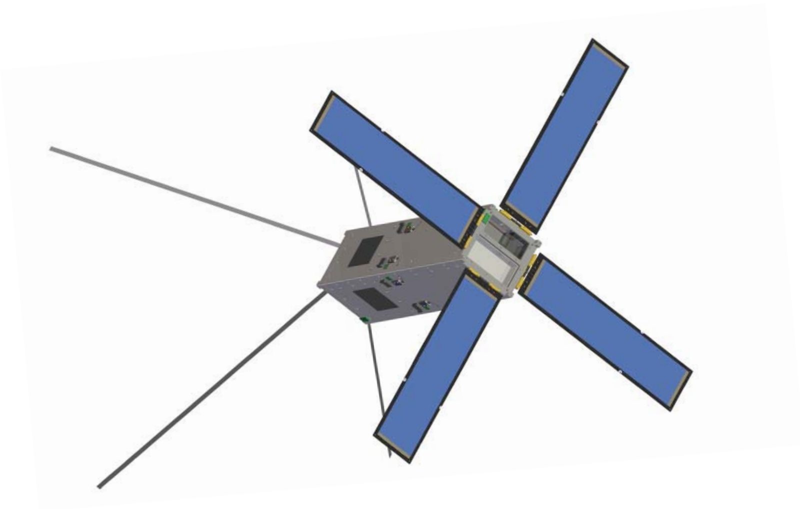
Master Thesis paper

Mechanical Design and Arrangement of nanosatellite Delfi-n3Xt



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Preface

When starting my Master's phase, I needed to make a decision for which one. I came across a project called Delfi-C^3, which was run as Master thesis project. As the design and development was almost completely finished by the time of actual start on literature study and thesis work, I was very glad to be invited to the kick-off meeting of Delfi-n3Xt.

As I indicated preference for working on the structural subsystem or the electrical power subsystem, and Robert Teuling had already started preliminary work on the electrical power subsystem, I started on the structural subsystem.
It was quite hard to imagine what the satellite would look like in the beginning and what kind of subsystems and payload would eventually fly. At this time the designs are converging and I hope to see the first flight hardware in the near future.
It has been a very rewarding experience to be part of this project, learning about different aspects and making decisions in the project. The result from various decisions can already be observed. Although I would have really liked to test the hardware as well, all phases leading to this point have been gratifying too.

Delfi-n3Xt is the work of a team and I would hereby like to thank a few people of the team. First of all my supervisor Geert Brouwer for all the input and feedback on my work, Jasper Bouwmeester as project manager, always available for the many problems encountered and joining in thinking of a solution and Mattias Genbrugge for the amount of requirements processed and the revision of several documents. The team I have worked with for all discussions and the sharing in fun and sometimes frustration.

Besides the team I would like to thank my family and friends, in particular my sister Wendy and boyfriend Lieuwe for a listening ear, writing difficulties and all their love and support.

Although I would have liked to stay longer on the project, the time for moving on has come and I hope to support the team in the future.

Jennifer Go

Delft, June 2009

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Abbreviations

ADCS	Attitude Determination and Control Subsystem
AIT	Assembly, Integration and Testing
AIV	Assembly, Integration and Verification
AIVT	Assembly, Integration, Verification and Testing
BOP	Bottom Panel
CDHS	Command and Data Handling Subsystem
CoM	Centre of Mass
COMMS	Communication Subsystem
COTS	Commercial Off-The-Shelf
DAB	Deployment and Antenna Board
DIMES	Delft Institute of Microsystems and Nanoelectronics
DNX	Delfi-n3Xt
EPS	Electrical Power Subsystem
GSE	Ground Support Equipment
GSN	Ground Support Network
I	Moment of Inertia
ICD	Interface Control Document
ISIPOD	Innovative Solutions In Space Picosatellite Orbital Deployer
ISIS	Innovative Solutions In Space
ITRX	ISIS Transceiver
MAB	Modular Antenna Box
MechS	Mechanisms Subsystem
MGSE	Mechanical Ground Support Equipment
MPS	Multifunctional Particle Spectrometer
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory)
OBC	On-Board Computer
PCB	Printed Circuit Board
POD	Picosatellite Orbital Deployer
P-POD	Poly-Picosatellite Orbital Deployer
PTRX	Primary Transceiver
SDM	Solar cell Degradation Measurement
SLR	Standard List of References
SP	Solar Panel
SPLASH	SPace fLASH
SSE	Space Systems Engineering, Chair of
STS	Structural Subsystem
STX	S-band Transmitter
$T^3\mu PS$	TNO, TU Delft and UTwente Micro Propulsion System
TBC	To Be Confirmed
TBD	To Be Determined
TCB	Test Connector Board
TCS	Thermal Control Subsystem
TFSC	Thin Film Solar Cells
TN	Technical Note
TNO	Dutch centre for Applied Scientific Research
TOP	Top Panel
TRX	Transceiver
TX	Transmitter
UHF	Ultra High Frequency
VHF	Very High Frequency
XPOD	eXperimental Push Out Deployer

1 Introduction

This chapter gives an introduction into CubeSats, the Delfi-program with emphasis on Delfi-n3Xt and the Structural Subsystem (STS) of satellites.

1.1 CubeSat

In 1999 California Polytechnic State University and Stanford University developed specifications for a miniaturized satellite with a volume of one litre. The project led by professor Bob Twiggs and professor Jordi Puig-Suari was called CubeSat. The standard they thought of was 10 cm x 10 cm x 10 cm (X x Y x Z). The CubeSat can be launched piggyback to larger satellites. Interface between the CubeSat and the rocket is a Picosatellite Orbital Deployer (POD). Most PODs use a spring mechanism to deploy the CubeSat. During ejection the CubeSat slides over guiderails within the POD. To protect the CubeSat from damage during launch, standoffs were added to the CubeSat, making the total volume 100 mm x 100 mm x 113.5 mm. Without the standoffs, components directly touch the deployer during launch. This can give damage when putting the satellite in the deployer or due to vibrations during launch.
With the market of interest already soon asking for a larger standard, also the two-unit CubeSat (100 mm x 100 mm x 227 mm) and the three-unit CubeSat (100 mm x 100 mm x 340.5 mm) was defined.
The idea behind CubeSats is that they have a short development time until launch (1-3 years) and are cheaper than larger satellites.

1.2 Delfi-program

The Delfi Program started as a design synthesis exercise (final third year project of Aerospace Engineering at TU Delft) with Delfi-1 in 1999. The name Delfi originates from Delft with as diminished form an –i at the end, stating the small size of the satellite. Delfi-0, the baseline satellite for Delfi-1, and Delfi-1 were of size 35 cm x 35 cm x 35 cm and were never more than preliminary studies. The year after, in 2000, another four studies were done as design synthesis exercise, of which the Delft University Satellite DEUS was chosen to be further investigated. DEUS also never made it further than a preliminary study.
In October 2004 Barry Zandbergen, staff member of Space Systems Engineering (SSE) TU Delft, heard of CubeSats at the International Astronautical Congress (IAC) in Vancouver. Having found several interested staff members and students, they started what was to become Delfi-C^3 in November 2004. The size of Delfi-C^3 is a three-unit CubeSat. Delfi-C^3 was launched on 28 April 2008.
Having such a success with Delfi-C^3, in October 2007 it was decided to continue the project with another satellite, which was to become Delfi-n3Xt, and concepts for extending to a whole family of Delfi-satellites, under the heading Delfi Program. The Delfi Program objective can be split in three general objectives [Standard List of References (SLR) 0001]: Education, technology advancement and platform advancement.

1.3 Delfi-n3Xt

Delfi-n3Xt is the successor of Delfi-C^3 and its launch is foreseen for mid 2010 (To Be Confirmed (TBC)) [SLR 0016]. As Delfi-C^3 Delfi-n3Xt is a three-unit CubeSat. The mission of Delfi-n3Xt is related to the Delfi Program objectives, which are stated in paragraph 1.2. The educational objective for Delfi-n3Xt is to have at least 20 MSc theses and 10 BSc theses as result from work on Delfi-n3Xt. For technology advancement Delfi-n3Xt has five payloads onboard:

1. $T^3\mu PS$, a cool gas MicroPropulsion System (μPS) developed by the Dutch centre for Applied Scientific Research (TNO), Delft University of Technology (TU Delft) and University of Twente (UTwente), in short $T^3\mu PS$
2. MPS, a Multifunctional Particle Spectrometer (MPS) from cosine research
3. SDM, a Solar cell Degradation Measurement (SDM) experiment measuring the change in performance of solar cells from the Delft Institute of Microsystems and Nanoelectronics (DIMES)
4. ITRX, a high-efficiency Transceiver (TRX) from Innovative Solutions In Space (ISIS), in short ITRX
5. SPLASH, a latch-up experiment called Space Flash (SPLASH) from the National Aerospace Laboratory (NLR)

The platform advancements for Delfi-n3Xt are:

- implementation of three-axis active attitude control
- providing high data-rate (≥9.6kbps) pass links
- a single-point-of-failure-free Electrical Power Subsystem (EPS) with energy storage

Besides the platform advancements mentioned, Delfi-n3Xt will not make use of a Commercial-off-the-Shelf (COTS) structure or flightboard. In comparison, Delfi-C^3 made use of the three-unit COTS structure and the FM430 flightboard of Pumpkin.

1.4 STS

The STS is the structural subsystem of the satellite and functions as protection of the satellite during launch and providing mechanical fastening for components. The STS is one of the most important subsystems in the satellite, since when the STS fails during launch, the mission may be lost. Furthermore the design of the STS determines the inside available volume for other subsystems and components.
The design for the STS of Delfi-n3Xt should have more accessibility to reduce the time needed for assembly, integration and testing, and improve handling capabilities with respect to the STS of Delfi-C^3. As a systems engineer for the STS goals are to design, develop and test a custom STS for Delfi-n3Xt.

Different to individual thesis work, working in a project team means that for solving a problem several people need to give input. This gives more insight on the various subsystems and is very valuable. On the other hand the design is dependent on inputs of system engineers and payload partners and decisions are therefore sometimes an extensive process.
To guarantee project continuation and promotion, writing conference papers (Appendix C) and attending conferences and workshops is part of the work. This is also done by giving presentations and handing out assignments for bonus points in collaboration with relevant Master courses given at Delft University of Technology. The latter has been done for instance for the course Spacecraft Structures.

1.5 Document structure

This document reflects the work done as one of the systems engineers on the STS over the last year. First the method of systems engineering is described in Chapter 2, continued with the various subsystems of Delfi-n3Xt and their placement within the satellite in Chapter 3. Chapter 4 discusses the design for the STS of Delfi-n3Xt. Chapter 5 gives some conclusions and recommendations for future work on the project.
In the appendices documents relevant to the work done on the STS are enclosed.

2 Systems Engineering for Delfi-n3Xt

To fulfil its mission, Delfi-n3Xt has several subsystems. Paragraph 2.1 gives an overview of these subsystems. Paragraph 2.2 discusses the design approach used for Delfi-n3Xt.

2.1 Satellite Subsystems

At the kick-off for Delfi-n3Xt the only thing known was that there would be another student nanosatellite, preferably as Delfi-C[3] a three-unit CubeSat. Starting from the Delfi-n3Xt mission concept, the architecture as shown on Figure 2.1 Left was generated.

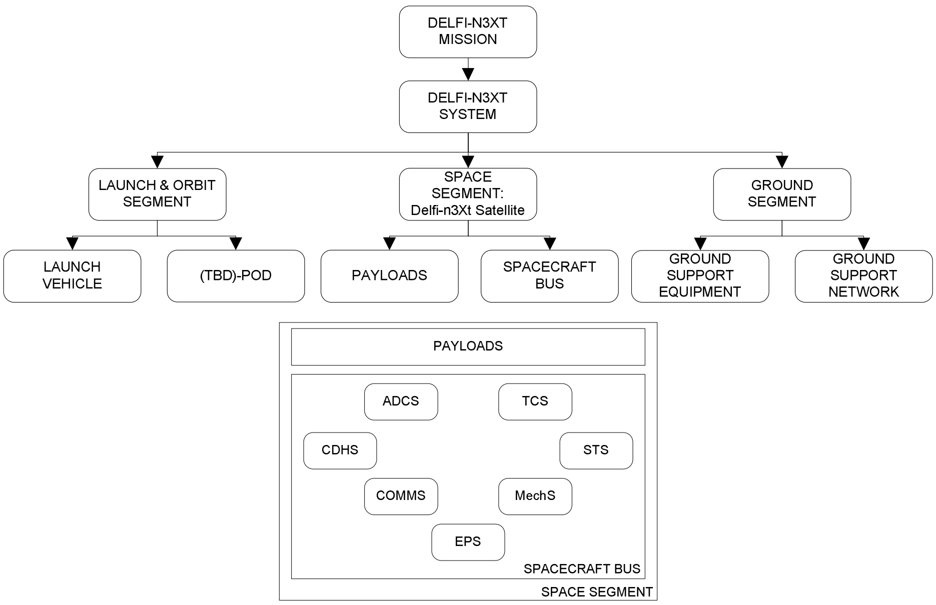

Figure 2.1 Left: Mission Segments [SLR 0316]; **Right:** Spacecraft Subsystems [SLR 0316]

For the start of the project the main focus has been the space segment. The space segment has been subdivided in payloads and spacecraft bus. For payload several Dutch companies were contacted. The spacecraft bus is modelled as shown on Figure 2.1 Right. In February 2008 a mission definition report was published [SLR 0001], presenting the mission concept. As can be read in [SLR 0001] the space segment is a three-unit CubeSat.
Table 2.1 shows the principal functions of the various subsystems of the spacecraft bus.

Table 2.1: Spacecraft Subsystem functions [SLR 0316]

Subsystem	Abbreviation	Principal functions
Attitude Determination and Control Subsystem	ADCS	Determine and control attitude, point and manoeuver the satellite, manage angular momentum
Command and Data Handling Subsystem	CDHS	Communicate with ground, support satellite tracking
Communication Subsystem	COMMS	Process commands, perform data processing/formatting, provide computing power
Electrical Power Subsystem	EPS	Generate and distribute power
Mechanisms Subsystem	MechS	Provide motion possibility to structural parts
Structural Subsystem	STS	Provide structural integrity
Thermal Control Subsystem	TCS	Control equipment temperature

2.2 Requirements STS

The Delfi-n3Xt mission concept makes use of systems engineering to get the least amount of iteration loops. Typical activities in a systems engineering process during the full life cycle of design, development and verification are shown in Table 2.2 [SLR 0364].

Table 2.2: Systems Engineering Life Cycle

Mission Need Definition
1. Identify and formulate need
Concept Exploration
2. System analysis
3. Requirements definition
4. Conceptual designs
5. Technology & risk assessment
6. Preliminary cost, schedule & performance of preferred concept
Demonstration & Validation
7. Concept design
8. Subsystem trade-offs
9. Preliminary design
10. Prototyping, test & evaluation
11. Integration of manufacturing & supportability considerations into design

To get a well-functioning satellite requirements have been set up. This document focuses on the structural and mechanical requirements. The requirements set for the satellite and top level STS design are presented in [SLR 0169] (Appendix B). The requirements have been generated and numbered in accordance with [SLR 0317]. Requirements of importance for the top level STS design have been divided into six categories:

1. General Requirements
2. Constraints
3. Functional Requirements
4. Performance Requirements
5. Interface Requirements
6. Payload Requirements

The requirements are directive for the design of the STS to get a design which fulfils the mission objectives. To prove that the requirements are met, the satellite needs to undergo several tests. Important tests for the STS are the mechanical test and the vibration test as described in [SLR 0169].

3 Arrangement of Delfi-n3Xt

With the various subsystems and payloads known, verification has been done to see whether it all fits in a three-unit CubeSat. Paragraph 3.1 presents the subsystems of Delfi-n3Xt in more detail. Paragraph 3.2 gives the placement requirements, Paragraph 3.3 gives the mass estimations and finally Paragraph 3.4 shows how the subsystems together with the payloads have been arranged within Delfi-n3Xt.

3.1 Subsystems Delfi-n3Xt

As can be read in paragraph 1.3, Delfi-n3Xt is a three-unit CubeSat. Delfi-n3Xt makes use of the coordinate system as shown in Figure 3.1 and as described in [SLR 0141] (Appendix A).

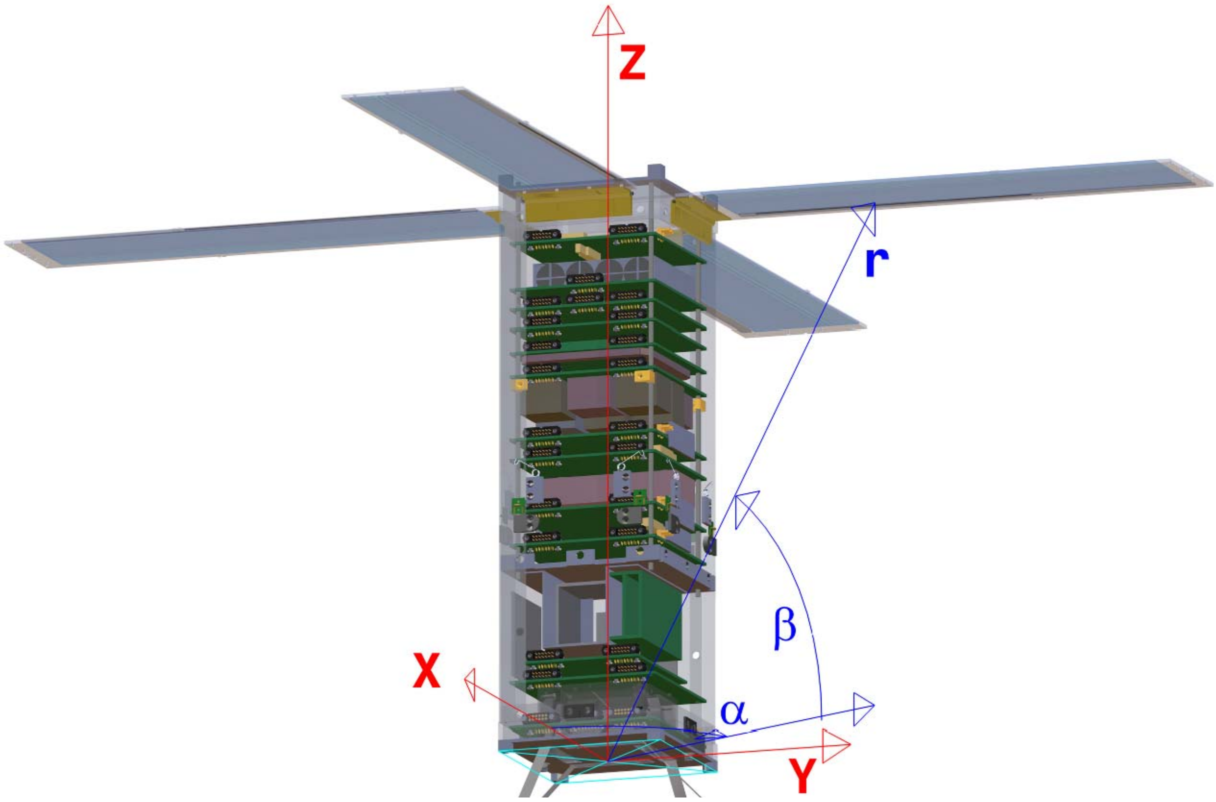

Figure 3.1: Coordinate system Delfi-n3Xt [SLR 0141]

The orientation of Delfi-n3Xt is Sun-pointing [SLR 0001], having all solar panels pointed in the direction of the Sun and keeping this position as much as possible. In line with [SLR 0141] this is the Z^+-side of the satellite.
There are seven subsystems and five payloads for Delfi-n3Xt. The paragraph gives the characteristics of the subsystems and payloads.

- Attitude Determination and Control Subsystem (ADCS): sensors and actuators, electronics
  ADCS uses two Printed Circuit Boards (PCBs): one for sensors and actuators, one for electronics. Further ADCS makes use of two actuators (magnetorquers) placed on the inside of the outer structure, a Sun sensor package placed on the Sun-pointed side, and twelve sensors (photodiodes) placed two by two on every side.
- Command and Data Handling Subsystem (CDHS): electronics
  One PCB, also called the On-Board Computer (OBC) board, is used for the main electronics of CDHS.
- Communication Subsystem (COMMS): electronics, antennas
  COMMS will make use of two different sorts of communication frequencies. One high frequency S-band, one lower frequency Ultra High Frequency (UHF)/Very High Frequency (VHF) band. The architecture in electronics differs and chosen is to have one PCB for the lower frequencies and

one for the high frequency. Antennas are used to link the signals to Earth. There are three (TBC) S-patch antennas placed on the outer structure. For UHF/VHF use is made of Modular Antenna Boxes (MABs) as used for Delfi-C^3. The MABs are fastened on the Deployment and Antenna Board (DAB), which facilitates the deployment circuitry for the antennas and the EPS solar panels, and furthermore the phasing circuit for the antennas. The phasing circuit gives the correct phase difference to the signals, which is needed as a consequence of using multiple antennas.

- Electrical Power Subsystem (EPS): electronics, batteries, solar panels, test connectors
  The EPS makes use of two PCBs, one for the electronics, one for the batteries. Test connectors are needed to test the system in full configuration. Further to supply power and recharge the batteries, four solar panels with seven solar cells each are used.
- Mechanisms Subsystem (MechS): deployment systems
  The MechS is concerned with all facilities for deployment of parts and is also referred to as Hold Down and Release Mechanism (HDRM). This includes the deployment circuitry, but also e.g. the hold down mechanisms and hinges to give the correct angle after deployment. The deployment circuitry does not require a whole PCB and is combined with the COMMS DAB (see paragraph 3.1 COMMS).
- Structural Subsystem (STS): outer structure, bottom, intermediate and top panel
  The STS is the primary structure protecting the satellite during launch and from the space environment. Further the STS supports the subsystems and payloads of the space segment. To fulfil these functions the STS consists of an outer structure composed of two unsymmetrical U-profiles, a Bottom (Z^--side of satellite) Panel (BOP) and Top (Z^+-side of the satellite) Panel (TOP). The MPs makes use of an Intermediate Panel (IP) for support to the structure.
  Threaded rods are used to integrate most subsystems and payloads to a PCB stack. The PCB stack is fastened to the TOP and intermediate panel. For the subsystems making use of the BOP fastening is done by means of long bolts.
- Thermal Control Subsystem (TCS): passive thermal control
  The satellite uses a passive thermal control system for regulating the temperature of the satellite. This can be done for instance with thermal control tape. For now is assumed a thin layer of thermal control tape on the bottom and top panel and the outer structure of the satellite. On the inside passive systems, such as cool fins on the communication boards can be considered. For thermal control on the inside of the satellite can be assumed that the influence on the volume of the subsystems is minimal.

The five payloads have been assigned a volume as shown in the volume budget [SLR 0303] (Appendix D). Characteristics of the payloads with respect to placement and the STS are presented:

- Payload $T^3\mu PS$: electronics, valve
  The microthruster is a cool gas microthruster system, delivering thrust in the order of 1– 100 mN. The system is integrated on one PCB and requires an outlet in the outer structure of the satellite for its valve.
- Payload MPS: electronics, window
  The MPS measures incoming radiation particles using a window of 300 micron thick. With 500 grams, the payload is fairly heavy, taking about a seventh of the total weight of the satellite. The MPS requires a structure for support. In collaboration between cosine and Delfi-n3Xt has been decided to use an intermediate panel as support for the MPS. This reduces the total volume needed for the MPS, otherwise requiring a separate support to the structure of the satellite.
- Payload SDM: electronics
  SDM makes use of the solar flux to measure the performance of the solar cells. The payload needs to be oriented perpendicular to the incoming solar radiation.
- Payload ITRX: electronics, antennas
  This payload is based on the transceiver of Delfi-C^3 with as main improvement a high efficiency power amplifier (Delfi-C^3 used a linear power amplifier), using one PCB. ITRX shares the same MABs as used by COMMS.
- Payload SPLASH: electronics
  SPLASH has a footprint of 50 mm x 50 mm and has been integrated with the OBC board of CDHS, since the OBC does not require the entire PCB either.

For the commanding of and providing power to subsystems and payloads CDHS and EPS use local EPS and CDHS circuitry. The circuitry is placed on the PCBs. A redundant 18 pins power and data bus is used with matching connectors on the PCBs. The connectors for the power and data bus are from the M80-540 series of Harwin. To get power from the solar panels, EPS makes use of a 6 pins connector, also from the M80-540 series. Other electrical wiring foreseen is for the deployment circuitry of MechS and possibly separate wiring at the top of the satellite for SDM and the ADCS Sun sensor package. Connectors for this wiring will be chosen from the M80-540 series as well. Between the communication boards and antennas radio frequency connectors and wiring is used. However on the precise type of connector, no decision is made yet. For now connectors from M80-313 have been taken.
To use the available space as optimal as possible 4 mm has been reserved between the outer structure and the PCBs of the subsystems and payloads. The PCBs are 90 mm x 90 mm x 1.6 mm in dimensions and 10.5 mm in width has been reserved on the X^+-side for the placement of the system bus connectors (see Appendix E). Further the PCB hole layout for the threaded rods and long bolts have been made symmetrical.

