HERSCHEL/PLANCK

SATELLITE USER MANUAL

CHAPTER 2 SYSTEM DEFINITION

TABLE OF CONTENTS

LISTE OF FIGURES

LISTE OF TABLES

2. SYSTEM DEFINITION

2.1. SYSTEM DESCRIPTION

2.1.1. HERSCHEL and PLANCK overview

Both Satellites will be launched on the same ARIANE 5 ECA in dual launch configuration as illustrated by Figure 2-1: PLANCK Satellite in lower position and HERSCHEL satellite in upper position.

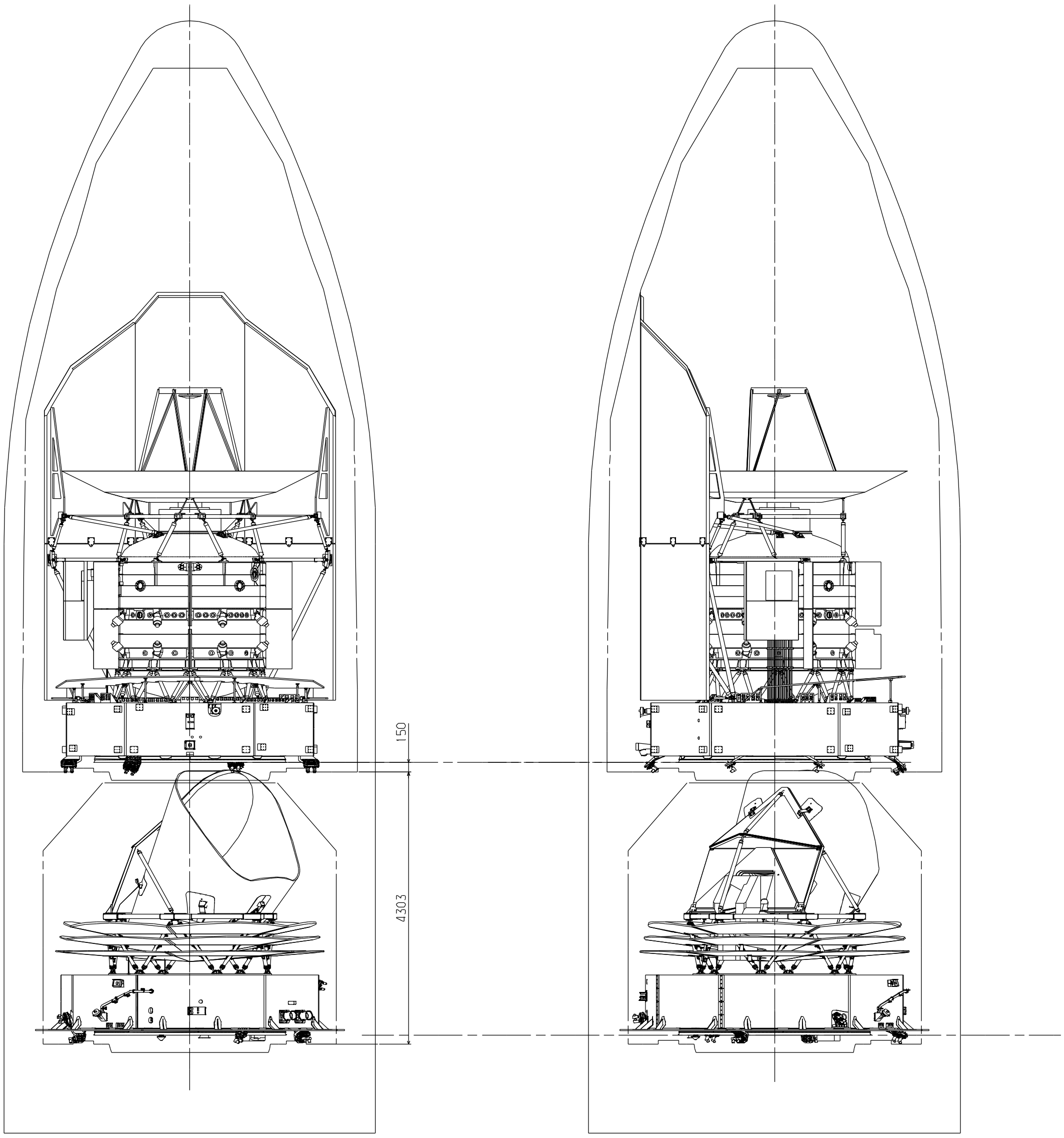


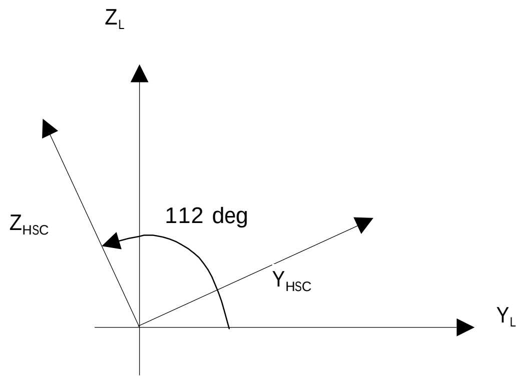
Figure 2-1 HERSCHEL and PLANCK configuration under fairing

There are no unfolded items on HERSCHEL and PLANCK satellites. The geometry in flight configuration is defined by:

- drawing PLS S000 A 002S for PLANCK
- drawing HES S000 A 002S for HERSCHEL.

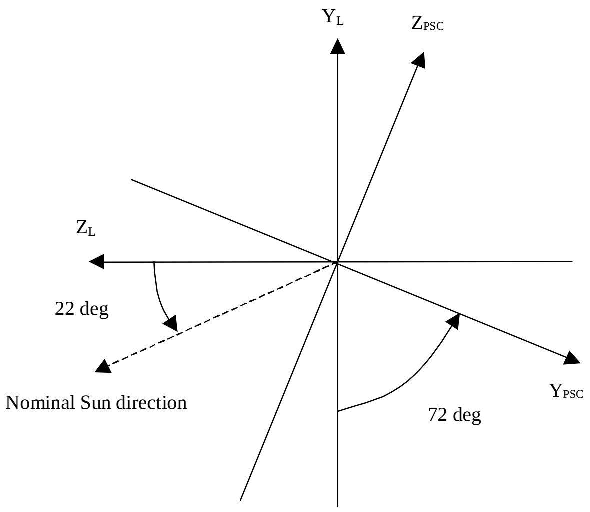
Clocking

Due to the sensitivity of the HERSCHEL spacecraft to Sun illumination, the clocking has to be determined to ensure that, during launch, the H-EPLM is not illuminated by the Sun. The defined clocking angle for HERSCHEL is now 112 deg as shown in the following Figure.



The axes Y_L and Z_L are the launcher axes, Y_{HSC} and Z_{HSC} are HERSCHEL spacecraft axes.

Figure 2-2 HERSCHEL clock angle definition



The axes Y_L and Z_L are the launcher axes, Y_{PSC} and Z_{PSC} are PLANCK spacecraft axes.

Figure 2-3 PLANCK clock angle definition

2.1.1.1. HERSCHEL overview

The current HERSCHEL configuration presents a modular concept, with two main modules:

– the **H-PLM** (HERSCHEL Pay-Load Module) which includes:

  - a large Cryostat Vacuum Vessel (CVV) in which are suspended the He I and He II tanks, the optical bench with focal plane units. The CVV carries external instrument LOU Assy and LOU radiator (part of HIFI)
  - a 3.5 m telescope in Silicium Carbide (SiC) supported on the top of the cryostat by a dedicated isostatic mounting structure
  - a Sunshield and Sunshade (HSS) forming a large screen surrounding the H-PLM on Sun side, ensuring a shadowing function of the cryostat and telescope and protecting them from direct Sun illumination. It ensures also a function of solar generator with a Solar Array implemented on sunshield.

– The **SVM** (Service Module) is formed by an octagonal box built around a conical tube (cone):

  - the SVM houses the equipment of the Avionics and Servicing S/S’s, the payload "warm" units (WU) for HIFI, PACS and SPIRE instruments
  - HERSCHEL SVM is designed to provide suitable mechanical and thermal environments during launch and in-orbit phases to the various equipment and instruments installed in it
  - the SVM supports the H-PLM Cryostat support truss on the top of the cone. It supports other H-PLM items as the SVM Shield for radiative de-coupling between SVM and cryostat, and HSS support truss (both on the top of the cone and upper closure panels)
  - the SVM ensures the mechanical link with the Launcher through the interface ring, and therefore ensures the main load path during launch.

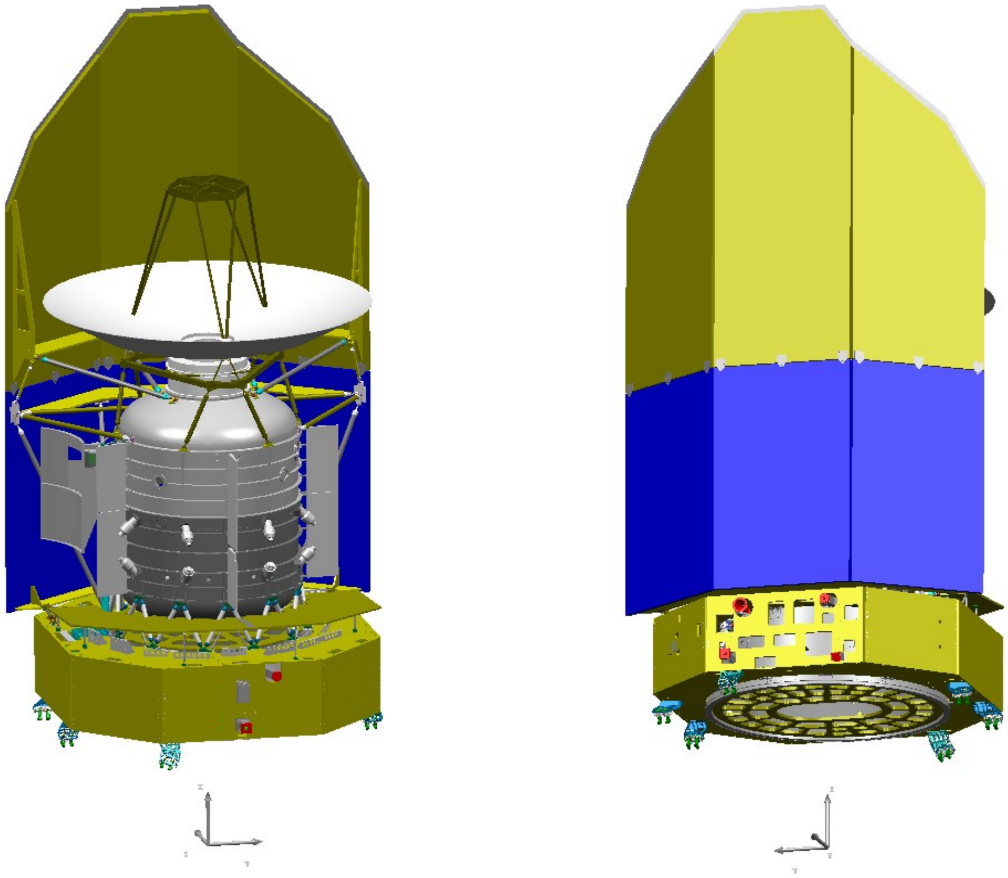
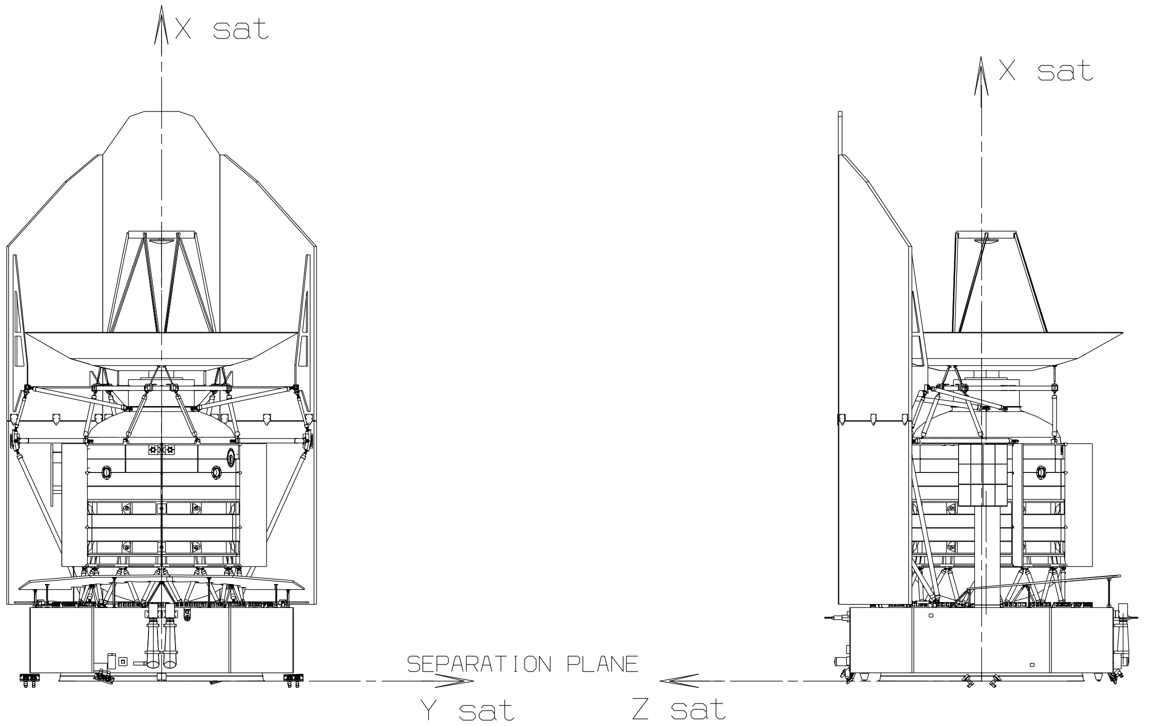


Figure 2-4 HERSCHEL spacecraft overall configuration

HERSCHEL axis convention

HERSCHEL satellite reference frame (O, Xs, Ys, Zs) is a right-handed Cartesian system with:

- its origin O located at the point of intersection of the longitudinal launcher and the satellite/launcher separation plane; the origin coincides with the centre of the satellite/launcher separation plane
- Xs axis coincides with the nominal optical axis of HERSCHEL telescope. Positive Xs axis is oriented towards the target source. The Xs axis coincides with the launcher longitudinal axis
- Zs is in the plane normal to Xs-axis, such that nominally the Sun will lie in the (Xs, Zs) plane (zero Roll angle with respect to Sun). Positive Zs-axis is oriented towards the Sun
- Ys completes the right handed orthogonal reference frame.



HERSCHEL SVM configuration

The Figure 2-5 and Figure 2-6 give the overall configuration of the HERSCHEL SVM.

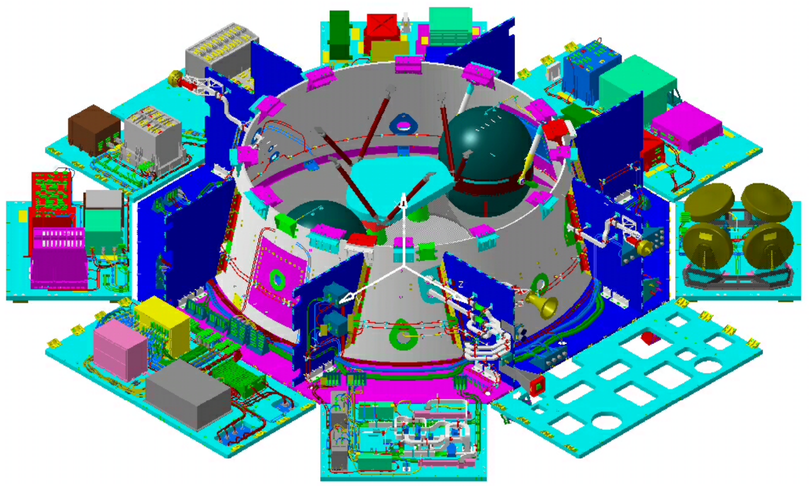


Figure 2-5 HERSCHEL SVM view

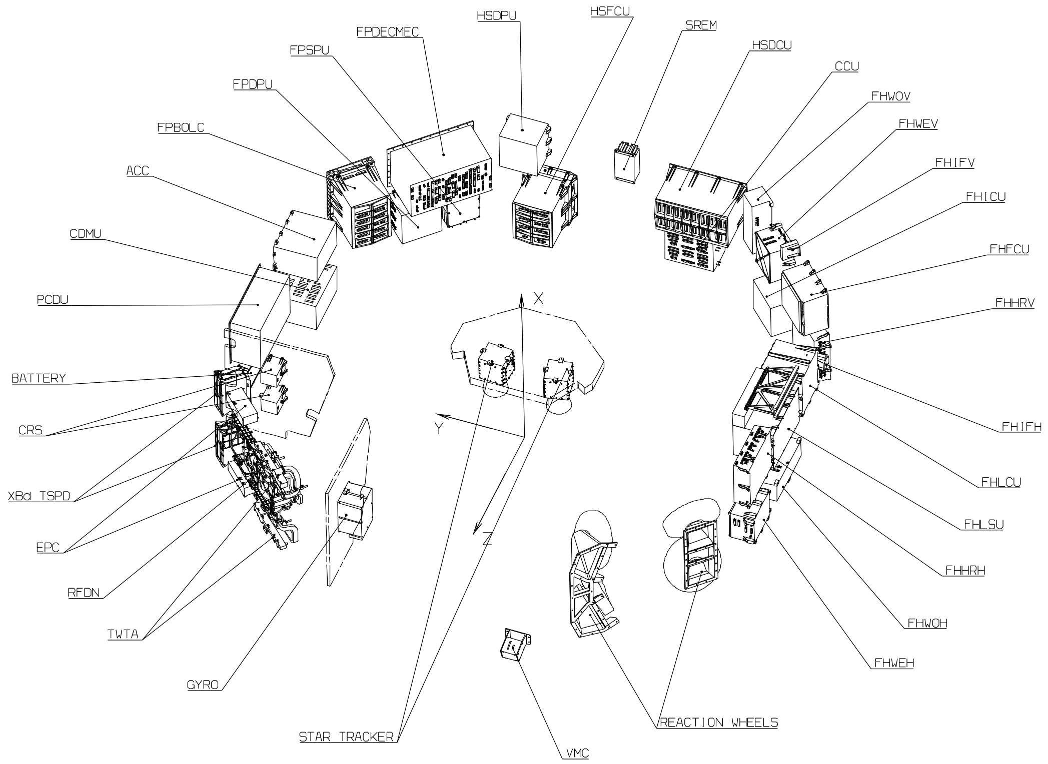


Figure 2-6 HERSCHEL SVM general layout

2.1.1.2. PLANCK overview

The current PLANCK configuration presents also a modular concept, and is basically composed of two modules:

- the **PLM** (Pay-load Module) which houses the "cold" part of the satellite and the focal plane unit. Its main constituents are:
  - the cryo-structure supporting the telescope
  - the Focal Plane Unit with associated electronics and cooling systems accommodated on the PPLM, and on the SVM structure via the Payload sub-platform and lateral panels
  - the main baffle enclosing the telescope and the FPU, for stray-light protection.
- The **SVM** (Service Module) is formed by an octagonal box built around a conical tube, which:
  - houses the equipment of the Avionics and Servicing S/S's, the payload "warm" boxes for HFI and LFI/SCS instruments; the PLANCK SVM is designed to provide the various equipment and instruments housed in it with suitable mechanical and thermal environments during launch and in orbit phases
  - supports the P-PLM cryo-structure truss
  - ensures the mechanical link with the Launcher adapter, and therefore ensures the main load path during launch.

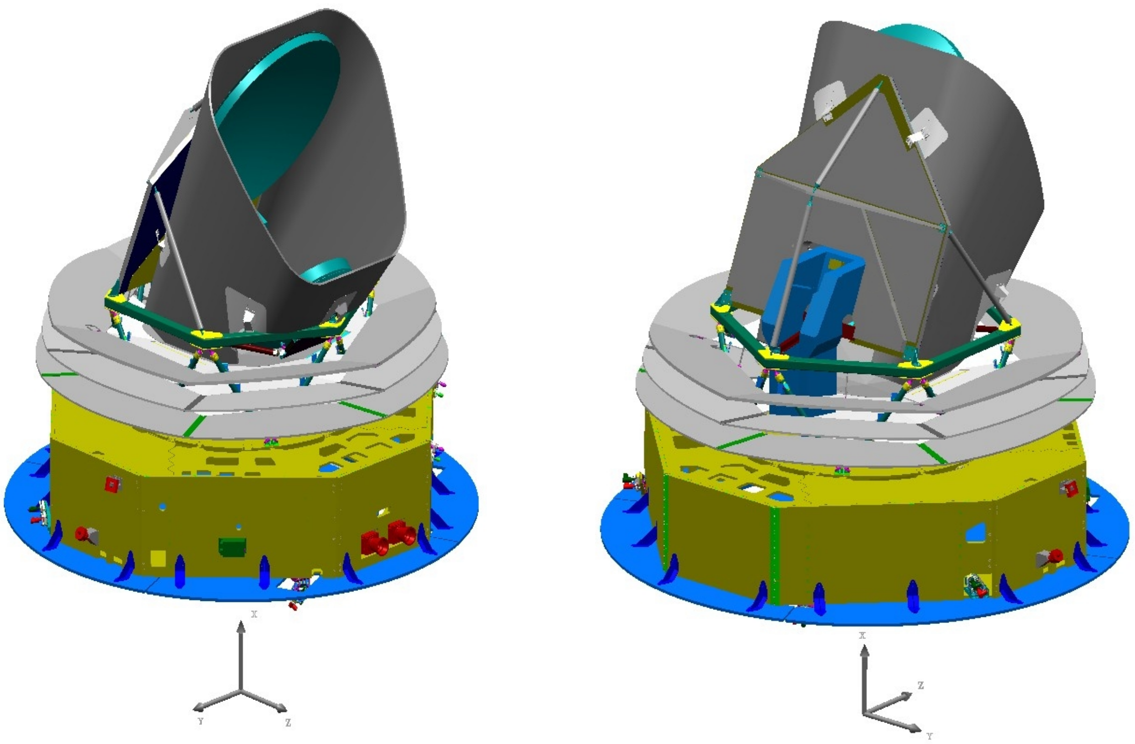


Figure 2-7 PLANCK spacecraft overall configuration

PLANCK axis convention

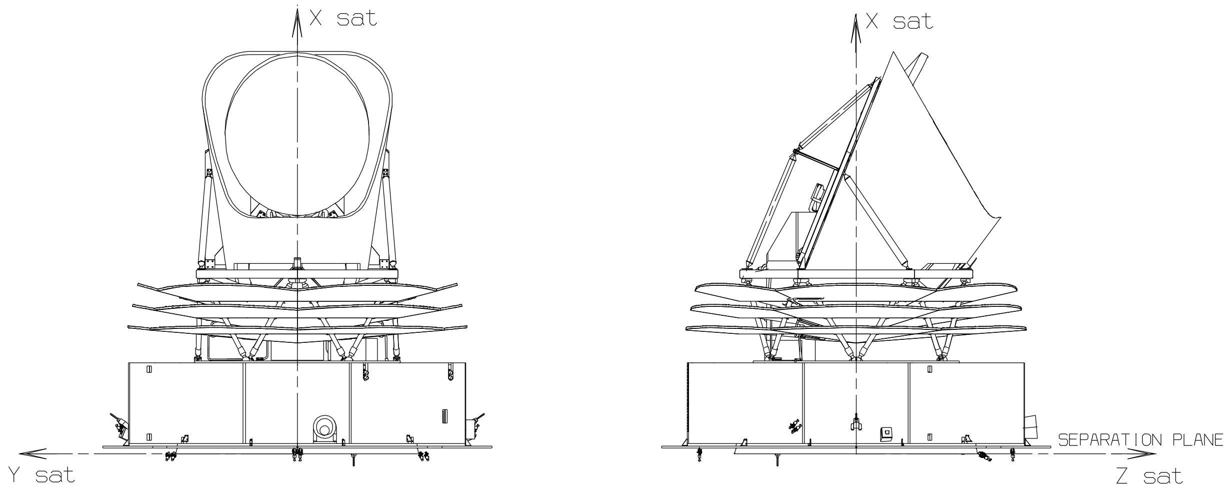
The PLANCK satellite reference frame (O, Xs, Ys, Zs) is defined such that:

- its origin O is located at the point of intersection of the longitudinal Launcher and the Satellite/Launcher separation plane; the origin coincides with the centre of the Satellite/Launcher separation plane

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

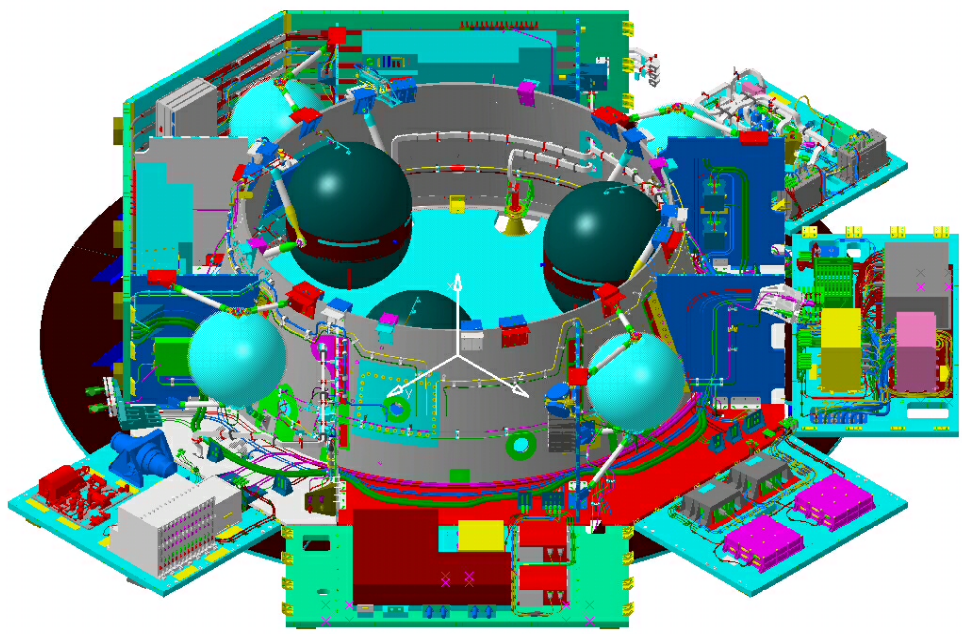
- Zs is such that the PLANCK telescope line of sight is in the (Xs, Zs) plane. The telescope is pointing in the +Zs half-plane

- Ys completes the right handed orthogonal reference frame.



PLANCK SVM configuration

The Figure 2-8 and Figure 2-9 give the overall configuration of the PLANCK



SVM.

Figure 2-8 PLANCK SVM view

Note: 4K CCR is not located as shown, but is on the opposite side of the FOG panel

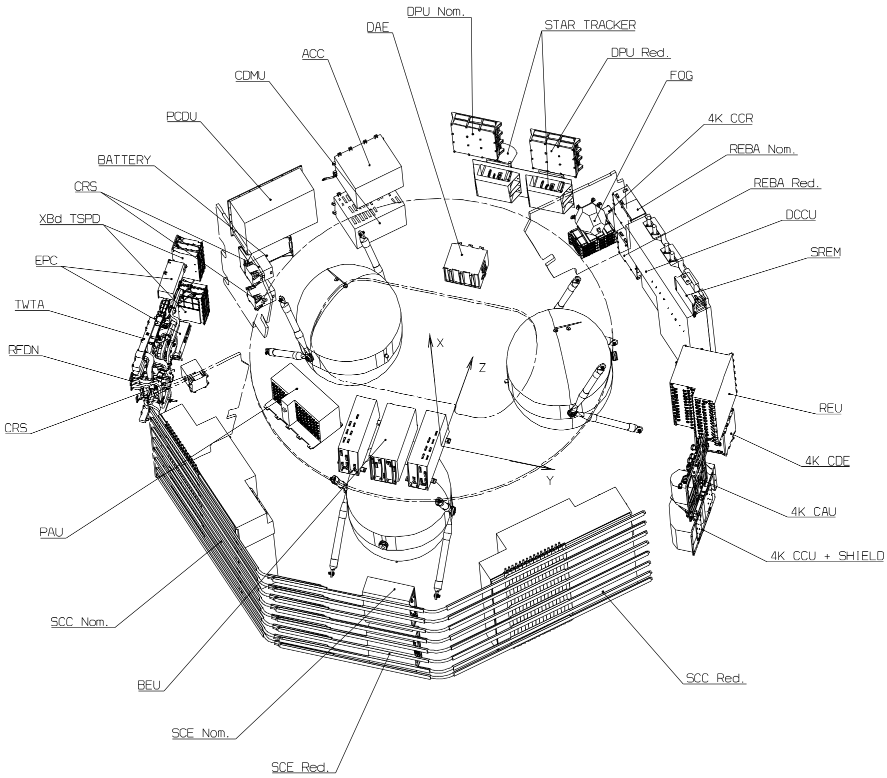


Figure 2-9 PLANCK SVM general layout Electrical and functional systems design

2.1.1.3. Electrical and functional systems design

2.1.1.3.1. Electrical design overview

The overall electrical architecture is conceived to satisfy both the instruments and spacecraft mission needs.

The baseline is presented in Figure 2-10 for HERSCHEL and Figure 2-11 for PLANCK. In line with the above drivers it is:

- decentralised, with the Data Handling tasks and the Attitude Control tasks running on 2 distinct computers
- high centralised within each Data Handling and Attitude Control computers, and a single Power Conditioning and Distribution Unit
- basically identical for both spacecraft's.

This design will be commented in the next sections but beforehand a functional level description is proposed, including functions related to spacecraft and instruments, and insight in the implementation is given. The main functions which will be discussed in the following are:

- the power generation
- the power protection and distribution
- the ground interface
- the telemetry acquisition and command and telecommand distribution
- the time management
- the thermal control
- the attitude and orbit control
- the fault protection
- the data storage
- the instruments and Payload Modules interfaces
- the interface with the non SVM units.

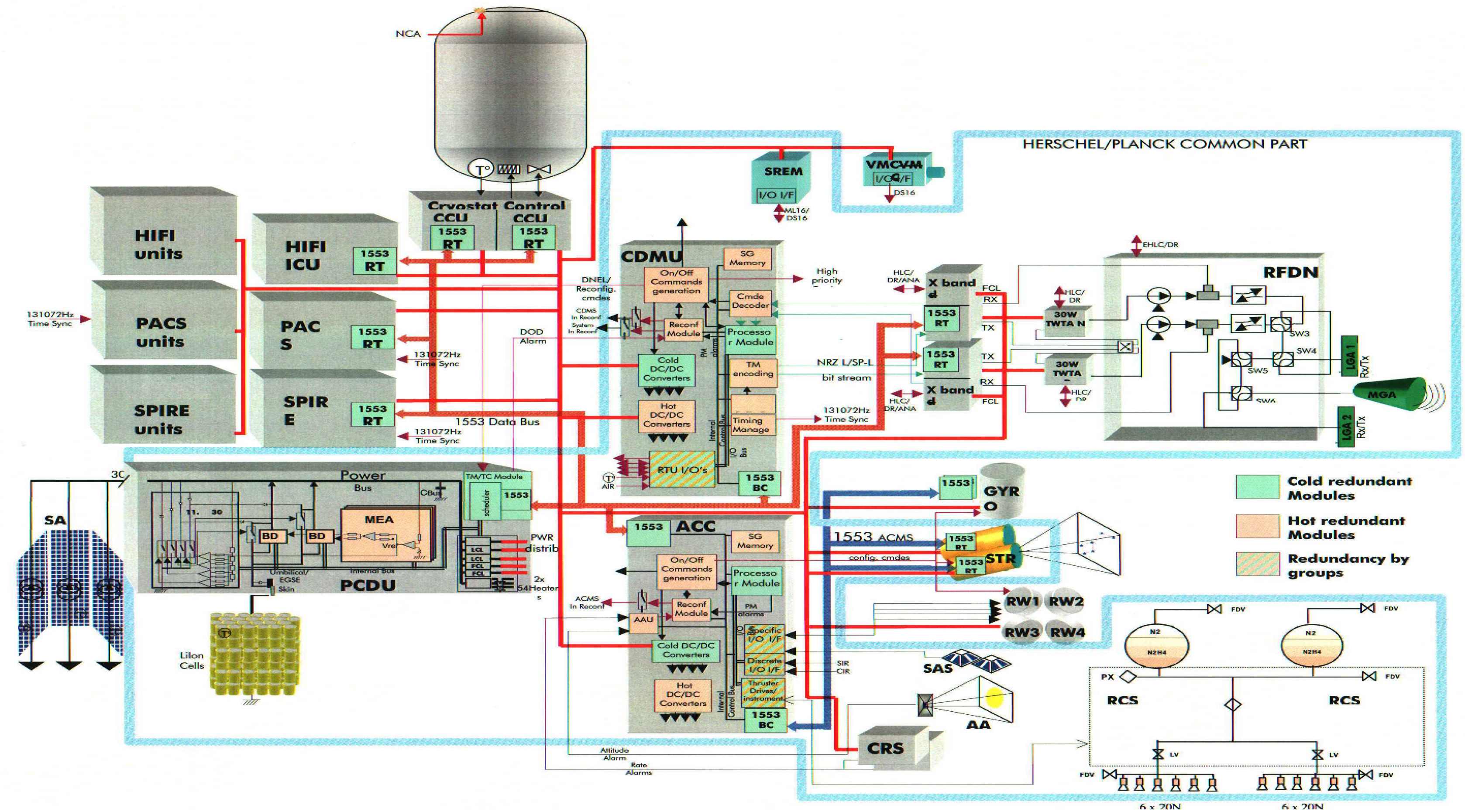


Figure 2-10 HERSCHEL electrical architecture

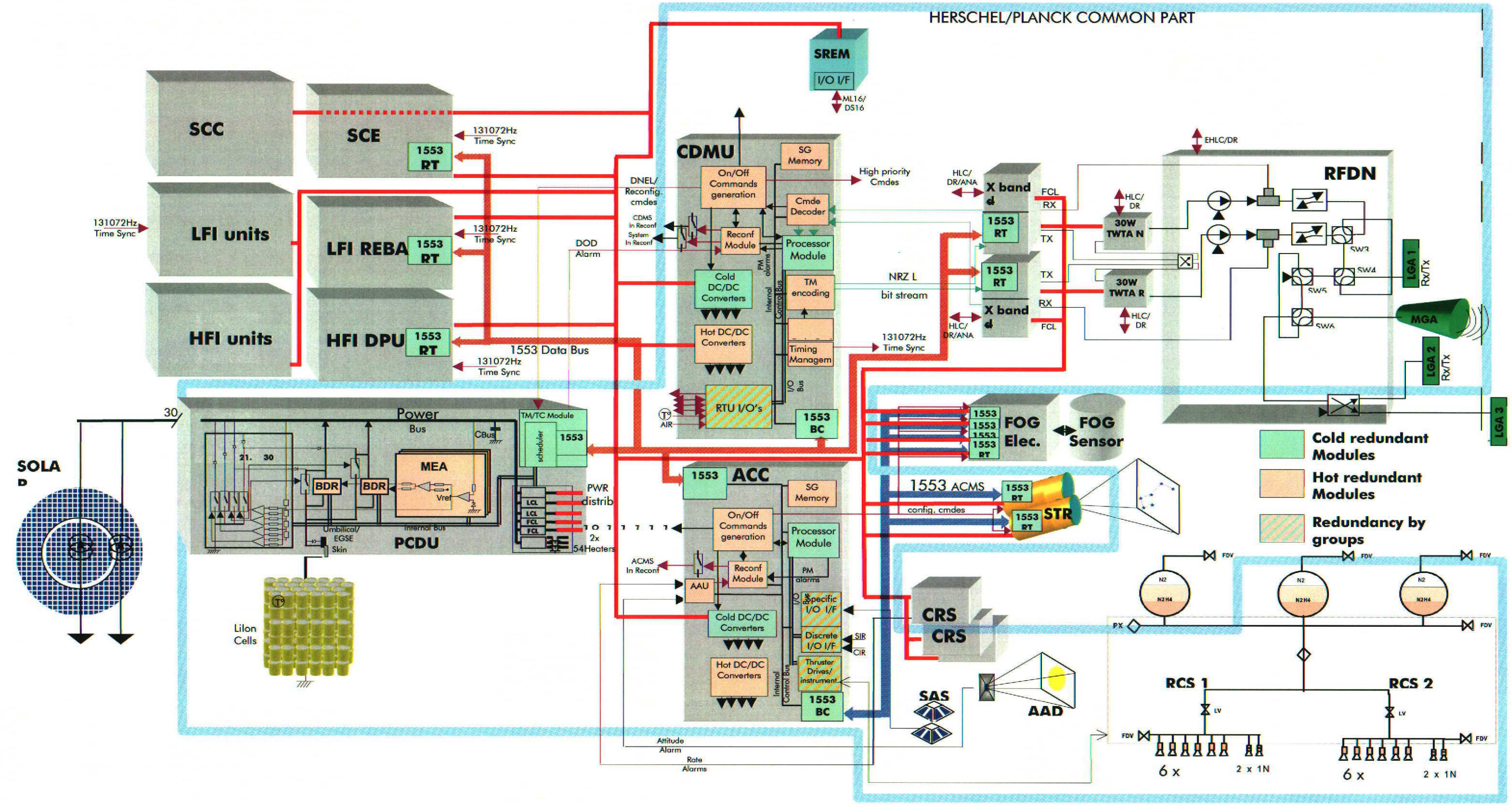


Figure 2-11 PLANCK electrical architecture

2.1.1.3.2. Power generation

High-power Solar Arrays provide the necessary power to a 28V regulated bus. They are capable to sustain the high temperatures induced by the mission requirements: indeed, the rear faces of the arrays must be blocked for HERSCHEL and for PLANCK to minimise the thermal leakage towards the cold Payload Modules. The performances are guaranteed in these conditions.

Due to the stable temperature and Sun illumination conditions which characterise both HERSCHEL and PLANCK missions, a power bus regulated by the S3R technique has been found optimum and is implemented.

Another common feature is that both missions are eclipse free; however, because of:

– the need to power ON the spacecraft during launch in order to have the spacecraft ready for fast and safe post separation activities

– the need to be robust to a loss of nominal Sun pointing in case of unexpected multiple-sources failure

an additional energy source is implemented consisting in a single, SPF tolerant, Lithium-Ion secondary battery. This battery is sized to cover the launch case, while the recharge rate is set high enough to take profit of the minimum illumination which could result from an attitude loss failure (SOHO lesson learnt).

The power generation function, essential to the satellite survival, is entirely hardware based. It is thus fully autonomous, especially for the Solar Array conditioning and battery charge/ discharge control, and is active as soon as energy is available from one of the sources.

2.1.1.3.3. Power distribution and protection

The 28V regulated power is distributed to the power bus users, spacecraft and instruments units, via Latched Current Limiters (LCL) and Fold Back Current Limiters (FCL). The FCL's allow an automatic turn ON of the units as soon as sufficient power is available. They are allocated to the elementary functions which are considered as critical for the mission safety and control, and which shall not be affected by a reconfiguration:

– RF receiver

– TC decoder

– Reconfiguration electronics

– On Board Time.

The other functions and units are supplied via switchable current limiters. These LCL's are nominally controlled by the data handling (CDMU) software via the 1553 data handling bus. For most of these LCL's, this commanding can however be overridden by High Level Commands issued by the CDMU reconfiguration electronics, and by direct ground TC's. A DNEL-like function, performed as part of a major recovery action allows to minimise the number of necessary HLC's, each of them suitably applies to groups of LCL's.

Both LCL's and FCL's also implement a protection function which ensure that any power problem in a unit does not propagate to the other units or functions.

Some LCL's feature a double switching mechanism to protect the user against failed ON conditions; these are:

- the LCL's for which the instruments have stated that they could not accept simultaneous ON of both nominal and redundant units
- the LCL's which failure in ON status would cause critical impact to the spacecraft (e.g. Sorption Cooler Compressor).

The heater lines are organised into groups, each group being protected by a LCL while the elementary lines are activated via individual electronic switch devices. Specific FCL's are also provided to support the heating of the spacecraft in emergency situations (see later, thermal control function).

2.1.1.3.4. Ground interface

As far as ground link is concerned, the HERSCHEL and PLANCK missions are characterised by:

- X-Band links for up and downlinks and the same modulation scheme. Frequencies allocations however are specific for each spacecraft
- the Earth to spacecraft distances during operation are very comparable for both spacecraft: 1.8 Mkm for HERSCHEL (large Lissajous), 1.6 Mkm for PLANCK (small Lissajous)
- the spacecraft to Earth aspects angles from telecommunication point of view are similar for both spacecraft: 15° maximum for PLANCK and HERSCHEL
- the uplink and downlink rates requirements, mainly driven by the science data, are identical

which calls for an obvious hardware commonality for both up and down links.

Downlink

The data collected by the CDMU is both transmitted in real time to one of the 2 cold redundant RF transmitter, and stored on board in the CDMU mass memory (see later) in case the RF link is not established. Each spacecraft will benefit from typically 3 hours of Daily Telecom Communication Periods (DTCP) during which it will be possible to establish the real time link, and download the stored data. 2 sets of antennae are provided:

- one Medium Gain Antenna permits to achieve the highest rate, but with a limited angular coverage; this is the nominal antenna for downlink and uplink during nominal operation
- 2 Low Gain Antennae on HERSCHEL, and 3 Low Gain Antennae on PLANCK are implemented to make possible the transmission of data, though at a limited rate, in any spacecraft orientation; these are the nominal uplink and downlink antennae in spacecraft Sun Acquisition Mode and spacecraft Survival Mode.

Depending on the ground station (New Norcia or Kourou), and on the transmitting antenna, 4 downlink rates can be programmed:

- 500bps with both stations on LGA's
- 5kbps with New Norcia on LGA's
- 150kbps with both stations on MGA
- 1.5Mbps with New Norcia on MGA.

In addition, the downlink rate of 150kbps with New Norcia on LGA's will be punctually used at the very beginning of HERSCHEL mission to download the VMC images.

The optimisation of the available telecom bandwidth and the proper share between real time and stored data is guaranteed by an extensive use of the Virtual Channel mechanism; among 8 VC's available, 6 are allocated with a defined priority scheme which ensures that both:

- the spacecraft HK and critical instruments HK data have priority over the science data
- the real time data has priority over the stored data.

This is then achieved by the following detailed allocation, from the highest to the lowest priority:

- VC0: real time essential spacecraft HK + essential instruments HK + Non periodic HK
- VC4: real time routine spacecraft HK + routine instruments HK (periodic)
- VC2: stored spacecraft HK (incl. non periodic HK+ stored instruments HK)

- VC1: real time science data
- VC3: stored science data
- VC7: idle frames

where a transfer frame from VCn will be transmitted only if no transfer frame from higher priority Virtual Channels is ready to be transmitted, and if the downlink rate permits it.

The instruments data rates allocations and the spacecraft HK rate current allocations are:

- spacecraft real time HK = 9 kbps, composed of 3 kbps of essential spacecraft HK and 6kbps of routine spacecraft HK (this mainly comprises data for attitude reconstruction on ground when the spacecraft in Nominal Mode of operation)
- instruments real time HK = 2 kbps/instrument, composed of 300 bps of essential HK and 1.7 kbps of routine instrument HK
- real time science data = 130 kbps for all instruments together.

They are defined such that:

- The 5kbps downlink rate allows:
  - when the S/C is in Sun Acq Mode at Launcher separation to transmit all the VC0 frames plus a few VC2 frames since no critical instrument HK (instruments are OFF), and no VC4 frames are present
  - when the S/C is in Sun Acq Mode, and when the link with New Norcia can be established, to transmit all the VC0 frames
  - the 500bps downlink rate permits to transmit via VC0, when the S/C has transitioned to Sun Acq Mode or Survival Mode, a subsampling (1 packet over 11) of the essential TM packets plus the non periodic TM packets.
- The 150 kbps downlink rate permits to transmit all the VC0, VC4, VC2 then VC1 frames; this rate allows nominal real time operations of the spacecraft and instruments even if the spacecraft is in visibility of only Kourou station.
- The 1.5Mbps downlink rate permits to transmit all the VC0, VC4, VC2, VC1 & VC3 frames in a Daily Telecommunication Period (DTCP), with New Norcia.

The down link modulation scheme is NRZ-L/BPSK/PM for low rates, SP-L/PM for medium rate and GMSK for medium for high rate.

The downlink rates, corresponding modulation scheme as well as the antennae configurations are set by software commands, depending on the current satellite mode (see later for the definition of the spacecraft modes); a safe configuration is however selected at initialisation (typically 500bps on LGA). Similarly the RF transmitter and the TWTA to be used for downlink are turned on at start of the DTCP, and then nominally turned off.

The CDMU outputs Reed Solomon and Convolutionaly encoded, pseudo randomised for the high data rate, NRZ-L telemetry signals, leaving the whole modulation process into the TTC function (transponder): this approach allows to have the responsibility of the whole modulation performance within one single subsystem with the associated technical and interface cleanliness benefit. The pseudo randomisation is mandatory on the GMSK modulated signal to be able to guarantee a bit transition density consistent in all cases with the ground station performance.

Uplink

The signal transmitted from ground is acquired by one of the 2 antenna sets:

- the Medium Gain Antenna in S/C Nominal Mode and Earth Acq Mode (see later for the definition of the S/C modes)
- the LGA's, oriented towards the +Z direction for HERSCHEL and -X direction for PLANCK in S/C Sun Acq Mode and Survival Mode. The other LGA's would be solicited only in case failure leading to an attitude loss. All LGA's together ensure an omnidirectional coverage.

Depending on the ground station (New Norcia or Kourou), 2 uplink rates can be used:

- 125bps with Kourou
- 4kbps with New Norcia.

The demodulation of the X-Band up stream is performed by one and possibly the 2 hot redundant Rx receivers, the signal on one of the receivers being in nominal much stronger than the other one. The demodulated data is then forwarded to the two hot redundant TC decoders which determine the best stream to lock on. Note that a priority scheme is implemented to avoid an erroneous lock on the weaker signal (lesson learnt from XMM: TC rejection anomaly).

Once decoded by the addressed decoder, the TC packets are either sent to the Command Priority Distribution Unit for direct commanding of e.g. the PCDU current limiters, or to the CDMU Processor Module in order to be processed by the software (Basic SW or Application SW).

Since the telecommand chain is basically in hot redundancy, only the receiving antenna and the uplink rate have to be selected by software.

2.1.1.3.5. Data acquisition/commands distribution

This function deals with the collection of telemetry data on board, and with the distribution of commands and telecommands.

The communication on board the 2 spacecraft's is organised around a redundant 1553 data bus, to which most of the units are connected. This permits a straightforward interfaces implementation since all the science data and most of the housekeeping collection as well as the instruments and most of the units commanding will be via 1553 messages.

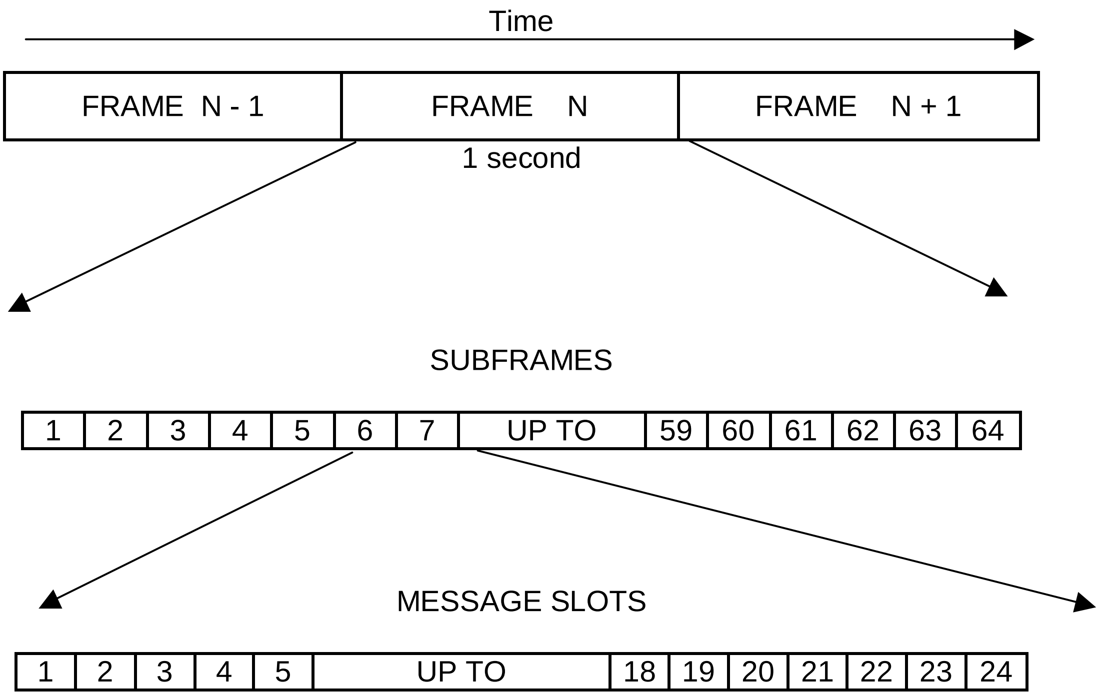
The main contributors to the load of this bus, the instruments and the ACMS computer, feature a packet level interface. The other units:

– either have a 1553 bus interface without packet I/F, i.e. the communication is at message level (PCDU, CCU for HERSCHEL, Transponders). These are called "non intelligent users")

– or have standard point to point interfaces (Transponders receiver part, TWTA, RFDN, SREM, VMC, thermal control): DS16/ML16, Bilevels, Relay Status, Analog, Temperatures, on/off commands.

In these 2 cases, the telemetry packets are built by the CDMU software.

The bus protocol implemented to ensure an efficient and robust transfer of data is based on a cyclic structure, synchronised to the On Board Time (see Figure 2-12). The bus time is split into 1s frames comprising 64 subframes. Each of these subframes is itself composed of 24 elementary, well defined, slots where each slot contains a 1553 Bus message. The content of the subframes specifies the RT addresses and the subaddresses to be polled or to command; it is defined by a so called Bus Profile.



Definition: 1 FRAME = 64 SUBFRAMES; 1 SUBFRAME = 24 MESSAGE SLOTS.

Duration: 1 FRAME = 1 second: 1 SUBFRAME = 1/64 second.

Figure 2-12 Data Bus Protocol principles

Rules have been defined such that:

- one subframe is allocated to one single TM packet transfer. The maximum TM packet size (1kbyte) is such that it can be transferred in one subframe only
- up to 3 TC packets can be transferred in one subframe, but each packet user shall only receive one TC per subframe.
- a complete subframe shall not necessarily be allocated to the transfer of non packetised 1553 messages: these messages can be interleaved in already allocated subframes.

Based on these rules, maximum subframes allocations have been specified in accordance with the instruments data rates and spacecraft subsystems data rates. The current allocations are shown in Figure 2-13 & Figure 2-14 for PLANCK and HERSCHEL as a function of the satellites modes. It shall be pointed out that the protocol capability in term of bandwidth, i.e. the maximum amount of useful data which be exchanged on the Bus, in some specific conditions, can be higher than 440 kbps, thus well in excess of the required performance.

PLANCK SUBFRAME ALLOCATION	Launch mode	S/C Sun Acquisition	Nominal Normal	S/C Earth Acquisition	Survival
LFI TM	0	15	15	15	0
HFI TM	0	15	15	15	0
Sorption Cooler HK TM	0	2	2	2	0
AOCS TM	4	4	4	4	4
PCDU TM	1	1	1	1	1
AOCS TC receipt Report TM	2	2	2	2	2
Subframes allocated to TC sending	4	4	4	4	4
FOG TM/TC	0	1	1	1	0
Total number of subframes allocated	11	44	44	44	11
Number of spare subframes	53	20	20	20	53
Max theoretical equivalent bit rate (bps)	90112	360448	360448	360448	90112
Actual equivalent bit rate (bps)	65024	327168	327168	327168	65024

Figure 2-13 PLANCK subframes allocation

HERSCHEL SUBFRAME ALLOCATION	Launch mode	S/C Sun Acquisition	Nominal Normal	Nominal Burst Mode	S/C Earth Acquisition	Survival
Prime Instrument TM	0	3	27	40	3	0
Non-Prime1 Instrument TM	0	3	3	3	3	0
Non-Prime2 Instrument TM	0	3	3	3	3	0
AOCS TM	4	4	4	4	4	4
PCDU TM	1	1	1	1	1	1
CCU-Nominal TM	1	1	1	1	1	1
CCU-Redundant TM	1	1	1	1	1	1
AOCS TC receipt Report TM	2	2	2	2	2	2
Subframes allocated to TC sending	4	4	4	4	4	4
Total number of subframes allocated	13	22	46	59	22	13
Number of spare subframes	51	42	18	5	42	51
Max theoretical equivalent bit rate (bps)	106496	180224	376832	483328	180224	106496
Actual equivalent bit rate (bps)	69120	142848	339456	445952	142848	69120

Figure 2-14 HERSCHEL subframes allocation

The Bus Profile in use depends on the current spacecraft configuration and on the current instruments operation. A set of 16 Default Bus Profiles can currently be pre-defined for each spacecraft and the switch from one profile to another one is performed upon telecommand. Each of the pre-defined bus profiles can be modified by telecommand down to the slot content, with the restriction that slot #1 and #23 cannot be modified at all.

In order to modify the definition of a given sub-frame of a Bus Profile, a specific telecommand has been defined, namely TC(8,4,6,1) "Update Sub-frame of Selected SCBP".

In order to specify the 16 Default Bus Profiles, 16*64=1024 Default TC(8,4,6,1) are defined.

The following operative Bus Profiles have been defined:

HERSCHEL: 9 Operative Bus Profiles

S/C Mode	Bus Profile
LM	– Launch: index 0 and defined by TC(8,4,6,1) identified by DC001189 to DC064189.
EAM	– Earth Acquisition: index 1 and defined by TC(8,4,6,1) identified by DC101189 to DC164189.
NOM	– HIFI Prime: index 2 and defined by TC(8,4,6,1) identified by DC201189 to DC264189.
	– SPIRE Prime: index 3 and defined by TC(8,4,6,1) identified by DC301189 to DC364189.
	– PACS Prime: index 4 and defined by TC(8,4,6,1) identified by DC401189 to DC464189.
SAM	– Sun Acquisition: index 5 and defined by TC(8,4,6,1) identified by DC501189 to DC564189.
SM	– Survival: index 6 and defined by TC(8,4,6,1) identified by DC601189 to DC664189.
NOM	– PACS Burst Mode: index 7 and defined by TC(8,4,6,1) identified by DC701189 to DC764189.
	– (SPIRE/PACS) Parallel Mode: index 8 and defined by TC(8,4,6,1) identified by DC801189 to DC864189.

PLANCK: 5 Operative Bus Profiles

- Launch: index 0 and defined by TC(8,4,6,1) identified by DC001189 to DC064189.
- Earth Acquisition: index 1 and defined by TC(8,4,6,1) identified by DC101189 to DC164189.
- Science: index 2 and defined by TC(8,4,6,1) identified by DC201189 to DC264189.
- Sun Acquisition: index 3 and defined by TC(8,4,6,1) identified by DC301189 to DC364189.
- Survival: index 4 and defined by TC(8,4,6,1) identified by DC401189 to DC464189.

The remaining Bus Profiles (7 for HERSCHEL and 11 for PLANCK) were declared as INACTIVE and filled with slots without any activity. This means that when selecting these bus profiles, only the synchronisation without data in sub-frame 1 and synchronisation with data in subframe 2 to 64 would have been issued on the S/C 1553B Bus. These INACTIVE Bus Profiles were anyway stored in CDMU EEPROM. In order to reduce the EEPROM memory budget, it has been decided not to define them anymore on-board and consequently save the associated memory (2816 bytes per Bus Profile).

Layout for TC(8,4,6,1)

Each TC(8,4,6,1) ("TC" item in HPSDB) in the delivered XML files refers to:

– command Header ("TCH" item in HPSDB) defined in HPSDB generic box

– command structure ("TC_STR" item in HPSDB) containing Function ID; Activity ID; SID which are defined as Command parameters ("COMMAND_PAR" items in HPSDB)

– command parameter ("COMMAND_PAR" item in HPSDB) defining Frame ID

– 22 (one for each of the 24 slots except slot#1 and 24) Command structures ("TC_STR" item in HPSDB) containing SPR; P/M; RT; SADR; T/R which are defined as Command parameters ("COMMAND_PAR" items in HPSDB).

All above command parameters have a default value expressed in decimal ("RawRadix" attribute set to "D").

This default value will be used into the TC packet ("TakesDefault" attribute of "TC_STR_DEF" item set to "Y").

Identification of TC(8,4,6,1) for the default bus profiles in HPSDB

For the identification of these TC packets, the "CdmuSwInitFlag" attribute of "TC" item has to be set to "Y".

In addition, two dedicated theoretical boxes for these TC packets have been defined:

– the box "H_DEF_BPROF" (box number 189) that is located in position 189 of D101 subsystem (CDMS_HER). It includes the default 1553 Spacecraft Data Bus profiles for HERSCHEL spacecraft

– the box "P_DEF_BPROF" (box number 188) that is located in position 189 of D201 subsystem (CDMS_PLA). It includes the default 1553 Spacecraft Data Bus profiles for PLANCK spacecraft.

Obviously some identical TC packet are present in both boxes (ie: they are duplicated into HPSDB).

The HPSDB identifier for these TC packets is DCnxx189, where:

– n (from 0 to F using hexadecimal notation) stands for the identification of the bus profile

– xx (from 1 to 64 using decimal notation) stands for the identification of the subframe.

Note that Short Description ("SDesc" attribute) and Long Description ("LDesc" attribute) of the "TC" item, also identify the bus profile and the subframe (eg: "SDesc" = SCBP0_SF1; "LDesc" = TC(8,4,6,1) for H Bus Profile 0 Subrame 1 Default Definition). They have to be considered for "human user" information whereas the automated process for code generation should rely on the HPSDB identifier.

Note that operationally, the sending of these TCs to spacecraft is not sufficient to set the default 1553 Spacecraft Data Bus profiles. Such a setting, in operational conditions, requires also the sending of appropriate TC(8,4,6,2) and TC(8,4,6,3).

Additional "Bus Profiles related" HPSDB parameters

The following HPSDB parameters are also requested by the BSW for its configuration:

Mnemonic	Description	HERSCHEL Value	PLANCK Value	Comment
DEFAULT_SCBP_INDEX_VALUE	Index of the Default Bus Profile to be used by the BSW after its initialisation up to the first selection of the active one by the CDMU ASW according to S/C mode.	0	0	The BSW will use the Launch Bus Profile Definition. This Bus Profile will allow to acquire TM from active RT after cold start, i.e. ACC and PCDU.
NBR_SCBP_DEF_VALUE	Number of Default Bus Profiles stored in EEPROM.	9	5	

These parameters are not included in the xml files including the Bus Profiles Definitions but shall be inserted in the database in relevant BSW boxes.

Delivered Files

The following files are delivered:

S/C	File Name	Issue	Content	Checksum
HERSCHEL	H_DefBusProf-v07.xml	-	Defines 576 TC(8,4,6,1) packets for the definition of HERSCHEL spacecraft Default Bus Profiles (9*64). These items are defined into the HPSDB box: "H_DEF_BPROF".	20064
HERSCHEL	StructForH_DefBusProf-v07.xml	-	Defines all Command parameters and TC structures for definition of any TC(8,4,6,1) packet to HERSCHEL spacecraft. These items are defined into the HPSDB box: "H_DEF_BPROF".	37106
PLANCK	P_DefBusProf-v07.xml	-	defines 320 TC(8,4,6,1) packets for the definition of PLANCK spacecraft Default Bus Profiles (5*64). These items are defined into the HPSDB box: "P_DEF_BPROF".	23738
PLANCK	StructForP_DefBusProf-v07.xml	-	Defines all Command parameters and TC structures for definition of any TC(8,4,6,1) packet to PLANCK spacecraft. These items are defined into the HPSDB box: "P_DEF_BPROF".	2106

These Bus Profiles definitions are compatible with issue 2.4 of CDMU BSW. The XML files are compatible with XML schema 3.1.5.

The checksum is computed using the UNIX “sum” command with SUN Solaris Operating System.

The files HdefBusProf-V07.xls and PdefBusProf-V07.xls provided in Annex 1 for HERSCHEL and in Annex 2 for PLANCK respectively contain the bus profiles definition used to build the above xml files. (Annexes to the chapter 2)

2.1.1.3.6. Time management

An essential parameter in the scientific data processing for both HERSCHEL and PLANCK missions is the time accuracy, and especially the time synchronisation between science and attitude data.

This function is basically implemented in hot redundancy within the CDMU which manages the On Board Central Time Reference and distributes synchronisation signals. More precisely, this CTR is:

- used to synchronise the time based on board operations
- distributed to the 1553 data handling Bus Remote Terminals at the subframe 33. This datation mechanism permits a relative accuracy of less than 50µs between the CTR and a given RT, i.e. a datation accuracy between the Attitude data packets and the science packets which can be far better than the specified 500µs

– distributed within the Packet Structure ICD service 9 to the packet users which can accept it, upon TC

– used to generated the 131072Hz synchronisation signals to the instruments units.

This function is implemented in hot redundancy, such that:

– the CTR reliability is improved: no single failure can stop/corrupt the On Board time.

The mechanism to synchronise the on board time with the ground Temps Atomic International (TAI) is provided in compliance with the Packet Telecommand standard, however no need is expressed for such an on board correlation. On the contrary, the instruments, if they look for an accurate on board synchronisation of all the events with a Central Reference Time, do not expect any jump in time, such as the ones which would result from the CTR synchronisation with the ground time. Eventually the baseline operation principle is to let the on board time "free running", and to perform on ground the necessary TAI correlation, on a daily basis. This offers the benefit to significantly relax the constraints on the long term stability of the on board oscillators.

In order to increase the accuracy of the on ground time correlation, a change in the Time TM packet sampling interval from 1 every 256 VC0 frame to 1 every 64 VC0 frame has been implemented.

2.1.1.3.7. Active thermal control

As a result of the drivers announced at the beginning of the chapter, the nominal thermal control function is essentially implemented via software, as illustrated in Figure 2-15, which allows to remain flexible in the setting of the different parameters until late in the development of the spacecraft's.

The temperature of each controlled interface point is monitored by 3 hot redundant sensors acquired by the CDMU I/O system. After a majority voting on these 3 measurements is computed the result is entered in either a Proportional-Integral regulation loop (fine regulation) or a simple min/max algorithm, depending on the interface point to regulate (fine regulation is currently applied to HIFI and STR units). As a result the corresponding nominal heater line is commanded in the PCDU via 1553 messages.

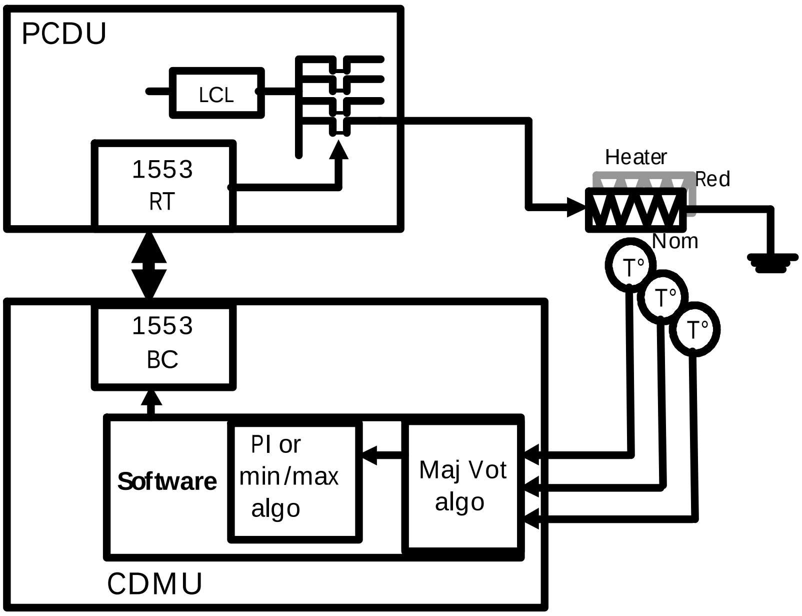


Figure 2-15 Nominal active thermal control

In order to cover the case of a critical failure ultimately leading to the loss of both CDMU's processor module, a survival thermal control is implemented, entirely relying on thermostats connected on permanent, FCL protected lines in the PCDU. This back up mode design is basically based on the following requirements:

– the thermostated control shall not interfere with the nominal operating mode: the survival temperatures thresholds shall be set such that there is no risk of overlap with the nominal thermal control thresholds

– the survival heating function does not aim to keep all the units within their operating or non operating ranges. Its purpose is to guarantee a minimum temperature level to the units essential for the spacecraft survival and to support it in the recovery from a dramatic SOHO-like failure case.

It has actually been shown that HERSCHEL and PLANCK thermal design were such that no part of the spacecraft would reach temperatures below the qualification levels in any failure condition. Thermostats are therefore only used on the battery to ease SOHO-like failure cases recovery by maintaining it within temperature ranges for which the charge efficiency is optimum.

2.1.1.3.8. Attitude and orbit control

This function deals with all the monitoring and control necessary to keep the spacecraft in a pointing attitude in line with the satellites modes and targeting requirements. It is characterised by:

– a fully autonomous implementation based on a dedicated computer, the ACC, and a full control of the subsystem units configuration

– a high commonality between HERSCHEL and PLANCK designs: in terms of hardware and in terms of operating modes.

The Attitude and Orbit Control function, in standby during launch, becomes active upon sensing of the launcher separation strap status. In parallel, at separation, all nominal and redundant ACMS sensors and actuators LCL's are turned on in the PCDU from CDMS commanding; the configuration of the ACMS units is then managed autonomously by the ACMS computer (the ACC) which acts in baseline directly at the level of ON/OFF switch implemented within each unit. Exceptions, apart from the Sun Acquisition Sensors and Attitude Anomaly Detectors are the Coarse Rate Sensors: their status is only controlled by the turn ON/OFF of the PCDU LCL's; they will nominally be switched ON before launch, and never by switched OFF during the mission.

It shall be pointed out that the LCL's role as far as ACMS units power lines are concerned is limited to the protection function. No recovery action at CDMS level will modify the configuration which remains in all cases under full control of the ACMS; as it will be discussed later, a failure upstream an ACMS unit (especially in a LCL) will simply be seen as a unit failure by the ACMS, and handled within the ACMS FDIR.

After separation, then, the ACMS automatically enters a Sun acquisition mode relying on a limited and reliable set of sensors/actuators. From this state the transition to normal mode and the associated pointing targets are received as CDMS telecommands wherever they are originated from (ground, mission timeline, FDIR). A feature of the design is that although the ACMS, in normal pointing mode, is basically slaved to the CDMS once the Sun acquisition is achieved, its commanding is performed via high level pointing commands which are decoded locally and realised autonomously in the ACMS.

In parallel to the normal mode of operation, the FDIR task is performed and has priority over all other tasks. In case of failure, ultimately, as it is addressed briefly in the following, and in a more detailed way in Section 3.1.3., the survival mode is engaged.

Apart from the design features directly derived from the performance requirements, the overall Attitude and Orbit Control function implementation is strongly driven by a small number of FDIR related rules:

– the survival mode is based on a specific, different set of sensors and actuators and does not rely on reaction wheels (on HERSCHEL

– the survival mode is triggered by units which do not participate to the normal mode or to the survival mode itself.

The different satellite mode and their relationships with ACMS modes and FDIR are be detailed later in Sections 3.1.3 and 3.1.5.

2.1.1.3.9. Fault protection

The fault protection function first aims to protect the spacecraft safety, including the instruments, in case of any single failure, and second in the cases where this is feasible, to optimise the mission scientific return.

It is basically distributed between hardware and software features on the one hand, and between the CDMS and the ACMS on the other hand.

The fault protection system is basically always active from the separation with the launcher, and runs in parallel to the other tasks which it interrupts in case of failure, with actions depending on:

– the failure critically

– the FDIR current mode.

The failure criticality is identified by 5 levels, from the less critical Level 0 which has no noticeable impact on operation to the system Level 4 which leads to initiate a survival mode. The implementation of the detection and of the recovery mechanisms fully depends on this failure criticality: software based for Levels 1 & 2, and hardware based for Levels 3 & 4, potentially both for the Level 0. The Levels 3 & 4 are supported by a reconfiguration electronics included in the CDMU and the ACC, hot redundant, supplied via FCL's and capable to detect the selected alarms, and as a result to start specific reconfiguration sequences.

There exist two FDIR modes:

– The Autonomous Fail Safe (AFS) mode actually implements the Failure Detection function, but not the Isolation nor the Recovery. The AFS mode is automatically engaged at launcher separation and is proposed to remain valid until each spacecraft is commissioned. It is designed to limit the consequences of the spurious raising of numerous false alarms which may happen before all the failure detection thresholds are properly adjusted. The AFS mode ultimately relies on the survival mode triggering to recover from a real failure.

– The Autonomous Fail Operational (AFO) mode implements the full FDIR function, with hierarchical recoveries following the failure criticality to optimise the use of the available hardware. The AFO mode is basically the operational mode which should be engaged once the spacecraft's commissioning is completed. The recovery actions are designed to minimise the impact on the scientific mission as long as spacecraft safety is not considered endangered.

These 2 modes and 5 criticality levels are applied to both ACMS and CDMS. It is intended to have the 2 subsystems run in the same FDIR mode. The interface between ACMS and CDMS as far as fault protection is concerned is kept simple: both sides report to the other one only the failures Levels 3 & 4 via status lines, but the current FDIR status is totally independent from one subsystem to the other. Especially a Level 4 failure recovery in one subsystem does not lead to trigger a Level 4 alarm in the other subsystem.

2.1.1.3.10. Data storage

Most of the mission time happens out of ground station visibility. The data storage function purpose is to offer hardware and associated software mechanisms to temporarily store the acquired science or housekeeping telemetry before they can be downloaded to ground.

The storage medium is constituted by a hot redundant Solid State Mass Memory (SSMM). Its size of 25Gbits EOL per redundancy allows the storage of all the data generated on board plus the storage of the Mission Timeline for more than 48 hours. In order to increase the reliability of the storage process, the acquired data is stored in parallel into the 2 SSMM's.

The data in each SSMM is organised in stores which number and size are fixed by command. By design, each store must be allocated to a single virtual channel and fulfill the following constraints:

- remain consistent with the virtual channels allocation on the one hand
- be in line with the HERSCHEL and PLANCK missions characteristics and instruments specific requirements
- ensure a good protection of the stored data
- the packet stores allocation and breakdown between Science data, HK data, each instrument is controlled by specific software services and remains essentially an operational issue (with the subsequent need to minimise the daily number of operations). Two packet stores are frozen, which are the critical event log and the default packet store. The allocation of other packet stores constitutes an operational issue.

The storage function is always active: during launch, all the acquired HK is stored, then is started to be downloaded when the RF link permits it. The storage is never interrupted, which guarantees a permanent access to the spacecraft configuration and status during the non visibility periods.

2.1.1.3.11. Instruments and PLM interfaces

Interfaces with the instruments have been kept as simple as possible.

From an hardware point of view:

- the power is distributed via a set of dedicated LCL lines, some implementing the "double switches" feature. The instruments do not internally control the switching ON/OFF of these power lines; only some secondary power switching may be performed at instrument level
- the telecommand and telemetry interface is only via the CDMS 1553 data bus

- individual 131072Hz clock, synchronised with the On Board Master Clock are distributed to some instruments for synchronisation purpose. HFI and LFI (PLANCK) use these lines for the precise datation of the science data. It is to be noticed that the standard procedure implemented to time synchronise the science samples with the spacecraft telemetry uses the 1553 data bus protocol, which distribute the CTR (Central Time Reference) with every second.

From a software point of view, the instruments interface is mainly restricted to the telemetry packets collection and telemetry packets distribution in accordance to the data bus protocol addressed beforehand (see Figure 2-12). The packet data interface mechanism is driven by Bus Profiles established for each mission configuration (and which can be changed in flight). Few additional functions also appeared necessary, these are:

- the procedures to turn ON/OFF a complete instrument

- the procedures to support the recovery of an instrument in case of failure of the instrument itself, or of the 1553 data Bus interface.

To limit the impact on the on board software process, the baseline is to go through an implementation using On Board Control Procedures (see § 3.1.2.2.).

The PLM interface somewhat differs between HERSCHEL and PLANCK.

On HERSCHEL it consists in:

- the control of the CVV valves and the temperature monitoring; this is performed via the Cryostat Control Unit (CCU)

- the monitoring and control of the telescope temperatures in order to implement a decontamination algorithm. The temperature sensors are acquired by the CDMU via the CCU, the HERSCHEL specific control law is performed within the CDMU ASW and the telescope heaters are commanded via the PCDU.

On PLANCK it consists in:

- the monitoring and control of the telescope reflectors and Focal Plane Unit temperatures in order to implement a decontamination algorithm. The temperature sensors are acquired directly by the CDMU, the PLANCK specific control law is performed within the CDMU ASW and the telescope and FPU heaters are commanded via the PCDU.

2.1.1.3.12. Extra payload and non SVM equipment interfaces

Some HERSCHEL and PLANCK units are not part of the actual Service Module definition; these are the Cryostat Control Unit, the Visual Monitoring Camera, the Standard Radiation Environment Monitor and the Fiber Optics Gyroscopes.

CCU

This unit acts as a "RTU" in charge of the HERSCHEL PLM interface as addressed in the previous paragraph. It is made of 2 strictly identical halves, operating in active hot redundancy. The hardware interfaces are simple: 2 power lines are distributed to the 2 CCU halves via 2 LCL's, and the data interface is via 2 CCU 1553 data bus connections, one for each half.

The CCU is in the "non intelligent" user category and receives/transmits non packetised messages. The specific software interfaces to communicate with the CCU are detailed in the Section 2.1.2.1.

Visual Monitoring Camera

This media-purpose camera is only installed on HERSCHEL. The hardware interfaces are very basic: 1 power line is distributed via one LCL, and the image and telemetry data is acquired via a standard DS16 serial interface.

Its mission and mode of operation are by steps:

1. The VMC is turned ON by the CDMU SW as part of the post separation sequence.
2. After 5s of warm up, it automatically starts to acquire images which integration time and acquisition period can be selected before launch via jumpers, among a set of pre defined values; integration time can be chosen between 0.7 and 5ms depending on the calculated illumination of the scene to capture, and the images acquisition rate can be every 1s to every 1.75s.
3. A maximum of 15 512x512x8bits images are stored in the VMC RAM. Once the VMC memory is full, it stops acquiring images, and the data remains stored until switch OFF.
4. Upon dedicated TC, the raw images are acquired by the CDMU, packetized, then transferred to a CDMU SSMM packet store. The specific software process is addressed in Section 2.1.2.2.
5. The packet store containing the VMC packets are transferred to ground, via VC0 virtual channel, upon telecommand.
6. The VMC can be turned OFF.

SREM

This unit is a CFE installed on HERSCHEL and on PLANCK which aims to continuously collect data on the radiation environment seen by the spacecraft over the mission. The hardware interfaces are: 1 power line is distributed via a single LCL, the housekeeping data is acquired via a standard DS16 serial interface while the commands are sent via a standard ML16 I/F.

The software interface is through a dedicated function and is detailed in Section 2.1.1.8.

FOG

The Fiber optics gyroscopes are CFE's installed on the PLANCK ACMS 1553 Bus. The FOG is actually constituted by 4 identical blocks (1 per measurement axis), each of them supplied by an individual power line via LCL and featuring an independent 1553 Remote Terminal. Each of the blocks can be commanded in ON/OFF state by the ACC which therefore controls the FOG configuration.

The FOG is not involved in the ACMS processing and a very basic FDIR is applied; the acquired telemetry is simply packetized then sent to the CDMU as part of the normal ACMS TM. One additional subframe is allocated to PLANCK ACC in the Bus profile for FOG packets acquisition (see Figure 2-12).

Details on the FOG functional implementation are provided in ACMS Design Report (ACMS RD-1).

2.1.1.4. CDMS Design

2.1.1.4.1. CDMS overview

The Command and Data Management Subsystem performs the following general tasks:

- Telemetry acquisition and formatting
    - To perform the Spacecraft monitoring and manage the emission of transfer frames as defined in the Packet TM Standard from the assembling into a frame to the encoding.
- Telecommand acquisition, decoding validation and distribution
    - To manage the reception of TC segment as defined in the Packet TC Standard from their acquisition to the routing towards the corresponding user.
- Data storage
    - To manage the saving of data to insure their integrity until dump to ground.

– Time distribution and time tagging

- To generate the required synchronisation signals, on board datation and its distribution especially to manage time tagging.

– Autonomy supervision and management

- To monitor that the other functions are running without failure. In that case, it manages the corresponding reconfiguration to bypass this failure.

In order to perform these functions, the CDMS interfaces with the payload instruments, the ACMS, the Power Control System and the Telemetry and TeleCommand subsystem. It is composed of a computer named CDMU for Control Data and Management Unit and a 1553 bus interface to communicate with the other subsystems and instruments, the System Data Bus SDB. The CDMU is basically a router which receives data from a user (ground, instrument, other unit) and transmits them to another user (mass memory, telemetry encoder,…). This representation allows to clearly identify each data flow within the CDMS in order to define the processing capability that has to be fulfilled by the CDMS. The diagram hereafter shows such a representation of the CDMS regarding data flow aspects.

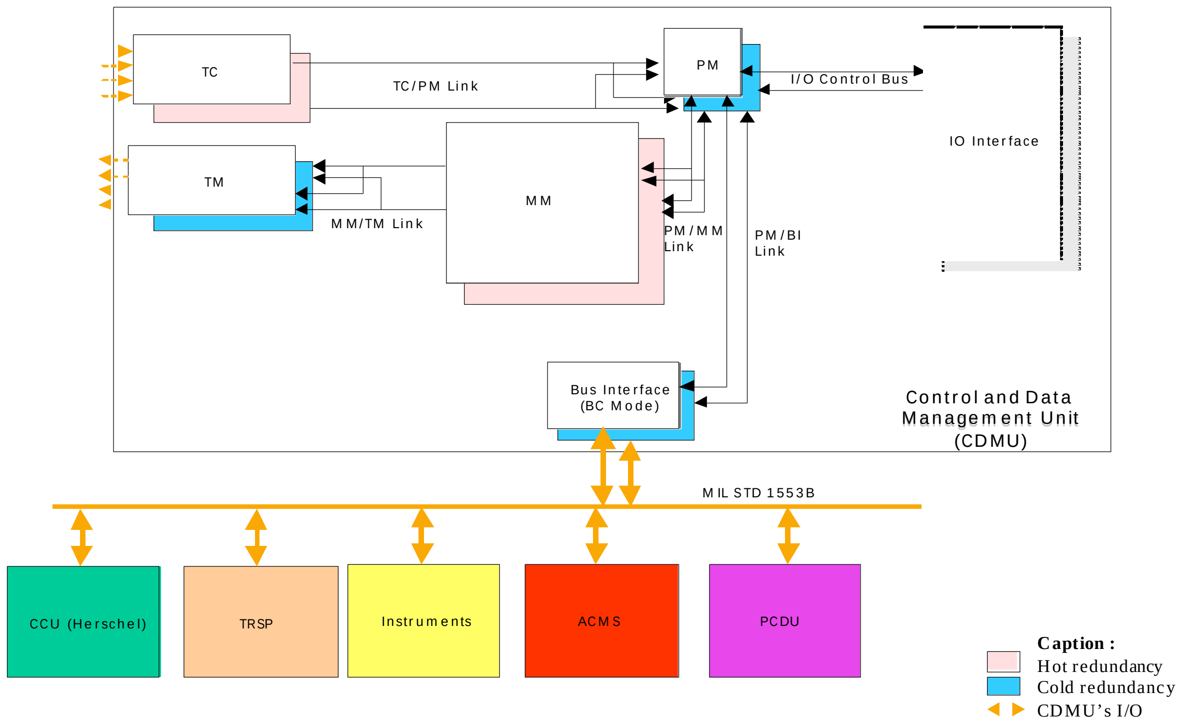


Figure 2-16 CDMS data flow

2.1.1.4.2. On-board software design description

The OBSW is part of the following SVM subsystems:

- the Command and Data Management Subsystem (CDMS)
- the Attitude Control and Measurement Subsystem (ACMS).

Both CDMS and ACMS include one computer based on ERC-32 microprocessor, respectively the Central Data Management Unit (CDMU) and the Attitude Control Computer (ACC), connected together by the mean of a 1553 B bus. Each computer implements its own dedicated software.

As far as the ACMS is concerned, this subsystem is also composed of equipment which includes software:

- Star Tracker SW
- Gyro SW.

The whole CDMU/ACC OBSW architecture has been conceived in order to fulfil the commonality requirement. For instance:

- HERSCHEL and PLANCK CDMU and ACC OBSW will be developed using the same standard Software Development Environment (SDE)
- CDMU OBSW for PLANCK and for HERSCHEL will be identical. They will only differ by the satellite database they are compiled with (the database is mainly used to load predefined tables and all messages definition) and mission specific functions (e.g. payload management and decontamination heating)
- Bootstrap Software, I/O drivers (when the used hardware is common), and scheduler (namely RTEMS) of CDMU and ACC OBSW will be the same.

Even if CDMU and ACC OBSW will be different, they will be designed according to the same software breakdown. Each of these OBSW is composed of the Application Software (ASW) and the Basic Software (BSW), as described in Figure 2-17.

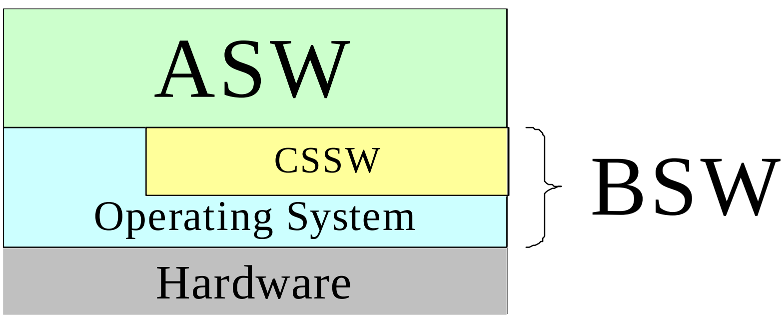


Figure 2-17 HERSCHEL/PLANCK CDMU/ACC OBSW breakdown

The ASW is the highest layer.

The BSW is essentially common to CDMU and ACC OBSW (although not strictly identical in the two cases). It supplies services to the ASW. These services are either basic ones to interface hardware devices included in the Operating System (OS) layer:

- Task scheduling capabilities
- Time management
- Events
- Inter-task-communication services
- I/O drivers
- Bootstrap

or common services to CDMU and ACC included in the Common Service Software (CSSW) layer:

- TC dispatching
- Event Management
- Functions Management
- TM Management
- Bus Management (1553).

The BSW also performs important functionality by itself, i.e.:

- Memory Management (patch/dump)
- On-Board Storage and Retrieval Service (SSMM Management)
- Low level FDIR (e.g. for S/C 1553 bus and hardware failures).

The CDMU ASW supports the following main functionality:

- Relevant Packet Services
- Mission specific functions

- Satellite mode management
- Power distribution management
- Thermal control
- Failure Detection Isolation and Recovery (FDIR)
- Mission Timeline (MTL) Management
- On-Board Control Procedure (OBCP) management.

The ACC ASW supports the following main functionality:

- Relevant Packet services
- FDIR
- ACMS Mode Management
- Sensors Data processing and actuators commanding
- Control law.

HERSCHEL and PLANCK ACMS specificity leads to the design of two distinct ACC ASW associated with two distinct ACC BSW. However, for commonality purpose, a Common Application Software (CASW) service layer has been identified, responsible e.g. for the basic communication with the ACMS units and the CDMU (through BSW services), and ACC Packet Services not supported by the BSW. Both ACC ASW will only differ by their respective Satellite Dependent Application Software (SDASW) layer, as described in Figure 2-18

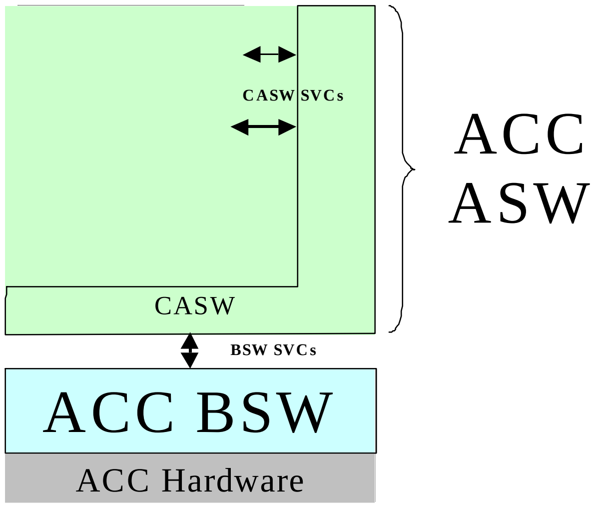


Figure 2-18 HERSCHEL/PLANCK ACC ASW breakdown

As far as packet services (as required in PS-ICD) are concerned, their implementation has been also dispatched between BSW and ASW as described in Table 2-1 below:

Service Type	Service Name	Services supported by			
		CDMS		ACMS	
		BSW	ASW	BSW	ASW
1	Telecommand Verification	Yes	Yes	Yes	Yes
2	Device Command Distribution Service	No	Yes	No	Yes
3	Housekeeping and Diagnostic Data Reporting	Yes	No	Yes	No
4	Not Used	No	No	No	No
5	Event Reporting	Yes	Yes	Yes	Yes
6	Memory Management	Yes	No	Yes	No
7	Not Used	No	No	No	No
8	Function Management	Yes	Yes	Yes	Yes
9	Time Management Service	No	Yes	No	Yes
10	Not Used	No	No	No	No
11	On-board Operations Scheduling Service	No	Yes	No	No
12	On-board Monitoring Service	No	Yes	No	No
13	Not Used	No	No	No	No
14	Packet Transmission Control Service	Yes	No	Yes	No
15	On-board Storage and Retrieval Service	Yes	No	No	No
16	On-board Traffic Management	Yes	No	No	No
17	Test Service	Yes	No	Yes	No
18	On-board Control Procedure Service	No	Yes	No	No
19	Event/Action Service	No	Yes	No	No
20	Not Used	No	No	No	No
21	Science Data Transfer Service	No	No	No	No
22	Not Used	No	No	No	No

Table 2-1 HERSCHEL/PLANCK packet services supported by SVM OBSW

Note:

– Service#1 & #5

- ASW generates verification and event reports by using services provided by the BSW. Note that this is applicable to telemetry packets generation in general.

