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HERSCHEL / PLANCK

TN PLANCK CRYOGENIC & THERMAL TEST PROGRAM

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ISSUE	DATE	§ : DESCRIPTION DES EVOLUTIONS *§ : CHANGE RECORD*	REDACTEUR *AUTHOR*
1	11/01/2002	First version	P. Armand
2	26/06/2002	Impacts on Plank cryogenic and thermal test program due to the unavailability of the Redundant Sorption Cooler for the STM/CQM test.	P. Armand
3	1/05/2004	Impacts on programmatic constraints and H/W unavailability in the CQM test program. Many changes see change bars.	P. Armand
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1. SCOPE

The thermal performances are one of the main challenges of the design and development of Planck. This document gives an overview of the whole Planck cryogenic and thermal test program.
It summarises the objectives and the major requirements for the CQM and PFM program. This document will serve as a basis for discussion with the instrument teams regarding the instrument test that will be performed at CQM and PFM levels in order to prepare the detailed test plan.
This Planck cryogenic and thermal test program is in line with the following constraints:

- The unavailability of the LFI instrument for Planck CQM test.
- The unavailability of the redundant Sorption cooler (due to the schedule) for the Planck CQM test. Nevertheless, in order not to impact the launch date it is planned to perform the Planck CQM test without the Sorption Cooler Compressor.
- The unavailability of the 0.1K Helium spheres (due to the schedule) for the Planck CQM test.
- The availability of the SVM STM is no longer valid for programmatic point of view. This unavailability implies that the SVM thermal balance shall be carried-out at S/C FM level and completed by tests done during the H-SVM TV/TB and analysis. The FM test #1 campaign dedicated to SCC & SCC radiator testing will allow to complete SVM the thermal qualification as soon as possible.

The main impacts are:

- for the Planck S/C CQM test:
    - The LFI instrument is substituted by a STM/MTD in order to provide the same thermal behaviour and to interface with HFI FPU and PPLM QM.
    - The Redundant Sorption Cooler Compressor is substituted by a dedicated GSE filled with gaseous hydrogen named "PACE GSE" (see §7.1) provided by “Air Liquide” for the fluidic & electrical behaviour.
    - The Filling of the HFI DCCU in isotope He_3 & He_4 will be perform by the HFI PGSE “ISSS-PGSE” instead of Helium tanks
    - The SVM STM will be replace by a SVM Dummy in order to handle the PPLM and HFI warm unit.
- for the Planck SVM TCS validation:
    - It was previously planned a SVM thermal control qualification with dedicated test at SVM level. This test is no longer valid for programmatic point of view. The SVM thermal verification is now based:
        - For the TMM correlation (except SA):
          By the Herschel SVM TV/TB test including the external equipment mounted on the sun side of the spacecraft (thrusters, antenna, sun sensors and the launcher interface ring).
          By dedicated Thermal balance during the Planck S/C FM test #1 for Planck SVM TCS peculiarities.
        - For the Solar Array
          By dedicated analysis with well-known boundary conditions and elementary tests on sample such as measurement of thermo-optical properties.
        - For the overall MLI assembly, integration & validation):
          By dedicated Thermal balance during the Planck S/C FM test #1.
    - for the Planck S/C FM test:
    - The PFM sequence is still split into 2 separated configuration but with an advanced one instead of both at the end:
        - The PFM test #1 will perform the functional test of the first Sorption Cooler Compressor (Redundant TBC). This test is a reduced test no functional test of the other coolers & instruments detection chain is planned. In addition the SVM thermal balance.
        - The PFM test #2 will perform the functional test of the second Sorption Cooler Compressor (Nominal TBC), and perform the full Instrument functional tests (down to 0.1K). In addition if any a delta SVM thermal balance and SVM thermal cycling will be done.

2. DOCUMENTATION

2.1 Applicable documents

Ref.	Reference of document	Title
AD01	H-P-1-ASPI-PL-0192	Planck Satellite Interface drawing
AD02	SCI-PT-IIDA-04624	Instrument Interface Document IID - part A
AD03	H-P-1-ASPI-LI-0058	Hardware Matrix
AD04	H-P-3-ASP-TN-0582	Planck CSL Supporting device micro vibration analysis
AD05	H-P-1-ASPI-PL-0009	Design & Development Plan
AD06	H-P-3-ASP-TN-0671	Planck CQM Technical Description

2.2 Reference documents

Ref.	Reference of document	Title
RD01	SCI-PT-IIDB/HFI-04141	Instrument Interface document IID part B "HFI"
RD02	SCI-PT-IIDB/LFI-04142	Instrument Interface document IID part B "LFI"
RD03	HP-3-AIRL-DF-4	PACE GSE Definition File
RD04	H-P-3-ASP-TS-0051	Requirement specification for the Planck Cryogenic facility
RD05	H-P-3-ASP-PL-0675	HFI Testing on CQM & SM level
RD06	H-P-3-ASP-PL-0676	Planck Instruments Testing on PFM S/C levels
RD07	H-P-3-ASPI-AN-0330	PPLM Thermal analysis

2.3 Acronyms and abbreviations

Acronyms	**Keys**
AD	Applicable Document
AIT	Assembly, Integration & Tests
AVM	AVionics Model
COG	Center Of Gravity
EGSE	Electrical Ground Support Equipment
ESA	European Space Agency
ESTEC	European Space research and Technology Center
GHe	Gaseous Helium
GSE	Ground Support Equipment
HFI	High Frequency Instrument
I/F(s)	Interface(s)
IID	Instrument Interface Document
ISSS-PGSE	Isotope Supply & Storage PGSE
JPL	Jet Propulsion Laboratory
LFI	Low Frequency Instrument
LHe	Liquid Helium
LN2	Liquid Nitrogen
MGSE	Mechanical Ground Support Equipment
MPL	Maximum Performing Load
MTD	Masse en Thermal Dummy
NA	Not Applicable
NC	Not Communicated
PACE	Pipe Assembly & Cold End
PACE - GSE	PACE - Ground Support Equipment
PFM	Proto-Flight Model
PGSE	Pneumatic Ground Support Equipment
PLM	PayLoad Module
PPLM	PLANCK PayLoad Module
RD	Reference Document
S/C	Spacecraft
STM	Structural & Thermal Model
SVM	SerVice Module
TBC	To Be Confirmed
TBD	To Be Defined
TBS	To Be Specified
TF-PGSE	Tank Filling - PGSE
THA	Transport Handling Adapter
TRA	Thermal Ring Adapter
TRR	Test Readiness Review
WU	Warm Unit

3. SPECIMEN DEFINITION

3.1 General presentation of the PLANCK program

PLANCK is the third Medium size mission of ESA long-term scientific plan Horizon 2000.
PLANCK is planned to be launched by Ariane 5 beginning of 2007 in a dual launch configuration with HERSCHEL satellite.
The objective of the PLANCK mission is to image over the whole sky the temperature anisotropy of the cosmic background radiation with a sensitivity ΔT/T < 2 10-6 and an angular resolution of 10 arcminutes. To achieve this objective, the whole sky will be mapped in nine frequency channels ranging between 25 and 1000 GHz, with a sensitivity and an angular resolution which allow the separation of the cosmological signal from all other sources of confusion.
The PLANCK concept is based on an off-axis telescope with a circular projected aperture of 1.5 m. This telescope is passively cooled at about 50K, its focal plane is shared by two instruments:

- LFI: Low Frequency Instrument in the range 30 to 70 GHz, LFI sensors are cooled at 20K by a sorption cooler.
- HFI: High Frequency Instrument in the range 100 to 1000 GHz, HFI detectors are cooled at 0.1K by a chain of 3 coolers: 20K sorption cooler, 4K Joule-Thomson cooler and 0.1 K dilution cooler.

The sky mapping is insured by the spin of the spacecraft at a rate of 1 turn per minute.
Planck will be on a small Lissajous orbit around the L2 Lagrangian point.

3.2 Spacecraft definition and interfaces

The spacecraft interfaces are defined in AD01.

The Spacecraft is composed of (see Figure 3-1):

- the SVM containing the warm units of instruments and the servicing equipment,
- a cryo structure with a set of thermal shields (V.grooves),
- the telescope
- the main baffle used as a thermal radiator on its external side.

The telescope is working at about 50 K while the SVM units are between 270 and 300K.
The attachment of the satellite on the MGSE will be done through the launcher interface ring located at the bottom of the SVM (solar array side): it is a standard 2.624 m Ariane V interface.

The mass of the satellite is approximately 1910 Kg wet and 1550Kg in dry condition.

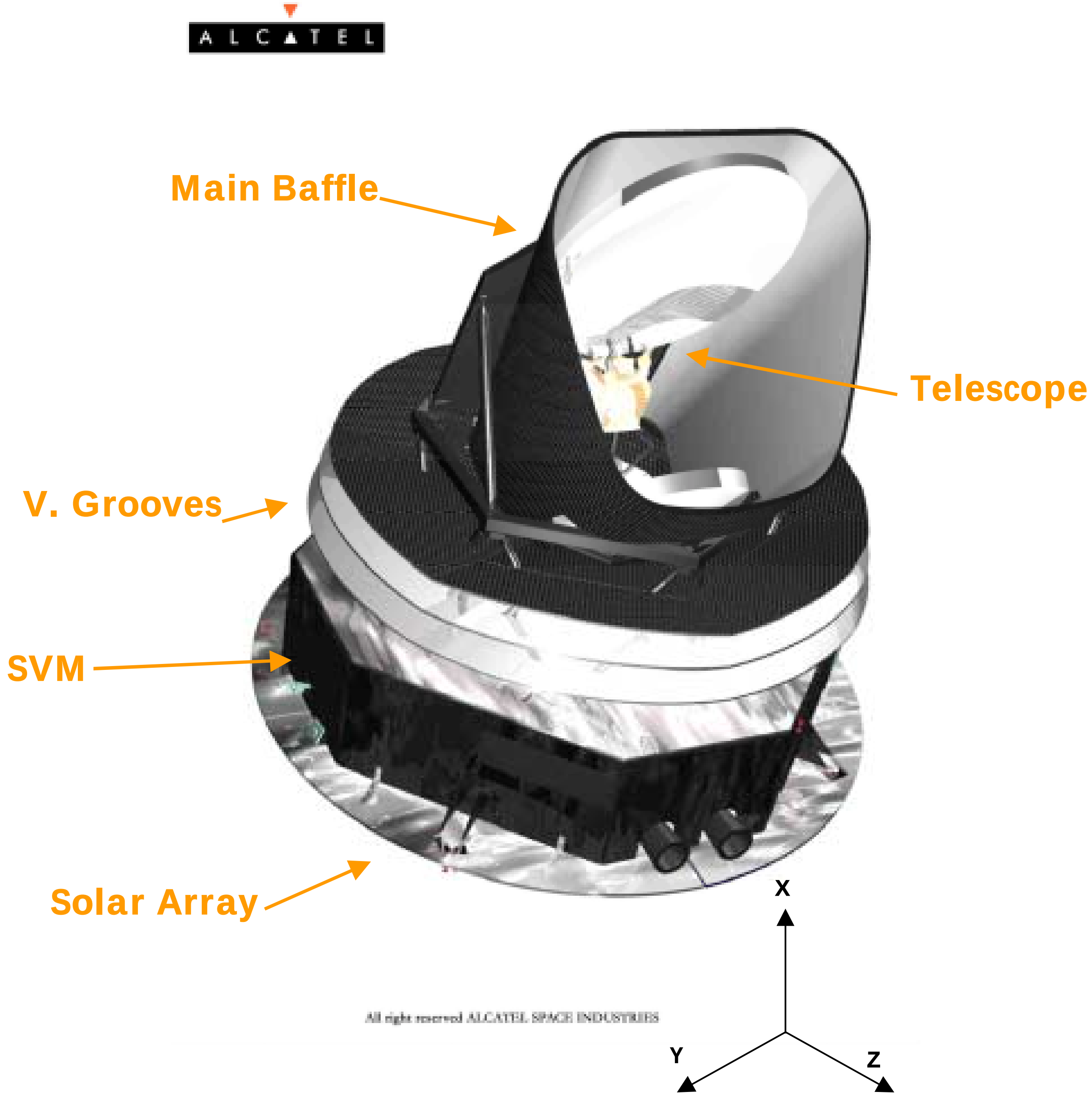

Figure 3-1: PLANCK overall layout

The overall dimensions of the spacecraft are given by the Figure 3-2 hereafter.

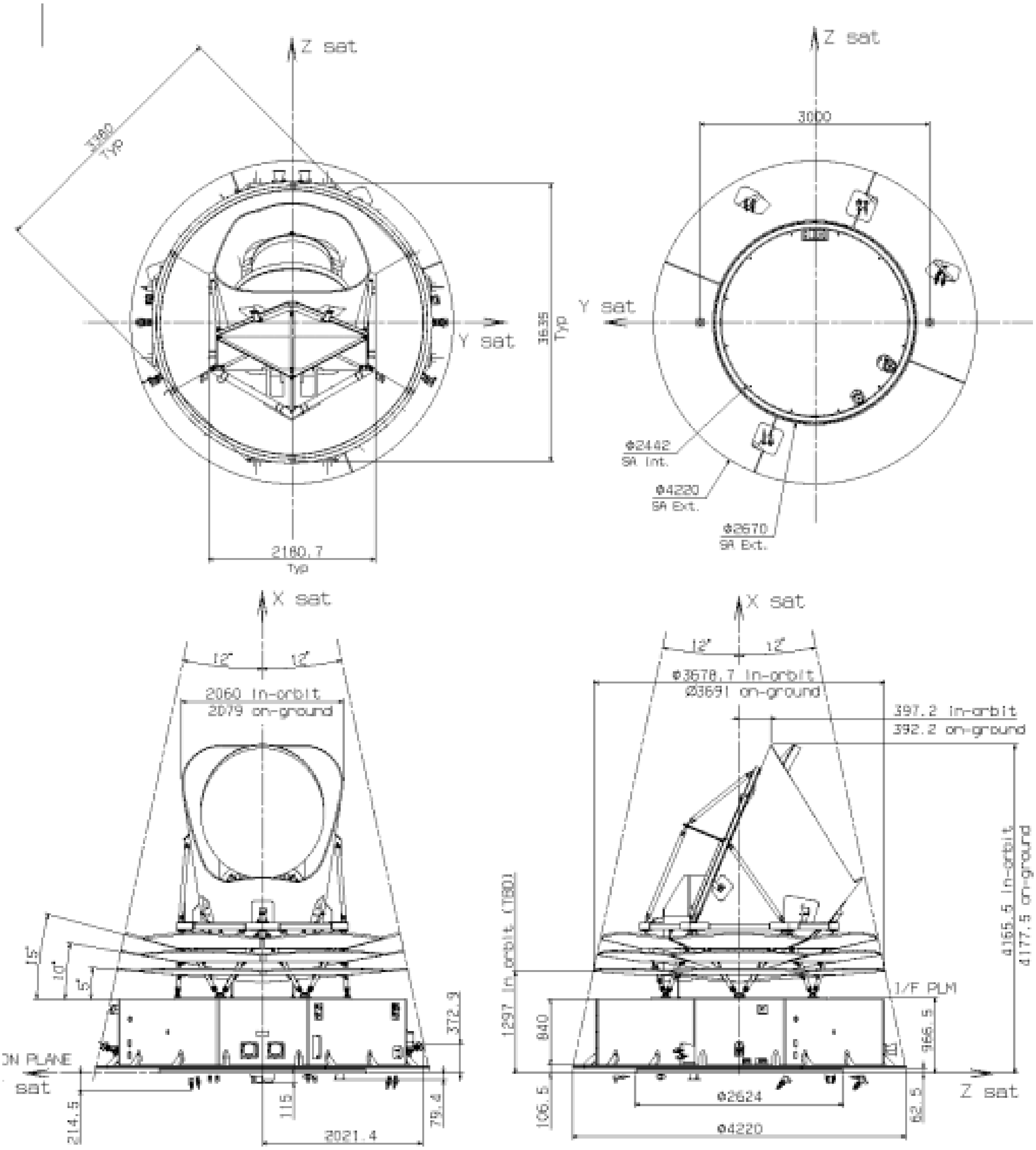

Figure 3-2: PLANCK overall dimensions

3.3 Model philosophy

The Planck model philosophy is based on the conclusions of the previous trade-off (cf. AD05) from which it is proposed to support the requirements for development, qualification and final flight acceptance of the Herschel and Planck satellites (ref. AD05).
The system model philosophy: CQM / AVM /PFM allows to optimise the cost, the risk and the schedule aspects of the Planck program. It has been made compatible with delivered models of the Customer Furnished Equipment (instruments and Planck reflectors).