3.2 Placement

Several of the subsystems of paragraph 3.1 and payloads have a requirement or preference for placement within the satellite. These are treated in this paragraph.

ADCS
The Sun sensor package is placed on the Sun-pointed side Z^+ and is attached to the TOP. Further ADCS has three magnetorquers, these need to be placed orthogonal each other. Two of the magnetorquers are placed on the inside of the STS outer structure. There is no placement requirement for these magnetorquers with respect to Z-location. The two PCBs for ADCS have no placement requirement, but advisable is to keep them together.

CDHS
There is no requirement with respect to placement in the satellite for the CDHS PCB.

COMMS
As mentioned, Delfi-n3Xt makes use of MABs for the UHF/VHF antennas of COMMS. A similar configuration as for Delfi-C^3 is used with the antennas deploying through the BOP. Delfi-n3Xt makes use of four MABs (in comparison, Delfi-C^3 made use of eight MABs, four at the TOP and four at the BOP-side). No redesign for the MABs with respect to the MABs of Delfi-C^3 is expected.
For S-band S-patch antennas are placed at the height of the MPS. This location is chosen as it is considered to disturb the least subsystems at this location.
The two PCBs for COMMS are advised to be kept together. Influence of the wire lengths on the frequency is negligible. However the boards may influence other subsystems which have high frequency components and vice versa.

EPS
The solar panels are fold out after orbit insertion 90° to Sun-pointing position. Before orbit insertion the solar panels are fastened to the body of the satellite. In this phase the solar cells are faced outwards, so that some power can be received from the Sun before solar panel deployment. The solar panels are directly connected on the EPS electronics PCB for maximum efficiency. To be able to test the satellite in full configuration, the PCB with the test connectors should be placed such that the connectors are not interfered by the solar panels in hold down phase. The Test Connector Board (TCB) is placed low on the Z-axis, with the TCB accessible through a side of the BOP. This is only possible when placing the TCB around the MABs of COMMS. This construction requires the MABs to be placed closer together on the DAB than was the original configuration of the MABs for Delfi-C^3. Changes in the antenna pattern for COMMS in this arrangement are negligible.

MechS
For the hold down of parts (solar panels and antennas) Dyneema wires are used, having high strength and being easy to melt through. For deployment after orbit insertion, the wire is burnt by a resistor. The solar panels of EPS use hinges situated at the sides of the TOP for deployment. There is an optimum distance for location of the Dyneema wire starting from the location of the hinge. The location has to do with deflection of

the solar panel (see [SLR 572]). Large deflections may damage the solar panel to the deployer's wall or can jam the satellite in the deployer before orbit insertion.
Besides Dyneema wires and deployment circuitry, hold down provisions in the form of position blocks and protection bolts are implemented for the solar panels.

STS
The BOP and the TOP both have support feet to protect the satellite during integration, giving a sturdy footing, and to protect during launch. The BOP is situated at the Z^--side of the satellite and the TOP at the Z^+-side of the satellite. The outer structure is fastened with bolts to the BOP and TOP. The intermediate panel is added as structural support for the MPS and its placement requirement is linked to the position of the MPS.

Payload $T^3\mu PS$
The microthruster is placed as close as possible to the Centre of Mass (CoM) of the satellite. This has been done out of an ADCS point of view [SLR 0142]. In the design phase, the CoM has been calculated by detailing the subsystems as much as possible with available mass and/or material information. Of course the location is an estimate and as such the position of the microthruster should be observed for changes up to integration. Further the valve of the $T^3\mu$PS has been oriented to the opposite site of the power and data bus due to structural arrangement.

Payload MPS
For the MPS it is of importance that the field of view of the MPS is not obstructed by parts, e.g. solar panels or antennas. Also particles coming from the microthruster can precipitate on the MPS window, obstructing the field of view. This is mostly the case when the window for MPS and the valve of $T^3\mu$PS are oriented to the same side. The MPS has been put as low on the Z-axis as possible, placing it above the DAB.

Payload SDM
The TOP is pointed towards the Sun; therefore this experiment has been placed at the Z^+-side of the satellite fastened to the TOP.

Payload ITRX
There is no placement requirement for ITRX. However it is advisable to keep this payload near the COMMS PCBs.

Payload SPLASH
SPLASH has no specific placement requirement for the satellite and thus no placement requirement for the OBC PCB on which it is placed.

3.3 Mass Delfi-n3Xt

For Delfi-n3Xt a mass budget has been made [SLR 0018] to keep track of the mass of the various subsystems and the entire satellite. The satellite target mass is 3000 gram with the mass budget currently at 2917 gram. If required the target mass is raised to a maximum of 3500 gram. At the moment the current best estimate (Table 3.1) is heavier as the target mass of 3000 gram. In the current best estimate connectors are already taken into account, but electrical wiring between the subsystems and payloads not yet. This will increase the total mass somewhat. The current best estimate has been made by detailing subsystem drawings by adding mass and/or material as currently known. This is done on the basis of inheritance of Delfi-C^3 subsystems or information received from Delfi-n3Xt system engineers. The current best estimate has been the basis for ordering the subsystems and payloads such that the placement requirements are met and the microthruster is as close as possible to the CoM (see also Table 3.2).
Suggestions to decrease mass without changing the target mass are:

- get a better estimation of mass for MPS.
- make adjustments in the design for the STS.
- check the mass for COMMS in the current best estimate with the COMMS systems engineer.
- keep the mass constraints, just as the volume constraints, in mind in design and during component selection.

Table 3.1: Mass comparison

Subsystem	Part	Mass budget [gram]	Current Best Estimate# [gram]
ADCS	Electronics	65*	78
	Magnetorquers	139*	90
	Photodiodes	12*	1
	Sensors and Actuator board	179*	175
	Sun sensor package	60*	86
CDHS	OBC	72°	55
COMMS	MABs	60°	102
	PTRX	105°	124
	S-patch antennas	60°	9
	STX	105°	124
EPS	Batteries	234°	345
	Electronics	49°	63
	Solar panels	80°	153
	Test connectors	48°	34
MechS	Deployment circuitry	0	0
	Deployment hinge	120°	99
	Hold down mechanisms	24°	15
STS	BOP	70°	107
	Intermediate Panel	70°	75
	Outer structure	396°	350
	TOP	70°	119
TCS	Thermal control tape	0	0
$T^3\mu PS$		108°	163
MPS		400°	600
SDM		80°	136
ITRX		111°	124
SPLASH		43°	78
Miscellaneous	Wiring etc	157°	71
Total mass		2917	3376

* data taken from [SLR 0142]
° data taken from [SLR 0018]
data taken from [SLR 0303]

3.4 Final layout

Taken into account paragraph 3.1, 3.2 and 3.3 the layout as shown on Figure 3.2 and Figure 3.3 has been made for Delfi-n3Xt [SLR 0169]. A summary of the subsystem and payload placement is shown in Table 3.2. Further a volume budget [SLR 0303] (Appendix D) has been made for Delfi-n3Xt, keeping track of the volumes assigned to each subsystem and payload and the total volume of the satellite. Values for the Centre of Mass (CoM) and moment of inertia of the satellite and the current best estimate for mass of the satellite are also given in [SLR 0303].

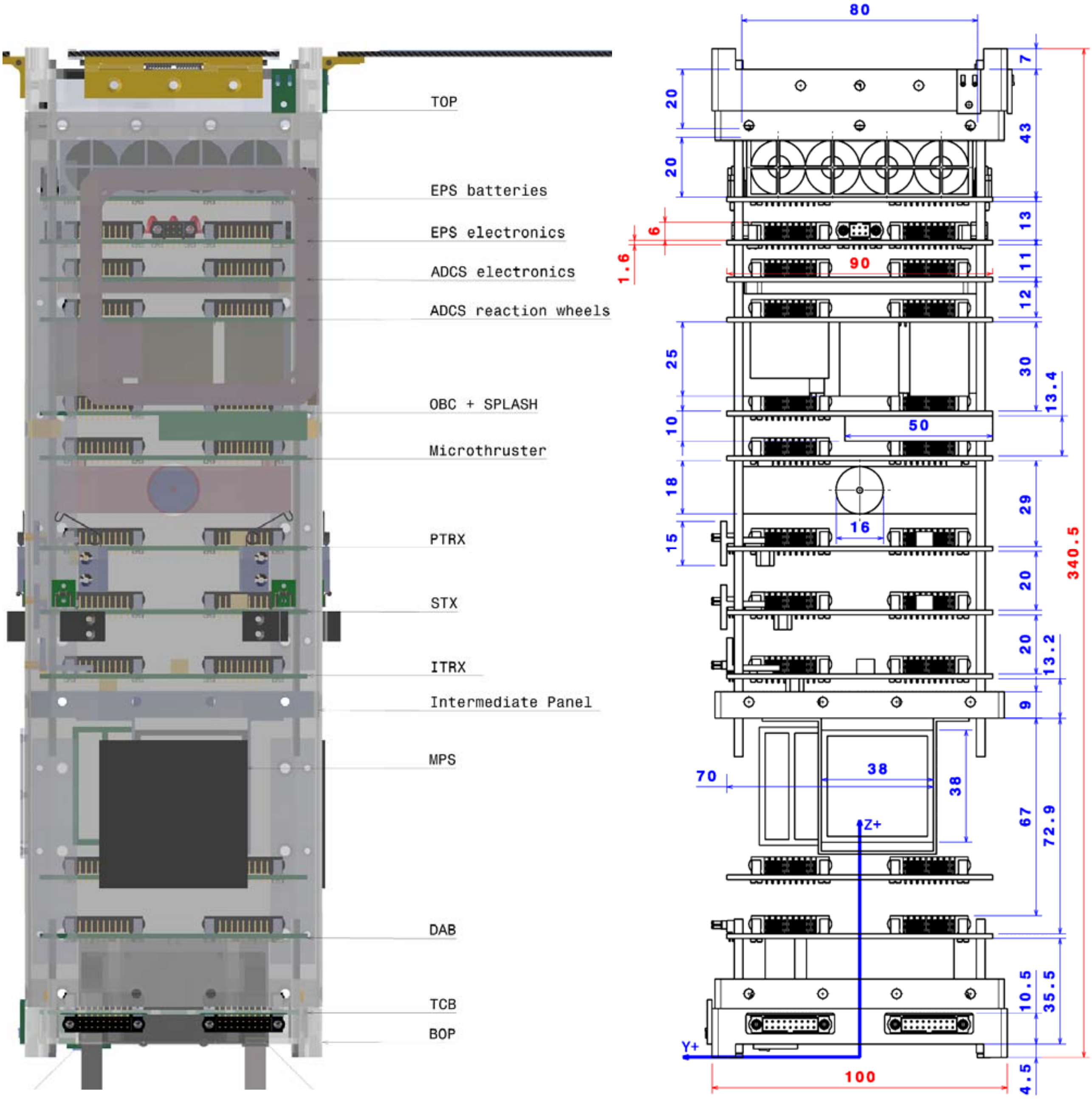

Figure 3.2: Layout of subsystems Delfi-n3Xt, X⁻-view

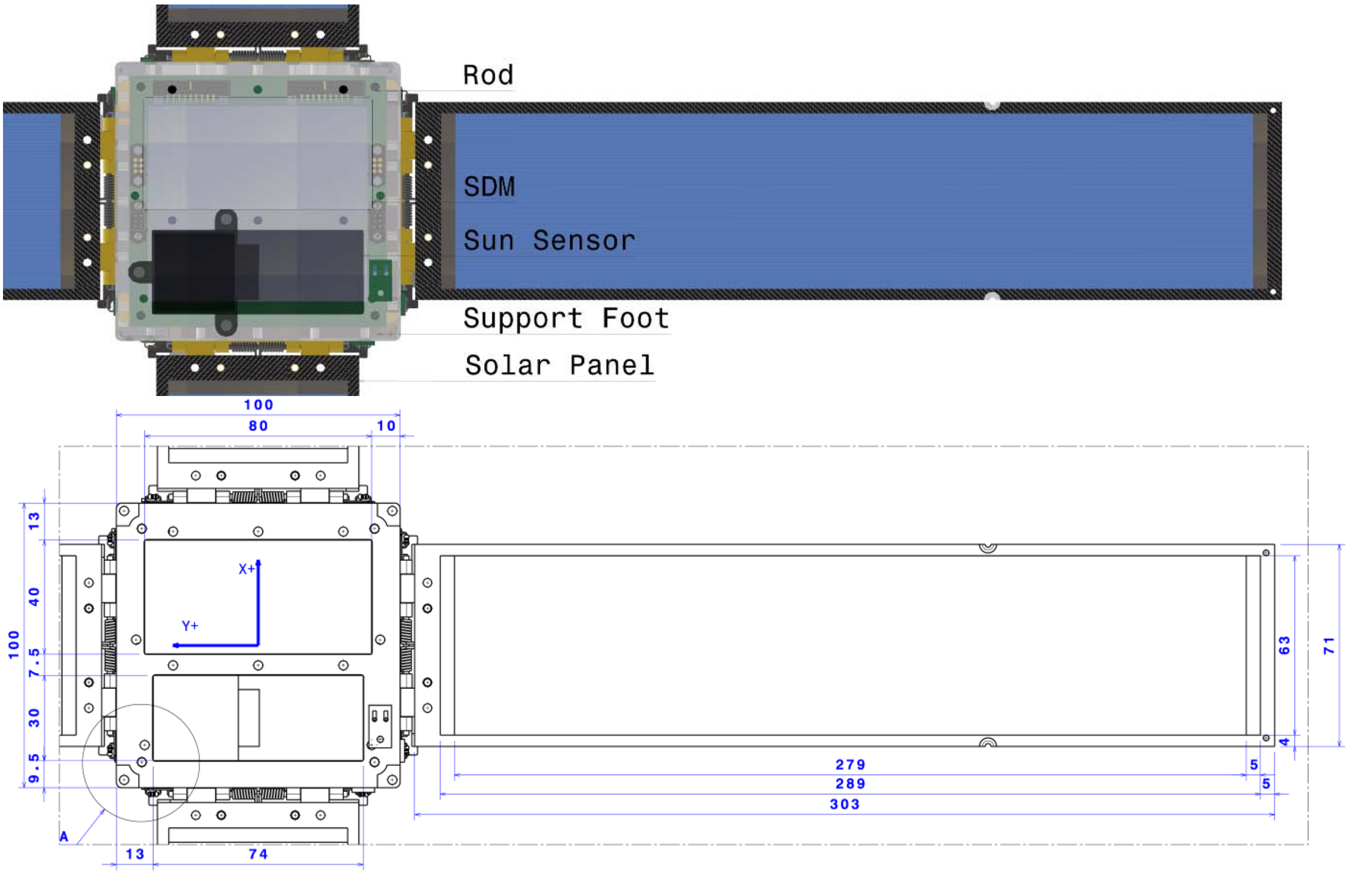

Figure 3.3: Layout of subsystems Delfi-n3Xt, Z^+-view

Table 3.2: Subsystem placement table

Subsystem	Part	Placement requirement	Actual placement
ADCS	Electronics		
	Magnetorquers	3 orthogonal sides, 2 on inside outer structure	X-- and Y--side
	Photodiodes	2 by 2 on every side on the outside STS	10 photodiodes on every side BOP, 2 on Z^+ TOP
	Sensors and Actuator board		
	Sun sensor package	Sun pointing	Through Z+ TOP
CDHS	OBC		
COMMS	MABs	Through BOP	On DAB
	PTRX		
	S-patch antennas	On outer structure	At height MPS
	STX		
EPS	Batteries		
	Electronics		
	Solar panels	Accomodation 7 cells	On long side Delfi-n3Xt in hold down phase
	Test connectors	No obstruction solar panels	As low as possible
MechS	Deployment circuitry		On DAB
	Deployment hinge	As high up as possible	On side of TOP
	Hold down mechanisms		Dependent on largest deflection solar panels
STS	BOP		At Z- side of the satellite
	Intermediate panel	Support MPS	Together with MPS
	Outer structure		Bolt to BOP and TOP
	TOP		At Z+ side of the satellite
TCS	Thermal control tape	On STS	On STS
	Passive systems	Per subsystem and payload dependent	
$T^3\mu PS$		As close as possible to CoM, orientation valve opposite power and data bus	As close as possible to CoM, valve at X--side
MPS		No obstruction field of view	As low as possible, orientation to Y-- or Y+-side
SDM		Sun pointing	Through Z+ TOP
ITRX			
SPLASH		Combine with OBC	

4 Mechanical Design

For Delfi-n3Xt, unlike Delfi-C^3, has been chosen for a custom design for the STS. Paragraph 4.1 presents the general concept for the STS; paragraph 4.2 goes into the details of the design for Delfi-n3Xt.

4.1 General concept STS

Delfi-n3Xt makes use of a custom-made STS. Focus for the STS design of Delfi-n3Xt are to have better accessibility, reducing the time needed for assembly, integration and testing, and improving handling capabilities with respect to the STS of Delfi-C^3. Several designs of CubeSats have been considered as possible option for Delfi-n3Xt [SLR 0169], namely:

- Card bus system
- Rod system with detachable side panels
- Male-female connectors on PCB
- Stack with PCB side panels
- PCB box

The options were traded on several points which could be divided in one of the four main groups:

- Performance
- Handling
- Flexibility in design
- Miscellaneous

The trade-off [SLR 0169] showed the rod system with detachable side panels to be the best option, followed by the male-female connectors. The result of the trade-off has been accepted, having experience with a rod system in the Delfi-C^3 project.

To come to the best solution for number and layout of the side panels, a trade-off was done as shown in Table 4.1 [SLR 0169]. In accordance with the trade-off two unsymmetrical U-shapes have been chosen as side panel for Delfi-n3Xt. Beneficial of this concept is that one of the U-profiles can be removed providing access to the PCB stack.

Table 4.1: Trade-off table number and layout side panels

		Criterion							
		Integration			**Inspection**	**Accessibility**	**Replacement**	**Stiffness**	
		Corners are free from nuts etc	Integration with inside structure	Integration with outside structure	Structure allows inspection of stack	Structure allows accessibility to the stack for connections	Similarity of panels for replacement	Stiffness of the side panels as a whole	**Total**
	Weight	2,3	1,4	1,4	3	4	2	5	19,1
Options	0 Detachable sides	1	-1	1	-1	-1	-1	1	-1,7
	1 Detachable side	-1	-1	1	0	-1	-1	1	-3,3
	2 Detachable sides, 1 L-shape	-1	0	1	1	1	0	-1	1,1
	2 L-shapes	-1	0	1	1	1	1	0	8,1
	2 U-shapes symmetrical	1	0	-1	0	0	1	1	7,9
	2 U-shapes, unsymmetrical sides	1	0	0	0	0	1	1	9,3
	4 Detachable sides	-1	1	1	1	1	1	-1	4,5

4.2 Detailed design

With the general concept, rod system with two unsymmetrical U-profiles as side panels, and requirements known the design is looked at in detail (see Figure 4.1).

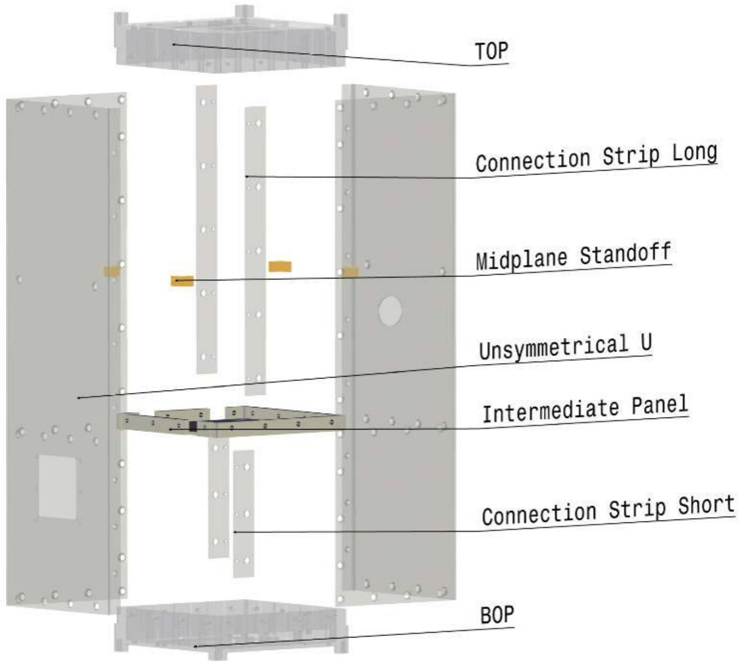

Figure 4.1: Elements of STS [SLR 0169]

4.2.1 Deployables

Deployer

There are several PODs available for three-unit CubeSats. The most notable differences for CubeSats are the available volume for deployables and the location of the guiderails used during ejection into orbit (see [SLR 0582] (Appendix E)).

- To be compatible with all deployers available on the market, the designs for deployables have been constraint to the smallest available volume for deployables, which is 340.5 mm x 87.7 mm x 8.5 mm for the Poly-Picosatellite Orbital Deployer (P-POD) of California Polytechnic State University.
- In the design for the U-profiles has been taken into account the requirement for the P-POD that each guiderail should be a minimum of 8.5 mm in width.

Solar panels

The solar panels provide for a string of seven solar cells. The test connectors should be accessible when the solar panels are hold down.

- The solar panels are 71 mm x 1.6 mm x 303 mm. The deployment of the solar panels is done by means of a hinge. Lacking space on the Z^+-side of the TOP, the solar panels are attached to the sides of the TOP.
- Fastening of the hinge to the TOP is done with M3 bolts.
- The width of the solar panels including hold down system is restraint by the guiderail requirement of the deployer.
- The thickness of the solar panel including hinge in hold down position and deflection of the deployables during launch, is restraint by the volume for deployables within the deployer.

Hold Down and Release Mechanism

Hold Down and Release Mechanisms (HDRMs) hold the solar panels down before orbit insertion.

- The HDRMs are situated at approximately two thirds of the solar panel, measured from the Z^+-side.
- Electrical wiring is needed for the deployment mechanism.

Protection during launch

To protect the CubeSat from damage during launch, support feet need to be taken into account.

- The BOP makes use of 4.5 mm high support feet; the TOP has 7 mm high support feet. With SDM has been agreed to an additional 3 mm in volume at the TOP as shown in the volume budget [SLR 0303]. The BOP only needs to take into account the head height of the long bolt.

4.2.2 Satellite structure

Bottom Panel

The BOP provides openings for the MABs, kill switches and bolt holes to offset the lower PCBs. Chosen is to have a raised side wall to fasten the outer structure to the BOP. The side wall also provides openings for the test connectors of EPS.

- The plate of the BOP is 2 mm thick; the side walls vary in thickness of 1 mm minimum up to a minimum of 3.65 mm thickness for parts which provide helicoils.
- For fastening of the U-profiles to the BOP M3 helicoils are used.

Intermediate Panel

The intermediate panel supports the MPS and provides holes for the PCB stack. On the sides, the intermediate panel is fastened to the outer structure.

- For fastening to the intermediate panel the MPS uses bolts and nuts. The plate is 2 mm thick.
- For fastening of the U-profiles to the intermediate panel M3 helicoils are used. The sides of the intermediate panel are 3.2 mm.
- To have a good connection of the intermediate panel to the outer structure on all sides of the panel, the power and data bus have been put as far apart as possible on the PCBs (constraint by the envelope for the threaded rods). This way the intermediate panel can have a connection point to the outer structure in the middle (see Appendix A).

Top Panel

The TOP provides openings for SDM, the ADCS Sun sensor package and holes for the threaded rods. Chosen is to have a raised side wall for the TOP to connect the hinges of the solar panels to and fasten the outer structure.

- SDM and the Sun sensor package are fastened by means of bolts and helicoils in the TOP. This way the Z^+-side, which is oriented to the Sun, can be finished with thermal tape to control the temperature within the satellite. The plate is 3.5 mm thick.
- For fastening of the U-profiles and the hinges to the TOP M3 helicoils are used. The side walls vary in thickness of minimum 1 mm up to a minimum of 3.65 mm thickness for parts which provide helicoils.

Midplane standoffs

The midplane standoffs offer the PCB stack an additional connection to the outer structure. The main function of the midplane standoffs is to add stiffness to the PCB stack.

- The midplane standoffs are small structural elements. One hole is implemented to let the threaded rods through; orthogonal a helicoil is implemented to fasten the standoff to the outer structure (see [SLR 0169]).

Outer structure

The design of the STS is constraint by the volume limitations set for a three-unit CubeSat and requirements with respect to the deployer. Further the thickness of the outer structure determines the available envelope for placement of subsystems.

The outer structure of Delfi-n3Xt consists out of 2 U-profiles, which are fastened to each other and to other structural elements, e.g. the BOP and the TOP.

