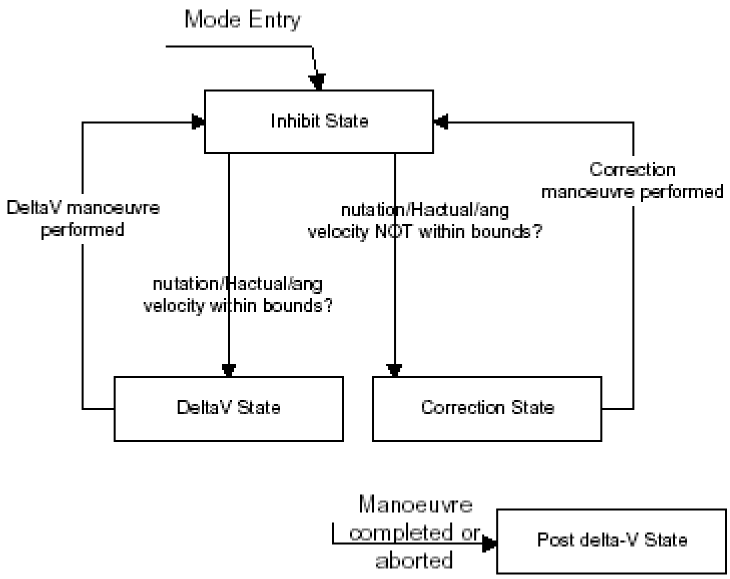


Figure Modes-15: OCM state flow diagram

9.5.2.2.5.2 OCM sensors and actuators

The sensor used for the OCM maneuvers is the STR.

The actuators used for the OCM maneuvers are the six 20 N thrusters, namely two UP thrusters, two FLAT thrusters, and two DOWN thrusters.

The driver for the selection of the different thrust directions was the injection into L2 manoeuvre. Therefore dedicated thrusters (FLAT) were accommodated to perform this manoeuvre with the maximum efficiency (TAA = 128°, being TAA the Thrust Aspect Angle, or angle of the thrust vector with respect to X body axis, that is nominally the Sun vector direction for the manoeuvre). The other two pairs were accommodated to provide the delta-V maneuvering capability for TAA above 128° (DOWN) or below 128° (UP). Each FLAT, UP and DOWN thrusting comprises two thrusters that nominally will generate small torque in the spacecraft when thrusting together. For most of the cases, combinations of two pairs of thrusters would be used altogether.

9.5.2.2.5.3 OCM entry/exit modes and conditions

The possible mode transitions depend on the current ACMS RM thresholds phase (low or high):

When in Low Threshold Phase:
Entry Mode:
From SCM: This transition takes place by TC.
From OCM: This transition takes place by SIR signal, CIR signal or by TC.
Exit Mode:
To HCM: This transition can takes place by TC.
To OCM: This transition can takes place by SIR signal, CIR signal or by TC.

When in High Threshold Phase:
Entry Mode:
From OCM: This transition takes place by SIR signal, CIR signal or by TC.
From SAM: This transition takes place by TC.
Exit Mode:
To OCM: This transition can take place by SIR signal, CIR signal or by TC.
To SAM: This transition can take place by TC.

Before entry into OCM, the spacecraft checks if the following conditions are met:
- At least one RCS branch is healthy.
- At least one STR is in the communication configuration and if this STR is healthy or (data temporarily) unavailable (no STR reconfiguration is being done).
- The ACMS mode of origin is SAM (RM high-threshold phase only), SCM (RM low-threshold phase only) or OCM.
- The direction of the angular momentum commanded for the manoeuvre (Htarget) is within the allowed domain (with respect to the Sun vector) for an OCM manoeuvre.
- The direction of the actual angular momentum (Hactual) is within the allowed domain (with respect to the Sun vector) for an OCM transition.
- No CIR nor SIR signals are present.

If any of these conditions is not met, the mode transition command is rejected.

9.5.2.2.6 Angular Momentum Control Mode (HCM)

The Angular Momentum Control Mode is the ACMS mode that the spacecraft uses to perform the slew maneuvers within the operational domain, aiming to acquire the different pointings needed for the science data gathering in SCM. The HCM has been designed to provide the spacecraft with the capability to perform accurately from very small to very large slews. The specifications for Planck require the orbit maneuvers to be performed with an accuracy of 0,1 arcmin.
The HCM supports three types of maneuvers. The first two are: Small Slews part of the science scanning law, and occasional Large Slews needed to repoint the spacecraft to a distant target. These two types of maneuvers are computed and commanded in a different way by the mode logic. In addition, a third type of manoeuvre appears from the fact that sometimes, in order to slew to a target pointing, the current nutation of the spacecraft has to be removed first. Therefore, the HCM supports as well dedicated Nutation Damping maneuvers, that again are computed and commanded in a different way than the Slews and the Large Slews themselves.
The HCM accepts commands in the form of target vectors for the Angular Momentum (Htarget) in the inertial frame. Exactly in the same way as in SAM and OCM, the HCM logic implements its maneuvers in terms of delta-H with respect to the current angular momentum. By changing the H direction, the spin axis is changed to its new target pointing. H is fixed in inertial space, and the spin axis rotates around it. The angle between the spin axis and H should be minimal, so that the spin axis stays as fixed as possible in inertial space and the pointing budgets are met. The angle between H and the spin axis is directly related to the nutation, so the nutation should be near zero at transition to SCM in order to meet the requirements.

The HCM mode logic autonomously decides which of the three types of maneuvers the spacecraft should execute, by comparing its current pointing to the commanded pointing, and by checking the spacecraft current nutation. Figure Modes-16 illustrates this decision logic. First, the ACMS computes the total angle for the slew, i.e. the angle between the current H and the Htarget. If the angle is lower that 10 arcmin (that is a tuneable parameter), a Slew is chosen. If the angle is higher, a Large Slew is chosen. Once the ACMS has decided which manoeuvre to command, it checks whether the manoeuvre can be performed without needing to damp the existing nutation first or not. If the nutation is small enough, the spacecraft can perform the Slew or the Large Slew and damp the existing nutation at the same time, with the Slew or Large Slew control logic itself (this is why it is called "combined slew & nutation damping"). If the nutation is large compared to the size of the slew, a dedicated Nutation Damping manoeuvre is needed first.

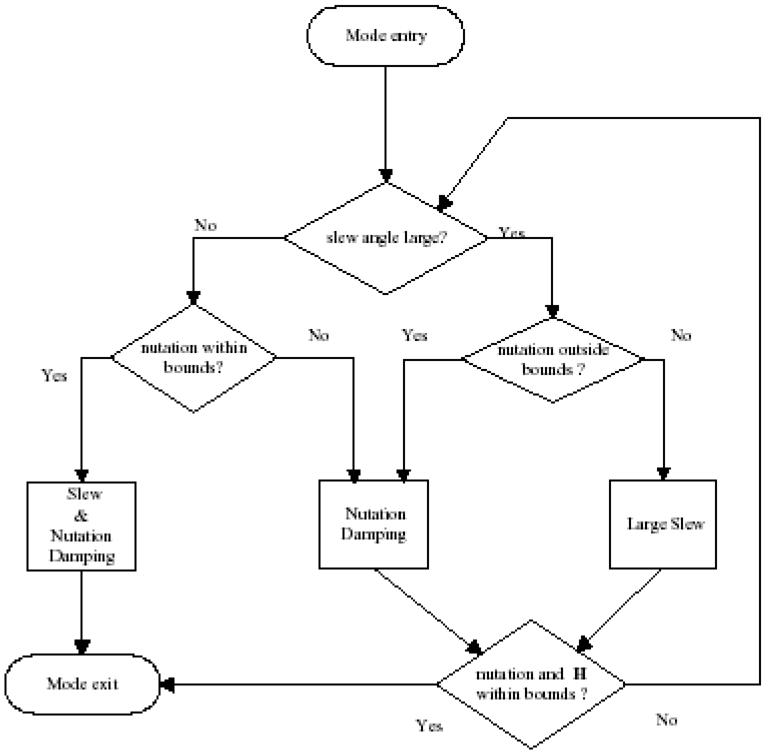


Figure Modes-16: HCM logig diagram

Contrary to the case of the 20 N thrusters, the spacecraft does not have full torque capability with 1 N thrusters.

9.5.2.2.6.1 HCM states

Planck implements two states in HCM:
- HCM Maneuvering state. It is the state where the slew pulses are executed.
- HCM Inhibit state. It is the entering state of the mode. In addition, inhibit is the state of the spacecraft after any thrusters pulse. It is used to wait until the attitude determination algorithms converge to a value that can be used by the control. In addition, the on times for the thrusters are computed in this state, just before transition to HCM Maneuvering state.

In addition, the spacecraft can be in Manoeuvre state in three different Activities, Slew, Large Slew, and Nutation Damping, depending on the manoeuvre that is being executed.
The following figure Modes-16 presents the different states in the context of the HCM logic.

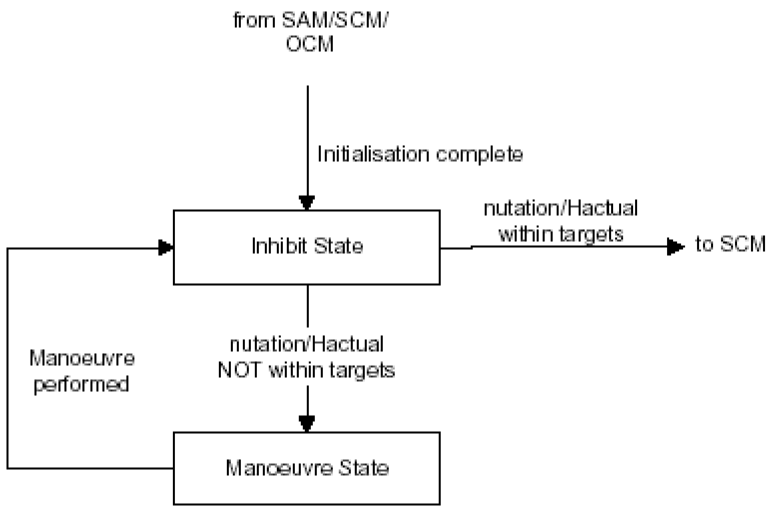


Figure Modes-16: HCM state diagram

9.5.2.2.6.2 HCM sensors and actuators

The sensor used for the HCM maneuvers is the STR.
The actuators used for the HCM maneuvers are the two 1 N thrusters.

9.5.2.2.6.3 HCM entry/exit modes and conditions

The possible mode transitions depend on the current ARAD threshold phase (Low or High).

In Low Threshold phase:
Entry mode:
From SBM: At SBM completion
From SCM: This transition takes place by telecommand, or when a CIR/SIR signal is raised in SCM
From OCM: This transition can take place by telecommand
From HCM: This transition can take place by telecommand, or due to a CIR/SIR signal raise in HCM
Exit mode:
To SCM: This transition can take place autonomously or by telecommand

In High Threshold phase:
Entry mode:
From SAM: This transition can take place by TC.

From SCM: This transition takes place when a CIR/SIR signal is raised.
From HCM: This transition can take place due to a CIR/SIR signal raise.
Exit mode:
To SCM: This transition can take place autonomously or by TC.

Before entry into HCM, the spacecraft checks if the following conditions are met:
- At least one RCS branch is healthy.
- At least one STR is in the communication configuration and if this STR is healthy or (data temporarily) unavailable (no STR reconfiguration is being done).
- The ACMS mode of origin is SAM (high-threshold phase only), SCM (low-threshold phase only), OCM (low-threshold phase only), or HCM.
- The direction of the angular momentum commanded for the manoeuvre (Htarget) is within the operational domain (with respect to the Sun vector).
- No CIR nor SIR signals are present.

If any of these conditions is not met, the mode transition command is rejected.

9.5.3 ACMS FDIR design and principles

9.5.3.1 Driving requirements

The major principle applied for guaranteeing the safety of the spacecraft is that the detection of system failures (level 4 FDIR) and the recovery are independent from nominal system functions. This is implemented with an hardware Attitude and Rate Anomaly Detection (ARAD) function.
The safe-mode software (SBSM and SASM) uses control algorithms that are independent from the control algorithms of the nominal software (SBM and SAM), but it does reuse common functions. The correctness of these reused functions is guaranteed by extensive code reviews and thorough testing.
In addition, the following requirements were considered driving for the design:

- No Single Point Failures allowed.
- Redundancy is present.
- Power dips, Double Event Upsets, and OS/Basic SW failures are considered as real failures, which will lead to a computer reset or a switch to the redundant ACC (Survival mode).
- Hierarchical structure: the FDIR design follows the concept of having five levels, and the checks are to be organised into a hierarchy.
- False alarms are to be avoided: for this purpose spike filtering is foreseen. In addition, data redundancy is sometimes used, and possible mode changes of units are taken into account.
- Two FDIR modes of operation: Autonomous Fail Safe (AFS) and Autonomous Fail Operational (AFO) modes are used in the design.
- Flexibility: the software will be maintainable, the parameters (thresholds) of the health checks will be updateable database parameters, and all checks and unit reconfigurations can be disabled.
- Safe attitude domain not to be exceeded: this is interpreted to mean that the combination of the FDIR checks, and reconfiguration logic/timing is such that the safe zone will not be exceeded.
- Major attitude control error detection: an independent Attitude and Rate Anomaly Detector (ARAD) function itself is used which signals independently of the ACC to the ACC Reconfiguration Module that the safe attitude region is violated or that the allowed rate is exceeded. If so, a switch to the redundant ACC is made, and Survival Mode is entered.

9.5.3.2 Design principles

9.5.3.2.1 No single points of failure

This has been implemented by redundancy in the units and EDAC implementation. Table FDIR-01 shows the redundancy implemented in the units:

Unit	Redundancy
AAD	fully redundant channels
ACC	cold redundant
CRS	redundant sensor
GYR	three-out-of-four hot redundant sensor, cold redundant electronics
RWS	three-out-of-four hot redundant
SAS	all sensors fully redundant channels
STR	cold redundant unit

Table FDIR-01: Hardware redundancy for ACMS units

In case of Herschel, three GYR's are used at the same time for nominal control. The fourth GYR is hot redudant. Nominally, four RWL's are used in nominal control to meet the performance goals. In case of a RWL failure, the faulty RWL is switched off, and the remaining three RWL's are used. A slightly lower performance results.

Apart from the redundant units, cross-strapping exists within the ACC itself. The cross-strapping is shown in figure FDIR-02. The STR and GYR are coupled to the PMs via a redundant 1553 databus.

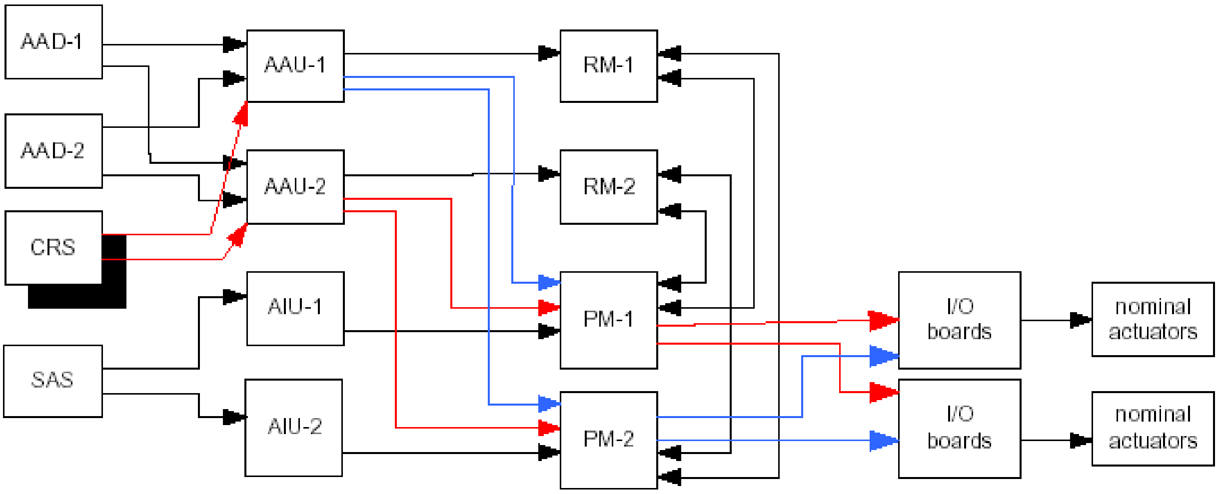


Figure FDIR-02: Cross strapping scheme within the ACC

9.5.3.2.2 Hierarchical structure

The FDIR concept is based on the observation that failures can manifest themselves on different levels. The failure levels are split up into five main levels (level 0 to level 4) characterised by:

- the **severity** of the failure;
- the functions involved in the **detection** of the failure (hardware or software functions);
- the **recovery** sequence.

This is also indicated in the following table:

Level	Functional	Scope	Detection Recovery
0	Unit	Unit	Unit
1	Unit	Communication ASW	ASW
2	Spacecraft positioning function	ASW	ASW
3	ACC (Computer)	independent software/hardware	independent hardware
4	System	independent hardware	independent hardware

Table FDIR-03: FDIR hierarchy

The effects of failures can propagate from one level to another. The ACMS must detect and handle internal failures on the five levels of severity, in ascending order:

- Level 0: Failures local to a unit that can be locally recovered and that do not impact functions outside the unit. These failures must be reported in TM, mostly through regular status telemetry from the ACMS units. Also recoverable ACC failures can occur such as a single-bit EDAC error. These must be recovered and reported by the ACMS BSW.
- Level 1: Failure of a unit (level 1a) or a unit s communication interface (level 1b), which can be recovered by reconfiguring to the redundant path. The ACMS ASW must check unit data and communication status to detect these failures.
- Level 2: Failure of an ACMS function, caused by propagation of undetected unit failure or otherwise. Inter-unit crosschecks are used for detection. Examples are the GYR Sum/Diagnostic check, and the implementation of autonomous unloading of angular momentum in SCM to recover from failure of the biasing function.
- Level 3: Failure of the ACC to properly execute the ACMS SW. The ACC reports internally detected failures (SW alarm, Under Voltage Detection, etc.) In addition, the BSW sends watchdog signals to the ACC_RM, which checks whether the watchdog signal toggles. After a failure (level 3a), two attempts to reset the PM are made. After the second unsuccessful attempt, a switch to Survival Mode will be initiated by the ACC_RM (level 3b). The ASW facilitates also CDMU level 3 failures, by taking actions when a System In Reconfiguration (SIR) or Computer In Reconfiguration (CIR) signal from the CDMU is true.
- Level 4: Failure of the ACMS to keep the attitude within safe bounds is detected and recovered the Attitude and Rate Anomaly Detector (ARAD) function which is implemented in hardware. Independent Sun Sensor and Rate Sensor hardware is used. Triggering of the ARAD causes the ACC-RM to switch the ACC Processor Module. The redundant ACC is configured to initialise Survival Mode, which uses sensors/actuators which were not used when the failure occurred, i.e. SAS-SM, CRS-SM and RCS-SM. Which physical units to use is defined in the Survival Mode Configuration, which is stored in protected memory (RM register).

The units will have local checks, and possibly local reconfiguration possibilities. The units report the error and possible reconfiguration to the ACC.
The ACC located power-on check verifies whether the power-on command to a unit was successful.
For the ACC it is important to trust the data. This means that the ACC must determine whether the communication is healthy in case of digital communication interface. This will be done by checking the 1553 protocol in case of a 1553 MIL bus and by checking an alive signal from the unit (STR/GYR). Also the broadcast check is considered to be a communication check.

- Housekeeping data checks are simple in-range checks on unit housekeeping data, like a temperature. Also error reports of the units which need to be handled by the ASW are subject to the H/K data checks.
- Continuity checks determine whether the output of a unit is consistent over a certain period of time. Several types of continuity checks can be distinguished:
- Simple data-in-range checks.
- Static checks, where repetition of data is checked (frozen data failure detection).
- Model continuity checks, where a model is used to make a kind of prediction of the new measurement. Examples are the expected velocities after RCS and RWL torque requests.

The FDIR concept results in a number of checks to be performed by the ASW. The detailed hierarchy of checks is depicted in figure FDIR-04.
The CRS check and the FCV status check are for Planck only, whereas the checks involving the GYR and RWL are for Herschel only.

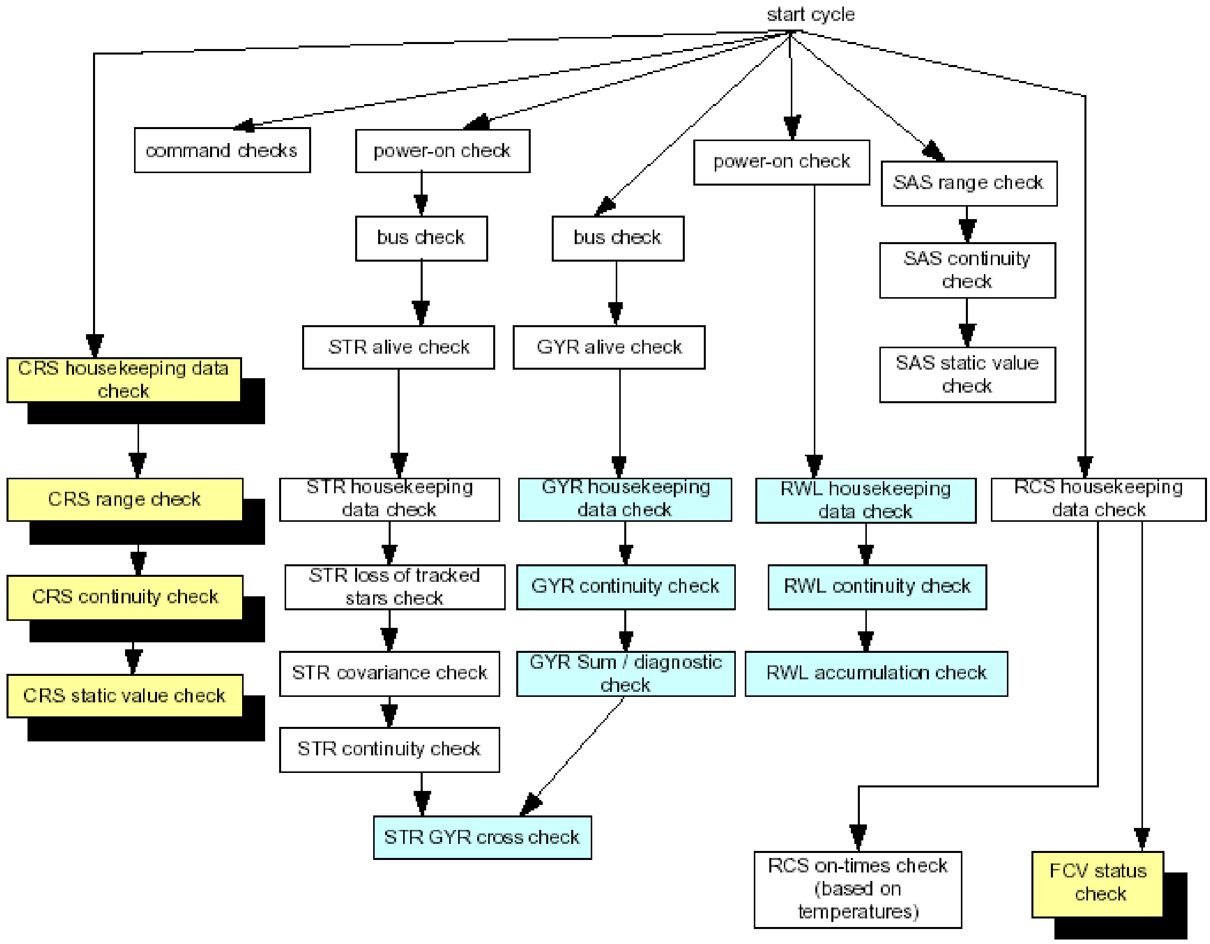


Figure FDIR-04: Health checks for FDIR functions

9.5.3.2.3 No false alarms

Checks are performed on the units which are being used and which are going to be used, i.e. all units which are in the Configuration In Use. For instance, in SAM when having powered the STR after TC, the STR which is in the configuration in use is already subject to the STR health checks, although in SAM the STR is not really used yet. This is done, because at a mode transition one wants to have healthy units which are used in that mode.
An exception is the Bus check, which checks all powered units which are in the Communication Configuration (but may not be in the Configuration In Use). But reconfiguration is only done if the faulty unit is in the Configuration In Use.
A distinction is made between the data validity and the health of the units. The two are related, but not the same: Data can be invalid for a certain period of time, whereas the unit is healthy: STR loss of stars, initialisation and warm up times, SEUs. However, this situation cannot last forever, and the unit must be considered unhealthy if this situation lasts too long.
When a unit becomes unhealthy, the data is to be considered invalid.
Due to the required spike filtering, it is possible that a "unit health check" concludes that the data is invalid (and thus that data replacement or other measures have to be taken), but not yet reconfiguration is to be done (i.e. the status is "unavailable").
Concluding:

- The unit health status drives the reconfiguration.
- The data validity drives the data replacement.

9.5.3.2.4 FDIR modes

The autonomous reaction to a detected failure depends on the ACMS FDIR mode:

Autonomous Fail Safe (AFS):
Detected anomalies of units will be reported as events and shown in telemetry, but the ACMS will not respond to them. Serious problems will lead to a trigger of the ARAD and transition to Survival Mode.

Autonomous Fail Operational (AFO):
The ACMS will autonomously reconfigure to the redundant RWL, GYR or STR if it detects a failure in one of these units. The purpose of this reconfiguration is to minimize the impact of failure on the mission time line.

The RCS must be checked but not reconfigured autonomously. After an RCS check triggering the unhealthy RCS branch is no longer used/commanded. For safety it is relied on the level-4 function (ARAD).
The SAS and CRS (Planck) are not reconfigured, because the redundant units are used in Survival Mode. The default FDIR mode after a cold ASW initialization is AFS. Therefore, during the Sun Acquisition state of SAM, a reconfiguration will never be initiated by the ASW. In the Sun Pointing state of SAM, Science Mode, Orbit Control Mode, and Angular Momentum Control Mode (Planck), it depends on the FDIR mode whether reconfiguration is allowed.
In AFS mode: checks will still be active, and units can still be declared unhealthy as a result of the checks data replacement is done when invalid data is detected stopping actuation (RCS) is allowed unit reconfigurations (STR, RWL, GYR) are not allowed, unless Ground decides otherwise by TC The allowed set of unit reconfigurations can be changed by TC both in AFS and AFO mode. After a hot start, i.e. after a computer reset, the ASW determines the actual FDIR mode from SGM.

9.5.3.2.5 Contingency domain excursions

The worst case design case is that the ACC, containing malicious SW, commands a valid thrust command to two thrusters simultaneously causing the satellite to leave the safe region. The ASW checks will not detect that the RCS is unhealthy, because the ACC ASW sends valid commands, and the RCS itself is healthy.
For this scenario, the most likely failure case is as follows.
When the attitude is at the edge of the operational zone, the velocity going "outside" the operational zone equals zero. Consequently when a failure occurs the initial speed in the contingency direction equals zero. Now two situations can be distinguished:

- The rate threshold of the ARAD is exceeded before the edge of the safe zone is passed. This implies that the size of the available contingency zone can be enlarged with the "unused space" of the safe zone.
- The rate threshold of the ARAD is exceeded after passing the edge of the safe zone. This means that the ARAD triggers on the attitude (AAD), and the initial velocity for the analysis is lower.

9.5.3.2.6 Flexibility

9.5.3.2.6.1 Enabling/disabling

Each separate check, safing and reconfiguration can be disabled by means of the command DISABLE. The reconfiguration can be disabled for each unit separately. For instance, switching to the redundant STR can be disabled, while a reconfiguration to a redundant GYR is still possible.
Also the transition to Survival Mode can be disabled, by disabling the individual alarms in the RM. Each separate function can be enabled (again) by means of the command ENABLE.
The triggering in the Reconfiguration Module can be disabled at different levels:
- The alarm from each individual sensor
- The total Reconfiguration Module reaction

Disabling FDIR functionality will be considered as a critical command, which requires a kind of confirmation.
The disable/enable status is maintained by the ASW in SGM. The default status after a cold start-up is "enabled", except for the LV status check. After a hot start, the ASW reads the status from SGM.

9.5.3.2.6.2 Reversing

Reversing a disable action can be done by enabling the function again. When enabling a check, the check becomes active (in principle), and the number of failures is reset to zero.
Reversing autonomously executed reconfiguration is more complex.
In order to reverse the reconfiguration, first the unit which was declared unhealthy (the cause of the reconfiguration) must be declared "healthy" again.
Further, in case of a reconfiguration to a hot redundant unit, a command to modify the configuration in use is sufficient. For instance, for the GYR a selection of GYR 1, 2, 3, 4 has to be specified.
In case of switching to a cold redundant unit, Ground needs to be involved to reverse the reconfiguration. The Ground needs to switch on the original unit, change the configuration in use, optionally switch off the other unit, and in some cases command mode transitions.
In case of reconfiguration to the redundant databus, Ground can enforce the use of the other bus. In case of a transition to Survival Mode, the role of Ground is evident. Commands to the CDMU to switch the ACC power are needed, temporarily disabling RM functionality, selecting the appropriate configuration in use, mode transitions etc. need to be done.
Note that changing the configuration in use cannot be coupled to the Power On command, because Ground must be able to verify a redundant unit independently of the use of the main unit.

9.5.3.2.6.3 Modifiable parameters

All parameters used in the checks or other FDIR related functions in the ASW will be updateable database parameters.
Also for the units with S/W/firmware it is required to be able to modify key parameters.
In the ARAD, trigger thresholds are updateable parameters.
Changing parameters in the database does not require disabling the function for which the parameter values are changed. Disabling the associated function does not add anything to the safety. After the database load, the function would have to be enabled anyway, with potentially the wrong parameter value, to continue operation. The database loads must have been verified by Ground prior to uploading. In addition, the ARAD still remains operational. Moreover, if during a database load process for a check the checks remain operational, safety is better guaranteed.

9.5.4 ACMS Budget summary

In table Budget-01 are summarized the actual performance of the Herschel ACMS. For detailed description refers to the "ACMS Pointing budget Report" (H-P-4-ANA-TN-001, section 5.1).

	HERSCHEL REQ		HERSCHEL PERF	
	Half Cone X axes (")	About X axes (')	Half Cone X axes (")	About X axes (')
APE pointing	2.25 / 0.21 / 0.24	2.0	1.13 / 0.32 / 0.24	0.3
Goal	*1.10*	-	*1.21*	-
APE scanning				
At ω sec/s	2.70 + 0.045 ω	-	1.31 + 0.0001 ω	-
Goal	*1.10 + 0.027ω*	-	*1.01 + 0.0003 ω*	-
PDE				
24 hours	0.35	2.95	0.35	0.14
RPE pointing				
60 sec	0.24	1.30	0.24	0.03
RPE scanning				
60 sec	1.07	1.3	0.88 + 0.0001ω	0.13
Goal	*0.78*	-	*0.81 + 0.0001ω*	-
AME	1.62 / 0.21 / 0.24	2.0	1.13 / 0.32 / 0.18	0.29
Goal	*0.75*	-	*1.17*	-
AME scanning				
At ω sec/s	2.07 + 0.027 ω	2.0	1.29 + 0.0001 ω	0.24
Goal	*0.75 + 0.018 ω*	-	*1.00 + 0.0002 ω*	-
SRPE				
Pointing	0.98 arcsec		1.40 arcsec	

Table Budget-01: Herschel ACMS performances wrt ACMS requirements

In table Budget-02 are summarized the actual performance of the Planck ACMS. For detailed description refers to the "ACMS Pointing budget Report" (H-P-4-ANA-TN-001, section 5.2).

	PLANCK REQ		**PLANCK PERF**	
	LOS (')	**Around LOS (')**	**LOS (')**	**Around LOS (')**
AME				
Required	0.48	1	0.223	0.204
Goal	*0.16*	-	*0.086*	-
APE				
Long term	33	35.1 (total)	0.249	15.749 (total)
Short term	1.5		0.925	
PDE				
Required	6.18	6.18	1.733	0.435
RPE				
Required	1.5	10	0.229	0.242
PRE				
Required	2.4	-	1.832	-
ARE	5.4 arcmin/sec		0.607 arcmin/sec	
Rotation Rate Stability	10^{-4} rpm		6.46×10^{-5} rpm	
Accuracy of spin axis depointing (up to 3')	0.4 arcmin (relative to the previous inertial target)		0.265 arcmin (relative to the previous inertial target)	

Table Budget-02: Planck ACMS performances wrt ACMS requirements

9.6 RCS

This chapter describe the major Subsystem and/or Equipment design. They are procured on the basis of the hereafter listed specification (included in the CDR data Package).