Nevertheless, due to the programmatic constraints, the model philosophy has not changed, but the build standard has been reviewed.

The Planck Development Plan is based on the following model philosophy at system level:

- Cryogenic Qualification Model (CQM) :SVM Dummy + Cryogenic Qualification Model of the PLM (except LFI).
- Avionics Model (AVM)
- Radio Frequency Qualification Model (RFQM)
- Proto-Flight Model (PFM).

Note: The CQM have 2 configurations, one for acoustic test at PPLM level (without HFI H/W) and one for the cryogenic test with HFI.

The Planck CQM will be composed of:

- The SVM Dummy
- The Cryogenic Qualification Model (CQM) of the Planck PLM equipped with:
  - PLM coolers are fully representative of flight ones except for:
    - The 20K-sorption cooler compressor which is replaced by an external supply system, named “PACE GSE”. This GSE is in charge of to fill the PACE in hydrogen and also of monitoring/powering-up the PACE thermal sensors and heaters.
    - The 0.1K isotopes filling (He_3 & He_4) will operate with by an external PGSE, named “ISSS-PGSE”, provided by HFI.

Cold units of instruments are mechanically and thermally representative, but only few active sensors are present on each instrument (for details refer to AD06).

The Planck FM is the single flight model; it will be subject to the system level acceptance/qualification sequence. All its equipment and units are Flight Models (FM) which will have passed acceptance testing as required and/or proto-flight equipment (PFM) which will have passed qualification testing at unit level.

The Planck FM will be composed of:

- The PFM of Planck SVM including the FM Solar Array and the PFM Primary Structure
- The PFM Planck PLM.

At satellite level, the PFM models will be equipped for the thermal test with STM solar array panels equipped with skin heaters after the mechanical test campaign. The SA supplier will do the SA thermal qualification at subsystem level prior to delivery.

3.4 Thermal/cryogenic qualification and acceptance

3.4.1 *Thermal verification logic*

Because of the very low cryogenic temperatures required by Planck experiments, the thermal aspects are of crucial importance and will be the core of the verification plan.

The qualification test sequence will be conducted on Planck S/C CQM, H-SVM STM and PFM models. The objective is to verify the performances of the system for the main thermal configurations in demonstrating the compliance with requirements with sufficient margin. Another objective is to validate and correlate the thermal mathematical model, in order to use it for assessment of evolution or non-testable configuration.

Note: One main drawback of the unavailability of the Redundant Sorption Cooler Compressor for the CQM test is that the verification of the global cryogenic chain (20K / 4K and 0.1K) is postponed at PFM level.

The Planck S/C PFM will be submitted to two environmental cryogenic tests.

The PFM test #1 will allow:

- To perform the cryogenic functional test of the SCC#R.
- The thermal validation of the S/C taking into account information coming from CQM test, H-SVM TV/TB test.

The PFM test #2 will allow to perform a full cryogenic functional test of the instruments and perform if any a complement of SVM thermal balance S/C acceptance. Only the SCC#N will be tested in -this configuration.

The thermal qualification test sequence for Planck is presented on Figure 3-3.

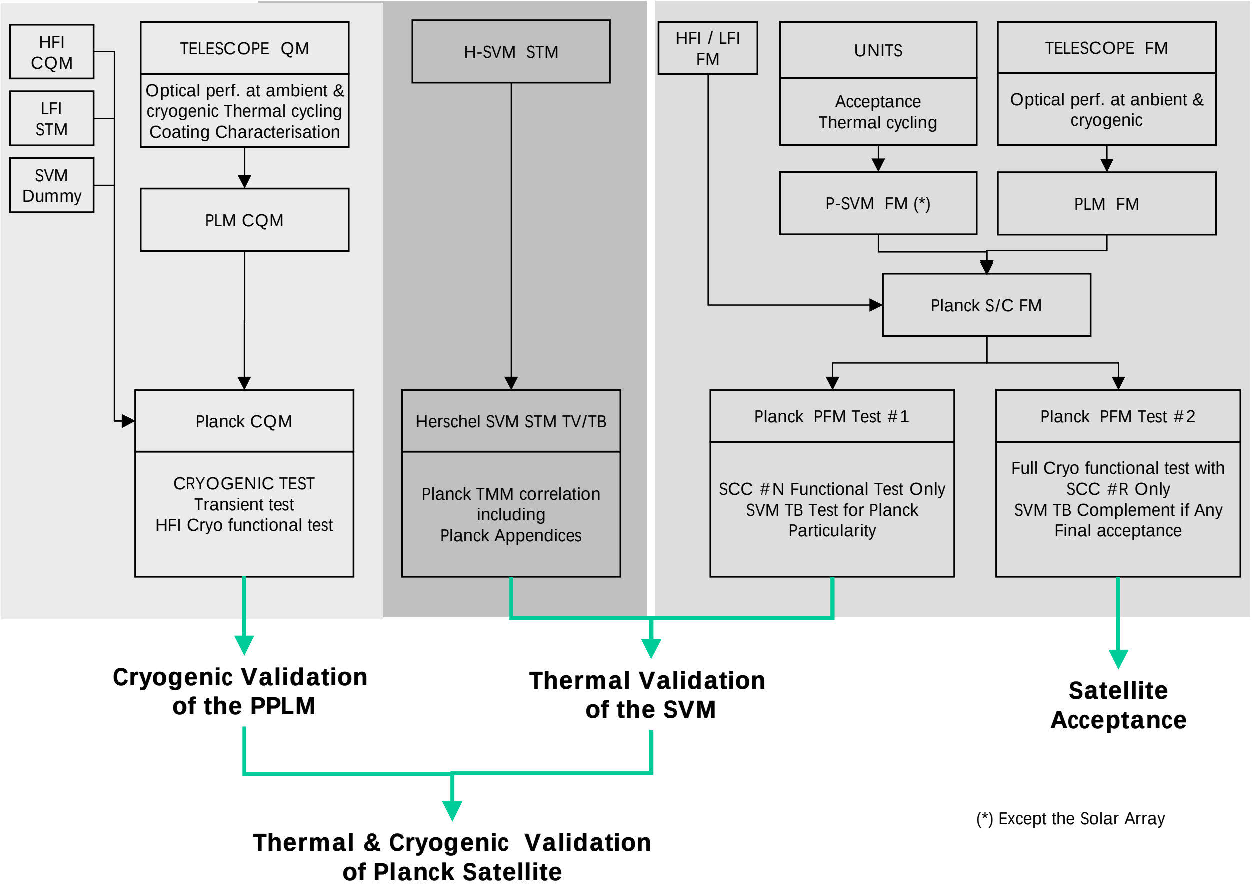

Figure 3-3: Thermal qualification of Planck

3.4.2 Thermal Control Design qualification

The validation of the thermal concept, the correlation of the overall thermal mathematical model and the verification of the thermal control subsystem performances will be performed by a combination of several tests done:

- At module level: Planck cryo-structure, baffle, Telescope and H-SVM STM
- At spacecraft level: S/C CQM & PFM.

Planck cryo-structure and baffle.
This structure will be fully tested under mechanical and thermal environment at system level (qualification levels for CQM, acceptance for FM). The Planck PLM Cryo-structure (including the Main Baffle, the grooves and the struts interfacing the SVM) thermal performance is managed at system level.
At subsystem level a minimum test qualification program is required which covers:

- Characterisation of materials and coatings behaviour at operating temperatures and part qualification
- Mechanical qualification for the QM & acceptance for the FM.

Planck Telescope.
The Planck Telescope will be tested under mechanical and thermal environment at module level. The Telescope thermal qualification doesn't takes part of the system thermal qualification, but take part of the Optical & RF verification, thermo-elastic behaviour. For programmatic constraints the thermal qualification has to be performed at 100K instead of 40K. Nevertheless, an improvement of the qualification at material level (number of cycles) and a QM modification of the test sequence (thermal before mechanical test) can provide the same information.

Planck PLM/CQM tests
To be properly tested the Planck PLM CQM must be assembled on a dummy structure of the SVM. In order to simplify the test set-up and to rationalise the test sequences, all the PPLM CQM environment tests including cryogenic tests are performed at Planck satellite CQM level. Nevertheless, due to the unavailability of the Planck LFI instrument only the HFI chain will be tested. For the 20 K stage only the PACE subsystem will be tested, the sorption cooler compressor is substituted by an external system (PACE-GSE).

Planck SVM/STM tests
Due to programmatic constraints, the previous baseline, validation of the thermal S/S of the SVM achieved thanks to a dedicated Planck SVM STM test, is no longer valid.
Now the validation of the thermal of the SVM is achieved:

- For the TMM (except the Solar Array) correlation thanks to:
  - H-SVM STM except for Planck particularity, see after, including appendixes in direct view of the sun (launcher interface ring, thrusters, antenna, sun sensors: SAS, Attitude anomaly detector AAD).
  - Planck PFM Test #1 for the Planck particularity. The table here below shows for each test objectives initially covered by P-SVM STM which is risk mitigation wrt to the test done at S/C level.

Items	Test objectives on STM	Effect	Risk mitigation
PAU/BEU Radiator	Verification of: Sub-Platform conductive properties, Contact conductance, MLI efficiency, Coupling PAU/BEU.	No preliminary verification on dedicated model (STM).	Sun simulation not needed. Advanced PFM Thermal Test #1 at CSL in fully flight configuration.
SCC Radiator	HP network conductance. Radiative I/F with SA. Rib contribution	No preliminary verification on dedicated model (STM).	HP qualification tests. Advanced PFM Thermal Test #1 at CSL (with SCC R) in fully flight configuration in order to: • Validate gradient across SCC panel • Validate fluctuation level on

Items	Test objectives on STM	Effect	Risk mitigation
			SCC I/F • Exhibit margin on temperature and fluctuation level/EOL if any. Completed with PFM Thermal Test #2 at CSL (SCC N). Note: heat flux from SA is adjustable during the test: simulated by heaters on SA STM
4K compartment - FOG	Temperature prediction on: CRU/FOG CEU/CCU Impact of CCU magnetic shield	No preliminary verification on dedicated model (STM).	Sun simulation not needed. Advanced PFM Thermal Test #1 at CSL in fully flight configuration. Test at unit level (RAL) allowing CCU TMM correlation. CCU CQM part of the PPLM CQM allowing magnetic shield thermal impact correlation.

- By dedicated analysis for the Solar Array items no covered by test

The table hereafter shows for each test objectives initially covered by P-SVM STM which analysis has been planned for risk mitigation.

Test objectives on STM	Effect	Risk mitigation
SA temperature level correlation.	Temperature max not verified during the test.	Covered by analysis with well-known boundary conditions and elementary tests on sample such as measurement of thermo-optical properties.
Multi-reflection due to protruding items.	Ref. Above.	Covered by Analysis to confirm low influence of multi-reflection.
Solar trapping in SA gaps. Impacts of variation of sun angle on SA.	Ref. Above.	Predictable by adequate design. Covered by Analysis showing low influence of the sun angle
SA panel edge behaviour	Ref. Above.	Covered by design
Conductive coupling between SA and lateral panels.	Ref. Above.	PFM S/C Thermal tests performed with SA STM equipped with heaters allowing adjusting the SA temperature during the PFM Thermal Test #1

- For the overall MLI assembly, integration & validation by dedicated thermal balance during the Planck S/C FM test #1

3.4.3 Planck System qualification - PFM tests

Due to suppression of the Planck SVM-STM and the availability of the LFI only at FM level, the completion of the system thermal design qualification will be demonstrated through the PFM test sequences.

4. CRYOGENIC/THERMAL TEST PROGRAM FOR PLANCK S/C CQM

4.1 CQM Definition

From thermal points of view the CQM is fully representative of the flight model of the PLM (including HFI H/W). The main differences are the following:

- No He tanks of the 0.1K dilution cooler, will be replaced by a dedicated external fluidic PGSE (ISSS-PGSE)
- PLM/CQM coolers are fully representative of flight ones except the Redundant 20K-sorption cooler compressor which is substituted by an external fluidic PGSE (PACE-GSE) in order to fill the PACE subsystem with the right mass flow & pressure.
- The SVM is replace by mass & thermal dummies (SVM Dummy) which provide the requested thermal behaviour in order to perform the PPLM thermal balance.

Cold units of instruments are mechanically and thermally representative, but only few active sensors are present on each instrument. The PACE CQM (Piping Assembly and Cold End) is associated to the PACE-GSE in order to provide the right temperature level at the different stages.
For detailed refer to AD06.

4.2 CQM Test Objectives

The CQM is the qualification model of the PLANCK spacecraft.
In this configuration, the CQM is mainly devoted to:

- Thermal Validation of the PPLM
- Qualification of the cryogenic chain of the PLM, except the SCC#R and the 0.1K tanks.
- Functional test of HFI
- Pre-validation of GSE, integration and test procedures.