- The wall thickness of the two U-profiles is 1 mm.
- Spacing for wiring and components such as ADCS magnetorquers are taken into account and set to 4 mm on the inside of the satellite.
- Fastening of the U-profiles to each other is done with connection strips along most of the length of the U-profiles. On the small side of the unsymmetrical U the connection strip is glued and supported by several M2 bolts and nuts to avoid adhesive bonding misalignment. The remaining part of the connection strip is connected to the long side of the other unsymmetrical U with M3 bolts and self-clinching nuts.
- Fastening of the U-profiles with other structural elements is done with countersunk M3 bolts.
- All the bolts for fastening are flush on the outer structure.

4.2.3 Inside satellite structure

ADCS magnetorquers
Two of the ADCS magnetorquers are placed on the inside of the outer structure.
- The magnetorquers are placed on the X^-- and Y^--side to the outer structure with dimensions 80 mm x 80 mm x 3.5 mm.

PCB envelope
Most subsystems make use of a PCB for mounting of components. For optimal usage of space the board and hole layout for the threaded rods and long bolts are symmetrical.
- The standard for PCBs in Delfi-n3Xt is 90 mm x 90 mm x 1.6 mm.
- Placed at every corner of the PCB are holes for the threaded rods and long bolts with centre at 4 mm offset towards the centre of the PCB.

Electrical wiring
Throughout the satellite is made use of cables and connectors for power, data and radio frequency signals.
- The X^+-side has been defined as the side where the power and data connectors have attachments to the stack.
- The Y^+-side is defined as the side for radio frequency connectors and cables.

More information about the details of the STS can be found in [SLR 0169] (Appendix B) and interfaces of other subsystems with the STS can be found in [SLR 0582] (Appendix E).

4.2.4 Mechanical Ground Support Equipment

Delfi-n3Xt, being the successor of Delfi-C^3, can make use of Delfi-C^3 legacy. For Delfi-C^3 a lot of custom-made Mechanical Ground Support Equipment (MGSE) has been manufactured. The MGSE worked well and is inherited as much as possible for Delfi-n3Xt. Almost all manufacturing and Assembly, Integration, Verification and Testing (AIVT) tools can be reused [SLR 0169]. Protection covers will have to be redesigned to Delfi-n3Xt specifications. To be able to use Delfi-C^3 AIVT tools, holes in the BOP and TOP have been added, consistent with the MGSE layout.

4.2.5 Integration satellite

The following integration order is recommended for the satellite [SLR 0169].
1. Assemble the BOP with TCB and DAB.
2. Assemble the TOP with SDM and Sun sensor package.
3. Assemble intermediate panel with rods
4. Assemble the PCB stack including midplane standoffs.
5. Assemble the TOP with the PCB stack & intermediate panel.
6. Assemble TOP/stack/intermediate panel with MPS
7. Assemble both U-profiles with components fastened to the profiles, such as the HDRMs and magnetorquers.
8. Assemble one U-profile with the BOP, intermediate panel and the TOP, leaving open the X^+-side.
9. Install and fasten the system busses.
10. Fasten the second U-profile.
11. Assemble the solar panel with the hinge.
12. Assemble the solar panel assembly with the TOP and HDRM.

Targets for the STS design (paragraph 4.1) were better accessibility to the stack to reduce the time needed for assembly, integration and testing, and improve handling capabilities with respect to the STS of Delfi-C^3. Although the assembly order seems rather long with twelve main assembly steps, the targets are met. This is because Delfi-n3Xt makes use of smaller subassemblies and part of the outer structure can be removed with respect to Delfi-C^3. When needing to test e.g. the PCB stack, the BOP assembly can stay assembled. This way the subsystems and payloads will be integrated and removed less often and handling is improved.

5 Conclusions & Recommendations

Conclusions on STS

Delfi-n3Xt is a three-unit CubeSat. Onboard are five payloads and seven subsystems. From the volume budget [SLR 0303] can be seen that everything fits within the CubeSat volume. A little margin is left for varying subsystem positions after taking into account 2 mm offsets between subsystems.

For the STS has been chosen a rod system with unsymmetrical U-profiles as side panels. The U-profiles provide better access to the stack, being able to take one or both profiles off. Also less time is needed for assembly, integration and testing. Since the entire satellite is assembled in subassemblies, handling capabilities are improved with respect to the STS of Delfi-C^3.

At the end of the thesis work it was meant to have a hardware model for the STS. Due to some uncertainties in the design of the subsystems (number of connections for power and data connectors, openings for payloads, etc.) influencing the design of the STS, the hardware manufacturing has been postponed.

Even though the design of the STS sounds like a fairly straightforward assignment, many interactions exist with the other subsystems and the payloads. During interface meetings the STS systems engineer has an advisory role on one hand and on other moments a determining role. This means always being prepared to and at meetings and that it is even better when envelope drawings are available.

Important as a systems engineer on the STS is to keep overview of all the subsystems. When too exotic designs are produced, they might not fit the STS volume. Also shared parts, such as the power and data bus, are important to take into account from the start.

Part of the learning process of being the STS systems engineer has been the many iterations in design to optimisation. A design is not perfect in one go, and even after several iterations, the design is still not hardware ready. This will stay this way up to launch, when no more changes can be made to, at least, the flight model.

Project Conclusions

The interdisciplinary nature of the project motivates to think in solutions. Besides this, also knowledge of other subsystems is gained indirectly. The design is a team effort and reflects not the accomplishments of an individual, but mostly of the team.

Due to the lack of (sub-)system engineers communication was sometimes very difficult, missing the correct and up-to-date information.

Due to the few system engineers design decisions were sometimes too quickly made, occasionally resulting in a redesign loop within a few weeks.

Starting from scratch gives a lot of design freedom and thinking about why certain decisions are frequently made in conservative designs.

Not starting from scratch, but having the mission with payloads already defined at the start of the project, would have helped a lot in the progression of the project.

Decisions have been fairly well documented (although most of the times not officially published on time).

Project Recommendations
Keep track of interfaces with the STS, also including volume. Make other subsystems take the volume into account with component selection.

Manufacture and test the STS as soon as major influences on the design are dissolved.

The mass of the satellite is higher than the target mass set. Review the mass of every subsystem and payload. Further remind the subsystems and payloads of the mass constraints during design and component selection.

Although several methods have been tried to attract new system engineers for the project, this does not seem to work. In future, PhD students or Bachelor students can be attractive for the project.

A system engineer needs to deal with only one subsystem, this also includes project managers.

More internal meetings should be held amongst systems engineers. During these meetings it is also helpful when other systems engineers are present to know what problems have arisen within the project.

The Mechanical Ground Support Equipment (MGSE) is a part of the project easily forgotten. For the AIVT phase of the project attention should be given to the design and development of the MGSE. One person focusing on the MGSE for the project should be appointed.

More frequent detail meetings should be held with payload partners. Not only is it important to know that the design is structurally sound, also aspects as power usage and data output are important factors.

General Recommendations
Starting thesis work on projects, such as Delfi-n3Xt, most university students lack hands-on experience. When working on a practical design, instead of a theoretical design, to have this experience from the start can avoid large delays in designing. This can, for instance, be added to the material practicals in the Bachelor phase, where the focus lies on working with material, and not how tools work or how tools can be used in a design.

In the Bachelor students learn to work with computer aided design tools, such as CATIA. These tools have so much more to offer, such as finite element modelling. Recommended is to put a small assignment for finite element modelling in the student computer aided design course.

List of Used References

Relevant SLR-numbers for this thesis work are given below. Data has been taken from the Delfi Standard List of References.

Document Code							Author	Document Title	Issue	Last Revision
Project		Organis.		Doc. Type		Ident. nr.				
DNX	-	TUD	-	RP	-	0001	Bouwmeester, J.	*Mission Definition Report of Delfi-n3Xt*	1.4	4-apr-08
SSE	-	TUD	-	PP	-	0003	Go, S.Y.	*Optimized Three-unit Cubesat Structure for Delfi-n3Xt (IAC2008)*	1.2	25-sep-08
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Appendices

Appendix A Delfi-n3Xt Conventions

Description: Definition of the reference frame chosen for Delfi-n3Xt

Subsystem(s) involved:

ADCS	CDHS	COMMS	EPS	MechS	STS	TCS	ITRX	MPS	$T^3\mu PS$	SDM	Splash	GSE	GSN	Launch
x	x	x	x	x	x	x	x	x	x	x	x			

Revision Record and Authorization

Issue	Date	Author / Editor	Reviewer checked	PM approved	Affected Section(s)	Description of change
0.1	3-sep-2008	Jennifer	SB	JB		
0.2	December 2008	Jennifer		JB		Update text and figure

Action Items

TBW	TBD	TBC	Applicable Section(s)	Description of action item

List of Used References

SLR code	Version	Data/Variable

Table of Contents

1 Introduction

To keep the same definitions throughout the project the conventions as used for the Delfi-n3Xt satellite have been defined. This TN will give the definition of these conventions so all team members are concise in using them.

This TN starts with the reference frame as defined for Delfi-n3Xt in chapter 2.

2 Definition

For Delfi-n3Xt a body fixed reference frame is used (see Figure 2.1). The reference frame lies on the centre line of the satellite, beginning from the support feet at the bottom panel of the satellite. The Z^+-axis is defined along the long side of the satellite in direction of the top panel towards which the solar panels fold out after orbit insertion for Sun-pointing. The X^+-axis is the side where the power and data connectors are attached to the stack. The Y^+-axis is the side where the radio frequency cables and connectors are.
Furthermore two angles are defined, α and β. α is defined as the angle between the X^+-axis to the Y^+-axis; β is defined as the angle from the XY-plane to the Z^+-axis. To fix the point given by the angles in space r is used for the distance to the origin.

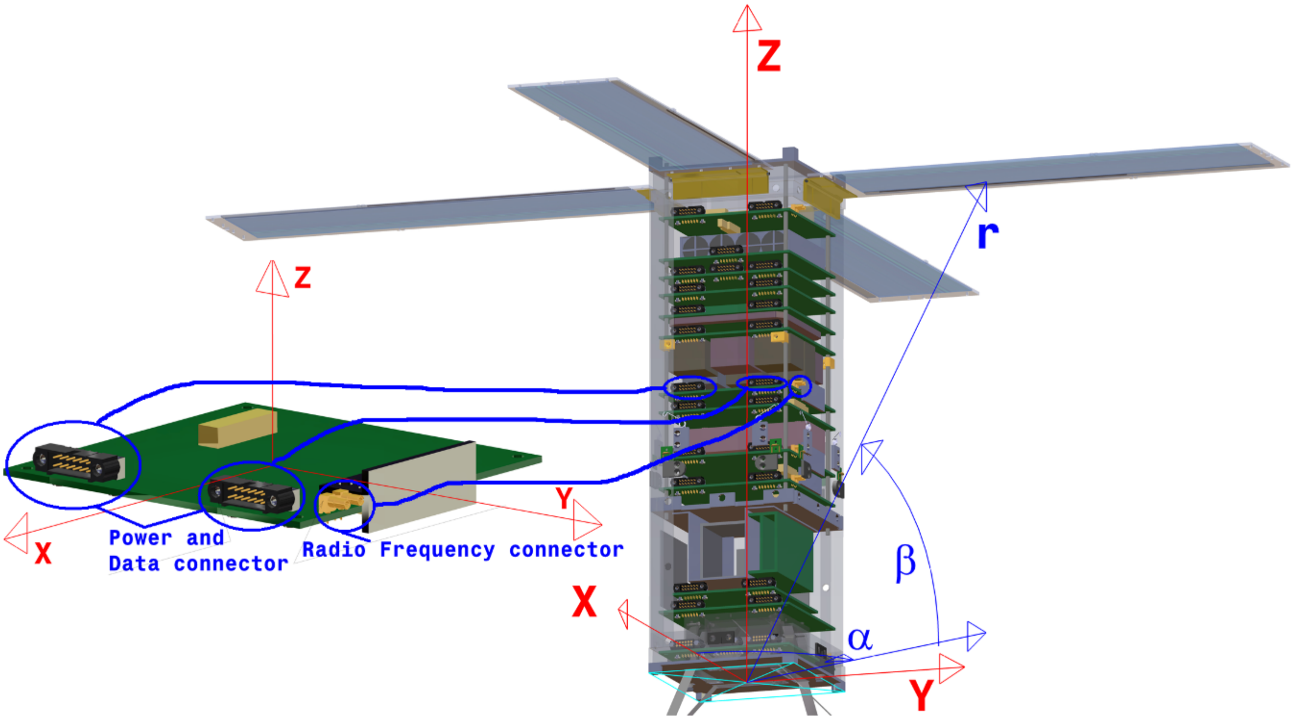


Figure 2.1: Delfi-n3Xt body fixed reference frame

Appendix B STS – Top Level Design of the Structural Subsystem

Description: Top level design, requirements STS, design drawing

Subsystem(s) involved:	ADCS	CDHS	COMMS	EPS	MechS	STS	TCS	ITRX	MPS	$T^3\mu PS$	SDM	Splash	GSE	GSN	Launch
					X	X									

Revision Record and Authorization

Issue	Date	Author / Editor	Reviewer checked	PM approved	Affected Section(s)	Description of change
1	10-09-2008	Jennifer	Martijn	Jasper	All	First issue
1.1	15-09-2008	Jennifer			7.2.14	Table added for CoM and I
2.0	27-04-2009	Jennifer	Robert/ Geert		All	New chapters and revision of old chapters.
2.1	15-05-2009	Jennifer				Removed references to antennas Z^+, some textual changes

Action Items

TBW	TBD	TBC	Applicable Section(s)	Description of action item
		x	8.2.6	Nr. of S-patches

List of Used References

SLR code	Version	Data/Variable
SLR 0001	1.4	MDR Delfi-n3Xt
SLR 0014	2.0	COMMS Top level TN
SLR 0028	11	CubeSat Design Specification
SLR 0105	2.0	CDHS System Design
SLR 0141	0.2	Dellfi-n3Xt conventions, Coordinate system
SLR 0142	1.6	ADCS Top level TN, +/- 5 mm misalignment $T^3\mu PS$ Z-direction (SAT.1.2.REQ.C.000)
SLR 0157	A	ECSS Materials
SLR 0158	A	ECSS Structures
SLR 0159	A	ECSS Mechanisms
SLR 0160	1	Compass One, Phase A study
SLR 0161	1	AAUSAT Conceptual Structural Design
SLR 0167	2.5	Requirement management tool Delfi-n3Xt, Requirements numbering
SLR 0181	1.0	ICD microthruster
SLR 0202	1.0	ICD MPS
SLR 0256	-	Harwin connectors
SLR 0269	1.0	Delfi-C^3 STS thesis
SLR 0299	2.0	Dnepr User manual
SLR 0303	1.3	Delfi-n3Xt Volume Budget
SLR 0308	1.0	DC^3 antenna deployment system
SLR 0317	0.2	Systems Engineering Team Members Manual
SLR 0325	2.1	Configuration Tree Delfi-n3Xt
SLR 0364	1.0	Lecture notes Systems Engineering, Figure 1-4
SLR 0373	1.1	Lecture notes Spacecraft Structures
SLR 0441	-	muRata filters datasheets
SLR 0481	1.0	DC^3 HDRM, hot spot tool
SLR 0484	1.0	DC^3 structures and mechanisms
SLR 0525	1.0	DC^3 integration and verification
SLR 0572	0.1	MechS TN
SLR 0582	1.1	Mechanical and Structural ICD
SLR 0583	-	Datasheet aluminium
SLR 0596	0.1	ICD Sun sensor package
SLR 0597	-	Clifa press nuts
SLR 0600	0.3	Workshop drawings

Abbreviations

ADCS	Attitude Determination and Control Subsystem
AIT	Assembly, Integration and Testing
AIV	Assembly, Integration and Verification
AIVT	Assembly, Integration, Verification and Testing
BOP	Bottom Panel
CoM	Centre of Mass
COTS	Commercial-off-the-Shelf
DAB	Deployment and Antenna Board
DC3	Delfi-C^3
DIMES	Delft Institute of Microsystems and Nanoelectronics
ECSS	European Cooperation for Space Standardization
EPS	Electrical Power Subsystem
ESA	European Space Agency
GSE	Ground Support Equipment
HDRM	Hold down and Release Mechanism
I	Moment of Inertia
ICD	Interface Control Document
ISIPOD	Innovative Solutions In Space Picosatellite Orbital Deployer
ISIS	Innovative Solutions In Space
ITRX	ISIS Transceiver
MAB	Modular Antenna Box
MGSE	Mechanical Ground Support Equipment
MPS	Multifunctional Particle Spectrometer
OBC	On-Board Computer
PCB	Printed Circuit Board
P-POD	Poly-Picosatellite Orbital Deployer
PTRX	Primary Transceiver
RF	Radio Frequency
SDM	Solar cell Degradation Measurement
SLR	Standard List of References
SP	Solar Panel
SPLASH	Space Flash
STS	Structural Subsystem
STX	S-band Transmitter
TBC	To Be Confirmed
TBD	To Be Determined
TBW	To Be Written
TCB	Test Connector Board
TN	Technical Note
TOP	Top Panel
UHF	Ultra High Frequency
VHF	Very High Frequency
XPOD	eXperimental Push Out Deployer

Table of Contents

1 Introduction

This Technical Note (TN) describes the top level design of the Structural Subsystem (STS). The design has been done using a systems engineering process [Standard List of References (SLR) 0364], supporting the full life cycle: design, development and verification, of the STS. Typical activities in this process are shown in Table 2.2 with the associated chapters in this TN.

Table 1.1: STS Life Cycle

Mission Need Definition
1. Identify and formulate need (Chapter 2)
Concept Exploration
2. System analysis (Chapter 3)
3. Requirements Definition (Chapter 4)
4. Conceptual designs (Chapter 5 & 6)
5. Technology & risk assessment (Chapter 6)
6. Preliminary Cost, schedule & performance of preferred concept
Demonstration & Validation
7. Concept Design (Chapter 7)
8. Subsystem trade-offs (Chapter 9)
9. Preliminary design (Chapter 8)
10. Prototyping, test & evaluation (Chapter 11)
11. Integration of manufacturing & supportability considerations into design (Chapter 12)

2 Mission Need Definition

The mission need definition for the STS has been deduced from requirement SYS.REQ.G.010 for Delfi-n3Xt [SLR 0167]:

Delfi-n3Xt shall be a three-unit CubeSat.

For Delfi-n3Xt a custom designed structure instead of a Commercial-off-the-Shelf (COTS) structure is used. A custom design can be tailor made to the satellite's need. For Delfi-C^3 the commercially available CubeSat kit was purchased, consisting of a three-unit CubeSat structure and an On-Board Computer (OBC) flight board. To the structure of Delfi-C^3 many modifications were necessary. The changes included a custom designed top and bottom panel and the addition of ten access holes to the tube chassis.

Besides modifications to the structure for accessibility, Delfi-C^3 encountered difficulties during assembly, integration and testing, which increases risks during handling too. Aim for the design of Delfi-n3Xt is to decrease these bottlenecks.

3 Delfi-n3Xt implementation

To accomplish the objectives stated in Chapter 2 and learning from the experiences of the previous team a summary for implementation in Delfi-n3Xt is given.

3.1 Accessibility of Delfi-n3Xt

One of the focus points for Delfi-n3Xt is a better accessible structure. A better accessible structure saves time on Assembly, Integration and Verification (AIV) and inspection of the satellite. Furthermore it might limit risks during assembly activities and it is expected, that it will reduce assembly/disassembly cycles. A study was conducted in August 2005 for Delfi-C^3 for more accessibility to the structure, but with the COTS structure used, the solution was not advantageous enough [SLR 0269].

3.2 Cable harness for Delfi-n3Xt

The cabling from the outside to the inside structure of Delfi-C^3 has been reported (questionnaire G.F. Brouwer, 17-12-2007) to be vulnerable; furthermore little room for cable routing was available. For the design of Delfi-n3Xt will be looked at the connections of the cables to make them sturdier and optimise routings.

3.3 Flight model for Delfi-n3Xt

Delfi-C^3 made use of a proto-flight approach, assuming a flawless design on paper. In the end several revisions of all subsystems were needed in order to work correctly. For Delfi-n3Xt a preliminary design phase with afterwards two design iterations are planned. After the second design phase aim is a prototype without issues. Production of flight hardware begins when is certain that remaining issues do not influence the produced subsystem [SLR 0001]. For the STS only flight hardware is foreseen.

3.4 Handling of Delfi-n3Xt

The Mechanical Ground Support Equipment (MGSE) as developed for Delfi-C^3 worked very well. Delfi-n3Xt will make use of the available MGSE as much as possible. Where needed modifications and additions will be made.

3.5 Integration and assembly for Delfi-n3Xt

As Delfi-C^3 Delfi-n3Xt will use a modular concept, meaning all components to be developed and tested separately and integrated in the end.

3.6 Mechanisms for Delfi-n3Xt

Delfi-C^3 used the PC/104 standard for Printed Circuit Boards (PCBs). The PC/104 standard is an industrial standard, which defines the layout of PCBs and connector dimensions. Disadvantages of the standard are the asymmetrical hole and board layout. Delfi-n3Xt will not use the PC/104 standard; instead to avoid faulty assembly the side of the system bus has been defined. This is a reference point for orientation of the PCBs, since every PCB should be connected to the system bus. Furthermore every PCB will have a definition of Z^+- and Z^--side.

4 Requirements Delfi-n3Xt Structural Subsystem

Requirements for the STS of Delfi-n3Xt have been set up. The numbering of the requirements has been done using the system explained in [SLR 0317] and shown in the configuration tree [SLR 0325]. The configuration tree focusing on STS is shown on Figure 4.1. For the STS the configuration tree can be seen as a functional hardware breakdown. The structural part (thus not electrical, but the actual physical board) of the PCB has also been taken into account as structural item.
The STS requirements have been set up using as input requirements from Delfi-C^3, requirements set for Delfi-n3Xt and Compass-1 [SLR 0160]. Also requirements from the European Cooperation for Space Standardization (ECSS) have been used as guideline [SLR 0157, SLR 0158 & SLR 0159]. Some requirements have been set up in consultation with concerning subsystems, e.g. payload requirements. The requirements for STS can be found in [SLR 0167]. This chapter puts the requirements into context.

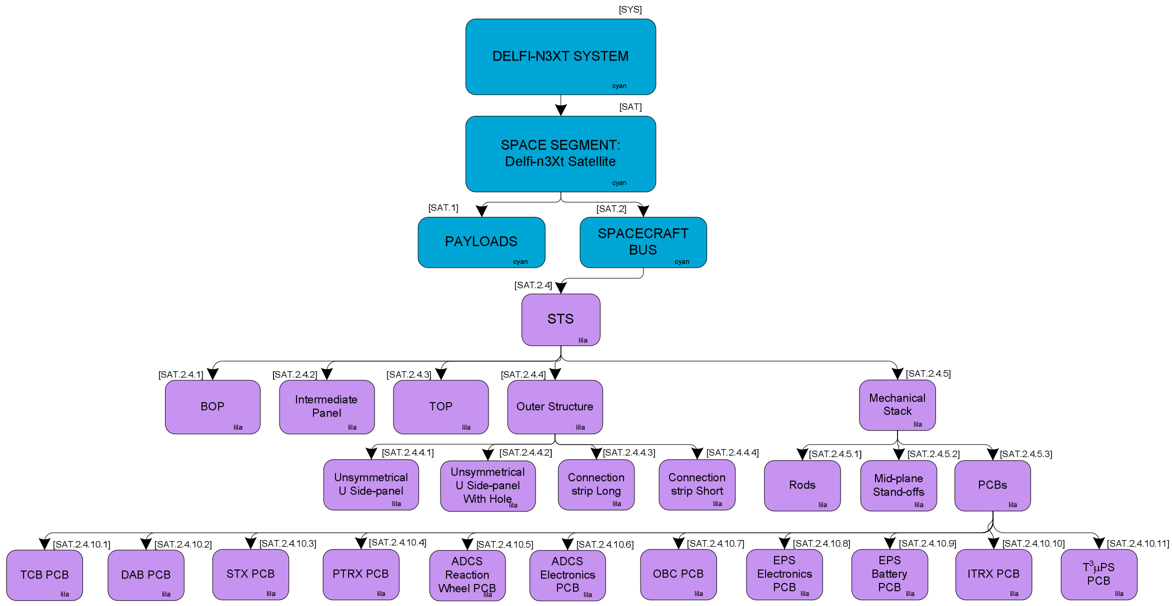


Figure 4.1: STS configuration tree (entire tree, see [SLR 0325])
Cyan: Delfi-n3Xt colour, Lila: STS colour

4.1 General Requirements

As said in chapter 2 Delfi-n3Xt is a three-unit CubeSat. This means that Delfi-n3Xt needs to fit all payloads and subsystems in the CubeSat standard format for a triple unit (SYS.REQ.G.010). Delfi-n3Xt shall be launched, making use of a COTS CubeSat deployer (SYS.REQ.G.011). From the main requirement SYS.REQ.G.010 the requirement SAT.2.4.REQ.G.000 has been flown down, which states that the STS of Delfi-n3Xt is based on the design of a three-unit CubeSat.
In the design of the STS, for simplicity and transparency during assembly and integration, holds that identically numbered items, e.g. midplane standoffs, are interchangeable in both function and dimension (SAT.2.4.REQ.G.001).