RCS Requirement Spec. H-P-SP-AI-0002 3 [RD-53]
Performance Specification for the Herschel/Plank Propellant Tank H-P-RILAM-SPE-0001 1
RCS Reaction Control Thruster Specification 10N-20N Thruster H-P-RILAM-SPE-0003 2
Procurement Specification-Propellant Filter-Hydrazine SystemMBST-RILAM-PS-1631-01 2
RCS Reaction Control Thruster Specification - 1N Thruster H-P-RILAM-SPE-0002 3
Procurement Specification for Fill and Drain Valve MBST-RILAM-PS-1640-01 1
Procurement Specification Latching Valve MBST-RILAM-PS-1652-01 2
Procurement Specification - Pressure Transducer MBST-RILAM-PS-1656-01 2

The major modification occurred from the PDR (June 2002) are hereafter briefly listed. Any details on the improved design with respect to the one presented at the PDR can be found in the applicable design report at Subsystem and/or Equipment level:
No major change occurred but only minor modification typical of phase C/D. The lay-out of the RCS piping has been optimised in terms of routing and mass. The Thruster positioning and the firing direction have been optimised and now frozen (for details see the next chapter and [RD-17].

9.6.1 General

The Reaction Control System (RCS) provides for both Herschel and Planck satellites the necessary forces and torque 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:
H-P-4-ASPI-SP-0019 "Requirements Specification" [RD-53]
H-P-1-ASPI-SP-0027 "General Design and Interface Requirements (GDIR)". [AD-12]
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:
- years for Herschel (GDIR: GDGE-210);
- 21 months for Planck (GDIR: GDGE-220).

The RCS components shall be selected to satisfy to the mission lifetime worst case of 4.5 years (GDIR: GDGE-240a).
Raising a propellant budget is not in the SVM scope, but the following propellant mass and required delta-vs are given for information for a better understanding of the RCS subsystem.

MANOEUVRE	Herschel Delta-V [m/s]	Planck Delta-V [m/s]	MARGINS (%)
Compensation for perigee velocity variation	10	10	0
Removal of launcher dispersion	40	40 + 20 (moon)	5
Manoeuvre 2 on day 12 from Perigee	4	4	5
Mid-course correction	3	3	5
Orbit injection and eclipse avoidance	0	225	0
Correction for injection	0	5	5
Orbit maintenance for mission lifetime	4.5	2.5	H: 39, P: 35
Orbit maintenance due to ACMS	4.4	2	H: 39, P: 35
Attitude Control	7.8	SEE NUTATION DAMPING	H: 39
Active Nutation Damping	0	7.8	P: 35

Figure 9.6.2.1-1 Δ-V Requirements for Herschel and Planck

Herschel 134 kg (within the 260 kg of Req. Spec.: RCP-030-H);
Planck 346 kg (within the 390 kg of Req. Spec.: 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 (Req. Spec.: RCD-055-C)
- the location and direction of the thrusters shall be selected to avoid, or at least minimise, contamination and plume impingement effects (Req. Spec.: RCD-065-C).

9.6.2.3 Design Requirements

Both Herschel and Planck RCS's shall be based on hydrazine propulsion system (Req. Spec.: RCD-005-C).

The feeding of propellant shall be in blow down mode (Req. Spec.: RCD-010-C) and nitrogen shall be used to pressurize the propellant (Req. Spec.: 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 (Req. Spec.: RCD-040-C).

Isolation of each branch from the fuel tanks shall be possible to prevent inadvertent firings.

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 (Req. Spec.: 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.

20N 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.
The RCS selected baseline is designed to work in blow-down mode starting from a BoL to EoL, with a blow-down ratio of 4:1.
The BoL pressure chosen is 21.4 bars @ 20 °C. The EoL pressure is calculated to be 5.5 bars @10 °C. This resuls is a maximum expected operating pressure (MEO) of 24 bars. However, in launch configuration up to the mission phase where the latching valve are commanded to be open, the pressure downstream the latching valve can increase, for temperature effects, up to the back pressure relief which can be between 2 and 12 bars. Therefore, the pressure downstream latching valve close can raise up to 36 bars.

The propellant is loaded via a common Fill and Drain valve. The pressurant (nitrogen) is loaded separately by means of one fill and vent valve per tank.
Each branch is equipped with a test port, to facilitate the internal leak check of the components. The pressure in the tanks is monitored by a Pressure Transducer.

Two Latch valves isolate the two thruster branches. A filter, upstream the Latch Valves prevent the branches from any contamination.

The RCS layout is shown in Figure 9.6.3.1-2.

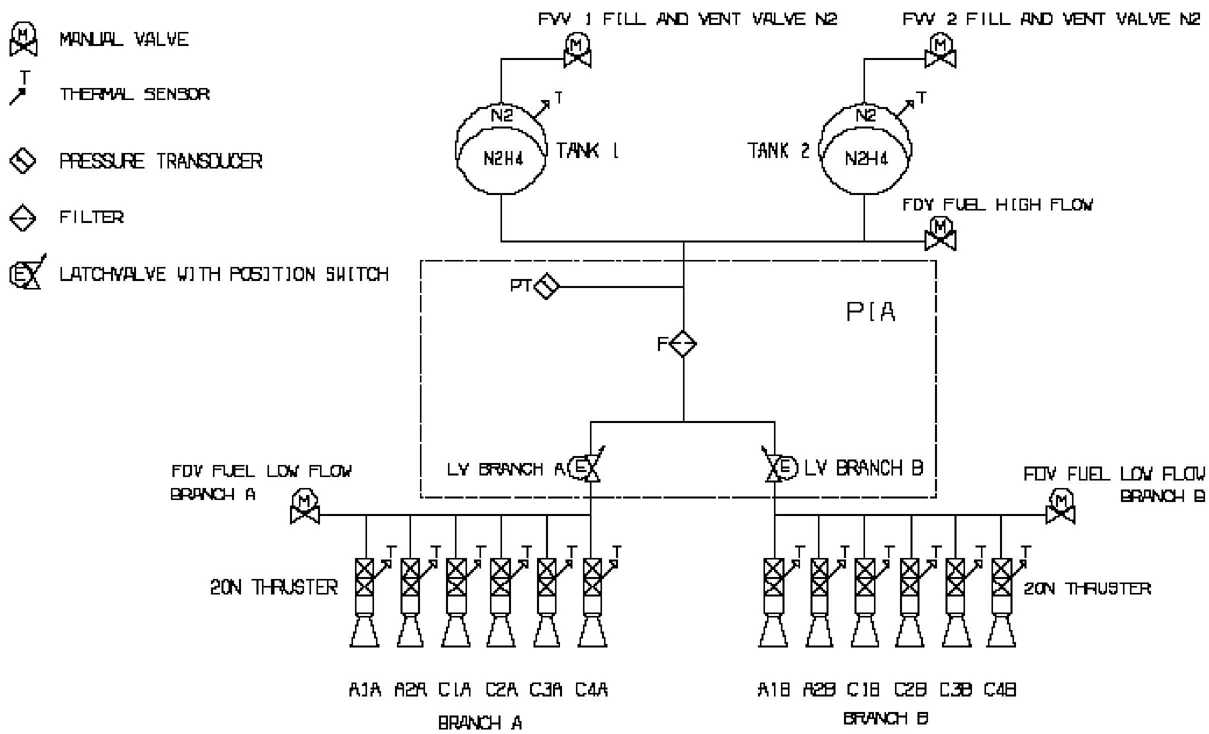


FIGURE 9.6.3.1-1 HERSCHEL RCS FUNCTIONAL DIAGRAM

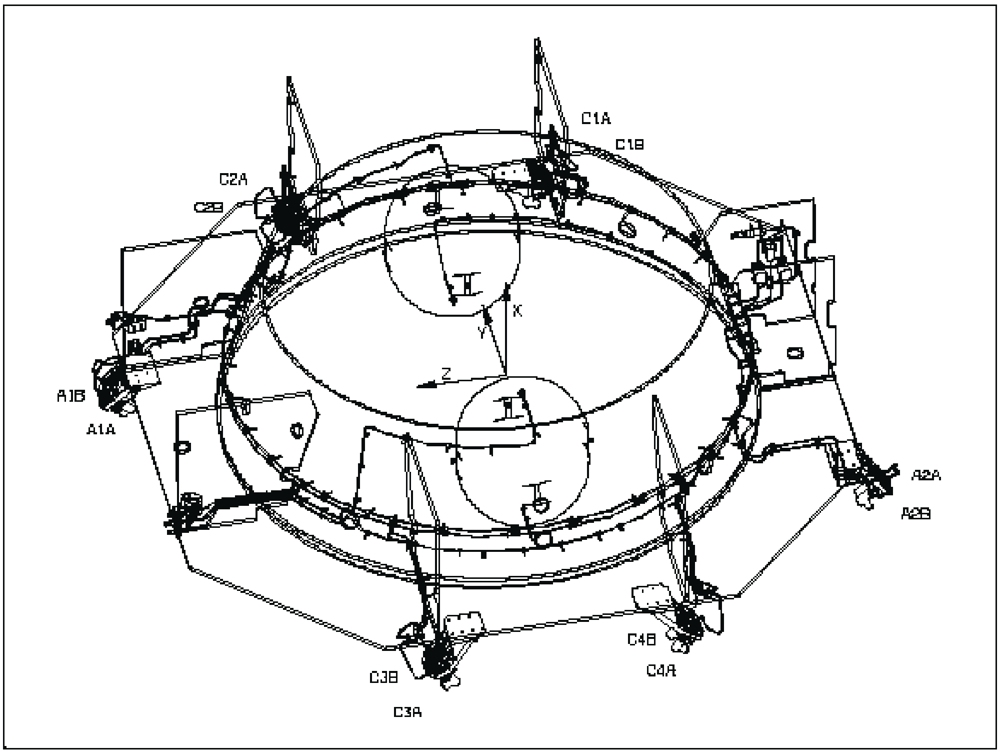


FIGURE 9.6.3.1-2 HERSCHEL RCS LAY-OUT

The Herschel RCS configuration is shown in the following Figure 9.6.3.1-3. The thruster configuration and the chosen angles are such that plume impingement on other S/C parts is avoided.

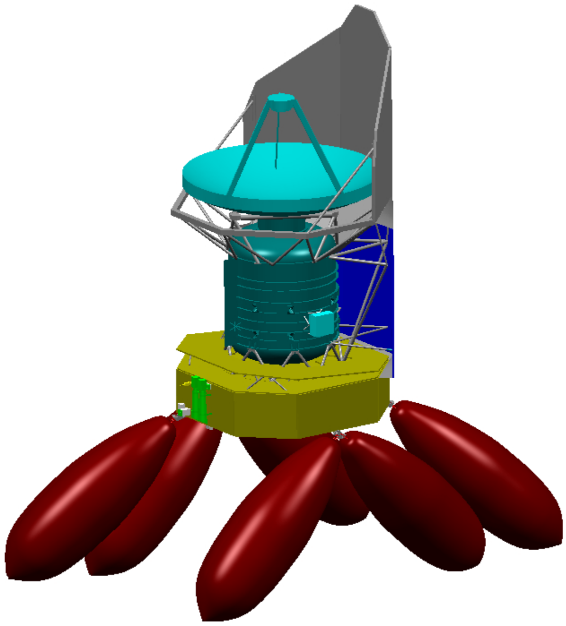


FIGURE 9.6.3.1-3 HERSCHEL RCS Configuration

Two 20N 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						
Thruster Number	Location			Exhaust direction		
	x [mm]	y [mm]	z [mm]	x [1]	y [1]	z [1]
A1A	-102.6	571.1	1635.0	-0.77333	0.20586	0.59966
A2A	-145.8	-772.6	-1649.6	-0.77177	-0.27304	-0.57430
C1A	-113.4	1700.0	-546.1	-0.57358	0.00000	-0.81915
C2A	-113.4	1700.0	546.1	-0.57358	0.00000	0.81915
C3A	-113.4	-1700.0	546.1	-0.57358	0.00000	0.81915
C4A	-113.4	-1700.0	-546.1	-0.57358	0.00000	-0.81915
A1B	-95.1	657.4	1616.3	-0.76996	0.23719	0.59237
A2B	-118.6	-859.3	-1640.0	-0.76274	-0.30312	-0.57126
C1B	-113.4	1610.0	-546.1	-0.57358	0.00000	-0.81915
C2B	-113.4	1610.0	546.1	-0.57358	0.00000	0.81915
C3B	-113.4	-1610.0	546.1	-0.57358	0.00000	0.81915
C4B	-113.4	-1610.0	-546.1	-0.57358	0.00000	-0.81915

Table 9.6.3.1-4 Herschel Thruster Layout

9.6.3.2 Planck RCS Description

Three fuel tanks, with a positive expulsion device (diaphragm) are implemented.
The RCS selected baseline is designed to work in blow-down mode starting from a BoL to EoL, with a blow-down ratio of 4:1.
The BoL pressure chosen is 21.4 bars @ 20 °C. The EoL pressure is calculated to be 5.5 bars @10 °C. This resuls is a maximum expected operating pressure (MEO) of 24 bars. However, in launch configuration up to the mission phase where the latching valve are commanded to be open, the pressure downstream the latching valve can increase, for temperature effects, up to the back pressure relief which can be between 2 and 12 bars. Therefore, the pressure downstream latching valve close can raise up to 36 bars.

The propellant is loaded via a common Fill and Drain valve. The pressurant (nitrogen) is loaded separately by means of one fill and vent valve per tank.
Each branch is equipped with a test port, to facilitate the internal leak check of the components. The pressure in the tanks is monitored by a Pressure Transducer.

Two Latching valves isolate the two thruster branches. A filter, downstream the Latching Valves prevent the branches from any contamination.

The Planck RCS functional diagram is shown in Figure 9.6.3.2-1.

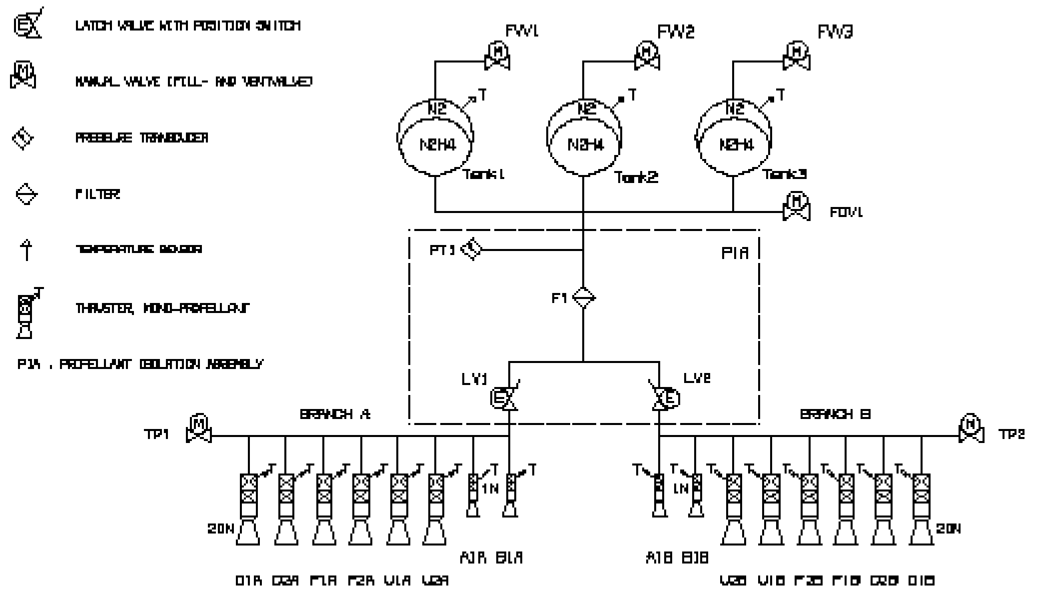


Figure 9.6.3.2-2 PLANCK RCS FUNCTIONAL DIAGRAM

Two thruster branches, main and redundant constitute the Planck RCS. The thrusters are the 20N and 1N monopropellant hydrazine types. There are three tanks, with a positive expulsion device (diaphragm). They supply the propellant to both the branches in blow down mode from a maximum of 24 bar down to 5.5 bar. Two Latching valves isolate the two branches. The propellant is loaded via a common Fill and Drain valve. The pressurant (nitrogen) is loaded separately by means of one Fill and vent valve per tank. Each branch is equipped with a test port, to facilitate the internal leak check of the components. The pressure in the tanks is monitored by a Pressure Transducer. A filter, downstream the Latching Valves prevent the branches from any contamination.

The RCS layout is shown in Figure 9.6.3.2-2.

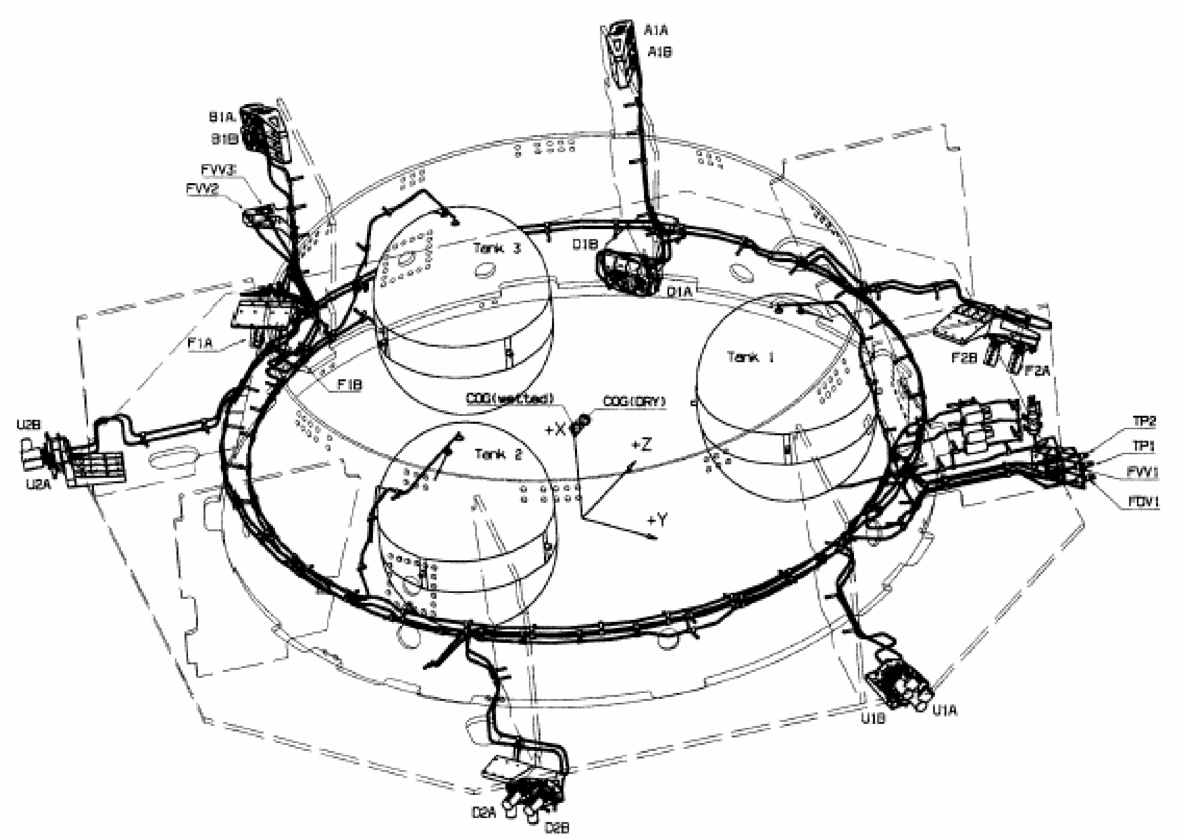


Figure 9.6.3.2-2 PLANCK RCS LAY-OUT

There are two different types of thrusters, 20N and 1N for, arranged in the following configuration:

- 3 pairs of 20N 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 about 127 de 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 .

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.

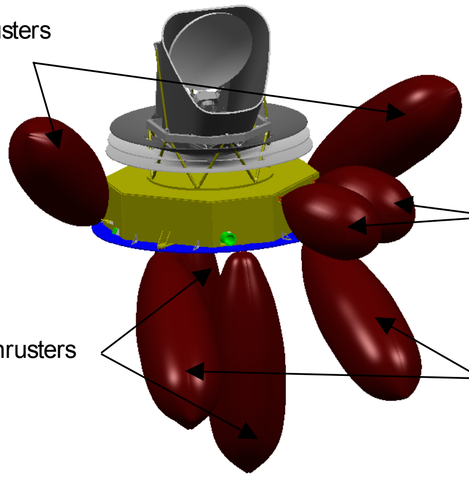


FIGURE 9.6.3.2-3 HERSCHEL RCS Configuration

The thruster layout for Planck is reported in Table 9.6.3.2-4.

PLANCK						
Thruster Number	Location			Exhaust direction		
	x [mm]	y [mm]	z [mm]	x [1]	y [1]	z [1]
D1A	-57.9	-575.4	1565.2	-0.99978	0.00790	0.01919
D2A	-61.1	575.4	-1565.2	-0.99978	0.00790	0.01919
F1A	-64.6	-1688.3	576.9	-0.61501	-0.26286	0.74342
F2A	-89.5	902.6	1571.8	-0.61501	-0.26286	0.74342
U1A	205.5	1837.8	-764.4	0.51558	0.59082	0.62057
U2A	208.1	-1840.7	-761.4	0.53113	-0.55607	0.63928
D1B	-57.9	-665.4	1565.2	-0.99978	0.00790	0.01919
D2B	-61.1	665.4	-1565.2	-0.99978	0.00790	0.01919
F1B	-70.1	-1602.9	604.7	-0.61000	-0.26314	0.74743
F2B	-68.9	816.5	1555.4	-0.61000	-0.26314	0.74743
U1B	281.7	1815.9	-808.5	0.45649	0.59118	0.66492
U2B	284.1	-1818.9	-805.2	0.47055	-0.55571	0.68540
A1A	826.5	-734.2	1718.1	-0.28343	-0.67811	0.67811
B1A	826.5	-1718.1	734.2	-0.28343	-0.67811	0.67811
A1B	740.2	-716.2	1700.1	-0.28343	-0.67811	0.67811
B1B	740.2	-1700.1	716.2	-0.28343	-0.67811	0.67811

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 Latching 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:

- Latching 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.

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 includes an elastomeric diaphragm used to separate the hydrazine propellant from the nitrogen pressurant and to limit liquid hydrazine sloshing. The tank internal volume is defined to allow a propellant growth of 20 %.

The baseline propellant tanks are those initially designed for use on the INTEGRAL RCS but, in order to comply with the H/P design requirements, the following changes are implemented:
The tank wall thickness is locally increased from 0.90 to 0.95 mm at the scalloped area;
The web thickness is increased from 13.9 to 16.5 mm.
These modification lead to obtain positive MoS for the environmental loads as well as to meet the 2 x MEOP burst safety factor requirement.
Besides, due to the utilization on Planck of the 1N Thruster, a new diaphragm material requested to be Silica free is under qualification at PSI (USA). This new membrane, named SIFA 35, will prevent the hydrazine contamination and, therefore, the reduction in the thruster performance can be excluded.

The tank shells, including the central ring, are forged and machined in Titanium 6Al 4V alloy in the annealed conditions.

Main characteristics of the propellant tank together with the mounting method inside the S/C are given in H-P-RILAM-RP-0002 “RCS Design Report”.

The tank will be submitted to a complete qualification in order to demonstrate its survivability w.r.t. the H/P mechanical environments (sine and random).

9.6.4.2.2 20 N Thrusters

The 20 N thrusters are used on both Herschel and Planck RCS's. This type of thruster has been designed, developed and qualified for the XMM/Integral satellites and, later, delta qualified for the MetOp program.
No delta mechanical qualification testing is needed for the 20 N thruster. Nevertheless, a shock test at assembly level (bracket + alignment plate + 2x20N thrusters) will be performed in order to ascertain its real dynamic behaviour to the H/P shock environment. In case the test fails, no modifications to the 20 N thruster are requested but the implementation of dedicated shock absorbers (already qualified and utilised for Integral Program) will adopted as recovery solution.
As far as the total amount of pulses and total accumulated firing duration are concerned, the qualification tests performed in the frame of EURECA, HAPS, XMM/Integral/MetOp Programs demonstrate that the selected 20 N is suitable to the H/P RCS.

The main characteristics of the 20 N thruster are reported in the following Table 9.6.4.2.2-1.

FUNCTIONAL PARAMETER	QUALIFICATION
Max thrust	24.0 N @ 22 bar
I_{sp}	228 s (@22 bar) - 215 s (@5.5 bar)
Minimum Impulse Bit	0.212 Ns (@22 bar) – 0.132 Ns (@5.5 bar)
Flow control valve	Dual seat, single coil, monostable

Table 9.6.4.2.2-1 20 N Thruster Characteristics

9.6.4.2.3 1 N Thrusters

The 1 N thrusters are used on Planck RCS' s only. The proposed thrusters were qualified in the frame of Globalstar Program but for their utilization on Planck a new qualification is needed with the following objectives:
hot firing qualification with exposed hydrazine
use of thermocouple fixed on the thruster (new installation)
increased number of pulses.

The scope of the qualification tests is to demonstrate design adequacy and that performance and safety of the equipment meet the specified levels according Planck requirements over the expected tange of operating conditions and environments.

The main characteristics of the 1 N thruster are reported in the following Table 9.6.4.2.3-1.

FUNCTIONAL PARAMETER	QUALIFICATION
Steady state thrust	1 N @ 22 bar to 0.32 N @ 5.5 bar
Steady state specific impulse	2185 m/s @ 22 bar to 2050 m/s @ 5.5 bar
Flow control valve	Dual seat, dual coil

Table 9.6.4.2.3-1 1 N Thruster Characteristics

9.6.4.2.4 Latching Valve

The same Latching Valve is used on both Herschel and Planck RCS' s.

The Latching 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 45 microns filter located at the inlet of the valve and it flows axially.

The latching Valve implements position status micro-switches to monitor the open and close position.

The latching valve provides a "back pressure relief" capability. In case of a pressure increase downstream the latching valve, the poppet will move back from the valve seat as soon as the force on the poppet (as a result of the downstream pressure) is higher than the spring force and, thus, will allow a pressure relief to the down stream system.

As far as the Latching Valve qualification status is concerned, no delta qualification tests are requested.

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.
Three different types of valves are used in the RCS H/P depending on the media used.
All the valves are qualified a MEOP level of 36 bar.
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.
No delta-qualification testing is needed to demonstrate the FDV/FVV compliance to the H/P requirements.

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.
No delta-qualification testing is needed to demonstrate the selected PT compliance to the H/P requirements.

9.6.4.2.7 Propellant Filter

The included filter traps the remaining particles carried by the propellant. The filtration rate is 20 micron absolute and the pressure drop is < 0.2 bar @ 63 g/s Hydrazine with 12 bar inlet pressure at 21 °C.
No delta-qualification testing is needed to demonstrate the selected PF compliance to the H/P requirements.

9.6.5 RCS Budget Summary

The mass, propellant/pressurant, power, temperature and leakage budgets are detailed in H-P-RILAM-RP-0002 “RCS Design Report” at the folowing paragraphs:

§ 6.7 Mass Budget
§ 6.10 Propellant/Pressurant Budget
§ 6.11 Power Budget
§ 6.12 Temperature Budget
§ 6.13 Leakage Budget

9.7 Control and Data Management

This chapter describe the major Subsystem and/or Equipment design. They are procured on the basis of the hereafter listed specification (included in the CDR data Package).

CDMU HW requirement specification H-P-SP-AI-0003 5 [RD-54]
ACC hardware requirement specification H-P-SP-AI-0008 5 [RD-55]

The major modification occurred from the PDR (June 2002) are hereafter briefly listed. Any details on the improved design with respect to the one presented at the PDR can be found in the applicable design report at Subsystem and/or Equipment level:

CDMU
Increase of PM EEPROM size from 1 (+1) Mbytes to 2 (+2) Mbytes.
Possibility of selection between 2 different SW images
Mass Memory operation changed from Cold to Hot Redundancy

ACC
Introduction of ACMS Auxiliary Unit Module for ARAD (Attitude and Rate Anomaly Detector)
Review of discrete I/O interfaces with other ACMS and RCS Equipment, in order to meet the Off-The-Shelf equipment characteristics
Increase of PM EEPROM size from 1 (+1) Mbytes to 2 (+2) Mbytes
Possibility of selection between 2 different SW images

9.7.1 General

This section provides the functional description of Control and Data Management Subsystem and gives a design overview of every single module with the relevant performances.

More details on S/S can be found in “CDMS Functional Description” H-P-TN-AI-0053, while this section is more oriented on Hardware description. For more details on CDMU, refer to the [RD-65] (P-HPL-NT-00021-SE).

The Control and Data Management has been suitably dimensioned to be compatible with both Herschel and Planck satellites. The CDMS provides such a high level of commonality to lead to an identical unit design for both Herschel and Planck SVMs.

Subsystem functions will be implemented in one Control and Data Management Unit (CDMU).

9.7.2 Requirements and Design Drivers

The Control and Data Management is designed in agreement with SVM Requirements Specification [AD-43]; functional requirements are given in para. 4.1.9, performance requirements are given in para. 4.2.9.
The main requirements of [AD-43] 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 encode/decode TM/TC packets:
  - Control and Data Management Unit (CDMU) is the Bus Controller on 1553 Data Bus, where Science Instruments, Power Control and Distribution Unit (PCDU), X-Band Transponders (XPND) 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 :
  - 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 .

  - In order to allow the transmission of the above telemetry modes, different Virtual Channels have been allocated to each mode.
  - As per SGICD [AD-07], the required bit rates are the following:
    - low bit rate: 500 bps, 5 kbps
    - medium rate: 150kbps
    - high rate: 1.5 Mbps

- The CDMS shall distribute all commands from ground, stored, and/or generated on board. The telecommand rate shall be switchable between the high bit rate of 4 kbps and low bit rate:
  - as per SGICD [AD-07], uplink low bit rate is 125 bps
  - uplink high bit rate is 4 kbps.

- All commands necessary to recover from the survival mode shall be executable on board without the intervention of on board software:
  - 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.
- The size of the on-board storage medium shall be sufficient to store all the mission data generated during 48 hours:
  - For this reason, the size of the mass memory shall be greater than 25 Gbit. Sizing justification is given in the following.
  - The major contributor to mass memory sizing is the payload, which generates average data rates up to 130 kbps.

Taking into account a 9 kbps average rate for satellite housekeeping (see TM/TC Budget [RD-116]), the required storage is 24 Gb. A mass memory of 25 Gb End of Life is planned on Herschel and Planck thus providing a further margin of 4 %.

- As required by SMCD-150, the mass memory shall behave as a disk unit to users and support a filing system. It shall support partial readout, manage free space and automatically mark bad areas; it shall make available on request information about free space, files stored and bad areas. It shall support simultaneous read and write operations.

Time distribution and time tagging function:

- The CDMS shall provide electrically isolated synchronisation signals and timing signals as required by the science instruments or spacecraft units:
    - as required by IID-A and IID-Bs [AD-01 to AD-06], 131072 Hz synchronisation signals have to be generated and distributed
    - Synchronisation between Local On Board Time and On Board Time will be achieved by synchronising a 1553 time code packet with a 8 Hz broadcast pulse generated within the CDMU.

9.7.3 Subsystem Overview

The Control and Data Management is devoted to the SVM and some payload units management.
The Control and Data Management functions are combined in a single **Control and Data Management Unit, CDMU**, partitioned into a Core system and I/O system, which is responsible for the following main functions:

- Data processing
- ESA Packet TC decoding
- ESA Packet TM generation and encoding
- TC distribution
- CDMU (and spacecraft) reconfiguration
- HK, Science data storage
- On Board Time generation and on-board users distribution
- Safeguard data storage
- Data exchange via I/O channels and MIL-STD-1553B bus with platform and payload units
- Data exchange via test and umbilical I/Fs.

In addition Basic Software (BSW) can be seen as an integral part of the CDMU. Its purpose is to handle hardware abstraction, runtime system and some higher level services.

The CDMU is a highly integrated unit where a processing function is available together with an extensive set of interface modules, enabling external interfaces with several other satellite units.

The following functional blocks can be identified:

- Telecommand Decoder, Telemetry Formatter, Safeguard memory, On Board Time and Reconfiguration Module housed in the TTR board.
- CPU, Communication I/Fs housed in the PM board
- Mass Memory Module
- Standard I/O interface (SBCH and SIOH)
- Power Converter

A Block Diagram of the CDMU is shown in the following figure.

