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HERSCHEL / PLANCK

Design & Development Plan
DDP
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1 INTRODUCTION

The Herschel/Planck Design & Development Plan (DDP) proposes a development and testing philosophy insuring a consistent approach to requirements verification and qualification of the satellites, modules, subsystems and units providing a high level of confidence on achievement of the scientific mission objectives.

After consolidation and further refinement in Phase B and beginning of Phase C, it will be the basis to issue the Verification Programme Plan (VPP) (refer to chapter 9) as illustrated by Figure 1.

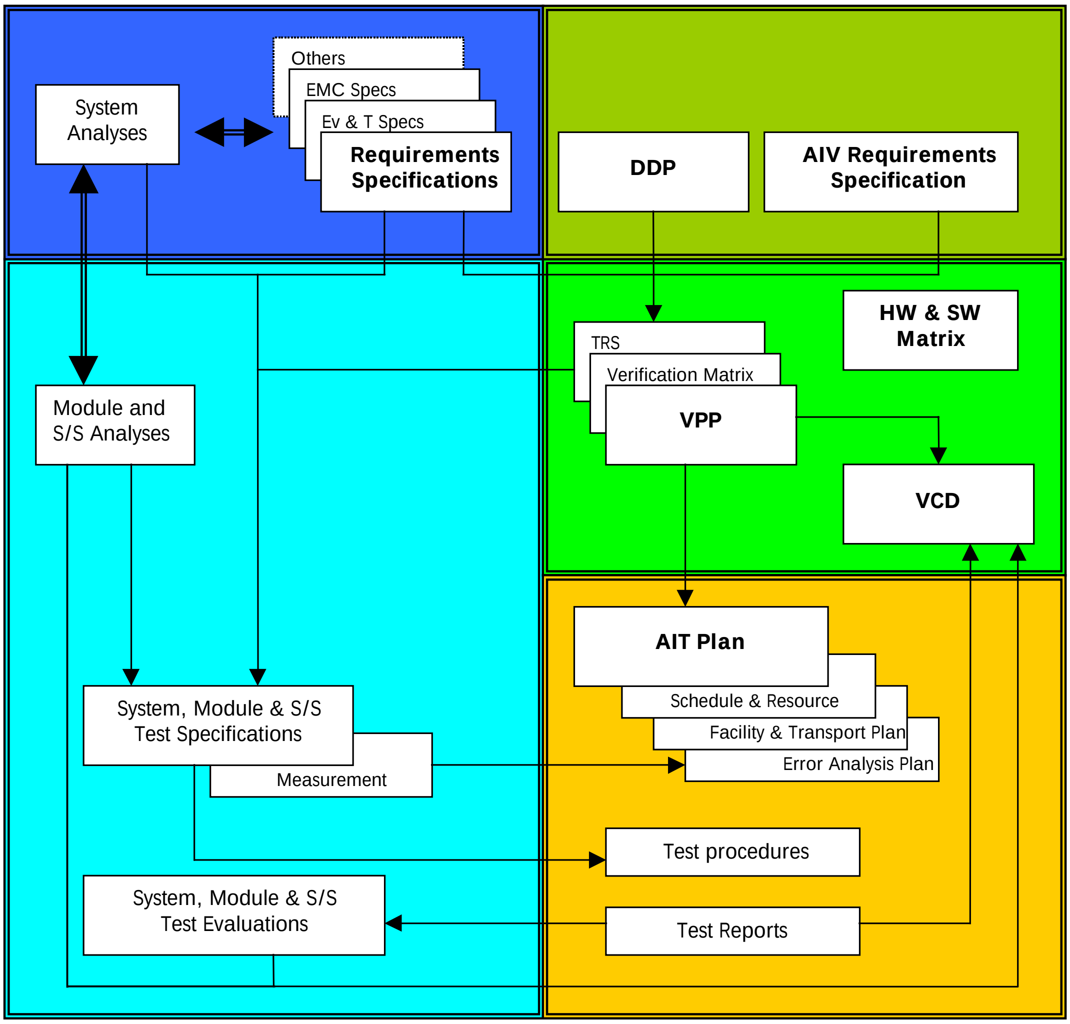

Figure 1. Verification logic and links

It consequently defines the models necessary at each level to achieve the mission objectives, the verification needs and the delivery of required hardware/software.

The DDP is built considering the following guidelines and constraints:

- to meet the specificity of the two payloads, in particular the severe cryogenic constraints of the various instruments
- to prevent Herschel and Planck Payloads including the FPU's from molecular and particulate contamination risks
- to provide flexibility for the instrument development, assembly, testing and calibration
- to achieve the design, manufacturing, assembly and testing of the two payloads and satellites in order to be launched together with the same flight in mid February 2007.

To meet these requirements the DPP is based on:

- maximum use of existing expertise, experience and heritage in order to introduce the concept of verification in the design
- modular concept (Telescope Assembly, PLMs and SVMs) with simple and limited interfaces allowing as far as possible separate design, development and test of each module
- Herschel concept and testing inherited from ISO. The use of the ISO experience, analysis and test results, as well as both on-board or GSE hardware has been permanently considered
- safe and reliable designs which rely on simple and proven concepts or technologies, supported by extensive and early analysis, simulations and trade-offs
- maximum use of flight proven equipment units for the service modules

- design of Herschel and Planck SVMs as similar as possible (at least by using the same architecture and technology) allowing minimum development, common procurement, common spares and common qualification and development tests.
- strong test programme allowing early verification and qualification at equipment, subsystem and module levels for early resolution of potential problems with appropriate schedule contingency
- independent software validation and early functional interface tests
- minimum number of models with maximum reasonable re-utilisation
- early definition and selection of existing test facilities with regard to the specific mission requirements (cryogenic and RF tests)
- cleanliness plan based on a design offering as far as possible cleaning possibilities and on a maximum use of protective covers
- maximum communality and use of the ground support equipment including during the launch campaign
- tight co-operation with the experimenters: integrated teams for design interfaces in Phase B, integration and testing all along Phase C/D.

2 APPLICABLE AND REFERENCE DOCUMENTS

2.1 APPLICABLE DOCUMENTS

AD1-1	**Herschel/Planck System Requirement Specification (SRS)** Document no. SCI-PT-RS-05991
AD1-2	**Herschel/Planck System AIV Requirement Specification** Document no. SCI-PT-RS-07430
AD1-3	**Herschel/Planck Product Assurance Requirements** Document no. SCI-PT-RS-04683
AD1-10	**Instrument Interface Document, Part A (IID-A)** Document no. SCI-PT-IID-A-04624

AD2-1	**ARIANE 5 User's Manual** Issue 03 Rev. 00 Date: Mar 2000

AD3-5	**Cleanliness Requirements Specification** Document no. H-P-1-ASPI-SP-0035
AD3-14	**Environment & Test Requirements Specification** Document no. H-P-1-ASPI-SP-0030
AD3-19	**EMC/ESD Control Plan** Document no. H-P-1-ASPI-PL-0038
AD3-20	**EMC Requirements Specification** Document no. H-P-1-ASPI-SP-0037
AD3-25	**Technical description of RF test proposed in the ALCATEL Compact Antenna Test Range** Document no. H-P-3-ASPI-TD-0054
AD3-45	**Specification of Facilities for Planck Cryogenic Test Sequence** Document no. H-P-3-ASPI-TS-0051

2.2 REFERENCE DOCUMENTS

RD1	**Risk Analysis** Document no. H-P-1-ASPI-RA-0069
RD2	**Lessons learnt – Strategy Plan** Document no. H-P-2-ASED-PL-0006
RD3	**Herschel TB/TV Test Trade-off** **Qualification Test Phase** Document no. H-P-2-ASED-TN-0036
RD4	**Herschel STM Thermal Balance Trade-off** Document no H-P-1-ASPI-TN-0047
RD5	**Herschel Alignment Concept** Document no H-P-2-ASED-TN-0002
RD6	**Planck Alignment Plan** Document no H-P-3-ASPI-PL-0078

3 ESSENTIAL REQUIREMENTS

3.1 MISSION REQUIREMENTS

In terms of Design and Development, the Herschel/Planck programme consists in two satellites with independent missions but launched together on the same ARIANE 5.

The chosen dual launch configuration allows to perform the development of each satellite independently. However, the commonality of the two SVM authorises important rationalisation of the test sequence and of Ground Support Equipment (GSE).

For Herschel and Planck satellites, the number and the intricacy of the on board instruments working at cryogenic temperature contribute to the complexity of the development. Consequently the verification flow shall be sufficiently flexible to adapt to potential problems with minimum impact on the final delivery date.

In most of cases, because of the need of cryogenic environment, end to end performance tests of the scientific payloads will not be possible at system level. The verification plan shall take into account such a constraint in order to insure that the performances are verified as totally as possible at other levels and that nothing can degrade these performances at system level.

The cryogenic temperatures required for the two missions are very constraining in terms of cost and schedule for the on ground tests. The development approach is built with emphasis on rationalisation and simplification of cryogenic tests at each level (from equipment to system), without affecting the confidence in the performance of the system.

Consequently:

- the schedule is made flexible by means of:
  - margins to integrate the technical risks
  - contingency period at the end of system AIT sequence.
- The validation sequences of the Satellites have to be reinforced by:
  - advanced validation of design by using other models than the Flight Models themselves

  - advanced validation of AIT tools (EGSE, test procedures, test sequences...).
- The qualification is achieved as early as possible by means of:
  - specific qualification or pre-qualification models
  - flexibility in the model philosophy such that it induces a high level of reactivity.
- The long duration of the development phase of the experiments is compensated by an adequate development plan at each level allowing overlapping of their development with the Satellites' one.
- The modular concept of the two satellites allows separate testing and flexibility in the overall AIT sequence.

3.2 EXTERNAL CONSTRAINTS

The following constraints imposed by the Agency have been taken into account:

a. The model philosophy of instruments and associated EGSE to be delivered.

=> overall model philosophy

b. The model philosophy of Herschel telescope and Planck reflectors (ESA furnished equipment: EFE) to be delivered.

=> overall model philosophy

c. The request to return CQM instruments and QM Planck reflectors at the end of utilisation for system test.

=> development and overall schedule.

d. The ESA requirement for flight spares of all units of the Herschel and Planck SVM.

=> model philosophy of SVM units

e. The use of Agency specified launch vehicle: ARIANE 5 ESV.

=> environmental test sequence.

f. The imposition by the Agency of major milestones in the programme (kick-off, instruments and EFE delivery, spacecraft delivery, launch date).

=> development and overall schedule.

g. The ESA requirement for a radio frequency model of Planck.

=> model philosophy of Planck

3.3 RISK ASSESSMENT

In the frame of the Phase B, a technical risk analysis has been initiated at Satellite and Module levels in order to put the right effort of development on the right points. The results and the action plan will be provided in document [RD1].

This document will define a risk reduction action plan for each critical item identified. It will clearly identify the milestones (in term of events and dates) to be followed in the schedule. Success or acceptance criteria shall also be identified (such as review completion, activity completion, H/W or S/W installation, …) to allow a detailed follow-up and formal closure for each action.

After completion of [RD1], it will supersede this paragraph as well as paragraph 7.2.

From the present definition, the following technical risks and consequently pre-development and/or advanced analyses in Phase B are identified.

3.3.1 Risk analysis for Herschel

– ACMS

  The main risk identified is the schedule impact due to its development duration. In order to secure the schedule, in Phase B, an important effort of the Core Team will be devoted to issue a detailed design and complete and coherent requirement specifications down to ACC as inputs for the ITT of this subsystem. It will required, as part of the ACMS ITT, that first issues of Equipment Requirements Specifications will be included in the proposal.

  This effort will also cover the verification aspect; the requirement verification method and tools will be specified.

– E-PLM Cryostat

  The E-PLM cryostat is based on the re-use of ISO technology. Apart following points, no area has been identified as critical for the mission.

LOU Optical Channel Windows

A pre-qualification phase is necessary before the start of phase C/D:

- to determine the characteristics of such windows in term of thermal and optical properties

- to qualify them regarding the space environment

The safety aspect will be addressed in this phase.

LHe Valves

Astrium recommends an improvement of the ISO LHe valves; thus a pre-qualification in phase B should be foreseen and the MAIT of the Liquid Helium Valves have to be started in the advanced Phase C/D.

He II tanks

Based on ISO experience, the main risk is the tightness. The tank material procurement will be part of the first ITT batch at the beginning of Phase B in order to prepare the tank manufacturing in early phase. Two tanks will be manufactured in parallel, in case of problem on the first one, the turning over of the second one in flight model can be done in two months without impacting the overall schedule thanks to time reserves presented in the schedule report.

Cryogenic Harness

The early start of MAIT activities for this critical and non-usual equipment is a prerequisite for the completion of the program in the given time limits. The PFM Cryogenic Harness will be installed for the mechanical and thermal test campaign on Herschel STM.

– CDMS

The main risk identified for the CDMS is the 48 hour-autonomy implying the storage of the mission timeline on-board for 48 hours. As for the ACMS, the Core Team will issue a complete CDMS and CDMS SW requirement taking into account these aspects for the on board Timeline Memory and Mass Memory sizing via suitable margins allocations, and FDIR design.

As far as FDIR is concerned, a dedicated software simulation, based on a specific tool (UML), of the selected implementation will be carried out as early as in phase B, thus permitting an advanced and exhaustive validation of the FDIR cases.

– Solar Arrays cells

The procurement of the Planck Solar Array and of the Herschel Sunshield will be co-ordinated. The Planck Solar Array and the Herschel Sunshield can be based on cells using dual or triple junction GaAs technology. The choice of different solar cells for Planck and Herschel is at time being left open, although cost and risks assessment should naturally lead to selection of a single cell supplier.

Analysing differences in design with cells already qualified or under qualification, the relevant sub-contractor will issue a specific Design & Development Plan for Solar Cells. This plan will reflect the complementary or full qualification tests to be performed to take into account the Planck Solar Array and Herschel Sunshield environment and designs.

Results should be available for the CDR.

The other SVM subsystems such as structure, RCS, power and telecommunication are not critical. These subsystems will, as far as possible be able to profit from their heritage of previous programmes and will use exclusively proven design, material and technologies, so no pre-development is necessary in this area.

3.3.2 Risks analysis for Planck

– Planck PLM (PPLM) temperature level and stability

The thermal performances of the passive stage of the PPLM are one of the main challenges of the design and development of Planck. These performances will be verified at an early stage in the program thanks to the specific cryogenic test to be performed on the STM/CQM of Planck.

The cooling of the PPLM and the need to reach a temperature of 0.1 K for HFI detectors is a key for the success of the Planck mission. The thermal design to reach this functional temperature is obviously sensitive to the thermo-optical parameters of the coating.

In order to consolidate the design of the thermal control and to reduce uncertainties of analytical predictions the following programme is proposed:

- measurement campaign of thermo-optical characteristics of emissive coatings at low temperature. This campaign will help to select the coating of the main radiator (external side of the telescope baffle and top side of groove 3), and to reduce uncertainties in the thermal performance prediction. The emissivity of potential candidate coatings is presently being measured on samples and at cold temperature,

- measurement campaign of thermal conductivity characteristics of the grooves face-sheets,

- to reach the emissivity performance of 0.9 at 50K, an optimisation of the geometrical pattern of the emissive surface associated to the coating efficiency must be done. Samples will be manufactured in order to qualify the manufacturing processes and to measure the performances of the emissive surface.

The improved knowledge of these sensitive parameters (emissivity and thermal conductance) associated to an optimisation of the geometrical pattern will allow assessing by analysis (with relevant uncertainties) the thermal performances of the passive stage of the PPLM prior to the cryogenic test where they will be verified and confirmed.

Additional information regarding these parameters will be obtained through the thermal test to be performed on the Cryo-structure and baffle.

The alternative to built a scaled down model of the PPLM is not retained due to the main drawback of the implied scale factor leading to increasing the uncertainty factors on the results of the analysis. The other drawback is that this scaled model shall be done in parallel to the STM/CQM sequence to be representative and consequently will not secure the schedule by managing two models at the same time.

– Thermal links between PPLM and SVM

The strong thermal links between PPLM and SVM due to instrument design induce to perform all thermal and cryogenic tests at Satellite level. This is solved by the availability of the SVM in due time with time reserves in the schedule and Primary Structure model philosophy (refer to § 6.2.1).

– Straylight reduction

The straylight rejection is the key parameter of the Planck mission performance. The design optimisation and the performance prediction requires accurate computation then measurement of the far field and near field radiated patterns over all the space for attenuation factors between 65 and 98 dB.

On one hand, the existing RF or optical software are not optimised for such an application and shall be used with care because they are not exact solvers and lot of simplifications is needed to meet reasonable computation time.

On another hand existing facilities do not cover individually all the requirements for RF testing of Planck and there is a lack of experience for such accurate measurements in a large spectral band and for a very large angular space.

The Radio Frequency Measurements planned on the Radio Frequency Qualification Model are planned as early as possible in phase C, when the QM telescope equipped with QM reflectors becomes available. Taking into account the criticality of the straylight for the mission, this RFQM test is judged too late to allow design modification and mainly test facility adaptation. So a development programme is proposed in phase B with the objective to validate very early both computation and measurement methods in the domain of application of Planck.

The principle of this validation is to compare model results with measurements on the existing reflectors from ARCHEOPS instrument. The output of such a validation will be:

- verification of software performance through
  - accuracy of the model
  - limits of the model
- limits of the model
- authorised/non-authorised simplifications for the modelisation
- demonstration of measurement feasibility
- validation of the facility and/or definition of necessary improvements.

The model used for this validation is called Radio Frequency Development Model (RFDM). It is made of ARCHEOPS reflectors mounted on a dedicated structure made together with a baffle dummy shape identical to Planck one. It is not fully representative of the Planck geometry but this is not mandatory with the here above objectives.

– PPLM integration

  This risk has already been identified in the previous studies. The integration mock-up developed by ALCATEL in 1999 was aimed at analysing this aspect. It has induced improvements reflected in the present design of the PPLM. This constraint has been taken into account in the trade-offs performed in particular regarding the grooves angle.

– Micro-vibration perturbations for the dilution cooler in flight and during on ground tests.

  This point and the relevant solutions are well known in ALCATEL from previous satellite projects. Specific analysis will be performed early in Phase B to consolidate the relevant solutions applicable to Planck objectives.

– CDMS

  Refer to Herschel in § 3.3.1.

– Thermal Control (Heat pipes)

  The heat pipes used for the sorption cooler radiator will be used with a power density above the one for which the available heat pipes on the market are qualified. So a complement of qualification is planned for this item early in Phase C.

– ACMS for spun satellite

  The main risks are the nutation monitoring/control, the attitude control during delta-V manoeuvres and the wobble impact. Based on Meteosat and MSG programmes and in the frame of the Avionics effort of the Core Team in Phase B, these aspects will be taken into account. Detailed design and complete/coherent requirement specifications down to equipment level will be issued. The wobble budget will be established and maintained up to date by the Prime Contractor.

3.3.3 System performances not verifiable by a global or End to End test.

According recommendation of the "ISO Lessons learnt", this paragraph presents the risk analysis on main system performances not verifiable by a global or End to End test. These main system performances are the following:

Herschel	Planck
Herschel optical performances	Planck optical/RF performances
Herschel instruments alignment	Planck external straylight (telescope RF diagram)
Herschel straylight	Planck internal straylight (telescope RF diagram & temperature fluctuations)
RF pattern of the TTC antennas	RF pattern of the TTC antennas

For each performance, the level where the verification is done and the used method are described. This approach aims to minimise the risks and to evaluate with a high accuracy the final performances of Herschel and Planck Satellites.

This approach will be supported by Analysis Requirement Sheet (ARS) covering also other specific performances not verifiable by global testing and to be listed in the Verification Program Plan (VPP).

3.3.3.1 Herschel

Optical performances

Verification level / method
Verified at telescope level in cold condition.
Alignment of the telescope with the cryostat (see next item)
Control of the alignment stability of telescope mirrors at system level.

Risks assessments
Same philosophy as the one used on ISO.
The risk is reported on the quality of alignments at instrument and spacecraft levels.
(See next item)

Instruments alignment

Verification level / method (Refer to [RD5])
Performed in several steps by theodolite measurements:

- alignment of instruments w.r.t. the optical bench (ambient).
- alignment of optical bench w.r.t. the cryostat vacuum vessel (ambient and cryostat cooled)
- alignment of the telescope w.r.t. the cryostat vacuum vessel (ambient).
- Misalignment in thermal vacuum verified by analysis.

A more direct control is possible through the HIFI-LOU alignment windows (HIFI-FPU w.r.t. CVV or telescope)

Telescope verified separately in cold conditions

Risks assessments
Acceptable due to low sensitivity of the optical performance to dimension change

Straylight

Verification level / method
Verified by analysis through a complete ASAP model from instrument to the telescope including cryostat, baffles and interface structures.
Measurement of the dark background seen by instrument inside the cryostat, (thank to a MGSE providing a cold plate at the entrance of the cryostat)

Risks assessments
Classical philosophy as used on ISO

RF pattern of the TTC antennas

Verification level / method
Verified on RF mock-up fully representative of the satellite including the PLM and all appendages impacting the radiation patterns and performances of the antennas.
The antennas will be also fully flight representative.

Risks assessments
Acceptable due to the good representativeness of the mock-up.

3.3.3.2 Planck

Optical/RF performances

Verification level / method (refer to [RD6])
Performed in several steps:

- Telescope WFE and alignment verified separately in cold conditions
- Alignment of FPUs w.r.t. telescope controlled with theodolite at system level
- Verification at ambient on the RFQM, with FPU mock-up equipped with representative horns.

End to end test performed at ambient with LFI 30 GHz at Planck PFM level.

Risks assessments
Acceptable due to low sensitivity of the optical/RF performances to dimension change

Planck external straylight (telescope RF diagram)

Verification level / method
Very early validation of computation process by measurement on a similar telescope (ARCHEOPS) equipped with a baffle fully representative of the Planck one on the RFDM (refer to AD3-25).
Measurements of telescope diagram performed on the RFQM from 30 GHz up to 500 GHz (TBC pending test facility performances).

Risks assessments
Acceptable due to:

- Design margins versus planet effects.
- Good representativeness of the RFQM and low sensitivity of the far outside lobes to the alignment and deformations

Planck internal straylight
(telescope RF diagram & temperature fluctuations)

Verification level / method
Validation of the RF model by far field measurements.
Cross check of two computation methods:

- direct computation of surface coupling in Multi GTD mode of GRASP8
- computation of the near field radiated pattern from the far field radiation pattern

Validation of the thermal mathematical model by specific transient tests during the STM/CQM thermal and cryogenic test.

Risks assessments
Acceptable due to the margin of one order of magnitude shown by analysis.

RF pattern of the TTC antennas

Verification level / method
Verified on RF mock-up fully representative of the satellite including the PLM and all appendages impacting the radiation patterns and performances of the antennas.
The antennas will be also fully flight representative.

Risks assessments
Acceptable due to the good representativeness of the mock-up.

3.4 TECHNICAL HERITAGE

ISO heritage

At the end of the ISO programme several lessons learnt in the form of recommendations for future programmes have been issued. It is particularly relevant to review them in the frame of the Herschel/Planck programme due to the technical and overall organisation similarities between the two programmes.

Thanks to the ISO experience, precautions have been already implemented in the Herschel/Planck design and development plan by ALCATEL and its core team to minimise the development risks in areas where the ISO development suffered from being the first development of an infra red space observatory.

For example the baseline for Herschel E-PLM is to reuse as far as possible existing design(s) and hardware from the ISO development. Consequently:

- the development of the Herschel cryostat can be limited to a proto-flight model
- a full qualification will be limited to cryostat units requiring a new design for Herschel. The other units that can be used directly or with only small modifications compared to ISO design will be acceptance tested only.

The ISO heritage gives also a good confidence in the AIT procedures (including SVM/PLM mating) as well as launch procedures regarding activities relative to the cryostat.

The optical and alignment philosophy can be inspired by the one successfully applied on ISO in addition to the contamination plan already mentioned in the risk analysis.

The ISO-QM cryostat is available to be used after modification for EMC C and RS (with external source) testing of the Herschel scientific payload at operating temperature.

But as part of the risk analysis presented here-below, a strategy plan to take into account the lessons learnt has been issued (refer to [RD2]).

As for risk analysis, this document will define an action plan for each identified recommendation derived from lessons learnt. It will clearly identify the milestones (in term of events and dates) to be followed in the schedule. Success or acceptance criteria shall also be identified (such as review completion, activity completion, H/W or S/W installation, …) to allow a detailed follow-up and formal closure for each action.

Heritage for SVM subsystems

By reusing several existing equipment or units that do not need major modifications in order to be compliant with Herschel/Planck requirements, the development and verification effort may be reduced and therefore no full qualification test programme is necessary. The selection of proposed units and equipment will be done during the Phase B such that a reduction of the AIV effort and costs will result.

The most important heritages are the propulsion subsystem (RCS), the harness, the structures and the Thermal Control, which use well-proven technology and hardware. The layout of these subsystems necessitates adaptations to Herschel and Planck Satellites and has to be qualified for these configurations. But the **unit** qualification programme may be considered as already achieved.