4.2 Constraints

Having a three-unit CubeSat, which satisfies the CubeSat format and a COTS deployer, puts limitations to the volume of the satellite. These limitations can be found in requirements SAT.REQ.C.004 & SAT.2.4.REQ.C.000 (volume limitation due to deployer for entire satellite and STS respectively) and SAT.REQ.C.005 & SAT.2.4.REQ.C.001 (volume limitation three-unit CubeSat for entire satellite and STS respectively).
Although components fastened to the STS require power, the STS itself shall not require power (SAT.2.4.REQ.C.002) to perform its functions (see paragraph 4.3).

4.3 Functional requirements

The functional requirements can be seen as the primary goal of the STS. Typical functions of a structure are:

- give access to other subsystems (SAT.2.4.REQ.F.000): This is for example that the STS allows the solar panels to be connected to the Electrical Power Subsystem (EPS) PCB.
- allow for inspection (SAT.2.4.REQ.F.001): After testing the satellite needs to be inspected to show whether all parts are still working correctly and are not damaged.
- integration with other subsystems (SAT.2.4.REQ.F.002): The STS allows for integration and removal of subsystems while on ground. This way adjustments can be made and subsystems can be tested separately.
- accommodation for the mounting of components (SAT.2.4.REQ.F.004): In the design of the STS should be taken into account that subsystems need to be fastened, while not interfering with volume requirements.
- providing mechanical interfaces to the subsystems (SAT.2.4.REQ.F.007): The STS is the mechanical connection to which to mount subsystems.

Further having a satellite, the STS should withstand the space thermal environment (SAT.2.4.REQ.F.003), be able to transfer heat (SAT.2.4.REQ.F.005) and withstand the loads induced during its complete lifetime, since refurbishment is a non-option after launch (SAT.2.4.REQ.F.006). The functional requirements of the separate STS parts are discussed in chapter 10.

4.4 Performance requirements

The performance requirements are set such that the STS does not fail during mission life time. Two phases the STS encounters are launch and mission. The rocket which launches the satellite induces vibrations which the satellite must be able to endure. This leads to requirement SAT.2.4.REQ.P.000.
During the mission the satellite encounters hot and cold temperatures the STS must withstand (SAT.2.4.REQ.P.001).

4.5 Interface requirements

To be able to fit all subsystems in the imposed volume, the interfaces between the subsystems need to be accurately defined. This is done in a separate interface control document [SLR 0582] for the STS, entirely devoted to the interfaces of this subsystem with others as stated in SAT.2.4.REQ.I.000.
Besides that other subsystems need to be compatible with the STS, the STS has its own interfaces to take into account. These are compatibility with the deployer (SAT.2.4.REQ.I.001) and integration working conditions (SAT.2.4.REQ.I.002). Also Attitude Determination and Control Subsystem (ADCS) imposed requirements need to be considered in the design (SAT.2.4.REQ.I.003, SAT.2.4.REQ.I.004 & SAT.2.4.REQ.I.005).

4.6 Payload requirements

For assembly, integration and modularity reasons it is convenient for the Solar cell Degradation Measurement (SDM) to have its own housing (SAT.1.3.REQ.A.000). This simplifies integration work for Delfi-n3Xt and makes handling of the payload easier.
The payload $T^3\mu PS$ requires an outlet for the valve (SAT.2.4.4.2.REQ.P.000). This needs to be taken into account for the STS design. Without an outlet, subsystems of Delfi-n3Xt might be damaged when the payload is thrusting. Further a requirement (SAT.1.2.REQ.C.000) has been set for the positioning of $T^3\mu PS$ in the satellite. This requirement is needed so that the ADCS can counteract the momentum generated after thrusting. The positioning should be such that the thrust vector of $T^3\mu PS$ goes through the Centre of Mass (CoM) with a total vector misalignment of +/- 5 mm in Z-direction as specified in [SLR 0142].
As stated in [SLR 0202] the MPS requires a window of 300 micron thickness (SAT.2.4.REQ.I.006). Sufficient provisions for this window in the outer structure need to be taken.

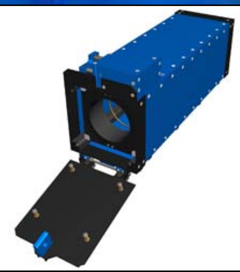
5 Determination configuration Delfi-n3Xt

This chapter is split up into two sections, i.e. POD and structure. POD deals with deployers for CubeSats. The second section, structure, discusses the various options for Delfi-n3Xt.

5.1 POD

There are several COTS deployers for CubeSats, however not all are fit for three-unit CubeSats. Possible deployers for three-units are P-POD, XPOD and ISIPOD. An overview of these deployers is shown in Table 5.1. For now, no recommendation is made for the choosing of a deployer.

Table 5.1: Deployers for CubeSats

P-POD	P-POD (Poly-Picosatellite Orbital Deployer) by Stanford University and California Polytechnic Institute holds three single CubeSats stacked on top of each other. Launch configuration: 3 x one-unit CubeSats 1 x two-unit CubeSat + 1 x one-unit CubeSat 1 x three-unit CubeSat. (source: http://cubesat.calpoly.edu/, 17-10-2008)	
XPOD	XPOD (eXperimental Push Out Deployer) is a custom, independent separation system that was designed and built at University of Toronto Institute for Aerospace Studies/Space Flight Laboratory for each satellite and may be tailored to satellites of different sizes ranging from a single CubeSat to larger nanosatellites of arbitrary dimensions. (source: http://www.utias-sfl.net/, 17-10-2008)	
ISIPOD	ISIPOD (Innovative Solutions In Space Picosatellite Orbital Deployer) is a separation system built by the company ISIS (Innovative Solutions In Space). The ISIPOD comes in one-unit, two-unit and three-unit variations. Opportunities for custom designed volumes are available. (source: http://cubesatshop.isispace.nl/, 13-03-2009)	

5.2 Structure

The following options are discussed further as possible options for the STS of Delfi-n3Xt:

- card bus system
- rod system with detachable side panels
- male-female connectors on PCB
- a stack with PCB side panels
- a PCB box

An overview of the main advantages and disadvantages of the options can be found in Appendix A.
For clarity the following body fixed reference system is used (Figure 5.1): X^+ is the direction of the system bus and Z^+ is defined as along the long side of the satellite in direction of the top panel. The starting point of the reference frame is the centre line of the satellite, at the support feet on the bottom panel.

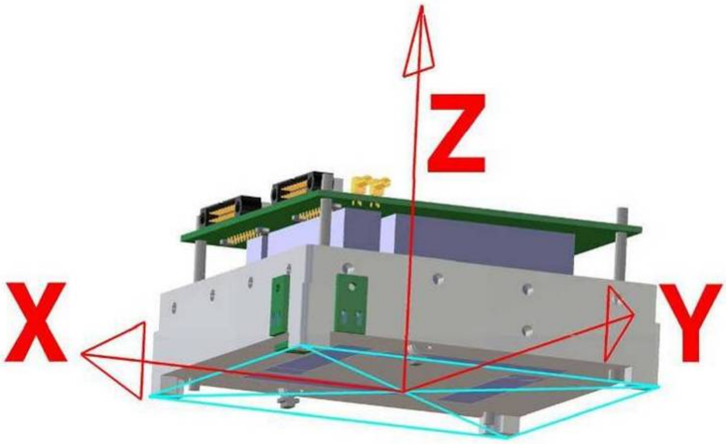


Figure 5.1: Reference system

5.2.1 Card bus system

This option focuses on the quick interchangeability of PCBs. At the X^--side the PCBs slide into the structure, where they are clamped to the Y-sides. On the X^+-side the PCBs are connected through a system bus. The system bus can be a cable or a panel with slots for the connectors. For better access to the inner structure a cable is preferred. The X^--side can be used to check whether the cable or structure is connected correctly, when this panel is made separable.

An example of a slider system is Temisat, see Figure 5.2. Temisat uses a cable for system bus; the connector is shown on Figure 5.2, left.

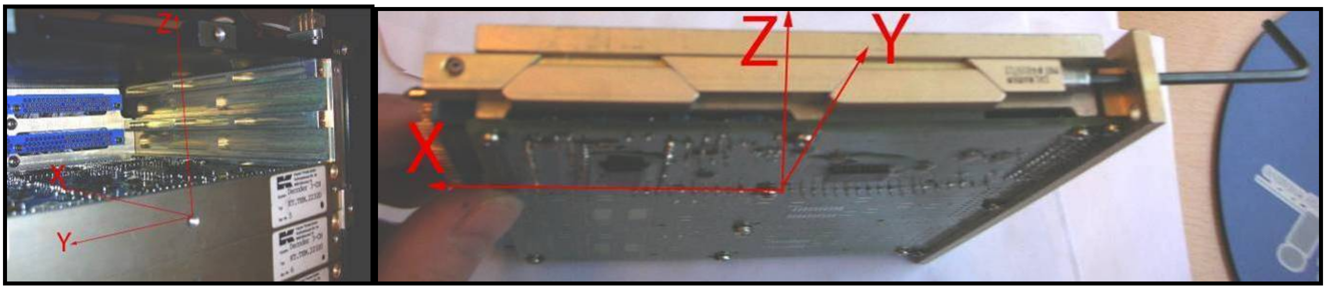


Figure 5.2: Temisat slider option, left: inside Temisat, right: PCB with slide system Temisat.

The PCBs can be integrated and removed from the structure independently of each other. Disadvantageous for this system are the stiffness and stress for the PCBs during tests and launch. High mass with respect to the other options is also a drawback.

An example of a CubeSat which implemented this system is GeneSat-1 by the Center for Robotic Exploration and Space Technologies, United States of America, see Figure 5.3. The left side of Figure 5.3 shows the card bus system. Figure 5.3 also shows multiple card slots for varying the distance between PCBs.

Figure 5.3: GeneSat-1 (source: http://tia.arc.nasa.gov/genesat1/, 17-10-2008).

5.2.2 Rod system with detachable side panels

This option is a variation to the rod system of the Delfi-C^3, but aims for better accessibility. The secondary structure consists of threaded rods where the PCBs are stacked upon (Figure 5.4), but to have better accessibility after integration in this situation, unlike Delfi-C^3, the X- and Y-side panels can be taken off. This means that removing PCBs for separate testing, modifications and/or replacing PCBs in this system is still time-consuming.
Advantageous for this option is that there is work-experience with a rod system and that the distance between PCBs can be easily varied with different bus lengths.

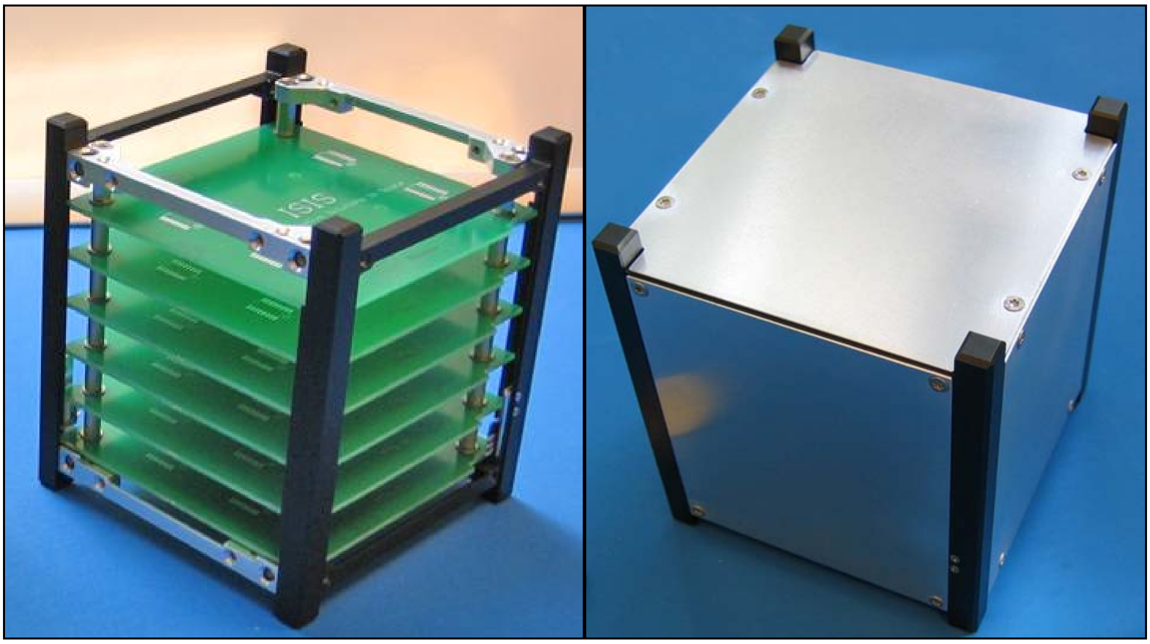


Figure 5.4: Innovative Solutions In Space (ISIS) solution for one-unit CubeSat (source: http://www.ISISpace.nl/, 17-10-2008)

5.2.3 Male-female connectors on PCB

This option is similar to the mentioned rod system, but instead of threaded rods male-female, non-electrical connectors are used. The idea is that a male connector is put on the Z^+- and Z^--side of the PCB, after which a female connector is screwed on (Figure 5.5). The downside is that one male and female side need to have a left-handed thread instead of the usually used right-handed thread. If, using only right-handed thread, for

example part 2 is turned loose, part 4 fastens more (Figure 5.5). Using different threads means extra attention during assembly. Further the male and female parts shall have to be custom manufactured.
For this system detachable X- and Y-panels are an option.

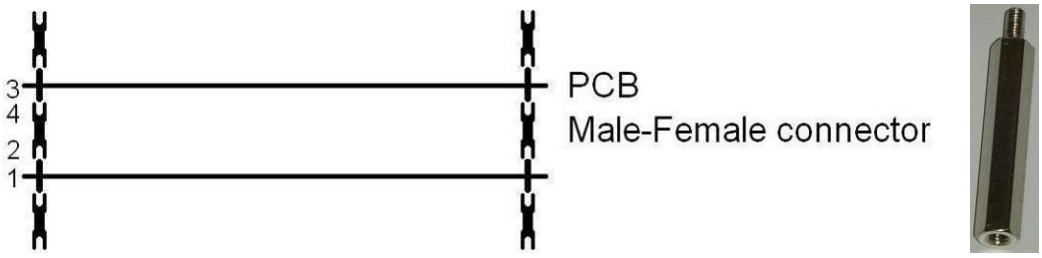


Figure 5.5: Left: Detailed view of male-female connector system
Right: Connector with a male, as well as a female output

An example of a CubeSat which implemented male-female plugs (no thread) is UWE-1 by University of Würzburg, Germany, see Figure 5.6.

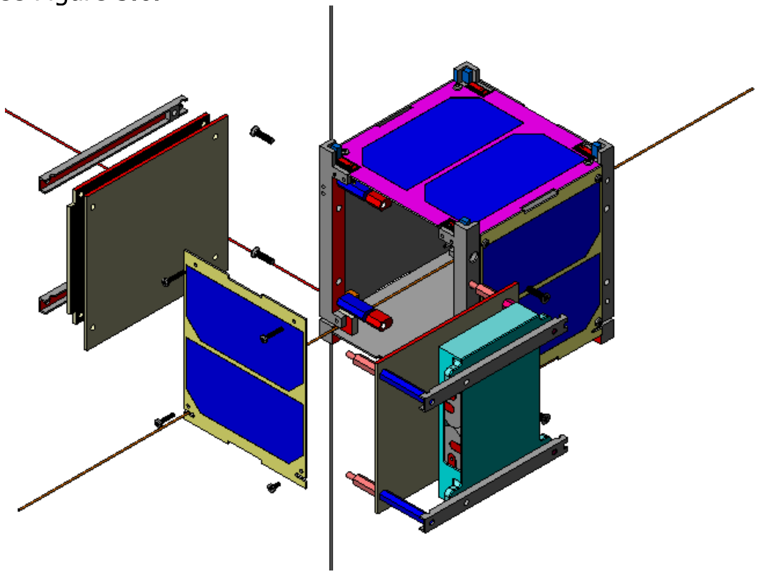


Figure 5.6: UWE-1 (source: http://www.informatik.uni-wuerzburg.de/en/chairs/lehrstuhl_fuer_informatik_vii/projects/cubesat/uwe-1/project_details/structure_and_thermal/, 17-10-2008)

5.2.4 Stack with PCB side panels

This option can be combined with the rod system and the male-female connectors. The PCBs are not the outer structure, but are protected by an outer structure. By orienting PCBs in Z-direction, more room can be created for payloads. Since a three-unit CubeSat is assumed, there is a possibility to have ribs on one-third of the length of the satellite and on two-thirds. This way all PCBs can have similar dimensions. For interference reasons (mechanically or electronically) the PCBs placed normal to the Z-axis have to be reduced in size. Having a stack with PCB side panels reduces the accessibility compared to the rod and male-female system. Further wiring is an issue which has to be looked into.

An example of a CubeSat which implemented this system is AAUsat by Ålborg University, Denmark, see Figure 5.7.

1. MECH: Frame structure
2. MECH: Side panels
3. MECH: Top or bottom panel
4. COM: Antenna
5. COM: Com CPB. Radio and modem included
6. PL: CCD camera, lens and frame included
7. PL: PL PCB
8. PSU: Photovoltaic solar cells
9. PSU: PSU PCB
10. PSU: Batteries
11. COMP: COMP PCB
12. ACS: Electromagnetic coils
13. ACS: ACS PCB
14. CSR: Kill switch
15. CSR: Optional data port access area
16. CSR: Flight pin access area

(CSR, CubeSat Requirements)

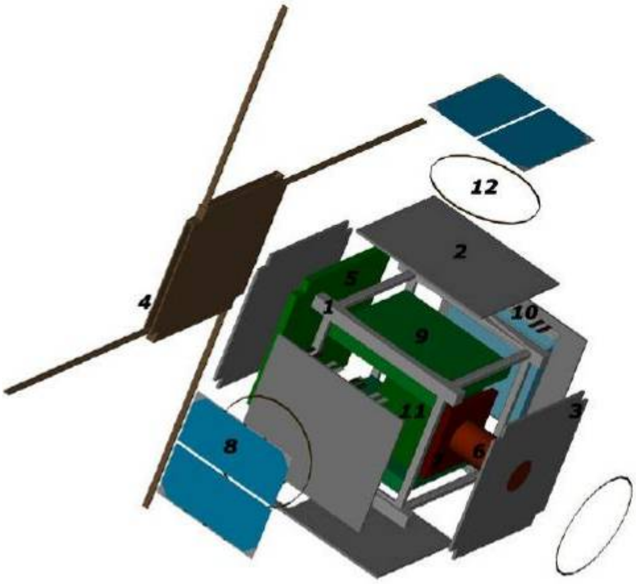


Figure 5.7: AAU CubeSat project [SLR 0161]

5.2.5 PCB box

The idea of the PCB box is that the PCBs have their own frame on the X- and Y-sides, which makes that the PCBs can be piled together via a rod system, as shown on Figure 5.8. The stack lacks accessibility and requires disassembling when needing a PCB from the stack. On the other side the handling risk is less, due to the framework on each PCB.

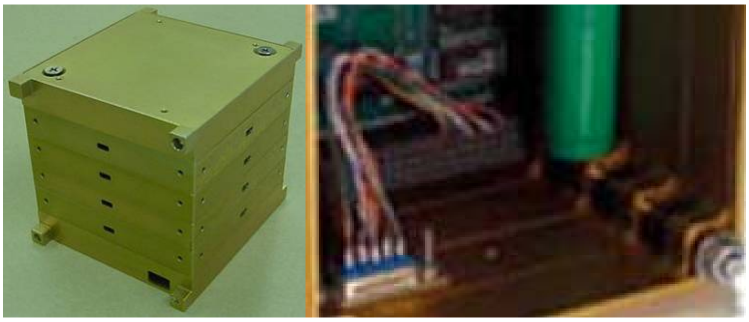


Figure 5.8: Mea Huaka (source: http://www-ee.eng.hawaii.edu/~cubesat, 17-10-2008)

6 Trade-off structural option

A trade-off has been done for the various options described in Chapter 4. In this chapter the rationale behind the criteria and weights are defined in paragraph 6.1. The results of the trade-off are given in paragraph 6.2. Paragraph 6.3 describes the implementation of the results for Delfi-n3Xt.

6.1 Rationale for criteria and weights

The six options in chapter 5 have been traded on several criteria. The criteria were divided into four main groups:

- Performance
- Handling
- Flexibility in design
- Miscellaneous

Delfi-n3Xt specific criteria as mounting of outer parts and structural interference due to payload have been taken into account. The criteria, weights and rationale for the criteria are given in Table 6.1. The criteria and weights have been chosen with knowledge of the Delfi-C^3 structure, and known problems of Delfi-C^3 with respect to its structure. Therefore the focal points as accessibility and assembly have been given a higher weight, while manufacturability is of less importance. Placement of PCBs is assumed perpendicular to the Z-axis.
The options are graded using an evaluation scale of one to five; one being unacceptable and five being excellent. This score is multiplied by the weight given to the criterion and added to a total number. The highest total is ranked first, but options that do not differ from the highest score by more than 10% are considered as well.

Table 6.1: Trade-off criteria and weights

Criterion	**Weight**	**Rationale**
Performance		
Interference due to payload	4	Impact of large payload on the structural design
Structural subsystem mass (outer structure and items for fastening PCBs to structure)*	5	Mass of the subsystem, modelled with a drawing
Stress	3	Response of the options wrt stress situations
Stiffness	4	Stiffness of the PCB stack
Structural manufacturability	1	The subsystem can be developed in-house
Handling		
Accessibility	5	Accessibility to PCB stack from X- & Y-panels
Assembly, integration and testing of PCBs and connectors	5	Amount of time needed for AIT of PCBs and connectors
Substitution of PCB	3	Easiness of replacing a PCB
Mounting of outer parts	3	Impact of mounting of parts on the outer structure to the inside PCB support structure
Flexibility in design		
Varying PCB distance in Z-direction	2	Amount of adaptation to structural elements when varying PCB distance in Z-direction
Miscellaneous		
Heritage	2	Inheritance from Delfi-C^3

* mass has been estimated making use of models

6.2 Results

The various options were traded by using the method described in paragraph 6.1. The grades the options have been given can be found in Appendix B. The table from Appendix B also shows the percentage the options score and on which rank the options end up.

The trade-off shows the best option for the structure is the rod system with 79%. Second is the male-female connector system. On the important criteria accessibility both score excellent. Also both options have not scored 'unacceptable' for any of the criteria.

Both the stacks with PCB side panels and the PCB box score very poorly on accessibility. The stack with PCB side panels is only accessible from the Z^+ and the Z^--side. The PCB box is not accessible when fully integrated.

6.3 Implementation for Delfi-n3Xt

Having experience with the rod system in the Delfi-C^3 project and anticipating problems with stiffness of the stack with the male-female connector system, in a team discussion the rod system was favoured. The side panels will be made detachable as discussed in chapter 7. About one-third of the satellite is reserved for the antenna board and Multifunctional Particle Spectrometer (MPS). The MPS requires its own structure in the satellite; the payload is quite large and heavy.

Delfi-C^3 has worked with the PC/104 standard throughout the satellite for the reason that they used the FM430 flightboard as OBC. Since a customized board will be used for Delfi-n3Xt, there is no constraint for using the PC/104 standard for Delfi-n3Xt. Characteristic for the PC/104 standard is the asymmetrical layout for PCBs with respect to dimensions and holes, where the threaded rods go through. There is no clear advantage in handling between having a symmetrical layout and an asymmetrical layout. Since a symmetrical layout will improve the area for placing connectors, Delfi-n3Xt will apply a symmetrical layout for both dimensions and holes.

As with Delfi-C^3, Delfi-n3Xt will have modular antenna boxes (MABs) and solar panels, of which the antennas and solar panels are deployable. However, for Delfi-n3Xt only one PCB with four MABs will be required. The second PCB with MABs the Delfi-C^3 used is removed by combining the Very High Frequency (VHF) antennas and the Ultra High Frequency (UHF) antennas. This means the number of deployables is reduced to eight (twelve for Delfi-C^3). The physical deployment and hold down systems are based on the same thermal knife principle which Delfi-C^3 used: a standard resistor cutting a Dyneema wire.

7 Side panels

To investigate which option is best for Delfi-n3Xt a trade-off has been done for the side panels. Table 7.1 and Figure 7.1 give the options for this trade-off.