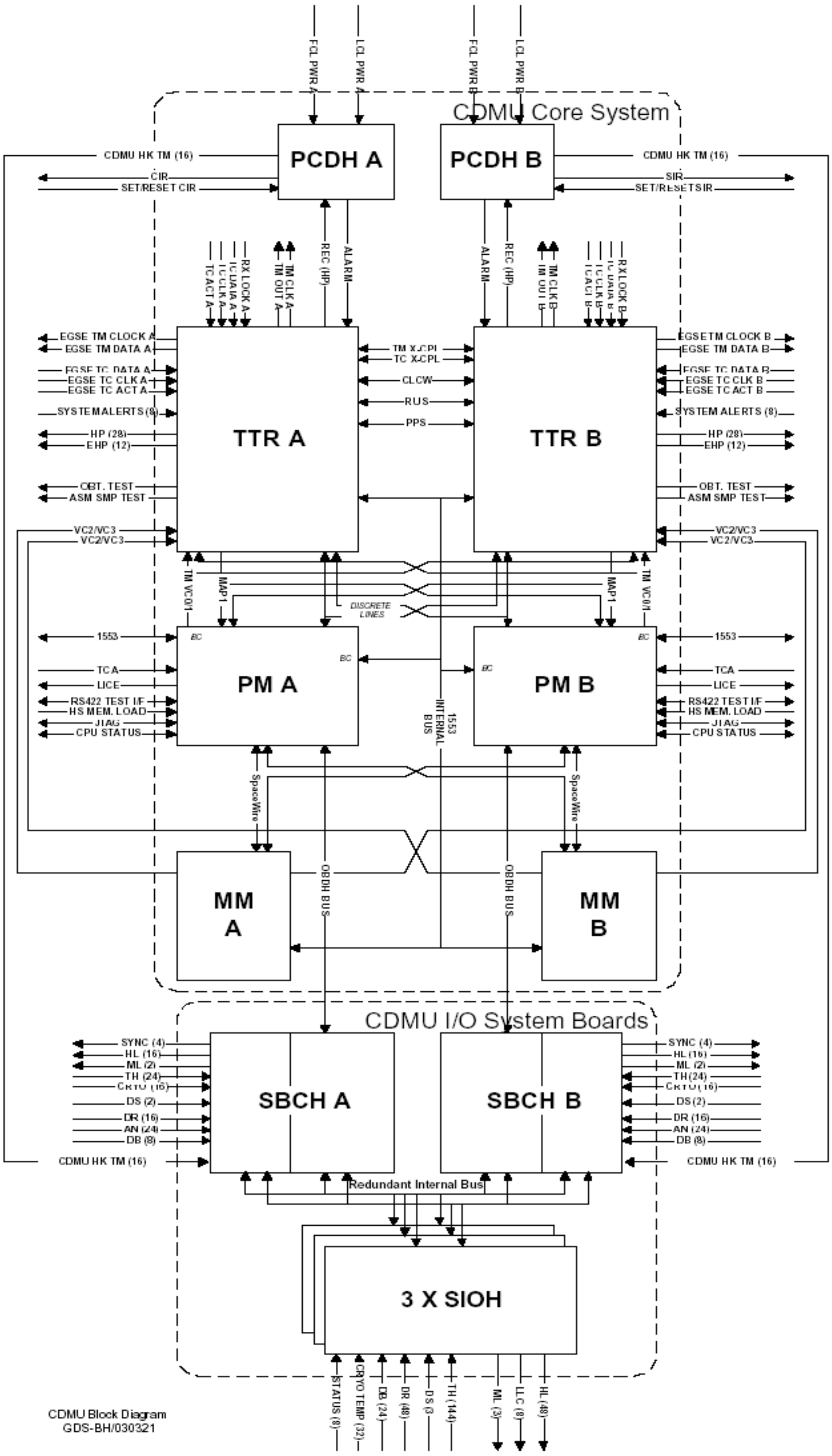


Figure 9.7.3-1 CDMU Functional Block Diagram

From the previous list the following blocks operate in redundancy mode:

- Blocks operating in hot redundancy with no power cross strapping:
    - Mass Memory (MM) A and Hot Power Converter A
    - Mass Memory (MM) B and Hot Power Converter B.

- Blocks operating in cold redundancy with no power cross strapping:
    - Processor Module (PM) A, Remote Core Function (RCF) A and Cold Power Converter A
    - Processor Module (PM) B, Remote Core Function (RCF) B and Cold Power Converter B.

- Blocks operating in hot redundancy with (partial) power cross strapping
    - Telemetry Telecommand & Reconfiguration (TTR) A and Cold Power Converter A
    - Telemetry Telecommand & Reconfiguration (TTR) B and Cold Power Converter B.

- Hot operating, non-redundant blocks. They are supplied from Cold Power Converter A or B. The redundancy achieved depends on how they are connected to the users:
    - Standard I/O Board (SIOH) 1
    - Standard I/O Board (SIOH) 2
    - Standard I/O Board (SIOH) 3
    - I/O part of Serial Bus Controller Board (SBCH) A
    - I/O part of Serial Bus Controller Board (SBCH) B

The Synchronisation Signal generation and distribution is shown in the following block diagram:

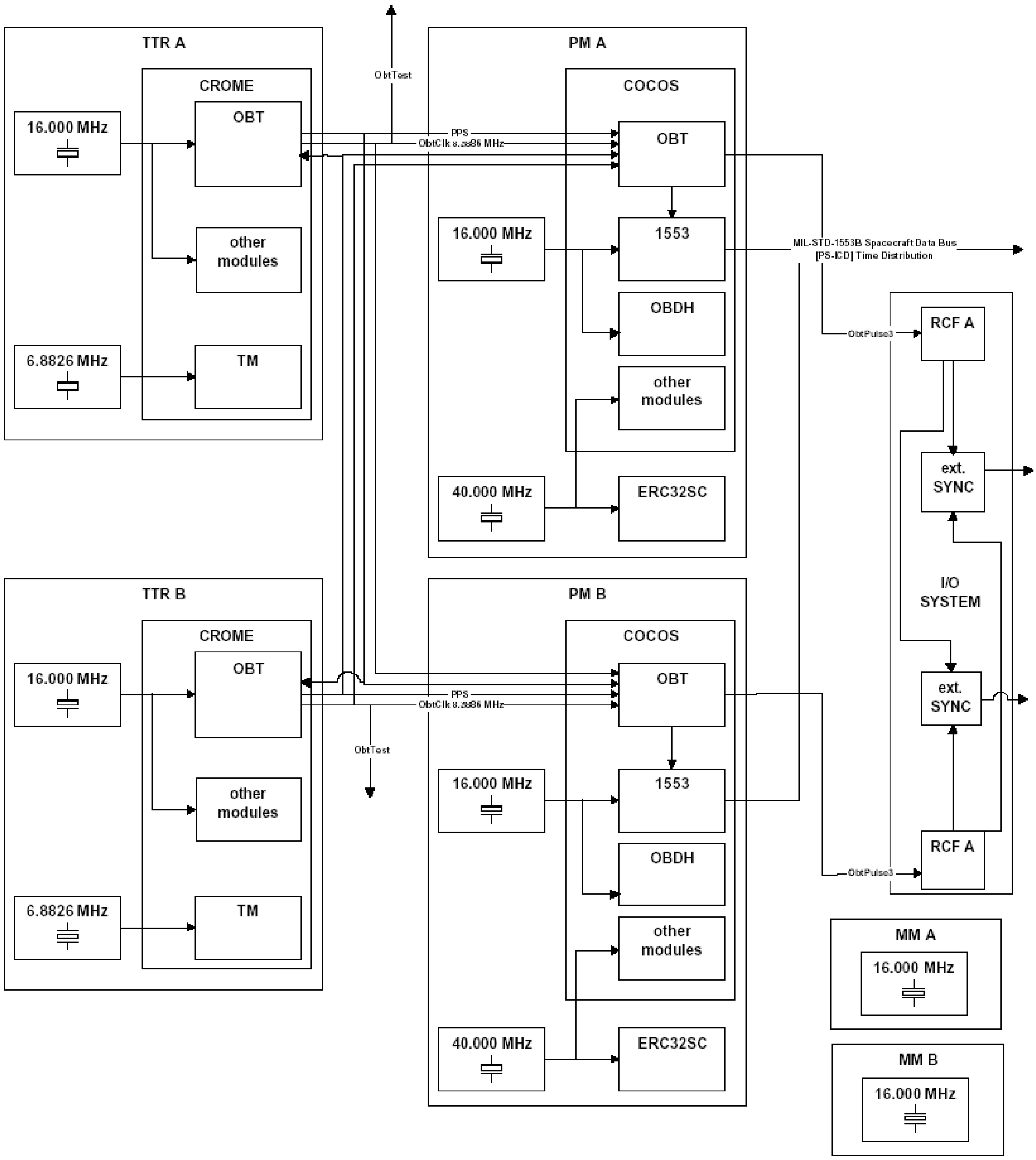


Figure 9.7.3-2 CDMU Synchronisation Signal generation and distribution Block Diagram

9.7.4 Functional Blocks description

The following paragraphs give more detail on the functional aspects, design and performance of the internal modules.

9.7.4.1 Telemetry Telecommand and Reconfiguration Board (TTR)

There are two TTR Boards operating in hot redundancy.

Each TTR Board includes the following functional blocks housed in a CROME ASIC:

- Telecommand Decoder
- Telemetry Encoder
- Command Pulse Distribution Module
- Reconfiguration Module
- On Board Time
- Internal Control Bus Remote Terminal
- Memory control Interface.

and other associated support functions which are represented by separate interface circuits as buffers, drivers, filters and protections.

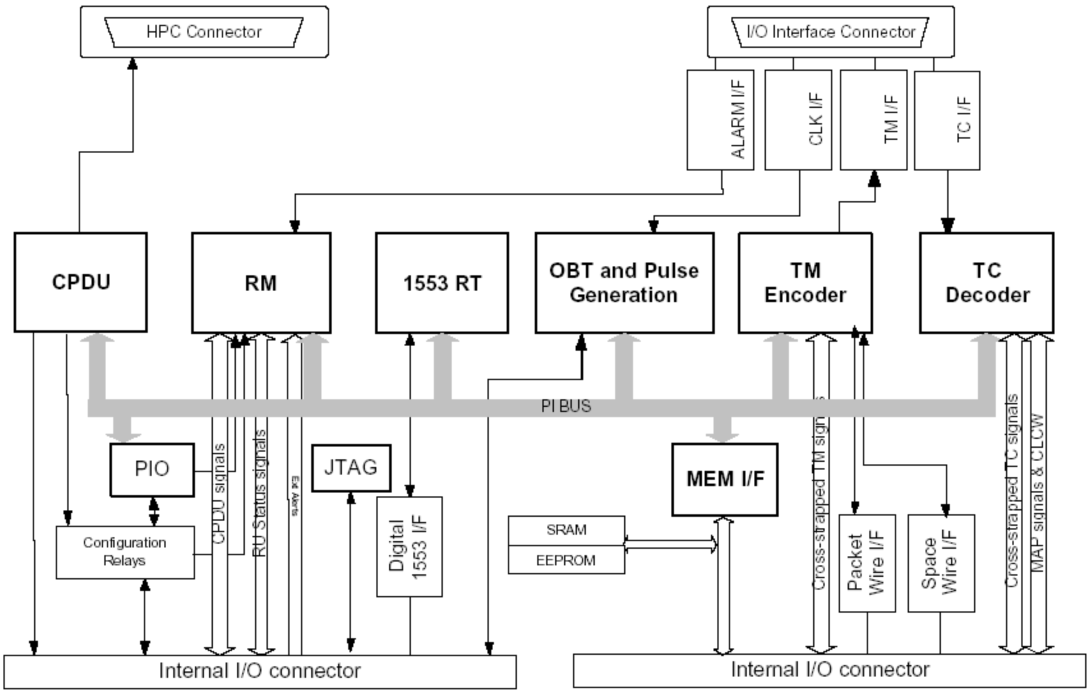


Figure 9.7.4-1 CDMU TTR Block Diagram

The initialisation is performed as soon as power is received from the PCDH hot section (INIT mode). After that, three possible modes are possible: only RM operating (RM INIT), all the other functions which involve TC, TM, OBT, SGM are fully operating (BASIC mode) or all functions are operating (FULL mode). Any way no HP TC can be issued before the TTR leaves the INIT mode and no HP TC from RM can be issued if the TTR is not in FULL mode.

9.7.4.1.1 Telecommand Decoder

Functional Description.
The TC Decoder is represented by the latest generation of SES PTD and implements the Packet Telecommand Protocol in compliance with [AD-25].
Each CDMU TC decoder is connected with the two Transponder receivers to get demodulated digital telecommand signals. In addition two interfaces for EGSE TC inputs are provided (one per decoder). Of the TC inputs, each decoder selects one of them via priority selection logic. The CDMU performs TC decoding in accordance with ESA Packet Telecommand Standard [AD-25]. Three types of commands are possible:
- high priority commands (HP TC), that are directly output as pulse commands from the TC decoder via CPDU
- telecommands that are distributed to the CDMU Processor Module
- telecommands that disable the RM.

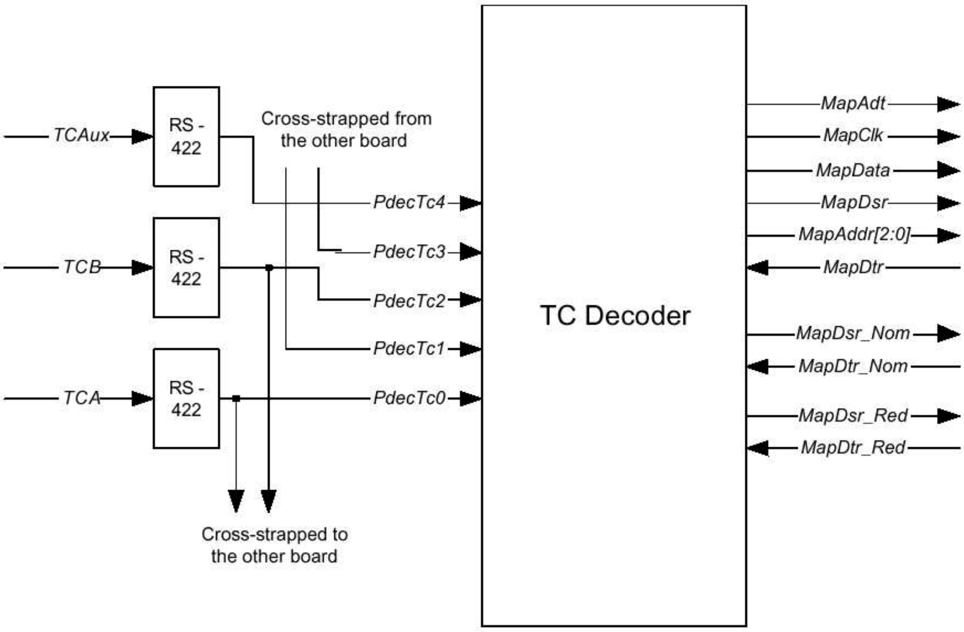


Figure 9.7.4-2 Command Decoder Interfaces

The Command Decoder is built using the following blocks:
- Serial Input Block (SIB)
- Authentication Block (AUB)
- Segmentation Layer and Router Block (SLRB)
- TeleMetry Block (TMB).

The received data stream is checked for a proper Start Sequence and the subsequent data code-words are decoded, with possible bit corrections.

The derived Transfer Frame is now checked to verify that the Frame Error Control and Frame Header are conform and contain the Spacecraft and the Virtual Channel Identification.
Finally the TF is processed by the Authentication Unit that checks the Frame Data Field and authorises the access to the spacecraft.

The authorised frame is sent to the Physical port indicated in the Segment Header. For the CDMU there are four MAP addresses which refer to the CPDU, PMs and RM.

Design and performance.

As per SGICD [AD-07], uplink bit rates are **125 bps** and **4 kbps**.

Herschel-Planck Mission specific parameters are stored in the EEPROM located on the TTR board.

The following parameters are stored (see CDMU User Manual P-HPL-NOT-00009-SE for details):
- Version Number: 002
- Reserved Field A: 002
- Spacecraft ID:
  - 1EA (CDMU EQM)
  - 1E6 (CDMU Herschel)
  - 1E9 (CDMU Planck)
- Virtual channel ID: 0 for TTR A; 1 for TTR B
- FARM Positive Window: 100
- FARM Negative Window: 100
- Authentication MAP Id Pointer: 0 (No MAPs are authenticated)
- De-randomizer: Disabled
- External recovery LAC: Disabled
- Authentication Key: Not Used

9.7.4.1.2 Telemetry Encoder

Functional description.
The TM Encoder receives TeleMetry data on a variable number of separate serial input interfaces, each connected to a Virtual Channel.
Eight Virtual Channels are provided and they are allocated to the following data:
- VC0 Real-time Essential and Critical HK telemetry (S/C and Instruments)
- VC1 Real-time Science telemetry
- VC2 Dump HK telemetry (S/C and Instruments)
- VC3 Dump Science telemetry
- VC4 Real Time Routine HK Telemetry (S/C and Instruments)
- VC5 Not used
- VC6 Not used
- VC7 Idle frames

The VCA blocks then generate, as main output, complete Transfer Frames where the Telemetry Packets coming from different sources are embedded.
Three types of frame stream can be selected depending on the type of coding:
- uncoded frames (up 1115bytes)
- reed-solomon coded frames (up 1115bytes plus 160 for check symbols)
- turbo-coded frames (up 1115bytes reduced by a factor R)

to which the Synchr Marker (4 octets) must be added.

In addition to the selected coding there is also the possibility to perform data randomisation of the single TF, or to perform Convolutional encoding of the entire output stream.

Other options are the selection of PSK o SPL modulation. If no randomisation or convolutional code is selected the output will be NRZ-L. The selected TM encoder drives all serial TM output. The unselected TM encoder is disabled, placed in a reset state and is not operating although it is continuously powered.
A reduced number of TM packets, if enabled, can be collected, with or w/o the processor involvement, only for failure investigations and addressed to a selected VC.

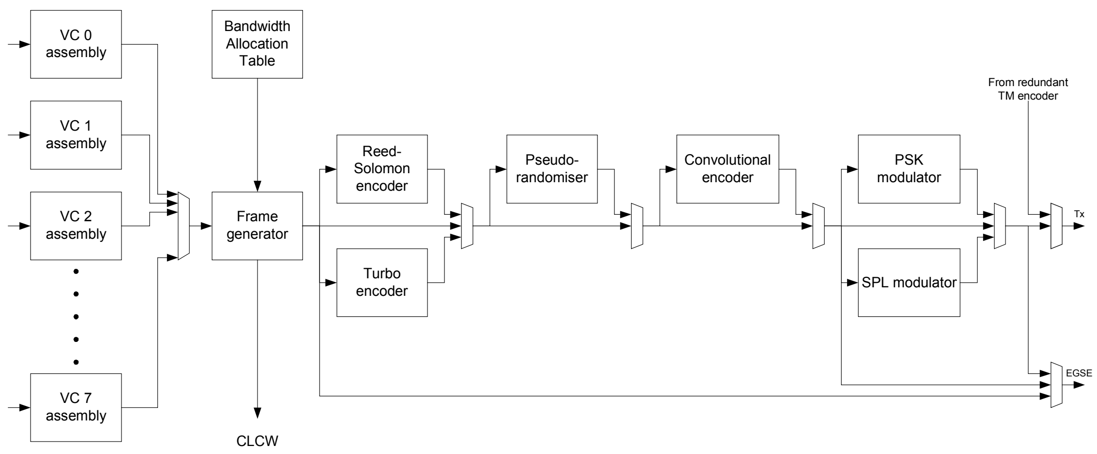


Figure 9.7.4-3 Telemetry Encoder Block Diagram

Design and performance.

The TM Encoder is adaptable to various mission needs. Hereafter the Herschel-Planck parameters and their mission specific selected values are listed. These parameters are initialized by hardware from the TTR EEPROM. Only the downlink information bitrate can be changed in flight.

Parameter	Value
Spacecraft Id (10 bits)	1EA (CDMU EQM) 1E6 (CDMU Herschel) 1E9 (CDMU Planck)
Frame Length	1115 octets
Insertion of Sec. Header, OPCF (CLCW) and FECW fields	Yes
Rate of ASM Time Strobe pulse output	Once per 64. The time strobe is asserted when VC0 Frame Count equals 0, 64, 128 and 192.
Idle Packet version field value	000
Idle Packet insertion timeout	VC0: Insertion after 1024 poll VC1: Insertion after 1024 poll VC2: Insertion after 1 poll VC3: Insertion after 1 poll VC4: 950 ms (BSW controlled).
Value of Data Field Sync flag and Packet Order flag	0,0
Value of the Segmentation Length Identifier field	11
Synch marker	1ACF_FC1D
CLCW selection	Alternating from TTR A and TTR B
BAT/Priority table values	0,4,2,1,3,7,7,7…. (totally 32 entries)
VC selection algorithm	Priority, in the following order: VC 0 - VC 4 - VC 2 - VC 1 - VC 3 - VC 7
TC Decoder selection for CLCW retrieval	Toggling
TC Decoder VC Identifier (6 bits)	0/1
Reed-Solomon encoding	yes
Convolutional encoding	yes
Convolutional code rate	1/2
Pseudo-randomisation of the frame	yes
Turbo encoding enabled	no
Turbo nominal code rate	NA
Test Pattern Generation	OFF
Modulation	Low-1: None (NRZ-L) (Default) Low-2: None (NRZ-L) Medium: None (NRZ-L) High: None (NRZ-L)
Downlink information bit rate Flight programmable to:	Low-1: 500 bps (Default) Low-2: 5000 bps Medium: 150 kbps High: 1.5 Mbps
Square-PSK Subcarrier frequency	Low-1: OFF (Default) Low-2: OFF Medium: OFF High: OFF

Table 9.7.4-1 TM Encoder parameters

9.7.4.1.3 On-Board Time Master

Functional Description.
The OBT master, resident in the hot redundant TTR modules, provides the reference time and distributes synchronised pulses in the system.

There are four main functions in the OBT module:
- OBT counter
- Numerical Controlled Oscillator (NCO)
- Sampling of OBT counter
- Pulse generation

The OBT counter can be sampled through an external hardware triggered signal or by software generated event.

The NCO is programmable to handle different relationship between the external source clock, which can use non-power-of-2 frequency, and the synchronised OBT generated clock.

The OBT also includes a programmable OBT synchronous pulse generator. This will be used for generating two types of pulses: one is generated when the counter reaches a certain value and the other is generated when a selected bit of the counter is used to decrement a preset value and zero value is reached.

A Pulse Per Second (PPS) is exchanged between the two OBTs, main and redundant, to maintain the synchronisation.

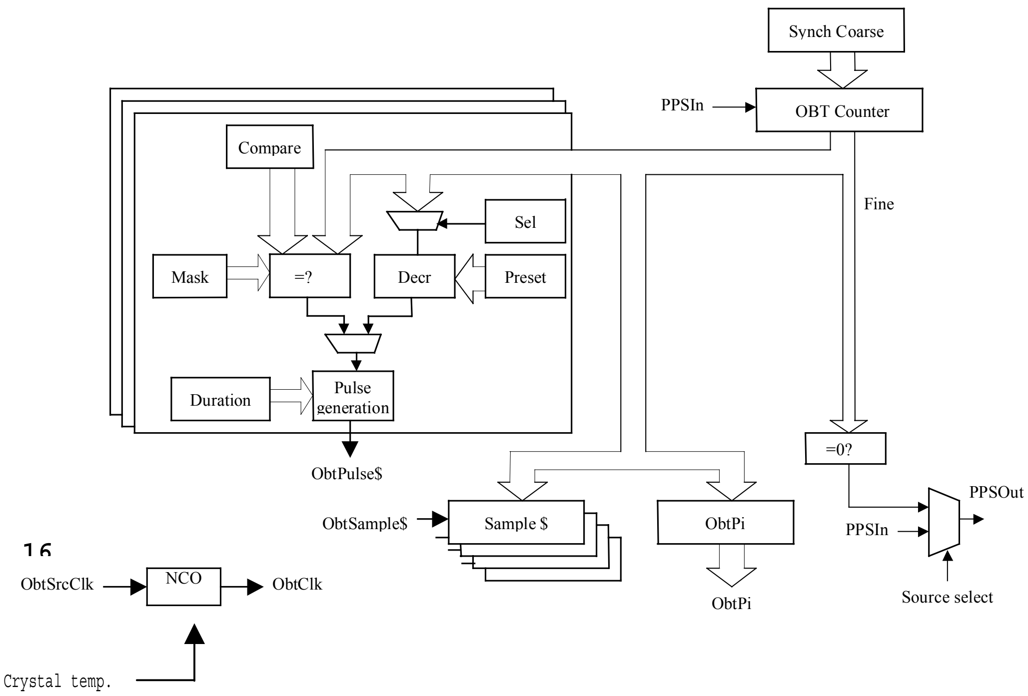


Figure 9.7.4-4 On-Board Time Diagram

Design and performance.

The OBT is implemented in the CROME ASIC.
The capability of the OBT counter is 55bit, where the 23 least significant bits represent sub seconds and the 32 most significant bits represent seconds. The 2^{23}Hz (8.388608 MHz) is the necessary input frequency of the oscillator, which allows using the full resolution. The requested frequency accuracy 1ppm is achieved using a standard crystal oscillator and adequate thermal compensation using a calibration table in EEPROM.

9.7.4.1.4 Reconfiguration Module

Functional description.
The reconfiguration function in the CDMU system is handled by two hot redundant Reconfiguration Modules that process up 8 external and 8 internal incoming alarms and generates CPDU packets for execution by the CPDU.
It also handles three additional alarms: the Active PM and the watchdog using two additional inputs (WdTrig and WdEnable).
The generated packets depend on the different alarms and H/W configurations.
All the incoming alarms are submitted to a conditioning process, which includes the following steps:
- synchronisation
- filtering for glitch suppression
- polarity recognising
- temporisation delay and mode (active or watchdog)
- pattern filtering
- majority voting
- enable/disable mask

after that the conditioned alarms will be handled for:
- predefined pattern matching
- CPDU packet generation

and in the end, subject to a CPDU command mask eventually.

All the above steps, relating to the RM functions, need of default values programmed in a non-volatile memory during manufacturing.

Moreover, the RMs generate a log when the reconfiguration is started in order to save the time, the current alarm situation and the CDMU H/W configuration in the TTR RAM memory, to be sent as a TM packet.

The following 8 internal alarms are received:

SW Alarm A
SW Alarm B
CPU Alarm A
CPU Alarm B
COCOS Alarm A
COCOS Alarm B
UVD Alarm A
UVD Alarm B

and the already mentioned three additional alarms:

Active Pm A
WdTrig
WdEnable

Information on external alarms allocation is given in TM/TC Budget [RD-116].

Design and Performance

The figure below shows the reconfiguration function, which consists of alarm sensors and command relays (not part of TTR) and two identical Reconfiguration Modules (RM).

The Reconfiguration Modules communicate to ensure that only one RM at a time can drive the Command Relays.

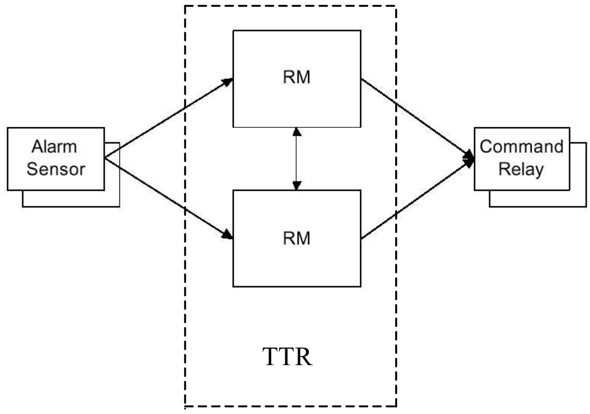


Figure 9.7.4-5 Reconfiguration Function

The glitch filter allows the suppression of all signals shorter than 100µs.
The temporisation delay can be programmed from 100µs to 836s.
The pattern filter suppresses every signal shorter than 50µs.

9.7.4.1.5 Safeguard Memory

Functional description.

The Memory is used for storage of essential housekeeping TM Source Packets and command data needed in case of automatic reconfiguration.
The SGM memory is powered in hot redundancy as part of TTR board.
The SGM will be written and read via Internal Control Bus.

Design and Performance.

The capacity of each SGM is 512 Kbytes. It includes EDAC protection. The memory consists of two areas, one accessible for writing new data and the other, protected, save last written complete context.

9.7.4.1.6 Command Pulse Distribution Unit

Functional description.

The CPDU can receive CPDU packets from three sources:
- the TC Decoder
- the Processor Modules (generated by the On-Board Software).via the Serial Link with the lowest priority
- the Reconfiguration Module with the highest priority.

The CPDU, after validation, executes packets forming a sequence of one or more HP On/Off commands

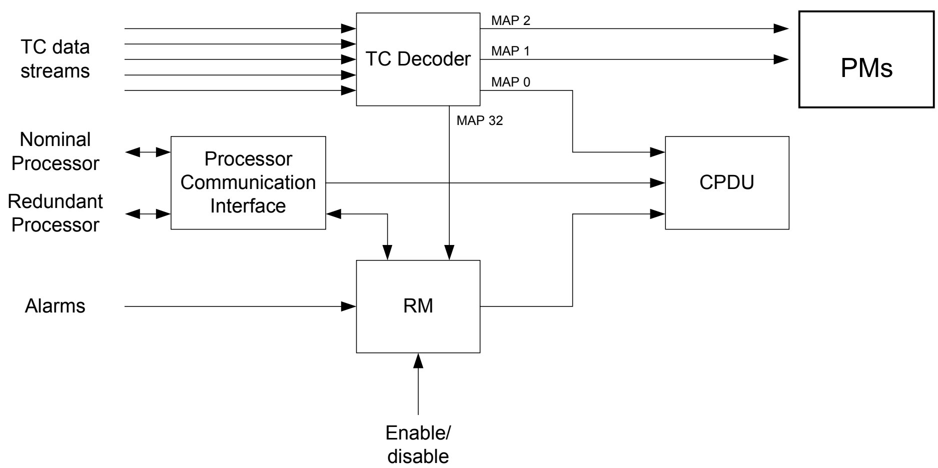


Figure 9.7.4-6 Handling of commands by the Decoder, RM and Processor

Arbitration and priority between these sources is handled by an input selector

The CPDU has a capability to block some outputs from being used by packets from the processor.
The CPDU packets from RM and Processor can be temporarily inhibited but allowing CPDU packets from TC Decoder to be still received.
The CPDU implements a direct telecommand capability by processing one or more CPDU commands present in the CPDU packets stored in the external RAM. Since these commands are critical, the packet is first verified to be clean and legal before being executed. The CPDU packet parameters are read from the external ROM.