The CQM test objectives are:

- To verify and qualify the whole cryogenic system of the scientific payload (demonstration that it is possible to reach 20 K on the LFI with external PACE-GSE for the Sorption cooler and 0.1 K on the HFI detectors).
- Functional & performance test of cooling systems (except the Sorption Cooler Compressor).
- Thermal control of the payload (passive cooling performances)
- Perform functional tests of HFI detection chain at operating temperature
- Check the thermal stability of the payload by transient tests
- An electromagnetic pre-qualification of the HFI scientific payload with all sensors operating at low temperature.
- To verify the µ-vibration environment generated by the test facility.

4.3 Main Requirements used for the Cryo Test

4.3.1 Instruments Thermal requirements

The thermal requirements necessary to operate the instruments are described in the IID-B's (RD01 & RD02). The present requirements are summarised in the following table.

Req N°	Parameter	Value	Comment
TR-1	Interface Temperature Sorption cooler Warm radiator	270 K	+ 10K to -10K
TR-2	Interface Temperature Warmest thermal shield	150 K	+ 10K to -10K
TR-3	Interface Temperature Intermediate thermal shield	100 K	+ 10K to -10K
TR-4	Interface Temperature Coldest thermal shield	<60 K	Requirement at interface, 50k goal.

Table 4-1: Summary of thermal requirements

4.3.2 Instruments Other requirements

Other requirements necessary to operate the instruments are described in the IID-B's (RD01 & RD02). The present requirements are summarised in the following table.

Req N°		Value	Comment
OR-1	HFI FPU micro vibrations	$<2,5^{-3}$ g rms	In range 0 to 30 Hz / (SQRT(x2+y2+z2))
OR-2	HFI FPU micro vibrations	$<2^{-3}$ g rms	In range 30 to 200 Hz / (SQRT(x2+y2+z2))
OR-3	HFI FPU micro vibrations	$<2^{-4}$ g rms	In range 50 to 70 Hz / SQRT(y2+x2)
OR-4	HFI FPU micro vibrations	$<2^{-4}$ g rms	In range 120 to 160 Hz / z
OR-5	Instrument Helium leaks	$<10^{-5}$ mbar.l/s $<10^{-9}$ mbar.l/s	In the SVM part In the PPLM part

Table 4-2: Summary of Other requirements

4.3.3 Cleanliness Requirements

Req N°		Value	Comment
CR-1	pressure inside the chamber	<10-4 Pa	
CR-2	Particulate contamination	class 10000	During the total duration of the test (including preparation and post vacuum activities)
CR-2	Particulate contamination	<145 ppm	From the baffle protective film removal, before the cryo vacuum cycle up to its reinstallation after cryo vacuum cycle.
CR-3	Molecular Contamination	$<2\ 10^{-7}$ g/cm²	During the total duration of the test (including preparation and post vacuum activities)
CR-4	Molecular Contamination	$<4\ 10^{-8}$ g/cm^2	From the baffle protective film removal, before the cryo vacuum cycle up to its reinstallation after cryo vacuum cycle.

Table 4-3: Summary of Cleanliness requirements

4.4 Test Sequence

The orientation of the spacecraft is defined in section 6.7.

The following phases will be tested:

- out-gassing/decontamination phase
- PLM cool down.
- PPLM thermal balance (with worst instrument heat load)
- Response of the PPLM to a power step (transient test).
- Instrument cooling & Functional phases

The fourth configuration will allow the validation of the thermal model in transient as used to determine the input data for internal straylight computation. As the fluctuations are expected to be very low and not measurable, it is planned to characterise the PPLM dynamic response to a sufficiently power step.

4.5 Test-flow

The proposed CQM test sequence will be the following and will be finalised in the CQM AIT Plan.
The total duration of the CQM test is estimated to 88 days with 41 days under vacuum.

Ambient phase: (30 working days[1])

Specimen instrumentation and preparation
Vacuum chamber preparation
Test set up installation
Specimen and GSE verification
Specimen cleaning
Ambient functional test
Last check before closure (thermocouples, test heaters check), last specimen control (photos…)
Leak check on hydrogen loop
Shrouds closure

Vacuum phase: (5 days)

Pumping
Ambient leak checks (Facility tight, instrument pipes/coolers leak tight, Hydrogen loop)
Instrument vibration measurement in parallel with above
De-sorption of CFRP under vacuum at ambient temperature: 2 days (TBC), vacuum better than 10^{-3} Pa
Temperature monitoring

Cooling phase: (8 days)

Cooling down of cryogenic shrouds
Wait for reaching 60K on the coldest v.groove shield (shield 3) ref. Table 4-1.
PPLM Thermal balance
    Wait for reaching the thermal equilibrium (stability of the coldest v.groove shield and of the telescope temperatures better than 10 mK per hour TBC) – (worst instrument heat load)
PPLM Transient test
    Add a power of TBD watts at TBD PPLM I/Fs[2] (power step). Wait for the thermal equilibrium (stability of the coldest v.groove shield, baffle and of the telescope temperatures better than TBD mK per hour.

---

[1] Simple shift

[2] I/Fs will defined on the basis of the thermal analysis (see RD[06]), Current results shows that the main contributor is the SCC VG3 I/F.

Instruments test phase: (25 days) to be confirmed with TRS (ref. to RD05 for detailed)

Switch-on the PACE-GSE.
Switch-on the pre-cooling of the HFI by the ground He loop until a TBD temperature criterion is met on HFI FPU
Wait for reaching 20 K on the LFI FPU.
Switch-on the HFI 4 K cooler (HFI pre-cooling loop will be stopped)
Wait for reaching 4 K on the HFI FPU and stable condition on the optical cryogenic shield
HFI cool-down - Start the Dilution cooler
Wait for reaching 0.1 K on the HFI detectors
HFI functional test
Electromagnetic compatibility tests except for the SCC.
Cooler failure tests (will be reduced due to the unavailability of the SCC).

Return to ambient: (3 days)

Instrument short ambient functional test.

Test Set-up dismounting: (4 working days[3])

Shrouds removal
S/C exit

Fonctional test at ambient (4 working days[4]) To be confirmed with TRS (ref. AD05)

Packing, loading and departure: (3 working days[5])

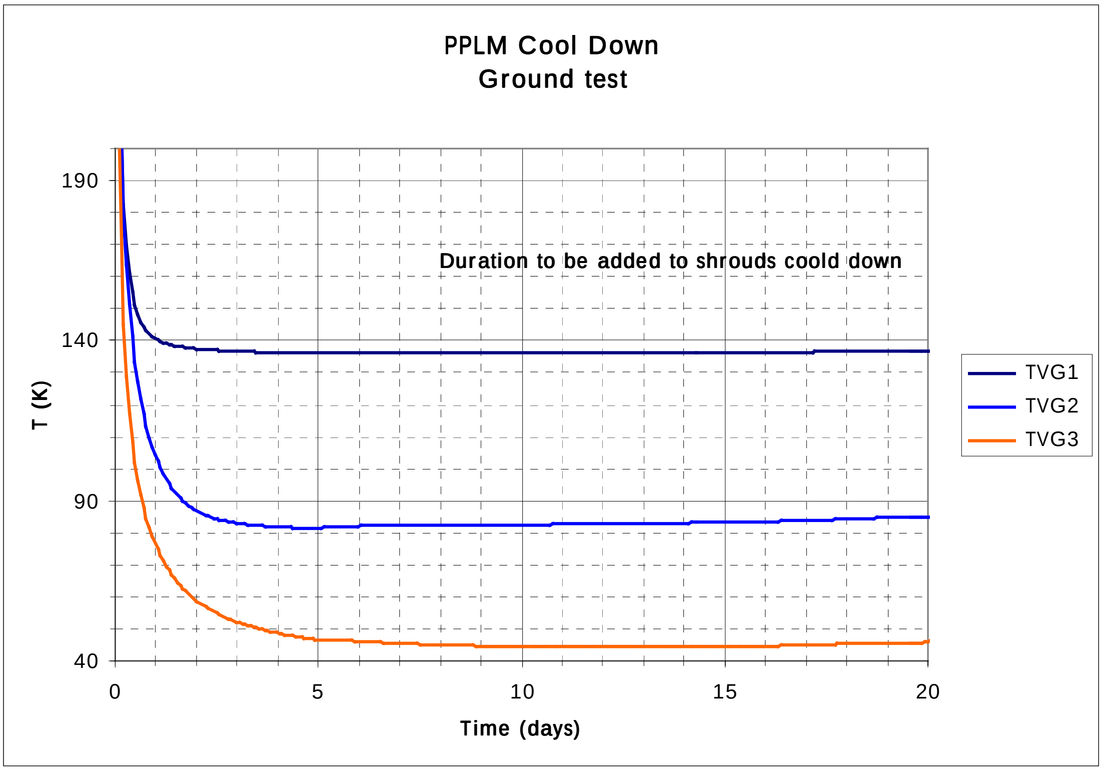

Figure 4-1: Cooling down of the passive cooler (without shroud coold down)

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[3] Simple Shift
[4] Simple Shift
[5] Simple Shift

5. CRYOGENIC/THERMAL TEST PROGRAM FOR PLANCK PFM

5.1 PFM Definition

The PFM is the flight model. When submitted to the cryogenic test the spacecraft will be in flight configuration except:

- The solar array panels which are replaced by STM ones equipped with heaters.
- The pressurisation of He tanks of the 0.1K dilution cooler which is reduced only for FM test #2.
- Hydrazine tanks are not filled and not pressurised at the nominal value.

The PFM sequence is still split into 2 separated configuration but with an advanced one instead of both at the end:

- The PFM test #1 will perform the functional test of the first Sorption Cooler Compressor (Redundant TBC). This test is a reduced test no functional test of the other coolers & instruments detection chain is planned. In addition the SVM thermal balance will be done in parallel.
- The PFM test #2 will perform the functional test of the second Sorption Cooler Compressor (Nominal TBC), and perform the full Instrument functional tests (down to 0.1K). In addition if any a delta SVM thermal balance and SVM thermal cycling will be done.

This proposed sequence is flexible wrt to the Planck instruments development constraints: if some Instrument H/W are not available at time, it is possible to be replaced them by STM/MTD without impacting the objectives of PFM test #1. This flexibility is also available for the SVM units.

5.2 PFM Test Objectives

The objectives of the PFM cryogenic test # 1 are:

- Functional and performance test of Sorption Cooler Compressor #R
- Thermal Balance of the SVM

The objectives of the PFM cryogenic test # 2 are:

- SVM thermal cycling.
- Functional and performance test of Sorption Cooler Compressor #N
- Functional and performance test of instrument cooling
- Functional tests of experiments at operating temperature.
- Acceptance and performance test of the PLM cryogenic system.
- Final acceptance of the thermal control subsystem. (Delta SVM thermal balance, if any).

5.3 Main Requirements used for the Cryo Test

All requirements for the Planck FM instruments are the same as for the CQM (cf. §4.3).

5.4 Test Sequence

The set-up for the Planck PFM is similar to the CQM set-up except that during:

- The PFM test #1 the redundant 20K cooler compressor (SCC#R) will be operated, thus the spacecraft will be oriented as defined in the section 6.7.
- The PFM test #2 the nominal sorption cooler (SCC#N) will be operated, thus the spacecraft will be oriented as defined in the section 6.8. In addition, the redundant sorption cooler (SCC#R) will be submitted during nominal SCC#R test sequence to a reduced electrical functional test including cooler switchover as allowed by its non-horizontal configuration.

The spacecraft will be nominally operated through the CCS.

Piloting the temperature of cryogenic shrouds in front of the SVM walls will perform the Thermal cycling of the spacecraft. The temperature of shrouds is adjustable from 100 K to 250 K

5.5 Test-flow

This PFM test-flow will be refined after the CQM sequence (lessons learnt). It will be finalised in the FM AIT Plan. The total duration of the whole PFM sequence listed below is estimated:

- For the FM test #1 at 68 days with 25 days under vacuum.
- For the FM test #2 at 89 days with 40 days under vacuum.

5.5.1 PFM test #1 flow : SCC#R testing

Ambient phase: (31 working days[6])
Specimen instrumentation and preparation
Vacuum chamber preparation
Test set up installation
Specimen and GSE verification
Specimen cleaning
Ambient functional test (To be adapted wrt the PFM#1 configuration)
Last check before closure (thermocouples, test heaters check), last specimen control (photos…)
Shrouds closure

Vacuum phase: (5 days)
Pumping
Ambient leak checks (Facility tight, instrument pipes/coolers leak tight)
Instrument vibration measurement in parallel with above
De-sorption of CFRP under vacuum at ambient temperature: 2 days (TBC), vacuum better than 10^{-3} Pa
Temperature monitoring

PLM cooling down and SVM thermal Balance & cycling (7 days)
Cooling down of cryogenic shrouds
SVM thermal balance (in parallel to other activities)

Instruments test phase: (10 days) refer to RD06 for details
Switch-on the Sorption Cooler Compressor #R. when the coldest V.groove shield (shield 3)< 60K
Wait for reaching 20 K on the LFI FPU
Switch on/off the LFI.

Return to ambient: (3 days)
Instrument short ambient functional test.

Shrouds removal: (3 working days)

S/C exit (3 working days)

Short Functional test at ambient (3 working days)
To be adapted wrt the PFM#1 configuration.

Packing, Loading and departure: (4 working days)
To be adapted wrt the PFM#1 configuration.

---

[6] simple shift assumption

5.5.2 PFM test #2 flow : SCC#N testing

This second configuration shall be confirmed after investigation.

Ambient phase: (37 working days)

see §5.5.1.

Vacuum phase: (5 days)

See §5.5.1

PLM cooling down (7 days)

Cooling down of cryogenic shrouds
Delta SVM thermal balance (in parallel to other activities if any)
SVM thermal cycling
Wait for reaching 60K on the coldest v.groove shield (shield 3).

Instrument test phase: (25 days)

Switch-on the Sorption Cooler Compressor #N.
Switch-on the pre-cooling of the HFI by the ground He loop until a TBD temperature criterion is met on HFI FPU
Wait for reaching 20 K on the LFI FPU.
Switch-on the LFI
Preliminary functional test & switch-on the optical cryogenic shield
Switch-on the HFI 4 K cooler (HFI pre-cooling loop will be stopped)
LFI functional test II
Wait for reaching 4 K on the HFI FPU and stable condition on the optical cryogenic shield
HFI cool-down - Start the Dilution cooler (in parallel with LFI functional test)
Wait for reaching 0.1 K on the HFI detectors
HFI functional test

Return to ambient: (3 days)

See §5.5.1

Shrouds removal: (3 working days)

S/C exit (3 working days)

Short Functional test at ambient (3 working days)

To be adapted wrt the PFM#1 configuration.

