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THE FACULTY OF POWER AND AERONAUTICAL ENGINEERING

WARSAW UNIVERSITY OF TECHNOLOGY





CRITICAL DESIGN REVIEW

Configuration Overview

November 2016

Issue no. 1

	PW-Sat2	Critical Design Review	
	2016-11-30	Configuration Overview	
	Phase C		

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Abbreviated terms

ADCS	Attitude Determination and Control System
AP	Argument of Perigee
AR	Acceptance Review
COMM	Communication subsystem
CONF	Configuration
DT	Deployment Team
EM	Engineering Model
EPS	Electrical Power System
ESA	European Space Agency
FM	Flight Model
FRR	Flight Readiness Review
GS	Ground Station
IADC	Inter-agency space debris coordination committee
LEO	Low Earth Orbit
MA	Mission Analysis
MDR	Mission Definition Review
PDR	Preliminary Design Review
SC	Spacecraft
SKA	Studenckie Koło Astronautyczne (Students' Space Association)
SW	Software
TBC	To Be Continued
TBD	To Be Defined
TCS	Thermal Control System
WUT	Warsaw University of Technology

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1 INTRODUCTION

1.1 PURPOSE AND SCOPE

This document should present a final PW-Sat2's configuration project as well as its structure design. Additionally, CONF team has been responsible for preparing integration plans for whole satellite and each subsystem. Design of the satellite's structure was one of the main tasks of the CONF team so it is fully summarized in this document. Closer description of other mechanical components can be found in [PW-Sat2-C-05.00-DT-CDR].

1.2 DOCUMENT STRUCTURE

Chapter 1 introduces the document, its structure, reference formal and project documents

Chapter 2 contains project's requirements and general description of PW-Sat2's configuration and its variants

Chapter 3 presents general description of PW-Sat2's configuration and its variants

Chapter 4 summarizes process behind structure's final design and configuration of every satellite's subsystem

Chapter 5 contains integration plans of every subsystem

Chapter 6 briefly describes mass budget, fulfilment of project's requirements and CONF team's future actions

1.3 PROJECT DOCUMENTATION STRUCTURE



See section 1.3 in [PW-Sat2-C-00.00-Overview-CDR].

1.4 REFERENCE DOCUMENTS

- [1] The CubeSat Program, Cal Poly SLO, "CubeSat Design Specification rev. 13," 2016.
- [2] Pumpkin Incorporated, "CubeSat Kit PCB Specification," Pumpkin Incorporated, 2009.
- [3] Inter-Agency Space Debris Coordination Committee, "IADC Space Debris Mitigation Guidelines," 2007.

1.5 APPLICABLE PROJECT DOCUMENTS



- [PW-Sat2-C-00.00-Overview-CDR] - overview of the PW-Sat2 project
- [PW-Sat2-C-05.00-DT-CDR] – overview of deployable structures on-board PW-Sat2 (Sail, SARM, SADS)
- [PW-Sat2-C-05.01-DT-Structure-Analyses]

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- [PW-Sat2-C-05.02-DT-Analytical-Calculations-and-Dynamic-Models]
- [PW-Sat2-C-10.01-CONF-MICD] – Mechanical Interface Control Document of PW-Sat2 satellite
- [PW-Sat2-C-10.02-CONF-Bill-of-Materials] – Bill of Materials (spreadsheet)
- [PW-Sat2-C-06.00-SunS] – overview of SunS experiment
- [PW-Sat2-C-09.00-TCS] – summary of analyses performed by Thermal Control System team
- [PW-Sat2-SATELLITE-Assembly-Plan]
- [PW-Sat2-SAIL-Production-and-Folding-Plan]
- [PW-Sat2-SARM-Assembly-Plan]
- [PW-Sat2-SS-Assembly-Plan]
- [PW-Sat2-SADS-Assembly-Plan]
- [PW-Sat2-SAIL-Assembly-Plan]

1.6 DOCUMENT CONTRIBUTORS

This document and any results described were prepared solely by PW-Sat2 project team members. CONF team members responsible for the final design: Paweł Brunne, Katarzyna Ciechowska, Kamil Gajc.

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2 PROJECT REQUIREMENTS

2.1 CUBESAT DESIGN SPECIFICATION REQUIREMENTS

In this section, all the requirements restricting typical CubeSat satellite are presented. They should serve as a baseline in every satellite's design process. CubeSat Design Standard and PCB Specification are the most important ones for PW-Sat2 mission and their subsections are compared to the final results of a configuration project at the end of this document.

Requirements presented in this section are all directly extracted from CubeSat Standard. All quotes relevant to PW-Sat2 mission (from configuration point of view) are divided between several groups: general, mechanical and electrical. Fulfilment of each of the subsection is usually necessary to gain permission from launch provider to put a CubeSat satellite on board of their rocket. To the very last moments of the PW-Sat2 project the launch provider remained unknown so the whole project is strictly based on CubeSat Design Standard requirements.



2.1.1 GENERAL

All (1) – (22) quotes are included in CubeSat Design Specification [1]. Bolded sentences are comments to

- “All parts shall remain attached to the CubeSat during launch, ejection and operation. No additional space debris will be created.” – **covered by PW-Sat2 mission's main goal**
- “No pyrotechnics shall be permitted.”
- “CubeSat materials shall satisfy the following low out-gassing criterion to prevent contamination of other spacecraft during integration, testing and launch.” – **crucial for any deployable and moving elements (mostly in DT document)**
- “CubeSats materials shall have a Total Mass Loss (TML) ≤ 1.0 %.” – **TML should be presented with the mass budget**
- “CubeSat materials shall have Collected Volatile Condensable Material (CVCN) ≤ 0.1 %.” – **presented in bill of materials**

2.1.2 MECHANICAL

- “The CubeSat coordinate system will match the P-POD coordinate system while integrated into P-POD. The origin of the CubeSat coordinate system is located at the geometric center of the CubeSat.” – **presented in 3.2 section of this document**
- “The –Z face of the CubeSat will be inserted first into the P-POD.”
- “No components on the green and yellow shaded sides shall exceed 6.5 mm normal to the surface.” – **crucial to CONF team's work and final satellite's design**
- “Deployable shall be constrained by the CubeSat, not the P-POD.” – **all deployable mechanisms are contained inside the satellite**

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- “*Rails shall have a minimum width of 8.5 mm.*” – points (10) – (13) covered in 6.3 section of this document
- “*Rails will have a surface roughness less than 1.6 μm .*”
- “*The edges of the rails will be rounded to a radius of at least 1 mm.*”
- “*The ends of the rails on the +/-Z face shall have a minimum surface area of 6.5 mm x 6.5 contact area for neighboring CubeSat rails.*”
- “*At least 75 % of the rail will be in contact with the P-POD rails.*”
- “*The maximum mass of a 2U CubeSat shall be 2.66 kg.*” – **points (15), (16) presented in mass budget section**
- “*The 2U CubeSat center of gravity shall be located within 2 cm from its geometric center in the X and Y direction and 7 cm in the Z direction.*”
- “*Aluminum 7075, 6061, 5005 and/or 5052 will be used for both the main CubeSat structure and the rails.*” – **Aluminum 7075 is used in PW-Sat2 mission**
- “*The CubeSat rails and standoff, which contact the P-POD rails and adjacent CubeSat standoffs, shall be hard anodized aluminum to prevent any cold welding within the P-POD.*” – **all aluminum elements are hard anodized**
- “*The 2U CubeSats shall use separation springs to ensure adequate separation. Spring will be centered on the end of the standoff on the CubeSat’s -Z face.*”

2.1.3 ELECTRICAL

- “*The CubeSat power system shall be at a power off state to prevent CubeSat from activating any powered functions while integrated in the P-POD from the time of delivery to the LV through on-orbit deployment.*”
- “*The CubeSat shall have, at a minimum, one deployment switch on a rail standoff.*” – **points (21), (22) covered in 4.1.1.3 section of this document**
- “*The Remove Before Flight (RBF) pin and all CubeSat umbilical connectors shall be within designated Access Port locations (green shaded areas shown in the Figure 2-2).*”



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Figure 2-1 Deployment switches and separation springs placement.

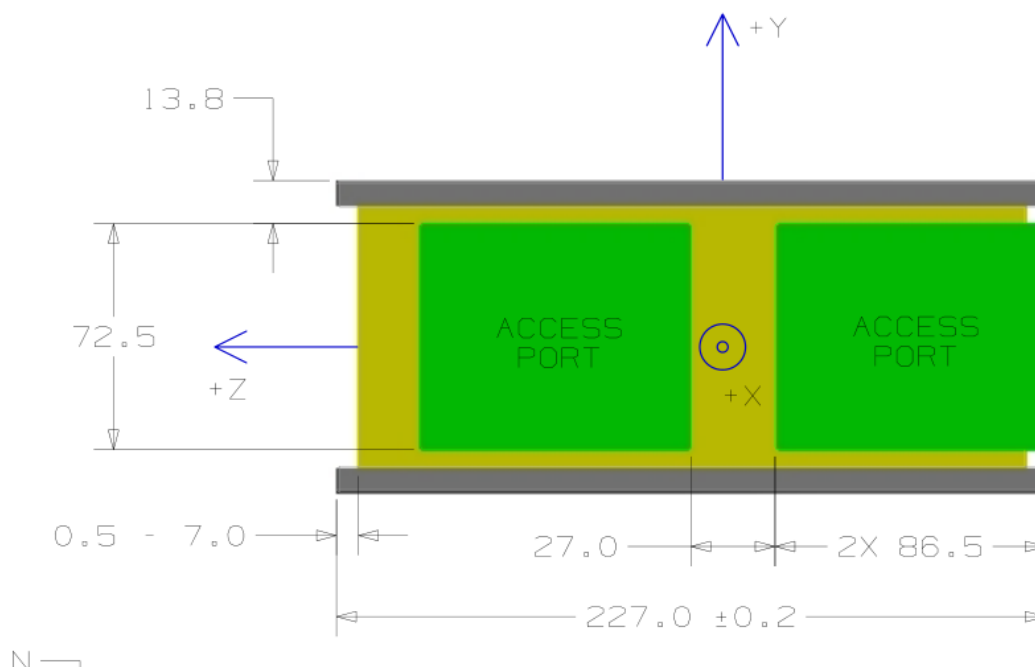




Figure 2-2 CubeSat's axes definition and access port placement

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2.2 PCB SPECIFICATION REQUIREMENTS

From configuration point of view PCB Specification covers holes spacing for PCB Stack mounting, thickness of the boards and distance between them. All of those requirements are crucial to the 4.3 section of this document.

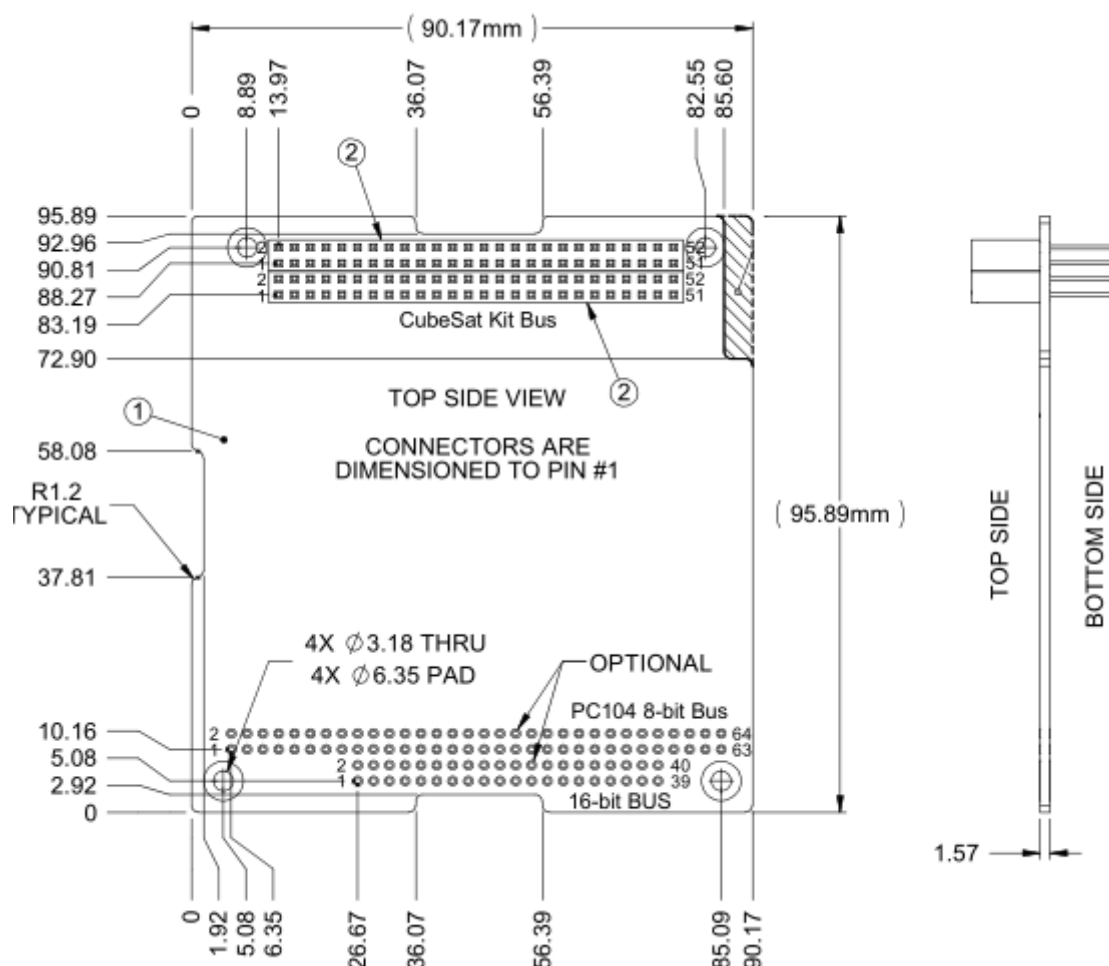




Figure 2-3 PCB board specification. Board's thickness and holes spacing are crucial to satellite's configuration.

2.3 LAUNCH PROVIDER REQUIREMENTS

According to the CubeSat Design Specification, PW-Sat2 structure has to fulfil many requirements, described in 2.1.2 section of document, namely: satellite and rails dimensions, radius and roughness of rails, materials and others.

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As PW-Sat2 is launched on Falcon 9 rocket, it has to withstand loads occurring during ascent and separation events. SpaceX, producer of the rocket, provides loads only on the main interface, where the primary payload is attached. CubeSats are deposited in so called QuadPack (CDS names it P-POD), which position in payload's assembly is not precisely defined. Because of that launch provider, ISIS, recalculated this loads and provided them as a loads defined on the QuadPack's rails. These values are presented in current chapter.

2.3.1 QUASI-STATIC

Structure and whole satellite have to withstand 18,75 g acceleration in every axis. Table 2-1 shows load during particular tests. Structure will be designed to hold out this acceleration occurring in all three axes at the same time, but test will be performed on one axis at a time.

Table 2-1 Quasi-static loads during tests

Characteristic		Qualification	Acceptance	Proto-flight
Test		Required	Not required	Required
Directions	{BRF}	X, Y, Z		X, Y, Z
Acceleration	{LRF}	+ 18.75 [g]		+ 18.75 [g]
Duration	Centrifuge	60 [sec]		30 [sec]
	Sine burst	≥ 5 [cycles @ full level]		≥ 5 [cycles @ full level]

2.3.2 NATURAL FREQUENCIES

According to the launch provider, fundamental frequency has to be higher than 90 Hz. Resonance survey test will be performed with sinus amplitude 0,4 g. Detailed specification of test is shown on Table 2-2.

Table 2-2 Resonance survey test specification

Characteristic		Qualification	Acceptance	Proto-flight
Test		Required	Required	Required
Directions	{BRF}	X, Y, Z	X, Y, Z	X, Y, Z
Type		Harmonic	Harmonic	Harmonic
Amplitude	See Notes, 2	0.4 [g]	0.4 [g]	0.4 [g]
Frequency range		5 – 2000 [Hz]	5 – 2000 [Hz]	5 – 2000 [Hz]
Sweep Rate		2 [oct/min]	2 [oct/min]	2 [oct/min]

2.3.3 RANDOM VIBRATIONS

Structure has to withstand random vibration levels described on Table 2-3 and Figure 2-4. All levels are assumed for each axis are the same. Structure is designed to survive most severe loads, namely qualification levels. Total RMS in random vibrations is 14,1 g.



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Table 2-3 Random vibrations test specification

Characteristic		Qualification	Acceptance	Proto-flight
Test		Required	Required	Required
Directions	{BRF}	X, Y, Z	X, Y, Z	X, Y, Z
Profile	Frequency range [Hz]	Amplitude [g^2/Hz]	Amplitude [g^2/Hz]	Amplitude [g^2/Hz]
	20	0.026	0.013	0.026
	50	0.16	0.08	0.16
	800	0.16	0.08	0.16
	2000	0.026	0.013	0.026
RMS acceleration		14.1 [g]	10.0 [g]	14.1 [g]
Duration		180 [sec/axis]	60 [sec/axis]	60 [sec/axis]

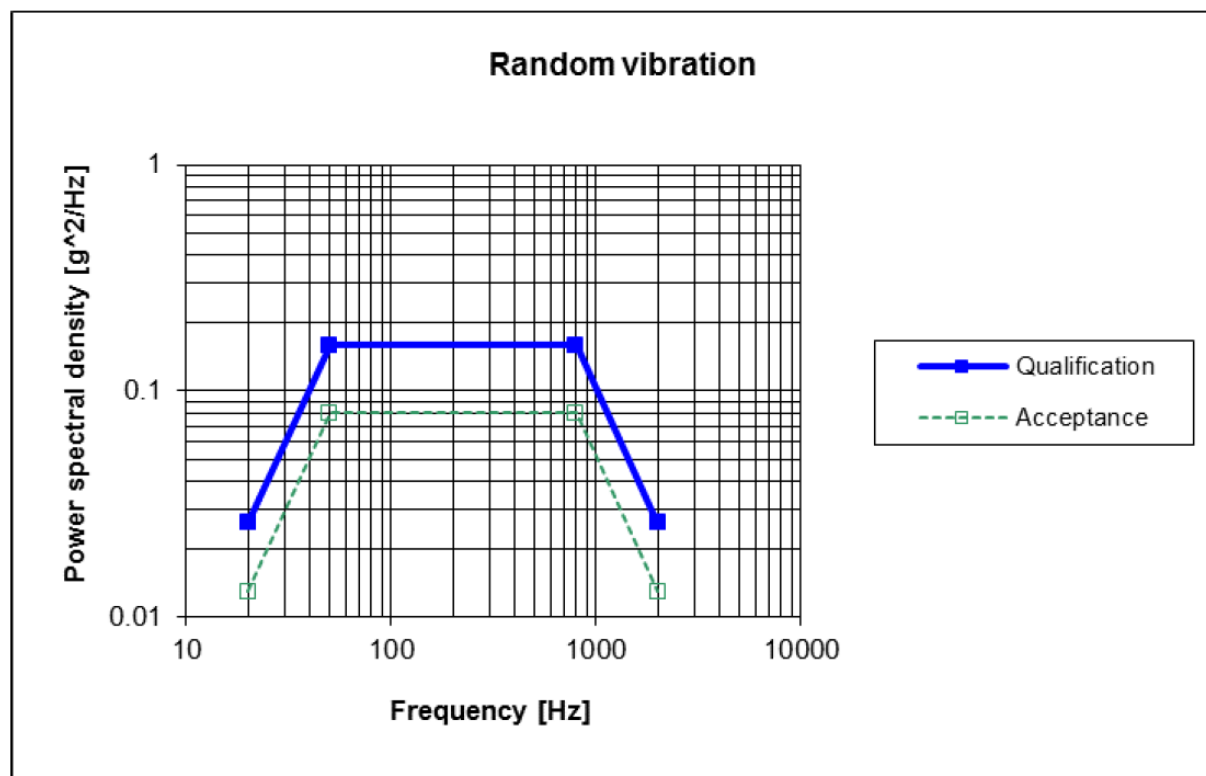




Figure 2-4 Random vibrations test specification

2.3.4 SHOCKS

Levels of shocks are depicted on Table 2-4, and they profile on Figure 2-5. Again loads are applicable for all three axes. It is possible, that FM will not need shock tests, provided sufficient FEM analysis. There is also considered carrying out shock test on the engineering model of the structure.