The duration of the pulse is specified as part of each CPDU command. The interpulse gap is set up by a parameter in the mission PROM.
The following internal CPDU commands are generated:

						HERSCHEL		PLANCK	
Type	Module	Nr	Dec	RM	PM	Command	To	Command	To
IntCPDU	CPDU A	10	x	x	NO	Watchdog A Disable	TTR A	Watchdog A Disable	TTR A
IntCPDU	CPDU A	11	x	x	NO	RM A Disable	TTR A	RM A Disable	TTR A
IntCPDU	CPDU A	12	x	x	NO	RM B Disable	TTR B	RM B Disable	TTR B
IntCPDU	CPDU A	13	x	x	x	Watchdog A Enable	TTR A	Watchdog A Enable	TTR A
IntCPDU	CPDU A	14	x	x	x	RM A enable	TTR A	RM A enable	TTR A
IntCPDU	CPDU A	15	x	x	x	RM B enable	TTR B	RM B enable	TTR B
IntCPDU	CPDU A	48	x	x	x	Use TM Encoder A	TTR A	Use TM Encoder A	TTR A
IntCPDU	CPDU A	49	x	x	x	Use PM A	TTR B	Use PM A	TTR B
IntCPDU	CPDU A	50	x	x	x	PM A on	PC A	PM A on	PC A
IntCPDU	CPDU A	51	x	x	x	PM A off	PC A	PM A off	PC A
IntCPDU	CPDU A	52	x	x	x	PM A Reset	PM A	PM A Reset	PM A
IntCPDU	CPDU A	53	x	x	x	MM A on / MM A Reset	MM A	MM A on / MM A Reset	MM A
IntCPDU	CPDU A	54	x	x	x	MM A off	MM A	MM A off	MM A
IntCPDU	CPDU A	55	x	x	x	Gen. Interrupt for Context Saving	PM	Gen. Interrupt for Context Saving	PM
IntCPDU	CPDU A	56	x	x	x	Set PM A bit 0	PM A	Set PM A bit 0	PM A
IntCPDU	CPDU A	57	x	x	x	Reset PM A bit 0	PM A	Reset PM A bit 0	PM A
IntCPDU	CPDU A	58	x	x	x	Set PM A bit 1 = Select SW Image 1	PM A	Set PM A bit 1 = Select SW Image 1	PM A
IntCPDU	CPDU A	59	x	x	x	Reset PM A bit 1 = Select SW Image 2	PM A	Reset PM A bit 1 = Select SW Image 2	PM A
IntCPDU	CPDU A	60	x	x	x	Set PM B bit 0	PM B	Set PM B bit 0	PM B
IntCPDU	CPDU A	61	x	x	x	Reset PM B bit 0	PM B	Reset PM B bit 0	PM B
IntCPDU	CPDU A	62	x	x	x	Set PM B bit 1 = Select SW Image 1	PM B	Set PM B bit 1 = Select SW Image 1	PM B
IntCPDU	CPDU A	63	x	x	x	Reset PM B bit 1 = Select SW Image 2	PM B	Reset PM B bit 1 = Select SW Image 2	PM B
IntCPDU	CPDU A	64	x	x	x	Use TM Encoder B	TTR A	Use TM Encoder B	TTR A
IntCPDU	CPDU A	65	x	x	x	Use PM B	TTR B	Use PM B	TTR B
IntCPDU	CPDU A	66	x	x	x	PM B on	PC B	PM B on	PC B
IntCPDU	CPDU A	67	x	x	x	PM B off	PC B	PM B off	PC B
IntCPDU	CPDU A	68	x	x	x	PM B Reset	PM B	PM B Reset	PM B
IntCPDU	CPDU A	69	x	x	x	MM B on / MM B Reset	MM B	MM B on / MM B Reset	MM B
IntCPDU	CPDU A	70	x	x	x	MM B off	MM B	MM B off	MM B
IntCPDU	CPDU B	10	x	x	NO	Watchdog A Disable	TTR A	Watchdog A Disable	TTR A
IntCPDU	CPDU B	11	x	x	NO	RM A Disable	TTR A	RM A Disable	TTR A
IntCPDU	CPDU B	12	x	x	NO	RM B Disable	TTR B	RM B Disable	TTR B
IntCPDU	CPDU B	13	x	x	x	Watchdog A Enable	TTR A	Watchdog A Enable	TTR A
IntCPDU	CPDU B	14	x	x	x	RM A enable	TTR A	RM A enable	TTR A
IntCPDU	CPDU B	15	x	x	x	RM B enable	TTR B	RM B enable	TTR B
IntCPDU	CPDU B	48	x	x	x	Use TM Encoder A	TTR A	Use TM Encoder A	TTR A
IntCPDU	CPDU B	49	x	x	x	Use PM A	TTR B	Use PM A	TTR B
IntCPDU	CPDU B	50	x	x	x	PM A on	PC A	PM A on	PC A
IntCPDU	CPDU B	51	x	x	x	PM A off	PC A	PM A off	PC A
IntCPDU	CPDU B	52	x	x	x	PM A Reset	PM A	PM A Reset	PM A
IntCPDU	CPDU B	53	x	x	x	MM A on / MM A Reset	MM A	MM A on / MM A Reset	MM A
IntCPDU	CPDU B	54	x	x	x	MM A off	MM A	MM A off	MM A
IntCPDU	CPDU B	55	x	x	x	Gen. Interrupt for Context Saving	PM	Gen. Interrupt for Context Saving	PM
IntCPDU	CPDU B	56	x	x	x	Set PM A bit 0	PM A	Set PM A bit 0	PM A
IntCPDU	CPDU B	57	x	x	x	Reset PM A bit 0	PM A	Reset PM A bit 0	PM A
IntCPDU	CPDU B	58	x	x	x	Set PM A bit 1 = Select SW Image 1	PM A	Set PM A bit 1 = Select SW Image 1	PM A
IntCPDU	CPDU B	59	x	x	x	Reset PM A bit 1 = Select SW Image 2	PM A	Reset PM A bit 1 = Select SW Image 2	PM A
IntCPDU	CPDU B	60	x	x	x	Set PM B bit 0	PM B	Set PM B bit 0	PM B
IntCPDU	CPDU B	61	x	x	x	Reset PM B bit 0	PM B	Reset PM B bit 0	PM B
IntCPDU	CPDU B	62	x	x	x	Set PM B bit 1 = Select SW Image 1	PM B	Set PM B bit 1 = Select SW Image 1	PM B
IntCPDU	CPDU B	63	x	x	x	Reset PM B bit 1 = Select SW Image 2	PM B	Reset PM B bit 1 = Select SW Image 2	PM B
IntCPDU	CPDU B	64	x	x	x	Use TM Encoder B	TTR A	Use TM Encoder B	TTR A
IntCPDU	CPDU B	65	x	x	x	Use PM B	TTR B	Use PM B	TTR B
IntCPDU	CPDU B	66	x	x	x	PM B on	PC B	PM B on	PC B
IntCPDU	CPDU B	67	x	x	x	PM B off	PC B	PM B off	PC B
IntCPDU	CPDU B	68	x	x	x	PM B Reset	PM B	PM B Reset	PM B
IntCPDU	CPDU B	69	x	x	x	MM B on / MM B Reset	MM B	MM B on / MM B Reset	MM B
IntCPDU	CPDU B	70	x	x	x	MM B off	MM B	MM B off	MM B

The allocation of External HP Commands is in the following table:

						HERSCHEL		PLANCK	
Type	Module	Nr	Dec	RM	PM	Command	To	Command	To
HP	CPDU A	16	x	x	x	DNEL Enable	PCDU	DNEL Enable	PCDU
HP	CPDU A	17	x	x	x	DNEL Fire	PCDU	DNEL Fire	PCDU
HP	CPDU A	18	x	x	x	LCL 31-CDMU Cold A- ON	PCDU	LCL 31-CDMU Cold A- ON	PCDU
HP	CPDU A	19	x	x	x	Set SIR Relay	CDMU	Set SIR Relay	CDMU
HP	CPDU A	20	x	x	x	Set CIR Relay	CDMU	Set CIR Relay	CDMU
HP	CPDU A	21	x	x	x	External ACC RM A Enable	ACC	External ACC RM A Enable	ACC
HP	CPDU A	22	x	x	x	External ACC RM A Disable	ACC	External ACC RM A Disable	ACC
HP	CPDU A	23	x	x	x	External ACC PM A OFF	ACC	External ACC PM A OFF	ACC
HP	CPDU A	24	x	x	x	External ACC RM B Enable	ACC	External ACC RM B Enable	ACC
HP	CPDU A	25	x	x	x	External ACC RM B Disable	ACC	External ACC RM B Disable	ACC
HP	CPDU A	26	x	x	x	External ACC PM B OFF	ACC	External ACC PM B OFF	ACC
HP	CPDU A	27	x	x	x	XPND1 TX ON	XPND1	XPND1 TX ON	XPND1
HP	CPDU A	28	x	x	x	XPND1 TX OFF	XPND1	XPND1 TX OFF	XPND1
HP	CPDU A	29	x	x	x	XPND2 TX ON	XPND2	XPND2 TX ON	XPND2
HP	CPDU A	30	x	x	x	XPND2 TX OFF	XPND2	XPND2 TX OFF	XPND2
HP	CPDU A	31	x	x	x	TWTA1 ON	EPC1	TWTA1 ON	EPC1
HP	CPDU A	32	x	x	x	TWTA1 OFF	EPC1	TWTA1 OFF	EPC1
HP	CPDU A	33	x	x	x	EPC1 ON	EPC1	EPC1 ON	EPC1
HP	CPDU A	34	x	x	x	EPC1 OFF	EPC1	EPC1 OFF	EPC1
HP	CPDU A	35	x	x	x	TWTA2 ON	EPC2	TWTA2 ON	EPC2
HP	CPDU A	36	x	x	x	TWTA2 OFF	EPC2	TWTA2 OFF	EPC2
HP	CPDU A	37	x	x	x	EPC2 ON	EPC2	EPC2 ON	EPC2
HP	CPDU A	38	x	x	x	EPC2 OFF	EPC2	EPC2 OFF	EPC2
HP	CPDU A	39	x	x	x	LCL 32-CDMU Cold B- ON	PCDU	LCL 32-CDMU Cold B- ON	PCDU
HP	CPDU B	16	x	x	x	DNEL Enable	PCDU	DNEL Enable	PCDU
HP	CPDU B	17	x	x	x	DNEL Fire	PCDU	DNEL Fire	PCDU
HP	CPDU B	18	x	x	x	LCL 31-CDMU Cold A- ON	PCDU	LCL 31-CDMU Cold A- ON	PCDU
HP	CPDU B	19	x	x	x	Set SIR Relay	CDMU	Set SIR Relay	CDMU
HP	CPDU B	20	x	x	x	Set CIR Relay	CDMU	Set CIR Relay	CDMU
HP	CPDU B	21	x	x	x	External ACC RM A Enable	ACC	External ACC RM A Enable	ACC
HP	CPDU B	22	x	x	x	External ACC RM A Disable	ACC	External ACC RM A Disable	ACC
HP	CPDU B	23	x	x	x	External ACC PM A OFF	ACC	External ACC PM A OFF	ACC
HP	CPDU B	24	x	x	x	External ACC RM B Enable	ACC	External ACC RM B Enable	ACC
HP	CPDU B	25	x	x	x	External ACC RM B Disable	ACC	External ACC RM B Disable	ACC
HP	CPDU B	26	x	x	x	External ACC PM B OFF	ACC	External ACC PM B OFF	ACC
HP	CPDU B	27	x	x	x	XPND1 TX ON	XPND1	XPND1 TX ON	XPND1
HP	CPDU B	28	x	x	x	XPND1 TX OFF	XPND1	XPND1 TX OFF	XPND1
HP	CPDU B	29	x	x	x	XPND2 TX ON	XPND2	XPND2 TX ON	XPND2
HP	CPDU B	30	x	x	x	XPND2 TX OFF	XPND2	XPND2 TX OFF	XPND2
HP	CPDU B	31	x	x	x	TWTA1 ON	EPC1	TWTA1 ON	EPC1
HP	CPDU B	32	x	x	x	TWTA1 OFF	EPC1	TWTA1 OFF	EPC1
HP	CPDU B	33	x	x	x	EPC1 ON	EPC1	EPC1 ON	EPC1
HP	CPDU B	34	x	x	x	EPC1 OFF	EPC1	EPC1 OFF	EPC1
HP	CPDU B	35	x	x	x	TWTA2 ON	EPC2	TWTA2 ON	EPC2
HP	CPDU B	36	x	x	x	TWTA2 OFF	EPC2	TWTA2 OFF	EPC2
HP	CPDU B	37	x	x	x	EPC2 ON	EPC2	EPC2 ON	EPC2
HP	CPDU B	38	x	x	x	EPC2 OFF	EPC2	EPC2 OFF	EPC2
HP	CPDU B	39	x	x	x	LCL 32-CDMU Cold B- ON	PCDU	LCL 32-CDMU Cold B- ON	PCDU

Packets for the other 16 HP commands can be generated by Command Decoder and RM only, i.e. they are not accessible by On-Board Software.

						HERSCHEL		PLANCK	
Type	Module	Nr	Dec	RM	PM	Command	To	Command	To
HP	CPDU A	0	x	x	NO	LCL 31-CDMU Cold A- OFF	PCDU	LCL 31-CDMU Cold A- OFF	PCDU
HP	CPDU A	1	x	x	NO	LCL 32-CDMU Cold B- OFF	PCDU	LCL 32-CDMU Cold B- OFF	PCDU
HP	CPDU A	2	x	x	NO	LCL 33-ACC Cold A- OFF	PCDU	LCL 33-ACC Cold A- OFF	PCDU
HP	CPDU A	3	x	x	NO	LCL 34-ACC Cold B- OFF	PCDU	LCL 34-ACC Cold B- OFF	PCDU
HP	CPDU A	4	x	x	NO	LCL 45-ACC RCS Thrusters A- ON	PCDU	LCL 45-ACC RCS Thrusters A- ON	PCDU
HP	CPDU A	5	x	x	NO	LCL 46-ACC RCS Thrusters B- ON	PCDU	LCL 46-ACC RCS Thrusters B- ON	PCDU
HP	CPDU A	6	x		NO	NCA Arm	PCDU		
HP	CPDU A	7	x	x	NO	NCA Disarm	PCDU		
HP	CPDU B	0	x	x	NO	LCL 31-CDMU Cold A- OFF -R	PCDU	LCL 31-CDMU Cold A- OFF -R	PCDU
HP	CPDU B	1	x	x	NO	LCL 32-CDMU Cold B- OFF -R	PCDU	LCL 32-CDMU Cold B- OFF -R	PCDU
HP	CPDU B	2	x	x	NO	LCL 33-ACC Cold A- OFF -R	PCDU	LCL 33-ACC Cold A- OFF -R	PCDU
HP	CPDU B	3	x	x	NO	LCL 34-ACC Cold B- OFF -R	PCDU	LCL 34-ACC Cold B- OFF -R	PCDU
HP	CPDU B	4	x	x	NO	LCL 45-ACC RCS Thrusters A- ON -R	PCDU	LCL 45-ACC RCS Thrusters A- ON -R	PCDU
HP	CPDU B	5	x	x	NO	LCL 46-ACC RCS Thrusters B- ON -R	PCDU	LCL 46-ACC RCS Thrusters B- ON -R	PCDU
HP	CPDU B	6	x		NO	NCA Arm -R	PCDU		
HP	CPDU B	7	x	x	NO	NCA Disarm -R	PCDU		

Design and performance.

A total of 72 (40 external, 32 internal) High Priority Commands and Extended High Priority Commands are provided by each TTR Board.
The outputs are driven by OCD (Output Command Driver) ASICs. Each OCD will drive eight outputs. The group switch, which also performs the pulse shaping, is shared between 4 OCDs, i.e 32 commands.

9.7.4.1.7 Communication with the Processor Modules

The hot redundant TTR boards communicate with the two cold redundant Processor Modules, when active, using:

One Internal Control Bus, the protocol and timing of which is compliant with MIL-STD-1553B.

Two SpaceWire links to transfer telemetry from the two PMs. One SpaceWire handles VC0 and VC1 from one PM.

Two PacketWire links to transfer the TC Segments on MAP1 to the two PMs.

There is also a number of discrete signals:
- PM Interrupt (from TTR to PM)
- OBT Clock Synchronisation Signal (from TTR OBT to PM OBT)
- OBT Clock Temperature compensated frequency (from TTR OBT to PM OBT)
- PM Alarms to the RM (from PM to TTR)
- PM Watchdog to the RM (from PM to TTR).

9.7.4.1.8 Communication with the Mass Memory

Each TTR board receives TM Source Packets from the Mass Memory over four discrete Packet Wire serial links, two from each MM board (VC2 and VC3).

9.7.4.2 Processor Module

Functional description.
The function of the Processor Module is mainly:
- to acquire messages, commands and provide responses via the Platform Interface bus
- to perform overall commanding, housekeeping collection and monitoring
- controlling the Mass Memory.

The main blocks of the Processor Board are:

- ERC32SC Processor
- COCOS ASIC
- Memories (Boot Prom, EEPROM, RAM, Mezzanine board)
- Oscillator
- Interfaces (MIL-STD-1553B, UART serial link, OBDH Data bus, Packet wire, Space wire, Parallel port, Configuration relays, Interrupts)
- Test Interfaces.

The PM initialisation starts when, in addition to the presence of LCL power from the cold converter, the PM latching relay is ON (INIT mode). After that the BSW and ASW initialisation follows to reach at the last, when they are fully operating, the NOMINAL OPERATION mode or the STANDBY OPERATION mode depending on the selected PM module.

The two CDMU Processor Modules operate in cold redundancy.

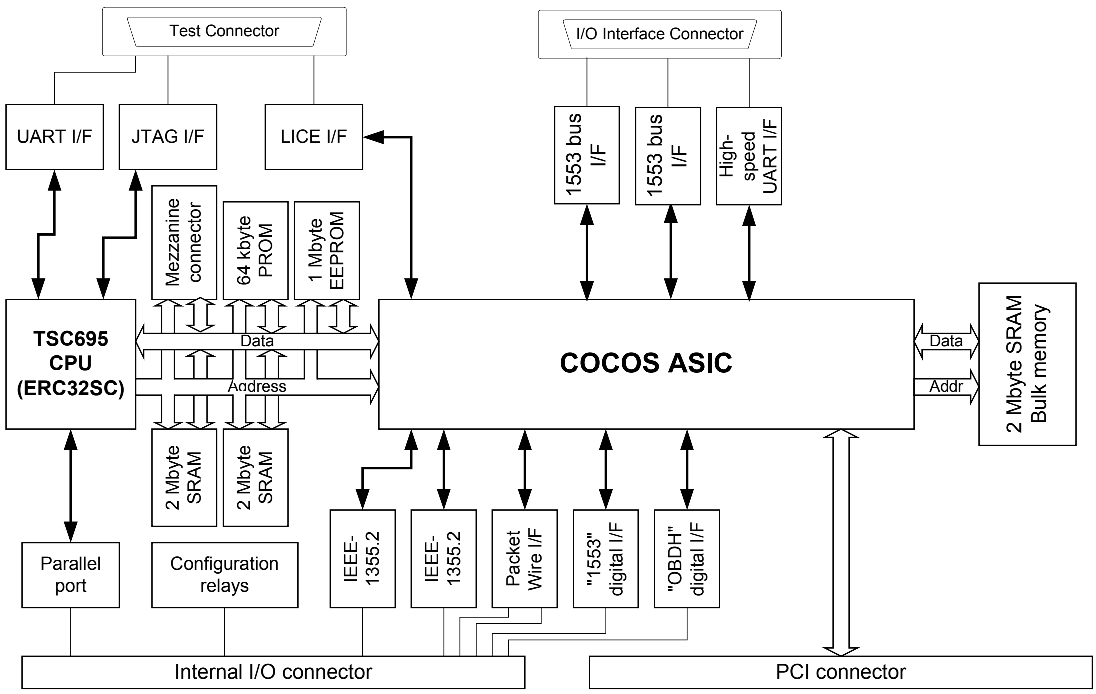


Figure 9.7.4-7 Reconfiguration Function

9.7.4.2.1 Processor

Design and performance.
The Processor Board will include the ERC 32SC radiation hardened single chip microprocessor (TSC695F).
It gives 14 MIPS with a clock frequency of 20MHz and will operate at 5V.

The processor TSC695F includes EDAC. It uses a seven Hamming code, which detects double bit errors and corrects all single bit errors on the 40-bit data bus (including EDAC bit and parity). The processor can be programmed to use the parity different modes and EDAC protection towards memory and to use the parity different modes towards I/O. The EDAC does not write back automatically to memory when a correctable error occurs, but an interruption is generated and the correction in memory is done by the Basic S/W. Also the scrubbing is under the Basic S/W control.

9.7.4.2.2 COCOS ASIC.

Design and performance.
It is developed by SE and implements the following functions:

- One processor interface towards ERC32SC.
- Two external High-speed UART interfaces.
- One motherboard PCI interface (Not used in Herschel/Planck).
- Alarm signal generator (connects to the RMs on the TTR boards).
- Watchdog.
- Two motherboard PacketWire transmit interface (The VC0, VC1 and VC4).
- Two external MIL-STD-1553 interfaces (Only one used in the CDMU).
- One motherboard MIL-STD-1553 interface (The ICB)
- One motherboard OBDH interface (Connected to a SBCH board for I/O system control).
- On-board time (Operating as slave to the OBTs on the TTR board).
- Interrupt controller.
- Two external and two motherboard SpaceWire interfaces (IEEE 1355).
- One TAP controller (IEEE-1149.1 JTAG).
- One external LICE interface.
- EDAC

The COCOS ASIC will run on the system clock provided by the ERC32SC and at the voltage of 3.3 V. The high level output is CMOS 3.3 V and the inputs are TTL compatible and tolerant to 5 V on the inputs.
The EDAC function is as described for the processor, but with a scrubbing function which checks periodically the memory and with a programmable rate.

9.7.4.2.3 Memories

Design and performance.
For booting of the processor, using 64Kbyte CMOS PROM is foreseen. Using a Boot PROM ensures a safe start up since the PROM is SEU and latch up free.

For storage of the application S/W, EEPROMs have been selected. 2Mbyte of memory is considered. The use of EEPROMs makes it possible to easily reprogram the PM during on-ground operations without the need to open the box. The EEPROM is radiation hardened and has not SEU problems in read mode.

The RAM devices foreseen for the baseline are 4 Mbytes. The RAM memory will be protected by the EDAC available in the ERC32SC, thus minimising the impact of Single Event Upsets, but it can be accessed by the COCOS. There is also a 2Mbytes RAM for the COCOS allowing DMA transfer to operate without affecting CPU operation.

The Mezzanine Board is provided to extend memory or change memory type.

9.7.4.2.4 Interfaces

Design and performance.
The PM provides communication with Science Instruments on a **MIL-STD-1553B data bus**. The data rate will be up 490kbps.Three dual redundant MIL-STD-1553B are implemented on each PM. Two of them are available on external connector (only one used on CDMU). One is used for internal control bus.
The interface can be configured as Bus Controller, Remote Terminal or Bus Monitor.

The PM board includes an **OBDH data bus**, used as link to the RCF part of the SBCH board, which controls the I/O system. An OBDH module is used to transmit and receive data over the OBDH data bus.
The I/O interface consists of two Litton-coded serial buses - the interrogation bus driven by the Central Terminal and the response bus on which Remote Terminals respond. The nominal bus frequency is 524288 Hz. The data to be sent is written to memory by the CPU and the OBDH module then reads the memory block via DMA and transmits the data on the bus. Data that is received from the bus is written to a memory area via DMA.

The **PacketWire** receive interfaces are used to receive telecommand packets from the TC Decoders. Two interfaces are connected over the backplane so that PM can receive from any of the two TTR boards.

Four IEEE 1355 interfaces (**SpaceWire)** for internal connections are implemented on the PM board. Two links are connected to the Mass Memory boards handling data transfers. The two other links are used to transfer PM generated TM data to the TM Encoders on the TTR board (VC0 and VC1). The link is full duplex.
A SpaceWire module is used to transmit and receive packets over either a nominal SpaceWire link A or a redundant link B. The packet(s) to be sent are written to the memory by the CPU and the SpaceWire module then reads the memory blocks via DMA and transmits the data on the link.

The PM board includes an 8-bit wide **Parallel Port** towards the motherboard. Every bit is configurable as in- or output individually. The control of the parallel port is handled from the General Purpose Port on ERC32SC.

The PM board implements three **Relays** used as configuration bits that can be configured from another module inside the equipment. The status from two of the relays is readable from the General Purpose Port. The third is used to disable the watchdog in the COCOS ASIC. The relay statuses are controlled by internal HP commands from the TTR board.

The PM board provides seven **Input Interrupts** from the backplane.

9.7.4.2.5 Test Interface

Design and performance.
A test interface is provided on the Processor Board allowing communication for the S/W monitor. The test interface uses two UARTs connected with ERC32 on-chip serial links RS-422. The baud rate for this interface is up 38400baud.
In addition a high-speed interface for the quick software loading uses two of the UARTs in the COCOS ASIC, which is conform to 38Kbps.

The ERC32 has a IEEE-1149.1 Standard (**JTAG**) Test Access Port (TAP), which may be used during CDMS testing and SW debugging in complement to the UART serial link. It is possible to control CPU.

9.7.4.2.6 Oscillators.

Design and performance.
The OBT on the PM board is synchronised to the OBT Master in TTR.
The ERC32SC and the COCOS ASIC operate using a 40MHz oscillator. The MIL-STD-1553B bus and the OBDH bus operate using a 16MHz oscillator.

9.7.4.2.7 Power Board Interface (Supply Voltages)

Design and performance.
The baseline design of the Processor Board uses 5 V and 3.3 V.

9.7.4.3 Mass Memory

Functional description.

The Mass Memory system of the CDMU consists of two redundant Mass Memory modules operating in hot redundancy, powered from the hot power supply but individually on/off switchable. Each memory is cross-coupled to both the PM and TTR boards.
The MM initialization starts when, in addition to the presence of FCL power from the hot converter, the MM latching relay is ON (INIT mode). After that the MM is operating under control from the PM (NOMINAL mode).
The Mass Memory stores TM data and housekeeping.

The Mass Memory Board is constituted by the following key blocks:
- COCOS ASIC
- FPGA
- SDRAM
- Interfaces

Each Mass Memory board interfaces with the two Processor Modules and the two telemetry encoder on the TTR Boards. The Control of memory is performed by means the CDMU internal digital 1553 bus, under the PM Bus controller. Data from the PM is received via two internal SpaceWire links while telemetry data to the TTR boards is transmitted using two Packet Wire buses which handle the VC2, VC3 virtual channels..

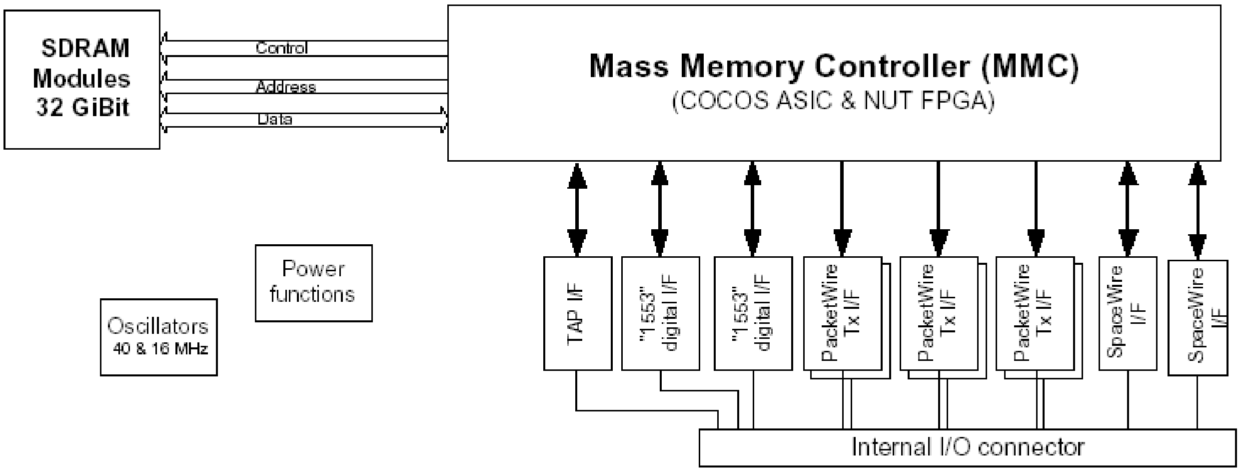


Figure 9.7.4-8 Mass Memory Board block diagram

The COCOS ASIC handles the interface towards the memory including functions such as refreshing, scrubbing and Reed-Solomon encoding. The ASIC also supports all the internal buses, SpaceWire, Packet Wire and digital 1553 configured as remote terminal. The memory controllers are realised in hardware.

The FPGA acts as a support for the COCOS ASIC, containing functions not supported by the ASIC or functions that requires faster interaction than what can be provided by the processor. The FPGA also helps to minimise the software load on the processor.

Design and performance.

The proposed Mass Memory Board provides 32 Gbit (34.36 $*10^9$ bits) storage using SDRAM memory cube devices where each device consists of 8 stacked 256 Mbit memory chips giving a 2 Gbit device. Twenty of these devices will make a 32 Gbit memory area, including checkbits, in 4 sections with 8 Gbit in each section. One of these sections is treated as redundant and can replace any of the other section. Calculating a loss of one section during mission leads to a memory capacity of 24 Gbit (25.77 $*10^9$ bits) End-Of-Life.
It has simultaneous record and play capability of up to 1.5Mbit/s.

The Mass Memory board also contains logic for power-on-reset and a 3.3V to 2.5V converter to support the FPGA core.

9.7.4.4 I/O System

Functional description.

The I/O system consists of two redundant Serial Bus Controller Board (SBCH), each split internally in two sections with different functions:

- the Remote Core Functions (RCF), interfacing with one PM through an internal OBDH bus and with three End Terminal Blocks (SIOH) via redundant crosscoupled SIUB busses. The two RCFs are powered in cold redundancy.

- the I/O boards provide standard I/O-functions to external and internal users. Internal signals are connected to the power converter boards, where telemetry signals are monitored for housekeeping. The capability is represented by 8 AN and 8 TH channels. The external signals include the synch pulse 131KHz signals. The I/O boards are forced in the ON mode as at least one of the cold converters are ON.

and three SIOH modules which implement the End Terminals blocks.

The SIOH modules are not redundant, implying that redundancy shall be made on channel allocation level. The allocation of the I/O channels on the I/O modules is made so that there will be 2 redundancy groups. One failure may cause loss of the interfaces connected to one of the groups.

The CDMU I/O interconnections are shown in Figure 9.7.4-6. The entire I/O system is controlled from the active Processor Module through its OBDH bus controller.
The I/O bus uses the ESA standard OBDH bus protocol.

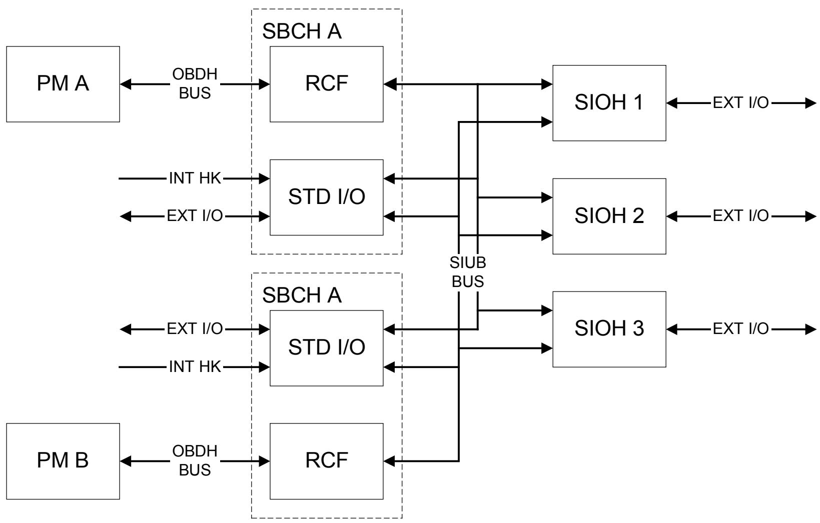


Figure 9.7.4-9 CDMU I/O Organisation

A basic set of standard I/O channels is included on the SBCH board. The remaining channels are partitioned on the three SIOH.

The SIOH external I/O channels capability is provided in the following table:

Interface	*Channels*
LLC	8
ML16	7
AN	48
CRYO TH	64
TH	192
DR	80
DB	40
SBDL (STATUS)	8
DS16	7
HL	80

Design and performance.

The main part of the RCF is implemented in an FPGA, but the RCF also controls a second level of multiplexers for analog signals and the relevant 12-bit A/D converter.

All interfaces in the I/O system are based on the concept of using End Terminals based on the highly configurable MARS ASIC. Each MARS contains support for handling two I/O groups.
For the analog (AN) acquisition each group contains 16 channels selected by a first level of multiplexer.
For the Temperature monitor (TH) and Cryo temperature acquisition it is similar to AN with the addition of conditioning resistors connected to a reference voltage.
For the Digital Bi-level (DB) acquisitions the MARS acts as controller for a 16 channels analogue multiplexer connected to a comparator.
For the Digital Relay (DR) acquisitions the MARS is used in the same way as for the DB with the addition of conditioning resistors on the inputs connected to a reference voltage
For Status Lines acquisitions the MARS is used in the same way as for the DB with the addition of Standard Balanced Digital Link (SBDL) input receivers on the inputs.
For the ML commands and the DS acquisitions the MARS can be configured as a ML1DS1 controller, providing an I/O group with 1 ML and 1 DS channel. Only SBDL interface circuits have to be added.
For the High Level (HL) and Extended High Level (EHL) commands the MARS acts as controller for two OCD ASICs each being capable of driving 8 pulse outputs. The pulse length can be programmed.
The Lower Level Command (LLC) commands will be distributed using the MARS in the same configuration as used for HL/EHL. The difference is that the OCDs will be replaced with SBDL drivers.

The I/O channels including the two RCF blocks shall be implemented using 5 boards.