3.5 HERSCHEL/PLANCK COMMONALITY

The Herschel/Planck programme consists in the development of two satellites in a common project with common procurements. In order to meet the objective of cost reduction the design with maximum commonality will be retained when possible even if it is not the technical optimum for one of the two satellites.

Partial or complete commonality is expected for the following items:

- Primary Structure of the SVM
- power supply (same range of power)
- CDMS including software
- RF and TT&C
- RCS components
- solar cells
- basic ACMS sensors
- ACMS basic concept including partially (i.e. common) software
- EGSE and MGSE interfacing with the SVM.

This SVM commonality is supported by the same SVM Contractor for Herschel and Planck.

3.6 MODULAR CONCEPT

In order to make the AIT more flexible and to simplify the system tests, the 2 satellites are divided in modules or assemblies that can be as far as possible tested individually.

- Herschel satellite will be decomposed in 3 modules or subassemblies illustrated by figure 3.7-1:
  - the Service Module (SVM)
  - the Extended Payload Module (E-PLM) including the cryostat, the Sunshade, the Sunshield/Solar Array and the truss interfacing the SVM
  - the Telescope
- Planck satellite will be decomposed in 2 main modules illustrated by Figure 3.7-2:
  - the Service Module (SVM) including the Solar Array subassembly
  - the payload module (PPLM) including the Telescope subassembly, The Baffle and the Cryo-Structure with the truss interfacing the SVM.

3.7 CONTAMINATION

Based on ISO experience, the Cleanliness Specification (refer to AD3-5) is the results of contamination analysis performed up to now.

The contamination budgets will be a driver for the AIT sequences and for the choice of the class of the room or adequate protection to perform critical phases. Specific requirements for the launch campaign up to the launch time is identified/specified be implemented during this period.

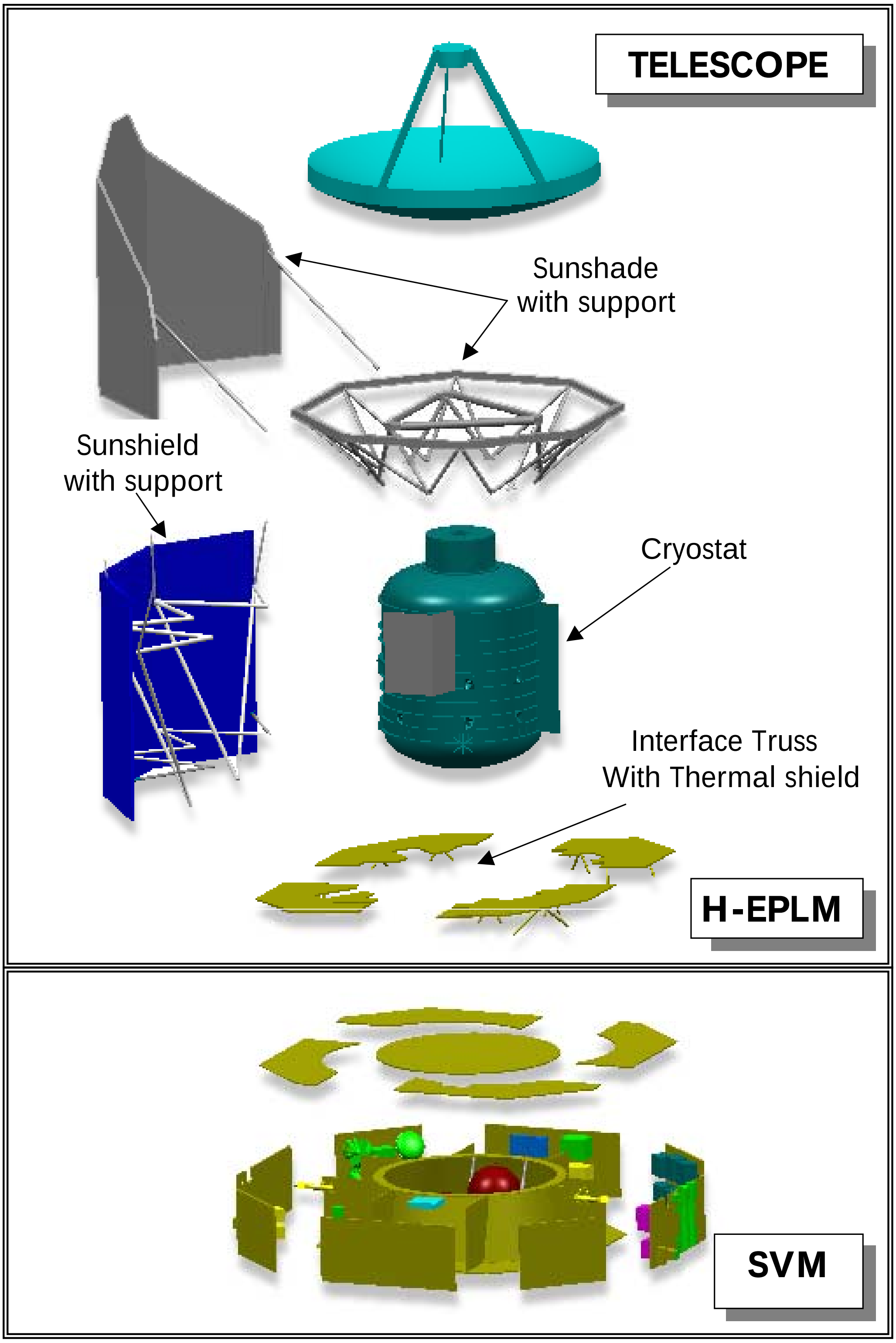

Figure 3.7-1: Exploded view of Herschel

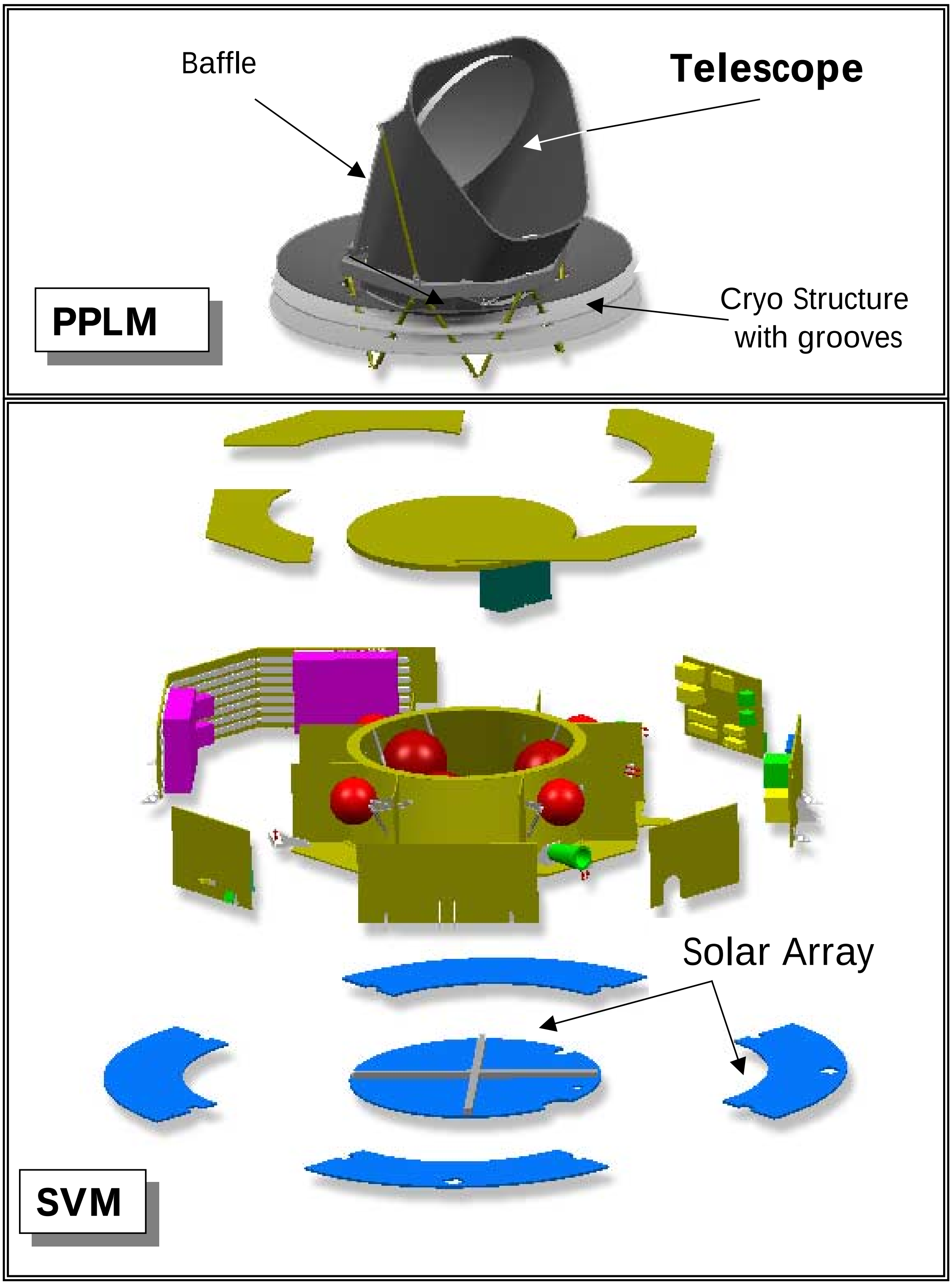

Figure 3.7-2: Exploded view of Planck

4 MODEL PHILOSOPHY DEFINITION

This section summarises the different assessments that have led to optimise the model philosophy to be used at system level.

The Model Philosophy definition process is schematised on Figure 4-1, it is based on:

- programmatic constraints
- level of performances
- risks investigation
- development status
- verification strategies
- integration and test programme constraints.

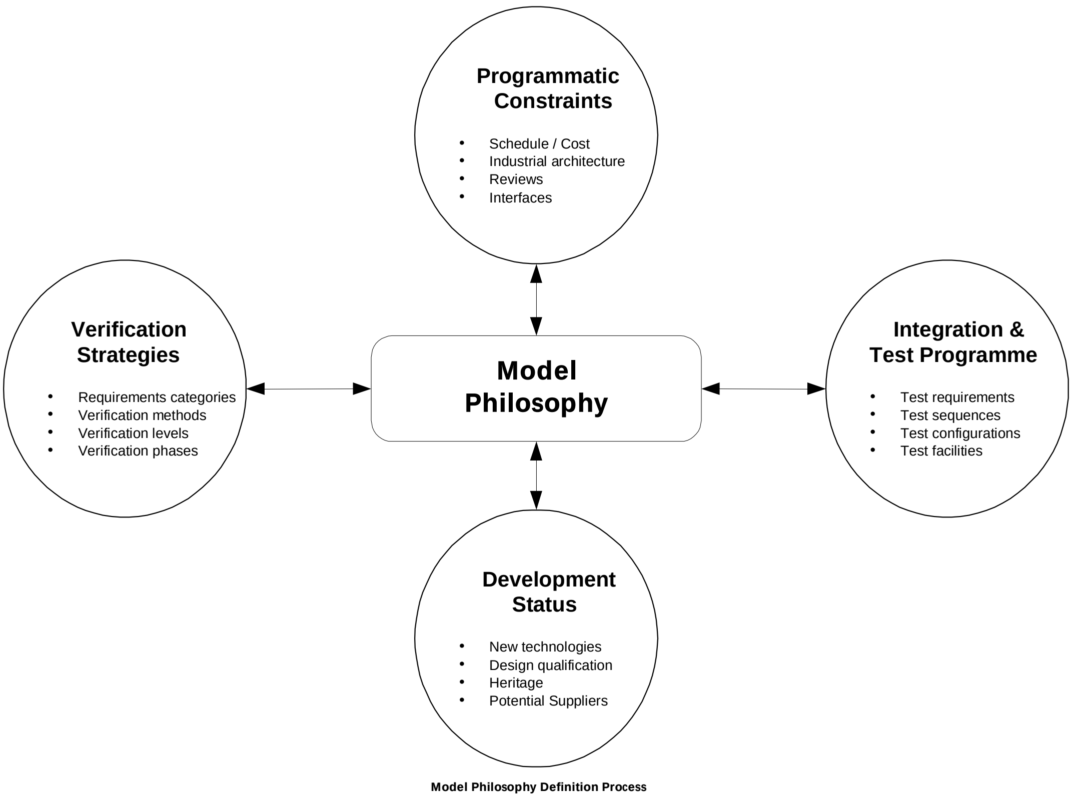

FIGURE 4-1: MODEL PHILOSOPHY DEFINITION PROCESS

Based on the diagram of the possible models presented in figure 4-2, to confirm the approach the following trade-offs have been examined:

- comparison between one multipurpose STM and two single purpose SM and TM
- comparison between AVM and EQM
- PFM philosophy compared with QM + FM philosophy.

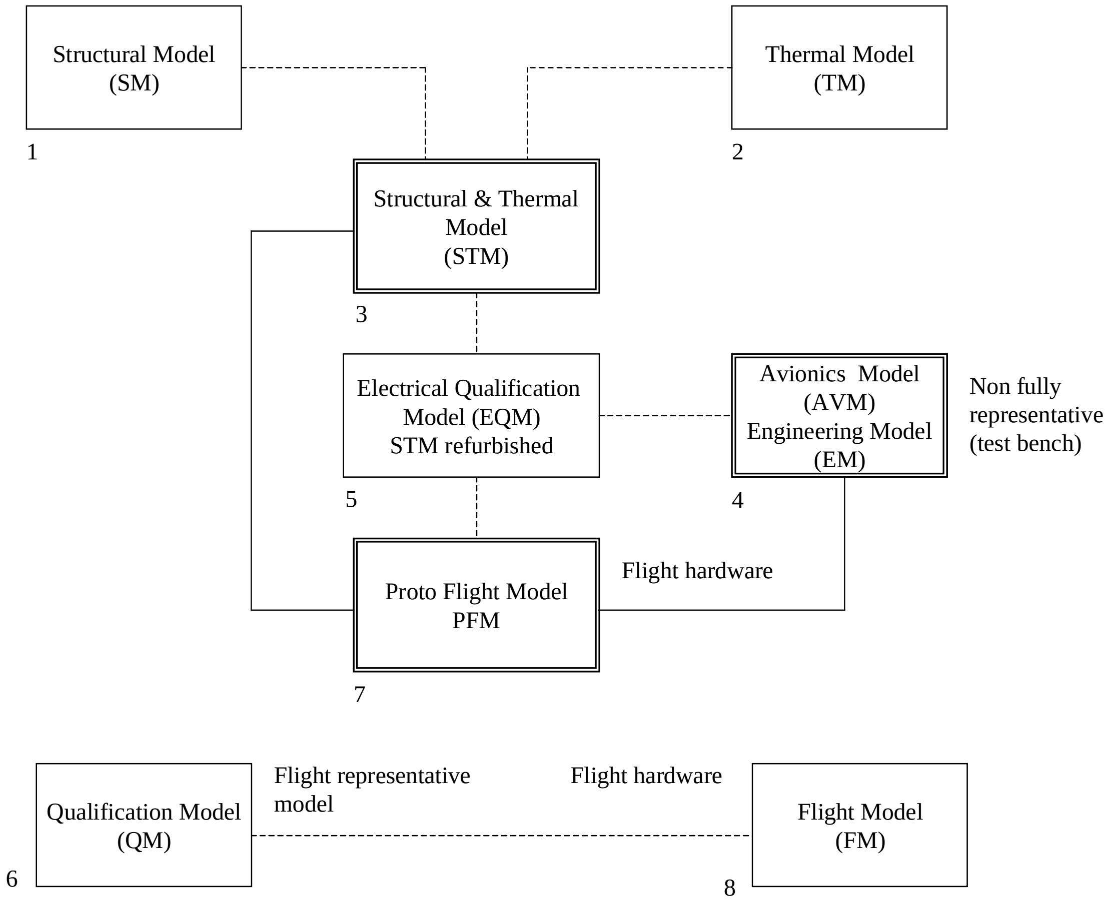

FIGURE 4-2: DIAGRAM OF THE POSSIBLE SYSTEM MODELS

4.1 STM VS SPECIFIC STRUCTURAL AND THERMAL MODELS (SM + TM)

Conclusion

The cost of single purpose structural and thermal models is too high with regards to the technical and schedule advantage. A multipurpose model dedicated to advanced mechanical and thermal pre-qualification is more attractive.

The STM approach has been considered as very useful for Herschel/Planck programme at Satellite level

4.2 AVIONICS MODEL (AVM) VS EQM

Conclusion

After consideration of the technical impacts (EMC qualification performed at PFM level), the single purpose AVM is shown to be convenient and certainly the less expensive solution for early electrical and software validation.

The same approach as the one successfully followed on ISO is proposed:

- no EQM at system or SVM levels, final EMC qualification tests on PFM
- PLM electrical and pre-EMC qualification at operating temperature on Herschel EQM and on a Planck CQM.

4.3 PFM APPROACH VS QM PLUS FM APPROACH

Conclusion:

To keep reasonable development costs a QM approach shall be limited at module or assembly presenting a technical risk such as the PPLM and telescope.
At system level, taking into account the low technical risks which have been identified, a PFM based approach with dedicated development models (AVM + STM) seems more convenient for cost and schedule risk reasons.

Thanks to the ISO heritage, a PFM philosophy is convenient for the Herschel cryostat and allows reducing significantly the cost in exchange of some schedule constraints that have to be considered in the overall planning. The electrical validation and EMC tests of instruments at cryogenic temperature will be performed using the refurbished ISO QM cryostat.

The system model philosophy: AVM/STM/PFM allows to optimise the cost, the risk and the schedule aspects of the Herschel/Planck programme.

The PFM proto-flight philosophy is considered the best solution for Herschel/Planck Satellites.

However performances at PLM and telescope levels have to be secured by specific qualification models.

4.4 CONCLUSION

The model philosophy applicable on Herschel and Planck is at system level based on:

- a multipurpose Structural & Thermal Model (STM)
- single purpose Avionics Model (AVM)
- a proto-flight model (PFM).

These models are completed by the followings PLM and telescope development models:

- an Engineering Qualification Model (EQM) and Proto-flight Model (PFM) of the Herschel E-PLM
- a Cryogenic and RF Qualification Model (CQM/RFQM) and a Flight Model (FM) of the Planck PLM (PPLM)
- a Radio Frequency Development Model (RFDM) of the Planck PLM
- a Qualification Model (QM) and a Flight Model (FM) of the Planck Telescope.

The main objectives of each model are given hereafter:

- AVM (Electrical Test Bench):
  - development model for functional design and S/S compatibility
  - development model for on board software validation
  - EMC pre-qualification.
- STM:
  - development model for structure lay-out and certification
  - development model for thermal control certification
  - confirmation of mechanical and thermal environment before flight models testing.
- PFM:

- Proto-Flight Model for qualification completion in the areas where this qualification has not been completely achieved with the other models, and acceptance for flight.

– EQM of Herschel E-PLM (reuse of ISO cryostat):

- development model for instrument compatibility and EMC at cryogenic temperature.

– PFM of Herschel E-PLM:

- Proto-Flight Model for mechanical and thermal qualification of the cryostat at Herschel STM level

– CQM/RFQM of Planck PLM:

- development model for mechanical and cryogenic qualification (CQM)
- instrument compatibility and EMC at cryogenic temperature
- Radio Frequency sub-millimetric performance certification (RFQM).

– RFDM of Planck PLM:

- specific model built around ARCHEOPS reflectors to validate and correlate the mathematical model.

– TTC RF Mock-up of Herschel and Planck Satellites:

- specific models to verify the RF pattern of the TTC antennas in both configurations.

The development logic is illustrated by Figure 4.7.

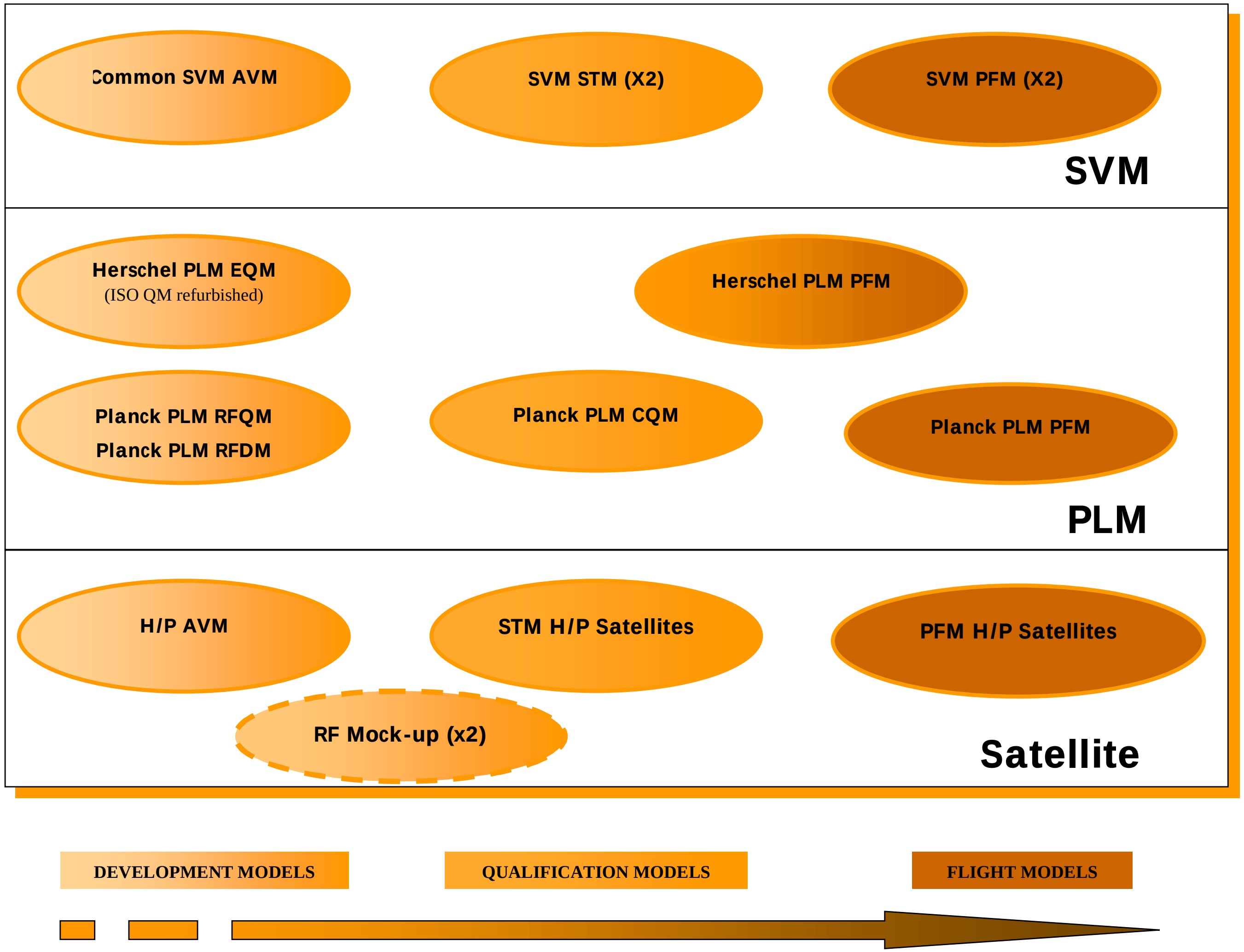

Figure 4.7: Development logic

5 AIT/AIV ORGANIZATION

As prime Contractor ALCATEL Space will manage the overall AIV of Herschel and Planck.

It will build the verification programme plan including the verification matrices and will manage the verification control documents. It will specify the requirements of higher level for MGSE and EGSE with emphasis into the commonality.

The SVM AIV and AIT will be under the responsibility of the SVM Contractor: Alenia SPAZIO. It will procure the common MGSE and EGSE used at SVM, Herschel E-PLM and satellite, and Planck PLM and satellite. It will also deliver fully integrated and electrically tested SVMs.

In order to limit transport activities and to simplify the interface, it is proposed to have the same AIV Contractor respectively at Herschel E-PLM and satellite levels, and at Planck PLM and satellite levels.

- Astrium-ED will be responsible for the AIV & AIT of the Herschel E-PLM and for the AIT of the Herschel satellite (refer to Table 5-1). It will procure specific MGSE for Herschel E-PLM and satellite integration and test.
- ALCATEL Space will be responsible for the AIV of the Herschel satellite(refer to Table 5-1).
- ALCATEL Space will be responsible for the AIV & AIT of the Planck PLM and the Planck satellite. It will procure specific MGSE for Planck PLM and satellite integration and test.

In order to take benefit of SVM AIT (lessons learnt) for Satellite AIT and thus to increase efficiency, it is proposed to carry out both SVM and satellite AIT with mixed teams from SVM Contractor and from respective Herschel and Planck AIT Contractors.