Table 2-4 Shocks test specification

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Characteristic		Qualification	Acceptance	Proto-flight
Test		Not required	Analysis required	Analysis required
Directions	{BRF}		X, Y, Z	X, Y, Z
Profile	Frequency [Hz]		Amplitude [g]	Amplitude [g]
	20		30	30
	2000		1000	1000
	10000		1000	1000
# of shocks			- [/axis]	- [/axis]

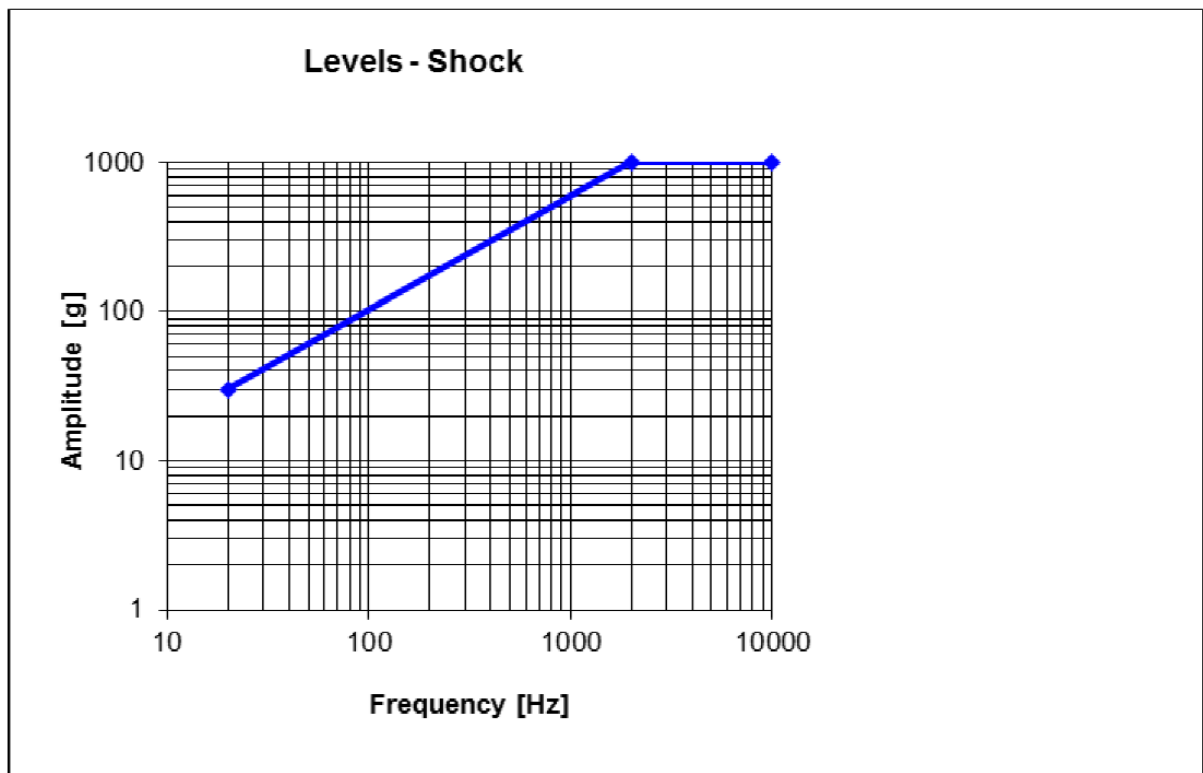




Figure 2-5 Shocks test specification

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3 PW-SAT2 CONFIGURATION

3.1 GENERAL CONFIGURATION DESCRIPTION

This chapter should present the general configuration of each subsystem in the whole assembly as well as interfaces between them. In the Figure 3-1 PW-Sat2 assembly is presented (outside walls are removed to show the inside of the satellite).

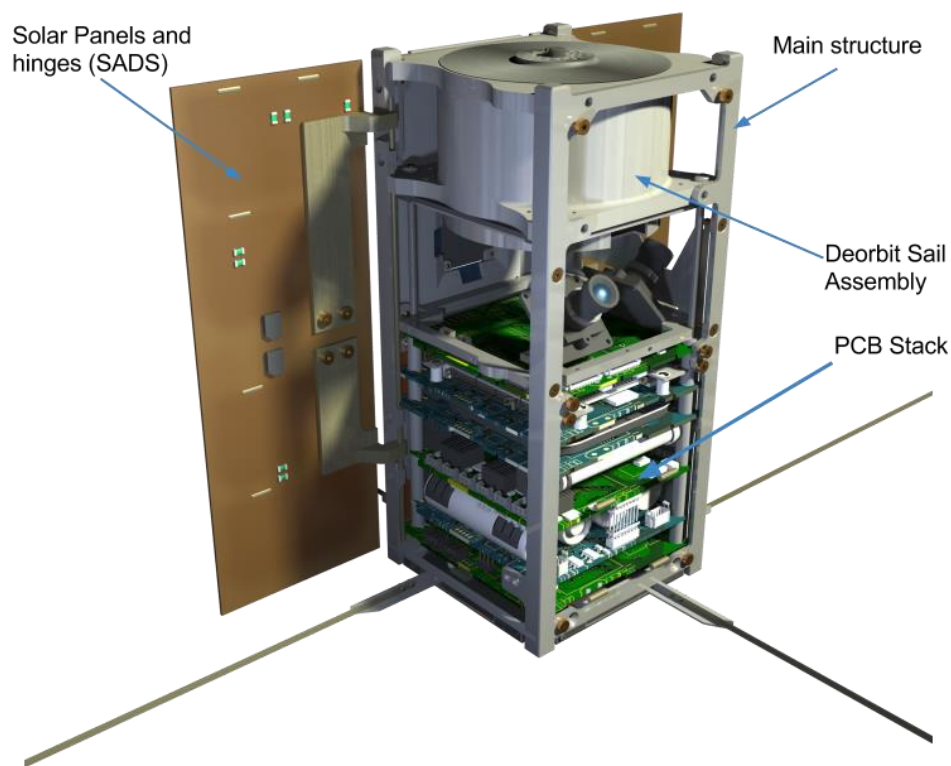




Figure 3-1 PW-Sat2 general configuration. Outside panels are not shown in the figure.

PW-Sat2 can be divided into several modules:

- Structure – two 2U X+, X- frames and Z- frame which is a base mount for PCB Stack
- SAIL – consists of: sail, sail's container and SRM – Sail Release Mechanism located under the container
- SS – Secondary Structure which serves both as an additional structural strengthening and cameras mount
- PCB Stack – consists of every piece of electronic equipment
- SADS and Solar Panels – one of the deployable mechanisms; Solar Arrays Deployable System consists of hinges on both Y sides of the satellite and Solar Panels connected to them

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- SARM – Solar Arrays Release Mechanism is not shown in the Figure 3-1 but is described later in the document; subsystem responsible to deploy the Solar Panels in the right time
- SunS – Sun Sensor is not shown in the Figure 3-1 but is described later in the document; one of the experiments of PW-Sat2 mission

3.2 AXES DEFINITION

In section 3.1 some of the parts are named after predefined axes of the satellite. Definition is based strictly on CubeSat Design Standard and configuration of the satellite in QuadPack. PW-Sat2's axes definition is presented in the Figure 3-2.

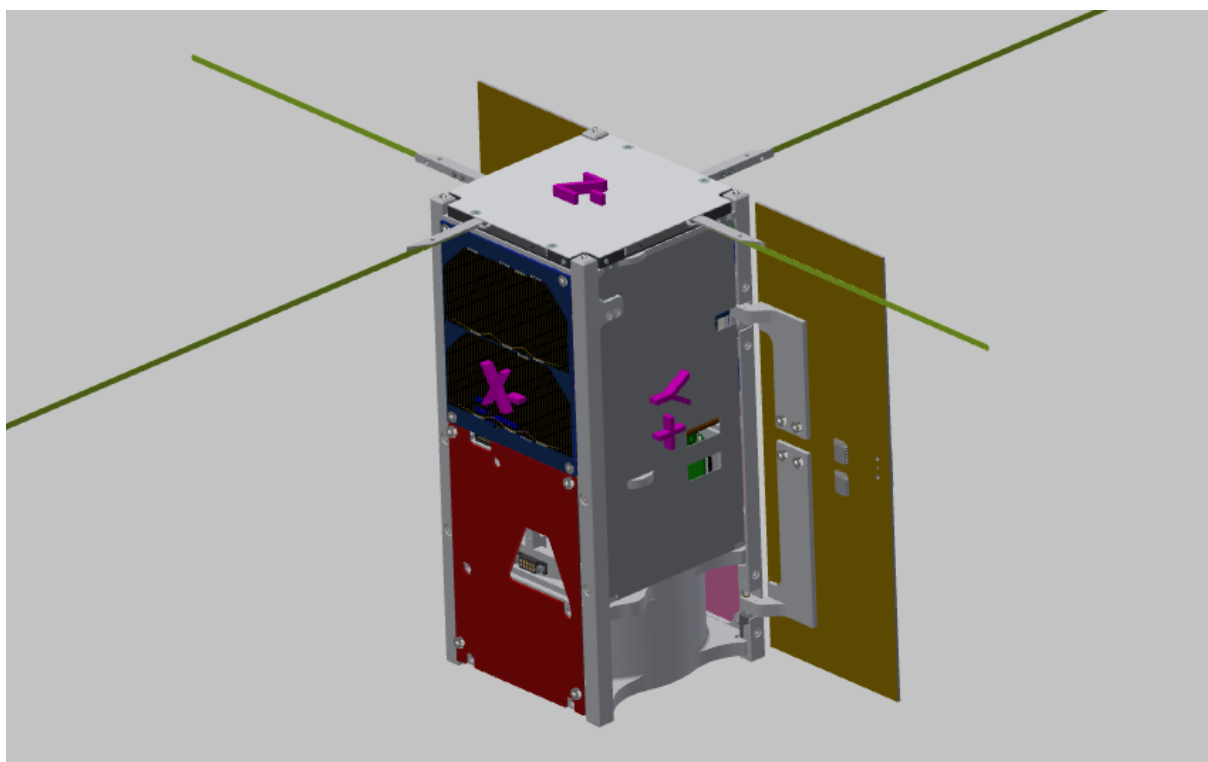




Figure 3-2 PW-Sat2 axes definition. Satellite is placed differently comparing to Figure 3-1 (antennas on top)

3.3 SUBSYSTEMS OF PW-SAT2 ASSEMBLY

In this section most important elements of each subsystem is shown. Figures 3-3 to 3.8 present generalized assembling procedure which is thoroughly defined in [PW-Sat2_SATELLITE_Assembling_Plan] document.

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3.3.1 PCB STACK

Figure 3-3 shows PCB Stack's configuration. It is a first step in PW-Sat2's assembling plan. Whole stack is mounted on 4 mounting rods fixed in Z- structure's frame. Board's order in stack is explained in 4.3.1 section of this document. From bottom to top: ANT (antennas), COMM (communication module), ACCU (accumulators), EPS (Electric Power System), ADCS (Altitude Determination and Control System), OBC (On Board Computer), PLD (payload module).

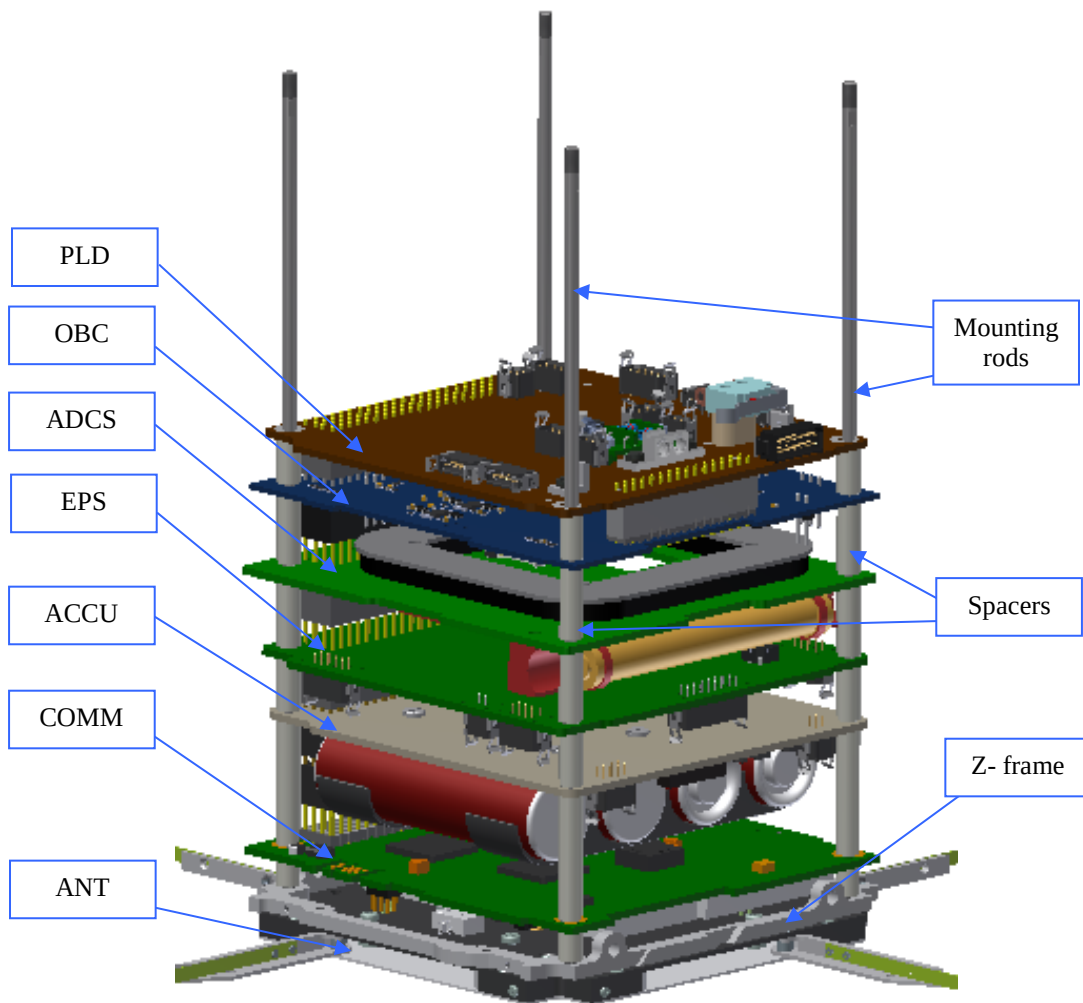




Figure 3-3 PCB Stack. First step of the assembly.

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3.3.2 SECONDARY STRUCTURE (SS)

Figure 3-4 presents next step in assembly procedure – Secondary Structure. It contains of 2 frames (Z- and Z+) and 4 supports. SS apart from strengthening the main structure is also a mount for CAM1 and CAM2.

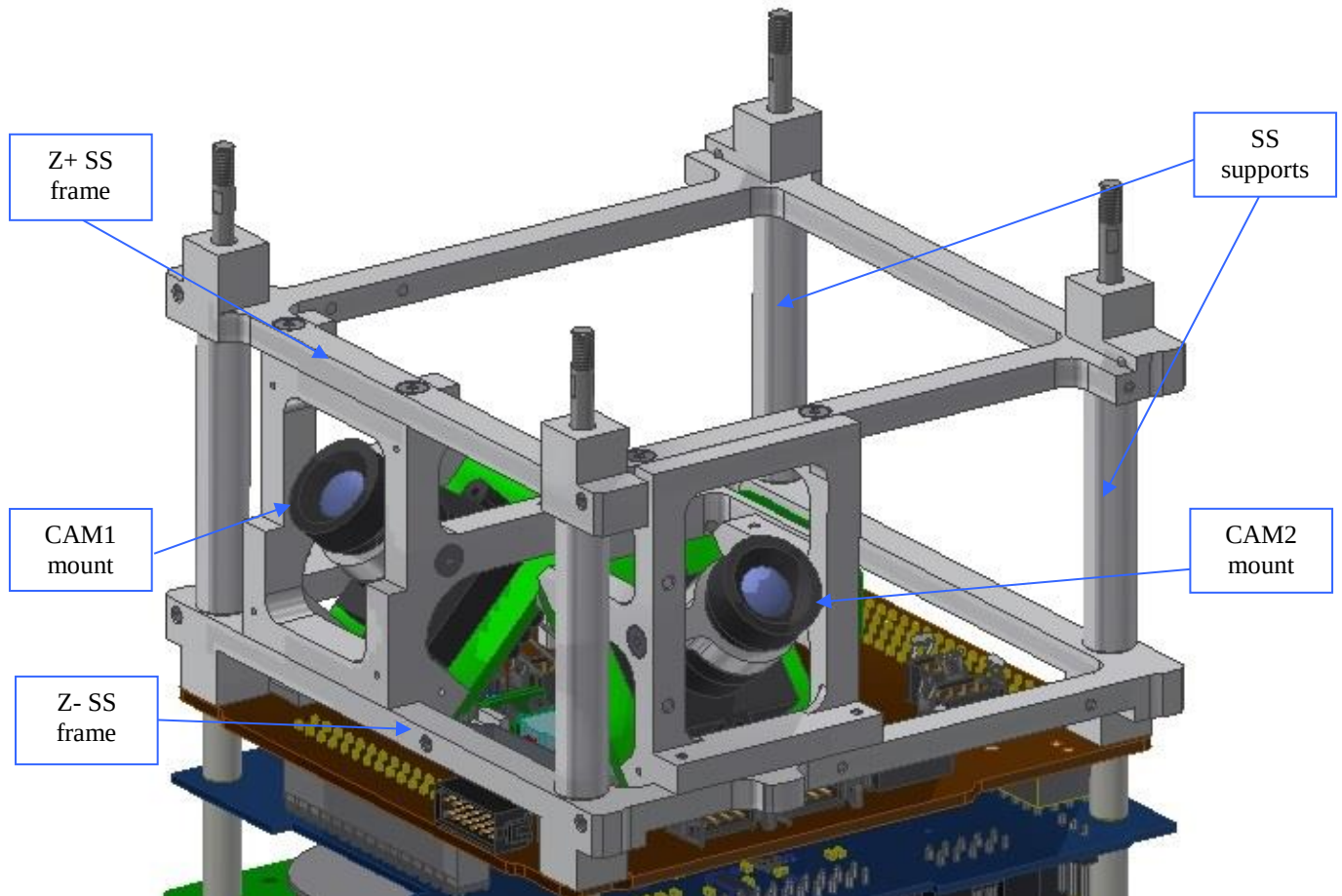
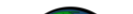



Figure 3-4 Secondary structure assembly mounted on top of PCB Stack.

