HERSCHEL / PLANCK

Planck Alignment Plan

H-P-3-ASPI-PL-0078

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Planck Alignment Plan

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RESUME D'AUTEUR

Ce plan est le plan d'alignement système (satellite) de Planck.

Les besoins d'alignement systèmes sont rappelés.
La séquence d'alignement et de vérification d'alignement est présentée
Les contributeurs sont identifiées, et les allocations sont présentées et justifiées.
Finalement les besoins d'alignement et stabilité sous-systèmes sont synthétisés.

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03	09/04/2004	Payload CDR Drawings update The alignment logic from the reflectors up to the satellite is described The current knowledge of the several LOS used at Satellite level is given in annex Lines of sight needed at satellite level are describes in annex Includes the answer to system PDR RID 8400 – point 2	PH. MARTIN
04	23/07/2004	Satellite CDR Reference is made to the Planck MCI test requirement spec CRS 3 LOS added	PH. MARTIN

TABLE OF CONTENTS

1. INTRODUCTION 7
1.1 PURPOSE OF THIS DOCUMENT 7
1.2 APPLICABLE AND REFERENCE DOCUMENTS 8
1.2.1 Applicable documents 8
1.2.2 Reference documents 8
1.3 ACRONYMS 9
2. PLANCK SPACECRAFT AND PAYLOAD DESCRIPTION 10
2.1 SPACECRAFT 10
2.1.1 PPLM Line Of Sight definition 11
2.1.2 Planck Telescope+cryostructure LoS definition 12
2.1.3 Cryostructure/SVM interface description 13
2.1.4 SVM Line of sight definition 13
2.1.5 FPU average focal surface definition 14
3. SYSTEM ALIGNEMENT REQUIREMENTS 16
3.1 ALIGNMENT REQUIREMENTS COMING FROM IMAGE QUALITY NEEDS 16
3.2 ALIGNMENT REQUIREMENTS COMING FROM POINTING 16
3.2.1 LOS requirements 16
3.2.2 Around-LOS requirements 16
3.2.3 Thrusters Alignment 17
4. INTEGRATION SEQUENCE, AND ALIGNMENT CHECKS 19
ALIGNMENT LOGIC 19
4.2 ALIGNMENT ACTIVITIES AT REFLECTORS LEVEL 20
4.3 ALIGNMENT ACTIVITIES AT TELESCOPE LEVEL 22
4.4 AT FPU LEVEL 24
4.5 PPLM ALIGNMENT ACTIVITIES 25
4.5.1 FM alignment activities 25
4.5.2 Alignment of the QM telescope for the RFQM tests 27
4.6 STM/FM ALIGNMENT ACTIVITIES AT SATELLITE LEVEL 28
4.6.1 STM/FM difference 28
4.6.2 Alignment sequence at satellite level 28
Spin axis alignment (see[RD14]) 33
4.6.4 Thrusters alignment 33
4.7 SATELLITE ALIGNMENT TEST REQUIREMENT SHEETS SUMMARY 35
5. ALIGNMENT SUB-LEVEL ALLOCATIONS 36
5.1 ALIGNMENT COMING FROM IMAGE QUALITY NEEDS 36
5.1.1 axial focus alignment needs 36
5.1.2 Radial focus position alignment needs. 37
5.2 INSTRUMENT LOS POSITION ACCURACY WRT ACMS LOS 39
5.2.1 PPLM contribution 39
5.2.2 SVM contribution 40
5.2.3 Mating contribution 40
5.2.4 Requirements synthesis 41
5.3 INSTRUMENTS AROUND LOS INSTABILITIES WITH REGARDS TO THE PLM-SVM INTERFACE 41
5.3.1 FPU internal around-LOS 41
5.3.2 Telescope+cryo-structure around-LOS stability 41
5.3.3 Synthesis 42
5.3.4 Requirement synthesis 42

5.4 INSTRUMENTS AROUND LOS KNOWLEDGE WITH REGARDS TO THE LAUNCHER INTERFACE PLANE................................ 43
5.4.1 Planck PLM contribution.. 43
5.4.2 Planck PLM alignment knowledge with regards to launcher Interface plane....................................... 43
5.4.3 Contingency 43
5.4.4 Requirements summary 44
5.5 WOBBLE ANGLE ADJUSTMENT ACCURACY 45
5.6 THRUSTER ALIGNMENT 46
5.6.1 thruster alignment accuracy allocations 46
5.6.2 thruster plume adjustment range needed for spacecraft activities... 47

6. ALIGNMENT REQUIREMENTS SYNTHESIS 49

6.1 AT SPACECRAFT LEVEL 49
6.2 AT SVM LEVEL.. 50
6.3 AT P-PLM LEVEL 51
6.3.1 At reflectors level 51
6.3.2 At cryo-structure+Telescope level 51
6.3.3 At FPU level.. 52

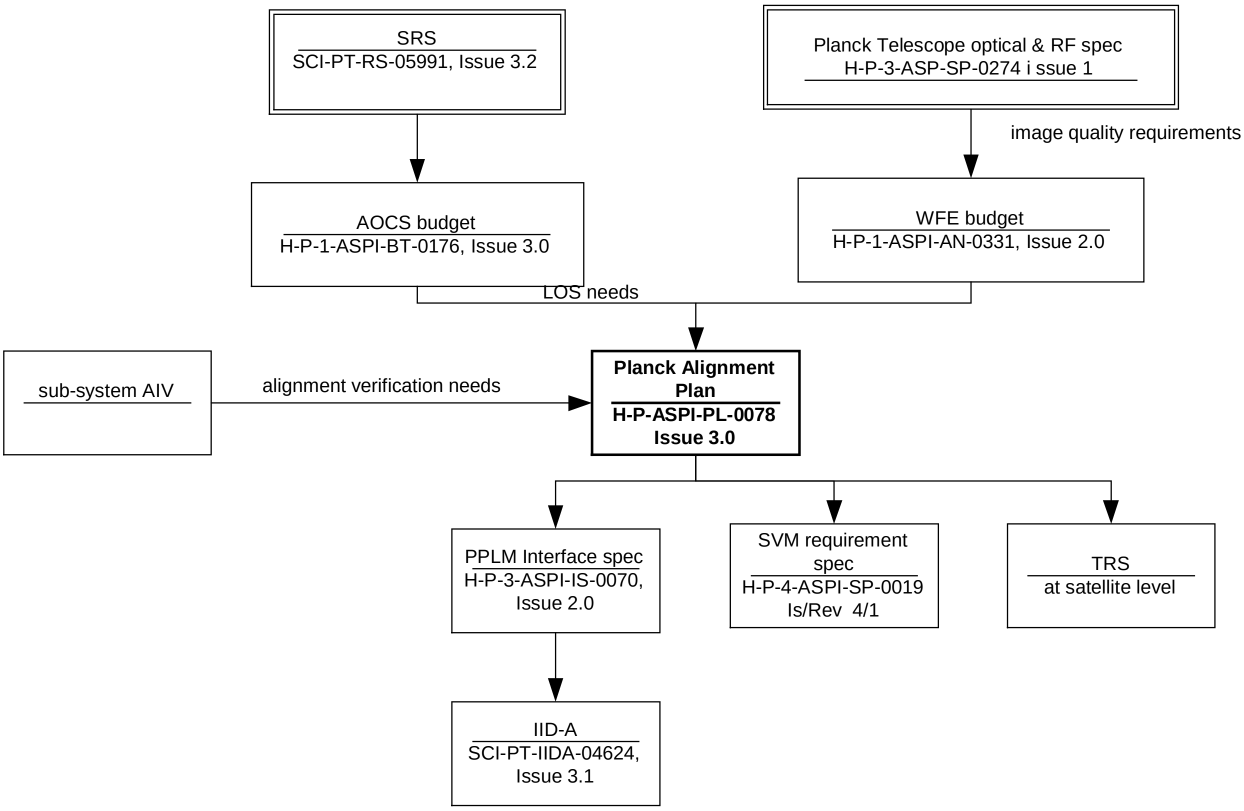
1. INTRODUCTION

1.1 Purpose of this document

This documents provide the alignment plan for PLANCK satellite.

It describes the alignment concept covering adjustments and measurement methods for PPLM, Focal Plane Unit (FPU) integration in the telescope focal plane and PPLM integration on SVM (Satellite level).
The internal alignment of the FPU (horns adjustment for LFI and HFI, LFI/HFI I/F adjustment are out of the scope of this document and are under LFI/HFI responsibility).

The flowchart is the following:



It defines the optical interfaces and associated OGSE necessary to implement this alignment concept.

Finally the alignment needs are synthesized, at each level in the final section

Instruments team, more interested in the alignment of the FPU with regards to the telescope are invited to have a direct look on the following sections:
2.1.5 "FPU average focal surface definition"
3.1: "alignment requirements coming from image quality needs"
4.1:"AIT sequence - At PPLM level"
4.3:"Alignment checks description"
5.1:"Axial focus alignment needs"
5.2 "radial focus position alignment needs"
6.3.3 "alignment requirements at FPU level"

1.2 Applicable and reference documents

1.2.1 Applicable documents

[AD1] " Planck telescope design specification "
SCI-PT-RS-07024. Issue 1. Revision 0. Date of issue: 31-Aug-2000. Author: ESA/SCI-PT Team.

[AD2] " Primary reflector / secondary reflector specification "
SCI-PT-RS-07422. Issue 5. Revision 2. Date of issue: 08-Aug-2003. Author: ESA/SCI-PT Team.

[AD3] System Requirement Specification "
SCI-PT-RS-05911. Issue 3. Revision 2.

[AD4] "ACMS inputs to Planck System Alignment Plan"
H-P-3-ASPI-TN-0245 Issue 1. Revision 0. Date of issue: 30-Mai-2002. Author: Alcatel/D. Guichon.

1.2.2 Reference documents

[RD1] "Planck PLM Optical Performances Analysis"
H-P-ASPI-AN-0331 Issue 2 Revision 0.

[RD2] "Planck Telescope Specification"
H-P-ASPI-SP-0004 Issue 2 Revision 0.

[RD3] "STB of alignment tools Cube Tooling ball-target"
ASPI/01/BO/IT/034 Issue 1 Revision 00 Date of issue: 21/05/2001. Author: Alcatel Alignment Team

[RD4] "Herschel/Planck Pointing Budget Module Allocation"
H-P-1-ASPI-BT-0176, Issue 3.0

[RD5] "Planck reflectors ICD"
PLA-ASED-RP-004 Issue 3 rev 1 date of issue 12/02/2003

[RD6] NA

[RD7] NA

[RD8] "planck telescope optical budgets"
H-P-3-CSAG-BD-2001 I4 R0

[RD9] Test requirement Sheet "mechanical axes" P-SAT-ALG-1

[RD10] Test requirement Sheet "thrusters alignment " P-SAT-ALG-2

[RD11] Test requirement Sheet "optical references and stability check " P-SAT-ALG-3

[RD12] HERSCHEL-PLANK SVM ALIGNMENT PLAN
ref H-P-PL-AI-0049

[RD13] RCS thruster bracket assy's user's manual
HP-RILAM-MA-0005

[RD14] Planck MCI test specification
H-P-3-ASP-SP-0761

[RD15] Reflectors & Telescope FM Optical Verification Status
H-P-3-ASP-RP-0817

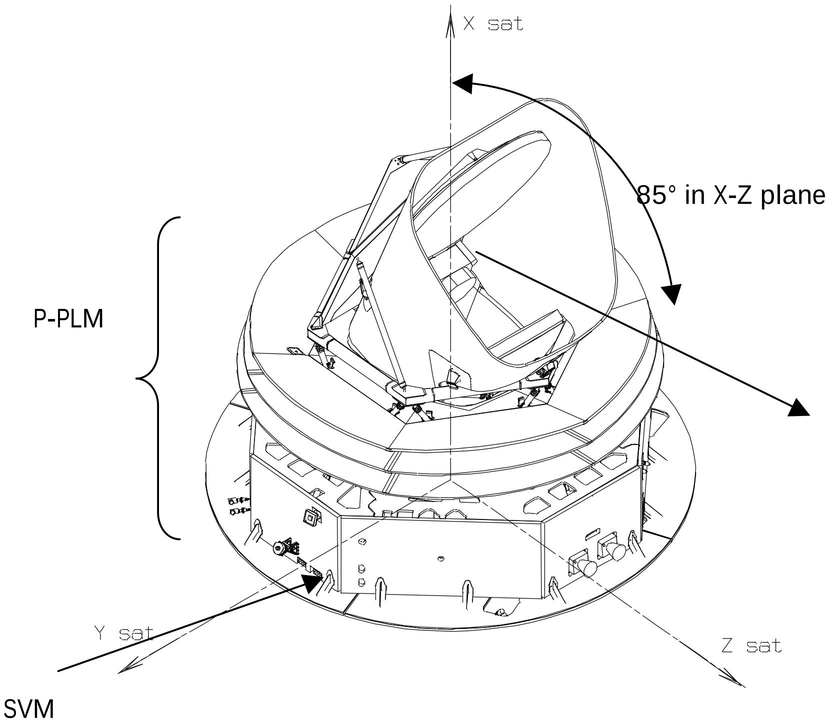
1.3 Acronyms

AC	Alignment Cube
ACMS	Attitude and Control Monitoring System
AOCS	Attitude and Orbit Control System
CATR	Compact Antenna Test Range
CoG	Center of Gravity
CRS	Corse Rate Sensor
HP	Herschel-Planck
H-(E)PLM	Herschel (Extended) Payload Module
LoS	Line of Sight
MRC	Master Reference Cube
I/F	Interface
RSS	Root Sum Squared
S/C	Spacecraft
S/P-I/F	SVM/H-PLM interface plane
Spec	Specification
SRS	System Requirements Specification
SVM	Service Module
T/P	Thruster plume
TBC	To Be Confirmed
TBD	To Be Defined
TRS	Test Requirement Sheet

2. PLANCK SPACECRAFT AND PAYLOAD DESCRIPTION

2.1 Spacecraft

This section describes the Planck spacecraft and defines the relevant coordinate systems



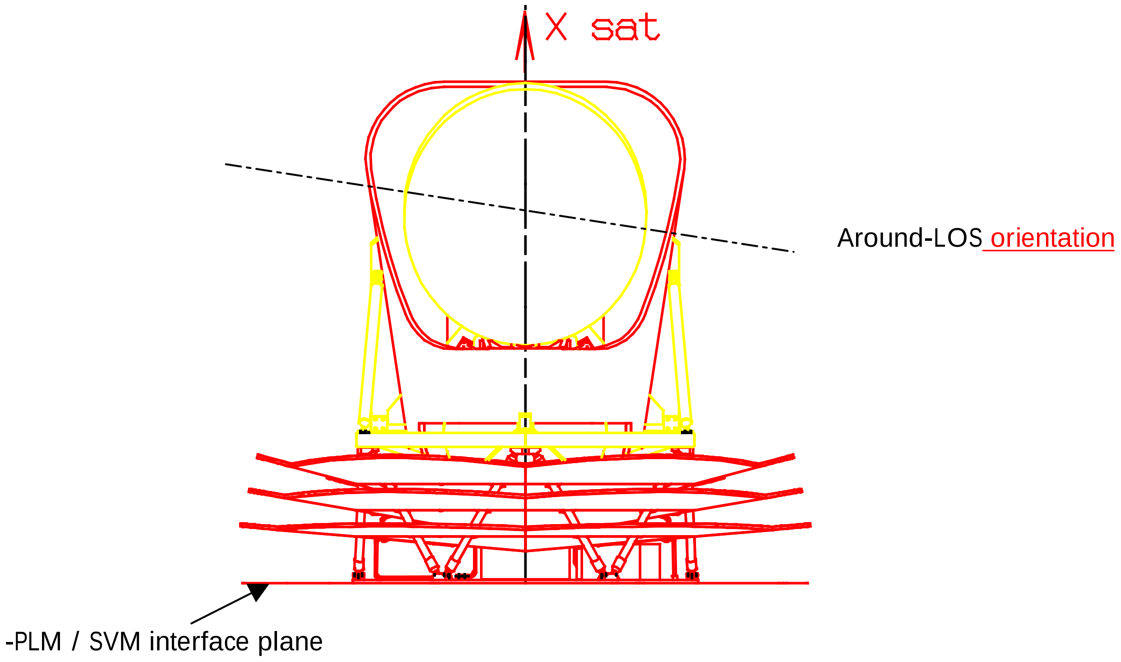
The Planck instruments Line of Sight is defined as the projection on the observed sky of the radiometric center of a detector's far field pattern as projected by the telescope

2.1.1 PPLM Line Of Sight definition

The PPLM Line of Sight is defined as the projection on the observed sky of the radiometric center of a detector's far field pattern as projected by the telescope. This direction is referenced with regards to the cryostructure/SVM interface.