– Service#2

- Though BSW does not implement Service#2, it provides all the necessary low level services to communicate with related devices (e.g. CPDU and OBDH access).

- As far as ACMS is concerned, only mission specific CPDU commands are supported (see PS-ICD for more details).

– Service#9

- On receipt of a Synchronise User request (TC[9,3]), the CDMU ASW will send the Enable Time Synchronisation request to the specified user (TC[9,4]) followed or not by the Time Code (TC[9,5]) according to the specific implementation of the Service#9 performed by the intelligent end-user (see PS-ICD for more details). E.g., TC[9,5] is not supported by ACMS OBSW and thus will not be sent by CDMS OBSW.

– Service#16

- No specific Service#16 TM/TC packet has been defined for the On-Board Traffic Management. The CDMS OBSW will report anomalies related to TM/TC packet routing and distribution. Then, in order to control the generation and transmission of individual packet (e.g. enabling/disabling of real-time down-linking and/or SSMM storage), it has been decided to expand the Packet Transmission Control Service #14 instead (see PS-ICD for more details).

– Service#21

- This services is only supported by Instruments.

2.1.1.4.3. Instruments management

The CDMU OBSW is responsible for the following main activities related to Instruments management:

– TC routing: any telecommand addressed to Instruments are first partly verified (Packet ID, length, Error control and Sequence Control) at CDMU BSW level before routing according to its APID via the S/C 1553 bus and according to Bus profile definition.

– TM acquisition, storage and down-linking: All the telemetry packets generated by Instruments are acquired on the S/C 1553 Bus according to Bus Profile definition by the CDMU BSW. Then, they are stored in dedicated packet stores in SSMM and/or down-linking to ground on request.

– TM processing: the CDMU OBSW is able to process on-board specific telemetry coming from instruments like:

  - HK packets: on request they can be stored in the CDMS datapool for parameters extraction by On-Board Control Procedures. Currently no such procedure is planned

  - events packets: each Instrument event packet (TM(5,x)) reception can be linked to an action to be performed by the CDMU ASW. Additionally, an OBCP can be asked to wait for the receipt of events generated by Instruments (either TM(5,x) or TM(1,x)).

– Central Time Reference (CTR) broadcasting: every second the CDMU BSW sends on the S/C 1553 the CTR according to the bus protocol. The CTR is to be used by Instruments for synchronisation purpose. Note also, that the synchronisation procedure can be started on request by using Service#9.

– Failure Detection Isolation & Recovery (FDIR): The CDMU OBSW performs health monitoring of the Instruments as any other intelligent users connected on the S/C 1553 bus (e.g. TFL FDIR and check that amount of generated TM is as expected). In case of anomaly, an event is generated and associated recovery actions are performed. In case of anomaly detected by the Instrument itself and whenever it needs CDMS support to recover, the Instrument has also to generate an event. As far as Instruments are concerned, the recovery procedures will be implemented via OBCP.

– Peak-Up (HERSCHEL only): On receipt of a dedicated peak-up event from the instrument, the CDMU ASW will issue toward the ACC a Peak-up Telecommand containing the relevant parameters acquired by the instruments (HIFI and SPIRE only) in peak-up mode. In peak-up mode the instrument establishes a pointing correction to be performed by the S/C in order to accomplish the observation. This information issued toward the ACC will allow fixing of the necessary pointing.

– Decontamination Heating.

2.1.1.5. ACMS design

2.1.1.5.1. ACMS overview

The following ACMS architecture has been designed in order to fulfil the HERSCHEL and PLANCK pointing requirements. HERSCHEL and PLANCK share the same computer (ACC), Star Tracker hardware, Coarse Rate Sensor (CRS) equipment, Sun Acquisition Sensor (SAS) equipment, Attitude Anomaly Detector (AAD) principle.

This section only draws the high level architecture of the ACMS. The details (modes, algorithm…) of the ACMS design are given in Section 4.2 and in ACMS design report, Doc. n° H-P-4-DS-TN-011.

2.1.1.5.1.1. HERSCHEL architecture

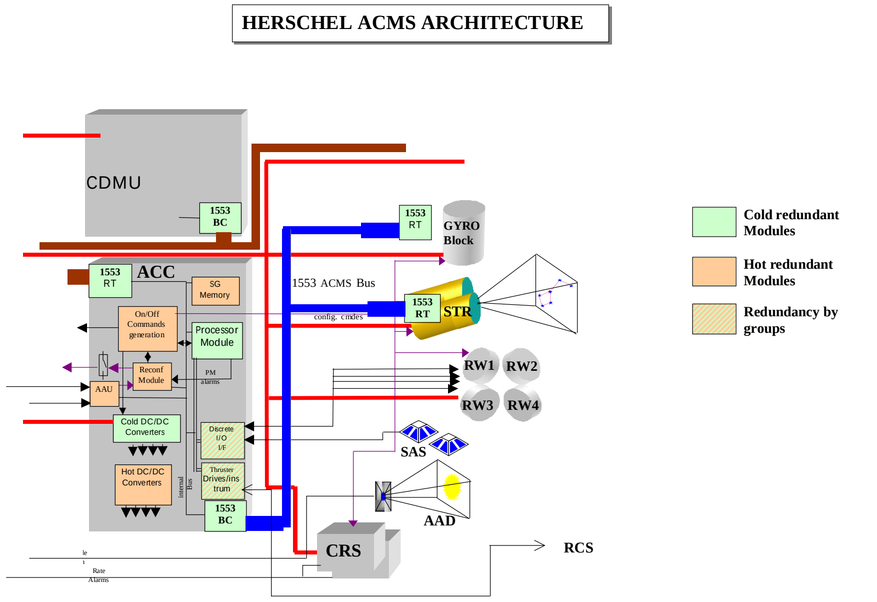


Figure 2-19 HERSCHEL ACMS Architecture

The associated equipment list is:

COMPONENT	NUMBER	SUPPLIER	ELECTRICAL I/F	COMMENT
AAD	2	TNO/TPD	Analogue Cross-strapped to ARAD	Internally redundant
CRS	2	AAS-I Milano	Analogue Two units are cross-strapped to ACC AAU Powered and activated (ON/OFF) by CDMU	3 axis information for each component Same unit as PLANCK
SAS	4	TNO/TPD	Analogue Cross-strapped to ACC AIU Located on –Z and + Z spacecraft faces	Same unit as PLANCK (internally redundant)
STR	2	GALILEO AVIONICA	MIL 1553B	Cold redundancy Same hardware as PLANCK
GYR	4	NORTHROP GRUMMAN	MIL 1553B	4 sensors in hot redundancy, redundant electronics
RWS	4	TELDIX	Analogue/single ended Cross-strapped to AIU	
ACC	1	SES	See dedicated section	
THR 20 N	12	ASTRIUM	Refer to RCS section 2.1.1.5	

Table 2-2 HERSCHEL equipment list and interfaces

2.1.1.5.1.2. PLANCK architecture

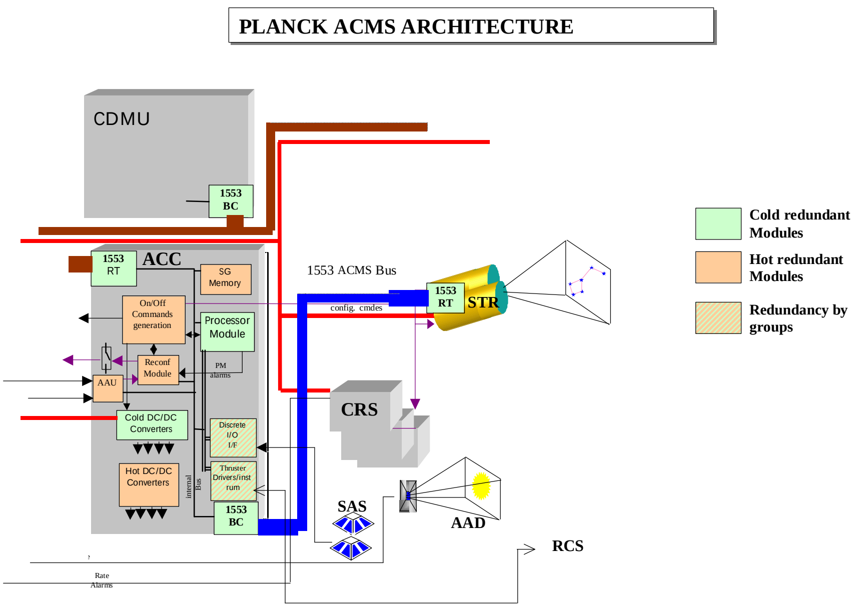


Figure 2-20 PLANCK ACMS architecture

The associated equipment list is:

COMPONENT	NUMBER	REDUNDANCY	ELECTRICAL I/F	COMMENT
AAD	2	TNO/TPD	Analogue Cross-strapped to ARAD	Internally redundant
CRS	3	AAS-I Milano	Analogue 3 units are cross-strapped to ACC AAU Powered and activated (ON/OFF) by CDMU	Same unit as HERSCHEL
SAS	4	TNO/TPD	Analogue Cross-strapped to AIU Located on –X and +Y spacecraft faces	Same unit as HERSCHEL (internally redundant)
STR	2	GALILEO AVIONICA	MIL 1553B	Same hardware as HERSCHEL Cold redundancy
ACC	1	SES	See dedicated section	
THR 1N	4	ASTRIUM	Refer to RCS section 2.1.1.5	
THR 20 N	12	ASTRIUM	Refer to RCS section 2.1.1.5	

Table 2-3 PLANCK equipment list and interfaces

NOTE: FOG (Fiber Optic Gyro) is connected to ACC via MIL1553. The FOG is an extra payload and is not used in PLANCK ACMS control algorithm.

2.1.1.5.2. ACMS external interfaces

The ACMS has interfaces with CDMS and RCS. CDMS communicates with ACMS via the satellite data management bus. Interface with RCS is done thanks to the THR board of the ACC.

2.1.1.5.3. ACMS modes

Under nominal conditions, the ACMS operates in the so-called nominal modes. In case of Level 3b or 4 failure, the ACMS switches to survival mode.

2.1.1.5.3.1. HERSCHEL modes

HERSCHEL has 4 nominal modes (Stand-by, Sun Acquisition Mode, Science Mode and Orbit Correction Mode) and 2 survival modes (Stand-by and Sun Acquisition Survival Mode).

- Stand-By Mode (SBM): the Stand-by mode provides basic communication with the CDMU and monitors the separation status. It initialises the ACMS for SAM and handles the twenty second separation delay

- Sun Acquisition Mode (SAM): the Sun Acquisition Mode is the mode that the spacecraft uses to acquire the Sun and to maintain a Sun pointing for the spacecraft Z axis

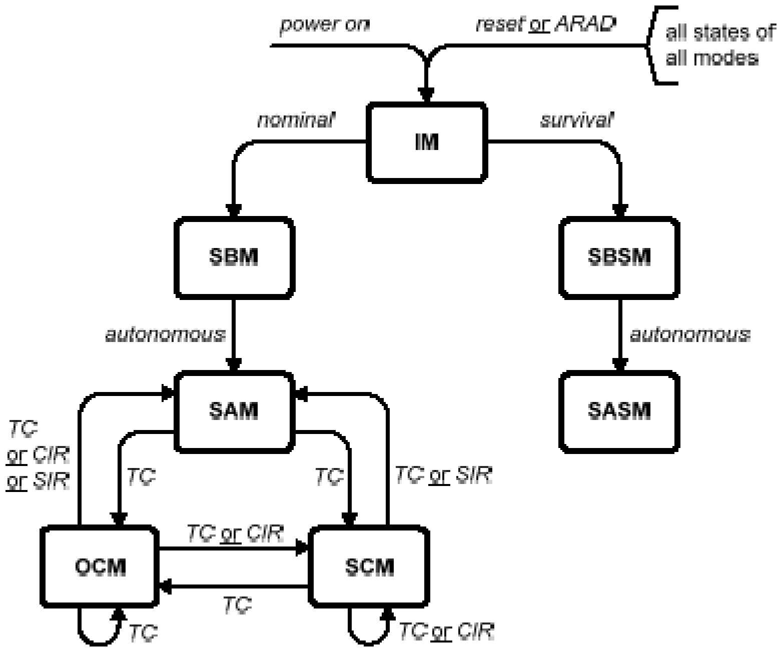
- Science Mode (called NOM or SCM): the Science Mode provides the control functions needed to perform science operations (fine pointing, raster pointing, line scanning, solar system object tracking, small attitude adjustments (peak-up))

- Orbit Correction Mode (OCM): the Orbit Control Mode is the ACMS mode that the spacecraft uses to perform all the foreseen Delta-V manoeuvres, namely dispersion correction manoeuvres (after separation from the launcher and during the transfer to L2) and periodic station keeping manoeuvres at L2

- Stand-by Survival Mode (SBSM): the Stand-by Survival Mode has the same role as SBM but initialises the SASM

- Sun Acquisition Survival Mode (SASM): the Sun Acquisition Survival Mode is the ACMS recovery mode in case of Level 3b or 4 failure putting the Satellite Z axis towards the Sun.

The HERSCHEL mode transition logic is illustrated on Figure below (simplified and detailed diagrams).


power on
reset or ARAD
all states of
all modes
nominal
IM
survival
SBM
SBSM
autonomous
autonomous
SAM
SASM
TC
or CIR
or SIR
TC
TC
TC or SIR
TC or CIR
OCM
SCM
TC
TC
TC or CIR

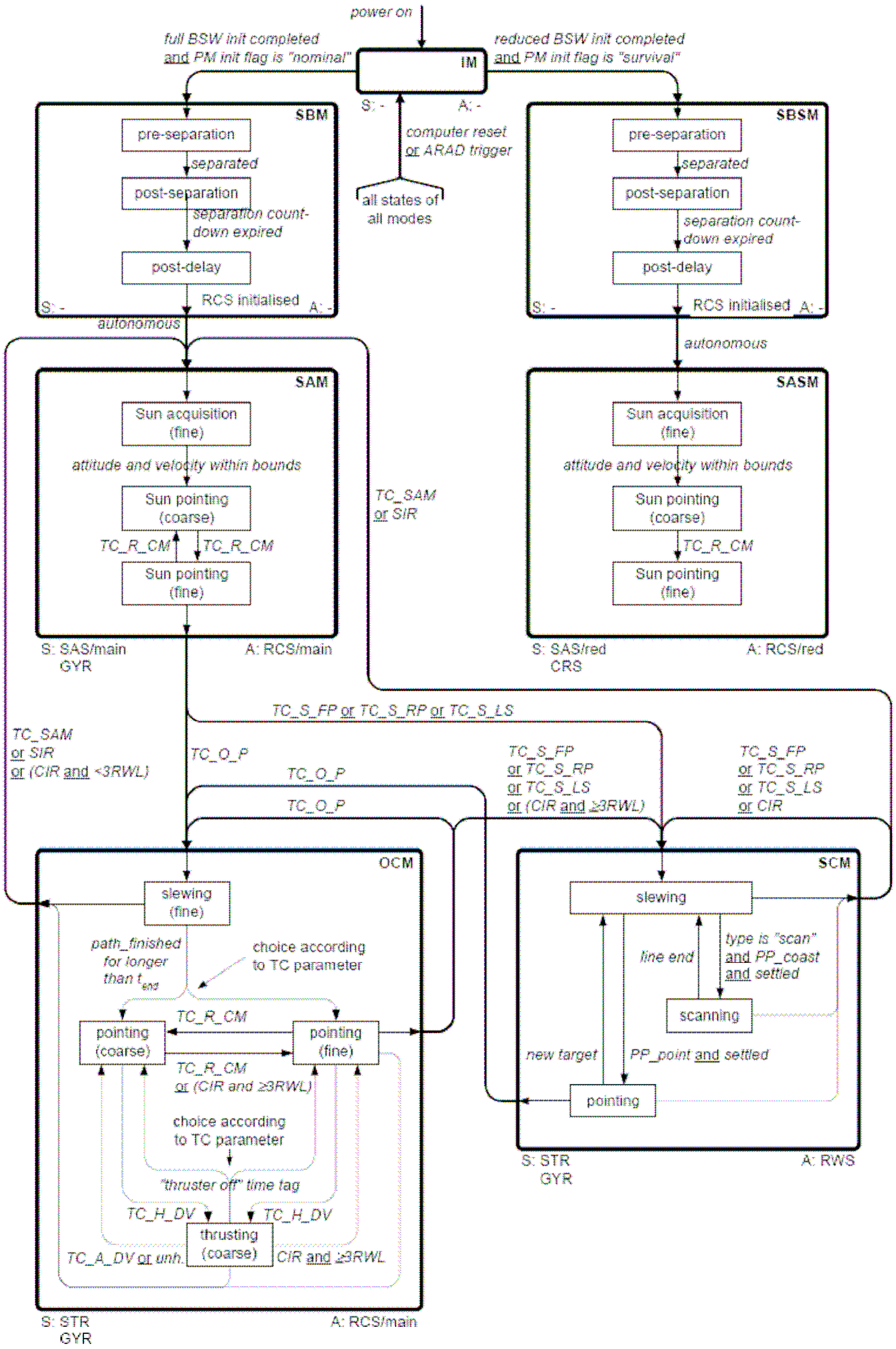


Figure 2-21 Mode transition for HERSCHEL
(TC are ground telecommands)

In addition to the nominal mode necessary for nominal scientific operations and orbit aspects, non nominal transitions occurs when ACMS receives external alarms or when ARAD triggers:

- In case of reconfiguration of the CDMU computer (signal CIR raised), the ACMS shall put the spacecraft in an Earth pointing attitude permitting to have the optimum downlink rate. So if ACMS is in science mode when CIR is raised or in OCM, ACMS will go to a new science mode with a predefined (Earth pointing) target if the number of operational wheels allows it (more than 3). If ACMS is in OCM and the number of wheels is not sufficient to go to SCM, it will go to SAM. Finally, ACMS will stay in SAM if already in SAM.

- In case of reconfiguration of the system (signal SIR raised), the ACMS will go from OCM or SCM to SAM.

The following Table presents the nominal sensor/actuator configuration per mode and the possible/allowed redundancy. Sensors used for ARAD are also given:

Mode	ACMS units for control	Redundant sensor/actuator	Sensor for ARAD	Comments
Sun Acquisition mode (SAM)	SAS +Z - Nom SAS -Z - Nom GYR - ABC RCS - A 1553bus - 1	 GYR DBC/ADC/ABD 1553bus - 2	AAD CRS - 1	No reconfiguration of RCS
Science Mode (SCM)	STR - 1 GYR - ABC RWL - 1234 1553bus - 1	STR – 2 GYR DBC/ADC/ABD RWL – 123/234/124/124 1553bus - 2	AAD CRS - 1	
Orbit Correction Mode (OCM)	STR - 1 GYR – ABC RCS - A 1553bus - 1	STR – 2 GYR DBC/ADC/ABD 1553bus - 2	AAD CRS - 1	No reconfiguration of RCS
Sun Acquisition Survival mode (SASM)	CRS - 2 SAS +Z – Red SAS -Z - Red RCS - B	Not applicable	Not applicable	

2.1.1.5.3.2. PLANCK modes

PLANCK nominal modes are Stand-By Mode (SBM), Sun Acquisition Mode (SAM), Angular Momentum Control Mode (HCM), Science Mode (SCM) and Orbit Correction Mode (OCM). As per HERSCHEL, a Survival Standby Mode (SBSM) and a Sun Acquisition (SASM) Survival Mode are present:

- Sun Acquisition Mode (SAM): the Sun Acquisition Mode is the mode that the spacecraft uses to acquire the Sun and to maintain an anti-Sun pointing for the spacecraft X-axis. The attitude of the spacecraft in SAM is Sun pointing, with nominal spin rate and small nutation

– Science Mode (SCM): the Science Mode is the ACMS mode that the spacecraft uses to gather the science data from the payload. It is a passive mode (no actuation)

– Angular momentum Control Mode (HCM): the Angular Momentum Control Mode is the ACMS mode that the spacecraft uses to perform the slew manoeuvres within the operational domain, aiming to acquire the different pointing needed for the science mode

– Orbit Correction Mode (OCM): the Orbit Control Mode is the ACMS mode that the spacecraft uses to perform all the foreseen Delta-V manoeuvres, namely dispersion correction manoeuvres (after separation from the launcher and during the transfer to L2), injection into L2 orbit manoeuvre, and periodic station keeping manoeuvres at L2

– Survival Mode: the Survival Mode is the ACMS recovery mode in case of level 3b or 4 failure.

The mode transition is more complex than the HERSCHEL one. 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. Indeed, PLANCK has two different sets of values (to be modified by ground and implying deactivation of RM) for the ARAD thresholds, depending on the phase of the mission. PLANCK high threshold phase and respectively low threshold phase are the phases where the transversal angular velocity thresholds are set to a high value and to a low value.

The idea behind the different thresholds is to limit the excursion out of the contingency zone in case of thruster (1N or 20 N) failure. Detailed rationales are given in ACMS FDIR analysis, doc. H-P-4-DS-TN-010. HCM and SCM have to have a low threshold or otherwise may not recover from a worst case 1N thruster left-open failure at the edges of the operational domain. SAM (20 N actuator) has to have a high threshold, or otherwise would trigger Survival Mode in nominal operational conditions. OCM may have either high or low thresholds for the Delta-V manoeuvres, depending on the typical mode of origin and destination.

Depending on whether the threshold is "low" or "high", some mode transitions are forbidden or allowed. For instance, it is not possible to go directly from SCM (low threshold) to SAM (high threshold) since kinematics of SAM are not compatible with low threshold and automatically a transition to SASM will occur if the transition is allowed.

The transitions allowed in both high and low threshold phases are illustrated below:

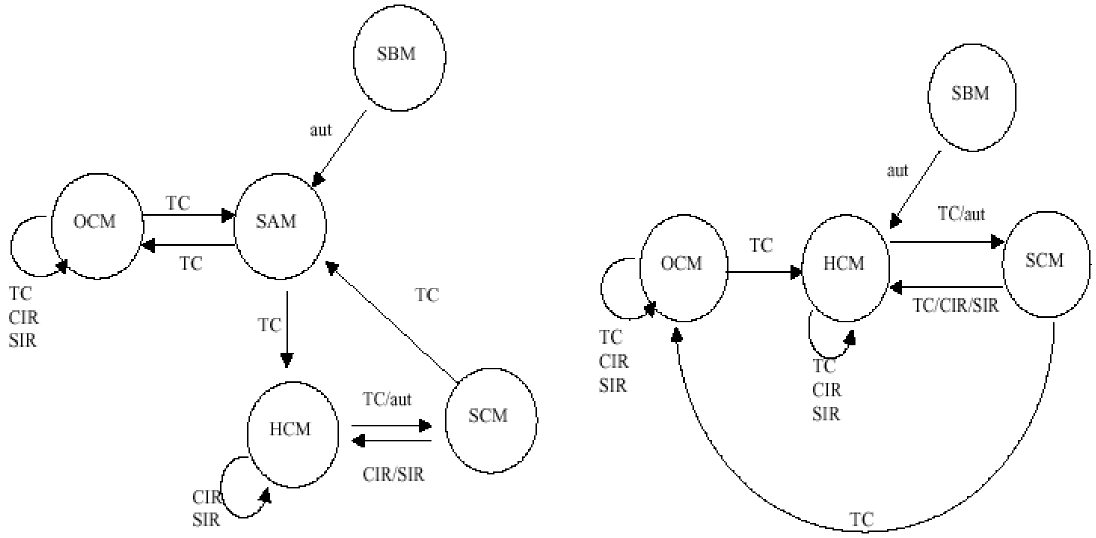


Figure 2-22 Mode transition for PLANCK "high" threshold phase (left) and "low" threshold phase (right)

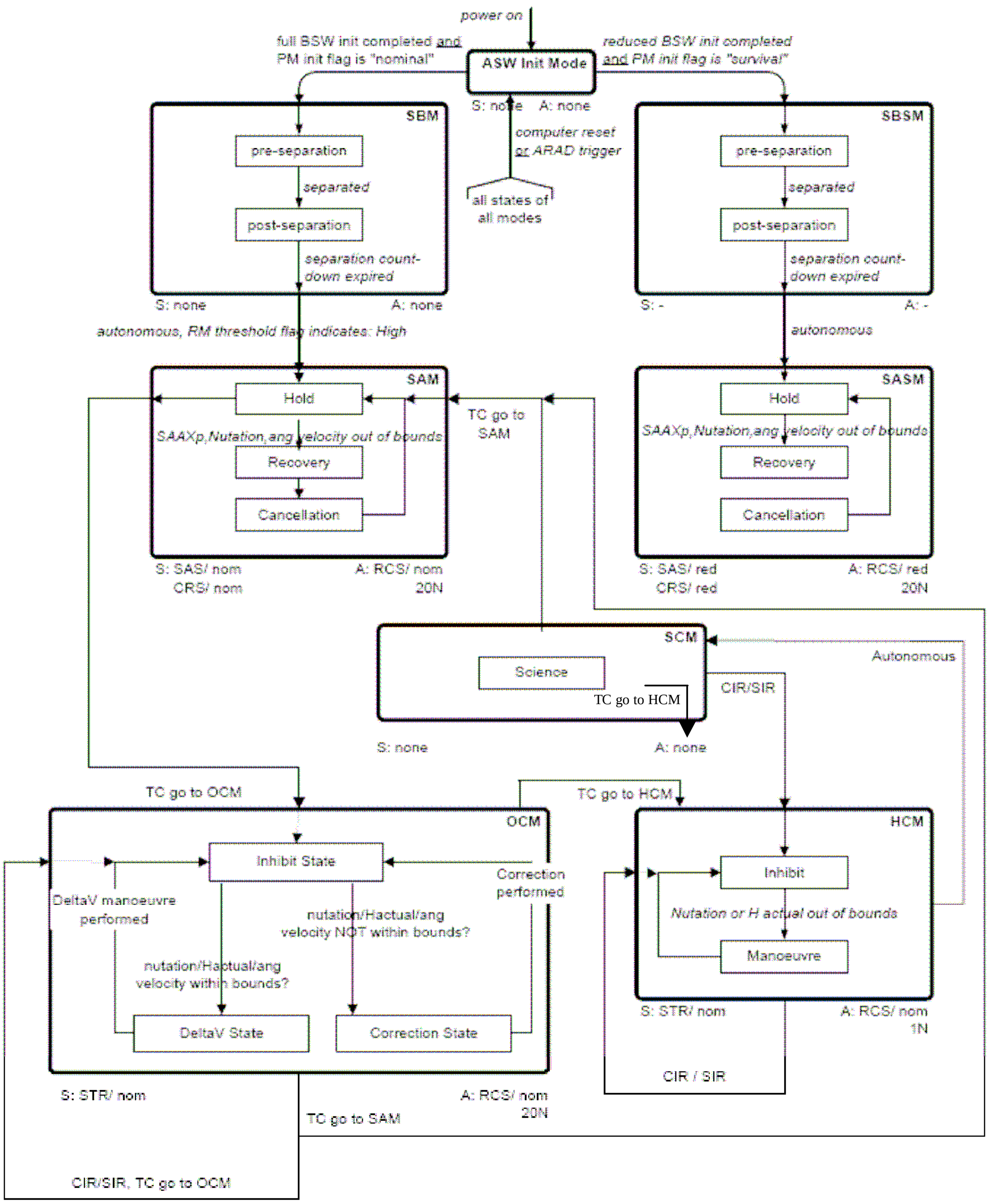


Figure 2-23 Detailed mode transition for PLANCK "high" threshold phase

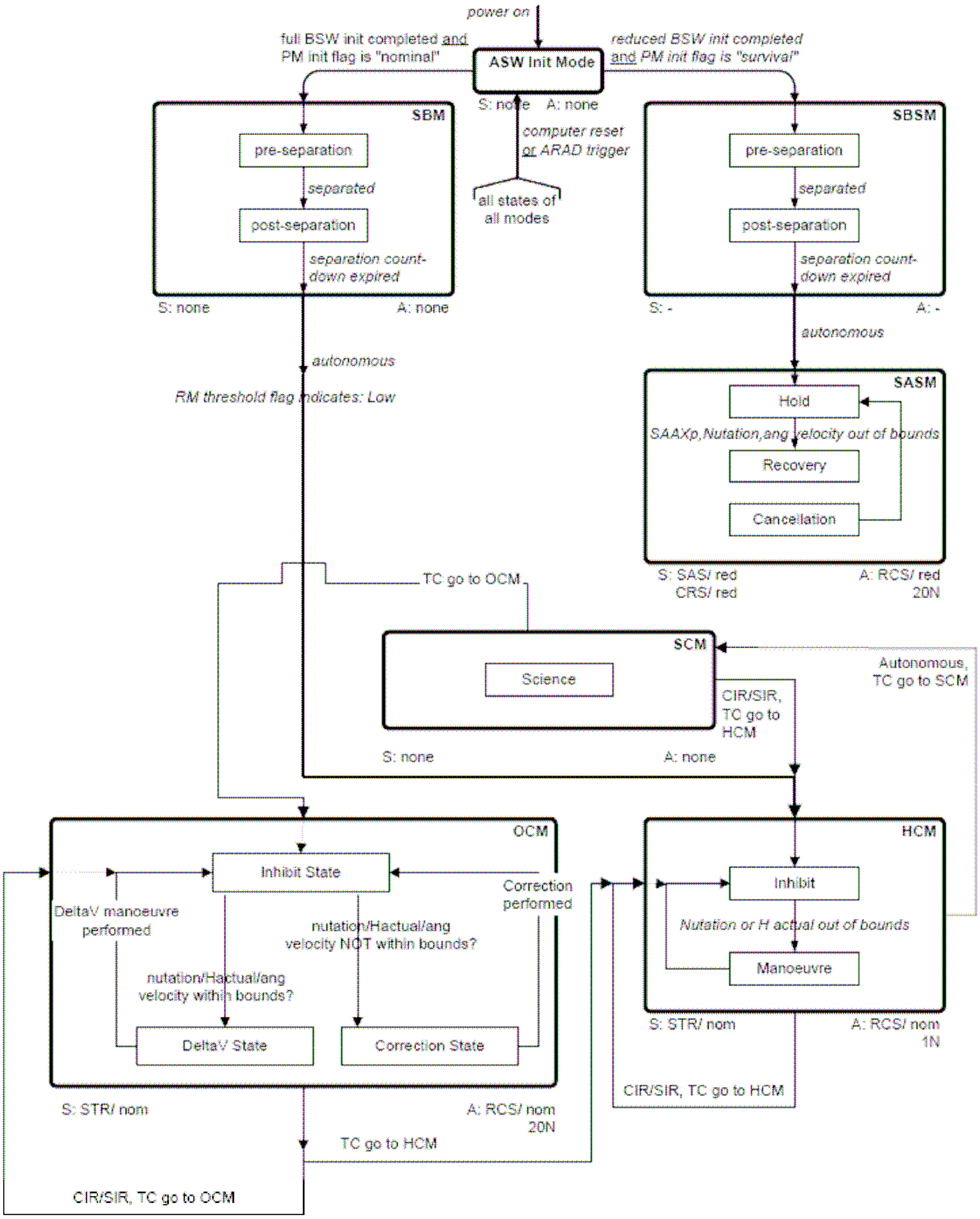


Figure 2-24 Detailed mode transition for PLANCK "low" threshold phase

The ACMS handles all possible non-nominal cases as follows:

- In case of satellite in reconfiguration (SIR signal raised by the CDMU):
  - When the PLANCK ACMS is in OCM, the ACMS commands an auto-transition to OCM and initiates a manoeuvre with null target Delta-V and pointing towards an anti-Sun pointing attitude, defined by the Angular Momentum direction Hsir (refreshed by ground and nominally coincident with Sun) stored in the SGM. The ARAD threshold value does not need to change
  - When the PLANCK ACMS is in HCM or SCM, the ACMS commands a transition to HCM and initiates a slew manoeuvre towards an anti-Sun pointing attitude, defined by the Angular Momentum direction Hsir stored in the SGM
  - When the PLANCK ACMS is in SAM, the ACMS ignores the SIR.
- In case of CDMU is in reconfiguration (CIR signal raised by the CDMU): same philosophy as per SIR management with Hcir target
- In case of level 3a failure, the ASW shall first detect the difference with a level 4 anomaly. This is done by reading the flag PM selection relay. If it says “nominal”, this means a reset of the computer (and not a reconfiguration to the other PM). Then, the action of the ACMS is depending on the high or low threshold current selection. It then reads the associated RM threshold flag. If high, a transition to SAM is commanded and if low, HCM is entered with Hsir target.

The following Table presents the nominal sensor/actuator configuration per mode and the possible/allowed redundancy. Sensors used for ARAD are also given:

Mode	ACMS units for control	Redundant sensor/actuator	Sensor for ARAD	Comments
Sun Acquisition mode (SAM)	SAS +Z - Nom SAS -Z – Nom CRS – 1 RCS – A 1553bus - 1	1553bus - 2	AAD CRS – 2	No reconfiguration of RCS Reconfiguration of SAS under ground responsibility
Science Mode (SCM)	STR - 1 1553bus - 1	STR – 2 1553bus – 2	AAD CRS – 2	
Angular Momentum Control Mode (HCM)	STR – 1 1553bus – 1 RCS 1N - A		AAD CRS - 2	No reconfiguration of RCS
Orbit Correction Mode (OCM)	STR - 1 RCS 20 N - A 1553bus - 1	STR – 2 1553bus - 2	AAD CRS - 2	No reconfiguration of RCS
Sun Acquisition Survival mode (SASM)	CRS - 3 SAS +Z – Red SAS -Z - Red RCS 20 N - C	Not applicable	Not applicable	

2.1.1.5.4. System pointing calibration

2.1.1.5.4.1. PLANCK system pointing calibration

The PLANCK system pointing calibration is not of Prime responsibility, in line with system requirement specification (AD-02, Section 4.4.2).

2.1.1.5.4.2. HERSCHEL system pointing calibration

2.1.1.5.4.2.1. Principle of calibration

In order to achieve the best performances, the long-term error between the instrument reference and the scientific mode attitude sensors has to be calibrated. The calibration phase aims mainly at the reduction of the bias errors.

This system calibration is mandatory mainly because of launch, which will cause relative misalignment between instrument and ACMS Line Of Sight. So, an extensive initial calibration (also called main calibration) will be necessary during the Performance Verification Phase. Then periodic check (also called calibration check) and calibration parameter update will be performed.

The calibration will be performed such as to point both the instrument and the ACMS sensors (Star Tracker) toward targets with well known directions (reference sources). The resulting ACMS attitude estimation will be compared with payload attitude data resulting in an estimation of the bias between instrument and ACMS sensors line of sight. The result of the calibration process is then used for commanding the pointing of the spacecraft (bias compensation).

The ACMS design foresees two star trackers to be used in cold redundancy. The bias is thus star tracker dependent. System pointing calibration will be performed between each instrument and each star tracker.

The next section is presenting the different ACMS HERSCHEL frames and the Attitude Commanding Frame (ACF) on which system calibration results.

2.1.1.5.4.2.2. ACMS frames

2.1.1.5.4.2.2.1. J2000 frame

Since star tracker data are provided in J2000, it is important to recall the definition of J2000 frame (even if it is standard) as given in ASTR design report, Doc. n° H-P-4-FAF-RP-0002.

The J2000 reference frame is a right-handed co-ordinate system used to represent the direction of the stars, and is defined as follows:

– The x-axis is defined to lie in the intersection of two planes: the plane of the Earth's equator and the plane of the Earth's orbit (ecliptic plane), directed to the vernal point (corresponding to the position of the Sun the first day of spring)

- The z-axis is perpendicular to the Earth's equator, and directed towards the North pole
- The y-axis completes a right handed system
- The centre of the frame is the solar system barycentre (i.e. near to the Sun centre).

Due to the precession of the equinoxes, an apparent movement of the star (star motion) occurs in this system at the rate of approximately 50 arcsec per year. For this reason, it is necessary to associate a date to a star reference frame. In the case of J2000, this date is January, 1 st , 2000.

2.1.1.5.4.2.2.2. Star tracker frames

The star tracker attitude is provided as a quaternion representative of the Boresight Reference Frame (BRF) orientation within J2000.

The BRF is defined as follows:

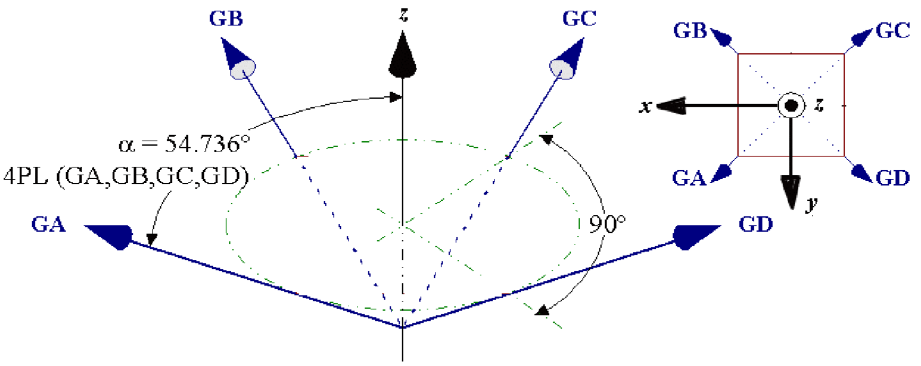
- The origin is the centre of the detector array
- The x-axis is the direction of an incoming collimated light ray that gives a measured position at the centre of the detector (origin of BRF)
- The y-axis is located in the plane perpendicular to x-axis and is nominally parallel to detector rows
- the z-axis completes a right handed system.

Two other star tracker frames are applicable mainly for ground purpose: the star tracker Alignment Reference Frame (ARF) which is attached to the star tracker cube and the star tracker Mechanical Reference Frame (MRF) attached to the unit baseplate. They are both defined in the star tracker user manual.

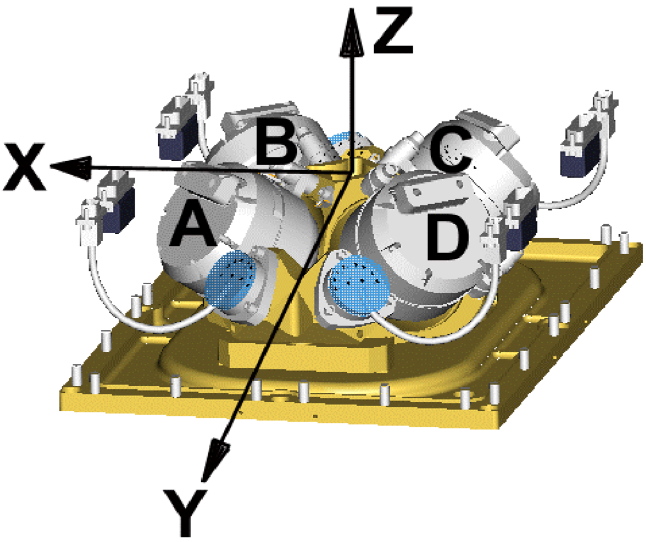
The star trackers are mounted on the spacecraft such that the absolute misalignment between their boresight and the instrument lines of sight is less than 0.47°.

2.1.1.5.4.2.2.3. HERSCHEL gyroscope measurement frame

The gyroscope is providing on the ACMS 1553 bus the four rate measurements along the four HRG sensor axes called GA, GB, GC and GD. The following picture gives the accommodation of the sensor axis in the unit reference frame.



Octahedral Tetrad



2.1.1.5.4.2.2.4. HERSCHEL ACMS co-ordinate frames

The ACMS Attitude Control Axes frames ACA-1 and ACA-2 are defined by rotation of STR 1 and 2 BRF frames by fixed transformation called qSTRiBRF (i=A & j = 1 or i = B & j = 2). These rotations are defined so these fixed transformations make the ACA 1 and 2 coincident with satellite frame on ground.

Convention: qACAi_J2000 (i=1 or 2) = qSTRiBRF ' qBRF_J2000 (i=A or B).

2.1.1.5.4.2.2.5. RWS commanding frame

According to the ACMS design, the actuator-commanding frame is the same as the one used for commanding the attitude of the spacecraft by the ground (the ACF).

2.1.1.5.4.2.2.6. Attitude Commanding Frame (ACF)

The ACF is the frame where attitude targets are provided to the spacecraft by ground. The ACF definition justification is provided in doc. H-P-1-ASP-TN-0838.

ACF is the mean frame between ACA-1 and ACA-2.

The attitude target shall be computed in the following way:

– System calibration gives the quaternion Qcalibi (i = 1, 2) which follows equation 1:

  - Equation 1: QACAi_J2000 = Qcalibi ' Qinstr_2000 i = 1 and 2.

– ACF is derived from ACA-i by a rotation represented by Qmisi i = 1, 2:

  - Equation 2: QACF_J2000 = Qmisi ' QACAi_J2000 i = 1 and 2.

– From the two previous equations, it is possible to write:

  - Equation3: Qmis1 ' Qcalib1 = Qmis2 ' Qcalib2.

  By the definition of ACF,

  - Equation 4: $Qmis1 = \overline{Q}mis2$.

– Qmis1 satisfies the equation:

  - Equation 5: Qmis1 ' Qmis1 = Qcalib2 ' $\overline{Q}$calib1.

A solution of this equation is given by:

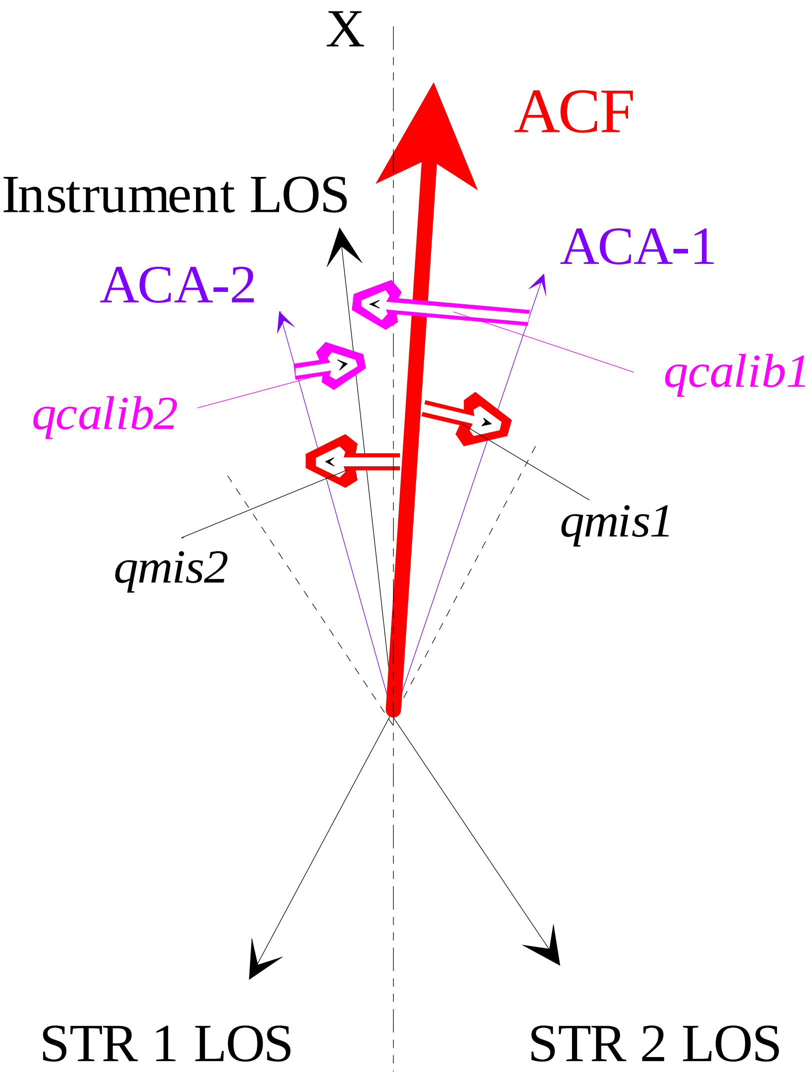
Equation 6: Qmis 1 = SQRT(Qcalib2 ' $\overline{Q}$calib1) = q (u, • /2)
Where u and θ are respectively the axis and angle of the rotation associated with
Qcalib2 ' $\overline{Q}$calib1

It is important to note that Qmis are theoretically independent of the instrument (since ACF is the mean of ACA-1 and ACA-2). Qmisi will be computed from the 3 instrument data and a consistency check will be performed. PACS data will a priori be used for updating the OBDB parameters H_NOM_AUX_STRi_CORR_MISLIGN_a_b.

To fulfil an instrument wish to have the attitude Qinstr_J2000, the ground shall compute and send to the ACMS the target QACF_J2000 computed by equation 7:

Equation 7: QACF_J2000 = Qmis1 ' Qcalib1 ' Qinstr_J2000.

The following picture gives an illustration of ACF from "Line Of Sight" point of view.



The next section enters into the detail of the HERSCHEL system calibration, which shall provide the Qcalibi quaternion as an output.

2.1.1.5.4.2.3. System calibration sequence

To fulfil the requested HERSCHEL APE and AME pointing performances, the Line Of Sight (LOS) of the three instruments shall be calibrated against the ACMS LOS before the beginning of the mission. The objective is to get the bias knowledge between instrument and star tracker lines of sight.

If PACS is healthy, PACS will be the first instrument to be calibrated.

The initial conditions shall be the following:

- ACMS is in SCM with star tracker STR1 in the loop (same logic applies with STR2).
- CDMS is nominal mode.

The instruments are in following modes:

- PACS is in chopped photometry nominal observation mode
- HIFI is in standard AOT mode
- SPIRE is in nominal observation mode.

Inputs of the Herschel system calibration:
Attitude of the instrument sources used for calibration in J2000

Outputs of the Herschel system calibration:
- Estimated misalignments between instrument LOS and ACAs (ACMS coordinate frames) called Qcalib
- OBDB values H_NOM_AUX_STRi_CORR_MISLIGN_a_b a= 1..7, b= 1..4, i = 1..2 representing the estimated misalignment between ACA-i and ACF.

PACS initial system pointing calibration

The first source to be used is selected. Q_source is the attitude of the instrument source.

Step 1: In order to put the source in the instrument detector field of view, a raster will be commanded to the ACMS using the telecommand **TC_PERFORM_SCM_RASTER_POINTING TC(8,4,101,210)** with the following features:

- interlacing = activation depends of the attitude of the source
- CP = off (calibration point is not used)

- q_rast = Q_source ' Q_ground_to_orbit where Q_ground_to_orbit represents the maximum predicted rotation between instrument LOS and ACA due to ground to orbit effects.
- N (number of lines)= next greater integer of 4*angle(Q_ground_to_orbit)/instrument detector FOV
- M (number of steps per line) = N
- Phi (Tilt angle defining the rotation of the scan pattern axes) = 0 deg
- d1 (angular distance between successive steps) = instrument detector FOV/2
- d2 = d1
- tslew (duration to reach first point – margin since first raster point =end of last scan) to be computed depending of previous pointing according to ACMS user manual H-P-4-DS-MA-007 Flight Section 9.4.1 (Herschel Slew time predictions)
- tp (Duration of stable pointing) = 60 s (to be confirmed by instrument)
- Tpp (Allowed duration of the point-to-point manœuvre) to be computed depending of N and d1 values according to ACMS user manual H-P-4-DS-MA-007 Flight Section 9.4.1 (Herschel Slew time predictions)
- Tll (Allowed duration of the line-to-line manœuvre) to be computed depending of M and d2 values according to ACMS user manual H-P-4-DS-MA-007 Flight Section 9.4.1 (Herschel Slew time predictions)
- qoff (Inertial target attitude quaternion of the OFF-position) = (0,0,0,1)
- K (Number of consecutive raster steps before going to the OFF-position) = 0
- Tsop (maximum slew time from a point in the raster to the OFF position.) = 0 s
- Top (off position duration) = 0 s
- Top-init (duration of initial off position for calibration) = 0 s

Step 2: Based on the instrument telemetry, the user will determine which attitude is associated with the point of raster where the source falls in the instrument FOV. The rotation between the predicted attitude source and the found attitude source (point of the raster where energy is found) is recorded as Q_rough_misalignment.

Step 3: Then, this attitude will be commanded again (fine pointing) to record sufficient samples by using the **TC_PERFORM_SCM_FINE_POINTING TC(8,4,101,200)** filled with the following features:

- Interlacing = activation depends of the attitude
- Qfine = previously determined attitude
- Tslew to be computed depending of angular distance between commanded attitude and last point of previous raster according to ACMS user manual H-P-4-DS-MA-007 Flight Section 9.4.1 (Herschel Slew time predictions)
- Tp = sufficient duration to allow PACS to perform chopper on and chopper off strategy as defined in PACS-ME-TN-039.

Step 4: The other PACS detectors (red photometry, blue and red spectroscopy) are then calibrated using the same source (if possible) sending fine pointing telecommand with "blue photometer" detector previous target compensated by the knowledge of angular distance between detectors

Step 5: Then, the other sources are used. TBD hours are to be waited between sources so that spacecraft reaches stable thermal conditions. Fine pointing are successively commanded for the different detectors and sources by using the **TC_PERFORM_SCM_FINE_POINTING TC(8,4,101,200)** filled with the following features:

- Interlacing = activation depends of the commanded attitude
- Qfine = attitude source compensated by Q_rough_misalignment and knowledge of angular distance between detectors.
- Tslew to be computed depending of angular distance between commanded attitude and last point of previous raster according to ACMS user manual H-P-4-DS-MA-007 Flight section 9.4.1 (Herschel Slew time predictions)
- Tp = sufficient duration to allow PACS to perform chopper on and chopper off strategy as defined in PACS-ME-TN-039.

Step 6: The following post processing is then necessary on ground:

ð The PACS telemetry is processed to derive the mean attitude of the instrument detector line of sight with respect to J2000 frame (the associated procedure is an instrument procedure). The averaging is done over the observation time. User gets Q_detectorLOS _J2000_k_j where k is the source index and j is the detector index. Note that Around LOS attitude is not derived from telemetry but from a priori knowledge.

ð In parallel, the mean ACA-1 attitude with respect to J2000 averaging the ETM parameters (AESA1002, AESA2002, AESA3002, AESA4002) is obtained. User gets Q_ACA1_J2000_k_j where k is the source index and j is the detector index.

ð The rotation between ACA-1 frame and detector frame is then computed: QACA1_J2000_k_j = Qcalib1_k_j ' Q_detectorLOS_J2000_k_j.

ð The average between the different sources is done giving Qcalib1_j, j is the detector index

Step 7: Enable Diagnostic packets associated with STR1 and 2 Sub Address 11 and power on the STR2. Wait TBD hours.

As post processing activities, the quaternions from the 2 star trackers are compared based on diagnostic telemetry.

Step 8: STR2 is put in the control loop according to ACMS FCP-xxx and STR1 is powered off. Wait TBD hours.

Step 9: Steps 3 to 6 are then repeated replacing STR 1 by STR 2, ACA-1 by ACA-2. The misalignment between the 2 STRs determined at step 7 is taken into account to point the detector LOS.

The output of this step is Qcalib2_j.

Step 10: ACF (Attitude Commanding Frame) is determined.

- Using blue photometer data, Qmis1 is determined according to Qmis1 ' Qmis1 = Qcalib2 ' $\overline{Q}$calib1
- H_NOM_AUX_STR1_CORR_MISLIGN_a_b a= 1..7, b= 1..4 = Qmis1_b whatever a is.
- H_NOM_AUX_STR2_CORR_MISLIGN_a_b = $\overline{Q}$mis1 what b is.

- As a check, solve the same problem using other detector data and verify similar misalignment qmis quaternion is obtained.

If STR-1 is unhealthy during the system calibration (meaning it will certainly not be available for the rest of the mission), the ACF frame will be the ACA-2 and vice-versa. H_NOM_AUX_STRi_CORR_MISLIGN_a_b will remain the same values as on ground.

PACS subsequent system pointing calibration

In case a new system calibration is performed, the previous steps apply but replacing ACA-i (i =1 and 2) by ACA-i transformed by Qmisi coming from previous calibration.

SPIRE initial system pointing calibration

The SPIRE beam steering mirror will be used to create the 7-point jiggle map that will provide the reference data to estimate the instrument LOS in J2000 frame (SPIRE-UCF-NOT-001818).

PACS procedure can be completely reused for SPIRE. If PACS has been previously calibrated, the procedure can be simplified. In this case, step 1 can be deleted and the fine pointing attitude target will be determined based on the knowledge between PACS and SPIRE reference frames.

Qmis1 obtained from SPIRE calibration shall not differ from Qmis1 obtained from PACS calibration by more than 1 arcsec.

SPIRE subsequent system pointing calibration

Same procedure as PACS one applies.

HIFI initial system pointing calibration

A 3x3 map will be commanded during the HIFI system pointing calibration (SRON-U/HIFI/TN/2006-004).

If PACS has been successfully calibrated, the same procedure applies deleting the step 1 and replacing the fine pointing with 3x3 raster pointing command combined with SSO tracking. These raster commands are to be detailed based on instrument features.

Qmis1 obtained from HIFI calibration shall not differ from Qmis1 obtained from PACS calibration by more than 1 arcsec.

HIFI subsequent system pointing calibration

Same procedure as PACS one applies.

End of system calibration

Upload H_NOM_AUX_STRi_CORR_MISLIGN_a_b a= 1..7, b= 1..4, i = 1..2 using ACMS FCP- Update parameters for STR main : H_FCP_AOC_4S81 / P_FCP_AOC_4S81

2.1.1.5.4.2.3.1. Main/initial calibration

The difficulty of the first calibration also called main calibration is the absence of knowledge below the tenth of degree of the thermal time constant. The observation duration is not the driver here. Duration of slew between observation has to be considered and the time to reach thermal equilibrium of the payload (several days) and SVM (several hours) are the more time consumer. For each observation, both star trackers have to be calibrated.

Duration of initial calibration will be around one week.

2.1.1.5.4.2.3.2. Calibration periodicity

Daily calibration check

A daily check will be performed using nominal instrument and ACMS telemetry. A single observation for the operational instrument (PACS, HIFI or SPIRE) is done. With the telemetry of this observation, the bias between ACMS sensor and instrument called "current bias" will be estimated at ground level.

The check will be to verify if the bias variation amplitude with respect to last calibration data is still in line with the pointing performance requirements.

New calibration

If the above check is positive, no new calibration will be requested. If not, a new calibration (procedure identical to the first one but with reduced duration since based on previous knowledge) will be necessary and shall be planned during one of the next visibility periods.

2.1.1.6. Power design

2.1.1.6.1. Power subsystem overview

The HERSCHEL PLANCK power subsystems have a very high degree of commonality, they both employ the same PCDU and battery, while the Solar Arrays are different but utilise a common solar cell type.

2.1.1.6.2. PCDU

The PCDU has been designed to interface with 30 sections of a Solar Array, provide a regulated 28V bus, distribute this power via protected outputs and to handle the battery charging/discharging.

The PCDU distributes the power to each user via either a Foldback Current Limiter (FCL) or a Latching Current Limiter (LCL). FCLs cannot be commanded OFF, they are reserved to supply essential loads. FCLs can be commanded OFF and ON via the 1553 bus and in addition for selected LCLs via discrete TC lines. LCLs are implemented in three classes depending upon the required limitation current. The LCL will start to limit the current after the LCL class current has been exceeded by 20 %, and once the limitation threshold has been achieved, will trip off after 10ms. The precise LCL current limitation can be anywhere in the range of 1.2x to 1.5x the LCL class current. All LCLs and FCLs provide status and current telemetry. The LCL classes are:

LCL Type	Iclass	$Ilimit_{min}$	$Ilimit_{max}$	Iovershoot	$Trip_{min}$	$Trip_{max}$
Class I	1A	1.2A	1.5A	2.25A	10ms	12ms
Class II	2.5A	3.0A	3.75A	5.63A	10ms	12ms
Class III	5A	6.0A	7.5A	11.25A	10ms	12ms
FCL	1A	0.25A*	1.5A	2.25A	-	-

* This value is achieved at the maximum fault condition, i.e. upon the application of an overload condition, the FCL will react to limit the current between Ilimitmax and Ilimitmin.

For applications which require more than 5A (Sorption Cooler and 4k Cooler) several Class III will be wired in parallel (4 for the Sorption Cooler and 2 for the 4k Cooler) to provide the required output current. The paralleling of the LCLs will be implemented in the PCDU harness with the ON/OFF commands to each LCL being sent in parallel to the group of LCLs, hence for the HERSCHEL PCDU where these high loads LCLs are not required it will be possible to utilise these LCLs individually while still maintaining an identical PCDU for both HERSCHEL and PLANCK.

One identified failure modes of LCLs which use FETs for the switching function is a gate-drain short circuit which leads that the FET cannot be switched OFF and will have a high dissipation. A survey of all the users have identified which LCLs must be protected against this failure mode, ones which cannot tolerate both the nominal and redundant units being ON at the same time, and a second series switch (FET) will be implemented within the LCL to ensure that it may always be switched OFF. To resolve the excess dissipation problem, all Class III LCLs will be implemented with series switches.

The essential loads are supplied via FCLs which do not trip off nor can they be powered off. All FCLs have the same characteristics. The problems associated with a re-triggerable LCL being constantly retriggered, usually at around 1Hz, and the possible sources of noise for the instruments, meant that FCLs were selected in preference to re-trigerable LCLs. The essential heaters are supplied by FCLs, redundant thermostats will be implemented to so that a single failure will not mean that the heaters are permanently powered.

The PCDU provides 10 FCLs and 62 LCLs.

In addition to the FCL/LCL distribution, the PCDU will also provide protected switchable heater lines. For each group of heaters a LCL type device (called Heater-Group Protection Switch - HPS) will supply 6 heater switches (series FETs), in case of an overload situation the bus will always be protected since the current will be limited. Each heater line is specified to be able to provide 3.75 A, while the HPS is rated at 10A. The PCDU will provide a total of 54 nominal + 54 redundant heater lines.

The battery charging concept is that the last three sections of the array can be connected to the battery if the battery requires charging. The connection (and disconnection) of the array sections to the battery is managed in a sequential manner by the MEA in conjunction with the BCR and BDR, the maximum battery charge current will correspond to the current of 3 sections (nominal 9A total) and as the battery becomes charged then a section is switched from the battery and made available to the mainbus as any other section. With a fully charged battery, the load on the last section is minimal (battery taper charging) and the current from the last section (less the battery taper current) is also made available to the mainbus.

The PCDU implements a 3 domain regulated power bus concept based upon the SR3 concept:

- Sunlight Domain - the power is supplied by the 30 Solar Array sections, the sections are either shunted or connected to the mainbus, the voltage regulation being achieved by having one section being switched at a high frequency (up to 3kHz) between shunt and mainbus.

- Battery Charge Domain - The last 3 sections of the array (designed to be normally shunted for the nominal power load) can be switched to the battery should the battery require charging. This assumes a battery recharge to be performed in a reasonable time. The complete recharge of the battery with the present conditions will be achieved in less than 4 hours after the separation from the launcher. The circuit controlling the domain ensures that the user load has priority over battery charging should there be insufficient power for both the bus users and battery charging. The control of the battery charging, autonomously performed by the PCDU, is managed by the MEA and by monitoring the battery voltage for the end of charge voltage (the end of charge voltage may be modified by software programming). There are no high current pulses applied to a battery with the implemented architecture and therefore the risk of damaging or degrading the battery performance is reduced.

- Battery Discharge Domain - Should the Mean Error Amplifier detect that the mainbus load exceeds the available Solar Array power then the battery will be discharged to provide the required power. The BDR is implemented as a push-pull PWM converter, the nominal power capability being 400 W each BDR, sufficient to supply the spacecraft in worst case launch conditions.

The Mainbus capacitor is implemented as both a central capacitor employing self healing capacitors and distributed capacitors on each module within the PCDU, therefore the mainbus capacitor is tolerant to a short circuited capacitor.

2.1.1.6.3. Battery

The battery proposed and selected for HERSCHEL PLANCK is from AEA, the technology is based upon a number of screened commercial low capacity cells arranged in a number of parallel strings (26 strings of 6 cells). The proposal from AEA has taken some pessimistic ageing and degradation factors into account, the sizing of the battery reflects these factors and lead to mass and volume penalties. Although the eclipse requirements at system level have been removed and the battery size could have been reduced, it was decided to maintain the baseline design to ensure generous battery power margins. The battery BOL energy capability is 777Wh with a capacity of 36 Ah (measured capacity on the EM gives 93 % capacity = 34.75Ah), the needs in the launch case are 330W for PLANCK and 254W for HERSCHEL for 50 minutes under the worst case operating conditions. The battery sizing case is the launch phase, although the battery will be used during the mission to handle peak power demands, this is well below the requirements of the launch condition.

2.1.1.6.4. Solar Array

The Solar Arrays are the main difference between HERSCHEL and PLANCK. The power requirements of the instruments and the lifetime requirements are different for the two missions. The requirements and available power for the Solar Arrays are summarised:

– HERSCHEL

	Requirement	Available	
BOL	1700 W	SS 0° Inclination	1709 W
EOL (3.5 Years)	1400W	SS 30° Inclination	1420 W
		WS 30° Inclination	1515 W

The minor non-compliance for BOL is accounted for in the power budget.

– PLANCK:

	Requirement	Available
BOL	1900 W	1913 W
21 months	1900 W	1860 W (SS 0°)
30 months	1700 W	1837 W (SS 0°).

While the shape and size of the arrays for HERSCHEL and PLANCK are different, the type of cell, substrate, interconnects, wiring, and manufacturing procedures will be common to both arrays. HERSCHEL will also have 1 section of 100 % European cells which are the same as the baseline RWE apart from a slight loss of efficiency.

2.1.1.6.5. Power distribution to instruments

The power to the instruments will be distributed as given in the following tables:

HERSCHEL Allocation	To	Type	Protected	Class	LCL n°
HIFI HRH	**FHHRH**	LCL	YES	III	63
HIFI HRV	**FHHRV**	LCL	YES	III	67
HIFI ICU Nom	**FHICU**	LCL	YES	III	64
HIFI ICU Red	**FHICU**	LCL	YES	III	68
HIFI LCU Nom	**FHLCU**	LCL	YES	III	53
HIFI LCU Red	**FHLCU**	LCL	YES	III	54
HIFI WEH	**FHWEH**	LCL	NO	II	43
HIFI WEV	**FHWEV**	LCL	NO	II	44
PACS BOLC Nom	**FPBOLC**	LCL	YES	II	27
PACS BOLC Red	**FPBOLC**	LCL	YES	II	28
PACS DPU Nom	**FPDPU**	LCL	NO	II	41
PACS DPU Red	**FPDPU**	LCL	NO	II	42
PACS DEC/MEC1	**FPMEC1**	LCL	YES	III	59
PACS DEC/MEC2	**FPMEC2**	LCL	YES	III	61
PACS SPU Nom	**FPSPU1**	LCL	NO	II	35
PACS SPU Red	**FPSPU2**	LCL	NO	II	36
SPIRE HSDPU Nom	**FSDPU**	LCL	YES	I	11
SPIRE HSDPU Red	**FSDPU**	LCL	YES	I	12
SPIRE HSFCU Nom	**FSFCU**	LCL	YES	III	51
SPIRE HSFCU Red	**FSFCU**	LCL	YES	III	52

PLANCK Allocation	To	Type	Protected	Class	LCL n°
LFI DAE Nom	PLBEU	LCL	YES	III	51
LFI DAE Red	PLBEU	LCL	YES	III	52
LFI REBA Nom	PLREN	LCL	YES	II	27
LFI REBA Red	PLRER	LCL	YES	II	28
HFI DCE	DCE	LCL	NO	II	36
HFI DPU Nom (PHBA-N)	PHBAN	LCL	YES	II	29
HFI DPU Red (PHBA-R)	PHBAR	LCL	YES	II	30
HFI REU belts group 0&1	PHBAR	LCL	NO	II	39
HFI REU belts group 2&3	PHBAR	LCL	NO	II	40
HFI REU belts group 4&5	PHBAR	LCL	NO	II	41
HFI REU belts group 6&7	PHBAN	LCL	NO	II	42
HFI REU belts group 8&9	PHBAN	LCL	NO	II	43
HFI REU belts group 10&11	PHBAN	LCL	NO	II	44
HFI REU Proc Nom	PHCBC	LCL	YES	I	11
HFI REU Proc Red	PHCBC	LCL	YES	I	12
HFI 4KC Drive bus Nom	PHDC	LCL	YES	2 Class III in Parallel	59/60
HFI 4KC Drive bus Red	PHDC	LCL	YES	2 Class III in Parallel	61/62
HFI 4KCDE Nom (PHDC)	PHDC	LCL	NO	II	37
HFI 4KCDE Red (PHDC)	PHDC	LCL	NO	II	38
Sorption Cooler Compressor Nom	PSM4	LCL	YES	4 Class III in Parallel	63/64/65/66
Sorption Cooler Compressor Red	PSR4	LCL	YES	4 Class III in Parallel	67/68/69/70
Sorption Cooler Electronics Nom	PSM4	LCL	YES	III	53
Sorption Cooler Electronics Red	PSR4	LCL	YES	III	54

2.1.1.6.6. DC/DC synchro

Previous ALCATEL experience with synchronised and non-synchronised power systems has shown that contrary to what may be expected, a synchronised system is not less noisy than a non-synchronised one. Early in the program, the instruments were requested to reconsider their need for a DC/DC synchronisation signal, with the intention to retain the DC/DC synchronisation only if a sound rationale could be provided. One instrument (LFI) had planned to use this DC/DC sync signal as an internal 131 kHz clock, not only for internal DC/DC synchronisation but for timing purposes. This was considered an inappropriate use of the signal since the quality of a DC/DC sync clock is generally inferior to a dedicated timing clock (accuracy, stability, duty cycle, jitter), so the DC/DC synchronisation signal has been removed and a 131072 Hz clock signal has been made available for each instrument.

2.1.1.7. Common HERSCHEL/PLANCK RCS design

The Reaction Control System (RCS) provides the necessary forces and torques to achieve spacecraft linear and angular momentum changes necessary for orbit transfer/insertion/maintenance and attitude control, respectively, during all phases of the mission.

This section describes the system aspects of the propulsion subsystem for both HERSCHEL and PLANCK, and the main features of its use in orbit and on ground.

Details on the subsystem aspects are provided in section 4.4 of this document.

2.1.1.7.1. RCS overview

The propulsion architectures of HERSCHEL and PLANCK are almost identical:

- Each individual diaphragm tank is connected to a dedicated pressurant (nitrogen) fill and vent valve
- The tanks propellant parts are connected one to another to the upstream pipe
- Tanks are used in blow down mode, with a MEOP of 24 bars
- A propellant fill and drain valve is connected to this upstream pipe, as well as a pressure transducer and a 20µm filter
- Two latching valves separate the upstream pipes from the downstream branches
- Each branch is equipped with six 20-N thrusters (plus two 1-N thrusters on PLANCK) and one test port for ground operations.

The propulsion equipment used by HERSCHEL and PLANCK presents the maximum possible commonality.

The thrusters and the latching valves are commanded by the ACC.

2.1.1.7.2. HERSCHEL propulsion

2.1.1.7.2.1. Required manoeuvres for HERSCHEL

The following manoeuvres are required for HERSCHEL:

MANOEUVRE	DELTA-V [m/s]	SUN ASPECT ANGLE [°]
Perigee velocity correction	92 (combined for these four manoeuvres)	[145-175]
Removal of launch dispersion		[145-170]
Manoeuvre on day 12		[0-180]
Mid-course correction		[0-180]
Orbit maintenance (3 m/s)	13.5	28.4 or 208.4

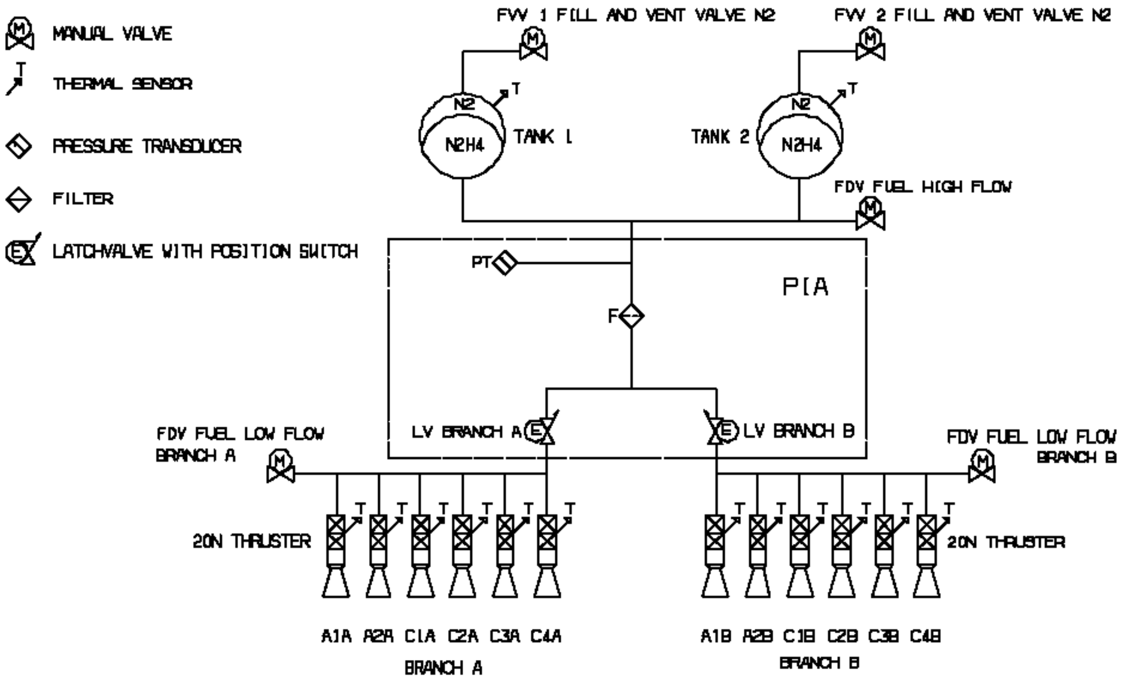
The 12 m/s for orbit maintenance includes the correction of the orbit perturbation brought by helium exhaust and the wheel off-loading. In addition, the system budgets account for the attitude control equivalent delta-V (due to reaction wheel off-loading), to the following extent:

MANOEUVRE	DELTA-V [m/s]	SUN ASPECT ANGLE [°]
Attitude Control	7.8	28.4 or 208.4

Most manoeuvres have no deterministic orientations. They will be calculated on-ground from the Doppler measurements, and commanded to the spacecraft. Only the orbit maintenance is systematically performed along the escape-velocity direction.

2.1.1.7.2.2. RCS configuration

HERSCHEL RCS configuration is the following:


MANUAL VALVE
THERMAL SENSOR
PRESSURE TRANSDUCER
FILTER
LATCHVALVE WITH POSITION SWITCH
FVV 1 FILL AND VENT VALVE N2
FVV 2 FILL AND VENT VALVE N2
N2
N2H4
TANK 1
TANK 2
FDV FUEL HIGH FLOW
PT
PIA
F
LV BRANCH A
LV BRANCH B
FDV FUEL LOW FLOW BRANCH A
FDV FUEL LOW FLOW BRANCH B
20N THRUSTER
A1A A2A C1A C2A C3A C4A
BRANCH A
A1B A2B C1B C2B C3B C4B
BRANCH B

2.1.1.7.2.3. Thruster configuration

The HERSCHEL thruster configuration is optimised with respect to the following criteria:

– Capacity to generate forces according to the mission analysis

– Capacity to generate torque's on all axes to control the spacecraft attitude in orbit control mode and to off-load the accumulated angular momentum

– Minimise the number of thrusters

– Avoid payload contamination.

HERSCHEL thruster configuration consists of 6 nominal thrusters (and 6 equivalent redundant):

– 4 control ("C") thrusters, located on the -X side of the SVM to avoid contamination of the payload, to generate torques. Choosing 2 thrusters among these 4 leads to 6 possibilities, creating torques in +X, -X, +Y, -Y, +Z and -Z. See torque table below

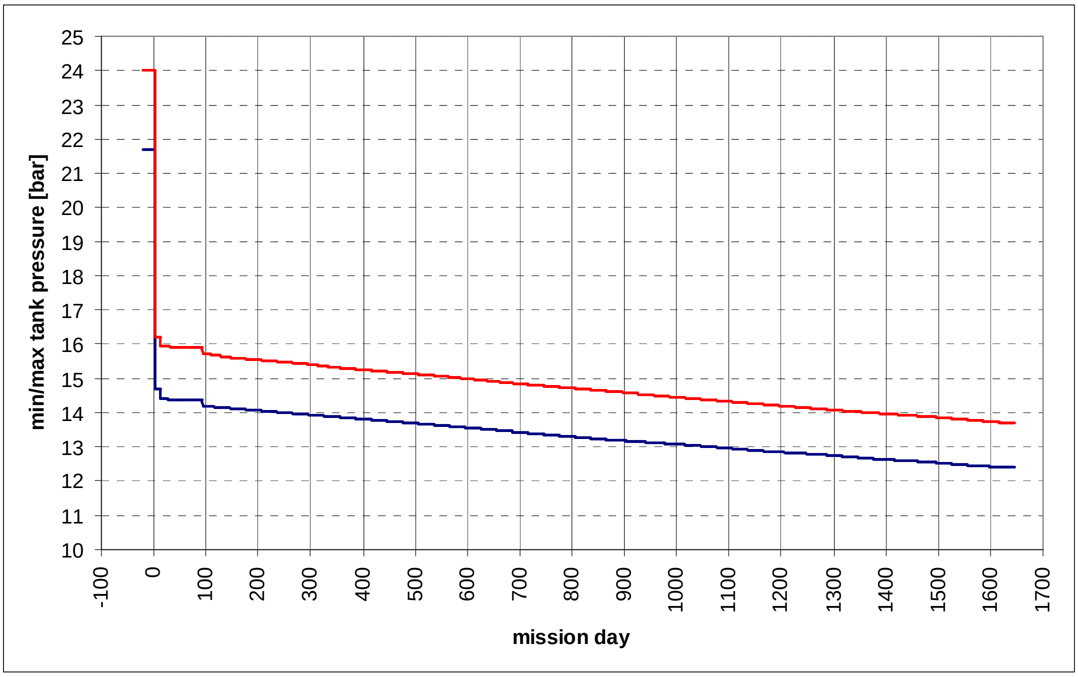
– 2 acceleration ("A") thrusters used to create the delta-V's. The "A" thrusters are used one at a time. They are pointing to the average centre of mass (with a tilt angle of about 40° from X-axis).

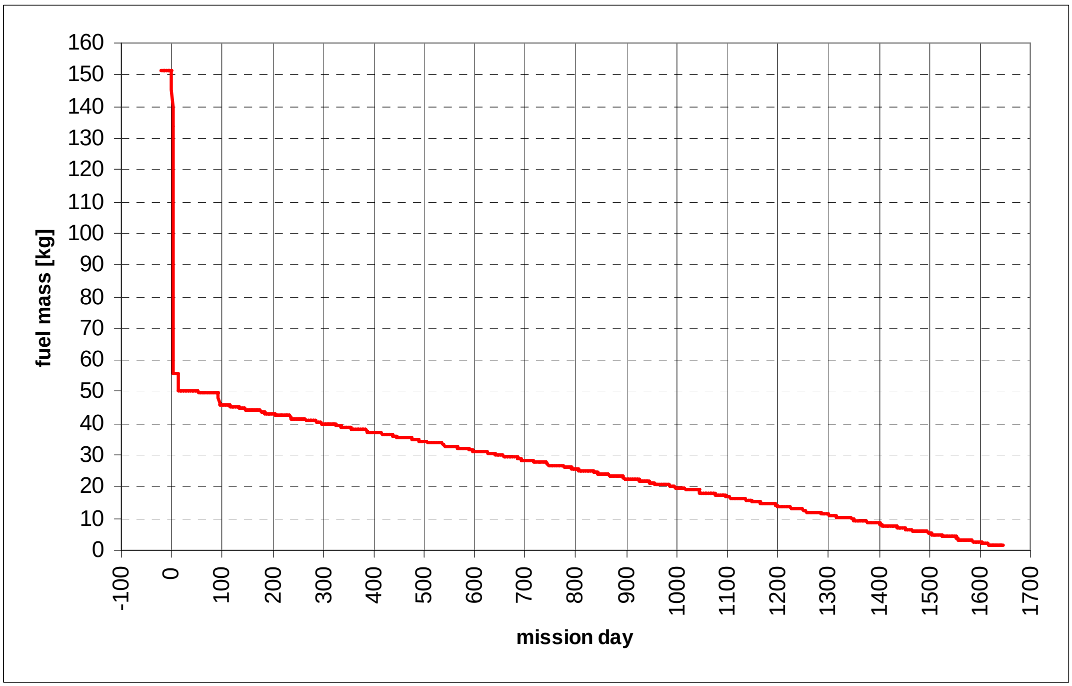
The location and orientation of the thrusters in satellite frame is the following:

			LOCATION IN S/C FRAME			DIRECTION IN S/C FRAME		
			x [mm]	y [mm]	z [mm]	x	y	z
Branch A	20N	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
Branch B	20N	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

Due to the initial tank-filling ratio, HERSCHEL 20-N thruster forces in steady state will be between 23.5N at BOL and maximum and 15.4N at EOL and minimum temperature.

Assuming that the delta-V's are performed completely, a typical evolution of the pressure inside HERSCHEL tanks (with min and max temperatures) and of the remaining fuel mass is shown on the graphs below:





The torques generated by the nominal thrusters (when their force is 20N), around the average centre of mass are:

		TORQUE IN S/C FRAME		
		Tx [N·m]	Ty [N·m]	Tz [N·m]
Branch A	A1A	-0.01	-0.02	-0.01
	A2A	0.00	0.03	-0.01
	C1A	27.85	29.30	-19.50
	C2A	-27.85	-28.73	-19.50
	C3A	27.85	-28.73	19.50
	C4A	-27.85	29.30	19.50
Branch B	A1B	0.00	-0.02	0.00
	A2B	-0.03	0.03	0.02
	C1B	26.38	29.30	-18.47
	C2B	-26.38	-28.73	-18.47
	C3B	26.38	-28.73	18.47
	C4B	-26.38	29.30	18.47

The two branches provide similar forces and torques.

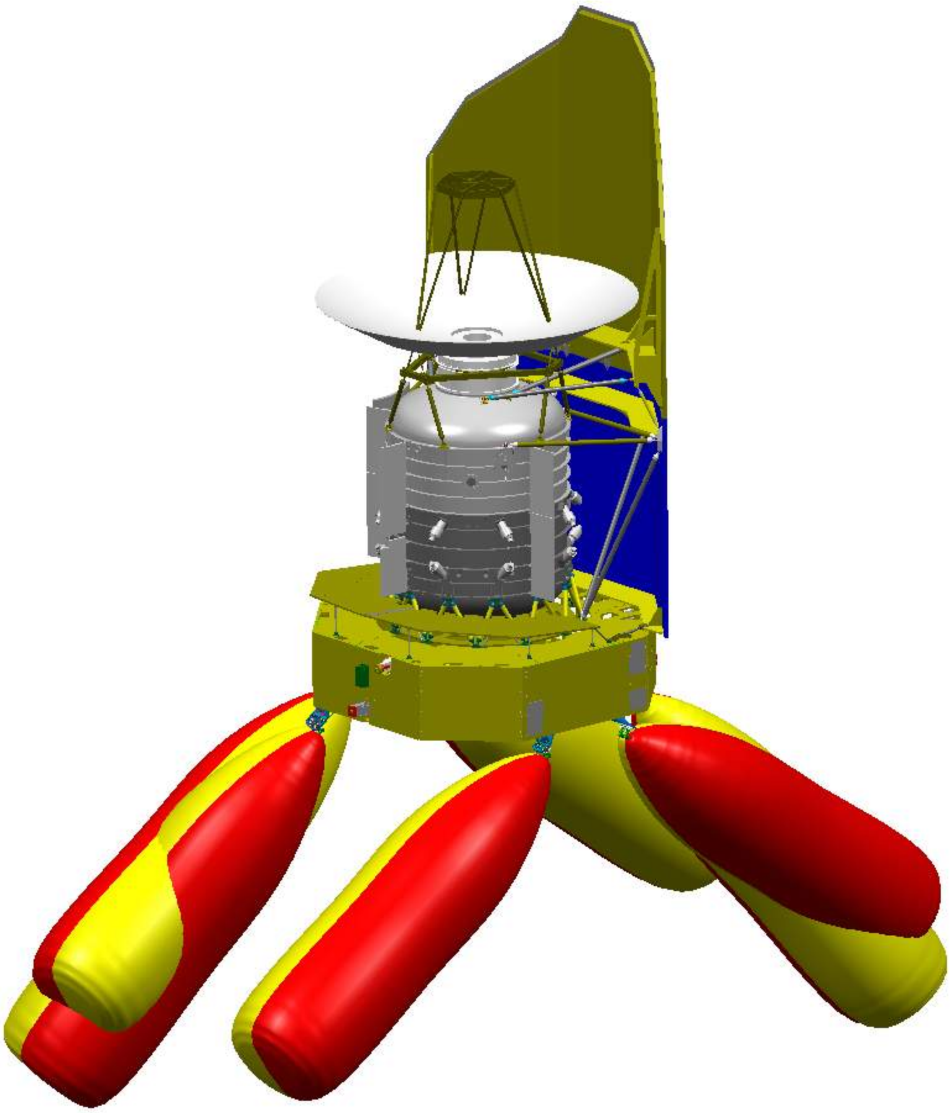
The ACMS generates the torques according to the following principle:

– The 3 components of the torque (X, Y, Z) are projected onto the 4 torque axes generated by the 4 thrusters. These projections are reworked to ensure that only positive components are kept

– The relevant thruster-on times are then computed

– In case one or more thrusters have an on-time lower than the minimum on-time, a combination of the four thrusters producing a nil torque is added, in order to ensure that all thrusters can be used properly, i.e. with a minimum on-time.

The following drawing shows HERSCHEL thruster plumes (6kW) for both nominal and redundant thrusters.



2.1.1.7.2.4. Thruster usage

This section presents the main characteristics of the thruster configuration and their use. More details are presented in the dedicated technical note (Thruster Utilisation, H-P-1-ASP-TN-0689).

The following Table describes the different possibilities to use the thrusters.

TYPE OF MANOEUVRE	A THRUSTERS	C THRUSTERS
Orbit correction	One thruster used continuously	Combination in ON-modulation
Torque generation	Not used	Combination in ON-modulation

HERSCHEL can generate a torque in any inertial direction without having to make an attitude manoeuvre.

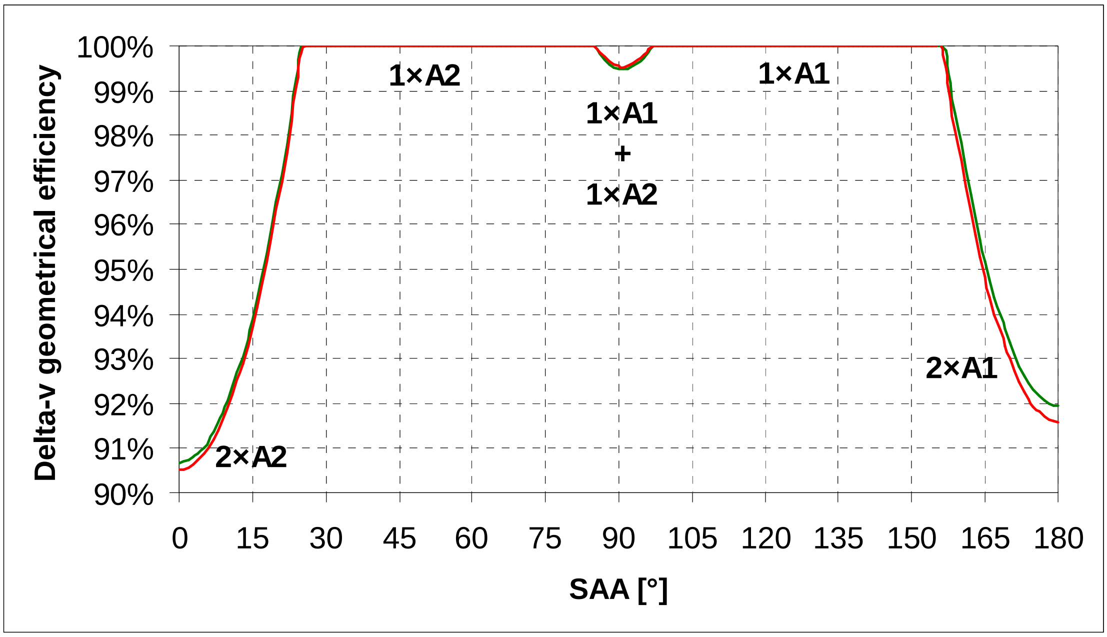
However, it has to slew to generate a delta-V in the required inertial direction. For this, HERSCHEL benefits of a large manoeuvre capacity:

- Any rotation about the Sun line, keeping +Z towards the Sun
- Rotation of ±1° around X (negligible impact)
- Rotation of ±30° around Y.