Herschel	VPP		TEST SEQUENCE	TEST SPECIFICATION	TEST PROCEDURE	TEST EXECUTION	TEST REPORT	TEST EVALUATION
	H/W & TEST CONFIGURATION	DEFINITION OF TEST						
Assembly	ALCATEL	N/A	Astrium	Astrium	Astrium	Astrium	Astrium	N/A
Mechanical	ALCATEL	ALCATEL	Astrium	ALCATEL	Astrium	Astrium	Astrium	ALCATEL
Thermal	ALCATEL	ALCATEL	Astrium	ALCATEL + SVM Contractor	Astrium	Astrium	Astrium	ALCATEL + SVM Contractor
Functional	ALCATEL	ALCATEL	Astrium	ALCATEL + SVM Contractor	Astrium	Astrium	Astrium	ALCATEL+ SVM Contractor
Instruments	ALCATEL + Instruments	ALCATEL + Instruments	Astrium + Instruments	Instruments	Astrium *+ Instruments	Astrium* + Instruments	Astrium* + Instruments	Instruments
EMC	ALCATEL	ALCATEL	Astrium	ALCATEL + SVM Contractor + instruments	Astrium	Astrium	Astrium	ALCATEL + SVM Contractor + instruments
SVTs	ALCATEL	ALCATEL	ESOC	ESOC	Astrium + ESOC	Astrium + ESOC	Astrium + ESOC	ESOC
PLM	ALCATEL + Astrium ***	ALCATEL + Astrium ***	Astrium	Astrium	Astrium	Astrium	Astrium	Astrium
Alignment	ALCATEL	ALCATEL + Astrium**	Astrium	ALCATEL + Astrium**	Astrium	Astrium	Astrium	ALCATEL + Astrium**

* Astrium for spacecraft related aspects (He II conditions, overall S/C configuration a.s.o.).
** Astrium for E-PLM and telescope aspects.
*** ALCATEL baseline being based on the joint studies from ESA 95 to 2000.

Table 5-1: AIV responsibilities for Herschel

Planck AIV

Planck	VPP		TEST SEQUENCE	TEST SPECIFICATION	TEST PROCEDURE	TEST EXECUTION	TEST REPORT	TEST EVALUATION
	H/W & TEST CONFIGURATION	DEFINITION OF TEST						
Assembly	ALCATEL	N/A	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL	N/A
Mechanical	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL
Thermal	ALCATEL	ALCATEL	ALCATEL	ALCATEL + SVM Contractor	ALCATEL	ALCATEL	ALCATEL	ALCATEL + SVM Contractor
Functional	ALCATEL	ALCATEL	ALCATEL	ALCATEL + SVM Contractor	ALCATEL**	ALCATEL**	ALCATEL	ALCATEL + SVM Contractor
Instruments	ALCATEL + Instruments	ALCATEL + Instruments	ALCATEL + Instruments	Instruments	ALCATEL + Instruments	ALCATEL + Instruments	ALCATEL + Instruments	Instruments
EMC	ALCATEL	ALCATEL	ALCATEL	ALCATEL + SVM Contractor + instruments	ALCATEL	ALCATEL	ALCATEL	ALCATEL + SVM Contractor + instruments
SVTs	ALCATEL	ALCATEL	ESOC	ESOC	ALCATEL + ESOC	ALCATEL + ESOC	ALCATEL + ESOC	ESOC
PLM	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL
Alignment	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL	ALCATEL

** After the first IST. Mating verifications and first IST to be made by Alenia with ALCATEL support.

Table 5-2: AIV responsibilities for PLANCK

6 MODEL PHILOSOPHY AND DEVELOPMENT

6.1 INTRODUCTION

The baseline model philosophy is defined:

- to allow by means of appropriate models the full qualification of each unit and subsystem together with the formal qualification of the overall satellite
- to define a realistic development sequence in order to guarantee the availability in due time for launch and in the cost envelope, of a flight model compliant with all system requirements
- to ensure through a series of verifications performed at each level, all along the development sequence, that the design is really suitable and compliant with the mission requirements.

This model philosophy is based on the conclusions of the previous trade-offs from which it is proposed to support the requirements for development, qualification and final flight acceptance of the Herschel and Planck satellites.

The proposed system model philosophy: AVM/STM/PFM allows to optimise the cost, the risk and the schedule aspects of the Herschel/Planck programme. It is compatible with delivered models for the Customer furnished equipment (instruments, Herschel telescope and Planck reflectors).

This approach is summarised by Figures 6.1-1 & 6.1-2.

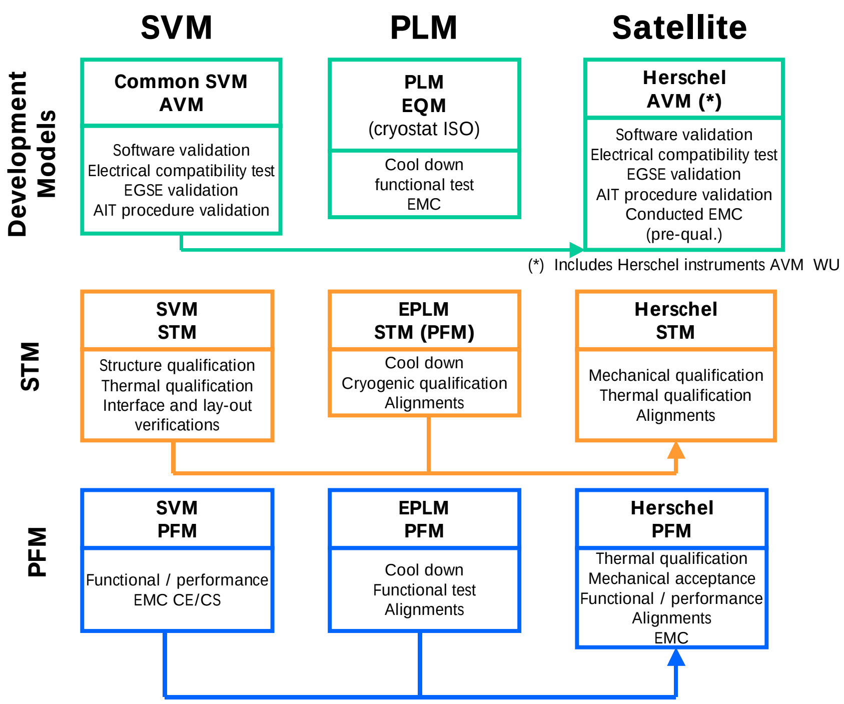

FIGURE 6.1-1: MODEL PHILOSOPHY FOR Herschel

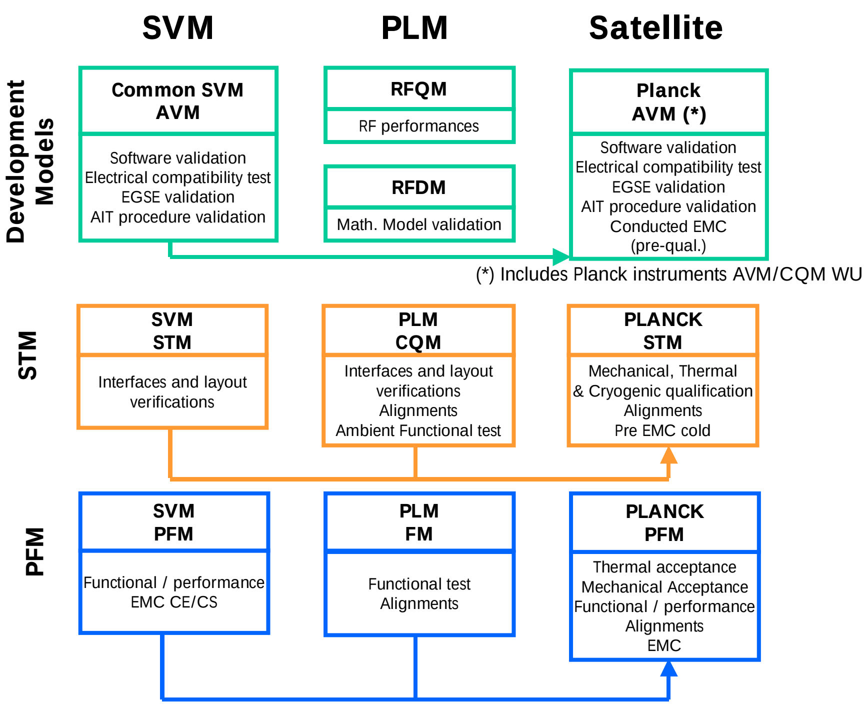

FIGURE 6.1-2 MODEL PHILOSOPHY FOR Planck

6.2 SYSTEM DEVELOPMENT MODELS

6.2.1 Structural & Thermal Model

The Mechanical and Thermal, including cryogenic, qualification tests sequence of Herschel and Planck Satellites is summarised in figure 6.2.1.

Herschel STM

The Herschel STM will be composed of:

- the STM of the Herschel SVM
- the PFM of the Herschel E-PLM including the PFM Cryostat equipped with dummy FPUs, STM Sunshade and STM Sunshield
- A telescope STM

Planck STM

The Planck STM will be composed of:

- the STM of Planck SVM including the Solar Array STM
- the Cryogenic Qualification Model (CQM) of Planck PLM including the QM telescope and the QM Cryo-structure.

As the delivery date for QM reflectors has been shifted after Planck STM test sequence, the STM/CQM Planck Satellite mechanical and thermal tests will be performed with a QM Telescope equipped with dummies of reflectors. These dummies are STM representative.

The overall Planck verification approach is detailed in chapter 10: Annex 1.

Herschel and Planck SVM STM as-build standard

The SVM STM shall consist of a structure (PFM one for Planck) and thermal hardware of flight standard design and configuration equipped with:

- mass & thermal dummies for subsystem units, accurately simulating unit masses, dimensions, centre of gravity, harness interfaces characteristics, and thermal dissipation
- mass & thermal dummies or STMs or QMs to simulate the on board scientific instruments
- at least flight standard RCS fill &drain valves, tank and tubing since the RCS tanks shall be filled with a propellant simulator during STM vibration and acoustic tests
- mechanically and mass representative electrical harness and RF cabling & wave-guides. Harness and RF cabling shall be mounted to the STM with flight representative brackets/fixations and shall give representative loads to the STM structure. For the thermal qualification the harness dummy will be replaced or completed by a thermal test harness for heater circuit activation and thermal control
- STM Solar Array of Planck SVM

STM test objectives

The STM shall be used for structural development and qualification tests. In addition, these tests allow validating at an early stage the specified mechanical & thermal environments.

PLM structure, harness, instrument piping, RF cabling and wave-guides will be mechanically qualified through the system STM tests.

The new arrangement of the “off-the-shelf” RCS components, the harness accommodation on the structure and the harness connections shall be mechanically qualified through the STM tests before being tested at system level on PFM.

In parallel of structural and thermal validation the STM will serve to validate the optical alignment performances and their stability with mechanical and cryogenic environment.

Static Testing

In order to anticipate any structural problem and thus to avoid any risks of PLM hardware degradation (PFM cryostat for Herschel and CQM instruments) the Primary Structure alone will be mechanically tested prior to system test. Thank to the communality of Herschel and Planck Primary Structures, this Static Load Test will be performed only on the Herschel Primary Structure STM, the validation of both SVM structures being done by similarity and analysis.

Sine and Acoustic Testing

STM will undergo sine and acoustic environment as defined [in AD2-1] at qualification levels

Shock Environment Qualification

For Herschel and Planck, the only source of shock is the launcher. There is no device allowing to perform a shock test on Satellite neither at acceptance/flight level nor at qualification level. So the demonstration of the Herschel and Planck ability to withstand the shock generated by the launcher will be achieved in three steps through qualification tests performed at equipment level, shock characterisation on STM Satellites and analytic demonstration.

First step: Qualification test to be performed at equipment level.

This test can be a shock test or another mechanical environment qualification test (i.e. random or sine) pending the predicted shock level to be experienced at the interface of the equipment with the structure and defined in the Environmental and Test Specification.

Second step: Shock test characterisation.

By generating a shock at the Satellite/Launcher interface, this test allows to measure interface levels and equipment base levels.
According to Arianespace, this test can be performed once. As the STM of Herschel and Planck provide a satellite structure close to the interface (i.e. primary structure of the SVM) and equipment locations and mounting fully flight representative, these models have been selected for this test in order to avoid over-stressing of flight equipment. Pending the device to be used, the generated shock can be higher than the expected flight one.

The shock generation will be obtained by a Shock Generation Unit (SHOGUN) and/or by a clamp-band release with a drop test pending the shock environment applicable to Herschel and Planck to be launched in 2007 with an upgraded version of Ariane 5.

Shock test on STM Satellites are combined with mechanical fit check.

Third step: Analytic demonstration of the qualification of the equipment.
This is obtained by comparing the equipment qualification levels (step #1) to the equipment base levels experienced applying the interface shock to be defined by Arianespace and the transfer functions deducted from the shock characterisation test (step #2). The Herschel and Planck ability to withstand the shock is achieved if a qualification margin of 3dB is demonstrated by comparison.

Thermal and Cryogenic Environment Testing

The STM shall be used also for thermal control (thermal vacuum/ thermal balance) and cryogenic qualification tests. The system thermal qualification with flight hardware (including SVM electronic units) will be performed at PFM level.

The two satellites will be pre-qualified regarding thermal environment at STM level according to the following test sequences.

For Planck, the PPLM cryogenic test will require a SVM structure, but the cryogenic aspect is not compatible with a Sun simulation.
For Planck, the solar inputs are only on the rear side of the SVM (launcher interface) and obviously on the Solar Array. For that reason and to avoid any risk of disturbing the complex and costly cryogenic test of the PPLM, it is proposed to perform the SVM thermal control validation during the Satellite cryogenic test. Skin heaters will simulate the well known solar inputs on the Solar Array and on the launcher interface ring.

The thermal control of specific external equipment mounted on the sun side of the spacecraft as thrusters, antenna, sun sensors, the launcher interface ring could be verified during the thermal balance test of Herschel SVM-STM. For that purpose the lower face of the specimen should be accommodated and a specific Planck configuration (including the Planck Solar Array STM with a coating providing the alpha and epsilon of the flight cells) with the rear side in font of the sunbeam added in the thermal test sequence of Herschel SVM-STM.

For Herschel, taking into account the thermal separation between the SVM and the E-PLM, the thermal pre-qualification is shared between the STM and the E-PLM as already done with ISO programme (refer to [RD4]).

The test sequence will be in two steps:

- thermal vacuum/thermal balance test on STM Herschel SVM alone allowing correlation of the SVM thermal model,
- thermal vacuum/thermal balance test on STM Herschel EPLM allowing correlation of the EPLM thermal model

The possible configurations of the STM Herschel EPLM during this test have been traded-off (refer to [RD3]).

- Configuration A = Herschel EPLM with PFM cryostat and STM Sunshield (SSH) mounted on a SVM thermal dummy but without STM Telescope, STM Sunshade allowing correlation of the thermal model of the CVV (including heat contribution of the SSH) with two points of the CVV temperature (constant temperature by active LN2 cooling and free floating temperature),
- Configuration B = complete Herschel STM EPLM with SVM STM acting as a thermal dummy allowing correlation of the thermal model of complete EPLM with two points of the CVV temperature, (constant temperature by active LN2 cooling and free floating temperature),
- Configuration C = thermal vacuum test on Sunshield and Sunshade elementary panels equipped with MLI allowing to determine in a more accurate way the efficiency of these MLIs and the accuracy of Telescope and CVV temperature predictions in flight configuration, to be combined with
- Configuration D = PFM Herschel cryostat alone allowing correlation of the thermal model of the CVV.

Pending additional analyses in progress at astrium, the baseline is to perform the test in configuration B. The back-up solution is the combination of configurations C & D.

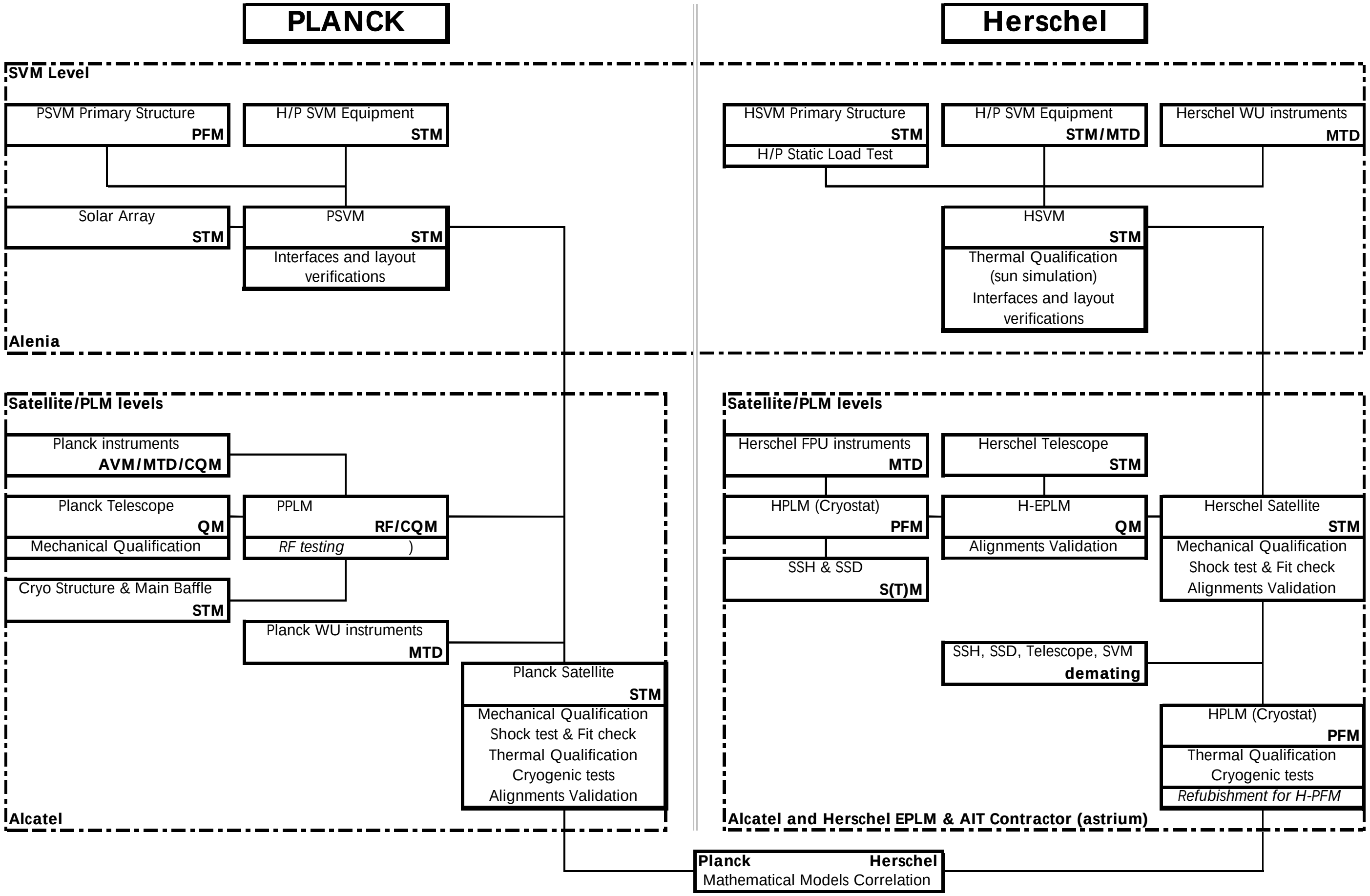

FIGURE 6.2.1 MECHANICAL AND THERMAL, INCLUDING CRYOGENIC, QUALIFICATION TESTS SEQUENCES OF HERSCHEL AND PLANCK SATELLITES

6.2.2 AVionics Model (AVM)

The Avionics Model is a bench model on which will be installed the electrical equipment of Herschel/Planck SVM subsystems and the Herschel/Planck Instruments "Warms" Units.

All items building it will be flight representative in electrical I/F and functionalities.

Only one AVM is proposed to be used either in the Herschel configuration (equipped with Herschel ACMS and with Herschel instruments AVM) or in the Planck configuration (equipped with Planck ACMS and with Planck instrument AVM).

The AVM will be kept operational all along the AIT sequence to be usable for potential failure analysis or for validation of software modification.

AVM As build standard

The AVM model set-up is shown in the Figure 6.2.2-1.

This model is based at three main parts, namely:

- Common SVM AVM including the common Herschel/Planck avionics subsystems like CDMS, Power S/S (batteries and PCDU), RF S/S and the common ACMS units (i.e. ACC computer and sensors units).
- Herschel and Planck SVM AVM including the specific units of Herschel and Planck in order to reach the related full SVM configuration both for Herschel and Planck, namely : specific ACMS Sensors and Actuators
- Herschel and Planck Satellite AVM including the relevant Instruments "Warm" Units

The AVM will be developed in order to allow the maximum flexibility between Herschel and PLANCK testing in terms to swap from Herschel to PLANCK configuration and vice-versa changing the H/W and S/W configurations in a short time, typically 48 hours.

For this the following capabilities will be implemented:

- Quick S/W loading on Avionics on board computer, ACC and CDMU, in order to quickly modify the S/W configuration from Herschel to PLANCK and vice-versa.
- I/F Connectors that allow to integrate easily the AVM Common Elements and the AVM Modular Elements.

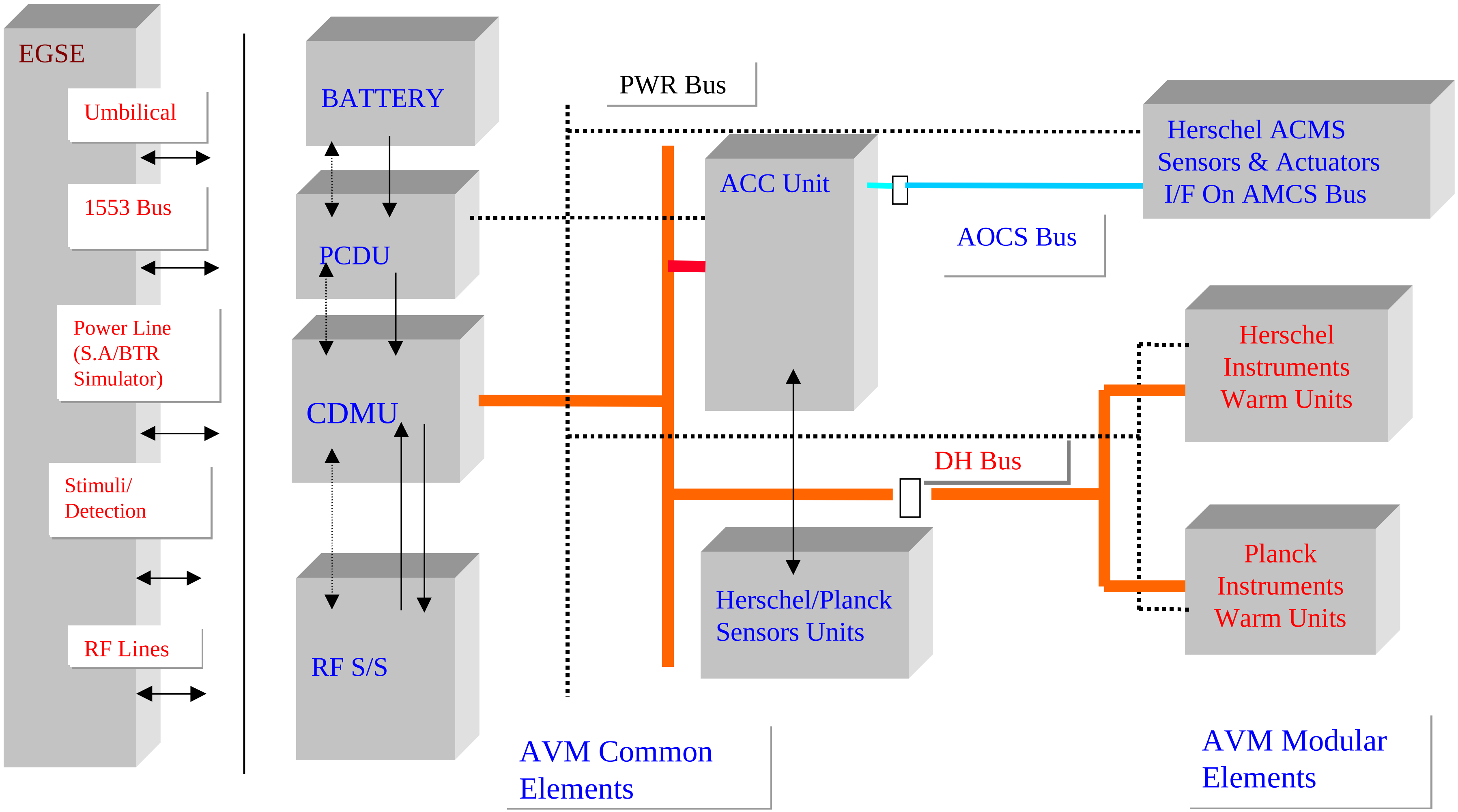

Figure 6.2.2-1: AVM Set-up

AVM Test objectives

The electrical system validation sequence is illustrated by Figure 6.2.2-2.