9.7.4.5 Power Converter and Cross-Coupling Board

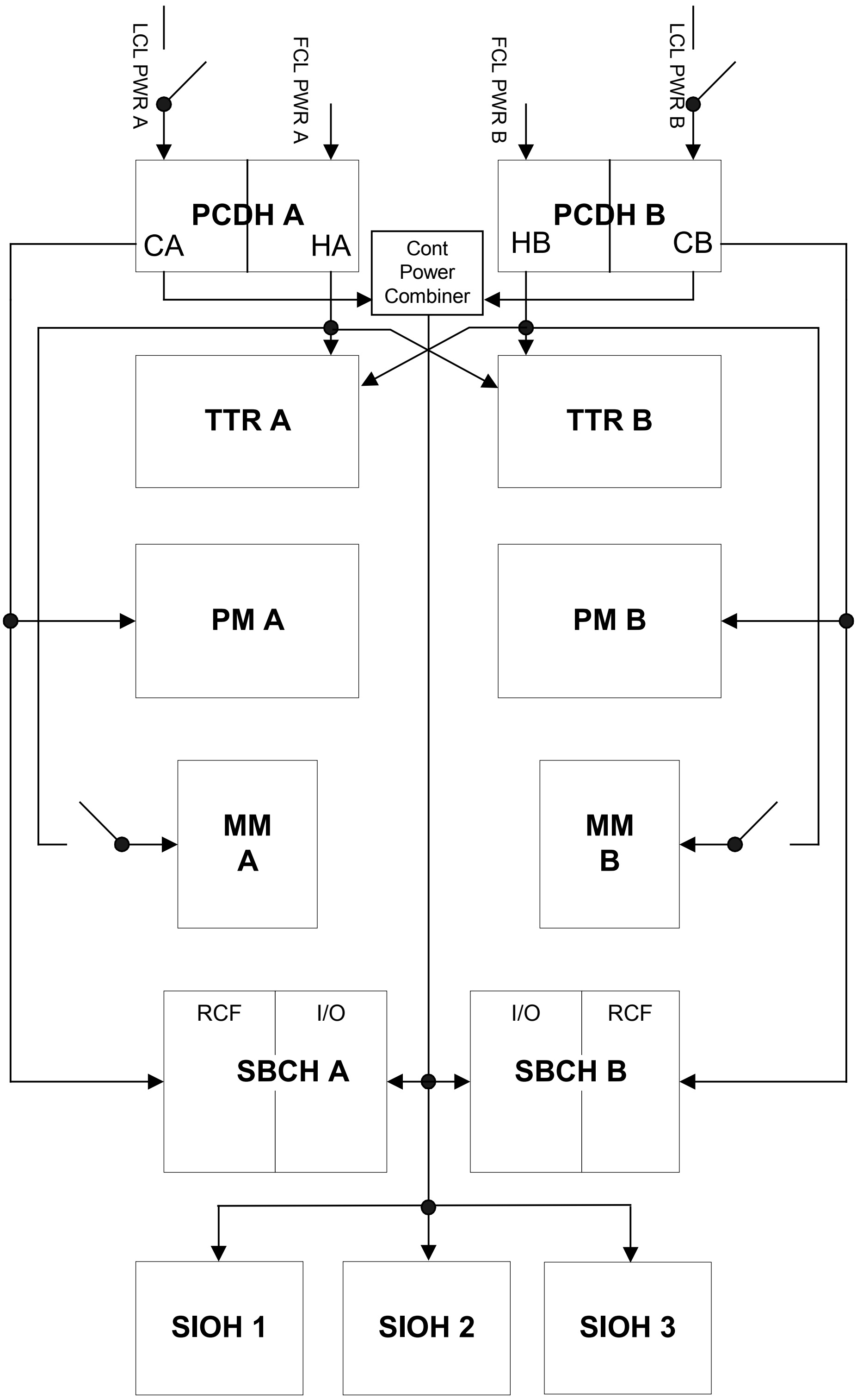
Functional description.

The main function is to distribute Secondary Voltages to the internal CDMU modules.
The Power converters (PCDH) provide two section: hot and cold. The first one is automatically powered ON as soon as power is applied and the second one is ON/OFF switchable by means of PM HP TC commands received from RM.

The hot and cold converter will share some design blocks (CM-filter, start-up supply etc.) in order to reduce the parts count.

The power converter consists of the following blocks:

- the Hot converter which supplies two TTR Boards and one MM board.
- the Cold converter which supplies one PM board and one RCF as part of SBCH.
- the CONT voltages, generated by the two cold sections and which supply the end terminals of the I/O system. They are automatically configured ON as soon as at least one of the cold converters are switched ON.


LCL PWR A
FCL PWR A
FCL PWR B
LCL PWR B
PCDH A
CA
HA
Cont
Power
Combiner
PCDH B
HB
CB
TTR A
TTR B
PM A
PM B
MM
A
MM
B
RCF
I/O
SBCH A
I/O
RCF
SBCH B
SIOH 1
SIOH 2
SIOH 3

Design and performance.

Each converter is supplied from a regulated power bus (26-30V).

The hot converter provides 4 output voltages: +3.3V, +3.7 V, +5V, + 15 V, -15 V, +28V and CMD +28 V.

The hot converter is based on an established current mode topology operating at fixed frequency, suitable for low power level.
The cold converter provides 5 output voltages: +3.3V, +5V, +15 V, -15 V and +28V.
The cold converter also provides 5 continuos voltages: +5V, +15 V, -15 V, +28 V and CMD +28 V. The continuos voltages are derived from the cold voltages and cross-coupled with the redundant cold converter.

The cold converter, which requires a considerably higher power capability, is based on a current fed dual switch topology.

A thermistor monitors the board temperature at the hot spot, other monitors are provided for the U/V detection and secondary voltages.

9.7.5 Commonality Assessment

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

CDMU will be the same for the two satellites.

9.7.6 Budget Summary

The following budgets are foreseen for the CDMU. The same numbers are applicable to both Herschel and Planck design.

Mass	13.72 +/- 0.568 kg
Unit Dimensions (incl. mounting feet)	277.4 mm x 234.5 mm x 382.2 mm (ZxYxX)
Board size	233 x 160 mm 14 boards
Power Dissipation Communication phase, Typical Autonomous phase, Typical Peak	 37.7 W 37.1 W 69.7 W
Performance CPU performance RAM memory EPROM memory PROM memory Mass Memory Safeguard memory	 14.3 MIPS 6MiB (6,29 Mbytes) 2 MiB (2,09 Mbytes) 64KiB (65,5 Kbytes) 2 x 32Gbit BOL; 25 Gbit EOL 2 x 512 KiB (524 Kbytes)

Table 9.7.6-1 CDMU Budget Summary

9.8 TT&C

9.8.1 General

In this chapter, the Tracking, Telemetry and Command function is described. Its main scope is the RF communication up and downlink between the spacecraft and the 2 ground stations baselined for Herschel and Planck missions, i.e. New Norcia and Kourou.
The TTC Subsytem and its components are procured on the basis of the hereafter listed specification (included in the CDR data Package).

RFDN and RF harness specification H-P-SP-AI-0023 3 [RD-62]
X/X band transponder specification H-P-SP-AI-0012 3 [RD-57]
Xband Travelling Wave Tube Assembly specification H-P-SP-AI-0016 4 [RD-60]
Xband Low Gain Antenna Specification H-P-SP-AI-0024 4 [RD-50]
Xband Medium Gain Antenna Specification H-P-SP-AI-0025 4 [RD-51]

The major modification occurred from the PDR (June 2002) are hereafter briefly listed. Any details on the improved design with respect to the one presented at the PDR can be found in the applicable design report at Subsystem and/or Equipment level:

RFDN
Remove of 2 coax switches (Agreed at System PDR)

XPND
Duplication of some 1553 TM/TC on discrete I/O interfaces, in order to be able to operate Rx also when 1553 I/F is OFF

MGA
Bracket re-design due to interferences with Ariane 5

LGA and TWTAs
No major change occurred but only minor modification typical of phase C/D

9.8.2 Requirements and Design Drivers

This paragraph presents an overview of the major requirements derived from the SVM Specification, driving the TT&C, providing consideration and discussion on their indented implementation.
The following features essentially characterize Herschel and Planck missions.

- Both use X-Band for Up and Downlinks. Frequency allocations however are specific for each spacecraft. The Earth to spacecraft distances of the two spacecraft during operation are comparable.
- The spacecraft to Earth aspects angles of Herschel and Planck from telecommunication point of view are similar:
  - +/-15° maximum for Planck with New Norcia G/S and +/-10° in case of Kourou G/S,
  - +/-10° maximum for Herschel with both New Norcia and Kourou G/S.
- the uplink and downlink data rates requirements are the same for the 2 spacecraft.

Which calls for an obvious hardware commonality between Herschel and Planck TTC subsystems.

9.8.2.1 General Requirements

TEF-005-C
The TT&C Subsystem shall be able to receive and demodulate telecommands, modulate and transmit the telemetry, and transpond the ranging signal, simultaneously. < SMTT-05>

TEF-010-C
The SVM shall have no requirements for telecommand and telemetry operation during the launch phase via its RF links. <SMTT-025>

TEF-015-C
The TT&C Subsystem shall support the following modes for the uplink:
- Carrier only
- Telecommand
- Ranging
- Simultaneous Telecommand and Ranging. <SMTT-030>

TEF-020-C The TT&C Subsystem shall support the following modes for the downlink:
- Carrier only
- Telemetry
- Ranging
- Simultaneous Telemetry and Ranging
- Doppler (to allow Doppler measurement by the ground) <SMTT-035>

TEF-025-C
The TT&C subsystem shall accept uplink signals and provide a demodulated digital telecommand signal to the CDMS for further processing. This function shall always be enabled without any possibility of switching it off. <SMTT-040>

TEF-030-C
The TT&C subsystem shall accept a digital telemetry signal from the CDMS and modulate it onto a downlink carrier. It shall be possible to disable this function. <SMTT-045>

TEF-035-C
The TT&C subsystem shall provide a range and/or range rate measurement capability. For ranging, it shall be capable to demodulate ranging tone from the uplink carrier and modulate the downlink carrier with this tone. <SMTT-050>

TEF-080-C
The receiver shall provide a status signal indicating the presence of an uplink signal. <SMTT-095>

TEF-085-C
Limited housekeeping data will be routinely delivered to the LGA's for transmission upon ground request. <SMTT-100>

TEF-095-C
The subsystem design shall ensure that all its relevant operational parameters are acquired via suitable sensors and provided to the CDMS for incorporation into the HK telemetry. <SMTT-165>

TEF-100-C
The TT&C subsystem shall be designed such as to be launched power "ON"; however, the telemetry function shall be disabled during launch. <SMTT-170>

The XPND receivers are designed to be always “ON” and are connected to PCDU FCL lines while the EPC of the nominal TWTAs is foreseen to be launched “ON” in the preheating mode.

9.8.2.2 ANTENNA CONFIGURATION AND COVERAGE

TEF-060-C
The antenna configuration shall ensure sufficient coverage and up-and downlink rate capability for all mission phases. <SMTT-075>

TEF-070-C
Telecommands shall be via the LGA’s and the MGA, and the subsystem shall provide the required telecommand capabilities at maximum distance from the Earth and in any S/C attitude. <SMTT-085>

TEF-090-C
A Medium-Gain Antenna (MGA) shall provide the primary communication for the downlink during the scientific operations phase and during the Commissioning and Performance Verification Phases. <SMTT-105>

The link coverage is ensured by LGA antennas independently from spacecraft attitude . A different configuration has been selected from HERSCHEL and PLANCK; in particular, an additional Antenna is considered necessary for Planck in order to avoid utilization of experiment “cold” area where measurement interferences can be generated.

9.8.2.3 REDUNDANCY AND RF SWITCHING

TEF-040-C
Hot redundancy shall be provided for the receive function and cold redundancy for the transmit function. <SMTT-055>

TEF-045-C
The receiver outputs shall be cross-coupled with the inputs of the CDMS command decoders. <SMTT-060>

TEF-050-C
The configuration shall be such that both receivers can receive and both decoders can decode simultaneously. <SMTT-065>

TEF-055-C
The transmitters shall be able to receive the telemetry stream from both parts of the redundant CDMS. <SMTT-070>

TEF-065-C
When switching between antennas it shall not be necessary to switch off the transmitter. <SMTT-080>

TEP-060-C
The TT&C subsystem shall not have any single point failure except for the radiating elements of the antennas and their associated cabling. It shall have the capability of recovering from a failure autonomously. In all cases, it shall be possible to override the autonomous recovery action by use of ground commands. <SMTT-160>

TEP-065-C
The radio frequency switching between antenna and transponders shall be done without single point failure. <SMTT-175>

The requirements for full redundancy and 0-SPF are implemented throughout all the TT&C Architecture where HW redundancies of Units and relevant interconnections allow parallel commanding paths through CDMS Decoder High Priority TC and RTU TC).

9.8.2.4 HERSCHEL/Planck COMMONALITY

GEF-025-C The components and interfaces of the both SVM shall be optimised as much as possible. <SGEN-005>

TEP-005-C
The uplink/downlink signals shall be in the range 7190-7235 MHz for telecommands and 8450-8500 MHz for telemetry. <SMTT-110>

[S/G-ICD - 2.1.1]
The satellite telecommunication subsystem will be allocated for a Category A (non Deep Space) Mission with a down link frequency in the 8450 – 8500 MHz frequency band (X-band) as follows:

Herschel
8468.5 MHz (TBC) Emission bandwidth: 7 MHz
Planck
8455.0 MHz (TBC) Emission bandwidth: 7 MHz

[S/G-ICD - 2.2.1] The satellite telecommunication subsystem will be allocated for a Category A (non Deep Space) mission with an uplink frequency in the 7190 - 7235 MHz frequency band (X-Band) as follows:

Herschel
7207.8483 MHz (TBC) Emission bandwidth: 3 MHz
Planck
7196.3580 MHz (TBC) Emission bandwidth: 3 MHz

Commonality between Herschel and Planck has been implemented to the maximum extent, taking into consideration the envelope of the requirements. In particular, as far as the TT&C is concerned, the following three aspects are worth to be mentioned:

LGA antenna configuration (2 on Herschel, 3 on Planck): the RFDN is designed to support connection of up to three LGA's.

Uplink/downlink frequencies: all equipments are designed to cover both Tx and Rx frequencies. and the transponders are designed to be adapted to both frequencies.

9.8.2.5 LINK BUDGETS AND DATA RATEs

TEP-015-C
The link budget margins shall be computed under the following assumptions :

- Telemetry : Telemetry bit error rate associated with 99.999% of transfer frame delivery corresponding to Eb/No = 2.7 dB theoretical for ESA standard concatenated FEC coding [AD 24].
- Telecommand : a) Under all conditions specified by the mission Telecommand Bit Error Rate of 10 -5 corresponding to Eb/No = 9.6 dB (theoretical), b) Under “no signal” conditions, the mean rate of spurious command generation must be less than one per two years.
- Ranging: to be commensurate with Herschel and Planck navigation requirements for range bias and range noise (TBD). range bias : 1 meter range noise : 1 sigma random error of 2 meters. <SMTT-120>

TEP-020-C
Link budgets for all mission phases shall be computed as defined in ESA PSS-04-105, RF and Modulation Standard [AD 21]. <SMTT-125>

TEP-025-C
The minimum values of those margins shall be :

- nominal margin : 3dB
- RSS worst case margin : 0dB
- mean - 3 sigma margin : 0dB

The applicable ground station characteristics are defined in the Space to Ground Interface Specification [AD 07]. The link budget calculation shall include in addition to TM and TC budget calculation: carrier acquisition, tone recovery, data recovery and minimum S/N for ranging. <SMTT-130>

TEP-030-C
The probability of frame loss on the downlink shall be < 10 E-5. <SMTT-135>

TEP-035-C
The LGA’s shall support an uplink high command rate of 4Kbps using the 35 m station at Perth / New Norcia and a low command data rate of 125 bps using the 15 m station at Kourou up to a distance from the Earth of 1.8 x 10^6 km for Herschel and 1.6 x 10^6 km for Planck. <SMTT-140>

TEP-040-C
The MGA shall support an uplink command rate of 4 kbps for both Perth / New Norcia and Kourou stations, up to a distance from the Earth of 1.8 x 10^6 km for Herschel and of 1.6 x 10^6km for Planck. <SMTT-142>

TEP-045-C
The LGA’s shall support the downlink of real time housekeeping data (spacecraft and payload) telemetry using the 35 m station at Perth / New Norcia and 500 bps using 15 m station at Kourou up to a distance from the Earth of 1.8 x 10^6 km for Herschel and 1.6 x 10^6 km for Planck. <SMTT-145>

TEP-050-C
The omni-directional coverage of the LGA’s shall overlap to the extend necessary to ensure that the antenna switching is never time-critical. <SMTT-150>

TEP-055-C
The MGA shall allow for the telemetry downlink with the Perth / New Norcia 35 m station and with the 15 m station at Kourou up to a distance from the Earth of 1.8 x 10^6 km for Herschel and 1.6 x 10^6 km during the telecommunication period at 10° elevation. <SMTT-155>

ESA recommended margins are satisfied both for the Up and Downlink, except for minor deviation, only for the Planck Satellite (Kourou GS), in case of simultaneous use of the 2 redundant Antennae at the distance of 1.6 10^6 Km.

9.8.2.6 MODULATION SCHEMES

[S/G-ICD-2.1.4]
The telemetry modulation scheme is a function of the bit rates to be transmitted as follows

Rate	Information rate	Modulation scheme	Subcarrier frequency
Low-1	500 bps	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine)
Low-2	5 kbps	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine)
Medium	150 kbps	PCM(SP-L)/PM	Not applicable
High	1.5 Mbps	GMSK	Not applicable

[S/G-ICD-2.2.4]
For telecommand rates below or equal to 4 kbps the telecommand modulation scheme is PCM(NRZ-L)/PSK/PM on a sinusoidal subcarrier. The selected subcarrier frequency is 16 kHz.

Rate	Modulation scheme	Subcarrier frequency
125 bps	PCM(NRZ-L)/PSK/PM	16 kHz (sine)
4 kbps	PCM(NRZ-L)/PSK/PM	16 kHz (sine)

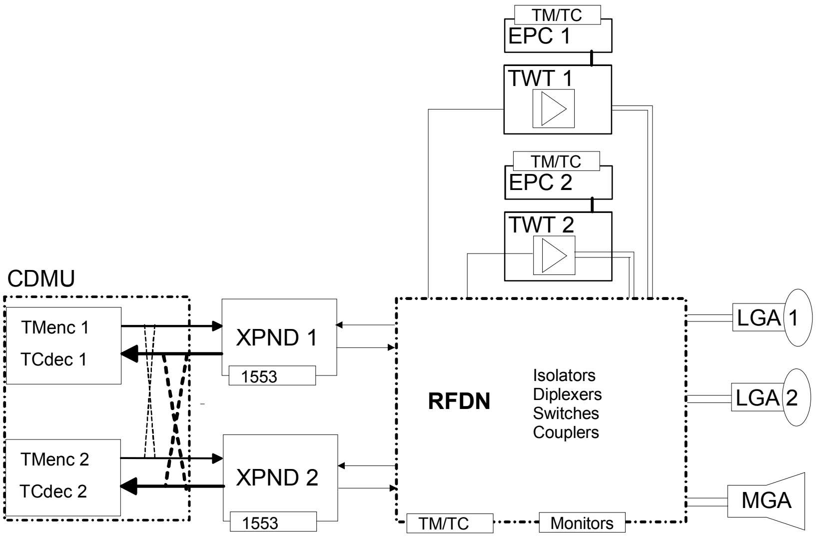
The ranging signal directly phase modulates (PM) the uplink carrier. For simultaneous ranging and telecommand, the two signals are added prior to phase modulation of the uplink carrier.
The telecommand bit rates refer to the digital bit stream at the physical layer, consisting of CLTUs and Idle/Acquisition sequences.

As far as the Ranging Tone concern, according to ESA clarification, it shall be placed on the range 600 – 700 kHz.
The driving modulation scheme for the selection is the MBR with SPL modulation because of possible interference with TM spectrum. at 150 kbps.
MPTS tone should in fact be placed in the neighborhood of a TM spectrum nulls (2*n*fs'), TM where spectral density is lower, but not exactly in a null because the XPND filtering present a clock residue just on top of it.
Available null is a 688.260 kHz so, according to SGICD the **ranging tone** as been placed at **698.260 kHz** taking into account 10kHz shift respect to the SPL null.

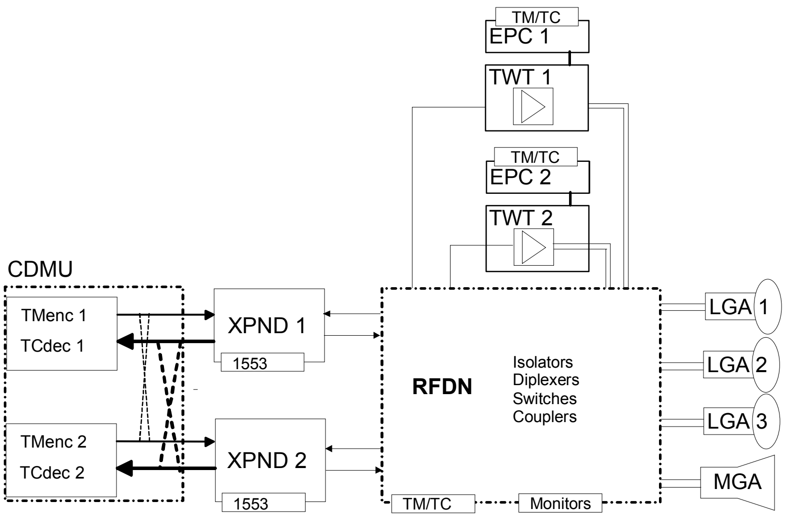
9.8.3 Functional Description

The TT&C function addresses the RF communication up and downlink between the spacecraft and the 2 ground stations baselined for HERSCHEL and Planck missions: New Norcia (Perth) and Kourou.

The H/P TT&C design is based on the maximum commonality between HERSCHEL and Planck TTC subsystems as presented in the diagrams below:



HERSCHEL TT&C Subsystem redundancy concept



PLANCK TT&C Subsystem redundancy concept

The TTC function thus comprises:

- Two Telemetry Encoders/Decoders allocated in the CDMU operated in hot redundancy for the receiving part and cold redundancy for the Tx one. In particular the TM encoders on the CDMU TTR boards are in charge of the TM stream generation and the Reed-Solomon and Convolutional Coding. They can generate the required TM data rates and provide the Transmitted Symbol Rate to the XPND TM interface according to the table below:

TM Rate	*Information Rate fb*	*Transmitted Symbol Rate fs'*
LOW-1	500.0065	*1147.1000*
LOW-2	5000.0645	*11471.0000*
MEDIUM	150001.93511	*344130.0000*
HIGH	1500019.3511	*3441300.0000*

At the same time they include two TC Decoders that receive the digital TC signal from XPNDs TC Demodulators, decode it and provide the Telecommands to the CDMU Processor Module and Command Pulse Distribution Unit (CPDU).
Two TC Rates are foreseen according to the requirements:

TC Rate	*TC Rate*	*TC SubCarrier*
LOW	125	*16 kHz*
HIGH	4000	*16 kHz*

- Two X-Band Transponders (XPND) operated in hot redundancy for the receiving part and cold redundancy for the Tx one. They are identical for Herschel and Planck with the obvious exception of the carrier frequencies setting; especially, the down and uplink data rates Telecommand and Telemetry streams are made common between Herschel and Planck, for sake of highest commonality. The Transmitting part accepts the Transmitted Symbol Rate from the CDMU TM Encoders and generates all the Modulations required according to the different data rates:

TM Rate	*Transmitted Symbol Rate fs'*	*Modulation scheme*	*Subcarrier frequency*
LOW-1	*1147.1000*	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine)
LOW-2	*11471.0000*	PCM(NRZ-L)/PSK/PM	45884.000 Hz (sine)
MEDIUM	*344130.0000*	PCM(SP-L)/PM	Not applicable
HIGH	*3441300.0000*	GMSK	Not applicable

Digital Shaping is used to implement GMSK and to limitate the RF signal occupied bandwidth for SP-L

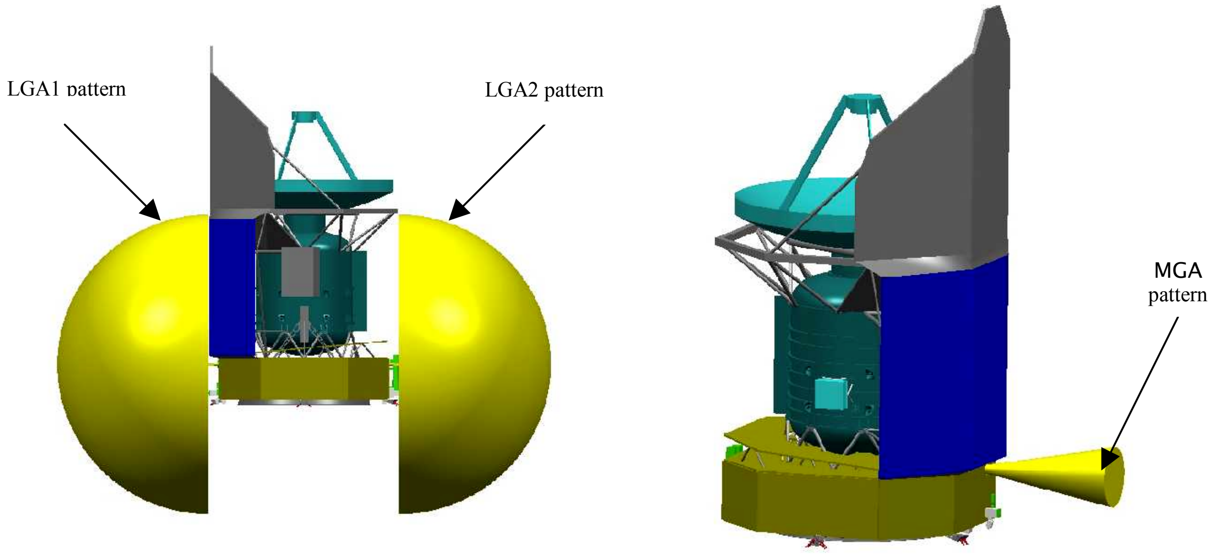
- Two cold redundant 32W TWTA used to guarantee the required downlink rates.

- One X-Band Medium Gain Antenna, to perform the High and Medium data rate downlink during the planned telecommunication sessions. It can also be used for Telecommand Uplink.

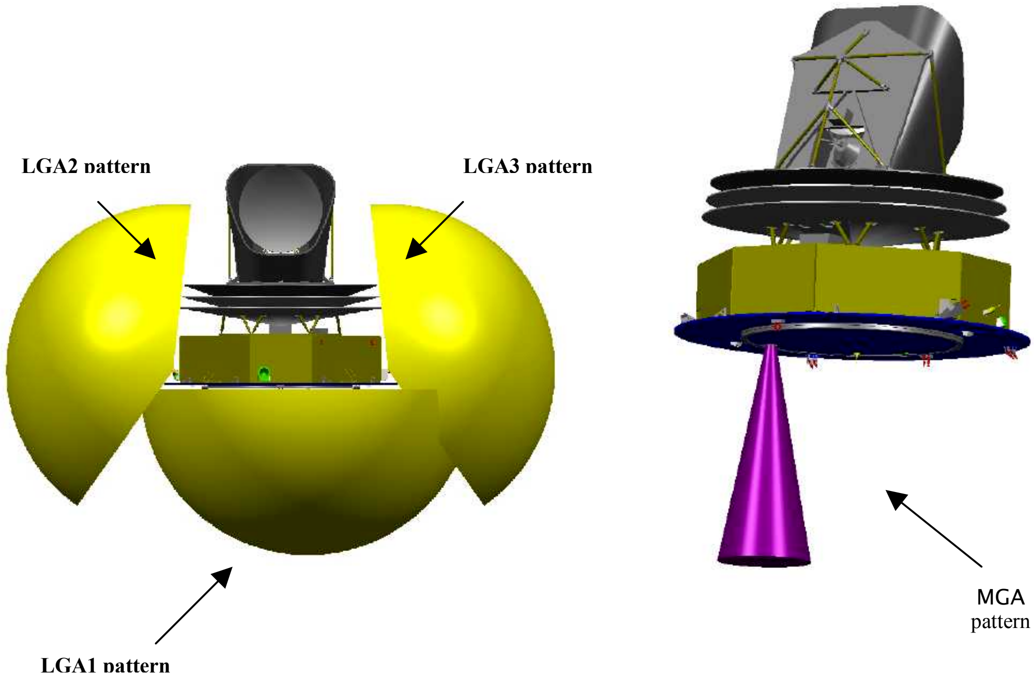
- Identical Dual band Rx/Tx Low Gain antennas, to perform the low rate downlink, mainly at start of the missions and in emergency cases, and to receive the telecommand uplink streams. They are accommodated in order to guarantee a quasi omnidirectional coverage in both TM and TC, thus making the spacecraft robust to the “attitude loss” failure mode. Specificities due to the different geometries, different attitude controls, and different Payload Module constraints, have led to use 2 LGAs for HERSCHEL, and 3 LGAs for Planck.

- The TTC architecture also comprises the suitable set of diplexers, hybrids and switches integrated in the so-called RFDN, with optimized trade-off between passive losses and number of switch/Tc.

In the following figures the satellites models with the antennas position are presented in order to clarify the main differences between the two spacecraft.



Herschel 2 LGAs and MGA accommodation and indicative radiation patterns



Planck 3 LGAs and MGA accommodation and indicative radiation patterns

9.8.4 Design and Performance

The TT&C architecture proposed for HERSCHEL and PLANCK is here below described.
As previously mentioned there is a common architecture between the two spacecraft. Both the spacecraft use the same transponders, TWTA, Low Gain Antennas and Medium Gain Antenna.

In particular:

HERSCHEL configuration:

- Up and Down link via 2 LGAs (LGA 1 nominal, in the Earth direction and LGA 2 redundant, in the opposite direction)
- Up and Down link with MGA (in the Earth direction)

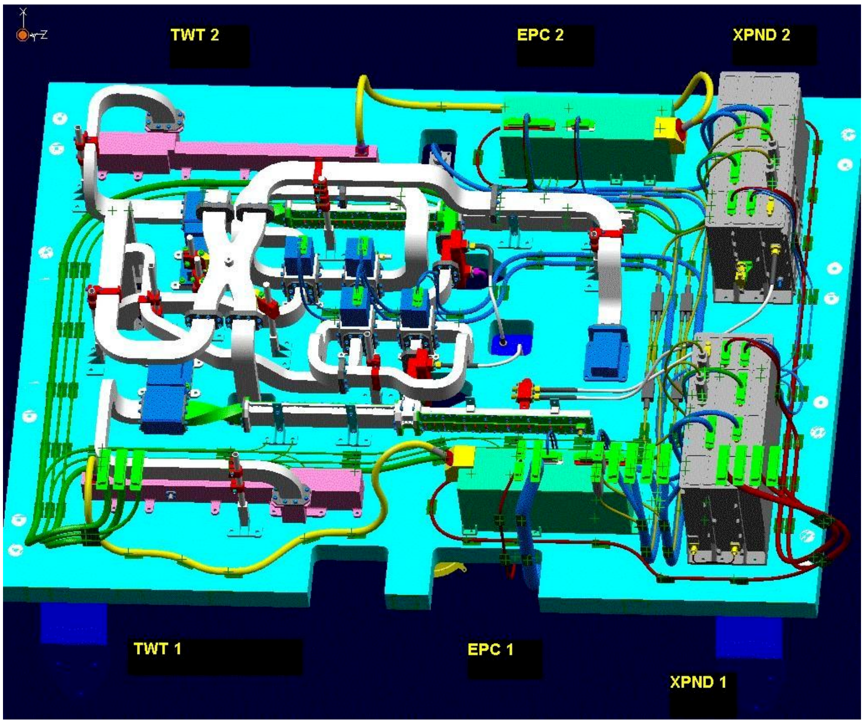
PLANCK configuration:

- Up and Down link via 3 LGAs (LGA 1 nominal, in the Earth direction and LGA 2 & 3 redundant and coupled in order to cover the opposite direction)
- Up and Down link with MGA (in the Earth direction)

The use of the LGA antennas assures an almost complete coverage independently on the spacecraft attitude and operational phases of the mission for Low data rates and emergency communication.

The RF output power from the transponder is raised through a TWTA up to 32 W. The output power from TWTA and the gain assured by the MGA are sufficient to transmit the high data rate required for the long range distance (1.8 Mkm for Herschel and 1.6 Mkm for Planck) in accordance with the ESA requirements.

A CAD picture of the SVM TT&C panel is shown in the following figure.