TYPE OF MANOEUVRE		A1 THRUSTER	A2 THRUSTER	C THRUSTERS
Branch A	Branch B			
Orbit correction SAA < 26.9°	Orbit correction SAA < 27.9°	Not used.	Used continuously, two times separated by a S/C slew.	On-modulated to generate torque.
Orbit correction 26.9° < SAA < 82.4°	Orbit correction 27.9° < SAA < 82.3°	Not used.	Used continuously, only once.	On-modulated to generate torque.
Orbit correction 82.4° < SAA < 98.1°	Orbit correction 82.3° < SAA < 97.8°	Used continuously, only once.	Used continuously, only once. A1 and A2 thrusts are separated by a S/C slew. The two thrusts of A1 and A2 can be performed in either order, never simultaneously.	On-modulated to generate torque.
Orbit correction 98.1° < SAA < 155.1°	Orbit correction 97.8° < SAA < 154°	Used continuously, only once.	Not used.	On-modulated to generate torque.
Orbit correction 155.1° < SAA < 180°	Orbit correction 154° < SAA < 180°	Used continuously, two times separated by a S/C slew.	Not used.	On-modulated to generate torque.
Torque generation	Torque generation	Not used.	Not used.	On-modulated to generate torque.

2.1.1.7.2.5. Thrust geometrical efficiency

The following graph shows the thruster efficiency with respect to the Sun Aspect Angle, with the assumption that -X is pointing towards the Sun. Branch A in green, Branch B in red.



The efficiency curve has been computed assuming no modulation of the thrusters.

The average efficiency over a sphere, assuming a uniform distribution is 99.5 % for both branches.

2.1.1.7.2.6. Latching valve usage

In order to cope with on ground and launcher safety regulations, the LV will remain closed during HERSCHEL ground operations.

In orbit, the latching valve commanding the redundant branch will remain closed. Only the nominal LV will be open. Thrusters of two different branches will then never be actuated simultaneously.

A typical sequence is:

	Latch Valve A status	Latch Valve B status
Launch	Closed	Closed
After Separation	Open	Closed
Reconfiguration	Closed	Closed
then	Closed	Open

2.1.1.7.2.7. Pressure transducer usage

The pressure transducer will be used to evaluate the remaining quantity of fuel. Its loss does not functionally constitute a single point failure, since the ACMS telemetry of the thruster usage will provide the necessary information to evaluate the consumed quantity of fuel. In addition, the ACMS maintains bookkeeping of all thrusts performed, which can be used as a back up to determine the pressure inside the tanks and the remaining quantity of fuel.

2.1.1.7.3. PLANCK propulsion

2.1.1.7.3.1. Required manoeuvres for PLANCK

The following manoeuvres are required for PLANCK:

MANOEUVRE	DELTA-V [m/s]	SUN ASPECT ANGLE [°]
Total allocation for orbit acquisition	406 m/s	
Orbit maintenance	2.5	28.4 or 208.4

In addition, the system budgets account for:

– The attitude control equivalent delta-V (due to the reorientation of PLANCK angular momentum towards a direction close to the Sun)

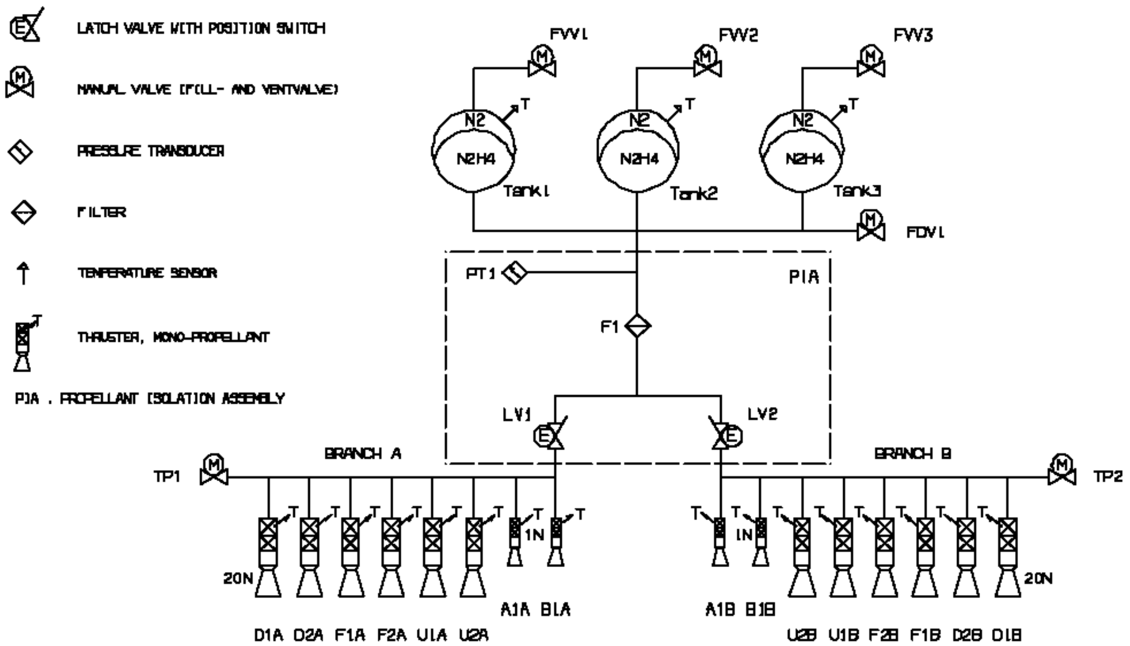
– The orbit control associated to the perturbation brought by the attitude control.

MANOEUVRE	DELTA-V [m/s]	SUN ASPECT ANGLE [°]
Attitude Control	3.6	28.4 or 208.4
Orbit maintenance due to attitude Control	2	28.4 or 208.4

Most manoeuvres have no deterministic orientations. They will be calculated on-ground from the Doppler measurements, and commanded to the spacecraft. The injection manoeuvre is systematically performed along the non-escape-velocity direction.

2.1.1.7.3.2. RCS configuration

PLANCK RCS configuration is the following:



2.1.1.7.3.3. Thruster configuration

The PLANCK thruster configuration is optimised with respect to the following criteria:

- Capacity to generate forces according to the mission analysis
- Capacity to generate torques on all axes to control the spacecraft attitude in orbit control mode and to off-load the accumulated angular momentum
- Minimise the number of thrusters
- Avoid payload contamination.

Each branch of 20-N thrusters consists of 3 pairs of thrusters ("D" for down, "F" for flat, "U" for Up). The thrusters of the same pair are oriented such as their simultaneous use does not create torque.

The D thrusters provide the capability to perform the manoeuvres with intermediate SAA. The D thrusters are oriented towards - X and are parallel in order to have the maximum efficiency.

The F thrusters provide the capability to perform the manoeuvres with intermediate SAA. Since it is the main contributor to the overall delta-V, some specific thrusters ("F") have been accommodated to perform this manoeuvre (SAA = 125°) with the maximum efficiency. In particular, they are parallel.

The U thrusters provide the capability to perform the manoeuvres with low SAA. Due to the presence of the PLM, it was not possible to orient the U thrusters parallel. The two thrusters of a pair form an angle of 70°, which was a compromise between the plume on the sensitive elements, the efficiency, and the sensitivity of the thruster reorientation to the location of PLANCK centre of mass.

The Delta-V thrusters are too strong to make the re-orientation manoeuvres with the desired accuracy. Specific 1-Newton thrusters are used for that purpose, integrated in the overall hydrazine system.

The 1-Newton thrusters are accommodated so that:

- One thruster (spin-up) has a lever arm of +0.65m around X
- The other thruster (spin-down) has a lever arm of -0.65m around X
- Both thruster provide a lever arm of 0.4m in YZ plane.

With this configuration, only one thruster can be used for each re-orientation manoeuvre (made in three pulses). The phases of the pulses is chosen to shift the angular momentum and reduce the nutation at the end of the last manoeuvres. Both the spin-up and the spin-down thrusters can perform any reorientation. The thruster choice is made on-board depending on whether the actual spin rate is below or above 1rpm. This allows to maintain the spin rate at 1 rpm ± 1.5 %, in accordance with the SRS requirement MOOF-050.

The location and orientation of the thrusters in satellite frame is the following:

			LOCATION IN SVM FRAME			**DIRECTION IN SVM FRAME**		
			x [mm]	**y [mm]**	**z [mm]**	**x**	**y**	**z**
Branch A	**20N**	**Down 1 (D1A)**	-57.86	-575.39	1565.18	-0.99978	0.00790	0.01919
		Down 2 (D2A)	-61.14	575.39	-1565.18	-0.99978	0.00790	0.01919
		Flat 1 (F1A)	-64.60	-1688.27	576.91	-0.61501	-0.26286	0.74342
		Flat 2 (F2A)	-89.46	902.59	1571.80	-0.61501	-0.26286	0.74342
		Up 1 (U1A)	205.46	1837.80	-764.42	0.51558	0.59082	0.62057
		Up 2 (U2A)	208.07	-1840.73	-761.38	0.53113	-0.55607	0.63928
	1N	**Spin Down (A1A)**	826.47	-734.19	1718.09	-0.28343	-0.67811	0.67811
		Spin Up (B1A)	826.47	-1718.09	734.19	-0.28343	-0.67811	0.67811
Branch B	**20N**	**Down 1 (D1B)**	-57.86	-665.39	1565.18	-0.99978	0.00790	0.01919
		Down 2 (D2B)	-61.14	665.39	-1565.18	-0.99978	0.00790	0.01919
		Flat 1 (F1B)	-70.08	-1602.88	604.71	-0.61000	-0.26314	0.74743
		Flat 2 (F2B)	-68.89	816.51	1555.38	-0.61000	-0.26314	0.74743
		Up 1 (U1B)	281.67	1815.89	-808.48	0.45649	0.59118	0.66492
		Up 2 (U2B)	284.05	-1818.91	-805.16	0.47055	-0.55571	0.68540
	1N	**Spin Down (A1B)**	740.16	-716.16	1700.06	-0.28343	-0.67811	0.67811
		Spin Up (B1B)	740.16	-1700.06	716.16	-0.28343	-0.67811	0.67811

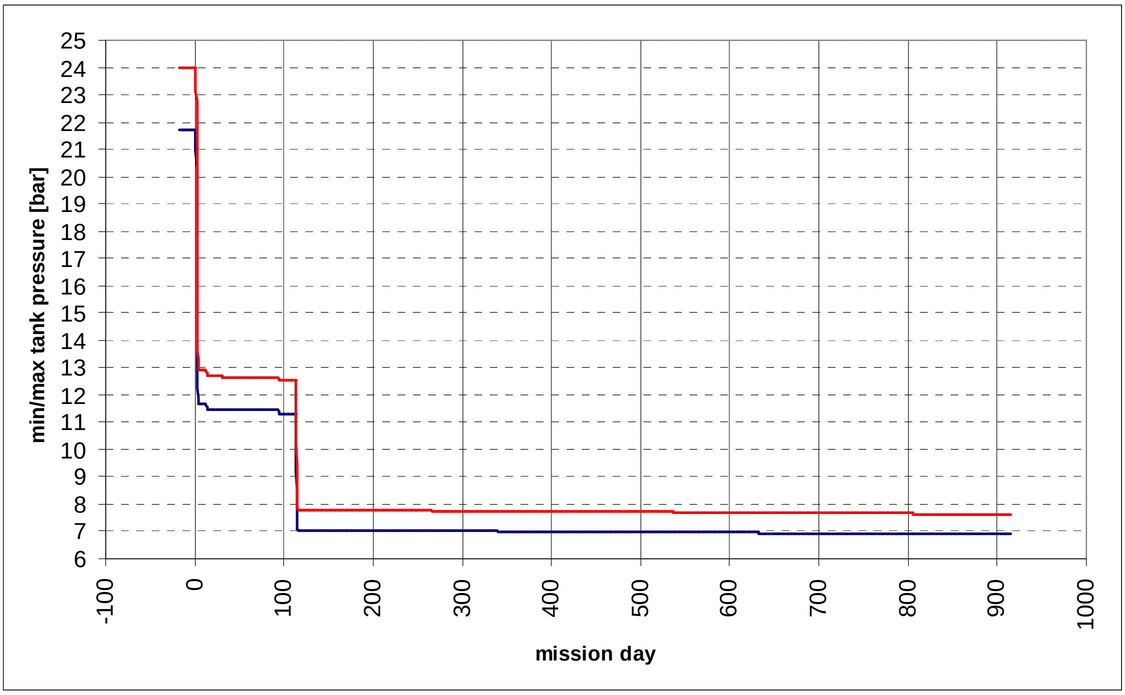
The torques generated by the nominal thrusters (forces of 20N and 1N), around the average centre of mass are:

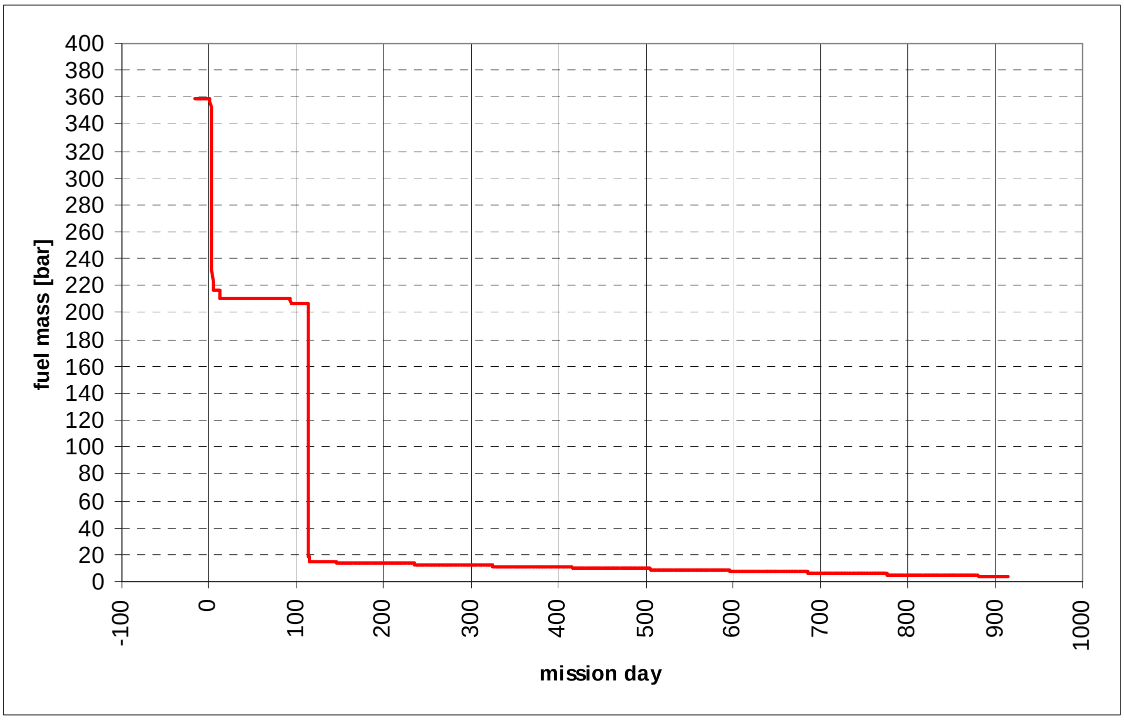
		Torque in S/C frame		
		Tx [N·m]	**Ty [N·m]**	**Tz [N·m]**
Branch A	**D1A (Down)**	0.47	31.30	11.51
	D2A (Down)	-0.47	-31.30	-11.51
	F1A (Flat)	21.88	-5.94	16.00
	F2A (Flat)	-21.88	5.93	-16.00
	U1A (Up)	-31.73	0.01	26.36
	U2A (Up)	31.72	0.01	-26.35
	A1A (Spin Down)	-0.68	0.46	0.17
	B1A (Spin Up)	0.65	0.18	0.45
Branch B	**D1B (Down)**	0.50	31.30	13.30
	D2B (Down)	-0.50	-31.30	-13.30
	F1B (Flat)	20.58	-5.81	14.75
	F2B (Flat)	-20.59	5.81	-14.76
	U1B (Up)	-33.60	-0.01	23.08
	U2B (Up)	33.60	-0.01	-23.08
	A1B (Spin Down)	-0.68	0.39	0.11
	B1B (Spin Up)	0.65	0.12	0.39

The two branches provide similar forces and torques.

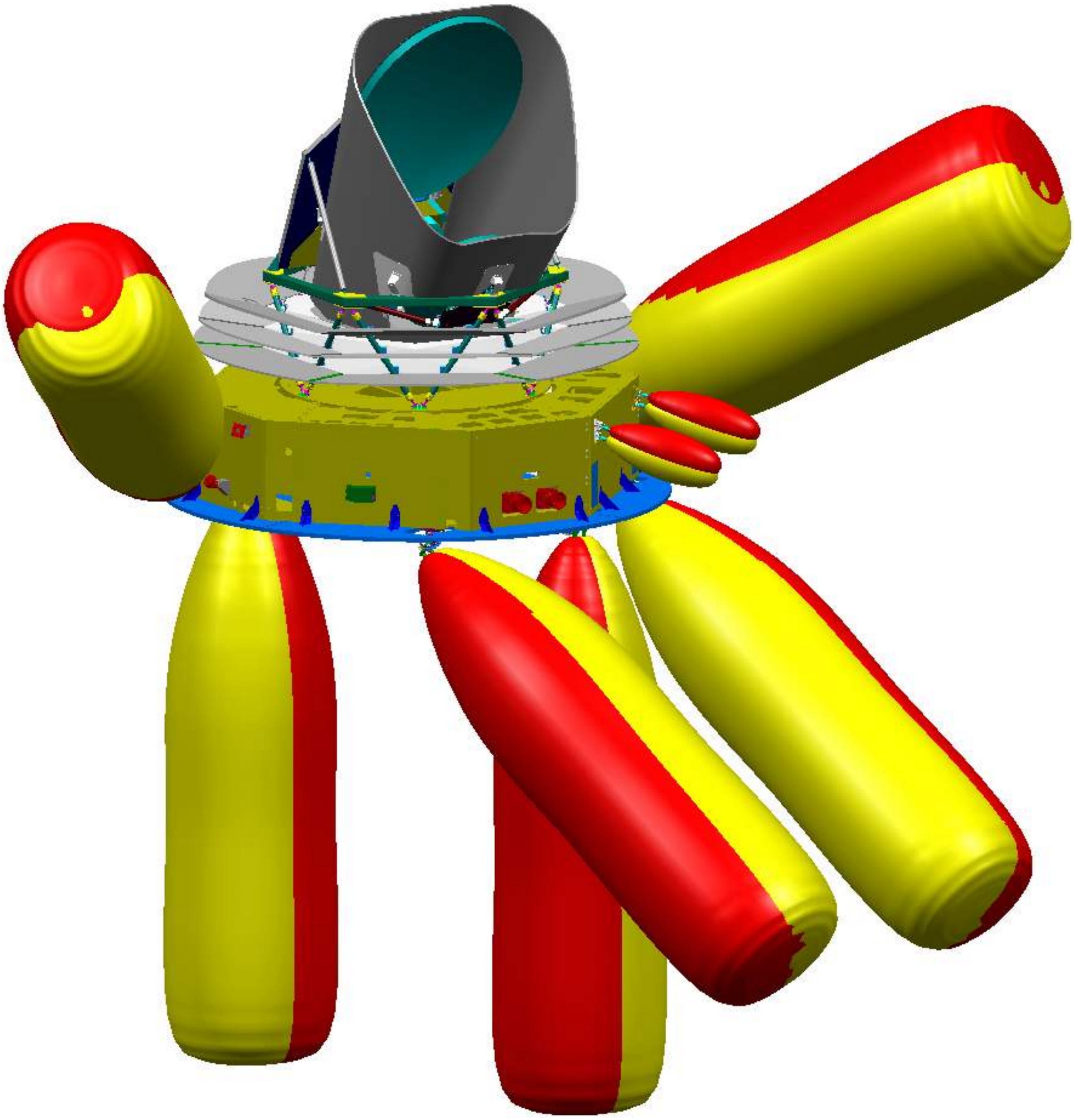
Due to the initial tank filling ratio, PLANCK 20-N thruster forces in steady state will be between 23.5N at BOL and 11.4N at EOL.

Assuming that the delta-V's are performed completely, a typical evolution of the pressure inside PLANCK tanks (with min and max temperatures) and of the remaining fuel mass is shown on the graphs below:


min/max tank pressure [bar]
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
-100
0
100
200
300
400
500
600
700
800
900
1000
mission day


fuel mass [bar]
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-100
0
100
200
300
400
500
600
700
800
900
1000
mission day

The following drawing shows PLANCK thruster plumes (6kW) for both nominal and redundant thrusters.



2.1.1.7.3.4. Thruster usage

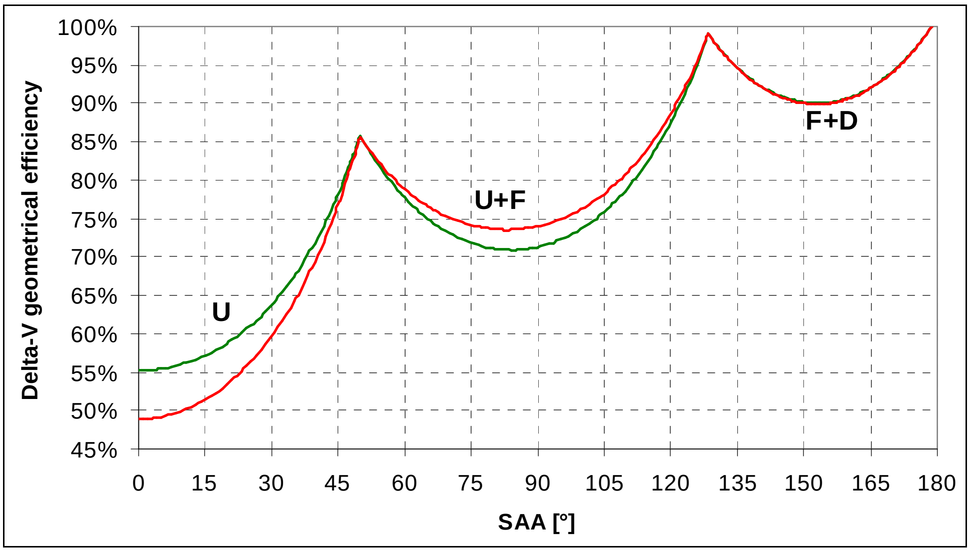
The following Table describes the different possibilities to use the thrusters.

Manoeuvre Type	Down thrusters	Flat thrusters	Up thrusters	1N thrusters
Orbit correction SAA<50 deg	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously, possibly Off-modulated.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously, possibly Off-modulated.	On-modulated to generate torque.	Not used
Orbit correction 50 deg<SAA<125 deg	On-modulated to generate torque.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously, possibly Off-modulated.	Thrust over one arc with adequate phase. Nominally two thrusters simultaneously, possibly Off-modulated.	Not used
Orbit correction 125 deg<SAA<180 deg	On-modulated to generate torque.	On-modulated to generate torque.	Thrust over either one arc or two opposing arcs with adequate phase. Nominally two thrusters simultaneously, possibly Off-modulated.	Not used
Torque generation	Pulse Mode	Pulse Mode	Pulse Mode	Not used
Re-orientation manoeuvre	Not used	Not used	Not used	A single thruster used three times (one pulse each time). Simultaneous use of two 1N thrusters to execute long slews

For all manœuvres, the maximum duty cycle is 6 continuous seconds every minute. The exception is for low SAA: the U thrusters can be fired twice every minute, still keeping a 10% ON - 90% OFF duty cycle.

2.1.1.7.3.5. Thrust geometrical efficiency

The following graph shows the thruster efficiency with respect to the Sun Aspect Angle, with the assumption that -X is pointing towards the Sun. Branch A in green, Branch B in red.



The efficiency curve has been computed with the Sun on -X, and assuming no modulation of the thrusters. PLANCK can be reoriented of 3.5° (maximum at BOL), and remains safe even in case of thruster failure. This small reorientation capability can be used to optimise the thrust efficiency. In particular, this helps reaching the maximum efficiency for the main injection, performed with an SAA of 125°.

The average efficiency over a sphere, assuming a uniform distribution is 78.5 % for both branches.

The maximum arc on which thrusters are continuously used is nominally 36°, changeable by command.

2.1.1.7.3.6. Latching valve usage

In order to cope with on ground and launcher safety regulations, the LV will remain closed during PLANCK ground operations.

In orbit, the latching valve commanding the redundant branch will remain closed. Only the nominal LV will be open. Thrusters of two different branches will then never be actuated simultaneously.

A typical sequence is:

	Latch Valve A status	Latch Valve B status
Launch	Closed	Closed
After Separation	Open	Closed
Reconfiguration	Closed	Closed
then	Closed	Open

2.1.1.7.3.7. Pressure transducer usage

The pressure transducer will be used to evaluate the remaining quantity of fuel. Its loss does not functionally constitute a single point failure, since the ACMS telemetry of the thruster usage will provide the necessary information to evaluate the consumed quantity of fuel. In addition, the ACMS maintains bookkeeping of all thrusts performed, which can be used as a back up to determine the pressure inside the tanks and the remaining quantity of fuel.

2.1.1.8. TTC subsystem design

This section describes the proposed architecture and design of the TTC subsystem on both HERSCHEL and PLANCK satellites.

This subsystem ensures a full X-X band TM&TC link with the ground stations, Kourou and New Norcia, and possibly Vilspa during the LEOP. It ensures reception of ground TC and downlink of all on-board housekeeping telemetries and instruments data. During the scientific observation phase, the Daily TeleCommunication Period (DTCP) with each satellite will last 3 hours per day and the high telemetry data rate, of 1.5 Mbps at user level, will be used to download the maximum amount of on-board data.

The uplink TC rate can be of 125bps (low bit rate 1) or of 4kbps (low bit rate 2), this for both HERSCHEL and PLANCK satellites. The capability of using the –preferred- LBR2 obviously depends on the distance between the satellite and Earth, and of the selected on-board antenna. Nominally, when at the final L2 orbit, the 4kbps bit rate can be used only with New Norcia ground station.

The difference in Gain between Low Gain Antenna (LGA) and Medium Gain antenna (MGA) is significative with –3dBi on aperture edges for the LGA and +12.8dBi for the MGA, but the second is obviously narrower (more directive) therefore cannot be used if the satellite antenna is not properly aligned with the Earth within a maximum aperture angle (15° maximum).

The spacecraft to Earth aspects angles have been optimised to cope with the different ground stations and associated performances. Kourou ground station is far less performant than New Norcia, with an EIRP by 16dB lower. Consequently, to keep the possibility of using Medium Gain Antenna (narrow beam) for high TC bit rate transmission, the satellites aperture angle (half cone) is reduced in that case from 15° to 10°.

All New Norcia link budgets are computed with an aperture half-cone angle of 15° whereas only 10° are used for Kourou.

The telemetry data rate (user rate) can be of 500 bps (LGA) or 150 kbps (MGA) with Kourou, and of 5K bps (LGA), 150 Kbps (MGA) or 1.5 Mbps (MGA) with New Norcia.

Originally, the following distribution concerning data rates, ground stations and antennas was required as baseline (SGICD):

Uplink

	LGA	MGA
Kourou	125 bps optionally 4Kbps up to 350 000km max	4 kbps
New Norcia	4 kbps	4 kbps

Downlink

	LGA	MGA
Kourou	500 bps optionally 5Kbps up to 750 000km max	150 kbps
New Norcia	5 kbps	1.5 Mbps

Then, after the system PDR, ESA required to analyse the possibility to transmit TCs at 4 Kbps, with Kourou with the LGA during the transfer phase. This has been analysed, see RF link budgets in H-P-BD-AI-005 § 3.2. The maximum distance between Earth and S/C that fulfils the 3 dB margin minimum on arithmetic link budget is 350 000 km.

An other scenario has been studied, that of transmitting LBR2 (5 Kbps) in TM, still with the LGA and with Kourou ground station. The maximum distance between Earth and S/C that fulfils the 3 dB margin minimum on arithmetic link budget is 750 000 km.

In addition, at the beginning of IOP, the 150kbps medium rate can be punctually used via LGA towards New Norcia to download the HERSCHEL VMC images.

2.1.1.8.1. TTC subsystem overview

Both TTC subsystems are fully identical at the exception of the PLANCK RFDN (RF distribution network) which slightly differs form the HERSCHEL one due to an increased number of redundant LGA's on PLANCK.

HERSCHEL/PLANCK satellites use a standard TTC architecture, which is also used for telecommunication data transmission to the ground (no separate channel):

- The TC receivers are operated in hot redundancy and deliver the telecommand stream together with indications of the lock and signal strength to two hot redundant TC decoders located inside the CDMU. The addressed decoder is then capable to select the valid signal from a priority based scheme

– The transmitting chain is operated in cold redundancy. It is composed of 2 TM transmitters, and 2 TWTA's RF power units plus the switches network and antennae. Each TTC transmitter (Tx) receives a concatenated encoded NRZ-L bit stream from both CDMU TM encoders, and subsequently performs all baseband filtering (spectrum confinement) and the carrier modulation.

Whereas the receiving chain is permanently ON (essential loads), even during launch (it cannot actually be switched OFF), the transmitting chain is only turned ON at separation to make the link to ground available three minutes after, at the end of the TWTA/EPC (main bus power converter) so called 'preheating mode'. Then the Tx section ON time is limited to the Daily TeleCommunication Periods mainly to avoid the disturbance of the scientific operations.

The different phases of the mission have led to different antennas and different bit rates, on both uplink and downlink. The required flexibility has been implemented in a very reliable switch network, called RFDN for Radio Frequency Distribution Network which, depending on the mission phase, connects the right antenna to the TC and TM paths.

The transponders can be commanded and monitored either via analogue lines or via the 1553 Bus, while the TWTA's and RFDN are using exclusively analogue lines.

The transponder design also offers range and Doppler measurements capabilities through the selectable ranging and coherent modes (same phase on uplink and downlink carriers). The ranging can be used in all modes except the High data rate (GMSK).

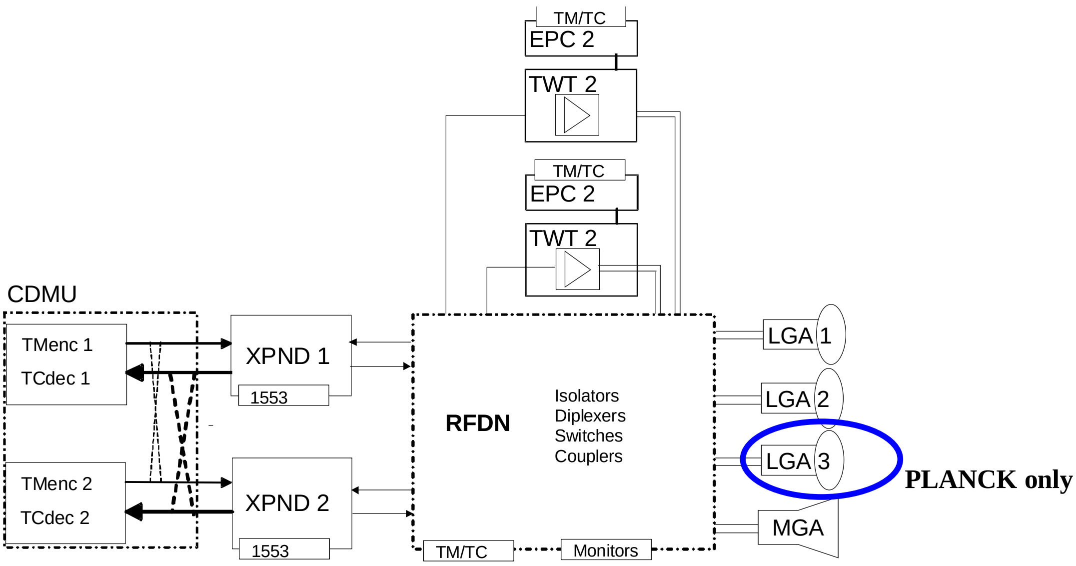


Figure 2-25 HERSCHEL/PLANCK TTC subsystem redundancy concept

CDMU dynamic mode ó TC receiver selection

Taking benefit of the large heritage in ESA project on multiple antennas systems, and also to avoid past problems (XMM) of wrong selection between two receivers, the CDMU supplier (SAAB) has now developed an automatic selection system, called 'dynamic mode'. This automatism will connect the active TC decoder to the strongest signal-to-noise ratio from the two TTC receivers.

By default, each TTC receiver provides a telemetry called "squelch" ensuring (when at HIGH) that a minimum in-loop TC carrier signal-to-noise ratio is achieved, thus allowing a proper TC decoding to the CDMU though this telemetry does not discriminate which receiver receives the strongest signal if both reach this minimum TC carrier in loop signal to noise ratio.

The CDMU dynamic mode, during the decoding process, in case of bit slippage or flip, will autonomously decide to switch to the other receiver.

2.1.1.8.2. TTC transponder and TWTA

The transponder is a new design, full X-band transponder built by AEO, making use of their large experience in S-Band transponders. The phase demodulator ASIC is totally re-used in this new design with a gain adjustment in the LNA module to comply with the L2 low carrier level (about - 140 dBm).

Up and down-conversion modules have been also added to move from S-Band to X-Band frequencies.

The GMSK modulation, like the low bit rate and medium bit rate modulations are digitally shaped in base-band (FPGA technology) and then modulate the RF carrier with an analogue I/Q phase modulator.

This unit provides low level signal acquisition and tracking (the TC carrier), and baseband processing (modulation and filtering) of the downlink telemetry carrier.

Both modulations and TC/TM bit rates are adjustable by telecommand, as well as the down link phase modulation indice (telemetry and ranging indices).

To supply the necessary RF power at L2 (1.8 million km) an external amplifier (TWTA) has been added to the transmit chain.

NOTE: The TTC transponder RF output power is settled within [- 6; + 3] dBm, which is still a very low power (mw).

The TWTA is supplied by ETCA, and can be splitted in a 35 W X-Band tube manufactured by THALES and an EPC from ETCA. The tube is very similar to the ROSETTA one and the EPC is derived from previous 1500 V EPCs.

2.1.1.8.3. Antennas

Low Gain Antenna

For both HERSCHEL and PLANCK satellites, omni-directional coverage is targeted by using a set of low gain antennas offering a -3dBi gain over an hemispherical coverage as shown on the following artistic views:

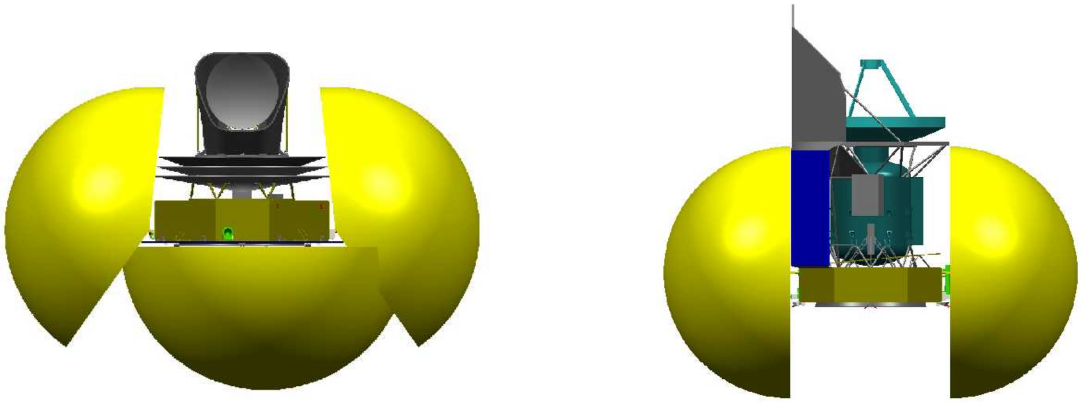


Figure 2-26 Low Gain Antennas (LGA's) location - combined coverage

Three antennas have been necessary on PLANCK in order to cope with the impossibility to install any antenna on +X axis (telescope side).

At system level a GTD analysis has been conducted for PLANCK to quantify the impact of the structure on the resulting LGA pattern. One outcome of this analysis has been the optimisation of the lateral LGAs tilt angle (35°) with respect to the SVM structure.

The following curves give the percentage of coverage in TC and TM for the various Herschel antenna configurations (LGA1, LGA2, LGA1+2)

With the nominal TC gain of –2dBi and TM gain of –3dBi, used in the TTC link budgets, the Herschel LGAs combined coverage lead to a percentage of about 94% in TC and 90% in TM.

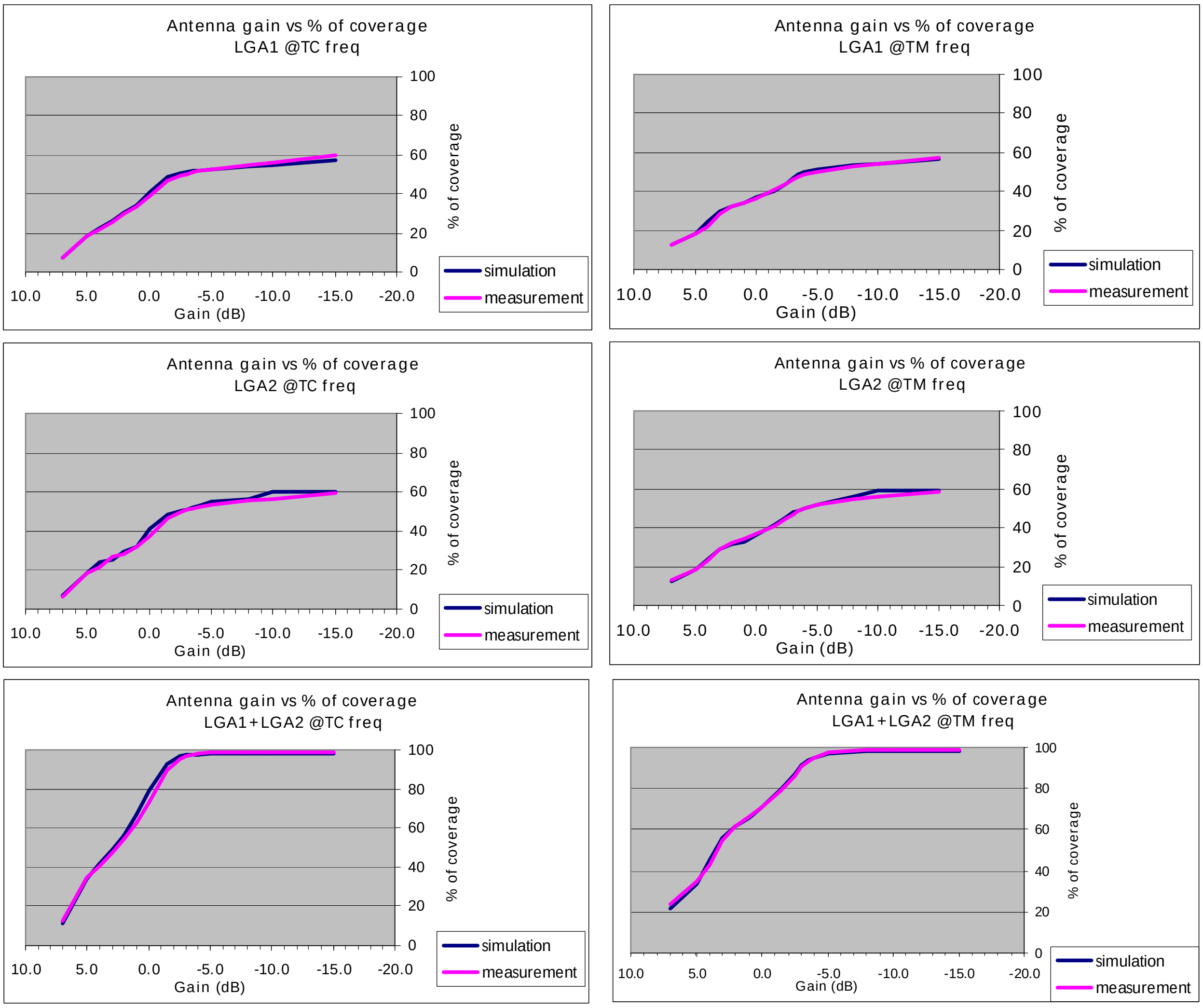


Figure 2-27 Herschel antenna coverage

The following curves give the percentage of coverage in TC and TM for the various Planck antenna configurations (LGA1, LGA2+3, LGA1+2+3)

Combining all 3 antennas, a coverage of 99% in TC and TM is obtained for –10dBi. Using New Norcia, this would allow to establish contact with the satellite in any attitude with data rates of 125 bps in uplink and 500 bps in downlink. This is also applicable to Herschel.

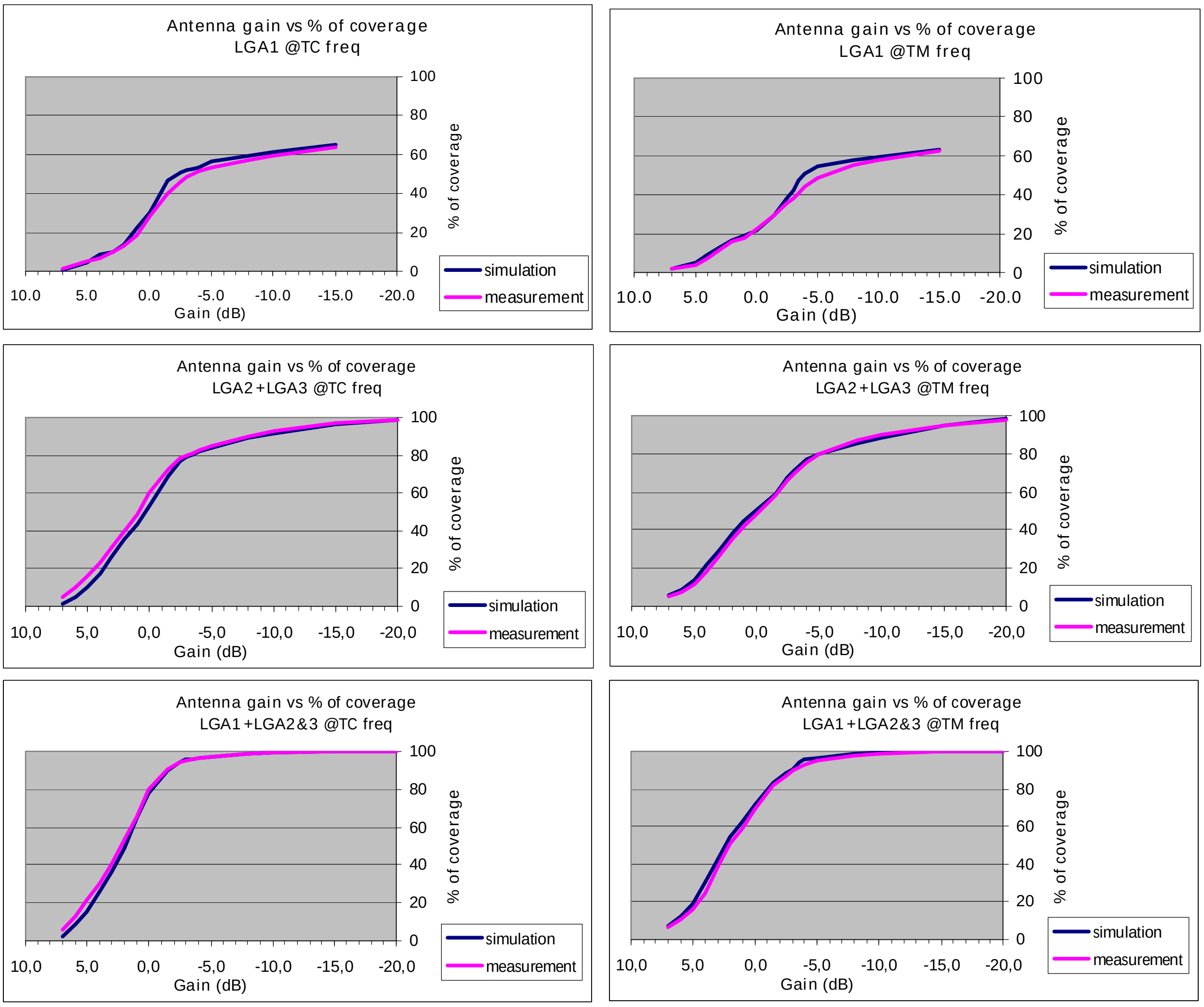


Figure 2-28 PLANCK antenna coverage

Medium Gain Antenna

A Medium Gain Antenna (peak gain 18dBi) is also installed on each satellite to give the necessary gain to RF link budgets when transmitting the high data rate (1.5 Mbps).

This antenna, also manufactured by RYMSA, offers about 16 dBi at 10° half cone angle and about 13 dBi at 15° half cone angle.

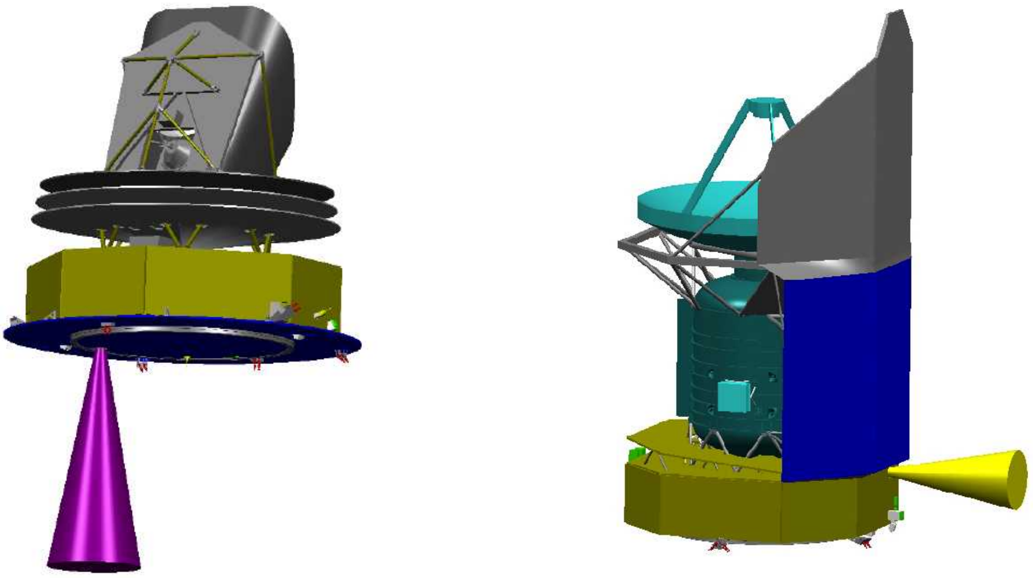


Figure 2-29 Medium Gain Antennas (MGA) location

2.1.1.8.4. Antennas switching network (RFDN)

This network is simplified to the maximum extent to reduce the complexity (reliability) and also the associated insertion losses that directly impact the RF link budgets margins.

The RFDN is split between an ‘internal RFDN’ installed on the SVM RF panel together with both TWTAs, transponders, and an ‘external RFDN’ composed of a succession of waveguides installed around the SVM central part (cone).

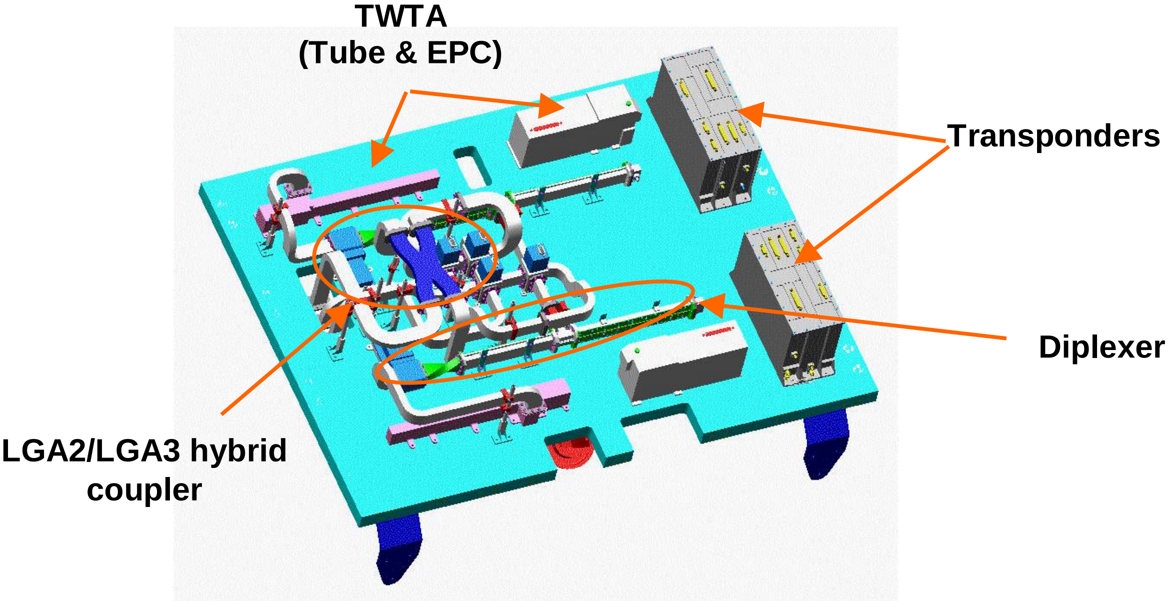
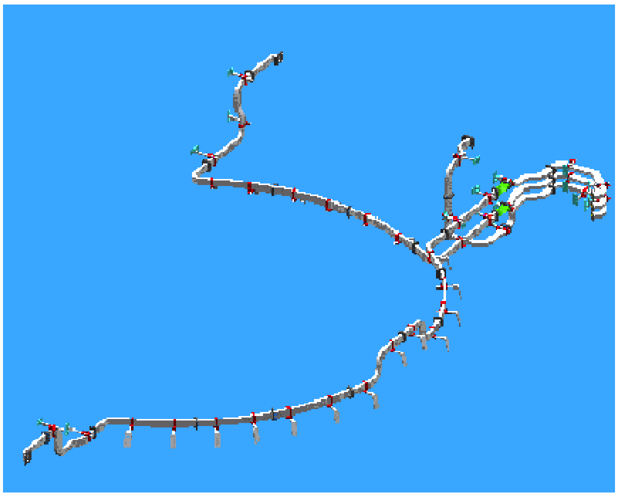
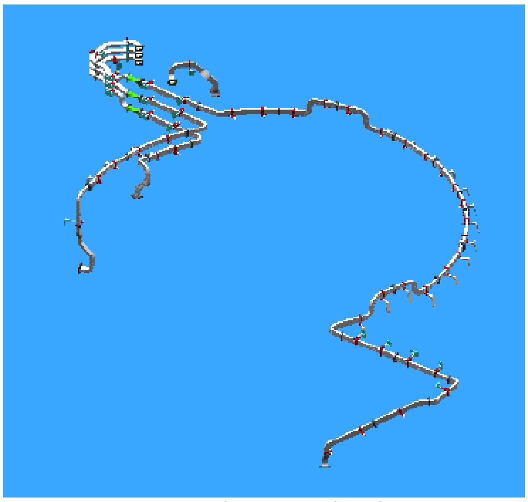


Figure 2-30 SVM RF panel with internal RFDN



External RFDN Herschel



External RFDN Planck

Figure 2-31 RFDN external parts (waveguides)

The proposed RFDN architecture can be split into a low power section using coaxial cables connected to the TC receivers, and a high power section connected to the high power tube amplifiers (TWTA). To minimise passive losses from the transmit section to the antennas, waveguide technology has been used.

To give an order of magnitude of the insertion losses:

Rx losses (from antennas to receivers)

- Nominal LGA
  - HERSCHEL (LGA1 to Rx): 2.2dB
  - PLANCK (LGA1 to Rx): 1.77dB
- Redundant LGA (wc)
  - HERSCHEL (LGA2 to Rx): 2.43dB
  - PLANCK (LGA2 to Rx): 6.27dB (hybrid in between)
- Medium Gain Antenna (MGA)
  - HERSCHEL (MGA to Rx): 2.85 dB
  - PLANCK (MGA to Rx): 1.8db

Tx Losses (from TWTA to antenna)

- Nominal LGA
  - HERSCHEL (LGA1 to Rx): 1.85dB
  - PLANCK (LGA1 to Rx): 1.57dB
- Redundant LGA (wc)
  - HERSCHEL (LGA2 to Rx): 2.08dB
  - PLANCK (LGA2 to Rx): 5.97dB (hybrid in between)
- Medium Gain Antenna (MGA)
  - HERSCHEL (MGA to Rx): 1.57 dB
  - PLANCK (MGA to Rx): 1.5dB.

2.1.1.9. Thermal control description

2.1.1.9.1. Thermal control overview

2.1.1.9.1.1. Service module

The SVM thermal control design is described in details in H/P TCS design description, doc. H-P-RP-AI-0039.

The main features are highlighted in the following:

- Extensive use of passive hardware: radiator, solar reflector, Multi Layer Insulation, fillers, washers, heat pipes

- Local use of active hardware on units and panels: heaters powered by the PCDU and controlled via thermistors by the on board software implemented in the CDMU. The "majority voting" law rules the selection of the temperature amongst the three thermistors implemented for each heating line. The power injection is made by standard ON/OFF law according to thresholds values adjustable in flight.

For HIFI units and star trackers on HERSCHEL, the power injection is made through a train of pulses with a frequency of 1 Hz, the needed power is computed every 10s using a standard Proportional Integration (PI) software.

2.1.1.9.1.2. HERSCHEL payload module

The thermal control design of the HEPLM is described in HERSCHEL EPLM design description, doc. HP-2-ASED-RP-0003.

The central part of the HEPLM is the Cryostat Vacuum Vessel (CVV). It provides a cold environment to the three instruments using the evaporation of superfluid helium.

The CVV is strongly thermally uncoupled from its environment in order to achieve an external temperature of ~70K. The lifetime is limited by the amount of superfluid helium and the heat leaks on the tank.

The CVV also carries the telescope, the LOU, the sunshield/sunshade and the star trackers.

The thermal control of the HEPLM is purely passive, using CFRP struts, Multi Layer Insulation, high emissivity radiator, conductive links and cooling by the vapour of evaporated helium.

2.1.1.9.1.3. PLANCK payload module

The PPLM is a cryogenic payload operating between ~ 150 K and 0.1 K at its coldest point.

The Payload is made of the main following components:

- An optical baffle, which also serves as a cryogenic radiator on its external side
- A set of three so-called "V-groove" shields, which provide the high level of radiative insulation between the warm SVM and the cryogenic radiator. The shield temperatures range from around 150 K (Shield 1) down to between 50 K and 60 K (Shield 3)
- A cryo-structure, which supports the different shields and radiator while providing conductive thermal insulation from the SVM
- A telescope, made of one primary reflector (1.5 m) and of one secondary reflector
- A Focal Plane Unit (FPU), which houses the instruments detectors as well as the cold ends of the cryogenic chain
- A cryogenic chain composed of three coolers, 20K sorption cooler, 4 K mechanical cooler and 0.1 K dilution cooler. The coolers units are spread over SVM and PLM.

The main feature of the overall PLANCK spacecraft thermal design lies in high level of thermal insulation required between the two modules forming the spacecraft. This feature is mandatory to achieve the low temperature requirements on the payload and also to minimise the level of straylight generated by the SVM onto the instrument detectors.

Thermal insulation between SVM and PPLM is implemented at the following levels:

- PPLM supporting truss: this truss is made of 12 GFRP struts for conductive thermal de-coupling. The inner volume of struts is filled with ECCOFOAM foam in order to avoid radiative exchange between hot and cold ends
- Top of SVM, including SVM upper closure panel, PPLM sub-platform and instruments warm units mounted onto the sub-platform (BEU/DAE and PAU)
- Back side of the external Solar Array.

High efficiency MLI blankets are installed on the elements described above in order to minimise the radiative loads onto the PPLM. To enhance the radiative insulation, MLI external layers are aluminium coated as for HERSCHEL.

2.1.1.9.2. Thermal Operating constraints

The following constraints imply a ground control intervention:

- SOHO case recovery scenario: the activation of the TCS heating lines will have to be delayed until the Sun acquisition is complete (refer to H/P SOHO thermal analysis, PLANCK scenario 2, doc. H-P-TN-AI-0070)

- Herschel HIFI units (according to Thermal Analysis Report H-P-RP-AI-0040 iss9):
  - § after a change of attitude (SAA) a maximum time of **10** minutes is necessary to reach the requested stability requirement (0.3 mK/s) for all HIFI units.
  - § after a change of HIFI units mode (from Stand-By to Prime mode) a maximum time of **10** minutes is necessary to reach the requested stability requirement (0.3 mK/s) for all HIFI units with the only *exceptions of **LCU** and **LSU** units*.

    For the **LCU** unit the requested stability requirement (0.3 mK/s) is met **after 220 minutes** with SAA=-30° (hot case) and **80 minutes** with SAA=+30° (cold case).

    For the **LSU** unit the requested stability requirement (0.3 mK/s) is met **after 160 minutes** with SAA=-30° (hot case) and **10 minutes** with SAA=+30° (cold case).

- Herschel SPIRE units (according to Thermal Analysis Report H-P-RP-AI-0040 iss9): after a change of SPIRE units mode (from Stand-by to Photometer) a maximum time of **105** minutes is necessary to reach the requested stability requirement (3 K/hour) for HSDCU.

- PLANCK warm radiator temperature adjustment: should the temperature of the SCC beds need to be adjusted in flight, the following procedure shall be executed step by step :

  1a- Assess the current minimum temperature measured on the 6 active beds (using the list of sensors in PL-LFI-PST-PR-025, p.51) => **JPL** (Tbed_current)

  1b- Assess the current TCS thermistors triplet temperature measured on the heat pipes (TCS_current=TM055602+TM103602+TM151602/3) => **ESOC**

  2- Determine the requested new temperature level => **JPL** (Tbed_new), the operating range [260;280K] shall not be exceeded

  3- Modify the FCCT low_op limit (loops index : 27-28, 32, 12-14, 8) if : [TCS_current - FCCT_low_op] < [Tbed_current - Tbed_new] +1 => **ESOC**

  4- Modify the OOL_low_op limit (loops index : 27-28, 32, 12-14, 8) if : [TCS_current - OOL_low_op] < [Tbed_current - Tbed_new] +1 => **ESOC**

  5- Shift down the thresholds of the loops index : 27-28, 32, 12, 8, 14, 13 in this exact sequence by the [Tbed_current - Tbed_new] => **ESOC**

  6- Repeat all previous steps in case of any reconfiguration

– FDIR Cross Correlated Table adjustment on ground/in-flight: the FCCT thermal settings defined for flight can generate some alarms on the launch pad due to some units being too cold or too hot. To avoid such alarms, the FCCT limits relative to these units shall be modified on the launch pad. Once in flight, the default FCCT values for each concerned unit shall be restored once it achieves the required temperature.

The attitude of HERSCHEL satellite shall be constrained according to H-EPLM Requirements Specification, doc. H-P-2-ASPI-SP-0250, to meet the thermal performance. From launcher separation, the H-EPLM shall remain in the following Sun centre directions:

– Between -1° and +1° from the (XHSC, ZHSC) plane

– Between +60° and +120° from the +XHSC axis.

For DTCP longer than 3 hours when HERSCHEL telecommunication with New Norcia, it is necessary to maintain the satellite within [0; +30°] SAA range (cold SAA) to avoid exceeding of temperature on TTC units.

From launcher separation to the end of the mission, PLANCK attitude is constrained so that the Sun direction remains below 10° from Xs spacecraft axis.

2.1.1.9.3. HERSCHEL telescope decontamination

A decontamination will be performed on HERSCHEL telescope starting during the LEOP. The temperature of the telescope shall remain above 313K for three weeks.

The cryo-cover will be opened only after the cool down of the telescope.

2.1.1.9.4. PLANCK telescope decontamination

There are two different operating modes for the PLANCK telescope decontamination:

- Anticontamination during the launch phase, shall be activated after SYLDA separation in order to maintain the instruments and reflectors hot enough to avoid any contamination during the transfer orbit.

- In orbit phase decontamination may be used from operational conditions to warm-up cold optics and instruments in case of pollution.

The decontamination thermal control is composed of heating lines and thermal sensors implemented on the primary reflector, the secondary reflector, FPU/HFI and FPU/LFI.

The installed power will allow to warm each element up to –20°C.

2.1.1.10. SREM design

2.1.1.10.1. SREM overview

The Standard Radiation Environment Monitor (SREM) is a monitor-class instrument intended for space radiation environment characterisation and radiation housekeeping purposes. SREM will provide continuous directional, temporal, and spectral data of high-energy electron, proton, and cosmic ray fluxes encountered along the orbit of the spacecraft, as well as measurements of the total accumulated radiation dose absorbed by the SREM itself.

The SREM may be operated in two different modes, a standard SREM mode and an IREM mode initially developed for the SREM unit on the INTEGRAL spacecraft. The IREM mode is identical to the standard SREM mode plus a few additional commands enabling automated SREM operation requiring no intervention from the CDMS for multiple accumulations. During the HERSCHEL/PLANCK mission, the standard SREM mode is employed. When powered ON, the SREM is always started in standard SREM mode.

The SREM operations to be performed during HERSCHEL/PLANCK mission are defined in the SREM User Manual, doc. SREM-UM-CSAG-003, which is reflected into section 5.1 of this document, in the SREM HERSCHEL/PLANCK Software User Requirements Document, doc. H/P-SREM-SURD-V004 and in ESA fax SCI-PT-19535.

The SREM hardware interface definition is comprehensively covered in the SREM Interface Control Document, doc. SREM-DI-CSAG-003.

The SREM is connected to the CDMS to which it communicates via OBDH standard serial links (DS16 and ML16).

There is only one SREM per spacecraft (no redundancy).

2.1.1.10.2. SREM management

The switching ON/OFF of the SREM is performed by ON/OFF command to the associated LCL#19 using the CDMU ASW "PCDU management function" (refer to H/P CDMU ASW User Manual, doc. H-P-4-SSF-MA-0001, and to H/P CDMU ASW Software Interface Control Document, doc. H-P-4-SSF-IC-0001).

To perform SREM ON/OFF switching, the PCDU management function TC packets to be used are defined into HPSDB with the following references (correspondence with H/P CDMU ASW Software Interface Control Document is also given in the following Table):

HPSDB		CDMU ASW ICD	
Reference	**Description**	**Reference**	**Description**
DC01A170	Start_PCDU_Management	TC(8,1,112)	Start PCDU Management
DC02A170	Stop_PCDU_Management	TC(8,2,112)	Stop PCDU Management
DC19D170	PCDU_LCL_19_SwOn	TC(8,4,112,5) for PCDU Unit : LCL#19	Switch PCDU Unit ON (LCL#19)
DC19B170	PCDU_LCL_19_SwOff	TC(8,4,112,3) for PCDU Unit : LCL#19	Switch PCDU Unit OFF (LCL#19)

On receipt of **DC01A170**, handling of "Perform activity of PCDU management function" TC packets: TC(8,4,12,x) will be enabled.

On receipt of **DC02A170**, handling of "Perform activity of PCDU management function" TC packets: TC(8,4,12,x) will be disabled.

On receipt of **DC19D170** and **DC19B170** TC packets, OBSW will generate the appropriate message to PCDU on 1553 spacecraft control bus.

Apart from the switching ON/OFF of the SREM, the complete SREM management is handled by the CDMU BSW (refer to BSW Software User's Manual, doc. H-P-4-SES-NT-0029 and to CDMU Interface Control Document for BSW, doc. H-P-4-SES-NT-0076).

A dedicated SREM function has been designed via Packet Service #8. This function is responsible for:

- Verification and execution of below SREM TC packets by translating requests into SREM-commands on the ML-line
- Acquisition of SREM accumulation data and packetisation in dedicated TM(8,7) packets. These packets are handled as any other TM packets, i.e. sent to a selected SREM Packet Store in the SSMM and/or real time Virtual Channel zero according to the setting of the different TM configuration tables [transmit/storage flag set by TC(14,5), Packet Store definition set by TC(15,x)…].

By telecommand, it is possible to perform the following activities:

- Start/Stop cyclical SREM data accumulation
- Dump SREM memory
- Load SREM patch
- Set/Get SREM registers.

The packets handled by the SREM function are defined into HPSDB with the following references (correspondence with the CDMU Interface Control Document for BSW is also given in the following Table):

HPSDB		CDMU BSW ICD	
Reference	**Description**	**Reference**	**Description**
TC packets			
DC811160	StartCycSREMAcq	TC(8,4,4,1)	Start Cyclic SREM Acquisition
DC812160	StopCycSREMAcq	TC(8,4,4,1)	Stop Cyclic SREM Acquisition
DC813160	DumpSREMMem	TC(8,4,4,2)	Dump SREM Memory
DC814160	LoadSREMPatch	TC(8,4,4,3)	Load SREM Patch
DC815160	SetSREMReg	TC(8,4,4,6)	Set SREM Register
DC816160	GetSREMReg	TC(8,4,4,7)	Get SREM Register
TM packets			
040808160	SREMMemoryDump	TM(8,7,4,2)	SREM Memory Dump
040809160	SREMRegContents	TM(8,7,4,7)	SREM Register Contents
040810160	SREMAccumulationData	TM(8,7,4,20)	SREM Accumulation Data
040811160	SREMTotalDoseData	TM(8,7,4,21)	SREM Total Dose Data

The execution of these TC's is done according to the following state machine:

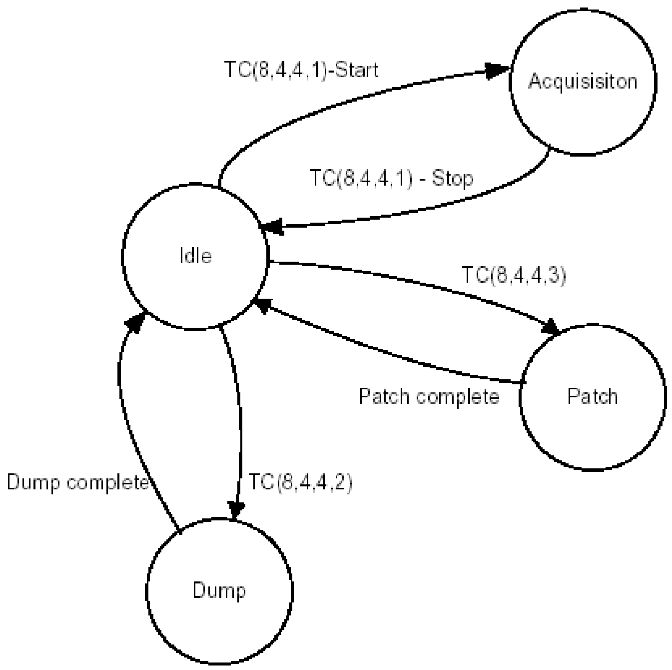


Figure 2-32 OBSW SREM states

Where the states are:

- Idle, when no acquisition, load or dump is on going
- Acquisition, when SREM accumulation and total dose data is acquired and delivered
- Patch, when a patch received by TC(8,4,4,3) is loaded into SREM memory
- Dump, when a requested SREM memory area is read from the SREM and reported in TM.

In any of the states above, SREM register read or write access may be performed in parallel.

Acquisition, patch and dump are mutually exclusive.

2.1.2. Specific HERSCHEL units

2.1.2.1. HERSCHEL Cryostat Control Unit design

2.1.2.1.1. CCU overview

The Cryostat Control Unit (CCU) will be mounted on the HERSCHEL spacecraft's Service Module (SVM) as one part of cryogenic cooling system for cold units of scientific instruments in Extended Payload Module (EPLM).

The CCU will be powered via a LCL by the PCDU and operated by the CDMU via MIL-Std 1553B bus interface.

The CCU will provide operational access to the cryostat instrumentation as well as to the HSS sunshade and telescope temperature sensors. Through its user interface the CCU will monitor the cryostat status by acquisition of the pressure and temperature sensor readings, will operate and monitor the Helium content measurement system and will operate the cryogenic-valves as well as acquire their status indicators.

There is one internal redundant CCU (A/B) on HERSCHEL. The CCU (A/B) can be operated in hot redundancy (A/B ON) which is the operating baseline. It is also possible to operate A (power ON) and B (power OFF) or vice versa.

2.1.2.1.2. Main functions

The main functions of the CCU are to:

- Provide operational access to the cryo instrumentation during ground testing and throughout the various mission phases till the end of the mission

- Operate the cryo instrumentation via its user interface consisting of dedicated interface lines to the various sensors and actuators of the cryo system
- Provide cryo control system monitoring by sequential acquisition of all pressure, temperature and He valve status sensors readouts
- Activate 6 He valves (three within CCU A, three within CCU B), according to related arming and switching commands
- Activate Direct Liquid Contents Measurement (DLCM) by triggering an automatic sequence of events
- To be able to interface with an armed DLCM heater and measure its current and voltage
- Provide an Auxiliary DC/DC Converter for internal use
- Provide the interface to the data handling subsystem (CDMS) via a Mil Std 1553 B bus
- Provide the interface to the electrical power subsystem (EPS) via dedicated power - lines controlled by the PCDU
- Provide the discrete He valves interfaces controlled by the launcher during the ascent
- Provide unit housekeeping monitoring by sequential acquisition of all housekeeping parameters necessary for the determination of the units health status
- Provide internal redundancy with identical functions. The nominal unit is CCU A and the redundant unit is CCU B. The redundancies are electrically isolated from each other and isolated with a metallic wall. Each part (A/B) of the CCU monitors and controls the same amount of sensors but a different set of sensors
- Provide adequate failure tolerance and protection circuitry to avoid failure propagation
- Operate as a non-intelligent unit. Commands and telemetry transfer will be controlled by the CDMU.

The functional block diagram of the CCU is presented in Figure 2-33.

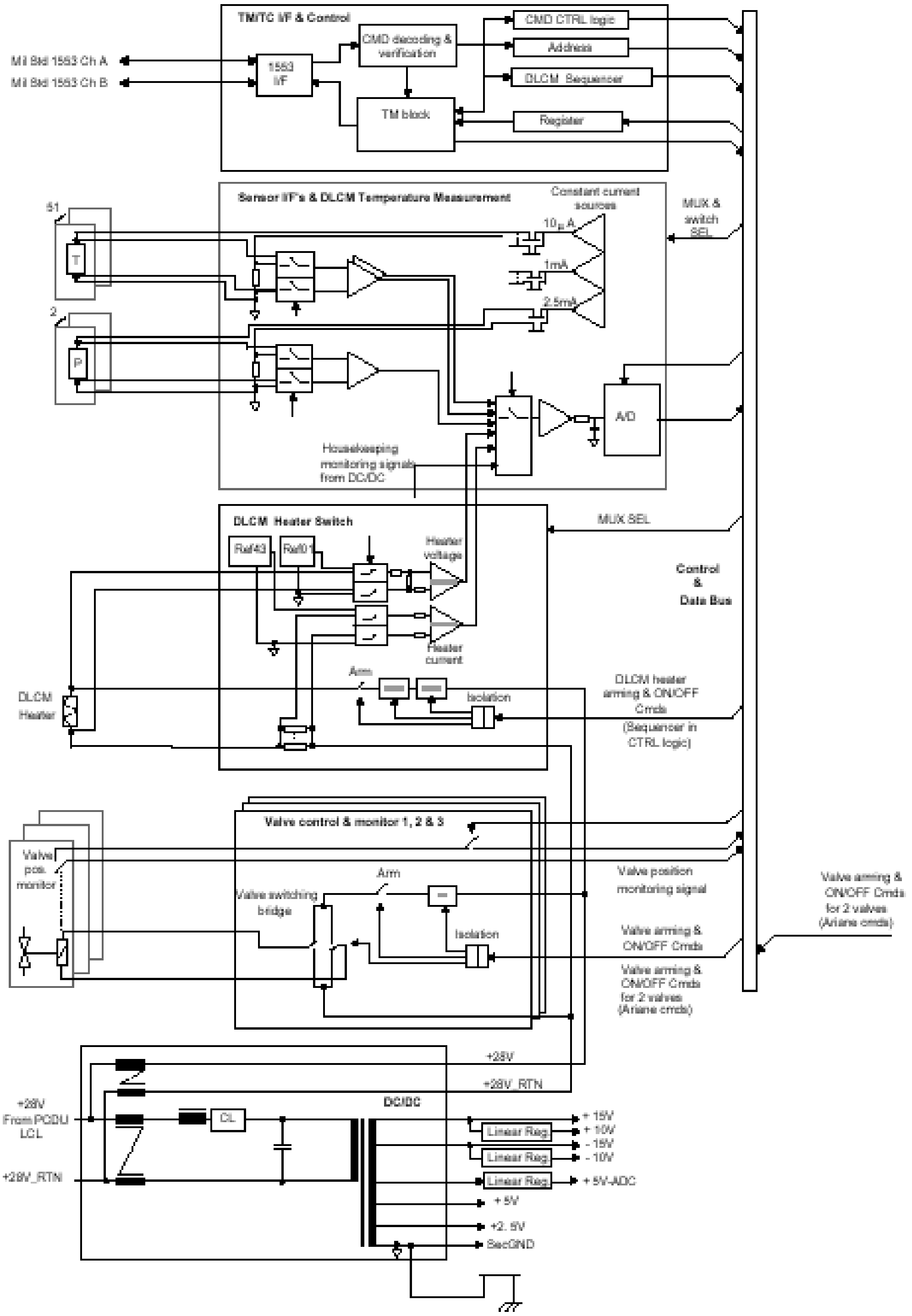


Figure 2-33 CCU block diagram

2.1.2.1.3. CCU management

The CDMU OBSW is responsible for the acquisition of the CCU telemetry via the S/C 1553 bus according to bus profile definition and current CCU mode.

In flight, each CCU can be asked to enter into the following main modes:

- Monitoring (nominal mode)
- DLCM (foreseen twice per year)
- LHe valve commanding.

On request to perform CCU mode transition (for each CCU half) via a dedicated Service#8 TC, the CDMU OBSW sends the related 1553 messages to the CCU in order to acquire the complete set of data associated to each CCU mode. The full set of data will only be available after a certain time from the request (up to 4s), depending on the requested number of parameters. New set of data is only acquired upon request initiated from the CDMU SW.

When commanded in **DLCM mode**, nominally via a dedicated CCU_DLCM TC originated from ground, the CDMU OBSW has to packetise all the received data into dedicated telemetry packets. These packets are handled as any other TM packets, i.e. sent to a selected Packet Store in the SSMM and/or real time Virtual Channel zero (VC0) according to the setting of the different TM configuration tables [transmit/storage flag set by TC(14,5), Packet Store definition set by TC(15,x)…]. The data in that mode is only for ground purpose and is not supposed to be processed on-board.

When commanded in **Monitoring Mode** via a dedicated CCU_Monitoring TC originated from ground, the CCU is cyclically commanded by the CDMU SW to initiate Monitoring measurement sequences. The acquired data is stored in the CDMS datapool from which it can be extracted and put in housekeeping packets and monitored. E.g. some data acquired in Monitoring Mode (telescope temperatures) are used by the decontamination heating algorithm (the decontamination algorithm will check that the CCU is in Monitoring Mode before starting). The CCU provides also the monitoring of temperature sensors involved in the recycling of HERSCHEL instrument sorption coolers.

The baseline is to periodically send a Monitoring Mode request to the CCU in accordance with the mission monitoring needs (typically between 4s and 3600s), and in parallel transfer the monitoring parameters to the CDMS datapool at a rate consistent with the 1553 Bus profile period, i.e. nominally every 1s.

Before launch, the CCU monitoring mode cycling value will be set to 8 seconds to allow for LHe valve open/close status control.

In operational phase, the CCU monitoring period shall be set by default to 512 seconds and all the monitoring parameters shall be acquired.
It is under ground responsibility to properly set the monitoring period and associated list of data to be measured during instruments recycling and decontamination heating phases, and to activate/deactivate related HK packets. In these cases, it is recommended to set a monitoring period of 8 seconds.

The telescope decontamination shall start early after the launch and will nominally last three weeks.

PACS and SPIRE recycling operations are planned to be performed every 2 days during 2.5 hours, with the following constraints:

- The instruments shall be in standby / cooler recycling mode.
- The Cooler recycling shall be performed during the DTCP. During this period, the detectors are heated up to 2K and can not be used (no observation possible)
- HIFI may continue observation during cooler recycling, but some temperature fluctuations at the interfaces are expected.

The **LHe valve commanding mode** will be used to change the status of liquid He valves from open to close or vice versa. The switching of the valves is performed by a single command via the CDMU to the CCU.

In parallel with the 3 above modes, the CCU housekeeping data is routinely acquired (period is 1s) and stored in the datapool.

A very simple FDIR will be applied to the CCU: the CCU will be checked to be in the mode it has been commanded (this is mainly to avoid DLCM to be triggered when not requested, upon CCU failure; this would indeed impact HERSCHEL cryostat lifetime).

In addition, one FDIR mechanism implemented by the CDMU BSW allows to detect communication problem with the CCU on the S/C 1553B bus. When such a problem is detected, the CDMU BSW raises a specific event report, TM(5,X,158) when the CCU A is invalid, TM(5,X,159) when the CCU B is invalid, and stops the decontamination heating.

Apart this FDIR mechanism, no event monitoring is required for any acquired CCU parameters.

The PCDU management function TC packets to be used are defined into HPSDB with the following references (correspondence with H/P CDMU ASW Software Interface Control Document is also given in the following Table):

HPSDB		**CDMU ASW ICD**	
Reference	**Description**	**Reference**	**Description**
DC10M170	Start_Payload_Management	TC(8,1,111)	Start Payload Management
DC11M170	Stop_Payload_Management	TC(8,2,111)	Stop Payload Management
DC37D170	PCDU_LCL_37_SwOn	TC(8,4,112,5) for PCDU Unit : LCL#37	Switch PCDU Unit ON (LCL#37)
DC37B170	PCDU_LCL_37_SwOff	TC(8,4,112,3) for PCDU Unit : LCL#37	Switch PCDU Unit OFF (LCL#37)
DC38D170	PCDU_LCL_38_SwOn	TC(8,4,112,5) for PCDU Unit : LCL#38	Switch PCDU Unit ON (LCL#38)
DC38B170	PCDU_LCL_38_SwOff	TC(8,4,112,3) for PCDU Unit : LCL#38	Switch PCDU Unit OFF (LCL#38)
DCT53170	Perform CCU monitoring	TC(8,4,111,1)	Perform CCU monitoring
DC12M170	Report Payload Management Status	TC(8,5,111)	Report Payload Management Status

Details on CCU Default Housekeeping packets can be found in Annex 3 to section 2.1, CCU_Default_HK_Packets.xls file.

2.1.2.2. HERSCHEL VMC design

2.1.2.2.1. VMC overview

The Visual Monitoring Camera (VMC) aims to film on request and during a short duration the spacecraft neighbourhood in a certain fixed direction, the baseline being to watch the separation from the launcher.

The VMC is connected to the SVM CDMS to which it communicates via standard serial links (only DS16, no ML16).

There is only one VMC on HERSCHEL (no redundancy).

The VMC operating modes are:

- OFF_MODE: this mode is entered when the VMC is switched OFF via a dedicated PCDU command (VMC_OFF_CMD). This will also be the mode at launch.

- ACQUISITION_MODE: this mode is entered when the VMC is switched ON via a dedicated PCDU command (VMC_ON_CMD). Then, the VMC autonomously performs the following sequence of actions:

  - It warms up during VMC_WARM_UP_DELAY (5   2 seconds)

  - Then, it acquires 15 images of 263176 bytes (512x512 8-bit pixels + few bits for additional information like image and line identifiers) and store them in its internal buffer. The total amount of data for the 15 images is thus 3947640 bytes

  - When the 15 images have been acquired, the VMC stops its acquisition activity. The delay between 2 images and the image integration time are HW configurable by setting the "System Status" pin connectors. The nominal settings correspond to a delay of 1.25s and to an integration time of 0.741917 ms.

Note that these modes are independent from any other S/C modes.

Switching OFF then ON the VMC will start the acquisition of 15 new images.

All VMC data are sent through the image frames structure; no specific VMC HK telemetry is identified.

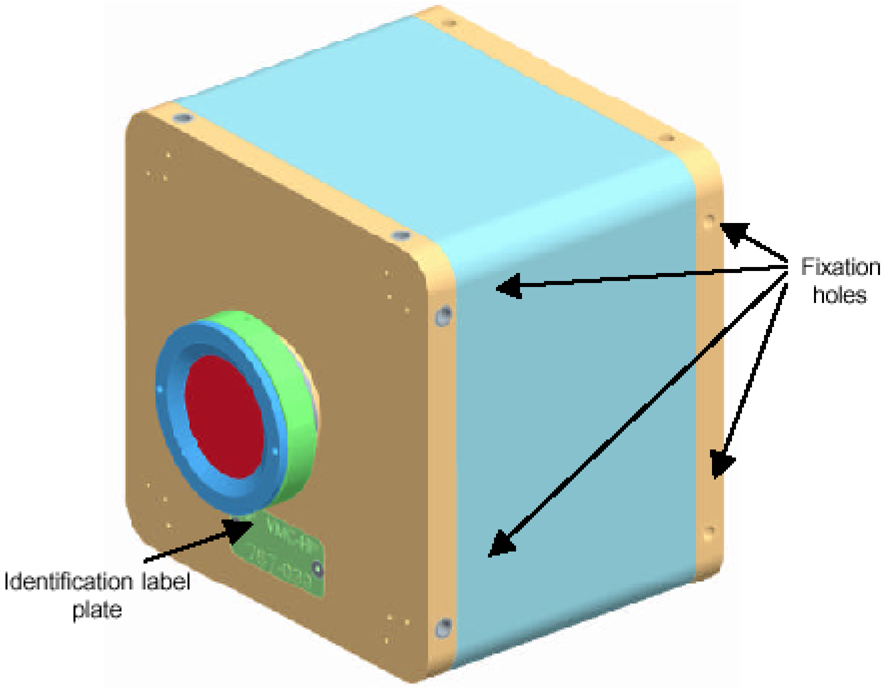


Figure 2-34 General view of the camera

2.1.2.2.2. VMC management

– CDMU ASW

The separation strap condition is detected by the ASW that will then start the separation sequence by switching ON the VMC (VMC LCL#20 closure). Then, as stated previously, the VMC will autonomously acquire 15 images.

Of course, at any time, the VMC can be switched ON/OFF by sending command to the PCDU using Packet Service#8 telecommand (PCDU management function handled by ASW or raw 1553 message handled by BSW).

– CDMU BSW

On receipt of a dedicated telecommand (Packet Service#8 used for VMC management function), the BSW starts the transfer of the data stored in the VMC internal buffer to the CDMS. This acquisition is done by sending a sequence of the same specific DS16 on the OBDH bus (625/second).

Once acquired, the BSW packetises the VMC data in dedicated TM(8,8) packets of maximum size (the last packet size being according to number of remaining data to be stored). These packets are handled as any other TM packets, i.e. sent to a selected VMC Packet Store in the SSMM and/or real time Virtual Channel zero according to the setting of the different TM configuration tables [transmit/storage flag set by TC(14,5), Packet Store definition set by TC(15,x)…]. At launch, the value for the transmit and storage flags of these packets are to be set to respectively disabled and enabled, i.e. VMC packets are stored in SSMM but not sent in real-time to avoid bandwidth saturation.

According to the amount of data to be transferred, the transfer of one image will last about 3min30s [263176*8bits/(625*16bits)=210.5 s], i.e. 52min38s for the 15 images [3158,112 s].

Before the completion of the VMC data transfer, a dedicated telecommand (Packet Service#8 used for VMC management function) can be sent to the BSW in order to stop the acquisition of the data stored in the VMC internal buffer. Whenever requested, the stop of the VMC data acquisition will be effective only after the completion of the in progress VMC packet building (to allow efficient data retrieval).

Note also that if any error linked to VMC data acquisition is detected (e.g. OBDH error), the VMC acquisition process will be stopped and an event report indicating the failure sent.

Finally, the acquisition of the VMC data is considered as a low priority process and will thus not interfere with other OBDH bus traffic.

The management function TC packets to be used are defined into HPSDB with the following references (correspondence with H/P CDMU ASW Software Interface Control Document is also given in the following Table):

HPSDB		**CDMU ASW ICD**	
Reference	**Description**	**Reference**	**Description**
DC20B170	PCDU_LCL_20_SwOn	TC(8,4,112,3) for PCDU Unit : LCL#20	Switch PCDU Unit ON (LCL#20)
DC20D170	PCDU_LCL_20_SwOff	TC(8,4,112,5) for PCDU Unit : LCL#20	Switch PCDU Unit OFF (LCL#20)
DC022161	StartStopVMCAcq	TC(8,4,5,1)	Start/Stop VMC Image Data Acquisition

2.1.3. Specific PLANCK FOG

2.1.3.1. FOG overview

The Fiber Optic Gyroscope (FOG) includes four channels. Each gyroscopic channel contains two main sub-assemblies: a sensing head called SIA (Sagnac Interferometer Assembly) and a FEM (FOG Electronic Module) both being linked by an undismountable GOH (Gyro Optical Harness).

The 4 SIA's are mounted on a regular tetrahedral structure called ICS (Inertial Core Structure) and protected by a MLI tent. The assembly so realised is called ICU (Inertial Core Unit).

The 4 FEMs are stacked together to form the GEU (Gyro Electronic Module).