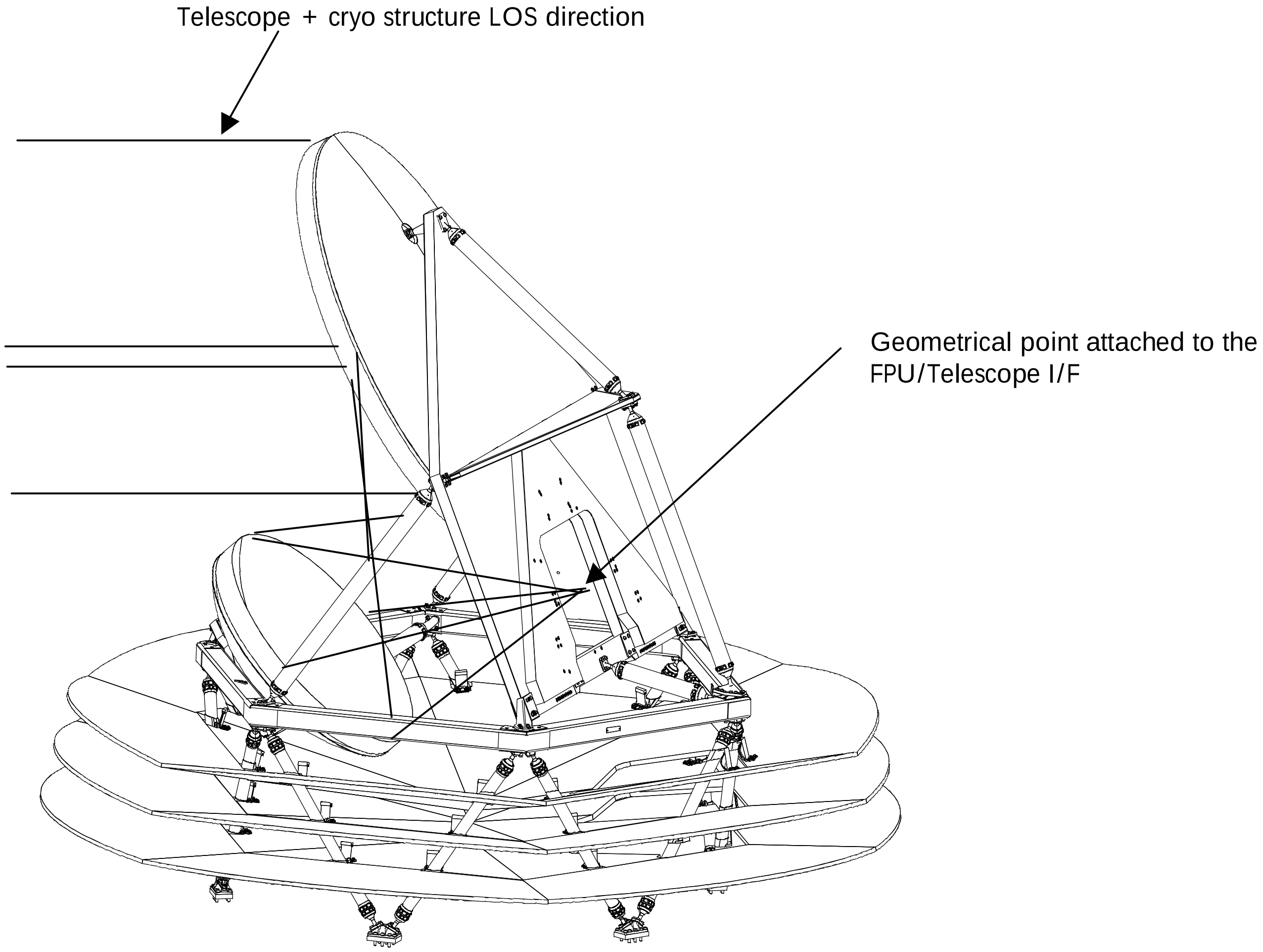
The PPLM Around Line of Sight is defined as the orientation of the projection on the observed sky of the radiometric center of a detector's lines far field pattern as projected by the telescope. This direction is referenced with regards to the cryostructure/SVM interface.

This definition is derived at Telescope+cryostructure level in the following way



Planck Telescope+cryostructure LoS definition

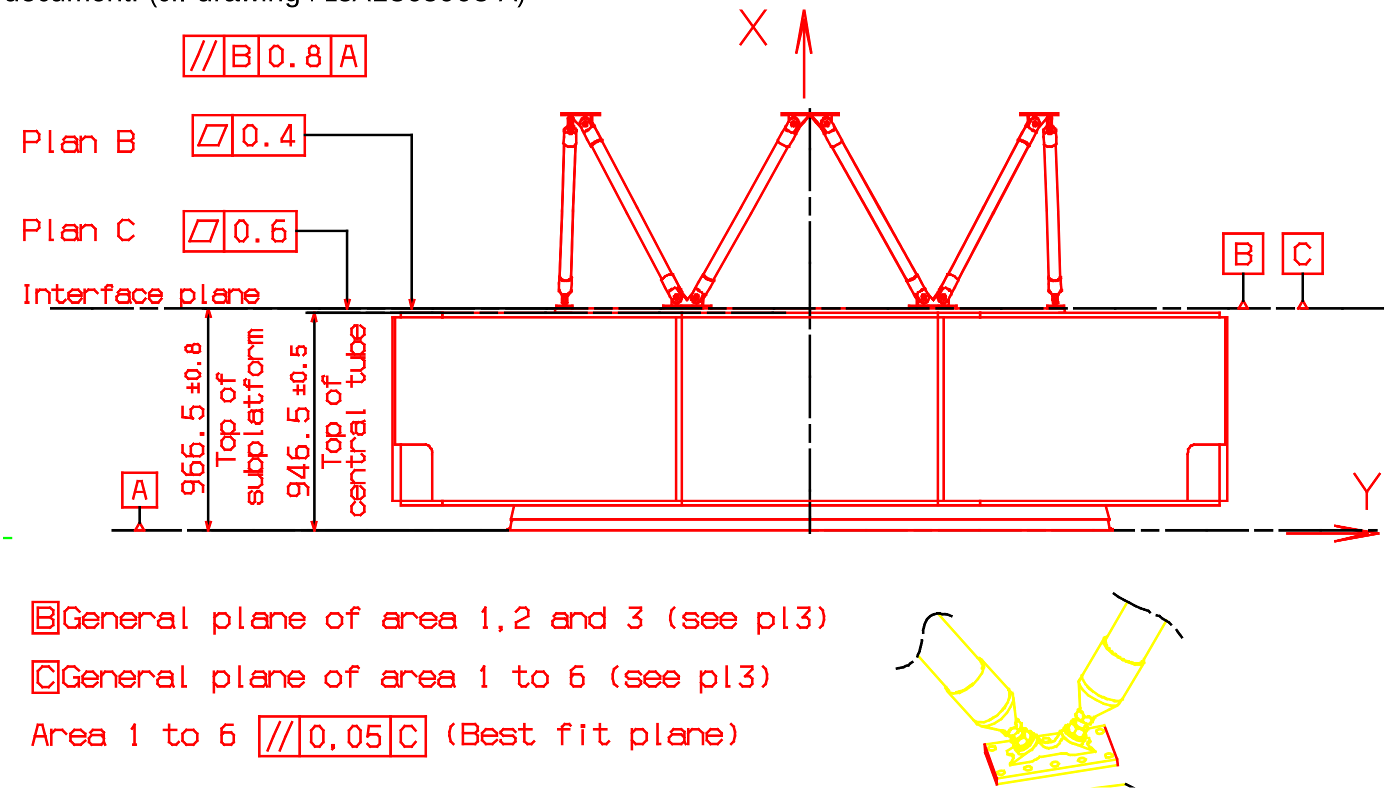
The Planck Telescope+cryostructure Line of Sight is defined as the projection on the observed sky of the center of the FPU/Telescope Interface, as projected by the actual telescope. This direction is referenced with regards to the cryostructure/SVM interface.



The Planck Telescope+cryostructure around Line of Sight angle is defined as the orientation (with regards to the cryostructure/SVM interface) of projection on the observed sky of FPU/Telescope Interface, as projected by the actual telescope.

2.1.3 Cryostructure/SVM interface description

The cryostructure/SVM interface is plane presented hereafter, and is called S/P I/F in the rest of this document: (cf. drawing PLSA180S005 A)



2.1.4 SVM Line of sight definition

The position and stability of the SVM interface plane with regards to the launcher I/F is a contributor to alignment requirements.

The line of sight of the SVM (LOS_{SVM}) is defined by the vector [sin(5°), 0, cos(5°)] in SVM/PLM interface frame.

2.1.5 FPU average focal surface definition

The average focal surface being defined as:
The FPU actual average focal surface - with regards to which the FPU alignment at telescope focus will be made - is the surface which:

- has the same shape than the theoretical one
- is shifted along Z_{RDP} of the distance D, D being defined hereafter:

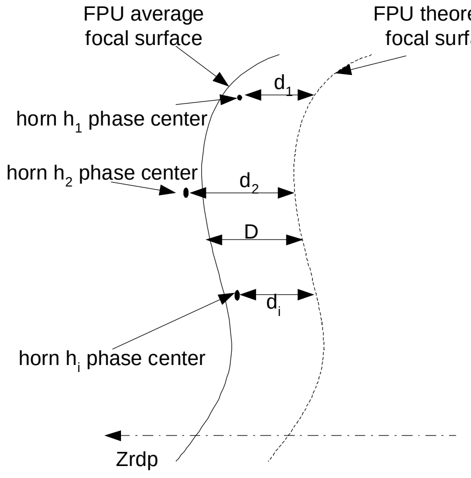
$$D = \frac{1}{\sum_{horn\ h_i} \frac{1}{\alpha_i}} \sum_{horn} \frac{d_i}{\alpha_i}$$

where

- the weighting factor α_i is the optical system WFE degradation requirement:

Horn frequency	Weighting factor
LFI-30 GHz	119
LFI-44 GHz	92
LFI-70 GHz	92
LFI-100 GHz	83
HFI-100 GHz	72
HFI-143 GHz	60
HFI-217 GHz	57
HFI-353 GHz	50
HFI-545 GHz	48
HFI-857 GHz	42

- d_i is the difference between
  the actual (in-orbit) horn h_i phase center Z_{rdp} coordinate
  and its theoretical Z_{rdp} coordinate



To answer PDR system RID 8400, the following clarification has to be made:
The Planck Telescope theoretical surface is defined by the minimum WFE for a given field position and apodization. This shall be superimposed to the FPU focal surface (defined by horn phase centers at microwave wavelengths). The last one shall be given by instruments (cf. Planck Alignment Plan H-P-3-ASPI-PL-0078 – this document), whereas the telescope focal surface will be measured at cryo temperature by Contraves. This last measurement will be performed without apodization. The apodization will be added in a post-processing.

3. SYSTEM ALIGNEMENT REQUIREMENTS

This section recalls the upper level alignment requirements. For each requirement, the relevant contributors are identified.

3.1 alignment requirements coming from image quality needs

The WFE is impacted by a misalignment between the Telescope best-focus and the FPU focal surface. This is true, as for all optical imaging systems along the Zrdp axis, because a defocus increase the WFE. It is the most sensitive misalignment. For Planck, as the telescope focal surface is not a plane, a radial de-positioning of a horn with regards to the telescope will also induce a WFE increase. This sensitivity is analyzed in the Planck optical analyses document[RD1].

The maximum allowed displacement have been derived in the Planck optical analyses document[RD1]

3.2 alignment requirements coming from pointing

These requirements are derived from pointing budgets. They are presented in [AD4]

3.2.1 LOS requirements

Thanks to a calibration in-orbit, the on-ground alignment of the ACMS LoS with regards to the instrument's Line of Sight is not that critical. However, if they are two much mis-aligned, it will induce cross terms in the ACMS evaluations. So, this misalignment has to be specified in the following way (cf. "Herschel and Planck Pointing budget Module allocation" [RD4] for further justifications):

The Planck instrument LOS shall be aligned with ACMS LOS with an accuracy of 1.50 degree maximum (requirement include ground error sources and in orbit effects [gravity release, launcher effects…]).

The in orbit misalignment stability shall allow to stay in the previous range.

3.2.2 Around-LOS requirements

No calibration being made in-orbit for around-LoS, the alignment between the around-LoS direction of the instruments, as projected by the telescope, and the inertia axes of the spacecraft has to be achieved on ground.

The main idea, and as discussed in section 4.6, is that the co-alignment of the around LoS direction of the FPU and the Spacecraft inertia axes will be made by adjusting the last ones in the frame of MCI measurements.

As expressed in the "Herschel and Planck Pointing budget Module allocation" [RD4], concerning the AME around-LOS, specified to be 6 arcmins total in SRS, 3 contributors related to alignment have be identified:
-in-orbit variation of the LoS P-PLM: 3.8 arcmin are allocated
-inertia axis alignment at satellite level with regards to the launcher interfaces: 2 arcmin are allocated
-on-ground instrument around-LoS knowledge with regards to the launcher interfaces: 3 arcmin are allocated.

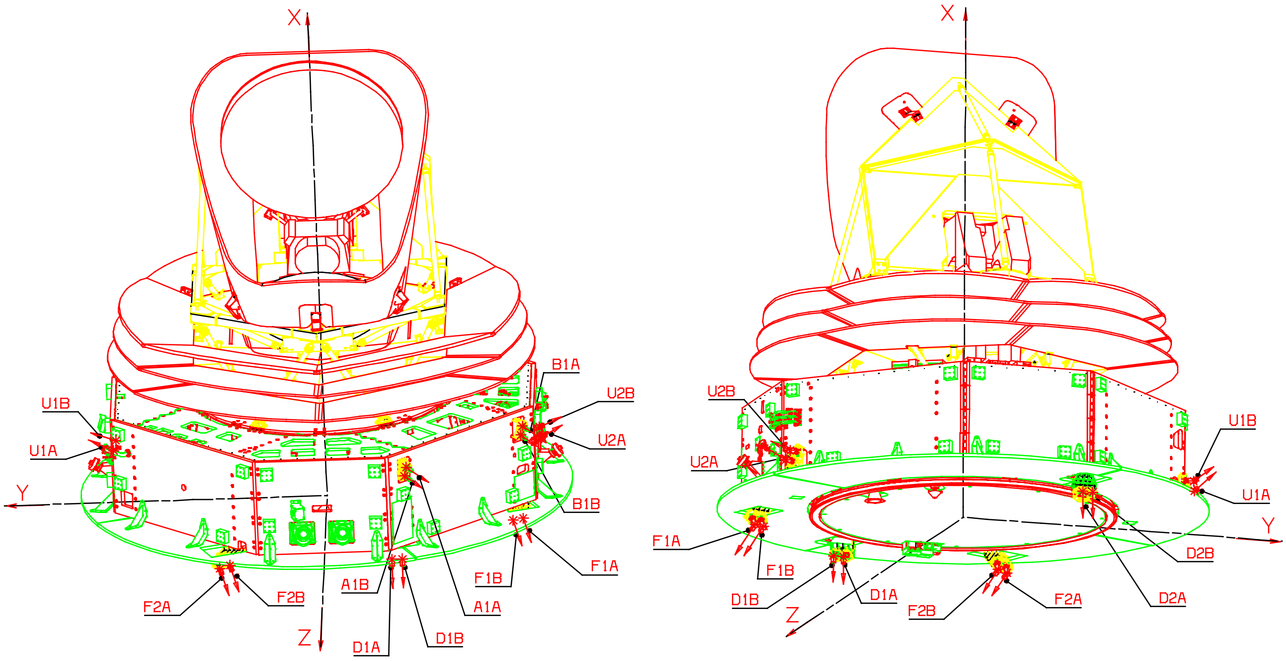
(P-PLM stability)
the stability around LOS_{PLM} axes with regards to PLM/SVM interface (due to launch and in orbits effects) shall not exceed 3.8 arcmin at 68% confidence level.

(Satellite alignment)
the wobble adjustment wrt satellite frame accuracy shall be better than 2 arcmin at 68% confidence level.

(Satellite alignment)
the around LOS misalignment knowledge wrt satellite frame accuracy shall be better than 3 arcmin at 68% confidence level.

3.2.3 Thrusters Alignment

The 10 N thrusters are used for orbit correction and maintenance (see MISS 095, SPER 045).). They are ideally all aligned with the S/C center of mass. Planck center of mass will vary during lifetime.



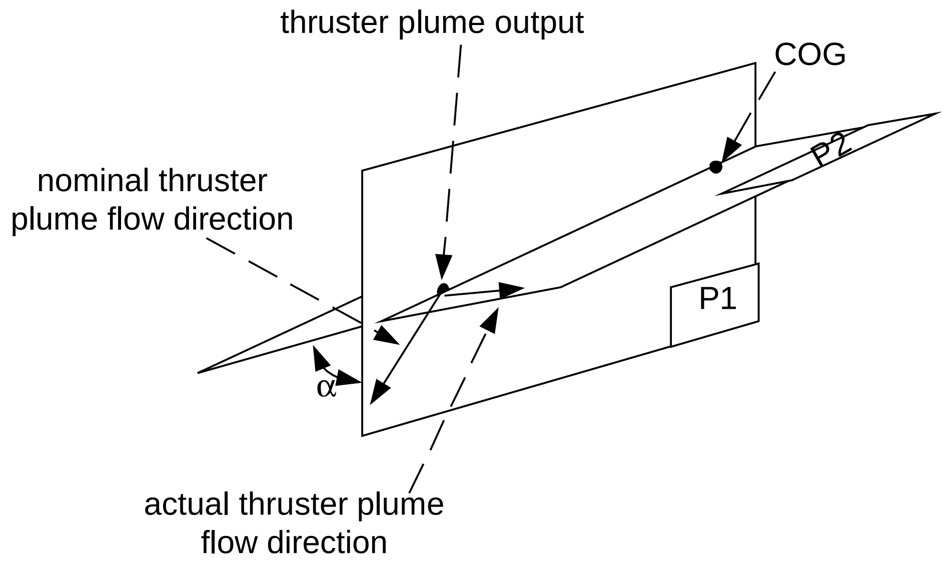
Taking in account thruster accommodation (typically in the order of 2 meter from center of mass), the alignment accuracy between the thruster push axis and the "Middle of Life" S/C CoG shall be better than 0.5°.

(2*sin(0.5°)= 1.7 cm representing around 20% of centre of mass variation)

More schematically, the thruster alignment need is presented in the following drawing:

P1 is defined by
- -the nominal CoG
- -the nominal thruster plume direction
- -the nominal thruster plume position

P2 is defined by
- -the actual CoG
- -the actual thruster plume direction
- -the actual thruster plume position



the angle alpha shall be lower than 0.5°

In order to be capable to adjust the thruster orientations at satellite level, the following is required.