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3.3.3 SAIL

SAIL modules is placed on top of the PCB Stack and SS assembly. It includes SRM placed underneath the container, container and sail hidden inside locked with a cover. With all those 3 steps 2U size is achieved.

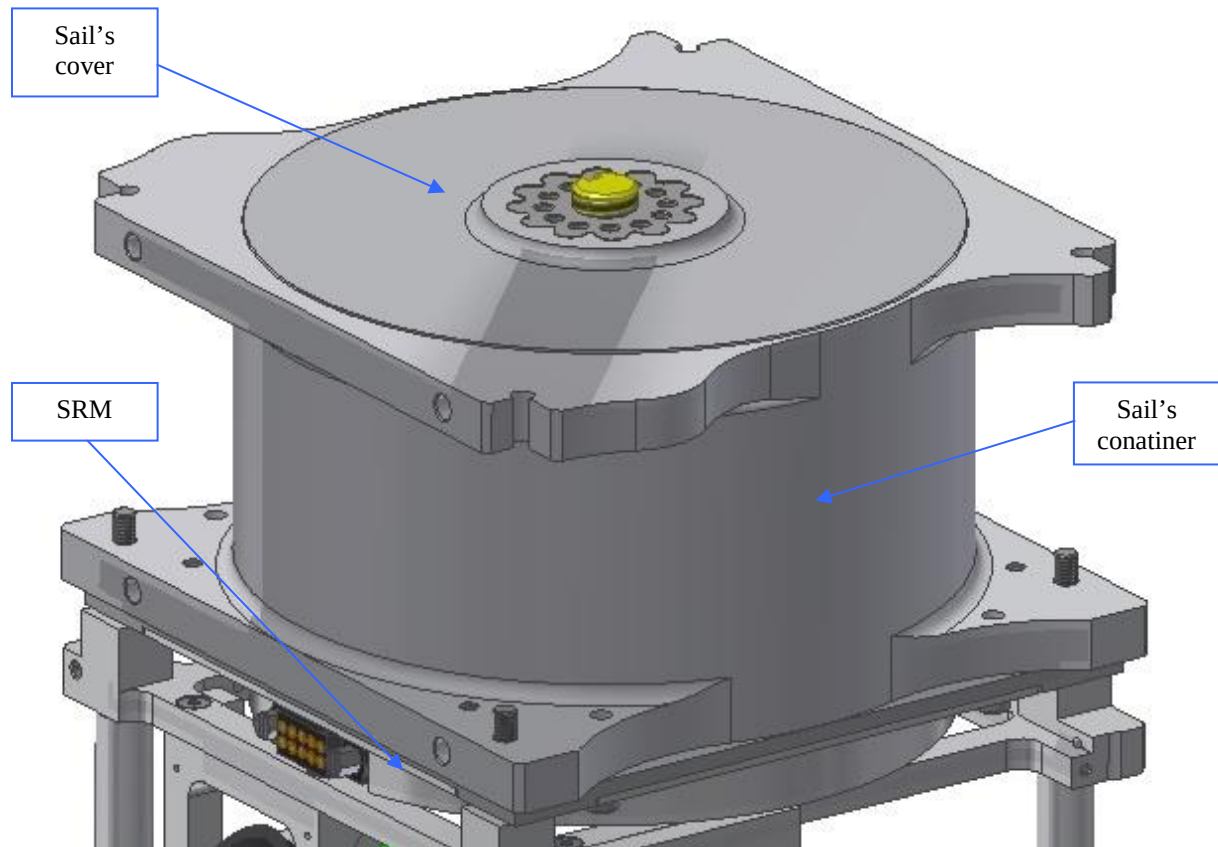




Figure 3-5 Sail's container with SRM.

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3.3.4 STRUCTURE AND SADS

Previous assembly is finally mounted with the main structure frames. SADS is mounted in X+ frame what required making 4 similar cuts in the rail.

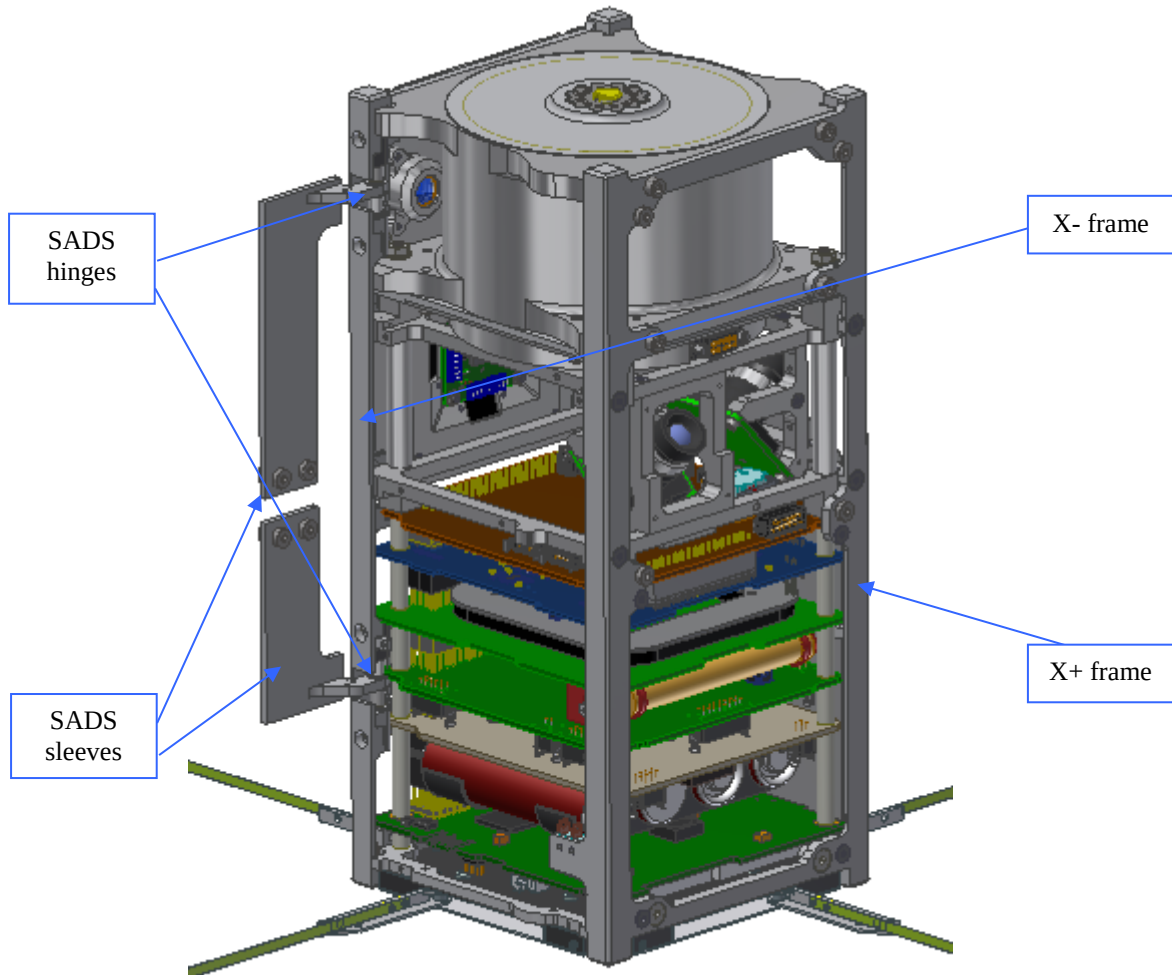




Figure 3-6 Structure with SADS hinges.

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3.3.5 REMAINING COMPONENTS

Final steps of integration consist of mounting closing walls and solar panels on the structure's frames or SADS' sleeves. Figure 3-7 shows the X- view of the fully assembled satellite and Figure 3-8 shows the X+ view with finally visible SunS Wall.

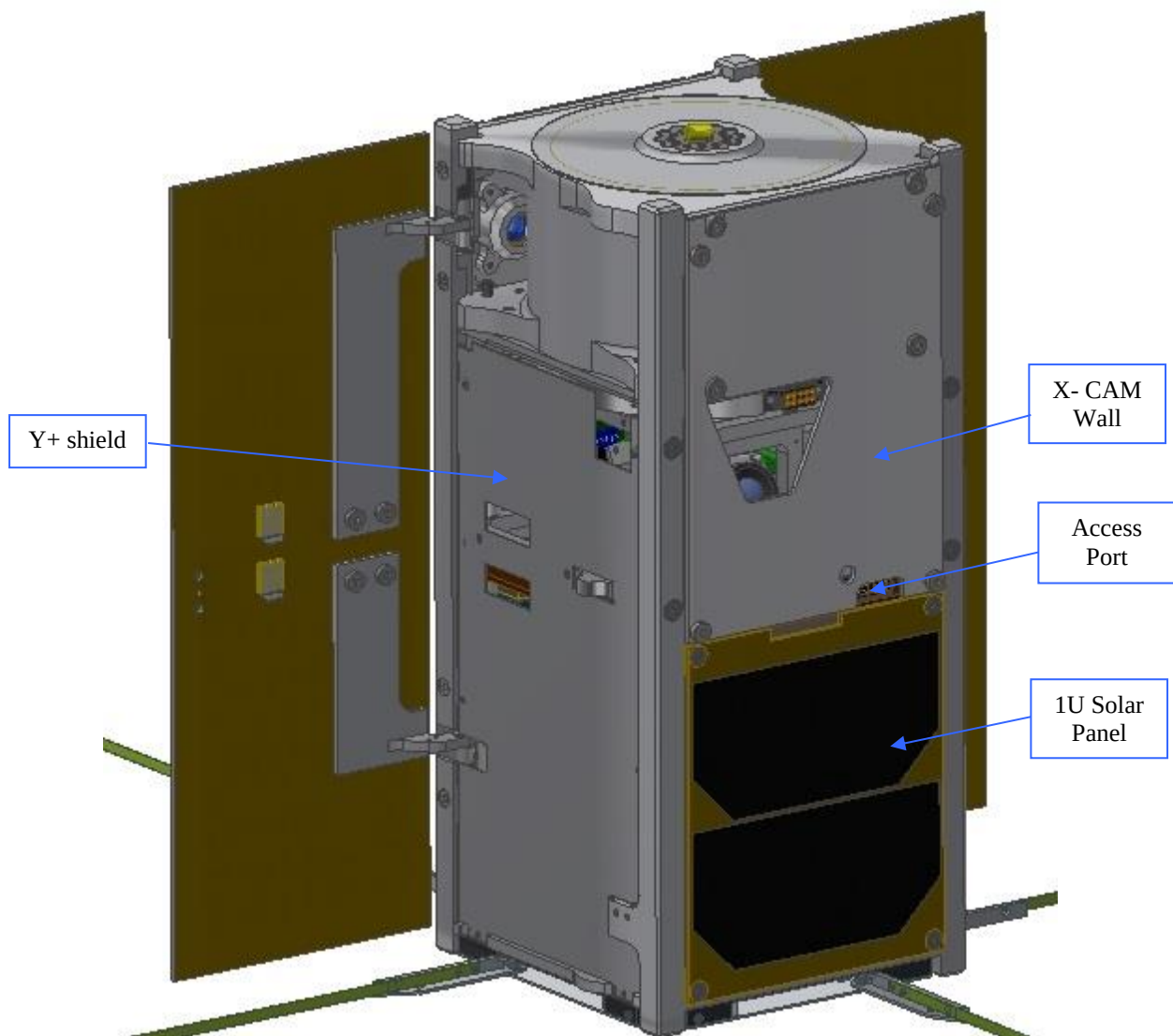




Figure 3-7 X- view of PW-Sat2 assembly.

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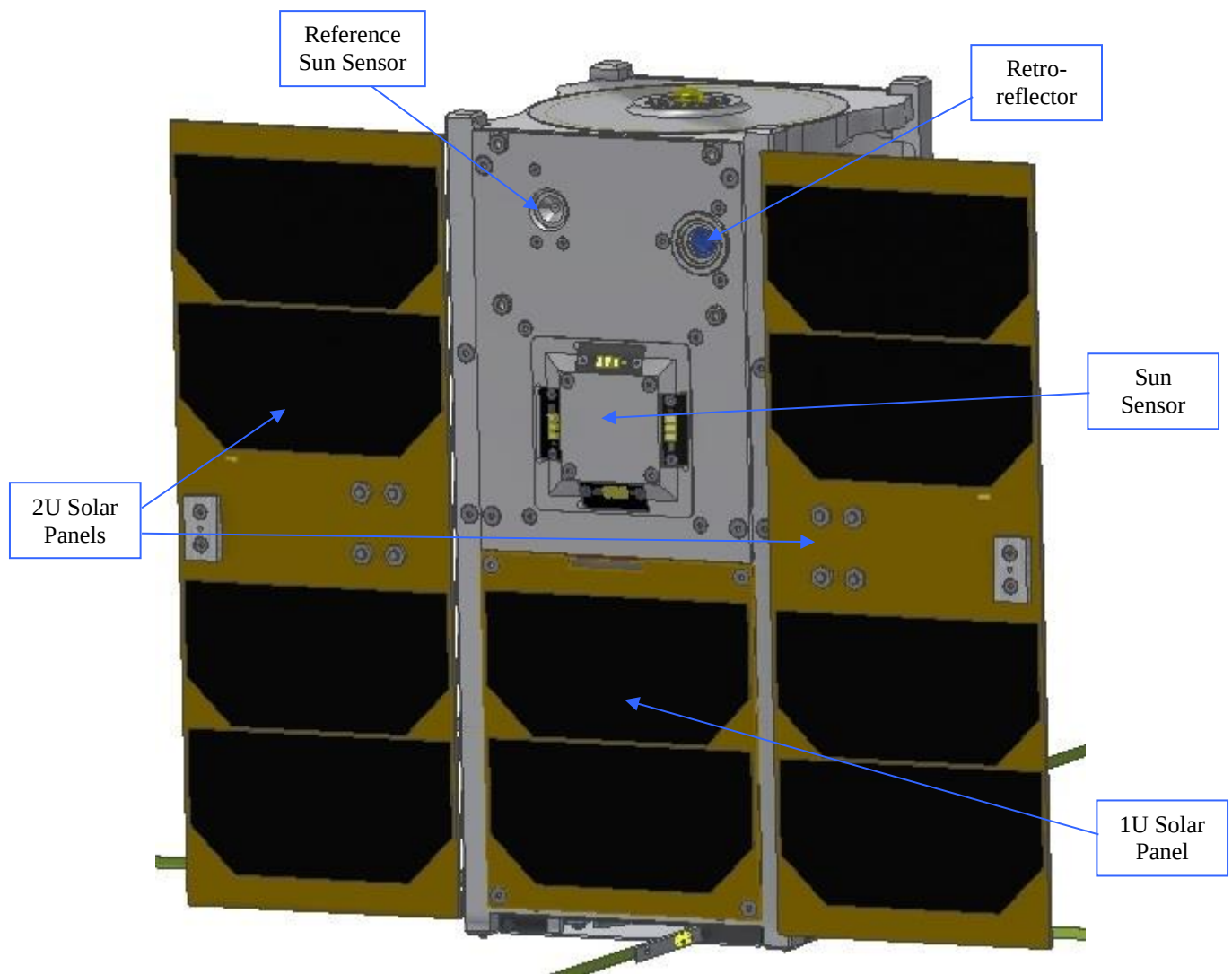




Figure 3-8 X+ view of PW-Sat2 assembly.

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4 FINAL DESIGN SOLUTIONS

4.1 STRUCTURE

4.1.1 ELEMENTS OF STRUCTURE

Structure, as it was assumed in the initial design, consists of 3 main frames. All structural elements are depicted in Figure 4-1. Definition of axes, which overlap with axes of QuadPack, are presented on Figure 4-1 as well. The frames are joined together by 4 screws ISO10642 M3x8, 2 on each side. Frame screw holes will contain Helicoils® M3x3mm inserts in order to increase strength. Frames are named according to satellite's coordinate system: X+ (blue frame), X- (yellow frame) and Z- (green frame). Contact surfaces between X+ Z- and X- Z- frames have different designs, which prevents inappropriate assembly of the structure. From Z+ side deorbit sail container in a support for the whole structure. This configuration stiffens the satellite and enables to withstand loads occurring during launch and operation on the orbit. All surfaces of structure are hard anodized.

Primary structure is also an interface for many elements on the satellite, such as PCB stack, SADM, 1U Solar Panels, Sun Sensor, Sail container and Secondary Structure. Structure positions them and is a stiff support for elements. Main structure is a mounting for kill switches and their rods as well.

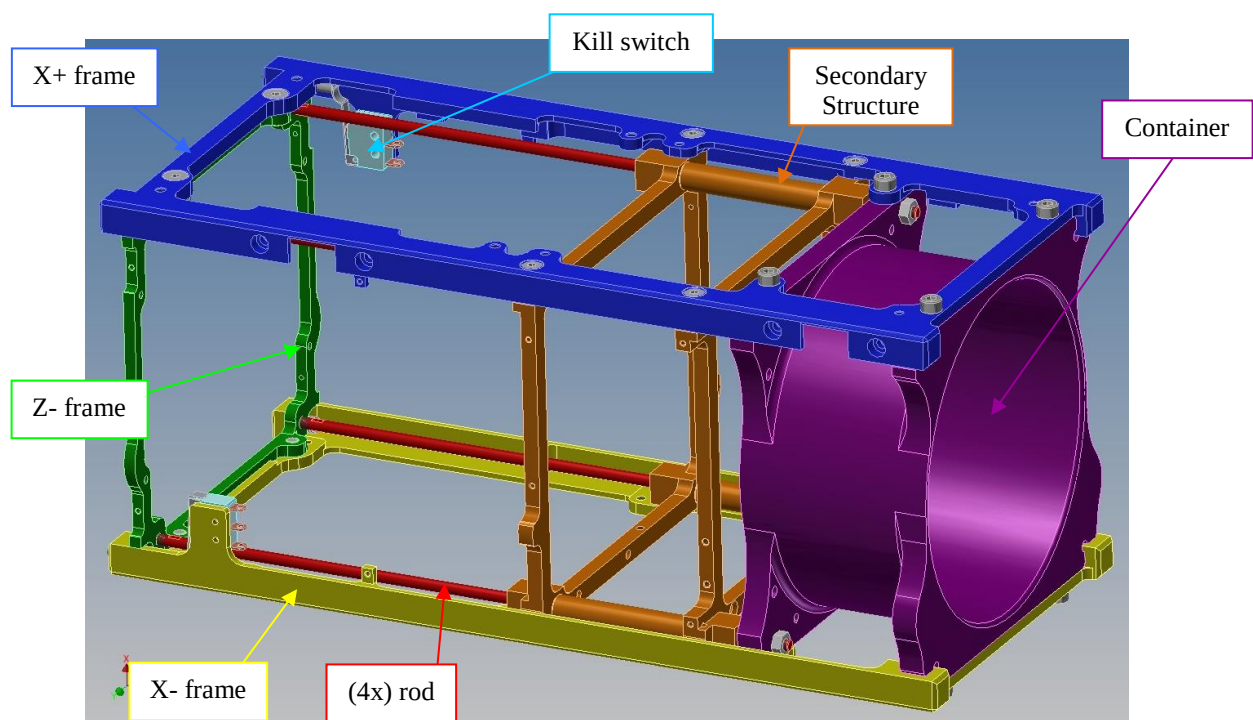




Figure 4-1 Assembly of entire structural elements.