Packing, Loading and departure: (4 working days)

6. TEST CONFIGURATION

6.1 Main constraints

The 3 following constraints impose to test the satellite with its X-axis horizontal and oriented (around X) so that the radiator of the active sorption compressor is horizontal and facing the bottom of the chamber:

- For performance reasons, the beds of the active 20K sorption cooler located on the SVM panels must be in the horizontal plane ± 5 degrees when operated.
- For thermal performance reasons and so as to allow functioning of the 20K sorption cooler, the transverse heat-pipes located on the SVM panel must be horizontal during test.
- For thermal performance reasons the part of longitudinal heat-pipes located on the SVM panel in front of the active compressor of the 20K cooler must be horizontal (± 0.25 degrees when operated) and on the bottom side. This is to have the warm source located at the lower level of the heat pipe (i.e. of the radiator)

6.2 Test configuration

6.2.1 Mechanical configuration:

The spacecraft is maintained in the chamber by its launcher interface through a specific MGSE:

- Transport Handling Adapter (THA ≈ 140 Kg including clan band);
- Thermal Ring Adapter (TRA ≈ 58 Kg) will be used to perform the SVM thermal balance (zero flux);
- Horizontal Hosting Adapter (HHA ≈ 380 Kg) will be the interface with the CSL test support by 3 pines.

The general configuration is shown on Figure 6-1.

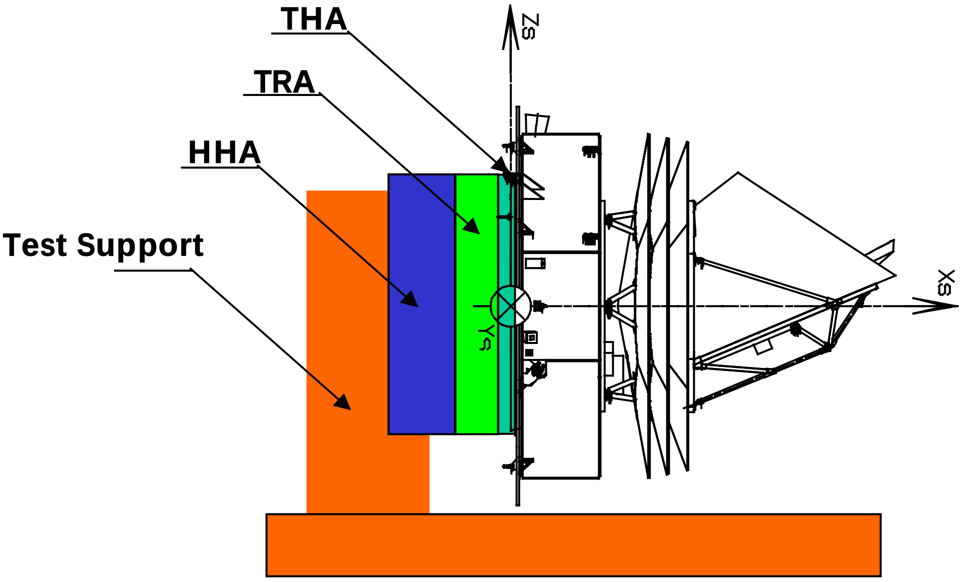


Figure 6-1: Test support and test adapters.

6.2.2 Thermal configuration

To allow the passive cooling of the PLM, a cryogenic shroud at a temperature lower than 20 K will surround the cold part of the spacecraft (above the upper SVM platform).
To allow the thermal control of the SVM, the warm part of the spacecraft will be surrounded by a cryogenic shroud at a temperature lower than 100K.

To allow the functional test of the experiments, an optical cryogenic shield < 5K will be placed in front of the FPU horn apertures (see section 6.4).

To simulate the thermal inputs due to the sun illumination the temperature of the lower panel (solar array) and of the launcher interface ring will be controlled. Heaters installed on the test adapters will perform the control of the interface ring temperature.

In order to limit the power dissipated inside the chamber the STM solar array panel, the attachment interface and the test adapter will be protected by MLI and/or low emissive coating.

Heaters on the SVM dummy structure will be used to simulate a step of the power dissipation during the transient test (on the CQM only).

The thermal cycling of the SVM will be obtained by adjustable temperature of N2 shrouds in front of the SVM walls.

Test harness and pipes will be routed and thermally controlled by the test facility contractor so that the thermal balance of the specimen is not disturbed.

6.3 Proposed test setting

The proposed test set-up is shown on Figure 6-2.

The cold part of the PLM is surrounded by a He shroud cooled at a temperature lower than 20K. The LN2 shroud allows to limit the heat loads on the He shrouds and to simulate the deep space environment for the cooling of the warm part of the spacecraft (SVM).

The cooler beds are horizontal (safety constraint), the transverse heat pipes are horizontal and the longitudinal ones have the condenser above the evaporator (located in front of the cooler bed).

The temperature of the N2 shrouds is adjustable in order to allow the thermal cycling of the SVM during the thermal vacuum test of the PFM satellite.

The main objective of the optical cryogenic shield is to avoid the saturation of instrument sensors by reducing the radiated background seen by sensors and to produce a stable target at low temperature (as far as possible compatible with flight like conditions).

The figure Figure 6-3 (CATIA views) shows the shroud configuration.

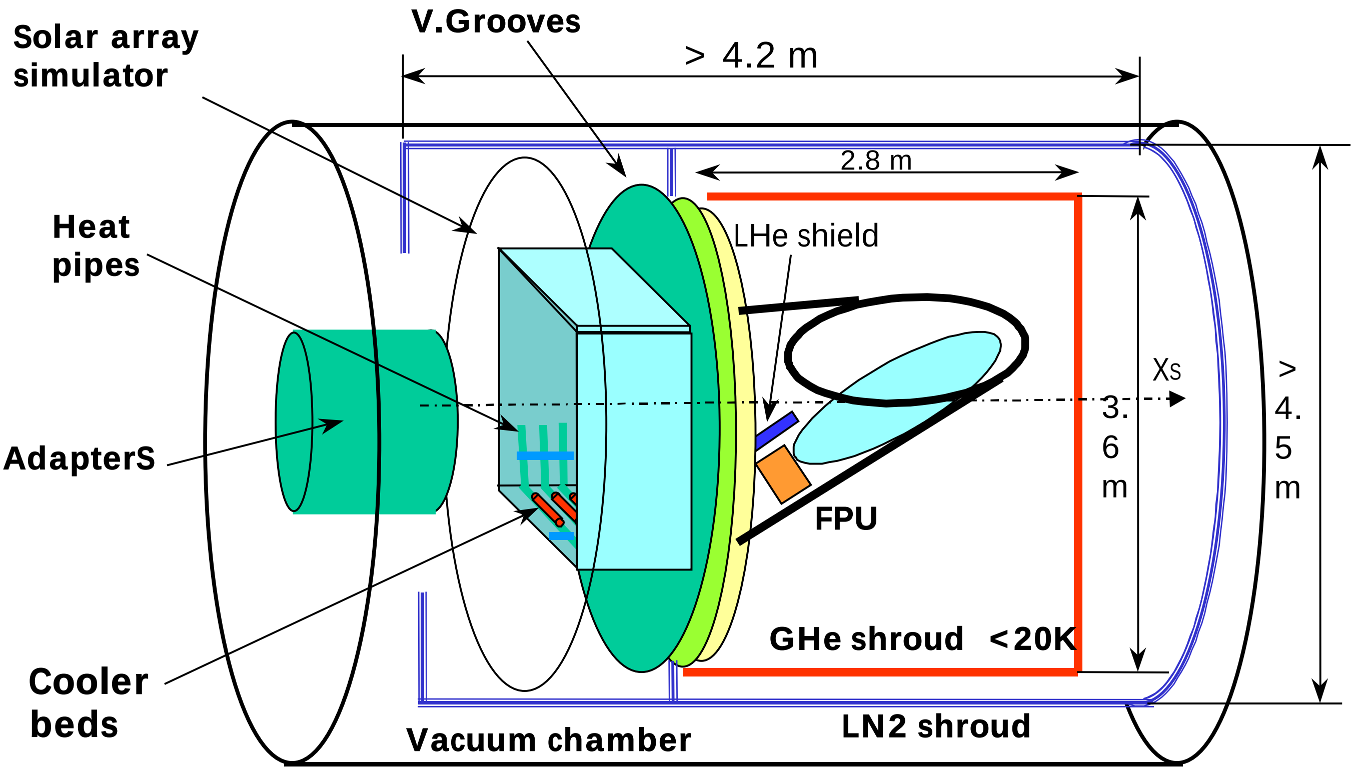


Figure 6-2: Thermal & cryogenic test configuration of Planck

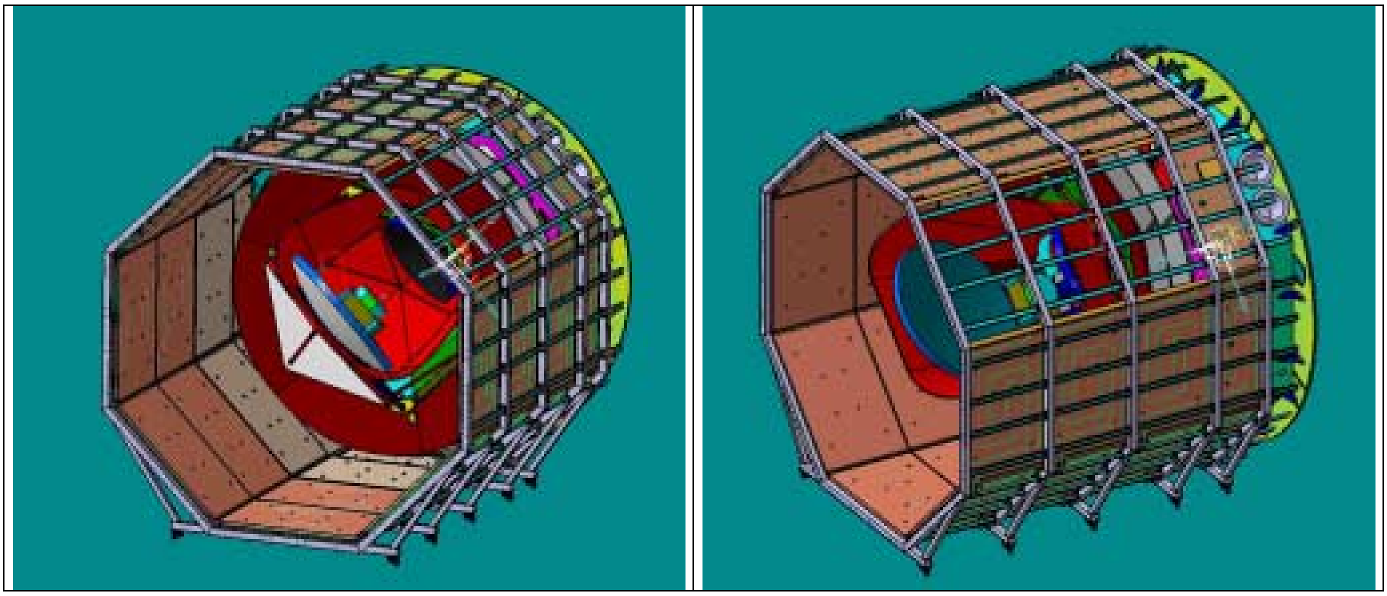


Figure 6-3: Test set-up Shrouds configuration

6.4 The Cold Target

The main objective of the cold target is to avoid the saturation of instrument sensors by reducing the radiated background seen by sensors and to produce a stable target at low temperature (as far as possible compatible with flight like conditions). This “Cold Target” used to perform the Planck instruments functional test is composed of:

- Optical Shield (part of the test facility)
- ECCOSORB sub-assembly (pyramids of ECCOSORB panels bounded on Pure Aluminium plate) provided by Officine Pasquali.

The design and the installation process are compatible with the allocated volume for the installation of the optical cryogenic shield defined on Figure 6-4. Nevertheless, due to the late decision to place an ECCOSORB sub-assembly (with specially shaped pyramids: 3cm high + 1cm base), the dimension of the ECCOSORB sub-assembly is out of the allocated volume defined but not critical.

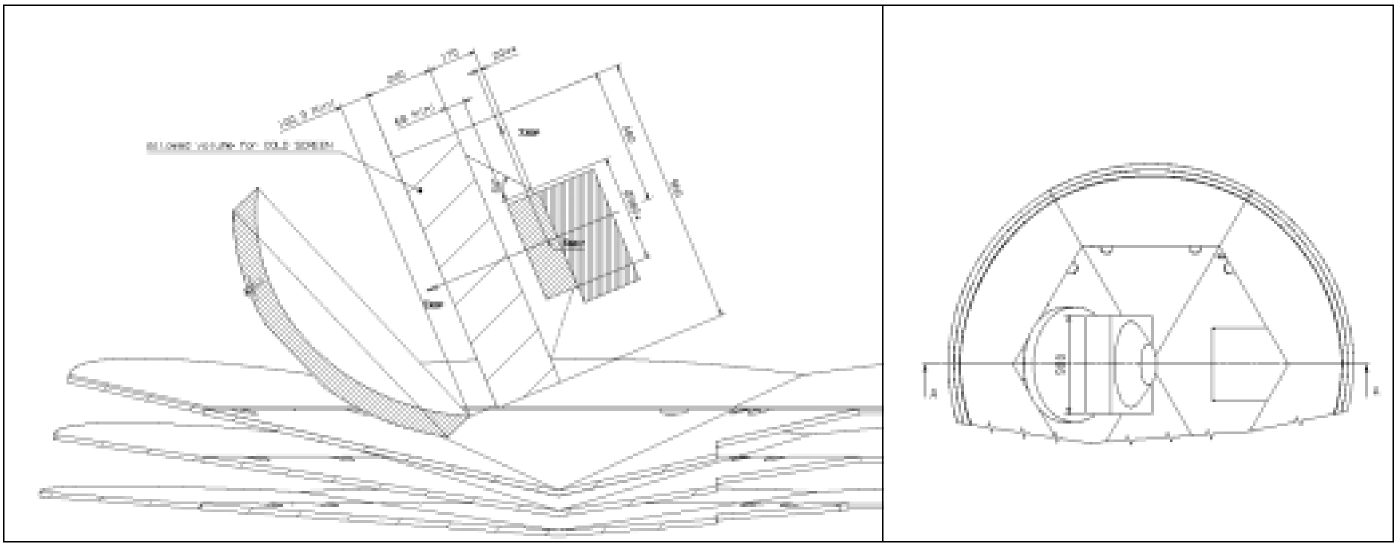


Figure 6-4: Optical cryogenic shield

The optical shield and its accessories (support, piping, …) will be such that it does not affect the thermal balance of the specimen.
For each horn aperture, the optical cryogenic shield will cover the field of view defined by a cone with a half angle higher than 50 degrees.
The figures here after show 3D CATIA views of the optical shield configuration during the test.