The main objectives of the AVM are:

- Check the electrical and functional interfaces between the units.
- Verify the functionality of the avionics subsystems and on-board software including the closed loop tests for ACMS functional verifications, prior to PFM implementation.
- S/C autonomy functional verification and validation of the On-Board Control Procedure (OBCP).
- Preliminary validation of communication and power interfaces between the Herschel/PLANCK Instruments Warm Units and the CDMS and EPS S/S.
- Test the EGSE – SVM interfaces including the EGSE software and verify the EGSE capability to perform the planned test.
- Validation of the test sequence to be re-used for PFM test campaign
- Perform EMC Conducted test on avionics units.

The AVM will be maintained after the AVM test campaign up to the commissioning phase in order to allow the debug activities for Herschel and Planck PFM in terms of development and testing of the operation procedures during the C/D and E1 phase.

Specific tasks (i.e. EGSE operations, overall electrical performances…) to be also done at Satellite AIT levels will be performed by an integrated team with the participation of involved SVM and Satellite AIT contractors.
In this manner it will realise an optimisation and flexibility on the PFM test activity for what concerns the S/W debugging and re-validation.
As an option, SVT0 can be performed on the AVM. The baseline is to perform SVT0 before the SVM PFM delivery.

After that it could be delivered at ESOC as ground reference model.

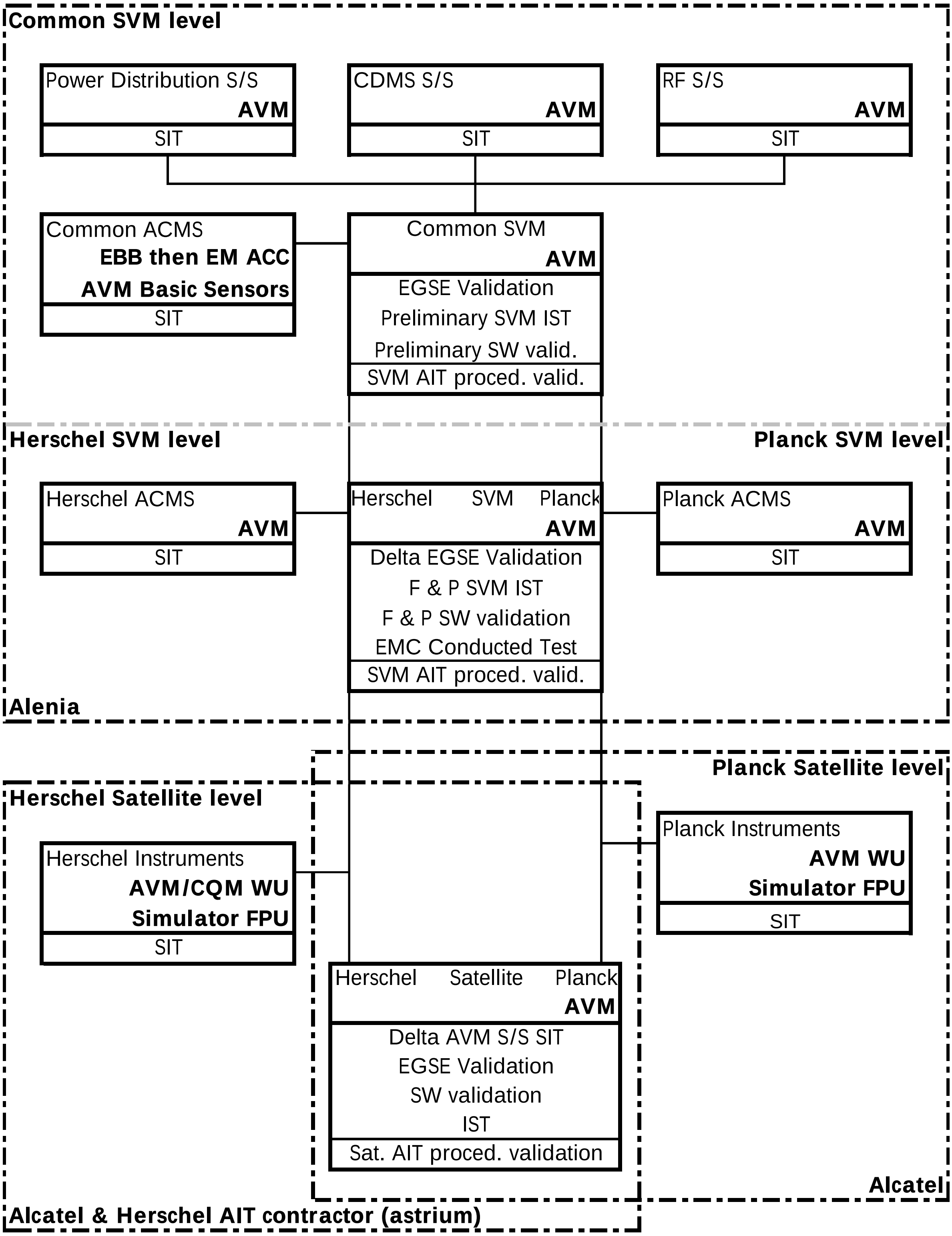

Figure 6.2.2-2: Electrical System Validation Sequence

6.2.3 Proto-Flight Model (PFM)

The PFM 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 proto-flight equipment (PFM) which will have passed qualification testing at unit or sub-system level.

As a consequence, the PFM satellites will undergo only mechanical acceptance levels.

Formal acceptance for launch is established after successful verification of performances during system acceptance/qualification tests with the integrated system.

Figure 6.2.3-1 summarises the verification sequence of the Herschel and Planck PFM's.

Figure 6.2.3-2 summarises the EMC verification including tests to be performed at module level. Details are provided with [AD3-19] & [AD3-20].

Herschel PFM

The Herschel PFM will be composed of:

- the PFM of the Herschel SVM
- the PFM of the Herschel E-PLM including the PFM Cryostat equipped with PFM FPUs, FM Sunshade and FM Sunshield
- the FM telescope

Planck PFM

The Planck PFM will be composed of:

- the PFM of Planck SVM including the FM Solar Array
- the FM PPLM including the FM telescope and the FM Cryo-structure.

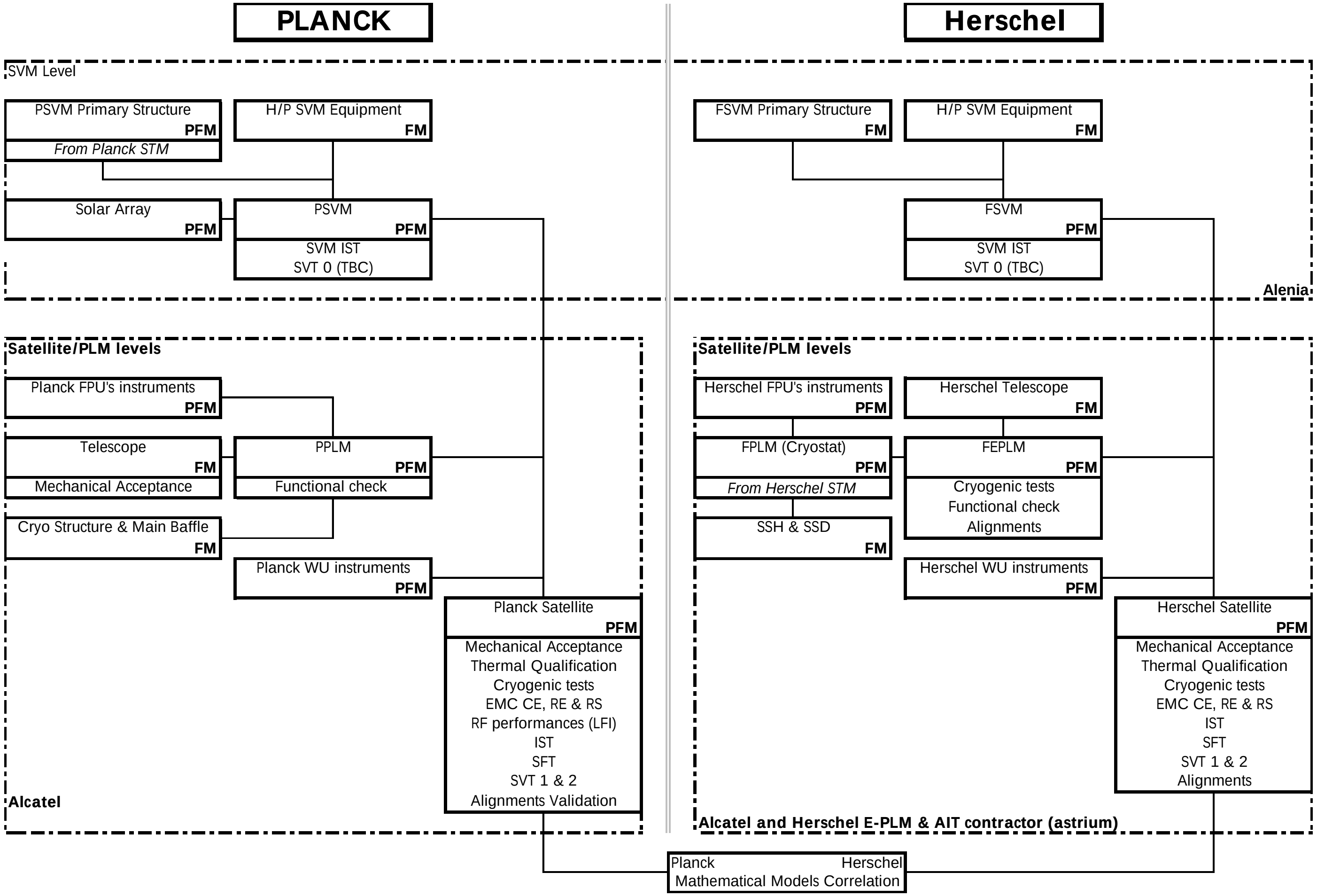

FIGURE 6.2.3-1 Verification sequence of the Herschel and Planck PFMs.

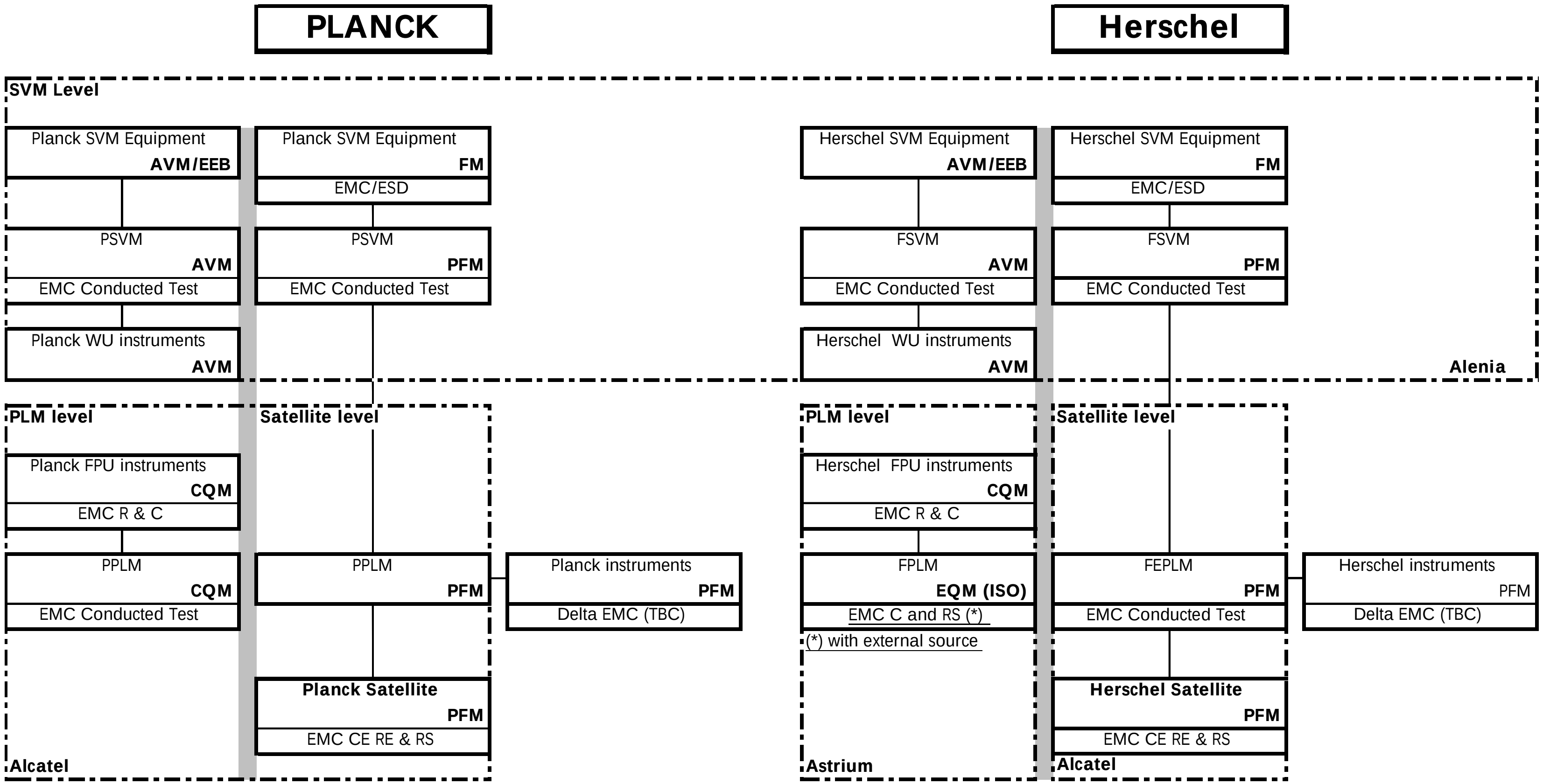

FIGURE 6.2.3-2: EMC/ESD verification

6.2.4 Satellites Test Matrix - Summary

		Herschel		Planck	
Test	**AVM**	**STM**	**PFM**	**STM**	**PFM**
Sine & Acoustic	-	Q (*)	A	Q	A
Shock test	-	X (**)	-	X (**)	-
Fit check	-	X	X	X	X
Mass properties	-	X	X	X	X
Alignments	-	X	X	X	X
Sun Simulation	-	at SVM level only	X (step #2)	Simulated by skin heaters	Simulated by skin heaters
Thermal Balance	-	Q at SVM A at PLM	Q (A for cryo)	Q (A for cryo)	Q (A for cryo)
Thermal cycling	-	-	A	-	A
Leak test	-	X	X	X	X
Cryogenic	-	On PLM EQM	X	X	X
ESD	-	-	On equipment	-	On equipment
EMC R	-	on PLM EQM (***)	X	-	X
EMC C	X	on PLM EQM	X	X	X
RF perfos.	-	-	-	On RFQM	LFI low freq.
TTC RF diagram	-	on RF mock-up		on RF mock-up	
IST	X	-	X	-	X
SFT	-	-	X	-	X
SW compatibility	X	-	X	-	X
SVT	SVT 0 (option)	-	SVT 1 &2	-	SVT 1 &2

X = test performed with :
Q = qualification level when relevant
A = acceptance level when relevant
“-“ = no test
(*) Low sine test on PLM in “warm” condition
(**) Q on equipment and final qualification achieved by analysis
(***) with external source

TABLE 6.2.4: HERSCHEL AND PLANCK SATELLITES – TEST MATRIX

6.3 MODULE DEVELOPMENT MODELS

6.3.1 SVM development models

The SVM development will follow the same logic as the system one with three models:

- AVM for electrical and software validation. The PLM interfaces being very limited for this model the system and SVM levels are only differentiated by the accommodation of instrument warm units.
- Herschel SVM STM for structural (Static Load Test) and thermal (balance) validation covering Herschel & Planck configurations at SVM module and then mechanical qualification at Herschel Satellite STM level
- Planck SVM STM for mechanical and thermal qualification at Planck Satellite STM level
- PFM submitted to electrical functional test, EMC tests and final software qualification. Neither mechanical nor thermal tests are planned at SVM level for the PFM. SVT 0 will be performed at SVM PFM's delivery.

6.3.2 PLM development models

Herschel E-PLM

Thank to ISO heritage the development of the Herschel E-PLM will use only two models:

- EQM which is the ISO QM cryostat modified to be a representative test set-up for the three scientific instruments, with these CQM of instrument FPUs, operated by the AVM of instrument warm electronics, according to [RD7] it will be used:
  - to demonstrate mechanical & thermal compatibility between the three instruments
  - for EMC test of instruments at operating temperature
  - to validate the alignment procedure between the HIFI-FPU and the HIFI-LOU
  - For limited validation of the functional performances with the use of the "Cold Background" device at this stage

- PFM used in two different phases:
    - a qualification phase where the PFM cryostat is equipped with dummies of instrument FPU to be used on Herschel STM for mechanical and alignment qualification and alone for thermal pre-qualification,
    - a PFM phase with the integration of the FM instruments followed by integrated system test and functional test. The final thermal qualification and mechanical acceptance will be performed at system level.

Such a sequence is well adapted with the planning constraints of instruments, making CQM instruments available in time for refurbishment into flight spares and putting the need date of the FM instruments at the latest.

Planck PLM (PPLM)

The development of the more complex and more critical PPLM will be based on four models:

- **RFDM** (Radio Frequency Development Model) to validate very early in the programme the computation and measurement methods of the radiated pattern and of the straylight rejection. This model will be a RF mock-up not fully representative of the exact geometry of Planck: it is based on the existing reflectors (from ARCHEOPS balloon borne experiment) mounted and adjusted on a dummy structure surrounded by a baffle with a shape identical to the real one.
- **RFQM** (Radio Frequency Qualification Model): used to qualify the telescope and the baffling system with regards to the straylight rejection and to characterise the main and secondary lobes. This model is necessary because a complete RF test is not feasible in cryogenic environment and because the instruments cannot be operated at ambient. At PFM level, only the test of the lower LFI channel (30GHz) is planned. The RFQM will be composed of the QM telescope with QM reflectors, QM baffle, QM third groove of cryo-structure and mock-up of instrument FPUs and with representative horns allowing RF measurements at ambient. It will
    - validate by measurement the optical and straylight mathematical models
    - determine by test the radio frequency performances
    - establish and verify the coherence between the optical properties (WFE) measured at telescope level and the radio frequency properties.

- **CQM** (Cryogenic Qualification Model) equipped with CQM instruments, coolers and QM telescope with dummies reflectors (refer to Chapter 10). This model will be used for functional qualification at cryogenic temperature and for mechanical and thermal qualification.

In order to simplify the test set-up and to rationalise the test sequences, all the PPLM CQM environment tests including the cryogenic tests are performed at Planck satellite STM level.

To cope with the very late delivery date of SCC CQM and in order to deliver the Warm Units of the instruments in time for AVM testing, it is proposed to perform the CQM cryogenic tests by using ground fluidic loop (H2) in place of Sorption Cooler Compressor.

- **FM** (Flight Model) equipped with FM instruments and coolers and submitted to an ambient functional test prior to delivery at system level for spacecraft integration and complete testing.

As the redundant chain of the Sorption Cooler System are not verified during the STM/CQM sequence (previous baseline), both SCC, nominal and redundant, shall have to be verified during the FM cryogenic test that needs two cool down sequences.

6.4 TELESCOPE DEVELOPMENT MODELS

6.4.1 Herschel Telescope

The Flight Model (FM) of the Herschel telescope will be delivered as Customer Furnished Equipment (CFE). FM will be mounted on the Herschel PFM.

No other development model will be delivered by ESA. A STM will be developed and procured by Herschel AIT contractor (Astrium) to be used during the Herschel STM test campaign. This procurement will be based on instrument design and interface specifications.

6.4.2 Planck Telescope

Two models will be manufactured:

- one Qualification Model (QM)
  - with dummy reflectors for qualification at CQM module and STM Satellite levels (refer to Chapter 10).
  - with QM reflectors for radio frequency qualification with RFQM models.
- one Flight Model (FM)
  - with FM reflectors for acceptance at PFM module and satellite levels.

The implementation of some modifications after the subsystem or system qualification test phase (Planck RFQM/CQM and STM) remains possible.

The Planck Telescope shall be assembled then shall be fully qualified (QM) or acceptance tested (FM) including environment tests and optical performances in cryogenic environment prior to be delivered to PPLM.

The QM reflectors of Planck shall be returned at the end of the PLM/spacecraft development sequence to be refurbished into flight spares.

6.5 SUBSYSTEM DEVELOPMENT MODELS

6.5.1 Electrical Subsystems

The general approach is based on the fact that no electrical subsystem development model is required except for validation of the On Board Software and for some specific units. So the hardware development plan of electrical units will be defined in the paragraph dedicated to unit development models.

In order to clarify the electrical subsystem approach the following considerations are identified:

Avionics

The Avionics functional chain validation will be performed taking into account development at different levels. The validation process has to demonstrate both the functional and performances specifications.

<u>At Subsystem level</u>

- Herschel & Planck ACMS development and validation up to the delivery of the relevant ACMS Test Beds – or SCOE - (ACMS-TB)
- Common CDMS development and validation up to the readiness of CDMS-OBSW running on CDMU-EBB/EM

<u>At AVM level:</u>

- delivery of the CDMS-TB with EBB/EM units to the AVM
- delivery of the Herschel ACMS-TB with EBB/EM units to the AVM
- delivery of the Planck ACMS-TB with EBB/EM units to the AVM
- integration and validation of relevant AVM SVM Herschel and Planck configurations by changing the H/W and S/W configurations (typically 48 hours)
- integration of instruments warm units and validation of AVM Satellite in Herschel and Planck configurations.

<u>At PFM level:</u>

- delivery of the Herschel and the Planck ACMS-TB's with FM units to the relevant PFM SVM
- delivery of both CDMS-TB's with FM units;
- integration and validation of Herschel and Planck PFM SVM;
- achievement of the Herschel and Planck PFM-TB's;
- integration of Payload Modules and validation of Herschel and Planck Spacecraft's PFM.

The performance validation is performed in closed-loop on an ACMS simulator. This ACMS simulator consists in a fully simulated part for environment, dynamics, sensors and actuators modelling. The ACMS algorithms shall be fully representative, both functionally and numerically, of the On-Board Software. The Target processor shall be fully representative of the flight processor.

Star Tracker concerns at the same time an electrical and optical unit or groups of units, it could be reduced to the unit approach. Meanwhile this unit may require to be coupled with the ACMS for some compatibility and functional subsystem tests before being tested at system level.

RF and TT&C Subsystem

Antenna pattern and performance will be verified with test mock-ups of the two satellites at system level.

Power Subsystem

The Solar Array will be treated apart as it interfaces with the structure and the thermal control subsystems.

For other units identical for Herschel and Planck (i.e. PCDU and batteries) only one common unit (EM) will be developed for the AVM.

The qualification regarding the common Herschel/Planck environment will be achieved with one PCDU QM that will be used as flight spare.

The design of the selected Li-Ion battery is based on existing battery EQM currently undergoing qualification testing. This induces a minor design development program supporting a PFM approach for the common Herschel/Planck battery The PFM model will undergo a full qualification test and will be used as flight model on Herschel (or Planck according SVM need in term of schedule). Two additional flight models are manufactured, one to be the flight model on Planck (or respectively Herschel) and the second to be the flight spare. These two models will undergo a full acceptance sequence.
In addition two STM for STM testing and an EM for AVM are manufactured. A key objective of this STM/EM program is to control and to reduce any residual risk to feed confidence into the detailed design of the flight models: PFM, FM and FS.

6.5.2 Mechanical Subsystems

SVM structure

In the frame of the Satellite PFM approach and due to the SVM commonality, for launcher compatibility, only one Primary Structure shall be submitted to Static Load Test (SLT). This SLT will combine the worst cases of Herschel and Planck configuration.

The CQM PPLM need for its own tests a SVM at an early stage, so the Primary Structure to be statically tested will be the one to be used for STM Herschel testing.

Two models, one STM and one FM will be manufactured for Herschel and Planck, however the reuse of some STM elements on FM can be envisaged with the following reserves:

- the refurbishment into flight model shall be compatible with the overall schedule
- the implementation of some modifications after the system mechanical test phase (STM) remains possible.

The panels dedicated to the instruments units will be delivered in advance on the rest of the SVM to the PLM Contractors for instrument warm units integration.

The Primary Structure to be used for Planck STM was preliminary planned to be refurbished for Planck PFM. The main drawback of this approach is to link the start of the Planck PFM activities to the end of the Planck STM/CQM activities.
In order not to impact the delivery of the Planck satellite PFM and the launch date due to a delay in the delivery date of the CQM instruments, it is proposed:

- to manufacture a second model (FM) of the Planck SVM Primary Structure
- to perform the SVM PFM sequence in ALENIA and in premises of RCS subcontractors with this additional structure.

Herschel Sunshield, Sunshade & associated structures

Two models of each item shall be supplied:

- one STM specifically adapted to the thermal test purposes, it will be used and qualified through mechanical and thermal qualification at Herschel STM level
- one Flight Model.