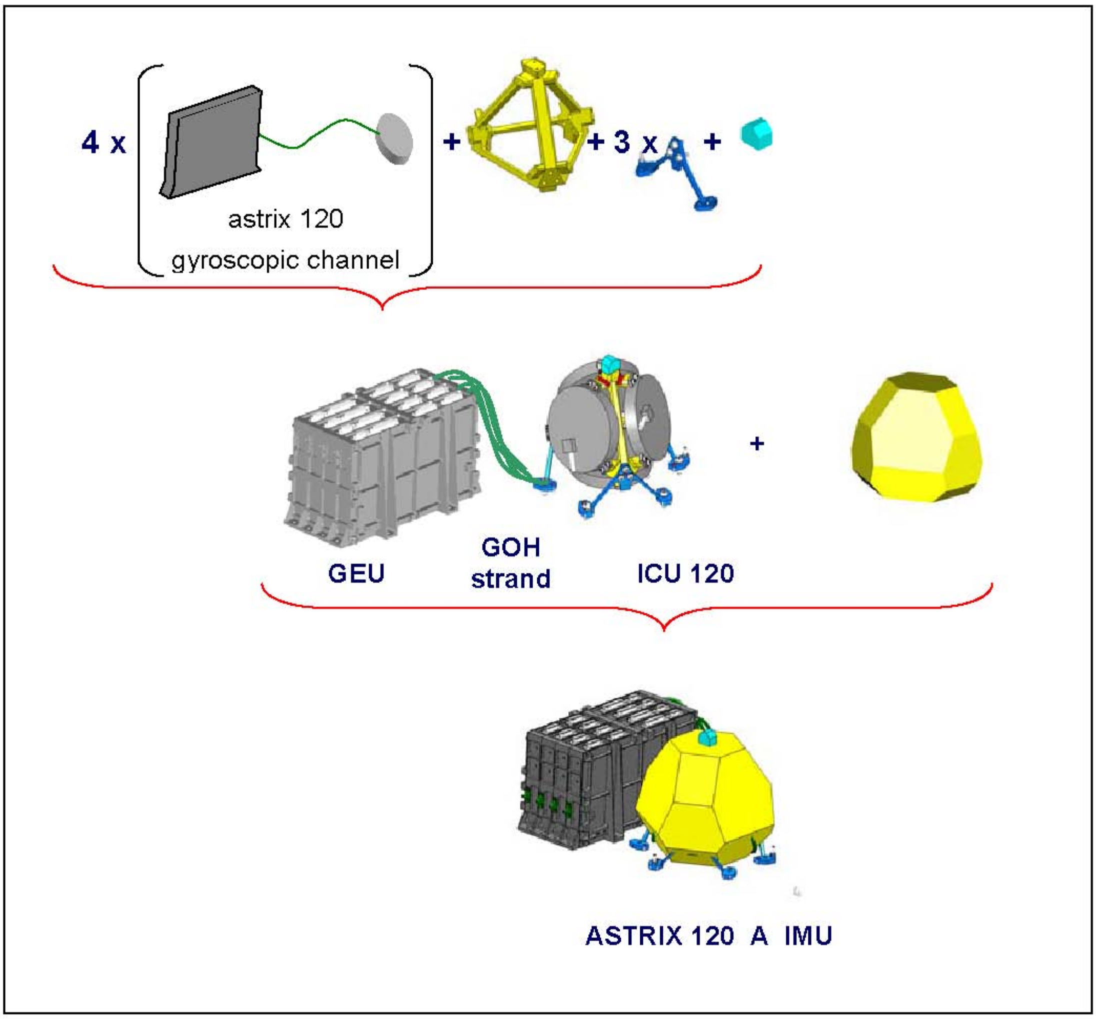


Figure 2-35 FOG composition

The FOG is powered via 4 LCL's by the PCDU and operated by the ACC via MIL-Std 1553B bus interface.

The 4 skewed gyro channels of the FOG allow the ACMS to use any triplet among the four axes to determine the spacecraft three axes rates.

The FOG three operating modes are:

– The Nominal Mode, directly reached after switch ON, is characterised by the closed loop control of the optical power delivered by the source module to the fiber optic gyroscope

– The Source Open Loop Mode, where the optical power delivered by the source module is directly proportional to the TC data: "Pump diode current command"

– The PinFet Protection Mode, automatically triggered after a too high optical power detected, to protect the optical detector component (PinFet). This PinFet Protection Mode is based on the source Open Loop Mode, but with the optical power delivered by the source module equal to a preset value.

There is no reason for activating the Source Open Loop Mode, or to fall into PinFet Protection Mode, except in case of failure occurrence.

2.1.3.2. FOG management

The power supply is provided to FOG by 4 LCL's controlled by the PCDU:

– LCL#13 supplies FOG channel 1

– LCL#14 supplies FOG channel 2

– LCL#26 supplies FOG channel 3

– LCL#35 supplies FOG channel 4.

Switching ON/OFF of these LCL's is performed by ON/OFF using the CDMU ASW "PCDU management function" (refer to H/P CDMU ASW User Manual, doc. H-P-4-SSF-MA-0001, and to H/P CDMU ASW Software Interface Control Document, doc. H-P-4-SSF-IC-0001).

The PCDU management function TC packets to be used are defined into HPSDB with the following references (correspondence with H/P CDMU ASW Software Interface Control Document is also given in the following Table):

HPSDB		CDMU ASW ICD	
Reference	**Description**	**Reference**	**Description**
DC01A170	Start_PCDU_Management	TC(8,1,112)	Start PCDU Management
DC02A170	Stop_PCDU_Management	TC(8,2,112)	Stop PCDU Management
DC13D170	PCDU_LCL_13_SwOn	TC(8,4,112,5) for PCDU Unit : LCL#13	Switch PCDU Unit ON (LCL#13)
DC13B170	PCDU_LCL_13_SwOff	TC(8,4,112,3) for PCDU Unit : LCL#13	Switch PCDU Unit OFF (LCL#13)
DC14D170	PCDU_LCL_14_SwOn	TC(8,4,112,5) for PCDU Unit : LCL#14	Switch PCDU Unit ON (LCL#14)
DC14B170	PCDU_LCL_14_SwOff	TC(8,4,112,3) for PCDU Unit : LCL#14	Switch PCDU Unit OFF (LCL#14)
DC26D170	PCDU_LCL_26_SwOn	TC(8,4,112,5) for PCDU Unit : LCL#26	Switch PCDU Unit ON (LCL#26)
DC26B170	PCDU_LCL_26_SwOff	TC(8,4,112,3) for PCDU Unit : LCL#26	Switch PCDU Unit OFF (LCL#26)
DC35D170	PCDU_LCL_35_SwOn	TC(8,4,112,5) for PCDU Unit : LCL#35	Switch PCDU Unit ON (LCL#35)
DC35B170	PCDU_LCL_35_SwOff	TC(8,4,112,3) for PCDU Unit : LCL#35	Switch PCDU Unit OFF (LCL#35)

The ACC will switch ON/OFF the four FOG channels independently through a TC(8,1,202).

A dedicated ACC TC(8,1,249) will set the FOG configuration.

Then, the ACC will be in charge of the acquisition of the FOG telemetry via the S/C 1553 bus.

2.2. HERSCHEL PAYLOAD MODULE DESCRIPTION

2.2.1. General description

The HERSCHEL Extended Payload Module (H-EPLM) accommodates the Focal Plane Units (FPU) of the three scientific instruments:

- Heterodyne Instrument for HERSCHEL (HIFI)
- Photo-conductor Array Camera and Spectrometer (PACS)
- Spectral and Photometric Imaging Receiver (SPIRE).

The three other major components of the H-EPLM are the telescope, the cryostat and extensions like the HERSCHEL Solar Array Sunshade (HSS).

The module provides an adequate thermal environment to the instrument FPU's and provides the optical interfaces between the FPU's and the telescope.

The H-EPLM also provides interfaces with the SVM.

The H-EPLM consists of:

- **The Optical Bench Assembly** (OBA), which accommodates the instrument FPU's in the Focal Plane Assembly (FPA), and provides the baffling. The OBA includes the Optical Bench (OB), providing the mechanical interface to the FPU's
- **A superfluid helium cryostat** designed to mechanically support and to maintain the FPU's and optical subsystem within the cryogenic environment
- **The H-EPLM/HERSCHEL telescope** which collects optical flux and focuses it into the cryostat
- **The H-EPLM thermal control** to maintain all equipment temperatures within their thermal design limits. The helium control system, which provides the cryogenic environment to the FPU's is part of the cryostat
- **H-EPLM harness**, including the science instrument harness
- **The Cryogenic Control Unit** monitoring the cryogenic instrumentation and performing actuation of the valves (described in section 5.2)
- **The Sunshield Sunshade** protecting the cryostat against Sun and accommodating the Solar Array (described in section 5.3)
- **The SVM shield** protecting the cryostat against the SVM thermal radiative flux.

The H-EPLM also accommodates the following (warm) payload equipment:

- The Local Oscillator Unit (LOU) of the HIFI Instrument
- The Buffer Amplifier Unit (BOLA) of the PACS instrument
- The wave guides from the HERSCHEL SVM to the EPLM LOU.

The Figure 2-36 shows the components outside the cryostat, whereas the Figure 2-37 shows the cryostat internal components.

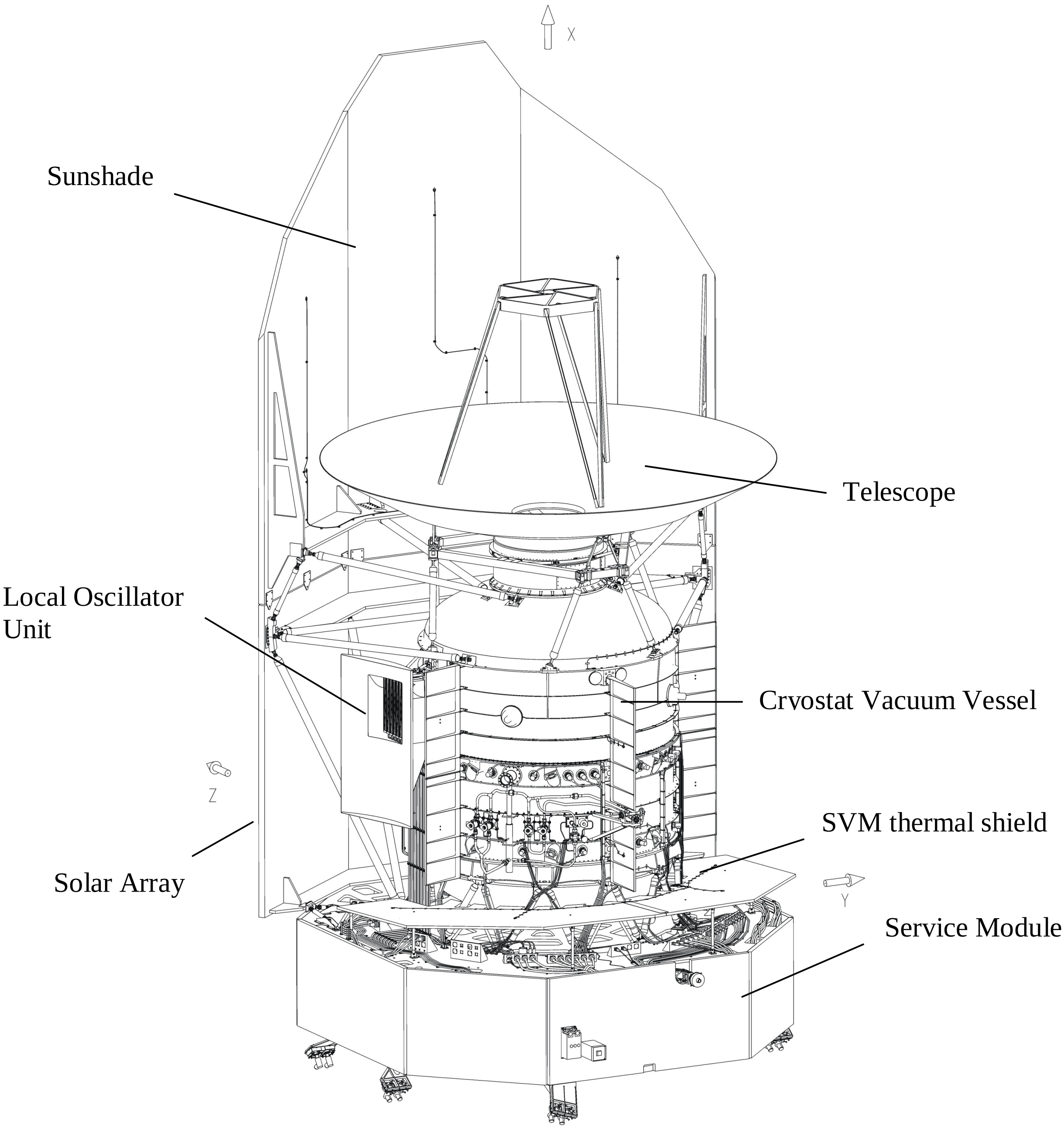


Figure 2-36 HERSCHEL spacecraft

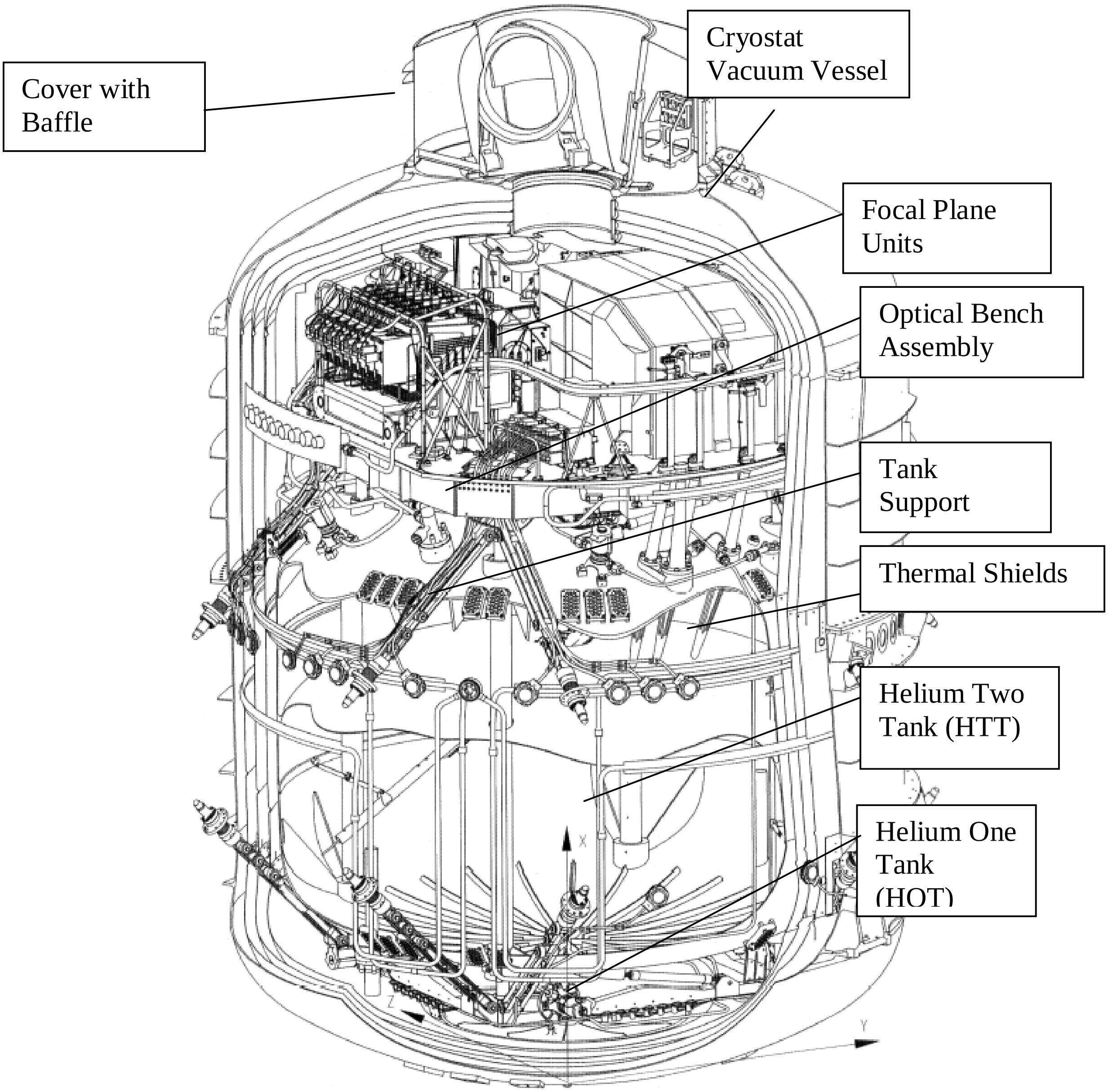


Figure 2-37 Cryostat cross section

To minimise the stray light the cryostat baffle is placed between CVV and telescope. This baffle is also structurally connected to the telescopes mounting structure (TMS) via 6 glass fibre struts.

The TMS is designed to carry the telescope and to provide a stiff and extremely plane I/F to the telescope. The TMS consists out of a frame and 6 load carrying struts. The strut design takes care that the deformation due to the CVV shrinkage in orbit (8 mm in diameter) will not cause telescope deformations (wave front error). Thermal insulation between the telescope and the CVV is required to limit the impact on the PLM life time during the decontamination phase of the telescope, where the telescope is heated up to 50^{o} Celsius. Therefore the struts are made from T300 carbon fibre reinforced plastics. The telescope frame is made from M55j, which has a CTE of almost zero.

The HIFI instrument on the OBA has a RF link to the LOU, which is mounted on the - y side of the CVV. To satisfy the HIFI needs the CVV has 7 windows of a diameter of 34mm and 2 additional alignment windows with a diameter of 24mm. The LOU shall have a temperature of 120 K and is thermally de-coupled from the CVV by GFRP struts. HIFI will provide a radiator, which controls the LOU temperature.

The RF waves are transferred by wave-guide to the LFU in the HERSCHEL Service Module.

To protect the CVV and the telescope from sunlight the HERSCHEL Solar Array/Sunshade (HSS) is used. It shall shadow the PLM for pitch angles of +- 30 degrees and roll angles of +- 1 degree. The lower part of the HSS is the solar generator of the Herschel S/C. GAGET2 solar cells with external Si-diode are used to fulfil the power requirements. The upper part is called sunshade and is covered with OSR to minimise the temperature of the sunshade and consequently minimise the telescope temperature. The HSS is mounted by glass fibre struts on the CVV and connected by carbon fibre struts on the SVM. The backside of the HSS is covered with MLI to minimise the radiation to the CVV.

The whole cryostat is mounted on the SVM via glass fibre struts. In order to maximise the life time and consequently to minimise the thermal conductance while fulfilling the overall stiffness requirements a configuration of 24 struts was found to be optimal.

Also on the SVM mounted is the SVM shield, which serves as baffle protecting the black parts of the CVV from the radiation of the “hot “ SVM. To minimise the shield temperature (about 120 K), the side pointing to the SVM is covered with gold plated Kapton foil. The other side is covered with a single Kapton foil. The minimum temperature is reached by tilting the shield by 5 degrees to the deep space (V groove effect). The thermal conductance to the SVM is minimised by using glass fibre struts.

Another link of the SVM to the PLM is the cryo harness. Starting from the connector brackets on SVM top platform the harness is routed on the CVV. The instrument and cryo control harness is routed through the vacuum tight feed through in the CVV to the instruments on the Optical Bench.

A detailed description of the design, function and performance of the H-EPLM can be found in HP-2-ASED-RP-0003 [RD-38]

2.2.2. H-EPLM overall dimensions

The figures following are showing the essential system dimensions.

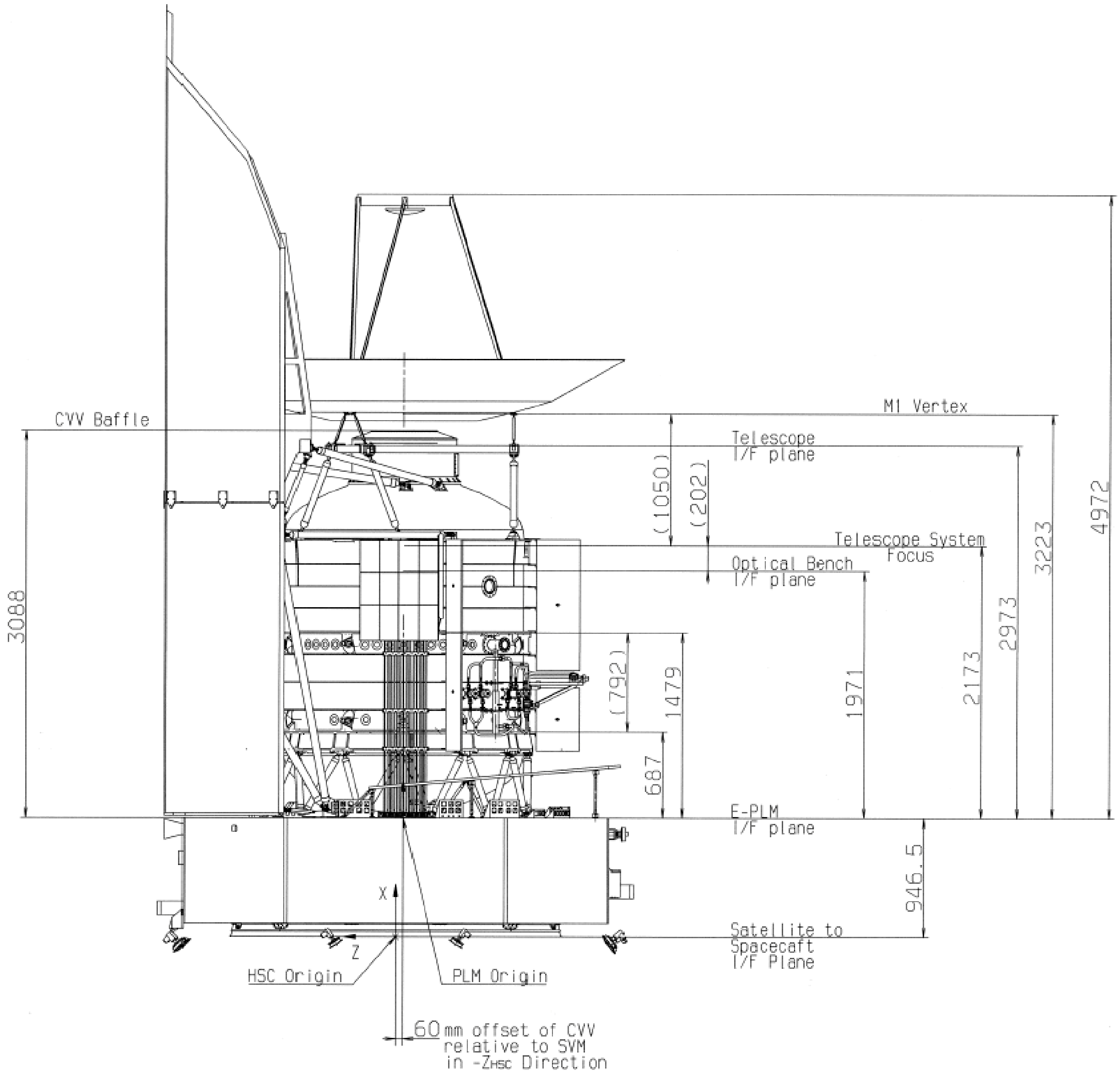


Figure 2-38 Herschel S/C view from -y

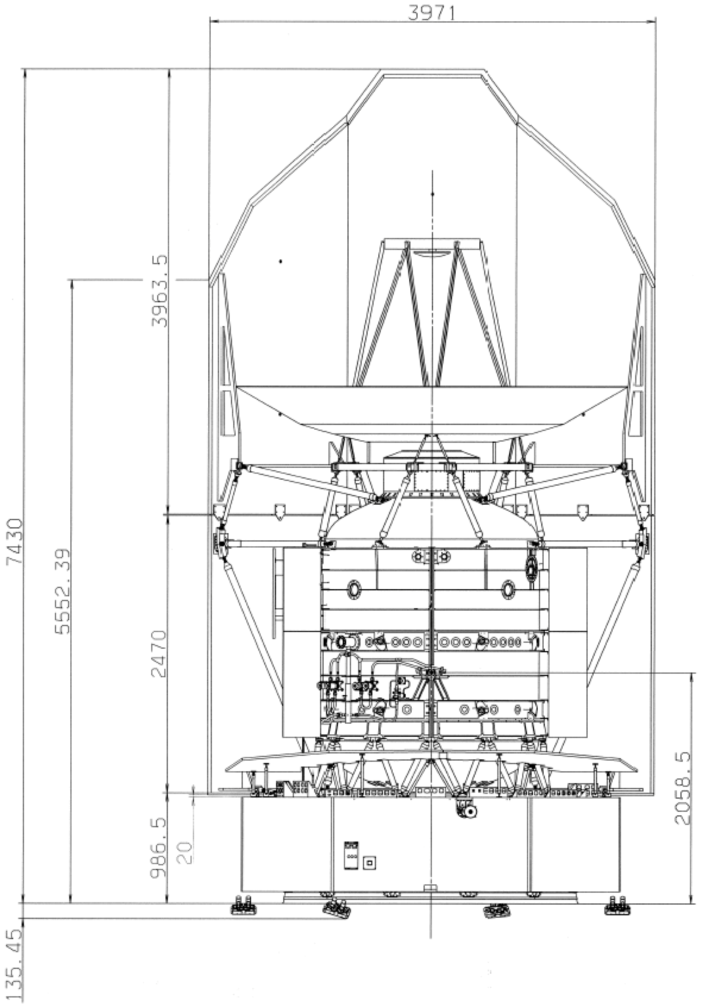


Figure 2-39 Herschel S/C view from -z

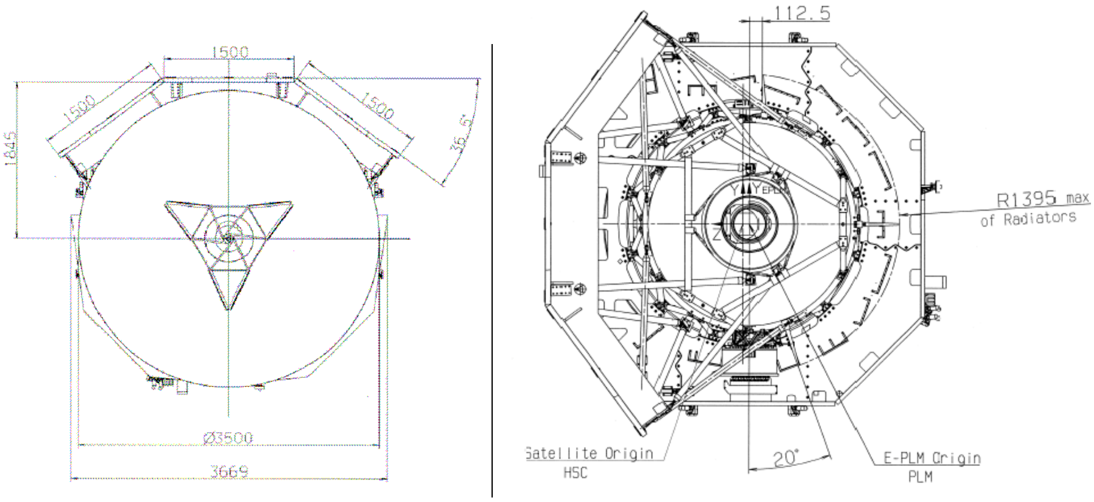


Figure 2-40 Herschel S/C view from –z, and PLM view form –x w/o telescope

2.2.3. Instrument accommodation

The accommodation areas of the scientific instruments HIFI, PACS and SPIRE are as follows:

Instrument unit	Location
HIFI FPU	Optical Bench Plate (OBP)
LOU and waveguides	Outer CVV, -Yside
LOU windows (7 channels + 2 alignment windows)	Outer CVV –Y side
PACS FPU	Optical Bench Plate (OBP)
SPIRE FPU, incl. JFET boxes	Optical Bench Plate (OBP)

The Optical Bench Assembly (OBA) provides the mechanical mounting interface for the FPUs as well as the interfaces for the instrument cooling. The mechanical fixation to the Optical Bench Plate (OBP) is achieved by bolts.

2.2.3.1. Optical Bench Assembly

The Optical Bench Assembly (OBA) provides through the Optical Bench Plate (OBP) itself a solid and alignment stable support of the Scientific Instruments (PACS, HIFI, SPIRE FPU, SPIRE-JFETs) within the Herschel cryogenic environment.
The OBP shall be a light aluminium plate, which is supported at four I/F points and provides I/F for the instruments and associated parts of instrument harness.

The OBA provides the interfaces to the instrument cooling with the following thermal I/F links:

- Level 0 FPU's to the HTT
- Level 1 FPU's to Optical Bench Helium Cooling Loop L1 (thermally isolated from OBP)
- Level 2 OBP temperature
- Level 3 JFET's to OBHCL 3

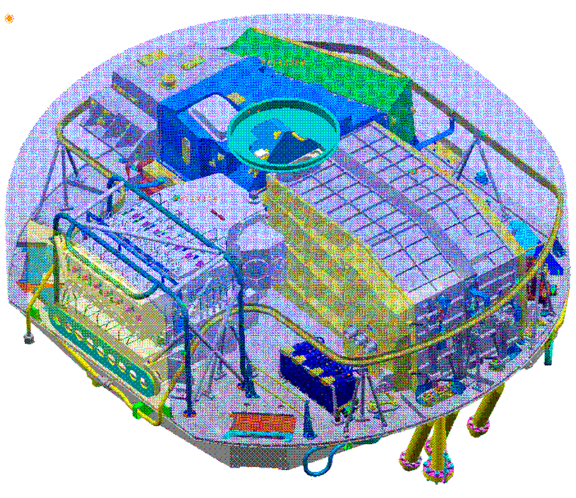


Figure 2-41 Instruments accommodation in the Optical Bench Assembly (HIFI front left, PACS front right, PACS in the back)

2.2.3.2. Units mounted outside the cryostat

One unit of the instruments is mounted on the outer side of the CVV, i.e. LOU of HIFI
The LOU mounting structure to the Herschel satellite consists of a GFRP strut system and a mounting base plate which provides

- mechanical support
- shrinkage-free stable alignment, i.e. thermally stable LOU interface position
- thermal insulation from CVV

The design of the LOU mounting structure and the routing of the LOU waveguides to the SVM is shown in the following figure

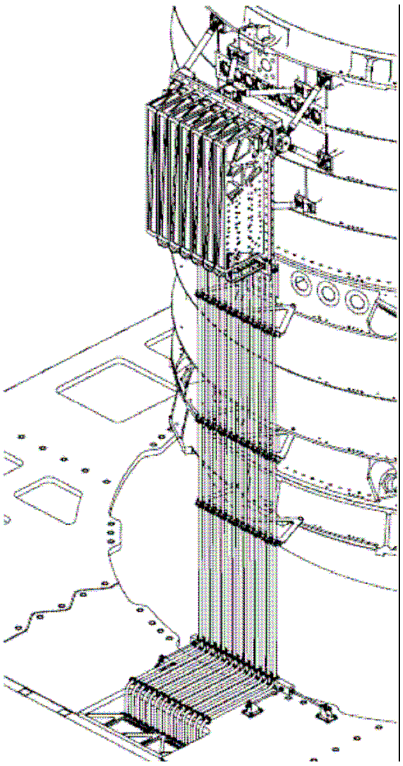


Figure 2-42 LOU and Waveguides Assembly interface on the Herschel satellite

2.2.4. Telescope Accommodation

The Herschel telescope is a Cassegrain telescope designed to be fixed on top of the Herschel helium cryostat inside which the science instruments PACS, SPIRE and HIFI are located.

The telescope major constituents are the following, starting from the Telescope/PLM interface:

1. Quasi-isostatic bipods, made of titanium, and attached to the primary reflector interfaces.

2. The primary reflector of diameter 3.5 meters, made of twelve silicon carbide segments brazed together at high temperature, then polished and coated.

3. Invar inserts clamped with screws on the primary reflector SiC interfaces. The inserts interfaces on the lower side with the bipods and on upper side with the hexapod invar fittings.

4. The hexapod assembly, also made of SiC. The hexapod legs have end fittings made of invar, which are glued on the SiC leg and screwed on the primary reflectors inserts. On the upper part, the hexapod legs are connected with a SiC barrel, on which the secondary reflector is mounted.

5. The secondary reflector, also made of SiC , with an integrated mount.

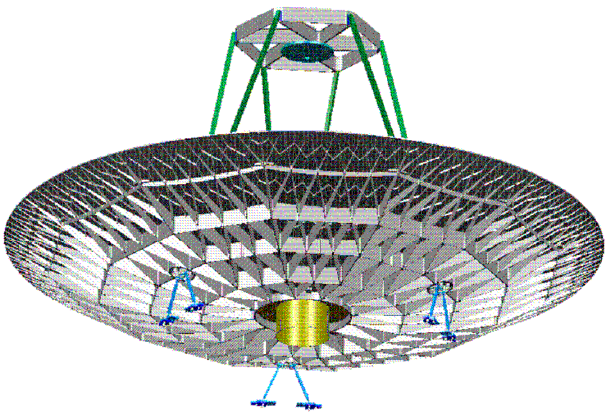


Figure 2-43 Herschel telescope without thermal H/W

The Herschel telescope is mounted on top of the CVV via the Telescope Mounting Structure (TMS).

The TMS consists of six struts connecting CVV and a hexagonal interface frame providing axial positional stability and stiffness (CVV struts). Additional six struts connect the hexagonal telescope mounting frame and the upper rim of the cryostat baffle (CB), thus providing lateral positional stability and stiffness. The telescope interface frame accommodates at its +Y side bracketry for the telescope heater and sensor lines.

The CVV struts (CFRP T300 struts) also provide sufficient thermal insulation to limit the heat flow from the telescope to the CVV. The CVV struts are designed such that a radial shrinkage of the CVV of 4 mm is possible without distorting the interface frame and its interface to the telescope. To avoid distortion of the telescope, the interface frame has to guarantee an interface planarity of 80 • m. The upper frame TMS allows radial shrinkage of the CVV interface and limits the distortion effects to the telescope.

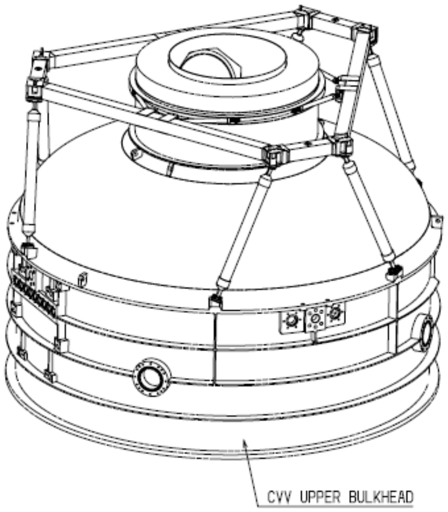


Figure 2-44 Herschel Telescope CVV fixation structure mounted onto CVV

2.2.5. Cryogenic subsystem

2.2.5.1. General description

The superfluid helium cryostat consists of:

- Structural and insulation components featuring an outer vessel, a suspension system to minimise heat conduction from outer vessel to the cryogenically cooled elements (OBA and associated FPU's) and the adequate shielding and thermal insulation to minimise the heat radiation from the outer vessel

- A helium subsystem to provide the adequate cryogenic environment to FPU's. This passive cooling system features a main helium tank, containing superfluid helium, a passive phase separator and the cryogenic components to operate it. It also features an additional helium tank designed to provide the required autonomy of the cryogenic system on the launch pad

- A cryo-cover which closes the cryostat on ground and preserves the sensitive optical components inside the cryostat from contamination during the first days on orbit

- Internal stray light and thermal baffles and a cavity between cryostat aperture and telescope.

The HERSCHEL helium control system is shown schematically in Figure 2-46.

The overall configuration is driven by the allowable volume under the ARIANE-5 fairing, the diameter of the telescope (3.5 m diameter), the need to protect the cryostat and the telescope from Sunlight and the required location for the centre of gravity. As a compromise to all these aspects, the centre of the cryostat is 60 mm shifted in –z direction wrt. launcher symmetry axis.

The cryogenic temperatures for the instruments are achieved using a classical ISO like cryostat as shown in Figure 2-45. The in orbit-cooling medium is superfluid liquid helium (He II) stored in the Helium Two Tank (HTT).

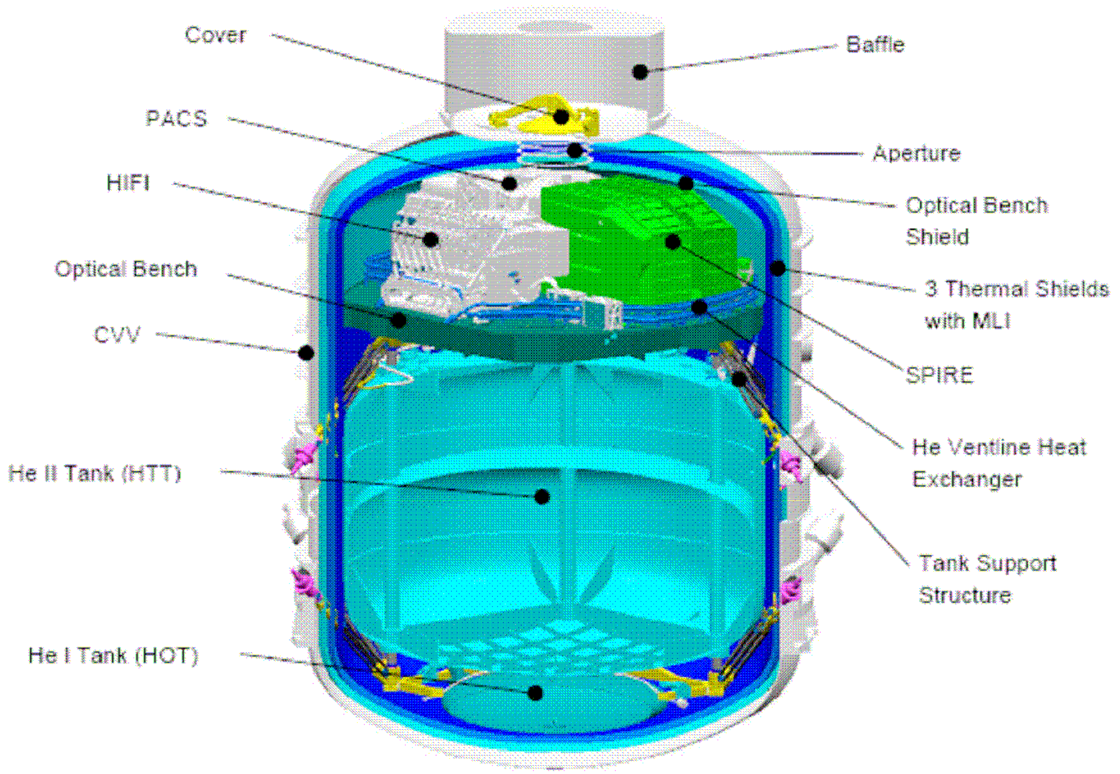


Figure 2-45 Cross section of the cryostat

For operations in orbit several heat sinks for dissipated energies from the focal plane instruments to the cryostat are required. The provided thermal links for these purposes are defined in four levels:

- Level 0: 10 direct thermal conductance links from an instrument I/F to the superfluid helium in the HTT (PACS 5, SPIRE 4, HIFI 1)
- Level 1: a thermal contact from an instrument I/F to the evaporated helium gas coming out of the PPS at the HTT in the sequence first PACS (3), than SPIRE (2) and HIFI (1)
- Level 2: the optical bench carrying the FPU's is thermally connected to the helium gas leaving the heat exchangers from Level 1
- Level 3: The helium gas leaving the optical bench is thermally connected to two JFET boxes from SPIRE before entering the vapour cooled radiation shields.

Ø **Cryostat Vacuum Vessel**

The CVV provides high vacuum environment for the helium subsystem and thermal insulation system. It is closed by the cryo cover for ground operation. As an essential cryostat component, the CVV shall provide the following functions:

- Mechanical support for the internally suspended helium subsystem
- Two evacuation ports for high vacuum generation
- One L He filling port
- One G He exit port
- Mechanical support for external He vent line and heater
- Two safety ports in flight configuration with safety valves (SV921/922), plus one in ground configuration (SV121)
- One opening for the telescope beam.

It is composed of three main parts of high strength aluminium, which are jointed by screwed junction.

The CVV main characteristics are summarised in the Table 2-4.

The primary function of the Cryostat Vacuum Vessel (CVV) is to provide vacuum environment for the whole inner parts on ground and during launch. The vacuum is needed for thermal insulation of the cryo system. In addition the CVV has a load carrying function for the telescope, the LOU and the HSS. These parts are connected via struts with the CVV. Directly mounted on the CVV are the harness and parts of the cryo system. The CVV has also to provide the feed through for the harness connectors. In orbit the CVV temperature shall be minimised. The expected temperature is about 70 K. Therefore the parts facing the “hot” HSS are covered with MLI and the parts pointing to the deep space are black. To increase the area of the black surface the three radiators are mounted on the CVV.

On the top, the CVV has an opening of diameter of 288 mm for the optical path from the telescope to the instruments. On ground the cryo cover closes this path.

HTT, HOT and OBA are mechanically supported by the Spatial Framework (SFW). It consists of a lower and an upper part. The upper part carries the OBA, the lower part the HOT; the HTT is clamped between the upper and lower part. The thermal function is to isolate the HTT from the heat coming from the Tank Support Suspension (TSS) and the dissipation by the instruments on the OBA. Therefore, items connecting the frame with the HTT are made from carbon fibre reinforced plastic. The axial loads are taken by 8 bones and the lateral force by 8 struts.

The mechanical needs and the requirement to maintain the ISO heritage, mainly for the Tank Support Suspension (TSS) drive the SFW geometry and properties.

The TSS consists of 16 chains, each chain is built up of 4 loops. The chains function under tension only, and are pre-loaded to cover with sufficient margin the launch loads and provide the required alignment in orbit. To minimise the thermal conductivity the 2 innermost loops made of CFRP and the others from GFRP. The TSS provides additionally the I/F for the three thermal shields. The chain design is identical to the ISO design, except the cross section.

The function of the thermal shields is to minimise the radiation from the “warm” CVV to the “cold” inner parts. The shields are covered with MLI and cooled by the vent line. The inner shield is also used for the thermal fixation of the harness.

Ø **Cryo Cover**

The Cryo Cover (CC) will provide a vacuum-tight closure of the cryostat aperture. The main functions of the CC are:

- To protect the experiments located inside the cryostat from contamination on ground, during orbital manoeuvres and during the telescope in-orbit out-gassing
- To prevent air from entering the cryostat during ground operations
- To open upon command in orbit (single shot device)
- To provide maximum reliability for this mission-critical function.

The CC assembly consists of the following subassemblies: Door Structure, Cover Heat Shield (CHS), Lever, Deployment Mechanism (DEM), Hold Down Release Mechanism (HRM), End Stops, Kick Springs and Connector Bracket.

The Door Structure provides the vacuum-tight closure of the CVV. It is mounted via a ball joint bearing to the Lever, which is used for the pre-loading of the Door Structure to the CVV.

The Lever is fixed to the CVV on one side via a one-axis rotational hinge system, which is also used for the deployment and actuation of the deployment. This hinge system is called Deployment Mechanism (DEM) and consists of two hinges with spring actuators.

On the other side, the Lever is clamped and pre-loaded by the Hold Down Release Mechanism (HRM).

The HRM consists of following main items:

- Knee Lever/Knee Lever Hinge
- Rotation Beam/Rotation Beam Hinge
- Connection Beam
- Release Unit with Separation nut.

The Separation Nut, named Non Explosive Device (NED), releases the bolt upon firing of the redundant spools and accommodates the bolt in a special housing. Therefore no part protrudes over the separated conical I/F after release.

The Separation Nut main characteristics are summarised in the Table 2-5.

It releases attached hardware when it receives an electrical signal from the PCDU to separate. Nut separation is complete, reliable and safe. Bolt release is virtually shock-free and no debris, contaminants or pollution is created. These highly reliable spools have been used extensively in space and military applications. When a separation signal is received (which is the same as for pyrotechnic initiators!), the spools unwind in milliseconds and free internal plungers. This releases a compression spring that moves a locking sleeve and separates the nut's threads from the attached bolt.

Note 1: There are three electrical inhibits on NED lines up to safe/arm plug connected in arm condition (end of filling activities), after there is two electrical inhibits. More over electrical lines are shielded.

Note 2: As there is vacuum inside CVV, in case of NED failed open, the release mechanism cannot open the cryo cover.

Ø **Helium One Tank**

– For instrument testing on ground and the phase on the launcher, the heat load on the HTT has to be minimised. This is performed by evaporating helium out of the Helium One Tank (HOT) through the venting system (heat exchangers) of the HTT by switching of valves.

The HOT shall provide a cold volume of 80 litres and will be filled to 100 % of its volume with helium one. It is composed of an upper dome and a lower dome.

It comprises ports for:

- Liquid Helium filling
- Gaseous Helium outlet
- Temperature sensors
- Pressure sensors
- Rupture disc (RD).

The HOT main characteristics are summarised in the Table 2-6.

Ø **Helium Two Tank**

The HTT is designed for a maximum volume of 2367 litre inside the boundary conditions of the cryostat together with the instrument and optical bench configuration. It will be filled with 337kg of helium to achieve a minimal lifetime of 3.5 years. The HTT also provides several interfaces to the helium control elements and thermal interfaces to the focal plane units. The mass is mainly driven by the structural and the internal and external pressure loads coming from the cryostat safety elements.

The HTT is composed of three parts (upper and lower domes, cylinder junction) with an internal dome.

It comprises ports for:

- Liquid Helium filling
- Gaseous Helium outlet
- Temperature sensors
- Pressure sensors
- Safety Valve (SV123)
- Rupture Disc (RD124).

The HTT main characteristics are summarised in the Table 2-7.

Ø **Safety valves**

- SV121

  The safety component SV121 will be operational during all test modes (except for vibration because of the risk to leakage), during all ground operations (except for helium filling, for which it will be replaced by a GSE safety valve) and during all cold transports.

  During the launch autonomy phase, the pressure within the He II tank is below 50 mbar and the HERSCHEL cryostat is protected against mechanical failure by the ARIANE fairing.

  SV121 is no longer mandatory during this phase and will be secured and sealed by a retaining device.

  Functional pressure of SV121 is 0.45 0.15 bar.

- SV123/723

  The cold safety valves SV123/723 are a spring-loaded safety device for protection of the Herschel HTT and HOT against pressure increase in case of failure.

The Safety Valve is an absolute pressure operated bellows relief valve with a soft seat. The valve is permanently closed by a spring. When the response pressure is reached in the inlet tube the pressure acting on a bellows via a conduction line opens the valve against the spring force. The outer space of this working bellows is in contact with the environmental pressure via housing bores so that the response pressure of the valve is always the differential pressure between inlet and environmental pressure. As the valve shall be located in the insulation vacuum of the HERSCHEL cryostat the reference pressure is always P = 0 bar so that the valve will be operated on absolute pressure. A small sealing bellows is designed such that the outlet pressure does not influence the response pressure of the valve. The set pressure is adjustable in the range of ± 10 % of the nominal set pressure. The valve housing is an all welded construction. Only for test purposes, sealing is allowed.

It is part of the HERSCHEL safety system.

The safety valve SV123 is located at the upper dished head of the HERSCHEL HTT.

The SV723 is located on He gas vent line of HOT.

In case of intolerable pressure increase inside the HTT tank He-gas will be released by SV123 via the filling port and SV121 into atmosphere.

Functional pressure of SV123/723 is 1.6   0.16 bar.

- SV921/922

They are parts of the HERSCHEL safety system.

The safety valves SV921/922 each consist of a guided valve seat, a spring pressing the seat against the interface flange of the vacuum vessel and the valve housing that holds the spring at its place. For evacuation of the cryostat vacuum vessel the safety valves are dismounted. After evacuation the valve seats are placed onto the vessel interface flange using an evacuation sluice. Then the valve body is installed onto the vacuum vessel. During all normal operation modes (ground operation, test, launch) the valves have to keep the vacuum vessel tight against air leakage. When the burst disks RD124/724 ruptures in the event of a great air leakage of the vacuum vessel the SV protect the vacuum vessel (CVV) against internal over pressure.

Functional pressure of SV921/922 is 0.4   0.05 bar.

- SV521

  It is part of the HERSCHEL safety system.

  The cold safety valves SV521 are a spring-loaded safety device for protection of the HTT and HOT against pressure increase in case of failure of heater H501 and line goggle.

  The safety valve SV521 is located after H501, between exit line and exhaust nozzle.

  Functional pressure of SV521 is 0.4 ± 0.06 bar.

Ø **Rupture disc**

The Rupture Discs (RD124/724) are present respectively on HTT and HOT. It is a safety device for protection of the HERSCHEL HTT and HOT against pressure increase in case of failure of all other safety devices. It is flanged to the surface of the tanks.

In case of intolerable pressure increase in one tank, He gas will release by the RD (124 or 724) into CVV and via SV921/922 into the atmosphere.

The functional pressure of RD is 2.8 ± 0.26 bar.

Ø **Heater H501**

The heater H501 is used to warm up the cold helium vent gas from 30 K to ambient temperature during the depletion of the HOT. It prevents subcooling of the vent gas line and the external valves and therefore condensation of water from air on these hardware items.

It consists of three single heater elements. They are wound to heat exchanger and integrated in a vacuum isolated housing. The heater element are pipes (stainless steel) in which the heat wire is embedded in high compressed magnesium oxide. The ends are closed by ceramic parts.

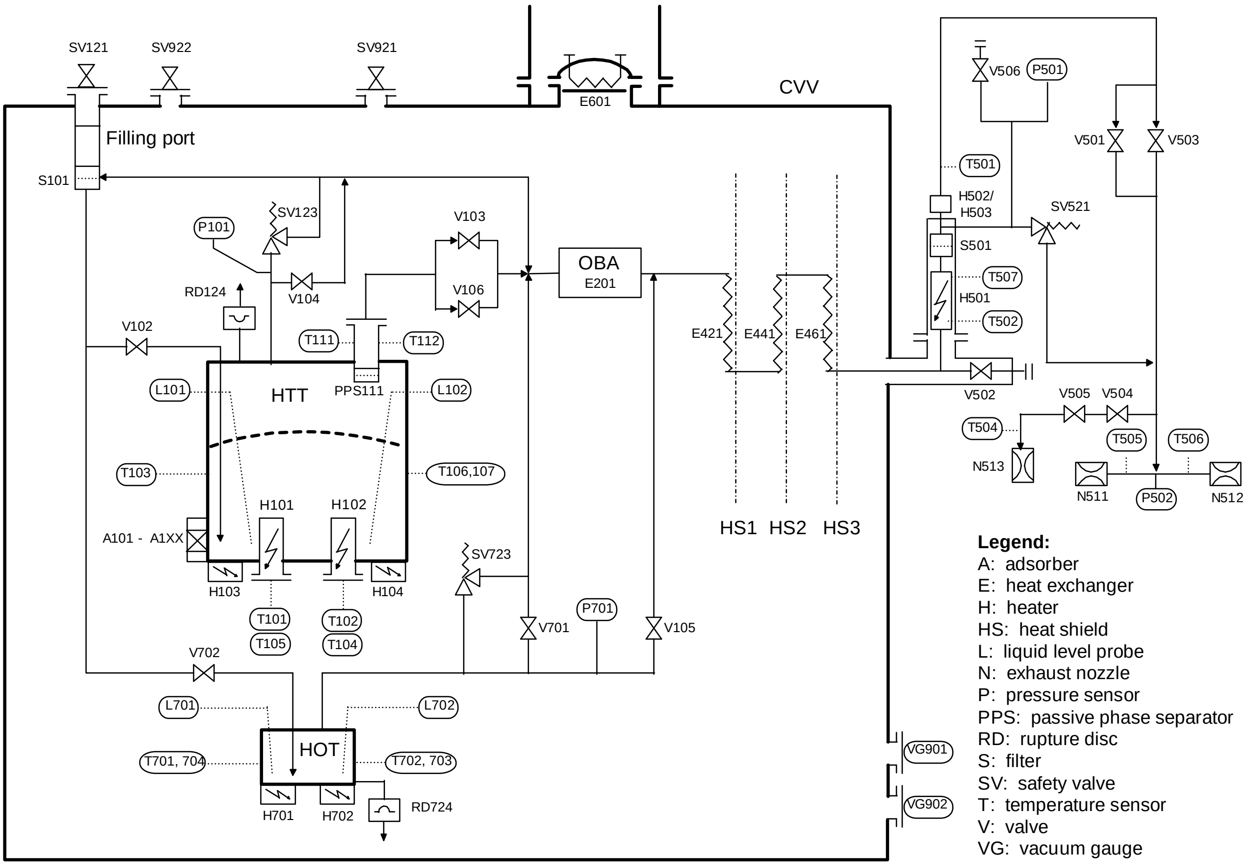


Figure 2-46 HERSCHEL Helium control system schematic

Operating fluids	Vacuum
Test fluids	GHe
Internal volume	NA
MEOP	Vacuum
Material used in fabrication	Aluminum AA5083 H 111/F
Safety Valve Opening Pressure	0.45 bar absolute

Table 2-4 CVV characteristics

Name	Non Explosion Device (NED)
Model	9421 (1/4 "bolt size)
Circuit Resistance	0.8 – 1.0 ohms (at ambient conditions)
Insulation Resistance	10 megohm min. at 500 VDC (= 30 sec.)
Dielectric Strength	5 µA leakage max. at 750 VAC
Actuation Voltage	3.5 VDC minimum
Actuation Current	3.5 A min, 6 A max.
Actuation Time	Less than 100 msec at a current applied 3.5 A minimum in ambient
"No Fire" Test Current	0.8 A DC applied for 5 minutes, ambient
Separation Time	1 second max.
Shell Material	AISI 304
Acceptance Bolt Load	11.12 kN
Qualification Bolt Load	22.24 kN
Previous use	Same type for XMM

NOTE: As it is not a pyrotechnic device, the NED is qualified for 0.8 A, 5 min, No fire.

Table 2-5 Separation nut characteristics

Operating fluids	Liquid Helium One
Test fluids	GHe/LHe
Internal volume	80 litres
MEOP	1.03 bar
Material used in fabrication	Aluminium AA5083 H 111/F
Safety Valve Opening Pressure	1.76 bar (1)
Rupture Disc Opening Pressure	3.06 bar

NOTE 1: Due to safety valve definition, internal pressure can increase up to 2 bar after valve opening.

Table 2-6 HOT characteristics

Operating fluids	Liquid Helium Two
Test fluids	LHe / GHe
Internal volume	2160 litres
MEOP	1.03 bar
Material used in fabrication	Aluminium AA5083 H 111/F
Safety Valve Opening Pressure	1.76 bar (1)
Rupture Disc Opening Pressure	3.06 bar

NOTE 1: Due to safety valve definition, internal pressure can increase up to 2 bar after valve opening.

Table 2-7 HTT characteristics

The Figure 2-47 shows filling port and gaseous helium nozzle location.

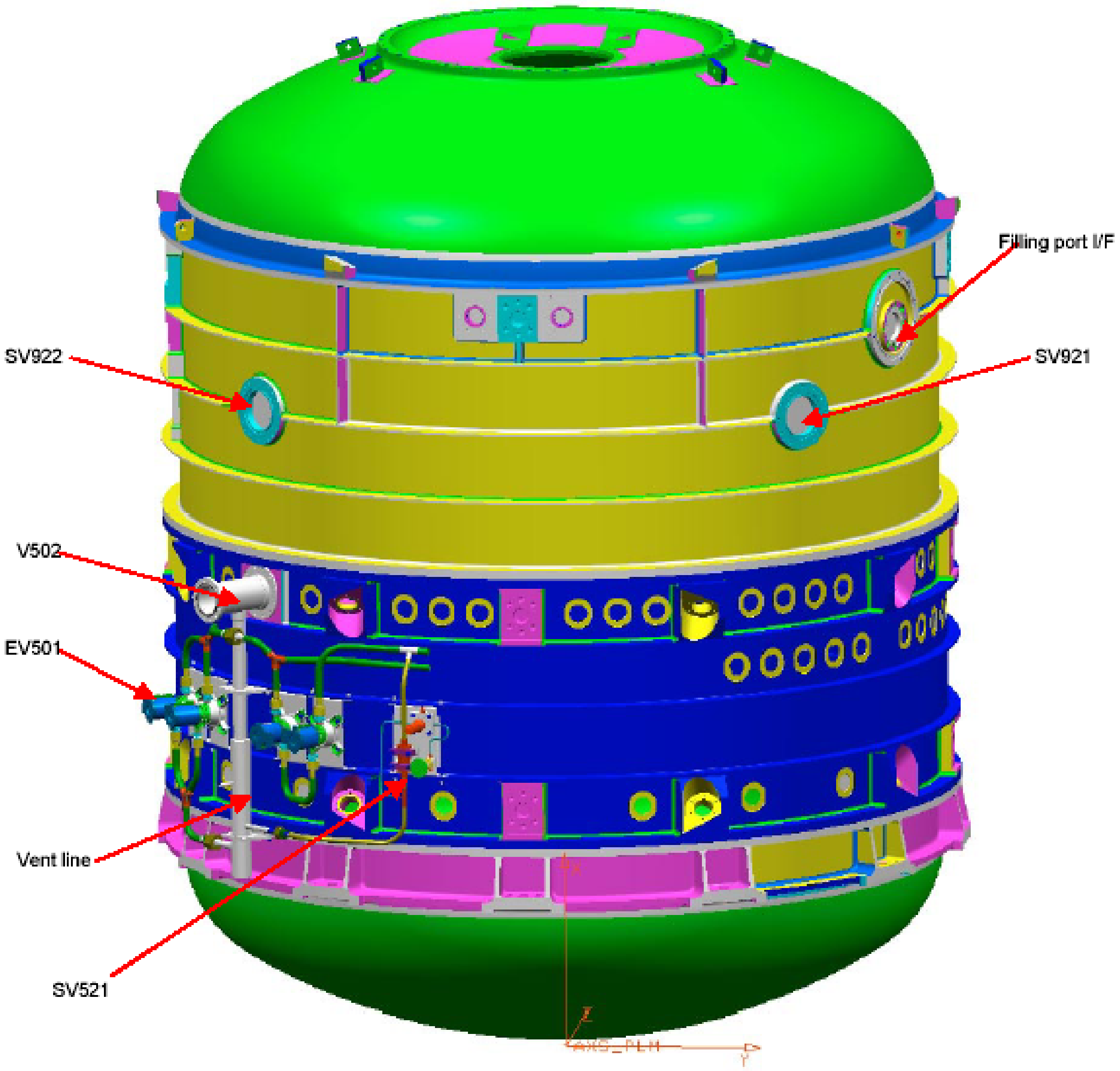


Figure 2-47 Filling port and nozzle location

2.2.5.2. Cryo control instrumentation

The Cryo Control Instrumentation shall provide:

- Sensor information to monitor the status of the Cryostat like
  - temperature
  - pressure
  - liquid level
  - acceleration
  - switch status
- Outputs to control the Cryostat status by means of
  - heaters
  - valves
  - non explosive device (NED).

The following Table shows the different categories and the number of single components included in the cryostat and EPLM subsystems.

Category	Number of Components
Accelerometer	22
Electrical Latch Valve	11
Heater	25
Liquid Level Sensor	4
NED	2
Pressure Sensor	4
Status Indicator	4
Status Monitoring	11
Temperature Sensor	129
Vacuum Gauge	2
Total	214

Table 2-8 Cryo Control Instrumentation categories

To distinguish their location, the instrumentation components are allocated to the main components of the cryostat and the EPLM subsystems:

– He-II tank: group 100
– Optical Bench Assembly: group 200.
– EPLM S/S: group 300
– Thermal shield group: group 400
– GHe external ventline: group 500
– Cover/cryostat baffle: group 600
– He-I tank: group 700
– Tank support structure: group 800
– CVV outside: group 900.

The Figure 2-41gives a schematic overview about the location of the components of the Cryostat Control Instrumentation (CCI), while the Figure 2-49 shows the distribution of the components in the ventline.

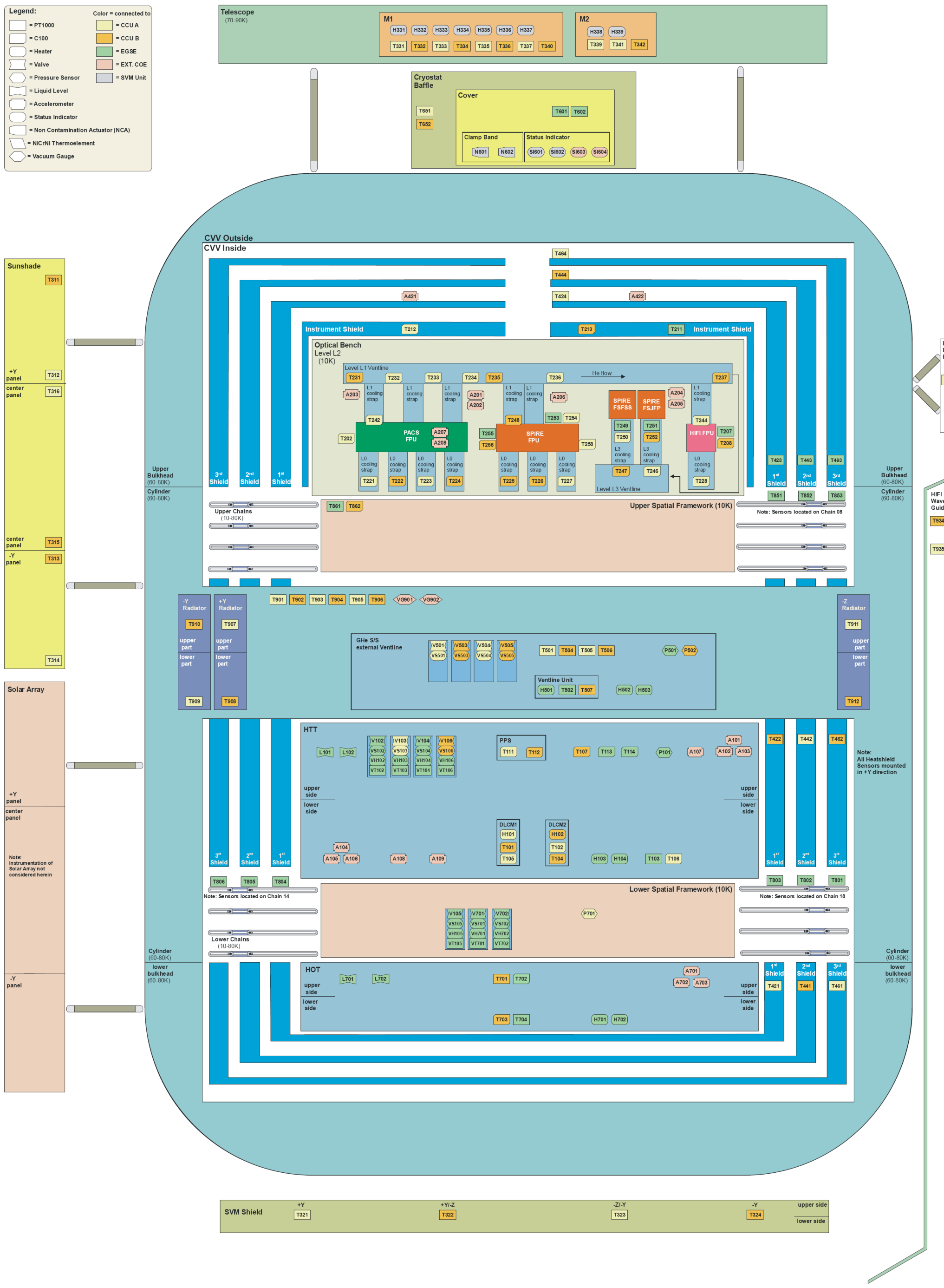


Figure 2-48 CCI component distribution general overview

* **Note**: one thermistor is missing on M1 -> T338 (CCUB)

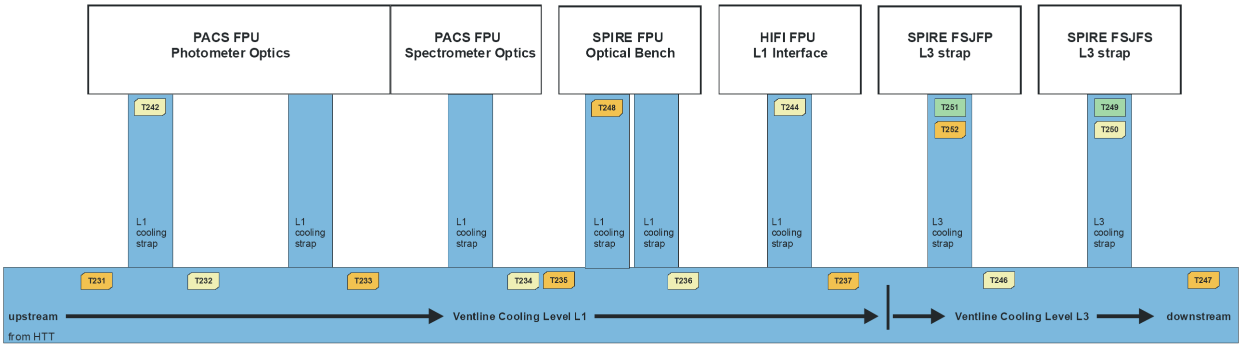


Figure 2-49 CCI component distribution on OBA ventline

During nominal operation the sensors will be operated via the CCU, as described in section 5.2.

Detailed description of the Cryostat Instrumentation components, their location and the measurement ranges in orbit, can be found in HP-2-ASED-TN-0048 [RD-23]

2.2.5.3. Helium content determination in orbit

The liquid content of the He II Tank (HTT) can be determined by a Direct Liquid Content Measurement device (DLCM), which measures the quantity of superfluid helium mass enclosed in the tank.

The DLCM is based on the ISO one.

The DLCM measurement in orbit is presently planned to be not more than two times per year in order to minimize the heat to the liquid Helium, and therefore preserve cryostat lifetime.

Two identical devices (DLCM1 & DLCM 2) are used for measuring the He II content of the HTT during ground operation as well as in orbit. They may also be used for depletion of the HTT during ground operation. The DCLMs will be located at the very bottom of the tank.

In a cylindrical housing, which is flanged to tank, a heating coil (H101, H102 respectively) is mounted on a smaller inner tube, which itself is situated concentrically within the outer perforated tube. Two C100 carbon resistors temperature sensors are fixed below the bottom of the inner tube in order to measure directly the temperature of the superfluid helium with high accuracy and resolution:

– T101 and T105 for DLCM1

– T102 and T104 for DLCM2

in which T105 and T102 are associated to CCU A, T101 and T104 to CCU B.

Due to the extremely high heat conductivity of superfluid helium all four of them can be calibrated relative to each other in the range of 1.7 to 2.15 K on ground, while merged in the fluid. An absolute calibration at the lambda point of helium, which is a very precise calibration point, will also be performed. This high resolution and accuracy will be used to determine the helium mass in orbit.

Caused by the surface tension of the LHe II under zero gravity the cavities within the DLCMs are filled with LHe II in orbit even when the tank is almost empty.

For measurement, the heater is powered for a predefined time (up to 200 seconds, ~4 kJ) by ground command, while all other FPU and monitoring electronics are switched OFF except CCU which is in DLCM mode. The heat pulse is adsorbed by the helium and its temperature will increase. The energy input Q is determined by integration of the measured current as well as the voltage via the 4-wire electric contact. Due to the very high heat- conductivity of LHe II this energy is distributed homogeneously in the liquid phase.

Before, during and after depletion of the heat pulse, the absolute temperatures and the temperature gradients of the helium II bath is measured by the C100 sensors inside the DLCMs and other appropriate tank temperature sensors, which will be identified during ground testing.

With the known specific heat of the LHe II and the calculated temperature increase (the so-called fore-drift/after-drift technique), the actual helium mass can be deducted by simple calculations:

$$m_{He} = \frac{Q}{(T_f - T_i) * (c_{P_f} + c_{P_i})/2}$$

with m_{He}= liquid helium mass; Q : the heat input; T : the temperature derived from the running average of all 4 DLCM sensors, Cp : the specific heat of helium (from the Annex 5) and i et f the initial, respectively final state. This simple formula is valid for a closed tank and ignores the presence of a gaseous phase.

Q : the heat input = Injected power X pulse duration
Power = U X I with : DLCM_Heat_cur : TM KD273300 (CCUA)
or KD273301 (CCUB)
DLCM_Heat_vol : TM KD272300 (CCUA)
or KD272301 (CCUB)
Pulse duration: parameter issued from TC DLCM ON: ZC0ZT999 (CCUA)
or ZC0ZU999(CCUB)
(parameter: KP101300, duration between 0 to 200 sec)

T : the temperature derived from the running average of all 4 DLCM sensors
TM DLCM1 (KD200303 and KD201302)
DLCM2 (KD200302 and KD201303)
Ti = average of the temperature before the power injection
Tf = average of the temperature after the power injection

Cp : the specific heat of superfluid helium which depends on the temperature (from the annex 5) and i et f the initial, respectively final state. $Cp_f = f(T_f)$ and $Cp_i = f(T_i)$

More details can be found in HP-2-ASED-TN-0178 [annex 7].

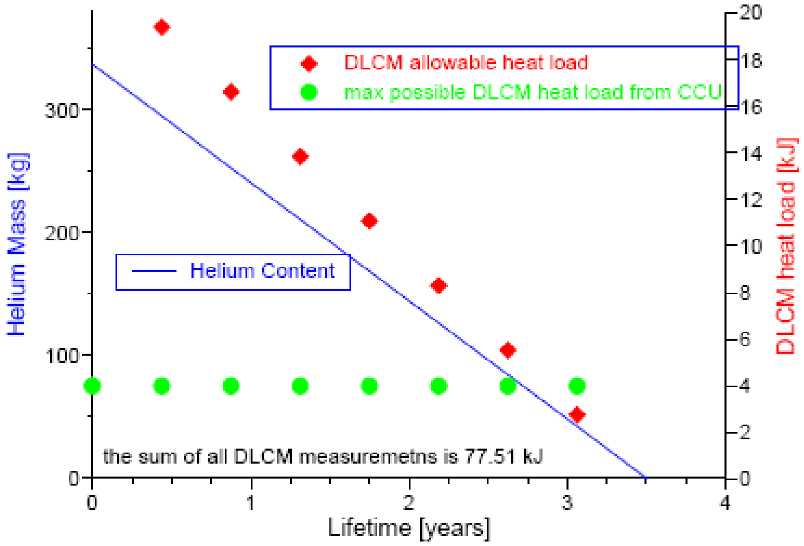


Figure 2-50 helium mass and DLCM heat load for 1% of nominal lifetime

The nominal lifetime is defined and calculated in [RD-39]
Considering:

Latent heat of vaporization @ 1.65 K is 23 kJ/kg
Helium mass in HTT at lift-off 337 kg
Nominal lifetime is 3.5 years

The required maximal energy of 1 % of nominal lifetime is *23 kJ/kg * 337 kg * 0.01 = 77.51 kJ.* This is the maximal energy for all seven DLCM measurements

Helium consumption is assumed to be constant over the life time (Figure 2-50) and for the same content measurement accuracy the necessary heat input is proportional to the current mass. This means that the necessary energy for DLCM measurements in the beginning of the mission is the highest.

In the figure, the maximum allowable energy for each of seven measurements (respecting an allowable total heat input of 77 kJ) is also shown.

DLCM heater power is 10 W each and the heat load is limited by the CCU, because the maximum duration of a single measurement is 200 sec. So max *Q = 2 * 10 W * 200 sec = 4 kJ.* Seven measurements dissipate together *4*7 = 28 kJ*, this would be equivalent to 0.36% of nominal lifetime (Refer to [RD-40])

Some simulations have been made with the HPLM TMM in order to assess if a simple law could link the mass flow to the temperature (or pressure) of the helium bath, within a range of 1.6 to 2.0 K. According to the expectations, there is no direct link between the mass flow and the temperature, as this flow strongly depends on the helium exhaust pipe and nozzle temperature. However, once the HPLM steady state is reached, the mass flow will not vary strongly (expectation around 2.2 mg/s), and it is recommended to evaluate once this mass flow between two distant DLCM measurement and propagate at the calculated rate until the next DLCM acquisition.

The DLCM is initiated by a 1553B commands (DLCM On) which contains a parameter for the selection of the heating time and duration of the measurement after heating. The DLCM sequence is composed of different phases:

– The Pre-Calibration which last 482ms.

– The DLCM sequence by itself which starts at the next frame and is composed of:

– The Pre-Monitoring which lasts 200 seconds

– The Heating which lasts from 0 to 200 seconds depending on related command parameter value

– The Post-Monitoring which lasts from 0 to 450 seconds depending on related command parameter value

– The Post-Calibration which last 280ms

This means that the DLCM sequence can last up to 852 seconds

The above explained process is performed with support of CCU as described in chapter 5.2 on Cryostat Control Unit.

In any case the DLCM measurement process has to be initiated by ground command through CDMU to CCU. Then, the CCU internal acquisition/monitoring process is activated.

2.2.5.4. Cryostat contingencies

The major contingencies (with little possibilities to intervene) considered for the cryostat are:

§ A leak in the Helium subsystem (HeS/S) into the CVV vacuum (most probably occurring during launch only)

§ An anomaly in the PPS start up (L+1100 sec)

§ Loss of sensors

§ Loss of CCU functionality A or B

§ Higher HTT temperature than predicted/ needed (several days/ weeks after launch)

§ Lower HTT temperature than predicted/ needed (several days/ weeks after launch)

§ Higher FPU I/F temperatures than predicted/ needed (several days/ weeks after launch)

§ Cryo cover does not open

The cryostat is required to be a passive system in orbit. Nevertheless there could be some possibilities of intervention to change the configuration/ thermal behaviour:

- Cryo cover opening (planned during commissioning ~ 40 d after launch)
- Switching of valves V103 and V106 for PPS venting
- Switching of valves V501 and V503 for open/ closure of the vent line
- Switching of valves V504 and V505 for open/ closure of the large nozzle
- The CCU can be commanded for enabling/disabling separately each sensor acquisition
- DLCM heater could in principal be used periodically to increase HTT pressure/ temperature (refer to annex 8)

More details about the actions to be taken in each contingency case can be found in HP-2-ASED-PR-0110 (annex 4)

2.2.6. H-EPLM thermal design

The Herschel EPLM thermal design shall be able to provide the required instrument interface temperatures for at least 3.5 years mission lifetime and to provide a cold environment for the Telescope that must be lower than 90 K. The central part of the Herschel EPLM is the CVV which is mounted on the SVM. Externally the CVV carries the Telescope, the Herschel Solar Array and Sunshade (HSS), as well as the LOU and the Star tracker. The CVV interior contains the Helium cooling system and the Optical Bench with the three instruments.

Detailed information about the CVV external and internal thermal control system can be found in HP-ASED-RP-0003 issue 4, section 5.11 [RD-38]

2.2.6.1. Instrument Thermal Interfaces to Helium Cooling System

The Helium Cooling System provides four different temperature levels for instrument cooling:

The superfluid helium tank provides the lowest cooling temperature level at 1.65 K. This is called the "**Level 0**" interface. The evaporated helium leaves the tank in a ventline that is connected to the focal plane interfaces of the instruments. This part of the ventline is thermally decoupled from the Optical Bench Plate (OBP) by means of CFRP struts and represents the "**Level 1**" cooling interface at (3-6) K. The adjacent part of the ventline downstream is thermally well connected to the OBP and provides the "**Level 2**" cooling interface at (8-12) K. Before the remaining ventline is then connected to the three thermal shields, a "**Level 3**" cooling interface has been introduced to cool the SPIRE JFETs to a temperature of about 15 K.

The PACS Focal Plane Unit (FPU) structure is thermally decoupled from the OBP via CFRP T300 feet and is cooled via three copper cooling straps connected to the Level 1 ventline. The SPIRE FPU structure is also thermally decoupled from the OBP and is cooled via two copper cooling straps connected to the Level 1 ventline downstream after the PACS straps. The HIFI FPU structure is directly mounted, i.e. thermally well connected to the OBP which itself is cooled via the Level 2 ventline. The HIFI FPU requires also an interface to the Level 1 temperature that is provided by a cooling strap attached to the ventline downstream after the SPIRE Level 1 interface.

The SPIRE instrument requires 3 separate Level 0 interfaces: for the 3He cooler evaporator, for the 3He cooler pump and for the detector enclosure structure. PACS requires 4 separate Level 0 interfaces: for the 3He cooler evaporator, for the 3He cooler pump, for the "Red Detector" and for the "Blue Detector". HIFI requires one Level 0 interface only.

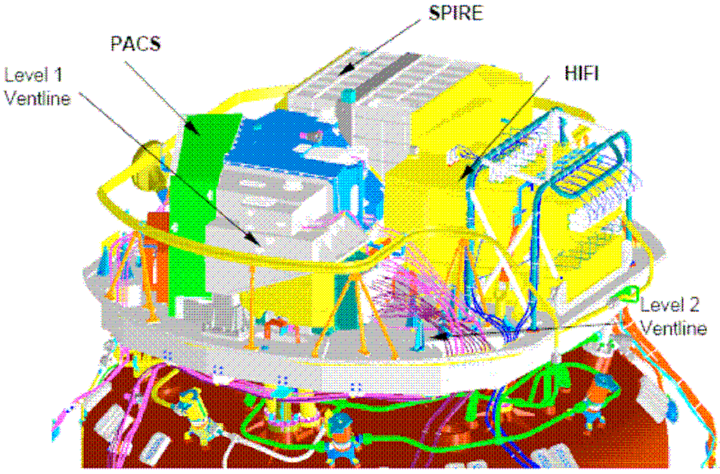


Figure 2-51 Level 1 and Level 2 Ventline Design

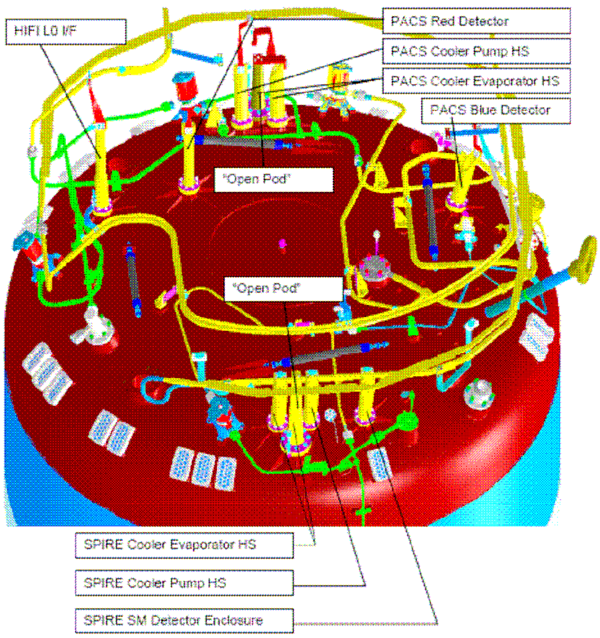


Figure 2-52 Instrument Thermal Links to HTT (Level 0)

2.2.6.2. Thermal performances

A detailed description of the H-EPLM thermal model, the H-EPLM and instruments temperature requirements and flight prediction analysis can be found in HP-2-ASED-RP-0011 [RD-39]

The analysis results for hot an cold environment at L2 orbit are shown in the sections below.