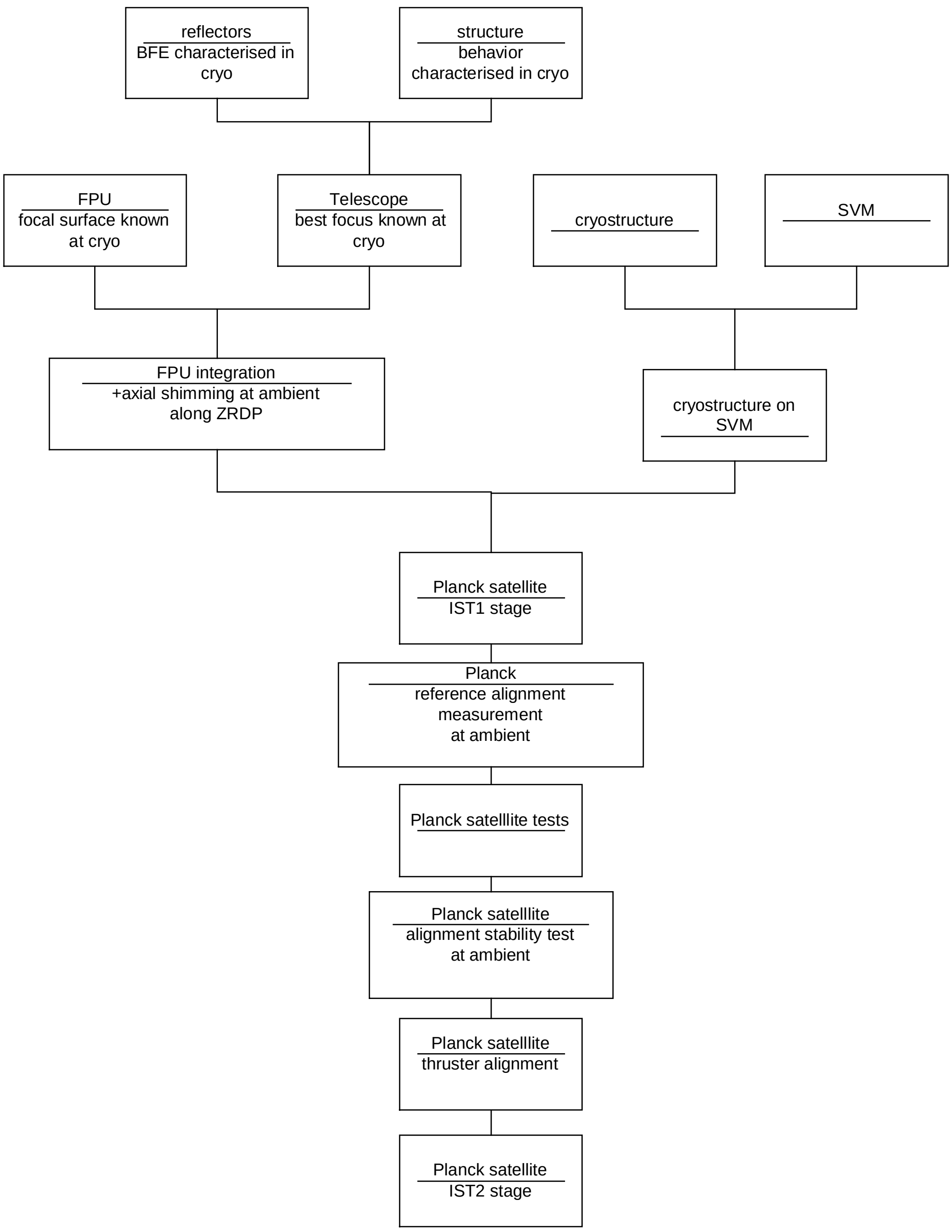
The thruster adjustment range shall be large enough to cover the difference between the theoretical CoG and the actual one at BOL.

A budget is built to assess which adjustment range is needed.

4. INTEGRATION SEQUENCE, AND ALIGNMENT CHECKS

This section describes the integration sequence, and underline the alignment and alignment check actions.

4.1 Alignment logic



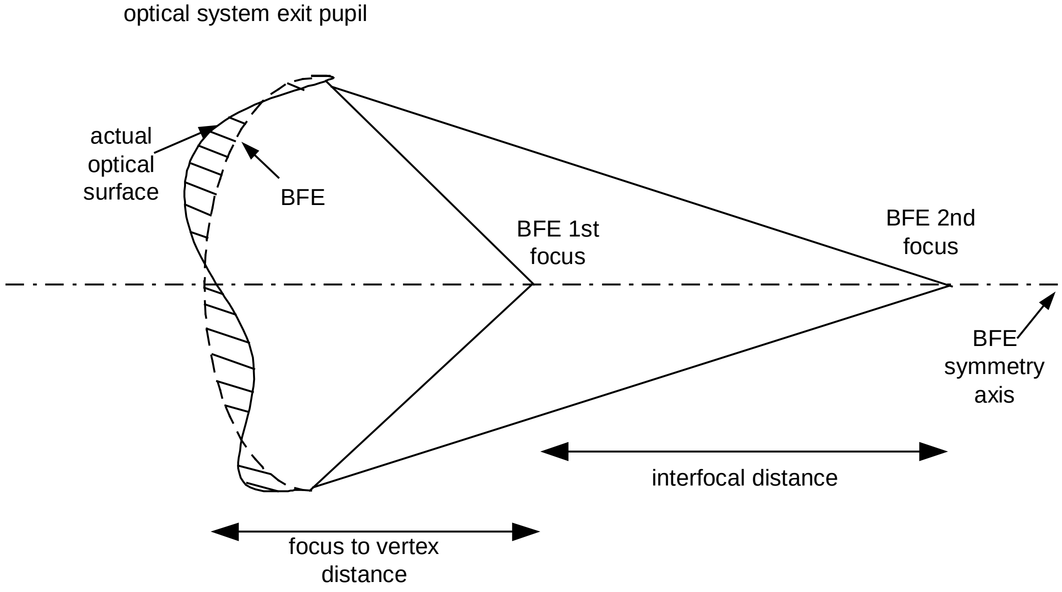
Each step is detailled in the next sections

4.2 Alignment activities at reflectors level

On the reflectors side, on top of the surface accuracy, which has to be compliant with the image quality needs, some other parameters have to be known

Note: The Best Fit Ellipsoid (BSF) is the rotational symmetrical ellipsoidal (with equal semi mirror axis) surface, which minimises the RMS difference with the measured profile.

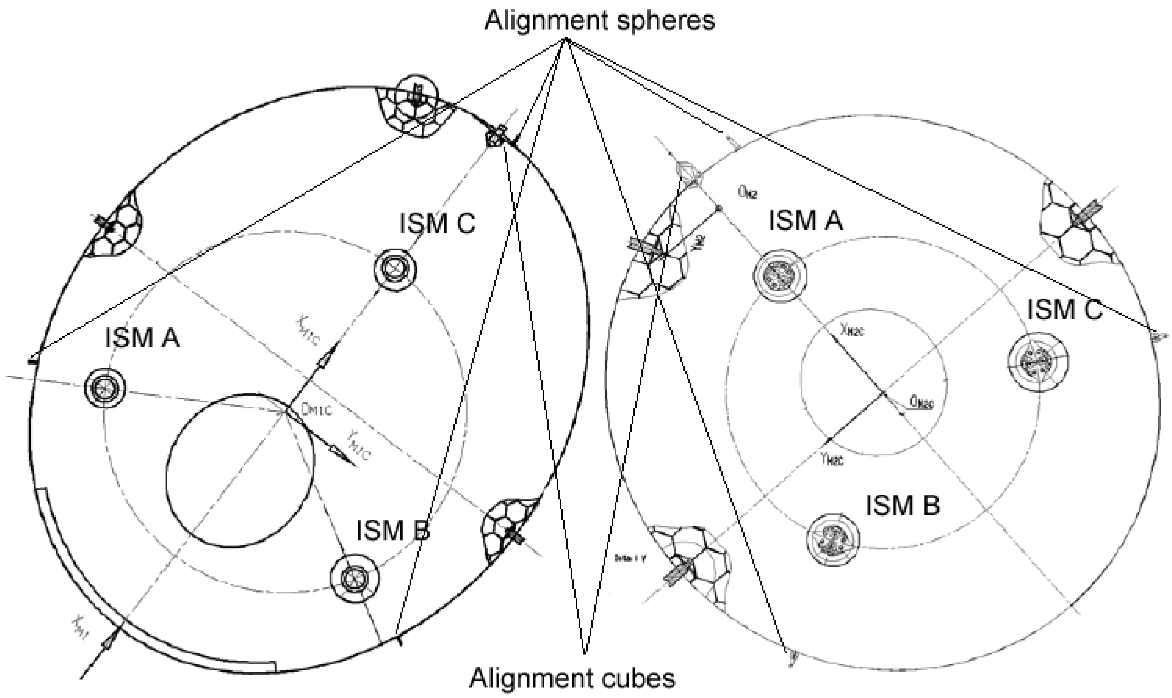
The pertinent parameters to describe the optical surface are describe in the next figure



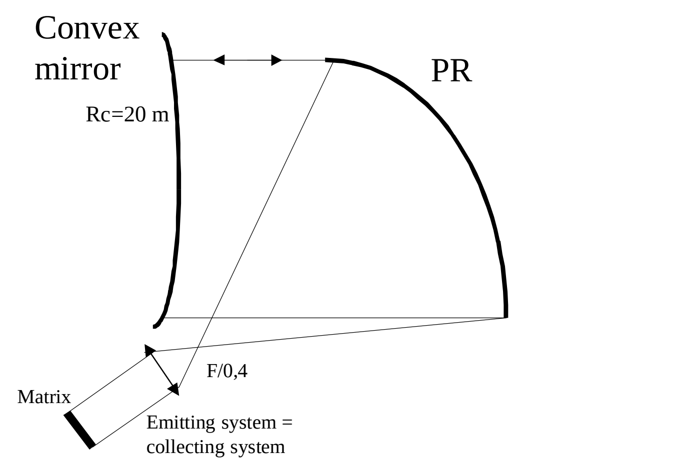
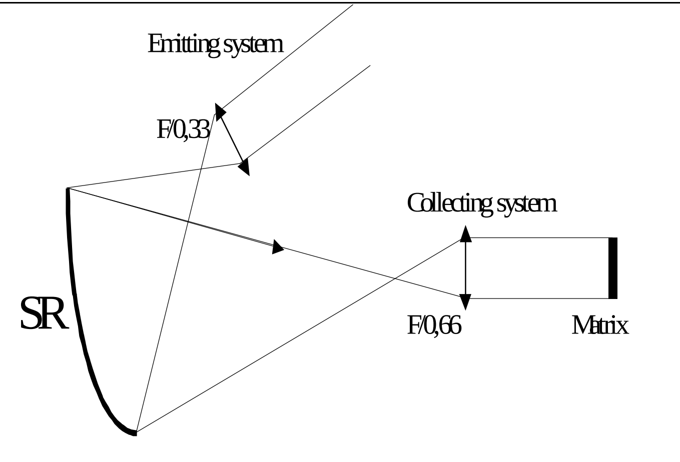
the following are required for the telescope ([AD2])

	Knowledge accuracy		Worst case values	
	PR	SR	PR	SR
BFE focus to vertex distance	+/-25µm	+/-25µm	+/-0.2mm	+/-0.4mm
BFE interfocal distance	+/-100µm	+/-25µm	+/-60mm	+/-0.3mm
BFE location/orientation with regards to the optical references (balls and cubes located on the reflectors rims)	0.1mm/0.1mrad		2mm in plane, 0.1mm out-of plane	

These values contribute to the alignment range at telescope level



The knowledge of the location of these optical references (cubes and balls) are measured with regards to the mechanical interfaces with a 3D machine.
The location of the foci are then measured via an interferometric test. The principle is the following:

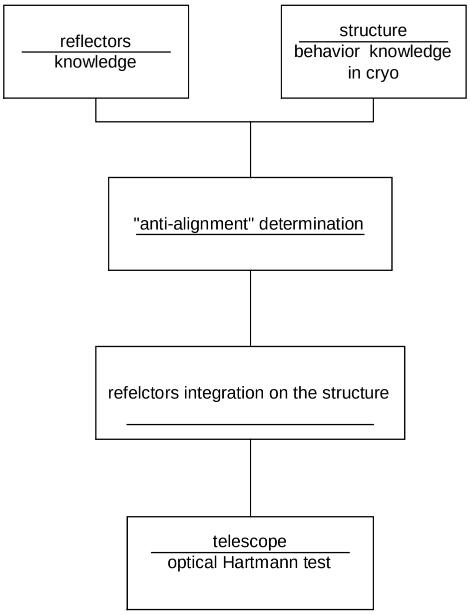
	
PR cryo-optical test Double pass interferometry	SR cryo-optical test simple pass interferometry

Note that the PR is not tested with a full aperture test, but with stitched subaperture, which doesn't change the logic.
Other deterministic effects such as gravity and moisture release are also characterized.

4.3 Alignment activities at telescope level

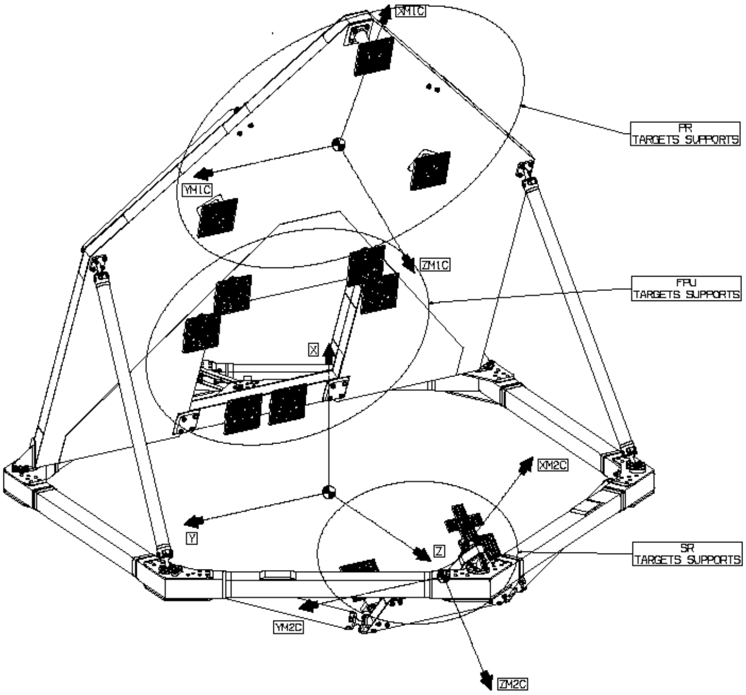
Objectives of this alignment are
-to provide an optimised telescope in terms of WFE
-to provide a telescope best focus located within a +/-2.5mm range with regards to the theoretic location
-to know the location of this best focus at cryo with a +/-0.25mm accuracy

The telescope is made of characterised reflectors mounted on a characterised structure
In order to optimise the performance at operational the policy is to following:



The structure behaviour at cryo is measured via a dedicated videogrammetric test at QM level: targets are sticked on the mechanical interfaces of PR, SR, and FPU, and their relative position is measured by a camera at ambient and in cryo, down to 100K.

The following figure represents the structure equipped with targets for the videogrammetric test



By this measurement, the location of the interfaces at 100K are measured with a +/-60µm accuracy with regards to the reference frame. As this test is performed at 100K, an extrapolation is performed down to the operational temperature 40K, giving the knowledge of PR, SR, FPU mechanical interfaces location at 40K. The related uncertainty (measurement + extrapolation) contributes to the optical error budgets.

Based on this knowledge, the final machining of the reflector adapters (part of the reflectors structure) is performed to obtain the required alignment of the telescope at operational temperature This is the so-called “anti-alignment”.

A dedicated budget is held by Contraves to check the compatibility between the alignment range offered by the structure design and the needed alignment range (see [RD8]).

PR	-X	+X	-Y	+Y	-Z	+Z
BFE tolerance	-0.8	0.8	0	0	-1.7	1.7
BFE location	-3.1	3.1	-3.3	3.3	-3.8	3.8
Dimensional compensation	0.3	0.3	0	0	0.1	0.1
Bias for lateral focus compensation	-1.4	1.4	0	0	-0.15	0.15
Bias for lateral focus baffle compensation	-0.34	-0.34	0	0	0.03	0.03
Total required range	-5.5	5.5	-3.3	3.3	-5.4	5.6
Available range	-	-	-	-	-5	+10

SR	-X	+X	-Y	+Y	-Z	+Z
BFE tolerance	-1.5	1.5	0	0	-0.9	0.9
BFE location	-2.9	2.9	-2.3	2.3	-3	3
Dimensional compensation	0.4	0.4	0	0	0.3	0.3
Bias for lateral focus compensation	-1.4	1.4	0	0	-0.5	0.5
Bias for lateral focus baffle compensation	-0.3	-0.3	0	0	0.1	0.1
Total required range	-5.6	5.8	-2.3	2.3	-4.0	4.8
Available range					-10	+4

The telescope structure CDR has raised a discrepancy between the needed adjustment range and the range allowed by the reflector adapter design. This has been addressed by CSAG and corrective actions have been taken to recover a compliance: refinement of some contribution and extension of some alignment ranges. Updated budget is under assessment.

Once the reflectors FM are received, they are simply integrated on the structure. An alignment check with theodolites looking at the optical references on the reflectors will then be performed. In the baseline approach, the reflectors are no more realigned after this stage.

The correct alignment of the reflectors and the structure is checked in cryo via a dedicated cryo-optical test See [RD15]

4.4 At FPU level

The FPU stability and characterisation policy is not completely known yet. The measurement at cryo shall provide the knowledge of the horns phase centre location with regards to the mechanical IF with a +/-0.1mm accuracy

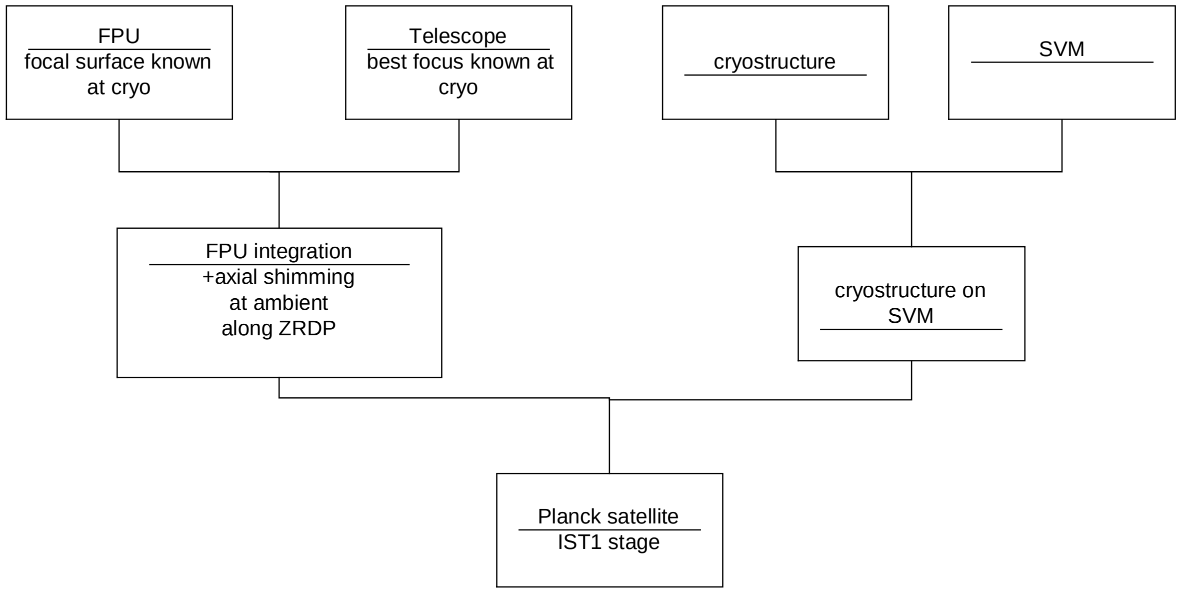
This knowledge will be used to

- -define the focal shim thickness to be integrated at telescope focus during PPLM AIT
- -know the around LOS contribution of the FPU

4.5 PPLM alignment activities

4.5.1 FM alignment activities

To achieve the satellite level, the following stages are thus necessary:



Two shimming steps are necessary:

FPU shimming along ORDP

The defocus is the main sensitive displacement of the FPU, and it will be induced by cool-down. So, the most efficient way to achieve a good image quality is to align the FPU focal surface at operational on the telescope best focus surface at operational along Z direction. This will be done by shimming at FPU/telescope interface. The shim thickness will be defined on the basis of measurements described in section 4.3 and 4.4. The alignment verification will be done by theodolite measurement .