Table 7.1: Side panel options

Option	Figure 7.1
0 Detachable sides	Figure 7.1a
1 Detachable side	Figure 7.1b
2 Detachable sides, 1 L-shape	Figure 7.1c
2 L-shapes	Figure 7.1d
2 U-shapes symmetrical	Figure 7.1e
2 U-shapes, unsymmetrical sides	Figure 7.1f
4 Detachable sides	Figure 7.1g

The trade-off table and results can be found in Appendix C. Main criteria for this trade-off were integration, inspection, accessibility, replacement and stiffness. As can be seen from the results in Appendix C three options are preferred above the others, i.e. 2 L-shapes, 2 U-shapes both symmetrical and unsymmetrical. The main difference in the three options is the fastening of the two shapes. For the 2 L-shapes this is done in the corners; the 2 U-shapes symmetrical in the mid and the unsymmetrical U-shapes between the corners and midpoint. A structural requirement for CubeSats [SLR 0028] is that (corner-) rails must be smooth and have a minimum of 8.5 mm in width. Some subsystems might require openings or large components on the panels (e.g. magnetorquers). To facilitate these properly the 2 U-shapes with unsymmetrical sides are chosen as shape for the side panels.

To come to the offset best for the unsymmetrical U-shapes the following criteria must be considered:

- the minimum offset for the rails,
- the length and fastening of the magnetorquers for the ADCS, and
- where the hold down supports are set.

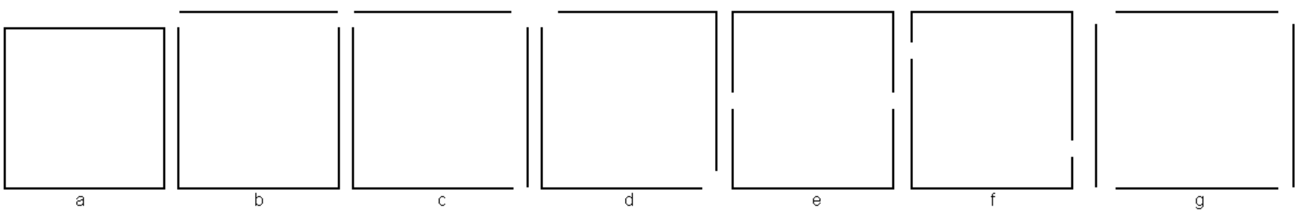


Figure 7.1: Options for side panels

8 Design

Because Delfi-n3Xt has more and bigger payloads and more advanced subsystems than Delfi-C^3, an accurate volume budget [SLR 0303] and verification drawings have been made for the entire satellite. This has been done to verify that all payloads and subsystems fit in a three-unit CubeSat. To be able to make a representative model, components and subsystems known from Delfi-C^3 have been implemented. The coordinate system used has been defined in [SLR 0141].
The difference between the volume budget and design drawing is that the volume budget shows in blocks the volumes assigned to the different subsystems, while the design drawings show the volume the subsystems actually take. The subsystem volume budget block is the volume agreed upon per subsystems; the design drawings of the subsystems should stay within the specified volume block of the subsystem. The volume budget is discussed in paragraph 8.1; the design drawing is discussed in paragraph 8.2.

8.1 Volume budget

The volume budget is a simple model developed from blocks (see [SLR 0303]). The blocks are fitted together, giving a presentable model for the total volume of the satellite. The total volume should not exceed the maximum volume of a three-unit CubeSat, being 100 mm x 100 mm x 340.5 mm (excl. Solar Panels (SPs)).
Every block represents one of the satellite's PCBs. Every block consists of:

- a 90 mm x 90 mm x 1.6 mm PCB,
- a power and data bus connector of 6 mm in Z^+-direction at X^+Z^+, and
- 3 mm on the Z^--side for soldering of pins.

Further as input has been taken the height of components as specified by payload partners, of similar subsystems as used on Delfi-C^3 and data as provided by the subsystem engineers.

If the budget exceeds the height of a three-unit CubeSat there are some options to consider:

- Decrease the margin between subsystems.
- Combine two subsystems which do not occupy an entire PCB to one PCB.
- Postpone a payload to the successor of Delfi-n3Xt.

As shown in [SLR 0303] the volume budget fits in the volume for a three-unit CubeSat. Margin between subsystems is 2 mm.

8.2 Design drawing

The design drawing (Figure 8.1) can be considered as the current best estimate. The design has the dimensions of a three-unit CubeSat. If needed, subsystems can have more overlap than in the volume budget, the design drawing being more dynamic in that respect. Keeping this in mind, changes need to be reported as soon as possible and are not always possible. Also the design philosophy should be the smaller, the better.

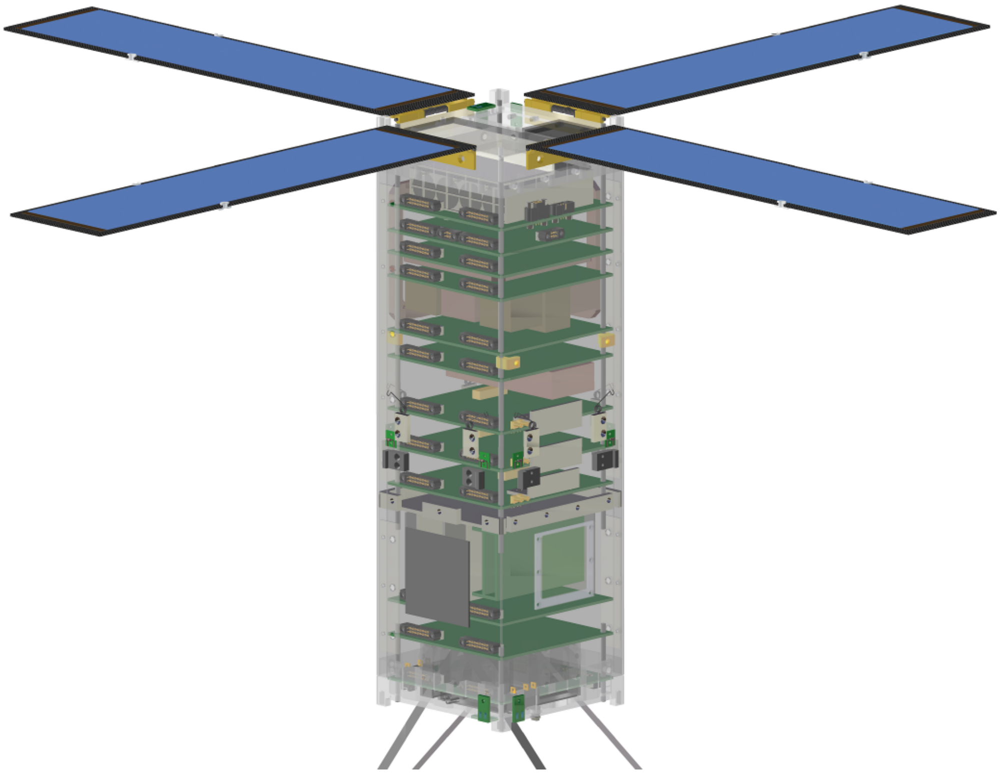


Figure 8.1: Delfi-n3Xt layout

General assumptions for the model were (see Figure 8.2):

- a 90 mm x 90 mm x 1.6 mm PCB,
- Harwin M80-54018 connectors [SLR 0256] as power and data bus connector at X^+Z^+,
- Harwin M80-313 connectors [SLR 0256] as Radio Frequency (RF) connector at Y^+Z^+, and
- M3 holes at every corner of the PCB with centre at 4 mm offset towards the centre of the PCB.

Further material and/or masses have been assigned to every component to give a representative model. Values for the Centre of Mass (CoM) and the moments of inertia (I) of this model can be found in [SLR 0303]. In Appendix D dimensioning and arrangement of the model can be found.

In the coming paragraphs the different subsystems are discussed.

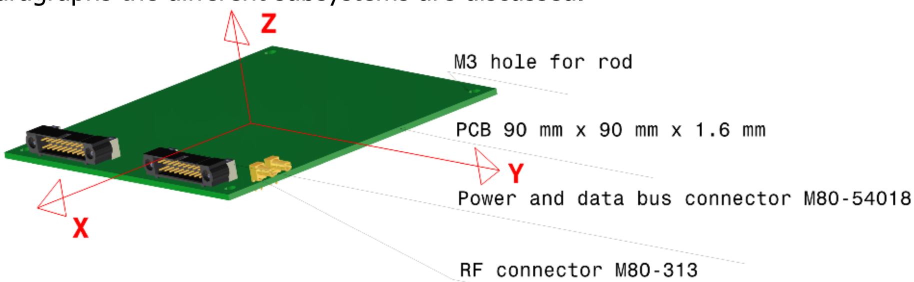


Figure 8.2: PCB model representation

8.2.1 BOP

As in Delfi-C^3 use is made of a BOP. The antenna board and test connector board are fastened with an offset to the BOP. The bottom plate provides openings for the kill switches and the MABs.
For redundancy two kill switches are used. In the design drawing kill switches similar to the kill switches supplied in the CubeSat kit from Pumpkin are used.
Delfi-n3Xt makes use of 4 MABs which are deployed through the BOP.
A more detailed description of the BOP can be found in chapter 10.

8.2.2 TCB

The function of the Test Connector Board (TCB) is to place test connectors for the satellite. The test connectors need to be accessible while the solar panels are not deployed and have been positioned low on the Z-axis.

8.2.3 DAB

As said, the Delfi-C^3 MABs are reused in Delfi-n3Xt. Unlike Delfi-C^3 only four MABs are used, instead of the eight MABs for Delfi-C^3. The four MABs of Delfi-n3Xt are fastened on the Deployment and Antenna Board (DAB) and go through the BOP. The MABs are put closer together for Delfi-n3Xt to provide room for the TCB (see 8.2.2).
The DAB further facilitates the circuitry for phasing of the antennas and circuitry for the hold down and release mechanisms.

8.2.4 MPS

The largest impact in mass and dimension in Z-direction comes from the MPS payload. The current specifications are a height of 65 mm (see Appendix D) and a mass of 600 g.
To minimize obstruction of the field of view of the MPS, due to for example a solar panel, the MPS has been put low on the Z-axis in the design.

8.2.5 Intermediate Panel

The satellite makes use of an intermediate panel. This panel makes the construction stiffer. The intermediate panel supports the PCB stack and the MPS, which are fastened to the panel. A more detailed description of the intermediate panel can be found in chapter 10.

8.2.6 Communications boards

Delfi-n3Xt has three communication boards: ITRX, PTRX and STX (see also [SLR 0014]). For communication Delfi-n3Xt is equipped with seven antennas.

- Four antennas are connected on the antenna board and deployed through the BOP.
- Three (To be Confirmed (TBC)) S-band antenna patches are implemented at the height of the MPS.

To reduce the height of the communication boards smaller coax connectors have been chosen. To reduce the height of the cool fin, instead of an L-shape, a T-shape is considered. This fin can use the space between the outer structure and the PCB, which is a space of 4 mm. Further has been taken into account that smaller filters can be selected with almost similar properties as the filters used for Delfi-C^3 [SLR 0441] and that the highest components on the PCBs (crystal and filters) can be placed on one side of the PCB, the components being through-hole components.
The mass for components on the communication boards has been taken similar to their equivalents on Delfi-C^3 communication boards.

8.2.7 Microthruster

To minimise the disturbance torques, caused by the microthruster, the thrust vector of the microthruster should go through the CoM as stated in requirement SAT.1.2.REQ.C.000. The weight of the microthruster is a maximum of 140 g as specified in [SLR 0181]. For the nozzle a cut-out in the structure has been made as specified in SAT.2.4.5.REQ.P.000.

8.2.8 OBC

For Delfi-n3Xt the decision has been made to put the NLR experiment Space Flash (SPLASH) on the OBC PCB [SLR 0105]. Size of SPLASH has been estimated as 50 mm x 50 mm x 8.4 mm (height is excluding PCB).

8.2.9 ADCS

In the design drawing six reaction wheels, three magnetorquers, two magnetometers and one gyro have been taken into account in accordance with [SLR 0142 vs. 1.4]. Since there is much unclearity about the layout and number of components of this subsystem, the design drawing for this subsystem has not been updated to current situation. In the design drawing two magnetorquers are put on the inside of the outer structure as mentioned in paragraph 8.2.11. The twelve photodiodes are put two by two on every side. The remaining components are implemented on two PCBs: one PCB to facilitate the electronics of this system and one board to place the reaction wheels, magnetometers and gyro on.

8.2.10 EPS

The EPS consists of four batteries and electronics. The solar panels are considered as a separate system. The EPS is implemented on two PCBs. One board is used for the electronics and one for the batteries. Since the batteries are cylindrical, a frame to mount the batteries to the PCB is implemented. The mass of the batteries is 186 g.
A power connection with the solar panels is made on four sides of the electronics PCB.

8.2.11 TOP

The TOP has two openings; one opening for the DIMES SDM experiment and one opening for a Sun sensor package. The TOP has support feet similar to the ones for Delfi-C^3 to protect the satellite during launch. Furthermore the SPs are attached to the side of the TOP.
SDM and the Sun sensor package both have their own housing and connection to the TOP.
A more detailed description of the TOP can be found in chapter 10.

8.2.12 Structure

The outer structure of the satellite is formed by 2 unsymmetrical U-shapes and four connection strips. The shapes are fastened with bolts and nuts at several places of the structure. The 2 U-shapes together have an outline of 100 mm x 100 mm. Both panels have a thickness of 1 mm and at the upper and lower side the structure is fastened to the BOP and TOP.
Two coils of the ADCS are attached to the inside of the structure, to the X^-- and Y^--side. On the outside structure, on X^-, X^+ and Y^-, S-band antenna patches are placed. For launch, the SPs are fastened to the outside of the structure. These are held down by the hold down and release systems, which are placed on the outer structure. After orbit insertion the SPs fold out 90° to the Z^+-plane of the satellite.
A more detailed description of the outer structure can be found in chapter 10.

8.2.13 Solar Panels

The satellite has four SPs for power generation. The SPs are attached to the sides of the TOP. The dimensions of a SP are 71 mm x 1.6 mm x 303 mm. The panels provide space for an array of seven solar cells.

8.2.14 Hold down supports & resistor

The hold down supports and resistors are attached on all X- and Y- panels. More details about the Hold Down and Release Mechanism (HDRM) can be found in [SLR 0572].

8.2.15 S-band antenna patches

Three S-band antenna patches are placed on the outer structure of the satellite. Dimensions for the patches are 50 mm x 50 mm x 3 mm. The patches are fixed at the same Z-location as the MPS.

9 PCB deflection

To have a decent model for the margin between the different subsystems, a calculation has been done for the deflection of a PCB during worst case vibration. A PCB has been taken, since the majority of subsystems make use of a PCB to fasten components. Further most components have a larger Young's modulus E (Young's modulus is a measure for the stiffness of the material), making the PCB have the largest deflection per subsystem. A minimal margin between subsystems is necessary for Delfi-n3Xt due to crowdedness. The minimal preferred margin is 2 mm between each subsystem.

For the calculation the material properties of FR-4 material are used. FR-4 stands for Flame Retardant 4 and is commonly used as PCB material. Advantages of FR-4 with respect to its predecessors are that the material absorbs less moisture and is better flame resistant. The PCBs for Delfi-n3Xt are square with sides 90 mm and thickness 1.6 mm and can be considered as simple supported structure. Since the PCBs are square, for the maximum deflection the diagonal of the PCB can be taken.

To calculate the deflection the load cases as illustrated on Figure 9.1 and Figure 9.2 can be considered. With help of the Myosotis formulas [SLR 0373] the deflection can then be calculated. This gives a deflection of $\delta = \frac{FL^3}{48EI}$ for Figure 9.1 and a deflection of $\delta = \frac{5FL^3}{384EI}$ for Figure 9.2.

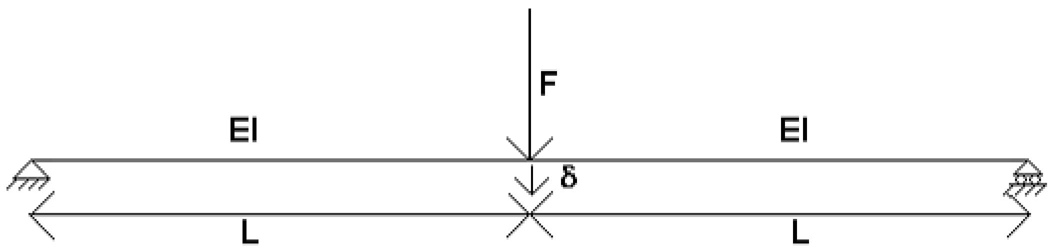


Figure 9.1: Load case point mass on beam

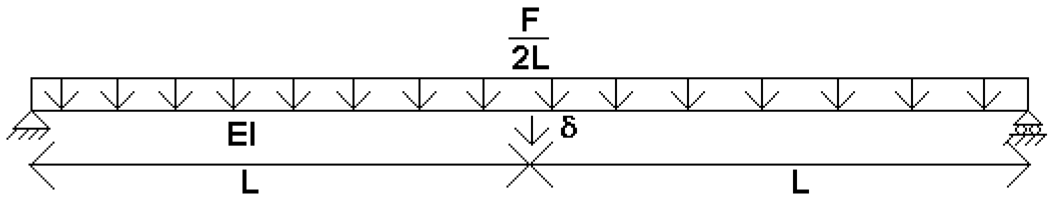


Figure 9.2: Load case distributed mass over beam

To calculate the deflection the values presented in Table 9.1 have been used. The calculated deflection has 1g acceleration. However during flight the satellite experiences higher accelerations than 1g. With help of the user guides of ARIANE 5, Soyuz, PSLV, DNEPR and Vega the worst case quasi-static loads have been taken, being 8.3g in longitudinal direction during the second stage burn for the DNEPR. When taking into account the safety factor of 1.3 during flight as given in the Dnepr User Guide [SLR 0299], the worst load case to take into account becomes 10.8g.
When looking at the random vibration on component level, the acceleration to take into account is 0.16 g^2/Hz. To calculate the load factor induced by random vibration, the formula $3\sqrt{\frac{\pi}{2} \cdot f_n \cdot Q \cdot W_{ii}}$ is used [SLR 0373]. The result of this formula is a load factor of 65 g, taken into account a safety factor of 1.25 which is commonly used by launchers for quasi static loading. As shown in Appendix E, this load factor induces a deflection of the midpoint of the PCB of 0.6 mm, which is well within the preferred two mm margin.

Table 9.1: Values used for calculation

g =	9,81	m/s^2	Standard gravity acceleration
t =	1,6	mm	Thickness PCB
E_{FR4} =	17	GPa	Young's modulus for FR4 material
Diagonal =	127,28	mm	Diagonal of PCB
L = b =	90	mm	Length and width of PCB
ρ_{FR4} =	1900	kg/m^3	Density of FR4 material
I_{plate} =	$4{,}34 \cdot 10^{-11}$	m^4	Moment of inertia of PCB
m_{PCB} =	24,6	g	Mass of PCB

10 Details STS

The details of the STS design are described in this chapter with respect to thicknesses, fastening and material. Further analysis on the STS, STS interfaces and the satellite integration order are discussed. Drawings of the STS elements can be found in [SLR 0600]. (Figure 10.1 shows the various elements of the STS.

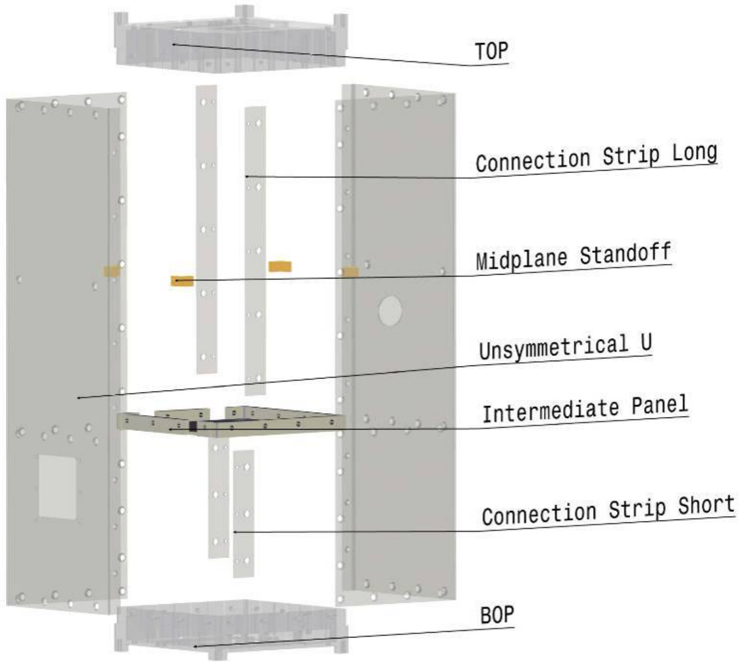


Figure 10.1: Elements of STS

10.1 BOP

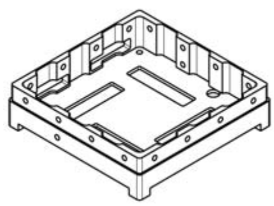


Figure 10.2: ISO-view BOP

Functions of the BOP are protection of components (SAT.2.4.1.REQ.F.000), adding stiffness to the satellite (SAT.2.4.1.REQ.F.001) and acting as fastening point for components (SAT.2.4.1.REQ.F.002). To comply with these functions the BOP is designed as panel with raised sides on support feet.
The BOP (Figure 10.2) is situated on the Z^--side of the satellite. The panel provides openings for four MABs, to allow the antennas in the MABs to deploy, and two kill switches. The required opening for the MAB is rectangular 43 mm x 10 mm. The position of the openings is dependent on the fastening of the MABs on the DAB and on the TCB dimensions around the MABs. For the kill switches an opening of 7 mm diameter is foreseen. Further four holes are implemented which are aligned with the holes in the PCBs. Four long bolts of diameter M3 are used to give the correct offset to the TCB and DAB. The head height of the M3 bolt (Torx head) is 2.4 mm, including 0.5 mm for an M3 washer, gives a height of 2.9 mm. To make sure nothing gets damaged or touches the POD besides the support feet, requires the support feet to have a minimum length of 3 mm. The support feet are chosen to be 4.5 mm.
The support feet have an inside rounding for tooling for the bolt. For MGSE, such as covers, the support feet are equipped with an M3 Helicoil. The location of the helicoil holes are at similar locations as used for Delfi-C^3.
The X- and Y-sides of the BOP have two thicknesses. The upper part is 1 mm thinner than the lower part. The lower part has been chosen to a height sufficient to accommodate for cut-outs for test connectors on the X^--side. Further on the Y-sides a hole for electrical grounding is implemented.
The height of the upper part of the sides is dominated by the fastening of the Unsymmetrical U's to the BOP. The fastening of the Unsymmetrical U's to the BOP is done using M3 Helicoils of 1.0D length. Bolts which are

flush with the structure are used for fastening with bolt head 1.65 mm. This gives, without margins a thickness for the upper part, 3.65 mm, and thus 4.65 mm for the thickness of the lower part.
To reduce the mass of the BOP, material on the sides, between the holes has been removed, up to a 1 mm thickness of the upper part (which is a total thickness of 2 mm for the lower part of the BOP).

10.2 Intermediate Panel

The intermediate panel has as function to add stiffness to the satellite (SAT.2.4.2.REQ.F.000) and to support the MPS (SAT.2.4.2.REQ.F.001). To comply with the first function the shape of the panel (Figure 10.3) has been chosen to be a solid panel fastened with bolts to the outer structure. For the fastening to the outer structure M3 helicoils of 1.0D length have been chosen. Taking into account an M3 CSK bolt with bolt head 1.65 mm gives a thickness without margins for the sides of 3.65 mm.

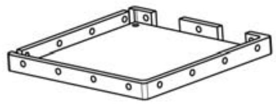


Figure 10.3: ISO-view intermediate panel

For modularity the MPS needs to be detachable, either with nuts or with helicoils. The panel at the moment has a thickness of 2 mm, however if the MPS requires helicoils, either locally the panel should be thicker or the entire plate should have a thickness of minimum 3.2 mm. The 3.2 mm entails an M3 helicoil and 0.2 mm tolerance.
Besides that the intermediate panel supports the MPS, also the PCB stack is supported by the intermediate panel. The holes for the PCB stack are aligned with the threaded rods. Further openings at the sides have been made to let all cables through.

10.3 TOP

Functions of the TOP are, similar to the BOP: protection of components (SAT.2.4.3.REQ.F.000), adding stiffness to the satellite (SAT.2.4.3.REQ.F.001) and acting as fastening point for components (SAT.2.4.3.REQ.F.002). With similar functions to comply with, the design of the TOP (Figure 10.4) is comparable to the BOP, a panel with raised sides on support feet. Differences are in the details.