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4.1.1.1 X- Frame

Comparison of X- and X+ frames is shown on Figure 1-4. X- frame has dimensions 227 x 100 x 8,5 mm. Thickness of the rails is 1,5 mm. Minimum radius of curvature is 3 mm, so, theoretically, during milling it will be possible to use 6 mm milling cutter for cost and time savings. Frame has 2 holes to join frame X- with frame Z+ (red arrow). In X-frame there are also 4 threaded holes for secondary structure fixation. 8 threaded holes (M2,5) are used in order to mount walls. Additionally, there is 4 clearance holes for sail container. More holes are for mounting kill switch and side shields. All interfaces of structure have been described further in this document.

4.1.1.2 X+ Frame

Frame X+ is very similar to X- frame. X+ frame has additional cuts in rails in order to allow the opening of the solar panels (for hinges). Near the cuts, on the one edge, radius is not 3 mm, but 1 mm, what is limited by SADM's design. These cuts are clearly visible in Figure 4-2 (right frame) and marked by green arrow. In addition, there are different cuts on the surfaces which have contact with Z+ frame to ensure the correct assembly of the X+ and X- frames with the Z+ frame. Frame X+ has single cut pointed by black arrow on Figure 4-2 and frame X- has double cuts also pointed by black arrow.

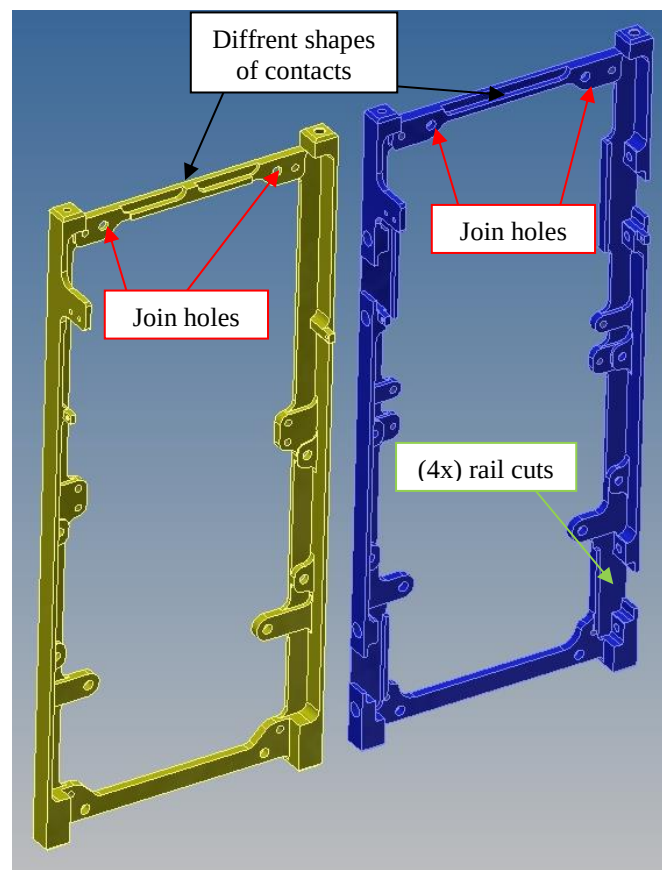




Figure 4-2 Comparison of X- frame (left) and X+ frame (right).

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4.1.1.3 Z+ Frame

This frame connects X+ and X- frames. Width is 100 mm, height is 96 mm and thickness of frame is 3 mm (not including frames connection holes). In this frame there are 4 threaded holes in PC-104 standard (Figure 4-3 – red arrow). The screw rods supporting other subsystems will be screw into these holes. In addition there are 4 holes (dark yellow arrow), in which the antenna module will be screwed in. **Błąd! Nie można odnaleźć źródła odwołania.**3 on the top there is single surface which suits cut in X+ frame (blue arrow). On the bottom there are double surfaces which suit X- frame (yellow arrow).

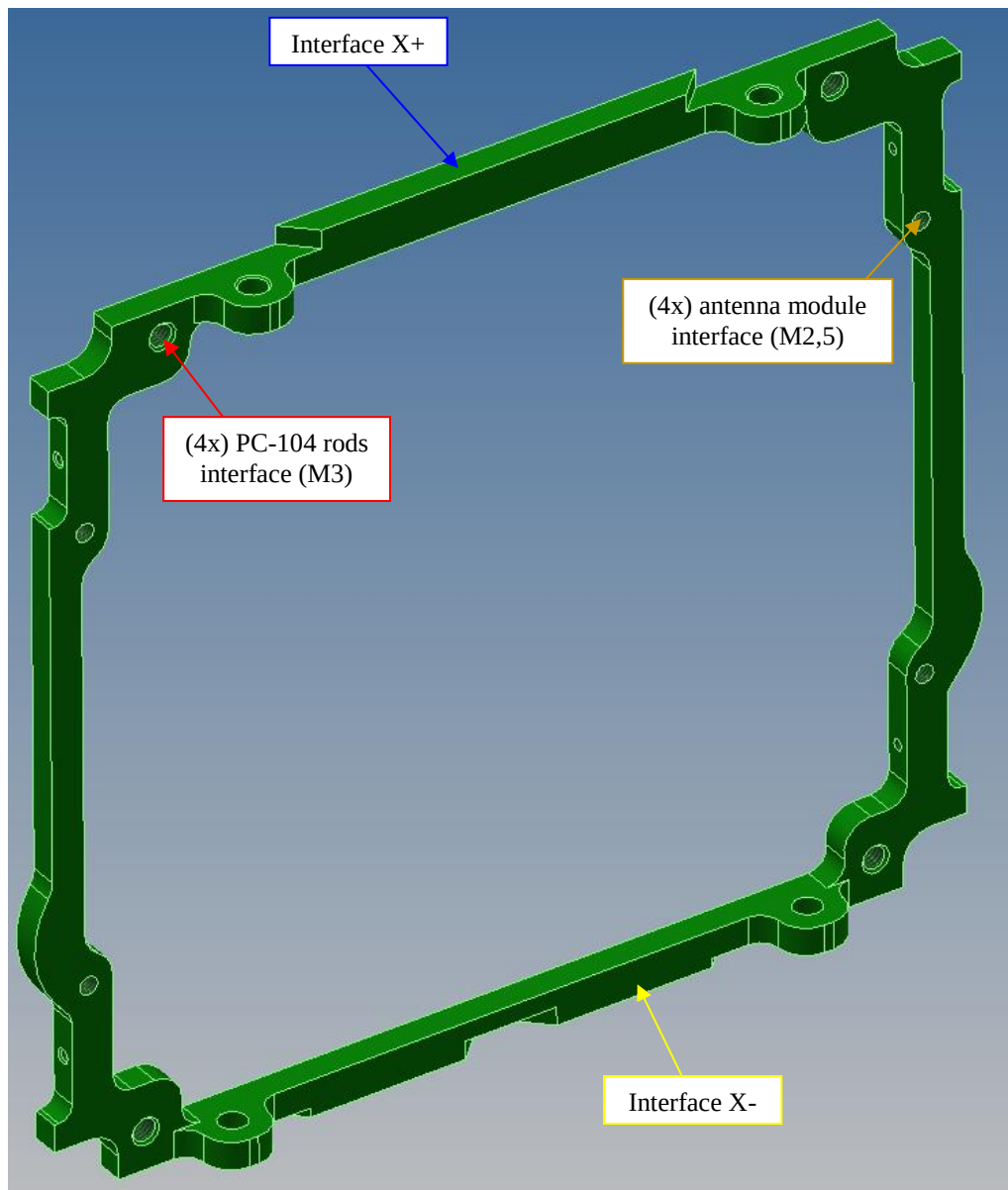




Figure 4-3 Z+ frame.

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4.1.1.4 Sail container

Detailed design of container is described in [PW-Sat2-C-05.00-DT-CDR]. Here is presented influence of container on design of main structure.

As seen in Figure 4-1, container has crucial role in supporting primary structure. From the beginning of the project container was assumed as a part of a structure. It carries loads from Z+ side so that whole structure has enhanced stiffness in X and Y axes. If there were not container, structure would not be possible to be assembled. There would be impossible to have required dimensions and insertion of satellite into Quad-Pack would not be possible.

4.1.1.5 Kill switches.

The purpose of the kill switches is to turn on power after deployment PW-Sat2 from QuadPack. Satellite has two redundant switches which are placed on Z- side. Configuration of deployment switches is depicted on Figure 2-1 (option B). Model of switch is: F4T7YCUL, the same as it was used in PW-Sat. Each switch is screwed into structure using two ISO 10642 M2x10 screws. Level of the switch is pressed by so called deployment pin. Configuration of switch and deployment pin is showed in Figure 4-4.

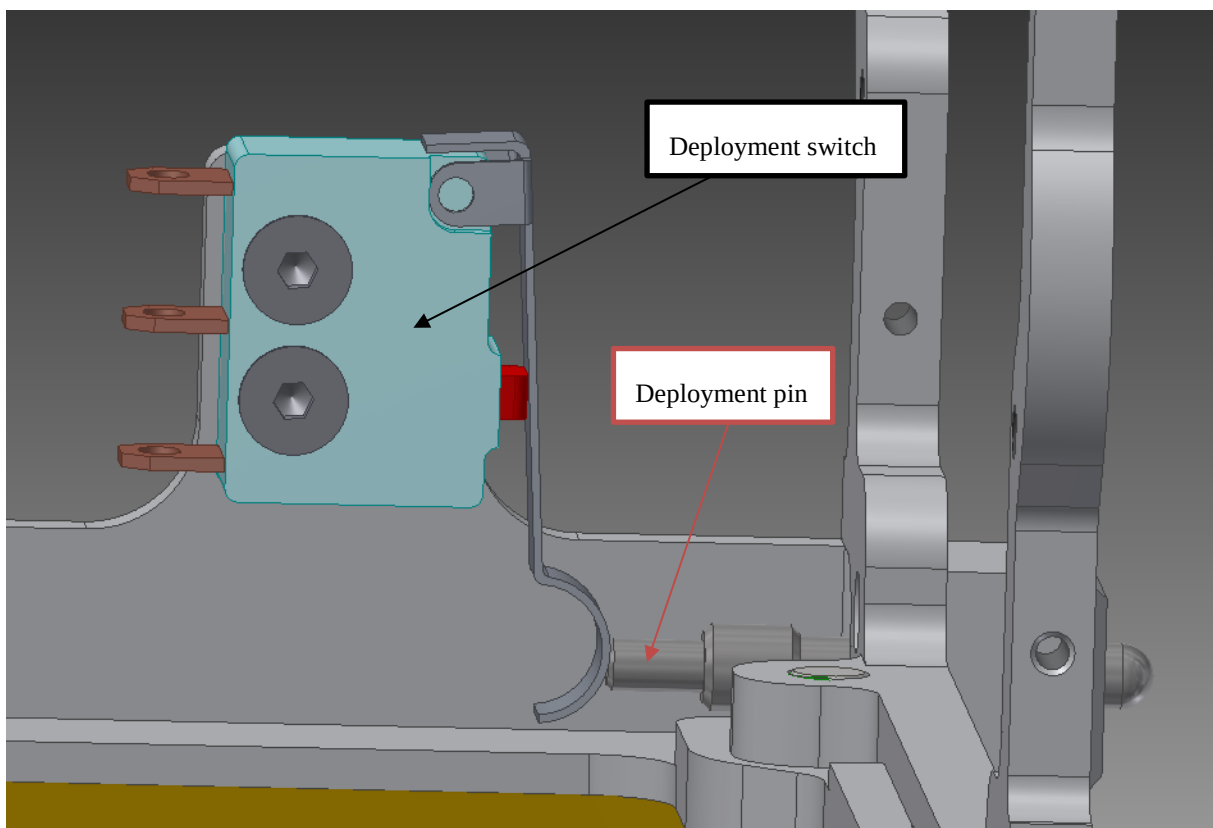




Figure 4-4 Switch and deployment pin.

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4.1.2 INTERFACES

Structure is a support for many satellite elements. Here are described all interfaces on the structure.

4.1.2.1 List of screws

Structure has interfaces with 56 screws and 4 M3 threaded PC104 rods. List of all screws is presented in Table 4-1.

Table 4-1 List of screws in the primary structure.



Standard	Name	Quantity	Interface
ISO 4762	M2,5x6	8	SADM
ISO 4762	M3x8	8	Container
ISO 10642	M2x10	4	Kill switches
ISO 10642	M2,5x4	8	1U panels
ISO 10642	M2,5x6	4	Sun Sensor
ISO 10642	M2,5x8	8	Secondary Structure
ISO 10642	M3x6	4	Main joint
ISO 14580	M1.6x3	4	Shield
ISO 14580	M1.6x5	4	Shield
ISO 14580	M3x5	4	X- Cam wall

4.1.2.2 Main joint

Frames are jointed with ISO 10642 M3x6 screws (countersink). Conical shape enables to hide screws under surface of X+ and X- frames, what allows to mount 1U panels. In Z- frame there are Helicoil M3x3 mm inserts, what strengthen entire joint. This interface is depicted in Figure 4-5.

4.1.2.3 1U panels interface

There are two 1U panels in satellite PW-Sat2. One is mounted on X+ frame and the other on X- frames. Both panels are as close to Z- side as possible. Each of them is mounted by 4 ISO 10642 M2,5x4 screws. Screws have rectangular patters with dimensions 91,6 mm x 76,2 mm. Type, size and pattern of mounting screws is determined by the producer of 1U solar panels. This interface on X+ frame is shown on Figure 4-6.

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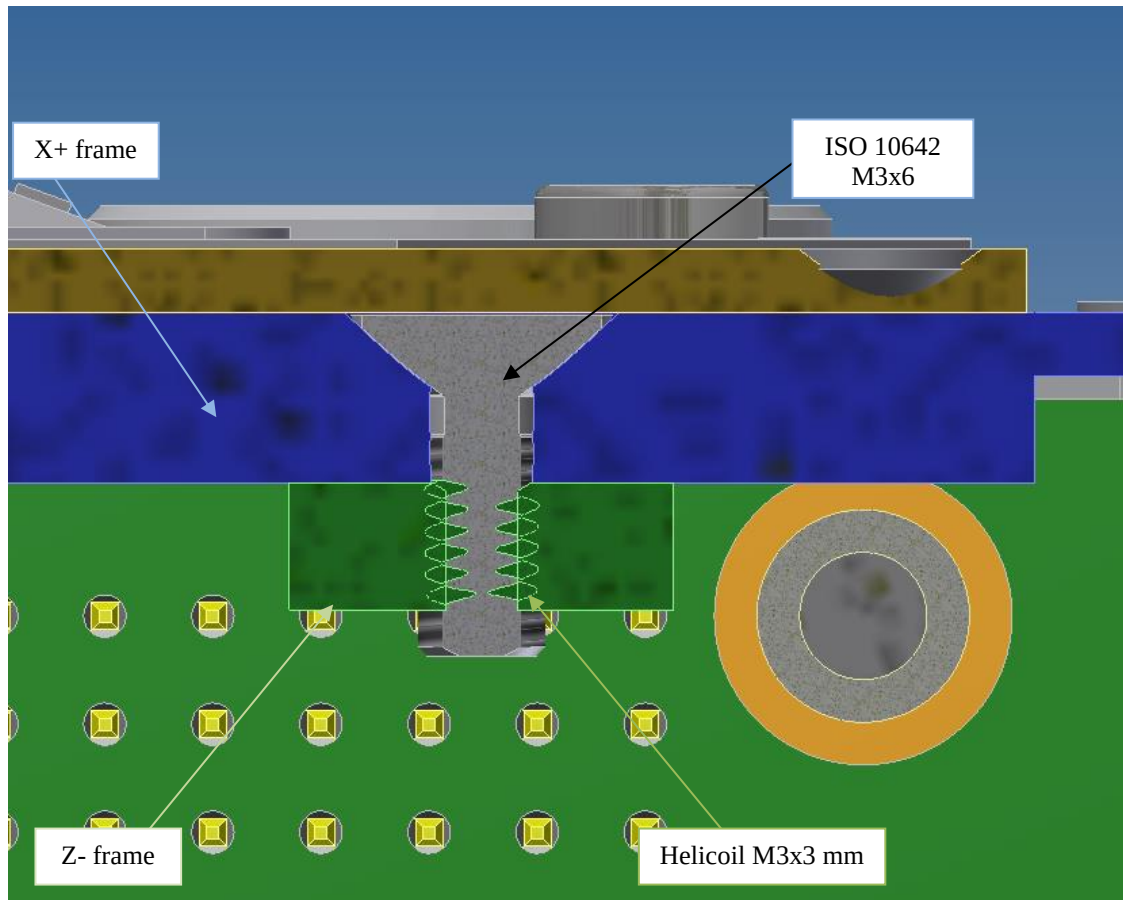


Figure 4-5 X+ and Z- frames interface.

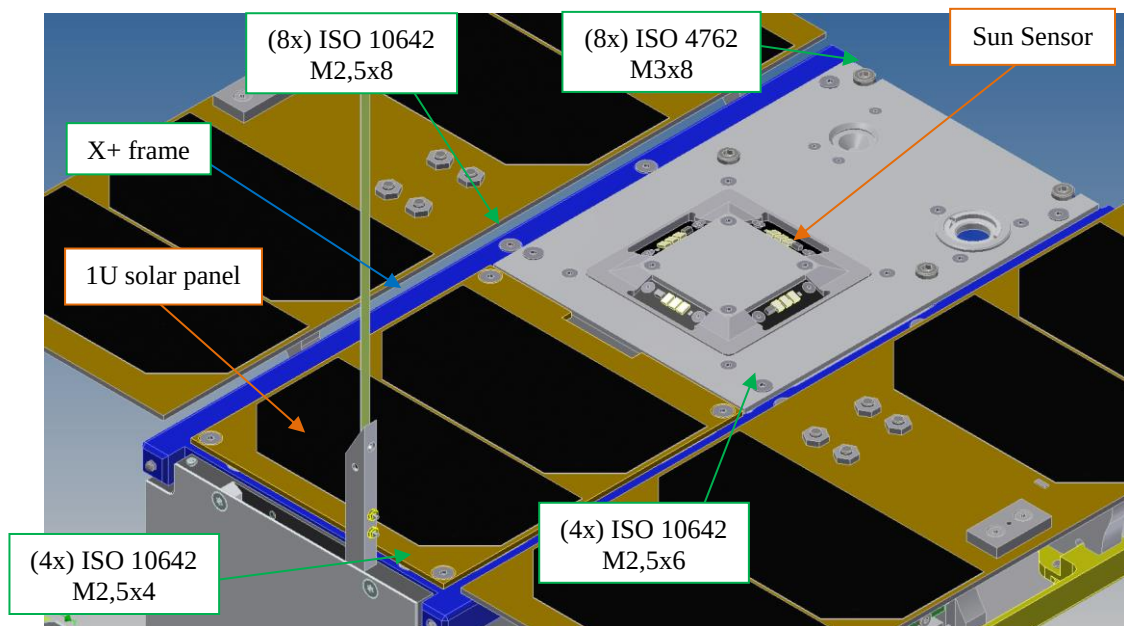




Figure 4-6 1U Solar panel, sun sensor, secondary structure and container interfaces.