No shimming is done in the plane.

The maximum shimming range is +/-3mm. Thanks to the shimming, the in-orbit distance between the telescope focus and the FPU focal surface will be shorter than 0.42mm. This corresponds to 10.3µm RMS apodized WFE for HFI 100GHz horns (λ/ 300), and 6.6µm for the HFI-857GHz (λ/50). This is taken into account in the WFE budget as presented in the optical performance budget (cf. [RD1])

Based on the telescope CDR results, the budget for the alignment range is the following:

item	Needed Adjustement range	Remark
Telescope	< +/-1.4 mm	As per [RD8]
FPU	< +/-0.5mm	As required toward instruments
sum	< +/-1.9mm	
requirement	< +/-3mm	

The adjustment range budget is compliant with the PPLM design.

Relative position of telescope focus and FPU focal surface in X/Y plane being less important with regards to image quality, the mechanical positioning of the FPU in this plane is sufficient. (cf. [RD1) for the detailed sensitivity analysis)

Cryostructure struts shimming along X

In order to ensure a good flatness (50µm) of the cryostructure struts at the telescope frame IF once mounted on the SVM FM, a shimming is performed struts by struts

This planarity is important as it directly contributes to the image quality, as shown in [RD1]

4.5.2 Alignment of the QM telescope for the RFQM tests

The RFQM test will be performed at ambient, for that purpose, the QM telescope (made of structure QM + reflectors QM), will be also aligned at ambient (Hartmann test)
The same approach as for FM will be followed, providing

- Well aligned Telescope with regards to WFE at ambient,
- best focus at ambient located at +/-2.5mm versus its theoretical location
- Knowledge of best focus at ambient within +/-0.5mm accuracy

4.6 STM/FM Alignment activities at satellite level

4.6.1 STM/FM difference

The STM logic is the same than the FM, but the thrusters and the spin axis are not aligned

4.6.2 Alignment sequence at satellite level

At this stage, the Spacecraft is built, and we reach IST1 stage (cf H-P-3-ASPI-PL-0208 Planck satellite AIT Plan for the detailed AIV sequence) the alignment sequence at satellite level is the following

1. The optical reference for the satellite is the satelliter optical cube (AC1 and AC2 on "Planck alignment cube access" ME.PLS.A010.A.001SA, given in annex), whose position and orientation will be referenced with regards to the launcher IF plane
2. A reference alignment measurement is performed with theodolites: the mating is verified, and all the accessible cubes are referenced with regards to the satellite cube
3. Satellite mass properties are measured, and the spin axis is adjusted with balancing masses
4. Once the mechanical tests completed, an alignment stability check is performed
5. The thrusters are aligned with regards to the measured CoG[2]
6. Once the thermal tests completed, the final alignment stability check is performed

The only alignments performed during Planck satellite AIT are

- Spin axis adjustment with regards to instruments LOS
- Thrusters alignment with regards to the measured satellite CoG

The relevant Test requirement Sheets are presented int he following table

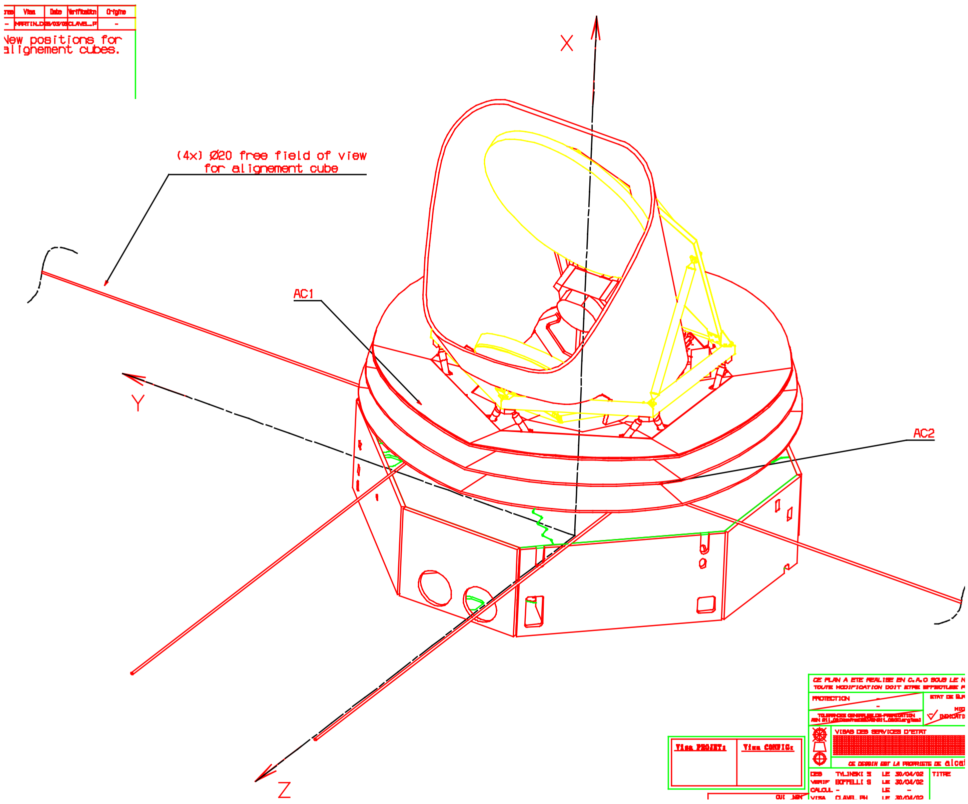
Specimen to be tested					TEST TO BE PERFORMED
Planck	SAT	STM/PFM	ALG	1	Satellite Mechanical axes determination and stability check
Planck	SAT	STM/PFM	ALG	2	Thrusters alignment[3]
Planck	SAT	STM/PFM	ALG	3	Equipment's optical references alignment and stability check with regards to S/C optical reference frame

[2] The referred CoG is the one at a given time of the mission, i.e. with a given fuel filling ratio, not the satellite CoG at the time of the measurement test

[3] on the STM, only the alignment range capability is checked

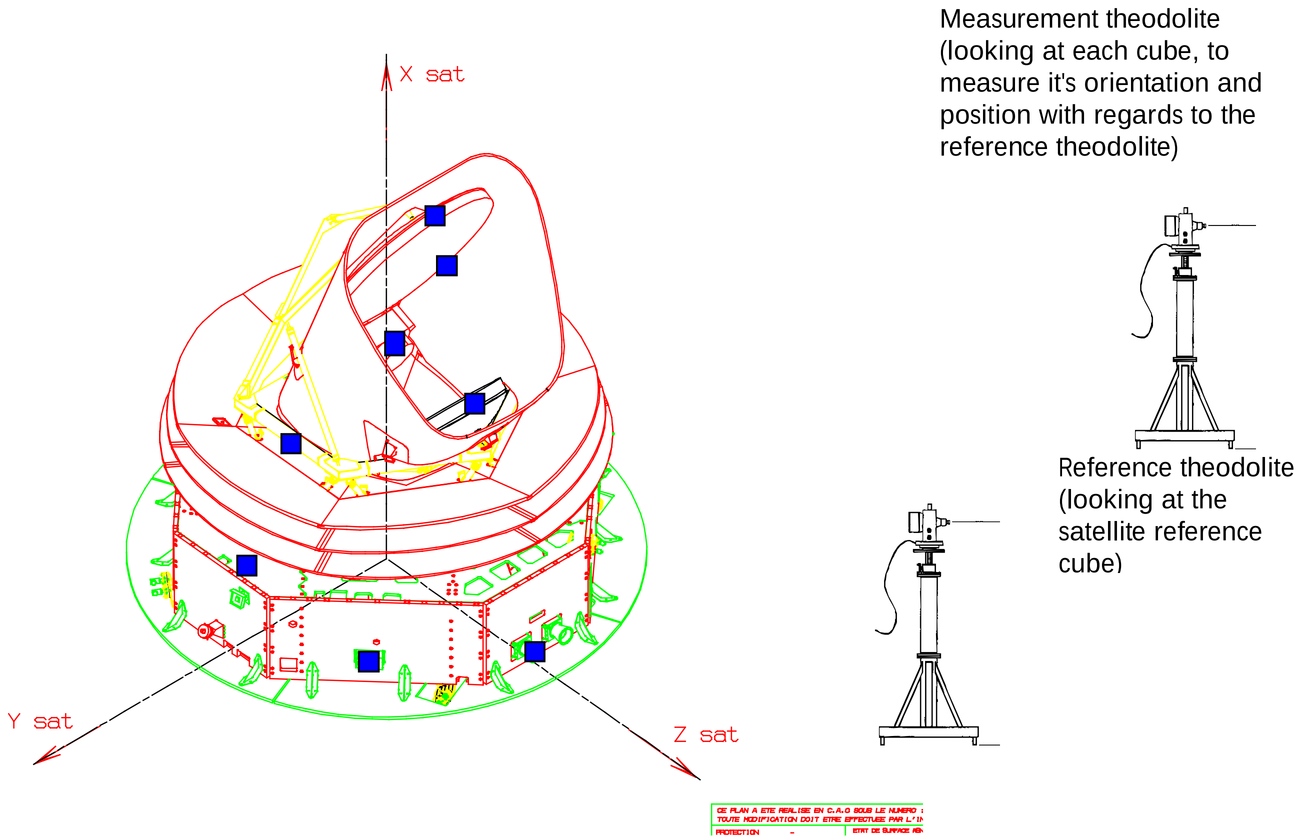
4.6.2.1 Spacecraft cubes

Spacecraft cubes are located at the following place



4.6.2.2 Alignment checks description

AT IST 1.5, SFT 1.3 and IST 2.2 stages, the alignment between each subsystems are checked in the following way . Theodolites are used



The optical cubes to be looked at are the following:

Element				Optical cube and balls quantity
PPLM		reflectors	PR	1 cube+1 ball[4]
			SR	1 cube+1 ball[5]
		mechanical frame		2 cubes (1N+1R)
		FPU		1 cube + 1 ball[6]
SVM (see [RD12])	external	SVM reference		2 cubes (1N+1R)
		Thrusters		16 cubes
		Star Trackers		2 cubes
		Antenna		3 cubes
	internal	CRS		3 cubes[7]
		AAD		1 cube
Satellite				2 cubes

Based on the first alignment measurement, (PFM IST-5), the alignment of the P-PLM interface frame with regards to the launcher interface will be assessed. This will be an input to the spin-axis alignment performed at IST1.6 stage.

[4] only the ball on +X will be used. The others will be dismounted before satellite AIT activities

[5] idem as forPR

[6] the location of these optical references on the FPU are still under discussion with instruments

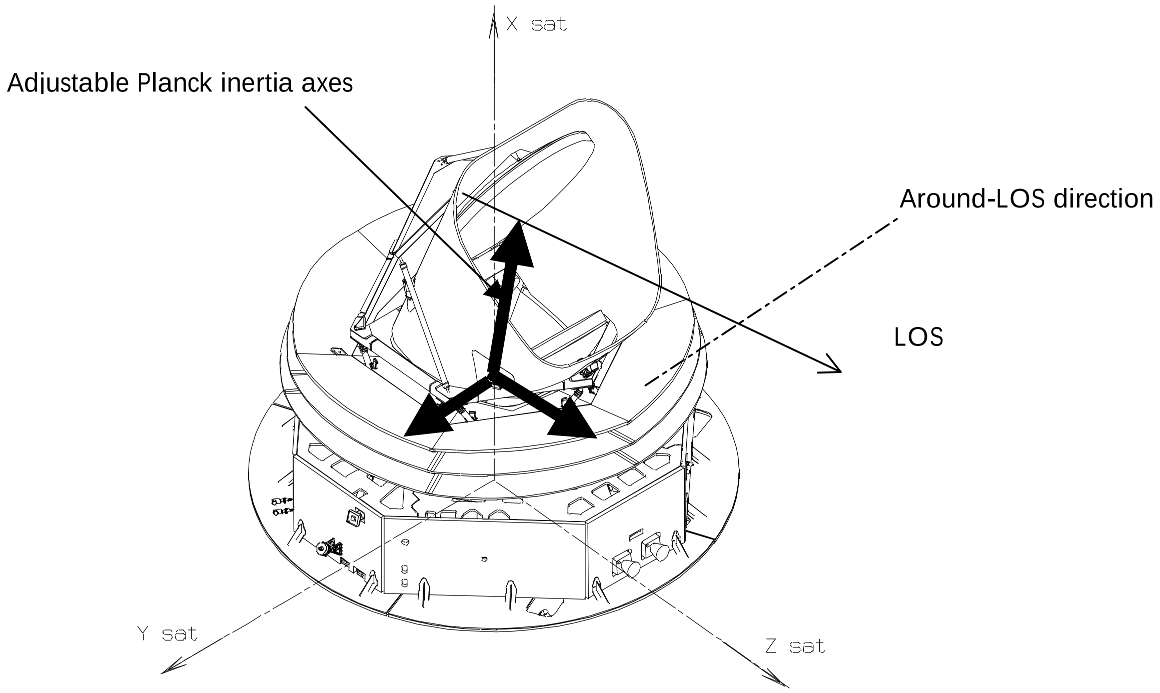
[7] Indeed, among the three CRS , only one LOS will be accessible for alignment check at S/C level. Two CRS reference cubes will be accessible.

- One for CRS 1 and 2
- One for CRS 3

These cubes will have been referenced with regards to the two MRC's cube at SVM integration level (see SVM alignment plan [RD12])

4.6.3 Spin axis alignment (see[RD14])

Once the in-orbit around-LOS axis is predicted (the launcher/I/F axes being the reference), the inertia axes are measured, and realigned, by mass addition, with regards to the known around LOS orientations.



4.6.4 Thrusters alignment

At IST 1.6 stage, the spacecraft balancing and measurement are performed. This is covered by the test requirement sheet RD14 Planck MCI test specification.

The 16 thrusters are distributed in the following way:

Thruster name	Quantity (Nominal + Redundant)	Force	Directed to
"D"-Down	2N+2R	10N to 20N	CoG included in "Down" thruster plane
"F"-Flat	2N+2R	10N to 20N	CoG included in "Flat" thruster plane
"U"-Up	2N+2R	10N to 20N	CoG included in "Up" thruster plane
"A1"-Spin Up	1N+1R	1N	See next drawing
"A2"-Spin Down	1N+1R	1N	See next drawing

Each thruster is equipped of a dismountable alignment cube, located in its nozzle. They will be dismounted before launch. See [RD13] ,thruster bracket user's manual

MODIFICATIONS

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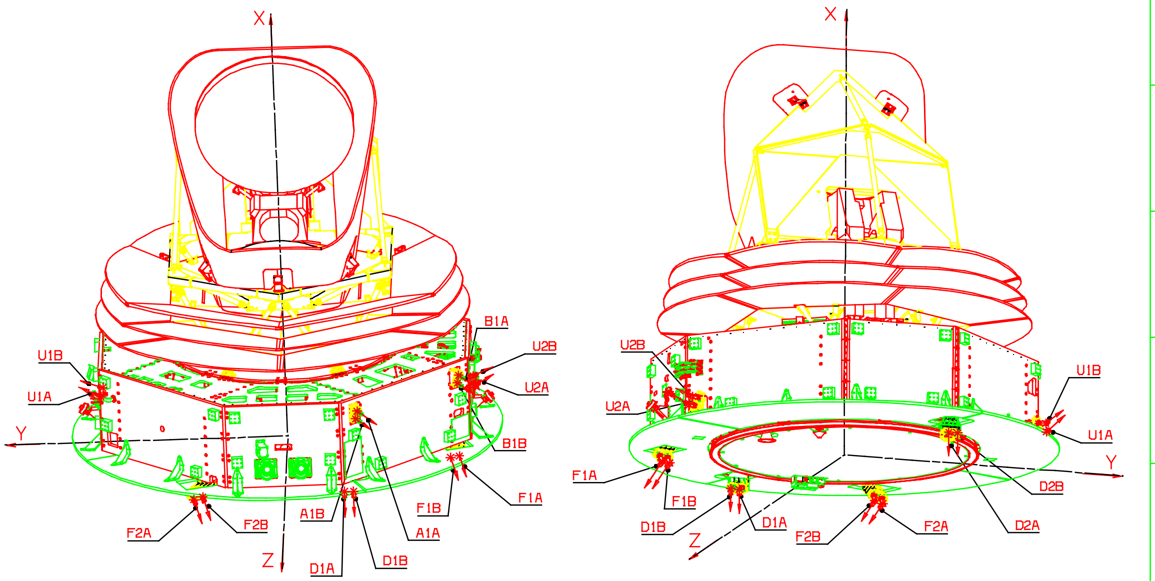
- New positions and orientations for Thrusters.