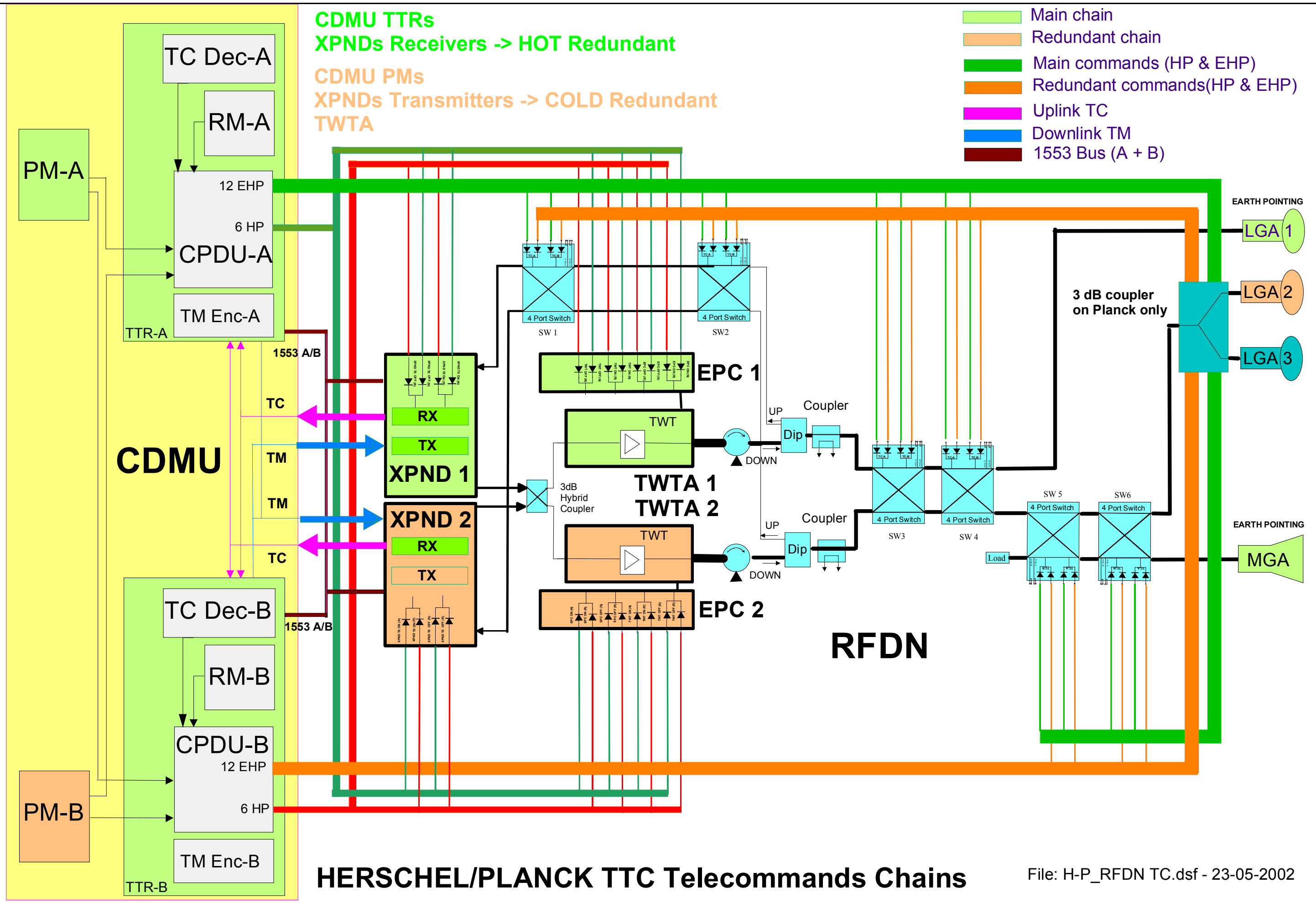
Particular efforts have been given on the RFDN design in order to respect the requirement of a single point failure free switching network. The use of waveguide technology is used the downlink path between the output of two TWTAs and the different antennas characterised by high RF power. The low power downlink distribution networks between the Transponders TX outputs and the TWTAs inputs and the uplink path from use coaxial technology.
The RFDN is equipped with a diplexers filter in charge to separate the uplink and downlink frequencies.
Directional couplers are connected after the diplexer to permit measurements of RF outputs transmitted to the antennas.
The RFDN has been designed to support both the Herschel and Planck configuration. The only difference is a coupler in the LGA2 path that permits to split this to the Planck LGA2 and LGA3.

All equipments have been designed to accept Telecommands from two independent sources in order to have a redundant chain of command. The TWTA and RFDN use discrete commands only (HP) while the Transponders used HP commands to switch ON/OFF the transmitters and Mil-1553 redundant bus for all other necessary commands.

As depicted in the picture below, the two CPDUs inside the CDMU TTR boards are used to generate the High Priority commands directed to XPNDs and TWTAs and the Extended High Priority commands directed to RFDN Switches.
One CPDU outputs are connected to the Nominal equipments commands and the other CPDU outputs are connected to the redundant ones.
Each CDPU can generate the HP commands under request from TC decoder, Reconfiguration Module and both Processor Modules.
With the configuration presented here commands coming from on-board SW (PM-A or PM-B) can be generated by both CPDUs (so SW can access to both Nominal and Redundant XPND, EPC (TWTAs) and RFDN command chains). At the same time, commands coming from Reconfiguration Modules and/or TC Decoders, can use the nominal command chain for TC Dec-A, RM-A and the redundant command chain for TC Dec-B, RM-B.

As far as The Uplink Telecommands signals and Downlink Telemetry signals the XPND1 is connected to the CDMU TTR-A and XPND2 is connected to CDMU TTR-B. Cross strapping is realised inside the CDMU.

For what concerns the Power redundancy the TC receiving part is designed to be Hot Redundant (TC Decoders, CDPU, XPND-1 and XPND-2 Receivers) while the transmitting part (XPNDs Transmitters, TWTAs) is designed to be operated in Cold redundancy.



HERSCHEL/PLANCK TTC Telecommands Chains

File: H-P_RFDN TC.dsf - 23-05-2002

9.8.5 Equipment Design

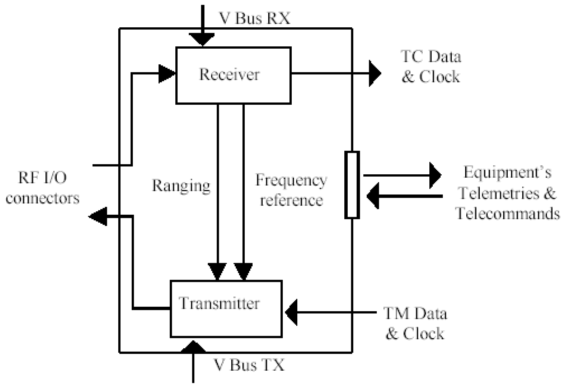
In the following pages the major equipment or components are described in detail.

9.8.5.1 Transponder (XPND)

The chosen Transponders are based on a digital architecture. In fact, the modern communication theory associated to digital signal processing has enabled the application of digital solutions instead of analog approach. In particular, the increasing of the maximum sampling rate achievable makes possible to move the boundary between analog and digital domain at higher frequency. This, in many cases, has allowed to increase performances reducing cost and maintenance requirements.

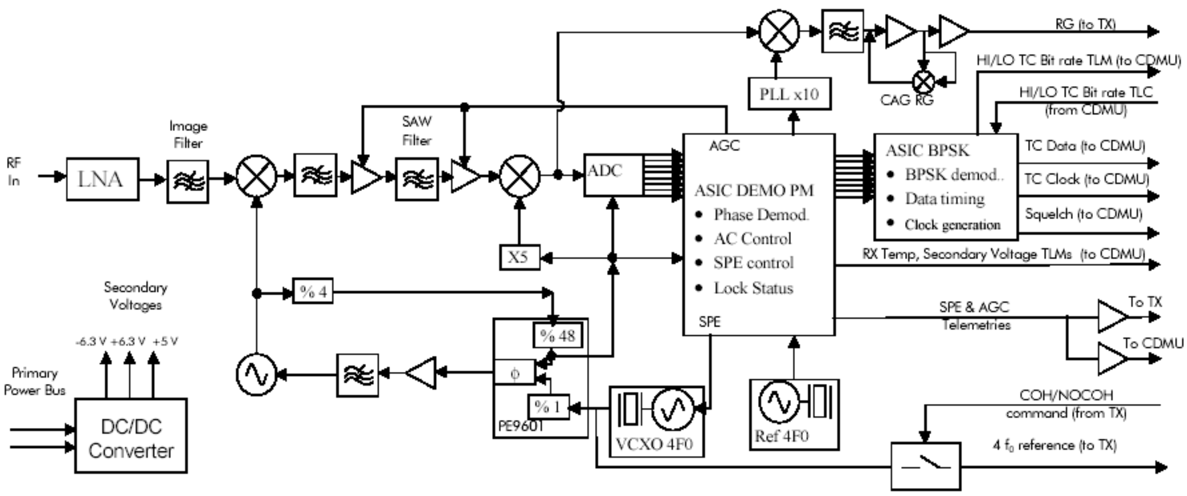
Two identical separate transponders are placed on each satellite, the main and the redundant.

The architecture of the transponder is depicted of the Figure below. The transponder is composed of two main blocks: The receiver and the transmitter.



9.8.5.1.1 Receiver

The receiver performs the Low noise amplification, the double frequency conversion with a local oscillator phase locked to the received signal, the variable gain amplification to compensate the input level variations, the phase demodulation of the carrier and the BPSK demodulation of the TC subcarrier.
The receiver generates two signals that are delivered to the transmitter: The ranging baseband signal and a frequency reference coherent with the received uplink signal.
The transmitter will generate the downlink carrier coherent using the selected reference frequency depending on the selected mode (coherent with the receiver, not coherent or external reference). The downlink carrier is generated coherent with this frequency reference by means of a phase locked loop. This carrier will be modulated, filtered and amplified up to the required output level.
Three modulation formats are implemented depending on the TM stream data rate. For Low data rate, PCM/NRZ-L/BPSK/PM modulation is implemented. With this type of modulation, the Ranging signal is added to the TM subcarrier before the final phase modulation of the carrier. For medium data rates, SPL/ PM modulation is implemented. This modulation is also a phase modulation but it is not compatible with simultaneous Ranging. Finally for High data rate, GMSK is implemented by means of a digital pulse shaping and an I/Q linear modulator.

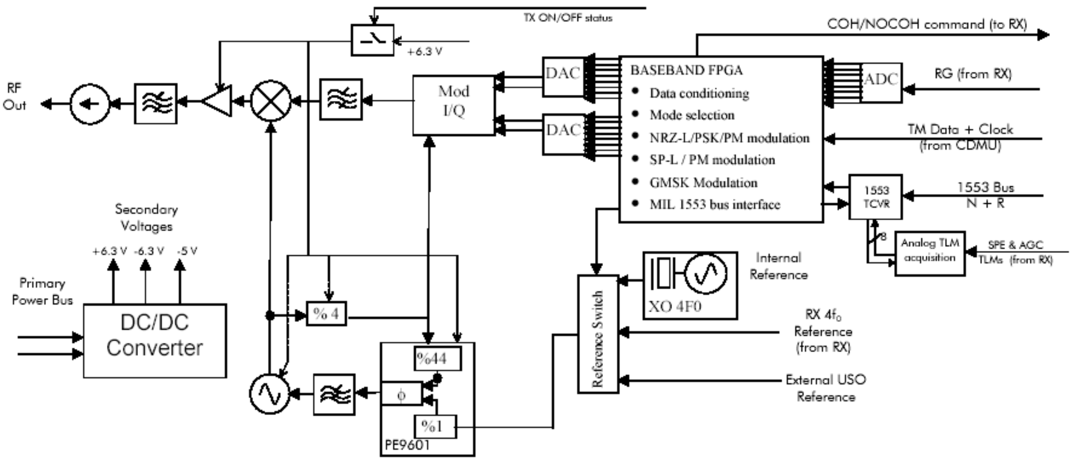


Receiver main characteristics are resumed in the table below:

• Receiver input frequency	7207.8483 (Herschel) / 7196.3580 (Planck) MHz
• Receiver input threshold range	
-Acquisition	-141 dBm
-Tracking	-135 dBm
• Input dynamic range	-141 to –45 dBm
• Noise Figure at the RF input port	NF ≤ 2 dB (for PIN < -90 dBm)
• Rest frequency stability	Δf ± 19 ppm Initial setting + power supply variations + variation in temperature
• Receiver wide phase loop	100 Hz ± 20%
• Sweep rate	Up to 500 Hz/s on ± 250 kHz sweep span
• TC modulation	16 KHz BPSK Subcarrier
• TC modulation index	0.3 to 1.5 rad-peak
• TC bit rate	125 / 4000 bps selectable by TLC
• Ranging format	MPTS
• Ranging frequency	688.270 kHz
• Ranging group delay stability	± 30 nsec
• Ranging bandwidth	1 dBpp from 3 to 1000 kHz Double-sided NBW< 3.5 MHz
• Power consumption	10 W (estimation)

9.8.5.1.2 TRANSMITTER

The picture below shows a detailed block diagram of the transmitter. In this block diagram the different modules that generate and process the downlink signal can be appreciated.



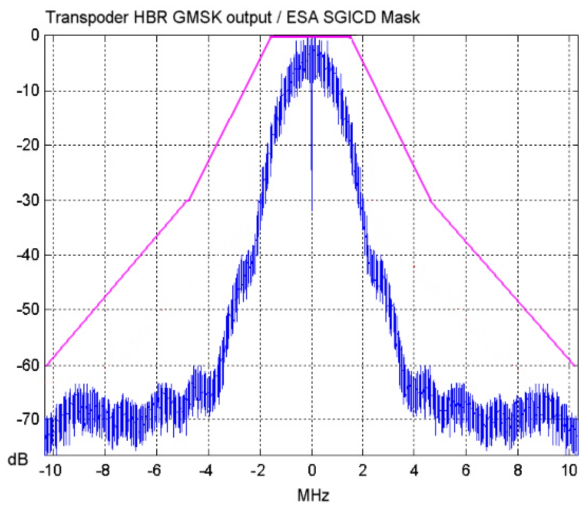
A X band VCO has been selected due to its better performances in terms of phase noise compared with lower frequency oscillators multiplied to reach the desired output frequency. A phase locked loop is used to lock it to a reference signal that can be the reference delivered by the receiver (in this case the transponder will work in coherent mode allowing Doppler and Doppler rate measures), a transmitter internal reference or an external reference.
The processing of the baseband signals is made digitally. An FPGA contents the digital circuitry that processes the input TM data stream and generates two 8 bit signals I and Q, that, after being converted to analogue signals, will modulate the carrier in a I/Q modulator generating the PM or GMSK signal.
Finally the modulated IF signal is up-converted and filtered. The output amplifiers will be in charge of the signal buffering and amplitude control of the transmitter output signal.
A DC/DC converter will generate, from the primary bus voltage, the secondary voltages required by the rest of modules of the receiver. Independent DC/DC converters feed the receiver and the transmitter to increase the reliability of the equipment.

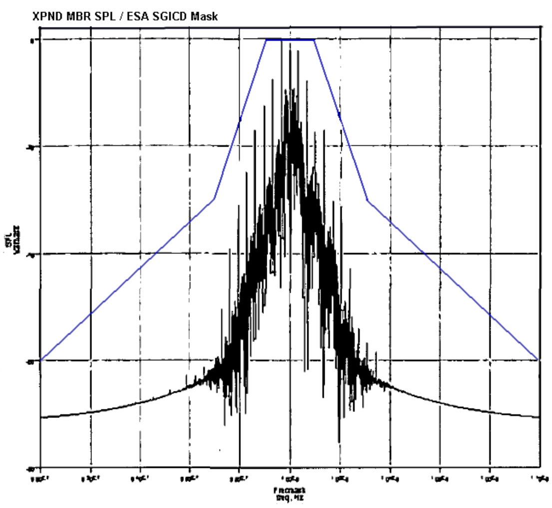
In order to comply with the Emission Masks requested in the Space to Ground ICD, the transponder will use GMSK for TM High Bit Rate and filtered SP-L for TM Medium Bit Rate. A preliminary test has been arranged at ESOC using a XPND breadboard to show the compatibility of SPL and GMSK with ESA grondstation and perform preliminary measurements. The obtained results demonstrated that the XPND design and development was good and fully compatible with ESA requirements. Modulation lossed were also measured and results have been taken into account in the link budgets evaluation.

Transmitter main characteristics are resumed in the table below:

• RF output power	-6 to +3 dBm, selectable by TLC
• RF output power stability	±0.5 dB
• Transmitter frequency	
-Coherent mode	$F_{TX} = \frac{880}{749} F_{RX}$
-Non coherent mode	8468.5 (Herschel) / 8455.0 (Planck) MHz
• Frequency stability (non-coherent mode)	Δf ± 19 ppm Initial setting + power supply variations + variation in temperature
• Spurious outputs	< -60 dBc
• TM Modulation Modes	PM / BPSK, SP-L
-High symbol rate	GMSK (3.44 Mbps)
-Medium symbol rate	SP-L/PM (344 kbps)
-Low symbol rates (1 & 2)	NRZ-L/PSK/PM (11.471 & 1.147 kbps; subcarrier frequency 45.884 kHz)
• TM modulation index	0.0 to 1.5 rad in 0.1 rad steps by TLC
• RG modulation index	0.0 to 0.7 rad in 0.1 rad steps by TLC
• Modulation index linearity	< ± 3%
• Phase noise	
-Subcarrier modulation	< 4° rms (10 Hz to 100 kHz, NOCOH mode)
-Suppressed carrier modulation	< 6° rms (10 Hz to 1 MHz, NOCOH mode)
• Power consumption	14.7 W, including 1553 I/F (estimation)
• Mass (including RX& DC/DC)	4070 gr (estimation)

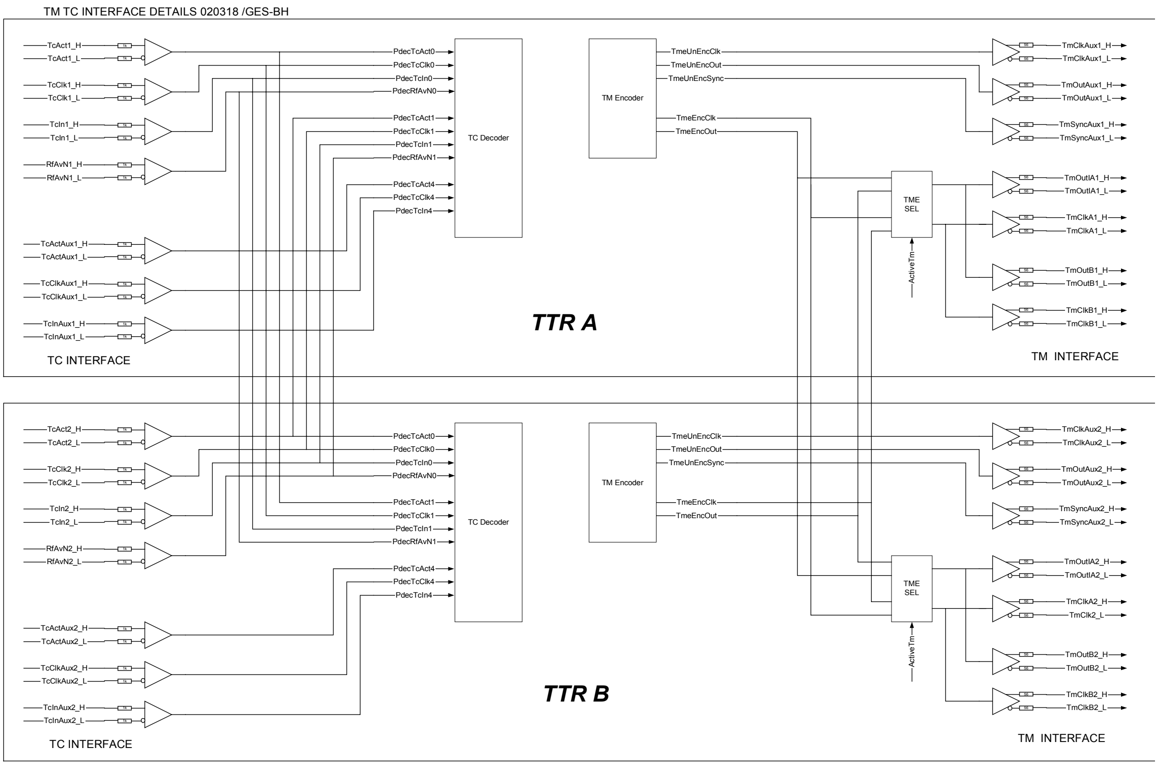
Preliminary Transponder RF output simulation and breadboard measurements have been performed showing the compliance with required emission mask. No degradation is expected after the TWT amplification while the GMSK is know not to suffer of amplifier distortion.





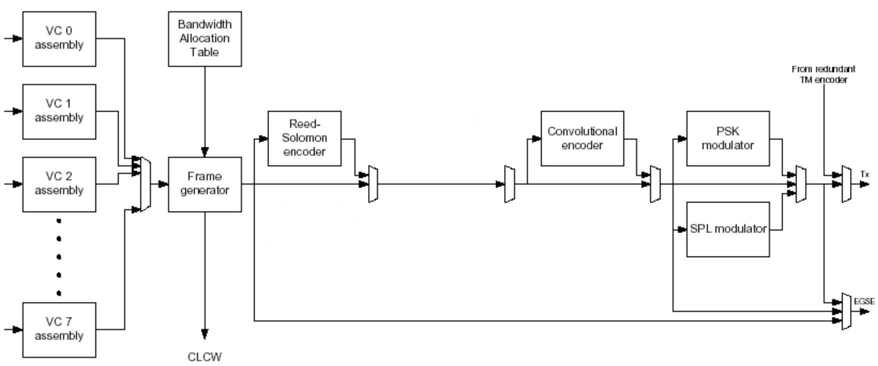
9.8.5.1.3 TRANSPONDER – CDMU Interface.

The transponder is connected to the CDMU through SBDL digital interfaces for Uplink TC and Downlink TM. Each Transponder is provided with two connectors with TM/TC signals. One connector is directed to the CDMU while the other is used for EGSE.
The cross-strapping is made inside CDMU as showed in the following diagram:

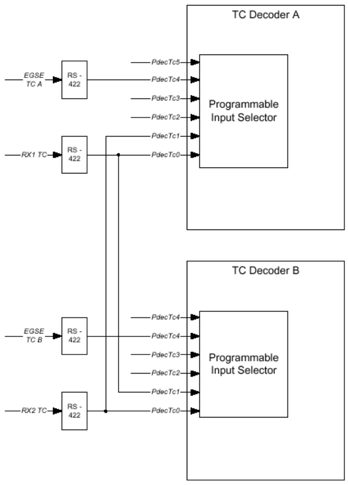


The use of digital interfaces, means that all the modulations required are completely performed inside the transponder. For this reason it is important that the digital modulation section will be synchronised to the CDMU TM generator. For this reason each CDMU TM Encoder foresees a Data and a Clock output and the XPND digital interface is synchronised to the this Clock signal.

The different TM bit rates and associated modulation scheme are selectable by TC.



The TC interface foresees also RF_Lock and Squelch signal that is used by the CDMU TC Decoders to select the XPND receiver best signal.



This interface is often critical in a satellite design and failures has occurred in some past programs (i.e. XMM). To avoid problems a new kind of priority selection scheme, the **Dynamic Mode** is used in the CDMU TC Decoders.

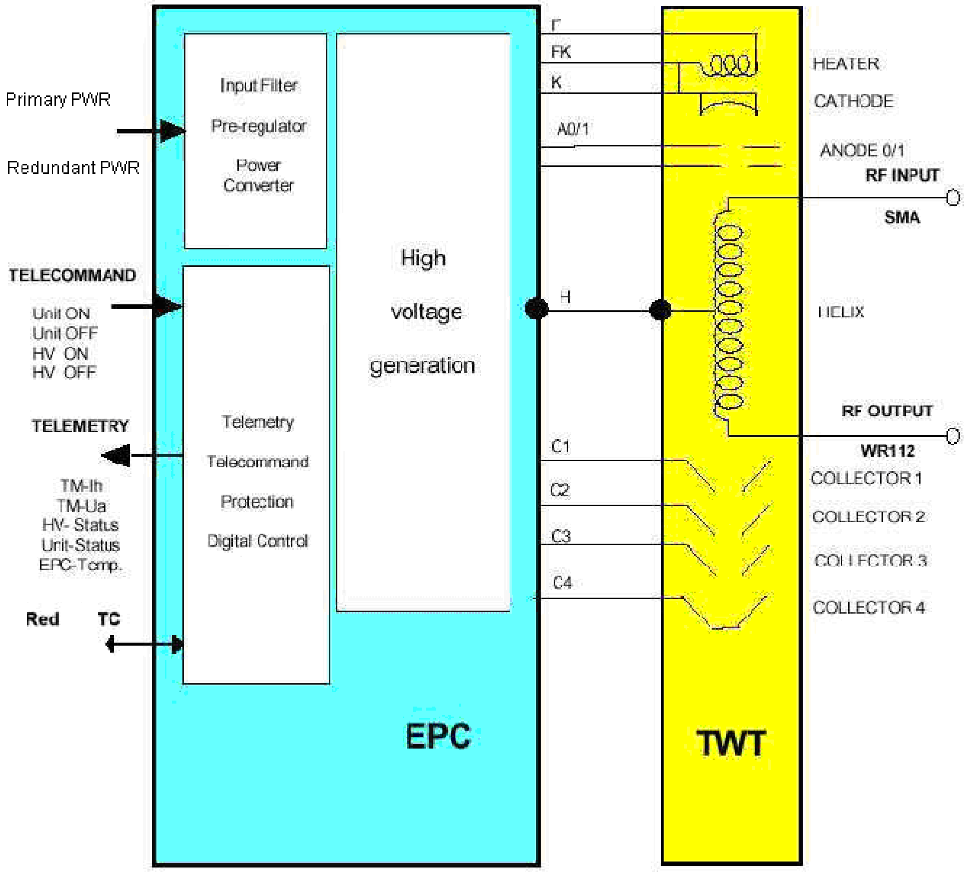
The **DynamicMode** operates as follows:

TCActive Receiver1	***TCActive Receiver2***	***TC Decoder 1 Input***	***TC Decoder 2 Input***
Active	**Active**	The first activated *i.e. RX1 TC Signal*	The first activated *i.e. RX1 TC Signal*
Active	Not Active	RX1 TC Signal	RX1 TC Signal
Not Active	**Active**	RX2 TC Signal	RX2 TC Signal
Not Active	Not Active	RX1 TC Signal	RX2 TC Signal

Once a channel has been deselected due to an error, i. e. the frame was abandoned, the ***search for a valid synchmarker on this channel will be delayed by one BitClk internally in the telecommand decoder***.
This implies that another TC channel with a better signal quality will have a chance to be selected before the marginal channel. The delay of one BitClk internally will be removed once a channel has been selected Proposed selection scheme (dynamic mode)

9.8.5.2 TWTA

The equipment is an X band Travelling Wave Tube Assembly consisting in a Travelling Wave Tube (TWT) and an Electronic Power Conditioning unit connected by a High Voltage Cable.
The assembly block diagram is presented in the picture below. The EPC is equipped with redundant Pwr/TM/TC connectors to improve reliability.
The TWT RF input is a SMA connector coming from the RFDN power splitter while the RF output is a WR112 flange that is connected to the RFDN waveguide circulator to protect the tube.



9.8.5.2.1 EPC TECHNICAL DESCRIPTION

The EPC is mainly constituted by a high efficient high voltage converter providing the various voltages required by the TWT and secondly by functionality such as:

Telecommand interfaces.
Telemetry signals
Process adapted for TWT operation (optimised start-up, and shutdown sequence, IK regulation).
Protections circuits for spurious switch off of TWT as well as any high voltage short circuit
Power Bus interface.
Auxiliary voltages generation.

The EPC topology is a buck type pre-regulator followed by a quasi resonant push-pull inverter. The main bus voltage is pre-regulated via the buck which supplies the input of the HV transformer through the resonant push-pull. An input filter is placed before the power chain to cope with the EMC specification.
The EPC is designed to be switched on by a EPC “ON “command and in this mode it provided the TWTA filament pre-heating current. After the preheating time (3 minutes typical) the TWTA is ready to be powered with the High Voltage with the command to EPC “TWT ON”.
All the management of the EPC is made by an ASIC circuit.

9.8.5.2.2 TWT DESCRIPTION

The proposed TWT is a direct derivative and improved version of in-orbit units on which a 4-stage collector has been implemented for global efficiency improvement and subassembly standardisation (vs commercial devices for Ka, Ku and X-Band applications) purposes.
This 4-stage collector is the standard collector design already implemented on the Ku-Band family up to 150W and most of the Ka and X-band programs delivered by TTE Velisy from six years. In addition the proposed TWT will mainly use the 100/150W Ku band TWTs technology.
This 100/150 W Ku band family is designed according to well established, conservative and safe layout rules.

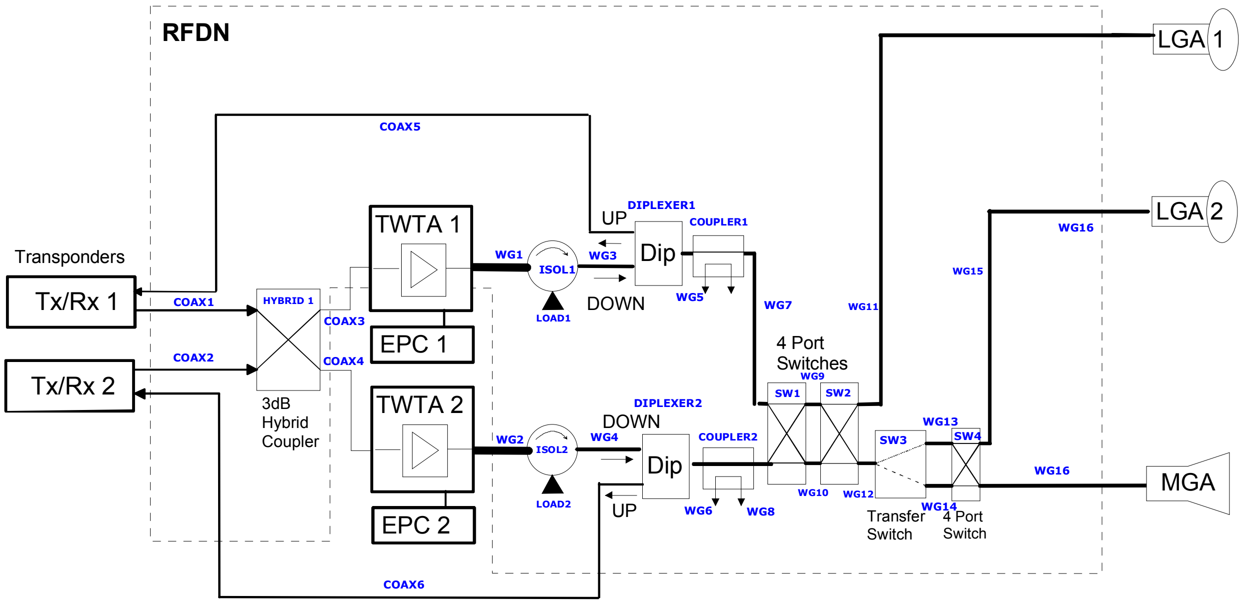
9.8.5.3 Radio Frequency Distribution Network (RFDN)

The RFDN has been divided in 3 main different parts:

- Internal RFDN (The one monted on the SVM panel including WG switches, isolators, couplers, diplexers)
- Coax KIT (The coaxial part mounted on the SVM panel to connect the receivers and Transponders to TWTAs)
- External (To connect throug Waveguides the internal RFDN on the SVM panel to the antennas installed on the satellites structure)

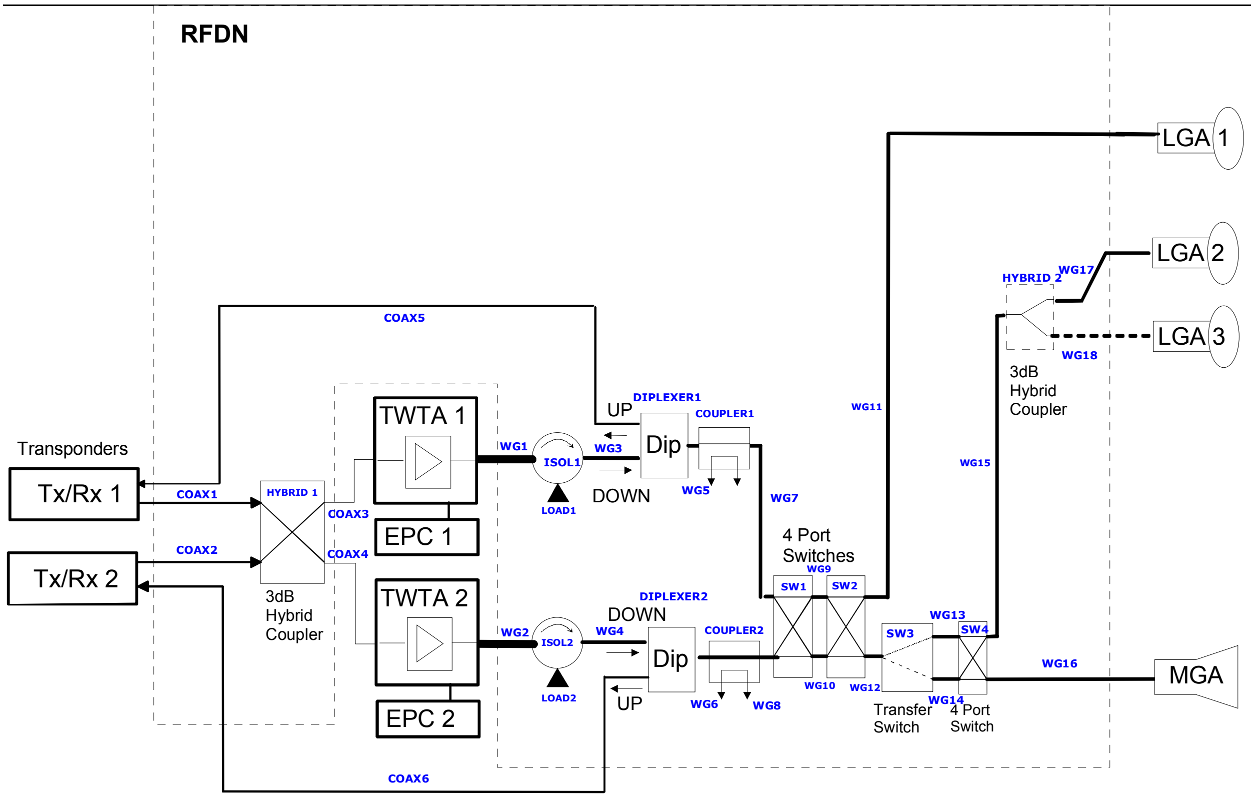
The high power downlink distribution network between the output of the TWTAs and the antennas uses waveguide technology type WR112.
The low power downlink distribution network hardware between the outputs of the transponders and the TWTAs and the uplink path use coaxial technology
Both uplink and downlink are in X-Band.