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4.1.2.4 Sun Sensor interface

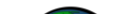

Sun Sensor is mounted to X+ frame by 4 ISO 10642 M2,5x6 mm. The pattern of screws is rectangle 97 x 75 mm. This pattern is determined by Sun Sensor design and can be slightly adjusted. Sun Sensor, similarly to 1U Panel lies on the surface aligned with rails. Interface is depicted on Figure 4-6.

4.1.2.5 Secondary structure interface

Secondary Structure is mounted to X+ and X- frames. There are 4 ISO 10642 M2,5x8 on each frame. The pattern of each joint is rectangle 90 x 44,5 mm. This interface is formed by 4 holes in the rails. It is also depicted on Figure 4-5.

4.1.3 STRUCTURAL ANALYSES

Structure is an integrated part of the entire satellite. Because of that it cannot be analysed as separated part, so that all analyses of structure are carried out with whole satellite model. Finite Elements Method structural analyses are described in [PW-Sat2-C-05.01-DT-Structure-Analyses] document.

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4.2 SECONDARY STRUCTURE

4.2.1 SS ASSEMBLY

The purpose of secondary structure is to support the main structure, stiffen the whole satellite frame and support other elements (including two cameras). Secondary structure is depicted on Figure 4-7. It is placed between the PCB Stack and the Sail's Container. Four spacers (1) rods have clearance holes in order to support PC104 rods. The cameras have their own supporting structures (2 and 3) with the additional holders for the lenses. Two frames (4 and 5) hold everything together. They also have holes for the PC104 rods and keep the distance between the PLD board and the Container. Frames have 8 threaded holes for mounting to the main structure. Also there are holes for the photodiodes boards mounting and Shields mounting. The elements on the frame (4) marked as (6) are the support for deployable Solar Arrays in the closed position, to minimize their vibrations during the launch.

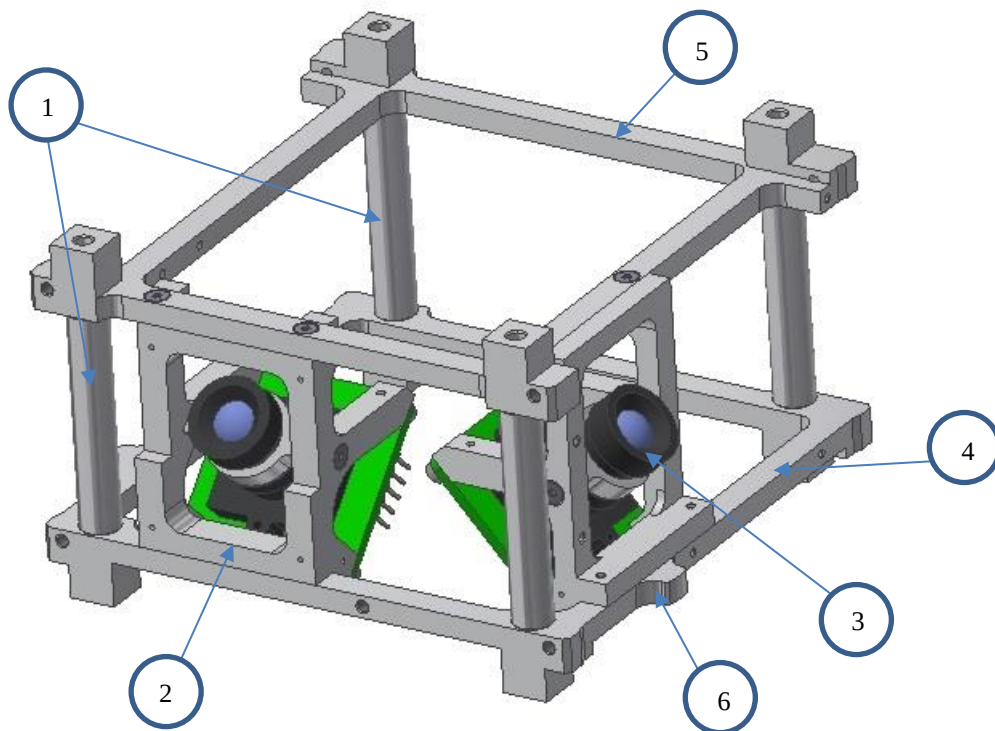
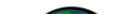



Figure 4-7 1U Secondary structure assembly.

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4.2.2 CAMERAS' MOUNTING AND POSITION EXPLANATION

The cameras are mounted through their holders in the specific places. The mounting angles are determined by the Sail visibility, with the diagonal fields of view 76° and 116° . The cameras coverage of the Sail structure is presented on the picture below. The CameraNadir is mounted on the X- side and the X- wall has a hole fitting to the cameras field of view. The CameraWing is mounted on the Y- side, under the deployable solar panel and requires opening it for operating. The cameras mountings have holders for the lenses, and lenses are hidden under the X and Y walls. The mountings are stiffening the Secondary Structure additionally.

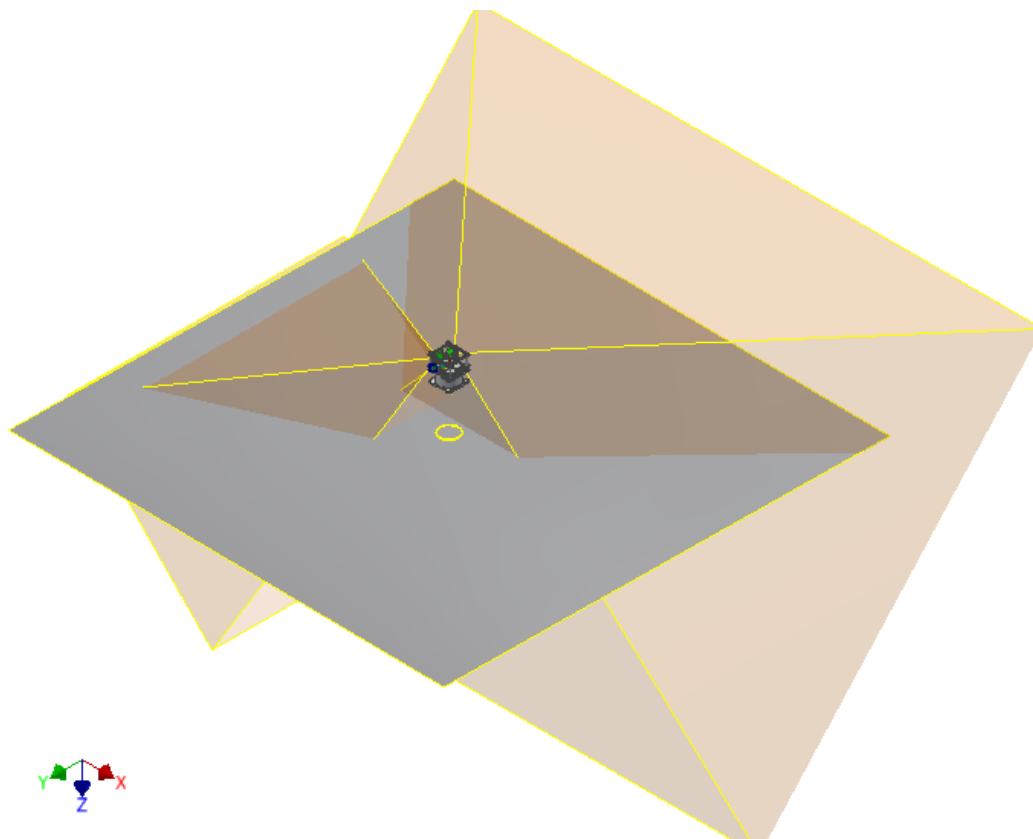




Figure 4-8 1U Field of view of both cameras.

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4.2.3 X- CAM WALL DESIGN

X- CAM Wall is one of the outside walls of the satellite. It is made from Aluminum 7075 with a mass of 35 g. Its main functionality is to ensure the proper line of sight for CAM1, accessibility of access port and RBL (Remove Before Flight) pin and balancing the temperatures inside the satellite. All the main mounting points for X- CAM Wall are presented in the Figure 4-9.

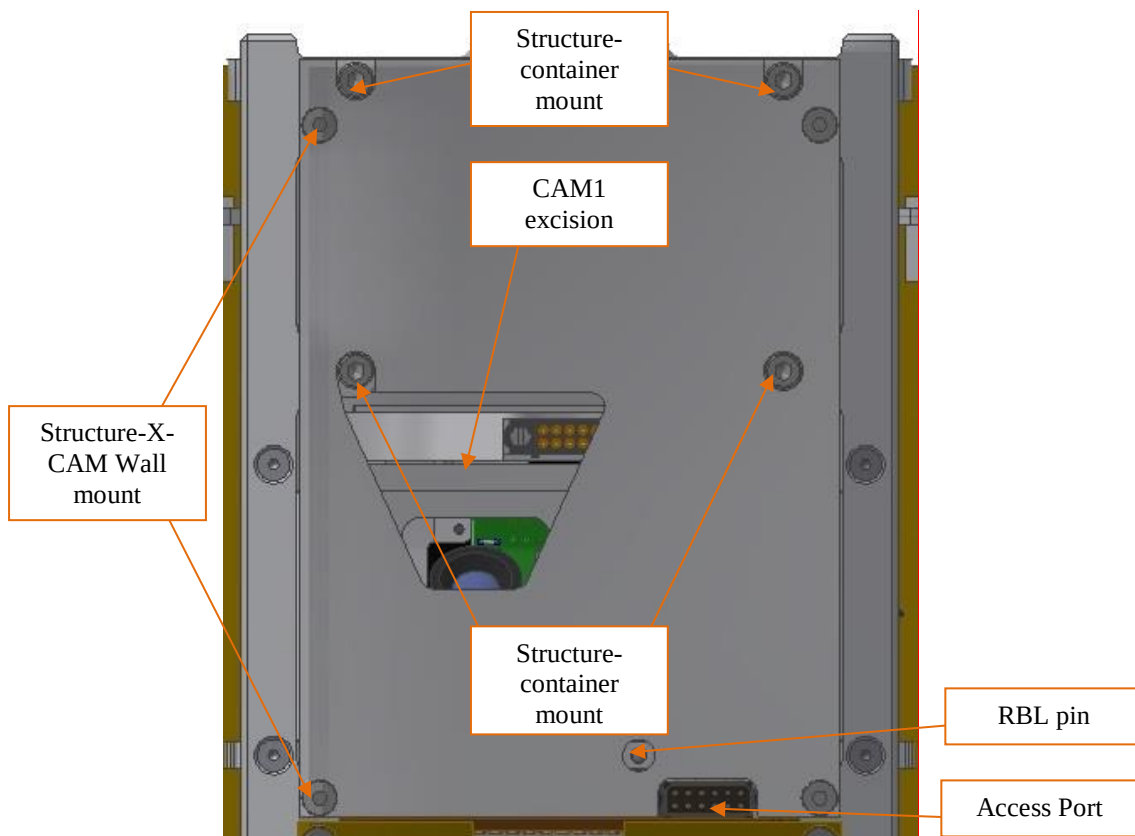




Figure 4-9 X- CAM Wall interfaces.

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4.3 PCB STACK

4.3.1 PCB STACK'S ORDER DEFINITION

One of the first tasks of CONF team was to determine the PCB boards configuration in the Stack. Each subsystem has different EMI susceptibility and EMI emissivity. Here, it is necessary to define an order within the PCB stack. We only possess general EMC data. To define the order all known data are shown below:

Table 4-2 PCB stack order definition – requirements.

Subsystem	EMI susceptibility	EMI emissivity	TCS requirements	Other comments
COMM	Very sensitive to EMI when the receiver is turned on. EMIs have a major influence on receiver sensitivity. Small EMI sensitivity when the receiver is switched off.	High EMI RF emission when the transmitter is turned on. Probably the module contains DCDC converters. Small EMI emission when the transmitter is switched off.	No special requirements	To reduce an RF path to the ANT module it should be as close as possible to the ATN module.
Battery Pack	EMI has no influence on the module	No EMI emission	Due to very short temperature limits, requires a good connection to heat sink	It shall be next to the EPS module.
EPS	EMI has very small influence on the module	Due to many DCDC converters, it has high EMI emission which depends on loads.	High heat dissipation at nominal mode – should be close to the structure interface	It shall be next to the BAT module.
iMTQ	If magnetometers are outside of the module, then EMI has small influence.	If magnetotorquers are switched on, then the EMI emission is high (but on low frequencies – see ADCS documentation).	No special requirements	-

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	If magnetometers are placed on iMTQ's PCB, then EMI has high influence on them.	No EMI emission when magnetotorquers are switched off.		
OBC	EMI has small influence on the module	Due to high speed digital signals (and very low rise/fall times) it emits HF interferences.	Low heat dissipation.	-
PLD	Very sensitive to EMI when theRadFET is turned on. If the RadFET is switched off, then EMI has no influence.	No EMI emission	No special requirements – low priority	It should be as close as possible to SunS and CAMs.

According to the table, the PCB stack order was defined which is shown in the Figure 4-10.

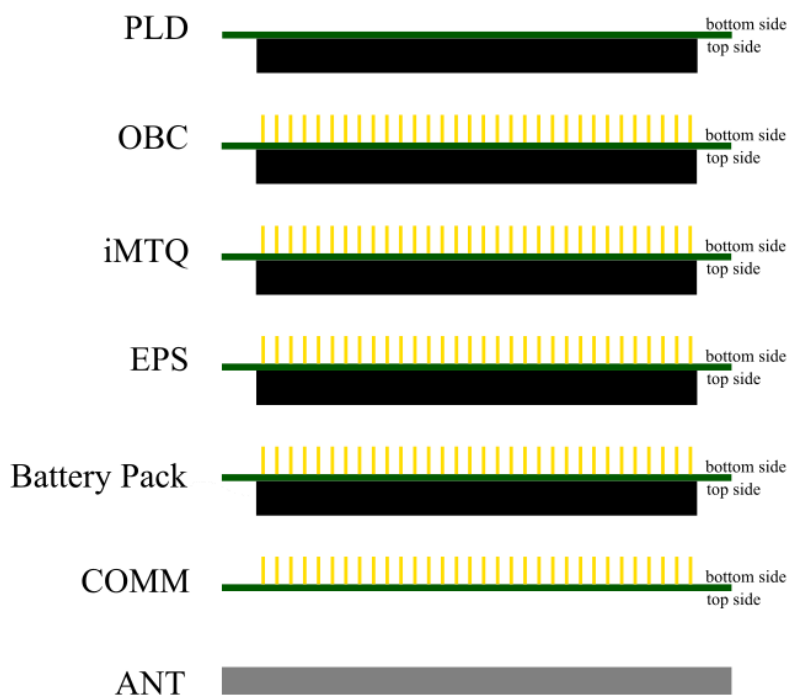




Figure 4-10 PCB stack order definition – drawing.

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Battery Pack module was used as an EMC-barrier, which is responsible to make an EMC separation between EPS and COM modules.

PLD module contains high sensitivity analogue circuits. To make some EMC separation, the circuits should be placed on the bottom side of the PCB (both bottom and top sides of the PCB are called according to the *Pumpkin CubeSat Kit PCB Specification* [2]).

4.3.2 DISTANCES BETWEEN BOARDS REQUIREMENTS

Distances between boards are determined strictly by connectors which provides information continuity inside the Stack. There are several kinds of connectors between boards. Connectors are presented in the Table 4-3.

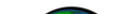

Table 4-3 Collection of all used connectors.

Nr	Connector	Quantity	Interface
1	Samtec-TSW-126-07-G-D	1	COMM-ACCU
2	Samtec-ESQ-126-39-G-D	4	ACCU-EPS, EPS-ADCS, ADCS-OBC, OBC-PLD
3	Samtec-TSW-115-07-L-D	1	OBC-PLD
4	Samtec-SSQ-126-21-G-D	1	PLD-OBC
5	Samtec-SSQ-115-01-G-D	1	PLD-OBC

Every connector presented in the table has its specification described by Samtec ESW, ESQ Series Specification. For all of the connectors pin insertion depths (one connector to another) are set to **3.68 – 6.35 mm range**. This piece of information determines the whole chain of dimensions in PCB Stack. Final distances between boards are presented in section 4.3.3.

4.3.3 STACK'S MOUNTING AND FINAL DISTANCES BETWEEN BOARDS

Whole PCB Stack is mounted on 4 identical 3 mm diameter, steel Mounting Rods with threaded ends. The start of each rod is fixed in the structure's Z- frame. PCB boards are distanced between themselves with various Teflon Spacers. Spacers have 3 mm inside diameter and 5 mm outside. Final distances determined by connectors' insertion depths are presented in the Figure 4-11.

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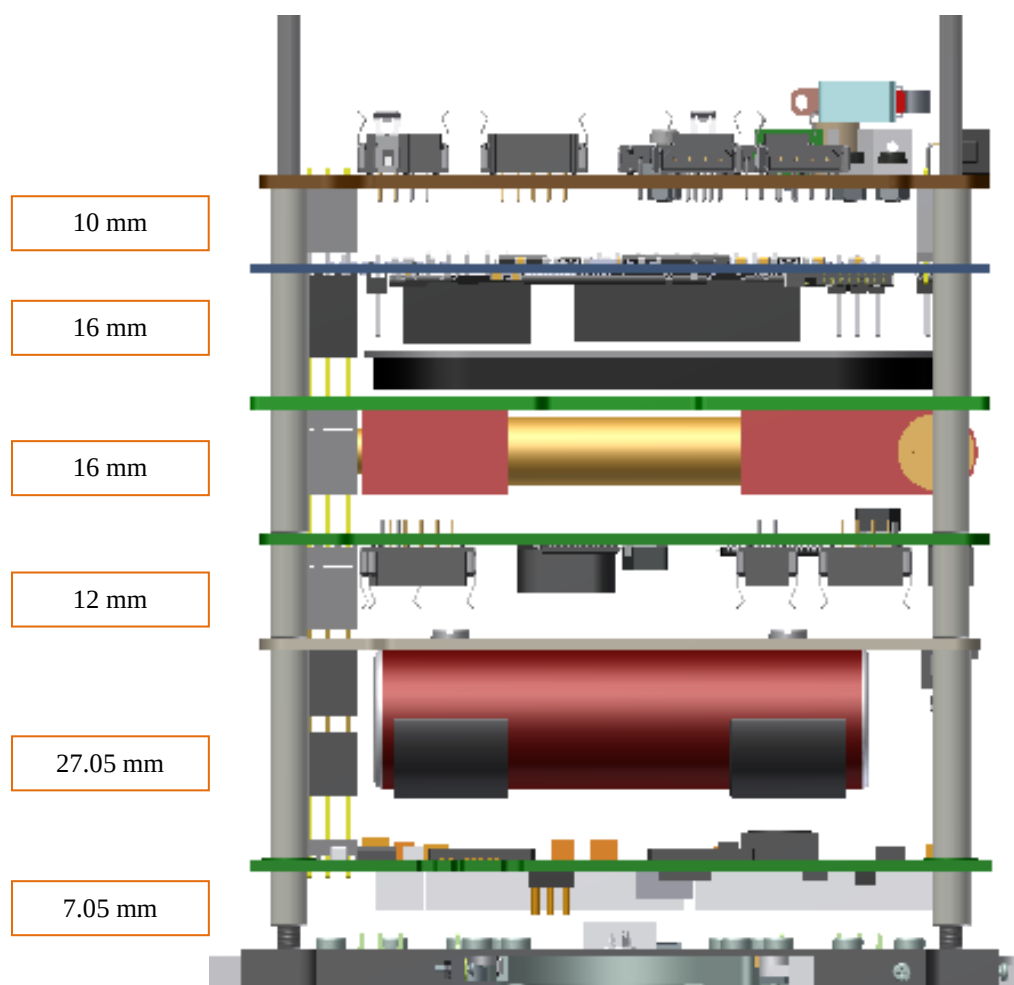




Figure 4-11 Final distances between boards.