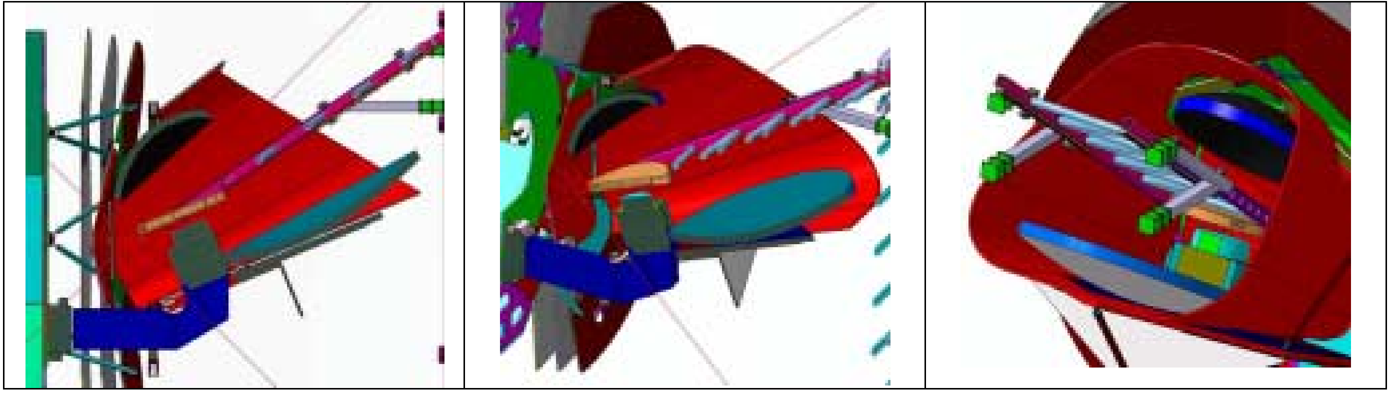
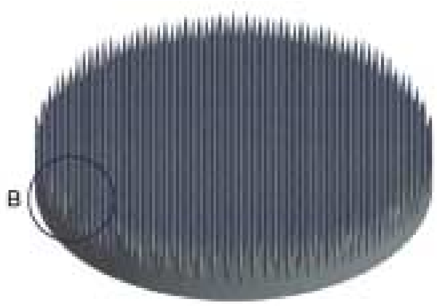


Figure 6-5: Optical shield configuration

ECCOSORB sub-assembly will cover the inner face of the optical shield. This subsystem will be composed of Eccosorb CR1110 pyramid panels bonded on a pure aluminium plate. The instrument team has defined the shape of this material:
Pyramid side: 5mm
Pyramid height: 30mm
Pyramid load thickness: 10mm
Aluminium Base: 10mm



Note: For manufacturing constraints, the Eccosorb sub-assembly will be made of 42 rectangular panels of 125mmx70mm. These ECCOSORB CR110 panels will be bonded on aluminium plate. This plate will be mechanicaly fixed on the CSL cooper helium bath with sufficient clearance in order to cope with the difference of CTE between copper and aluminium.

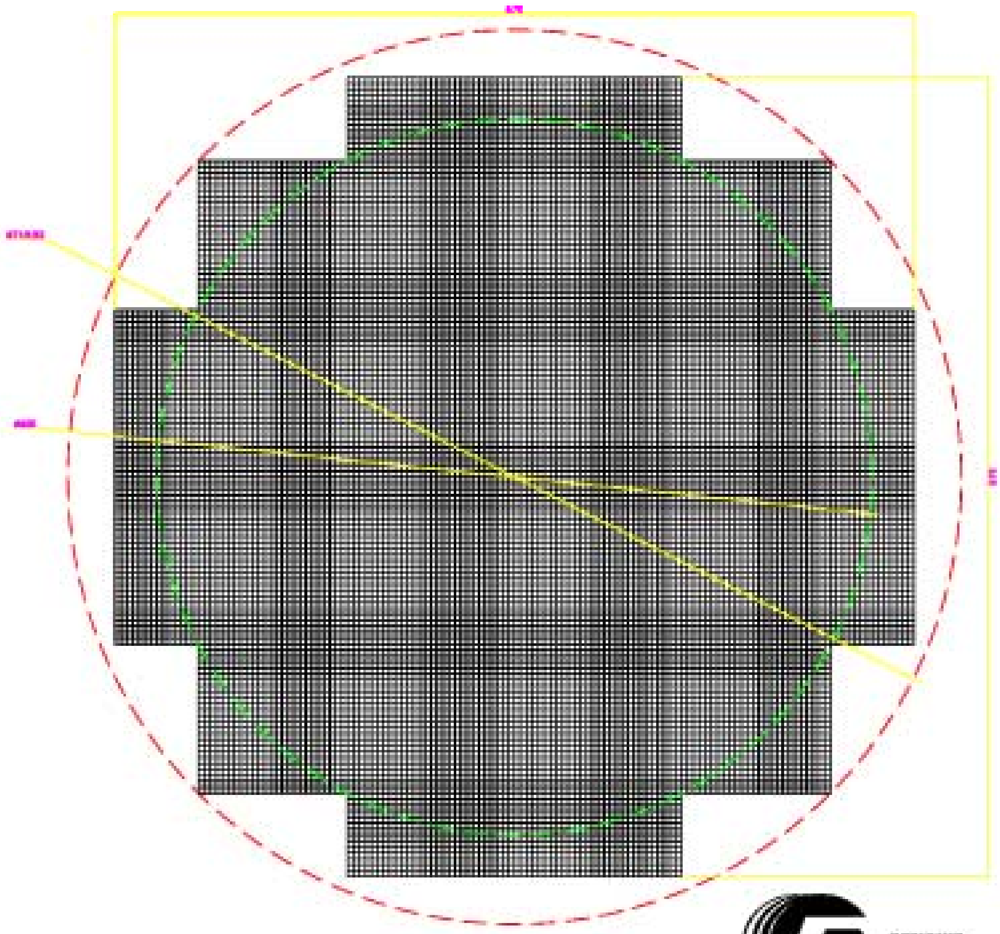


Figure 6-6: Layout of pyramids of ECCOSORB CR110 on Optical Shield

The test facility (CSL) will guarantee a temperature of the optical shield lower than the temperature of the satellite during the test sequence for contamination purpose. The following requirements will be applied during the instrument measurement period at the CSL helium bath I/F:

- The temperature of the optical shield will be lower than 5K during the measurement period.
- The temperature homogeneity over the optical shield surface will be better than or equal to 0,1K.

The temperature stability will be better than 1 mK/minute any time during noise measurements.

The introduction of the ECCOSORB sub-assembly will impact the following parameters of the optical shield:

- The temperature of the cooper I/F panel will be increased by 0,3K (TBC) but lower than 5K during the measurement period.
- The temperature of the Eccosorb pyramids will be higher than cooper I/F panel. This figure is still TBC.

6.5 Mechanical stability and micro-vibrations

The dilution cooler is susceptible to micro-vibrations, which could be created by the pumping system, and by the circulation of the cryogenic fluids.
The table here after shows the actual status of the µ-vibration level during the Planck S/C test (for the FM configuration). Theses figures are based on coupled analyses done by Alcatel (ref. AD[04]).
The following levels of micro-vibrations are applicable at the FPU I/F and derived at S/C mechanical mounting interface:

Spec	Bandwith (Hz)	Level I/F FPU (grms) (1)	Axis combination (2)	ASP Coupled Analysis (FPU I/F) (3)	ASP Coupled Analysis (CSL I/F) (4)
1	0-30	2,50E-03	SQRT(x2+y2+z2)	7,30E-04	1,80E-04
2	30-200	2,00E-03	SQRT(x2+y2+z2)	1,70E-03	2,10E-03
3	50-70	2,00E-04	SQRT(y2+x2)	8,10E-04	3,30E-04
4	120-160	2,00E-04	z	2,40E-04	5,30E-04
3 bis	54-70	2,00E-04	SQRT(y2+x2)	5,20E-04	3,30E-04

Table 6-1: µ-vibration level status

(1) Instrument specification
(2) Type of axis combination for the specified level
(3) Computed values at the FPU I/F
(4) Computed values at the CSL square support I/F

Base on these results, the proposed design is not fully compliant:

- 4 times the specification in the [50-70]Hz bandwidth (limited at 2.5 within the [54-70]Hz bandwidth.
- Marginally not compliant in the [120-160]Hz bandwidth.

Theses non-compliances cannot be solved by an improvement of the CSL square support, as the main contributors are coming from the ground. The only way to come back within the specification is to implement dampers between the square support and the feet (linked to the ground). Due to the important difference between the CQM model and the FM model it has been decided and agreed with ESA not to implement this solution but to improve the knowledge of the µ-vibration status by:

- Additional µ-vibration test campaign of the facility noise
- Additional accelerometer on the specimen to have a better understanding during the CQM test.

6.6 Cleanliness and cleanliness control

The following cleanliness requirements are deduced from the HERSCHEL / PLANCK cleanliness control plan.
The clean room will be compatible with the particulate contamination level of CR-2 and CR-3 §4.3.2 according to the proposed test set-up integration sequences.

The molecular contamination for the total duration of the test during preparation at ambient will not exceed CR-4 & CR-5 §4.3.2.

Contamination witnesses and particulate counter will continuously monitor the cleanliness outside the chamber. Contamination witnesses and spectro-analyser will continuously monitor the contamination inside the chamber. This task including witness analysis is fully under the responsibility of the test facility contractor.

From a contamination point of view, during the warm-up sequence the spacecraft will not be the coldest point. During the return to ambient temperature of the cryogenic shrouds the telescope temperature will be always 50 K (TBC) above the temperature of the shrouds (when lower than 230K). During this phase, the spacecraft temperature will be actively controlled, in particular the temperature of the reflectors (for the FM) and of the Focal Plane Units.

It is agreed by LFI that a flight contamination heater is now the baseline for the FM. Nevertheless for the CQM, provided by Alcatel, is not planned to mount such heater. For the warm-up the simulation of this heater will be done by over boosting the existing heaters used nominally to simulate the power dissipation. In addition it is also envisaged to fill the "precooling loop" with hot helium to warm-up the instruments.

In order to limit molecular contamination of the specimen during the transition phases of the cryogenic shrouds, a cold trap will be installed inside the chamber and in the vicinity of the specimen.
To avoid any risk of moisture condensation on the specimen during the pressure recovery sequence, the following steps will be done:

- Fill the vacuum chamber with GN2 until 300 mbar
- Continue with filtered dry air until 1000 mbar with an adapted atmospheric speed recovery.

Other constraints will be addressed in the Test Requirement Sheet.

6.7 Spacecraft orientation to test the redundant 20K cooler

To operate the redundant 20K cooler the spacecraft will be oriented with its SVM panel +Y/-Z horizontal and facing the ground. (See Figure 6-7).

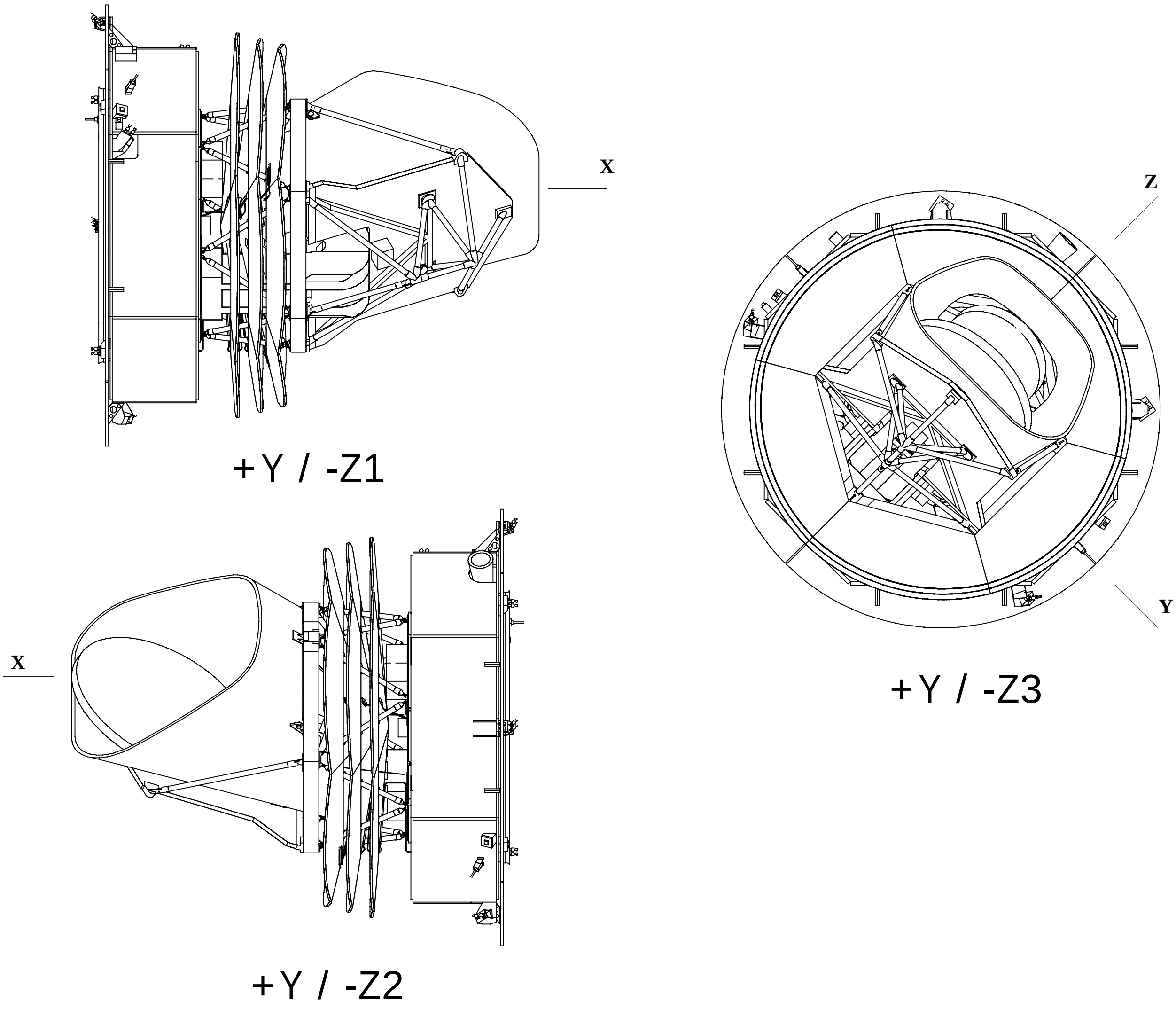
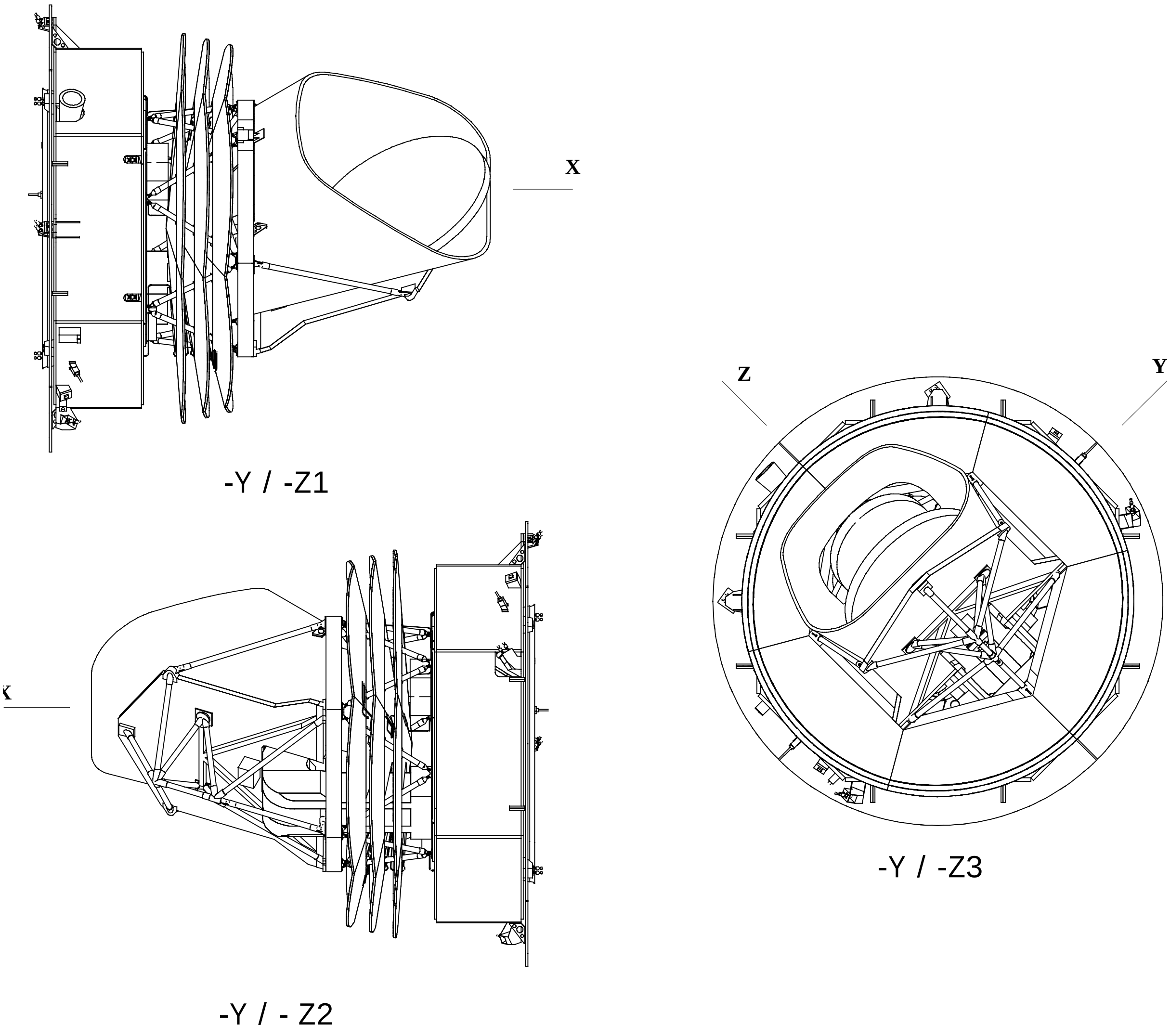