The above figure shows the block diagram of the HERSCHEL/PLANCK TTC configuration.



HERSCHEL RFDN proposed architecture.

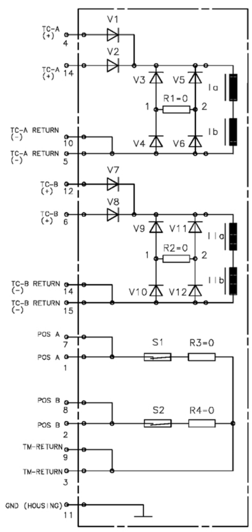
File: HERSCHEL_RFDN.dsf - 02-04-2003

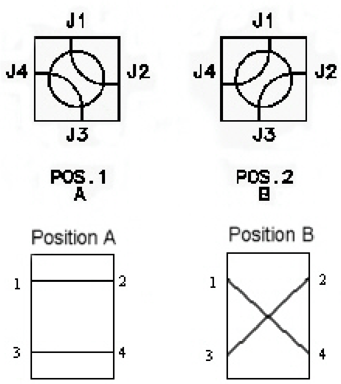


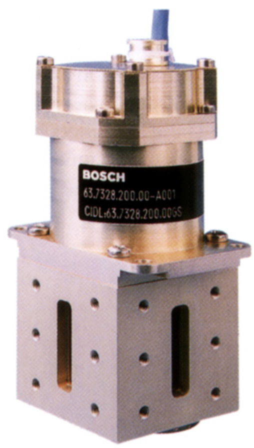
PLANCK RFDN proposed architecture.

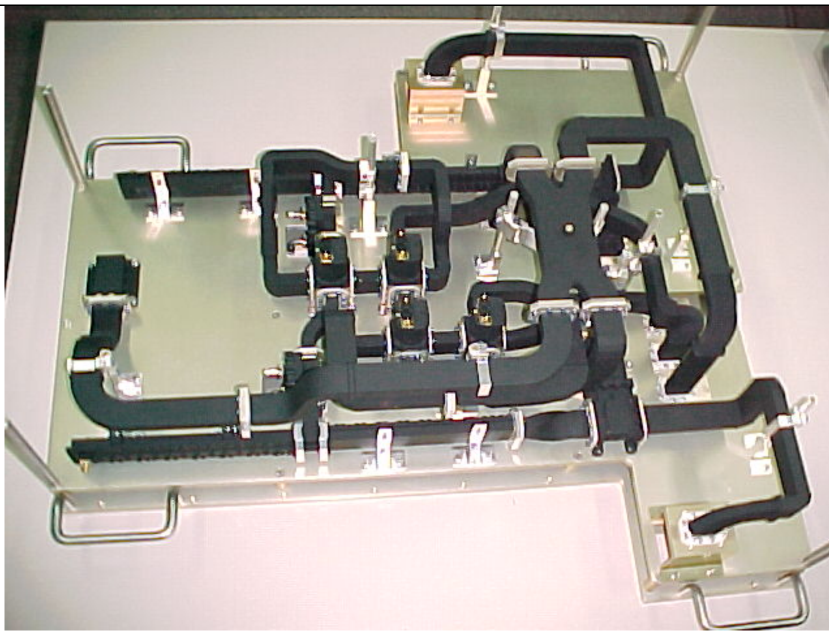
File: Planck_RFDN.dsf - 02-04-2003

All the RFDN is based on cascade of two 4 port switches to assure a single point failure tolerant configuration. In particular the operational modes are described in the figures here below:









In the uplink path the received signal from the two LGAs passes through the WG switches towards the two Diplexers and then the Transponders RX inputs.

In downlink the output from one of the two transponders feed a 3 dB Hybrid Coupler that supply contemporarily the two TWTA. This solution is more reliable with respect to 4 Port Switch solution because it is only passive connection without any moving mechanical parts. (Same approach has been usuccessfully used on Rosetta dn Mars Express) The RF losses due to the 3 dB Hybrid Coupler insertion are not relevant because the RF signal will be amplified by the TWTA.
From each TWTA a RF signal output level close to 32 W is obtained. The TWTAs are in cold redundancy: this means that only one is powered on at the same time. Each TWTA output supplies an isolator to protect it from mismatches then a Diplexer and two 4 PS. From these 4PS it is possible to feed directly the LGA1 or another two Switches (SW5 and SW6) to route the RF output signal toward LGA2 or the MGA.

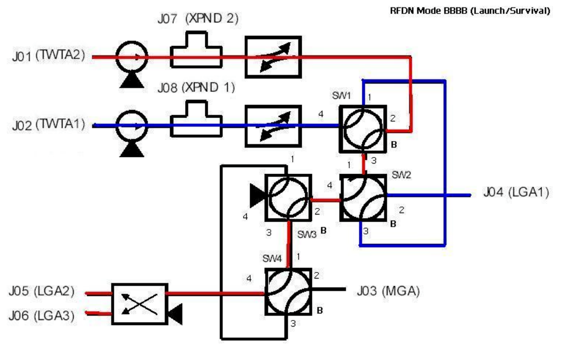
Two Directional Couplers are also foreseen to permit RF output power measurements without disconnecting the RFDN inputs/outputs.

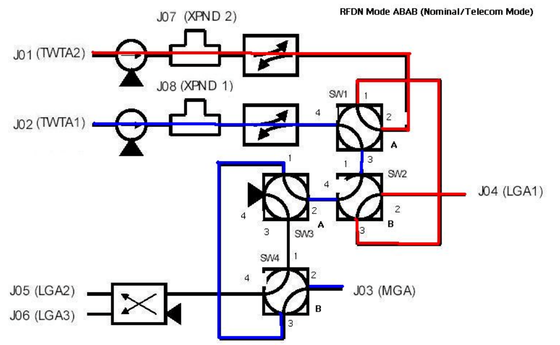
A picture of the RFDN (Planck) is presented here after:

In the table here below are summarised the main operational modes available in the H/P RFDN configuration:

Herschel/Planck RFDN Modes									J03=MGA J04=LGA1 J05=LGA2 J06=LGA3
					TX Chain		RX Chain		
MODE	J09 SW1	J10 SW2	J11 SW3	J12 SW4	J01 TWTA2	J02 TWTA1	J07 RX2	J08 RX1	Note
01	A	A	A	A					
02	A	A	A	B					
03	A	A	B	A					
04	A	A	B	B					
05	A	B	A	A					
06	**A**	**B**	**A**	**B**	*LGA1*	*MGA*	*LGA1*	*MGA*	*Nominal Telecom Mode*
07	A	B	B	A					
08	A	B	B	B					
09	B	A	A	A					
10	B	A	A	B					
11	B	A	B	A					
12	B	A	B	B	*LGA1*	*LGA2/3*	*LGA1*	*LGA2/3*	*Launch/Survival Mode (TTC Branch B)*
13	B	B	A	A					
14	B	B	A	B					
15	B	B	B	A	*MGA*	*LGA1*	*MGA*	*LGA1*	*Nominal Telecom Mode (TTC Branch B)*
16	**B**	**B**	**B**	**B**	*LGA2/3*	*LGA1*	*LGA2/3*	*LGA1*	*Launch/Survival Mode*

As explanation of the two most used modes, also diagramsshowing the signals paths are reported here after:





The downlink hardware, in particular the switches interfacing with the TWTAs power handling, guarantee at least 3 dB of margin with respect to the TWTAs RF output power of 32 W.
The switches are realised with a unique transactor actuator. Typical insertion loss is 0.05 dB. The isolation cross coupling typical is 60 dB.
The impulse current required for this WG switches realised in waveguide usually presents a switching time close to 500 ms and a maximum sink current in the order of 300mA.
To drive them dedicated Extended High Priority Command lines will be used by the CDMU (840ms length)
During CDMU design it came out that the EHPC current is in the region of 280mA, so alternative solutions are under study in order to provide to the switches the required (plus margins) current.
.
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 is completely single point failure tolerant:

- considering an approach that uses a redundant switches configuration foreseeing Time Tagged Command approach to recover from an unlikely switch neutral (midpoint) position .
- having the possibility to command the switches both by PM, RTU and TcDec.
- Implementing an on-board software routine that is able (by looking at the Transponder and AOCS attitude monitors) to position correctly the switches in case of a failure on the transponder Receiver or a loss of the expected attitude.

The foreseen RFDN interfaces are:

Telemetry:

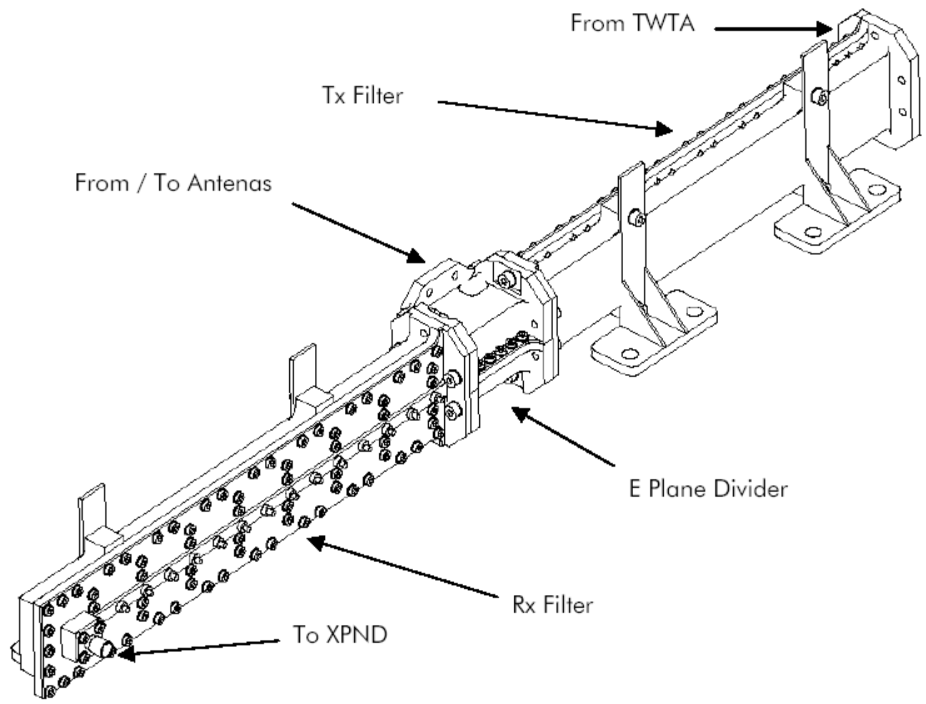
- 4 Switch position A status
- 4 Switch position B status

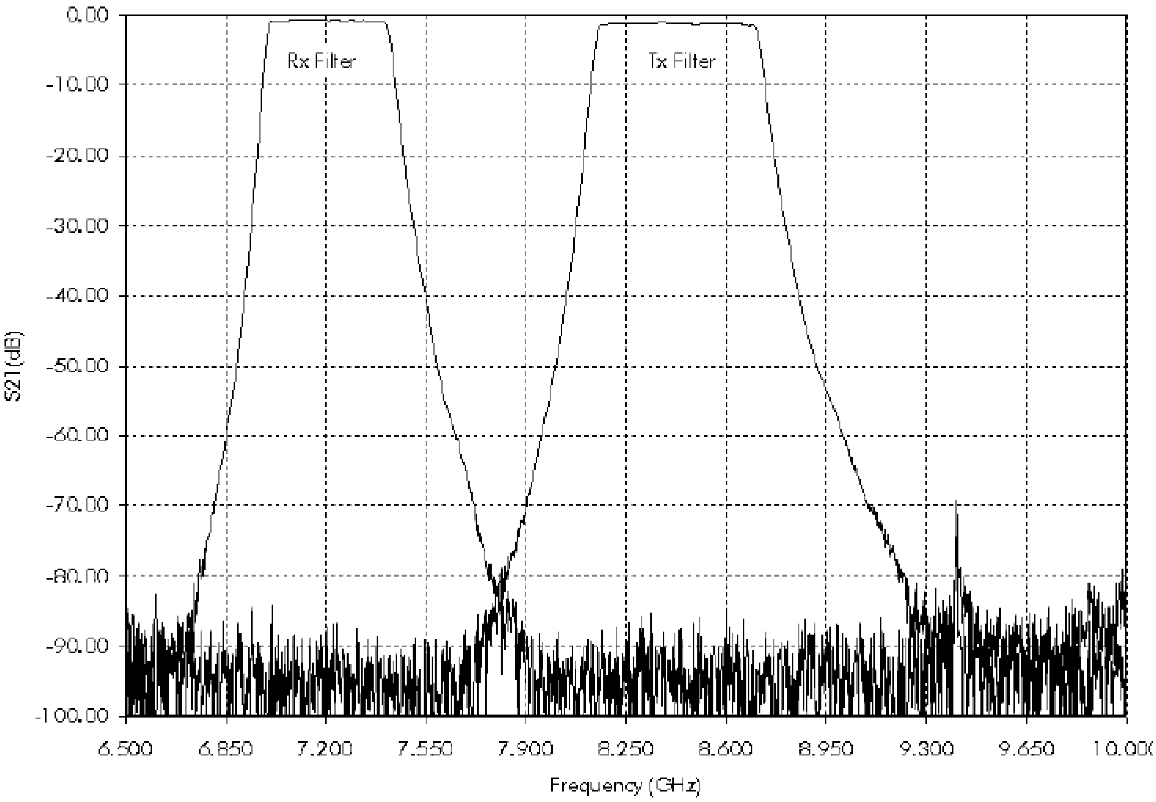
- 2 High Power Isolator temperature.
- 2 Diplexers temperature

Telecommand:

- 4 Switch position A Extended High Priority Command (nominal)
- 4 Switch position A Extended High Priority Command (redundant)
- 4 Switch position B Extended High Priority Command (nominal)
- 4 Switch position B Extended High Priority Command (redundant)

Two Diplexers are also included in the RFDN to split the TX signal from the RX one, these are a Rosetta program heritage and a preliminary transfer curve from EQM measurements is presented here below:





The available RFDN insertion losses data are:

HERSCHEL RFDN Path (From)	*To*		*Insertion Losses [dB]*
UPLINK			
LGA1	Rx1/2	including coax cables	**1.6**
LGA2	Rx1/2	including coax cables	**1.6**
MGA	Rx1/2	including coax cables	**1.6**
DOWNLINK			
TWTA 1/2	LGA1		**1.25**
TWTA 1/2	LGA2		**1.25**
TWTA 1/2	MGA		**1.25**
Waveguides Path	***Type***	***Lenght [mm]***	***Attenuation [dB]***
RFDN LGA1 out – LGA1	WR112		**0.6**
RFDN LGA2 out – LGA2	WR112		**0.83**
RFDN MGA out – MGA	WR112		**0.32**

PLANCK *RFDN Path (From)*	*To*		*Insertion Losses [dB]*
UPLINK			
LGA1	Rx1/2	including coax cables	**1.3**
LGA2&3	Rx1/2	including coax cables	**5.1**
MGA	Rx1/2	including coax cables	**1.5**
DOWNLINK			
TWTA 1/2	LGA1		**1.1**
TWTA 1/2	LGA2&3		**4.8**
TWTA 1/2	MGA		**1.2**
Waveguides Path	***Type***	***Lenght [mm]***	***Attenuation [dB]***
RFDN LGA1 out – LGA1	WR112		**0.47**
RFDN LGA2 out – LGA2	WR112		**1.17**
RFDN LGA3 out – LGA3	WR112		**0.10**
RFDN MGA out – MGA	WR112		**0.30**

While the Input/Output return loss will be better that 20dB

9.8.5.4 Waveguide Routing

In order to connect the RFDN outputs to the antennas, WR112 waveguides are used.
The SVMs configuration and layout have been optimized in order to maximize the similarity between the two waveguides routing. The WG routing has been designed in collaboration with the RFDN supplier in order to get the best design and avoid interferences with other structures/subsystems. Overall architecture including the Waveguide routing can be found in [RD-17]

The following waveguides, external to RFDN are foreseen:

HERSCHEL SVM

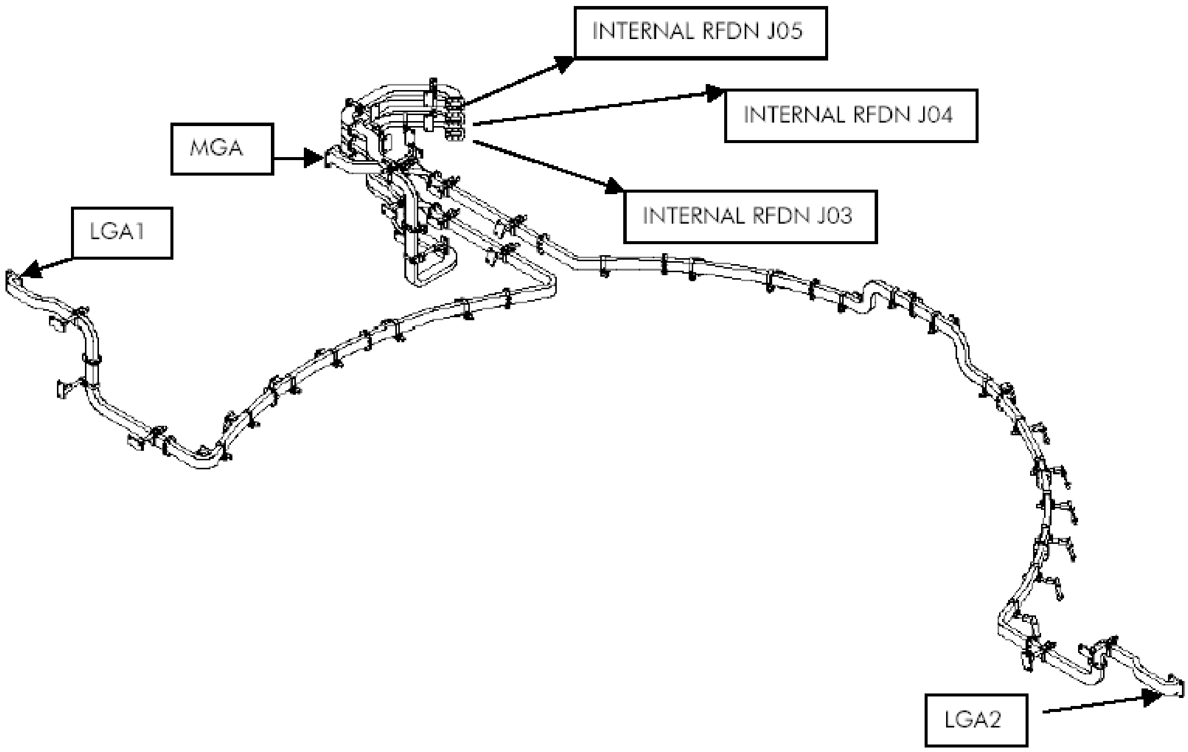


Figure 9.8-1: Herschel Waveguides routing

PLANCK SVM

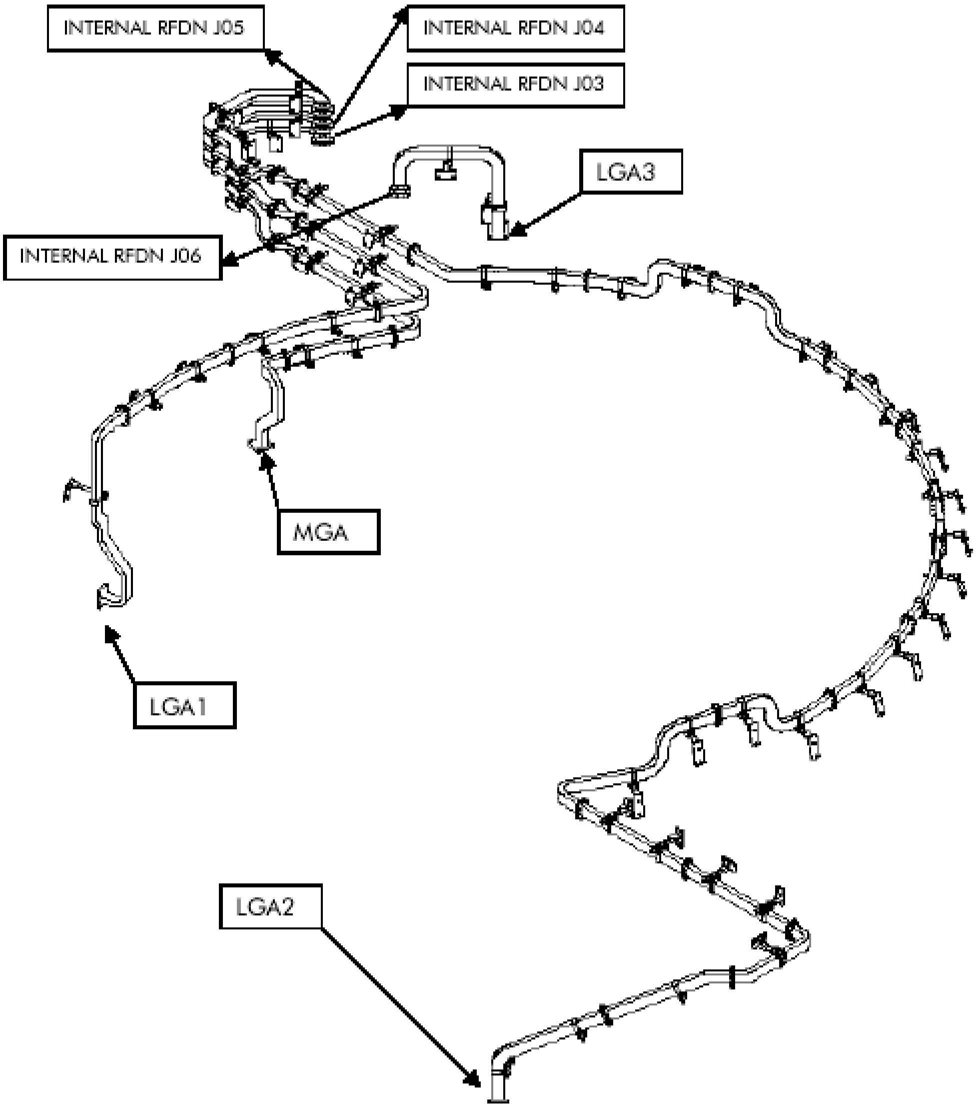
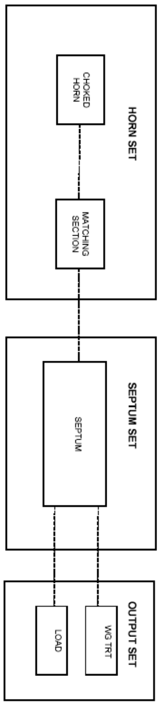


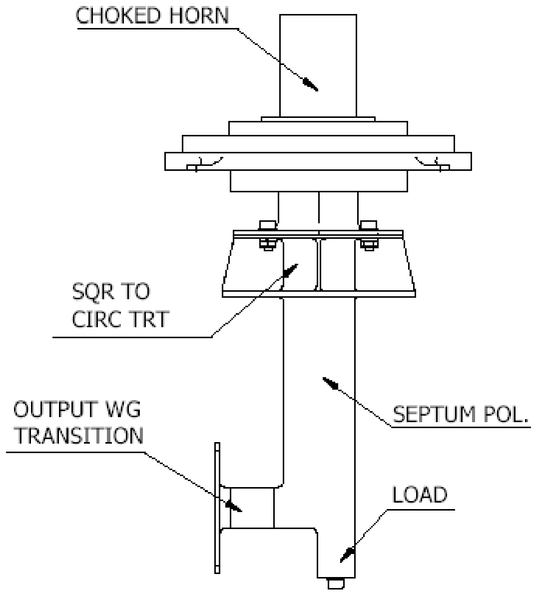
Figure 9.8-2: Planck Waveguides routing

9.8.5.4.1 Low Gain Antenna (LGA)

The X band Low Gain Antennas are low gain chocked antennas which are designed for Telemetry and Command on board satellite missions.
Each single antenna covers in radiation pattern an hemisphere and it works at a moderate frequency band. Rear radiation is poor in such a way that interference effects with the satellite are diminished, is very important in the case of Herschel /Planck program because of the possible influence of the s/c over the antenna radiation pattern.

The block diagram of each antenna is the following:





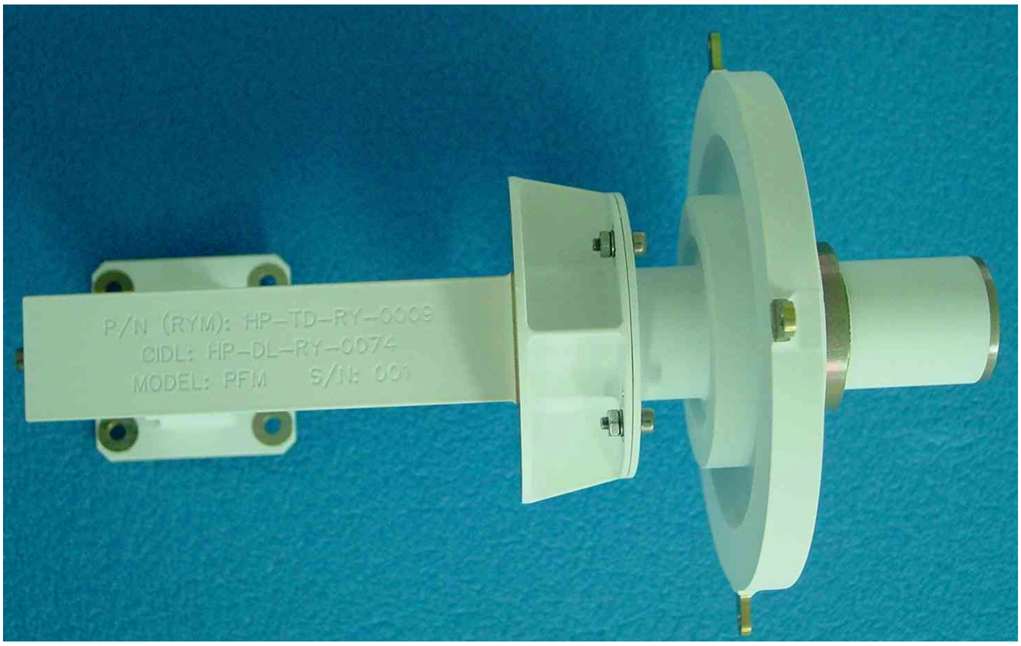
From electrical point of view, each antenna is composed by a radiating element, an OMT/Septum polarizer and electrical interfaces.

Radiating element set.
This element includes a small chocked horn with corrugations placed behind the circular aperture. These corrugations improve the axial ratio of the antenna in the front radiation pattern and diminish the influence of the backed antenna structure. The aperture is excited by the TE11 mode in circular waveguide and the corrugations allow to get reduced crosspolar excitation. The radiation pattern shows a good axial symmetry and it is characterized by a single Ø-cut.
A matching section is used to improve the return loss of the horn. It consists in a change to different diameter in circular WG. Furthermore, a transition from circular to square waveguide is included.

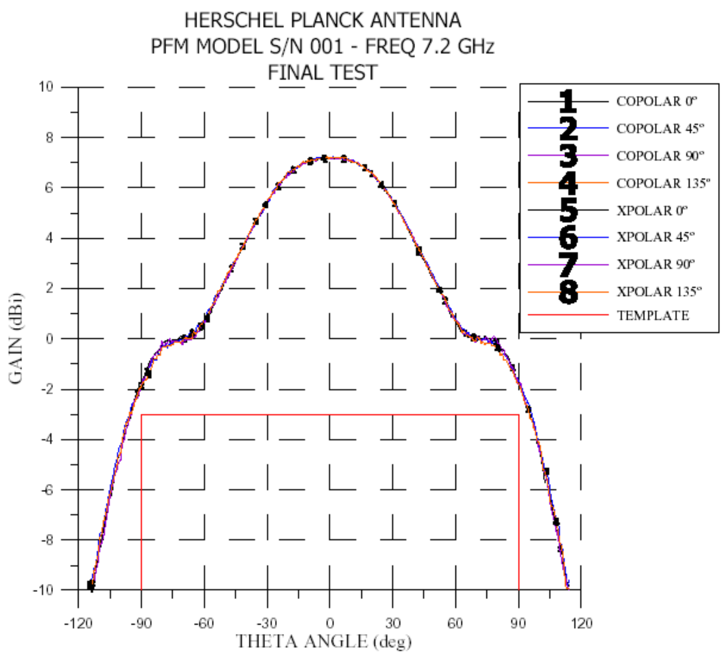
Septum set.
This block includes the septum polarizer itself made in rectangular & square waveguides The element allows to join two separate inputs (rectangular WG a/b ratio equal to 1/2) to a common output (square WG) with different sense of circular polarization. Dominant modes work in the septum/OMT ports. The internal plate, separately both half waveguides, will be five steps because wide bandwidth is required for operating both TX & RX frequencies.
For Herschel/Planck, one of the ports is closed and one load is included.

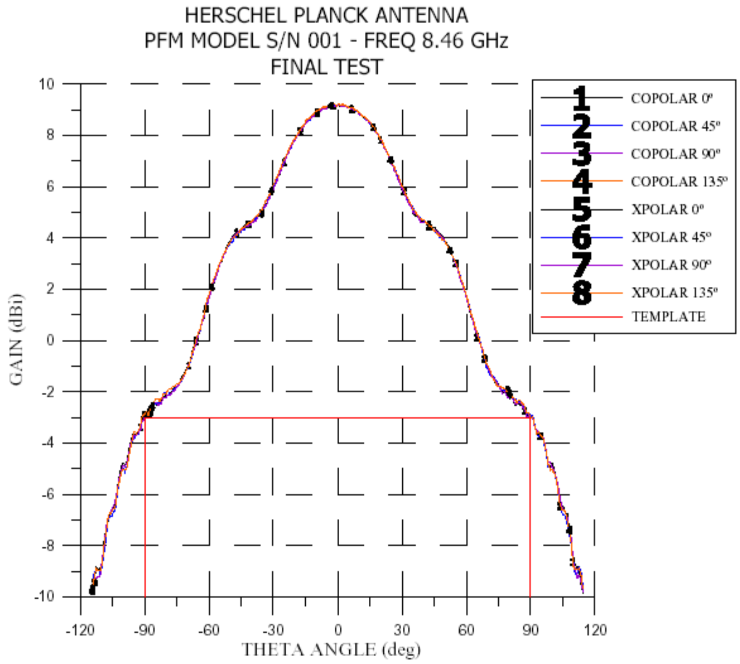
Electrical Interfaces.
WR112 WG electrical interface is used for the open port, it is placed with its direction perpendicular to the antenna boresigth.