4.3.4 LIST WIRES AND PLUGS USED IN THE PROJECT

TBD. Initial value of wires' mass is estimated as 150 g.

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4.3.5 PLD BOARD ELEMENTS' CONFIGURATION

The other main problem with PCB Stack was placement of necessary elements on PLD board. The board does not have a large area and some of the elements already required a precise placement on it. For example, SARM subsystem, access port and RBL kill switch must be fixed in the area presented in the Figure 4-12.

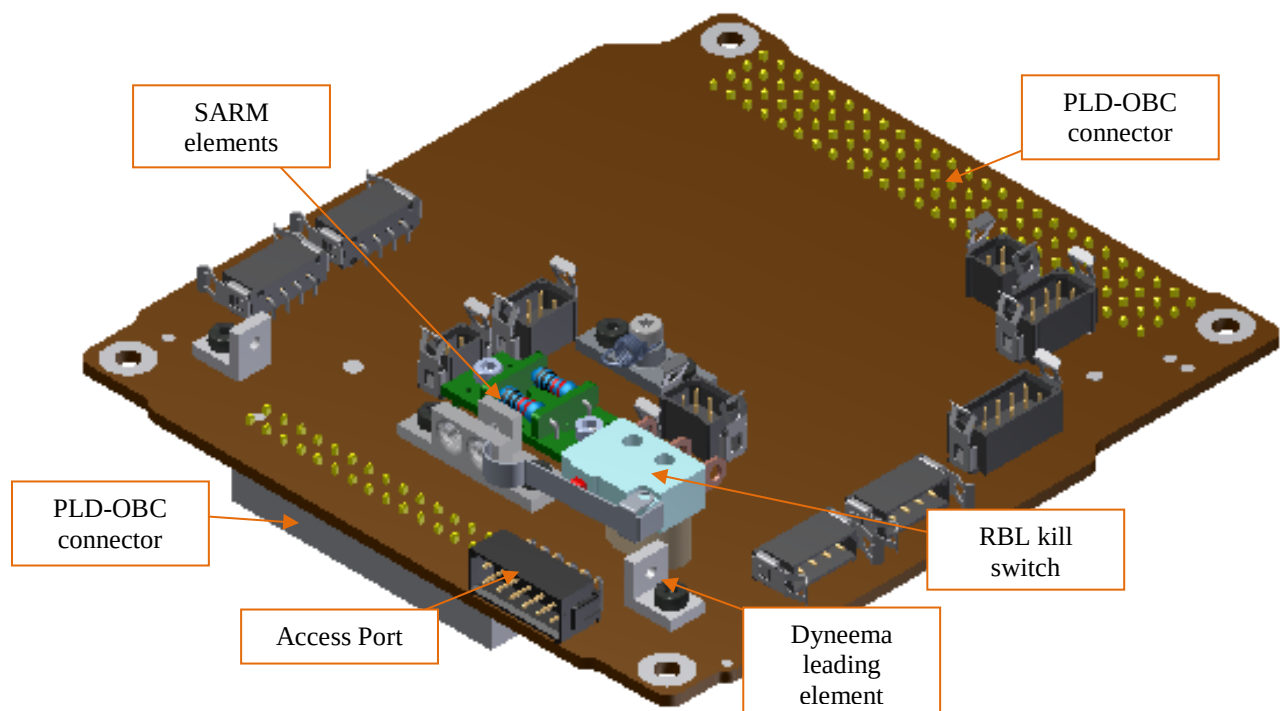




Figure 4-12 Distribution of elements on PLD board.

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4.4 SAIL

Sail's final design is fully described in [PW-Sat2-C-05.00-DT-CDR] document. As a main payload of the satellite its placement has always been known. From the start of the project, sail has been decided to take Z+ side of the satellite. Before deployment it is completely hidden inside the sail's container. CONF team has not participated much in progress of this subsystem but, mostly container's final height and diameter have a lot of consequences on internal chain of dimensions. It is also one of the most crucial parts in Structure's stability.

4.4.1 POTENTIAL COLLISIONS WITH CONTAINER

Container is a final segment of assembly mounted on 4 Mounting Rods. It is 51 mm high (0.5U high) and its outside diameter equals 90 mm. Container's dimensions constrained SADS and SunS subsystem the most because of its low distance between Container-Structure interface and between Container and walls of the satellite.

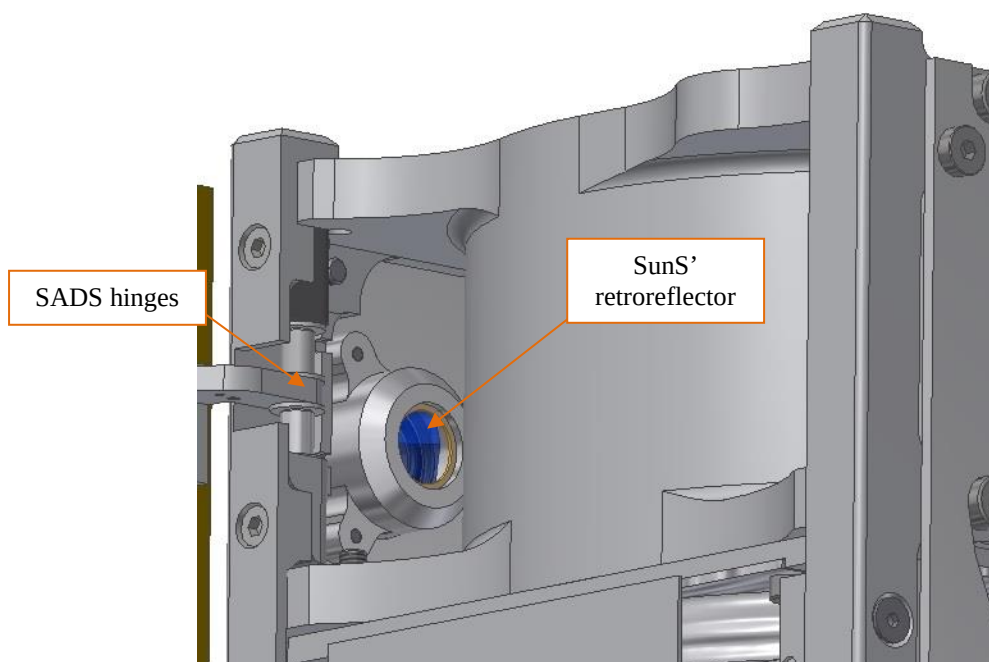




Figure 4-13 Potential collisions between Container and other subsystems.

4.4.2 SRM PLACEMENT

SRM design is fully described in [PW-Sat2-C-05.00-DT-CDR] document. Main configuration problem behind SRM project was to try not to increase resultant SAIL subsystem height. Finally, the whole assembly is 54 mm high measuring in the mounting points. Whole assembly has only one exit point to connect itself to PLD board – through connector presented in the Figure 4-14.

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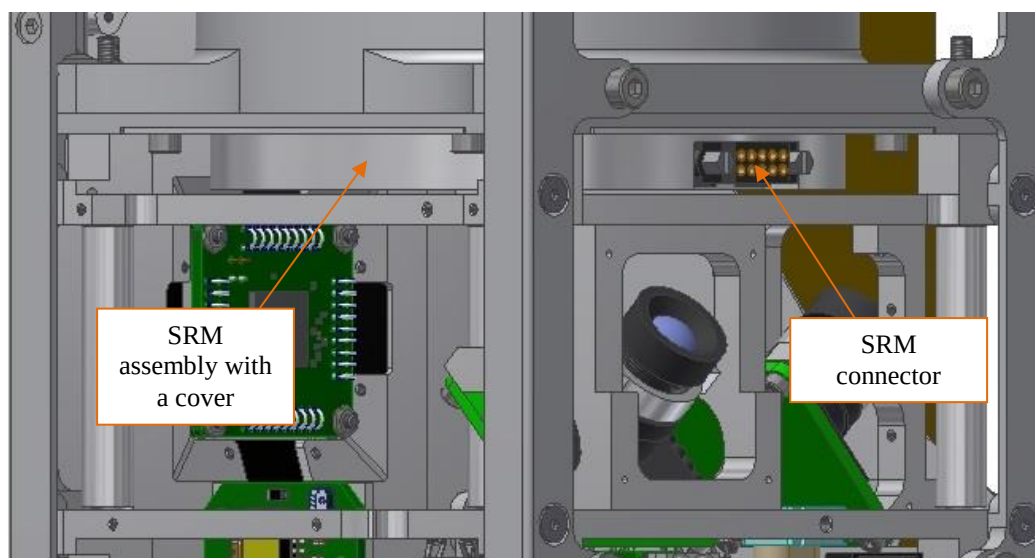


Figure 4-14 Potential collisions between Container and other subsystems.

4.5 SADS

4.5.1 SADS DESIGN

SADS design is summarized in [PW-Sat2-C-05.00-DT-CDR] document. It has changed several times during PW-Sat2's project. The final design consists of two hinges per side of the satellite (Y+ and Y-). Both pairs are placed on the X+ frame's rails. Each hinge consists of 2 pasted parts mounted to the Structure, a shaft, 2 springs fixed on the shaft, 4 washers and a sleeve.

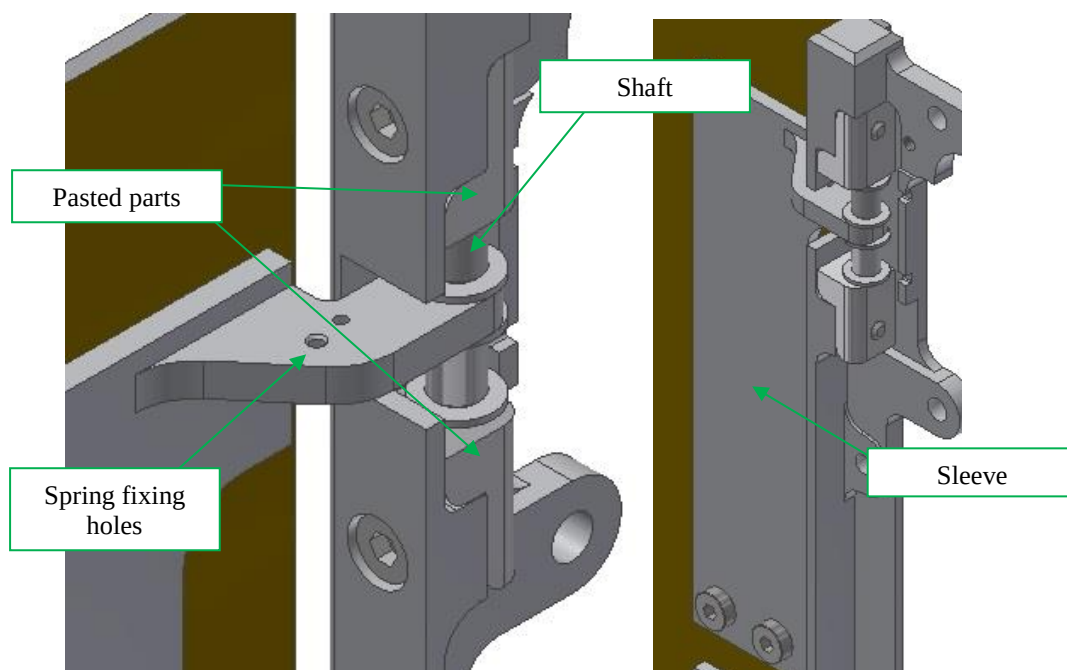




Figure 4-15 Hinges design.

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4.5.2 HINGES FINAL PLACEMENT

Hinges requires not only 2x38 mm of X+ frame's rail but also its whole width. At the Z- side of the satellite, SADS elements have to fit between PCB boards while on the other side of the satellite hinges have to fit between mounting points of the Container. Final hinges' positions are presented in Figure 4-16.

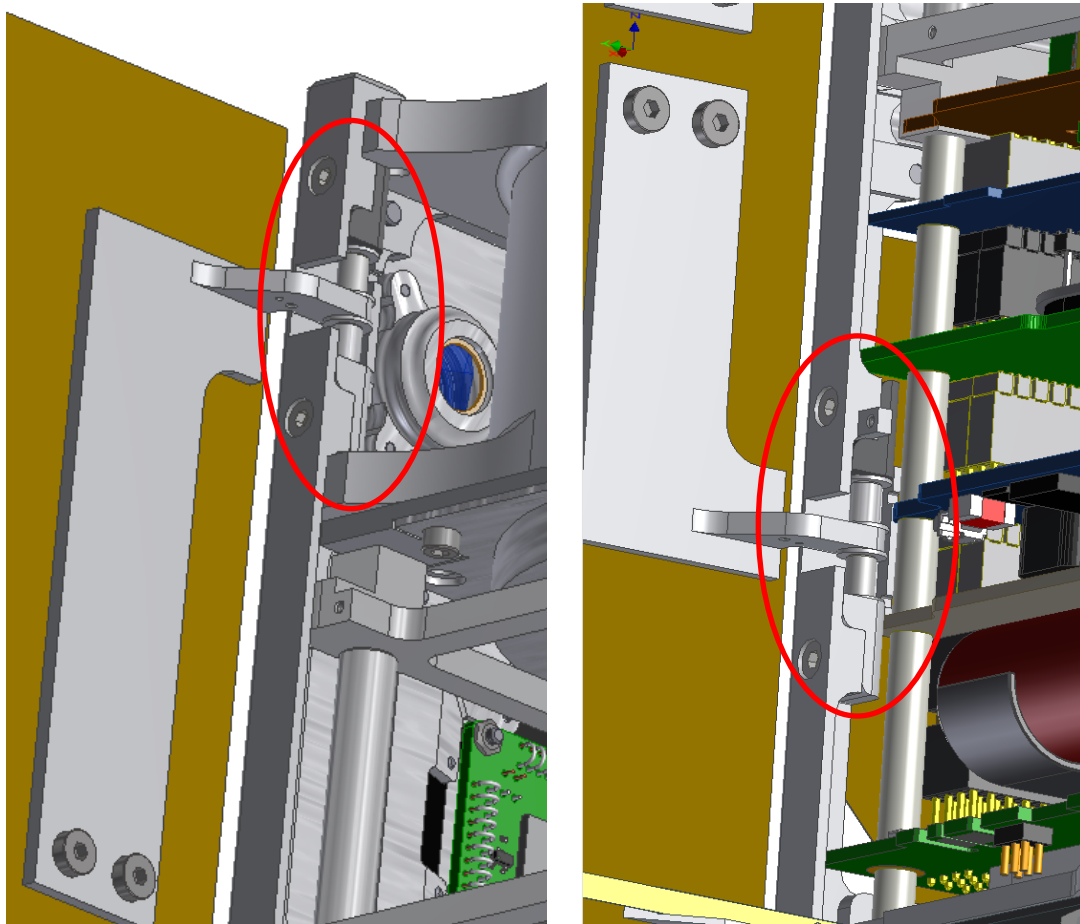




Figure 4-16 Z+ (left) and Z- (right) hinges placement.

4.5.3 CONNECTION TO SOLAR PANELS

The Solar Panel is connected with satellite by two sleeves which are parts of SADS. The shape and connection method is the result of the solar panel construction. There are two hinges on each Solar Panel which have to be mounted as wide as possible, but the only free space on the Panel, where holes for screws can be done, is in the middle of it. Because of that, the Solar Panel is connected with sleeves both by screws and glue. Two screws M3 for each sleeve are located in the middle of the Panel. The whole sleeves' surface is glued to the inner Solar Panel surface.

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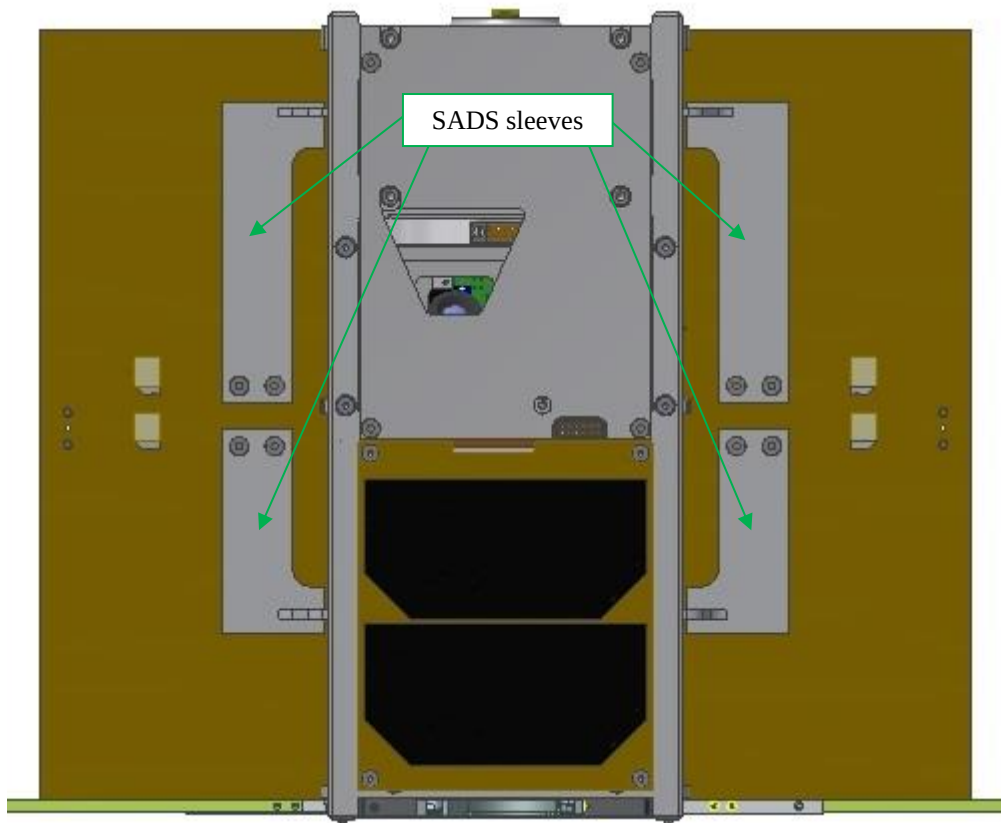
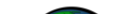



Figure 4-17 Hinges-Solar Panels interface.

4.5.4 2U SOLAR PANELS

In PW-Sat2 mission 4 sets of Solar Panels are used: 2 deployable 2U Solar Panels fixed with the SADS' hinges to the Structure and 2 1U Solar Panels which are fixed to the structure permanently. 2U Solar Panels are bought so their design is custom. However, given the circumstances of SADS' hinges-SP interface presented in previous section some modifications were required.

Firstly, all of the area covered by SADS' sleeves require to be covered with an adhesive so it should be free of any electronic traces. In addition to that, several mounting holes were needed: 4 through holes to mount the sleeves and 3 through holes to mount SARM's panel attachment (described in section 4.7). Final desired design is presented in the Figure 4-18.