TBD panels of the Sunshield STM will be equipped with flight solar cells in critical areas. It will be submitted to a full qualification sequence before delivery to E-PLM integration.

In addition, a "flasher" test is performed before delivery of the Flight Model as reference; this test will repeated at system level to perform the trend analysis and to evaluate the performance degradation if any.

Prior to assembly, the fixation struts will be statically tested at qualification level for STM and at acceptance level for FM.

Planck Solar Array

In addition to the flight model used on Planck PFM Satellite, a STM will be manufactured for Planck STM Satellite. The STM as-built is:

- Structural panels fully flight representative,
- dummy cells, with a coating providing the alpha and epsilon of the flight cells and the final mass properties,
- two panel types (one from internal part, one from external part) partly covered (at least 5%) in critical areas by flight cells in addition to the above dummy cells

The mechanical qualification is achieved on STM:

- at subsystem level by the two panels partly covered by flight cells which will undergo complete mechanical test sequence at qualification level,
- and completed by tests performed at Satellite level.

As, there is no thermal test planned at system level with SA PFM, the complete Solar Array thermal qualification is achieved on PFM at subsystem level. The complete Solar array will be fully tested at ambient temperature and in thermal environment before delivery:

- two panel types (one from internal part, one from external part) will undergo thermal environment at qualification level,
- other panels will undergo thermal environment at acceptance level.

The thermal environment being the critical case for the Planck Solar Array, this last test also acts as workmanship verification.

In addition, a "flasher" test is performed before delivery as reference; this test will be repeated at system level to perform the trend analysis and to evaluate the performance degradation if any.

At system level, the Planck SA PFM will be used:

- for mechanical adjustment with Planck PFM Primary Structure
- for electrical continuity validation at Planck SVM PFM level (flood test)
- for mechanical testing at satellite PFM level

At system level, the Planck SA STM will be used:

- for preliminary mechanical adjustment with Planck Primary Structure
- for SVM STM thermal Balance in Planck configuration (Herschel SVM Primary Structure shall be adapted),
- for mechanical testing at satellite STM/CQM level,
- for thermal/cryogenic testing at satellite STM/CQM level and at satellite PFM level with heaters to simulate sun illumination.

Planck PLM Cryo-structure

This subsystem includes the Main Baffle, the grooves and the truss interfacing the SVM.

Two identical models will be manufactured (CQM and FM), but the implementation of some modifications after the subsystem or system qualification test phase (RFQM/CQM/STM) remains possible.

This structure will be fully tested under mechanical and thermal environment at system level (qualification levels for CQM, acceptance for FM). The thermal performance is managed at system level. At subsystem level a minimum test qualification programme 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

Herschel E-PLM support truss (interfacing SVM)

As for Planck, this support truss shall be considered as “primary structure”. So before integration on Satellite, test qualification programme will be developed on specific units taking into account mechanical and thermal loading.

The Flight Models will be acceptance tested at room temperature.

Thermal control

The thermal control of each module is independent. For each of them, two identical subsystems (QM and FM) will be manufactured, (the 1st one used at STM level for thermal qualification, the 2nd one for flight) but the implementation of some modifications after the system thermal test phase (STM) remains possible.

For the heat-pipes and radiator of the panel structure accommodating the Sorption Cooler only one PFM set will be provided with relevant spares.

RCS

The RCS will use qualified components so the development philosophy is as follow:

- One RCS "STM" comprising tanks, pipes & brackets, valves, pressure transducer and thrusters at STM standard. It will serve for each Satellite STM system mechanical and thermal test phases :

- to qualify the new arrangement of the "off-the-shelf" RCS components
- to provide the representativeness of the tank filling ratio (impact of the sloshing modes)

- One complete RCS FM will be manufactured for flight models for full validation and acceptance tests at all levels (equipment, module and satellite).

Harness

For each STM SVMs, STM harness will be provided for mechanical and thermal tests and integrated on the structure using flight standard workman ship. The harness will be mechanically qualified at this level.

The STM harness consists of a mass representative of power and signal interfaces harness. A limited number of signal harness wires will be provided with crimp contacts manufactured in flight standard but made from commercial parts to qualify the connections.

STM harness shall be mounted to the STM with flight representative brackets/fixations and shall give representative loads to the STM structure. It will be accommodated to fulfil the thermal test requirements (power supply of thermal dummies, temperature sensors…)

The complete FM harnesses will be installed on the PFM's.

RF and TT&C Subsystem

Some elements of this subsystem as LGA/MGA horns, wave-guides and RF cabling need to be qualified from mechanical and thermal point of view.
These elements are considered as mechanical parts and will be installed on the STM to be partly tested and qualified at system level, independently from the subsystem itself and without relation with the electronic units to which they are connected.

Two sets per Satellite will be manufactured:

- one will be used at STM level for mechanical and thermal qualification tests
- one will be installed on flight model

The possibility to implement some modifications after the subsystem test or the system mechanical test (STM) phases remains possible.

6.6 UNITS DEVELOPMENT MODELS

6.6.1 Units Model Classification and Model philosophy

The unit model classification is defined as follows:

- *MTD (Mass & Thermal Dummy) :*

A MTD is only representative of the mechanical and thermal interfaces defined by relevant specification.
Providing successful and no over-stressing testing, structural parts of MTD can be used as for FM or flight spares.

- *EBB (Elegant Bread Board) :*

The EBB (or DM) is representative of the flight model in terms of conducted emissions and in-rush currents. Volume shall be representative as much as possible. It cannot survive thermal and vibration environment.

- *EM (Engineering Model) :*

The EM is fully equivalent in form fit and functions to the FM unit, including mechanical and thermal aspects. The EM EEE parts are not Hi-Rel, but from the same type and from the same manufacturer as the FM unit.
EM can be used as integration spare for functional test but not as flight spare.

- *EQM (Engineering & Qualification Model) :*

The EQM is an EM that is also devoted to partial qualification testing at equipment and subsystem level.
EQM can be used as integration spare but not as flight spare.

- *QM (Qualification Model) :*

The QM is built to FM standard with Hi-Rel parts and full quality assurance and configuration control. It is devoted to full qualification testing at equipment and subsystem level.
Providing successful and no over-stressing testing, QM can be used as FM or flight spares.

- *FM (Flight Model) :*

The flight model shall be of flight standard and shall be submitted to acceptance testing.

The unit or subsystem development plan shall be based on a realistic development approach taking into account the system development requirements on one side and the unit or subsystem development requirements on the other side.

Some units or subsystem are identically used on Planck and Herschel. In that case only one development or qualification unit is necessary and only one FS is requested.

The general unit procurement philosophy for the avionics shall be based primarily on the re-use of existing design or design with minor adaptation.

Furthermore, the number and the quality of unit development models is dependent on, the number of subsystem and system (AVM - STM - PFM) development models previously identified and of the status of the development of the equipment.

From a technical point of view, the unit development plan shall satisfy several conditions:

- Verify the compliance of the design of each unit or subsystem with its specifications decreasing the development time and cost to the minimum.
- Achieve the full qualification as soon as possible.
- Guaranty the delivery of flight units or subsystems in due time to system AIT.

So the development approach strongly depends on the design itself and on the qualification status. From this point of view the units are split in four categories.

6.6.2 Existing and already qualified units (Category A)

The previous considerations are no more necessary as these “of the shelf” units are considered as fully qualified. In addition to Flight Models to be used on PFM Satellites, an additional Flight Model shall be delivered as Flight Spare (FS).

For system AVM purpose, an EM or EBB will be delivered.

6.6.3 Existing but not completely qualified units (Category B)

These "off the shelf" units have been already used and qualified on another programme, but a delta qualification is necessary as the mechanical, thermal, or EMC qualification level range is not fully compliant with Herschel/Planck requirements. The design validation being already achieved, the delta qualification will be performed on a first Qualification Model (QM) fully flight representative in order to be refurbished as Flight Spare (FS). The second model will be manufactured as FM.

For system AVM purpose, an EM or EBB will be delivered.

6.6.4 Existing units requiring minor modifications (Category C)

These "off the shelf" units have been already used and qualified on another programme, but minor modifications have to be implemented to be compliant with Herschel/Planck technical requirements. The design validation and possible corresponding delta qualification will be performed using the first Qualification Model QM) fully flight representative in order to be refurbished as Flight Spare (FS). The second model will be manufactured as FM.

For system AVM purpose, an EM or EBB will be delivered.

6.6.5 Units of new design (Category D)

For this category it is necessary to verify very early in the programme that this new design is really compliant. This will be done by means of EBB or EM: non-flight units, without redundant chains, non Hi-Reel parts, with (EM) or without (EBB) physical representativeness.

Then the design qualification will be done by means of flight representative units using commercial or Mil. Grade parts (EQM) or Hi-Rel parts (QM) depending on the procurement and manufacturing duration. In any case the manufacturing process and procedures have to be identical to the ones used later for the flight articles.

In case of QM philosophy, this model will be reused as flight spare after refurbishment. In case of EQM philosophy, an additional flight model will be delivered as flight spare.

For system AVM purposes, pending on procurement and manufacturing duration, either the EM /EBB or EQM will be delivered.

6.6.6 Units – Model philosophy

Taking into account that for STM purposes, only MTD are necessary, the development approach, combined with the Satellites development plan, leads to the following models:

Cat.	AVM	STM Herschel	STM Planck	PFM Herschel	PFM Planck	Spare
A	EM	MTD1	MTD2	FM1	FM2	FM3
B	EM	MTD1	MTD2	FM1	FM2	QM refurb.
C	EM	MTD1	MTD2	FM1	FM2	QM refurb.
D	EM or EQM	MTD1	MTD2	FM1	FM2	QM refurb. (or FM3 in case of EQM philo)

Table 6.6.6: Units – Model Philosophy

6.7 MODEL PHILOSOPHY FOR SCIENTIFIC INSTRUMENTS

The following models of instruments (PACS, HIFI, SPIRE, LFI and HFI) will be delivered as Customer Furnished Equipment (CFE):

- AVionic Model (AVM)
- Cryogenic Qualification Model (CQM)
- ProtoFlight Model (PFM).

The instrument development is generally based on AVM of the warm units, simulator and CQM for coolers and FPUs and PFM for both.

These models will be used for integration and qualification at system level as indicated by the following Tables 6.7-1 & 6.7-2.

Pending model philosophy adopted by instruments, flight spares are the refurbishment of the above CQM or/and spare kits.

ALCATEL will procure:

- the mass and thermal dummies (MTD) of the warm units to be used in the relevant SVM STM
- the mass and thermal dummies (MTD) of the cold units to be used in the Planck PLM STM
- the Planck instrument RF mock-up used for Planck RF development models

Astrium will procure:

- the mass and thermal dummies (MTD) of the cold units to be used in the Herschel E-PLM STM

The procurement will be based on instrument design and interface specifications.

Associated MGSE and EGSE will be provided by instrument as CFE.

- The instrument EGSE will be used throughout all Phases of the programme including: instrument level tests; PLM tests, satellite tests and in-orbit operations.
- The test procedure developed for the Instrument level tests will be re-used during system tests in the system EGSE environment with no or minimal modifications.
- The instrument EGSE and the flight control system will be based upon SCOS-2000.

	Herschel Satellites and Modules			
	AVM	**PLM EQM**	**STM**	**PFM**
SPIRE				
Warm Units	AVM	AVM	*MTD (*)*	PFM
FP Units	DRCU Simul.	CQM	*MTD (*)*	PFM
HIFI				
Warm Units	AVM	CQM	*MTD (*)*	PFM
FP Units	Simulator	CQM	*MTD (*)*	PFM
PACS				
Warm Units	AVM	AVM	*MTD (*)*	PFM
FP Units	Simulator	CQM	*MTD (*)*	PFM

(*) MTD are not part of instrument delivery

TABLE 6.7-1 UTILISATION OF Herschel INSTRUMENT MODELS AT SYSTEM LEVEL

	Planck Satellites		
	AVM	**CQM/STM**	**PFM**
HFI			
Warm Units	CQM	CQM/*MTD (*)*	FM
FP Units	Simulator	CQM	FM
4K Cooler	CQM & Simul.	CQM	FM
O.1 K Cooler	CQM & Simul.	CQM/*MTD (*)*	FM
LFI			
Warm Units	AVM/CQM	CQM/*MTD (*)*	PFM
FP Units	loads	CQM	PFM
SCS			
Nominal	simulator	STM	FM1
Redundant	N/A	MTD	CQM = FM2

TABLE 6.7-2 UTILISATION OF PLANCK INSTRUMENT MODELS AT SYSTEM LEVEL

Avionics Model (AVM)

According to AVM system test objectives as defined in §6.2.2, the instrument AVM units must have the following built standard:

- electronics flight standard except for parts. Commercial parts have to be of the same technology as FM parts
- software flight standard, software of flight quality must be able to be run
- form, fit and function of the flight model
- for Planck the AVM units used with the CQM shall be compatible of thermal vacuum environment in order to allow performing the cryogenic test.

In order to save cost the AVM reducing redundancy may reduce hardware contents:

- cold redundant units or channels may be deleted if no automatic switch-over is involved
- multiple redundancy of hot redundant units or modules may be reduced by electrical dummies (to e.g. dual redundancy) for AVM objectives
- simulators may be supplied for units not directly interfacing with the spacecraft subsystems. The level of these simulators, to be agreed with ESA, will allow verification of the correct execution of the flight procedures.

Qualification Models

Because of their new development status and/or the criticality of their performance to the flow of the AIV programme, specific units will deliver QM models for the assembly tests at payload module level.

These are:

- Herschel Focal Plane Units (SPIRE, PACS, HIFI including LOU)
- Planck Focal Plane Unit (HFI, LFI)
- Planck coolers (20K Sorption Cooler, 4K JT Cooler, 0.1K Dilution Cooler).

The qualification models standard will be the same as for flight models, cold redundant units (20K-sorption cooler) may be replaced by dummies, and the number of similar channels may be reduced.

Flight Model

The PFM test objectives is the qualification of spacecraft system by functional and environmental tests. The FM units therefore shall have full flight standard verified by formal functional and environmental acceptance tests.

6.8 SPARE PHILOSOPHY

In order not to interrupt the Satellite PFM AIT sequence, including the launch campaign, flight spares of all units belonging to the Herschel and Planck SVM will be provided according the following rules:

Structures

The experience shows that spares of structural elements are generally not necessary. However a minimum repair kit could be considered: elementary GFRP or CFRP rods, raw materials, adhesives…

Harness

No spare is proposed (excepted a limited number of spare connectors) because any damage can be easily repaired.

Thermal control

At least one heater of each type will be procured as spare.

For washers, fillers, straps, OSRs and paints a repair kit is sufficient.

MLIs can be repaired in case of accidental tear or STM/QM MLI could be used, but to not degrade cleanliness and performances a provision of pre-assembled MLI sheets is recommended.

At least one heat-pipe of each type will be procured as spare.

RCS

Most of the elements are standard items and thus the spares can be considered as part of the series effect at unit Manufacturer level. A limited number of spare parts for critical elements (thrusters…) will by supplied.

Planck Solar Array

No spare is proposed. The risk is limited to the damage of some cells or cover glasses. At the end of the test sequence after a detailed visual inspection the necessary exchange of damaged parts will be done, and the SA status verified by a flasher test.
A repair kit is necessary including solar cells of the various current classes, OSRs, cables and connectors.

Electrical units

For electronic units, the spare model philosophy is presented in § 4.5 and summarised hereafter:

Cat.	Spare
A	Fully Flight Model
B	QM refurbished
C	QM refurbished
D	QM refurbished or Fully Flight Model if EQM philosophy

Antennae

For antennae, the spare philosophy is the same as the one for electronic units:

Cat.	Spare
A	Fully Flight Model
B	QM refurbished
C	QM refurbished
D	QM refurbished or Fully Flight Model if EQM philosophy

6.9 MODEL PHILOSOPHY SUMMARY TABLES

	Herschel /Planck AVM	Herschel E-PLM EQM	Herschel Satellite STM	Herschel Satellite PFM	Spare
H-TELESCOPE	N/A	N/A	STM	FM	N/A
H-EPLM					N/A
Cryostat	N/A	ISO QM	PFM	PFM	N/A
Sunshade	N/A	N/A	S(T)M	FM	N/A
Sunshield	N/A	N/A	S(T)M	FM	N/A
Interface truss	N/A	N/A	STM	FM	N/A
Exp. FPU's					
HIFI	Simulator	CQM	MTD	PFM	FS
SPIRE	DRCU Sim.	CQM	MTD	PFM	CQM refurb.
PACS.	Simulator	CQM	MTD	PFM	CQM refurb.
H-SVM					
Structure	N/A	N/A	H-STM	H-FM	Kit
Thermal Control	N/A	N/A	H-STM	H-FM	Kit
Harness	EM	N/A	H-STM	H-FM	Kit
RCS	N/A	N/A	H-STM	H-FM	Kit
ACMS					
Unit Cat A	EM	N/A	H-MTD	H-FM1	H-FM2
Unit Cat B	EM	N/A	H-MTD	H-FM	H-QM
Unit Cat C	EM	N/A	H-MTD	H-FM	H-QM
Unit Cat D	EM(EQM)	N/A	H-MTD	H-FM	H-QM (FM2)
CDMS					
Unit Cat A	EM	N/A	MTD1	FM1	FM3
Unit Cat B	EM	N/A	MTD1	FM1	QM refurb.
Unit Cat C	EM	N/A	MTD1	FM1	QM refurb.
Unit Cat D	EM(EQM)	N/A	MTD1	FM1	QM ref. (FM2)
Power supply S/S					
Unit Cat A	EM	N/A	MTD1	FM1	FM3
Unit Cat B	EM	N/A	MTD1	FM1	QM refurb.
Unit Cat C	EM	N/A	MTD1	FM1	QM refurb.
Unit Cat D	EM(EQM)	N/A	MTD1	FM1	QM ref. (FM2)
TT&C S/S					
Unit Cat A	EM	N/A	MTD1	FM1	FM3
Unit Cat B	EM	N/A	MTD1	FM1	QM refurb.
Unit Cat C	EM	N/A	MTD1	FM1	QM refurb.
Unit Cat D	EM(EQM)	N/A	MTD1	FM1	QM ref. (FM2)
Exp. warm units					
HIFI	AVM	AVM	MTD	PFM	Spare kits
SPIRE	CQM	CQM	MTD	PFM	Spare kits
PACS.	AVM	AVM	MTD	PFM	Spare kits

TABLE 6.9-1 HERSCHEL MODEL PHILOSOPHY

	Herschel/ Planck AVM	Planck PLM CQM	Planck Satellite STM	Planck Satellite PFM	Spare
PPLM					N/A
Cryo-Structure	N/A	QM	QM	FM	QM refurb.
Telescope	N/A	QM	QM	FM	QM refurb.
Reflectors	N/A	Dummy QM on RFQM	Dummy	FM	N/A
Exp. FPU's					
HFI	Simulator	CQM	MTD	PFM	FS
LFI	Simulator	CQM	MTD	PFM	TBD
P SVM					
Structure	N/A	N/A	P-STM	FM	Kit
Thermal Control	N/A	N/A	P-STM	FM	Kit
Harness	EM	N/A	P-STM	FM	Kit
RCS	N/A	N/A	P-STM	FM	Kit
ACMS					
Unit Cat A	EM	N/A	P-MTD	P-FM1	P-FM2
Unit Cat B	EM	N/A	P-MTD	P-FM	P-QM
Unit Cat C	EM	N/A	P-MTD	P-FM	P-QM
Unit Cat D	EM(EQM)	N/A	P-MTD	P-FM	P-QM (FM2)
CDMS					
Unit Cat A	EM	N/A	MTD2	FM2	FM3
Unit Cat B	EM	N/A	MTD2	FM2	QM refurb.
Unit Cat C	EM	N/A	MTD2	FM2	QM refurb.
Unit Cat D	EM(EQM)	N/A	MTD2	FM2	QM ref. (FM2)
Power supply S/S					
Unit Cat A	EM	N/A	MTD2	FM2	FM3
Unit Cat B	EM	N/A	MTD2	FM2	QM refurb.
Unit Cat C	EM	N/A	MTD2	FM2	QM refurb.
Unit Cat D	EM(EQM)	N/A	MTD2	FM2	QM ref. (FM2)
TT&C S/S					
Unit Cat A	EM	N/A	MTD2	FM2	FM3
Unit Cat B	EM	N/A	MTD2	FM2	QM refurb.
Unit Cat C	EM	N/A	MTD2	FM2	QM refurb.
Unit Cat D	EM(EQM)	N/A	MTD2	FM2	QM ref. (FM2)
Exp. warm units					
HFI	AVM	AVM	MTD	PFM	FS
LFI	AVM	AVM	MTD	PFM	Spare kits
SCS	N/A	CQM/MTD	CQM/MTD	FM/CQM refur.	N/A

TABLE 6.9-2 PLANCK MODEL PHILOSOPHY

6.10 GROUND SUPPORT EQUIPMENT (GSE)

6.10.1 Mechanical Ground Support Equipment (MGSE)

The Mechanical Ground Support Equipment shall support the complete spacecraft verification program from unit to system level. The main functions of MGSE are:

- Handling and Integration
- Transport and Storage
- Testing Support
- RCS Operations
- Mechanical, Contamination and Chemical Cleanliness Protection

The First/Planck SVM MGSE will be designed to the maximum commonality. Some MGSE designed to support the AIT tasks at SVM level will be used during the Integration and Testing activities at Satellite Levels. Furthermore some MGSE will be designed interchangeable to support also the integration of the F/P PLM in order to increase the flexibility of use to the maximum extent; relevant dedicated adapters will cover the different I/F requirements.

The design of MGSE of previous program will be used to the maximum extent in order to reduce the cost and the development phase.
The use of refurbished items from XMM/Integral/Rosetta Programs is considered.

6.10.2 Electrical Ground Support Equipment (EGSE)

In order to minimise the cost and the development phase, the EGSE are defined according the following guidelines:

- Commonality between Herschel/PLANCK EGSE to guarantee support of the following test configurations:
  - The Herschel/PLANCK AVM Integration and Functional test
  - Herschel E-PLM Test Activities
  - Planck PLM Test Activities
  - PFM Herschel SVM Test Activities
  - PFM PLANCK SVM Test Activities

- PFM Herschel Satellite AIT, environmental testing and launch campaigns activities
- PFM Planck Satellite AIT, environmental testing and launch campaigns activities

– Reduce costs and simplify management

– Heritage from running programme. To reuse to the maximum extent existing suitable design (e.g. Rosetta, Mars Express…).

– Guarantee that new developments or porting/up-grades are baseline on low-cost and generally available platforms

– Use well established LAN I/F standards for the P/L EGSE's to be integrated with the Satellites' EGSE, again inheriting them from previous programs as above

– Common S/W (or part of) between CCS, SIS, SVF, ACMS SCOE & Instruments SCOE

– Procurement at SVM/Equipment level and re-use at upper level (SVM and Satellites)

– The hosting of the Satellite Data Base.

– The access via internet to external users (e.g. P/L scientists) of the archived data (WWW)

Thanks to the AVM, EGSE will be validated prior to be used at Satellite levels.

6.10.3 Optical Ground Support Equipment (OGSE)

To a large extent standard products, which are available off the shelf or which already exist at ALCATEL and or at Herschel AIT Contractor (Astrium) will be used as OGSE.
For specific WFE measurement of Planck Telescope, a Sharck-Hartmann method will be used. The wave-front sensor at 10.6µm shall be developed.

6.10.4 Cryo Vacuum Support Equipment (CVSE)

The CVSE is the mechanical non-flight equipment that supports the vacuum and cryogenic ground activities with the Herschel E-PLM. The CVSE shall:

- ensure that the function of the Herschel cryo/vacuum system in its intended environment is fully supported and carried out easily and safe.
- be able to cover the Herschel-He S/S requirements starting with the PLM integration and ends with the launch campaign of the PFM Herschel Satellite.
- be used to perform all cryogenic and vacuum operations of the Herschel-He S/S on PLM and System level.

The CVSE will be designed and manufactured according the one already developed in the frame of ISO programme.

6.10.5 RF Suitcase

A common Herschel/Planck RF suitcase shall be developed for Ground Segment Compatibility Tests requirements (RF Compatibility Tests).
This suitcase shall simulate the RF uplinks and downlinks characteristics of the satellites and shall be delivered to the ground.
It will be manufactured according to the same design as the corresponding RF subsystem and CDMU but using commercial parts.

6.11 ON BOARD SOFTWARE (OBS) DEVELOPMENT

6.11.1 Introduction

The Herschel/Planck on-board software design, development and verification phase requires to be run independently of the hardware design and development. The on board software will be structured such that the modifications to any individual code module have a minimum impact on the other modules.

Dedicated Software test beds will be defined independently by each software developer. Prior to formal delivery, each software shall be proved to run on the Software Validation Facility (SVF) to guarantee the representativeness of ISV and further ground maintenance activities.