THRUSTER	X	Y	Z	Fx	Fy	Fz
A1A	826.466	-734.194	1718.094	-0.28343	-0.678110	0.678110
A1B	740.157	-716.157	1700.057	-0.28343	-0.678110	0.678110
B1A	826.466	-1718.094	734.194	-0.28343	-0.678110	0.678110
B1B	740.157	-1700.057	716.157	-0.28343	-0.678110	0.678110
D1A	-57.856	-575.394	1565.180	-0.999785	0.007900	0.019190
D1B	-57.856	-665.394	1565.180	-0.999785	0.007900	0.019190
D2A	-61.144	575.394	-1565.180	-0.999785	0.007900	0.019190
D2B	-61.144	665.394	-1565.180	-0.999785	0.007900	0.019190
F1A	-64.605	-1688.273	576.913	-0.615008	-0.262859	0.743418
F1B	-70.082	-1602.877	604.714	-0.610002	-0.263141	0.747432
F2A	-89.459	902.585	1571.802	-0.615008	-0.262859	0.743418
F2B	-68.895	816.510	1555.377	-0.610002	-0.263141	0.747432
U1A	205.461	1837.803	-764.420	0.515580	0.590821	0.620571
U1B	281.669	1815.889	-808.480	0.456491	0.591181	0.664921
U2A	208.071	-1840.734	-761.381	0.531132	-0.556072	0.639283
U2B	284.054	-1818.909	-805.162	0.470549	-0.555709	0.685399

Visa PROJET: Visa CONFIG:

ALCATEL

PLANCK
THRUSTER ACCOMMODATION

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4.7 Satellite alignment test requirement sheets summary

FM/STM	Mechanical axes	Thruster alig[8]	Alignment reference/stability check		
	TRS-P-ALG-1	TRS-P-ALG-2	TRS-P-ALG-3		
			P-PLM	S/C	SVM equipments
	TBC LOS	16 LOS	8 LOS 3 balls	2 LOS	57 LOS
S/C alig check	X		X	X	X
After mechanical environnement			X	X	X
Thruster alig		X			
Last alig check after thermal test	X		X	X	X

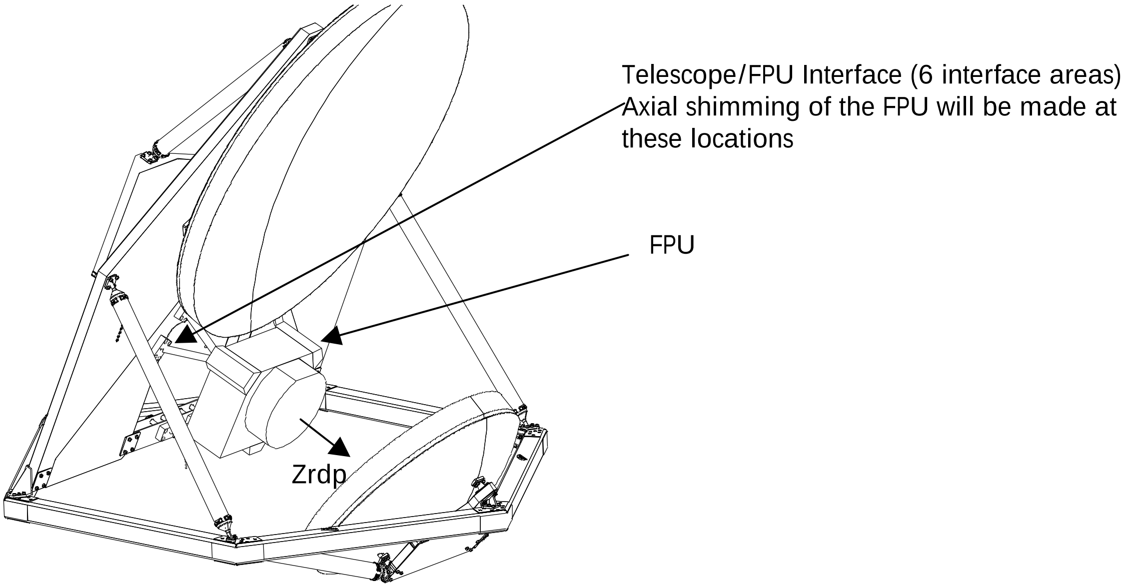
[8] on STM, only thruster alignment range capability is checked

5. ALIGNMENT SUB-LEVEL ALLOCATIONS

For each requirement, each identified contributor is analyzed, and an allocation, in phase with the current baseline is made. These allocations are the requirements to the sub-systems: P-PLM, SVM, and to the system activities

5.1 Alignment coming from image quality needs

Taking into account what has been presented in the previous section, and particularly the fact that the best focus location of the telescope will be known at cryo-temperature, and that a shimming is performed in axial direction, the following contributors tree represents the contribution of misalignments to Wave-Front Error



5.1.1 axial focus alignment needs

5.1.1.1 FPU internal requirements

"The horns must be located with the following accuracy w.r.t the mounting interface to the telescope FPU:

+/-0.1mm maximum deviation (position and stability) along Z axis wrt to average focal plane surface

+/-0.1mm knowledge accuracy of the average focal plane surface Z axis position wrt its theoretical Z position."

5.1.1.2 Telescope best focus knowledge requirement

The following is required to the P-PLM, (directly at Planck Telescope manufacturer level)

P-TEL-PHY-050 The best focus of the telescope shall be known to be within a cylinder of diameter of 0.5 mm (TBC) and length of 0.5 mm, with the cylinder axis in the Z_{FPU} direction of the FPU co-ordinate system.

Note : the best focus of the telescope is the point along the telescope axis at which the WFE at operational condition is minimum.

5.1.1.3 Telescope/FPU interface stability

The stability along Zrdp of the Telescope/FPU interface points with regards to the Telescope interface frame shall be better than +/-0.1mm.

5.1.1.4 Shimming accuracy

The following figure is required for shimming:

-manufacturing precision of focal shim thickness is +/-10µm.
-Maximum focal shim parallelism tolerance is 0.1 arcmin

5.1.1.5 Requirements Synthesis

		Contribution	Status	Reference
FPU	Average focal surface knowledge	0.1mm	Specified	IIDA
	Maximum deviation wrt average focal surface	0.1mm	Specified	IIDA
Telescope	best focus knowledge	+/-0.25mm	Specified	Planck Telescope specification [RD3]
	FPU I/F stability	+/-0.1	Specified	Planck Telescope specification [RD3]
Shimming accuracy		+/-0.01µm	AIT specification	State of the art

The sum of all these contributors leads to a total defocus of 0.56mm, and all these contributors are taken into account in the WFE budget (cf. [RD1]

5.1.2 Radial focus position alignment needs.

No adjustment is foreseen in radial (Xrdop-Yrdp) plane. Due to the fact that the focal surface is not a plane, a radial location mismatch between the telescope best focus and the FPU focal surface induces a local defocus. The subcontributors to this radial position mismatch are the following:

-FPU internal :horn radial (X/Y) position accuracy with regards to the FPU I/F plane (everything being considered at operational)
-Telescope best focus radial position
-Telescope/FPU Interface stability
-Telescope/FPU shim realization and positioning accuracy

5.1.2.1 FPU requirement:

The instruments are requested to provide the following alignment:

"The horns must be located (in-orbit) with the following accuracy w.r.t the mounting interface to the telescope:

+/-0.4mm translation (position and stability) along each X and Y axis"

5.1.2.2 Telescope best focus position requirement

The following is required to the PPLM, (directly at Planck Telescope manufacturer level)

P-TEL-PHY-045 The best focus of the telescope shall be within a cylinder of diameter of 1 mm (TBC) and length of 5 mm around the nominal focus position, with the cylinder axis in the Z_{FPU} direction of the FPU co-ordinate system.

Note : the best focus of the telescope is the point along the telescope axis at which the WFE at operational condition is minimum.

5.1.2.3 Telescope/FPU interface stability

The stability of the telescope/FPU interface in the X/Y plane with regards to the Telescope interface frame has to be better than +/-0.1mm.

5.1.2.4 Shimming accuracy

The following figure is required for shimming:

Mounting accuracy=+/-0.05mm in X/Y plane

5.1.2.5 Requirements Synthesis

		Contribution to radial focus position mismatch	Status	Reference
FPU horn positionning accuracy		+/-0.4mm	Specified	IIDA
Telescope	best focus position	+/-0.5mm	Specified	Planck Telescope specification [RD3]
	FPU I/F tability	+/-0.1	Specified	Planck Telescope specification [RD3],
Shimming accuracy		+/-0.05µm	AIT specification	State of the art

The sum of all these contributors lead to a total radial focus position mismatch of 1.05mm, and all these contributors are taken into account in the WFE budget (cf. [RD1])

5.2 instrument LOS position accuracy wrt ACMS LOS

According to the alignment sequence, and particularly to the fact that there is no shimming foreseen at system level to adjust the star-trackers with regards to the instruments Line of sight, the contributors are:

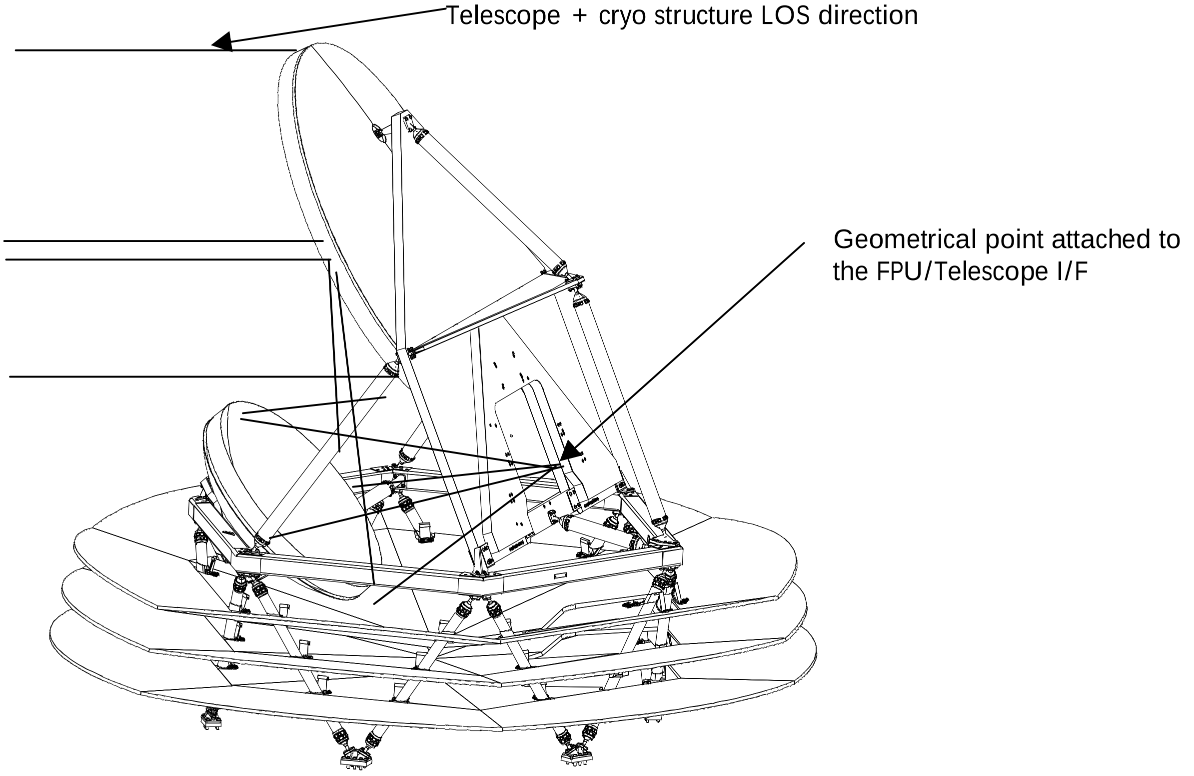
The P-PLM, including
- cryostructure bias and stability
- telescope LOS bias and stability
- instruments LoS bias and stability

the SVM, with the ACMS LoS bias and stability
the mating of the P-PLM on the SVM

5.2.1 PPLM contribution

5.2.1.1 Cryostructure + telescope

The in-orbit cryo-structure+telescope Line of sight shall remain in its theoretical position +/-40 arcmin with regards to the P-PLM/SVM insterface frame. This includes on-ground bias and in-orbit variations.



5.2.1.2 Instrument contribution

The FPU is located at the Telescope focus. Thus, a radial displacement or instability fo the FPU or horns induces a shift of the Line of Sight.

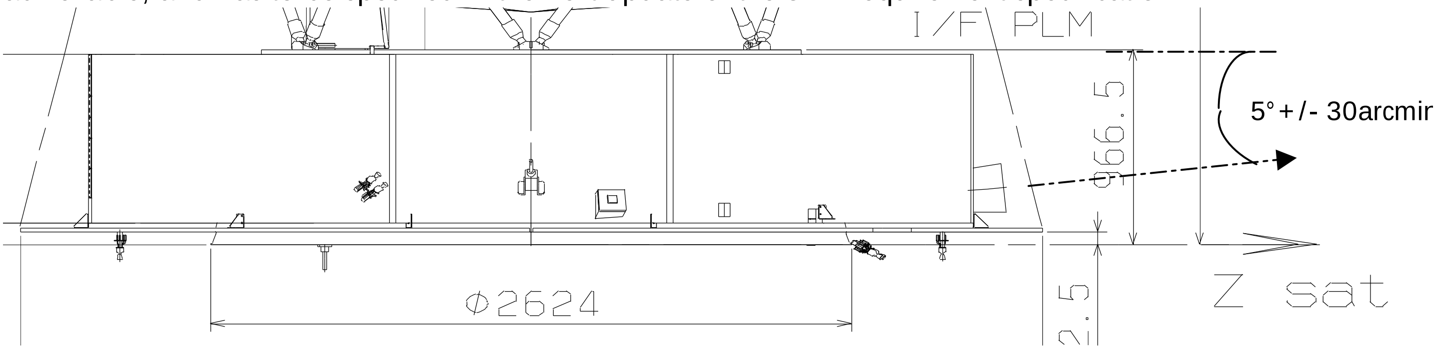
The instruments are requested to provide the following alignment:

"The horns must be located (in-orbit) with the following accuracy w.r.t the mounting interface to the telescope:
+/-0.4mm translation (position and stability) along each X and Y axis"

Due to the 1600mm focal length of the Planck Telescope, this leads to a +/-0.9 arcmin

5.2.2 SVM contribution

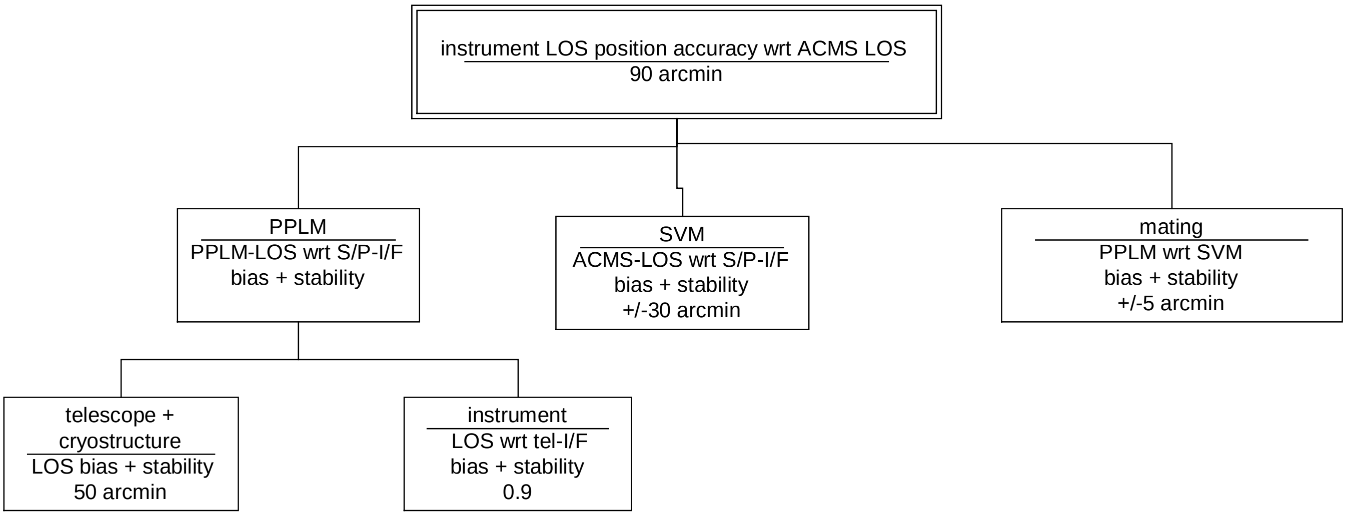
The in-orbit AOCS Line of sight shall remain in its theoretical position +/-30arcmin with regards to the PPLM/SVM interface frame. This includes on-ground bias and in-orbit variations. .This is considered as a achievable, and has to be specified in the next update of the SVM requirement specification



5.2.3 Mating contribution

The mating of the PPLM on the SVM shall not induce a rotation around Ysat of more than 5 arcmin.
This is in line with the current interfaces.
This is well in line (with margins) with the P-PLM-SVM interface drawing, which specified a parallelism of +/-0.25mm on the interface points, i.e. a worst case slope of 0.5/2000rad<1arcmin.

5.2.4 Requirements synthesis



5.3 Instruments around LOS instabilities with regards to the PLM-SVM interface

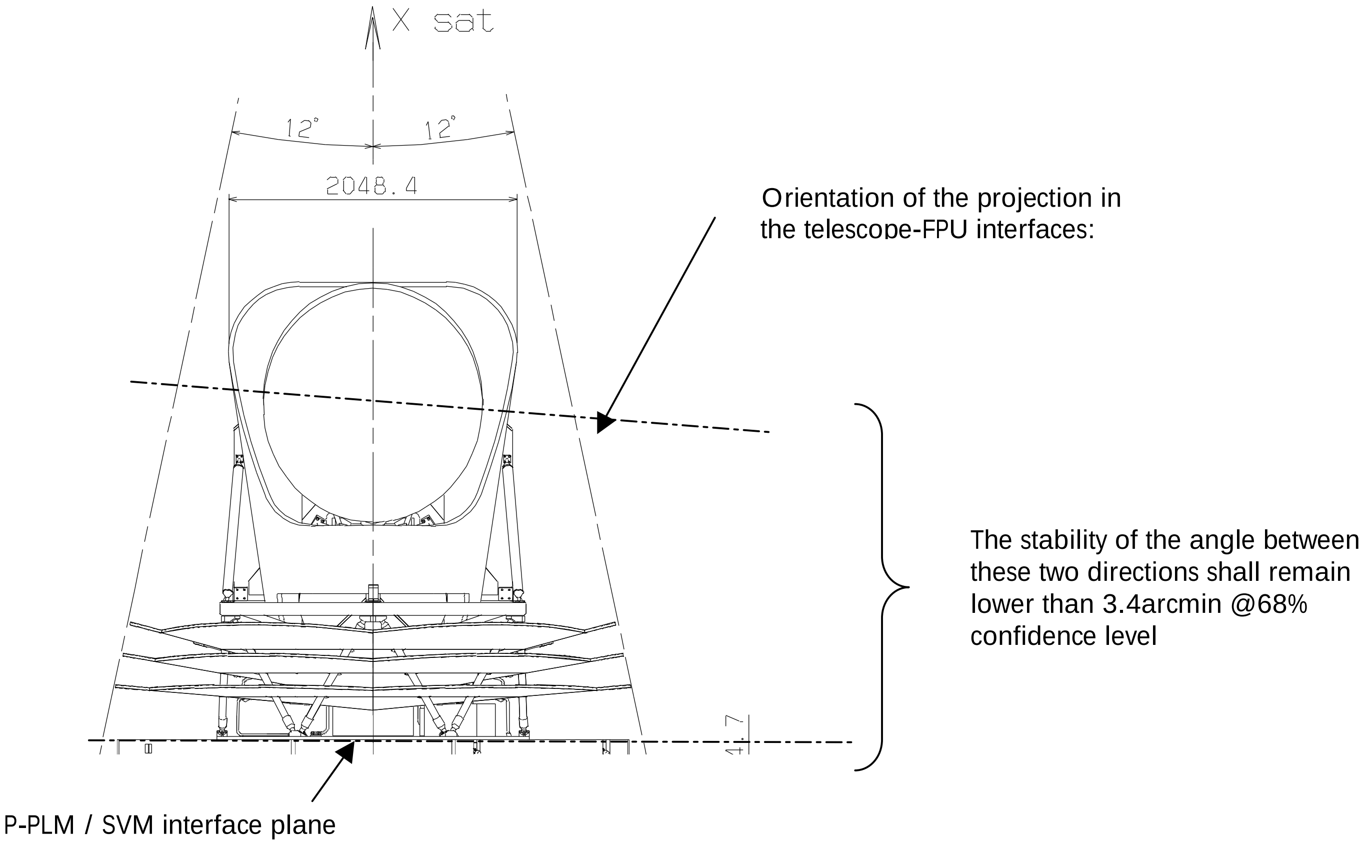
The subcontributors are the FPU internal instabilities (along X and Y), the PPLM instabilities, and the SVM internal instabilities.