2.2.6.2.1. Heat Flow Charts

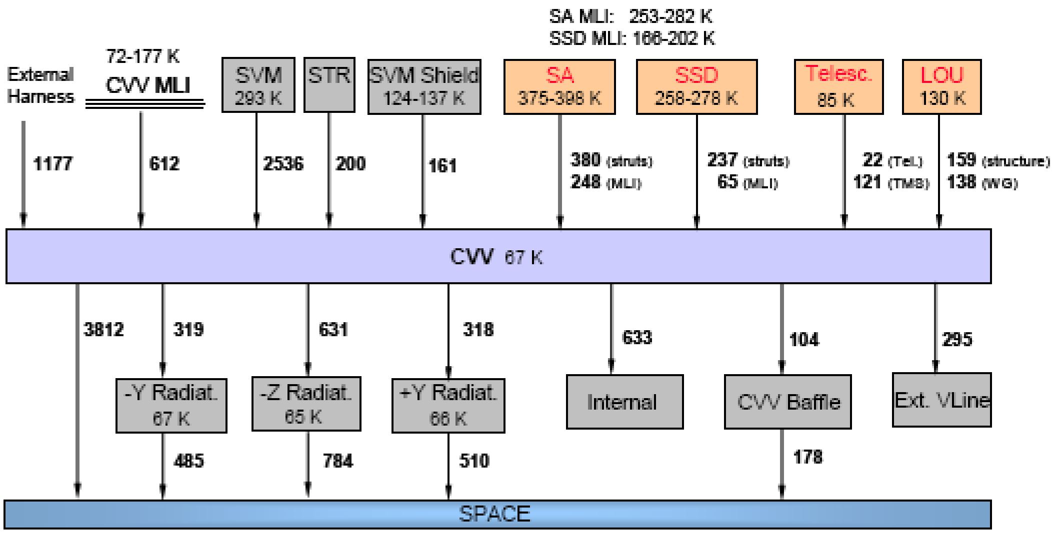


Figure 2-53 CVV Heat Flow Chart in Hot Case Environment at L2 (in mW)

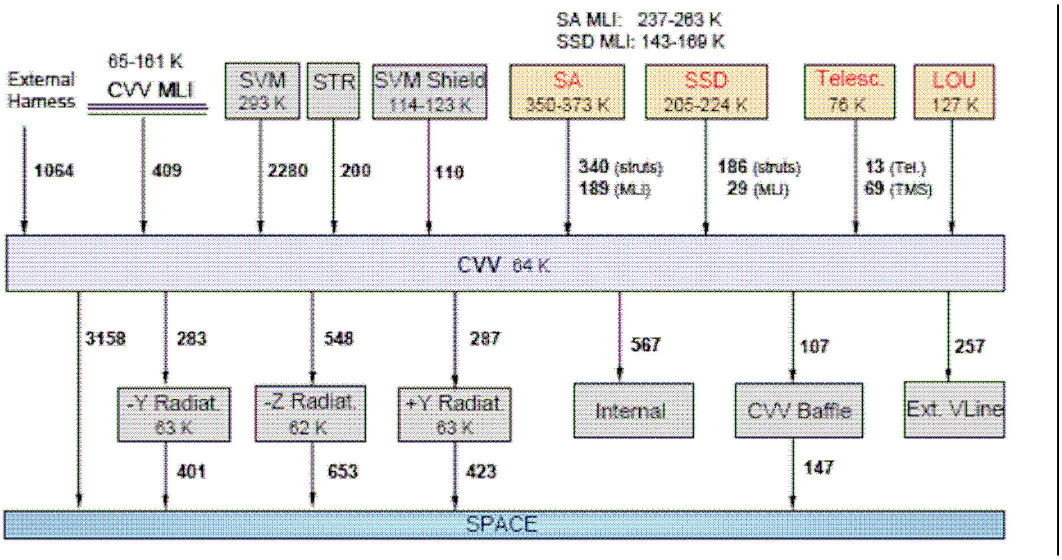


Figure 2-54 CVV Heat Flow Chart in Cold Case Environment at L2 (in mW)

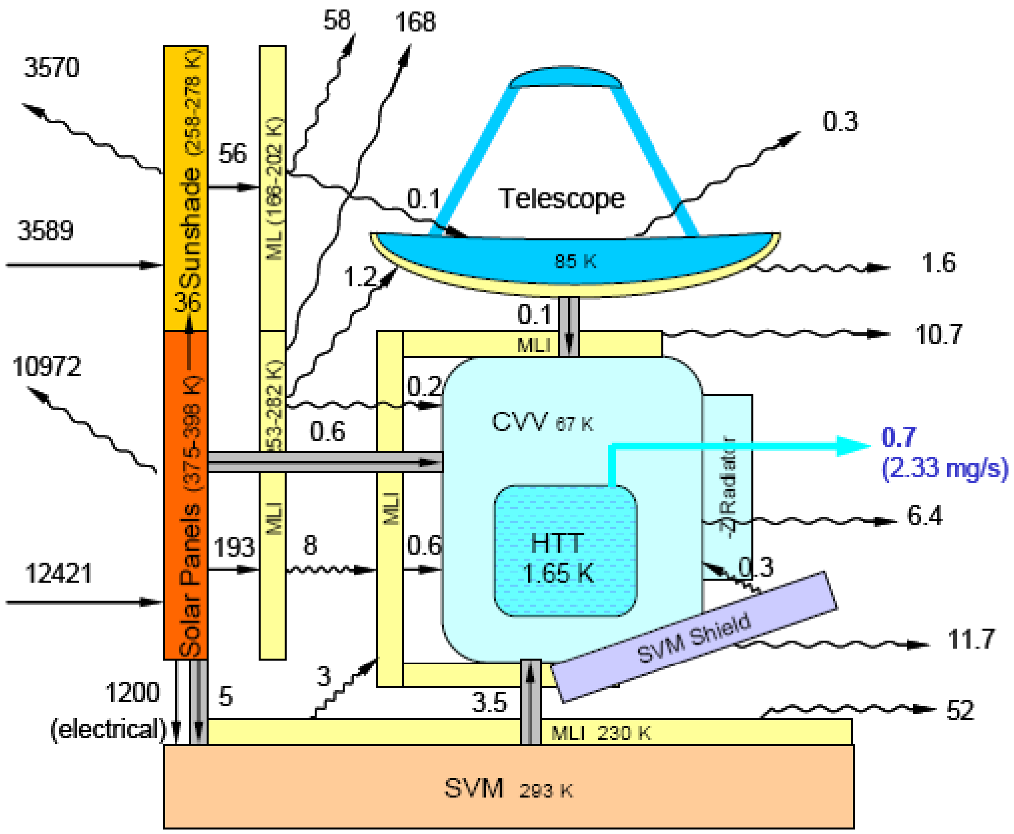


Figure 2-55 CVV External Heat Flow Chart in [W] (Hot case)

2.2.6.2.2 EPLM temperatures

Item	Node	T, cold case [K]		T, hot case [K]	
SA MLI, center panel	[7100]	253	+19 / -32	270	+20 / -34
SA MLI side panel	[7101]	241	+18 / -30	258	+19 / -32
SSD MLI, center panel	[7160]	157	+11 / -18	196	+15 / -25
SSD MLI side panel	[7161]	148	+10 / -16	184	+14 / -23
Telescope	[8000]	78.3	+4 / -6	87.8	+5 / -6
LOU support plate	[4200]	132	± 2	136	± 3
Solar Array, center panel	[7000]	371		396	± 5
Solar Array, side panel	[7001]	352		376	± 5
SSD (OSR's), center panel	[7060]	219		276	± 11
SSD (OSR's), side panel	[7061]	205		258	± 11
SVM Thermal Shield	[6204]	122		135	± 3

Table 2-9 EPLM Temperatures with uncertainties in L2 Orbit

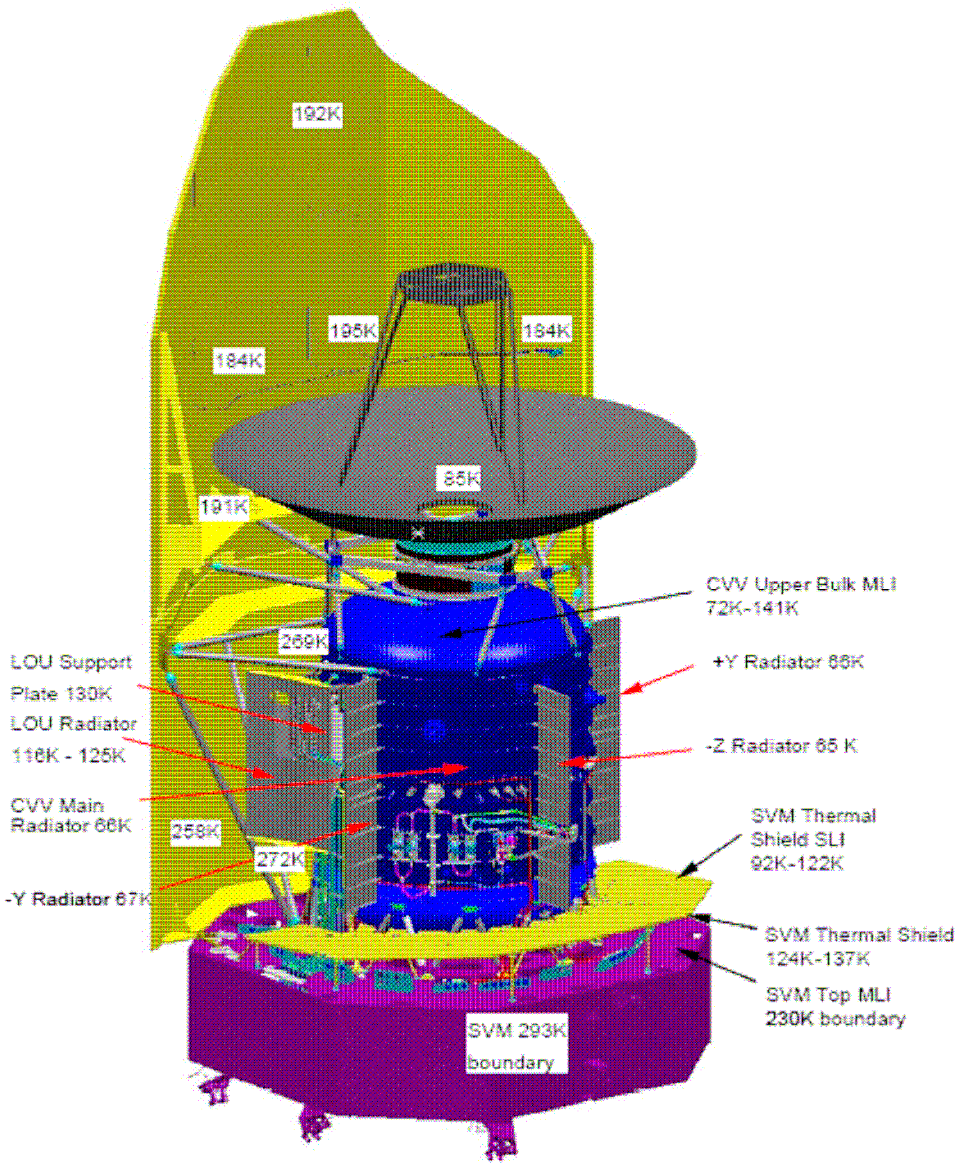


Figure 2-56 H-EPLM Temperature Distribution for Hot Case Environment at L2

2.2.6.2.3. Instrument Interface Temperatures

	Interface	I/F Requirement		Node	Analysis Results	
		Heat Load	Temperature		2.1 mg/s	2.2 mg/s
Level 0	PACS Red Detector	0.8 mW	1.6 K ... 1.75 K	721	1.68 K ±0.06K	1.68 K ±0.06K
	PACS Blue Detector	2.0 mW	1.6 K ... 2 K	723	1.73 K ±0.06K	1.73 K ±0.06K
	PACS Cooler Pump	2.0 mW	1.6 K ... 5 K	761	1.73 K ±0.06K	1.73 K ±0.06K
		500 (peak) mW	1.6 K ... 10 K		12.0 K ±0.06K	12.0 K ±0.06K
	PACS Cooler Evapor.	15 mW	1.6 K ... 1.85 K	762	1.796 K ±0.06K	1.796 K ±0.06K
	SPIRE Detector	4 mW	< 2 K	814	1.74 K ±0.06K	1.74 K ±0.06K
		1 mW (goal)	< 1.71 K (goal)		(1.68 K ±0.06K)	(1.68 K ±0.06K)
	SPIRE Cooler Pump	2 mW	< 2 K	815	1.69 K ±0.06K	1.69 K ±0.06K
		500 mW (peak)	< 10 K (peak)		9.77 K ±0.06K	9.77 K ±0.06K
	SPIRE Cooler Evap.	15 mW	< 1.85 K	816	1.70 K ±0.06K	1.70 K ±0.06K
		15 mW (goal)	< 1.75 K (goal)			
	HIFI Detector	6.8 mW	< 2 K	949	1.98 K ±0.06K	1.98 K ±0.06K
Level 1	PACS FPU	30 mW	2 K ... 5 K	781	3.60 K ±0.18K	3.55 K ±0.18K
				782	4.34 K ±0.18K	4.24 K ±0.18K
				783	4.57 K ±0.18K	4.43 K ±0.18K
	SPIRE FPU	15 mW	< 5.5 K	800	4.43 K ±0.35K	4.22 K ±0.35K
		13 mW (goal)	< 3.7 K (goal)			
	HIFI L1	15.5 mW	< 6 K	939	5.77 K ±0.32K	5.37 K ±0.32K
Level 2	OBP near PACS	0 mW	< 12 K	371	11.8 K ±0.5K	10.9 K ±0.5K
	OBP near SPIRE	0 mW	< 12 K	381	11.4 K ±0.5K	10.6 K ±0.5K
		0 mW (goal)	< 8K (goal)			
	Instr. Shield / SPIRE	0 mW	< 16 K	315	11.5 K ±0.5K	10.6 K ±0.5K
	HIFI FPU	22 mW	< 20 K	919	13.3 K ±0.5K	12.4 K ±0.5K
Level 3	SPIRE PM-JFET	50 mW	< 15 K	831	16.1 K ±0.5K	15.1 K ±0.5K
	SPIRE SM-JFET	25 mW	< 15 K	832	14.6 K ±0.5K	13.7 K ±0.5K
LOU	LOU (HIFI)	7000 mW	90 K ...150 K	4200	(132-136) K* ±3K	

Table 2-10 Calculated Instrument Temperatures, Hot Case conditions at L2

2.2.7. H-EPLM Operations

2.2.7.1. Mission phases

The EPLM operation activities during the pre-launch/launch phases are described in the annexed document HP-2-ASED-TN-0052 “Cryo Operations on Launcher”.

An overview on the specific sequence of CCU events after the launch is given in the table below:

Event	Time after launch	Operation Description	Inititation	Remarks
1.Open Valves V501 and V503	L0(lift-off) + 4 min	V501 and V503 will be opened by related current pulses from the CCU	AR 5, dry loop CMDs	After external pressure has decreased below 50mbar, for HOT evacuation during launcher ascent.

				*HOT valves are not useful anymore due to leakage reasons
2. Open Valves V103 and V106	L0 + 20 min 40s	V103 and V106 will be opened by related current pulses from the CCU	AR 5, dry loop CMDs	Just before entering µG environment
3. Monitoring of EPLM status	First acquisition	Acquisition of selectable monitoring tables	By related TC from CDMU	The monitoring function can be triggered whenever housekeeping status information from the cryo system is needed
4. DLCM Operation	COP	Injection of about 20 W over 200 sec. into the HTT	By related TC from CDMU	According cryo system operational needs. About once per 6 month over the mission expected
5. Close Valves V504 and V505	3 to 4 weeks	Valve actuation by related current pulses from CCU	By related TC from CDMU	TC to be given according to temperature and He mass-flow

Afterwards only events 3 and 4 will occur during nominal mission operation.

The following table summarises the Herschel PLM activities during the post-launch mission phases and before starting the routine operations:

Phase	Duration	Activities
Initial Orbit Phase	From T0 to T0+2 weeks	Close Valves V504 an V505 Switch on telescope heating
Commissioning Phase	From T0+2 weeks to T0+2 months	P/F checkout P/L switch-on and checkout End of telescope heating (T0+3w) Telescope cool-down Cryo-cover opening
Performance and Verification Phase	From T0+2 months to T0+3 months	End of telescope cool-down P/L performance verification an calibration

2.2.7.2. H-EPLM Commanding

The CCU will receive, decode, process, and execute the commands generated by the CDMU and distributed via the Mil Std 1553 B bus. The following Mil Std 1553 B bus command types will be processed by the CCU:

- Valve commands (including arming) used to switch the He valves into open or closed position
- DLCM commands (including arming) used to initiate the direct liquid content measurement function
- Monitoring commands used to
  - initiate monitoring function (table acquisition selected by CMD parameter) or
  - to modify the acquisition tables content

2.2.7.3. Operational constraints

ü During the DLCM all instruments need to be switched off or in standby to ensure constant dissipation and a precise temperature measurement.

ü Only one of the valves or DLCM can be armed or operated at the time.

ü DLCM function has precedence over Monitoring function.

ü Arm and open command pair for valves can not be used cross-wise between Ariane dry-loop and MIL-Bus.

2.3. PLANCK PAYLOAD MODULE DESCRIPTION

2.3.1. General description

The Planck Payload Module (PPLM) is the current name used to define a module including:

– The PLANCK telescope including Primary and Secondary reflectors both supplied by ESA/DSRI

– The cryo-structure which interfaces the telescope onto the SVM

– The main baffle

– The PLANCK instrument units, supplied by the principal investigators which have to be accommodated on the PPLM.

The instruments are composed of:

– A Focal Plane Unit (FPU) and the associated electronic units (HFI JFET, LFI BEU, HFI PAU) located respectively on the telescope and PPLM structure at a specific position from the FPU

– The active cryogenic cooling systems routing from the SVM to the FPU

– Warm electronics mounted on the SVM panels.

The "extended PPLM" is composed of the PPLM plus 6 of the 8 SVM lateral panels (the ones used for instrument units implementation).

The Figure 2-57 and Figure 2-58 show the PPLM as described above. The QM PPLM mounted onto the SVM dummy for the CQM-A acoustic test campaign is displayed in the Figure 2-59.

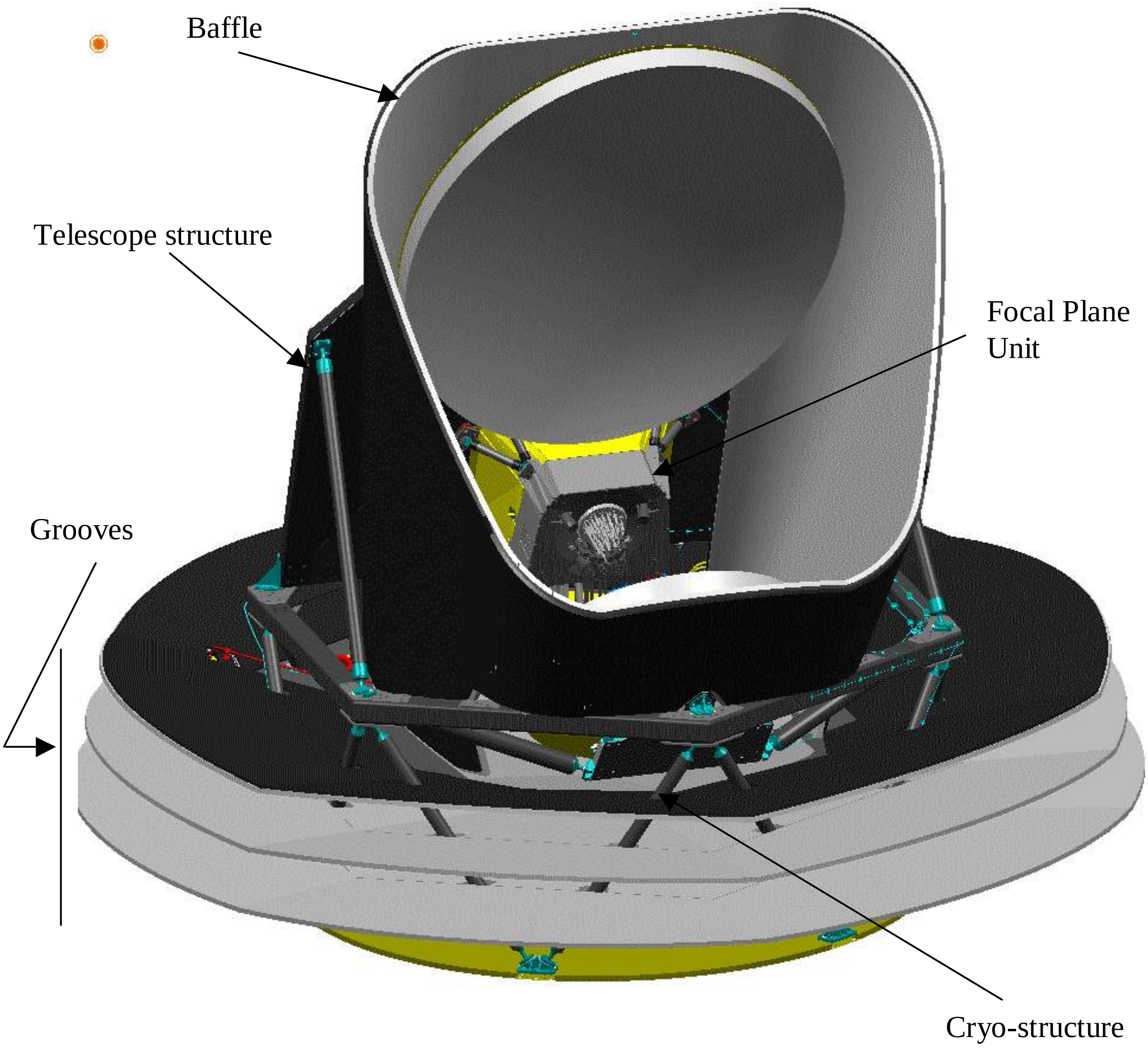


Figure 2-57 PLANCK PLM overview (front side)

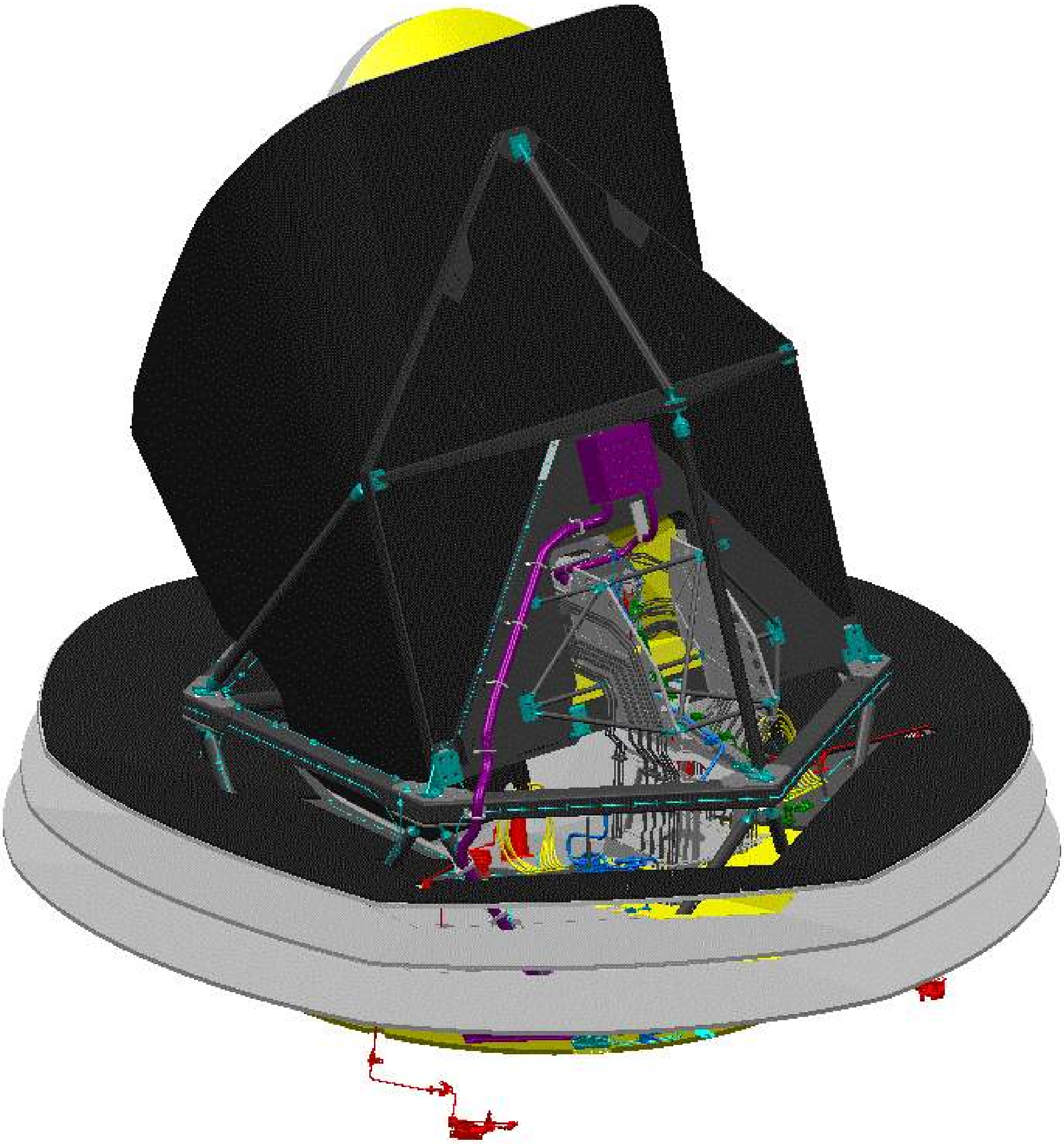


Figure 2-58 PLANCK PLM general overview (rear side, -Z)

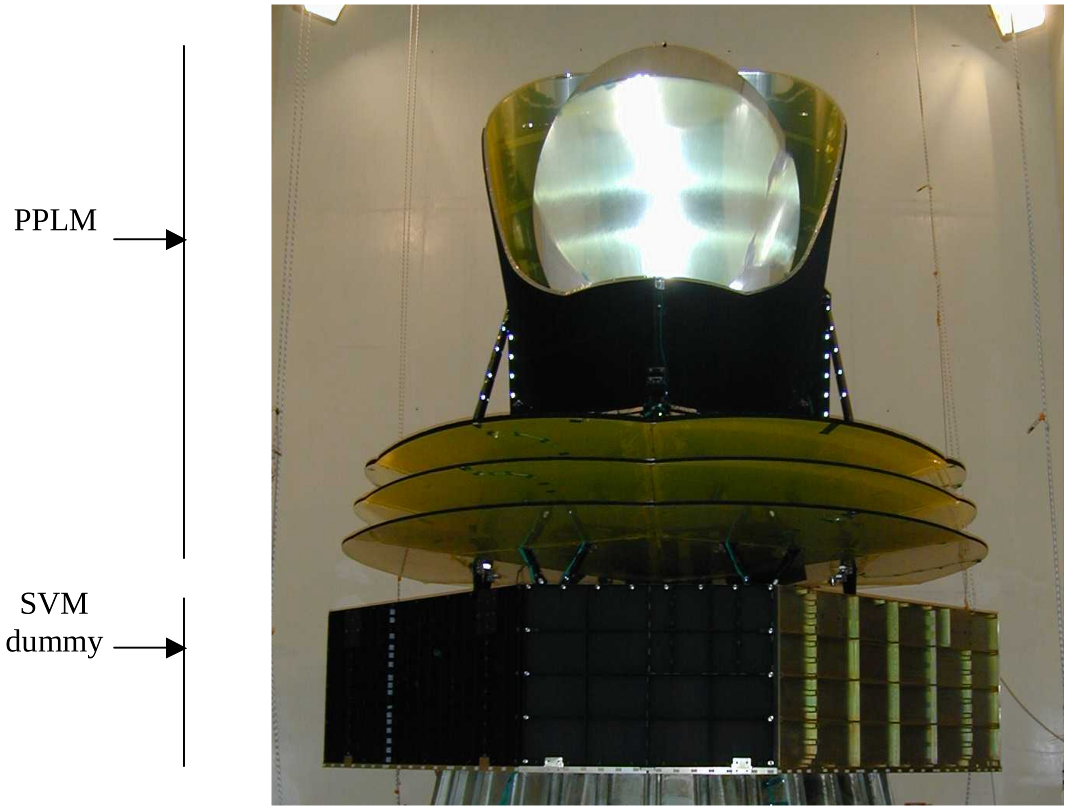
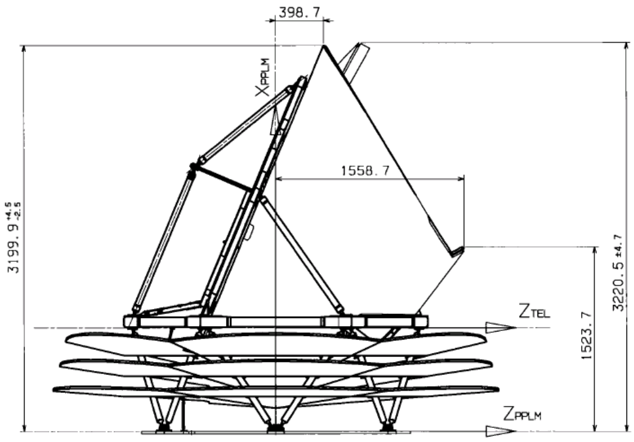


Figure 2-59 PPLM CQM-A before acoustic test campaign

2.3.2. PPLM overall dimensions

The overall dimensions of the PPLM at ambient and operational temperatures are described here after.



(from ICD drawing : PLAPLM0S9200A sheet 2)

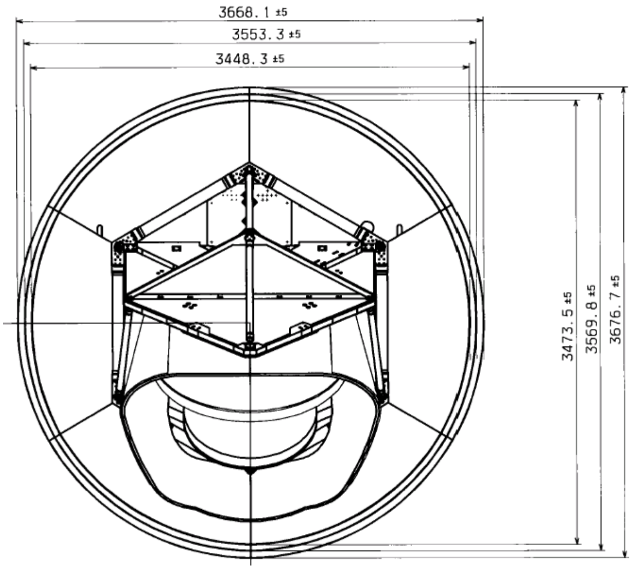
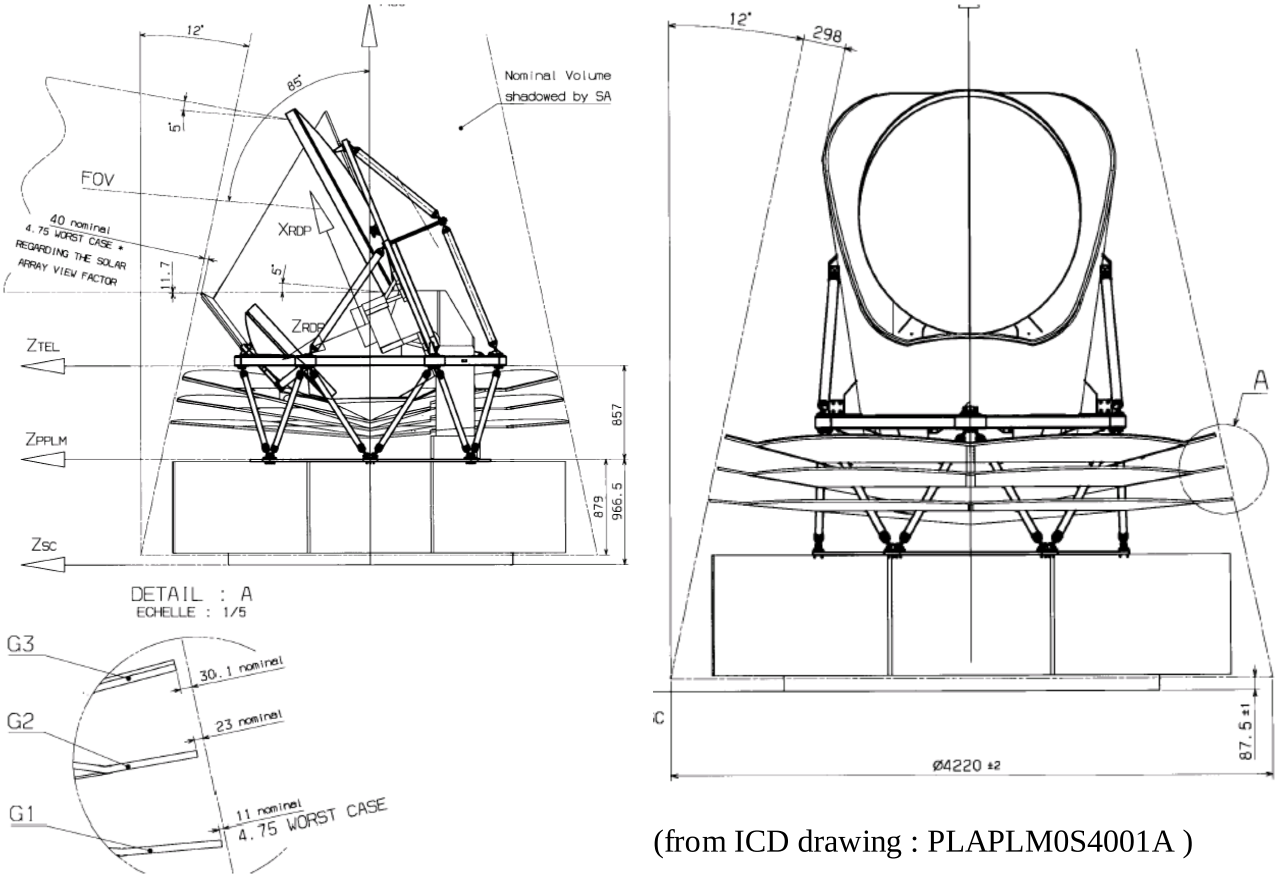
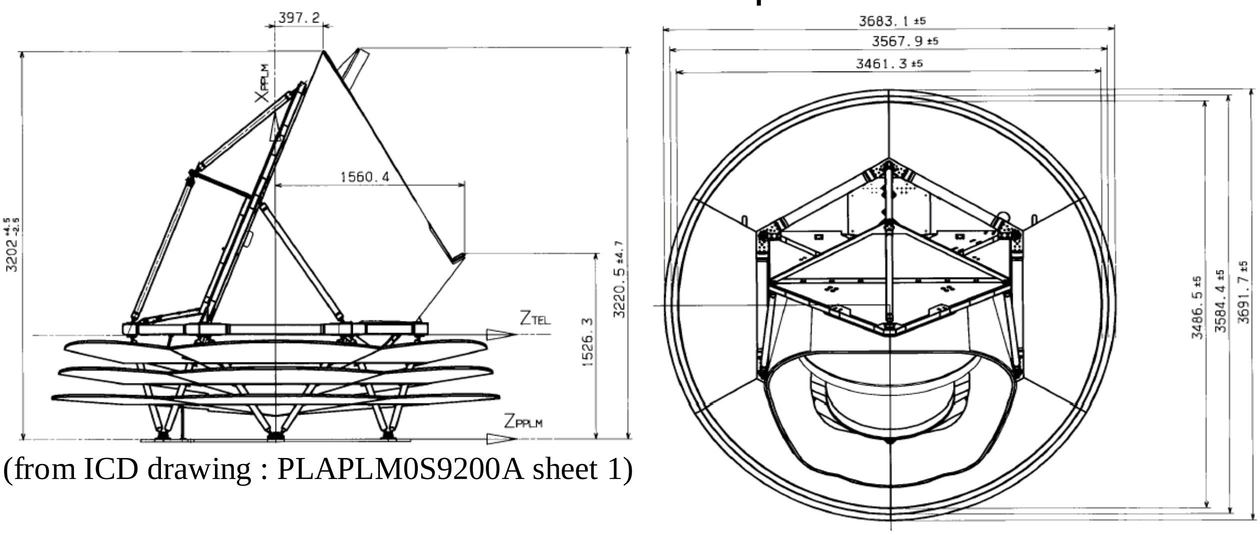


Figure 2-60 PPLM main dimensions at operational temperature



(from ICD drawing : PLAPLM0S4001A)

Figure 2-61 PPLM main dimensions at operational temperature with the 12° shadowed cone and the optical beam



(from ICD drawing : PLAPLM0S9200A sheet 1)

Figure 2-62 PPLM main dimensions at ambient temperature

THALES

2.3.3. Telescope description

2.3.3.1. Optical design

The telescope has an off axis 1.5 m diameter projected aperture. It is composed of:

- An ellipsoidal Primary Reflector (PR)
- An ellipsoidal Secondary Reflector (SR)
- The telescope structure.

The design of the optical layout is described in Figure 2-63.

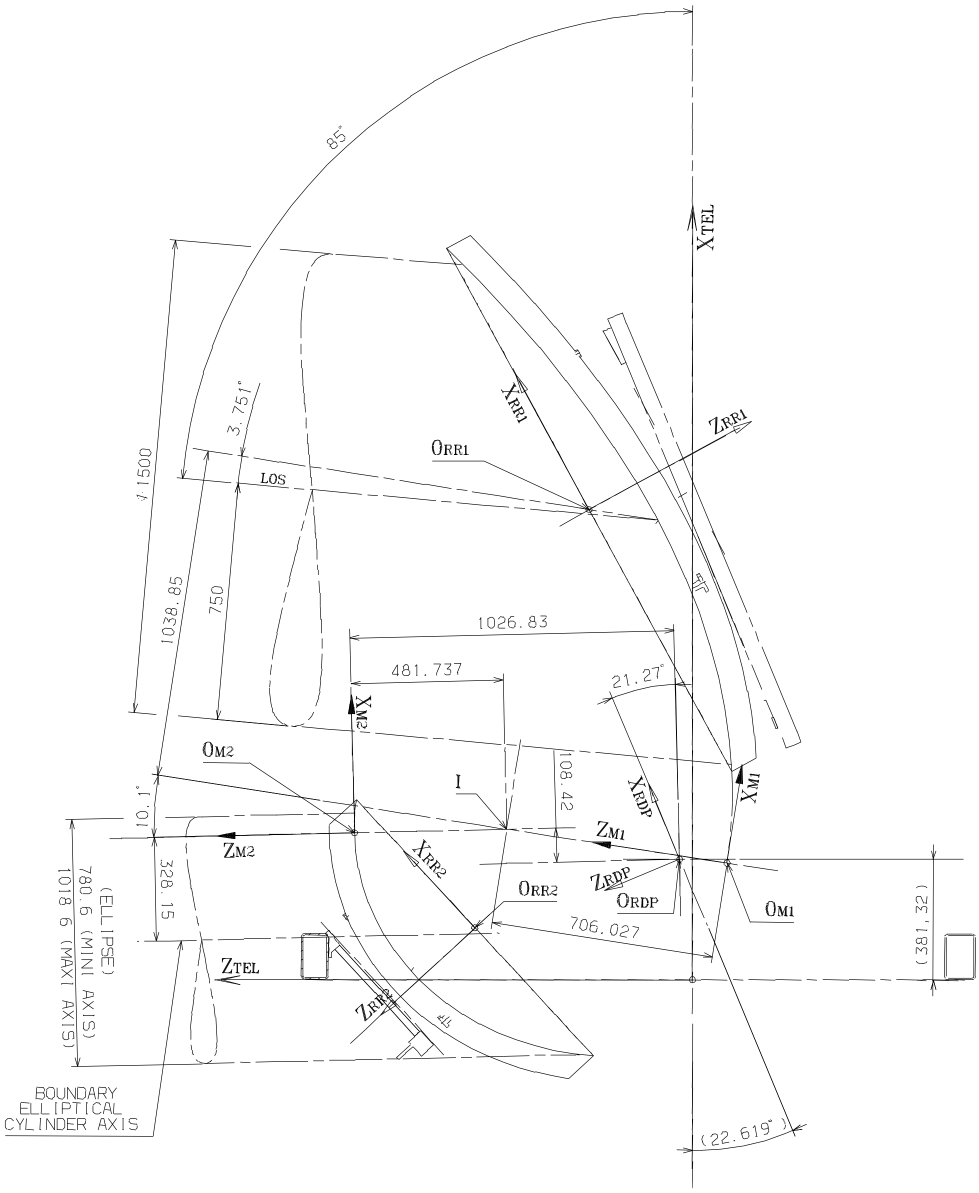


Figure 2-63 Telescope optical layout

2.3.3.2. Overall design

The telescope is designed to be integrated and tested separately from the PPLM structure. An overview of its design and of the main dimensions are given here after:

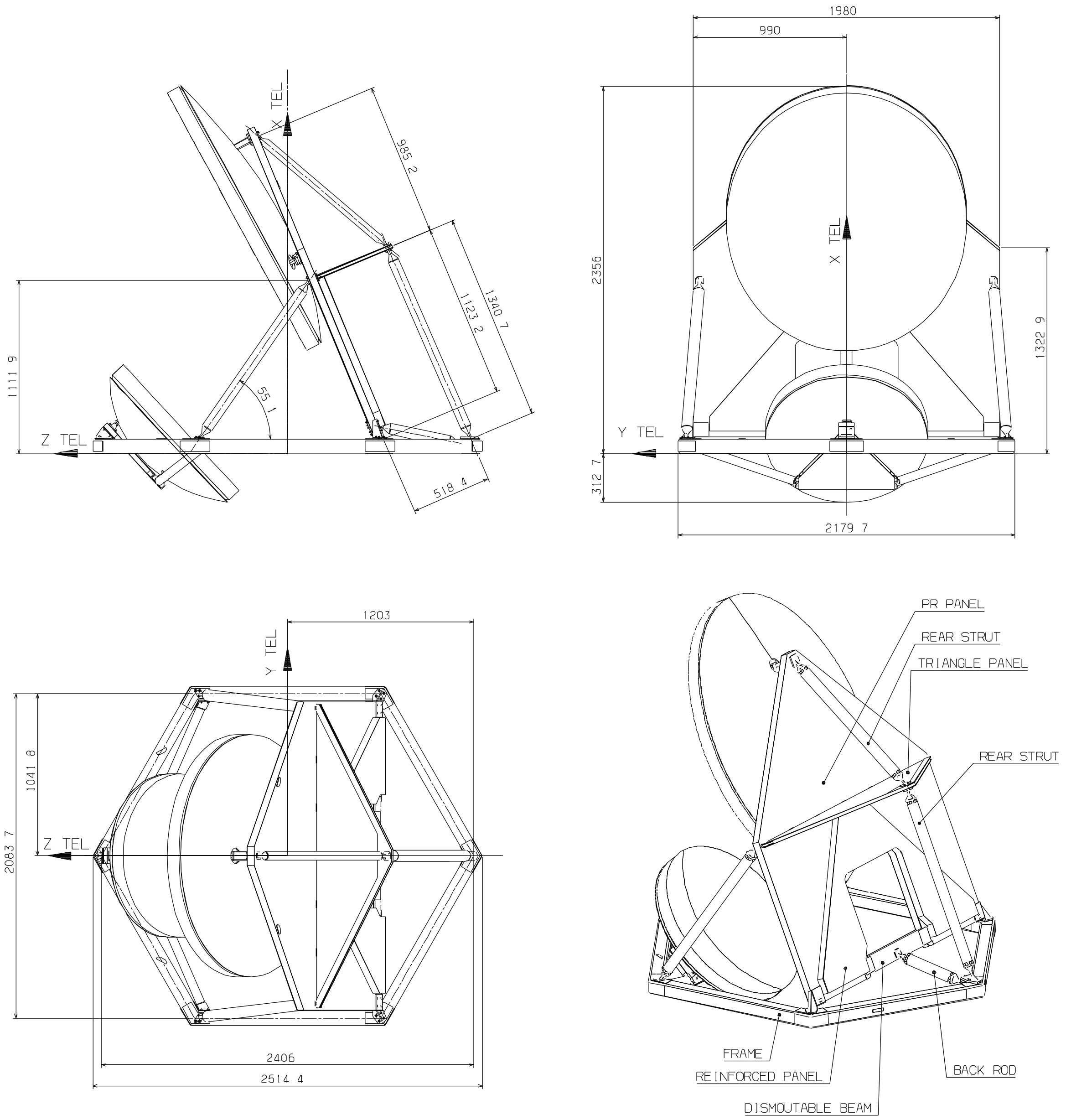


Figure 2-64 Overall telescope design

The main dimensions of the reflectors are the following:

- PR main dimensions: the maximum dimensions implemented for the PR volume are 1886.79 mm x 1555.98 mm x 95mm (containing 15mm for MLI locally adjusted: 1 mm max at the centre of the flat and 0 on the lower edge)

- SR main dimensions: the maximum dimensions implemented for the SR volume are 1104.36 x 1050.96 x 80 mm^3 (containing 15 mm for MLI locally adjusted 1mm max at the centre of the flat).

2.3.3.3. Telescope structure description

The allocated volume and interface definition of the different elements of the telescope structure i.e. the hexagonal frame, the PR support structure and the SR support structure are described hereafter.

The hexagonal frame

Frame interfaces:

- 3 front areas for the blades of the baffle (on the upper side)

- 2 areas for the struts of the PR Support structure + 2 areas for the PR Panel (+/-Y and upper sides)

- 1 area for the rear strut of the PR Support structure (rear and upper side)

- 2 areas for the struts of the SR Support structure (+/-Y and internal sides) + 3 areas for the SR Panel (front side)

- 2 areas for the 0.1K pipes (rear internal side –Y)

- 2 areas for the 4K pipes (rear internal side +Y)

- 1 area for the HFI Bellow (rear external side -Y)

- 2 areas for the WG Lower Support structure (rear and lower side).

The frame cross section is a square profile of 90 mm x 90 mm.

The preliminary design and the main dimensions of the hexagonal frame are presented here after:

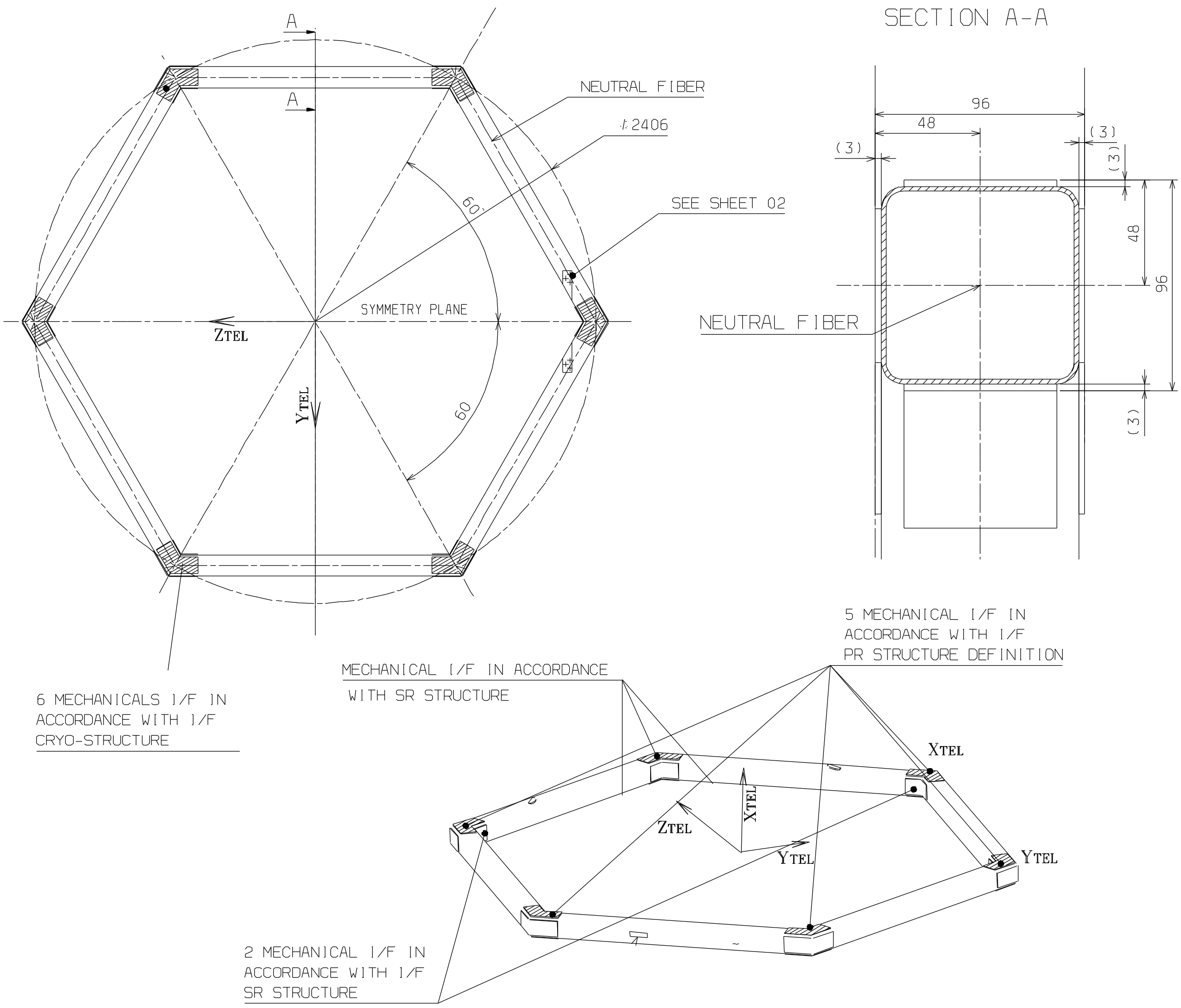


Figure 2-65 Hexagonal frame main dimensions

The Primary Reflector support structure

The PR support structure is mainly constituted of the following parts:

– A main sandwich panel (t: 50 mm) with aluminium honeycomb (3/16'') and CFRP skins (t: 1mm)

– A panel doubler on the rear side of the main panel (triangular shape) with the same characteristics than the ones of the main panel.

– A dismountable beam (in fact a long rectangular panel) to support the lower bipod of the FPU at the bottom of the PR Panel: sandwich panel (t: 52 mm) with aluminium honeycomb (3/16'') and CFRP skins (t: 4mm)

– A CFRP back rod attached at the centre of the dismountable beam that links the frame

– The main struts of the PR support structure are made of CFRP with diameters of 70 mm and thickness of 3 mm, the end fittings are made of Ti6AI4V ELI

– An horizontal triangle sandwich panel, (t: 20 mm) with aluminium honeycomb (3/16'') and CFRP skins (t: 2mm), which links the 2 upper support points of the PR Panel (at X: +1134 mm / Tel co-ordinate system) and adds stiffness in the area supporting the 2 FPU upper bipod and the 2 reflector lower ISM sandwich panel.

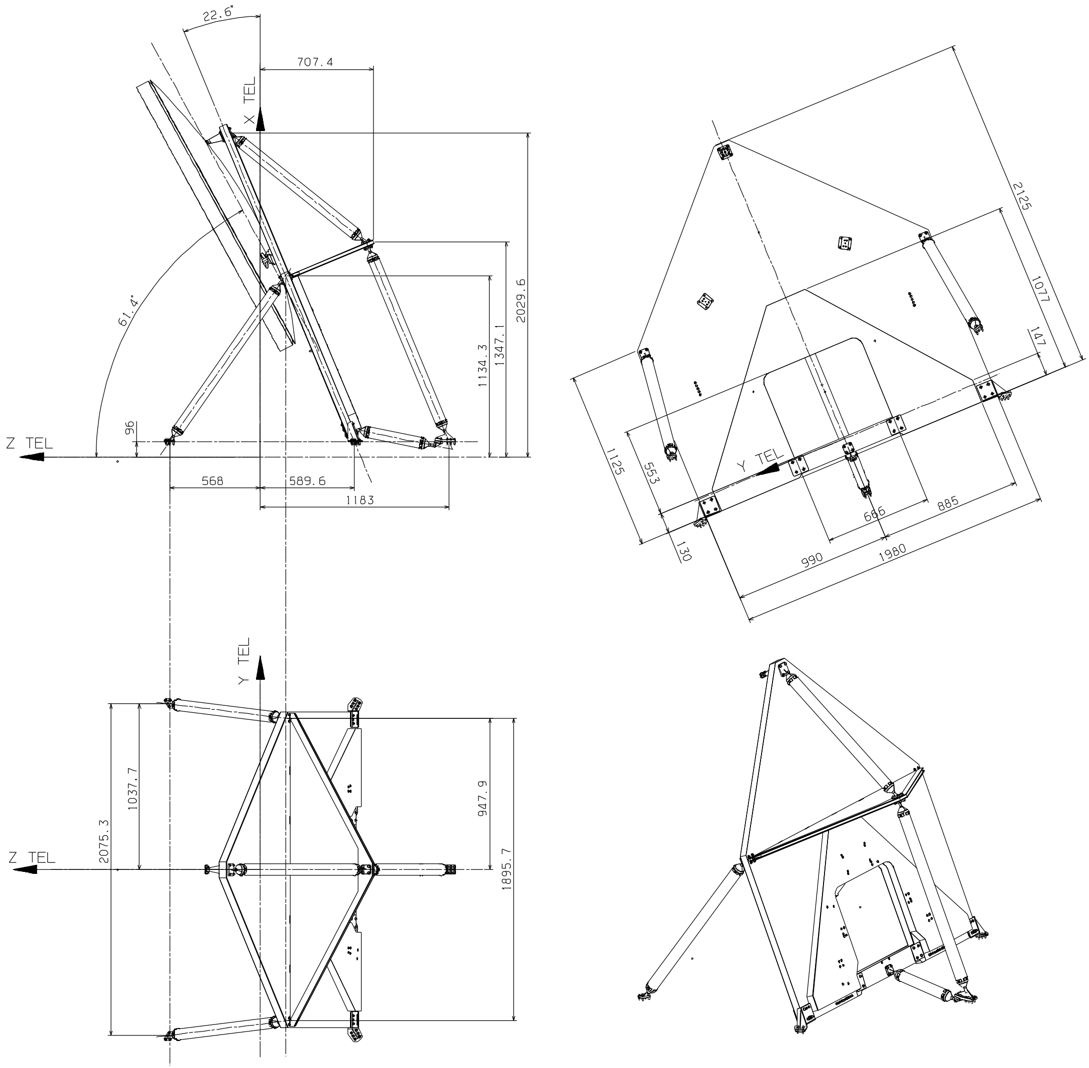
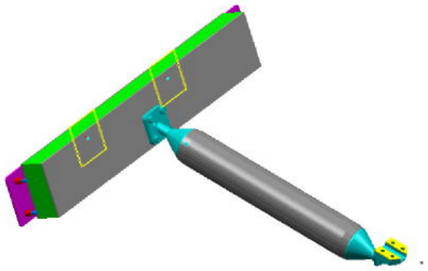


Figure 2-66 PR support structure

The reflector ISM mechanically filter relative displacements and rotations in order to respect the required values: the flexible blades allow to minimise the strength and torque introduced at the reflector interfaces by the telescope structure instabilities (integration, launch, hygro-elastic effects, cool down...) as well as to guarantee the stiffness requirement of the reflector subsystem.

The FPU is fixed to the telescope structure via 3 bi-pods. Shim plates will allow to perform the FPU adjustment: shim plate thickness: 5 mm +/-3 mm.

For integration reasons, the dismountable beam and the back rod will be integrated as one part from the front to the backside: -Z direction (because of the WG presence at the rear side of the PR Panel). This is the reason of the dismountability requirement for the lower bipod of the FPU.



The Secondary Reflector support structure

The SR support structure is mainly constituted of the following parts:

- A sandwich panel (t: 25 mm) with aluminium honeycomb (1/8") and CFRP skins (t: 2mm)

- 2 struts of the PR support structure are made of CFRP with diameters of 55 mm and thickness of 3 mm, the end fittings are made of Ti6Al4V ELI.

The reflector is mounted via 3 isostatic mounts to a triangular sandwich panel mounted on the hexagonal frame with 2 struts.

The design of the SR isostatic mounts is based on the same concept used for the primary reflector one.

The SR panel is attached to the telescope frame by three points, one on the top corner of the triangle panel and the two other support points on the lower side of the frame.

The following drawing shows the current SR support structure.

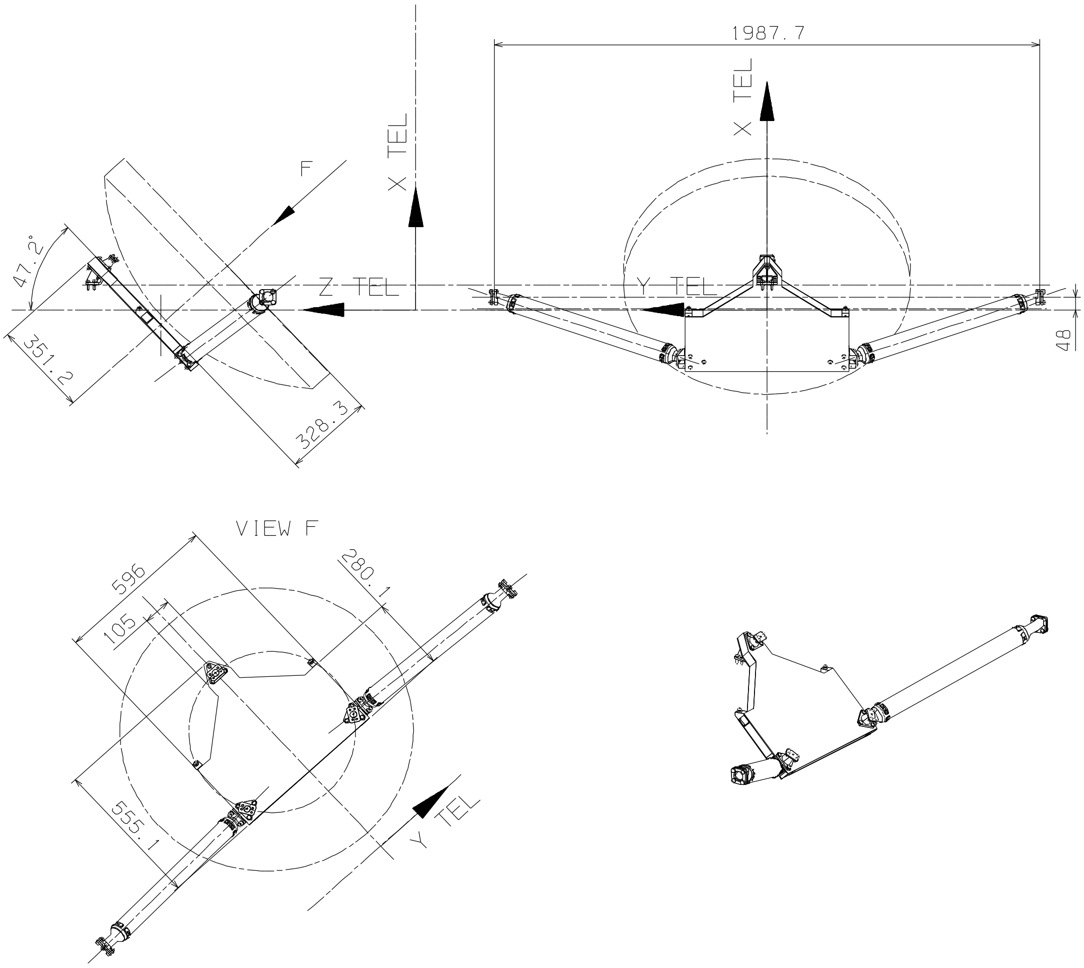


Figure 2-67 SR support structure

Material

Used materials are the following:

- Telescope frame body and doublers in CFRP M55J/954-3, quasi-iso lay-up (-45°/0°/°45°/90°) and/or oriented lay-up (-20°/0°/°20°)
- Struts of PR and SR support structures in CFRP M55J/954-3, oriented lay-up (-20°/0°/°20°)
- PR and SR Panel skins in CFRP M55J/954-3 quasi-iso lay-up (-45°/0°/°45°/90°)
- Strut end fittings, inserts, anchor plates, screws are in Titanium: Ti6AI4V ELI (Extra Low Interstitial).

This choice of materials leads to a low CTE (carbon fibre, Titanium) and CME (cyanate matrix) difference between the different parts.

The ELI version of titanium alloy allows to use this material down to 20°K with no embrittlement due to the very low level of impurities (such iron and oxygen).

2.3.4. Cryo-structure description

The cryo-structure is composed of a support structure: a truss made of 12 struts and of 3 facetted V-groove shields.

The support structure design is optimised to provide both the PPLM required stiffness to be compatible to the Planck satellite eigenfrequency requirements and a maximum conductive thermal uncoupling between the SVM and the telescope.

The lower part of the truss interface with the SVM at the interface diameter of the SVM Central Tube to reach an optimum mechanical behaviour. The upper part of the truss interfaces with the telescope structure.

The assembly is shown on the two following Figures.

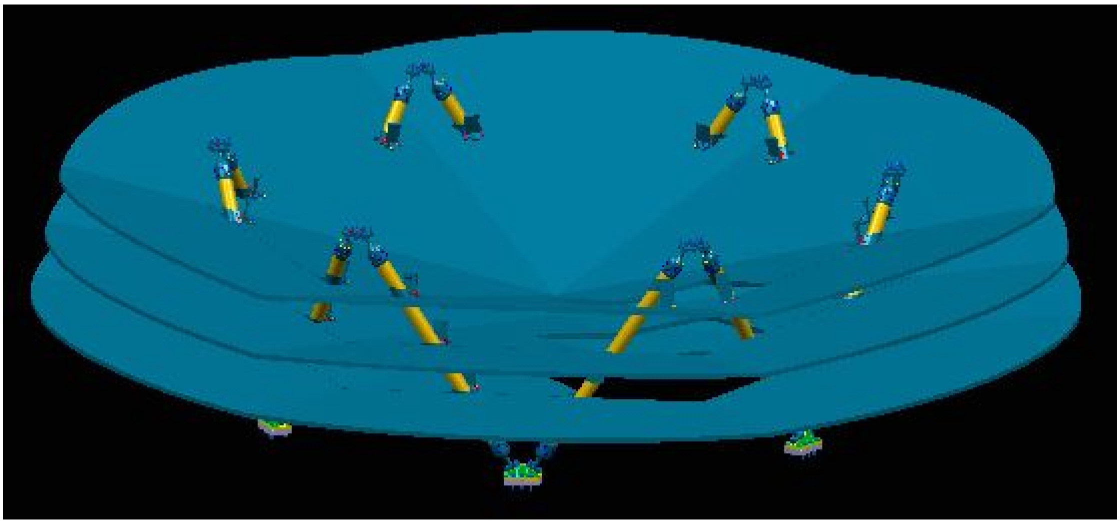


Figure 2-68 Cryo-structure design (with entire V-groove shields)

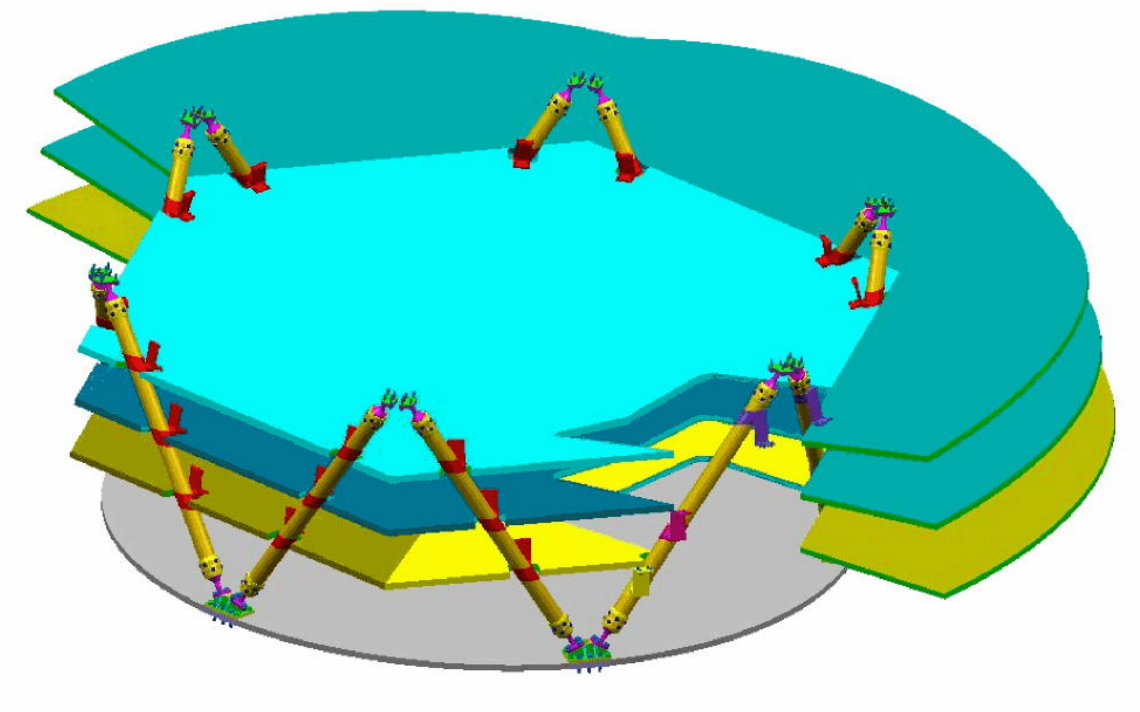


Figure 2-69 Cryo-structure without external petals on –Y side
Attachment blades of each V-Groove interface on the GFRP struts are shown in red

Grooves are facetted with 6 flat sectors of 60° each. This technical solution has shown two main advantages: easier integration regarding translation along the coolers pipe heat exchangers and a lightened manufacturing process.

Since the groove material is aluminium with a large displacement due to thermo-elastic behaviour at cryo temperature (about 7 mm) it will be necessary to compensate the cool down shrinkage of the external diameter.

The internal petals are attached radial with thin splices, the small steps induced are acceptable since they are oriented in the radial direction (very low impact on the thermal radiative rejection). The external petals are attached to the internal ones with a clamped system: U shape insert in the internal part. This leads to an external petal thickness lower than the one of the internal petals: 17 mm for 20 mm. The 6 external petals are added individually at the end of the integration sequence.

It has to be noticed that the thermo-elastic compensation is only done on the external diameter, this implies that all the pipe fixations will have to withstand the groove shrinkage (interface location defined in integration environment for instruments and structure).

The cryo-structure height (+5 mm) and the groove angles (5°/10°/15°) lead to a vertical distance of 51 mm between each groove, and consequently about 150 mm at the internal/external petals junction (~ϕ 1.1 m) and about 215 mm at the external diameter of the grooves (~ϕ 3.5 m). These dimensions give the possibility to act on the pipe heat exchangers or on the attachment points even after the groove integration.

The thermal straps between baffle, groove 3 and telescope are defined as follows:

- Main link between baffle and groove3 at the bottom of the baffle
- Link between baffle and PR panel at the panel mid height
- Link between PR panel and groove3.

The following Figure shows one of the GFRP struts with its end fittings. These ones are one-piece manufactured better for stability and mass saving. In order to withstand the thermal environment around 50 K, the attachment between the GFRP strut and the fitting (internal diameter) is bonded and riveted with the adjunction of an external GFRP ring for local reinforcement.

Selection of the adequate bonding material; optimisation of the CTE, bonding length and end fitting shape are design to minimise the internal stress.

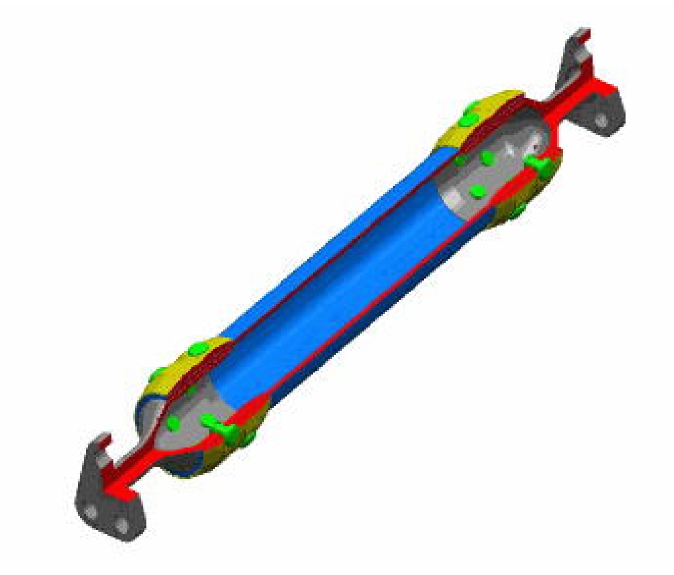


Figure 2-70 Cryo-structure strut (3D cut view)

The following drawing shows the main dimensions of the complete cryo-structure.

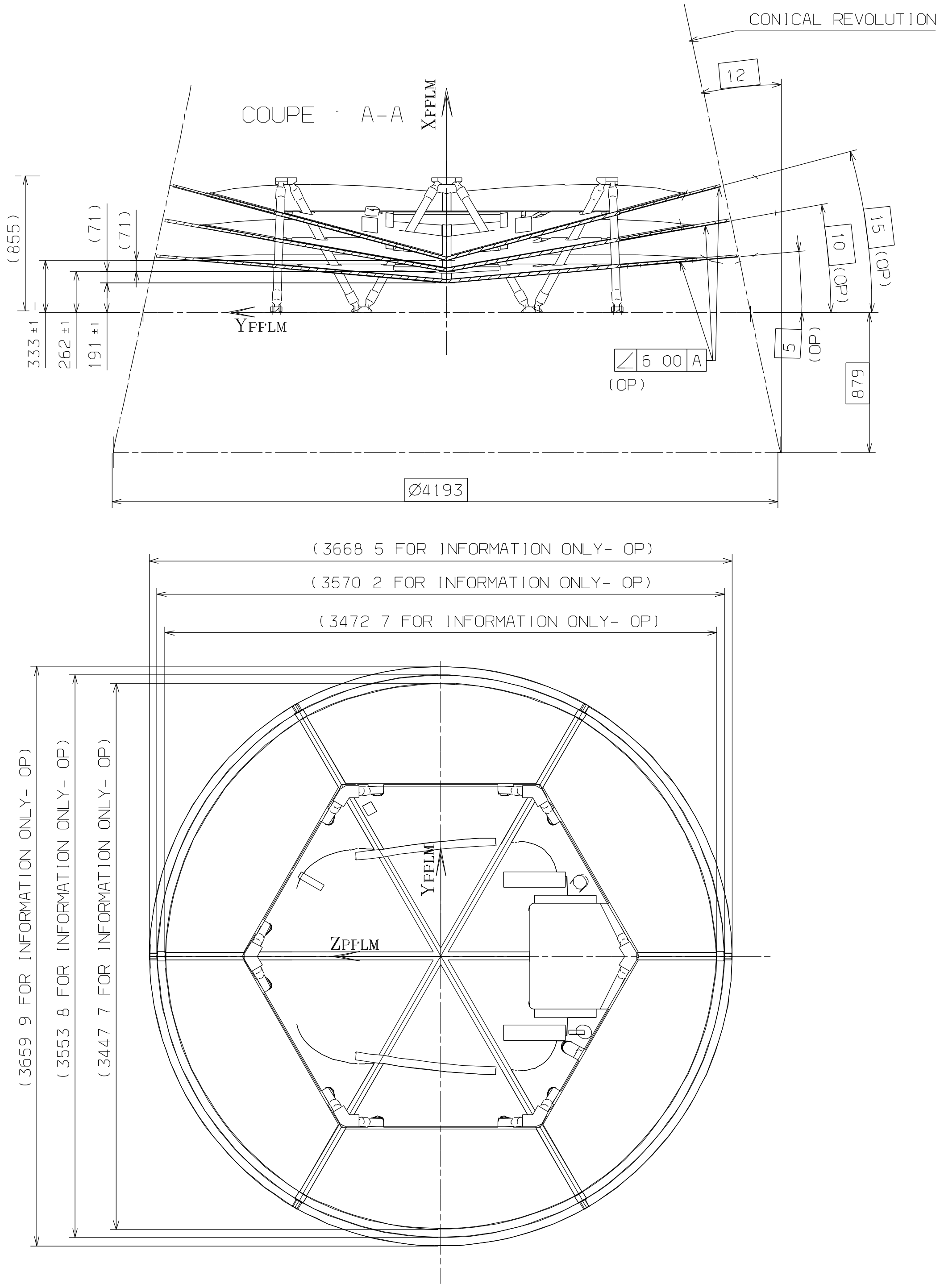


Figure 2-71 Cryo-structure main dimensions

Dimensions are given at Integration Temperature except those with (OP) given at Operational Temperature

The grooves are mounted on the structure using specific flexible devices (radial blades) which fulfil the cryo-structure requirements in terms of mechanical and thermo-elastic strength (I/F loads), mass, stiffness and operational stability performances.

Thus, those devices will have to minimise distortions induced by the differential shrinkage between the grooves and the struts during the cool-down phase.

Furthermore, each groove is thermally anchored to the cryo-structure struts to intercept parasitic heat coming from the SVM, and reject it to cold space by means of the "V-groove" effect. The conductive thermal coupling requirement between the struts and the groove is reached using for example copper braid.

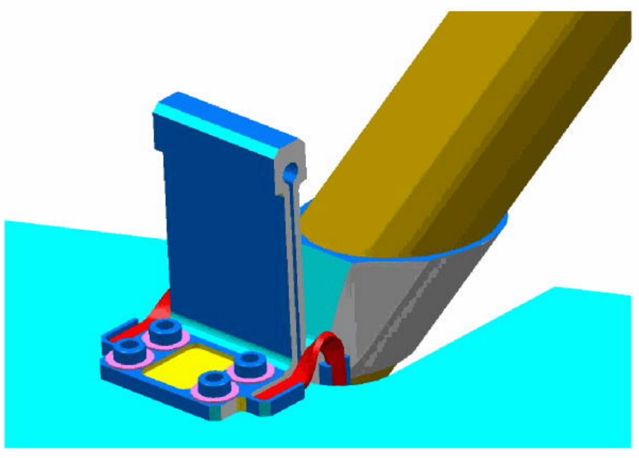


Figure 2-72 Flexible blade for groove attachment on cryo-struts

V-Groove shields

The material used fulfil as better as possible the Cryo-structure requirements in term of mechanical and thermo-elastic strength, mass, stiffness and operational stability performances.

The material is aluminium sandwich with a thickness of 20 mm (internal petals) and of 17 mm (external petals). The skins are made in a very pure aluminium to increase the thermal conductivity performance: **Miro 27** (**AA 1085**) with a very thin thickness of **0.25mm** (+/-0.02mm). This material allows using a single layer approach: limitation of the technical risk and mass saving. It is also expected to exhibits sufficient low emissivity with a high-gloss-finished surface: mass saving with no additional VDA Kapton Foil or adhesive layer. The material strength is also sufficient to allow this kind of skin thickness (about 150 MPa for Yield strength).

The following Figures show the implementation of all the interface of the grooves shields with Instruments Heat exchangers.

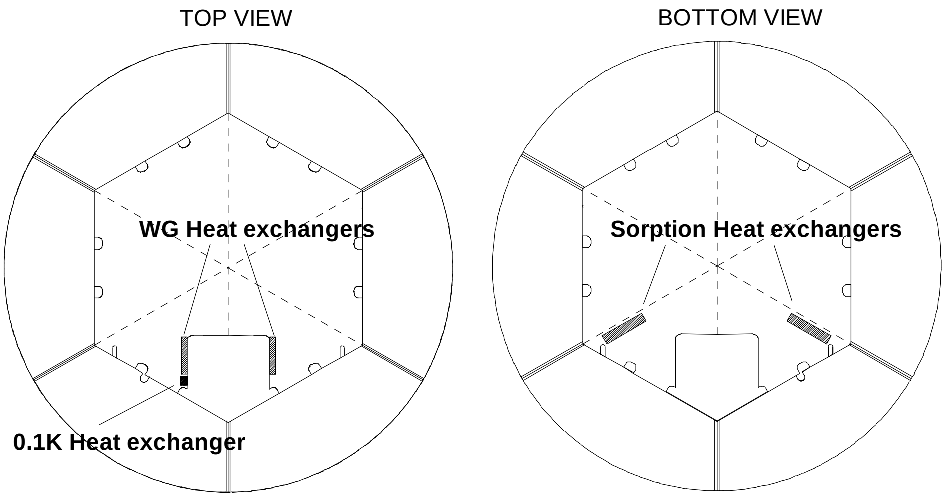


Figure 2-73 Grooves 1 and 2: heat exchangers locations

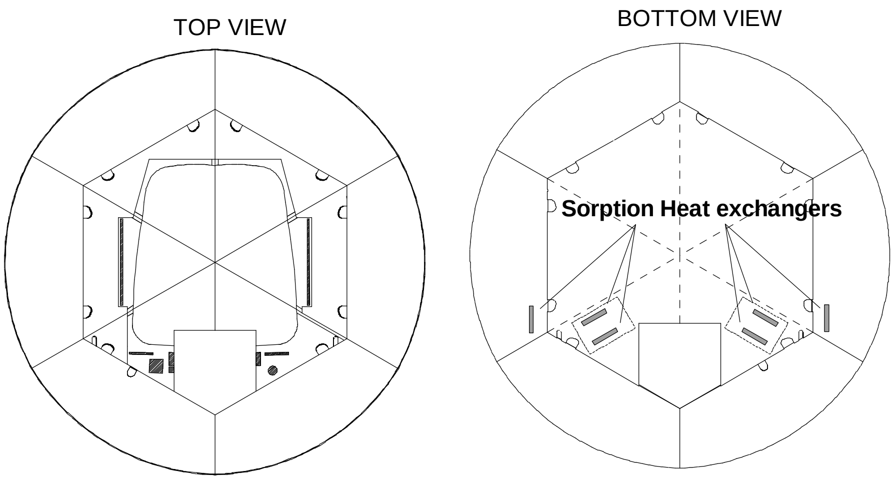


Figure 2-74 Groove 3: heat exchangers locations

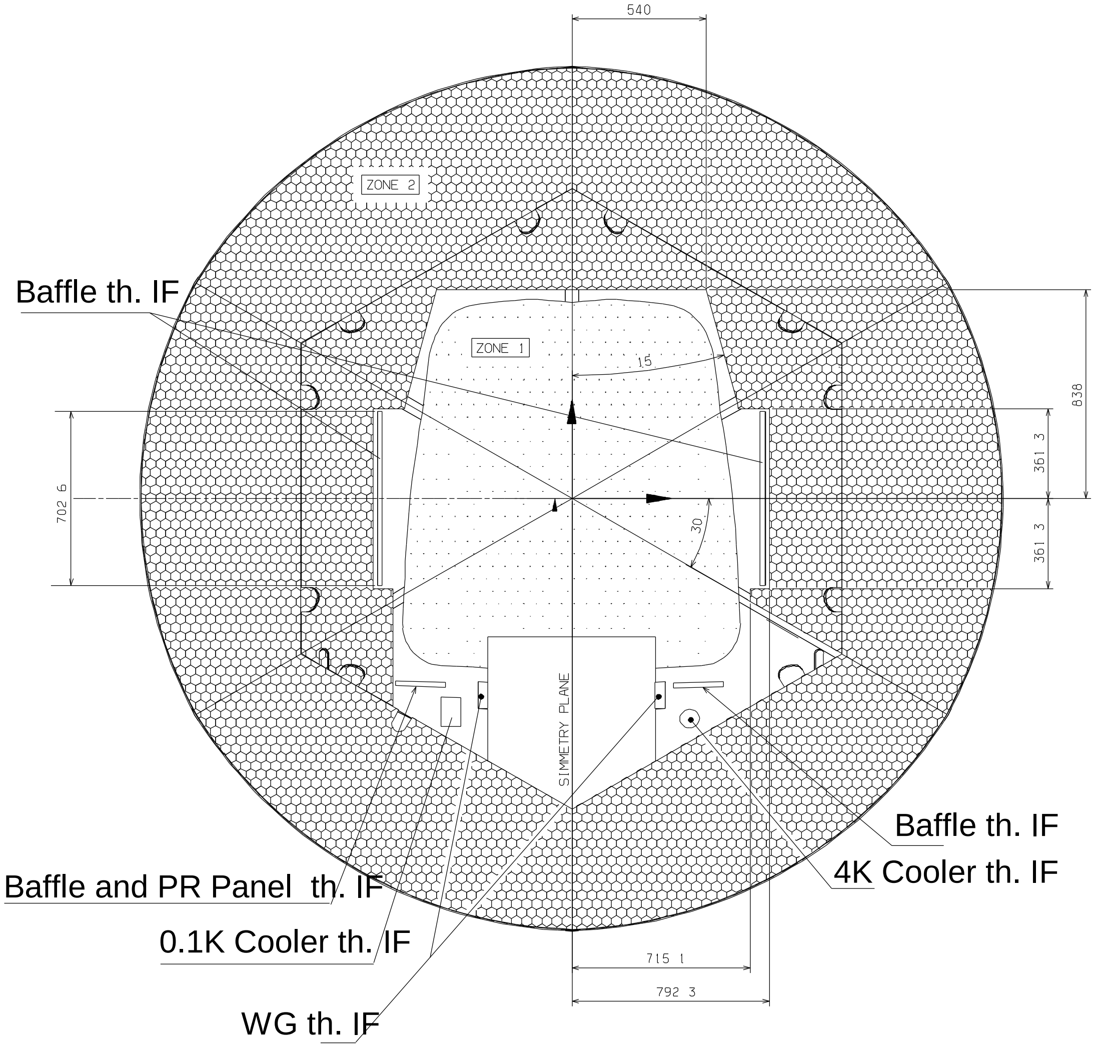


Figure 2-75 Groove 3: thermal areas and heat exchangers locations on the upper side

2.3.5. Baffle design

The telescope is surrounded by the main baffle. Its main functions are:

- To protect the telescope from the straylight
- To provide the optimum radiative surface compatible with the PLANCK telescope operational temperature.

For integration reasons, the baffle is cut in two single parts. The cut lines will be covered with Aluminium foil. For straylight protection, the baffle structure is elongated close to the groove 3 and the residual gap is sealed and thermally connected by Aluminium foil.

The whole baffle assembly is fixed onto the telescope support frame and on the PR panel by a set of 7 attachment brackets consisting in 7 flexible blades with a convergence near the geometric centre of the baffle. These brackets are part of the baffle. Their design guarantees that the loads induced by the differential thermo-elastic behaviour during cool-down are adequate.

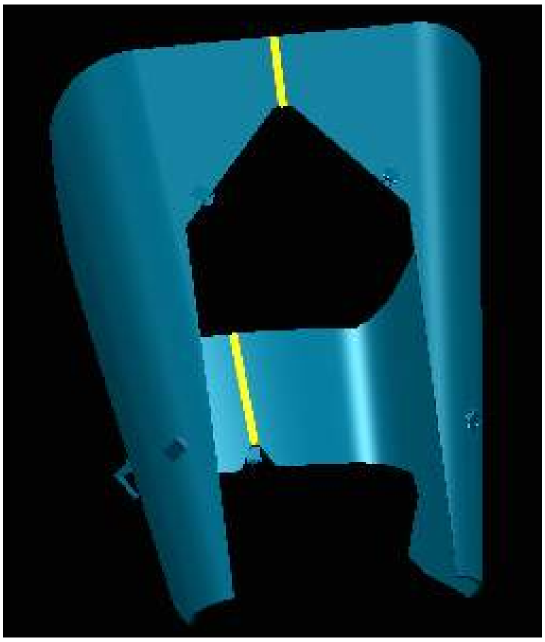


Figure 2-76 Design of the baffle

2.3.6. PPLM thermal control description

2.3.6.1. Passive radiator

2.3.6.1.1. General design

As previously described in the mechanical and thermal architecture section, the passive thermal control design is based on:

- A 3 stage "V-Groove" radiative shield allowing to thermally uncouple efficiently SVM hot interface (300 K) from PPLM cold instruments interfaces and optical environment (#50 K).

  The "V-Groove" rejection enhancement relies on low emissive and highly specular coatings, as well as controlled flatness and global geometry

- An important (15 m²) and high emissive radiative surface implemented on 50K elements providing cold PPLM parts with sufficient heat rejection potential

- Low conductive struts mechanically supporting the 50 K elements on the SVM.

- Thermal homogeneity is moreover globally ensured in order to optimise the radiating surface rejection and to limit hot spots around instruments local heat inputs (use of thermal braids, high conductive materials…).

2.3.6.1.2. Cryo structure design

Shield and baffle three faceted shields (Aluminium sandwich) compose the “V-Groove” system. Their proper definition and manufacturing are mandatory for an efficient heat rejection.

Unlike the two others, the shield 3 (coldest one) supports a high emissive coating including black painted open honeycomb.

The three shield edges (thickness at outer periphery) are painted black in order to enhance the shield power rejection ability.

The shields sandwich skins are made of MIRO27 [EN AW 1085 H18 (Al 99.85)] coated with PVD [EN AW 1199 (Al 99.99%)]. This quite pure Aluminium presents the great advantage to be highly conductive at cold temperature. Moreover, its PVD coating ensures good thermo-optical properties (low emittance, high specularity).

Defaults and singularities (flatness, screws, holes…) of shields surface have systematically been minimised in order to make the most of MIRO ideal thermo-optical properties:

- Screws are covered by Aluminium tape and chamfers have been chosen instead of steps
- The pipes routing has been chosen so that it may yield the minimum radiative screening (pipes in radial direction when feasible), the mechanical blades are hidden behind the struts
- The screens used to blind the shields “Wave Guides holes” have been designed in order to allow at best radial radiation rejection
- “Pipes and struts holes” are blinded by Aluminised Kapton foils (blinding enhanced by two Kapton layers on both sides of shield1&2).

Shields facets are linked by three different interface designs, as described in Figure 2-77, Figure 2-78 and Figure 2-79.

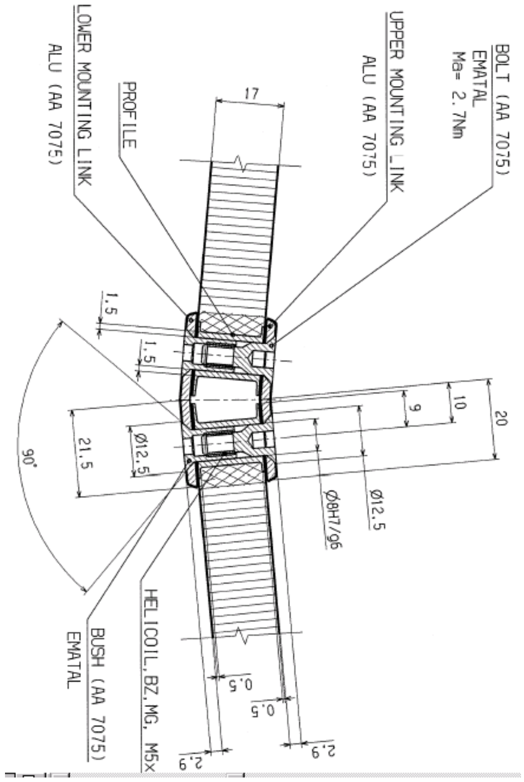


Figure 2-77 Shields facets links: external - external

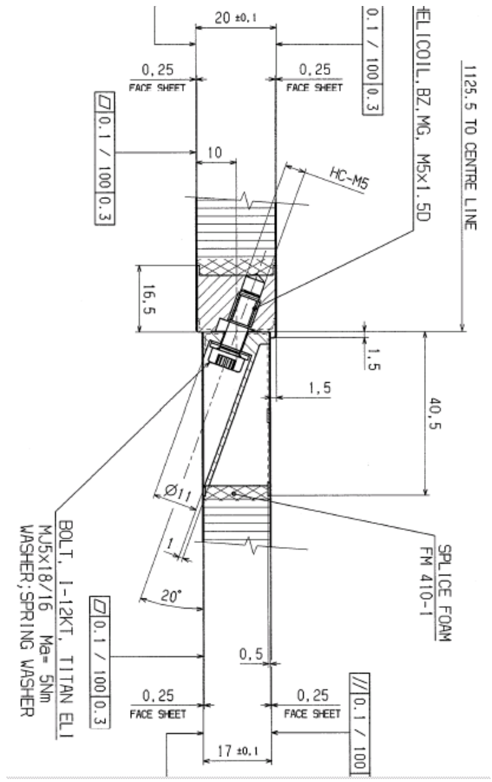


Figure 2-78 Shields facets links: internal - external

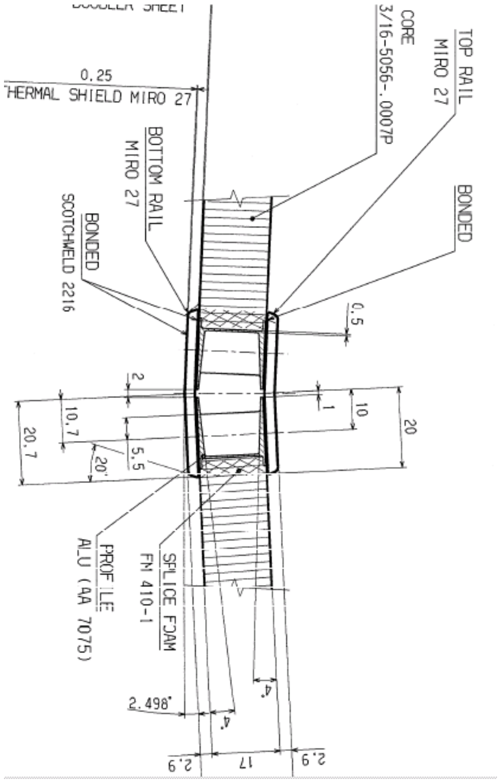


Figure 2-79 Shields facets links: internal - internal

The links use additional Aluminium doubler (internal-internal & external-external) or facet-to-facet direct screwing (internal-external).

Unlike the internal-internal interface, based on glued contacts, the two other interfaces are based on dry contact surfaces. Dry contacts being in general very design sensitive, it has been necessary to comfort the associated thermal performance with dedicated measurements on representative samples at operational temperature.

The baffle sandwich has also MIRO27 skins and supports an important part of the overall radiative area (about 70 % of external baffle surface is equipped with black painted honeycomb).

2.3.6.1.3. Cryo struts

The cryo struts are made of GFRP for thermal insulation reasons. They are heat sinked to the shields by means of Aluminium blades and additional copper straps, as shown in Figure 2-80. Cryo struts inner volume is filled with low conductive ECCOSTOCK foam in order to prevent inner radiative couplings from degrading the insulating function of the struts.

Note that bracing struts between SVM and shield 1 are also made of GFRP.

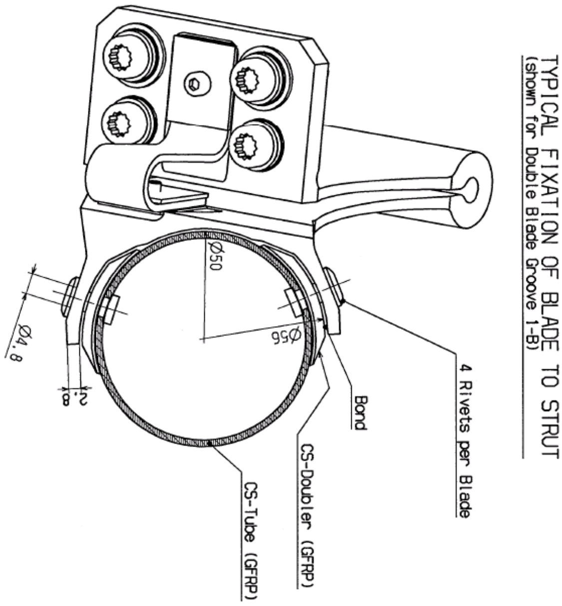


Figure 2-80 Struts/shields link

2.3.6.1.4. Telescope

Reflector panels are made of CFRP/Aluminium sandwich. Due to its large dimensions, primary reflector panel is covered by an important radiating area (part of which is black open honeycomb). Exception made of elements in view of the optical cavity, all telescope elements are black painted in order to improve heat rejection ability.

2.3.6.1.5. High emissivity coating

PUK (MAP) is used for the PLANCK PLM high emissivity coating.

The PUK is used associated with open honeycomb; 14.3mm height for 3/8" cells.