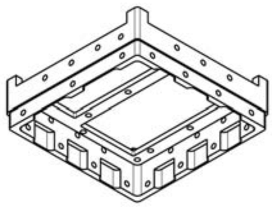


Figure 10.4: ISO-view TOP

The top plate is situated on the Z^+-side of the satellite. There are two large openings in the TOP; one for SDM and one for a Sun sensor package. Both are fastened using bolts. At the TOP provisions are made for M3 helicoils of length 1.0D. As total thickness for the plate 3.5 mm is taken. This has been chosen as such, so the bolts do not disturb the TOP further and thermal control tape can be easily fastened to the TOP.
As for the BOP (section 10.1) four holes of 3.2 mm are implemented in line with the holes in the PCBs. The threaded rods are constraint at the TOP using a washer (0.5 mm) and nut (2.4 mm), giving a minimum length of 3 mm for the support feet. The length for the support feet is chosen at 7 mm. Similar again to the BOP the support feet have an inside rounding for tooling for the bolt. For MGSE, such as covers, the support feet are equipped with an M3 Helicoil. The location of the helicoil holes are at the same locations as used for Delfi-C^3. Holes for protection covers of SDM and the Sun sensor package are not yet implemented.
The side of the TOP has two thicknesses. The upper part is 1 mm thicker than the lower part. The upper part has been chosen to a height sufficient to accommodate the hinges for the solar panel. Besides the hinges, on the X-sides a hole for electrical grounding is also implemented.
The height of the lower part is dominated by the fastening of the Unsymmetrical U's to the TOP. The fastening of the Unsymmetrical U's to the TOP is done using M3 Helicoils of 1.0D length. Bolts which are flush with the structure are used for fastening with bolt head 1.65 mm. This gives, without margins a thickness for the lower part, 3.65 mm, and thus 4.65 mm for the thickness of the upper part.
To reduce the mass of the TOP, material on the sides, between the holes has been removed, up to a 1 mm thickness of the lower part (which is a total thickness of 2 mm for the upper part of the TOP).

10.4 Outer Structure

The function of the outer structure is protection of subsystems (SAT.2.4.4.REQ.F.000) and providing fastening for components (SAT.2.4.4.REQ.F.001). Further the outer structure needs to comply with the requirements as stated in paragraph 4.3.
To comply with the requirements, as design has been chosen two U-profiles fastened to each other by connection strips (SAT.2.4.4.3.REQ.F.000 & SAT.2.4.4.4.REQ.F.000) (see Figure 10.5). For the outer structure sheets of 1 mm thickness have been chosen. The shapes are fastened with bolts and nuts at several places of the structure. The small side of the U-shape has a part of the connection strip directly glued behind it (see detail Figure 10.6); this connection is supported with M2 bolts to avoid adhesive bonding misalignment. The remaining part of the connection strip is bolted with M3 bolts to the long side of the other U-shape. The M2 bolts use a washer and nut for connection with the connection strip; the M3 bolts use self-clinching nuts as connection. The nut is pressed in the connection strip by means of a press tool as explained in [SLR 0597].
Next to the connection strips, the U-shapes have M3 bolt fastening to the BOP, intermediate panel and TOP. All bolts are flush with the U-profile especially at the points where M2 bolts have been used, since the fastening is done there in the area restricted by the POD for guide rails.
The U-profiles accommodate for a window for the MPS and an outlet for the microthruster to fulfil the payload requirements (Chapter 4.6). Holes for protection covers for MPS and $T^3\mu PS$ are not implemented yet.

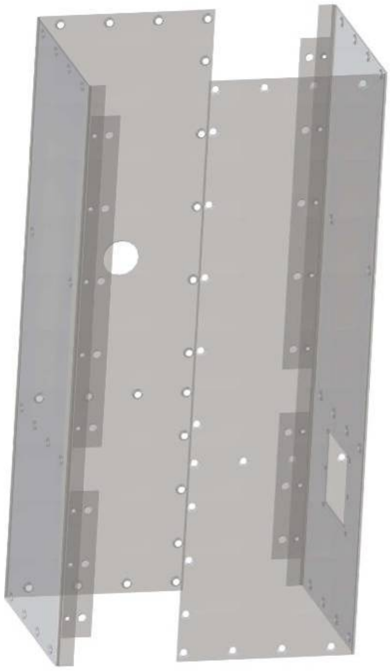


Figure 10.5: Outer structure

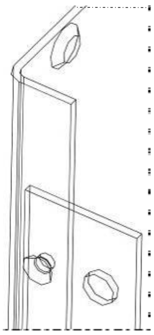


Figure 10.6: Detail of connection strip glued to U-shape

10.5 Midplane Standoffs

The midplane standoffs are used to make the PCB stack stiffer (SAT.2.4.5.2.REQ.F.000). The midplane standoffs are small structural items, on one side constraint to the outer structure with a bolt. The threaded rods are guided through the standoffs and are fastened through them to the structure. In the design of the standoffs has been taken into account the position of the threaded rods through the PCBs, restricted areas for POD guide rails and minimum thicknesses for helicoils.

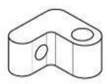


Figure 10.7: ISO-view midplane standoff

10.6 Materials

The STS comprises several milled parts and several sheets. Milled parts are BOP, Intermediate Panel, TOP and Midplane Standoffs; sheet parts are the U-profiles and the Connection Strips. An overview of the used materials and surface treatments is given in Table 10.1.

Table 10.1: Overview materials for STS parts

Part	Material	Surface Treatment
BOP	Aluminium 6082	Alodine 1500
Intermediate Panel	Aluminium 6082	Alodine 1500
TOP	Aluminium 6082	Alodine 1500
Midplane Standoffs	Aluminium 6082	Alodine 1500
U-profiles	Aluminium 5083	Alodine 1500
Connection Strips	Aluminium 5083	Alodine 1500

The materials need to fulfil a few requirements with respect to manufacturing and handling [SLR 0583]. Some aluminium alloys are not resistant to normal atmospheric conditions without additional treatment; some alloys are better usable for cold forming or removing of materials than others. Taken all the anticipated environments and manufacturing steps into account, for the milled parts the alloy Aluminium 6082 has been chosen and for the sheet parts the alloy Aluminium 5083 in consultation with the manufacturers. As surface treatment has been chosen Alodine 1500, because this treatment can also easily be done in-house, when small modifications are made to the product for example.
As minimum thickness 1 mm has been taken for the structural parts. This is sufficient for handling and manufacturing. When smaller thicknesses are used, accidental bends or dents in the material are easily made during handling. Also the material can smear during manufacturing when the material is too thin.

10.7 Verification analysis

A verification calculation similar to the PCB deflection calculation (chapter 9) can be done for all items. Besides the two load cases shown in chapter 9, a possibility is a clamped-clamped load case as shown in Figure 10.8. The outcome of Figure 10.8 is a deflection of $\delta = \frac{1}{24}\frac{FL^3}{EI}$ in the mid.
In this paragraph three calculations are worked out, with the assumption of 40g random vibration for the entire satellite (PSD acceleration is $0.053g^2$/Hz on instrument level [SLR 0373]).

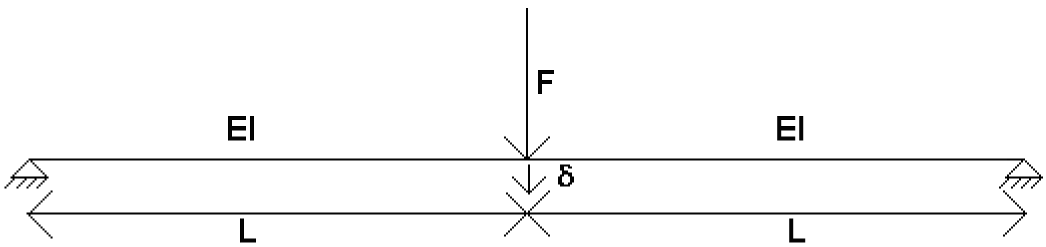


Figure 10.8: Example clamped-clamped structure

10.7.1 Verification outer structure

When making a verification calculation for the STS, it can crudely be analysed as a hollow tube of length and width L=W=100 mm, height H=340.5 mm and wall thickness t=1 mm. The tube is loaded under compression. The Myosotis formulas are not usable for this case. The maximum load the structure can take before buckling is calculated, as well as the maximum expected load. The maximum load, encountered during launch, is $P_L = 4 \cdot 40g \approx 1570N$ and the critical load, under which the tube fails $P_{cr} = \frac{4\pi^2 EI}{L^2} \approx 15.4MN$, with the modulus of elasticity E=70 GPa for aluminium and the moment of inertia $I = \frac{1}{12}(b^4 - (b-2t)^4) = 6.5 \cdot 10^{-7}$. Comparing the two loads, shows the simple assumed tube meets the load case easily.

10.7.2 Verification of intermediate panel

A verification calculation is done for the intermediate panel, since this component supports the relatively high mass of the MPS. The intermediate panel is clamped on all sides to the outer structure. This can be modelled by a clamped-clamped structure in both X- and Y-direction as shown on Figure 10.8. The panel is assumed symmetrical in length and width for this calculation, which is 98 mm. By superposition of the two two-dimensional load cases in X- and Y-direction, the deflection is found to be half of the deflection in one direction.
The MPS has been modelled for this calculation as a point mass applied in the middle. The formula used is $\delta = \frac{1}{24}\frac{FL^3}{EI}$, which is valid for a clamped-clamped structure and calculates the deflection at midpoint. The deflection is about 0.85 mm under a load of 40g, further values used can be found in Table 10.2. With the mass of the MPS at this moment still fluctuating and assuming, when fastening is determined, that the model may be represented by either a uniformly distributed mass or distributed point masses of lower value, the total deflection will become lower. For now, the deflection is considered not decisive.

Table 10.2: Overview used values calculation intermediate panel

g =	9.81	m/s^2	Standard gravity acceleration
t =	2	mm	Thickness intermediate panel
E_{AL} =	70	GPa	Young's modulus for aluminium
L = b =	98	mm	Length and width of panel
ρ_{AL} =	2800	kg/m^3	Density of aluminium
I_{IP} =	65.3*10^{-12}	m^4	Moment of inertia of panel
m_{MPS} =	500	g	Mass of intermediate panel

10.7.3 Verification of a beam of material

As example calculation the TOP is taken. At the TOP there is a beam between SDM and the ADCS Sun sensor package of 90.7 mm x 7.5 mm x 3.5 mm (length x width x thickness) (see Appendix D). The beam can be modelled as a clamped-clamped structure. For this model the largest deflection is in the mid, for which can be calculated with the Myosotis formulas $\delta = \frac{1}{24}\frac{FL^3}{EI}$. This results in a deflection of about 40 nm under a loading of 40g, which can be neglected. Values used for this calculation can be found in Table 10.3, with the moment of inertia $I = \frac{1}{12}WL^3$.

Table 10.3: Overview used values calculation beam

g =	9,81	m/s^2	Standard gravity acceleration
m_{SS} =	100	g	Mass of Sun sensor package [SLR 0596]
L=	90.7	mm	Length of beam
W=	7.5	mm	Width of beam
t=	3.5	mm	Thickness of beam
E_{AL}=	70	GPa	Young's modulus for aluminium
I_{beam}=	$4.66*10^{-7}$	m^4	Moment of inertia of beam

10.8 Interfaces

Since the STS consists of multiple parts which are fastened together, it is important to keep an eye on the interfaces, when changing something. All STS internal interfaces are discussed in this paragraph. Interfaces of the STS with other subsystems (SAT.2.4.REQ.I.000) can be found in [SLR 0582].

10.8.1 Placement and size of fastening holes

The placement of fastening holes is a tuned process, therefore when changing the placement in one part, this has influence on another part.
A different placement for holes in the:

- BOP -> the placement of fastening holes for the BOP in the U-profiles need to be revised.
- Intermediate Panel -> the placement of fastening holes for the Intermediate Panel in the U-profiles need to be revised.
- TOP -> the placement of fastening holes for the TOP in the U-profiles need to be revised.
- Connection Strips -> the placement of fastening holes for the Connection Strips in the U-profiles need to be revised.
- U-profiles -> the placement of fastening holes of the BOP, Intermediate Panel, TOP and connection strips need to be revised.

Besides placement, this is of course also valid for the size of the hole.

10.8.2 Subsystem location changes

Changes of subsystems in Z-direction have influence on placement and fastening.
Change in Z-direction for:

- Intermediate Panel -> location of fastening holes for the Intermediate Panel in the U-profiles need to be revised.
- Midplane Standoffs -> location of fastening holes for the Midplane Standoffs in U-profiles need to be revised.
- Connection Strips -> location of fastening holes for the Connection Strips in U-profiles need to be revised.

It can also occur that the intermediate panel influences the placement of the connection strip, which would mean a revision of the length of the connection strips, a revision of the placement of the holes of the connection strips and a revision of the intermediate panel and connection strip holes in the U-profiles.

10.8.3 Length U-profile

When the length of the U-profiles is changed, this has influence on all structural parts, meaning mostly hole placement and location. When the length is changed, these should then of course be checked.

10.9 Integration order

The STS exists of several elements; to correctly put these together with the rest of the satellite a recommendation for top level integration is given.

13. Assemble the BOP with TCB and DAB.
14. Assemble the TOP with SDM and Sun sensor package.
15. Assemble intermediate panel with rods
16. Assemble the PCB stack including midplane standoffs.
17. Assemble the TOP with the PCB stack & intermediate panel.
18. Assemble TOP/stack/intermediate panel with MPS
19. Assemble both U-profiles with components fastened to the profiles, such as the HDRMs and magnetorquers.
20. Assemble one U-profile with the BOP, intermediate panel and the TOP, leaving open the X^+-side.
21. Install and fasten the system busses.
22. Fasten the second U-profile.
23. Assemble the solar panel with the hinge.
24. Assemble the solar panel assembly with the TOP and HDRM.

11 Test Plan

Before the satellite can be launched, the satellite needs to undergo several tests as prove that the requirements are met, e.g. stiffness and strength. This chapter discusses the various tests of importance for the STS.

11.1 Mechanical testing

As can be read in paragraph 4.6 $T^3\mu PS$ has a positioning requirement. To be able to meet this requirement, the mass and centre of mass need to be known for every subsystem. In [SLR 0525] test templates of Delfi-C^3 can be found for:

- Geometry check: to ensure the dimensions are within the specified range
- Visual inspection: inspect for damage, dirt
- Centre of mass
- Mass measurement

11.2 Vibration test

Before launch the satellite needs to undergo a vibration test. Of importance for the STS is to show that the STS has been correctly designed and has enough strength and stiffness (SAT.2.4.REQ.F.006 & SAT.2.4.REQ.P.000) to fulfil the mission lifetime.

12 Mechanical Ground Support Equipment

During the second ESA (European Space Agency) Space Systems Design, Verification & AIT (Assembly, Integration and Testing) Workshop in April 2003 P. Giordano said 'MGSE are specific mechanical items procured for each program to safely and extensively support all the AIT processes and on-ground operations.' This summarizes the use of and the need for good MGSE. MGSE helps with handling of delicate components (e.g. protection covers), precision during integration (e.g. manufacturing tools) and a stable environment (e.g. AIVT tools).
Baseline for MGSE for Delfi-n3Xt is to use as much as possible the MGSE of Delfi-C^3 (DC3). Where needed adaptations to the designs are proposed. The MGSE has been subdivided into three categories:

- manufacturing tools (Paragraph 12.1),
- Assembly, Integration, Verification and Testing (AIVT) tools (Paragraph 12.2), and
- protection covers (Paragraph 12.3).

12.1 Manufacturing Tools

Delfi-n3Xt is planned to be entirely custom-made. This puts additional strain on the correct manufacturing and integration of components as deployment springs and antennas. To help in the manufacturing process Table 12.1 shows the manufacturing tools foreseen for Delfi-n3Xt. Figure 12.1 to Figure 12.5 give an overview of the manufacturing tools developed for Delfi-C^3, which are going to be used for Delfi-n3Xt. For Delfi-n3Xt different press nuts are foreseen. For these the manufacturer recommends a different tool as found in [SLR 0597].

Table 12.1: Overview Manufacturing Tools

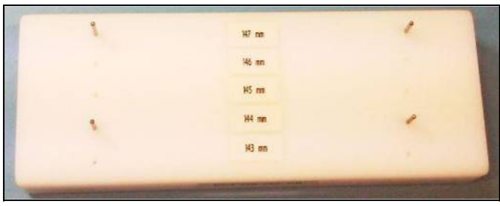
Tool	Inherit DC3	Modification
Solar panel Deployment Spring (Figure 12.1)	Yes	No
Press nut instalment (Figure 12.2)	No	Press with adjustable pressure level needed [SLR 0597]
Wire length hold down system (Figure 12.3)	Yes	No
Antenna winding (Figure 12.4)	Yes	No
MAB instalment (Figure 12.5)	Yes	No
Resistor Hot spot (Figure 12.6)	Yes	No
Antenna drill jig (Figure 12.7)	Yes	No
Antenna assembly (Figure 12.8)	Yes	Move fastening block and hole
STS drill jigs (Figure 12.9)	No	Different locations and openings for cut-outs and holes

The springs in Delfi-C^3 have been handmade with a manufacturing tool (Figure 12.1). This tool can be used for Delfi-n3Xt without adaptations.

Figure 12.1: Solar panel deployment spring tool

A tool for instalment of press nuts has been used for Delfi-C^3 (Figure 12.2). Uncertain is whether this tool is usable, and otherwise it will need to be adapted.

Figure 12.2: Press nut instalment tool



This tool (Figure 12.3) has been developed to get the correct wire length needed for the hold down system of Delfi-C^3. This tool can be used without further adaptations for Delfi-n3Xt.

Figure 12.3: Wire length tool for hold down system

The wind tool (Figure 12.4) was developed for Delfi-C^3 to roll the MAB antennas easily [SLR 0308]. A similar tool will be used for Delfi-n3Xt.

Figure 12.4: Wind tool for MABs

The MAB instalment tool (Figure 12.5) has been developed for Delfi-C^3 to easily integrate the antenna in the MAB [SLR 0308]. This tool will be reused for Delfi-n3Xt without further adaptation.

Figure 12.5: MAB instalment tool

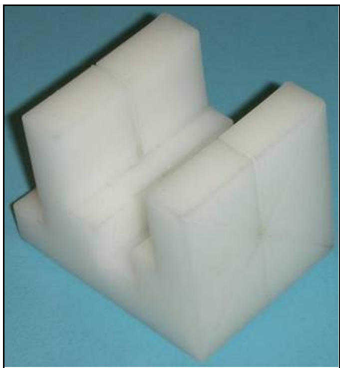


Figure 12.6: Resistor hot spot tool

The hold down and release mechanisms of Delfi-C^3 make use of resistors for burning Dyneema wires. To determine the best orientation [SLR 0481] for the resistor the resistor hot spot tool (Figure 12.6) was developed. This tool can be reused for Delfi-n3Xt without adaptation.

Figure 12.7: Drill jig for antennas

A drilling tool (Figure 12.7) has been developed for the antennas of Delfi-C^3 [SLR 0308]. This tool can be reused for Delfi-n3Xt without adaptations.

Figure 12.8: Assembly tool for antennas

An assembly tool for antennas has been developed for Delfi-C^3 (Figure 12.8). This tool was found to be unstable as is. Proposed adaptation for this tool is to move the fastening block and hole to the left to increase the stability of the antenna during assembly.

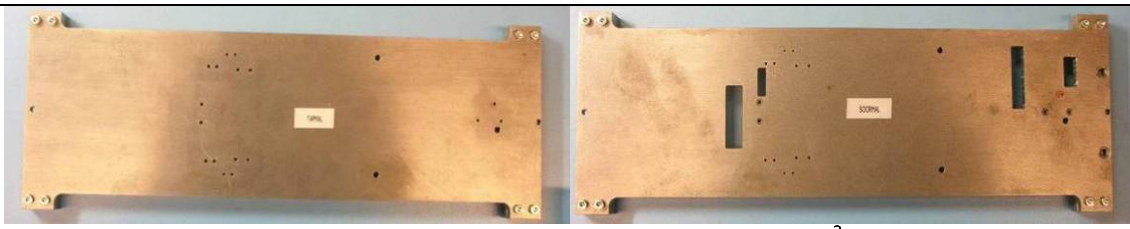


Figure 12.9: Pre-drill and drill jig STS Delfi-C^3

Jigs for pre-drilling and drilling have been made for the structure of Delfi-C^3 (Figure 12.9). For Delfi-n3Xt different locations for cut-outs and holes are required with respect to Delfi-C^3.

12.2 AIVT Tools

Delfi-n3Xt is the same size as Delfi-C^3. Most of the AIVT tools of Delfi-C^3 do not need modification. Largest impact for the AIVT tools is the altered size of the solar panels and possibly the POD which will be used. Table 12.2 gives an overview of the AIVT tools and what level of modification is necessary. Figure 12.10 to Figure 12.14 show which AIVT tools of Delfi-C^3 will be reused for Delfi-n3Xt.

Table 12.2: Overview AIVT

Tool	Inherit DC3	Modification
Jig (Figure 12.10)	Yes	No
Vibration adapter (Figure 12.11)	Yes	Extra holes for fastening solar panel and POD during tests
PCB stands (Figure 12.12)	Yes	No
Handling tool (Figure 12.13)	Yes	No
Grounding tool (Figure 12.14)	No	Facilitate grounding point on satellite for fastening by a bolt

Figure 12.10: Assembly and Integration Jig

For Delfi-C^3 the jig [SLR 0484] shown on Figure 12.10 was developed. Delfi-n3Xt will reuse the jig without modifications.

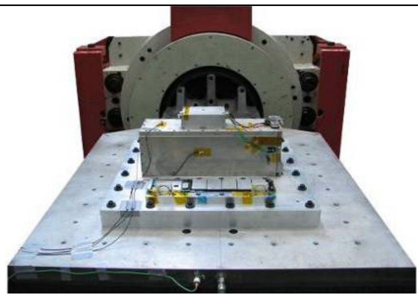
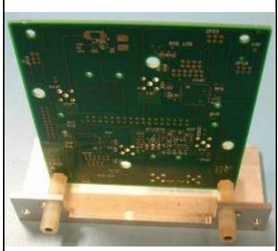


Figure 12.11: Vibration adapter on shaker table

For vibration testing of Delfi-C^3 was made use of a vibration adapter as shown on Figure 12.11. Some adaptations, such as drilling extra holes, are foreseen for Delfi-n3Xt.

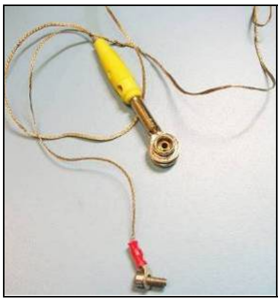


For testing of PCBs a PCB stand (Figure 12.12) was developed [SLR 0484] for Delfi-C^3. Delfi-n3Xt will reuse the stands without modifications.

Figure 12.12: PCB stand

For Delfi-C^3 a handling tool (Figure 12.13) for putting the satellite in the CubeSat deployer was developed [SLR 0484]. This tool can be reused for Delfi-n3Xt without making adjustments.

Figure 12.13: Handling tool



To ensure comparable test conditions at different locations and to avoid short-circuits the satellite needs to be electrically grounded. Delfi-C^3 made use of a clip for grounding. Delfi-n3Xt will make use of bolts for grounding as shown on Figure 12.14. Two holes for grounding have been implemented in both BOP and TOP

Figure 12.14: Electrical Grounding cable

12.3 Protection Covers

Protection covers function to protect fragile components from damage, contamination and make handling during AIVT-phases easier. Elements of Delfi-C^3 for which protection covers were developed (see [SLR 0484] for more information) are the solar cells (Figure 12.15) and Sun sensors (Figure 12.16). Since Delfi-n3Xt is equipped with more solar cells and different sensors and components needing covers, the covers of Delfi-C^3 cannot be reused and new covers will have to be developed. Table 12.3 gives an overview of the expected covers needed for Delfi-n3Xt and the minimum amount of protection covers needed. Besides the mentioned covers of Table 12.3, the MPS and T^3µPS also require protection covers, which will be supplied by the payload partner responsible. Figure 12.15 and Figure 12.16 show the covers as developed for Delfi-C^3. Covers for Delfi-n3Xt will be developed on the same principles.

Table 12.3: Overview covers needed for Delfi-n3Xt

Component	Amount	
Solar cells	4+1 spare	Cover for string of seven cells
SDM	1*	Cover for solar cell experiment
Sun sensor package	1*	Cover for Sun sensor package

* Cover for SDM and Sun sensor package might be combined to one cover

Figure 12.15: Left: cover solar cells, right: cover thin film solar cells

For Delfi-C^3 a cover for protection of the solar cells and thin film solar cells was used (Figure 12.15). Since more solar cells will be used (seven cells in a string instead of five cells) a modified cover is needed for Delfi-n3Xt.

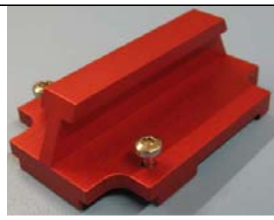


Figure 12.16: Protection cover Sun sensor

Delfi-C^3 had two autonomous wireless Sun sensors. For these sensors protection covers (Figure 12.16) were developed. Delfi-n3Xt is also equipped with Sun sensors, which are not of the same size. Therefore new protection covers will have to be designed.