Figure 6-7: S/C orientation to test the redundant 20K cooler.

6.8 Spacecraft orientation to test the nominal 20K cooler

To operate the nominal 20K cooler the spacecraft will be oriented with its SVM panel -Y/-Z horizontal and facing the ground (see: Figure 6-8).

This second configuration shall be confirmed after investigation.



-Y / -Z1

-Y / -Z3

-Y / - Z2

Figure 6-8: S/C orientation to test the nominal 20K cooler.

6.9 EGSE Configurations and interfaces

6.9.1 Configuration of spacecraft GSE for the CQM

6.9.1.1 EGSE configuration

The Figure 6-7 shows the configuration of EGSE used to operate the spacecraft and for performance testing during the STM/CQM test campaign. These EGSE are grouped to form a spacecraft station. The instrument EGSE interfaces with the spacecraft CCS.

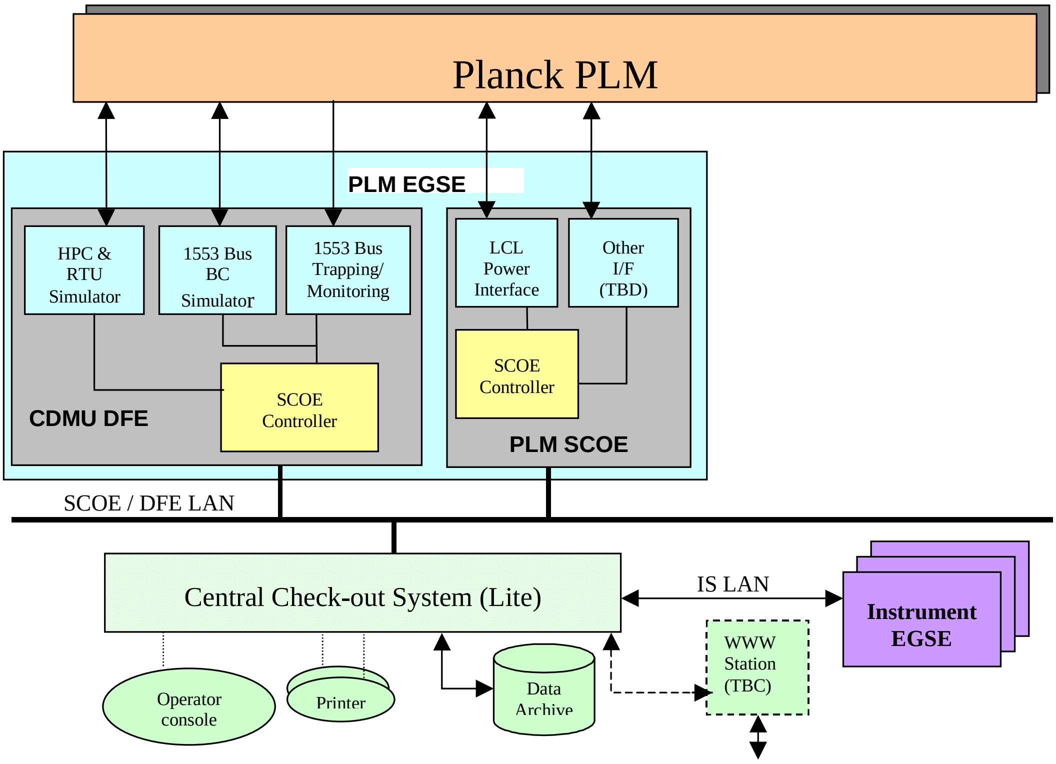


Figure 6-9: S/C Configuration of spacecraft EGSE for CQM

The detailed EGSE configuration for the CQM test is described hereafter.

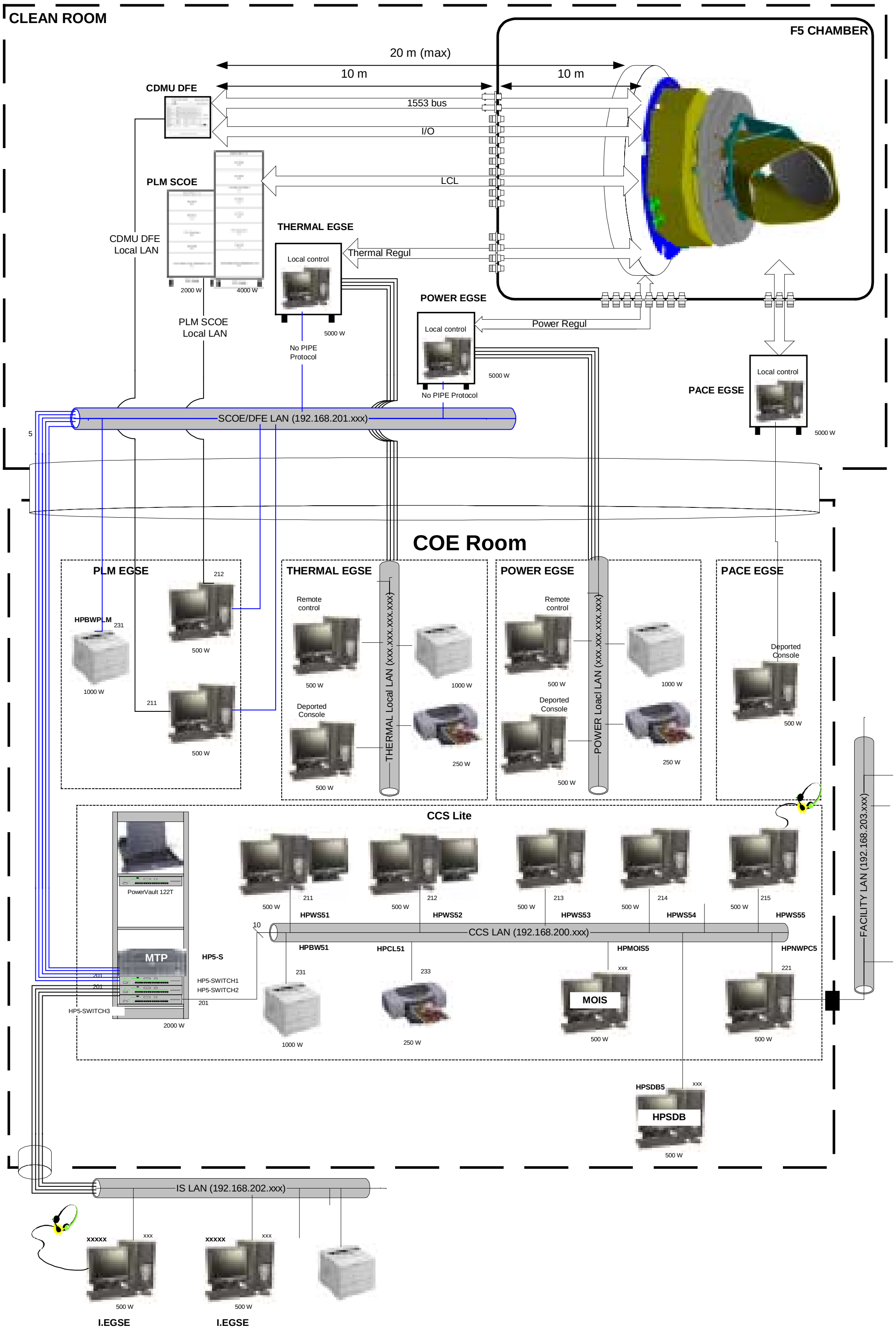


Figure 6-10: Detailed EGSE configuration for the CQM test

6.9.1.2 PGSE configuration

An "ISotope Supply & Storage Pneumatic Ground Support Equipment" supplied by HFI will be used to:

- Fill the 0.1K Focal Plane to low pressure with required isotopes purity (He_3 and He_4).
- Accelerate the cooling down of the HFI FPU with the Precooling loop (in/out).
- Recover and store the He3/He4 mixture during ground tests.

A "PACE Ground Support Equipment" supplied by Alcatel (§7.1) will be used to:

- Fill the hydrogen Piping Assembly and Cold End (PACE) with the requested flow and pressure.
- Exhaust hydrogen coming from the PACE outside the building.
- Monitor and Power-up the PACE temperature sensors & heaters

6.9.1.3 Thermal EGSE

A “Power regulation EGSE” will be used to inject a regulated power to the test heater lines:

- Simulation of instrument H/W power dissipation onto the PPLM and LFI Main Frame STM.
- Power the MTD.

A "Thermal regulation EGSE" will be used to obtain the requested temperature by injection of power (for programmatic constraints this regulation will be done manually based on measurement done by the facility acquisition system:

- Regulation of SVM dummy parts (cone/radiators)
- Upper plateform
- Cryo structure struts I/F with SVMD

6.9.2 Configuration of spacecraft GSE for the PFM

6.9.2.1 EGSE configuration

The Figure 6-11 shows the configuration of EGSE used to operate the spacecraft and for performance testing during the PFM test campaign.

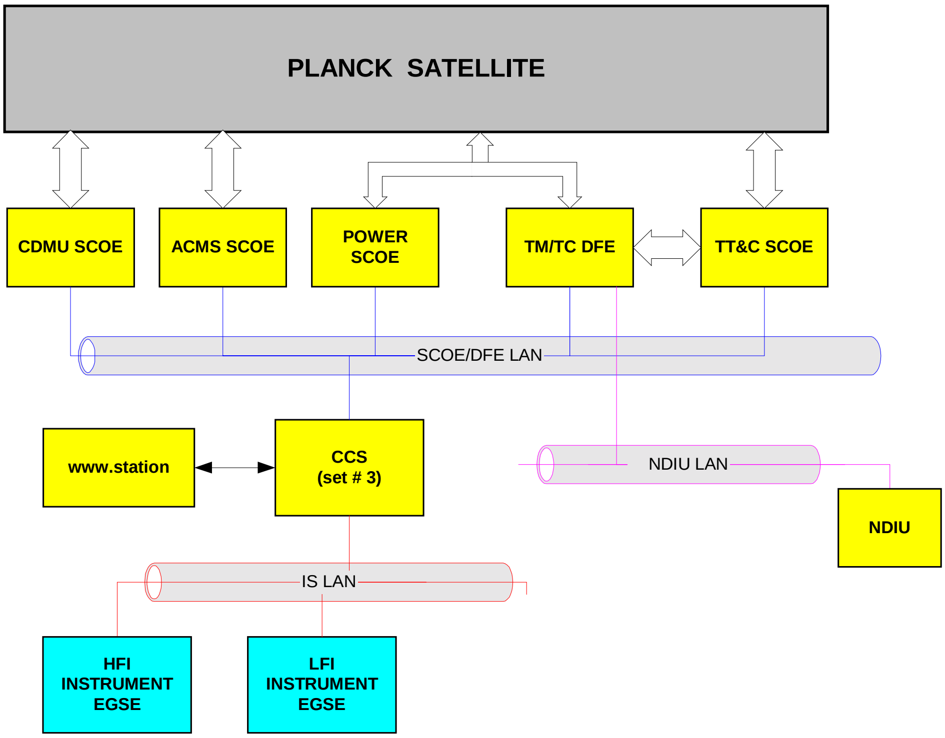


Figure 6-11: Configuration of spacecraft EGSE for PFM

The CCS controls the sequencing of the test and any stimuli required, the experiment EGSE have a passive role limited to monitoring the status of the experiments and of the test. The system level EGSE will take inputs from the satellite in the defined standard formats, build telemetry and telecommand files and the test procedures to be executed at system level. During the system level tests the experiment EGSE is required to support all the tests, the only exception to this being the abbreviated functional test.
In the flight operations phase the experiment EGSE may form part of the system used by the experiment team to analyse the experiment data.