5.3.1 FPU internal around-LOS

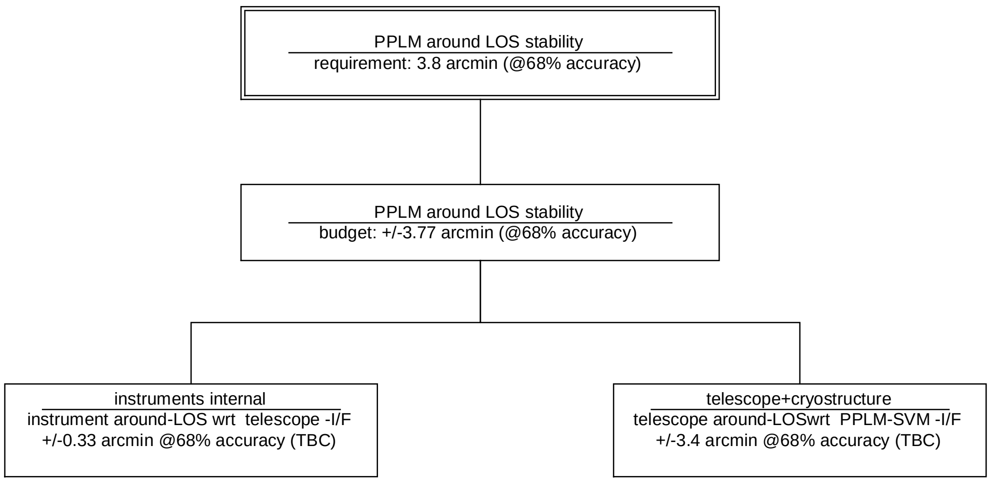
The instruments are requested to provide the following alignment:
"Each detector line will have to be known to be aligned parallel to Y axis wrt telescope/FPU mechanical interface with 1 arcmin accuracy"
This requirement includes knowledge and stability. To build a conservative budget, we will consider the case where the worst case instability would be 1 arcmin. 1 arcmin being at 3 sigma, this leads to a 0.33 arcmin at 1 sigma (68% confidence level)

5.3.2 Telescope+cryo-structure around-LOS stability

The stability of the orientation of around LOS stability of the telescope+cryostructure (including cryostructure, telescope stability, and Telescope-FPU i/F stability) shall be less than 3.4 arcmin at 68% confidence level. This requirements is specified in the P-PLM interface requirement spec, and the compliance is justified in the PPLM optical performances analysis [RD1]



5.3.4 Requirement synthesis



5.4 Instruments around LOS knowledge with regards to the launcher interface plane

A knowledge step-by-step will be performed. In this context, the contributors list is the following

P-PLM around-LoS knowledge with regards to the Planck Telescope frame
Planck Telescope frame orientation, at satellite level, with regards to the launcher interface plane

On another hand, thanks to an RF end-to end test at ambient, the knowledge of around-LOS alignment with regards to satellite axis might be accessible.

5.4.1 Planck PLM contribution

5.4.1.1 Instruments around-LOS knowledge

The instruments are requested to provide the following alignment:
"Each detector line will have to be known to be aligned parallel to Y axis wrt telescope/FPU mechanical interface with 1 arcmin accuracy"
This requirement includes knowledge and stability. To build a conservative budget, we will consider the case where the worst case knowledge would be 1 arcmin. 1 arcmin being at 3 sigma, this leads to a 0.33 arcmin at 1 sigma (68% confidence level)

5.4.1.2 Telescope around-LOS knowledge

The in-orbit telescope around LOS knowledge with regards to Planck Telescope frame shall be better than 1 arcmin at 68% confidence level.

5.4.2 Planck PLM alignment knowledge with regards to launcher Interface plane

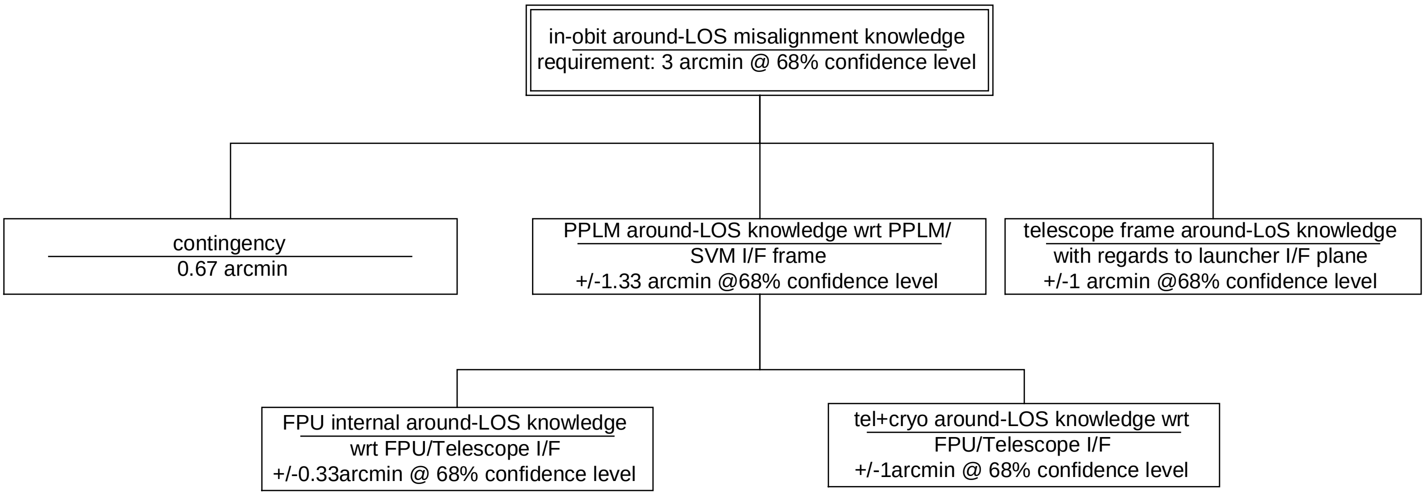
During the alignment reference measurement PFM-IST 1.5, the orientation of the Planck Telescope frame cube will be measured with regards to the launcher interface plane. The accuracy will be better than 1 arcmin

5.4.3 Contingency

A contingency of 0.67 arcmin is preserved to cope with any evolution of this alignment knowldege philosophy.

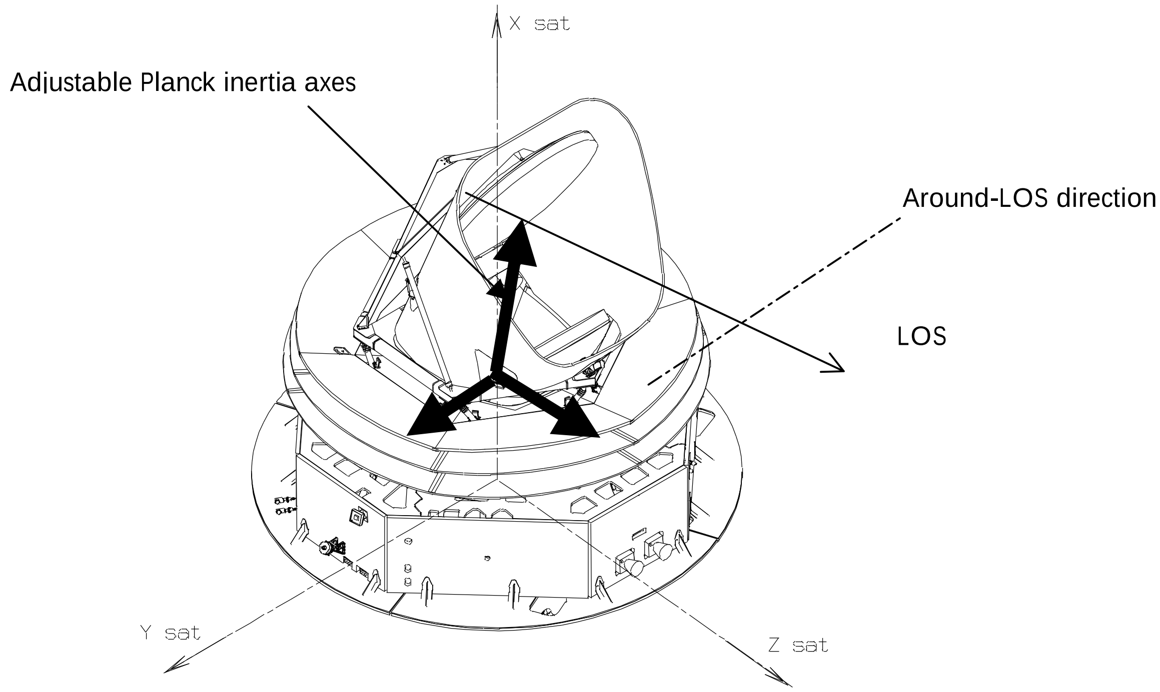
5.4.4 Requirements summary

The requirement tree is the following:



5.5 Wobble angle adjustment accuracy

Once the in-orbit around-LOS axis is predicted (the launcher/I/F axes being the reference), the inertia axes are measured, and realigned, by mass addition, with regards to the known LOS and around LOS orientations.



The measurement accuracy shall be better than 2 arcmin at 68%confience level, the reference being the launcher interfaces. This shall be specified in a TRS.

5.6 Thruster alignment

5.6.1 thruster alignment accuracy allocations

Due to the alignment of the thruster with regards to the measured CoG, the contributor's list is the following:

-alignment in-orbit long term between the thrusters and the CoG(this shall not take into account the in-orbit CoG displacement, which is a part of an upper level ACMS budget (cf. "Herschel and Planck Pointing budget Module allocation" [RD4]).)
-on-ground alignment bias, including:
- -spacecraft CoG knowledge
- -thruster-plume push direction knowledge
- -thruster-plume alignment accuracy

5.6.1.1 Thruster stability and knowledge

The in-orbit alignment stability of the thruster together with it's on-ground "push direction" knowledge wrt SVM I/F reference frame shall be less than +/-0.25°. This is well in line with the stability which is specified by Alenia (SVM responsible) in the SVM structure specification

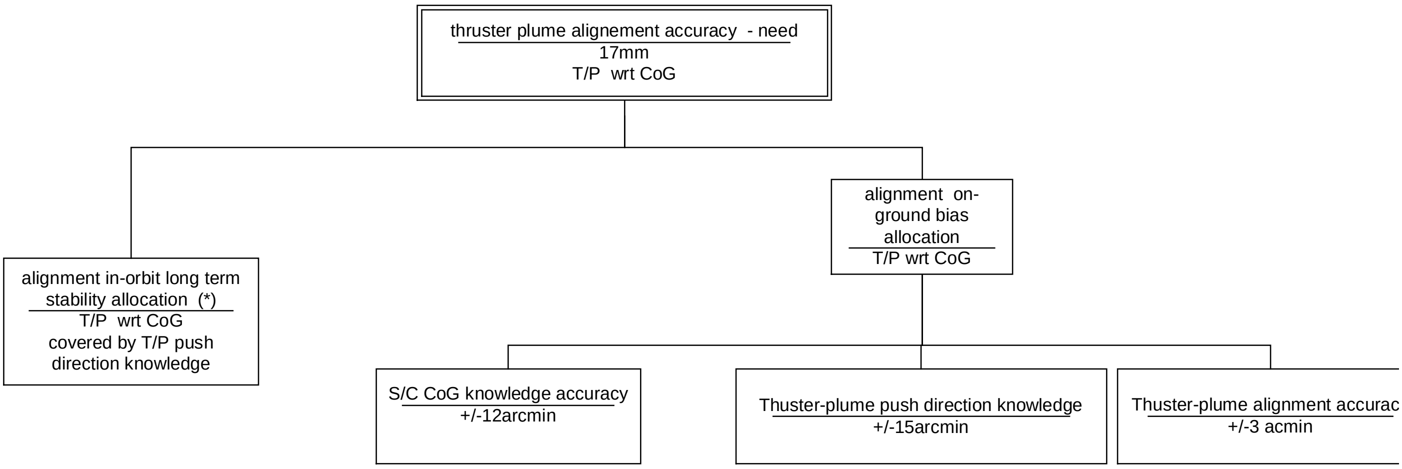
5.6.1.2 Thruster plume alignment accuracy

The alignment accuracy of the thruster plume with regards to the Spacecraft Coordinate System - at system level-shall be better than 3 arcmin

5.6.1.3 Spacecraft CoG measurement accuracy

The Spacecraft CoG location on-ground knowledge accuracy shall be better than [+/-7;+/-0.5;+/-0.5]mm (fulfilled with margins by [RD14]) in Spacecraft Coordinate system. This corresponds to 12 arcmin.

5.6.1.4 thruster-plume alignment accuracy – requirements synthesis



5.6.2 thruster plume adjustment range needed for spacecraft activities

this section presents the budget of the angular adjustment ranges for all thrusters, needed at satellite level to align them with the spacecraft CoG
By summing the probabale excursions at system level, the needed adjustment range at thruster level is assessed. This is a bottom up budget.

The contributors lists is the following:

-Spacecraft CoG worst case location with regards to the theoretical location
-thruster-plume push direction knowledge
-thruster-plume alignment accuracy

5.6.2.1 Spacecraft CoG bias

The distance between the actual on-ground location of S/C CoG and its theoretical position shall be less than +/-30mm. This corresponds to a +/-0.86° angular adjustment range.

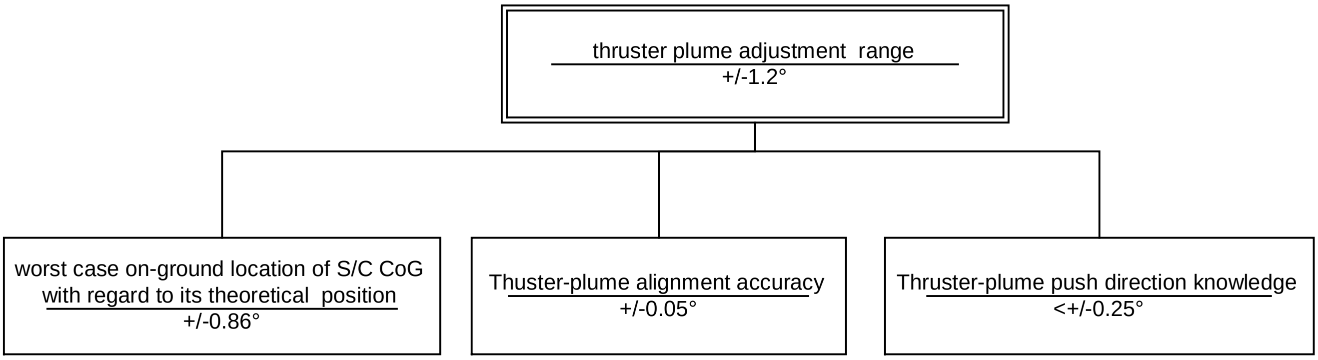
5.6.2.2 Thruster-plume push direction knowledge

the on-ground push direction knowledge shall be less than +/-0.25°. This corresponds to +/-8.5mm distance between thruster-plume push direction and CoG. This is covered by the alignment accuracy allocation.

5.6.2.3 Thruster-plume alignment accuracy at satellite level

The alignment accuracy of the thruster plume with regards to the S/C-CS - at system level-shall be better than 3 arcmin. This corresponds to 1.7mm distance between thruster-plume push direction and CoG. This is covered by the alignment accuracy allocation.

5.6.2.4 thruster plume adjustment range- requirements summary



to coever the system level misalignments, an adjustment ampltude of at least 1.2dg is neededd. The SVM will be required to provide 2°.

6. ALIGNMENT REQUIREMENTS SYNTHESIS

This section describes, for each level, the alignment specification to be considered.

6.1 At spacecraft level

#

The mating of the P-PLM on the SVM shall not induce a rotation around Ysat of more than 5 arcmin.

#

#

The spacecraft inertia axes measurement accuracy shall be better than 2 arcmin at 68%confience level, the reference being the launcher interfaces.

#

#

The alignment accuracy of the thruster plume with regards to the Spacecraft Coordinate System - at system level-shall be better than 3 arcmin.

#

#

The S/C CoG on-ground knowledge accuracy shall be better than [+/-7;+/-2;+/-2]mm (TBC) (in satellite coordinate system)

#

#

The distance between the actual on-ground location of S/C CoG and its theoretical position shall be less than +/-30mm. This corresponds to a +/-0.86° angular adjustment range.

#

#

The spacecraft shall be equipped with two balls and two cubes.

#

A possible implementation is presented in section 4.3

6.2 At SVM level

#

The in-orbit ACMS Line of sight shall remain in its theoretical position +/-30arcmin with regards to the PPLM/SVM interface frame. This includes on-ground bias and in-orbit variations.

#

#

The knowledge of the P-PLM/SVM interface Y axis direction with regards to the launcher I/F frame shall be better than +/-1 arcmin at 68% confidence level.

#

#

The in-orbit and launch alignment stability of the thruster together with it's on-ground "push direction" knowledge with regards to SVM I/F reference frame shall be less than +/-0.25° half cone.

#

#

- SVM reference frame shall be equipped with 2 cubes and 4 optical balls.

#

6.3 At P-PLM level

6.3.1 At reflectors level

#

Each reflector shall be equipped with 3 optical balls minimum and 1 corner cube. On each reflector, 1 ball and the cube will have to be visible at satellite stage (with baffle), this might be done by removable mount, which would be taken off before launch in order to save space under cover.

#

#

Each reflector will be equipped with 3 optical balls minimum and 1 corner cube. On each reflector, 1 ball and the cube will have to be visible at satellite stage(with baffle).

#

#

The optical surface of the reflectors (Best Fit Ellipsoid) must be measured with respect to these optical references.

#

#

Misalignment(including knowledge) of best fit ellipsoid (BFE) w.r.t. to the reflector mechanical interface must be lower than:

PR: +/-0.1mm translation along each axis, and +/-0.1mrad rotation around each axis

SR: +/-0.1mm along each axis, and +/-0.1mrad around each axis

#

6.3.2 At cryo-structure+Telescope level

#

The in-orbit cryo-structure+telescope Line of sight shall remain in its theoretical position +/-50 arcmin with regards to the P-PLM/SVM interface frame. This includes on-ground bias and in-orbit variations.