12.4 Facilities

Baseline for AIVT is working in cleanroom of the Faculty of Aerospace Engineering in Delft. The cleanliness of the cleanroom is class 100.000. When other facilities are needed for e.g. tests, the cleanliness level for these facilities needs to be taken into account.

13 Next Steps

Future steps with respect to the structural subsystems are:

- detailing elements as the intermediate panel.
- making a prototype of the structure including BOP and TOP.
- making more detailed drawings for payloads and subsystems.
- looking into fastening and read-out electronics of ADCS photodiodes.
- revising placement subsystems.
- making additions for MGSE.

A Options list

Card bus system

Advantages	Disadvantages
Interchangeability via slide system Accessibility with separable back and front panel Stresses are spread Extra holes needed for varying distance between PCBs are easily made	Wear of the sliders Vertical placement of PCBs Mass

Rod system, detachable side panels

Advantages	Disadvantages
Accessibility stack Experience with rod system Integration of more PCBs Mass of the system	Time consuming for testing and interchanging

Male-female connectors

Advantages	Disadvantages
Interchangeability Accessibility Accessibility with detachable side panels	More PCBs in stack -> bus lengths Mass may be a problem Left-handed/right-handed thread

Stack with PCB side panels

Advantages	Disadvantages
Integration of more PCBs Ribs on 1/3 and 2/3 length satellite	Accessibility PCB stack dimensions might have to be reduced in size Wiring needs to be looked into Time consuming for testing and interchanging

PCB box

Advantages	Disadvantages
Interchangeable PCB have own side panelling Handling Made into stack easy	Accessibility Vertical placement of PCBs Mass may be a problem

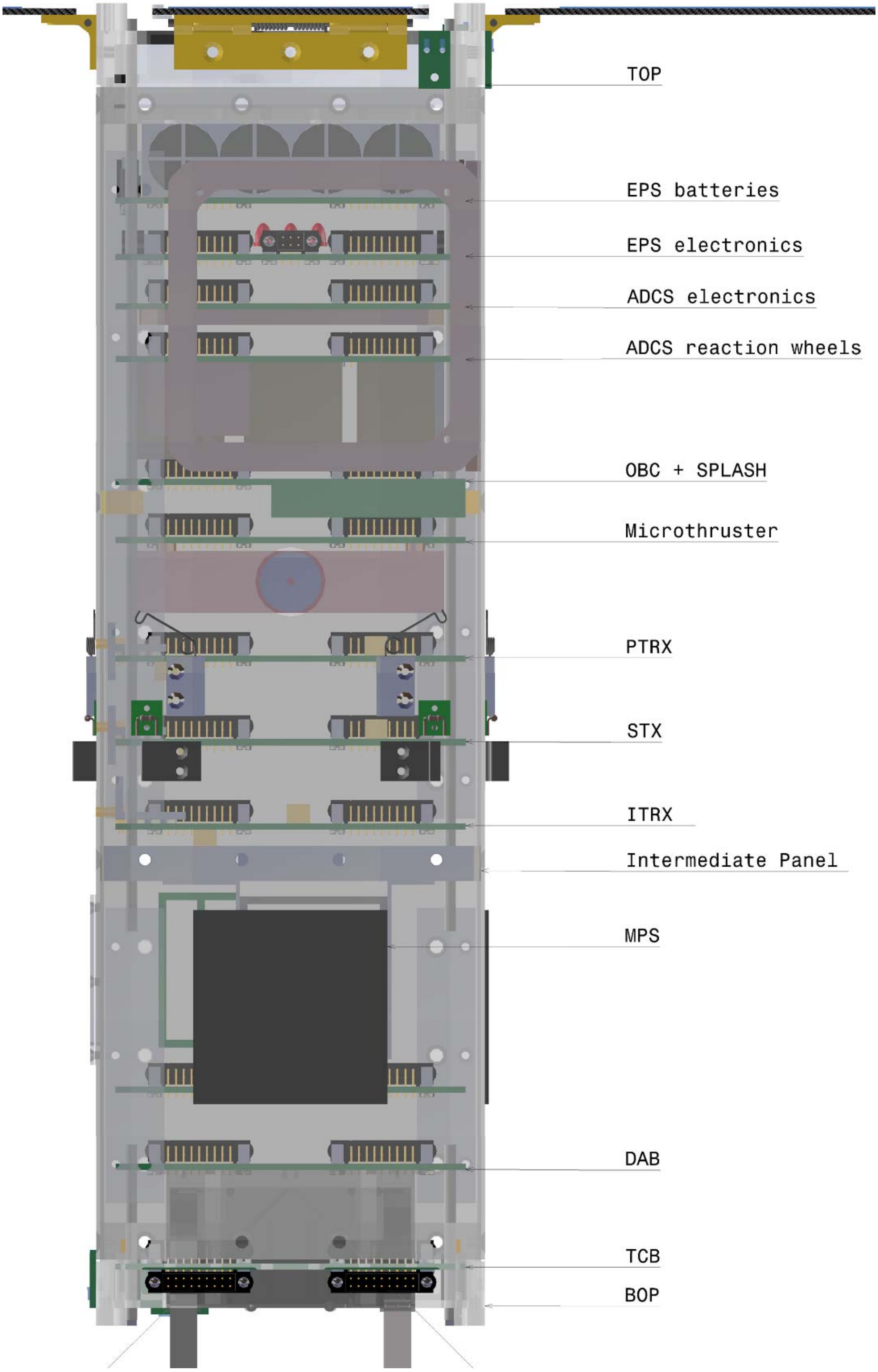
B Trade-off STS options

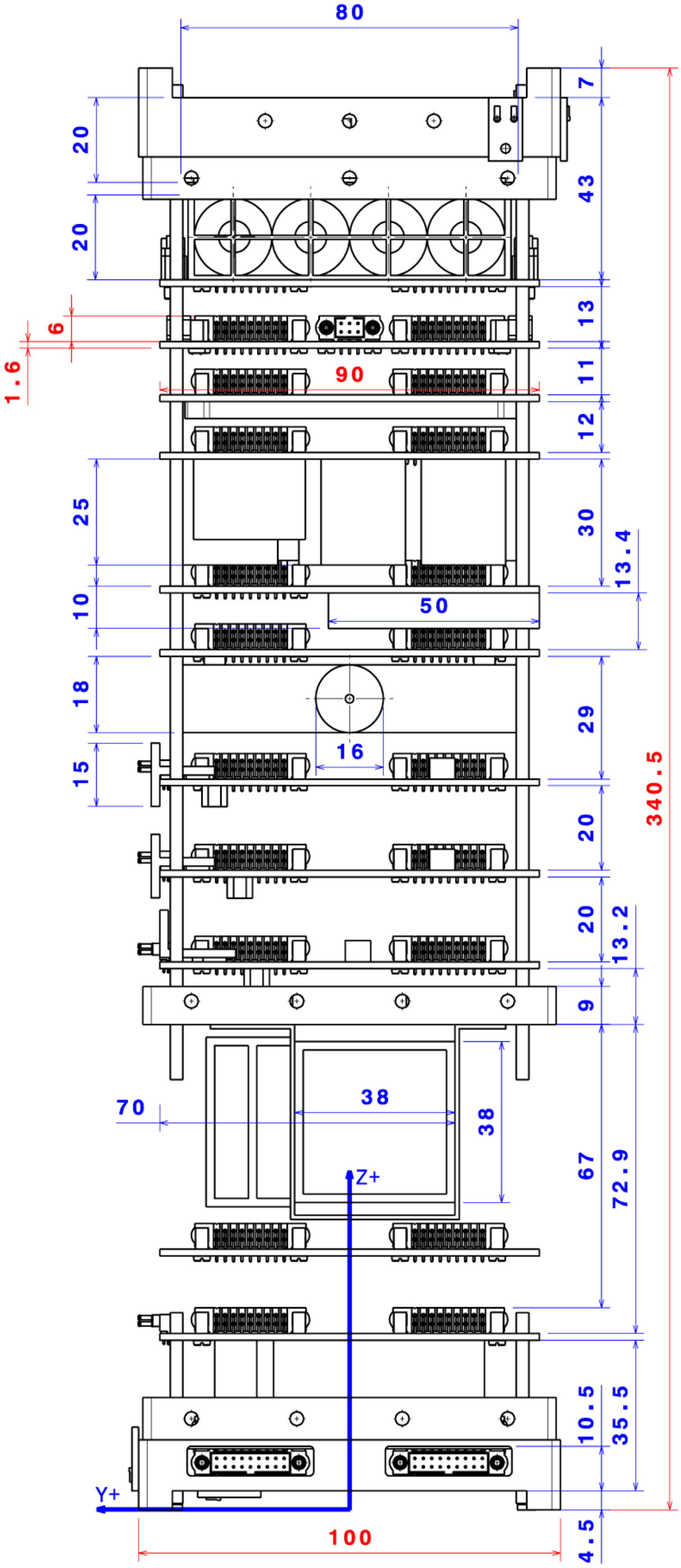
Criterion	Weight	Options					
		Card bus system	Rod system, loose side panels	Male-female connectors	Stack with PCB side panels, rod system	Stack with PCB side panels, male-female connector	PCB box
Interference due to payload	4	2	3	3	1	1	2
Structural subsystem mass	5	2	5	4	5	4	3
Stress	3	1	5	5	3	3	2
Stiffness	4	2	4	4	4	4	3
Manufacturability	1	3	5	2	4	2	1
Accessibility to stack	5	3	5	5	1	1	1
Assembly, integration and testing of PCBs and connectors	5	5	2	2	1	1	4
Substitution	3	5	2	2	1	1	4
Mounting of outer parts	3	1	5	5	1	1	4
Variation of PCB distance	2	5	4	2	4	2	1
Heritage	2	2	5	3	3	2	2
Total	185	104	147	131	88	75	97
Percentage	100	56	79	71	48	41	52
Ranking		3	1	2	5	6	4

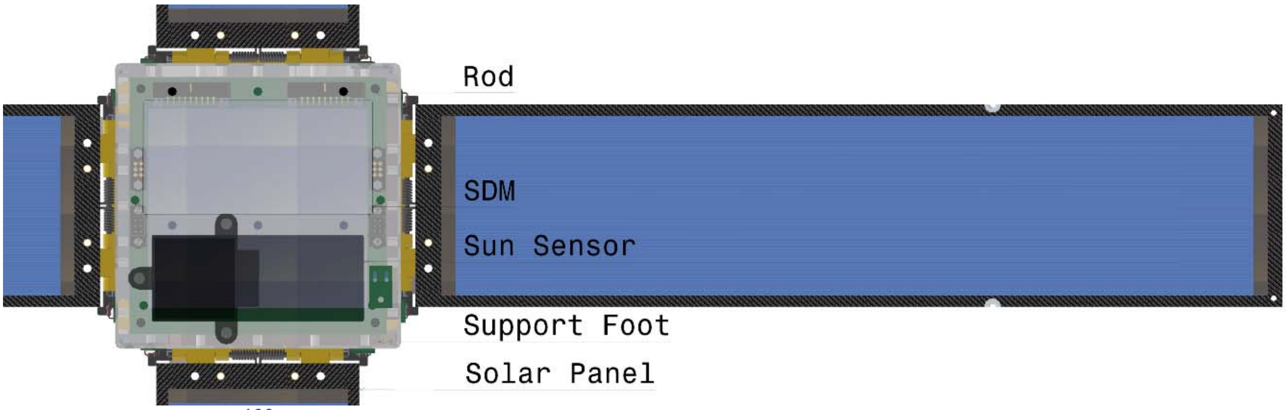
C Trade-off Side panels

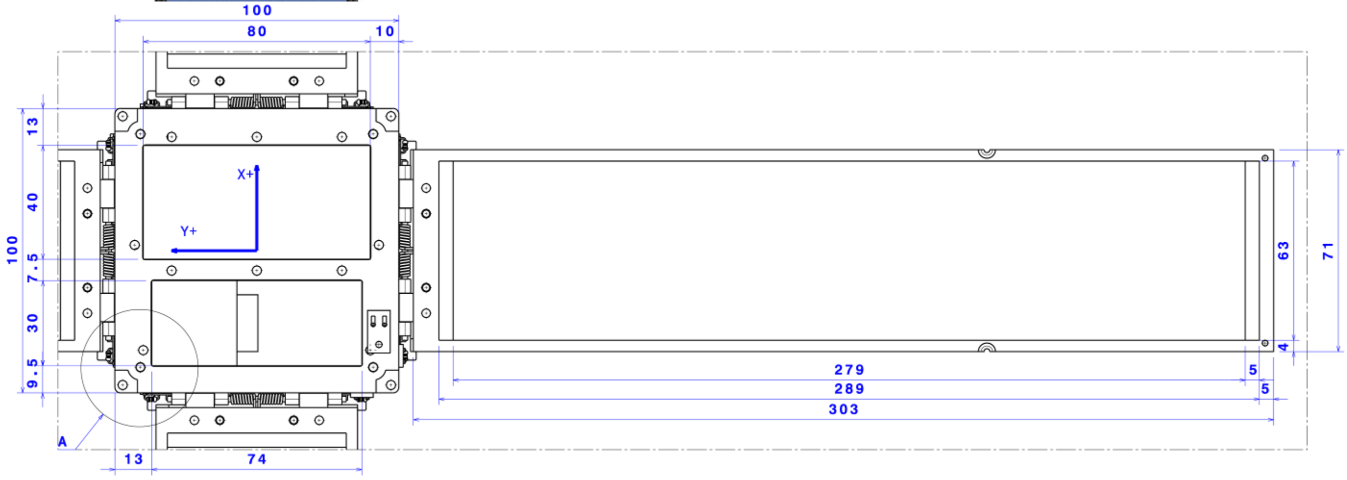
		Criterion							
		Integration			Inspection	Accessibility	Replacement	Stiffness	
		Corners are free from nuts etc	Integration with inside structure	Integration with outside structure	Structure allows inspection of stack	Structure allows accessibility to the stack for connections	Similarity of panels for replacement	Stiffness of the side panels as a whole	Total
	Weight	2,3	1,4	1,4	3	4	2	5	19,1
Options	0 Detachable sides	1	-1	1	-1	-1	-1	1	-1,7
	1 Detachable side	-1	-1	1	0	-1	-1	1	-3,3
	2 Detachable sides, 1 L-shape	-1	0	1	1	1	0	-1	1,1
	2 L-shapes	-1	0	1	1	1	1	0	8,1
	2 U-shapes symmetrical	1	0	-1	0	0	1	1	7,9
	2 U-shapes, unsymmetrical sides	1	0	0	0	0	1	1	9,3
	4 Detachable sides	-1	1	1	1	1	1	-1	4,5

D Delfi-n3Xt Renderings




80
7
43
20
20
6
1.6
13
90
11
12
25
30
13.4
10
50
18
29
16
15
340.5
20
20
13.2
9
70
38
38
Z+
67
72.9
10.5
35.5
Y+
100
4.5


Rod
SDM
Sun Sensor
Support Foot
Solar Panel


100
80
10
13
40
7.5
30
9.5
X+
Y+
A
13
74
279
289
303
5
5
63
71
4

E PCB Deflection

Design loads Delfi-n3Xt

PCB			SI		
g =	9.81	m/s^2		9.81	m/s^2
t =	1.6	mm		1.6E-3	m
E_{FR4} =	17	GPa		17.0E+9	Pa
Diagonal =	127.3E+0	mm		127.3E-3	m
L = b =	90	mm		0.09	m
ρ_{FR4} =	1.9E+3	kg/m^3		1.9E+3	m/kg^2
I_{plate} =	43.4E-12	m^4		43.4E-12	m^4
m_{PCB} =	24.6E+0	g		24.6E-3	kg

g	Uniform mass =	$5*m_{PCB}*g*Diagonal^3/384/E_{FR4}/I_{plate}$			Point mass =	$m_{PCB}*g*Diagonal^3/48/E_{FR4}/I_{plate}$			
1	8.8E-6	m	8.8E-3	mm	δ =	14.0E-6	m	14.0E-3	mm
5	43.9E-6	m	43.9E-3	mm		70.2E-6	m	70.2E-3	mm
10	87.8E-6	m	87.8E-3	mm		140.5E-6	m	140.5E-3	mm
11	96.6E-6	m	96.6E-3	mm		154.5E-6	m	154.5E-3	mm
15	131.7E-6	m	131.7E-3	mm		210.7E-6	m	210.7E-3	mm
20	175.6E-6	m	175.6E-3	mm		281.0E-6	m	281.0E-3	mm
25	219.5E-6	m	219.5E-3	mm		351.2E-6	m	351.2E-3	mm
30	263.4E-6	m	263.4E-3	mm		421.5E-6	m	421.5E-3	mm
35	307.3E-6	m	307.3E-3	mm		491.7E-6	m	491.7E-3	mm
40	351.2E-6	m	351.2E-3	mm		562.0E-6	m	562.0E-3	mm
45	395.2E-6	m	395.2E-3	mm		632.2E-6	m	632.2E-3	mm
65	571.9E-6	m	571.9E-3	mm		915.0E-6	m	915.0E-3	mm
100	878.1E-6	m	878.1E-3	mm		1.4E-3	m	1.4E+0	mm

g-factor with a 1 and 2 mm deflection

g =	113.9E+0	1 mm	g =	71.2E+0	1 mm
	227.8E+0	2 mm		142.3E+0	2 mm

random vibration required for 2 mm overlap

PSD frequency:	2.3E+3	Hz

QSL factor DNEPR = 8,3g
Safety Factor = 1.3

10.79	g

Without amplification, scale loads for 11g

random vibration
PSD = 0.16
Safety factor for random vibration usually 1.25

QSL factor due to random vibration	65.1E+0	g

Appendix C Optimized Three-unit CubeSat Structure for Delfi-n3Xt (IAC2008)

IAC-08-B4.6.A1
SMALL SATELLITE MISSIONS SYMPOSIUM (B4.)
Design and Technology for Small Satellites - Part I (6.A)

OPTIMIZED THREE-UNIT CUBESAT STRUCTURE FOR DELFI-N3XT

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Abstract

For the Delfi-n3Xt mission, follow-up to CubeSat Delfi-C^3 [1] of Delft University of Technology, several concepts concerning the Structural Subsystem (STS) have been analysed. One of the main objectives is to reduce the time needed for assembly, integration and testing, and to improve handling capabilities. Lessons learned from Delfi-C^3 have been taken into account in a trade-off between several candidate design options.
A brief description of the structure of Delfi-C^3 is given. Afterwards the candidate options for the STS of Delfi-n3Xt are discussed, followed by the final structure selection and implementation.

1 Introduction

Since the first CubeSat was designed and built, many followed. Their structure designs reveal a variety of possibilities, although some designs have constraints, e.g. by the use of a bought-out CubeSat kit. Based on the lessons learned from the first three-unit CubeSat of Delft University of Technology, Delfi-C^3 (see Figure), several options for the structure have been investigated for the successor, Delfi-n3Xt. The structure of Delfi-n3Xt is to accommodate the five technological and scientific payloads [1] as well as the subsystems of Delfi-n3Xt.

Main issues from the Delfi-C^3 have been the amount of time needed for assembly, integration and testing of the Printed Circuit Boards (PCBs) into the structure in relation to the restrictions set by the bought-out structure. A substantial number of adaptations and custom designed parts have been implemented as replacement for the standard kit parts of the bough-out structure. Furthermore a lot of time in the development phase was spent for the mounting, integration and testing of the PCBs.

The structural subsystem is an important subsystem in any satellite, providing support and protection to payloads, mechanical and electronic subsystems. An optimum structure is not only able to accomplish the functions during mission life, but is also better to handle during the development of the satellite. The structural subsystem of the nanosatellite, Delfi-n3Xt, should allow for a smooth and more time-efficient assembly, integration and test. This also results in a reduction of risks during handling.

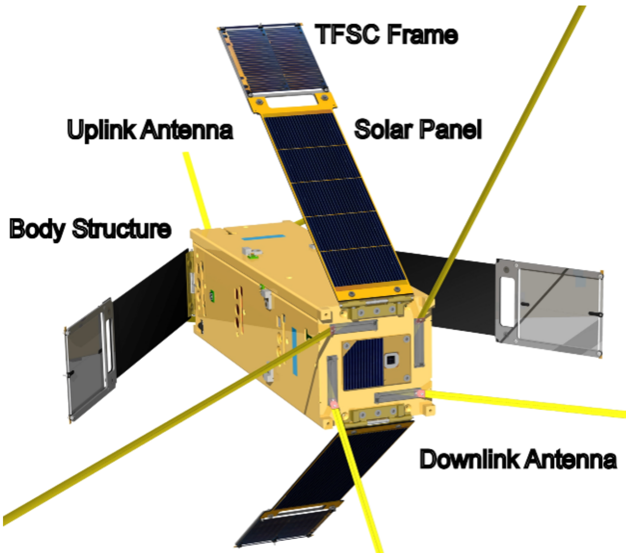


Figure 1. - Delfi-C^3 flight impression

2 Delfi-C^3

Delfi-C^3 makes use of a bought-out CubeSat structure [3], consisting of a primary and secondary structure (see Figure). The primary structure consists of a tube chassis and top and bottom panel. The secondary structure consists of four rods and midplane stand-offs for better performance in stiffness. When the tube chassis is installed, there is very little access to the inside structure.
Integration and assembly took a lot of time for Delfi-C^3. Delfi-C^3 had a specific order for the integration of the PCBs. When a PCB from the middle of the stack had to be removed, the complete stack had to be disassembled.
To reduce the time for assembly, integration and testing of PCBs and accessibility to the structure, concepts for the structure of Delfi-n3Xt have been explored.

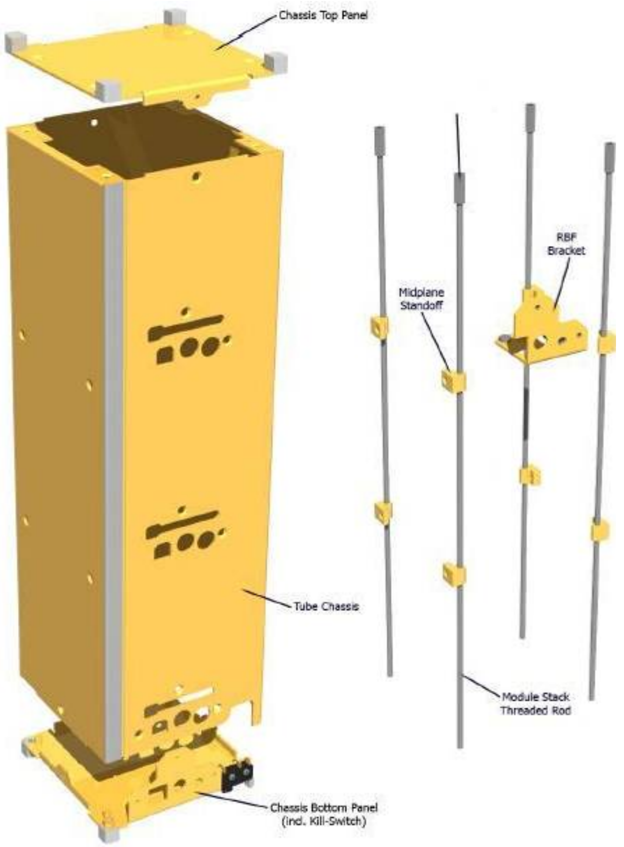


Figure 2. - Delfi-C^3 primary and secondary structure

3 Design options

The known issues from Delfi-C^3 have been focus points in a Structural Subsystem (STS) trade-off. The trade-off has been done between six different options, namely:

1. Card bus system
2. Rod system with detachable side panels
3. Male-female connectors with detachable side panels
4. Rod system with PCB side panels
5. Male-female connectors with PCB side panels
6. PCB box

The different options will be discussed from section 3.1. to 3.5.

For Delfi-n3Xt, a body fixed reference frame is used (see Figure). The reference frame is on the centre line of the satellite, beginning from the support feet at the bottom panel of the satellite. The Z^+-axis is defined along the long side of the satellite in direction of the top panel. The X^+-axis is the side where the system bus has attachments to the stack.