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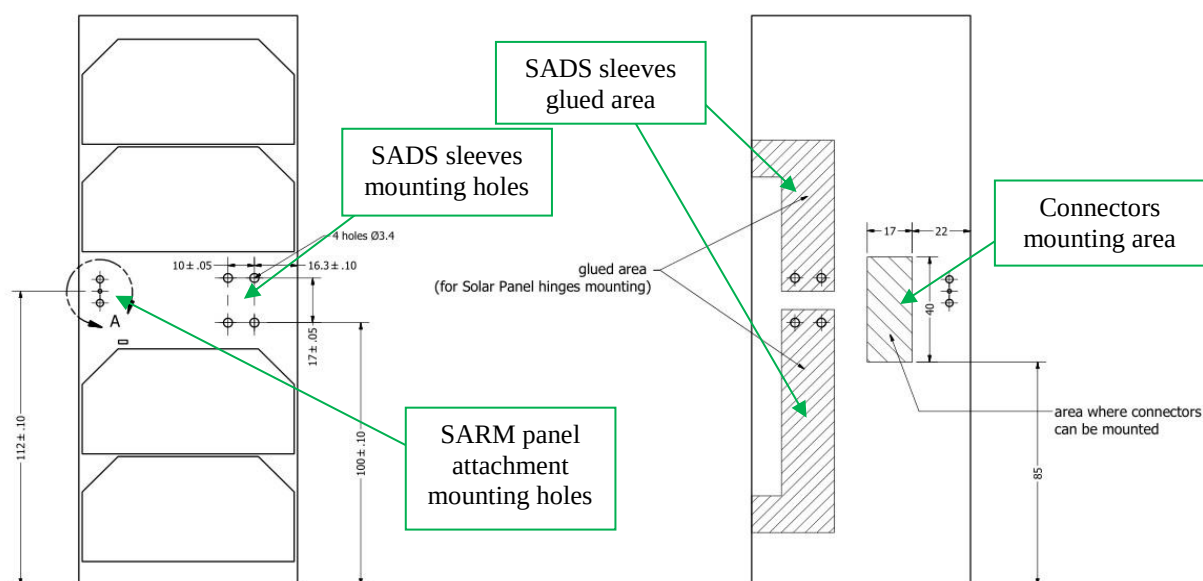


Figure 4-18 2U Solar Panels desired design.

4.5.4.1 Connectors placement

One additional area marked in the Figure 4-18 is the connectors mounting area. 2 connectors are placed on each of the Solar Panels (2U and 1U). Before 2U Solar Panels ordering process 3 connectors mounting area scenarios were tested. Main requirement to their placement is to achieve the shortest wires length from connectors to EPS board. Additionally, the wires should be easy to fix to the satellite during the integration process. The winning scenario is presented in the Figure 4-18. Two others assumed connectors to be fixed on top and on bottom side of the Panel. Both scenarios were rejected because of impossibility of using areas behind solar arrays of the panels.

4.5.4.2 Wires routs

From each of the connectors a harness is routed to the EPS module. The easiest and the only way to get into the board is through SADS' hinges excision in both Shields. The excision is shown in Figure 4-19.

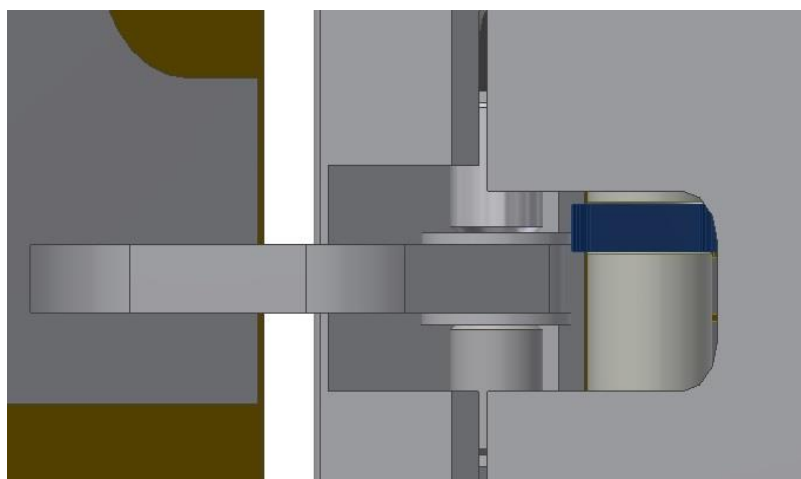




Figure 4-19 Excision through which the wires are routed.

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4.5.5 1U SOLAR PANELS

1U Solar Panels are also custom made. In this case no corrections have been made. Panel is fixed to the structure with 4 screws. In the Figure 4-20 X+ side Solar Panel (located below the SunS Wall) is shown. The second Solar Panel is placed on the opposite side of the satellite (below X- CAM Wall). 1U Solar Panel has an undercut for ribbon cable routed from solar arrays. Its 2 connectors have a similar placement to 2U Panels but in this case they are located very close to the EPS board so the wires' length can be really low.

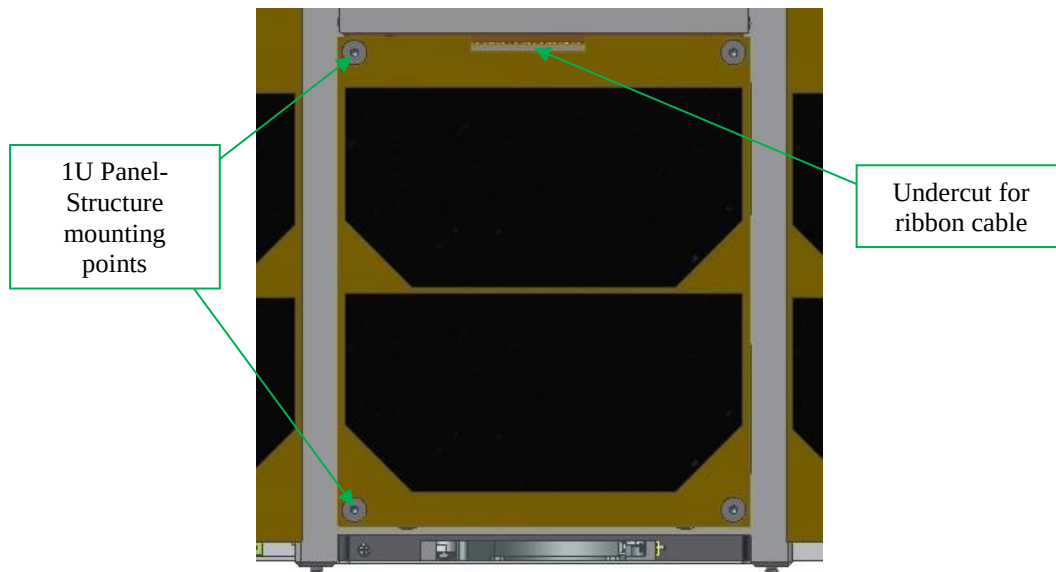




Figure 4-20 X+ 1U Solar Panel mounting.

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4.6 SARM

SARM subsystem design is summarized in [PW-Sat2-C-05.00-DT-CDR] document. Its primary task is to open the Solar Panels in the right moment after deployment from the QuadPack. Subsystem consists of little amount of elements located on the PLD board and panel attachments on the 2U Solar Panels. Before SARM's existence, CONF team were to decide where exactly the subsystem will be placed. Two scenarios were considered: first with Dyneema string fixed on the top and bottom part of the satellite and the second one with string fixed in the center part. The second option has been chosen.

The main requirements of SARM is to keep the same level of Dyneema string's route. It goes through its mounting elements on PLD board, excisions in Shields and finally is guided through the panel attachment on the 2U Solar Panel. Its route is presented in the Figure 4-21.

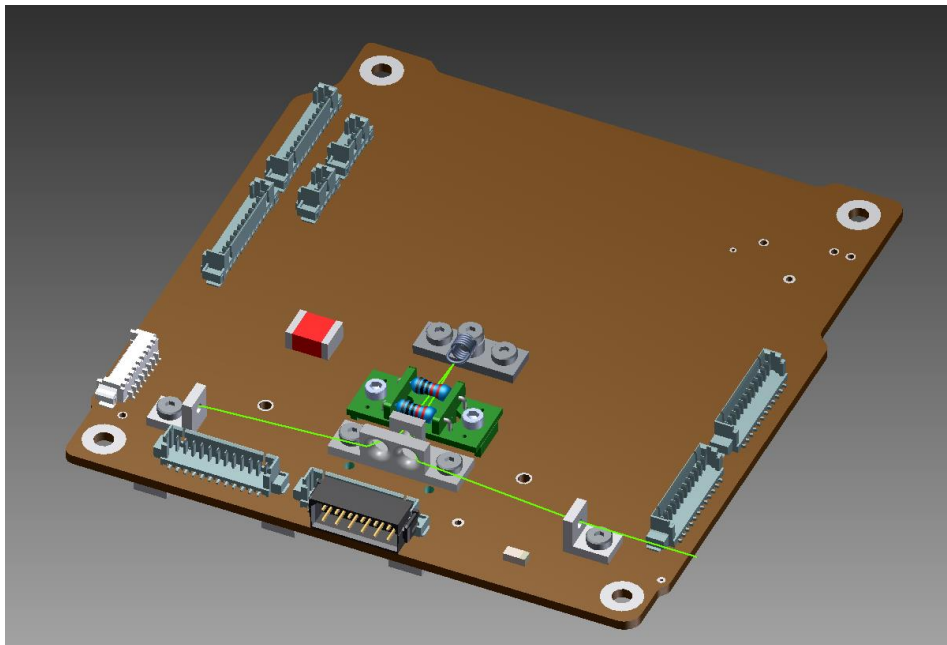




Figure 4-21 SARM's Dyneema string route on the PLD board (green line).

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4.7 SUNS

Sun Sensor design is also presented in [PW-Sat2-C-06.00-SunS-CDR] document. Part of the X+ Wall was planned as a space to attach experimental Sun Sensor. This Sun Sensor works with ADCS System and retroreflector. Image below shows an arrangement of elements on the Wall.

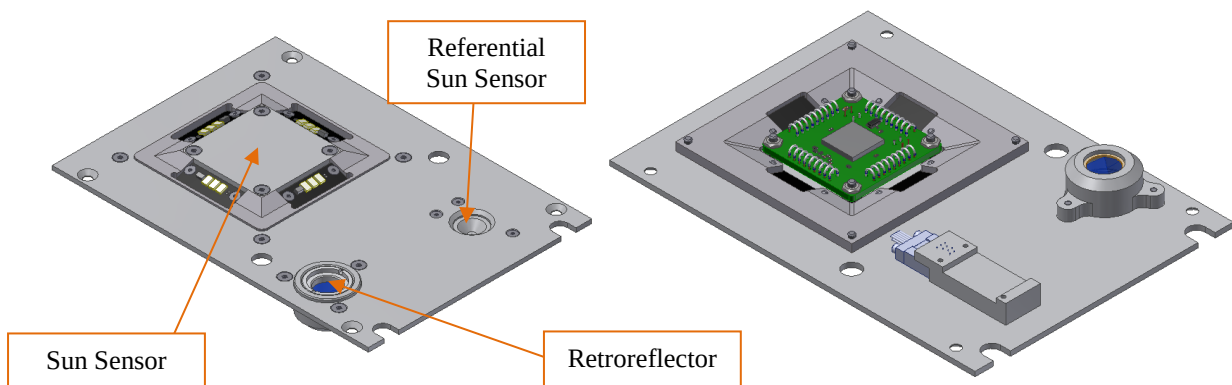


Figure 4-22 Both sides of the SunS assembly.

This configuration allows integration of the module with other parts of the satellite. Main reason for this location of the Sun Sensor and retroreflector is to fit them into free space around the container. In addition, it was necessary to fit connector inside the sensor and extract cables from both sensors to the PLD Plate. Mounting of the retroreflector was designed in a way that it provides dependable attachment to the Wall and it can fit next to a tray. Thickness of the Wall is 1,5mm.

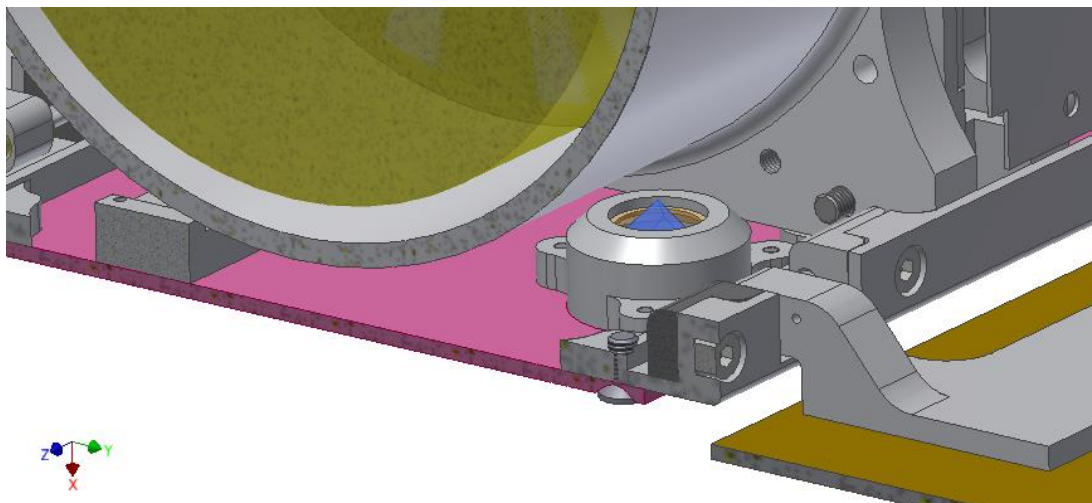




Figure 4-23 Retroreflector mounting.

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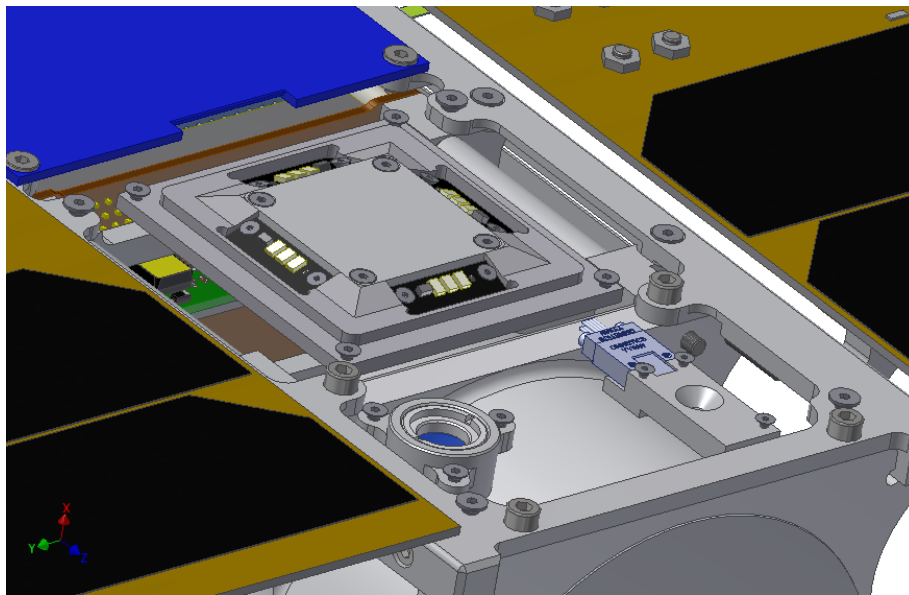


Figure 4-24 SunS' configuration (without SunS' Wall).

The SunS Wall unit is going to be assembled into one part before attaching it to the structure. The Wall has got four through holes to prevent container's screws from disruption in assembling process. Wall is fixed to a structure with four M2.5 screws.

According to the prototype, the highest element – SunS – is 3.71 mm high above rail of the satellite. Retroreflector reach up to 10.5 mm beneath the rail.

4.8 TCS

4.8.1 PCB STACK ISOLATION NECESSITY

Thermal Control System has not been described in previous sections because it does not have any actual elements in the satellite. TCS team has been responsible for preparing analysis of temperature distribution in the PW-Sat2. All analysis has been prepared in ESATAN. In every iteration worst case has been presented as a restrictive value. Worst case contains of two issues: sun pointing and cold case. All the results are presented in [PW-Sat2-C-09.00-TCS-CDR] document.

The most fragile pieces of PW-Sat2's equipment are PCB boards. Their temperature restrictions are presented in Figure 4-25. This case covers application of Y+ and Y- protective shields which should balance temperatures inside the satellite. Grey areas represent temperature ranges in which the boards work properly and green areas present temperature ranges acquired from ESATAN simulation.

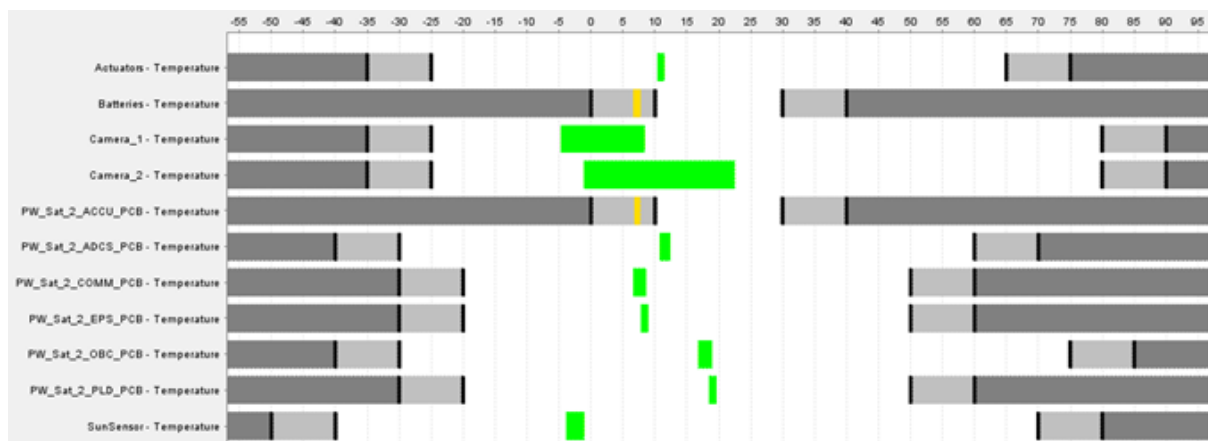


Figure 4-25 TCS analysis results for Y+ and Y- shields application.

In comparison to results presented in Figure 4-25 first temperature ranges (before applying shields) were much more worrying. In sun pointing case temperature inside the satellite, especially on most fragile accumulator, exceeded the maximum values drastically. In cold case those results were also not satisfying. Cold case results are presented in Figure 4-26.