#

#

The stability of the orientation of around LOS stability of the telescope+cryostructure (including cryostructure, telescope stability, and Telescope-FPU i/F stability's) shall be less than 3.4 arcmin at 68% confidence level.

#

#

The in-orbit telescope around LOS knowledge with regards to Planck Telescope frame shall be better than 1 arcmin at 68% confidence level.

#

The following is required to the P-PLM, (directly at Planck Telescope manufacturer level:

#

P-TEL-PHY-045 The best focus of the telescope shall be within a cylinder of diameter of 1 mm and length of 5 mm around the nominal focus position, with the cylinder axis in the Z_{FPU} direction of the FPU co-ordinate system.

#

#

P-TEL-PHY-050 The best focus of the telescope shall be known to be within a cylinder of diameter of 0.5 mm and length of 0.5 mm, with the cylinder axis in the Z_{FPU} direction of the FPU co-ordinate system.

Note : the best focus of the telescope is the point along the telescope axis at which the WFE at operational condition is minimum.

#

#

The stability of the telescope/FPU interface in each axis (Xrdp, Yrdp, Zrdp) shall be better than +/-0.1mm

#

#

Telescope reference frame shall be equipped with 2 cubes and 4 optical balls.

#

6.3.3 At FPU level

The horns must be located (in-orbit) with the following accuracy w.r.t the mounting interface to the telescope FPU:

#

+/-0.4mm translation (position and stability) along each X and Y axis, and +/-0.5mrad rotation around each X Y axis

#

#

+/-0.5mm translation (manufacturing + cool-down)along Z axis of the actual average focal plane surface wrt its theoretical Z position (manufacturing + cool-down)

#

#

+/-0.1mm maximum deviation (position and stability) along Z axis wrt to actual average focal plane surface

#

#

+/-0.1mm knowledge accuracy of the actual average focal plane surface Z axis position wrt its theoretical Z position.

#

#

Each horn position (X and Y) will have to be known wrt telescope/FPU mechanical interface with a accuracy better than +/-0.1mm

#

#

Each detector line will have to be known to be aligned parallel to Y axis wrt to telescope/FPU mechanical interface with a 0.1 arcmin accuracy – this has a direct impact on around LOS knowledge.

#

#

The instruments (HFI inside LFI) FPU must be delivered with an alignment cube and optical ball mounted at the rear side.
The location of this optical reference w.r.t the mechanical interface must be known with the following accuracy:

Lateral	0.05mm
Longitudinal	0.05mm
Tilt	20arcsec

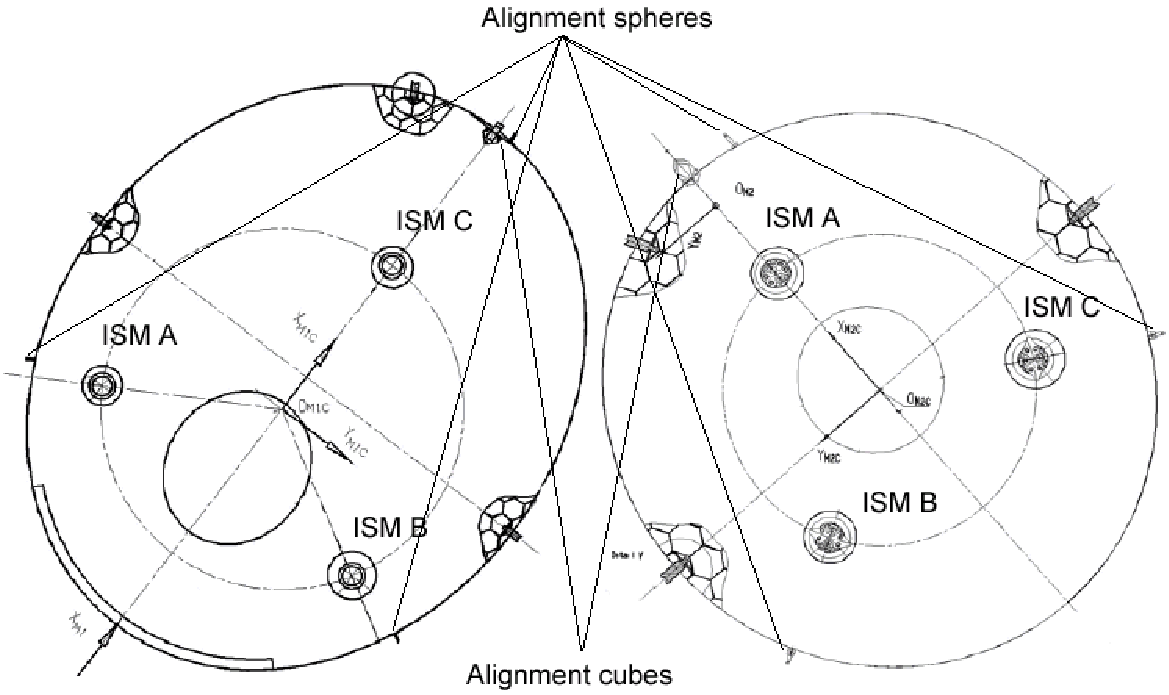
This alignment tolls shall be visible at satellite level (with the baffle), as defined in the ID-320 plan.

#

APPENDICES : alignment cubes access

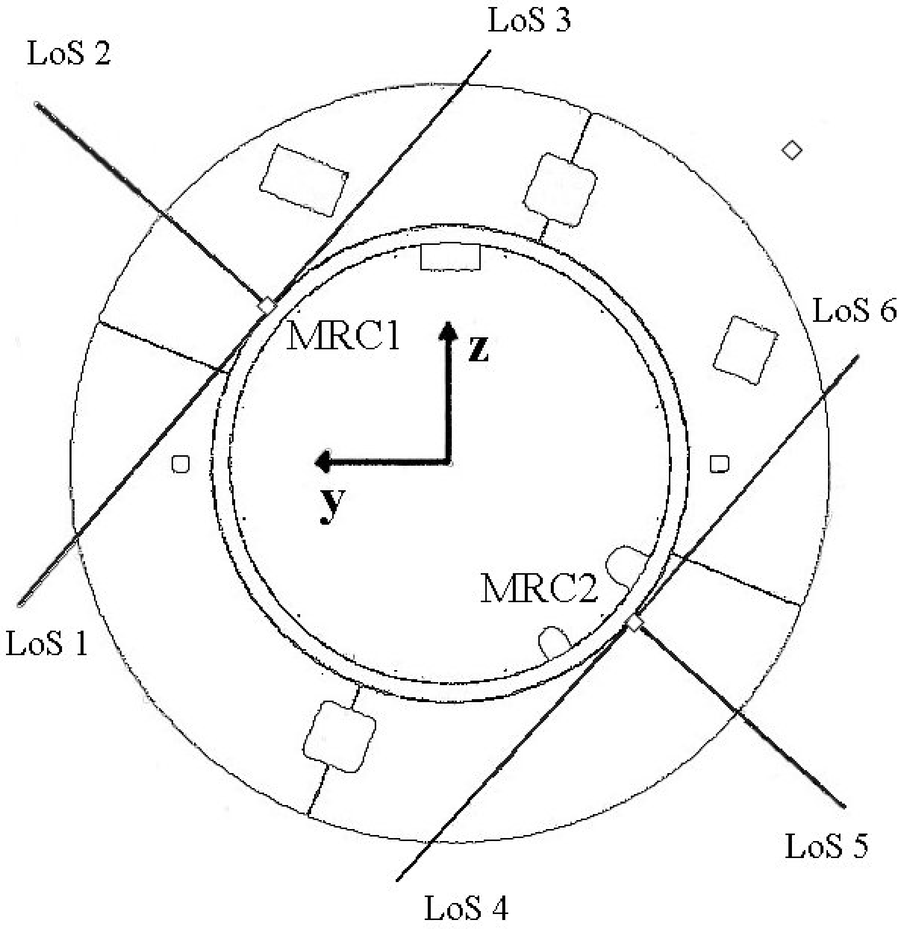
This annex shows, for information, the current knowledge of alignment cubes accessibility at satellite AIT level

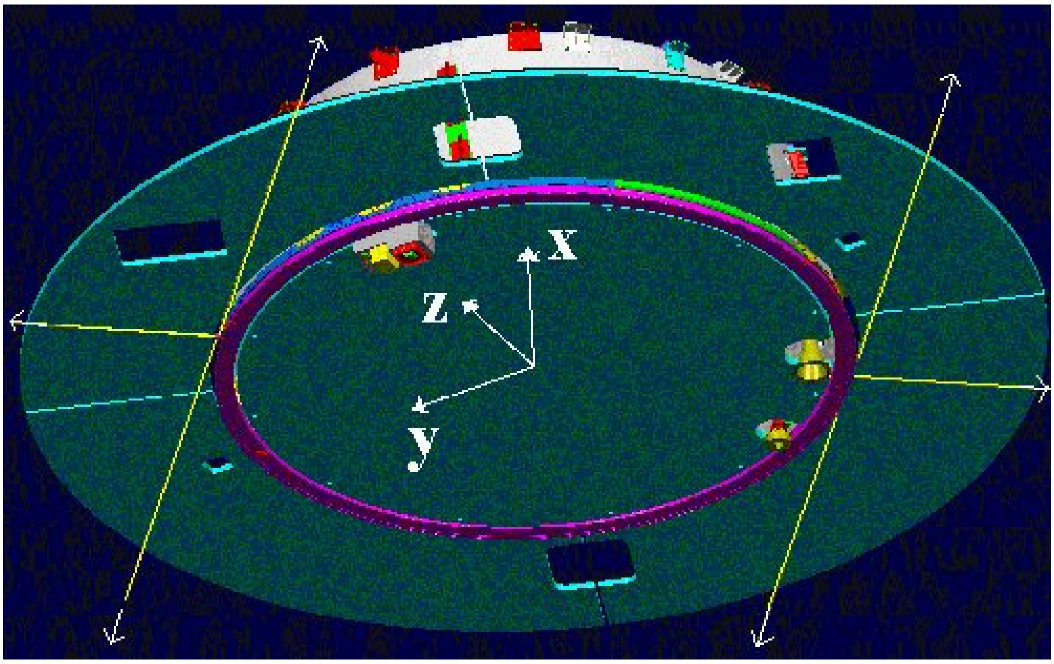
Reflectors optical references



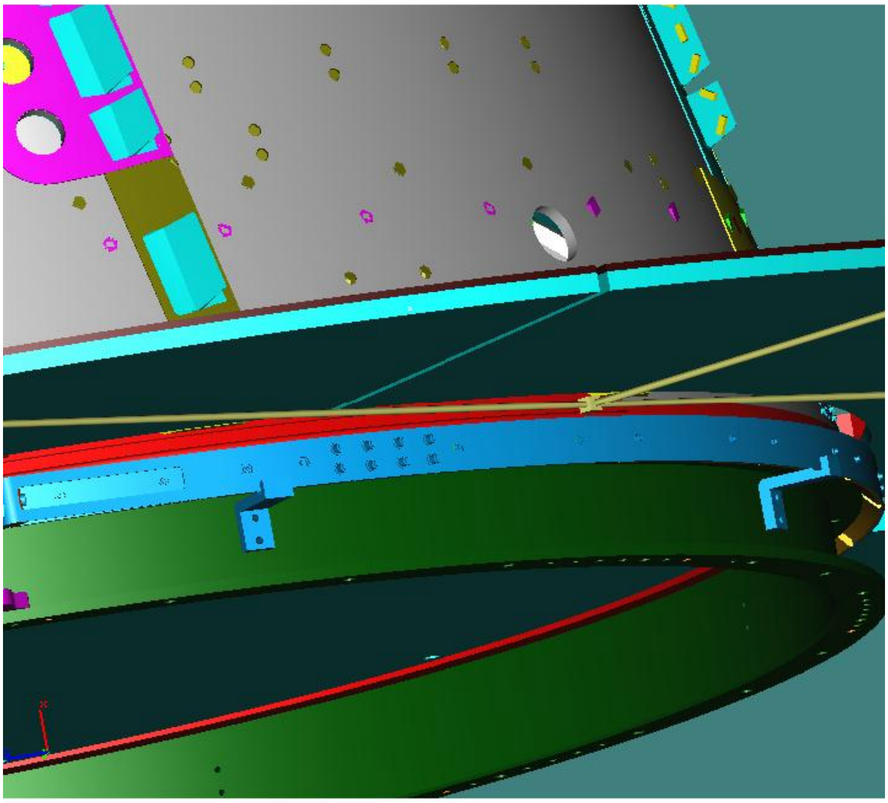
Only the cubes and balls in +X position will be used at PPLM and satellite level

SVM cube access (see [RD12])



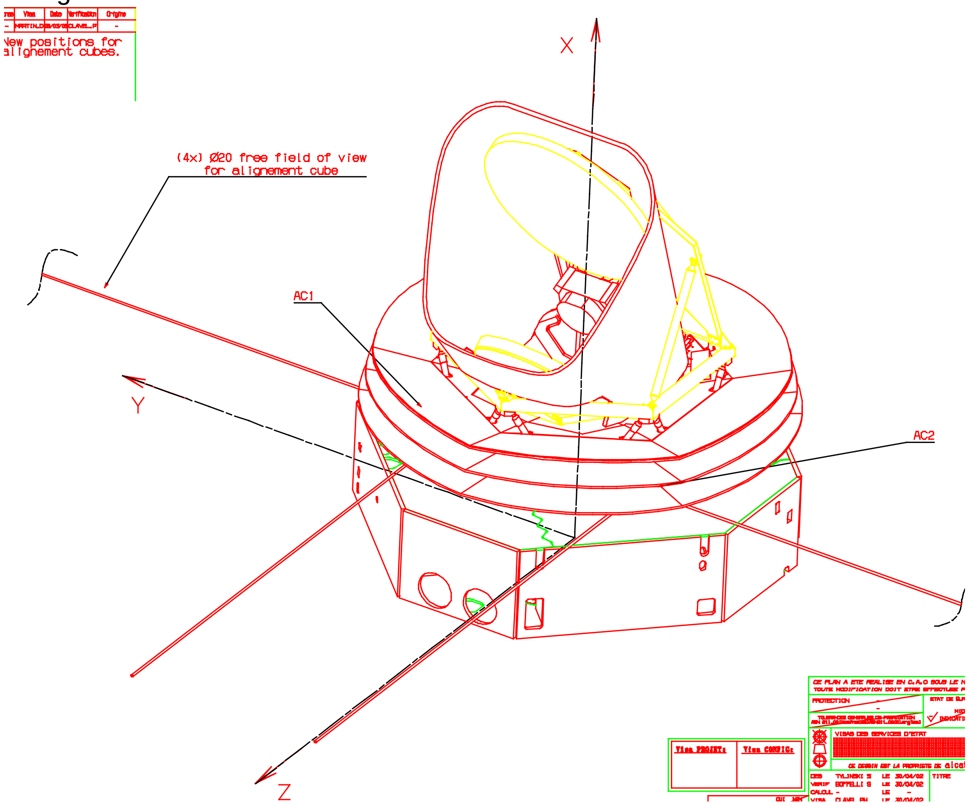


Planck SVM LOS



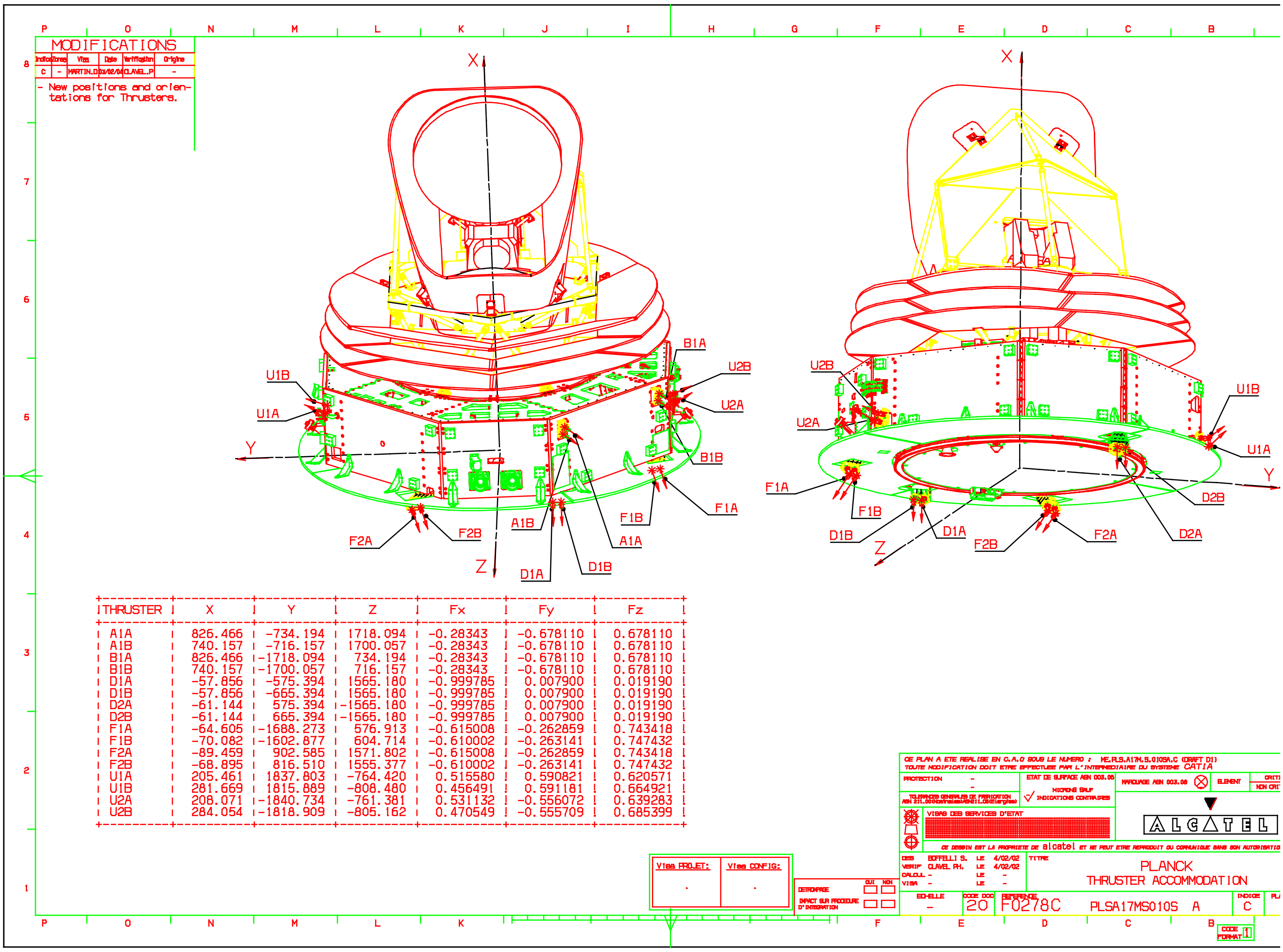
Planck SVM MRC location (TBC)