A picture of the antenna is showed in the figure below:

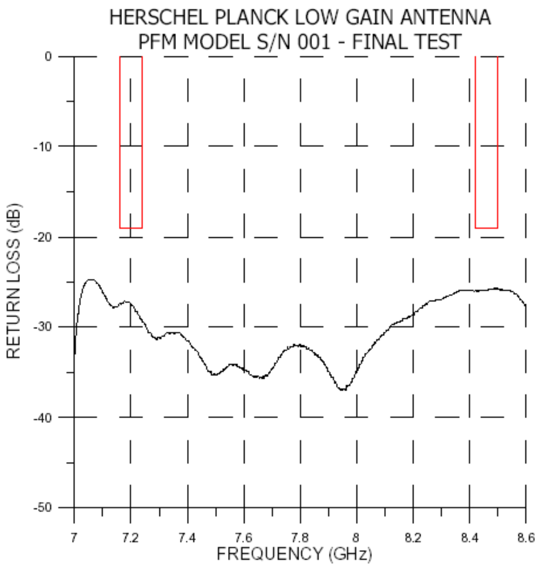


The pattern diagrams from FM measurements are presented in the following graphs.

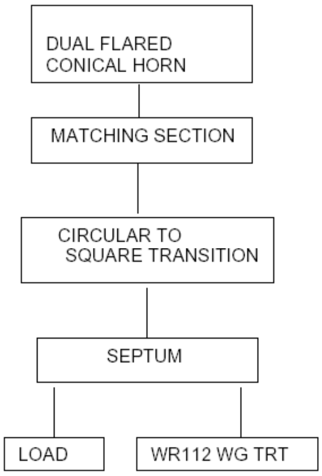




Measured VSWR is better than specification:



The antennas have been procured together with the associated brackets necessary to install them on the satellite structure.

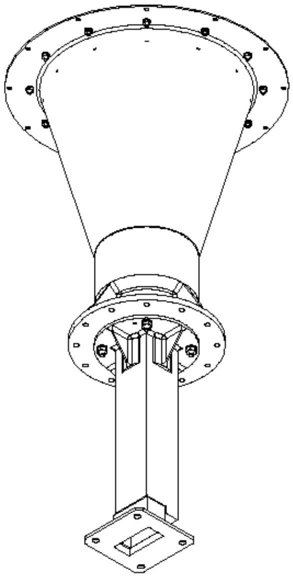


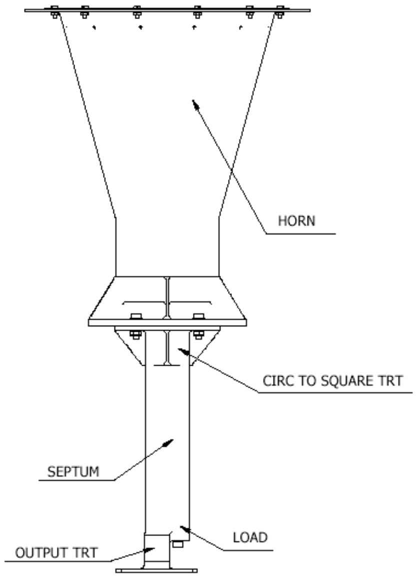
9.8.5.4.2 Medium Gain Antenna (MGA)

The proposed MGA is a conical dual flared horn. Even in this case the septum polarizer is also made by escalation of previous developed ones. The MGA is composed from the electrical point of view, by the following elements:

- -A) Transition to WR 112 waveguide (axial or normal to septum main body)
- -B) 5 Step septum polarizer (because requirement is broad band)
- -C) Waveguide load
- -D) Square to circular transition
- -E) Dual flared conical horn

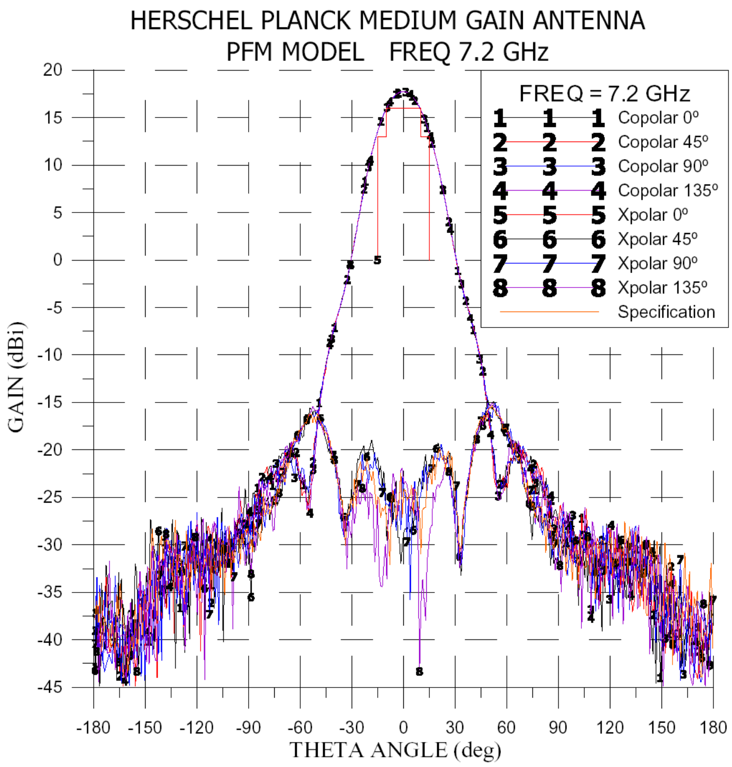
The minimum antenna gain has been ensured to be close to 16 dBi at 10° and 13 dBi at 15°.
In particular it withstands up to 70 W RF in input.

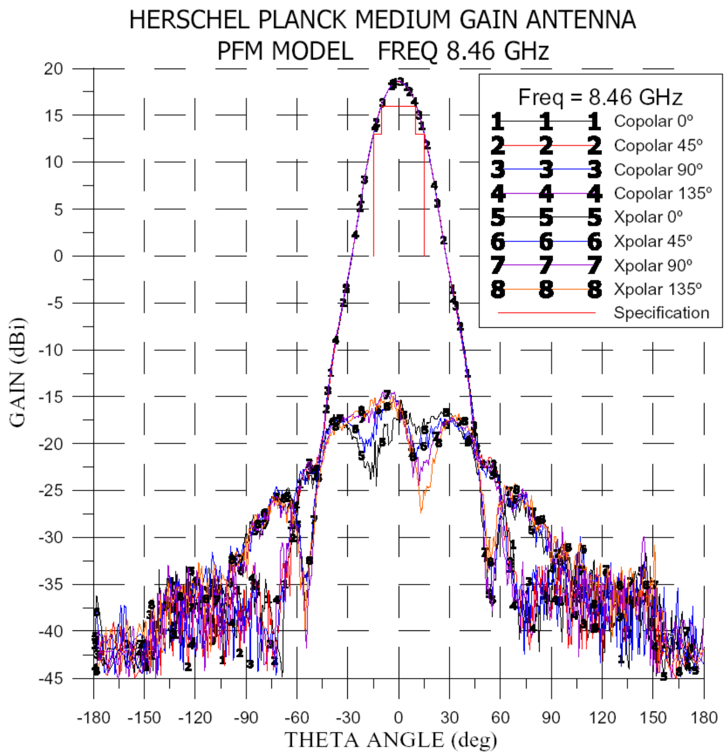




Electrical Interfaces.
WR112 WG electrical interface is used for the open port, it is placed with its direction perpendicular to the antenna boresigth.
A picture of the antenna is showed in the figure below:

The pattern diagrams from FM measurements are presented in the following graphs.
The minor NC ant TC frequency (at 13°) is not considered an issue while the TC link budgets in uplink show great link budgets.




HERSCHEL PLANCK MEDIUM GAIN ANTENNA
PFM MODEL FREQ 8.46 GHz
Freq = 8.46 GHz
Copolar 0°
Copolar 45°
Copolar 90°
Copolar 135°
Xpolar 0°
Xpolar 45°
Xpolar 90°
Xpolar 135°
Specification
GAIN (dBi)
THETA ANGLE (deg)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180

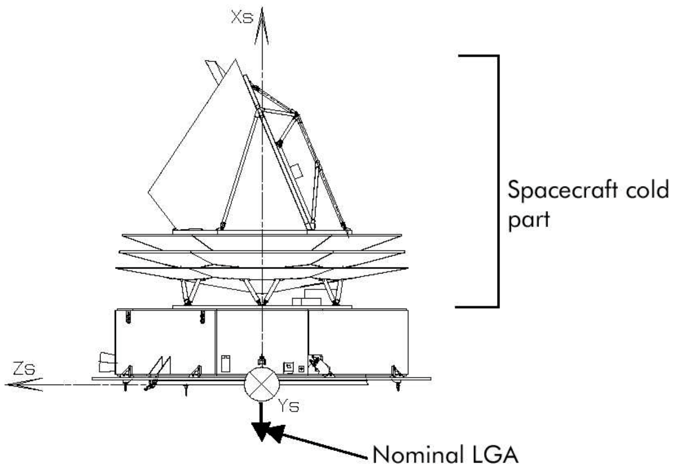
9.8.6 Commonality Assessment

For both Herschel and Planck satellite, omni-directional coverage of the low gain antennas is specified in order to cover cases such as:

- Launch: at separation from launcher, the Sun/SC/Earth angle is above 90 deg during around 20 minutes.
- Survival Mode: in case of attitude loss, omni-directional coverage has to be provided to be able to communicate with the spacecraft.

While this is not a constraint for Herschel, the specific configuration of Planck makes it more difficult to achieve.

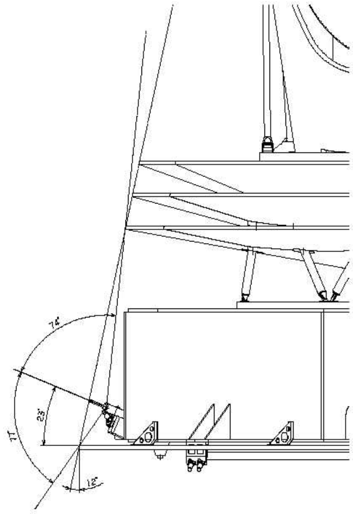
Figure: Planck nominal LGA position



As shown in the figure above, the nominal LGA is implemented on the spacecraft –X side which is nominally facing Sun and Earth. Ideally, to complete the coverage, an antenna on +X side should be implemented, i.e. on the Planck PLM top in order to have hemispherical coverage.
This has been rejected for the following reasons:

- modularity: the antenna belongs to the SVM and will have to be connected to it by a long waveguide. This will create a complex interface between SVM and PLM
- antenna environment: the thermal environment at the PLM top is below 60 K. Qualification of an antenna at that temperature can be complex
- PPLM performance: the antenna implementation with its waveguide will create a direct thermal link between the cold PPLM (< 60 K) and the warm SVM (...300 K). Very efficient thermal decoupling would have to be implemented to avoid heat leaks to the PLM and performance degradation.

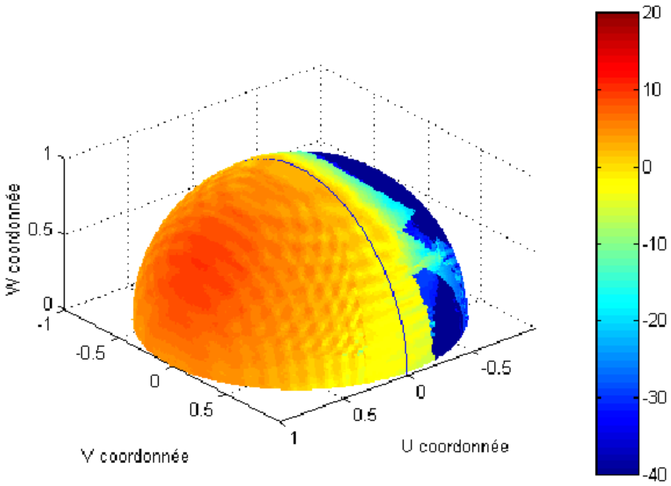
An alternative configuration has been preferred which avoids the above mentioned drawbacks. It consists in implementing, on the SVM, a pair of LGA connected by an hybrid coupler. The antennas are implemented in the (X,Y) plane, on the +Y and –Y panels.
In order not to induce thermal fluctuations on the PPLM, it has to be located inside the shadow of the Planck SVM Sunshield. This leads to an accommodation in a narrow space below the grooves, almost like a cavity and this results in a slightly distorted pattern of the LGA as the structural environment generates reflections and therefore some phase interference phenomenons within the antenna field of view.



Planck redundant LGA position.

The redundant LGAs implementation is shown in the figure above. For commonality reasons, the same LGA as for Herschel or for the Planck nominal LGA has been considered.
The use of three LGA antennas for PLANCK with respect to the two ones used in Herschel should increment the visibility time of the ground station.
In particular an assessment on the two LGAs mounted laterally on the body spacecraft has been achieved and, to select the better solution, a GTD analysis has been performed using the LGA available data.

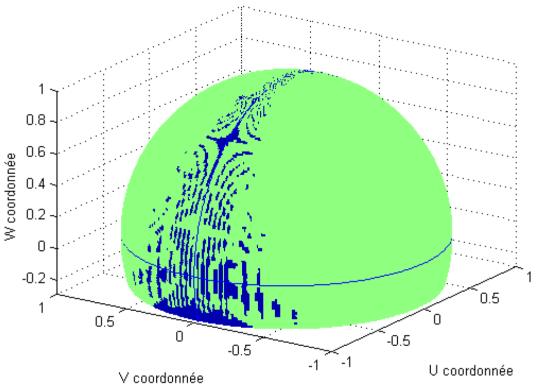
To achieve it, the antenna tilt angle has been optimised (35°) to improve the coverage efficiency.

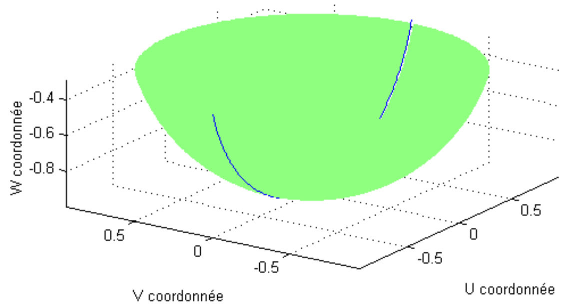


PLANCK GTD analysis with horn lateral LGA.

Using an elementary antenna with a narrower pattern than a usual LGA conical helix type antenna, like a choked horn concept limits the side and backward radiations, and thus the phase interferences within the pattern. However, the omni-directionality of the antenna is difficult to predict and will be measured on a mock-up model.
The foreseen solution permits to use for all the LGAs a Dual Horn Antenna

The GTD results in fact show a coverage of 94.85% with a - 3 dBi.





The use of three LGA antennas impose the use of a 3 dB Hybrid Coupler on Planck RFDN in charge to distribute the RF output signal from the two TWTA to LGA2 or LGA3 antenna. Vice versa the receiving signal from LGA2 or LGA3 pass through the 3 dB Hybrid Coupler feeds the 4 Port Switch toward the transponders. A part this 3 dB Hybrid Coupler the Planck RFDN is of the same design as for Herschel.

9.8.7 Budget Summary

9.8.7.1 HERSCHEL Mass budget

In the table below the mass budget estimated for the Herschel TTC configuration is presented:

	HERSCHEL SVM TT&C		Nominal Mass [kg]	Uncertainty New 20%	Der 15%	Mod 10%	Exis 5%	Maximum mass [kg]
TT&C TOTAL			21.2					24.3
ACRONYM	NAME	Location						
EPC	Electric Power Conditioner	+Z / -Y	1.50			1		1.65
EPC	Electric Power Conditioner	+Z / -Y	1.50			1		1.65
X/B LGA	Low Gain antenna	-Z	0.30			1		0.33
X/B LGA	Low Gain antenna	+Z	0.30			1		0.33
MGA	Medium Gain Antenna (incl. Support)	+Z	0.80			1		0.88
RFDN	Radio Frequency Distribution Network	+Z / -Y	5.60	1				6.72
XPND	TRANS X/B	+Z / -Y	3.80		1			4.37
XPND	TRANS X/B	+Z / -Y	3.80		1			4.37
TWTA	Travelling Wave Tube Amplifier	+Z / -Y	0.80			1		0.88
TWTA	Travelling Wave Tube Amplifier	+Z / -Y	0.80			1		0.88
WG1	*Wave Guide RFDN-MGA (1m)*		0.25			1		0.28
WG2	*Wave Guide RFDN-LGA 1 (2.5m)*		0.65			1		0.72
WG3	*Wave Guide RFDN-LGA 2 (4.5m)*		1.13			1		1.24

9.8.7.2 Planck Mass budget

In the table below the mass budget of the Planck TTC configuration is presented:

	PLANCK SVM TT&C		Nominal Mass [kg]	Uncertainty New 20%	Der 15%	Mod 10%	Exis 5%	Maximum mass [kg]
TT&C TOTAL			22.3					25.6
ACRONYM	NAME	Location						
EPC	Electric Power Conditioner	-Y	1.50			1		1.65
EPC	Electric Power Conditioner	-Y	1.50			1		1.65
TWTA	Travelling Wave Tube Amplifier	-Y	0.80			1		0.88
TWTA	Travelling Wave Tube Amplifier	-Y	0.80			1		0.88
X/B LGA	Low Gain antenna	-X	0.30			1		0.33
X/B LGA	Low Gain antenna	-Y	0.30			1		0.33
X/B LGA	Low Gain antenna	+Y	0.30			1		0.33
MGA	Medium Gain Antenna (incl. Support)	-X	0.80			1		0.88
RFDN	Radio Frequency Distribution Network	-Y	6.13	1				7.36
XPND	TRANS X/B	-Y	3.80		1			4.37
XPND	TRANS X/B	-Y	3.80		1			4.37
WG1	*WaveGuide RFDN-MGA (1m)*		0.25			1		0.28
WG2	*WaveGuide RFDN-LGA 1 (2.2m)*		0.55			1		0.61
WG3	*WaveGuide RFDN-LGA 2 (4.5m)*		1.13			1		1.24
WG4	*WaveGuide RFDN-LGA 3 (1.5m)*		0.38			1		0.42

9.8.7.3 Herschel/Planck Power budget

In the table below the power budget of the two satellites TTC configuration is presented. It has been assumed that only one Tx is powered on during the visibility window and two receivers are always powered on.

	PLANCK SVM TT&C	Unit	Nominal PWR W	Power W
TT&C POWER BUDGET				
ACRONYM	NAME			
XPND RX	Electric Power Conditioner	2	7.00	14
XPND TX	Electric Power Conditioner	1	6.00	6
TWTAs	Travelling Wave Tube Assembly	1	76.00	76
RFDN	Radio Frequency Distribution Network			
TOTAL POWER (W)				96

If TX is active, during DTCP, the power consumption is **96 W**,
while during science mode, when only two receivers are “ON”, the power consumption is **14W**.
During Launch, it’s foreseen to have two receivers “ON” and one EPC in preheating mode, so the power consumption will be **23W** (EPC power consumption is 9W).

9.8.7.4 RF link budgets

The link budgets have been calculated considering the Ground Station characteristics ad data given in the Space to Ground ICD

Kourou
Herschel and Planck nominal configuration

- Uplink 125 bps with LGA,
  kbps via MGA
- Downlink 500 bps via LGA and
  150 kbps via MGA

New Norcia
Herschel and Planck nominal configuration

- Uplink 4 kbps with LGA and MGA,
- Downlink 5 kbps via LGA,
  150 kbps via MGA
  1.5 Mbps via MGA

As a support to the complete set of link budgets provided in the SVM Budget Report, this section summarises the system margins in the same format as the one used during the proposal:

HERSCHEL UPLINK BUDGETS				KOUROU G/S						NEW NORCIA G/S						
			Mode / Antennas	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only
			Antennas	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	MGA
			BIT RATE (kbps)	0.125	0.125	0.125	0.125	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
			S/C ALTITUDE (* 10^6 km)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
PARAMETER	MARGING	ESA Margin dB		calculated margins (dB)						calculated margins (dB)						
Carrier Recovery	Nominal	3		4.69	4.14	4.28	3.72	23.54	22.99	20.72	20.37	20.53	19.95	39.79	39.44	39.73
	mean -3*sigma	0		3.32	2.75	2.90	2.33	21.24	20.67	18.92	18.56	18.65	18.14	36.99	36.64	36.93
	margin - wc RSS	0		3.34	2.78	2.93	2.36	21.94	21.38	19.19	18.83	18.99	18.41	38.03	37.68	37.97
Telecommand Recovery	Nominal	3		5.02	4.47	4.61	4.06	8.83	8.27	6.00	5.65	5.81	5.24	25.08	24.72	25.01
	mean -3*sigma	0		4.18	3.60	3.76	3.18	7.05	6.47	4.63	4.26	4.37	3.84	22.71	22.34	22.64
	margin - wc RSS	0		4.03	3.46	3.62	3.04	7.51	6.95	4.77	4.41	4.58	3.99	23.57	23.21	23.51

PLANCK UPLINK BUDGETS				KOUROU G/S					NEW NORCIA G/S						
			Mode / Antennas	TC only	TC+RNG	TC only	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only	TC+RNG	TC only
			Antennas	LGA 1	LGA 1	LGA 2&3	MGA	MGA	LGA 1	LGA 1	LGA 2&3	LGA 2&3	MGA	MGA	MGA
			BIT RATE (kbps)	0.125	0.125	0.125	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
			S/C ALTITUDE (* 10^6 km)	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
PARAMETER	MARGING	ESA Margin dB		calculated margins (dB)					calculated margins (dB)						
Carrier Recovery	Nominal	3		5.71	4.02	1.45	24.62	24.07	21.74	20.25	17.65	17.30	37.87	37.52	37.87
	mean -3*sigma	0		4.34	2.63	0.01	22.32	21.75	19.94	18.44	15.72	15.36	35.20	34.84	35.19
	margin - wc RSS	0		4.36	2.66	0.08	23.02	22.46	20.21	18.71	16.10	15.74	36.15	35.79	36.14
Telecommand Recovery	Nominal	3		6.04	5.49	1.78	9.90	9.35	7.02	6.67	2.93	2.58	23.15	22.80	23.15
	mean -3*sigma	0		4.18	4.62	0.87	8.13	7.55	5.65	5.28	1.43	1.07	20.92	20.55	20.91
	margin - wc RSS	0		5.05	4.48	0.77	8.59	8.03	5.79	5.43	1.68	1.32	21.69	21.33	21.69

As identified in the first issue of link budgets, the uplink performances are marginal (on Planck only) with Kourou ground station (identified to be used not as nominal) when using the low gain antennas (LGA2&3 in emergency mode). Though, the telemetry subcarrier recovery margins remain acceptable. The Planck to Kourou link through the two redundant LGAs has been evaluated at the 1,6 10^6 km distance and only in the TC mode as this is an emergency situation.

No criticality identified on the uplink budgets.

HERSCHEL DOWNLINK BUDGETS				KOUROU G/S						NEW NORCIA G/S						
			Mode	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only
			Antennas	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	MGA
			BIT RATE (kbps)	0.5	0.5	0.5	0.5	150.0	150.0	5.0	5.0	5.0	5.0	150.0	150.0	1500.0
			S/C ALTITUDE (* 10^3 km)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
PARAMETER	MARGING	ESA Margin dB		calculated margins (dB)						calculated margins (dB)						
Carrier Recovery	Nominal	3		8.95	8.41	8.80	8.15	21.53	21.48	21.34	20.79	21.41	20.53	34.13	34.08	44.15
	mean -3*sigma	0		7.74	7.10	7.59	6.82	16.35	16.28	19.97	19.22	20.00	18.91	28.74	28.65	42.70
	margin - wc RSS	0		7.67	7.05	7.52	6.77	17.20	17.13	20.07	19.35	20.14	19.05	29.81	29.73	43.12
Telemetry Recovery	Nominal	3		6.19	5.65	6.04	5.38	3.14	3.09	8.57	8.03	8.64	7.76	15.74	15.69	6.04
	mean -3*sigma	0		5.54	5.08	5.39	4.84	2.21	2.18	7.78	7.38	7.82	7.14	14.63	14.60	5.17
	margin - wc RSS	0		5.44	4.97	5.29	4.72	2.38	2.34	7.85	7.44	7.92	7.19	15.01	14.98	5.37

PLANCK DOWNLINK BUDGETS				KOUROU G/S					NEW NORCIA G/S						
			Mode	TM only	TM+RNG	TM only	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only	TM+RNG	TM only
			Antennas	LGA 1	LGA 1	LGA 2&3	MGA	MGA	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	MGA
			BIT RATE (kbps)	0.5	0.5	0.5	150.0	150.0	5.0	5.0	5.0	5.0	150.0	150.0	1500.0
			S/C ALTITUDE (* 10^3 km)	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
PARAMET	MARGING	ESA Margin dB		calculated margins (dB)					calculated margins (dB)						
Carrier Recovery	Nominal	3		9.97	9.43	5.74	22.55	22.50	22.36	21.81	18.34	18.61	32.15	31.80	42.17
	ean -3*sigı	0		8.76	8.12	4.36	17.37	17.30	20.99	20.21	16.77	17.10	26.86	26.20	40.84
	rgin - wc F	0		8.69	8.07	4.32	18.22	18.15	21.09	20.35	16.93	17.26	27.84	27.23	41.20
Telemetr y Recovery	Nominal	3		7.21	6.67	4.06	4.16	4.11	9.59	9.05	6.66	6.39	13.76	13.41	4.06
	ean -3*sigı	0		6.56	6.10	3.46	3.23	3.20	8.80	8.41	5.90	5.61	12.79	12.54	3.34
	rgin - wc F	0		6.46	5.99	3.36	3.40	3.36	8.87	8.47	5.99	5.71	13.12	12.84	3.49

Comfortable margins achieved on all downlinks and here as well no criticality identified.

10. GSE

The Ground Support Equipment comprises all mechanical and electrical support equipment necessary for Satellite transportation, handling, assembly, integration and testing including the launch preparation activities.
The following types of GSE are foreseen-:
- Mechanical Ground Support Equipment (MGSE)
- Electrical Ground Support Equipment (EGSE)

10.1 MGSE

MGSE IDENTIFICATION	QTY	REMARKS
INTEGRATION & HANDLING		
EQUIPMENT PANEL TROLLEY (EPT)	13	
PANEL TILTING TROLLEY (PTT)	6	
EQUIPMENT PANEL LIFTING DEVICE (ELD)	4	
MULTI-PURPOSE TROLLEY (MPT)	3	
VERTICAL INTEGRATION STAND (VIS)	6	
SVM LIFTING DEVICE (SLD)	3	
TRANSPORT & HANDLING ADAPTER (THA)	6	
HANDLING CLAMP BAND (HCB)	4	
TEST CLAMP BAND (TCB)	3	
ADJUSTABLE INTEGRATION PLATFORM (AIP)	1	
SVM STIFFENER SET (SSS)	2 set	
HORIZONTAL LIFTING ADAPTER	2	
SCC PANELS STIFFENER DEVICE (SPSD)	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)	2	provided by S/A 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)		as agreed by all parties, not to be provided
SIMULANT LOADING EQUIPMENT (SLE) (TBC)		as agreed by all parties, not to be provided
LEAK TEST EQUIPMENT (LTE)		as agreed by all parties, not to be provided
1 N Thruster leak test adator	1	
1 N Thruster alignment tool	1	
20 N Thruster leak test adator	1	
20 N Thruster alignment tool	1	
MECH. & CLEANLINESS PROTECTION		
Planck SA PROTECTION COVER	2 sets	(1 for STM, 1 for FM) provided by relevant H/W supplier
Herschel SA PROTECTION COVER	N/A	
SENSORS PROTECTION COVERS		provided by relevant H/W Supplier
THRUSTERS PROTECTIVE CAPS	2 sets	(for FM only)
THRUSTERS PROTECTION COVERS	2 sets	(for FM only)
OSR COVERS	1 set	(for Herschel only) provided by TCS sub-co
MISCELLANEOUS		
EQUIPMENT DRIVE UNIT (EDU)	3	
SVM MASS DUMMY (SMD)	1	
ALIGNMENT TEST EQUIPMENT		alignment tools for thrusters provided by RCS sub-co

Figure 10.1-1

10.2 EGSE

Different test activities are foreseen to be performed on AVM / SVM, in particular:

- HERSCHEL/PLANCK AVM Integration and Functional test
- FM HERSCHEL SVM test activities
- FM PLANCK SVM test activities.

Regardless the ongoing activities, the EGSE configuration will be always the same and it is shown in figure 6-2.

The AVM / SVM Herschel/Planck EGSE will be built with the following equipment:

- Central Check Out System (CCS)
- The Power Control Subsystem SCOE (Power SCOE)
- The Telemetry, Tracking and Command SCOE (TT&C SCOE)
- The Telemetry and Telecommand Data Front End Equipment (TM/TC DFE)
- The Attitude and Control Measurement Subsystem SCOE (ACMS SCOE)
- The Central Data management Unit SCOE (CDMU SCOE).

All the above items are interconnected through an Ethernet Local Area Network (LAN) used to exchange both data and command & control information.

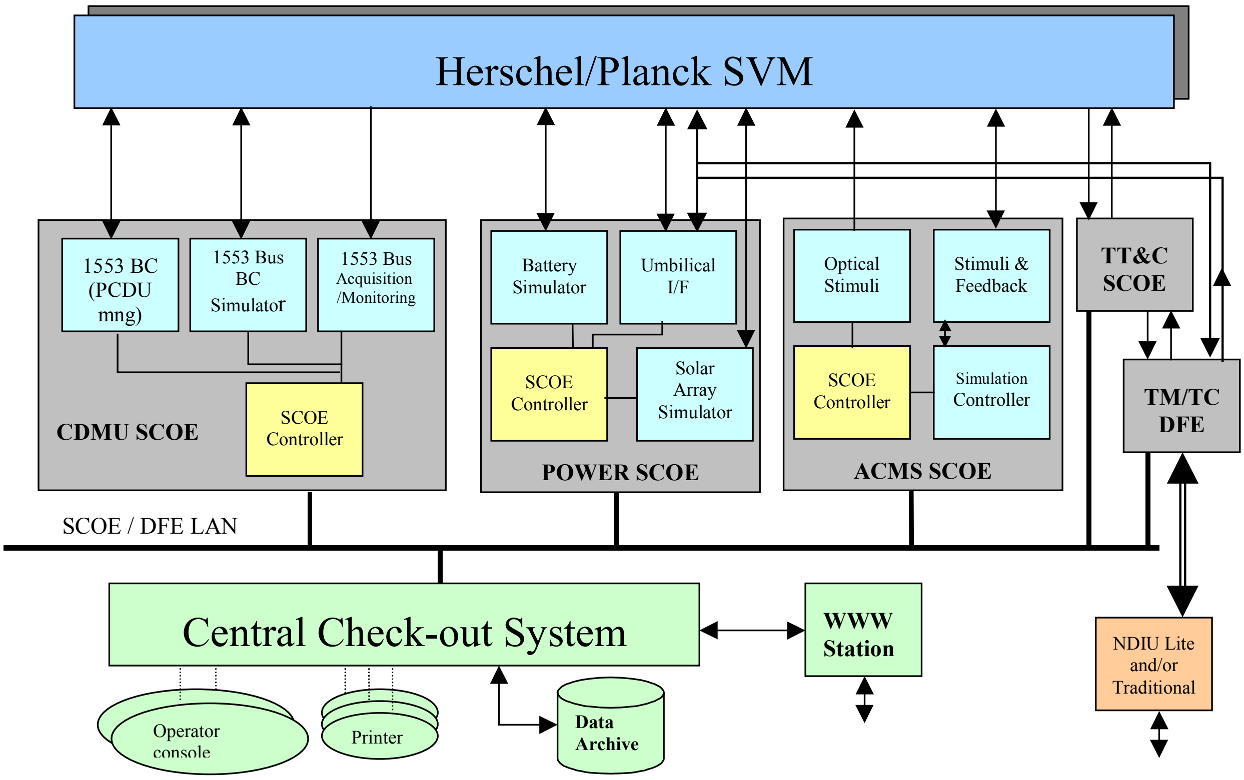


Figure 10-2 Herschel/Planck AVM/SVM EGSE functional architecture

10.3 EGSE USER S/W

During testing activities the Herschel/Planck AIV Team will be able to develop all the required "USER S/W" in order to automate the execution of the functional and performance verifications of the Satellite.
Most of the Test Software will be developed on MOIS (where possible) and CCS and it will consists mainly of:

- Test Sequences
- Synoptic Displays
- Data Evaluation and Test Analysis Software
- Simulation Software Master sequences (mainly for ACMS S/S).

On the contrary, on the SCOE's/DFE only a very peculiar type of software will be developed; it will mainly consist of:

- Configuration/set-up files for SCOE's/DFE instrumentation
- Sequence of commands
- Simulation files for Dynamic control and ACMS Sensors simulation
- Telemetry Simulation file for Missing Unit (Experiments).

10.4 AIT TOOLS TEST AID AND BREAK OUT BOXES

A number of B.o.B.s and relevant extension cables sufficient to cover both the AVM and PFM Herschel and PLANCK AIT activities has been procured in addition to proper terminations for 1553 Bus test purposes and cable for the CDMU QSL.