6.9.2.2 PGSE configuration

A "Tank Filing Pneumatic Ground Support Equipment" supplied by HFI will be used to:

- Fill the helium tanks to medium/high pressure with the required isotopes purity.
- Vent the pipes during the integration phase.

An "ISotope Supply & Storage Pneumatic Ground Support Equipment" supplied by HFI will be used to:

- Accelerate the cooling down of the HFI FPU with the Precooling loop ((in/out).
- Recover and store the He3/He4 mixture during ground tests/

6.9.2.3 Thermal EGSE

A "Thermal regulation EGSE" will be used to obtain the requested temperature by injection of power (for programmatic constraints this regulation will be done manually based on measurement done by the facility acquisition system:

- Regulation of solar array
- TRA (TBC)

6.9.3 Vacuum Chamber Interfaces

The Figure 6-12 shows the interface configuration used to operate the spacecraft and for performance testing during the STM/CQM test campaign.

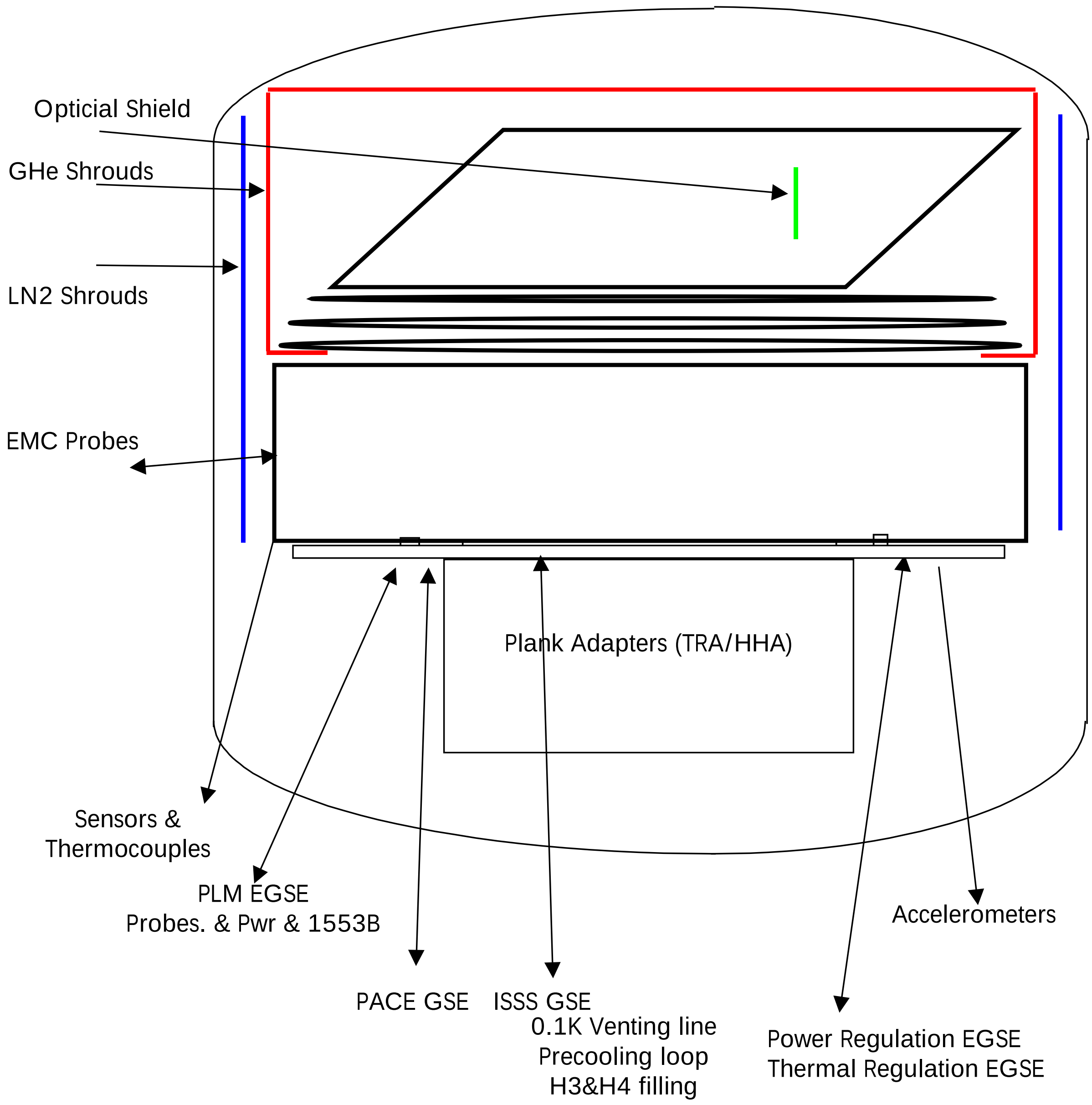


Figure 6-12: CQM Interface configuration

The Figure 6-13 shows the interface configuration used to operate the spacecraft and for performance testing during the PFM test campaign.

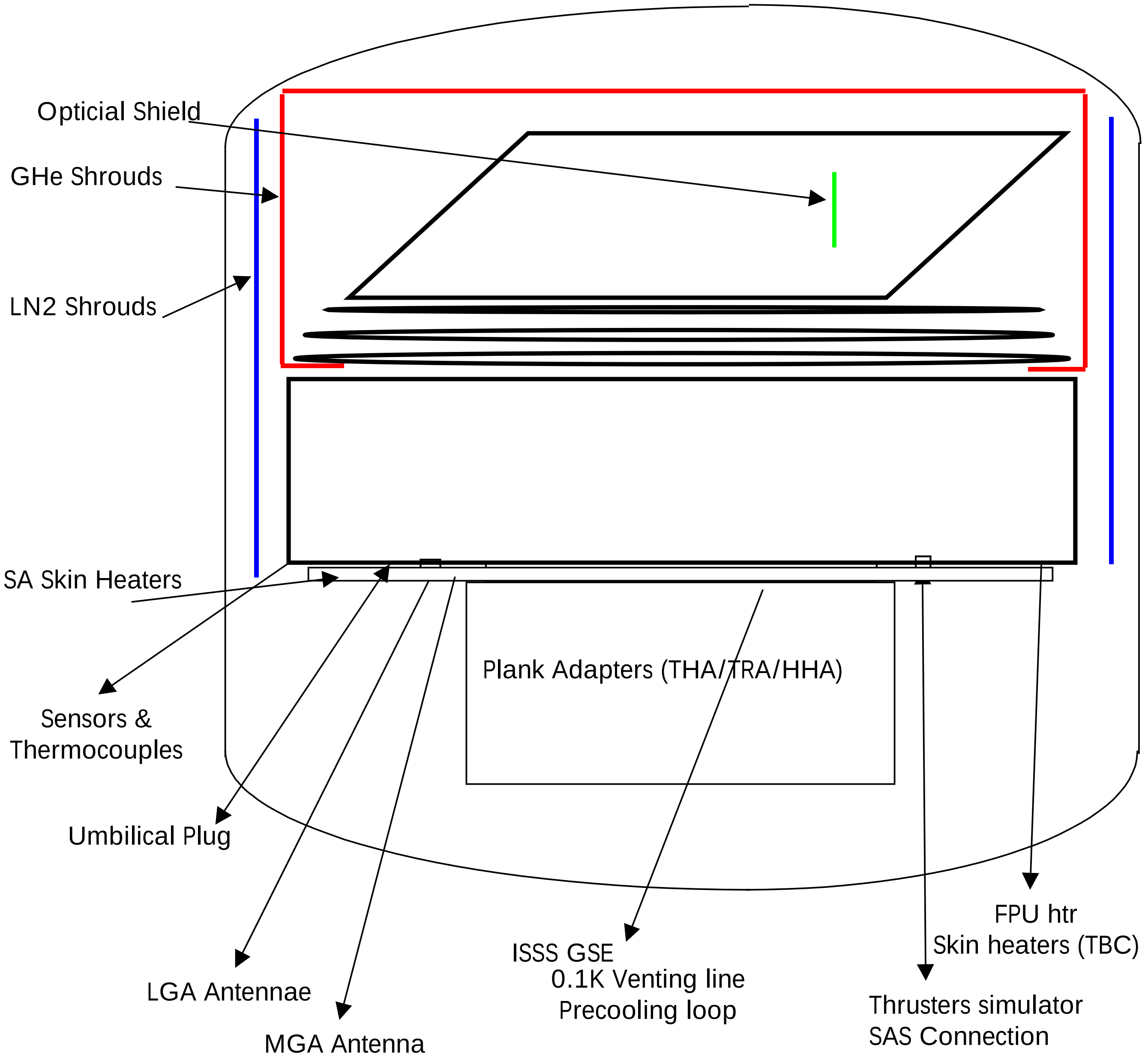


Figure 6-13: PFM Interface configuration

6.10 Test Organisation

6.10.1 *Test Responsibility*

The flowchart hereunder (cf. Figure 6-14) presents the general way and the responsibility in order to perform the Planck Test program.

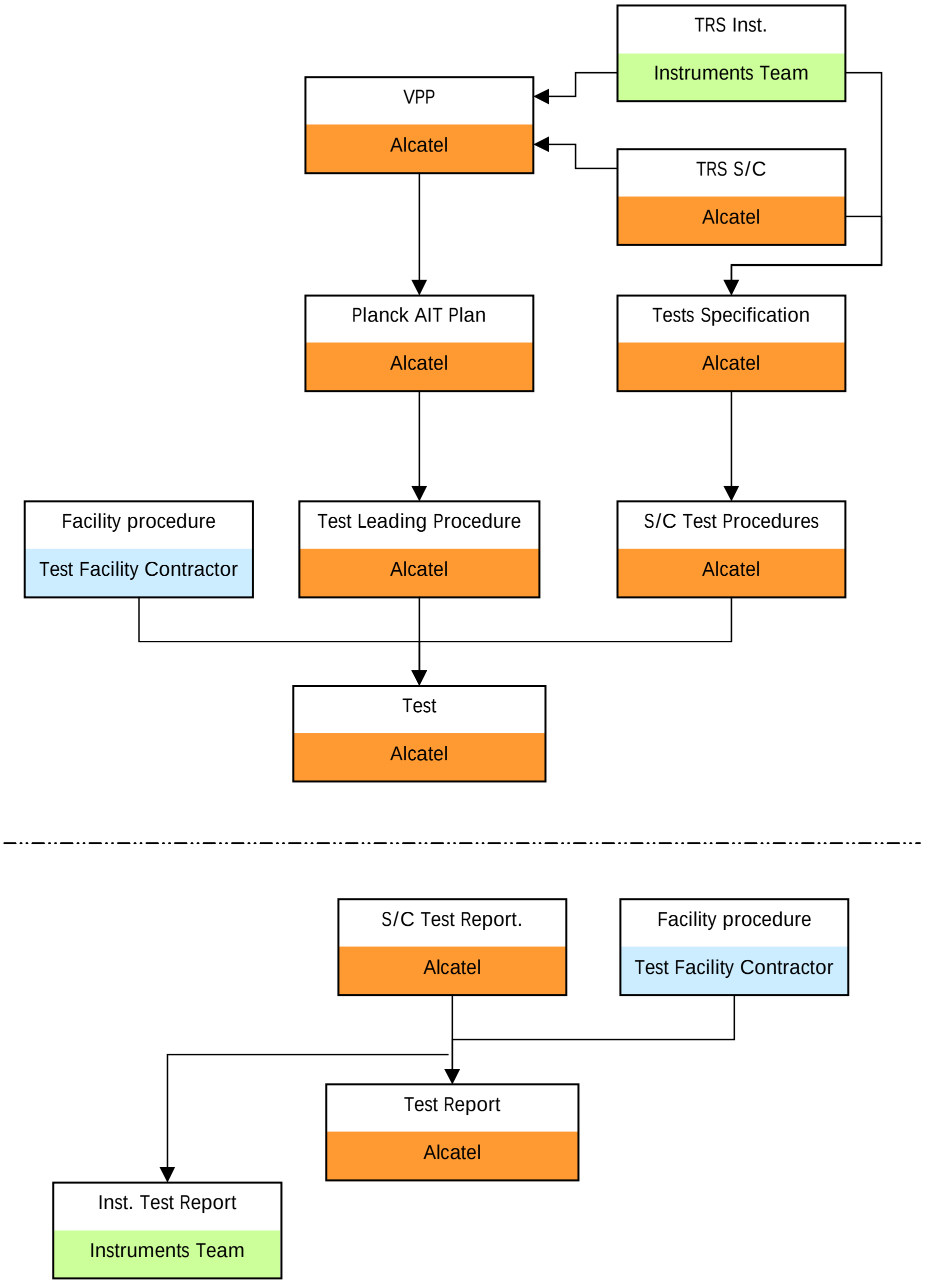


Figure 6-14: Test Document breakdown and associated responsibility

The flowchart on the next page (Figure 6-15) presents in detail the test management with the associated responsibility between Alcatel, the Instrument Teams and the Test Facility Contractor.