As described in Figure 2-81 and Figure 2-82, baffle and shield 3 high emissive coatings combine areas covered with black open honeycomb or flat paint.

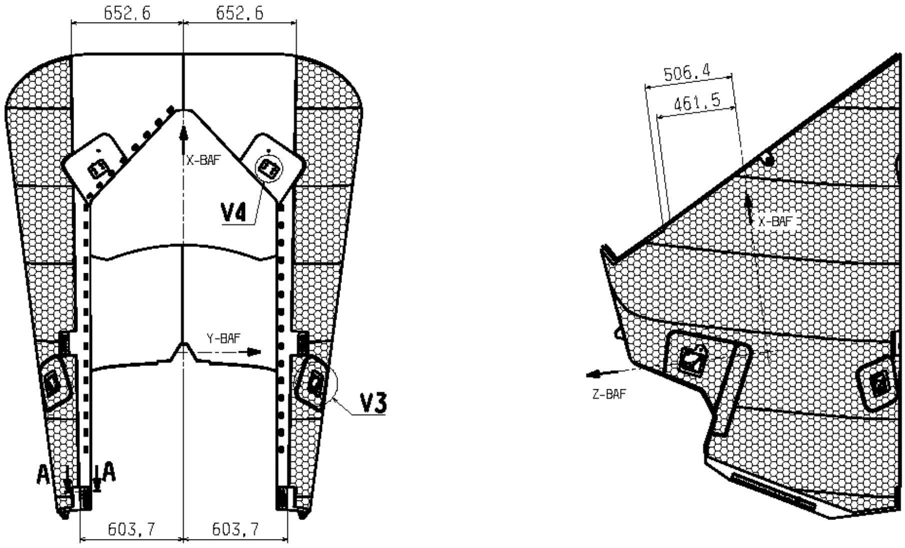


Figure 2-81 Baffle open honeycomb coverage

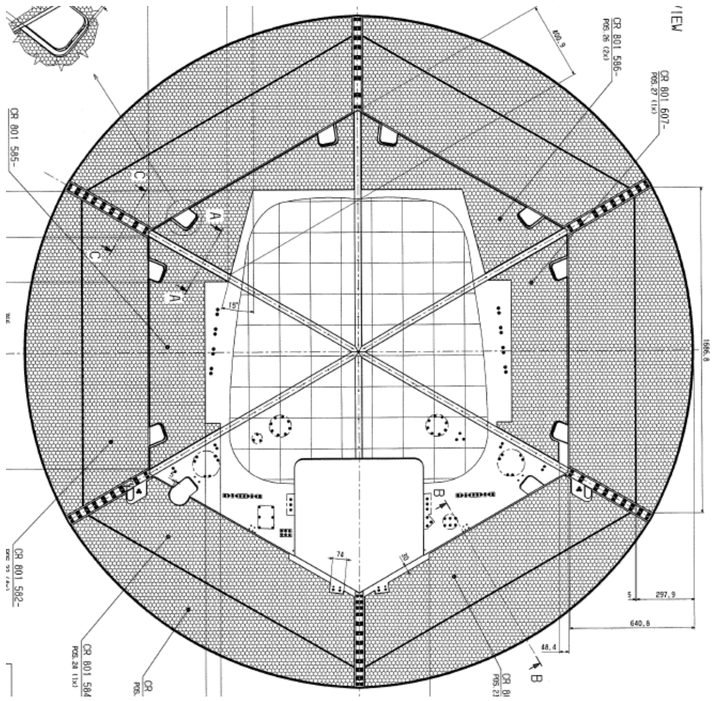


Figure 2-82 Shield 3 open honeycomb coverage

Open honeycomb areas themselves are made of different patches with significant gaps between (not shown in drawings). Observations on hardware allowed to estimate the actual distribution between flat areas and open HC areas. For instance, baffle open honeycomb can be considered as covering 90 % of the theoretical surface, and represents 70 % of the baffle overall external surface.

2.3.6.2. Active thermal control

The PPLM active thermal control (excepted the cryo-cooler system) is composed of decontamination heating lines and temperature sensors. All the electrical interfaces are described in PLANCK PLM EICD, doc. H-P-3-ASP-ID-0550.

2.3.6.2.1. Reflector and FPU decontamination heating lines

The decontamination heating lines are summarised here after:

Heating lines	Line definition	Type	Max delivered power (W)
Primary Reflector	PR_N1	N	60
	PR_N2	N	60
	PR_R	R	60
Secondary Reflector	SR_N	N	60
	SR_R	R	60
Focal Plane Unit -HFI	FPUHFI_N	N	60
	FPUHFI_R	R	60
Focal Plane Unit -HFI	FPULFI_N	N	60
	FPULFI_R	R	60
Total nominal line	5		
Total redundant line	4		

They are composed of the following hardware:

– Heaters

- PR heater type 1:
  - Geometry: as defined in DRW 2540-4100-30A01B of PLANCK reflector ICD reference PLA-ASED-RP-004 Issue 3.1
  - Resistance: 492.3 Ω
  - Resistance tolerance: ≤ 5 %
- PR heater type 2:
  - Geometry: as defined in DRW 2540-4100-30A02B of PLANCK reflector ICD reference PLA-ASED-RP-004 Issue 3.1
  - Resistance: 391.6 Ω
  - Resistance tolerance: ≤5 %

- SR heater:
  - Geometry: as defined in DRW 2540-4200-30A01B of PLANCK reflector ICD reference PLA-ASED-RP-004 Issue 3.1
  - Resistance: 534.1 Ω
  - Resistance tolerance: ≤5 %.

– Harness and connectors:

- Harness between the heater mats and the ISMs (50K stage):
  - Twisted pair of copper wires AWG 28 with kapton insulation and polyimide lacquer according to ESA / SCC 390 10 1910 B
- Harness between the ISMs (50K stage) and the PPLM subplatform connector:
  - Twisted pair of brass wires AWG 24 with PTFE insulation according to specification ESA / SCC 3901 and ASP specification 878468 Issue 01.00.
- Connector type on the PPLM subplatform, at the PPLM/SVM interface:
  - 1 x 340100201B DAMA15P NMB to connect the PR and SR nominal lines
  - 1 x 340100201B DAMA15P NMB to connect the PR and SR redundant lines
- Contact type at the PPLM/SVM interface: ESA/SCC 3401 005 01B.

The definition of the FPU heaters are under instrument responsibility. Their description is part of the instrument documentation.

2.3.6.2.2. Temperature sensors

There are two needs for temperature acquisition, the first is during nominal observation, whereby the science community require the thermal knowledge of critical areas e.g. the telescope reflector temperatures and instrument thermal interfaces (FPU, sorption cooler heat exchanger, wave guide, Jfet). These temperature sensors are known as “Operational Sensors”. The requirements for these operational sensors are given in the following table:

Description	Quantity	number (ID)	Type	Nominal T	Range	Accuracy **(1)**
Groove 1						
SC heat exchanger 1	1	1	N	135K	40-350K	±2.5 K
	1	101	R	135K	40-350K	±2.5 K
SC heat exchanger 2	1	2	N	135K	40-350K	±2.5 K
	1	102	R	135K	40-350K	±2.5 K
+Z External edge	1	3	N	113K	40-350K	±2.5 K
	1	103	R	113K	40-350K	±2.5 K
Sub total1	**6**					
Groove 2						
SC heat exchanger 1	1	4	N	80K	40-350K	±2.5 K
	1	104	R	80K	40-350K	±2.5 K
SC heat exchanger 2	1	5	N	80K	40-350K	±2.5 K
	1	105	R	80K	40-350K	±2.5 K
Sub total 2	**4**					
Groove 3						
SC heat exchanger 1	1	6	N	50K	40-70K	± 1K
	1	106	R	50K	40-70K	± 1K
SC heat exchanger 2	1	7	N	50K	40-70K	± 1K
	1	107	R	50K	40-350K	±2.5 K
Wave Guides Interface1	1	8	N	50K	40-70K	± 1K
	1	108	R	50K	40-350K	±2.5 K
Wave Guides Interface2	1	9	N	50K	40-70K	± 1K
	1	109	R	50K	40-350K	±2.5 K
Optical cavity	1	10	N	50K	40-70K	± 1K
	1	110	R	50K	40-350K	±2.5 K
Sub total 3	**10**					
PR panel						
JFET interfaces	1	11	N	40K	40-70K	± 1K
	1	111	R	40K	40-70K	± 1K
FPU interface 1(lower beam)	1	12	N	40K	40-70K	± 1K
	1	112	R	40K	40-350K	±2.5 K
FPU interface2 (+Y)	1	13	N	40K	40-70K	± 1K
	1	113	R	40K	40-70K	± 1K
FPU interface3 (-Y)	1	14	N	40K	40-70K	± 1K
	1	114	R	40K	40-350K	±2.5 K
Sub total 4	**8**					

Description	Quantity	number (ID)	Type	Nominal T	Range	Accuracy(1)
Baffle						
Baffle 1 (Front face)	1	15	N	40K	40-70K	± 1K
	1	115	R	40K	40-350K	±2.5K
Baffle 2 (Lateral face medium)	1	16	N	40K	40-70K	± 1K
	1	116	R	40K	40-350K	±2.5K
Baffle 3 (Lateral face upper position)	1	17	N	40K	40-70K	± 1K
	1	117	R	40K	40-350K	±2.5K
Baffle 3 (Rear face)	1	18	N	40K	40-70K	± 1K
	1	118	R	40K	40-350K	±2.5K
Sub total 5	**8**					
Reflectors						
PR1	1	19	N	40K	40-70K	± 1K
	1	119	R	40K	40-70K	± 1K
PR2	1	20	N	40K	40-70K	± 1K
	1	120	R	40K	40-70K	± 1K
SR1	1	21	N	40K	40-70K	± 1K
	1	121	R	40K	40-70K	± 1K
SR2	1	22	N	40K	40-70K	± 1K
	1	122	R	40K	40-70K	± 1K
Sub total 6	**8**					
Total of small range sensor	**24**					
Total of wide range sensor	**20**					
Total	**44**					

Table 2-11 PPLM Temperatures sensors definition

(1) : Accuracy for the electronic only, worst case with out calibration. Calibration is requested to improve the value.

Note that for most of the operational sensors the Nominal sensor is used to acquire a narrow temperature range with a high accuracy, and the Redundant sensor is used to acquire an extended temperature range with reduced accuracy. However there are exceptions to this general rule, particularly for the telescope reflectors, the Jfet, FPU interface 2, SC heat exchanger 1.

The second need for temperature sensors for the PLM is the closed loop control of the heaters during the decontamination phase. These types of sensors are referred to as Decontamination Thermistors. The requirements are given in the following table:

Description	Quantity	number (ID)	Type **(2)**	Nominal T	Range	Accuracy**(1)**
Primary Reflectors						
PRTC1	1	50	A	40K	40-350K	± 2.5K
PRTC2	1	51	B	40K	40-350K	± 2.5K
PRTC3	1	52	C	40K	40-350K	± 2.5K
Sub total 1	**3**					
Secondary Reflectors						
SRTC1	1	53	A	40K	40-350K	± 2.5K
SRTC2	1	54	B	40K	40-350K	± 2.5K
SRTC3	1	55	C	40K	40-350K	± 2.5K
Sub total 2	**3**					
FPU-HFI						
FPUHFITC1	1	56	A	4K	40-350K	± 2.5K
FPUHFITC2	1	57	B	4K	40-350K	± 2.5K
FPUHFITC3	1	58	C	4K	40-350K	± 2.5K
Sub total 3	**3**					
FPU-LFI						
FPULFITC1	1	59	A	20K	40-350K	± 2.5K
FPULFITC2	1	60	B	20K	40-350K	± 2.5K
FPULFITC3	1	61	C	20K	40-350K	± 2.5K
Sub total 4	**3**					
Total of wide range sensors	**12**					

Table 2-12 PPLM Decontamination sensors definition

(1) : Accuracy for the electronic only, worst case with out calibration. Calibration is requested to improve the value.
(2): To improve reliability the sensors type A, B and C shall be connected to different failure groups within the CDMU.

Drawings showing the sensors location can be found in annex 6.

They are composed of the following hardware:

– Sensors

- Sensor type: Rosemount 118 MF 2000 2 wires
- Potting: Stycast 2850 FT

– Harness and connectors

- Fixation its support : bonded with Stycast 1266
- Cable: Twisted pair of brass wires AWG 28 with PTFE insulation and polyimide lacquer, according to specification ESA / SCC 3901 and ASP specification 878468 Issue 01.00.
- Connection between the sensor and the cable: Cable joint 324369
- Connector type on the PPLM subplatform, at the PPLM/SVM interface:
  - 1 x 340100201B DEMA 9S NMB to connect the PR nominal sensors
  - 1 x 340100201B DEMA 9S NMB to connect the PR redundant sensors
  - 1 x 340100201B DEMA 9S NMB to connect the SR nominal sensors
  - 1 x 340100201B DEMA 9S NMB to connect the SR redundant sensors
  - 1 x 340100201B DEMA 15S NMB to connect the FPU decontamination loop nominal sensors
  - 1 x 340100201B DEMA 15S NMB to connect the FPU decontamination loop redundant sensors
  - 1 x 340100201B DDMA 50S NMB to connect the PPLM structure nominal sensors
  - 1 x 340100201B DDMA 50S NMB to connect the PPLM structure redundant sensors

Contact type at the PPLM/SVM interface: ESA/SCC 3401 005 04B.

2.3.6.3. Thermal performances

Four steady states have been analysed :

- Operating modes
  - Nominal case related to typical assumptions
  - Hot case related to pessimistic assumptions
  - Cold case related to optimistic assumptions
- Non-operating mode
  - Cold case related to optimistic assumptions

The analysis results for the nominal operating case is shown below:

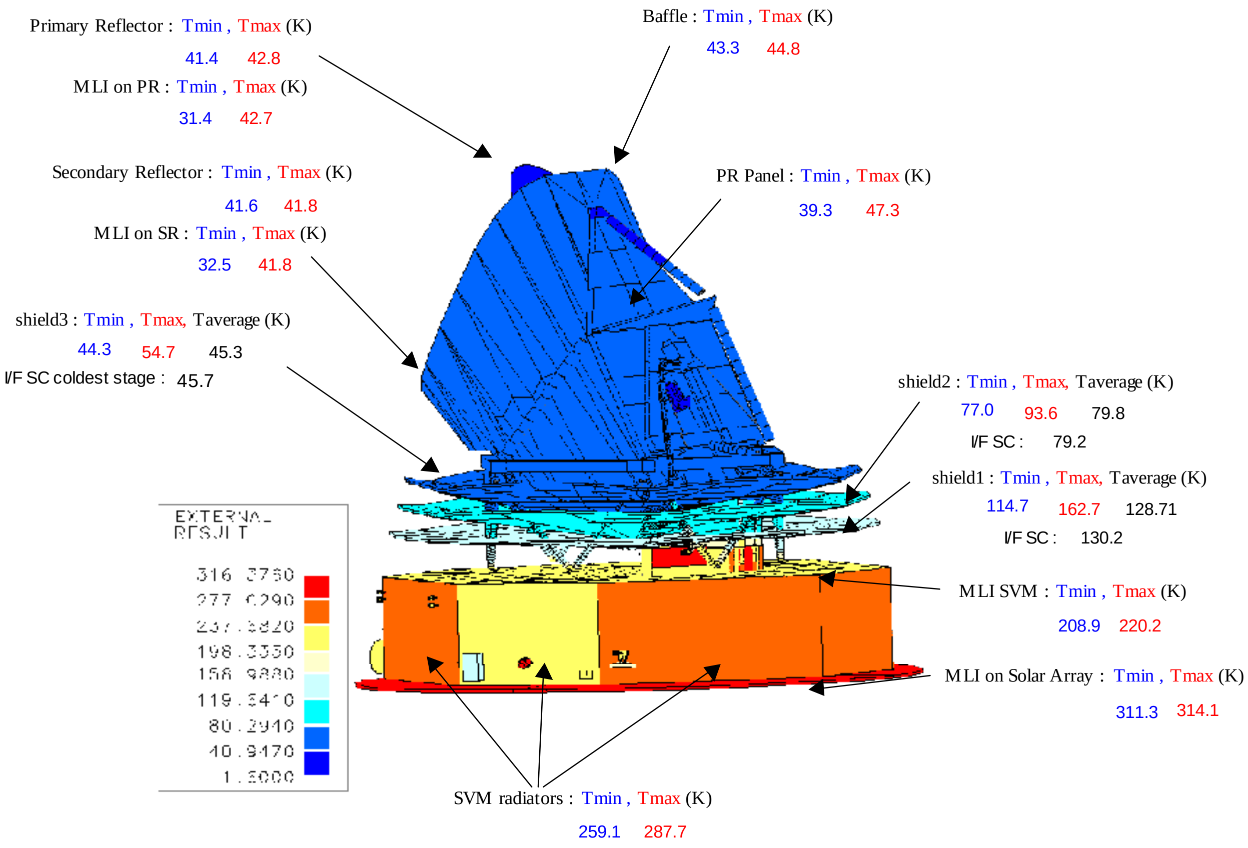


Table 2-13 Nominal PPLM temperature cartography

Refer to H-P-3-ASPI-AN-0330 “Planck PLM thermal analyses” for further information [RD-41]

2.3.7. Instruments accommodation

2.3.7.1. General accommodation

The general accommodation of the instruments with their interfaces on the PPLM structural side (over the PPLM subplatform, X > 966.5 mm) are presented here after.

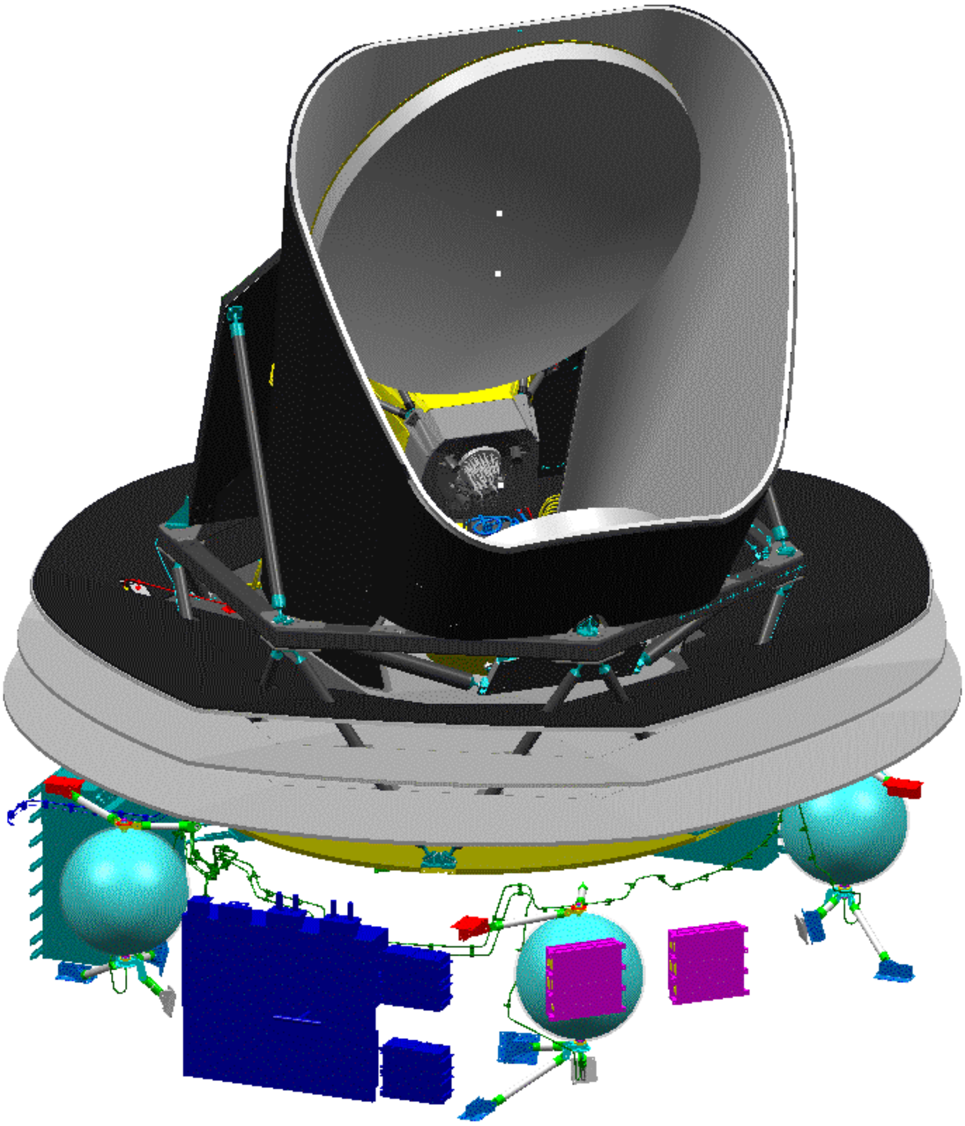


Figure 2-83 Instruments general implementation (front side)

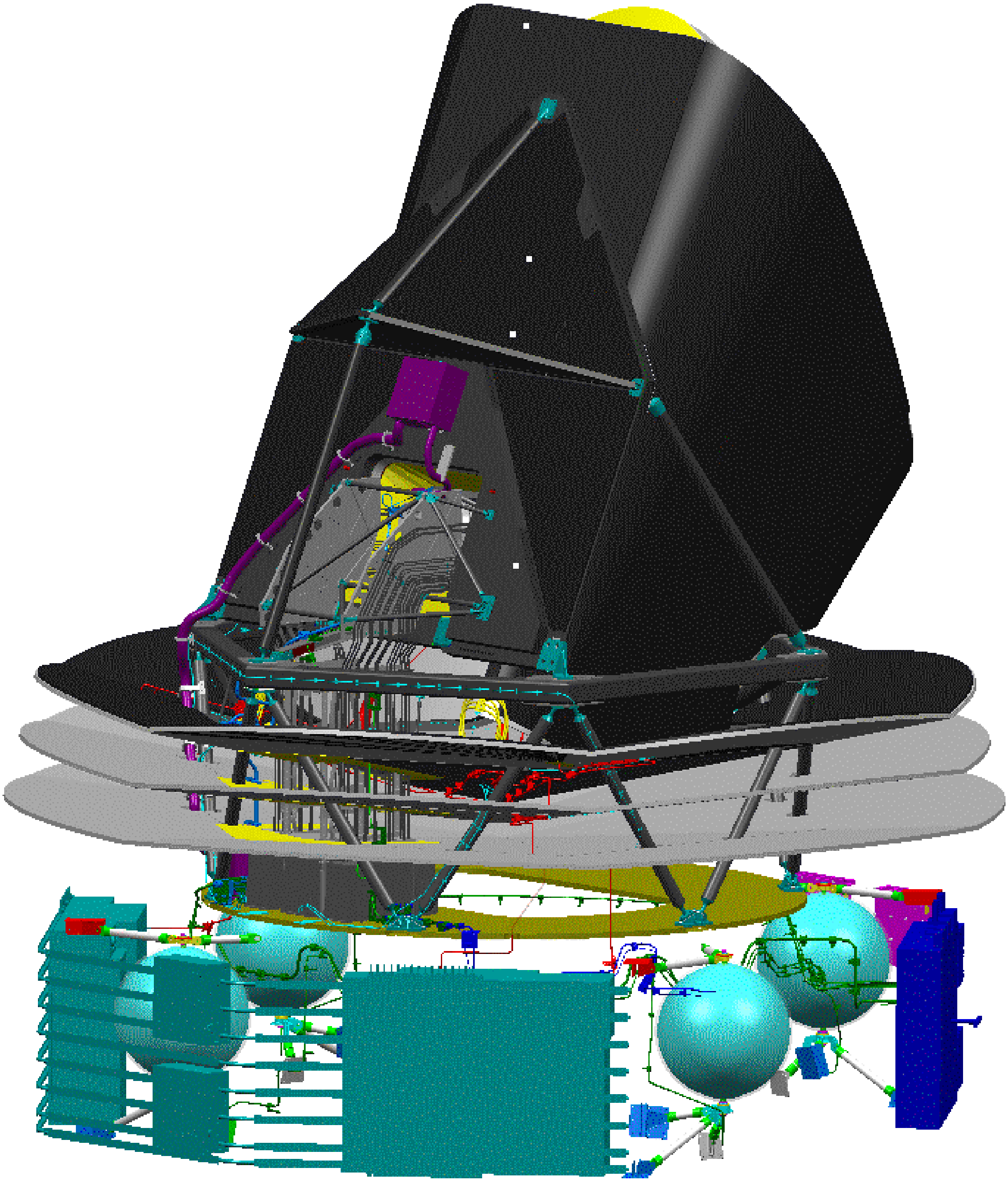


Figure 2-84 Instruments general implementation (rear side)

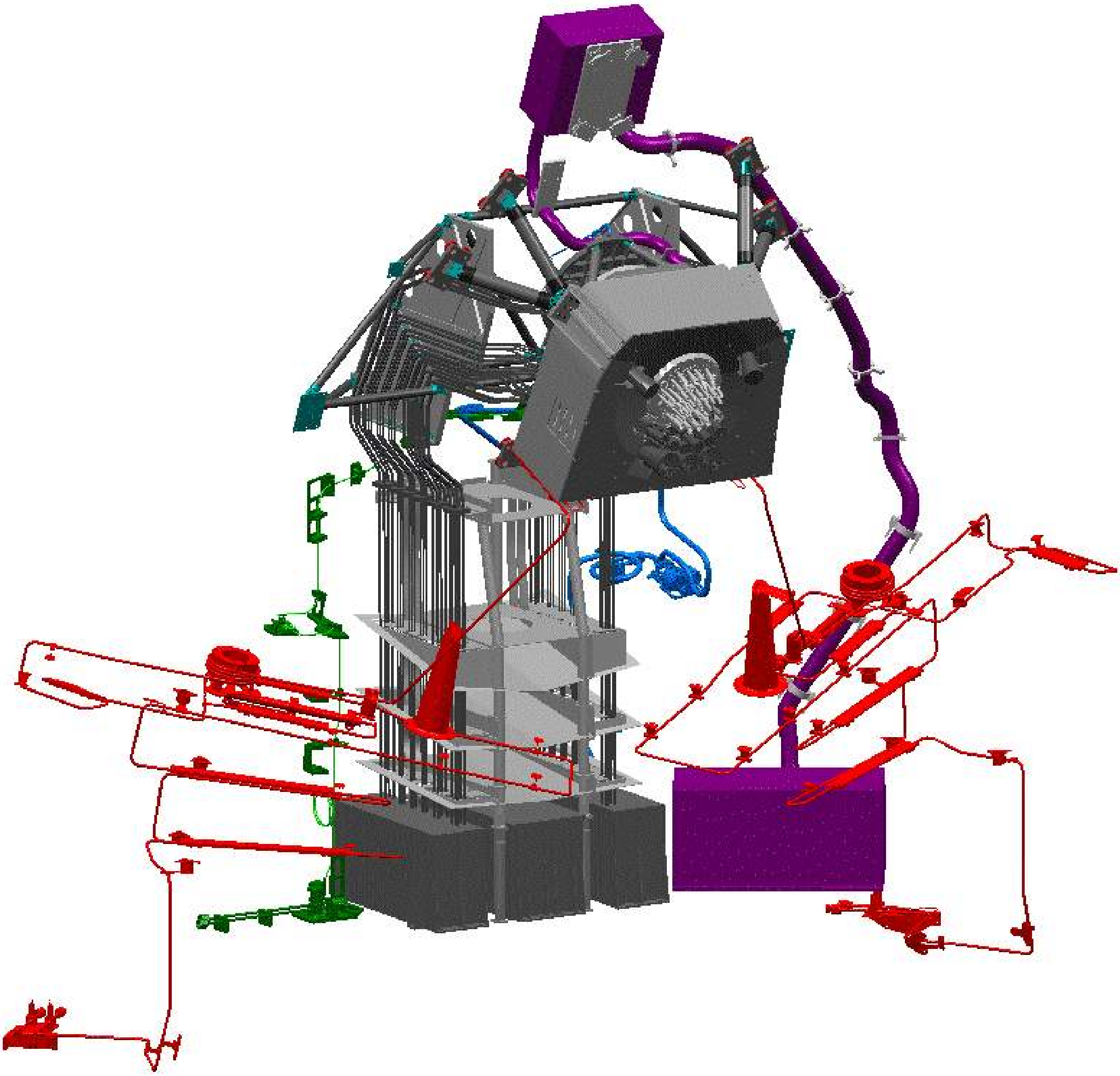


Figure 2-85 PPLM instruments without structure – general view (front side)
Colour code: RAA assembly: grey, Sorption cooler: red, HFI Bellow/PAU/J-FET: purple, Dilution Cooler: blue, 4K coole: green

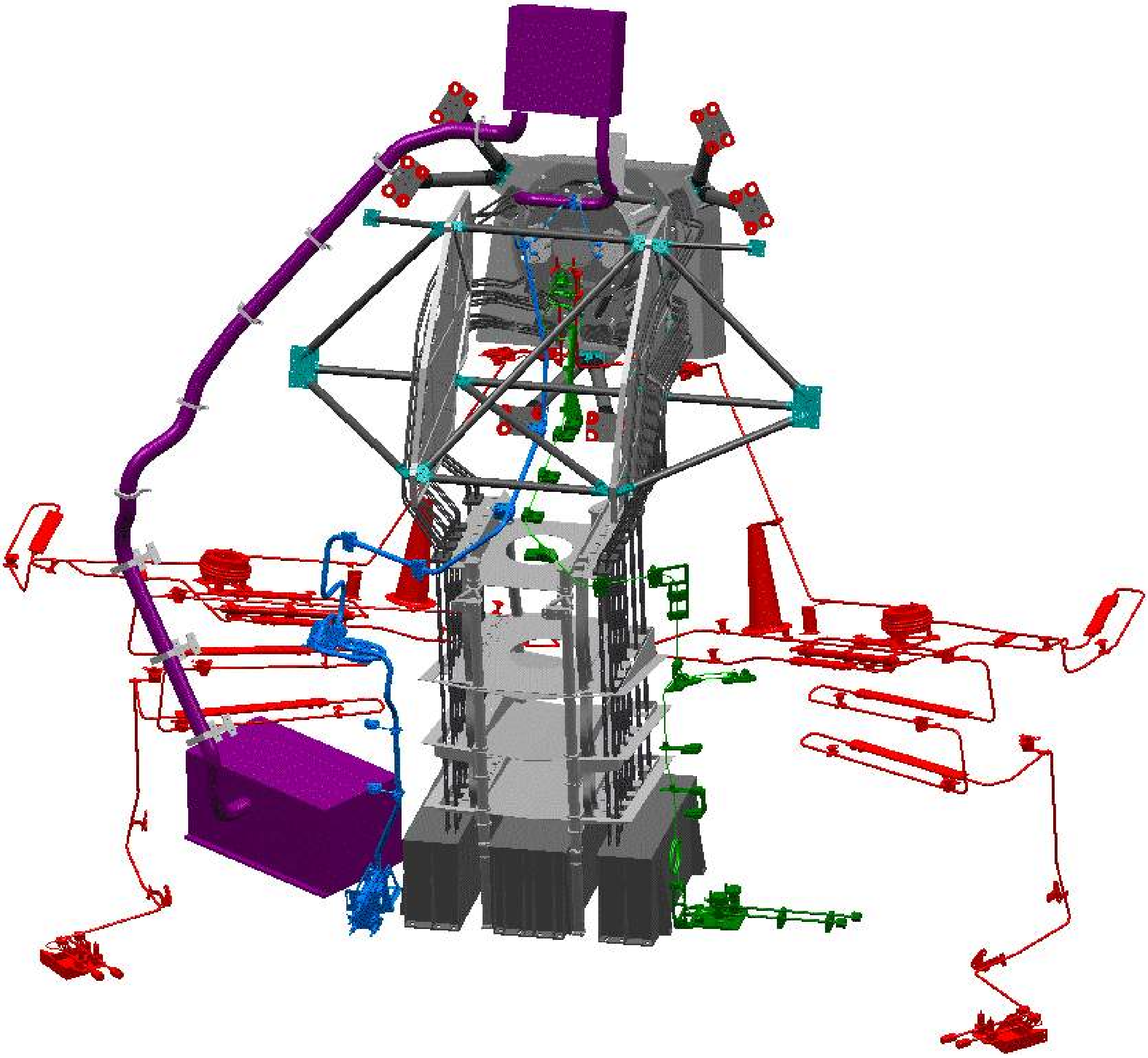


Figure 2-86 PPLM instruments without structure – general view (rear side)
Colour code: RAA assembly: grey, Sorption cooler: red, HFI Bellow/PAU/J-FET: purple, Dilution Cooler: blue, 4K cooler: green

2.3.7.2. Radiometer Array Assembly

The complete assembly of the RAA is a ''monobloc'' structure, it includes the:

– FPU interfacing:
  - The PR panel with the 3 bipod
  - The PR Panel through the RF shield
– Wave Guides (WG) supported by the upper and lower structures
– Upper structure interfacing the PR panel
– Lower structure interfacing:
  - The telescope frame
  - The grooves through the 3 SLI shields and the thermal straps
  - The SVM on the upper side of the subplatform
– BEU (lateral trays & DAE box) interfacing the SVM (subplatform)

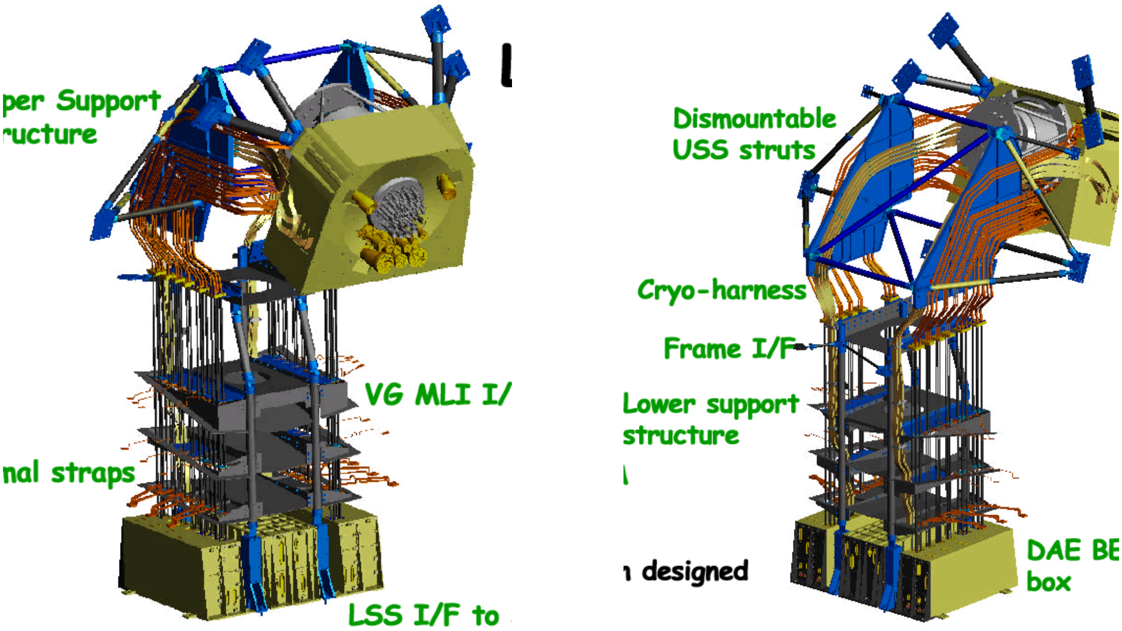


Figure 2-87 Overview of the complete RAA

– Shimming of the RAA.

THALES

2.3.7.3. PAU/Bellow/J-Fet

The bellow 50K is routed:

Outside the Frame, for integration reason regarding the delivered assembly (PAU/bellow/JFET as a single part).

Along and attached on one of the cryo-strut for strength reason (much more stable and stiff than the grooves).

The JFET is now oriented with the connector sides vertically (X), this configuration is the best regarding the length of the bellows and the mountability of the connectors (with the bellow 18K).

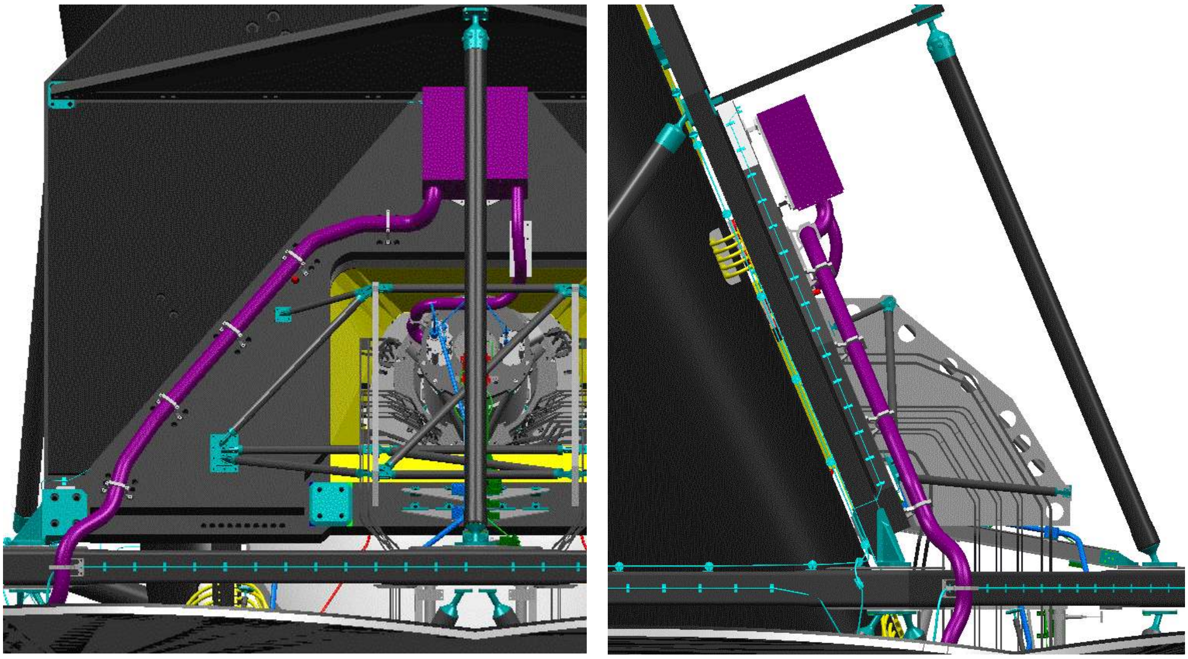


Figure 2-88 Bellow 50K/JFET/Bellow 18K on telescope

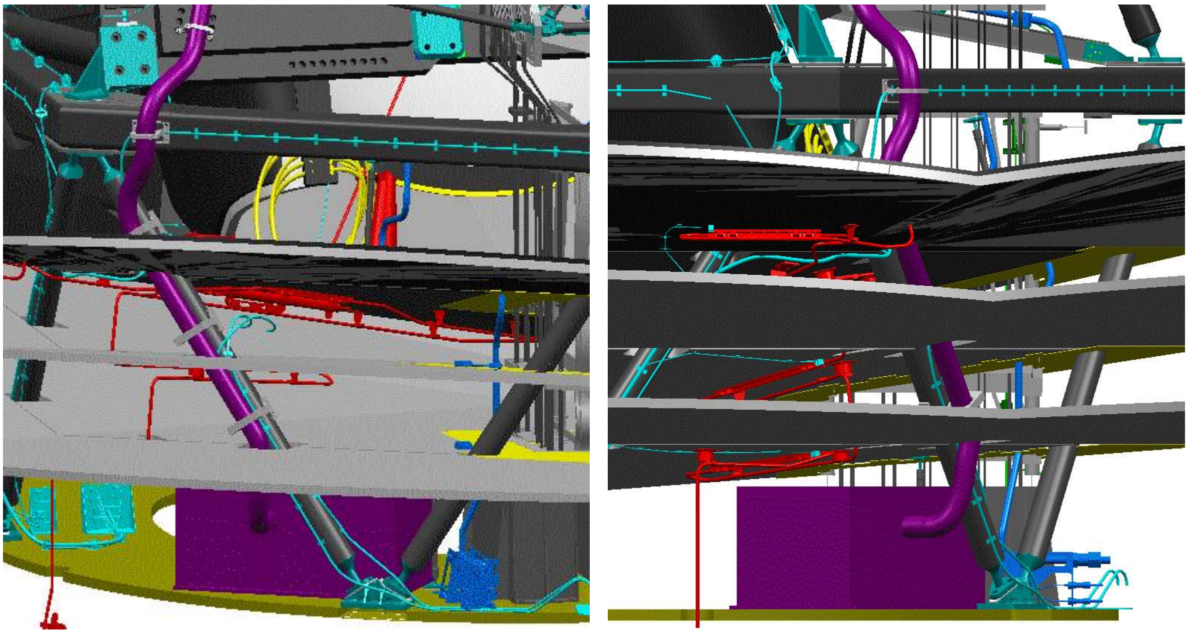


Figure 2-89 Bellow 50K/PAU on cryo-structure

The bellow length (CAD value) are the following:

- PAU – JFET (Bellow 50K): 2 290 mm
- JFET – 1st point on the 18 K plate: 372 mm.

Note: the total length of the bellow 18 K is 670 mm.

2.3.7.4. Sorption cooler

The general implementation is shown in the following Figure:

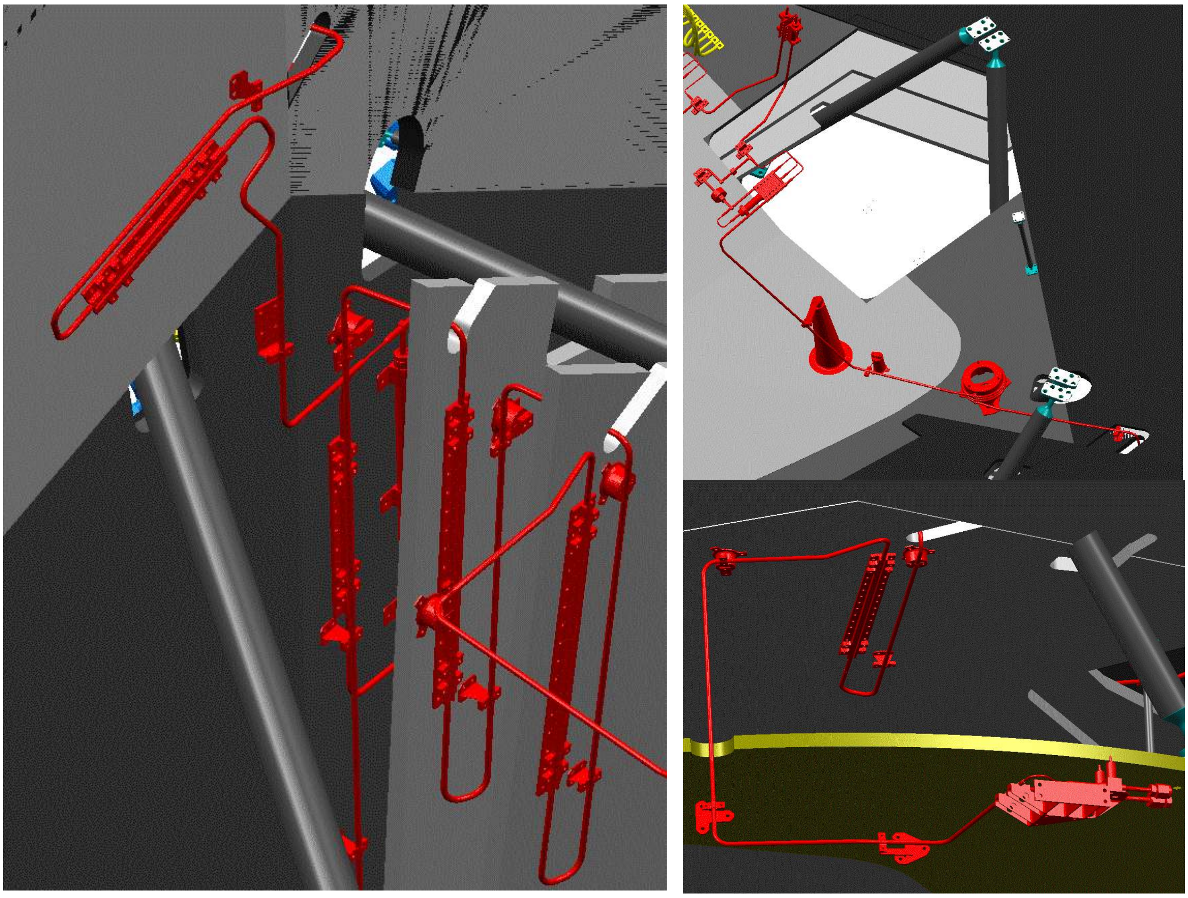


Figure 2-90 Sorption cooler pipes mounted on cryo-structure (-Y side)

The sorption cooler pipe length are the followings:

- SCC – Precooler 1A (nominal one, -Y): 1 290 mm
- Precooler 1A – Precooler 2A: 1 443 mm
- Precooler 2A – Precooler 3A: 2 875 mm
- Precooler 3A – Precooler 3B: length inside JPL internal volume
- Precooler 3B – Precooler 3C: 524 mm.

Precooler 3C – SCCE (entry): 3 346 mm.

2.3.7.5. 4K cooler

The general implementation is shown in the following Figure:

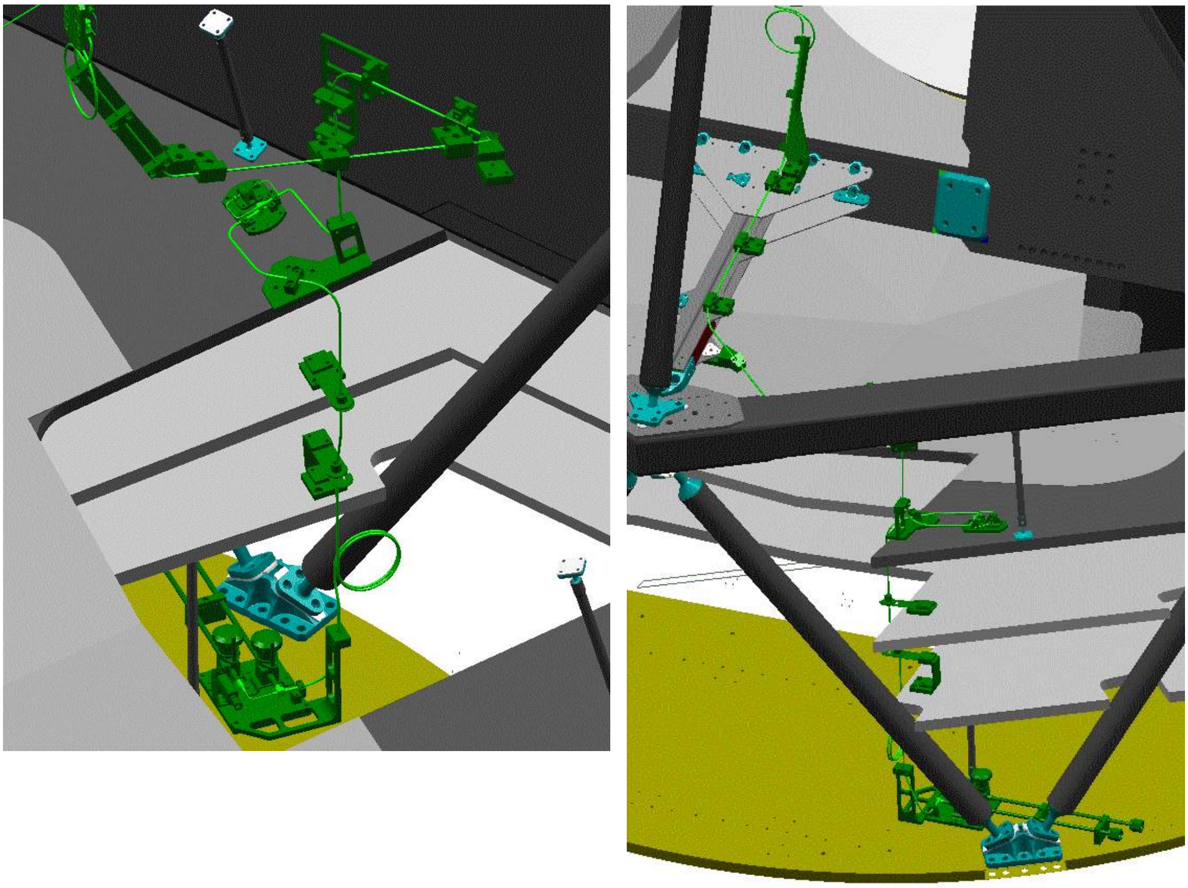


Figure 2-91 4K cooler pipes mounted on grooves and telescope

The 4K pipe length are the followings:

- 300K disconnection box – 50K precooler: 769 mm (without length on subplatform)
- 50K precooler – FPU (18K plate) : 1 364 mm.

2.3.7.6. Dilution cooler

The general implementation is shown in the following Figure:

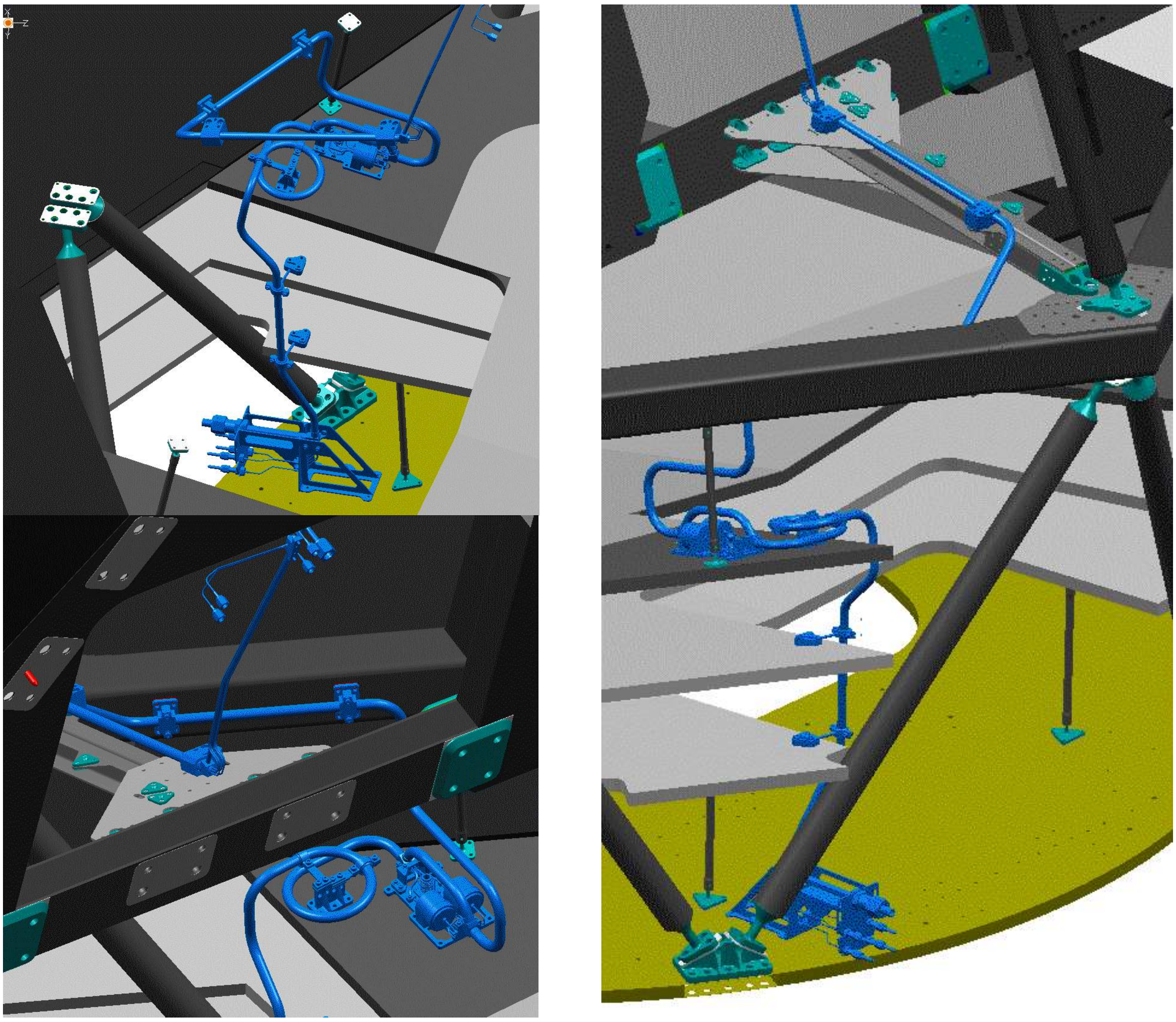


Figure 2-92 0.1K cooler pipes mounted on grooves and telescope

The Dilution pipe lengths are the followings:

- 300K disconnection box – Groove 1: 214 mm
- Groove 1 – Groove 2 : 159 mm
- Groove 2 – 50K precooler: 735 mm
- 50K precooler – FPU (18K plate): 1 734 mm.

2.4. INSTRUMENT DESCRIPTION

HERSCHEL and PLANCK Instruments are cryogenic Instruments, and are therefore composed of a Cryogenic FPU (Focal plane unit), located in the Cryogenic Payload module of each satellite, and of warm units located in the Service Modules (SVM) dedicated to control of the instrument, processing of signal, and transmission of TM/TC (scientific & housekeeping data). Cryoharness (or Wave-Guides for LFI) links the warm units to the FPU.

2.4.1. HERSCHEL instruments

The HERSCHEL satellite accommodates 3 instruments:

– PACS: Photo-detector Array Camera & Spectrometer. The PACS Consortium is lead by the MPE Garching (D) The PI is A.Poglitch.

– SPIRE: Spectral Photometer Imaging Receiver. The SPIRE consortium is led by the Cardiff University (UK) where the PI is M. Griffin), and the Rutherford Appleton Laboratory with the project team.

– HIFI: Heterodyne Instrument for the Far Infra-red. The HIFI Consortium is led by the SRON (Space Research Organisation of the Netherlands, NL), and the PI is T. de Graauw).

The implementation of the FPUs of these instruments onto the HERSCHEL Optical Bench is illustrated in the following figure.

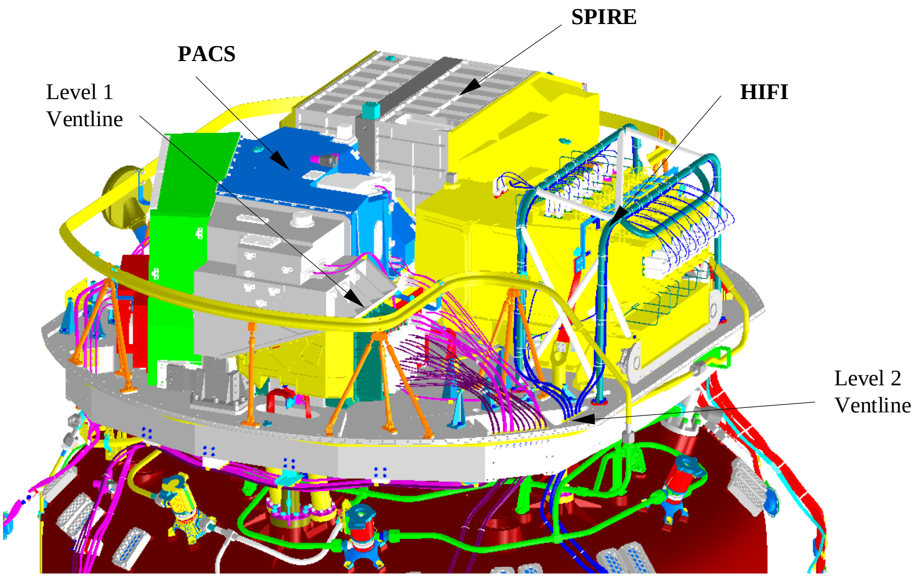


Figure 2-93 3D image of the HERSCHEL FPU's on the optical bench/draft view supplied by ASED

2.4.1.1. PACS

The PACS Instrument provides imaging photometry and integral field spectroscopy over the spectral band from 57 - 210 µm. Except for the shared entrance optics, the photometer and the spectrometer branches of the instrument are independent sub-units. The entrance optics contains a chopper for sky modulation and 2 calibration sources. At the end of the entrance optics the focal plane is split into separate fields of view, one for photometry and the other for spectroscopy. From there on, the optical trains are fully separated.

The **Photometer** branch employs two large format, filled arrays of silicon bolometers, a fixed dichroic beam splitter, and straightforward re-imaging optics to image the same field of view simultaneously in two spectral bands (60 - 130 µm and 130 - 210 µm), with full diffraction beam sampling. The short wavelength band is divided into two sub-bands (60 - 85 µm or 85 - 130 µm) by exchangeable filters such that either one of them can be observed together with the long wavelength band. The bolometer arrays are cooled to 0.3 K by an instrument-internal 3He sorption cooler which works against the He II level (L0) provided by the satellite.

The **Spectrometer** uses a reflective image slicer which feeds a long-slit grating spectrograph in Littrow mode, to achieve simultaneous spectral multiplexing and two-dimensional imaging with the two-dimensional photoconductor arrays. A fixed dichroic beam splitter is used to separate the grating diffraction orders and distribute them to the two detector arrays. The first diffraction order (105 - 210 µm) is detected with a high-stressed Ge:Ga array operated at ~1.8 K while the second (57 - 105 µm) and third (55 - 72 µm) orders are detected with a low-stressed Ge:Ga array operated at ~2.5K. Exchangeable filters are moved in front of the short-wave detector to select one or the other of the 2nd and 3rd orders.

PACS is composed of:

Project code	Instrument unit
FPFPU	Cold Focal Plane Unit
FPDECMEC	Detector & Mechanism Control
FPBOLC	Bolometer / Cooler Control
FPDPU	Digital Processing Unit (DPU nominal + redundant)
FPSPU	Signal Processing Unit (SPU nominal + redundant)
FPWIH	"Warm" Interconnect Harness

The following figures show the PACS FPU (3D view and photos of the QM), the warm units, and the instrument Block Diagram.

Refer to the dedicated PACS User Manual [RD-30] for further information and detailed description.

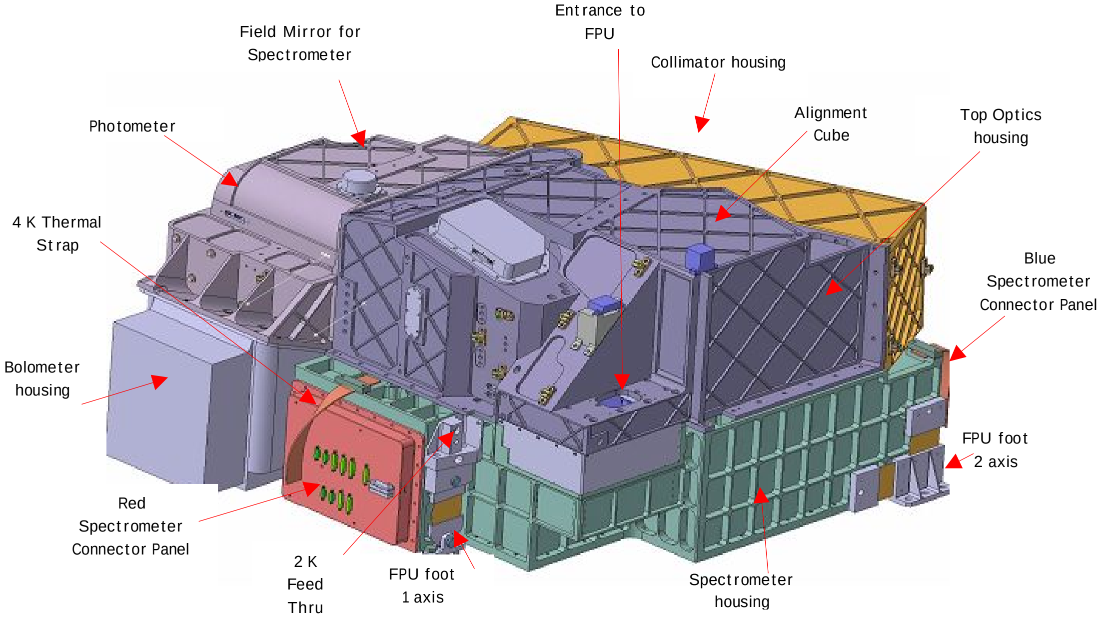


Figure 2-94 Overview of the PACS Focal Plane Unit

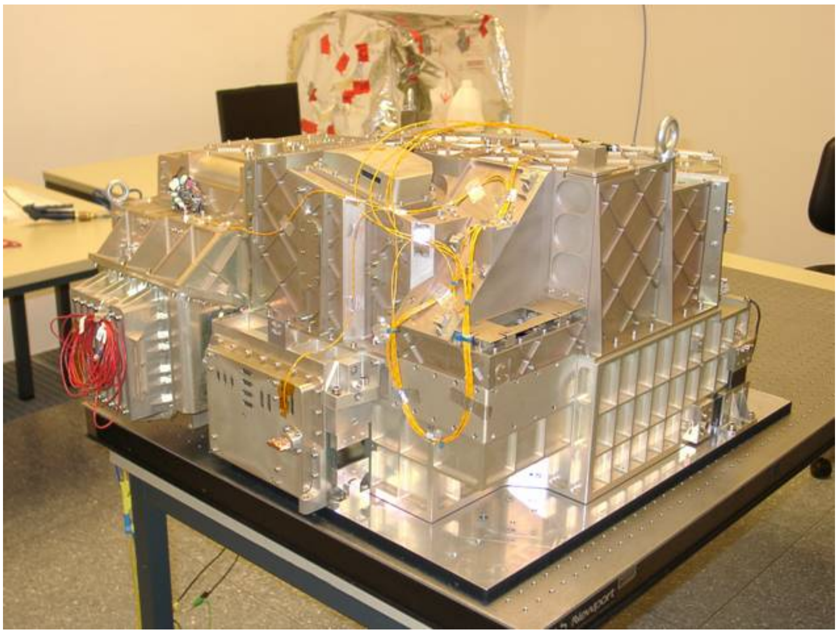


Figure 2-95 Photo of the PACS FPU STM prepared for cryo-vibration tests

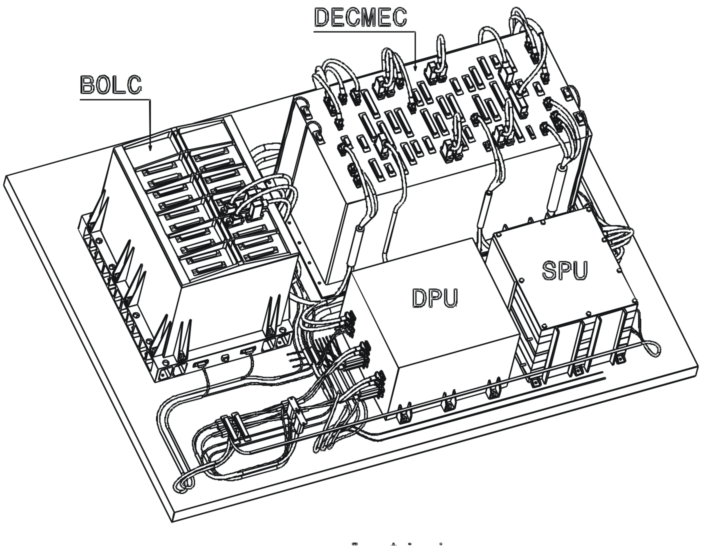


Figure 2-96 PACS warm units assembled with WIH on SVM panel

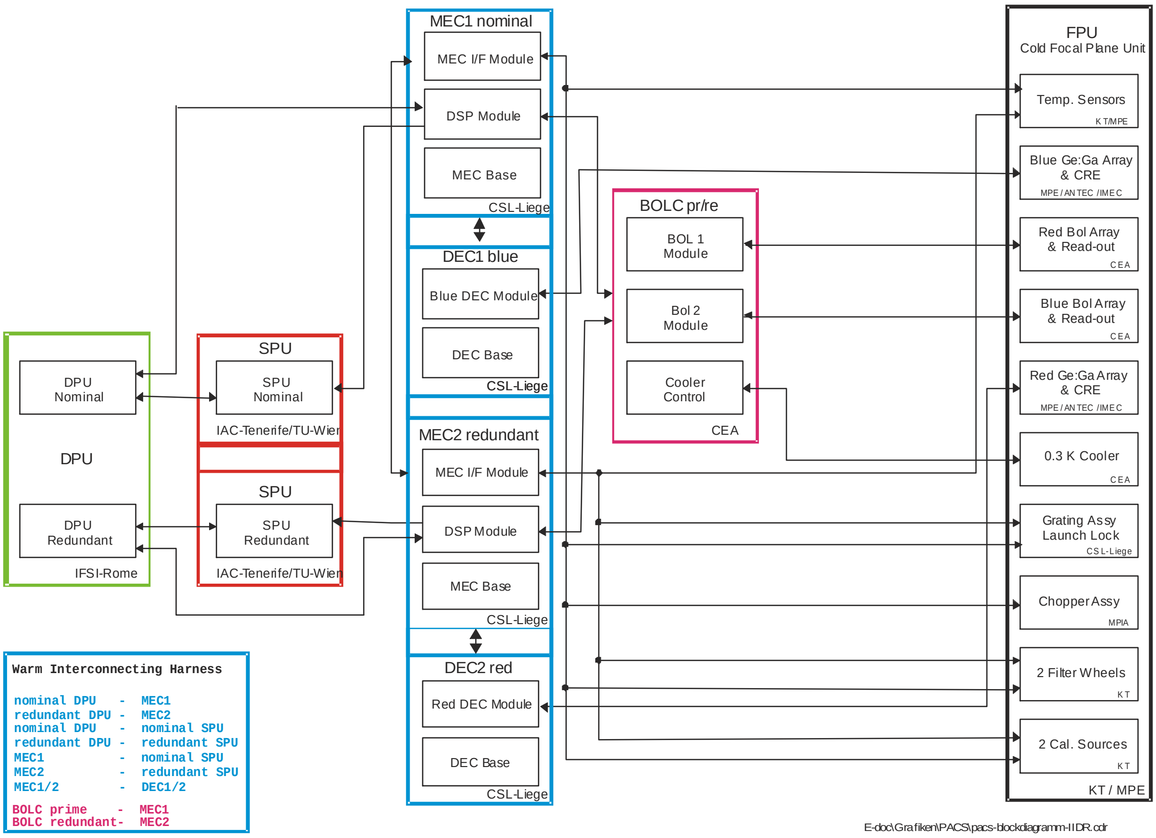


Figure 2-97 PACS internal block diagram

2.4.1.2. SPIRE

SPIRE (Spectral & Photometric Imaging REceiver) is a **bolometer** instrument comprising a three-band imaging **photometer** covering the 200-500 μm range and an imaging Fourier Transform **Spectrometer** (FTS) with a spectral resolution of at least 0.4 cm^{-1} (corresponding to $\lambda/\Delta\lambda$ = 100 at 250 μm, covering wavelengths between 200 and 670 μm. The detectors are bolometer arrays cooled to 300 mK using a ^3He refrigerator. The photometer is optimised for deep photometric surveys, and can observe simultaneously the same field of view of 4 x 8 arcminutes in all three bands.

The SPIRE instrument consists of:

HSFPU	Focal Plane Unit (FPU): 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 detectors 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 detectors 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 (on Herschel SVM) A warm analogue electronics box for detector read-out analogue signal processing, multiplexing, conversion, and array sequencing.
HSFCU	Focal Plane Control Unit (on Herschel SVM) 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 (on Herschel SVM) A warm digital electronics box for signal processing and instrument commanding and interfacing to the spacecraft telemetry.
HSWIH	Warm interconnect harness (on Herschel SVM) Harness making connections between SPIRE electronics boxes.

Refer to the dedicated SPIRE User Manual [RD-32] for further information and detailed description.

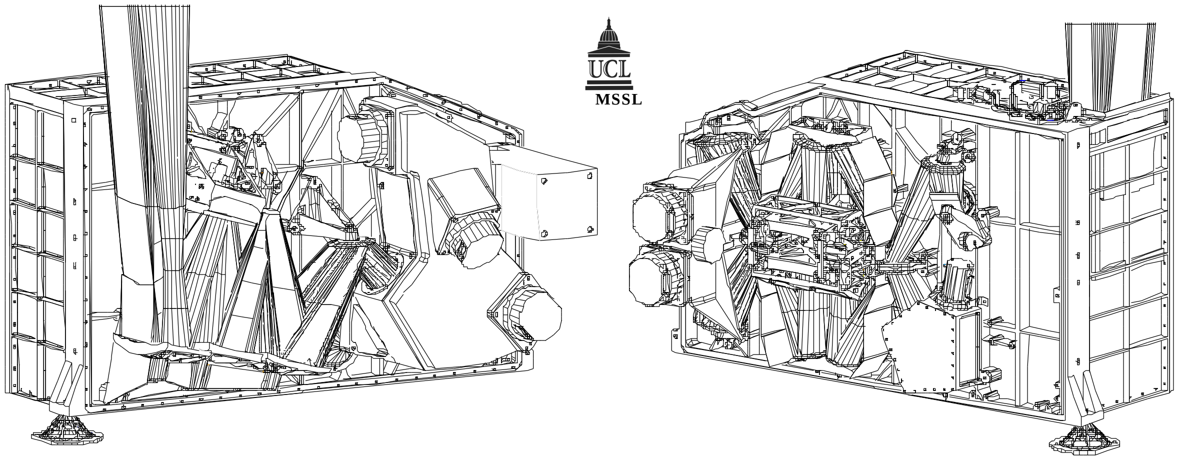


Figure 2-98 Two halves of SPIRE FPU: photometer shown on left, spectrometer on the right

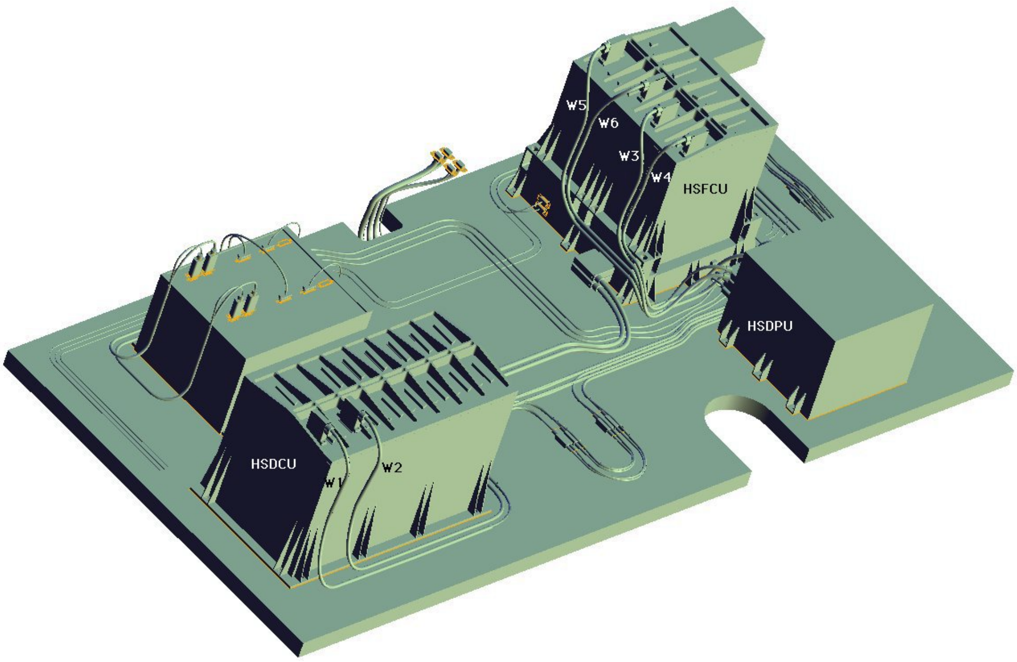


Figure 2-99 SPIRE warm units as mounted on SVM panel

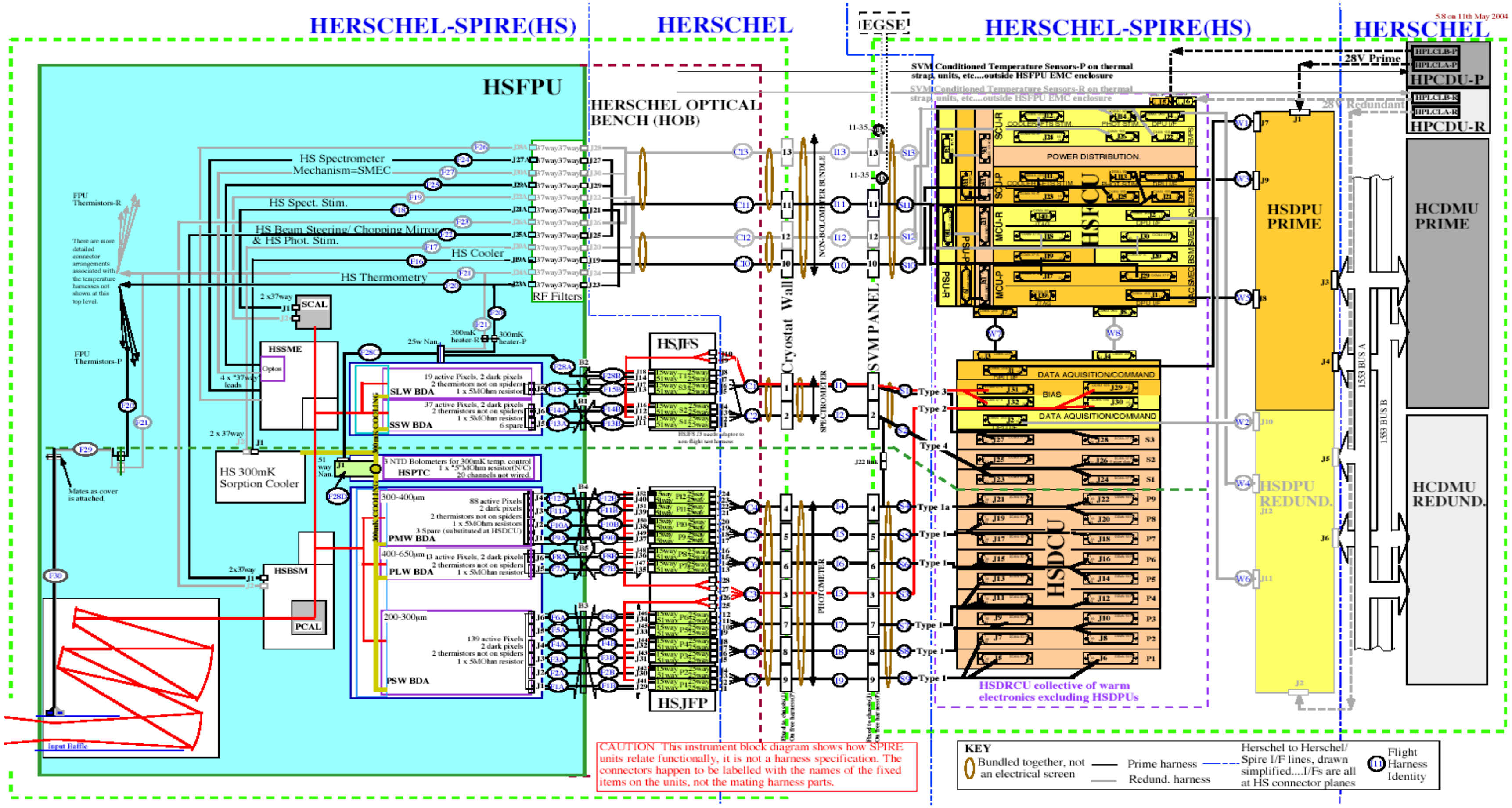


Figure 2-100 SPIRE block diagram

2.4.1.3. HIFI

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

The HIFI Back-End subsystems will allow to process at the same time the signal coming from both polarisations of the Front-End. The Back Ends consist of a Wide-Band Spectrometer (Acousto-Optical Spectrometer - AOS), covering a total frequency range of 8 GHz, and High-Resolution Spectrometer, (Auto-Correlation Spectrometer - ACS), covering up to 4 kHz. The Wide-Band Spectrometer (WBS) will have a resolution of 1.1 MHz (~0.6 to 0.16 km/s in the frequency range of the HIFI). The High-Resolution Spectrometer (HRS) will have four observing modes, a normal one with 270 kHz spectral resolution (1 GHz total bandwidth), a high resolution mode with 140 kHz resolution (0.5 GHz total bandwidth), a low resolution mode with 0.54 MHz resolution (2 GHz total bandwidth) and a wide band mode with 1.1 MHz resolution (4 GHz total bandwidth). The HRS modes give instrument velocity resolutions of 180 to 65 m/s and 100 to 55 m/s respectively in the frequency range of HIFI after including the effect of the local oscillator finite line-width.

HIFI consists of:

Project code	Instrument unit
FHFPU-XX-Y	HIFI Focal Plane Unit
FHFCU-XX-Y	HIFI Focal Plane Control Unit
FHIFH- XX-Y	IF up-converter Horizontal
FHIFV- XX-Y	IF up-converter Vertical
FHLOR-XX-Y	HIFI Local Oscillator Radiator
FHLOU-XX-Y	HIFI Local Oscillator Unit
FHLCU-XX-Y	HIFI Local Oscillator Control Unit
FHLSU-XX-Y	HIFI Local Oscillator Source Unit
FHHRV-XX-Y	HIFI High-Resolution Spectrometer, Vertical polarisation
FHHRH-XX-Y	HIFI High-Resolution Spectrometer, Horizontal polarisation
FHWEH-XX-Y	HIFI Wide-Band Spectrometer Electronics Horizontal Polarisation
FHWEV-XX-Y	HIFI Wide-Band Spectrometer Electronics Vertical Polarisation
FHWOH-XX-Y	HIFI Wide-Band Spectrometer Optics Horizontal Polarisation
FHWOV-XX-Y	HIFI Wide-Band Spectrometer Optics Vertical Polarisation
FHICU-XX-Y	HIFI Instrument Control Unit
FHWIH-XX-Y	HIFI “Warm” Interconnect Harness

Legend:

- XX = model: DM, EM, QM, FM, FS
- Y = serial number, if relevant.

Refer to the dedicated HIFI User Manual [RD-31] for further information and detailed description.

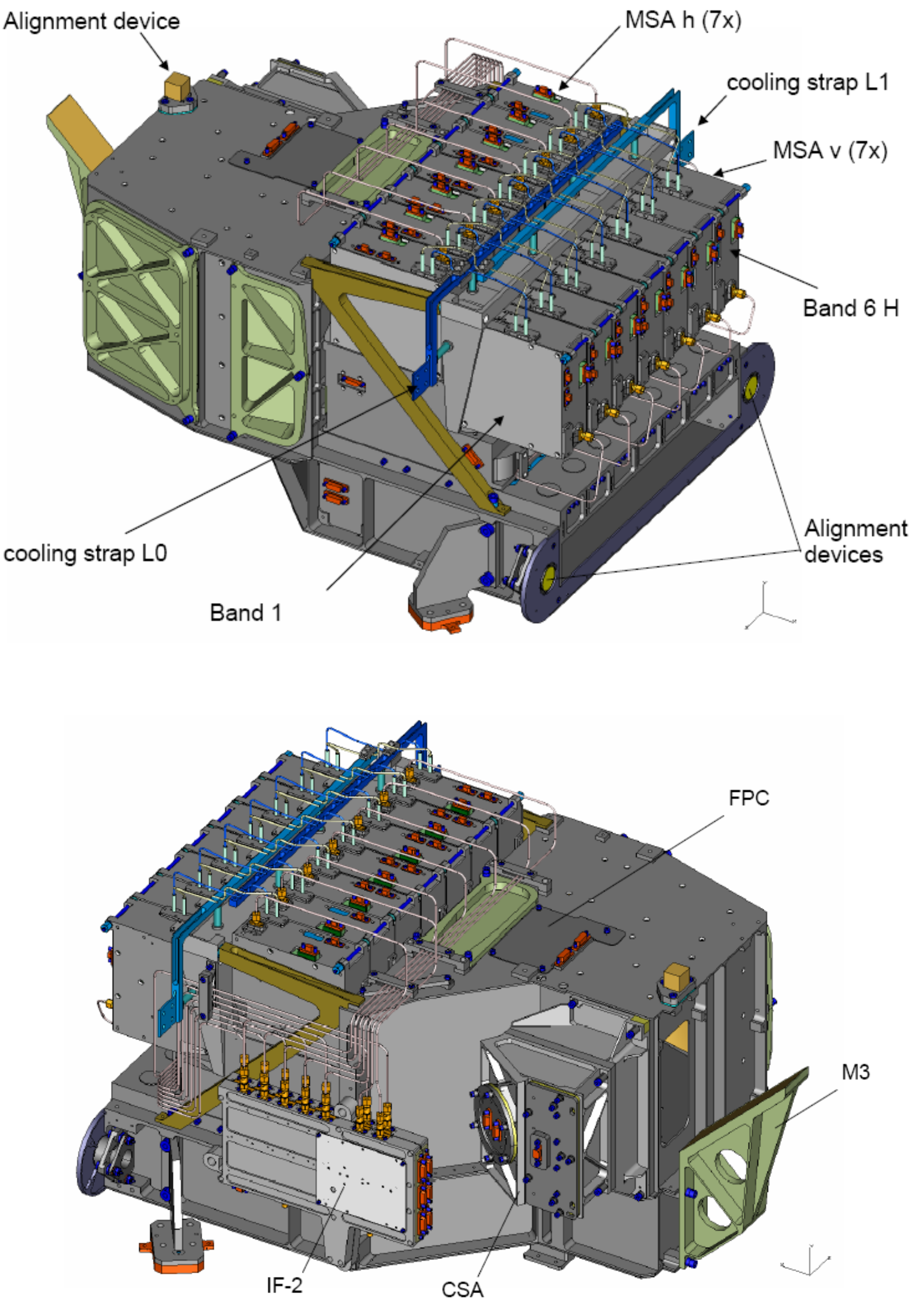


Figure 2-101 HIFI FPU

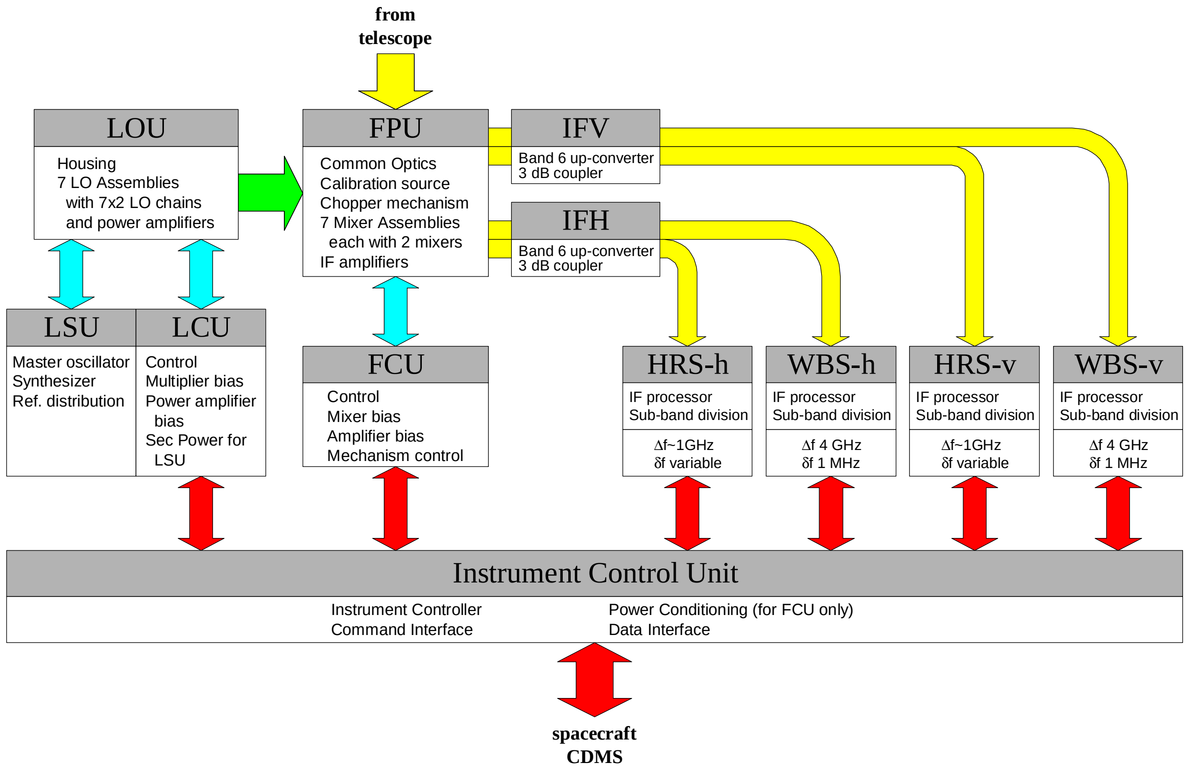


Figure 2-102 HIFI functional block diagram

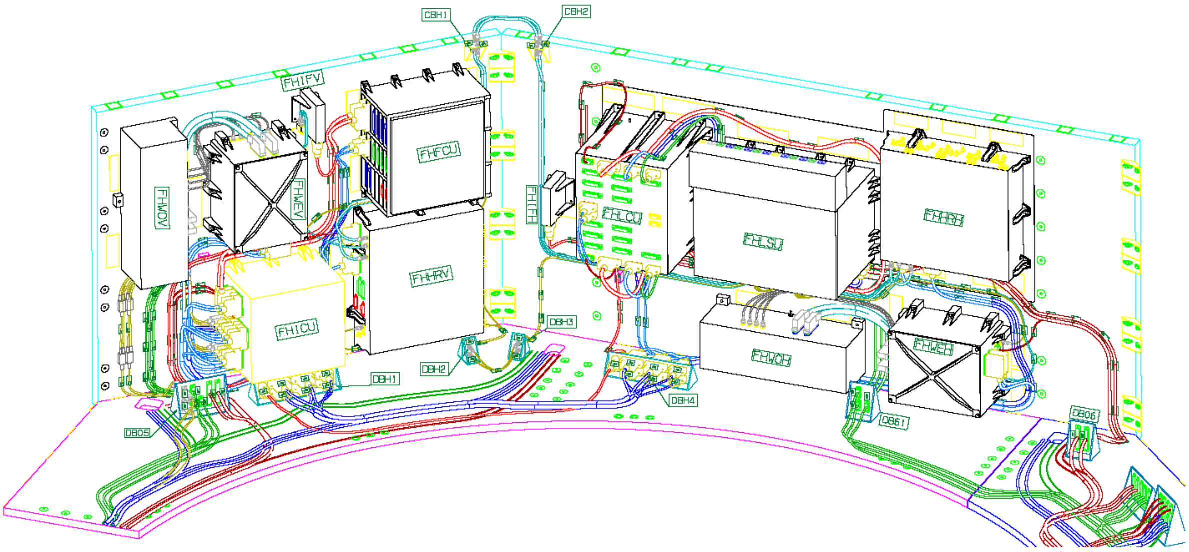


Figure 2-103 HIFI Warm units on 2 SVM Panels

2.4.2. PLANCK instruments

The PLANCK Satellite accommodates two instruments:

– LFI Low Frequency Instrument, developed by a Consortium led by N. Mandolesi (TESRE-Bologna-I)

– HFI High Frequency Instrument, developed by a Consortium led by J.L. Puget (IAS-Orsay-F).