A standardised software development environment will be used for the CDMS and the ACMS software design and development. This will reduce the programme risk. The development environment will be duplicated in each development site (including the Independent software validation and software maintenance facility).

The standard development environment is the central part of the SVF. It comprises a standard processor type, standard development language, standard software developments tools and single development team per subsystem.
The on-board software will be developed according to the state-of-the-art rules for spacecraft software.

- Uses of a software design tool
- Use of high level of code, supplemented by small sections of code
- Consideration of testability and failure indication already during the design stages.
- Insurance of clearly designed module interfaces (principles of information hiding). This to simplify the mechanism supporting the patching of OBS in flight.
- Use of a set of test tools including:
  - Code analysis tools to ensure the compliance with the project coding standard and to quantify the code complexity, testability and maintainability in terms of suitable software metrics.

- Standardised SVF, simulating the complete environment of the software (including Hardware) but allowing a more through testing, independent from the hardware availability, but with a representative timing behaviour.

– Automation of test (to facilitate regression testing) and treatment of software packages plus related test environment as one configuration item (to facilitate the software maintenance).

– Application of ESA software engineering standard ESA ECSS-E-40 and ECSS Q-80 and conduction of formal reviews with the Prime contractor

6.11.2 Software Validation Facility (SVF)

All software produced will be verified by an independent software verification team different from the software supplier. A Software Validation Facility (SVF) will support the software verification.

The SVF typically comprises one or several target processor modules, software models of avionics hardware (e.g. communication bus) and simulations of the background environment.

The Herschel/Planck SVF Hardware will be used for different activities carried out by different users, according to the main phases of the Herschel/Planck AIT sequences. The same SVF will give the possibility to validate different On-Board Software, as CDMS SW, ACMS SW … in a stand-alone configuration.
The necessity to run two or more On-board Software in parallel and synchronised to the same simulated real time will be considered and evaluated during phase B.

The SVF will be integrated with the Software Development Environment (SDE) and the Software Maintenance Facility (SMF) in order to provide a unified environment:

– for many of the different spacecraft's software's test activities with hardware in the loop;

– as target for the Independent Software Validation (ISV);

– for software maintenance at ESOC during the operational phase of Herschel and Planck.

6.11.3 Software Validation

The purpose of the software validation is the verification of the software conformity with the "On Board SW Design Requirement", Doc. H-P-1-ASPI-SP-0046.

The SW development and validation is arranged such that it can support all test activities. It has been required that each On Board Software product be designed to support partial deliveries, coherent with overall system test schedule. These Intermediate Software deliveries may become essential to reduce significantly program risks:

- Intermediate Software deliveries shall be clearly identified and introduced in the Software Development Plan.
- All On Board Software shall be designed to allow the intermediate deliveries of fully validated software versions.
- Intermediate Software deliveries shall be made to correct possible failures detected during system testing.

If made necessary to reduce the schedule risks, three OBSW issues are preliminarily identified, basically in line with the AVM integration needs

- Issue 00 = CDMS_SW Data TM/TC service, exchange protocol with I/F subsystems.

- Issue 01 = Issue 00 + modes management + spacecraft management: TM/TC plan management, thermal regulation, battery management, P/F and P/L monitoring). The ground/board interface (commandability and observability) and CDMS level FDIR are validated by these tests.

- Issue 02 = Issue 01 + Herschel or Planck ACMS_SW and ACMS_eqt_SW.

6.11.3.1 ACMS Software Validation

The ACMS_SW is validated according to the following phases:

- unit tests to ensure that the procedures and functions of the ACMS_SW are correct with respect to their functional description, and that the interfaces between its components behave correctly
- pre-validation by using a fully numerical computer simulator
- HW/SW integration are to check the correct interaction of the I/O software, the HW dependent SW and the real time core when running on the computer representative model (EBB)
- Validation phase is to verify the conformance of the complete ACMS_SW (the real one on a representative environment) with the ACMS_SW SRD and ICD

The ACMS_SW may be staggered in line with ACMS validation needs

6.11.3.2 CDMS-OBSW Validation

The CDMS_OBSW is validated according to the following phases:

- unit tests to ensure that the procedures and functions of the OBSW are correct with respect to their functional description
- HW/SW integration to check the correct interaction of the I/O software, the HW dependent SW and the real time core when running on the computer representative model (EBB)
- Validation phase is to verify the conformance of the complete CDMS_OBSW (the real one on a representative environment) with the OBSW SRD and ICD

6.11.4 Independent Software Validation (ISV)

All produced software shall be verified by the supplier and an Independent Software Validation (ISV) team different from the software supplier.

The objectives of the ISV tasks are to achieve an independent validation of the Herschel/Planck On Board Software. Except if re-used as is from a previous application, the following On Board Software shall be independently validated:

- Bootstrap Firmware
- CDMS Software (incl. Kernel & Mass Memory management Software)
- ACMS Software (incl. Kernal Software)
- Startracker Software

For this, a team, independent from the on-board software development contractor(s), shall perform reviews and tests of the Herschel / Planck On Board Software.
This validation shall use :

- the software specifications produced by the Prime, and the SVM contractor,
- the User Requirements Documents (URDs) produced by the Prime, the SVM contractor and possibly lower level contractors,
- the Software Requirements Documents (SRDs) produced by the software contractor(s),
- the Software Design Documents (ADDs and DDDs) produced by the software contractor(s),
- the code (source + executable) produced by the software contractor(s),
- and the Software Validation Facility (SVF).

The Independent Software Validation activities shall be performed on the Software Validation Facility in 2 main steps:

- First step on the "AVM" release, composed of the complete and integrated versions of the above software (Issue 02)

- Second step on the "PFM" release, composed of the same SW products at the time of the SVM PFM integration

During PFM AIT activities, SW changes (bugs, new requirements,…) on the "PFM" release will go through the nominal validation process ("NCR" Review Board) at SW subcontractor, then possibly system level. In nominal , they will not individually go through an ISV run except if it is recommended by the conclusions of the "NCR" Review Board.

After the launch and until the end of the mission, the software maintenance and validation will be performed by ESOC.

7 DESIGN AND DEVELOPMENT FLOW

7.1 SYSTEM REVIEWS – DEFINITION

The basic development plan of Herschel/Planck is to provide a programme so built as to achieve a logical, sustainable schedule of events allowing an orderly design phase, comprehensive design qualification and soundly based manufacture and proto-qualification time scale.

The development plan and the schedule are set up against the technical development logic with the following main drivers:

- the selected model philosophy
- the end of Phase B being the real Phase C/D activities start up
- the launch date requirement for Herschel/Planck by mid February 2007

At appropriate steps during the progress of the Herschel/Planck programme, systems reviews will be held to monitor the status of the development and to approve the start of the next phase. The following systems reviews will be performed during the Herschel/Planck programme:

- **System Requirement Review (SRR)**

To be held early in Phase B, the SRR aims to establish

- Requirement baseline from system down to module and subsystem levels
- Interface definition down to subsystem level
- The product assurance requirements

– **Preliminary Design Review (PDR)**

To be held at the end of Phase B, the PDR will be the start of Phase C/D activities. The main objectives will be to verify the compliance of the system design with the requirement including the performances. The outputs will be

- The requirements specifications down to equipment level
- The preliminary definition documentation
- The design justification file
- The draft ICD's
- Hi-Rel parts procurement status (to be confirmed)
- LLI procurement status (to be confirmed)

– **Critical Design Review (CDR)**

To be held in the first part of the Phase C/D, the CDR aims

- To assess the design, the performance and the development status of the Herschel/Planck programme
- To present qualification test plans
- To issue the final ICD's
- To release the manufacturing of flight model hardware

– **Qualification Review (QR)**

At an appropriate time, the QR will be conducted on the basis

- of qualification reports
- of complete Design Justification files

– **Flight Acceptance Review (FAR)**

At the end of the qualification and acceptance programme, the FAR will

- Confirm the completion of the Phase C/D objectives
- Declare the readiness for shipment to the launch site

In addition, ALCATEL will support the agency during the two following system reviews

– **Flight Readiness Review (FRR)**

The aim of the FRR is to declare Herschel and Planck Satellites ready for launch and flight.

– **In-Orbit Commissioning Review (IOCR)**

Following the in-orbit commissioning (Phase E1), the IOCR will

- Pronounce the in-flight acceptance
- Authorise the entry into service
- Ensure feedback to the actors in the programme (lessons learnt)

7.2 CRITICAL AREAS AND DEVELOPMENT MILESTONES

7.2.1 Introduction

In support of the risk assessment developed in Chapter 3.3, major development milestones have been defined by ALCATEL considering the following elements:

- Driving performance requirements,
- Design implementation,
- Development plan and model philosophy,
- Programme schedule,
- Cost.

Complementary milestones are also defined in addition to the above major reviews.

These milestones correspond to the verification of a key performance in the development plan. Successful achievement of **such milestones will indicate a major step down in the risk assessment** for the rest of the programme.

7.2.2 Planck PLM

Numbering	Milestone title	Item of risk	Comment
MS-PPLM-01	Telescope WFE	Optical performance demonstration at 50K	Provides indirect measurement of the optical performance and allows to refine the main lobe characteristics (gain, polarisation, …)
MS-PPLM-02	RFQM measurement	SIN computation verification	Telescope + baffle radiation pattern at all possible frequencies (up to 500 GHz TBC)
MS-PPLM-03	Main baffle and groove 3 emissivity measurement	Thermal performance of the passive stage	Elementary material tests at 50K
MS-PPLM-04	CQM TV/TB test	Passive / active cooler chain performance verification in flight representative configuration	First verification of the complete chain leading to the achievement of 0.1K on the HFI bolometers

7.2.3 Herschel E-PLM

Numbering	**Milestone title**	**Item of risk**	**Comment**
MS-FPLM-01	FM He II tank acceptance	Tightness to superfluid Helium	Key planning issue.
MS-FPLM-02	Cryo-harness technology qualification	Mechanical behaviour at operating temperature	ISO experience + Herschel increase of connection number (ISO X 5)
MS-FPLM-03	Cryo-valves acceptance	Leakage / operation in cold conditions	ISO experience
MS-FPLM-04	MLI efficiency test	Accuracy of telescope & CVV temperature predictions	Elementary test
MS-FPLM-05	TV/TB test on PFM cryostat	Cryogenic lifetime verification in cold conditions	Allows correlation of thermal model with 2 points of CVV temperature
MS-FPLM-06	GaAs solar cells	Power budgets	Qualification in progress. Status available at CDR

7.2.4 Planck spacecraft

Numbering	Milestone title	Item of risk	Comment
MS-PL-01	CQM TV/TB test completion	Refer to MS-PPLM-04	Includes SVM thermal control validation
MS-PL-02	CQM mechanical tests completion	Verification of frequencies / loads / mechanical properties	Validation of assumptions for FPU, coolers components, tanks, and telescope
MS-PL-03	AVM tests completion in Planck configuration	Validation of electrical interfaces	Minimises risks at PFM level

7.2.5 Herschel spacecraft

Numbering	Milestone title	Item of risk	Comment
MS-H-01	STM mechanical tests completion	Verification of frequencies / loads	Validation of assumptions for FPU, helium components, tanks, telescope and LOU
MS-H-02	FM TV/TB test completion	Telescope temperature	First test with a flight representative telescope. Sun simulation impact inside the TV chamber to be assessed
MS-H-03	AVM tests completion in Herschel configuration	Validation of electrical interfaces	Minimise risks at PFM level

7.2.6 Instruments

7.2.6.1 LFI

Numbering	Milestone title	Item of risk	Comment
MS-LFI-01	Wave guides manufacturing Custom Microwave (US) or Forestel (I)	According to RF and thermal design.	all elements must be ready for radiometer chain integration
MS-LFI-02	Phase switches	Problems in achieving performances of 100MHz phase switches	
MS-LFI-03	HEMT's	Sensitivity to ESD and environment	

7.2.6.2 HFI

Numbering	Milestone title	Item of risk	Comment
MS-HFI-01	0.1K cooler DM delivery	Reaching 0.1K	
MS-HFI-02	Multi-mode horn	Measurement of polarisation	Solved by polarisation sensitive Bolometer

7.2.6.3 Sorption cooler

Numbering	Milestone title	Item of risk	Comment
MS-SCC-01	EBB tests	Schedule	
MS-SCC-02	CQM delivery	Schedule	

7.2.6.4 HIFI

Numbering	Milestone title	Item of risk	Comment
MS-HIFI-01	LOU delivery	LOU development	LOU PDR in March 2001
MS-HIFI-02	WBS delivery	WBS development	WBS PDR by end 2001

7.2.6.5 SPIRE

Numbering	Milestone title	Item of risk	Comment
MS-SPIRE-01	Cryo-mechanisms	FTS, …	STM performance review

7.2.6.6 PACS

Numbering	Milestone title	Item of risk	Comment
MS-PACS-01	Cold Readout Electronics Development Cycle	If performances not reached, use alternative technology	6 months Development Cycle
MS-PACS-02	Cryo-mechanisms Schedule	Ball bearing Components developments	

7.2.7 Planck Reflectors

Numbering	Milestone title	Item of risk	Comment
MS-PR-01	QM delivery	Planck Development	Separated test sequences: STM/CQM test with dummies. RFQM test with QM Refer to chapter 10

7.2.8 SVM

Numbering	Milestone title	Item of risk	Comment
MS-SVM-01	Planck SVM STM structure delivery	Planck CQM schedule	Flight representative
MS-SVM-02	Software URD issue (CDMS, ACMS)	Avionics schedule	Important effort of the core team in phase B to secure avionics planning
MS-SVM-03	Completion of ACMS tests on AVM	Validation of avionics (core + Herschel + Planck)	Further SVM AVM tests will follow

7.2.9 SVM Subsystems

Numbering	Milestone title	Item of risk	Comment
MS-SS-01	Static Loading Test	Structure qualification	Structure fully flight representative
MS-SS-02	AVM ACMS delivery	AVM schedule	Important effort of the core team in phase B to secure avionics planning
MS-SS-03	AVM CDMS delivery	AVM schedule	Important effort of the core team in phase B to secure avionics planning
MS-SS-04	GaAs solar cells	Power budgets	Qualification in progress. Status available at CDR
MS-SS-05	Heat pipes for Sorption Cooler radiator	Power density	Sorption Cooler performances

8 ASSEMBLY, INTEGRATION AND TESTS FLOW

8.1 GENERAL AIT FLOW

In general the sequences for spacecraft AIT are structured in four distinct phases:

- the first phase includes the **mechanical/electrical integration and unit function tests**. This phase will be finalised by a SIT. In order to have a well-proven spacecraft a reduced SIT will be performed at SVM level prior to the mating with PLM. Once the PLM and the SVM are merged a full SIT will be performed
- following the system integration phase all functions of the spacecraft will be tested. For this purpose a full **Integrated Satellite Test (IST)** under ambient conditions will be performed. During this IST the spacecraft will be operated in defined mission modes operated fully automatically from the central checkout system. The functional test programme will be completed by specific performance tests required by the scientific payload.
- With the end of the functional test phase under ambient conditions the **environmental test programme** will start. For the PFMs the following test facilities are needed:
    - acoustic noise
    - vibration & shock
    - thermal vacuum and cryogenic
    - EMC
    - mass properties determination
    - compact antenna test range for RF ambient test of Planck.

Each major environmental test includes the following sub-activities:

set-up and check of set-up

Short Functional Test (SFT)

alignment verification prior and post environmental load

specialised system functional test in the specific environment

dismounting and transportation to next test set-up.

- Full **ground segment compatibility test** under flight operational conditions

8.2 TEST FACILITIES

Herschel and Planck will follow similar but independent AIT sequences in separate facilities.

As far as possible the environmental test programme will run at one test location, thus limiting transport and set-up activities to a minimum, except for Planck which requires a specific cryogenic facility only available in Liège (CSL).

The facility evaluation has been performed considering:

- the overall size of various modules
- the overall size of satellites
- the ability of the facility to fulfil the aims of the test
- the use of existing ones

The following European Coordinated tests facilities have been considered:

- ESTEC
- IABG
- INTESPACE
- CSL

and

- ALCATEL Cannes

The baseline (under-lined when option) is presented in Table 8.2. Details and final choice will be reflected in relevant AIT Plans.

Activity	SVM	Herschel EPLM	Herschel Satellite	Planck PLM	Planck Satellite
AIT Sequence	Alenia premises	Astrium premises	Astrium premises	ALCATEL premises	ALCATEL premises
AVM sequence	Alenia premises				
SVM/PLM mating			Astrium premises or ESTEC		ALCATEL premises
Thermal and Cryogenic Environment	ESTEC IABG INTESPACE	ESTEC IABG	ESTEC		CSL
Static load Test	Primary Structure Contractor premises				
Mechanical Environment		IABG (low level runs)	ESTEC		ALCATEL premises
EMC **Cond.** **Rad.**	 Alenia premises N/A	(on EQM) Astrium premises	 ESTEC ESTEC		ALCATEL premises (in selected RF facility)
Mass Properties	ESTEC IABG INTESPACE	IABG	ESTEC		ALCATEL premises
Radio Frequency				RFDM : ALCATEL premises RFQM : ALCATEL premises or Astrium premises	ALCATEL premises

Table 8.2: Baseline for facilities

8.3 SATELLITE AIT FLOW

8.3.1 Herschel STM AIT flow

After integration/test of the SVM (refer to §8.5.2) and of the E-PLM (refer to §8.6.2.1) by the relevant Contractor, the logical flow at system level will be:

- SVM/E-PLM mating
- integration of sunshield/Solar Array
- alignment check
- RCS filling and pressurisation
- sine vibration
- alignment check
- acoustic noise test
- alignment check
- shock test and ARIANE 5 adapter fit check
- mass and COG determination
- RCS leak test
- RCS draining & drying
- SVM/PLM demating
- H-EPLM Thermal Balance Test (refer to [RD4])
- depletion & warm up
- disintegration.

The cryostat is cooled in He I during all the test sequence.

The AIT flow is depicted in the relevant AIT Plan.

8.3.2 Herschel PFM AIT flow

After integration/test of the SVM (refer to §8.5.3) and of the E-PLM (refer to §8.6.2.2) by the relevant Contractors, the logical flow at system level will be:

- SVM/PLM mating & integration tests
- Sunshield/Solar Array integration
- alignment check
- system integration tests
- He II production and top-up
- integrated satellite test
- EMC tests
- Conversion to He I
- RCS filling and pressurisation
- acoustic noise test
- alignment check
- sine vibration tests
- SFT including alignment check
- He II production and top-up
- thermal test
- Conversion to He I
- alignment check
- COG/MOI determination
- final integrated satellite test.

The cryostat will be delivered to the system AIT cooled in He I; it will be kept in He I all along the PFM AIT sequence including the transportation to the launch site and the launch preparation phase. The only exception concern the EMC and thermal tests performed with the cryostat in He II.

The logical AIT flow is depicted in the relevant AIT Plan.

8.3.3 Planck STM/CQM AIT flow

After integration/test of the SVM (refer to §8.5.1) and of the PPLM (refer to §8.6.3) by the relevant Contractors, the logical flow at system level will be:

- SVM/PPLM mating
- alignment check
- PLM functional test at ambient (integrated PLM test)
- RCS filling and pressurisation
- sine vibration & acoustic noise test
- shock test and ARIANE 5 adapter fit check
- mass and COG determination
- RCS leak test
- RCS draining & drying
- preparation for thermal test
- thermal balance test and cryogenic test including EMC C (cold)

To cope with the very late delivery date of SCC CQM and in order to deliver the Warm Units of the instruments in time for AVM testing, it is proposed to reverse the environmental tests sequence: thermal/cryogenic tests before mechanical tests

- alignment check
- PLM short functional test (ambient)
- SVM/PPLM de-mating
- PPLM disintegration.

The AIT flow is depicted in the relevant AIT Plan.

8.3.4 Planck PFM AIT flow

After integration/test of the SVM (refer to §8.5.3) and of the PPLM (refer to §8.6.3) by the relevant Contractors, the logical flow at system level will be:

- SVM/PPLM mating & integration tests
- thermal control & Solar Array integration
- Satellite Integration Tests (SIT)
- alignment check
- reference Integrated Satellite Test (IST 1)
- EMC tests (ambient)
- RF ambient test of the LFI
- sine vibration and acoustic tests
- alignment check
- COG/MOI determination
- thermal vacuum/thermal balance/cryogenic test

As the redundant chain of the Sorption Cooler System are not verified during the STM/CQM sequence (previous baseline), both SCC, nominal and redundant, shall have to be verified during the FM cryogenic test thus imposing two cool down sequences.

- alignment check
- final Integrated Satellite Test (IST 2).

The logical flow is depicted in the relevant AIT Plan.

8.4 AVM AIT FLOW

The AVM test sequence will be organised in order to optimise the schedule maximising the Herschel/Planck common verifications based on the design commonalties.

As the AVM instruments (Warm Units) will be used to manage the CQM instruments (Focal Plane Units) mounted on the relevant PLM CQM, the AVM system test will be performed at the completion of the PLM CQM test sequences.

The following activities are planned on the AVM:

– electrical integration and interface verification
– unit function tests
– Avionics system test
– system integration test
– integrated satellite test
– specific performance tests
– conducted EMC test
– validation of software updates.

The common Avionics subsystem like CDMS, EPS and RF will be tested performing a common functional test campaign. The ACMS will be verified performing a dedicated test session either for Herschel or for Planck.

The Herschel and Planck instruments warm units will be integrated into the AVM model to verify the communication and functional compatibility with the Avionics units in particular checking the 1553B bus communication with the CDMS and the power compatibility with the PCDU (e.g. LC L-power lines)

The logical flow is depicted in the relevant AIT Plan.

8.5 SVM AIT FLOW

8.5.1 Planck SVM STM AIT flow

The logical flow is depicted in relevant AIT Plan.

Integration tasks

The Structure will be delivered with the RCS already integrated but without the relevant "Instruments' panels" sent to ALCATEL.

During this phase also some RCS thermal control equipment (heaters/MLI) could be integrated as well as relevant critical mechanical and thermal test instrumentation in case of later accessibility limitation.

The solar panels will not be integrated because its envelope could require oversizing of the SVM transport container (road transportation constraints). The installation of the hold-downs and a fit check of the Solar Array dummy panel will be performed before delivery.

Alignment measurement

Alignment measurements are performed on the units requiring optical alignment measurement/adjustment.

The results of these measurements will be kept as reference for the following checks to be performed during the System AIT campaign.

RCS overall leakage check

The RCS leakage test will be performed with the central structure inside the SVM transport container and the measured values will be kept as reference for the following leakage checks performed after mechanical and thermal environmental testing.

Refurbishment

After Planck STM tests campaign the SVM Primary Structure is no longer refurbished to become the Planck FM one.

8.5.2 Herschel SVM STM AIT flow

The logical flow is depicted in relevant AIT Plan.

Static Test

The Structure will be delivered to the RCS Integration site after the successful completion of the static load test. For commonality of the SVM structures, the applied testing loads will fully envelop also the design loads of Planck.

Integration tasks

Before delivery of the SVM structure to Alenia, the RCS integration will be successfully performed.

During this phase also some RCS thermal control equipment (heaters/MLI) could be integrated as well as relevant critical mechanical and thermal test instrumentation in case of later accessibility limitation.

Alignment Measurement

Alignment measurements are performed on the units requiring optical alignment measurement/adjustment.

The results of these measurements will be kept as reference for the following checks to be performed after the transportation to test facility before and after the SVM thermal balance.

Then the SVM will be fully integrated including the “Instrument panels” for alignment measurement and environmental testing.

Environmental testing tasks

- RCS overall leakage test
- Mass properties measurement
- SVM thermal balance test (with Sun simulation)
- Alignment stability check
- Overall RCS leak check

This check will be performed with the SVM inside its transportation container. Then only a blanket pressure will be maintained inside the RCS circuit and the SVM will be delivered to support the system AIT activities.

8.5.3 SVM FM AIT flow

The Herschel/Planck SVM FM AIT sequence will be common as much as possible in order to maximise the commonality on the verifications of the two FM SVMs.

The verification of the common part of the two service modules will be performed using the same test sequence in order to reduce debug-time and schedule.

The specific Herschel or Planck part will be verified performing dedicated test sequence based to the AVM test campaign and to tests performed at unit/subsystem level.

The mission timeline and the OBCPs will be verified on the frame of the SITs and IST.

The Herschel/Planck SVM FM AIT will be performed through the following activities:

Integration task

This test phase starts with the readiness of the flight structure (STM refurbished for Planck SVM) with the RCS already integrated by the RCS Subcontractor.

The Herschel SVM “Instruments' panels” are sent to Astrium. The Planck SVM “Instruments' panels” are already in ALCATEL.

The units I&T are the first electrical activity that is performed on the unit/subsystem after the mechanical installation onto the spacecraft. The shielding, grounding distribution and connection will be verified during this process.

UFT: Unit Function Test

This will ensure the successful integration of the units on the S/C and will be a subset of the IST.

This test also checks functions that are not possible to be verified at S/C completely integrated (e.g. power LCL trip-off verification, etc, …).