Attribute: Temperature

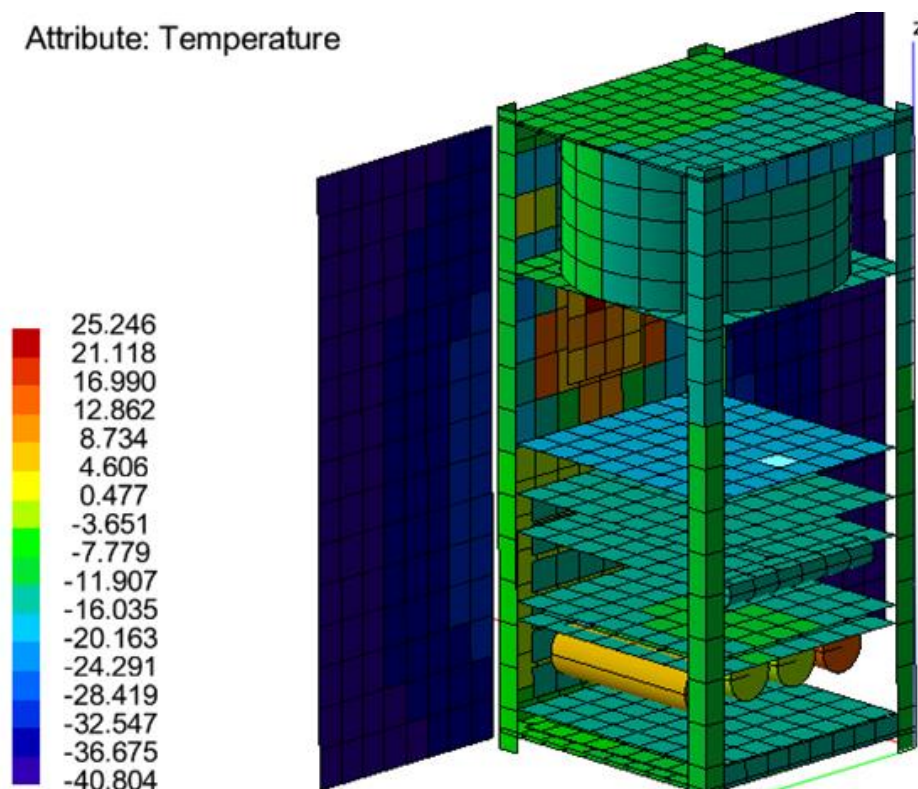




Figure 4-26 TCS analysis results without Y+ and Y- shields (cold case).

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4.8.2 Y+ AND Y- SHIELDS

Both Y+ and Y- shields are made from Aluminum 7075 with their masses equal – 17 and 15 g. Their main goal is to completely cover PCB Stack to balance temperatures inside the satellite. That is why they reach from ANT module to container. Shields poses several excisions. They should allow certain elements to pass through the shield's barrier. All the excision areas are presented in Figure 4-27. Smaller holes (1.8 mm diameter) visible in the figure are the mounting points to the main or secondary structure. Y- Shield has one extra excision, made exclusively to provide CAM2 line of sight.

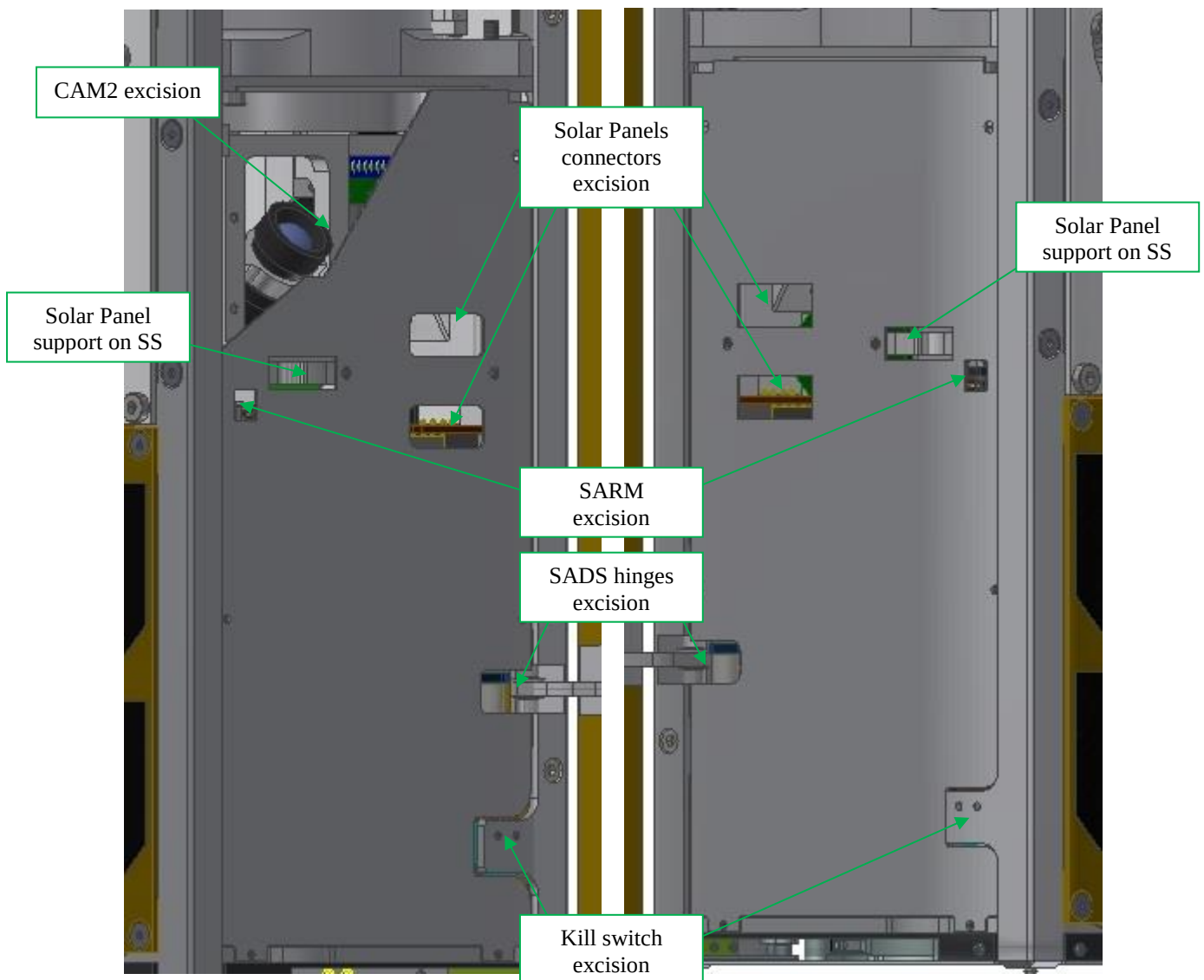




Figure 4-27 Y- (left) and Y+ (right) Shields and the excision areas.

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5 INTEGRATION PLANS

5.1 PW-SAT2 ASSEMBLING PLAN

This chapter covers the assembling plans for PW-Sat2 satellites. Plans contains of exact step-by-step integration procedures, necessary elements checklists and critical action comments. All of the steps are supported by assembling photographs or CAD models' screenshots. Integration plan should always be used during assembling procedure. There are couple of documents describing full integration procedure:

- SATELLITE Assembling Plan
- SAIL Production and Folding Plan
- SAIL Assembling Plan
- SADS Assembling Plan
- SS Assembling Plan
- SRSM Assembling Plan

Main Assembly procedure which describes step-by-step integration of the whole satellite is presented in [PW-Sat2-SATELLITE-Assembly-Plan] document.

5.2 SAIL PRODUCTION AND FOLDING PLAN

The procedure is presented in [PW-Sat2-SAIL-Production-and-Folding-Plan] document.

5.3 SAIL ASSEMBLY PLAN

The procedure is presented in [PW-Sat2-SAIL-Assembly-Plan] document.

5.4 SADS ASSEMBLY PLAN

The procedure is presented in [PW-Sat2-SADS-Assembly-Plan] document.

5.5 SS ASSEMBLY PLAN



The procedure is presented in [PW-Sat2-SS-Assembly-Plan] document.

5.6 SRSM ASSEMBLY PLAN

The procedure is presented in [PW-Sat2-SRSM-Assembly-Plan] document.

5.7 SARM ASSEMBLY PLAN

The procedure is presented in [PW-Sat2-SARM-Assembly-Plan] document.

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6 MASS BUDGET AND REQUIREMENTS FULFILMENT



6.1 MASS BUDGET

According to CubeSat standard the maximum mass of the 2U CubeSat is 2,66 kg and mass presented in Table 6-1 fulfils this requirement.

The table below contains the simplified satellite mass budget. All the elements of which the satellite is built are taken into account. Some of the elements are still not finally determined, so their mass can change. In the mass budget the worst possibility was placed.

Table 6-1 PW-Sat2's simplified mass budget (2016-11-28, values may change).



Component		Mass [g]	Mass + 20% [g]
PCB Stack	PCB	878.05	1053.66
	Mounting	48.76	58.51
Structure	Frames	120.00	144.00
	Others	81.46	97.75
	Secondary Structure	136.16	163.39
DM	SADS	330.42	396.50
	SRM	98.56	118.27
	SARM	6.71	8.05
	SAIL	671.41	805.69
SunS	Sun Sensor	85.73	102.88
Others	Wires	150.00	180.00
		2607.25	3128.70

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6.2 CENTRE OF GRAVITY AND INERTIAL PROPERTIES

All the information about center of gravity and inertial properties are obtain from Inventor 2014 program. In the future, measurement of those parameters on physical models are planned. Values are presented for 4 different scenarios of mechanisms deployment:

- No elements deployed
- ANT deployed
- ANT and SP deployed
- ANT, SP and Sail deployed

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6.2.1 NO ELEMENTS DEPLOYED

Scenario with no elements deployed is presented in the Figure 6-1. All analyses are made on simplified models.





Figure 6-1 COG measurement scenario with no elements deployed.

COG and inertial properties values are presented in Tables 6-2.

Table 6-2 COG and inertial properties measurement values - scenario with no elements deployed.

COG			ANT:	CLOSED				
x [mm]	y [mm]	z [mm]	SADS:	CLOSED				
1.78	-6.99	7.81	SAIL:	CLOSED				
Inertial Properties								
Principal [kg mm^2]			Global [kg mm^2]			COG [kg mm^2]		
I1	I2	I3	Ixx	Ixy	Iyy	Ixx	Ixy	Iyy
14292.99	14149.85	4630.66	14551.48	57.07	14309.54	14287.31	27.20	14155.23
Rx [deg]	Ry [deg]	Rz [deg]	Ixz	Iyz	Izz	Ixz	Iyz	Izz
0.12	-0.30	-11.22	-84.09	110.47	4756.02	-50.71	-20.80	4630.97

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6.2.2 ANT DEPLOYED

Scenario with no elements deployed is presented in the Figure 6-2.

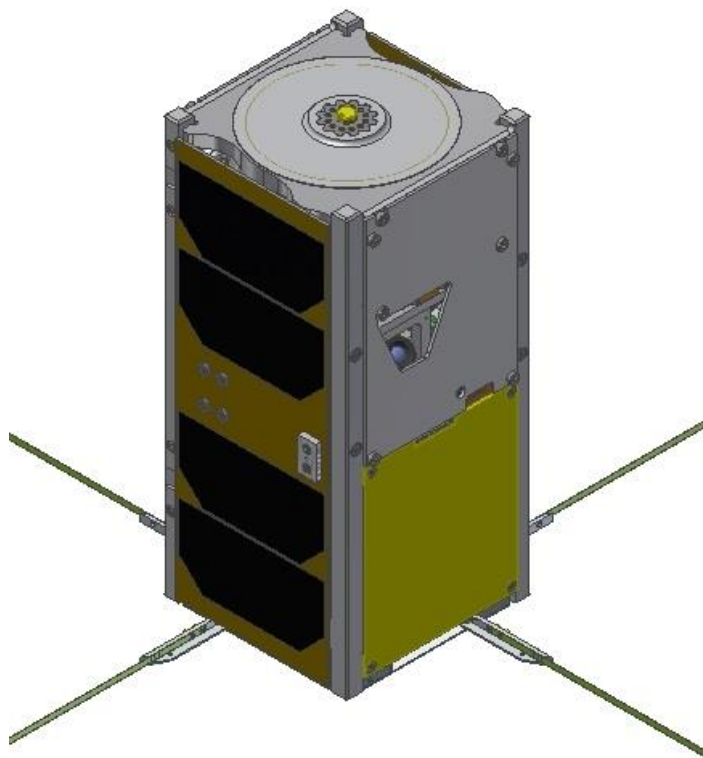
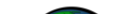



Figure 6-2 COG measurement scenario with ANT deployed.

COG and inertial properties values are presented in Tables 6-3.

Table 6-3 COG and inertial properties measurement values - scenario with ANT deployed.

COG			ANT:	OPENED				
x [mm]	y [mm]	z [mm]	SADS:	CLOSED				
1.78	-6.99	7.56	SAIL:	CLOSED				
Inertial Properties								
Principal [kg mm^2]			Global [kg mm^2]			COG [kg mm^2]		
I1	I2	I3	Ixx	Ixy	Iyy	Ixx	Ixy	Iyy
14253.12	14273.32	4802.38	14513.41	39.00	14411.97	14259.03	9.20	14267.09
Rx [deg]	Ry [deg]	Rz [deg]	Ixz	Iyz	Izz	Ixz	Iyz	Izz
0.13	-0.31	33.60	-83.50	105.90	4927.38	-51.24	-20.89	4802.70

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6.2.3 ANT, SADS DEPLOYED

Scenario with no elements deployed is presented in the Figure 6-3.

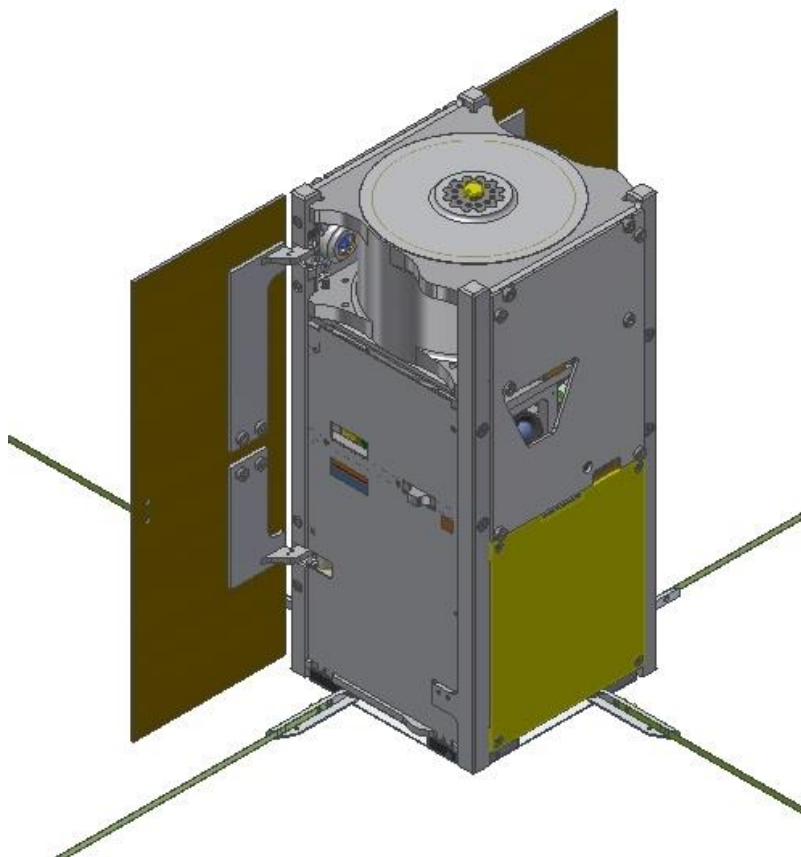




Figure 6-3 COG measurement scenario with ANT and SADS deployed.

COG and inertial properties values are presented in Tables 6-4.

Table 6-4 COG and inertial properties measurement values - scenario with ANT and SADS deployed.

COG			ANT:	OPENED				
x [mm]	y [mm]	z [mm]	SADS:	OPENED				
6.62	-6.98	7.57	SAIL:	CLOSED				
Inertial Properties								
Principal [kg mm^2]			Global [kg mm^2]			COG [kg mm^2]		
I1	I2	I3	Ixx	Ixy	Iyy	Ixx	Ixy	Iyy
15456.67	14745.76	6479.06	15710.98	118.31	14988.34	15456.54	7.35	14745.72
Rx [deg]	Ry [deg]	Rz [deg]	Ixz	Iyz	Izz	Ixz	Iyz	Izz
0.21	0.15	-0.59	-96.62	96.53	6701.47	23.62	-30.28	6479.23

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6.2.4 ANT, SADS, SAIL DEPLOYED

Scenario with no elements deployed is presented in the Figure 6-4.

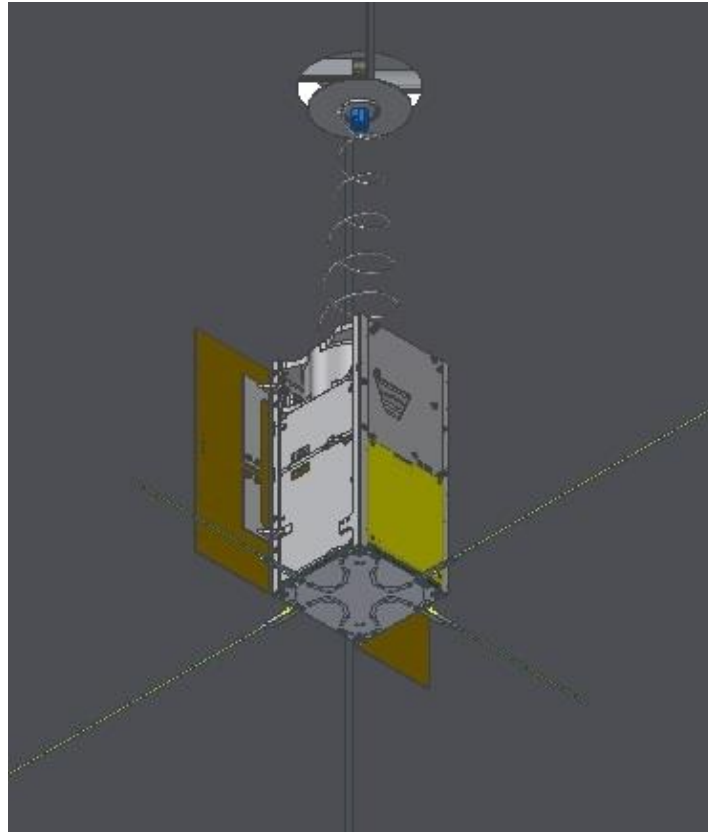




Figure 6-4 COG measurement scenario with ANT, SADS and SAIL deployed.

COG and inertial properties values are presented in Tables 6-5.

Table 6-5 COG and inertial properties measurement values - scenario with ANT, SADS and deployed.

COG			ANT:	OPENED				
x [mm]	y [mm]	z [mm]	SADS:	OPENED				
6.62	-6.82	82.70	SAIL:	OPENED				
Inertial Properties								
Principal [kg mm^2]			Global [kg mm^2]			COG [kg mm^2]		
I1	I2	I3	Ixx	Ixy	Iyy	Ixx	Ixy	Iyy
251748.31	250916.42	343778.37	268653.40	335.44	267940.13	251689.51	224.16	250982.86
Rx [deg]	Ry [deg]	Rz [deg]	Ixz	Iyz	Izz	Ixz	Iyz	Izz
-0.08	-0.52	-16.39	-518.77	1265.62	343993.38	830.34	-124.23	343770.72

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6.3 BILL OF MATERIALS

Full summary of the materials used in the PW-Sat2 satellite is presented in the [PW-Sat2-C-05.03-DT-Bill-of-Materials] document. All those materials meet the CubeSat Design Specification's [1] material outgassing requirements.