Common to the two instruments is the sorption cooler, developed by JPL (one of the 6 US contributions to the HERSCHEL/PLANCK program). The Sorption cooler is a subsystem of LFI, and managed by LFI. The Sorption cooler electronics is developed under the responsibility and funding of HFI.

Both instruments have a cryogenic Focal Plane unit (FPU) that receive and process the CMB signal, hosted by the PLANCK Payload Module (PPLM) and a set of warm units that amplify, digitise and process the electrical signal and that are accommodated in the PLANCK Service Module. The link between FPU and SVM is via Wave-guides + harness (LFI) and Harness (HFI).

Both instruments have also dedicated chains of coolers that provide the instrument with their ultimate temperatures (20 K for LFI, 0.1K for HFI), and that interface the satellite in the SVM (compressors, control electronics), and in the PPLM (heat exchangers and pipes).

The Satellite provides the services (Power, data handling, pointing, TM/TC, security,…) and the proper environment (Mechanical at launch, thermal) both for the warm units (270 - 300 K) and the PPLM (Telescope, Precooling at 50 K for the coolers, Straylight insulation).

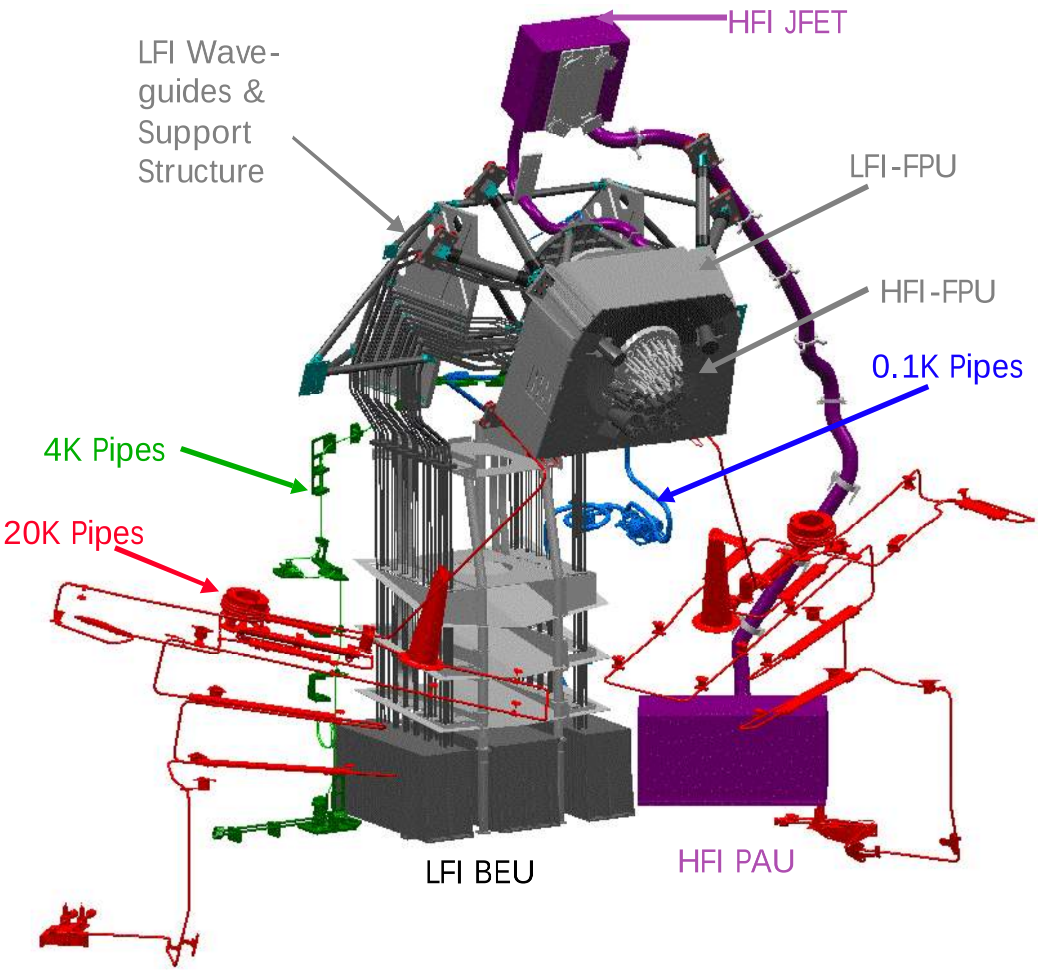


Figure 2-104 PLANCK instruments to be accommodated on PPLM

2.4.2.1. HFI

The High-Frequency Instrument (HFI) is designed to carry out high-sensitivity, multi-frequency microwave measurements of the diffuse sky radiation in the frequency range 83-1000GHz.

These measurements will be used, together with those from the Low-Frequency Instrument (LFI), to produce a map over most of the sky of the anisotropies of the Cosmic Microwave Background (CMB). This map will in turn be used to constrain the main parameters that determine the large scale structure of the Universe.

HFI is composed of the following units:

description	code	code
Focal Plane Unit (FPU)	PH	A
Data Processing Unit (DPU) Nominal & Redundant	PH	BA-N, R
JFET Box	PH	CA
Pre-Amplifier Unit (PAU)	PH	CBA
Readout Electronics Unit (REU)	PH	CBC
4K Cooler Compressor Unit (CCU)	PH	DA
4K Cooler Ancillary Unit (CAU)	PH	DB
4K Cooler Electronics Unit (4K-CDE)	PH	DC
4K Cooler Cold End (CCE), pipes and cryoharness & brackets from SVM bracket to FPU	PH	DD
4K Cooler Current Regulator (CCR)	PH	DJ
4K warm pipework and harnesses from CAU to SVM bracket	PH	DE
0.1K Dilution Cooler GSU He Tanks	PH	EAAA, B, C, D
Tank-/0.1K-DCCU piping + Support	PH	EABA, B, C, D
0.1K Dilution Cooler Control Unit (0.1K-DCCU)	PH	EB
Helium exhaust	PH	EEF
0.1K Cooler Pipes	PH	ECxx
WIH & Cryo-Harnesses	PH	

Refer to the dedicated Planck HFI User Manual [RD-33] for further information and detailed description.

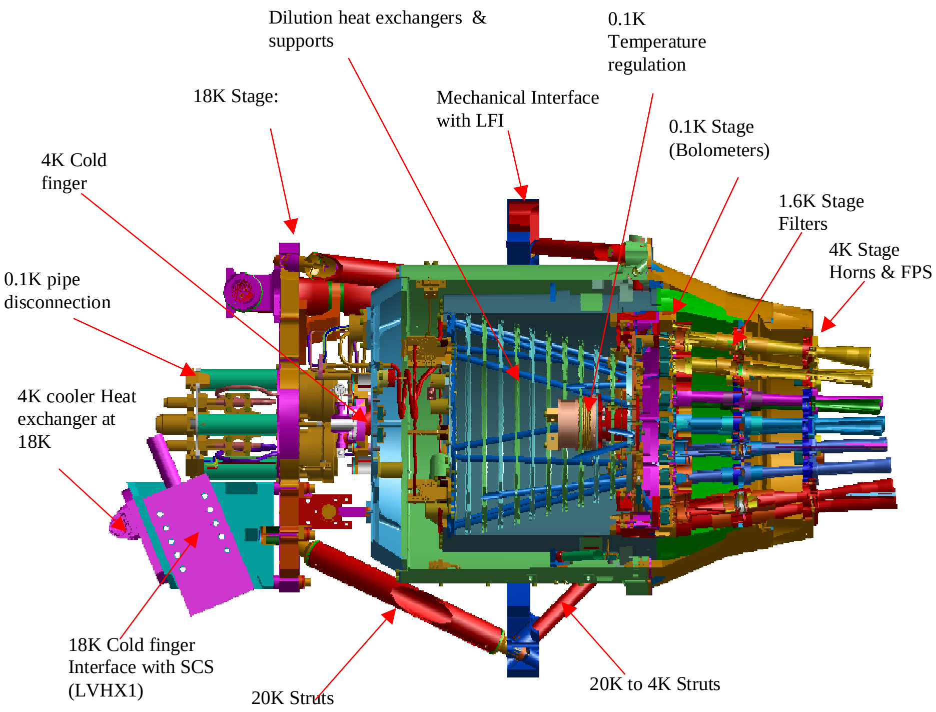


Figure 2-105 HFI FPU

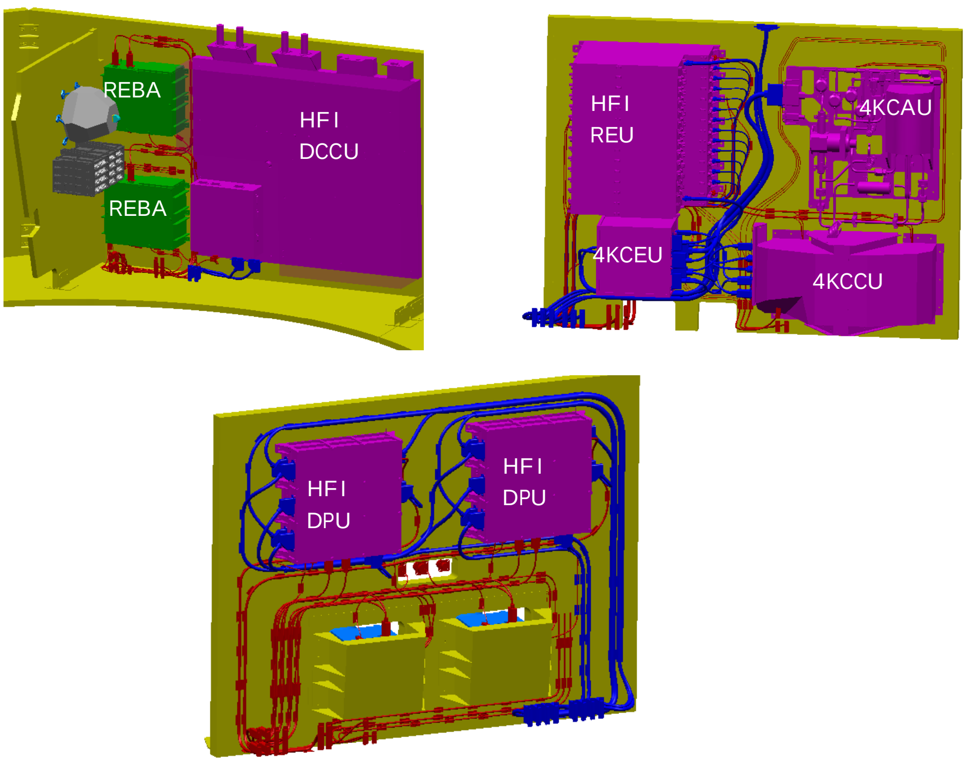
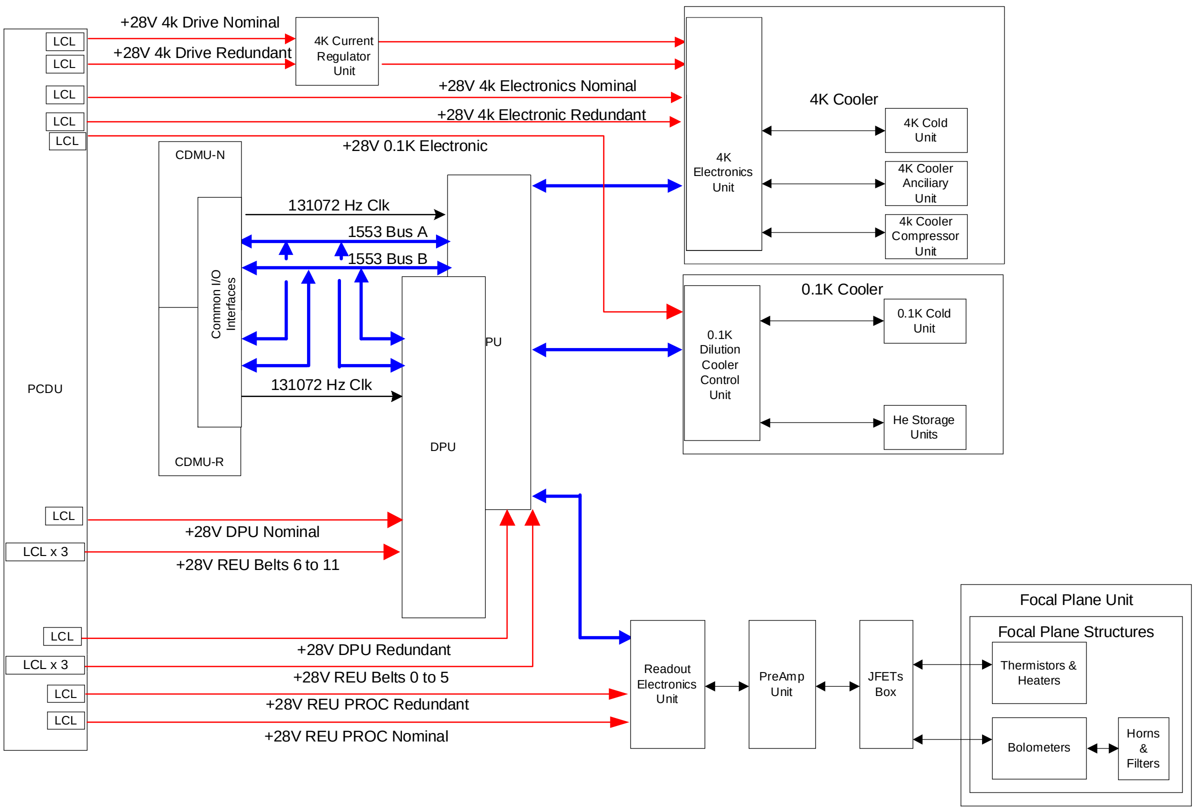


Figure 2-106 HFI warm units (4KCCR & PAU not shown)



HFI

Figure 2-107 HFI electrical interfaces block diagram

2.4.2.2. LFI

The Low-Frequency Instrument (LFI) is designed to produce high-sensitivity, multi-frequency measurements of the microwave sky in the frequency range 30-70 GHz (2.3-4.2 mm wavelength). These measurements will be used, together with those from the High Frequency Instrument (HFI) to produce a full-sky map of the anisotropies of the Cosmic Microwave Background (CMB) with unprecedented precision. This map will in turn be used to extract a wealth of cosmological information, including the accurate determination of the main cosmological parameters which characterise the large scale structure and the evolution of the universe.

The coherent LFI receivers will operate at four well-separated bands: 30, 44 and 70 GHz. These frequencies are chosen to provide an excellent CMB anisotropy signal with sufficient range to allow clean separation of galactic and CMB signals. Combined with the High Frequency Instrument (HFI) the full frequency range of minimum foreground emission will be sampled to determine all known galactic emission components and still have independent, redundant CMB anisotropy measurements.

The receivers are split into the cold Front End Modules (FEM), located in the Front End Unit (FEU) in the Focal Plane Unit (FPU) at 20K, and the Back End Modules (BEM) part of the Back End Unit (BEU) located on the upper platform of the SVM, and connected to the FEM by a set of 4 x 11 = 44wave-guides. (was 4 x 23 = 92 before removal of the 100GHz).

LFI is composed of the following units:

Project code	Instrument unit
PLFEU	Front End Unit including 4K load, cryo-harness, and FEU internal harness (LFI part of common LFI/HFI FPU)
PLWG	Wave-guides (2 bundles) and support structure
PLBEU	Back End Unit (BEU) BEU internal harness Power box to BEU and BEM harness DAE Power Box
PLREN	REBA nominal (2)
PLRER	REBA redundant (2)
PLIH	REBA to BEU harness

Refer to the dedicated Planck LFI User Manual [RD-34] for further information and detailed description.

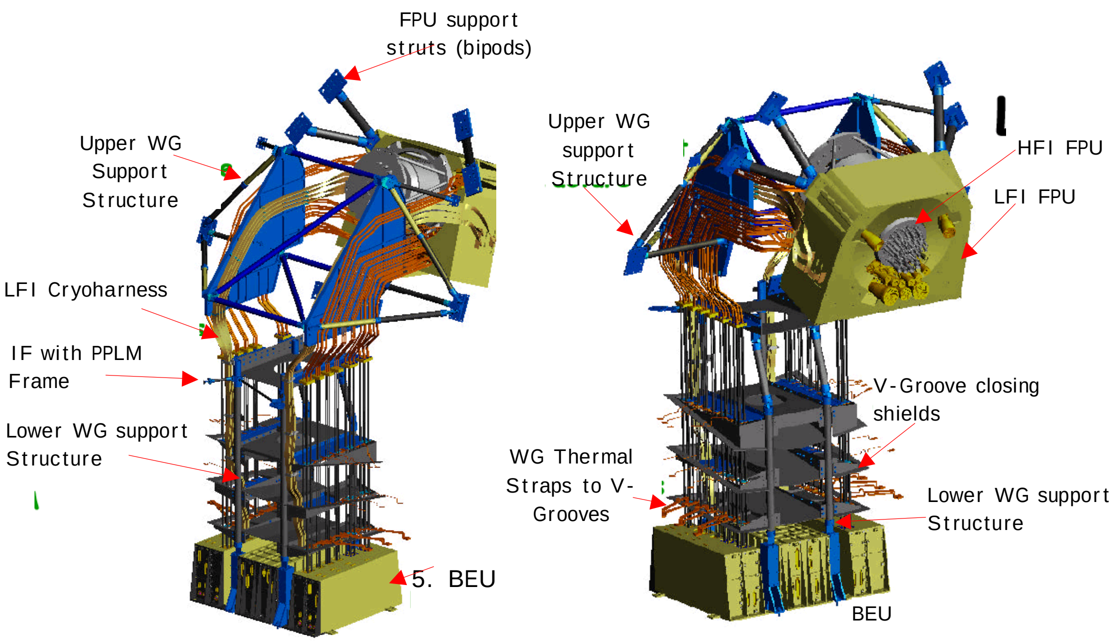


Figure 2-108 LFI RAA (FEU, wage-guides and BEU)
(Note: HFI also shown inside LFI)

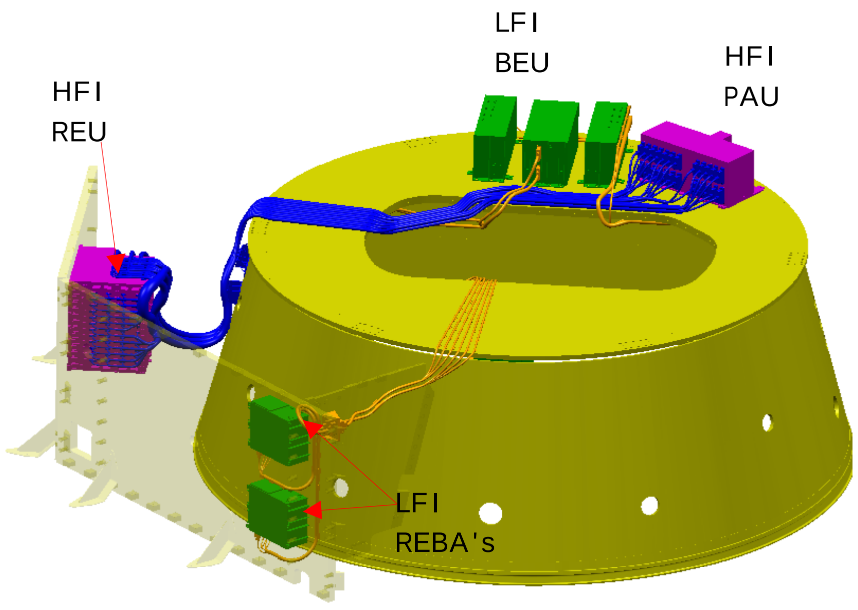


Figure 2-109 LFI warm units on SVM

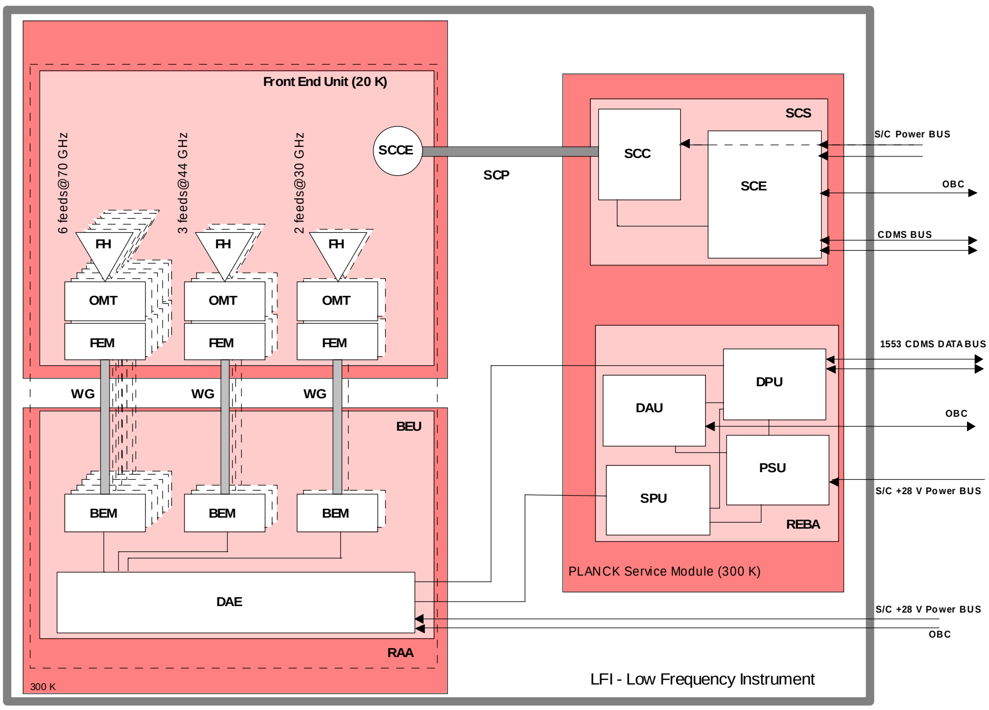


Figure 2-110 LFI functional block diagram

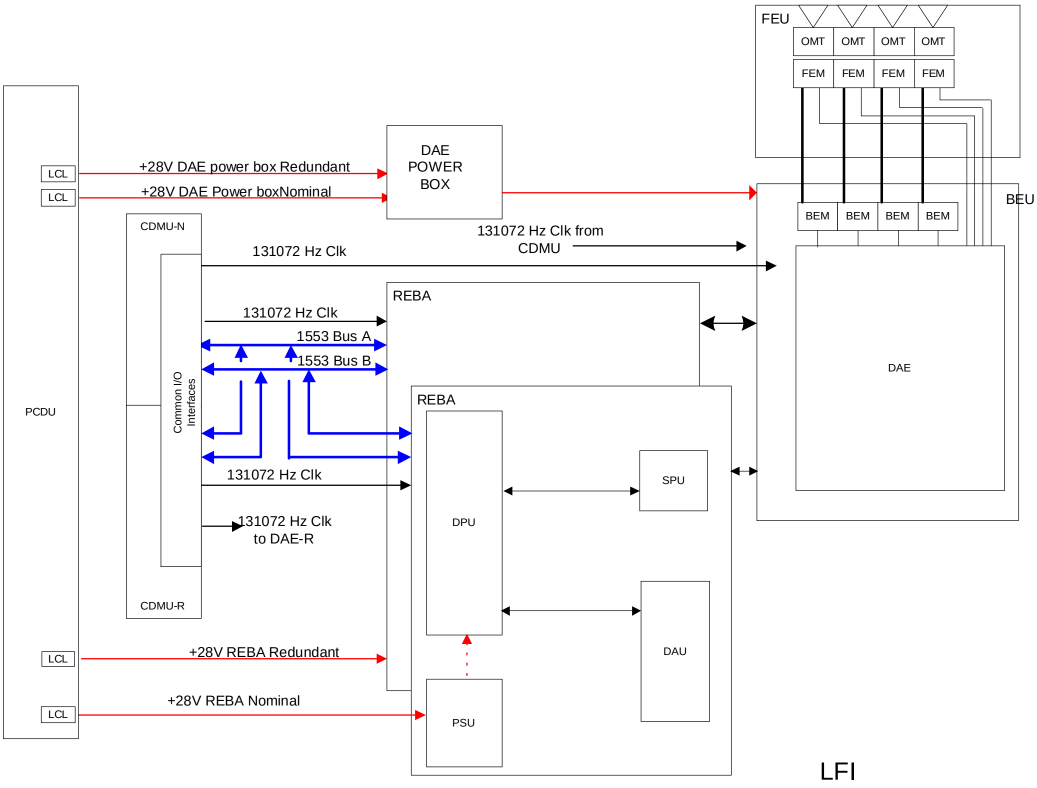


Figure 2-111 LFI electrical interfaces block diagram

2.4.2.3. PLANCK Sorption Cooler Subsystem

PLANCK sorption cooler is not an instrument but is part of LFI.

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 pre-cooling 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 Pipe Assembly and Cold End (PACE)

– the Sorption Cooler Electronics (SCE)

– the internal harnesses.

It should be noted that the SCC, SCCE, and PACE 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.

Refer to the dedicated Planck SCS User Manual [RD-35] for further information and detailed description.

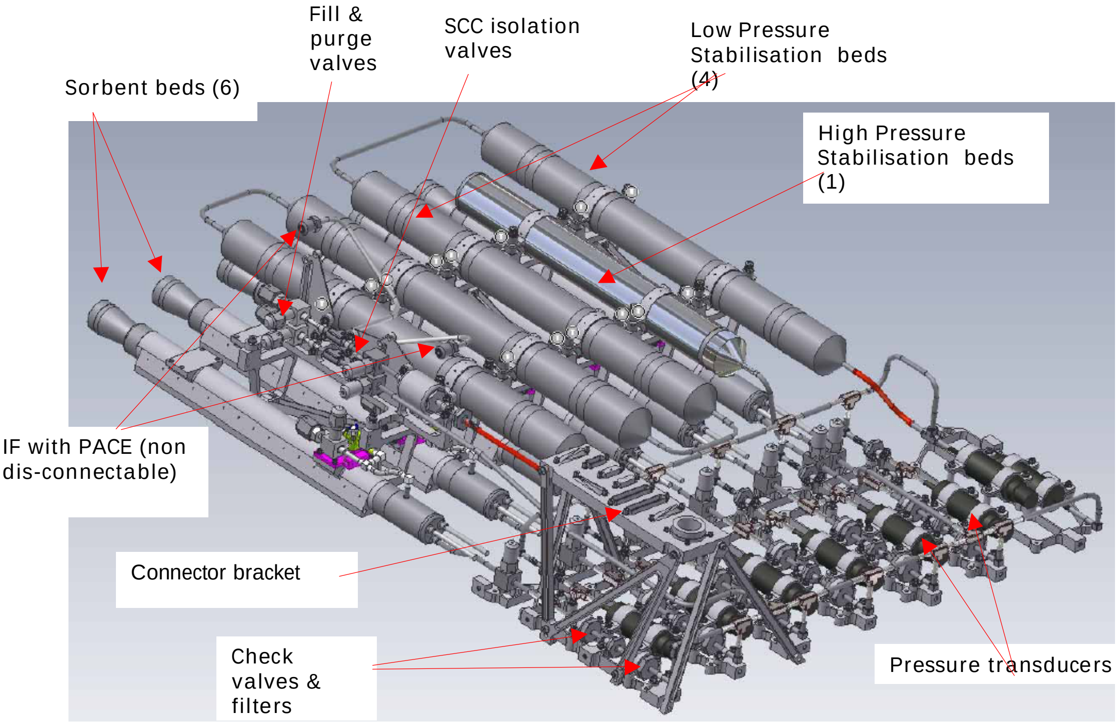


Figure 2-112 Sorption cooler compressor sketch

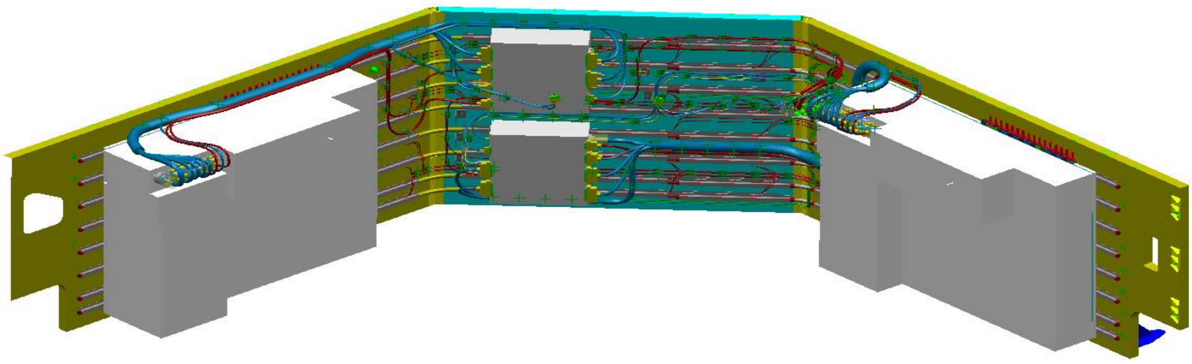


Figure 2-113 Sorption cooler compressors and electronics integrated on 3 SVM panels, on heat pipes

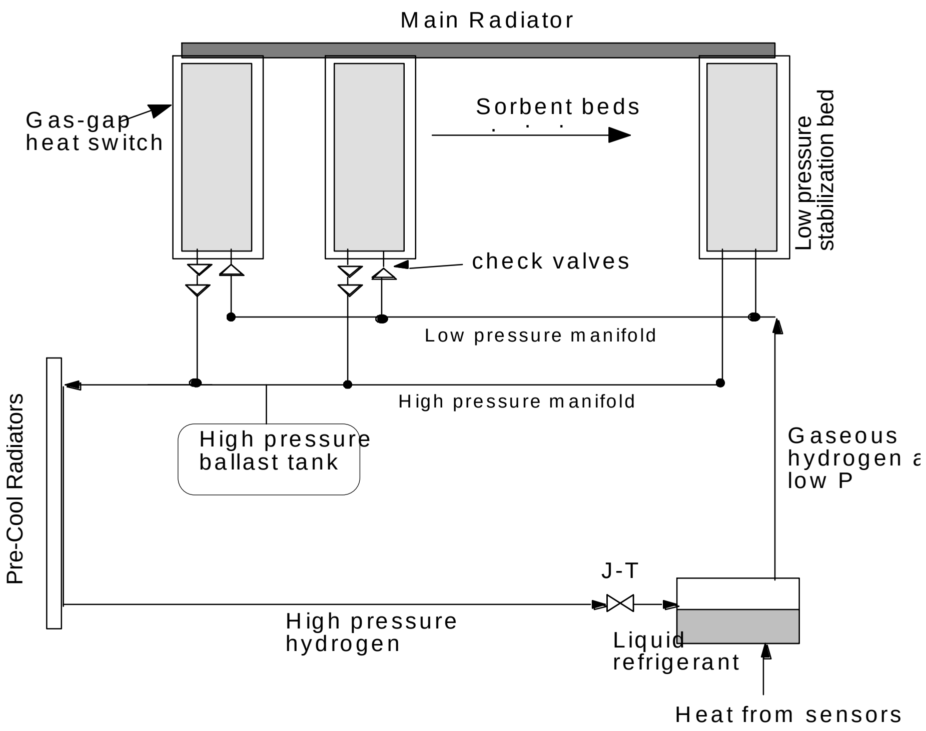


Figure 2-114 SCS functional block diagram

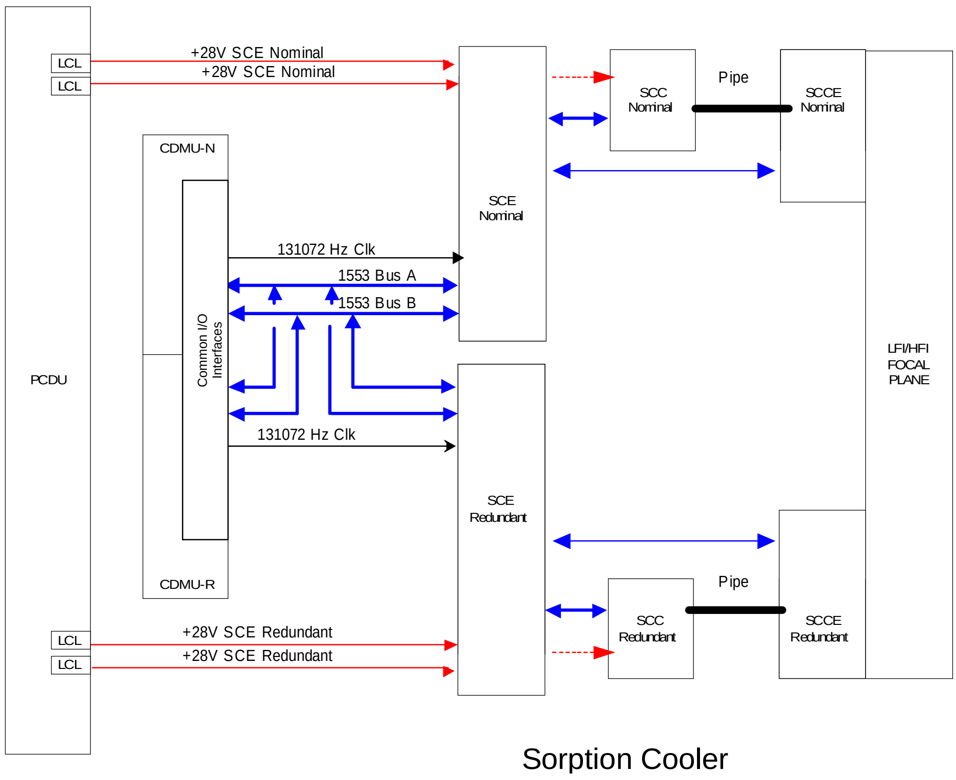


Figure 2-115 SCS electrical interfaces block diagram

2.5. SYSTEM CONFIGURATIONS

2.5.1. Units switching status

2.5.1.1. HERSCHEL satellite units switching status

The following Table provides the units switching status of HERSCHEL satellite except instruments. Instruments switching status is detailed in Table 2-16.

S/S	Switchable Unit	Launch Mode	IOP SAM	IOP NOM	IOP OCM	COP NOM	Nominal Mode	ROP OCM	Earth Acqu. Mode	Sun Acq. Mode	Survival Mode
CDMS											
	CDMU	ON (LAM) Rx: 4 kbps Tx: OFF	ON (SAM) Tx: 5 kbps TM rate can be increased to 150Kbps by TC to download VMC data	ON (NOM) Baseline: Tx enc : 150 kbps Alternative up to 350000Km: Tx enc: 5Kbps Alternative up to 750000Km: Tx enc: 5Kbps Alternative above to 750000Km: Tx enc: 500 bps	ON (NOM) Baseline: Tx enc : 150 kbps Alternative up to 350000Km: Tx enc: 5Kbps Alternative up to 750000Km: Tx enc: 5Kbps Alternative above to 750000Km: Tx enc: 500 bps	ON (NOM) Tx: 150 kbps (or 1.5 Mbps on ground TC)	ON (NOM) Tx: 150 kbps (or 1.5 Mbps on ground TC)	ON (NOM) Tx: 150 kbps (or 1.5 Mbps on ground TC)	ON (EAM) Tx: 150 kbps	ON(SAM) Tx: 500 bps	ON(SM) Tx: 500 bps
ACMS											
	ACC	ON (SBM)	ON (SAM)	ON (NOM)	ON (OCM)	ON (NOM)	ON (NOM)	ON (OCM)	ON (NOM)	ON (SAM or SM)	ON (SAM or SM)
	STR 1	OFF	OFF	ON	ON	ON	ON	ON	ON	OFF	OFF
	STR 2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	GYR [H]	ON	ON	ON	ON	ON	ON	ON	ON	ON	OFF
	RW 1 [H]	OFF	OFF	ON	ON (constant speed)	ON	ON	ON (constant speed)	ON	OFF	OFF
	RW 2 [H]	OFF	OFF	ON	ON (constant speed)	ON	ON	ON (constant speed)	ON	OFF	OFF
	RW 3 [H]	OFF	OFF	ON	ON (constant speed)	ON	ON	ON (constant speed)	ON	OFF	OFF
	RW 4 [H]	OFF	OFF	ON	ON (constant speed)	ON	ON	ON (constant speed)	ON	OFF	OFF
	CRS 1	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	CRS 2	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	SAS +Z	Not used	Used	Not used	Not used	Not used	Not used	Not used	Not used	Used	Used
	SAS -Z	Not used	Used	Not used	Not used	Not used	Not used	Not used	Not used	Used	Used
TTC											
	Transponder 1	Rx 4 kbps Tx modulation scheme: OFF	Rx 4 kbps Tx modulation scheme: PCM(NRZ-L)/PSK/PM (5 kbps)	Baseline: Rx 4kbps Tx :150 kbps with KRU and NN via MGA Alternative up to 350000Km: Rx 4kbps Tx :5 kbps with KRU via LGA Alternative up to	Baseline: Rx 4kbps Tx :150 kbps with KRU and NN via MGA Alternative up to 350000Km: Rx 4kbps Tx :5 kbps with KRU via LGA Alternative up to	Rx 4 kbps Tx modulation scheme: PCM(SP-L)/PM (150 kbps) or GMSK (1.5 Mbps)	Rx 4 kbps Tx modulation scheme: - DTCP: PCM(SP-L)/PM (150 kbps) or GMSK (1.5 Mbps) - Out of DTCP: OFF	Rx 4 kbps DTCP: Tx modulation scheme: PCM(SP-L)/PM (150 kbps) or GMSK (1.5 Mbps)	Rx 4 kbps DTCP: Tx modulation scheme: PCM(SP-L)/PM (150 kbps)	Rx 4 kbps Tx modulation scheme: PCM(NRZ-L)/PSK/PM (500 bps)	Rx :125 bps Tx : OFF

S/S	Switchable Unit	Launch Mode	IOP SAM	IOP NOM	IOP OCM	COP NOM	Nominal Mode	ROP OCM	Earth Acqu. Mode	Sun Acq. Mode	Survival Mode
				750000Km: Rx:125 bps Tx :5 kbps with KRU via LGA Alternative above to 350000Km: Rx:125 bps Tx :500 bps with KRU via LGA	750000Km: Rx:125 bps Tx :5 kbps with KRU via LGA Alternative above to 350000Km: Rx:125 bps Tx :500 bps with KRU via LGA						
	Transponder 2	Rx 4 kbps Tx modulation scheme: OFF	Rx: 4 kbps Tx: OFF	Rx: 4 kbps up to 350000km, 125 kbps above 350000km Tx: OFF	Rx: 4 kbps Tx: OFF	Rx 4 kbps Tx : OFF	Rx 4 kbps Tx modulation scheme: OFF	Rx 4 kbps Tx modulation scheme: OFF	Rx 4 kbps Tx modulation scheme: OFF	Rx 4 kbps Tx modulation scheme: OFF	Rx: 125 bps Tx : 500 bps
	EPC 1	OFF	ON	ON	ON	ON	DTCP: ON Out of DTCP: OFF	DTCP: ON	ON	ON	OFF
	ECP 2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON
	TWT 1	OFF	ON	ON	ON	ON	DTCP: ON Out of DTCP: OFF	DTCP: ON	ON	ON	OFF
	TWT 2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON
	RFDN	LGA 1 on Rx1 LGA 2 on Rx2 LGA 1 on Tx1 LGA 2 on Tx2	LGA 1 on Rx1 LGA 2 on Rx2 LGA 1 on Tx1 LGA 2 on Tx2	Baseline: MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2 Alternative up to 350000Km: LGA1 on Rx1 LGA 2 on Rx2 LGA1 on Tx1 LGA 2 on Tx2 Alternative up to 750000Km: LGA1 on Rx1 LGA 2 on Rx2 LGA1 on Tx1 LGA 2 on Tx2 Alternative above to 350000Km: LGA1 on Rx1 LGA 2 on Rx2 LGA1 on Tx1 LGA 2 on Tx2	Baseline: MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2 Alternative up to 350000Km: LGA1 on Rx1 LGA 2 on Rx2 LGA1 on Tx1 LGA 2 on Tx2 Alternative up to 750000Km: LGA1 on Rx1 LGA 2 on Rx2 LGA1 on Tx1 LGA 2 on Tx2 Alternative above to 350000Km: LGA1 on Rx1 LGA 2 on Rx2 LGA1 on Tx1 LGA 2 on Tx2	MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2	MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2	MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2	MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2	LGA 1 on Rx1 MGA on Rx2 LGA 1 on Tx1 MGA on Tx2	LGA 1 on Rx2 LGA 2 on Rx1 LGA 2 on Tx1 LGA 1 on Tx2

S/S	Switchable Unit	Launch Mode	IOP SAM	IOP NOM	IOP OCM	COP NOM	Nominal Mode	ROP OCM	Earth Acqu. Mode	Sun Acq. Mode	Survival Mode
PCS											
	PCDU	Battery discharge up to fairing separation Battery charge after	Battery charge	Battery charge/discharge or SA mode	Battery charge/discharge or SA mode	Battery charge/discharge or SA mode	Battery charge/discharge or SA mode	Battery charge/discharge or SA mode	Battery charge/discharge or SA mode	Battery charge or SA mode	Battery charge/discharge or SA mode
RCS											
	Pressure transducer	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	LV-A	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)
	LV-B	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)
	20 N Branch A Thrusters	OFF (LCL 45 OFF) Catbed heater OFF Survival heaters ON	ON/OFF cycles(LCL 45 On) Catbed heater ON Survival heaters ON	OFF(LCL 45 On) Catbed heater OFF Exception: ON for RW off-loading (needs CBH) Survival heaters ON	(LCL 45 On) ON/OFF cycles Catbed heater ON Survival heaters ON	OFF(LCL 45 On) Catbed heater OFF Exception: ON for RW off-loading (needs CBH) Survival heaters ON	OFF(LCL 45 On) Catbed heater OFF Exception: ON for RW off-loading (needs CBH) Survival heaters ON	(LCL 45 On) ON/OFF cycles Catbed heater OFF Survival heaters ON	OFF(LCL 45 On) Catbed heater OFF Exception: ON for RW off-loading (needs CBH) Survival heaters ON	(LCL 45 On) ON/OFF cycles Catbed heater OFF Survival heaters ON	OFF(LCL 45 On) Catbed heater OFF Survival heaters ON
	20 N Branch B Thrusters	OFF (LCL 46 OFF) Catbed heater OFF Survival heaters ON	OFF(LCL 46 N) Catbed heater OFF Survival heaters ON	OFF(LCL 46 N) Catbed heater OFF Survival heaters ON	OFF(LCL 46 N) Catbed heater OFF Survival heaters ON	OFF(LCL 46 N) Catbed heater OFF Survival heaters ON	OFF(LCL 46 N) Catbed heater OFF Survival heaters ON	OFF(LCL 46 N) Catbed heater OFF Survival heaters ON	OFF(LCL 46 N) Catbed heater OFF Survival heaters ON	OFF(LCL 46 N) Catbed heater OFF Survival heaters ON	ON/OFF cycles(LCL 46 N) Catbed heater OFF Survival heaters ON
Telescope decontamination											
	Telescope heaters	OFF	OFF/ON (L+3 h)	ON since (L +3h)	ON	ON until L + 21 d	OFF	OFF	OFF	OFF	OFF
LOU Baffle decontamination											
	LOU Baffle heaters	OFF	OFF	OFF	OFF	OFF	OFF (only ON if required)	OFF	OFF	OFF	OFF
Extra P/L											
	SREM	OFF	OFF/ON	ON	ON	ON	ON	ON	ON	ON	OFF
	VMC	OFF	ON just after launcher separation, OFF after ground images acquisition	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

S/S	Switchable Unit	Launch Mode	IOP SAM	IOP NOM	IOP OCM	COP NOM	Nominal Mode	ROP OCM	Earth Acqu. Mode	Sun Acq. Mode	Survival Mode
Herschel EPLM											
	CCU	ON (N+R)	ON	ON	ON	ON	ON	ON	ON	ON	ON
	Valve V501	Open by A5 dry loop command at L + 3min 46s	Open	Open	Open	Open	Open	Open	Open	Open	Open
	Valve V503	Open by A5 dry loop command at L + 3min 56s	Open	Open	Open	Open	Open	Open	Open	Open	Open
	Valve V103	Open by A5 dry loop command at L + 20min 40s	Open	Open	Open	Open	Open	Open	Open	Open	Open
	Valve V106	Open by A5 dry loop command at L + 20min 40s	Open	Open	Open	Open	Open	Open	Open	Open	Open
	Valve V504	Open	Open	Open	Open	Closed at L + 20 to 29 d	Closed	Closed	Closed	Closed	Closed
	Valve V505	Open	Open	Open	Open	Closed at L + 20 to 29 d	Closed	Closed	Closed	Closed	Closed
	Cryostat cover	Closed	Closed	Closed	Closed	Open at L + ~30 d	Open	Open	Open	Open	Open

Table 2-14 HERSCHEL satellite units switching status

2.5.1.2. PLANCK satellite units switching status

The following Table provides the units switching status of PLANCK satellite except instruments for each of the satellite modes. Instruments switching status is detailed in Table 2-17.

S/S	Switchable Unit	Launch Mode	IOP SAM	IOP NOM	IOP OCM	COP NOM	Nominal Mode	ROP OCM	Earth Acqu. Mode	Sun Acq. Mode	Survival Mode
CDMS											
	CDMU	ON (LAM) Rx: 4 kbps Tx: OFF	ON(SAM) Tx: 5 kbps	ON(NOM) Baseline: Tx enc : 150 kbps Alternative up to 350000Km: Tx enc: 5Kbps Alternative up to 750000Km: Tx enc: 5Kbps Alternative above to 750000Km: Tx enc: 500 bps	ON(NOM) Baseline: Tx enc : 150 kbps Alternative up to 350000Km: Tx enc: 5Kbps Alternative up to 750000Km: Tx enc: 5Kbps Alternative above to 750000Km: Tx enc: 500 bps	ON(NOM) Tx: 150 kbps (or 1.5 Mbps on ground TC)	ON(NOM) Tx: 150 kbps (or 1.5 Mbps on ground TC)	ON(NOM) Tx: 150 kbps (or 1.5 Mbps on ground TC)	ON(EAM) Tx: 150 kbps	ON(SAM) Tx: 500 bps	ON(SM) Tx: 500 bps
ACMS											
	ACC	ON (SBM)	ON (SAM)	ON (SCM or HCM)	ON (OCM)	ON (SCM or HCM)	ON (SCM or HCM)	ON (OCM)	ON (OCM, HCM or SAM)	ON (SAM or SM)	ON (SAM, SM, OCM or HCM)
	STR 1	OFF	OFF	ON	ON	ON	ON	ON	ON if OCM or HCM, else OFF	OFF	ON if OCM or HCM, else OFF
	STR 2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	CRS 1	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	CRS 2	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	CRS 3	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	SAS +Z	Not used	Used	Not used	Not used	Not used	Not used	Not used	Used in SAM, else not used	Used	Used in SAM or SM, else not used
	SAS -Z	Not used	Used	Not used	Not used	Not used	Not used	Not used	Used in SAM, else not used	Used	Used in SAM or SM, else not used
TTC											
	Transponder 1	Rx 4 kbps Tx: OFF	Rx 4 kbps Tx modulation scheme: PCM(NRZ-L)/PSK/PM (5 kbps)	Baseline: Rx 4kbps Tx :150 kbps with KRU and NN via MGA Alternative up to 350000Km: Rx 4kbps Tx :5 kbps with KRU via LGA	Baseline: Rx 4kbps Tx :150 kbps with KRU and NN via MGA Alternative up to 350000Km: Rx 4kbps Tx :5 kbps with KRU via LGA	Rx 4 kbps Tx modulation scheme: PCM(SP-L)/PM (150 kbps) or GMSK (1.5 Mbps)	Rx 4 kbps Tx modulation scheme: - DTCP: PCM(SP-L)/PM (150 kbps) or GMSK (1.5 Mbps) - Out of DTCP: OFF	Rx 4 kbps DTCP: Tx modulation scheme: PCM(SP-L)/PM (150 kbps) or GMSK (1.5 Mbps)	Rx 4 kbps DTCP: Tx modulation scheme: PCM(SP-L)/PM (150 kbps)	Rx 4 kbps Tx modulation scheme: PCM(NRZ-L)/PSK/PM (500 bps)	Rx :125 bps Tx : OFF

S/S	Switchable Unit	Launch Mode	IOP SAM	IOP NOM	IOP OCM	COP NOM	Nominal Mode	ROP OCM	Earth Acqu. Mode	Sun Acq. Mode	Survival Mode
				Alternative up to 750000Km: Rx:125 bps Tx :5 kbps with KRU via LGA Alternative above to 750000Km: Rx:125 bps Tx :500 bps with KRU via LGA	Alternative up to 750000Km: Rx:125 bps Tx :5 kbps with KRU via LGA Alternative above to 750000Km: Rx:125 bps Tx :500 bps with KRU via LGA						
	Transponder 2	Rx 4 kbps Tx: OFF	Rx 4 kbps Tx: OFF	Rx: 4 kbps up to 350000km, 125 kbps above 350000km Tx: OFF	Rx: 4 kbps up to 350000km, 125 kbps above 350000km Tx: OFF	Rx 4 kbps Tx : OFF	Rx 4 kbps Tx : OFF	Rx 4 kbps Tx: OFF	Rx 4 kbps Tx: OFF	Rx 4 kbps Tx: OFF	Rx: 125 bps Tx : 500 bps
	EPC 1	OFF	ON	ON	ON	ON	DTCP: ON Out of DTCP: OFF	DTCP: ON	ON	ON	OFF
	ECP 2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON
	TWT 1	OFF	ON	ON	ON	ON	DTCP: ON Out of DTCP: OFF	DTCP: ON	ON	ON	OFF
	TWT 2	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON
	RFDN	LGA 1 on Rx1 LGA 2 and 3 on Rx2 LGA 1 on Tx2 LGA 2 and 3 on Tx2	LGA 1 on Rx1 LGA 2 and 3 on Rx2 LGA 1 on Tx2 LGA 2 and 3 on Tx2	Baseline: MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2 Alternative up to 350000Km: LGA1 on Rx1 LGA 2/3 on Rx2 LGA1 on Tx1 LGA 2/3 on Tx2 Alternative up to 750000Km: LGA1 on Rx1 LGA 2/3 on Rx2 LGA1 on Tx1 LGA 2/3 on Tx2 Alternative above to 350000Km: LGA1 on Rx1 LGA 2/3 on Rx2 LGA 1 on Tx1 LGA 2/3 on Tx2	Baseline: MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2 Alternative up to 350000Km: LGA1 on Rx1 LGA 2/3 on Rx2 LGA1 on Tx1 LGA 2/3 on Tx2 Alternative up to 750000Km: LGA1 on Rx1 LGA 2/3 on Rx2 LGA1 on Tx1 LGA 2/3 on Tx2 Alternative above to 350000Km: LGA1 on Rx1 LGA 2/3 on Rx2 LGA 1 on Tx1 LGA 2/3 on Tx2	MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2	MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2	MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2	MGA on Rx1 LGA 1 on Rx2 MGA on Tx1 LGA 1 on Tx2	LGA 1 on Rx1 MGA on Rx2 LGA 1 on Tx1 MGA on Tx2	LGA 1 on Rx1 LGA 2 and LGA 3 on Rx2 LGA 1 on Tx1 LGA 2 and LGA 3 on Tx2

S/S	Switchable Unit	Launch Mode	IOP SAM	IOP NOM	IOP OCM	COP NOM	Nominal Mode	ROP OCM	Earth Acqu. Mode	Sun Acq. Mode	Survival Mode
PCS											
	PCDU	Battery discharge up to SYLDA5 separation, Battery charge after	Battery charge	Battery charge/discharge or SA mode	Battery charge/discharge or SA mode	Battery charge/discharge or SA mode	Battery charge/discharge or SA mode	Battery charge/discharge or SA mode	Battery charge/discharge or SA mode	Battery charge or SA mode	Battery charge/discharge or SA mode
RCS											
	Pressure transducer	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	LV-A	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)	Open(LCL 47 ON)
	LV-B	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)	Open(LCL 48 ON)
	20 N Branch A Thrusters	OFF (LCL 45 OFF) Catbed heater OFF Survival heaters ON	ON/OFF cycles(LCL 45 ON) Catbed heater ON Survival heaters ON	OFF(LCL 45 On) Catbed heater OFF Survival heaters ON	(LCL 45 On) ON/OFF cycles Catbed heater ON Survival heaters ON	OFF(LCL 45 On) Catbed heater OFF Survival heaters ON	OFF(LCL 45 On) Catbed heater OFF Survival heaters ON	(LCL 45 On) ON/OFF cycles Catbed heater ON Survival heaters ON	(LCL 45 On) OCM, SAM: ON/OFF cycles HCM: OFF Catbed heater OFF Survival heaters ON	(LCL 45 On) ON/OFF cycles Catbed heater ON Survival heaters ON	OFF(LCL 45 On) Catbed heater OFF Survival heaters ON
	20 N Branch B Thrusters	OFF (LCL 46 OFF) Catbed heater OFF Survival heaters ON	OFF(LCL 46 ON) Catbed heater OFF Survival heaters ON	OFF(LCL 46 On) Catbed heater OFF Survival heaters ON	OFF(LCL 46 On) Catbed heater OFF Survival heaters ON	OFF(LCL 46 On) Catbed heater OFF Survival heaters ON	OFF(LCL 46 On) Catbed heater OFF Survival heaters ON	OFF(LCL 46 On) Catbed heater OFF Survival heaters ON	OFF(LCL 46 On) Catbed heater OFF Survival heaters ON	OFF(LCL 46 On) Catbed heater OFF Survival heaters ON	ON/OFF cycles(LCL 46 On) Catbed heater OFF Survival heaters ON
	1N Branch A Thrusters [P]	OFF(LCL 45 OFF) Catbed heater OFF	OFF(LCL 45 ON) Catbed heater OFF	(LCL 45 ON) SCM: OFF HCM: ON/OFF cycles Catbed heater ON	OFF(LCL 45 ON) Catbed heater OFF	(LCL 45 ON) SCM: OFF HCM: ON/OFF cycles Catbed heater ON	(LCL 45 ON) SCM: OFF HCM: ON/OFF cycles Catbed heater ON	OFF(LCL 45 ON) Catbed heater OFF	(LCL 45 ON) Catbed heater OFF OCM, SAM: OFF HCM: ON/OFF cycles	OFF(LCL 45 ON) Catbed heater OFF	OFF(LCL 45 ON) Catbed heater OFF
	1N Branch B Thrusters [P]	OFF(LCL 46 OFF) Catbed heater OFF	OFF(LCL 46 ON) Catbed heater OFF	(LCL 46 ON) OFF Catbed heater OFF	OFF(LCL 46 ON) Catbed heater OFF	OFF(LCL 46 ON) Catbed heater OFF	OFF(LCL 46 ON) Catbed heater OFF	OFF(LCL 46 ON) Catbed heater OFF	OFF(LCL 46 ON) Catbed heater OFF	OFF(LCL 46 ON) Catbed heater OFF	OFF(LCL 46 ON) Catbed heater OFF
Telescope decontamination											
	Telescope heaters	OFF	OFF/ON (L+3h)	ON since (L +3h)	ON	ON until L + 14 d	OFF	OFF	OFF	OFF	OFF
Extra P/L											
	SREM	OFF	OFF/ON	ON	ON	ON	ON	ON	ON	ON	OFF
	FOG	OFF	OFF	OFF	OFF	ON	ON	ON	ON	ON	OFF

Table 2-15 PLANCK satellite units switching status

2.5.1.3. HERSCHEL instruments units switching status

The following Table provides the units switching status of HERSCHEL instrument units for each satellite mode.

S/S	Switchable Unit	Launch Mode	COP NOM	Nominal Mode#1	Nominal Mode#2	Nominal Mode#3	Nominal Mode#4	EAM/SAM	Survival Mode
HIFI		**OFF**	**STANDBY**	**PRIME**	**STANDBY**	**STANDBY**	**STANDBY**	**STANDBY**	**OFF**
	FPU (on OBP)	OFF	OFF	ON	OFF	OFF	OFF	OFF	OFF
	FCU (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	3DH (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	3DV (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	LOU (on CVV)	OFF	ON	ON	ON (thermal control only)	ON (thermal control only)	ON (thermal control only)	ON (thermal control only)	OFF
	LCU (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	LSU (in SVM)	OFF	ON	ON	Reference oscillator is ON, Synthetisor is OFF	Reference oscillator is ON, Synthetisor is OFF	Reference oscillator is ON, Synthetisor is OFF	Reference oscillator is ON, Synthetisor is OFF	OFF
	HRH (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	HRV (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	WEH (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	WEV (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	WOH (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	WOV (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	ICU (in SVM)	OFF	ON	ON	ON (but Science data is OFF)	ON (but Science data is OFF)	ON (but Science data is OFF)	ON (but Science data is OFF)	OFF
PACS		**OFF**	**SAFE**	**SAFE**	**PRIME**	**SAFE**	**PARALLEL**	**SAFE**	**OFF**
	FPU (on OBP)	OFF	OFF	OFF	ON	OFF	ON	OFF	OFF
	DECMEC (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	BOLC (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	DPU (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF
	SPU (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF

S/S	Switchable Unit	Launch Mode	COP NOM	Nominal Mode#1	Nominal Mode#2	Nominal Mode#3	Nominal Mode#4	EAM/SAM	Survival Mode
SPIRE		**OFF**		**STANDBY**	**STANDBY**	**PRIME**	**PARALLEL**	**STANDBY**	**OFF**
	FPU (on OBP)	OFF	OFF	Detector Bias ON Cooler ON BSM ON Photometer Cal Source OFF Spect. Cal Source OFF FTS Mechanism OFF.	Detector Bias ON Cooler ON BSM ON Photometer Cal Source OFF Spect. Cal Source OFF FTS Mechanism OFF.	Detector Bias ON Cooler ON BSM ON **Spectro:** Spect. Cal Source ON FTS Mechanism ON Photometer Cal Source OFF. **Photo** Spect. Cal Source OFF FTS Mechanism OFF Photometer Cal Source ON /OFF	Detector Bias ON Cooler ON BSM ON **Spectro:** Spect. Cal Source ON FTS Mechanism ON Photometer Cal Source OFF. **Photo** Spect. Cal Source OFF FTS Mechanism OFF Photometer Cal Source ON/OFF	Detector Bias ON Cooler ON BSM ON Photometer Cal Source OFF Spect. Cal Source OFF FTS Mechanism OFF.	OFF
	JFET amplifiers (on OBP)	OFF	OFF	ON	ON	ON	ON	ON	OFF
	FCU + DCU (in SVM)	OFF	OFF	ON	ON	ON	ON	ON	OFF
	DPU (in SVM)	OFF	ON	ON	ON	ON	ON	ON	OFF

Table 2-16 HERSCHEL instruments units switching status

2.5.1.4. PLANCK instruments units switching status

The following Table provides the units switching status of PLANCK instrument units for each satellite mode.

S/S	Switchable Unit	Launch Mode	COP NOM	Nominal Mode #1	Nominal Mode #2	Nominal Mode #3	Earth Acqu. Mode	Sun Acq. Mode	Survival Mode
HFI		**LAUNCH**	**STANDBY**	**PRIME**	**PRIME**	**STANDBY**	**STANDBY**	**STANDBY**	**OFF**
	FPU	OFF	OFF	ON	ON	OFF	OFF	OFF	OFF
	DPU N	OFF	ON	ON	ON	ON	ON	ON	OFF
	DPU R	OFF	OFF	ON	ON	OFF	ON	OFF	OFF
	JFET	OFF	OFF	ON	ON	ON	ON	ON	OFF
	PAU	OFF	OFF	ON	ON	OFF	OFF	OFF	OFF
	REU	OFF	step 1: - REU proc: OFF - REU belts 01 to 11: OFF step 4: - REU proc: ON - REU belts 01 to 11: OFF	ON	ON	ON	ON	ON	OFF
	4K CAU	OFF	OFF	ON	ON	ON	ON	ON	OFF
	4K CEU (4KCDE)	OFF	step 1: OFF step 4: ON	ON	ON	ON	ON	ON	OFF
	4K PRU (4KCCR)	ON	OFF	ON	ON	OFF	OFF	OFF	OFF
	4K CCU	ON	OFF	ON	ON	ON	ON	ON	OFF
	0.1 K DCCU DCE	OFF	step 1: OFF step 4: ON	ON	ON	ON	ON	ON	OFF
LFI		**OFF**		**PRIME**	**STANDBY**	**PRIME**	**STANDBY**	**STANDBY**	**OFF**
	FPU	OFF	OFF	ON	OFF	ON	OFF	OFF	OFF
	BEU	OFF	OFF	ON	OFF	ON	OFF	OFF	OFF
	DAE	OFF	OFF	ON	OFF	ON	OFF	OFF	OFF
	REBA N	OFF	ON	ON	ON	ON	ON	ON	OFF
	REBA R	OFF	OFF	ON	ON	ON	ON	ON	OFF
SCS		**OFF**							**OFF**
	SCC N	OFF	OFF	ON	ON	ON	ON	ON	OFF
	SCC R	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	SCE N	OFF	ON	ON	ON	ON	ON	ON	OFF
	SCE R	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

Table 2-17 PLANCK instruments units switching status

2.5.2. Units redundancy

2.5.2.1. HERSCHEL and PLANCK common subsystems redundancy

The following Table provides the units redundancy which are common to HERSCHEL and PLANCK. In some cases, a [P] or [H] indicates the unit is specific to a satellite.

Sub-system	Unit/Equipment	Nominal	Redundant	Hot/Cold
CDMS				
	Hot Power Converter	A	B	Hot
	Cold Power Converter	A	B	Cold
	Processor Module	A	B	Cold
	TM Encoder	A	B	Cold
	TC Decoder	A	B	Hot
	CPDU	A	B	Hot
	SGM	A	B	Hot
	OBT	A	B	Hot
	Reconf. Module	A	B	Hot
	SSMM	A	B	Hot
	1553 Bus Controller A	Nom.	Red.	Cold
	1553 Bus Controller B	Nom.	Red.	Cold
	Serial Bus Controller Board (SBCH)	A	B	Hot
	I/O interface (SBCH)	A	B	Cold
	SIOH	1	2.3	Hot
ACMS				
	Hot Power Converter	A	B	Hot
	Cold Power Converter	A	B	Cold
	Processor Module	A	B	Cold
	CPDU	A	B	Hot
	SGM	A	B	Hot
	OBT	A	B	Hot
	Reconf. Module	A	B	Hot
	AGSA	A	B	Hot
	Serial Bus Controller Board (SBAH)	A	B	Hot
	1553 Bus Controller A	Nom.	Red.	Cold
	1553 Bus Controller B	Nom.	Red.	Cold
	1553 Remote Terminal A (from System)	Nom.	Red.	Cold
	1553 Remote Terminal B (from System)	Nom.	Red.	Cold
	I/O interface (SBAH toward ACMS equipment)	A	B	Cold
	RCS Input/Output Board (RIOH)	1	2	Hot
	RWL [H]	1, 2, 3,4	Degraded :3 used	N/A
	STR	1	2	Cold
	CRS [H]	1 used for ARAD rate detection (Not in ACMS SAM) 1 used in SAM and SM during recovery	N/A	N/A
	CRS [P]	2 used for ARAD rate detection (one of them will also be occasionally used for control in Sun Acquisition Mode) 1 used for control in Survival Mode	N/A	N/A
	AAD	Internally redundant		
	SAS	Internally redundant		
	Gyro [H]	1, 2, 3	4	Hot
	Gyro Electronics [H]	Nom.	Red.	Cold
TT&C				
	TWTA	1	2	Cold
	EPC	1	2	Cold
	Receiver (Rx)	1	2	Hot
	Transmitter (Tx)	1	2	Cold
	1553 Remote Terminal (XPND1)	Nom.	Red.	Cold
	1553 Remote Terminal (XPND2)	Nom.	Red.	Cold
	RFDN	4 switches redundant in pairs: Switch 1 Nom Switch 3 Nom	Switch 2 Red Switch 4 Red	Cold
	LGA1	1	N/A	N/A
	LGA2	1	N/A	N/A
	LGA3 [P]	1	N/A	N/A
	MGA	1	N/A	N/A

Sub-system	Unit/Equipment	Nominal	Redundant	Hot/Cold
PCS				
	PCDU TM/TC Module	N	R	Cold
	PCDU Media Bus	N	R	Cold
	PCDU Battery Discharge Regulator	N	R	Hot
	PCDU Main Error Amplifier	1.2	3	Hot
	Battery	1	N/A	N/A
	Solar Array	30 Nom. sections	N/A	N/A
RCS				
	Latch Valve	A	B	Cold
	Thruster 20N	6 Nom. Branch	6 Red. Branch	Cold
	Thruster 20N FCVs	6 Nom. Branch	6 Red. Branch	Cold
	Thruster 20N CBHs	2 Nominal CBHs for each thruster	2 Redundant CBHs for each thruster	Cold
	Thruster 1N	2 Nom. Branch	2 Red. Branch	Cold
	Thruster 1N FCVs	2 Nom. Branch	2 Red. Branch	Cold
	Thruster 1N CBHs	1 Nominal CBH for each thruster	1 Redundant CBH for each thruster	Cold
	Tank	2 (Herschel) 3 (Planck)	N/A	N/A
TCS				
	HPS	9 Nominal	9 Redundant	Cold
	HCS	6 HCS for each nominal HPS	6 HCS for each redundant HPS	Cold
	ATC Lines	46 (H) / 48 (P) nom.	46 (H) / 48 (P) red.	Cold
	ATC lines Thermistors	3 for each line	N/A	N/A
	Decontamination lines	9		Hot

Table 2-18 HERSCHEL and PLANCK common S/S redundancy

2.5.2.2. Specific HERSCHEL units redundancy

The following Table provides the units status of HERSCHEL specific units for each of the satellite modes.

Sub-system	Unit/Equipment	Nominal	Redundant	Hot/Cold
	Telescope Decontamination lines	6 on M1, 1 on M2	1 on M1, 1 on M2	Hot
	LOU Baffle Decontamination lines	2	1	Cold
Extra P/L				
	VMC	no redundancy		
HEPLM				
	CCU	A	B	Hot
	Internal valve	V103	V106	Hot
	External valves	V501 V504	V503 V505	Hot
	Cryostat Cover - NCA	1	1	Cold
HIFI				
	FPU	no redundancy		
	FCU	nominal	redundant (internal)	Hot
	IFH	no redundancy		
	IFV	no redundancy		
	LOU	no redundancy		
	LSU	nominal	redundant (internal)	Hot
	LCU	nominal	redundant (internal)	cold
	HRH	no redundancy		
	HRV	no redundancy		
	WEH	no redundancy		
	WEV	no redundancy		
	WOH	no redundancy		
	WOV	no redundancy		
	ICU	nominal	redundant	cold
PACS				
	FPU	Partial redundancy		
	BOLC	Partial redundancy		
	DECMEC	MEC1	MEC2	cold
	DPU	nominal	redundant	cold
	SPU	nominal	redundant	cold
SPIRE				
	FPU	no redundancy		
	JFET	no redundancy		
	HSDPU	prime	redundant	cold
	HSDCU	no redundancy		
	HSFCU	prime	redundant	cold

2.5.2.3. Specific PLANCK units redundancy

The following Table provides the units status of PLANCK specific units for each of the satellite modes.

Sub-system	Unit/Equipment	Nominal	Redundant	Hot/Cold
	Decontamination lines	4	4	Cold
Extra P/L				
	FOG	3	1	
HFI				
	DPU	nominal	redundant	Cold
	REU	nominal	redundant (digital boards only)	Cold
	DCCU	no redundancy		
	4KCCU (comp. Electr.)	no redundancy		
	4KCDE (Cooler Drive Elec.)	no redundancy		
	4KCCR (Regulator)	no redundancy		
	4KCAU (ancillary unit)	no redundancy		
LFI				
	REBA	nominal	redundant	Cold
	SCC	nominal	redundant	Cold
	DAE	no redundancy		
	BEU	no redundancy		
SCS				
	SCC + PACE	nominal	redundant	Cold
	SCE	nominal	redundant	Cold
	Harness	nominal	redundant	Cold

Table 2-20 PLANCK specific units redundancy

2.6. SYSTEM BUDGETS

2.6.1. HERSCHEL budgets

2.6.1.1. Mass

HERSCHEL spacecraft mass budget is shown hereafter in Table 2-21.

maximum mass: 3430 kg

nominal mass: 3375 kg

mass margin: 1.6%.

	Responsibility	Nominal Mass [kg]	Mass Margin [kg]	Maximum Mass [kg]	Allocated Maximum Mass [kg]	Mass Perfo - Reqt [kg]
HERSCHEL (Dry) HERSCHEL (Wet)		2779,2 3375,1	55,7 55,7	2834,8 3430,7		
Dry Service Module	Alenia	612,3	9,3	621,6	600,0	+21,6
Dry Payload Module - CFE Helium	EADS	1426,3 336,0	38,3 0,0	1464,6 336,0	1825,0	-24,4
Telescope SREM	ESA	314,5 2,6	0,0 0,0	315,0 2,7	315,0 2,7	0 -0,1
Hydrazine Nitrogen VMC Balancing masses	Alcatel	256,0 3,9 0,6 0,0	0,0 0,0 0,0 0,0	256,0 3,9 0,6 0,0	0,5 0,0	+0,1 0
HIFI	HIFI	197,8	0,8	198,6	229,0	-30,4
SPIRE	SPIRE	91,6	0,0	91,6	96,0	-4,4
PACS	PACS	133,4	6,7	140,1	140,0	+0,1

Table 2-21 HERSCHEL mass budget

2.6.1.2. Centre of mass and inertia

The following centring and inertia budget has been computed with conditions very similar to those of the nominal mass (dry mass of 2792 kg vs. 2779 kg). This budget will be updated later on with the latest weighed masses.

No balancing masses are needed on Herschel (contrarily to Planck).

<u>Sign convention:</u>

The three inertia cross products are given with the standard sign convention:
$P_{XY} = + \bullet x\ y\ dm$ $P_{YZ} = + \bullet y\ z\ dm$ $P_{ZX} = + \bullet z\ x\ dm$

When noted algebraically, the sign of the cross products must be changed in the inertia matrix.

2.6.1.2.1. Beginning of life

Conditions:

- Hydrazine: launch conditions (200 kg).
- Helium: launch conditions (336 kg).
- nominal dry mass conditions
- total mass: 3332.0 kg

Centre of Mass [mm]			Inertia at CoM [kg·m²]					
X	Y	Z	Ixx	Iyy	Izz	Pxy	Pyz	Pzx
2004,0	**-15,8**	**-1,2**	**3927,1**	**8464,0**	**9034,7**	**-99,12**	**-68,44**	**672,14**

R = 15,9 mm	**I max**	9126,3	***around***	0,126203	-0,083260	-0,988504
	I med	8461,9	***around***	0,033578	0,996259	-0,079626
	I min	3837,6	***around***	-0,991436	0,023143	-0,128526

Table 2-22 Centre of mass and inertia at BOL

Herschel wet centre of mass is compliant with Ariane 5 (15.9 mm < 30 mm required).

2.6.1.2.2. Beginning Of Mission

Conditions:

- Hydrazine: 2×20 kg
- Helium: 300 kg (90% of initial load)
- nominal dry mass conditions
- total mass: 3136.0 kg

Centre of Mass [mm]			Inertia at CoM [kg·m²]					
X	Y	Z	Ixx	Iyy	Izz	Pxy	Pyz	Pzx
2080,2	**-16,9**	**-0,5**	**3921,1**	**8073,2**	**8547,7**	**-94,67**	**-68,41**	**669,84**

R = 16,9 mm	**I max**	8647,9	***around***	0,137820	-0,094663	-0,985923
	I med	8070,6	***around***	0,037290	0,995212	-0,090343
	I min	3823,6	***around***	-0,989755	0,024314	-0,140690

Table 2-23 Centre of mass and inertia at BOM

2.6.1.2.3. End Of Life

Conditions:

- Hydrazine: empty.
- Helium: empty.
- nominal dry mass conditions
- total mass: 2796.0 kg

Centre of Mass [mm]			Inertia at CoM [kg·m²]					
X	Y	Z	Ixx	Iyy	Izz	Pxy	Pyz	Pzx
2108,8	**-19,1**	**6,3**	**3795,2**	**7847,6**	**8299,1**	**-92,98**	**-67,99**	**668,90**

R = 20,1 mm	**I max**	8401,6	***around***	0,141102	-0,097232	-0,985209
	I med	7844,8	***around***	0,038162	0,994960	-0,092728
	I min	3695,5	***around***	-0,989259	0,024513	-0,144102

Table 2-24 Centre of mass and inertia at EOL

2.6.1.3. Power consumption and available energy

2.6.1.3.1. HERSCHEL average energy budget

The table below presents the HERSCHEL spacecraft energy budget during launch. It takes into account the BDR efficiency of 92.5%. It shows a maximum DoD of 36% at launch, fully within the battery capacity (more than 90%).

	SVM Margin	Launch
INSTRUMENTS		**11,0**
HIFI		
PACS		
SPIRE		11,0
EXTRA PAYLOAD		**11,2**
Cryostat Control Unit		11,2
SREM		
Visual Monitoring Camera		
TELESCOPE DECONTAMINATION		**0,0**
Decontamination heaters		
TT&C		**16,8**
Receiver		16,8
Transmitter		0,0
TWTA		0,0
CDMS		**36,5**
CDMU		36,5
ATTITUDE CONTROL S/S		**74,8**
ACC		31,3
Reaction Wheels		
Star Tracker		
CRS		15,0
Gyros		28,5
PROPULSION S/S		**25,6**
20-N Cat Bed Heaters		25,6
20-N Firings		
Latch Valves		
Pressure Transducer (accounted for in ACC)		0,0
THERMAL CONTROL S/S		**100,0**
WU heaters		
TTC subsystem heaters		
RCS subsystem heaters		5,0
ACMS subsystem heaters		95,0
Battery heaters		
POWER CONTROL CONTROL S/S		**29,0**
PCDU consumption		29,0
MARGINS		**91,5**
ESA Margin		91,5
Development margins		0,0
SUM ALL USERS		**396,3**
S/C Power Demand (W) at PCDU output		**403,7**
PCDU loss including PCDU input Harness losses		**35,1**
S/C Power Demand (W) at PCDU input		**438,8**
Depth of Discharge		**50,9%**

Table 2-25 HERSCHEL energy budget during launch

At BOL the average power need is lower than the power resources in any phase,

	Decon Warm-Up	Decon Steady State	Decon Steady State Max Pointing Angle	Science BOL	OCM DTCP BOL	Telecom BOL	Moon transit BOL	Survival BOL
INSTRUMENTS	**0,0**	**0,0**	**0,0**	**423,5**	**423,5**	**423,5**	**423,5**	**0,0**
HIFI				291,5	291,5	291,5	291,5	
PACS				58,0	58,0	58,0	58,0	
SPIRE				74,0	74,0	74,0	74,0	
EXTRA PAYLOAD	**13,8**	**13,8**	**13,8**	**13,8**	**13,8**	**13,8**	**13,8**	**11,2**
Cryostat Control Unit	11,2	11,2	11,2	11,2	11,2	11,2	11,2	11,2
SREM	2,6	2,6	2,6	2,6	2,6	2,6	2,6	
Visual Monitoring Camera	0,0	0,0	0,0					
TELESCOPE DECONTAMINATION	**517,0**	**189,2**	**251,7**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
Decontamination heaters	517,0	189,2	251,7					
TT&C	**106,3**	**106,3**	**106,3**	**29,5**	**106,3**	**106,3**	**29,5**	**106,3**
Receiver	16,8	16,8	16,8	16,8	16,8	16,8	16,8	16,8
Transmitter	14,7	14,7	14,7	12,7	14,7	14,7	12,7	14,7
TWTA	74,8	74,8	74,8		74,8	74,8		74,8
CDMS	**36,5**	**36,5**	**36,5**	**36,5**	**36,5**	**36,5**	**36,5**	**36,5**
CDMU	36,5	36,5	36,5	36,5	36,5	36,5	36,5	36,5
ATTITUDE CONTROL S/S	**108,8**	**148,4**	**148,4**	**148,4**	**108,8**	**130,2**	**108,8**	**46,3**
ACC	31,3	31,3	31,3	31,3	31,3	31,3	31,3	31,3
Reaction Wheels	22,0	61,6	61,6	61,6	22,0	43,4	22,0	
Star Tracker	12,0	12,0	12,0	12,0	12,0	12,0	12,0	
CRS	15,0	15,0	15,0	15,0	15,0	15,0	15,0	15,0
Gyros	28,5	28,5	28,5	28,5	28,5	28,5	28,5	
PROPULSION S/S	**25,6**	**25,6**	**25,6**	**25,6**	**55,9**	**25,6**	**25,6**	**63,5**
20-N Cat Bed Heaters	25,6	25,6	25,6	25,6	42,6	25,6	25,6	36,9
20-N Firings					13,3			26,6
Latch Valves								
Pressure Transducer (accounted for in ACC)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
THERMAL CONTROL S/S	**522,0**	**484,0**	**484,0**	**293,0**	**264,0**	**264,0**	**293,0**	**583,0**
WU heaters								
TTC subsystem heaters								
RCS subsystem heaters								
ACMS subsystem heaters								
Battery heaters								
POWER CONTROL CONTROL S/S	**31,0**	**31,0**	**31,0**	**34,0**	**34,0**	**34,0**	**34,0**	**30,0**
PCDU consumption	31,0	31,0	31,0	34,0	34,0	34,0	34,0	30,0
MARGINS	**46,9**	**46,9**	**46,9**	**0,0**	**0,0**	**0,0**	**0,0**	**100,0**
ESA Margin	46,9	46,9	46,9	0,0	0,0	0,0	0,0	100,0
Development margins	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
SUM ALL USERS	1407,9	1081,7	1144,2	1004,3	1042,8	1033,9	964,7	976,8
S/C Power Demand (W) at PCDU output	1435,4	1102,7	1166,4	1023,7	1063,0	1053,9	983,3	995,8
PCDU loss including PCDU input Harness losses	77,6	66,0	65,3	65,9	68,3	68,0	65,7	64,9
S/C Power Demand (W) at PCDU input	1513,0	1168,7	1231,7	1089,6	1131,3	1121,9	1049,0	1060,7
Depth of Discharge								
SA Power, 1 failed string	1696,5	1696,5	1696,5	1696,5	1696,5	1696,5	1526,9	1696,5
@ Sun aspect angle	0°	0°	0°	0°	0°	0°	0°	0°
Worst case sun aspect angle	0°	0°	30°	30°	30°	30°	0°	5°
Solar Array, no failed string (W)	1709,2	1709,2	1480,2	1480,2	1480,2	1480,2	1538,3	1702,7
Failed section	-63,3	-63,3	-54,8	-54,8	-54,8	-54,8	-57,0	-63,1
10% EOL loss								
Battery charge (w.c.)	-11,0	-11,0	-11,0	-11,0	-11,0	-11,0	-9,9	-11,0
RESOURCES at PCDU input	1619,6	1619,6	1401,1	1401,1	1401,1	1401,1	1457,6	1613,4
Power margin (W)	106,6	450,9	169,4	311,6	269,9	279,3	408,7	552,7
Power margin (%)	6,6%	27,8%	12,1%	22,2%	19,3%	19,9%	28,0%	34,3%

Table 2-26 HERSCHEL average power budget @ BOL

As shown in the next table, the average power need is lower than the power resources in every phase at EOL conditions.

	Science EOL	OCM DTCP EOL	Telecom EOL	Moon transit EOL	Survival EOL
INSTRUMENTS	**423,5**	**423,5**	**423,5**	**423,5**	**0,0**
HIFI	291,5	291,5	291,5	291,5	
PACS	58,0	58,0	58,0	58,0	
SPIRE	74,0	74,0	74,0	74,0	
EXTRA PAYLOAD	**13,8**	**13,8**	**13,8**	**13,8**	**11,2**
Cryostat Control Unit	11,2	11,2	11,2	11,2	11,2
SREM	2,6	2,6	2,6	2,6	
Visual Monitoring Camera					
TELESCOPE DECONTAMINATION	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
Decontamination heaters					
TT&C	**29,5**	**106,3**	**106,3**	**29,5**	**106,3**
Receiver	16,8	16,8	16,8	16,8	16,8
Transmitter	12,7	14,7	14,7	12,7	14,7
TWTA		74,8	74,8		74,8
CDMS	**36,5**	**36,5**	**36,5**	**36,5**	**36,5**
CDMU	36,5	36,5	36,5	36,5	36,5
ATTITUDE CONTROL S/S	**148,4**	**108,8**	**130,2**	**108,8**	**46,3**
ACC	31,3	31,3	31,3	31,3	31,3
Reaction Wheels	61,6	22,0	43,4	22,0	
Star Tracker	12,0	12,0	12,0	12,0	
CRS	15,0	15,0	15,0	15,0	15,0
Gyros	28,5	28,5	28,5	28,5	
PROPULSION S/S	**25,6**	**55,9**	**25,6**	**25,6**	**63,5**
20-N Cat Bed Heaters	25,6	42,6	25,6	25,6	36,9
20-N Firings		13,3			26,6
Latch Valves					
Pressure Transducer (accounted for in ACC)	0,0	0,0	0,0	0,0	0,0
THERMAL CONTROL S/S	**252,0**	**206,0**	**206,0**	**252,0**	**516,0**
WU heaters					
TTC subsystem heaters					
RCS subsystem heaters					
ACMS subsystem heaters					
Battery heaters					
POWER CONTROL CONTROL S/S	**34,0**	**34,0**	**34,0**	**34,0**	**30,0**
PCDU consumption	34,0	34,0	34,0	34,0	30,0
MARGINS	**0,0**	**0,0**	**0,0**	**0,0**	**100,0**
ESA Margin	0,0	0,0	0,0	0,0	100,0
Development margins	0,0	0,0	0,0	0,0	0,0
SUM ALL USERS	963,3	984,8	975,9	923,7	909,8
S/C Power Demand (W) at PCDU output	981,8	1003,8	994,7	941,5	927,4
PCDU loss including PCDU input Harness losses	**66,1**	**67,2**	**66,9**	**64,6**	**63,7**
S/C Power Demand (W) at PCDU input	1047,9	1071,0	1061,6	1006,1	991,1
Depth of Discharge					
SA Power, 1 failed string	**1410,1**	**1410,1**	**1410,1**	**1422,5**	**1580,5**
@ Sun aspect angle	**30°**	**30°**	**30°**	**0°**	**0°**
Worst case sun aspect angle	**30°**	**30°**	**30°**	**0°**	**5°**
Solar Array, no failed string (W)	**1420,6**	**1420,6**	**1420,6**	**1433,1**	**1586,2**
Failed section	**-52,6**	**-52,6**	**-52,6**	**-53,1**	**-58,7**
10% EOL loss	**-124,4**	**-124,4**	**-124,4**	**-125,5**	**-138,9**
Battery charge (w.c.)	**-9,2**	**-9,2**	**-9,2**	**-9,3**	**-10,3**
RESOURCES at PCDU input	**1222,9**	**1222,9**	**1222,9**	**1233,7**	**1365,5**
Power margin (W)	**175,0**	**151,9**	**161,3**	**227,6**	**374,4**
Power margin (%)	**14,3%**	**12,4%**	**13,2%**	**18,4%**	**27,4%**

Table 2-27 HERSCHEL average power budget @ EOL

2.6.1.3.2. HERSCHEL peak power budget

Herschel has the following peak power contributors:

- Active Thermal Control
- Reaction Wheels
- Decontamination Heaters
- Cat Bed Heaters if OCM during pre-Op (30 minute duration)

Although active thermal Control peaks can be high with respect to the average power, they are a very limited duration of 20-30 seconds and can occur infrequently.

The Reaction wheels peaks have only been considered during the phases where there could be a slew of the satellite which causes the reaction wheel peak consumption, namely during the science phases including Moon Transit.

The peaks due to ATC and/or reaction wheels pose no problem, they are covered by margins and even if these margins are discounted then the transient peak is of such a short duration and amplitude that the battery will be recharged before the next peak.