SIT: System Integration Test

Test performed on each subsystem during the process of integration to validate the communication interface between themselves and to perform functional verification of the related operative modes.

IST: Integrated SVM Satellite Test

The aim of the SVM IST is to ensure the integrity and functionality of all equipment installed onto the platform and to verify the correct operation of the fully integrated SVM in a series of representative mission modes including back-up modes. Deep hardware and software interactions among subsystems are usually verified in this frame.

SPT: Specific Performance Test

In this category fall the specific configurations or set-up required for the need of SVM subsystems when they are different from the standard configurations. It is included the verification of particular requirements that need to be performed at a particular time in the spacecraft integration and test process, or cannot be included in the standard SFT due to particular spacecraft condition required. Typical examples of SPT are the RCS leak test, or Solar Arrays flash test, light tightness, unit periodical maintenance etc. They will be organised as a series of automated stand-alone tests, that can be executed stand-alone or in the frame of the IST.

EMC conducted test

The conducted emission tests, will demonstrate that levels measured in the most emissive modes do not exceed the specified limits.

The conducted susceptibility tests will demonstrate that the satellite will perform within its specifications. During these tests the SVM will not exhibit spurious or inadvertent response to any combination of operational modes and conditions that are tested. If this occurs the susceptibility threshold will be established.

Alignment Measurement

The alignment measurements are to ensure and demonstrate that certain relative positions and or attitude are within the specified requirements.

RCS leak test

The objective of the Leak Test is to verify the mechanical integrity of the propulsion subsystem. The measurements will be accomplished through a total leak rate measurement. For this purpose the S/C will be installed inside the shipping & transport container.

Satellite database validation

Special care shall be put on the satellite data base validation. It is foreseen to have one part of the SDB common for Herschel and Planck and two dedicated parts one for Herschel and one for Planck.

The Satellite Database (SDB) validation will be performed following a bottom up approach starting from the integration of the Avionics units up to the SVM IST through the SITs.

SVT 0

As an option the SVT 0 can be performed at SVM level prior delivery for mating with PLM. This test will be performed via a NDIU or similar interface to the MOC via communication network connection (e.g. ISDN link).

Solar Array integration

The Planck Solar Array integration will be performed at satellite level before the Planck system environmental test campaign.

The logical flow is depicted in relevant AIT Plan.

8.6 H-EPLM AIT FLOW

8.6.1 Herschel PLM EQM AIT flow

The ISO QM cryostat is used for the electrical and functional testing of the scientific instruments in a representative in-flight environment. It has been modified in order to get a "Herschel" representative test set-up from instrument point of view and the modified ISO cryostat is called Herschel EQM cryostat.

The cryo harness of the PLM EQM will be Herschel flight representative in order to perform a realistic EMC test.

The integration of the EQM cryostat will take place in a clean room Class 100 environment. The integration of the external elements as LOU, BOLA or external harness will take place in a clean room Class 100.000 environment.

A simulator will substitute the Cryostat Control Unit (CCU).

The instrument warm units (WU) are needed during the PLM EQM test sequence and are accommodated inside a SVM dummy located at the base of the cryostat at a distance allowing a harness layout similar to the flight one.
The electrical and functional verification will then be performed in an integrated module test (IST) and EMC test. Both tests need to be done in flight representative thermal environment, which means that the cryostat must be filled with liquid Helium and super fluid Helium has to be produced.

During the timeframe due to delay in the delivery of CQM instruments, some advanced tasks using the MTD instruments in place of the CQM ones are performed. These MTD instruments are those to be used for STM program with adequate thermal representativeness. This approach provides more confidence with regard to the behaviour of the cryostat and a validation of cryogenic operations. So, the EQM activities are split in two main steps.

Step #1:

- ISO PLM QM de-integration (upper & lower part, He I tank)
- modification of the ISO QM upper part to Herschel standard
- integration of the inner harness, He I tank bypass
- preparation of the optical bench (OB) with integration of the MTD instruments onto OB
- integration of the OB onto cryostat
- closing of the cryostat.

- evacuation and leak test
- cool-down and filling (in clean room 100 000)
- cold leak test
- He II production and Top-up
- He S/S performance
- Background test validation (temperature)
- alignment at appropriate steps
- depletion and warm-up
- opening of cryostat upper part (in clean room 100) = end of step #1

Step #2

- preparation of the optical bench (OB) with integration of the CQM instruments onto OB
- integration of the OB onto cryostat
- closing of the cryostat.
- evacuation and leak test
- cool-down and filling (in clean room 100 000)
- mating of pre-integrated SVM dummy equipped with CQM WU instruments
- He II production and Top-up
- Performance of instrument testing (IST, EMC and Background tests)
- alignment at appropriate steps
- depletion and warm-up
- opening of cryostat upper part (in clean room 100) = end of step #2

The logical flow is depicted in relevant AIT Plan.

8.6.2 Herschel E-PLM PFM AIT FLOW

The Herschel E-PLM PFM AIT flow is divided into two phases:

- the thermal and mechanical qualification of the Herschel cryostat with the E-PLM PFM part of the qualification test phase of Herschel Satellite STM
- the workmanship verification, electrical and functional verification after integration of the PFM focal plane units during an acceptance test prior to delivery to Herschel Satellite PFM.

8.6.2.1 Herschel E-PLM PFM qualification phase

The qualification test phase of the Herschel E-PLM PFM serves to verify that the Herschel Cryostat, Sunshield, Sunshade meets the mechanical requirements. It allows a first estimation of the quality of the cryostats thermal model.

This test phase comprises the complete integration of the Herschel cryostat including the Helium S/S, the insulation S/S, the optical bench and the cryo-harness. The instrument FPUs are represented by STMs.

The integration of the Herschel PFM cryostat will take place in a clean room Class 100 environment. The following steps will form the main parts of the integration activities:

- assembly He II tank, cylindrical shielding and CVV
- integration inner harness
- assembly He I tank, tubing
- MLI integration
- closing cryostat lower part
- preparation optical bench and pre-integration FPU MTD onto OB
- integration OB & inner harness
- MLI closure
- closing of cryostat upper part
- evacuation & leak test ⇒ transport to clean room Class 100.000.

The integration of the external elements as LOU, BOLA or external harness will take place in clean room 100.000 environment. The cryostat control electronic will be mounted on a support structure close to the cryostat. The warm units of the instrument will not be needed during this test phase. For mechanical and thermal qualification tests STMs of the warm units will be integrated.

After completion of the Cryostat integration a low-level sine vibration test at ambient temperature will provide the first information of the cryostat modal characteristics and will verify the workmanship.

The structural qualification of the Herschel E-PLM will be done in cold conditions on satellite level after integration of the SVM SM. The E-PLM mated to the Service Module consist of a sunshield STM, a telescope SM, a sunshade SM and a Support Truss PFM. The instruments are represented by STMs. The structural qualification consists of an acoustic noise test and a cold vibration test with qualification level in all three axes. A separation shock test complete the mechanical load tests.

The SVM STM, Telescope SM and Sunshade SM will be dismounted after these tests. The verification of the Thermal Mathematical Model (TMM) will be done on E-PLM level according [RD4].

The following tests will be performed:

- He II production and top-up
- ground lifetime test (limited test)
- He II top-up
- launch autonomy verification
- launch simulation (rapid depletion, vent-line evacuation and launch transient)
- thermal vacuum test to verify the thermal model.

The qualification test phase will be completed with the depletion and warm-up of the cryostat. The upper part of the cryostat will be opened in clean room Class 100 environment and the STMs of the FPUs will be removed.

The logical flow is depicted in the relevant AIT Plan.

8.6.2.2 Herschel E-PLM PFM acceptance phase

The acceptance test phase of the Herschel E-PLM PFM serves to verify that the PFM instruments are proper integrated and that the Herschel E-PLM - together with the instruments - meets the electrical and functional requirements. The structural and thermal acceptance tests will be performed within the environmental tests on satellite level.

This test phase comprises the integration of PFM FPUs into the Herschel cryostat and the integration of the warm instrument units on the relevant SVM fixed to a MGSE replacing the missing part of the service module.

The integration of the FPU-PFM into the cryostat will take place in a clean room Class 100 environment.

The following steps will form the main parts of the integration activities:

- integration of the FPU PFMs onto OB
- integration of the pre-integrated OB into cryostat
- completion of the inner harness
- closing of cryostat upper part
- evacuation & leak test ⇒ transport to clean room Class 100.000.

The exchange of the external elements as LOU or BOLA will take place in clean room 100.000 environment. A warm vibration in one axis at low level in the beginning of the test phase shall verify the workmanship and eigenfrequencies.

The cryostat control electronic, as well as the instrument warm units, will be mounted on the relevant SVM panels supported by the specific MGSE.

It has to be noted that the wave-guides must not be opened after this test phase.

The electrical and functional verification of the experiment PFM will be done in an integrated module test and a dark background test, both in Helium II conditions. These tests will be supported by a special cavity device, which allows checkout of the instruments by simulating a cold background.

The following tests will be performed:

- He II production and top-up
- integrated module test including instruments operational programme
- dark background tests
- conversion to He I.

After completion of the electrical and optical tests of the instruments the FM Sunshield, the FM telescope and FM Sunshade have to be integrated for the mating of the E-PLM to the Service Module (SVM). The integration order can be modified to optimise AIT flow.

The Herschel E-PLM PFM will be delivered to Satellite AIV in cold (He I) conditions.

The logical flow is depicted in the relevant AIT Plan.

8.7 PLANCK PLM AIT FLOW

The two models of PPLM, the RF/CQM and the PFM, have to be integrated following the same general sequence. AIT activities are mainly dedicated to mechanical and electrical integration, the environmental test programme being performed at system level.

The logical flow is depicted in the relevant AIT Plan.

- bench test of instruments before integration on the PPLM
- assembly of sorption coolers on SVM panels, the piping and cold ends are supported by a dedicated MGSE
- mounting of the 2 first grooves (central part) on the PPLM platform. The grooves are for the moment supported by MGSE
- assembly of GFRP struts and fixation of grooves.
- Assembly of the third groove (central part)
- mounting of the LFI RAA (including HFI FPU) on the PPLM platform. The RAA is supported by its MGSE
- mounting of the telescope on the intermediate structure

Note: For the Planck PLM CQM, the baseline was to integrate the QM telescope with the QM reflectors. Due to delay in the delivery of the QM reflectors, the Telescope QM used at this level is equipped with reflectors dummy (Refer to Annex 1).

- fixation of the FPA on the telescope structure, adjustment of the interface shim under the BEU, then removing of the supporting MGSE of LFI RAA
- integration of warm units
- harness and piping connections
- thermal anchoring of pipes, wave guides and harness
- closure of integration apertures of grooves and assembly of external petals of grooves
- integration of the main baffle
- Integrated Module Test (IMT)
- leak test of cooler gas circuit at ambient temperature

The PPLM will be integrated in clean room of Class 100000 with protective covers on sensitive areas. Special attention shall be put on the cleanliness requirements during assembling and connection of cryo-cooler piping.

The telescope is assumed to be aligned at lower level. The focal plane assembly alignment will be obtained by the mechanical mounting, the alignment versus telescope will be controlled with theodolites.

9 VERIFICATION PLAN

9.1 OVERALL LOGIC

The satellite design and development shall be verified against the System Requirement Specification [AD1-1] and shall be governed by the Verification Programme or Control Plan (VPP/VCP).

The VPP/VCP governs all verification activities at unit, subsystem, module and system levels. For each precise and identified requirement, referenced to the document it stems from, the proposed methods and levels of verification will be indicated.

The VPP/VCP will be completed by Verification Control Documents (VCD) applicable to each level of verification.

This chapter gives the main rules to be used to establish the VPP/VCP and the VCD; they are based on the ECSS-E-10-02A.

The logic and the links between all documents are illustrated by the figure 1 (page 8).

9.2 RESPONSIBILITIES

Within the Herschel/Planck verification programme, the responsibilities for all programme levels from system level down to unit level are allocated to the dedicated programme Contractors as follows:

- the system level responsibility is with the Prime Contractor ALCATEL. This system level responsibility has to perform the verification of the complete Herschel/Planck system versus the Agency (ESA)
- the module or subsystem level responsibility (mainly PLMs and SVMs), is with this level corresponding to the Major Subcontractors. It has to assure full verification of his module/subsystem versus the Prime Contractor ALCATEL
- the unit or subsystem level responsibility is with this level corresponding to the Subcontractor. It has to assure full verification of his unit or subsystem versus the Major Subcontractor.

The system verification effort is an overall system responsibility, conducted by engineering, AIV and PA organisations as follows.

Test Requirements will be issued by the engineering team at least for the main tests resulting from an analysis of specifications requirements, calculation and mathematical modelling such as:

- physical measurements
- alignments
- vibrations
- acoustic noise
- separation shock
- thermal vacuum/thermal balance
- EMC
- cryogenic functional tests.

Integration and test procedures are issued by AIT team, from integration and test specifications if applicable, verified by engineering and approved by AIV and PA.

Integration and test reports are issued by AIT team, certified by the AIT Manager, agreed by PA and approved by AIV.

Inspection procedures are issued by Quality Control, from inspection specifications when applicable, verified by engineering and approved by PA.

Inspection reports are established by QA and approved by PA.

Evaluation reports (from integration, test, inspection reports and Request for Material Review) are established by the cognisant engineering responsible, verified by System Technical Manager and approved by AIV and PA.

9.3 VERIFICATION PROGRAMME PHASING

According to the process described here above, three major phases may be defined each of them being concluded by a specific issue of the verification matrixes:

a. Requirements identification

This 1st phase of the verification task will be to extract from the system specifications all requirements which have to be verified and to list them in the corresponding area of the verification matrix (refer to chapter 9.5.7). This phase takes place during the design phase and shall be concluded when all specifications are approved by a draft issue of the VPP available for the Preliminary Design Review (PDR).

b. Verification methods and level selection

This phase consists in finalising for each requirement, the most appropriate verification method(s) selected amongst those described after, with support of subsystems and scientific instruments verification plans when applicable.

This second run takes place during the development and shall be concluded at the Critical Design Review (CDR) by the final issue of VPP.

c. Verification process and control

This final phase takes place all along the development and AIT sequences, and shall be concluded at the Flight Acceptance Review (FAR) by a final edition of the VCD. Each requirement fulfilment will be indicated by the reference of demonstration document such as technical note, test report, test evaluation report, analysis report, design report or inspection report.

Approved waivers and non-conformance documentation will be addressed when applicable.

9.4 ENGINEERING DATA BASE

The Engineering database is an element of prime importance to be involved in the satellite development. The verification process will be supported by an Engineering database which allows:

- systematic traceability of all requirements at each verification level ;
- the possibility to perform coherence checks between products and levels ;
- monitoring of the verification process throughout the project life cycle ;
- identification of impacts at the various levels in case of change of requirements or criticality during lower level verification ;
- immediate and flexible reporting of data in support of the preparation of the project verification documentation ;
- minimisation of repetitive tasks ;
- elimination of errors ;
- integration into the higher level of the lower level verification data.

9.5 VERIFICATION PROGRAMME/CONTROL PLAN (VPP/VCP)

The Herschel/Planck VPP or VCP shall ensure a homogeneous approach to demonstrate design and development qualification and acceptance from unit level up to satellite level, covering all aspects of flight hardware and software as well as mechanical and electrical ground support equipment. For that,

- It determines the required analysis, the models to be tested and the test activities with associated tools and facilities as well as the rationale of the logical sequence of verification necessary to demonstrate that the Herschel and Planck satellites fulfil the performance, interfaces, safety and operational requirements of the envisaged missions.
- It provides a system wide visibility on compliance of hardware and software with the requirements and optimises the use of ground support equipment and test facilities.
- It defines the strategy implemented to guaranty the fulfilment of mission requirements and to control and minimise the risks at specification level, at definition level and at realisation level.

It is built from the following considerations:

- the VPP is aimed at demonstrating the capability of the satellite to fulfil the mission requirements
- the VPP has to be considered globally from unit to system levels, hence the verification task is a continuous and coherent process starting from the design phase to the launch
- the VPP results from an analytical process combining the consideration of technical risk, feasibility, availability of required means, schedule and cost
- the VPP drives the overall development of the project, of which it has to guaranty the successful completion
- the VPP includes at the same time the flight hardware and software to be certified and the support equipment necessary for this purpose
- the VPP involves the participation of all the project team (engineering, PA, AIV) and of all Contractors and Subcontractors.

For this purpose the VPP shall define:

- the necessary means and methods to demonstrate the compliance of the flight model with the Customer requirements
- the organisation implemented to control the good performance of the verification process
- the responsibility breakdown between the different Contractors at all levels and the concern of engineering, product assurance and AIV/AIT in the verification process.

The verification process will be considered completed when the Customer and the Supplier mutually agree that, on the basis of proper documented evidence, the identified requirements have been verified and the associated verification objectives fully reached. The requirements not fully verified at a certain level shall be identified and resolved.

9.5.1 Verification objectives

The verification objectives shall be primarily:

a. To qualify the design.

b. To ensure that the product is in agreement with the qualified design and is free from workmanship defects and acceptable for use.

c. To verify that the satellites (including tools, procedures and resources) will be able to fulfil mission requirements.

d. To confirm product integrity and performance after particular steps of the project life cycle (e.g. integration, test, and pre-launch).

The model philosophy supports the overall development of the satellites; the VPP is dedicated to ascertain, from the model philosophy, that the flight hardware delivered for launch will be capable to fulfil the mission requirements.

The verification objectives are:

- to achieve the mechanical qualification of each unit and subsystem (including instrument units), together with the mechanical qualification of the overall satellite (Herschel and Planck)
- to achieve the thermal qualification of each unit and subsystem (including instrument units), together with the thermal qualification of the overall satellite (Herschel and Planck)
- to achieve the cryogenic qualification of instrument cryogenic units, together with the cryogenic qualification of the overall PLM or satellite (Herschel and Planck)
- to achieve the electromagnetic qualification of each unit and subsystem (including instrument units), together with the electromagnetic qualification of the overall satellite (Herschel and Planck)
- to achieve the electrical and performance qualification of the design of each unit and subsystem (including instrument units), together with the performance verification of the overall satellite (Herschel and Planck) in all environment conditions
- to achieve the on-board software qualification, together with the functional qualification of the overall hardware and software system (Herschel and Planck)
- to achieve the certification of the compatibility of all elements of the complete Herschel/Planck programme having a part in the success of the missions: Herschel and Planck satellites and ground segment
- to achieve the full acceptance of each flight unit and subsystem (including instrument units), together with the acceptance of the overall satellite (Herschel and Planck).

9.5.2 Verification concept

The VPP covers all on-ground tasks up to the final acceptance review of the PFM.

The VPP shall serve to provide the maximum confidence obtainable within the financial and schedule boundary conditions.

To achieve these objectives, the VPP will provide visibility and appropriate control during the incremental verification steps and will ensure proper maintenance of the corresponding documentation.

The verification concept will be based on the specification of clearly defined verification requirements, which will be reflected within the Herschel/Planck engineering database. The verification requirements of the database will be derived from the satellite performance, operational and interface requirements as laid down in the Herschel/Planck requirements documents.

The Herschel/Planck engineering data base shall cover the above mentioned verification requirements and additionally provide all required information concerning the methods, types and levels of verification and the logical sequence of verification tasks on satellite level.

The verification process will be conducted on satellite level for Herschel and Planck hardware and software items. In special cases the satellite verification process will be extended to lower levels, if explicitly required by the satellite verification requirements.

Verification tasks performed at higher integration levels will use lower level results.

9.5.3 Verification approach

To reach the verification objectives a verification approach shall be defined in an early phase of the project by analysing the requirements to be verified taking into account:

- design peculiarities
- qualification status of candidate solution
- availability and maturity of verification tools
- verification and test methodologies
- programmatic constraints
- cost and schedule.

The basic verification approach shall be derived through an iteration process, based on technical/cost/schedule considerations, which define the "what", "how", "where" and "when" of verification by:

- identifying a consistent set of verifiable project requirements which can be subjected to the verification process
- selecting methods of verification
- selecting levels of verification and the associated model philosophy
- selecting facilities

– identifying resources required
– identifying the stages and the events in which the verification is implemented.

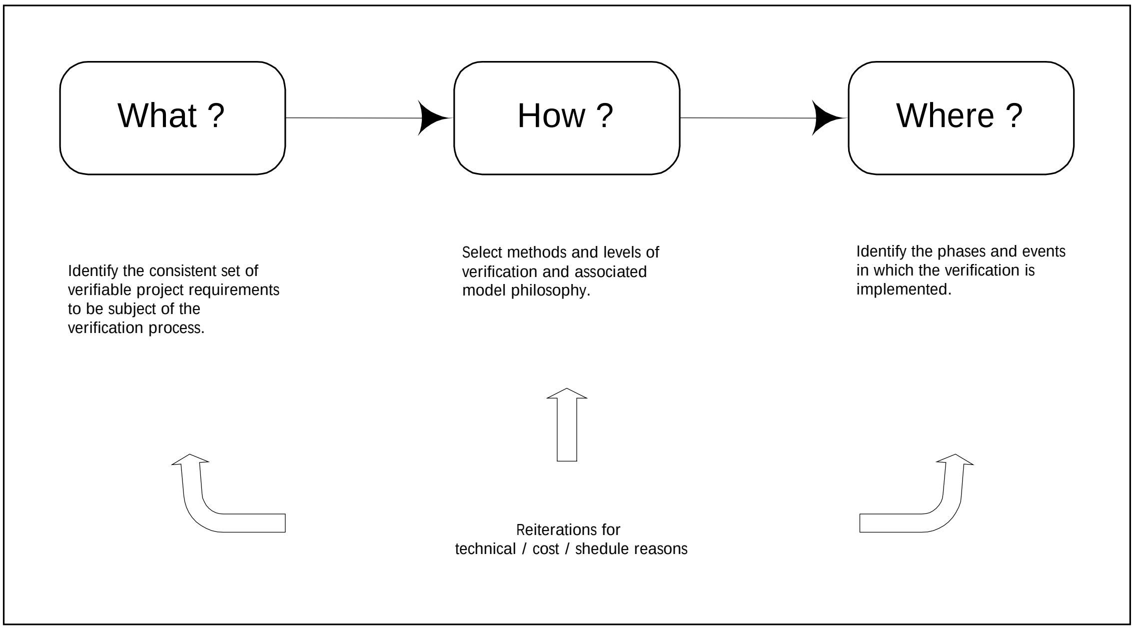

Table 9.5.3 Verification approach

9.5.4 Verification types

The verification consists of two types as follows:

– **Qualification (Q)**

The objective of the qualification is the formal contractual demonstration that the design implementation and manufacturing methods have resulted in hardware and software conforming to the specification requirements.

The purpose of qualification testing is also to demonstrate that the items perform satisfactorily in the intended environments with a sufficient margin.

The qualification levels shall be defined in order to cover the worst case environmental conditions, so they shall exceed the maximum predicted levels by a factor of safety which assures that, even with the worst combination of test tolerances, the flight levels will not exceed the qualification test levels.

This verification process starts with analysis and is completed by test, either using flight or non-flight hardware, provided that this hardware is representative for the test being performed.

The standard of qualification dedicated models may be slightly relaxed with respect to flight standard, by using lower quality MIL-Grade parts instead of the space qualified hi-reel ones (e.g. EQM), without affecting the test validity. Some minor changes to the models used for qualification testing are allowed, if they do not impact the qualification objectives, for example, in order to accommodate such items as thermocouples, strain gauges and monitoring leads, necessary to conduct the test.

This verification type may be split into:

- certification of the design established as early as possible by analysis and assessment or elementary tests at component or unit levels. The objective of this phase is to validate the design, select the options, evaluate the performances

- certification of the performances, to be carried out by test of flight representative hardware and correlation with the analysis results.

This stage may also include re-qualification in the case that the design is modified after initial qualification has been achieved.

- **Acceptance (A)**

  Verification aimed at demonstrating by tests the compliance of the performance of the flight hardware with the requirements. This acceptance test sequence is nominally applied to any flight hardware from unit to satellite level.

  The purpose of these tests is to demonstrate conformance to specification requirements and to act as quality control screens to detect manufacturing defects, workmanship errors, incipient failures and other performance anomalies, not readily detectable by normal inspection techniques. The acceptance tests are formal tests conducted to demonstrate the adequacy and readiness of an item for delivery and subsequent usage.

  Acceptance testing should not create conditions that exceed safety margins or cause unrealistic modes of failure.

  Acceptance tests are conducted on flight models under environmental conditions not more severe than those expected during the mission. The acceptance tests shall be conducted on all the flight products (including spares) according to the model philosophy.

  For cost or schedule reduction the qualification demonstration completion may be carried out with the flight hardware itself (protoflight philosophy). In this case a combined Qualification/Acceptance sequence will be applied to this hardware, but demonstration, by analysis and comparison between the test levels and the safety margins, shall be done that the flight hardware will not be over-stressed by the tests themselves.

  The article involved in acceptance test shall be manufactured in agreement with the qualified design and shall perform as the qualified product.