Planck Satellite alignment cube access



SVM equipment (see [RD12])

thrusters

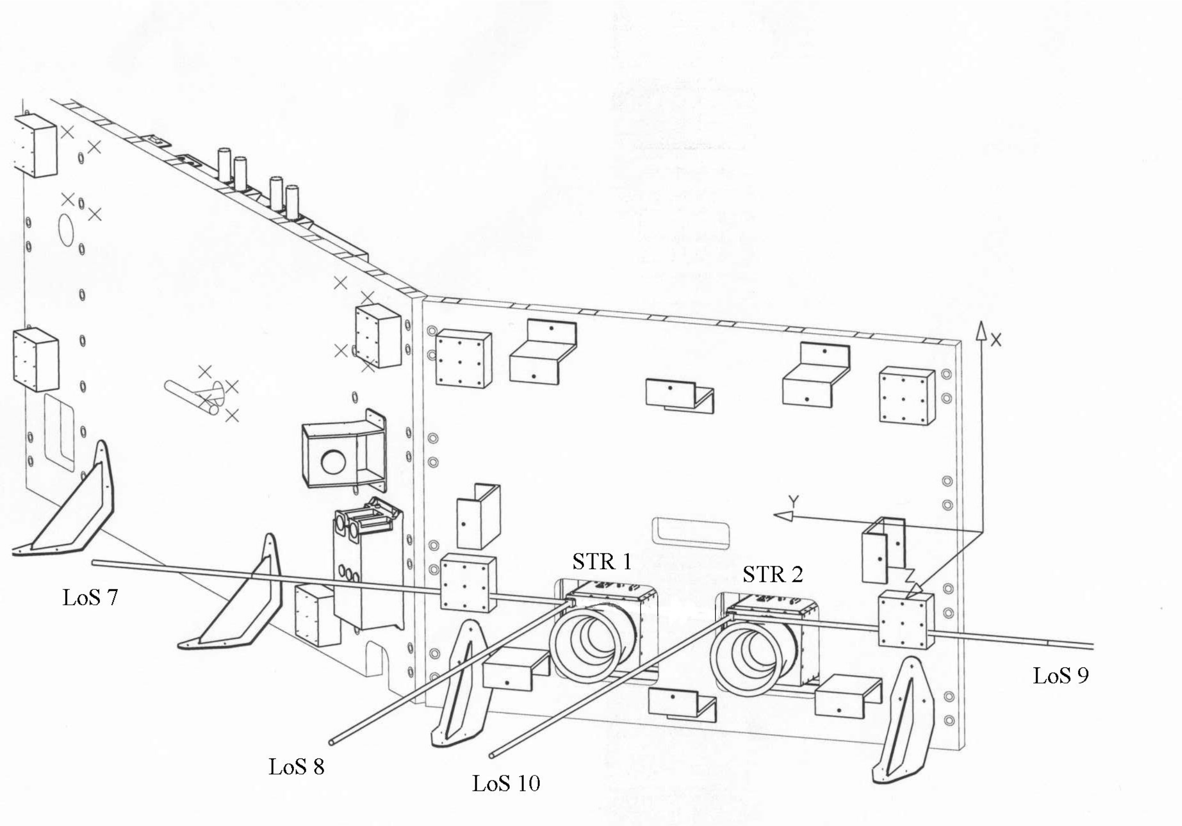


THRUSTER	X	Y	Z	Fx	Fy	Fz
A1A	826.466	-734.194	1718.094	-0.28343	-0.678110	0.678110
A1B	740.157	-716.157	1700.057	-0.28343	-0.678110	0.678110
B1A	826.466	-1718.094	734.194	-0.28343	-0.678110	0.678110
B1B	740.157	-1700.057	716.157	-0.28343	-0.678110	0.678110
D1A	-57.856	-575.394	1565.180	-0.999785	0.007900	0.019190
D1B	-57.856	-665.394	1565.180	-0.999785	0.007900	0.019190
D2A	-61.144	575.394	-1565.180	-0.999785	0.007900	0.019190
D2B	-61.144	665.394	-1565.180	-0.999785	0.007900	0.019190
F1A	-64.605	-1688.273	576.913	-0.615008	-0.262859	0.743418
F1B	-70.082	-1602.877	604.714	-0.610002	-0.263141	0.747432
F2A	-89.459	902.585	1571.802	-0.615008	-0.262859	0.743418
F2B	-68.895	816.510	1555.377	-0.610002	-0.263141	0.747432
U1A	205.461	1837.803	-764.420	0.515580	0.590821	0.620571
U1B	281.669	1815.889	-808.480	0.456491	0.591181	0.664921
U2A	208.071	-1840.734	-761.381	0.531132	-0.556072	0.639283
U2B	284.054	-1818.909	-805.162	0.470549	-0.555709	0.685399

o111290 FRAME 1 FEBRUARY 4, 2004 12.55.24

star-trackers

STR's LoS measurement will be performed directly using the SVM MRC as reference.
In order to have LoS 7 & 9 visible, balancing masses on panel +z will be removed.



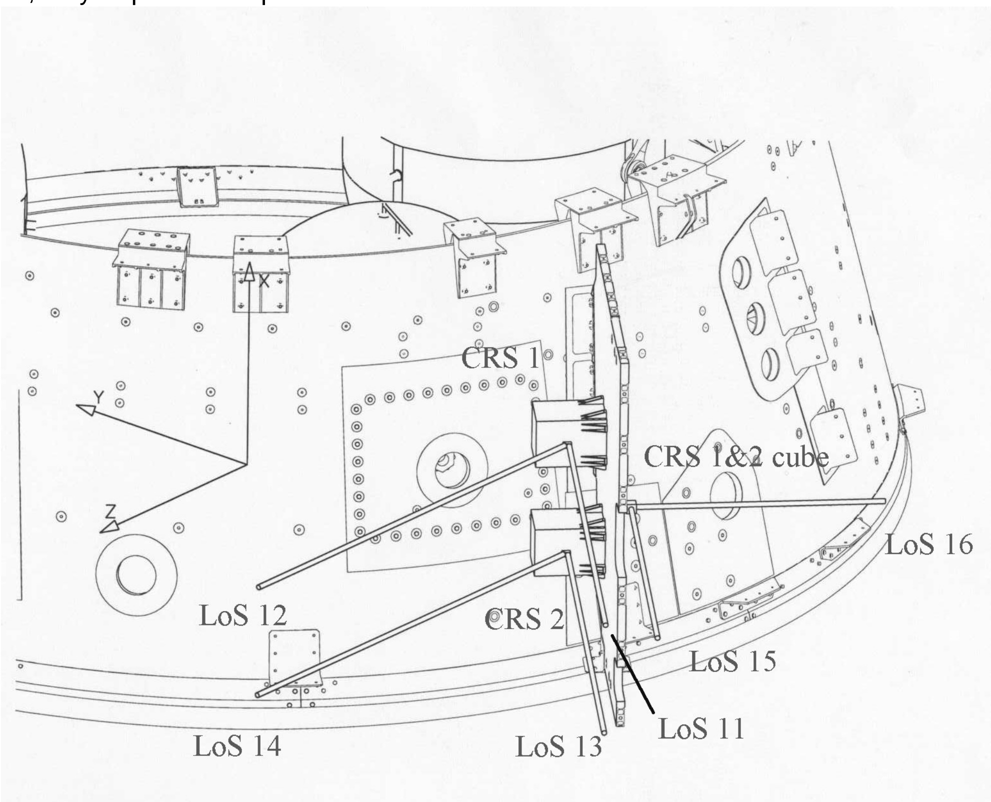
CRS

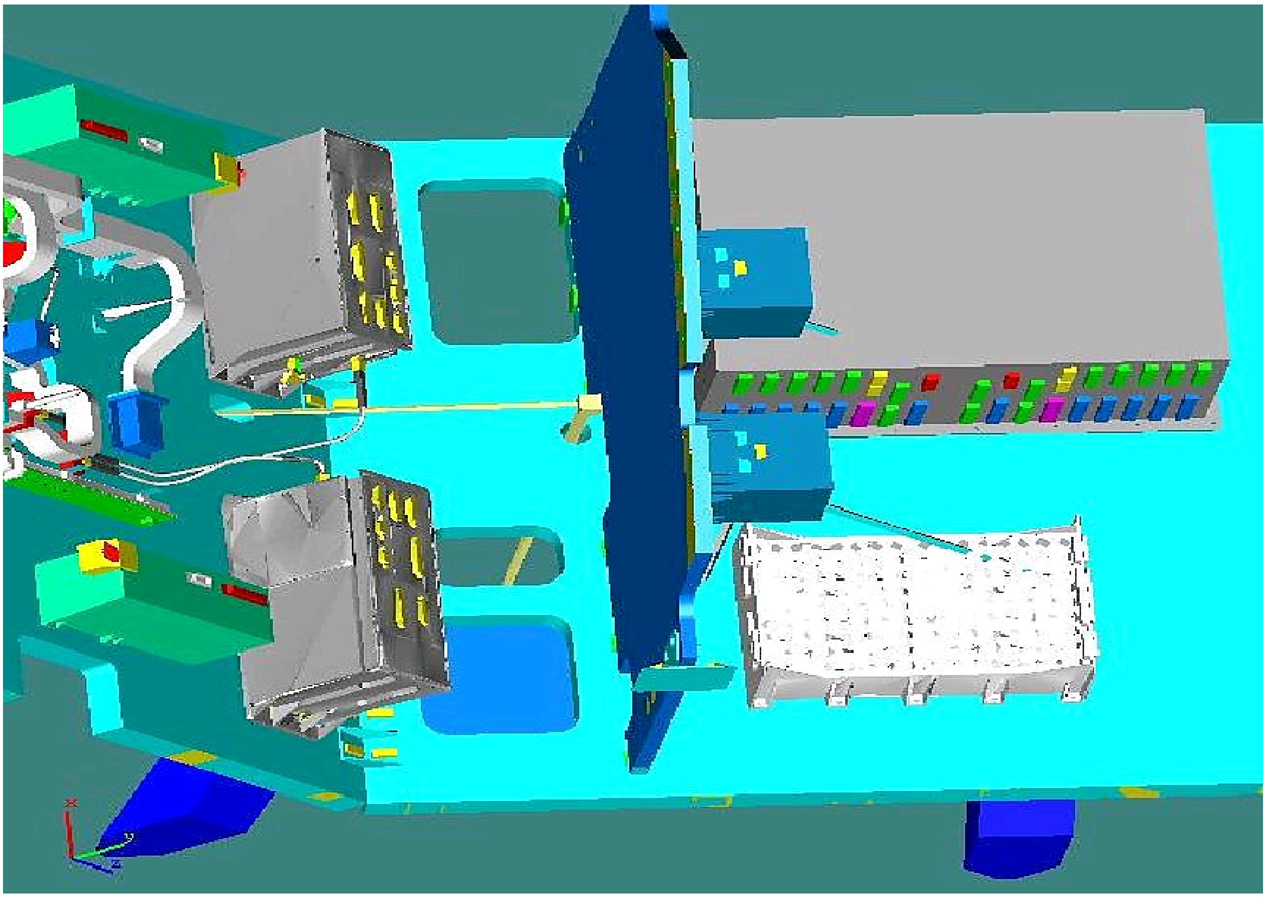
CRS 1 & 2 are installed on -Y+Z shear panel; as no possibility of aiming directly to their LoS is available (possible cut out position are not compatible with PWR panel and units) the alignment measurement will be performed in two steps at SVM level.

1. Measurement of CRS 1&2 reference cube (LoS 15 & 16) using MRC as reference.
   This measurement will be performed with all panels closed; LoS 15 & 16 will be visible through dedicated cut outs on PWR (+z-y) panel and TT&C (-y) panel.

2. Measurement of CRS 1 (LoS 11 & 12) and CRS 2 (LoS 13 & 14) using CRS 1&2 reference cube as reference.
   This measurement will be performed after PWR (+z-y) panel opening.

At spacecraft level, only step 1 will be performed



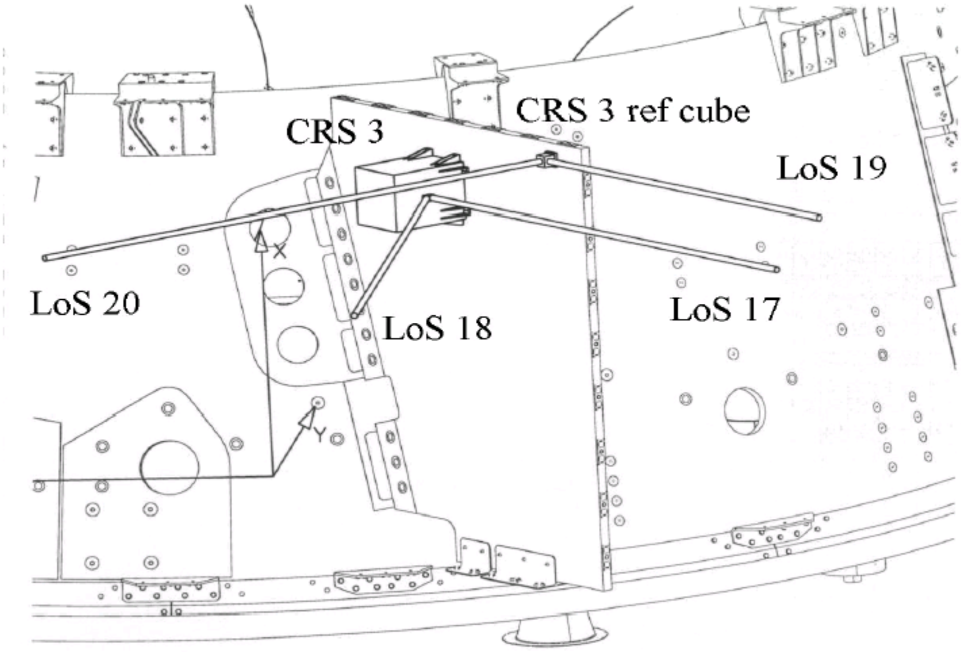


CRS 3 is installed on –Y-Z shear panel (TBC); as no possibility of aiming directly to their LoS is available the alignment measurement will be performed in two steps at SVM level.

1. Measurement of CRS 3 reference cube (LoS 19 & 20) using MRC as reference.
   This measurement will be performed with all panels closed; LoS 19 & 20 will be visible through dedicated cut outs the panels.

2. Measurement of CRS 3 (LoS 18 & 17) using CRS 3 reference cube as reference.
   This measurement will be performed after panel opening.

At spacecraft level, only step 1 will be performed



AAD, FOG and SAS
LOS are TBD by ALS

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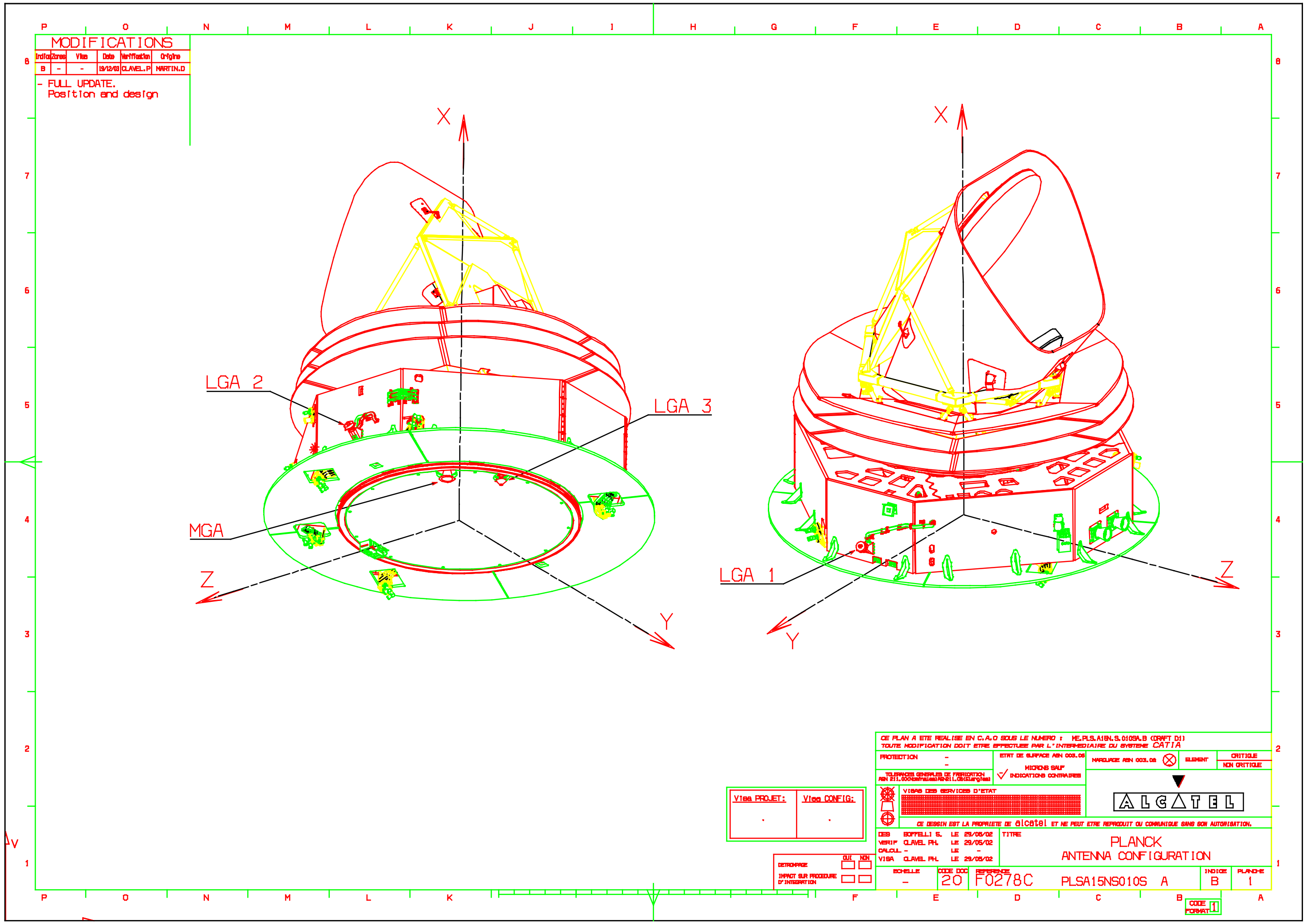

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