The peak caused by the **catbed heaters** is not a transient as for the ATC and reaction wheels, but **the amplitude of 30 minutes and limited power need is well within the capability of the battery under all conditions**

The decontamination heaters are arranged as follows : 6 lines of 95 W + 1 line of 65W for the primary reflector. When the reflector has reached the decontamination temperature, the heater duty cycle is 0.4. And 2 lines of 21W each for the secondary Reflector

The decontamination is not really a peak, it is more a steady state situation where time to reach decontamination temperature is in the order of 20 hours. In order to balance the power budget in pre-op phase, an operationnal strategy has been implemented for decontamination. The operation sequence allows sequential turn on of decontamination for M1 and M2 reflectors, where M2 heaters are only turned when the M1 reflector has archieved the required decontamination temperature. Therre will be periodic discharge / charge cycless during the decontamination period.

The time and power available during the off part of the heating duty cycle is more than adequate to ensure that the battery is recharged.

	SVM Margin	Launch	Pre-op BOL	Science BOL	OCM DTCP BOL	Telecom BOL	Moon transit BOL	Survival BOL	Science EOL	OCM DTCP EOL	Telecom EOL	Moon transit EOL	Survival EOL
INSTRUMENTS		**0,0**	**0,0**	**506,1**	**506,1**	**506,1**	**506,1**	**0,0**	**506,1**	**506,1**	**506,1**	**506,1**	**0,0**
HIFI				328,0	328,0	328,0	328,0		328,0	328,0	328,0	328,0	
PACS				105,3	105,3	105,3	105,3		105,3	105,3	105,3	105,3	
SPIRE				72,8	72,8	72,8	72,8		72,8	72,8	72,8	72,8	
EXTRA PAYLOAD		**11,2**	**13,8**	**13,8**	**13,8**	**13,8**	**13,8**	**11,2**	**13,8**	**13,8**	**13,8**	**13,8**	**11,2**
Cryostat Control Unit	10%	11,2	11,2	11,2	11,2	11,2	11,2	11,2	11,2	11,2	11,2	11,2	11,2
SREM	0%		2,6	2,6	2,6	2,6	2,6		2,6	2,6	2,6	2,6	
Visual Monitoring Camera	10%		0,0										
TELESCOPE DECONTAMINATION		**0,0**	**677,8**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
Decontamination heaters			677,8										
TT&C		**20,0**	**109,5**	**32,7**	**109,5**	**109,5**	**32,7**	**109,5**	**32,7**	**109,5**	**109,5**	**32,7**	**109,5**
Receiver	10%	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0
Transmitter	5%	0,0	14,7	12,7	14,7	14,7	12,7	14,7	12,7	14,7	14,7	12,7	14,7
TWTA	10%	0,0	74,8		74,8	74,8		74,8		74,8	74,8		74,8
CDMS		**37,7**	**37,7**	**37,7**	**37,7**	**37,7**	**37,7**	**37,7**	**37,7**	**37,7**	**37,7**	**37,7**	**37,7**
CDMU	10%	37,7	37,7	37,7	37,7	37,7	37,7	37,7	37,7	37,7	37,7	37,7	37,7
ATTITUDE CONTROL S/S		**76,2**	**110,2**	**174,9**	**110,2**	**131,6**	**174,9**	**48,2**	**183,4**	**110,2**	**131,6**	**183,4**	**48,2**
ACC	10%	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4	32,4
Reaction Wheels	10%		22,0	86,7	22,0	43,4	86,7		95,3	22,0	43,4	95,3	
Star Tracker	10%		12,0	12,0	12,0	12,0	12,0		12,0	12,0	12,0	12,0	
CRS	5%	15,8	15,8	15,8	15,8	15,8	15,8	15,8	15,8	15,8	15,8	15,8	15,8
Gyros	5%	28,0	28,0	28,0	28,0	28,0	28,0		28,0	28,0	28,0	28,0	
PROPULSION S/S		**25,6**	**43,0**	**25,6**	**55,9**	**25,6**	**25,6**	**63,5**	**25,6**	**55,9**	**25,6**	**25,6**	**63,5**
20-N Cat Bed Heaters (Survival + CatBed)	10%	25,6	43,0	25,6	42,6	25,6	25,6	36,9	25,6	42,6	25,6	25,6	36,9
20-N Firings	5%				13,3			26,6		13,3			26,6
Latch Valves	5%												
Pressure Transducer (accounted for in ACC)	5%	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
THERMAL CONTROL S/S		**0,0**	**610,0**	**354,0**	**340,0**	**340,0**	**354,0**	**672,0**	**296,0**	**260,9**	**260,9**	**296,0**	**613,0**
WU heaters													
TTC subsystem heaters													
RCS subsystem heaters													
ACMS subsystem heaters													
Battery heaters													
POWER CONTROL CONTROL S/S		**29,0**	**31,0**	**34,0**	**34,0**	**34,0**	**34,0**	**30,0**	**34,0**	**35,0**	**34,0**	**34,0**	**30,0**
PCDU consumption	10%	29,0	31,0	34,0	34,0	34,0	34,0	30,0	34,0	35,0	34,0	34,0	30,0
MARGINS		**77,7**	**78,2**	**28,8**	**32,3**	**32,0**	**28,8**	**127,2**	**29,6**	**32,4**	**32,0**	**29,6**	**127,2**
ESA Margin		59,9	46,9	0,0	0,0	0,0	0,0	100,0	0,0	0,0	0,0	0,0	100,0
Development margins		17,8	31,3	28,8	32,3	32,0	28,8	27,2	29,6	32,4	32,0	29,6	27,2
SUM ALL USERS		277,3	1711,2	1207,5	1239,4	1230,3	1207,5	1099,3	1158,9	1161,4	1151,2	1158,9	1040,3
S/C Power Demand (W) at PCDU output		282,3	1744,8	1231,0	1263,5	1254,2	1231,0	1120,6	1181,4	1184,0	1173,5	1181,4	1060,5
PCDU loss including PCDU input Harness losses		28,7	82,4	68,8	69,9	69,5	68,8	66,5	67,7	67,6	68,3	67,6	65,3
S/C Power Demand (W) at PCDU input		311,0	1827,2	1299,8	1333,4	1323,7	1299,8	1187,1	1249,1	1251,6	1241,8	1249,0	1125,8
Depth of Discharge		36,1%											
SA Power, 1 failed string			1696,5	1696,5	1696,5	1696,5	1526,9	1696,5	1410,1	1410,1	1410,1	1422,5	1580,5
@ Sun aspect angle			0°	0°	0°	0°	0°	0°	30°	30°	30°	0°	0°
Worst case sun aspect angle			0°	30°	30°	30°	0°	5°	30°	30°	30°	0°	5°
Solar Array, no failed string (W)			1709,2	1480,2	1480,2	1480,2	1538,3	1702,7	1420,6	1420,6	1420,6	1433,1	1586,2
Failed section			-63,3	-54,8	-54,8	-54,8	-57,0	-63,1	-52,6	-52,6	-52,6	-53,1	-58,7
10% EOL loss									-124,4	-124,4	-124,4	-125,5	-138,9
Battery charge (w.c.)			0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
RESOURCES at PCDU input			1630,5	1412,1	1412,1	1412,1	1467,5	1624,3	1232,0	1232,0	1232,0	1242,8	1375,7
Power margin (W)			-196,6	112,3	78,6	88,4	167,7	437,2	-17,1	-19,5	-9,8	-6,2	249,9
Power margin (%)			-12,1%	8,0%	5,6%	6,3%	11,4%	26,9%	-1,4%	-1,6%	-0,8%	-0,5%	18,2%

Table 2-28 HERSCHEL peak power budget

2.6.1.4. RF Links budgets

The link budgets are based on the following selected hardware:

- X-band transponder
- TWTA
- RFDN
- low gain antennas
- medium gain antennas
- representative length of cables.

As required by the SGICD, the following budgets are established:

UPLINK X-band [kbps]	Low Gain Antenna		Medium Gain Antenna	
Kourou 15 m	0.125	4	0.125	4
New Norcia 35 m	4		4	
Villafranca 15 m	4		4	
DOWNLINK X-band [kbps]	**Low Gain Antenna**		**Medium Gain Antenna**	
Kourou 15 m	0.5		5	150
New Norcia 35 m	5		150	1500
Villafranca 15 m	5		5	

All link budgets show comfortable margins on both uplink and downlink, that guarantee that the TC and TM link quality (BER and PFL) are met in all conditions.

All up- and down-link margins are positive.

2.6.1.4.1. HERSCHEL link with Kourou

The link budgets are the following with Kourou ground station:

HERSCHEL		Ground Station	KOUROU						
		Antenna	LGA 1	LGA 1	LGA1	LGA 2	LGA 2	MGA	MGA
		Ranging	No	Yes	Yes	No	Yes	No	Yes
UPLINK		TC bit rate [bps]	125	125	4 000	125	125	4 000	4 000
		distance [km]	1 800 000	1 800 000	350 000	1 800 000	1 800 000	1 800 000	1 800 000
		PSS req. margin							
Carrier Power	nominal		5,29	5,29	6,42	5,25	5,25	10,28	10,28
	mean - 3 s		1,51	1,57	2,94	1,37	1,43	8,93	9,28
	marg-wc.RSS		4,19	4,28	5,40	4,13	4,22	9,17	10,28
Carrier Recovery	nominal	3 dB	11,04	9,20	23,60	10,98	10,00	28,62	27,53
	mean - 3 s	0	6,58	4,38	19,62	6,35	5,51	26,47	25,43
	marg-wc.RSS	0	8,77	6,87	21,67	8,69	7,65	26,67	25,60
TC Recovery	nominal	3 dB	8,42	6,34	7,09	8,35	7,25	12,13	11,03
	mean - 3 s	0	4,79	2,56	3,65	4,56	3,51	10,71	9,67
	marg-wc.RSS	0	6,96	5,07	5,66	6,87	5,80	10,60	9,59
DOWNLINK		TM bit rate [bps]	500	500	5 000	500	500	150 000	150 000
		distance [km]	1 800 000	1 800 000	750 000	1 800 000	1 800 000	1 800 000	1 800 000
		PSS req. margin							
Carrier Recovery	nominal	3 dB	10,00	9,22	16,78	9,87	8,64	23,85	23,66
	mean - 3 s	0	8,16	7,28	14,72	7,90	6,82	20,24	19,81
	marg-wc.RSS	0	8,50	7,55	14,90	8,32	7,01	20,33	19,95
TM Recovery	nominal	3 dB	7,33	6,55	4,12	7,10	5,97	4,20	4,00
	mean - 3 s	0	5,51	4,69	2,20	5,15	4,24	3,23	3,02
	marg-wc.RSS	0	6,26	5,54	3,13	5,96	5,08	3,16	2,99
RNG Recovery	nominal	3 dB	N/A	12,16	27,16	N/A	12,49	N/A	37,65
	mean - 3 s	0	N/A	7,47	21,16	N/A	7,40	N/A	26,42
	marg-wc.RSS	0	N/A	6,04	19,77	N/A	5,89	N/A	27,79

Table 2-29 HERSCHEL link budget with Kourou

All margins are above specification.

2.6.1.4.2. HERSCHEL link with New Norcia

The link budgets are the following with New Norcia ground station:

HERSCHEL		Ground Station	NEW NORCIA						
		Antenna	LGA 1	LGA 1	LGA 2	LGA 2	MGA	MGA	MGA
		Ranging	No	Yes	No	Yes	No	Yes	No
UPLINK		TC bit rate [bps]	4 000	4 000	4 000	4 000	4 000	4 000	4 000
		distance [km]	1 800 000	1 800 000	1 800 000	1 800 000	1 800 000	1 800 000	1 800 000
		PSS req. margin							
Carrier Power	nominal		8,45	8,45	8,30	8,30	24,03	24,03	24,03
	mean - 3 s		4,90	4,90	4,72	4,72	22,05	22,05	22,04
	marg-wc.RSS		7,62	7,62	7,51	7,51	23,20	23,20	23,19
Carrier Recovery	nominal	3 dB	26,72	25,62	26,25	25,16	42,36	41,27	42,36
	mean - 3 s	0	23,17	22,08	22,74	21,64	40,18	39,06	40,17
	marg-wc.RSS	0	25,08	23,96	24,72	23,60	40,70	39,58	40,70
TC Recovery	nominal	3 dB	10,22	9,12	9,76	8,66	25,88	24,78	25,88
	mean - 3 s	0	6,97	5,87	6,54	5,43	24,09	22,97	24,08
	marg-wc.RSS	0	8,95	7,82	8,62	7,48	24,60	23,47	24,59
DOWNLINK		TM bit rate [bps]	5000	5000	5000	5000	150 000	150 000	1 500 000
		distance [km]	1 800 000	1 800 000	1 800 000	1 800 000	1 800 000	1 800 000	1 800 000
		PSS req. margin							
Carrier Recovery	nominal	3 dB	21,12	21,42	22,06	21,28	33,45	32,66	34,27
	mean - 3 s	0	18,95	18,85	20,14	18,72	30,19	28,37	32,94
	marg-wc.RSS	0	19,09	18,79	20,64	18,75	29,93	28,12	33,01
TM Recovery	nominal	3 dB	8,46	8,76	9,39	8,61	13,80	13,01	4,11
	mean - 3 s	0	6,44	6,48	7,49	6,33	12,44	11,44	2,86
	marg-wc.RSS	0	7,50	7,36	8,43	7,35	12,76	11,77	3,13
RNG Recovery	nominal	3 dB	N/A	40,17	N/A	39,68	N/A	56,78	N/A
	mean - 3 s	0	N/A	27,99	N/A	20,56	N/A	41,26	N/A
	marg-wc.RSS	0	N/A	26,81	N/A	27,38	N/A	42,21	N/A

Table 2-30 HERSCHEL link budget with New Norcia

2.6.1.4.3. Herschel link budgets with Villafranca

HERSCHEL		Ground Station	VILLAFRANCA	
		Antenna	LGA 1	LGA 1
		Ranging	RNG	RNG
UPLINK		TC bit rate [bps]	4 000	N/A
		distance [km]	350 000	N/A
		PSS req. margin		
Carrier Power	nominal		6,42	N/A
	mean - 3 s		2,69	N/A
	marg-wc.RSS		5,40	N/A
Carrier Recovery	nominal	3 dB	23,60	N/A
	mean - 3 s	0	19,88	N/A
	marg-wc.RSS	0	21,85	N/A
TC Recovery	nominal	3 dB	7,09	N/A
	mean - 3 s	0	3,65	N/A
	marg-wc.RSS	0	5,66	N/A
DOWNLINK		TM bit rate [bps]	5 000	5 000
		distance [km]	350 000	750 000
		PSS req. margin		
Carrier Recovery	nominal	3 dB	21,03	14,48
	mean - 3 s	0	20,89	14,66
	marg-wc.RSS	0	18,55	12,49
TM Recovery	nominal	3 dB	8,37	1,82
	mean - 3 s	0	8,49	2,16
	marg-wc.RSS	0	7,00	0,01
RNG Recovery	nominal	3 dB	38,21	25,79
	mean - 3 s	0	30,18	21,15
	marg-wc.RSS	0	26,61	17,51

Table 2-31 Herschel link Budget with Villafranca

All margins are above specification.

2.6.1.5. Telemetry and Telecomamnd Budgets

2.6.1.5.1. Herschel TM budget

The following budgets give, for each downlink rate, the allocation per type of TM and per virtual channel. The allocations for SVM housekeeping telemetry is:

- 400 bps of SVM housekeeping telemetry when the downlink rate is 500 bps
- 4 Kbps of SVM housekeeping telemetry when the downlink rate is 5 Kbps
- 9 Kbps of SVM housekeeping telemetry when the downlink rate is 150 Kbps or 1.5 Mbps

For the instruments, the data from the IID-B's have been taken into account. The following tables give the instrument data rates for each of the instrument modes

Herschel	PACS	SPIRE	HIFI	TOTAL
PACS prime	130 Kbps Science + HK	2 Kbps HK	2 Kbps HK	8 Kbps HK 126 Kbps Science
SPIRE prime	2 Kbps HK	6.5 Kbps HK + 119.5 Science	2 Kbps HK	10.5 Kbps HK 119.5 Kbps Science
HIFI prime	2 Kbps HK	2 Kbps HK	2 Kbps HK + 98 Kbps Science	6 Kbps HK 98 Kbps Science
Parallel mode	60 Kbps Science + HK	2 Kbps HK + 50 Kbps Science	2 Kbps HK	8 Kbps HK 106 Kbps Science
SPIRE serendipity	2 Kbps HK	2 Kbps HK + 99.3 Kbps Science	2 Kbps HK	6 Kbps HK 99.3 Kbps Science

For PACS, a "raw" HK data rate of 4 kbps is indicated in the IID-B. This has been considered as PACS HK data rate in prime and parallel mode.

A data rate of 1 kbps has been considered in all case for instruments essential TM, subtracted to the overall instrument HK TM rate, except for 500 bps for which an essential TM rate of 100 bps has been considered for instruments.

The following tables include the following cases:

– 500 bps downlink rates, all modes

– 5 Kbps downlink rates, all modes

– 150 Kpbs downlink rates, with 3 subcases, one for ACMS in SCM, one for ACMS in OCM and on with ACMS in SAM with VMC data downlink.

– 1,5 Mpbs downlink rates, with 3 subcases, one for ACMS in SCM, one for ACMS in OCM and on with ACMS in SCM with DLCM activity

In each budget, a "margin for asynchronous TM" is indicated which is the difference between Essential SVM TM plus Periodic SVM TM, if applicable, and the SVM allocation. This is the only available margin in the budget for 500 bps and 5 Kbps. In 150 Kbps case, another margin appears, which is identified as "Stored science data". Similarly, at 1.5 Mbps, any increase in HK rate due to asynchronous TM or diagnostic packets will impact the stored science data downlink rate.

Kbps	VC0	VC4	VC2	VC1	VC3	VC7	TT&C Config
	Real time ess SC HK Essential instr HK Non periodic HK	Real time routine SC HK Routine instr HK	Stored SC HK	Real time science	Stored science data	Idle frames	
500 bps, all modes							LGA + KRU
0,5	0,5						
CDMS Essential (1 out of 11)	0,074						
ACMS Essential (1 out of 2)	0,16						
Instr essential (1 out of 11)	0,1						
Margin for asynchronous TM	0,166						
5 Kbps, all modes							LGA + KRU
5	5	0	0				LGA + NN
CDMS Essential	0,813						LGA + VILSPA
ACMS Essential	0,32						
Instr essential	1						
Margin for asynchronous TM	2,867						
150 Kbps, ACMS OCM							MGA + KRU
150	3,81						MGA + NN
CDMS Essential	0,813						
CDMS Periodic		1,775					
ACMS Essential	0,32						
ACMS Periodic		4,415					
Instr essential	1						
Margin for asynchronous TM	1,677						
PACS Prime		13,19	133				
Science				126	7		
Instr periodic		7					
SPIRE prime		15,69	130,5				
Science				119,5	11		
Instr periodic		9,5					
SPIRE serendipity		11,19	135				
Science				99,3	35,7		
Instr periodic		5					
HIFI Prime		11,19	135				
Science				98	37		
Instr periodic		5					
PACS + SPIRE		13,19	133				
Science				106	27		
Instr periodic		7					

Kbps	VC0	VC4	VC2	VC1	VC3	VC7	TT&C Config
	Real time ess SC HK Essential instr HK Non periodic HK	Real time routine SC HK Routine instr HK	Stored SC HK	Real time science	Stored science data	Idle frames	
150 Kbps, ACMS Science Mode							MGA + KRU
150	3,972						MGA + NN
CDMS Essential	0,813						
CDMS Periodic		1,775					
ACMS Essential	0,32						
ACMS Periodic		4,253					
Instr essential	1						
Margin for asynchronous TM	1,839						
PACS Prime		13,028	133	126	7		
Science				126	7		
Instr periodic		7					
SPIRE prime		15,528	130,5	119,5	11		
Science				119,5	11		
Instr periodic		9,5					
SPIRE serendipity		11,028	135	99,3	35,7		
Science				99,3	35,7		
Instr periodic		5					
HIFI Prime		11,028	135	98	37		
Science				98	37		
Instr periodic		5					
PACS + SPIRE		13,028	133	106	27		
Science				106	27		
Instr periodic		7					

With VMC, ACMS in SAM							LGA + NN < 100 000 km
150	145,531	4,469	0				
CDMS Essential	0,813						
CDMS Periodic		1,775					
ACMS Essential	0,32						
ACMS Periodic		2,694					
Instr essential	0						
Instr periodic		0					
Margin for asynchronous TM	3,398						
VMC data	141						

Kbps	**VC0**	**VC4**	**VC2**	**VC1**	**VC3**	**VC7**	**TT&C Config**
	Real time ess SC HK Essential instr HK Non periodic HK	Real time routine SC HK Routine instr HK	Stored SC HK	Real time science	Stored science data	Idle frames	
1,5 Mbps, ACMS OCM							MGA+NN
1500	3,81						
CDMS Essential	0,813						
CDMS Periodic		1,775					
ACMS Essential	0,32						
ACMS Periodic		4,415					
Instr essential	1						
Margin for asynchronous TM	1,677						
PACS Prime		13,19	1483	126	1357		
Science				126	1357		
Instr periodic		7					
SPIRE prime		15,69	1480,5	119,5	1361		
Science				119,5	1361		
Instr periodic		9,5					
SPIRE serendipity		11,19	1485	99,3	1385,7		
Science				99,3	1385,7		
Instr periodic		5					
HIFI Prime		11,19	1485	98	1387		
Science				98	1387		
Instr periodic		5					
PACS + SPIRE		13,19	1483	106	1377		
Science				106	1377		
Instr periodic		7					

Kbps	VC0	VC4	VC2	VC1	VC3	VC7	TT&C Config
	Real time ess SC HK Essential instr HK Non periodic HK	Real time routine SC HK Routine instr HK	Stored SC HK	Real time science	Stored science data	Idle frames	
1,5 Mbps, ACMS Science Mode							
1500	3,972						MGA+NN
CDMS Essential	0,813						
CDMS Periodic		1,775					
ACMS Essential	0,32						
ACMS Periodic		4,253					
Instr essential	1						
Margin for asynchronous TM	1,839						
PACS Prime		13,028	1483	126	1357		
Science				126	1357		
Instr periodic		7					
SPIRE prime		15,528	1480,5	119,5	1361		
Science				119,5	1361		
Instr periodic		9,5					
SPIRE serendipity		11,028	1485	99,3	1385,7		
Science				99,3	1385,7		
Instr periodic		5					
HIFI Prime		11,028	1485	98	1387		
Science				98	1387		
Instr periodic		5					
PACS + SPIRE		13,028	1483	106	1377		
Science				106	1377		
Instr periodic		7					

Kbps	**VC0**	**VC4**	**VC2**	**VC1**	**VC3**	**VC7**	**TT&C Config**
	Real time ess SC HK Essential instr HK Non periodic HK	Real time routine SC HK Routine instr HK	Stored SC HK	Real time science	Stored science data	Idle frames	
1,5 Mbps, ACMS Science Mode with DLCM							
1500	6,244						MGA+NN
CDMS Essential	0,813						
CDMS Periodic		1,775					
ACMS Essential	0,32						
ACMS Periodic		4,253					
Instr essential	1						
Margin for asynchronous TM	1,839						
CCU A+B DLCM	2,272						
PACS Prime		13,028	1480,728	126	1354,728		
Science				126	1354,728		
Instr periodic		7					
SPIRE prime		15,528	1478,228	119,5	1358,728		
Science				119,5	1358,728		
Instr periodic		9,5					
SPIRE serendipity		11,028	1482,728	99,3	1383,428		
Science				99,3	1383,428		
Instr periodic		5					
HIFI Prime		11,028	1482,728	98	1384,728		
Science				98	1384,728		
Instr periodic		5					
PACS + SPIRE		13,028	1480,728	106	1374,728		
Science				106	1374,728		
Instr periodic		7					

2.6.1.5.2. CDMU I/O budget

The CDMU CPDU provides 48 External High Priority Commands generated by Command Decoder, RM and PM and 16 HP commands generated by Command Decoder and RM only, i.e. they are not accessible by On-Board Software. Besides these High Priority Commands, the CDMU CPDU provides 16 Extended High Priority Commands, which packets can be generated by Command Decoder / Reconfiguration Module / Processor Module. Extended High Priority (EHP) Commands have the same characteristics of High Priority Commands, with the exception of the extended pulse length (832ms instead of 26ms). The EHP Commands are used to set the RFDN switches.

The CDMU provides 80 High Level Commands, 8 Low Level Commands and 7 Memory Load Commands.

– High Level Commands

  The command signal is a single ended positive voltage pulse, distributed to the user on a dedicated line. The HLC commands delivered by the CDMU to user Subsystems are only of one type and are able to drive 180 mA (relay command type).

– Low Level Commands:

  The Standard Balanced Digital Link (SBDL) is a fully differential interface, with a "true line" and a"complementary line". The status of the signal is defined as high when the true line has a positive voltage "1" level with reference to the ground and the complementary line has a "0" level with reference to the ground. The signal is defined as low when the true line is at "0" and the complementary line is at "1". No Low Level Commands are foreseen

– Memory Loads 16

  The LLC are of Standard Balanced Digital Line type with a pulse duration > 10 ms.

  The purpose of the Memory Load Command (or 16 bits serial load command) link is to transfer a 16 bits dataword in serial form by means of three lines provided to each user:

  - Sample (or address)
  - Clock
  - Data (16 bits serial NRZ-L).

  Only one ML16 Command, issued by CDMS to SREM, is foreseen.

CDMU receives from Spacecraft equipment the following type of monitors:

– Analogue Telemetry (AN)
– Thermistors (TH)
– Cryo-Temperature Sensors (CR)
– Digital Relay Status (DR)
– Digital Bi-Level (BL)
– Standard Balanced Data Link Status Lines (SBDL Status)
– Digital Serial Acquisition (DS16).

The summary CDMU Command and Telemetry allocation is reported in the following Tables.for which 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).

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	Total
CDMS	CDMU	58	4			4							2								BC	6
Power	PCDU		8	16		32				2	1		4				4				2	61
	BAT										4											4
TT&C	XPND1		4			4				5	2		1	1				1	1	1	1	17
	XPND2		4			4				5	2		1	1				1	1	1	1	17
	RFDN				16						4		8									28
	EPC1		8							2	1			3								6
	EPC2		8							2	1			3								6
TCS	Control										144											144
	Monitoring										3											3
ACMS	ACC		12			18				2	5		2	10							2	39
Solar Array	SA											6										6
EGSE	UMB												2				6	2		2		12
CFE	VMC															1						1
	SREM							1								1						2
	CCU																				2	2
HIFI	FHICU																				2	2
PACS	FPDPU																				2	2
	FPDECMEC								2													2
SPIRE	HSDPU																				2	2
PPLM	NCA												2									2
Total		58	44	16	16	58	0	1	2	18	167	6	20	18	0	2	10	4	2	4	14	402
Availability		64	48	16	16	80	8	7	8	48	192	64	80	40	8	7	16	4	2	4		648
Spare		6	4	0	0	22	8	6	6	30	25	58	60	22	8	5	6	0	0	0		
Percentage Spare		9%	8%	0%	0%	28%	100%	86%	75%	63%	13%	91%	75%	55%	100%	71%	38%	0%	0%	0%		

Table 2-32 HERSCHEL CDMU I/O allocation budget

2.6.1.6. Memory budget

Each nominal and redundant mass memory consists of 4 banks of 8 Gbit.

At EOL, with the worst case assumption of one bank failure (i.e. after a double failure), the minimum capacity of each mass memory is 3×8 Gbit = **24 Gbit = 25.77 × 10^9 bit**.

This capacity exceeds the 25×10^9 bit requirement.

The rates from each contributor are:

spacecraft real time HK = **9000 bit/s** (specified in the SVM I/F specification) total instruments average data rate (all instruments + all data) = **130 000 bit/s**. This includes each instrument real time HK = 2000 bit/s, composed of 300 bit/s of « quick look » HK and 1700 bit/s of routine instrument HK.

In addition, the MTL will contain at most 1.5 Mbyte = **0.013 × 10^9 bit**.

An allocation of 200 OBCPs of 64kbyte stored in mass memory = **0.105 × 10^9 bit**.

After 48 hours, the mass memory will contain:

(0.013+0.105) × 10^9 bit + (9000 + 130 000) bit/s × 2 days = **24.137 × 10^9 bit**.

This represents **93.7%** of the worst case capacity of the mass memory.

2.6.1.7. Timing budget

The following budgets are presented:

- timing information delivery, according to the requirement SMCD-225 of the SRS
- timing budget from central time reference to Star Tracker
- time correlation between instruments and ACMS data, according to the requirement SINT-075 of the SRS.

2.6.1.7.1. Timing information delivery

Location	**Contributor**	**Timing Error Contribution**		**Remark**
		Requirement [µs]	**Performance [µs]**	
CDMU	Bus Controller Latency	0 / 20	0 / 2	The CDMU design report states < 2µs
CDMU 1553	Transmission	0	0	negligible
Instrument	Remote Term. Processing	0 / 40	0 / 20	< 20 µs (1 word)
Instrument	User Contribution	0 / 20	0 / 10	Includes contribution up to local time synchro < 10 µs
Margin		0 / 20	NA	
TOTAL		**< 100 µs**	**< 32 µs**	**compliant**

The maximum timing information delivery will be inferior to 32µs, compliant with the 100µs requirement of SMCD-225.

2.6.1.7.2. Timing budget from CTR to Star Tracker

Location	Contributor	Timing Error Contribution		Remark
		Requirement [µs]	Performance [µs]	
CDMU	Bus Controller Latency	0 / 20	0 / 2	The CDMU Design report states < 2µs
CDMU 1553	Transmission	0	0	negligible
ACC	Remote Term. Processing (on CDMU bus)	0 / 20	0 / 21	20µs + few 100ns according to ACC Design Report issue 5
ACC	Bus Controller Latency (on ACC bus)	0 / 20	0 / 2	Same as for the CDMU
ACMS Bus	Transmission	0	0	negligible
Star Tracker	Remote Term. Processing	0 / 40	0 / 20	same as other RTs.
Star Tracker	User Contribution	0 / 100	0 / 40	Telemetry time-tag, H-P-4-GAF-TN-0005 and TN-0006
TOTAL		**0 / 200 µs**	**0 / 85 µs**	**compliant**

Star tracker time correlation with the CTR will be made with a maximum delay of 85µs.

This causes negligible impact on the accuracy of the attitude control and a posteriori reconstruction.

2.6.1.7.3. Time correlation between instruments and ACMS

SINT-075 of the SRS requires a correlation between attitude information (i.e. Star Tracker information) and the instruments date better than 500µs.

The comparison is made at the CDMU level, where instruments delays are counted positively and attitude information are counted negatively.

Location	Contributor	Timing Error Contribution Requirement [µs]	Timing Error Contribution Performance [µs]	Remark
attitude information side				
CDMU => STR	correlation of STR wrt to Central Time Reference	-200 / 0	-85 / 0	
STR => CDMU	error of STR date as seen from the CDMU	0	0	the ACC packet contains attitude information corrected with the STR date.
instrument information side				
CDMU => Instr.	timing delivery	0 / 100	0 / 32	
Instrument	User contribution	0 / 100	0 / 40	same as STR
Instr. => CDMU	error of instrument date as seen from the CDMU	0	0	the instrument packet contains the date information.
Margin				
Margin		-300 / 300	NA	
TOTAL		**-500 / 500 µs**	**-85 / 72 µs**	**compliant**

The timing correlation of the instruments and the Star Tracker, as seen from the CDMU, will be better than 85µs, i.e. in line with the required 500µs.

2.6.1.8. Propellant budget

The propellant and ΔV budget is summarized in the following Table:

The delta-V have been updated in accordance with Crema 3.1 amended by document 0705530-hp-lawi-wp508.pdf

The total hydrazine needed for the mission is 202 kg. However it is foreseen to fill up the tanks completely which will amount to approximately 256 kg.

	Delta-v [m/s]	Manoeuvre Efficiency	Isp × g [m/s]	Mass Margin	Helium Loss [kg]	S/C Mass before Dv [kg]	Hydrazine consump. [kg]	S/C Mass after Dv [kg]
								3377,183
Compensation for perigee velocity variation	42	90%	2206	0%	0	3377,183	70,689	3306,494
Removal of launcher dispersion	45	92%	2191	5%	1,4	3305,094	76,516	3228,578
Manoeuvre on day 12 from perigee	3	90%	2185	5%	7,6	3220,978	5,156	3215,823
Mid-course correction	2	90%	2184	5%	0	3215,823	3,434	3212,389
Orbit maintenance for mission lifetime	13,5	97%	2182	39%	145	3067,389	27,040	3040,349
Attitude Control	7,8	98%	2000	39%	0	3040,349	16,759	**3023,590**

	Helium	Hydrazine
Consumption from launch to last Delta-v [kg]	154,000	199,593
Residual mass in tanks after last Delta-v [kg]	***182,000***	1,734
Residual mass in feed lines after last Delta-v [kg]	0,000	1,193
Total mass at launch [kg]	336,000	202,520

	Dry	Helium	Nitrogen	Hydrazine	TOTAL
Satellite Mass after last Dv =	2834,836	182,000	3,827	2,927	3023,590

Table 2-33 HERSCHEL propellant and DV budget

2.6.1.9. Pointing budget

Herschel is compliant with all pointing requirements except SRPE. This non compliance is cover by DS RFD-10, which is accepted by ESA under conditions (dense star areas, gyro-based control implemented.

error	LOS [Arcsec]				Around LOS [Arcmin]			
	performance	*requirement*	compliance	margin percentage	**performance**	*requirement*	compliance	margin percentage
APE Pointing goal	**2,05** **1,16**	*3,70* *1,50*	C C	45% 23%	**0,52** **0,48**	*3,00* *3,00*	C C	83% 84%
APE Scanning	**2,55** **+ 0,0001** w	*3,70* + 0,05ω	C	31%	**na**	*na*	na	
goal	**1,59** **+ 0,0002** w	*1,50* + 0,03ω	C					
PDE 24 hours	**0,47**	*1,20*	C	61%	**0,03**	*3,00*	C	99%
RPE 1 min Pointing	**0,24**	*0,30*	C	20%	**0,03**	*1,50*	C	98%
RPE 1 min Scanning goal	**0,96** **0,62**	*1,20* *0,80*	C C	20% 23%	**0,11** **0,10**	*1,50* *1,50*	C C	93% 94%
AME Pointing goal	**1,99** **1,12**	*3,10* *1,20*	C C	36% 7%	**0,43** **0,38**	*3,00* *3,00*	C C	86% 87%
AME Scanning	**2,53** **+ 0,0001** w	*3,10* *+ 0,02* w	C	18%	**0,51**	*3,00*	C	83%
goal	**1,58** **+ 0,0001** w	*1,20* *+ 0,02* w	C		**0,49**	*3,00*	C	84%
AME Slew Goal	**2,61** **1,71**	*10,00* *5,00*	C C	74% 66%	**0,51** **0,50**	*3,00* *3,00*	C C	83% 83%
SRPE (goal)	**1,97** **1,32**	*1,00* *1,00*	NC	-97% -32%				
SRPE with GYR-based control (goal)	**1,12** **1,05**	*1,00* *1,00*	NC	-12%				
APE with GYR-based control	**2,69**	*3,70*	C	27%				
AME with GYR-based control	**2,68**	*3,10*	C	13%				

Table 2-34 HERSCHEL pointing budget

The following generic conditions are requested to meet all goals:

- Perform a system calibration using STR interlacing mode and required instrument conditions before the observation,
- Use 9 calibration points for system calibration,
- Use STR interlacing mode during observation. Availability of 18 stars in STR FOV is the associated pointing conditions,
- Observe with sun aspect angle between –10° and + 20° (it leads to reduction of SVM and HPLM structure stability ; the range is the concatenation of SVM and HPLM conditions about SAA).

With these conditions only, the following goals are met:

- APE pointing,
- RPE scanning,
- AME slewing.
- SRPE and SRPE with GYR-based control.

In addition, some specific conditions are needed to meet other goals:

- APE Scanning: scan rate above 4 arcsec/s
- AME Scanning: Scan rate above 19 arcsec/s

2.6.1.10. Alignment budget

2.6.1.10.1. H-PLM Line of Sight and ACMS LOS co-alignment budget

In order to allow a correct in-orbit calibration of the instruments, the instruments LOS and STR LOS shall not be too much misaligned. This value is considered in the upper level ACMS budget.

CONTRIBUTOR		CONTRIBUTION 2s	STATUS
SVM	Stability	< 0.008arcmin	SVM design report
	bias	10 arcmin	
H-PLM	CVV	1.7 arcmin	H-PLM CDR budgets
	Tel	0.4 arcmin	Telescope budget
Total (RSS)		10.2 arcmin	fulfils ACMS needs
AOCS need		18arcmin	

Table 2-35 Herschel PLM LOS and ACMS LOS co-alignment budget

2.6.1.10.2. Around Line of Sight alignment knowledge budget

As the around-LOS will not be calibrated, the knowledge on ground will be necessary.

	CONTRIBUTION 2s	STATUS
HPLM bias	0.6 arcmin	H-PLM CDR budgets
Mating	0.06 arcmin	State of the art
Total	0.66 arcmin	Compliant
AOCS need	1 arcmin	

Table 2-36 Herschel around LOS alignment knowledge budget

This is compliant to the AOCS need, with margins.

2.6.1.10.3. Thruster plume alignment budget

In order to have a proper spacecraft attitude control, the thrusters shall be well aligned with regards to the satellite CoG.

	CONTRIBUTION TO ALIGNMENT ACCURACY	**STATUS**
Thruster-plume stability	±2arcmin	Measured on S/C STM
System level thruster-plume alignment accuracy	±2arcmin	Measured on SVM STM
S/C CoG on-ground knowledge accuracy	±12arcmin	+/-5mm COG localization required to AIT as per H-P-2-ASP-TS-0720 issue 2/0
Total (RSS)	±12.5arcmin	Compliant
Alignement need	±30arcmin	

Table 2-37 Herschel thruster plume alignment budget

2.6.1.11. Helium lifetime budget

Three lifetime conditions are presented:

- best knowledge FPU dissipations (as mentioned in HIFI, PACS and SPIRE IID-Bs), with a 15% margin of Helium, with error bar (lower side),
- best knowledge FPU dissipations (as mentioned in HIFI, PACS and SPIRE IID-Bs), with a 15% margin of Helium, without error bar,
- best knowledge FPU dissipations (as mentioned in HIFI, PACS and SPIRE IID-Bs), without a 15% margin of Helium without error bar.

Astrium have evaluated the Helium lifetime for these three cases, from which the following contributors must be subtracted (part of the ESA margin):

- -16 days due to SPIRE over-shielding,
- -7 days due to change of LOU radiator impacting the CVV radiative efficiency,
- -14 days due to Star Tracker Assembly mounting on the CVV.
- the contribution of the external LOU baffle and the SMEC launch lock additional device are not computed yet.

the current total amounts to –37 days (0.10 year).

CASE		Instrument knowledge (lower error bar)	Instrument knowledge (nominal)	Realistic
Conditions	**FPU dissipation**	IID-B	IID-B	IID-B
	ESA Helium reserve	15% – 0.10 year	15% – 0.10 year	0% – 0.10 year
Contractual total		**3.73 years**	4.07 years	~ 4.7 years
Requirement		**3.5 years**	N/A	N/A
Compliance status		**C**	N/A	N/A
Expected lifetime		3.63 years	3.97 years	~ 4.6 years

In "contractual" conditions, compliance can be stated.

The realistic case exhibits a much more favourable margin (about one year), more or less in line with the extended lifetime duration of 4.5 years.

2.6.2. PLANCK budgets

2.6.2.1. Mass

PLANCK spacecraft mass budget is shown hereafter in Table 2-38.

- maximum mass: 1973 kg
- nominal mass: 1920.5 kg
- mass margin: 2.7%.

This mass budget considers a fuel loading of 384 kg (128 kg in each tank) which corresponds to the maximum fuel loading.

	Responsibility	Nominal Mass [kg]	Mass Margin [kg]	Maximum Mass [kg]	Allocated Maximum Mass [kg]	Mass Perfo - Reqt [kg]
PLANCK (Dry) PLANCK (Wet)		1525,2 1920,5	52,8 52,8	1577,9 1973,2		
Dry Service Module	Alenia	736,4	30,4	766,8	680,0	+86,8
Dry Payload Module - CFE Hydrazine Nitrogen Balancing masses	Alcatel	253,0 384,0 3,6 65,0	7,6 0,0 0,0 0,0	260,6 384,0 3,6 65,0	268,0	-7,4
Reflectors FOG SREM	ESA	43,4 5,9 2,6	0,0 0,0 0,0	43,4 5,9 2,6	45,1 6,0 2,7	-1,7 -0,1 -0,1
Dry HFI Helium	HFI	215,4 7,7	0,4 0,0	215,9 7,7	244,0	-20,4
LFI w/o SCC Sorption Cooler	LFI	90,0 113,5	0,0 0,2	104,0 113,7	104,0 132,0	0 -18,3

Table 2-38 PLANCK mass budget

2.6.2.2. Centre of mass and inertia

The following centring and inertia budget has been computed with a dry mass of 1560 kg. This budget will be updated later on with the latest weighed masses, especially in order to refine the prediction of the quantity of balancing masses.

The balancing optimises the cross-products (Pxy, Pzx) at the middle of mission (average between Beginning of Mission and End of Life), while keeping the centre of mass within the Ariane requirement of 30mm.

Because the cross product P_{ZX} was too negative (–55 kg·m²), it was not possible to balance Planck cross-products and keeping the centre of mass within Ariane requirements, using solely the patterns on the SVM. Therefore, two masses of 10 kg each mounted on the corners +Z+Y and +Z–Y of the telescope frame are considered (handling points exist at these locations, with suitable fixation means).

In addition to these masses on the telescope frame (20 kg in total), the balancing masses used on Planck are located on four panels at the bottom of the SVM:

- panel –Y (TT&C): 3.84kg on–Z side,
- panel –Y–Z (SCC): 8.5kg on –Y side, 8.5kg on –Z side,
- panel –Z (SCE): 8.5kg on –Y side, 8.5kg on –Z side,
- panel +Y–Z (SCE): 5.77 kg on –Z side
- **TOTAL: 20+43.61 = 63.61 kg**

An allocation of 65 kg for balancing masses is taken into account in the budget.

The sensitivity of the balancing to Planck mass properties (cross products P_{XY}, P_{ZX} and centre of mass in YZ) plane is high, and there is still an uncertainty on the distribution of the balancing masses.

Sign convention:

- The three inertia cross products are given with the standard sign convention: P_{XY} = + • x y dm P_{YZ} = + • y z dm P_{ZX} = + • z x dm

When noted algebraically, the sign of the cross products must be changed in the inertia matrix.

2.6.2.2.1. Beginning of life

Conditions:

- Hydrazine: launch conditions.
- Helium: launch conditions.
- corresponding total mass = 1949 kg

Centre of Mass [mm]			Inertia at CoM [kg·m²]					
X	Y	Z	Ixx	Iyy	Izz	Pxy	Pyz	Pzx
812,8	**1,3**	**-23,7**	**3069,9**	**2551,8**	**2637,5**	**0,18**	**-24,88**	**-3,34**
R =	23,7 mm							
I =	1,1822		**I max**	3069,9	***around***	0,999970	0,000017	0,007724
wobble Y =	-26,55'		**I med**	2644,2	***around***	-0,007463	0,260093	0,965555
wobble Z =	0,06'		**I min**	2545,1	***around***	0,001992	0,965583	-0,260086
wobble =	26,55'							

Table 2-39 Centre of mass and inertia at BOL

Planck wet centre of mass is compliant with Ariane 5 (23.7 mm < 30 mm required).
Planck wet wobble angle is compliant with Ariane 5 (26.6 arcmin < 1° required).

The λ value 1.1822 is compliant with the ACMS needs: $^{8}/_{7} < \lambda < ^{5}/_{4}$.

2.6.2.2.2. Beginning of mission

Conditions:

- Hydrazine: 3×50 kg (corresponding to the average scenario at the end of the main injection, and as well to the minimum factor λ).
- Helium: initial load (low sensitivity to this parameter)
- corresponding total mass = 1716 kg

Centre of Mass [mm]			Inertia at CoM [kg·m²]					
X	Y	Z	Ixx	Iyy	Izz	Pxy	Pyz	Pzx
859,4	**1,5**	**-26,8**	**2917,0**	**2444,0**	**2529,8**	**0,07**	**-24,54**	**-1,22**
R =	26,8 mm							
I =	1,1718		**I max**	2917,0	***around***	0,999995	0,000024	0,003164
wobble Y =	-10,88'		**I med**	2536,3	***around***	-0,003064	0,256983	0,966411
wobble Z =	0,08'		**I min**	2437,5	***around***	0,000790	0,966416	-0,256981
wobble =	10,88'							

Table 2-40 Centre of mass and inertia at BOM

The wobble angles are due to the non centred CoG, causing an asymmetrical depletion of the tank with respect to this CoG. The wobble angles remain however compatible with the pointing allocations, showing that there is no need to balance the CoG.

The λ value 1.1718 is compliant with the ACMS needs: $^{8}/_{7} < \lambda < ^{5}/_{4}$.

2.6.2.2.3. End of life

Conditions:

- Hydrazine: empty.
- Helium: empty.
- nominal dry mass conditions
- total mass = 1560 kg

Centre of Mass [mm]			Inertia at CoM [kg·m²]					
X	**Y**	**Z**	**Ixx**	**Iyy**	**Izz**	**Pxy**	**Pyz**	**Pzx**
916,3	**1,6**	**-29,1**	**2807,0**	**2330,9**	**2416,0**	**-0,06**	**-23,23**	**1,22**
R =	29,1 mm							
l =	1,1816		**I max**	2807,0	***around***	0,999995	-0,000021	-0,003124
wobble Y =	10,74'		**I med**	2421,9	***around***	0,003032	0,247205	0,968959
wobble Z =	-0,07'		**I min**	2324,9	***around***	-0,000752	0,968963	-0,247203
wobble =	10,74'							

Table 2-41 Centre of mass and inertia at EOL

The wobble angles are due to the non centred CoG, causing an asymmetrical depletion of the tank with respect to this CoG. The wobble angles remain however compatible with the pointing allocations, showing that there is no need to balance the CoG. They are the opposite of the wobble angles at Beginning of Mission, since Planck is balanced to be optimised at the middle point between the Beginning of Mission and the End of Life.

The λ value 1.1816 is compliant with the ACMS needs: $^{8}/_{7} < \lambda < ^{5}/_{4}$.

2.6.2.3. Power consumption and available energy

2.6.2.3.1. Summary on PLANCK launch energy budget

The Table hereafter presents the PLANCK spacecraft energy budget during launch. It takes into account the BDR efficiency of 92.5%. The results show a maximum DoD of 42%, fully within the battery capacity (more than 90%).

	SVM Margin	Launch
INSTRUMENTS		**53,0**
LFI		
Sorption Cooler		
HFI		53,0
EXTRA PAYLOAD		**0,0**
SREM		
FOG		
REFLECTORS/FPU DECONTAMINATION		**0,0**
Primary Reflector Decontamination Heaters		
Secondary Reflector Decontamination Heaters		
Focal Plane Unit Decontamination Heaters		
TT&C		**16,8**
Receiver		16,8
Transmitter		0,0
TWTA		0,0
CDMS		**36,0**
CDMU		36,0
ATTITUDE CONTROL S/S		**55,0**
ACC		31,3
Star Tracker		
CRS		23,7
PROPULSION S/S		**17,0**
1-N Cat Bed Heaters		0,0
20-N Cat Bed Heaters		17,0
1-N Firings		
20-N Firings		
Latch Valves		
Pressure Transducer (accounted for in ACC)		0,0
THERMAL CONTROL S/S		
WU heaters		
TTC subsystem heaters		
RCS subsystem heaters		25,0
ACMS subsystem heaters		
Battery heaters		
CRS Heaters		57,6
POWER CONTROL S/S		**28,0**
PCDU consumption		28,0
MARGINS		**61,7**
ESA Margin		61,7
Development margins		0,0
SUM ALL USERS		**350,1**
S/C Power Demand (W) at PCDU output		**330,3**
PCDU loss including PCDU input Harness losses		31,9
S/C Power Demand (W) at PCDU input		**362,2**
Depth of Discharge		**42,0%**

Table 2-42 PLANCK energy budget during launch

2.6.2.3.2. Summary of PLANCK budget @ BOL

In all cases there is a significant power margin even after considering the ESA margin, “development” margins, Solar array losses and failures.

	Pre-op BOL	Science BOL	OCM DTCP BOL	Telecom BOL	Moon transit BOL	Survival BOL
INSTRUMENTS	**0,0**	**684,3**	**684,3**	**684,3**	**684,3**	**0,0**
LFI		70,3	70,3	70,3	70,3	
Sorption Cooler		386,0	386,0	386,0	386,0	
HFI		228,0	228,0	228,0	228,0	
EXTRA PAYLOAD	**22,6**	**22,6**	**22,6**	**22,6**	**0,0**	**0,0**
SREM	2,6	2,6	2,6	2,6		
FOG	20,0	20,0	20,0	20,0		
REFLECTORS/FPU DECONTAMINATION	**189,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
Primary Reflector Decontamination Heaters	67,0					
Secondary Reflector Decontamination Heaters	47,0					
Focal Plane Unit Decontamination Heaters	75,0					
TT&C	**106,3**	**29,5**	**106,3**	**106,3**	**29,5**	**106,3**
Receiver	16,8	16,8	16,8	16,8	16,8	16,8
Transmitter	14,7	12,7	14,7	14,7	12,7	14,7
TWTA	74,8		74,8	74,8		74,8
CDMS	**36,0**	**36,0**	**36,0**	**36,0**	**36,0**	**36,0**
CDMU	36,0	36,0	36,0	36,0	36,0	36,0
ATTITUDE CONTROL S/S	**67,0**	**67,0**	**67,0**	**67,0**	**67,0**	**67,0**
ACC	31,3	31,3	31,3	31,3	31,3	31,3
Star Tracker	12,0	12,0	12,0	12,0	12,0	12,0
CRS	23,7	23,7	23,7	23,7	23,7	23,7
PROPULSION S/S	**21,6**	**21,6**	**44,0**	**21,6**	**21,6**	**34,1**
1-N Cat Bed Heaters	4,6	4,6	4,6	4,6	4,6	0,0
20-N Cat Bed Heaters	17,0	17,0	34,1	17,0	17,0	34,1
1-N Firings		0,0		0,0	0,0	
20-N Firings			5,3			
Latch Valves						
Pressure Transducer (accounted for in ACC)	0,0	0,0	0,0	0,0	0,0	0,0
THERMAL CONTROL S/S	738,0	287,0	262,0	262,0	297,0	738,0
WU heaters						
TTC subsystem heaters						
RCS subsystem heaters						
ACMS subsystem heaters						
Battery heaters						
CRS Heaters	53,9	57,6	57,6	44,5	57,6	53,9
POWER CONTROL S/S	**31,0**	**35,0**	**35,0**	**35,0**	**35,0**	**30,0**
PCDU consumption	31,0	35,0	35,0	35,0	35,0	30,0
MARGINS	**80,0**	**22,4**	**22,4**	**35,5**	**0,0**	**46,1**
ESA Margin	80,0	22,4	22,4	35,5	0,0	46,1
Development margins	0,0	0,0	0,0	0,0	0,0	0,0
SUM ALL USERS	1291,5	1205,4	1279,6	1270,3	1170,4	1057,5
S/C Power Demand (W) at PCDU output	1318,6	1230,6	1306,3	1296,9	1194,8	1079,6
PCDU loss including PCDU input Harness losses	72,2	69,3	72,0	72,0	67,0	63,3
S/C Power Demand (W) at PCDU input	1390,8	1299,9	1378,3	1368,9	1261,8	1142,9
Depth of Discharge						
SA Power, 1 failed string	1898,1	1898,1	1898,1	1898,1	1695,1	1898,1
@ Sun aspect angle	10°	10°	10°	10°	10°	10°
Worst case sun aspect angle	10°	10°	5°	10°	0°	5°
Solar Array, no failed string (W)	1913,0	1913,0	1935,1	1913,0	1734,7	1935,1
Failed section	-74,1	-74,1	-75,0	-74,1	-67,2	-75,0
10% EOL loss						
Battery charge (w.c.)	-12,4	-12,4	-12,4	-12,4	-11,0	-12,4
RESOURCES @ PCDU input	1826,5	1826,5	1847,7	1826,5	1656,4	1847,7
Power margin (W)	435,6	526,6	469,4	457,6	394,6	704,8
Power margin (%)	23,9%	28,8%	25,4%	25,1%	23,8%	38,1%

Table 2-43 PLANCK power budget @ BOL

2.6.2.3.3. Summary of PLANCK budget @ EOL

The Table hereafter presents the PLANCK spacecraft average power budget during the EOL phases. The worst cases is Moon Transit at EOL which exhibits over 240W surplus.

	Science EOL	OCM DTCP EOL	Telecom EOL	Moon transit EOL	Survival EOL
INSTRUMENTS	870,3	870,3	870,3	870,3	0,0
LFI	70,3	70,3	70,3	70,3	
Sorption Cooler	572,0	572,0	572,0	572,0	
HFI	228,0	228,0	228,0	228,0	
EXTRA PAYLOAD	29,4	29,4	29,4	0,0	0,0
SREM	2,6	2,6	2,6		
FOG	26,8	26,8	26,8		
REFLECTORS/FPU DECONTAMINATION	0,0	0,0	0,0	0,0	0,0
Primary Reflector Decontamination Heaters					
Secondary Reflector Decontamination Heaters					
Focal Plane Unit Decontamination Heaters					
TT&C	29,5	106,3	106,3	29,5	106,3
Receiver	16,8	16,8	16,8	16,8	16,8
Transmitter	12,7	14,7	14,7	12,7	14,7
TWTA		74,8	74,8		74,8
CDMS	36,0	36,0	36,0	36,0	36,0
CDMU	36,0	36,0	36,0	36,0	36,0
ATTITUDE CONTROL S/S	67,0	67,0	67,0	67,0	67,0
ACC	31,3	31,3	31,3	31,3	31,3
Star Tracker	12,0	12,0	12,0	12,0	12,0
CRS	23,7	23,7	23,7	23,7	23,7
PROPULSION S/S	21,6	44,0	21,6	21,6	34,1
1-N Cat Bed Heaters	4,6	4,6	4,6	4,6	0,0
20-N Cat Bed Heaters	17,0	34,1	17,0	17,0	34,1
1-N Firings	0,0		0,0	0,0	
20-N Firings		5,3			
Latch Valves					
Pressure Transducer (accounted for in ACC)	0,0	0,0	0,0	0,0	0,0
THERMAL CONTROL S/S	62,0	48,7	48,7	72,0	710,0
WU heaters					
TTC subsystem heaters					
RCS subsystem heaters					
ACMS subsystem heaters					
Battery heaters					
CRS Heaters	51,8	51,8	38,8	51,8	58,1
POWER CONTROL S/S	35,0	35,0	35,0	34,0	30,0
PCDU consumption	35,0	35,0	35,0	34,0	30,0
MARGINS	21,4	21,4	34,4	0,0	49,9
ESA Margin	21,4	21,4	34,4	0,0	49,9
Development margins	0,0	0,0	0,0	0,0	0,0
SUM ALL USERS	1172,2	1258,1	1248,7	1130,4	1033,3
S/C Power Demand (W) at PCDU output	1196,6	1284,4	1274,8	1154,0	1054,9
PCDU loss including PCDU input Harness losses	71,3	75,1	73,7	69,8	63,7
S/C Power Demand (W) at PCDU input	1267,9	1359,5	1348,5	1223,8	1118,6
Depth of Discharge					
SA Power, 1 failed string	1835,2	1835,2	1835,2	1651,6	1835,2
@ Sun aspect angle	10°	10°	10°	10°	10°
Worst case sun aspect angle	10°	5°	10°	0°	10°
Solar Array, no failed string (W)	1849,5	1870,9	1849,5	1690,2	1849,5
Failed section	-71,7	-72,5	-71,7	-65,5	-71,7
10% EOL loss	-161,6	-163,5	-161,6	-147,7	-161,6
Battery charge (w.c.)	-11,9	-11,9	-11,9	-10,8	-11,9
RESOURCES @ PCDU input	1604,2	1622,9	1604,2	1466,3	1604,2
Power margin (W)	336,3	263,5	255,8	242,5	485,7
Power margin (%)	21,0%	16,2%	15,9%	16,5%	30,3%

Table 2-44 PLANCK power budget @ EOL

2.6.2.3.4. PLANCK peak power budget

Following TV/TB test, the Planck peak budget has been updated. The peak power dissipation derived from thermal analyses has been kept and the unit consumption has been updated. All peak power budgets show positive margins. The minimum is for Moon Transit EOL for which 7W margin is available on top of all required margins.

No problem can be envisaged for the Planck power budget even considering a worst case peak. It is very unlikely that the battery will ever be in discharge mode for a time exceeding 10 seconds and with a very limited amplitude. In all cases there is no risk that the battery cannot be maintained in a fully charged state.

	SVM Margin	Launch	Pre-op BOL	Science BOL	OCM DTCP BOL	Telecom BOL	Moon transit BOL	Survival BOL	Science EOL	OCM DTCP EOL	Telecom EOL	Moon transit EOL	Survival EOL
INSTRUMENTS		53,0	0,0	684,3	684,3	684,3	684,3	0,0	870,3	870,3	870,3	870,3	0,0
LFI				70,3	70,3	70,3	70,3		70,3	70,3	70,3	70,3	
Sorption Cooler				386,0	386,0	386,0	386,0		572,0	572,0	572,0	572,0	
HFI		53,0		228,0	228,0	228,0	228,0		228,0	228,0	228,0	228,0	
EXTRA PAYLOAD		0,0	22,6	22,6	22,6	22,6	0,0	0,0	29,4	29,4	29,4	0,0	0,0
SREM			2,6	2,6	2,6	2,6			2,6	2,6	2,6		
FOG			20,0	20,0	20,0	20,0			26,8	26,8	26,8		
REFLECTORS/FPU DECONTAMINATION		0,0	189,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Primary Reflector Decontamination Heaters			67,0										
Secondary Reflector Decontamination Heaters			47,0										
Focal Plane Unit Decontamination Heaters			75,0										
TT&C		16,8	106,3	29,5	106,3	106,3	29,5	106,3	29,5	106,3	106,3	29,5	106,3
Receiver		16,8	16,8	16,8	16,8	16,8	16,8	16,8	16,8	16,8	16,8	16,8	16,8
Transmitter		0,0	14,7	12,7	14,7	14,7	12,7	14,7	12,7	14,7	14,7	12,7	14,7
TWTA		0,0	74,8		74,8	74,8		74,8		74,8	74,8		74,8
CDMS		36,0	36,0	36,0	36,0	36,0	36,0	36,0	36,0	36,0	36,0	36,0	36,0
CDMU		36,0	36,0	36,0	36,0	36,0	36,0	36,0	36,0	36,0	36,0	36,0	36,0
ATTITUDE CONTROL S/S		55,0	67,0	67,0	67,0	67,0	67,0	67,0	67,0	67,0	67,0	67,0	67,0
ACC		31,3	31,3	31,3	31,3	31,3	31,3	31,3	31,3	31,3	31,3	31,3	31,3
Star Tracker			12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0
CRS		23,7	23,7	23,7	23,7	23,7	23,7	23,7	23,7	23,7	23,7	23,7	23,7
PROPULSION S/S		17,0	21,6	21,6	44,0	21,6	21,6	34,1	21,6	44,0	21,6	21,6	34,1
1-N Cat Bed Heaters		0,0	4,6	4,6	4,6	4,6	4,6	0,0	4,6	4,6	4,6	4,6	0,0
20-N Cat Bed Heaters		17,0	17,0	17,0	34,1	17,0	17,0	34,1	17,0	34,1	17,0	17,0	34,1
1-N Firings				0,0		0,0	0,0		0,0		0,0	0,0	
20-N Firings					6,3					5,3			
Latch Valves													
Pressure Transducer (accounted for in ACC)		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
THERMAL CONTROL S/S			1095,0	449,0	440,0	440,0	459,0	1095,0	303,0	290,0	290,0	313,0	1083,0
WU heaters													
TTC subsystem heaters													
RCS subsystem heaters		25,0											
ACMS subsystem heaters													
Battery heaters													
CRS Heaters		57,6	53,9	57,6	57,6	44,5	57,6	53,9	51,8	51,8	38,8	51,8	50,1
				5,0		222,0		991,0	111,0		32,6		975,0
POWER CONTROL S/S		28,0	31,0	35,0	35,0	35,0	35,0	30,0	35,0	35,0	35,0	34,0	30,0
PCDU consumption		28,0	31,0	35,0	35,0	35,0	35,0	30,0	35,0	35,0	35,0	34,0	30,0
MARGINS		61,7	80,0	22,4	22,4	35,5	0,0	46,1	21,4	21,4	34,4	0,0	49,9
ESA Margin		61,7	80,0	22,4	22,4	35,5	0,0	46,1	21,4	21,4	34,4	0,0	49,9
Development margins		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
SUM ALL USERS		350,1	1648,5	1367,4	1457,6	1448,3	1332,4	1414,5	1413,2	1499,4	1490,0	1371,4	1406,3
S/C Power Demand (W) at PCDU output		330,3	1683,3	1396,0	1488,1	1478,7	1360,3	1444,2	1442,8	1530,8	1521,3	1400,2	1435,9
PCDU loss including PCDU input Harness losses		31,9	72,2	69,3	72,0	72,0	67,0	63,3	71,3	75,1	73,7	69,8	63,7
S/C Power Demand (W) at PCDU input		362,2	1755,5	1465,3	1560,1	1550,7	1427,3	1507,5	1514,1	1605,9	1595,0	1470,0	1499,6
Depth of Discharge		42,0%											
SA Power, 1 failed string			1898,1	1898,1	1898,1	1898,1	1695,1	1898,1	1835,2	1835,2	1835,2	1651,6	1835,2
@ Sun aspect angle			10°	10°	10°	10°	10°	10°	10°	10°	10°	10°	10°
Worst case sun aspect angle			10°	10°	5°	10°	0°	5°	10°	5°	10°	0°	10°
Solar Array, no failed string (W)			1913,0	1913,0	1935,1	1913,0	1734,7	1935,1	1849,5	1870,9	1849,5	1690,2	1849,5
Failed section			-74,1	-74,1	-75,0	-74,1	-67,2	-75,0	-71,7	-72,5	-71,7	-65,5	-71,7
10% EOL loss									-161,6	-163,5	-161,6	-147,7	-161,6
Battery charge N/A for Peaks Analysis			0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
RESOURCES @ PCDU input			1838,8	1838,8	1860,1	1838,8	1667,4	1860,1	1616,2	1634,9	1616,2	1477,0	1616,2
Power margin (W)			83,3	373,5	299,9	288,1	240,1	352,5	102,1	28,9	21,2	7,1	116,6
Power margin (%)			4,5%	20,3%	16,1%	15,7%	14,4%	19,0%	6,3%	1,8%	1,3%	0,5%	7,2%

Table 2-45 PLANCK peak power

2.6.2.4. RF link

The link budgets are based on the same assumptions as for Herschel. See section 2.6.1.4.
All up- and down-link margins are positive, except in with Kourou on LGAs 2 and 3, which is demonstrated not to be critical.

2.6.2.4.1. PLANCK link with Kourou

PLANCK		Ground Station	KOUROU						
		Antenna	LGA 1	LGA 1	LGA1	LGA 2+3	LGA 2+3	MGA	MGA
		Ranging	No	Yes	Yes	No	No	No	Yes
UPLINK		TC bit rate [bps]	125	125	4 000	125	125	4 000	4 000
		distance km]	1 600 000	1 600 000	350 000	1 600 000	1 600 000	1 600 000	1 600 000
		PSS req. margin							
Carrier Power	nominal		6,34	6,34	19,45	3,01	2,96	11,21	11,21
	mean - 3 s		2,52	2,58	15,68	-1,72	-1,70	9,93	10,02
	marg-wc.RSS		5,22	5,31	18,41	1,70	1,73	10,12	10,21
Carrier Recovery	nominal	3 dB	12,01	11,01	23,64	7,92	6,97	29,49	28,39
	mean - 3 s	0	7,59	7,16	19,88	1,93	0,89	27,68	26,64
	marg-wc.RSS	0	9,79	9,19	21,87	5,28	4,22	27,73	26,67
TC Recovery	nominal	3 dB	9,48	8,39	6,44	4,83	3,69	13,00	11,90
	mean - 3 s	0	5,81	4,76	2,81	0,08	-0,99	11,71	10,66
	marg-wc.RSS	0	8,00	6,94	4,99	3,30	2,21	11,58	10,52
DOWNLINK		TM bit rate [bps]	500	500	5 000	500	500	150 000	150 000
		distance km]	1 600 000	1 600 000	750 000	1 600 000	1 600 000	1 600 000	1 600 000
		PSS req. margin							
Carrier Recovery	nominal	3 dB	11,12	10,33	16,88	7,58	6,79	24,81	24,03
	mean - 3 s	0	9,23	8,33	14,71	4,39	3,53	21,29	19,60
	marg-wc.RSS	0	9,61	8,61	14,88	5,70	4,80	21,32	19,76
TM Recovery	nominal	3 dB	8,45	7,67	4,22	4,91	4,13	5,16	4,37
	mean - 3 s	0	6,58	5,75	2,21	1,73	0,92	4,29	3,37
	marg-wc.RSS	0	7,37	6,66	3,19	3,35	2,60	4,20	3,33
RNG Recovery	nominal	3 dB	N/A	15,31	28,24	N/A	7,11	N/A	44,61
	mean - 3 s	0	N/A	9,89	21,15	N/A	0,59	N/A	33,00
	marg-wc.RSS	0	N/A	8,56	19,86	N/A	0,17	N/A	34,35

Table 2-46 PLANCK link budget with Kourou

All margins are above specification, except with the LGA2 and 3 on the operational orbit, this case exhibiting slightly non compliant margins due to the presence of the 3 dB hybrid (two redundant LGAs operate simultaneously).

This case is not critical:

– Planck is a spinner around the LGA-1 boresight, and as the LGA2/3 will have to be used only in case of major failure (Plank rotated in the opposite side of earth/sun), the LB will change second by second during the spin, ensuring a 93% coverage. The link with Kourou remains possible, but there is a risk to lose the link temporarily (typ. every ½ spin period, i.e. 30s).

– When Planck is in visibility of New Norcia, the up-link margin becomes largely positive, considering an overall –10 dBi isotropic low gain antenna,

2.6.2.4.2. Planck link with New Norcia

PLANCK		Ground Station	NEW NORCIA								
		Antenna	LGA 1	LGA 1	LGA 1	LGA 2+3	LGA 2+3	all LGAs -10 dBi	MGA	MGA	MGA
		Ranging	No	Yes	Yes	No	Yes	Yes	No	Yes	No
UPLINK		TC bit rate [bps]	4 000	4 000	4 000	4 000	4 000	125	4 000	4 000	4 000
		distance km]	1 600 000	1 600 000	20 000	1 600 000	1 600 000	1 800 000	1 600 000	1 600 000	1 600 000
		PSS req. margin									
Carrier Power	nominal		9,89	9,89	46,22	6,51	6,51	13,87	24,96	24,96	24,96
	mean - 3 s		6,14	6,14	42,46	2,10	2,85	12,37	23,05	23,05	23,04
	marg-wc.RSS		9,04	9,04	45,36	5,43	5,43	13,02	24,15	24,15	24,15
Carrier Recovery	nominal	3 dB	28,17	27,08	63,69	23,50	22,41	18,15	43,23	42,14	43,23
	mean - 3 s	0	24,40	23,30	59,59	18,40	17,30	15,97	41,16	40,04	41,14
	marg-wc.RSS	0	26,51	25,39	61,69	21,61	20,50	16,53	41,62	40,50	41,62
TC Recovery	nominal	3 dB	11,68	10,58	46,91	6,99	5,89	15,92	26,75	25,65	26,75
	mean - 3 s	0	8,21	7,10	43,42	2,43	1,32	14,07	25,07	23,95	25,06
	marg-wc.RSS	0	10,38	9,25	45,57	5,62	4,49	14,59	25,54	24,40	25,53
DOWNLINK		TM bit rate [bps]	5 000	5 000	5 000	5 000	5 000	500	150 000	150 000	1 500 000
		distance km]	1 600 000	1 600 000	20 000	1 600 000	1 600 000	1 800 000	1 600 000	1 600 000	1 600 000
		PSS req. margin									
Carrier Recovery	nominal	3 dB	23,72	22,94	59,25	20,18	19,40	14,92	34,41	33,62	35,23
	mean - 3 s	0	21,60	20,11	56,74	16,76	15,51	12,49	31,23	29,44	33,99
	marg-wc.RSS	0	22,21	20,26	56,95	18,30	16,79	13,25	30,92	29,12	34,04
TM Recovery	nominal	3 dB	11,05	10,27	46,58	7,51	6,73	12,25	14,76	13,97	5,07
	mean - 3 s	0	8,95	7,75	44,33	4,11	3,06	10,69	13,49	12,50	3,92
	marg-wc.RSS	0	9,97	8,84	45,43	5,94	5,10	11,25	13,80	12,31	4,17
RNG Recovery	nominal	3 dB	N/A	42,69	83,67	N/A	35,57	27,20	N/A	57,79	N/A
	mean - 3 s	0	N/A	29,78	67,37	N/A	24,36	18,79	N/A	42,53	N/A
	marg-wc.RSS	0	N/A	28,82	66,42	N/A	24,28	20,70	N/A	43,38	N/A

Table 2-47 Planck link Budget Margin with New Norcia

All margins are above specification.

2.6.2.4.3. PLANCK link with Villafranca

PLANCK		Ground Station	VILLAFRANCA	
		Antenna	LGA 1	LGA 1
		Ranging	RNG	RNG
UPLINK		TC bit rate [bps]	4 000	N/A
		distance km]	350 000	N/A
		PSS req. margin		
Carrier Power	nominal		19,45	N/A
	mean - 3 s		15,68	N/A
	marg-wc.RSS		18,41	N/A
Carrier Recovery	nominal	3 dB	23,64	N/A
	mean - 3 s	0	19,88	N/A
	marg-wc.RSS	0	21,87	N/A
TC Recovery	nominal	3 dB	6,44	N/A
	mean - 3 s	0	2,81	N/A
	marg-wc.RSS	0	4,99	N/A
DOWNLINK		TM bit rate [bps]	5 000	5 000
		distance km]	350 000	750 000
		PSS req. margin		
Carrier Recovery	nominal	3 dB	21,13	14,58
	mean - 3 s	0	20,94	14,71
	marg-wc.RSS	0	18,64	12,58
TM Recovery	nominal	3 dB	8,47	1,92
	mean - 3 s	0	8,54	2,21
	marg-wc.RSS	0	7,17	0,89
RNG Recovery	nominal	3 dB	38,35	25,94
	mean - 3 s	0	30,16	21,15
	marg-wc.RSS	0	26,65	17,56

Table 2-48 Planck link Budget Margin with Villafranca

All margins are above specification.

2.6.2.5. Telemetry and Telecomamnd Budgets

2.6.2.5.1. PLANCK TM budget

The following budgets give, for each downlink rate, the allocation per type of TM and per virtual channel. The allocations for SVM housekeeping telemetry is:

- 400 bps of SVM housekeeping telemetry when the downlink rate is 500 bps
- 4 Kbps of SVM housekeeping telemetry when the downlink rate is 5 Kbps

– 9 Kbps of SVM housekeeping telemetry when the downlink rate is 150 Kbps or 1.5 Mbps

For the instruments, the data from the IID-B's have been taken into account. The following tables give the instrument data rates for each of the instrument modes

Kbps	VC0	VC4	VC2	VC1	VC3	VC7	TT&C Config
	Real time ess SC HK Essential instr HK Non periodic HK	Real time routine SC HK Routine instr HK	Stored SC HK	Real time science	Stored science data	Idle frames	
500 bps, all modes							LGA + KRU
0,5	0,5						
CDMS Essential (1 out of 11)	0,072						
ACMS Essential (1 out of 2)	0,17						
Instr essential (1 out of 11)	0,1						
Margin for asynchronous TM	0,158						
5 Kbps, all modes							LGA + KRU < 750 000
5	5	0	0				LGA + NN
CDMS Essential	0,787						LGA + VILSPA
ACMS Essential	0,34						
Instr essential	1						
Margin for asynchronous TM	2,873						
150 Kbps, ACMS Science mode							MGA + KRU
150	3,976	13,024	133	122	11		MGA + NN
CDMS Essential	0,787						
CDMS Periodic		1,771					
ACMS Essential	0,34						
ACMS Periodic		4,253					
Instr essential	1						
Instr periodic		7					
Margin for asynchronous TM	1,849						
150 Kbps, ACMS HCM							MGA + KRU
150	4,252	12,748	133	122	11		MGA + NN
CDMS Essential	0,787						
CDMS Periodic		1,771					
ACMS Essential	0,34						
ACMS Periodic		3,977					
Instr essential	1						
Instr periodic		7					
Margin for asynchronous TM	2,125						

Kbps	**VC0**	**VC4**	**VC2**	**VC1**	**VC3**	**VC7**	**TT&C Config**
	Real time ess SC HK Essential instr HK Non periodic HK	Real time routine SC HK Routine instr HK	Stored SC HK	Real time science	Stored science data	Idle frames	
150 Kbps, ACMS OCM							MGA + KRU
150	4,074	12,926	133	122	11		MGA + NN
CDMS Essential	0,787						
CDMS Periodic		1,771					
ACMS Essential	0,34						
ACMS Periodic		4,155					
Instr essential	1						
Instr periodic		7					
Margin for asynchronous TM	1,947						
1,5 Mbps, ACMS Science Mode							MGA+NN
1500	3,976	13,024	1483	122	1361		
CDMS Essential	0,787						
CDMS Periodic		1,771					
ACMS Essential	0,34						
ACMS Periodic		4,253					
Instr essential	1						
Instr periodic		7					
Margin for asynchronous TM	1,849						
1,5 Mbps, ACMS HCM							MGA+NN
1500	4,252	12,748	1483	122	1361		
CDMS Essential	0,787						
CDMS Periodic		1,771					
ACMS Essential	0,34						
ACMS Periodic		3,977					
Instr essential	1						
Instr periodic		7					
Margin for asynchronous TM	2,125						
1,5 Mbps, ACMS OCM							MGA+NN
1500	4,074	12,926	1483	122	1361		
CDMS Essential	0,787						
CDMS Periodic		1,771					
ACMS Essential	0,34						
ACMS Periodic		4,155					
Instr essential	1						
Instr periodic		7					
Margin for asynchronous TM	1,947						

2.6.2.5.2. CDMU I/O budget

The CDMU Capacity is the same as for Herschel and is described in section 2.6.1.6.

The Planck I/o allocation is presented bellow

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	Total
CDMS	CDMU	58	4			4							2								BC	6
Power	PCDU		8	12		40				2	1		4				4				2	65
	Battery										4											4
TT&C	XPND1		4			4				5	2		1	1				1	1	1	1	17
	XPND2		4			4				5	2		1	1				1	1	1	1	17
	RFDN				16						4		8									28
	EPC1		8							2	1			3								6
	EPC2		8							2	1			3								6
TCS	Control										126											126
	Monitoring										18											18
ACMS	ACC		12			18				2	5		2	10							2	39
Solar Array	SA											6										6
EGSE	UMB												2				6	2		2		12
CFE																						0
	SREM							1								1						2
HFI	PHBAN								1												1	2
	PHBAR								1												1	2
LFI	PLREN								1												1	2
	PLRER								1												1	2
	PLBEU								2													2
SCS	PSM4								1												1	2
	PSR4								1												1	2
PPLM	Cr Temp											56										56
Total		58	44	12	16	66	0	1	8	18	164	62	18	18	0	1	10	4	2	4	12	460
Availability		64	48	16	16	80	8	7	8	48	192	64	80	40	8	7	16	4	2	4		648
Spare		6	4	4	0	14	8	6	0	30	28	2	62	22	8	6	6	0	0	0		
Percentage Spare		9%	8%	25%	0%	18%	100%	86%	0%	63%	15%	3%	78%	55%	100%	86%	38%	0%	0%	0%		

Table 2-49 PLANCK CDMU I/O allocation budget

2.6.2.6. Memory budget

Each nominal and redundant mass memory consists of 4 banks of 8 Gbit.

At EOL, with the worst case assumption of one bank failure (i.e. after a double failure), the minimum capacity of each mass memory is 3×8 Gbit = **24 Gbit = 25.77 × 10^9 bit**.

This capacity exceeds the 25×10^9 bit requirement.

The rates from each contributor are:

spacecraft real time HK = **9000 bit/s** (specified in the SVM I/F specification)

total instruments average data rate (all instruments + all data) = **130 000 bit/s** (specified in RD-1). This includes each instrument real time HK = **2000 bit/s**, composed of 300 bit/s of « quick look » HK and 1700 bit/s of routine instrument HK.

In addition, the MTL will contain at most 1.5 Mbyte = 0.013 × 10^9 bit.

An allocation of 200 OBCPs of 64kbyte stored in mass memory = **0.105 × 10^9 bit.**

After 48 hours, the mass memory will contain:

(0.013+0.105) × 10^9 bit + (9000 + 130 000) bit/s × 2 days =
24.137 × 10^9 bit.

This represents **93.7%** of the worst case capacity of the mass memory.

2.6.2.7. Timing budget

Refer to section 2.6.1.8.

2.6.2.8. Propellant budget

The propellant and ΔV budget is summarised in the following Table:

The delta-V budget has been updated in accordance with Crema 3.1 amended by document 0705530-hp-lawi-wp508.pdf

406 m/s have been allocated for the launch and transfer phase. For a better accuracy of the numerical calculation, these 406 m/s have been split in 7 virtual maneuvers

The total hydrazine needed for the mission is 343 kg, which is below the 384 kg maximum loading of the tanks.

	Delta-v [m/s]	Manoeuvre Efficiency	Isp × g [m/s]	Mass Margin	Helium Loss [kg]	S/C Mass before Dv [kg]	Hydrazine consump. [kg]	S/C Mass after Dv [kg]
								1932,905
overall 406 m/s (part 1/7)	58	100%	2209	0%	0	1932,905	50,085	1882,820
overall 406 m/s (part 2/7)	58	100%	2200	0%	0	1882,820	48,988	1833,831
overall 406 m/s (part 3/7)	58	100%	2193	0%	0	1833,831	47,872	1785,959
overall 406 m/s (part 4/7)	58	100%	2187	0%	0	1785,959	46,751	1739,208
overall 406 m/s (part 5/7)	58	100%	2181	0%	0	1739,208	45,634	1693,574
overall 406 m/s (part 6/7)	58	100%	2177	0%	0	1693,574	44,528	1649,046
overall 406 m/s (part 7/7)	58	100%	2173	0%	0	1649,046	43,435	1605,611
Orbit maintenance for mission lifetime	2,5	58%	2171	35%	0	1605,611	4,297	1601,314
Orbit maintenance due to attitude control	2	58%	2171	35%	0	1601,314	3,430	1597,885
Attitude Control	3,6	98%	2000	35%	0	1597,885	3,956	**1593,929**

	Helium	Hydrazine
Consumption from launch to last Delta-v [kg]	0,000	338,976
Residual mass after last Delta-v [kg]	7,690	2,099
Residual mass in feed lines after last Delta-v [kg]	0,000	1,502
Total mass at launch [kg]	7,690	**342,577**

	Dry	Helium	Nitrogen	Hydrazine	TOTAL
Satellite Mass after last Dv =	1577,945	7,690	4,693	3,601	**1593,929**

Table 2-50 PLANCK propellant and DV budget

2.6.2.9. Pointing budget

The pointing budgets are synthesised in the Table below.

	LOS [Arcmin]				Around LOS [Arcmin]			
error	**performance**	*requirement*	compliance	margin	**performance**	*requirement*	compliance	margin
APE	12,77	37	C	65%	7,12	37	C	81%
PDE 24 hours	1,74	6,2	C	72%	0,39	6,2	C	94%
RPE 55 min	0,22	1,5	C	85%	0,22	10	C	98%
PRE	1,84	2,5	C	26%				
AME	0,20	0,5	C	60%	4,80	6	C	20%
goal	0,12	0,2	C	41%				
Spin axis repointing	0,26	0,4	C	34%				
RRS (rpm/h)	6,46E-05	0,0001	C	35%				
ARE (arcmin/sec)	0,61	5,4	C	89%				

Table 2-51 PLANCK pointing budget

Full compliance is stated on the SRS requirements.

There is only one goal on Planck, on the LOS Attitude Measurement Error.

The only condition necessary to achieve the goal is the reduction of the sloshing term. The relatively rapid damping of the sloshing obtained in very conservative analysis (pure surface tension tank) with time constants of about 20 seconds, implies that the goal conditions will be satisfied throughout most of the nominal 55 minute observation period, and may be exceeded only immediately after the spin axis repointing manoeuvre.

Note that no specific conditions are necessary at PPLM level since PPLM error is already negligible in nominal AME LOS budget.

2.6.2.10. Alignment budget

2.6.2.10.1. Line of Sight maximum deviation budget

The maximum deviation between the instruments LOS and STR LOS are synthesised in the Table below.

CONTRIBUTOR		LOS POSITION WORST CASE	STATUS
PPLM	Telescope+ cryostructure	<13 arcmin	P-PLM CDR status
	FPU internal	+/- 0.69arcmin	Specified
SVM		+/- 30 arcmin	specified
budget		43 arcmin	Compliant
Need		90 arcmin	

Table 2-52 PLANCK LOS deviation budget

2.6.2.10.2. Around Line of Sight instability budget

The maximum instability between instruments and STR around LOS are synthesised in the Table below.

CONTRIBUTOR		AROUND-LOS STABILITY 68 % CONFIDENCE LEVEL	STATUS
PPLM	Telescope+ cryostructure	+/- 2.2 arcmin	P-PLM CDR status
	FPU internal	+/- 0.33 armin	Specified
Budget		+/- 2.59 arcmin	Compliant
Need		<3.8 arcmin	

Table 2-53 PLANCK Around LOS stability budget

2.6.2.10.3. Around Line of Sight alignment knowledge budget

As around-LOS is not calibrated in orbit, the knowledge on-ground has to be performed.

CONTRIBUTOR		AROUND-LOS KNOWLEDGE 68 % CONFIDENCE LEVEL	STATUS
PPLM	Telescope	+/- 1 arcmin	Specified
	FPU internal	+/- 0.33 armin	Specified
Telescope frame orientation measurement with regards to launcher I/F		+/- 1 arcmin	State of the art
total		+/- 2.33 arcmin	Compliant
Need		<3.0arcmin	

Table 2-54 PLANCK Around LOS alignment knowledge budget

2.6.2.10.4. Thruster plume alignment budget

The maximum Thruster plume alignment is synthesised in the Table below.

	CONTRIBUTION TO ALIGNMENT ACCURACY	STATUS
Thruster-plume knowledge & stability	±2 arcmin	This is specified by Alenia
System level thruster-plume alignment accuracy	±2 arcmin	State of the art with margin
S/C CoG on-ground knowledge accuracy	±24 arcmin	Specification to AIT
Total (RSS)	±25 arcmin	Compliant
need	±30 arcmin	

Table 2-55 PLANCK thruster plume alignment budget

2.6.2.11. Helium lifetime budget

The HFI IID-B issue 3.2 states that:

The initial quantity of helium is (section 5.5 of the IID-B):

- 1.54 kg of He3, i.e. 513 moles
- 3×2.05 kg of He4, i.e. 1537 moles.

The consumption of helium in observation mode is (section 4.4.7.3.2.1 of the IID-B):

- 6.3 µmol/s of He3 as measured on the Development Model
- 18 µmol/s of He4, as measured on the Development Model.

The lifetime is therefore:

- He3: 513 mol / (6.3 µmol/s) = 942 days = 2.58 years
- He4: 1537 mol / (18 µmol/s) = 988 days = 2.70 years.

The He3 consumption drives HFI lifetime: **2.58 years**. This is in consistent with the requirement for a 2½ extended lifetime requirement.

2.6.3. Launch mass budget

The launch mass budget is the following:

maximum mass:	**5504.0 kg**, i.e. **89 kg within requirement**.
nominal mass:	**5395.5 kg**, i.e. 108.5 kg less than the maximum mass.
mass margin:	**2%**, overall.

	Nominal Mass [kg]	Mass Margin [kg]	Maximum Mass [kg]	Allocated Maximum Mass [kg]	Mass Perfo - Reqt [kg]
Launch Mass with reserve	**5395,5**	**108,5**	**5504,0**	**5593,0**	**-89,0**
Payload	**5295,5**	**108,5**	**5404,0**	**5493,0**	**-89,0**
Herschel	3375,1	55,7	3430,7		
Planck	1920,5	52,8	1973,2		
ESA Reserve	**100,0**	**0**	**100,0**	**100,0**	**0**
Remainining ESA Reserve	**198,6**	**-8,1**	**190,5**		
Part of reserve taken by H	**-42,3**	**7,5**	**-34,8**		
Herschel Telescope	0	0,0	0		
HIFI	-31,2	0,8	-30,4		
SPIRE	-4,4	0,0	-4,4		
PACS	-6,6	6,7	+0,1		
SREM	-0,1	0,0	-0,1		
Part of reserve taken by P	**-56,3**	**0,6**	**-55,7**		
Planck Reflectors	-1,7	0,0	-1,7		
HFI	-20,9	0,4	-20,4		
LFI	-14,0	0,0	-14,0		
Sorption Cooler	-18,5	0,2	-18,3		
SREM	-0,1	0,0	-0,1		
FOG	-1,1	0,0	-1,1		

Table 2-56 Launch Mass

The ESA reserve status is the following:

Actual ESA reserve with CFE nominal masses:	**198.6 kg**
Actual ESA reserve with CFE maximum masses:	**190.5 kg**
Specified ESA reserve:	**100 kg**