  This stage may also include re-certification in the case that the representative configuration is disassembled (e.g. due to failure or repair actions), or where it has undergone long-term storage.

9.5.5 Verification methods

Test, analysis, assessment or a combination may demonstrate fulfilment of a requirement. At least one of the following verification methods shall be selected for each of the individual performance requirements.

Whatever the verification method may be, the corresponding data shall be made available in form of reports (test, analysis, inspection reports, technical notes...). Correlation of test data with analysis data shall be made when applicable.

The verification process will start early in the development phase to demonstrate by analysis and evaluation the expected performance, the design feasibility and the compliance to the requirements.

Testing will be the main verification method and will be used as far as possible to verify the hardware performances and compliance with the specifications at each level. The other methods (analysis, assessment) will be dedicated to verify the requirements for which testing is not convenient or applicable, or to precede or complete the testing method.

At subsystem and system levels, testing will be the method to be used to validate the nominal and contingency procedures (including on-board software management : load, dump, check, …) referenced in the Satellite User Manual (SUM).
The SUM will be used as a reference to generate the IST and the test reports. Test evaluations shall be used to maintain the SUM and to insure it is in line with the subsystem / system behaviour.

- **Verification by Test (T)**

Two different types of tests shall be implemented to verify the qualification or the acceptance of a unit, subsystem, module or satellite. These are functional tests under ambient conditions and environmental tests where external constraints are applied.

The functional tests consist of compatibility tests, interface tests and performance tests verifying that the electrical, mechanical or radio-electrical criteria are met. In general they are performed under ambient conditions, but for certain units they are only possible in thermal vacuum.
The environmental tests consist in a selection of tests to be carried out in an environment similar to that found during launch and/or during the mission phases.

- **Verification by Analysis (A)**

Verification by analysis may be performed and may replace tests at all levels in particular if it can be shown that analysis provides a better method of verification of requirements.

If verification is accomplished by analysis, the analytical method shall be established in terms of technical, cost and schedule advantages.

- **Verification by Similarity (S)**

Verification by similarity may be applied to equipment or subsystems coming from another programme when reuse "as is" or minor modifications are proposed and the environmental conditions are common or scoped by existing qualification.

For units coming from another programme and reused with no or minor modifications, an analysis of the qualification and acceptance test results of the other programme shall be carried out against the requirements of the current programme. Acceptance by ALCATEL of a proposal for Verification by Similarity will be done on a case by case basis.

- **Design Verification Assessment (ROD)**

Verification by Assessment may be achieved by Inspection or by Review Of Design. In each case, the Contractor will have to provide a full technical assessment, detailing the conformity of the part to the applicable requirements for the intended application.

9.5.6 Verification levels

The different verification operations shall be carried out at equipment, subsystem, module or system levels. The VPP shall ensure the coherence and the complementarily of all these verification steps in order to ascertain that the full verification process covers entirely the specification requirements. The Manufacturer or Contractor responsible for the AIV task of the corresponding level (equipment, subsystem, group of subsystem, module or satellite will perform the verification operations).

9.5.6.1 Equipment level (Unit)

The unit or equipment specifications are the base of the lower level verification process. All specification requirements have to be verified and demonstration has to be done that the unit fulfils its own requirements and the general applicable system requirements such as design, EMC, environmental specifications.

The same verification process as for satellite level is applicable to equipment level. The Manufacturer shall demonstrate that the two verification types have been performed using appropriate methods.

The unit VPP will define case by case the test philosophy applicable in order to achieve a complete qualification at Herschel/Planck programme levels, taking into account the actual status of the design and the classification expressed in §6.6.

It is the task of each Subcontractor/Manufacturer:

- to justify through the documentation (unit & subsystem specifications, design description, performance evaluation...) the design of each unit, component or subsystem under his responsibility w.r.t. the system specifications
- to certify the design, manufacture and performance (analysis and calculation files, drawings, manufacturing procedures and processes...) of each item w.r.t. the Herschel/Planck requirements
- to verify before delivery the compliance of hardware with the accepted design (qualification or acceptance test sequences).

In particular, if the equipment qualification cannot be considered as fully achieved for the programme by similarity with another one, the Manufacturer, according to the qualification plan, shall demonstrate on a specific model, that the unit meets all the qualification requirements (expected flight environment levels with a proper margin).

For Herschel/Planck the present status is presented in Tables 9.4.6.1-1 to-3 (to be fulfilled and/or updated after equipment contractor selection).

MODULE	SUBSYSTEM Equipment	Type	Remark
SVM	**PRIMARY STRUCTURE**		
	Central Cone & webs	D	
	Instruments Panels	D	
	"Service" Panels	D	
	Platforms	D	
	Brackets	D	
SVM	**HARNESS**		
	Primary Power	C	
SVM	**THERMAL CONTROL**		
	Multi Layer Insulation	C	
	Heaters	A	
	Thermostats	A	
	Thermistors	A	
	OSR	A	
	Heat-pipes	B	
SVM	**POWER CONDITIONING**		
	PCDU	D	
	Batteries	C	
SVM	**PLANCK SOLAR ARRAY**		
	Panel Structure	D	
	Electrical Wiring	C	
	S/A Cells	C	complementary or full functional and qualification testing

Table 9.4.6.1-1a SVM Equipment Classification w.r.t Qualification Status

MODULE	SUBSYSTEM Equipment	Type	Remark
SVM	**PROPULSION**		
	10 N Thruster	A	
	1 N Thruster	A	
	Tanks	A	
	Latch Valves	A	
	FVV	A	
	Fill & Drain Valve	A	
	Pressure Transducer	A	
	Filter	A	
	Piping	B	
	Brackets	B	
SVM	**CDMS**		
	CDMU	D	
SVM	**TT & C**		
	Transponder	D	
	RFDN	B	
	TWTA	C	
	EPC	C	
	Med. Gain Antenna	C	
	Low Gain Antenna	C	
SVM	**ACMS**		
	ACC	D	
	Reaction Wheel System	A	
	Gyro Unit & Electronic	A	
	Star Tracker Sensor & Electronic	C	
	Fine Sun Sensor & Electronic	A	
	QRS	A	
	Sun Acquisition Sensor	A	
	Star Mapper Sensor & Electronic	A	
	Attitude Anomaly Detector	A	

Table 9.4.6.1-1b SVM Equipment Classification w.r.t Qualification Status

MODULE	SUBSYSTEM Equipment	Type	Remark
Planck PLM	**Cryo-Structure**		
	Struts	D	
	Grooves	D	
	Main Baffle	D	
Planck PLM	**Telescope**		
	Structure	D	
Planck PLM	**Thermal Control**		
	MLI's	C	
	Thermal braids	D	
	Heaters	A	
	Temperature sensors	A	
	ATC Harness	B	

Table 9.4.6.1-2 Planck PLM Equipment Classification w.r.t Qualification Status

MODULE	**SUBSYSTEM** Equipment	**Type**	**Remark**
Herschel E-PLM	**Cryostat Structure**		
	Cryostat Vacuum Vessel	D	
	Tank straps	C	ISO
	Spatial Framework	D	
	Cryostat Cover	D	
	Entrance Baffle	D	
	Instrument Optical Bench	D	
Herschel E-PLM	**Cryostat Helium**		
	He II Tank	D	
	Passive Phase Separator	B	ISO
	Liquid Measurement Device	A	ISO
	He II Probe	B	ISO
	He I Probe	B	ISO
	Tank Surface Thermometer	B	ISO
	Tank Heaters	A	ISO
	Ventline	A	ISO
	Rupture Disc	A	ISO
	Safety Valves He II	A	ISO
	Safety Valves He I	A	ISO
	Safety Valves Cryostat Vessel	A	ISO
	Absorber	B	ISO
	Filling Port	C	ISO
	Liquid Helium Valves	B	ISO
	He I Tank	D	
	He I Pressure Sensor	B	ISO
	He I Ventline External Heater	C	
	He I Tank Surface Thermometer	C	
	Ventline Nozzle	D	
	Vacuum Measurement Sensor	B	ISO
	Tubing	D	

Table 9.4.6.1-3a Herschel E-PLM Equipment Classification w.r.t Qualification Status

MODULE	SUBSYSTEM Equipment	Type	Remark
Herschel E-PLM	**Cryostat Insulation**		
	External MLI's	C	
	Thermal Shields	B	ISO
Herschel E-PLM	**Cryostat Electrical**		
	Cryostat Control Unit (CCU)	C	ISO
	Instrumentation	B	ISO
	Cryo Harness	D	
Herschel E-PLM	**Structures**		
	Cryostat/SVM Interface Struts	D	
	SVM Shield	D	
	BOLA Support Structure	D	
	LOU Support Structure	D	
	Optical Windows	D	
	LOU Waveguides Support	D	
	Harness Supports	B	
	MLI Supports	B	
Herschel E-PLM	**SUNSHIELD/SUNSHADE**		
	Structural Panels	D	
	Support Struts	D	
	Electrical Wiring	D	
	Solar Cells	C	complementary or full functional and qualification testing
	MLIs'	B	
	Thermistors	A	

Table 9.4.6.1-3b Herschel E-PLM Equipment Classification w.r.t Qualification Status

9.5.6.2 Subsystem level (S/S)

The subsystem Subcontractor shall demonstrate by test the full compatibility and performance of his subsystem before delivery to module or system AIT.

This demonstration is usually a collation of unit level test results, completed if necessary by a series of functional tests at defined temperatures, in order to ascertain, that the overall subsystem fulfils its requirements (S/S acceptance test sequence).

The environmental tests will be performed at unit level or at higher level rather than at subsystem level. When several units or components have to be tested together under environmental conditions to demonstrate the S/S qualification, this will be done at satellite or module or subassembly level through the STM, QM or PFM sequences.

9.5.6.3 Module or subassembly level (Mod.)

A module is defined as a group of subsystems constituting mechanically and functionally a self-sufficient element of the satellite that can be tested and qualified as a whole.
This definition excludes simple subsystems such as power or TT&C S/S which are not mechanically independent, but corresponds to the Herschel and Planck telescopes, and obviously to the Extended Payload and Service Modules.

The mechanical or thermal qualification of a module is a significant step that may simplify the corresponding satellite qualification and allows obtaining significant results earlier in the programme schedule.

9.5.6.4 System level (SY)

The satellite level verifications will be performed using the development models (STM, AVM and PFM) to complete the unit and subsystem verifications.

The proposed verification philosophy leads to consider the single flight model as a Proto-Flight in order to complete the qualification on a fully representative model, when the lower level tests combined with the system tests performed on the development models are not conclusive enough.

So the VPP will be conducted step by step by a combination of tests at unit, subsystem, module and satellite levels. Collation of all verification results at each level will allow declaring the formal system qualification and acceptance.

When it is not possible to test the satellite as a single entity, major assemblies or modules or stages of the S/C will be tested instead, with the support of suitable analyses, simulations and/or simulators.

9.5.7 Verification Matrixes

The VPP includes Verification Matrixes issued by the relevant responsibles of any hardware and software item, from the requirements of the corresponding level specifications.

The unit matrixes issued from the Manufacturers will be collated at subsystem level and the Subcontractor responsible for the subsystem will add additional level of verification referenced to the subsystem specifications, if any.

The major Subcontractors of the PLMs and of the SVMs will define the module verification matrixes, based on the module level specifications. They will sum up the information coming from the lower level matrixes which will be used to govern the module level AIV.

The Prime Contractor will define the system verification matrix, based on the system level specifications. It will sum up the information coming from the lower level matrixes which will be used to govern the system level AIT.

This plan will be used all along the development and test phases and filled in when performed, with references to the corresponding justifying documents (technical note, analysis report, test report...) allowing to verify that it has been properly followed.

The verification matrixes will indicate:

- the parameters and functions to be verified (after analysis of the specifications requirements)
- the specification they stem from
- the level of verification: unit, subsystem, module, system (the same verification may be performed at several levels)
- the selected verification method: test, analysis, assessment (several complementary methods may be used)
- Comments if any

Satellite Name: <Herschel> and/or <Planck>
Reference Document: <Name> <ID> <Issue/revision> <Date>
Upper Reference Document: <Name> <ID> <Issue/revision> <Date>

Req. Numb.	Header Text	Traces (1)	Types (2)	Verification methods (3)				Remark
				SY	Mod.	S/S	Unit	
			Q, A	T, A, S, ROD	T, A, S, ROD	T, A, S, ROD	T, A, S, ROD	

(1) Traces = Requirement number in upper Reference Document
(2) Types = Q for qualification, A for Acceptance
(3) Verification methods = T for test, A for Analysis, S for assessment by similarity, ROD for assessment by Review of design

Figure 9.5.7: Example of Verification Matrix Sheet Format

9.5.8 Test Requirement Sheets

The VPP includes Test Requirement Sheets (TRS) to be issued with the support of the engineering team. This TRS issued prior to the Test Requirement will content at least the following information:

Test to be performed	Exact wording of the test to be performed				
Specimen to be tested	*Satellite*	*Level*	*Model*	*Type*	*Number*

TEST OBJECTIVES
Objectives of the test and how and why it aims at fulfilling a relevant requirement.

TYPE OF TEST
Summary of the test to be performed.

SUMMARY TEST DEFINITION

- Satellite test definition
Simplified configuration of the item to be tested

- Environment
Type of Clean room Class
Type of “thermal” environment: ambient, cryogenic,…
Definition of the environment to be applied in case of environmental test

- Test sequence
Sequence of the test itself but also its position in the overall test flow.

- Measurements Definition
List and type of measurements requested in the frame of the test

TEST SET UP AND TEST SUPPORT
Ground Support Equipment and test facility requested by the test as well as the outputs requested for its evaluation.

TEST ACCEPTANCE CRITERIA
Criteria to conclude on the end of the test itself and to give the go-ahead for the next one.

RESPONSIBILITIES
Responsibility of each company/team for the relevant tasks

9.5.9 Analysis Requirement Sheets

The Analysis Requirement Sheets (ARS) present analyses aiming at demonstrating the system performances not verifiable by a global or End to End test. The engineering team will issue these ARS in early Phase C/D and will content at least the following information:

Performances to be demonstrated	
Analysis to be performed	

ANALYSIS OBJECTIVES
Objectives of the analysis and how and why it aims at fulfilling a relevant requirement that cannot directly verify by test.

TYPE OF ANALYSIS
Summary of the analysis to be performed.

TESTS TO BE PERFORMED
List of tests performed at System and/or lower levels with inputs for system analysis.

- List of tests performed at System level
Reference to relevant TRS

- List of tests performed at lower levels
Reference to test performed at lower levels

- Test sequence
Sequence of the above tests with their position in the verification flow.

RESPONSIBILITY
Responsibility of each company/team for the relevant tasks

9.6 VERIFICATION CONTROL DOCUMENT (VCD)

When a specified requirement is verified, reference of the approved document demonstrating its fulfilment is filled in the Verification Control Document (VCD).

The VCD will provide clear visibility of the complete verification process. That means, the starting point of the process for the Herschel/Planck satellite verification and its control are formed by the requirements of the Herschel/Planck Engineering database that is derived from the ESA maintained Requirements Documents.

The VCD maintenance covers:

- monitoring of the verification activities (tests, analyses, design reviews, inspections)
- updating of the respective documentation
- the incorporation of the results into the Engineering Data Base

The VCD will indicate:

- the parameters and functions to be verified (after analysis of the specifications requirements)
- The reference of the RFW, if any
- the level of verification: unit, subsystem, module, system (the same verification may be performed at several levels)
- the selected verification method: test, analysis, assessment (several complementary methods may be used)
- the reference of documents where this verification is precisely defined (AIT plan, test plan, test procedure, …)
- the reference of the verification report. Once the verification has been performed
- the verification status to follow the progress of the VPP.

For verification of items of lower hierarchical level, the same procedure will be applied with same documents and responsible personnel.

Satellite Name: <Herschel> and/or <Planck>
Reference Document: <Name> <ID> <Issue/revision> <Date>

Req.	Header	Serial	RFW	Verification methods				Verif	Verif.	Status	Remark
Numb.	Text	Numb.		SY	Mod.	S/S	Unit	plan	Report	O/C	
(4)				(4)	(4)	(4)	(4)	(1)	(2)	(3)	

(1) = test specification, …
(2) = test evaluation, or analysis, or relevant document for assessment by Similarity or ROD
(3) = O for on-going verification, C for successfully achieved verification
(4) from Verification Matrix

Figure 9.5 : Example of VCD Sheet Format

10 ANNEX PLANCK VERIFICATION APPROACH

As the delivery date for QM reflectors has been shifted after STM Satellite tests, it is proposed:

- to perform the STM/CQM Planck Satellite mechanical & thermal tests sequence with dummies of reflectors in a STM standard.

As the FM reflectors delivery is then close to QM reflectors need date, it is proposed:

- to perform WFE cryogenic test on FM telescope "only".

With this approach:

- the QM telescope (with dummy reflectors) stability is qualified with alignment measurements at cryogenic temperature.
- the Planck satellite STM AIT activities start with dummies of reflectors on the QM telescope.
- the RFQM test is performed after the STM Planck Satellite tests sequence with QM reflectors mounted on the QM telescope.
- only one WFE cryogenic test at telescope level is performed on the FM.
- The Planck Satellite STM test objectives remain and the schedule is secured.

The figures 10-1 & -2 present the verification logic associated with this approach respectively at STM/CQM level and PFM level.

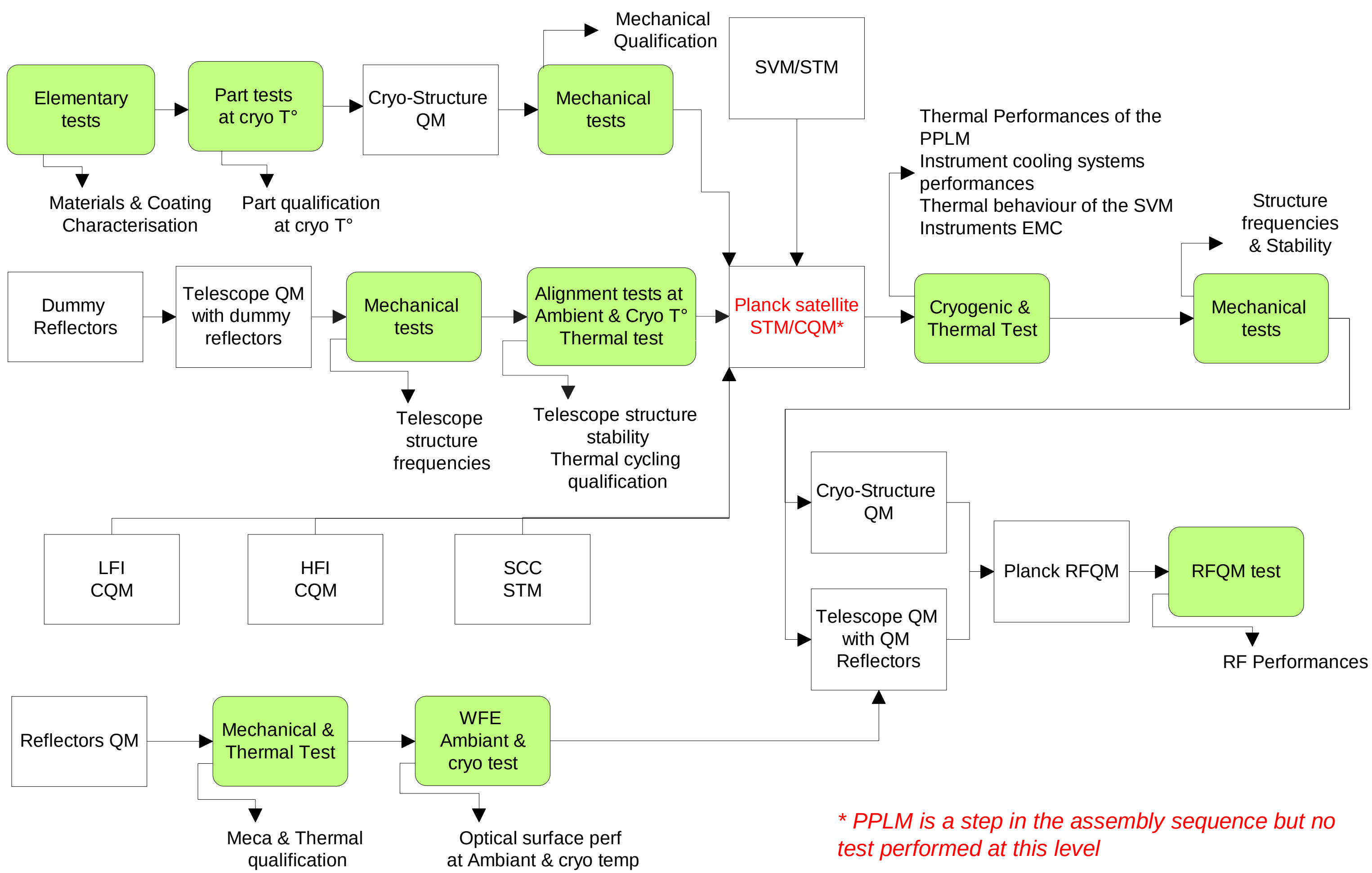

Figure 10-1 Planck Verification logic for STM/CQM

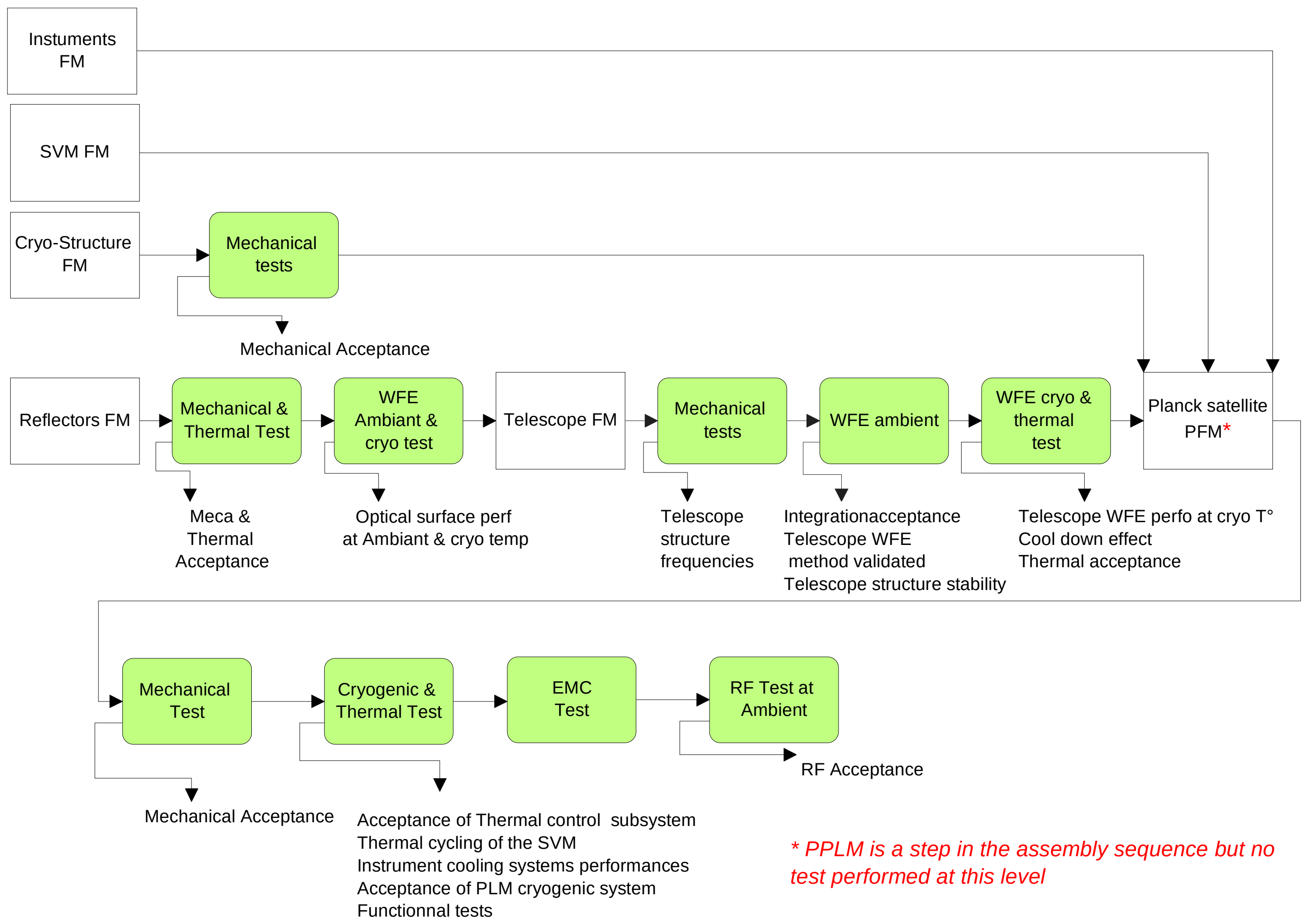

Figure 10-2 Planck Verification logic for PFM

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