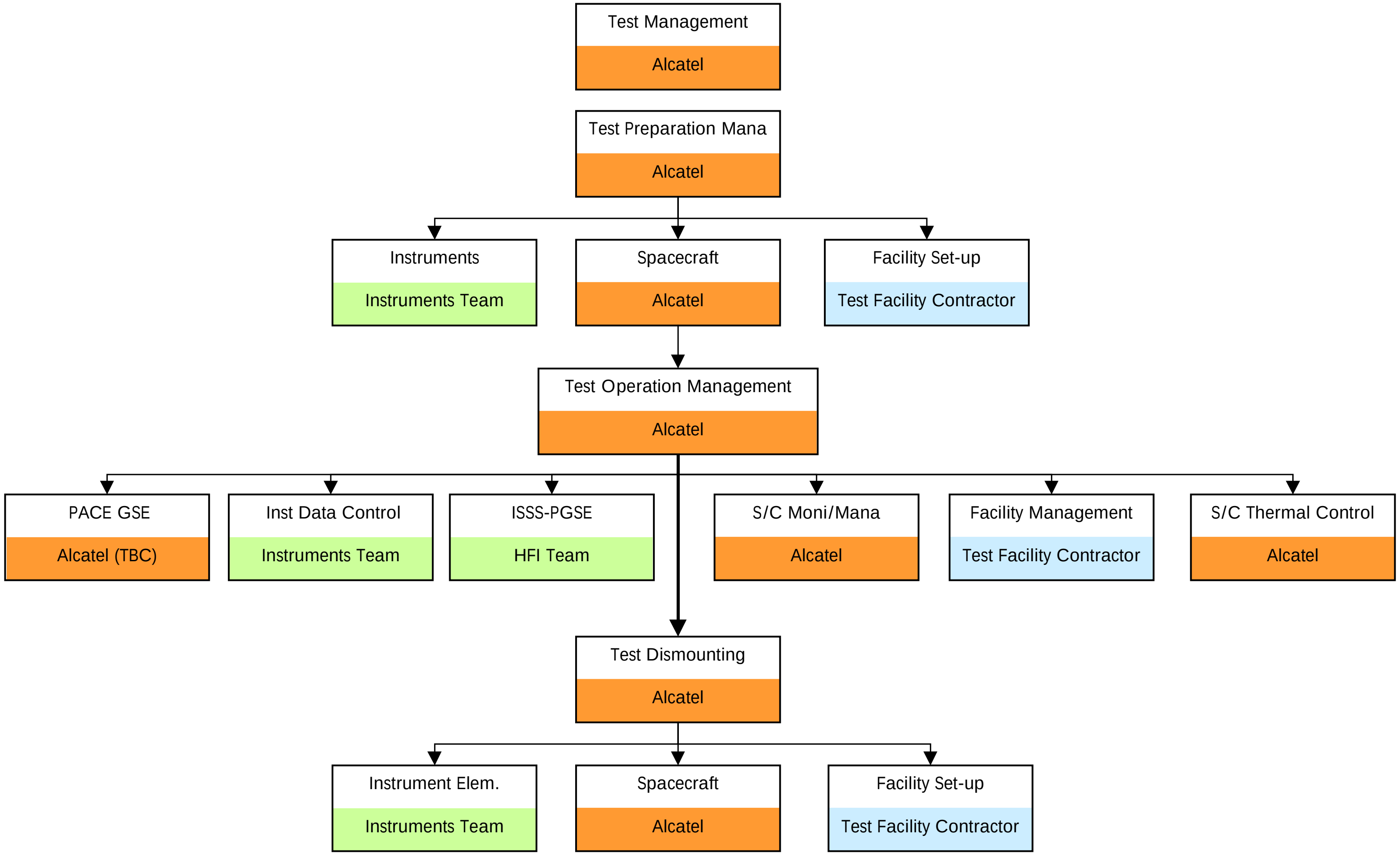


Figure 6-15: Detailed Test management breakdown and associated responsibility

7. ANNEX

7.1 PACE GSE definition

7.1.1 *Introduction*

This PACE GSE system will be provided by the “Air Liquide” France under Alcatel responsibility. This chapter provides a definition of the PACE GSE system with the main interfaces (see Figure 7-1) based on information extracted from “Air Liquide” (ref. RD03).

The PACE GSE is a Ground Support Equipment that will be used during the Planck Spacecraft CQM test at CSL to

- Deliver high pressure hydrogen (typically 48. bar abs, 5 Nl/min)
- Recover low pressure hydrogen (typically 0.4 bar abs, 5 Nl/min)
- Monitor temperature sensors and control heaters of the PACE.

The PACE (Piping Assembly and Cold End) is a part of a closed 20 K loop using a sorption compressor to obtain high-pressure hydrogen and a Joule Thompson orifice (with counter flow heat exchangers in between).
The PACE GSE is composed of:

- The PACE PGSE (Pneumatic GSE)
- The PACE ESGE (Electrical GSE)
- The PACE EGSE is composed of:
  - The electrical cabinet including harness going from/to the electrical/mechanical equipment
  - The PC and the software

7.1.2 *Description of the PACE GSE*

The Figure 7-1) shows the Process & Instrumentation Diagram (PID) of the PACE GSE.

The B50 cylinders will be installed outside the CSL buildings within 4 racks of 9 to 12 B50 cylinders each. All the cylinders inside a same rack shall be manifolded together and the manifold shall end by a main isolation valve (V1a & V1b on the proposed PID).

The equipment installed near the cylinders is used to clean the PACE GSE and to reduce the pressure in order to have a lower (and nearly constant) pressure in the pipes going through the CSL building. The piloted valve FV060 allows to keep the pipe in pure gas during storage and to stop the flow near the B50 source in case of H2 detection in the CSL building.

The interfaces I2, I3, I4 and I5 are of the ‘quick connect’ type (female part on the GSE and male part on the external tool). They are tight when connected or disconnected; however isolation valves (HV050, HV110, HV250, HV450) remain the main ‘tightness’ barrier.

The PR080 mechanical pressure regulator expands the gas from the upstream pressure (in the range of 60 to 200 bar) to 57 ± 2 bar. This allows to have a limited pressure in the pipe going through the CSL building. The P070 and P080 pressure gauges allow to know the upstream and downstream pressure.

The BD090 burst disc and the SV090 safety valve allow to keep the pressure lower than 71 bar in the pipe going through the building, in case of failure of PR080. The burst disc allows to have a perfect tightness whereas the safety valve allows to close again the line after the burst of BD090 and pressure reduction. The pressure gauge between these 2 pieces of equipment allows the operator to verify that the burst disc is not burst.

The HV100 valve allows to isolate the PACE GSE during storage and transportation. The FT100 0.5µ filter allows to filter particles. This filter also allows to limit the flow rate in failure scenario due to operator errors. The FV140 valve is an on/off air controlled valve that is normally closed (fail safe position) and which allows to stop the flow in case of failure detection (over pressure, H2 detection, power breakdown….). The FV500 and FV700 valves at the inlet and outlet of the PACE GSE recovery line have the same function as FV140 and FV060.

The PR180 pressure control valve allows the user to control the supply pressure measured by the PT180 sensor. The MFT160 mass flow meter allows to measure the mass flow rate supplied to the PACE (the mass flow rate is nearly linear with the inlet pressure due to the Joule Thomson orifice of the PACE).

The GT200 purifier and its associated inlet/outlet valves and outlet filter (0.003µ) allow to trap H2O contained in N60 gas (up to 0.5 ppmv) and, in addition, some dozens of ppb of other contaminants (O2, CO, CO2, CnHm, ….).

The HV150 hand valve allows to by-pass the PR180 pressure controller and the MFT160 mass flow meter during the out-gassing phase done by vacuum pumping (because they create large pressure drops).

The HV230 hand valve allows to by-pass the GT200 purifier during the cleaning phase in order to avoid saturating the purifier with contaminants.

The connection between the PACE PGSE and the vacuum chamber I/F port will be done with rigid pipes, whereas the connection between the vacuum chamber I/F port and the PACE I/F will be done with the FHP02 and FHP03 flexible hoses.

The 5 manual valves located in the vacuum chamber (HV300, HV370, HV400, V20 and V30) are used only during the integration and cleaning phase. HV370 is closed during the use of the GSE with H2 whereas the 4 other valves are open.

On the pressure recovery line, the DV600 back-pressure control valve allows the user to control the upstream pressure measured by the PT600 sensor that has a low pressure range and only accepts a low overpressure. In case of overpressure detected by the other PT500 pressure sensor of the outlet line, the FV500 valve is closed.

The MFT620 flow meter allows measuring the recovered mass flow rate (it should be the same as the supplied flow rate if there is no leak and if the outlet pressure is kept constant). On the long term (several hours or days), the H2 mass through MFT160 and MFT620 may be compared by the PC in order to allow the detection of a large leak.

The H2O sensor allows detecting when the line is cleaned during the cleaning phase (with HeG) and verifying that the H2 gas is not contaminated by external air during the use of the PACE. If contamination is found, the PC puts the GSE in fail safe mode.

The HV630 hand valve allows to by-pass FV500, the DV600pressure controller, the H2O sensor and the VP640 vacuum pump in case of momentary loss of power (or loss of control that would lead to stop the pump and to close the piloted valve). This valve is also used during the cleaning phase to clean the part between BD490 and CV510 and to clean the venting line up to the chimney before starting the vacuum pump.

The CV800 check valve prevents air from entering the pipe (when the pump is not working) whereas the flame arrestor located at the chimney vent allows to prevent flame diffusion in the outlet pipe in case of inflammation of the vented H2 (which is not burned nominally).

All the pieces of equipment of the PACE PGSE are located inside a dedicated gas cabinet. This gas cabinet is air ventilated and some analysers (H2 sensor + flame detection) are installed near the aspiration pipe to detect the presence of H2 or flame. A H2 detector is also installed directly into the vacuum pump housing to avoid any H2 within the air used to ventilate the motor of the pump.

The 10 PACE temperature sensors (of the CERNOX type) located on the PACE inside the vacuum chamber are conditioned by a specific conditioner/transmitter located on the EGSE cabinet. This conditioner electrically supplies the temperature sensors, converts the signal coming from the sensors into Kelvin and sends the temperature data to the PC.

The 3 heaters located on the PACE (JT, F9 and LR3) inside the vacuum chamber are piloted by the PC and electrically supplied through the PACE EGSE cabinet.
A passive cooler allows controlling the temperature at the inlet of the PACE I/F. The PACE Heat Exchanger will reduce the temperature of H2 from room temperature down to the SVM temperature (260 K min). The PACE Hex also includes an on/off manual HV20 valve and a FT300 filter used to prevent contamination of the PACE between its installation into the SVM at ALCATEL and the test at CSL. On the outlet pipe a tube with a HV30 valve allows interfacing the PACE I/F with the pipe coming from the PGSE.

The 2 pressure controllers, the VP640vacuum pump, the 4 air operated valves and the 3 PACE heaters are controlled through a PC located near the PACE GSE or through a PC located in the control room. The GSE is also able to receive status from the H2 analysers located in the PACE GSE's building and from the CSL analyser (mass spectrometer) located in the vacuum chamber. The signal from these analysers goes through the PACE EGSE

The 2 PC is able to communicate together through an Ethernet link.

The PC is also monitored the status of the H2 and flame detector located at the (air) outlet of the PACE PGSE's air ventilated cabinet.

An emergency push button allows the user to put the PACE GSE in fail safe mode either from the EGSE cabinet (located aside or on top of the PGSE cabinet) or from the PC.

The transmitters are linked to the PC either by a serial link or by input/output Fieldpoint communication module. The operator nominally controls the GSE from the PC. However the 4 air operated on/off valves, the 2 PACE on/off heaters (H33 and H36 or their redundant H34 and H35 heaters) and the VP640 vacuum pump can be also switched on/off by the operator from the EGSE cabinet directly.

Some monitoring is also performed to try to detect what could be the beginning of a failure :

- comparison of the inlet/outlet mass computed by the inlet/outlet mass flow
- comparison of all the signals with predefined ranges

In case of detection, warnings are sent to the user, but the GSE is not stopped.

In case of failure (pressure out of upper range, H2O over and upper range, H2 signal over an upper range, watchdog detection), the PC put the GSE in the fail safe mode? In that case, the 4 air operated on/off valves, the 2 PACE on/off heaters (H33 and H36 or their redundant H34 and H35 heaters) and the VP640 vacuum pump are switched off.

In case of watchdog detection, H2 detection or stop of the air extractor, the safety relay puts the GSE in fail safe mode and also sends a signal to the PC.

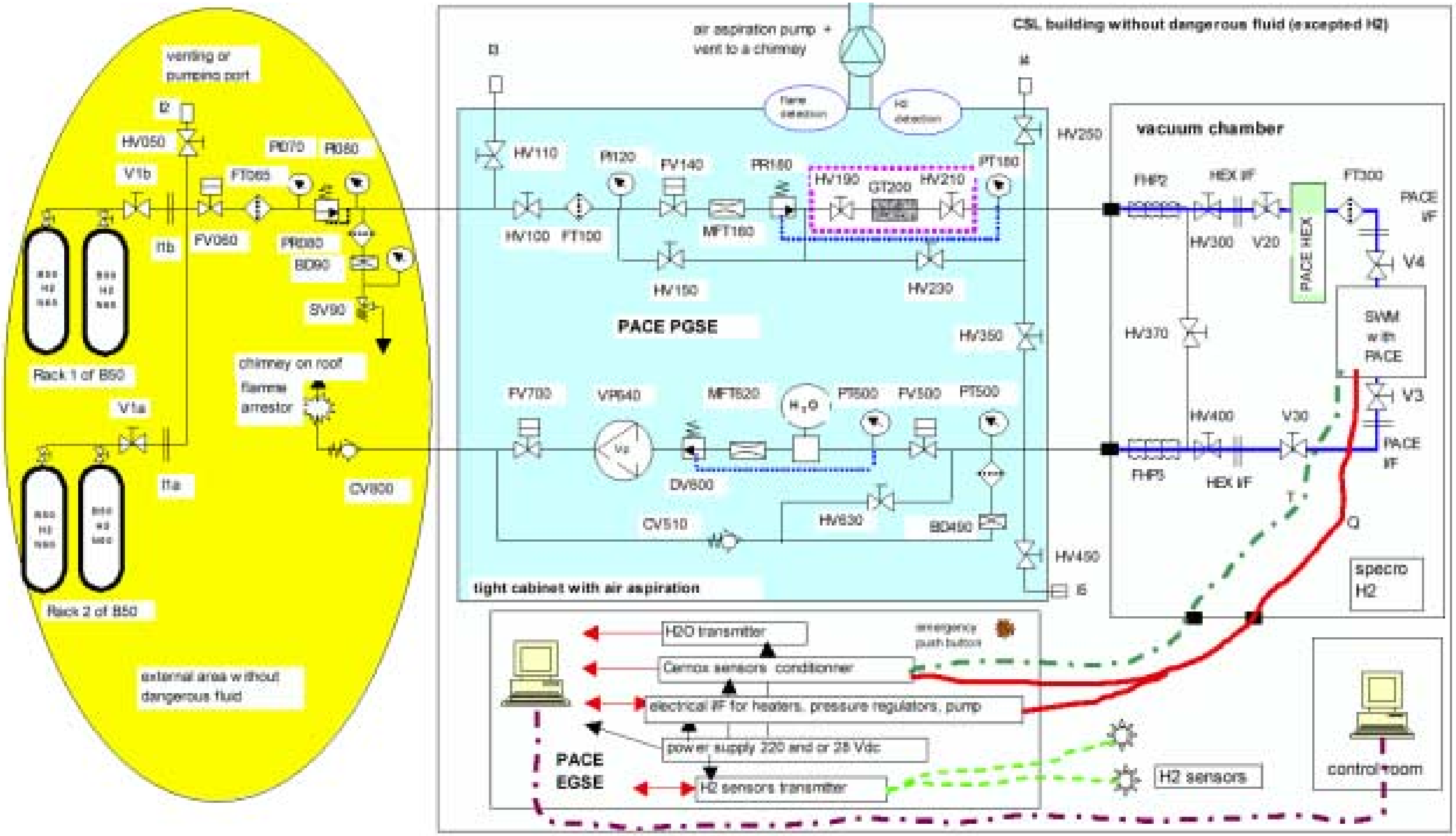


Figure 7-1: PACE-GSE Process & Instrumentation Diagram

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