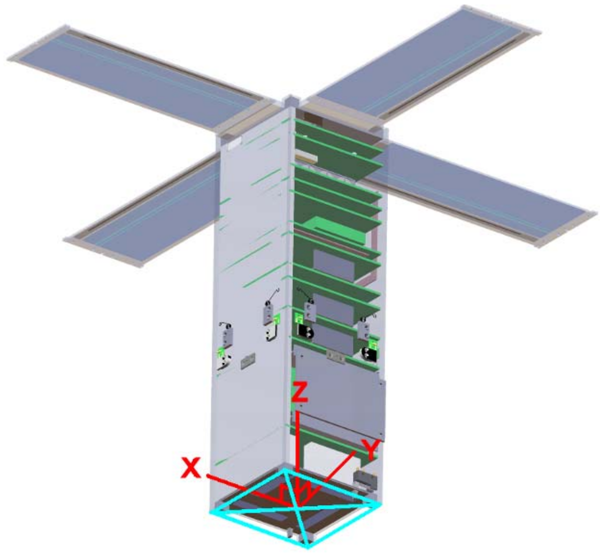


Figure 3. – Definitions used for Delfi-n3Xt

3.1 Card bus system

This option concentrates on the quick interchangeability of PCBs. An impression of this system is shown in Figure . Via the X-side panels the PCBs slide into the structure, where they are clamped to the sides. On the X^+-side the PCBs are connected via a system bus. The system bus can be a cable or a panel with slots for the connectors. The X^--side is used to check whether the cable or structure is connected correctly. A separable X^+- and X^--panel make the inner structure more accessible, therefore a cable is preferred above a slotted panel. The PCBs can be integrated and removed independently of each other from the structure. Disadvantageous for this system are the stiffness and stress for the PCBs during tests and launch. High mass with respect to the other options is also a drawback.

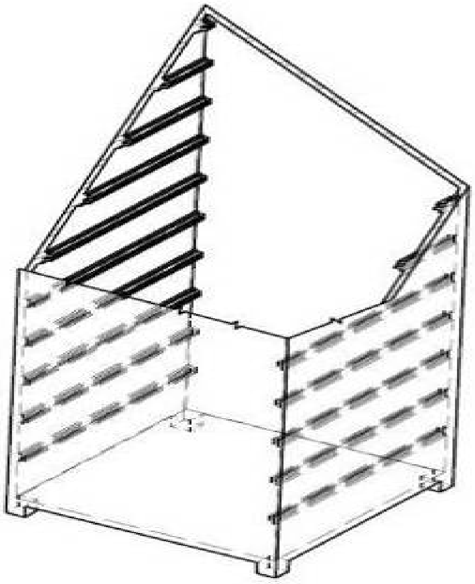


Figure 4. - Impression of card bus system

3.2 Rod system with detachable side panels

This option is a variation to the rod system of the Delfi-C^3, but aims for better accessibility. The secondary structure consists of rods where the PCBs are stacked upon (Figure), but to have better accessibility after integration in this situation, unlike Delfi-C^3, the X- and Y-side panels can be taken off. This means that removing PCBs for separate testing, modifications and/or replacing PCBs in this system is still time-consuming.
Advantageous for this option is that there is work-experience with a rod system and that the distance between PCBs can be easily varied with different bus lengths.

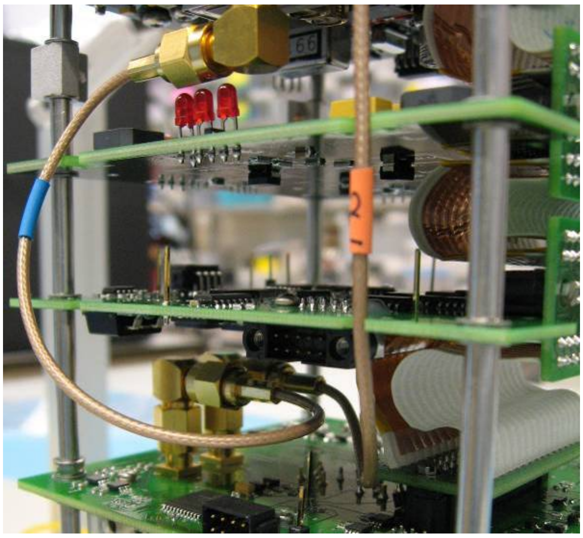


Figure 5. – Detailed view of rod system

3.3 Male-female busses on PCB

This option is similar to the mentioned rod system, but instead of rods is worked with male-female, non-electrical connectors. These connectors decrease the time needed for interchanging PCBs. A male connector is put on the Z^+- and Z^--side of the PCB, after which a female connector is screwed on (Figure).

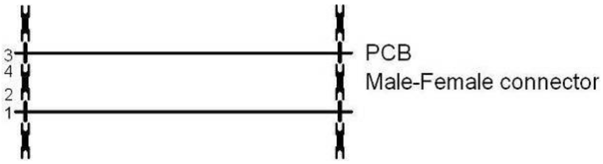


Figure 6. - Detailed view of male-female connector system

The busses can be chosen to appropriate lengths as needed. Also a standard length can be chosen for modularity.
For this system detachable X- and Y-panels are an option. This not only makes the structure interchangeable, but also better accessible.

3.4 Stack with PCB side panels

This option can be combined with the rod system and the male-female connectors. The PCBs are not the outer structure, but are protected by an outer structure. By orienting PCBs in Z-direction, more room can be created for payloads. Since a three-unit CubeSat is assumed, there is a possibility to have ribs on one third of the length of the satellite and on two third. This way the PCBs can still have a square form. For interference reasons (mechanically or electronically) the PCBs placed normal to the Z-axis have to be reduced in size. Having a stack with PCB side panels reduces the accessibility compared to the rod and male-female system.

3.5 PCB box

The idea of the PCB box is that the PCBs have their own frame on the X- and Y-sides, which makes that the PCBs can be piled together via a rod system, as shown on Figure . If more space is needed due to larger payload, the frame of the PCBs needs to be reduced in height. Also the stack lacks accessibility and needs disassembling when needing a PCB from the stack. On the other side the handling risk is less, due to the framework on each PCB.

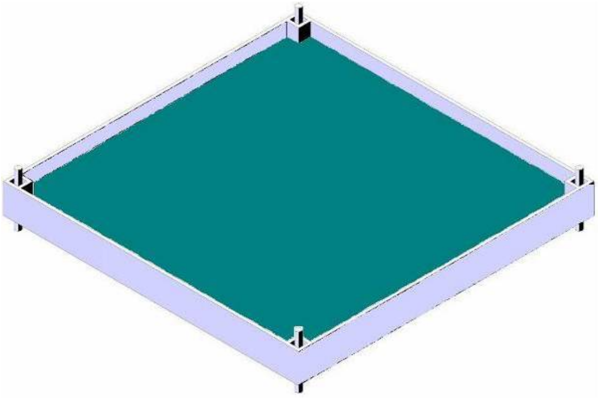


Figure 7. – Detailed view of PCB box

4 Trade-off

The six options discussed have been traded on several criteria. Not only general criteria, such as accessibility and Assembly, Integration and Testing (AIT) have been taken into account, also Delfi-n3Xt specific criteria as mounting of outer parts and structural interference due to payload. The criteria can be found in Table 1. The trade-off showed no clear winner for the best structure, however the rod and male-female connector system scored clearly better than the other options. Having experience with the rod system in the Delfi-C^3 project and foreseeing problems with stiffness of the stack with the male-female connector system, in a team discussion the rod system was favoured.
The number of side panels which will be made detachable is still to be determined. Unlike Delfi-C^3, Delfi-n3Xt will make use of a symmetrical rod layout for PCBs. Delfi-C^3 used the PC/104 [4] standard, making use of the commercially available PC/104 systems.

Table 1 - Criteria for the Delfi-n3Xt STS

Performance
Interference due to payload
Structural subsystem mass (outer structure and items for fastening PCBs to structure)
Stress
Stiffness
Structural manufacturability
Handling
Accessibility
Assembly, integration and testing of PCBs and connectors
Substitution of PCB
Mounting of outer parts
Flexibility in design
Varying PCB distance in Z-direction
Miscellaneous
Heritage

Since for Delfi-n3Xt all electrical boards will be custom made, this standard is not necessary. Making the PCB rod layout symmetrical has further advantages in usable space per PCB.

5 Delfi-n3Xt

Delfi-n3Xt implements more and bigger payloads and more advanced subsystems than Delfi-C^3. To verify all payloads and subsystems fit in a three-unit CubeSat, drawings for each subsystem have been made. Components and subsystems known from Delfi-C^3 have been implemented, likewise volumes and masses as defined by payload partners and team members. Integration of all subsystems into the drawing (see Figure) showed that it is possible to put all subsystems as defined within the envelope of (100 x 100 x 340.5) mm, according to three-unit CubeSat specifications [4].
The largest impact comes from the Multifunctional Particle Spectrometer (MPS) payload. This payload has a large effect on the total mass of the satellite and relatively high in Z-direction. The current preliminary design specifications are 60 mm in height and 0.5 kg.
At the moment all the subsystem fit into the structure. However the MPS being so heavy, it requires its own supporting structure. To minimize obstruction of measurements and obstruction to other subsystems, the MPS has been put low on the Z-axis. This leaves only an antenna board and bottom panel below the payload. This is about one third of the total height of the satellite. While the rest of the satellite will be integrated onto rods, the structural support for the MPS is still to be determined.

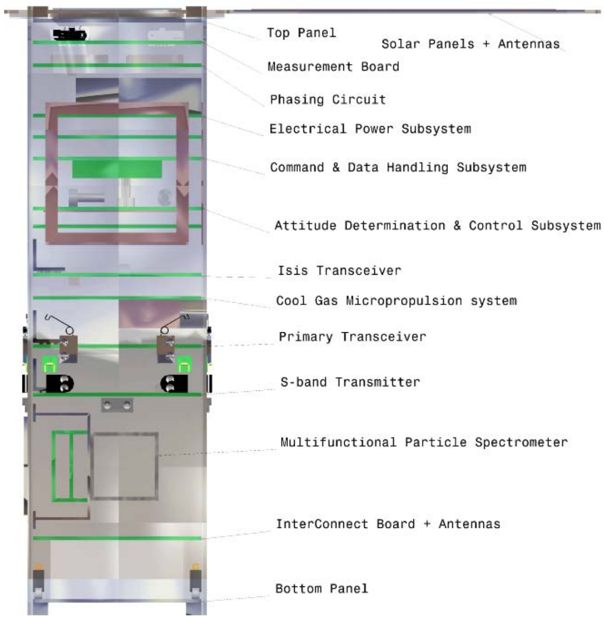


Figure 8. - Delfi-n3Xt layout

Other subsystems with considerable mass are the batteries and the micropropulsion system. What the effect on the centre of mass is due to these subsystems together with the solar panels, is to be determined.

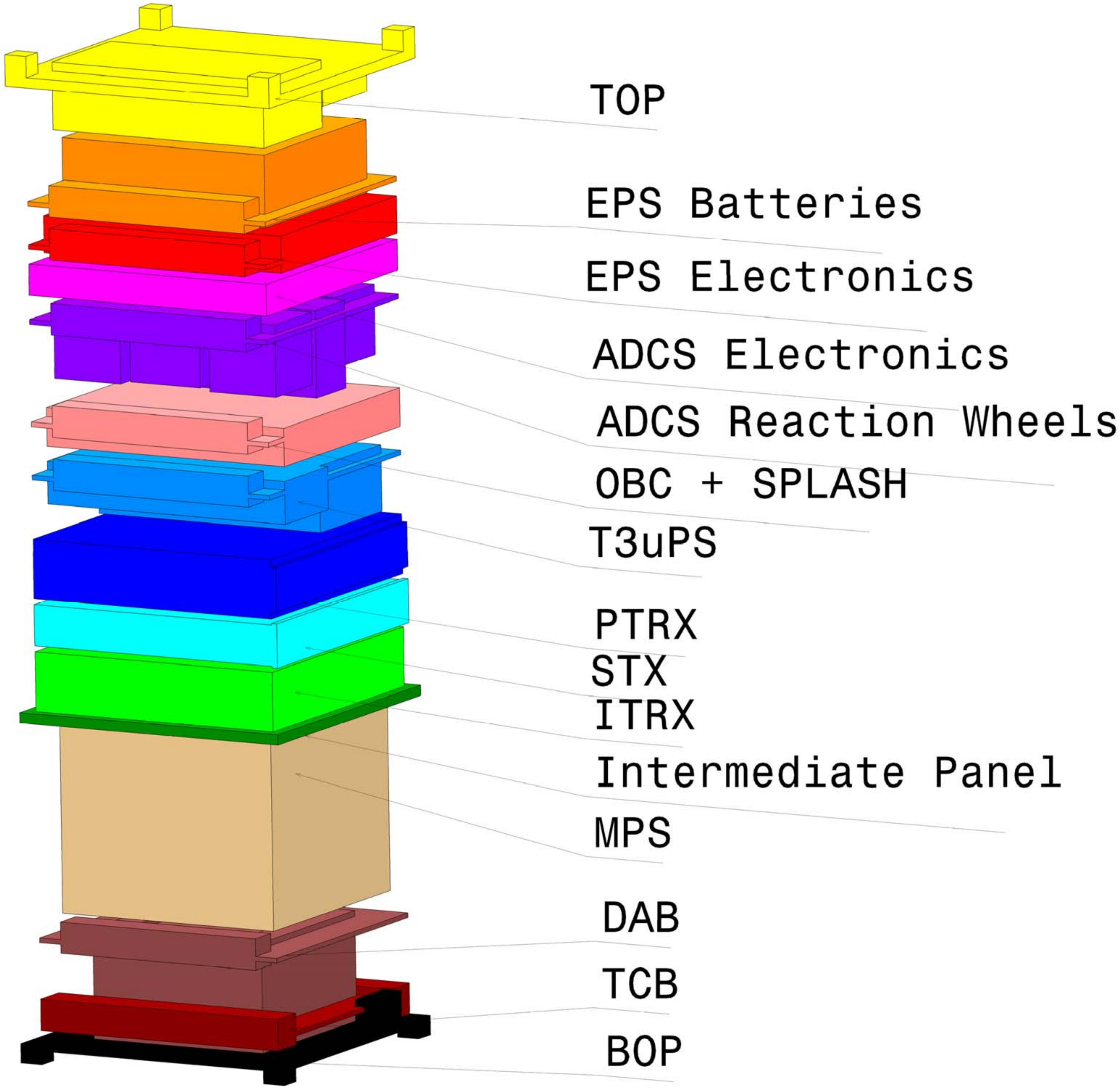
6 Conclusion

For Delfi-n3Xt an option for the structural subsystem has been sought, which should allow for a smooth and more time-efficient assembly, integration and testing than for Delfi-C^3. Options considered for the structure have been a card bus system, a rod system with detachable side panels, male-female busses on the PCB, stack with PCB side panels and a PCB box. A trade-off showed that the rod system is the best option for Delfi-n3Xt. For two third of the satellite, rods will be implemented; the integration to the structure of the last third is to be determined. An important difference with Delfi-C^3 is that one or more panels are detachable.
Furthermore it is shown for Delfi-n3Xt that all payloads and subsystems fit into the envelope of a three-unit CubeSat.
With a structural subsystem chosen, the project will advance into determining the number of detachable side panels, detailing the integration of the stack to the outer structure and making more advanced drawings for payloads and subsystems.

7 References

[1] Hamann, R.J. et al., *Nanosatellites for Microtechnology Pre-Qualification: The Delfi Program of Delft University of Technology, Proceedings of 6th Symposium on Small Satellites for Earth Observation*, Berlin, Germany, 2007
[2] De Jong, S. et al., *The Delfi-n3Xt nanosatellite: Space weather research and qualification of microtechnology, Proceedings of 59th International Astronautical Congress 2008*, Glasgow, Scotland, 2008
[3] http://www.pumpkininc.com/
[4] http://www.pc104.org/
[5] http://www.cubesatkit.com/

Appendix D Volume Budget



Delfi-n3Xt Volume Budget, Appendix Calculation
Revision Record and Authorization

Issue	Date	Author / Editor	Reviewer checked	PM approved	Affected Section(s)	Description of change
1	2-3-2009	Jennifer			All	First issue
1.1	2-3-2009	Jennifer				small changes
1.2	23-3-2009	Jennifer				inserted Inertia tab
1.3	10-5-2009	Jennifer				updated centre of mass calculation and volume budget

Z-direction	budget	comments	Reference SLR
BOP	6,5	feet + thickness BOP	
(TCB)	(12)	around MABs	
DAB	41,1	from BOP Z+ side up to connector	
MPS	65		202
IP	3,5		
ITRX	20	without cooling fin, assumption muRaTa + Neosid filter same side, can be extended to 22 mm	182
STX	14	without cooling fin	
PTRX	20	without cooling fin, assumption muRaTa + Neosid filter same side, can be extended to 22 mm	
$T^3\mu PS$	25,6	incl connector	181
OBC	16		
ADCS RW	32,6	incl connector	
ADCS EB	10,6		
EPS	12,6		
Batteries	24,5		
TOP	27	incl SDM	
offset	21		
total height	**340**		

maximum height satellite 340.5 mm

PCB 1.6 mm
connector Z+ 6 mm
connector Z- 3 mm

Note
Two filters are required for PTRX and ITRX; 1 for the receiver, 1 for the transmitter.

Possibility is taking a smaller filter for the receiver end. If other components cannot be made smaller, the total height becomes 25 mm. When all components on the receiver side are smaller than the replaced filter, the total height becomes 22 mm. Solution for putting both filters on the same side, a total height of 19 mm is foreseen.
For now 20 mm has been taken as the height for both PTRX and ITRX

Centre of Mass calculation for Stack version 4.0

Data taken from CATIA output, SP fold out situation

Order: BOP, TCB, DAB, MPS, IP, ITRX, STX, PTRX, $T^3\mu PS$, OBC, ADCS electronics, ADCS RW, EPS electronics, EPS Batteries, TOP, STS

STS consists of SP, outer structure, HDRS and S-patches

Component	Density[kg_m3]	Mass[kg]	Gx[mm]	Gy[mm]	Gz[mm]
BOP		0,127			12,3
TCB		0,034			15,2
DAB		0,105			14,9
MPS		0,600			88,7
IP		0,075			116,8
ITRX		0,124			128,8
STX		0,124			150,3
PTRX		0,124			171,9
$T^3\mu PS$		0,163			195,3
OBC		0,133			214,5
ADCS electronics		0,078			253,1
ADCS RW		0,205			244,5
EPS electronics		0,063			276,0
EPS Batteries		0,345			298,7
TOP		0,395			312,2
STS		0,687			236,3
Stack version 4	Not uniform	3,376	-0,919	-0,348	194,977
excel		3,382			194,5
height satellite		340,5			
geometric centre		194,98			

if necessary, microthruster can be placed after PTRX or OBC

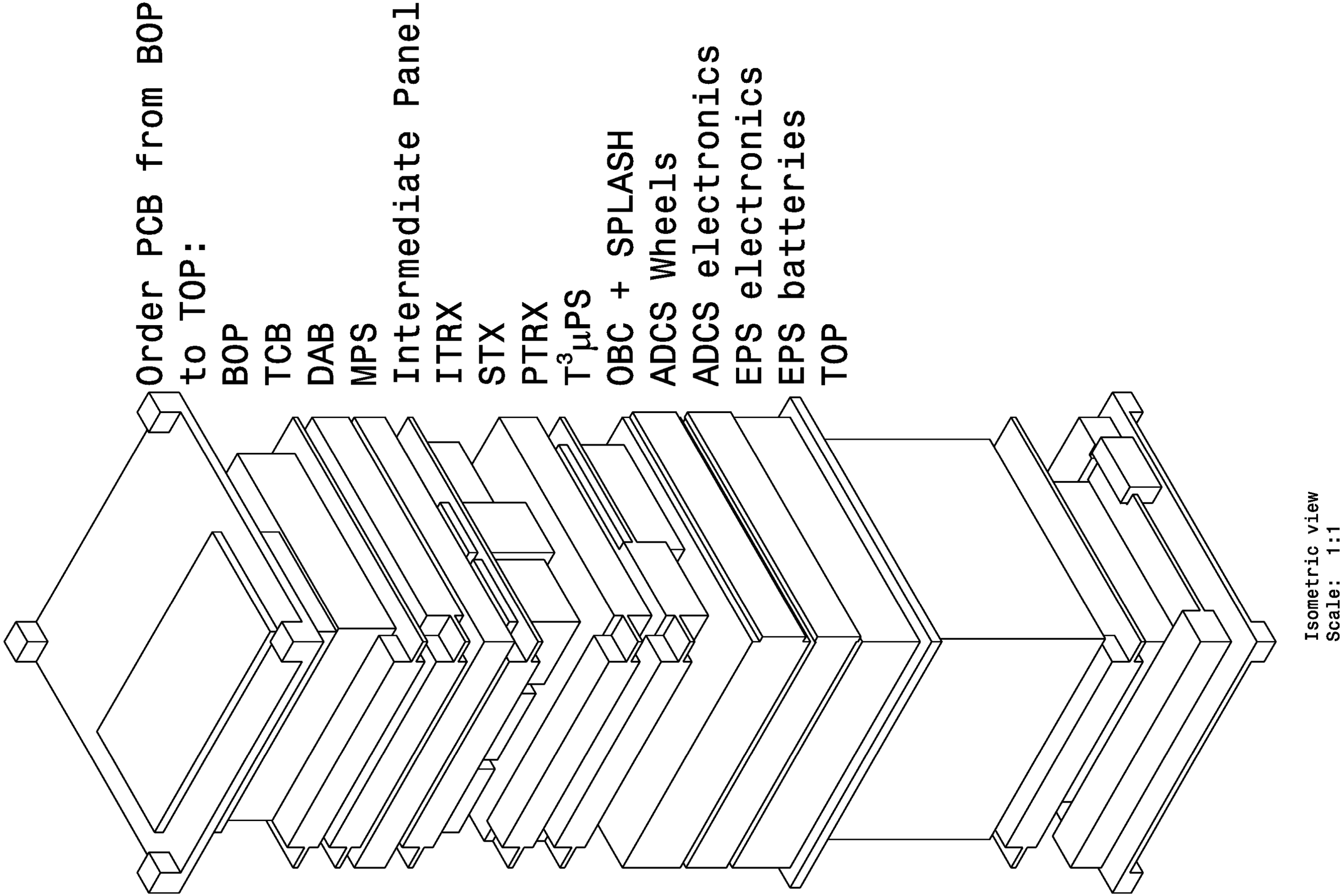
CoM and I for stack vs 4 Solar Panel Folded

mass		3,40	kg
CoM	x	-0,90	mm
	y	-0,34	mm
	z	187,18	mm
I	xx	-3,70E-02	kg m^2
	xy	1,06E-05	kg m^2
	yy	3,70E-02	kg m^2
	xz	2,26E-04	kg m^2
	zz	6,00E-03	kg m^2
	yz	1,42E-05	kg m^2

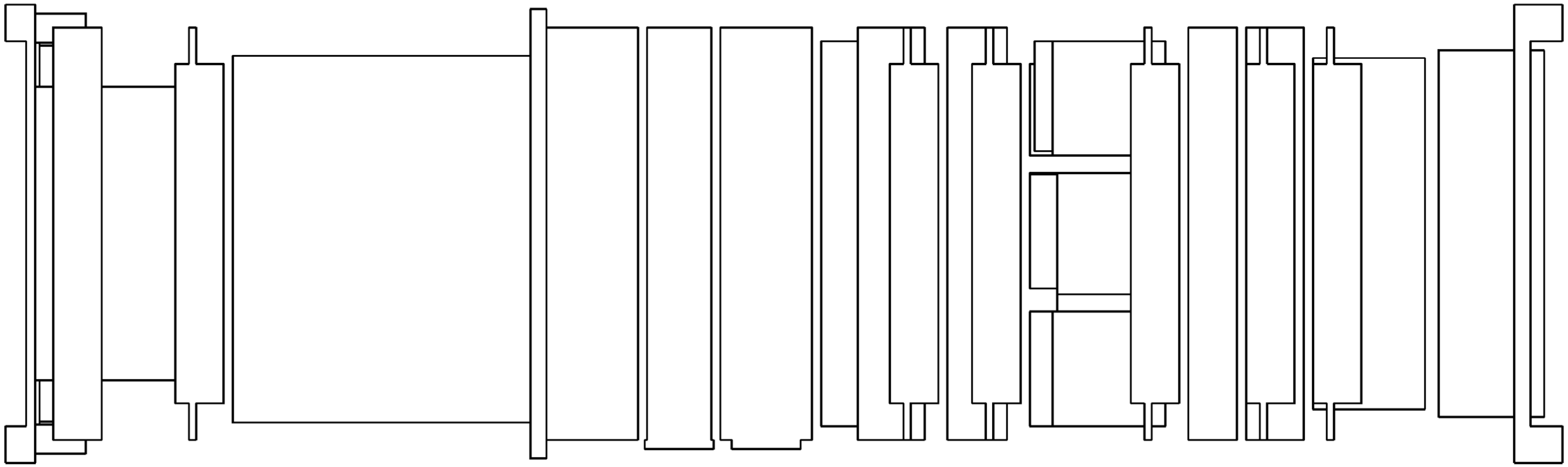
Solar Panel Fold Out

mass		3,38	kg
CoM	x	-0,92	mm
	y	-0,35	mm
	z	194,98	mm
I	xx	4,40E-02	kg m^2
	xy	1,30E-05	kg m^2
	yy	4,30E-02	kg m^2
	xz	1,94E-04	kg m^2
	zz	1,30E-02	kg m^2
	yz	-8,65E-06	kg m^2

Moments of inertia calculated with respect to the centre of gravity
Numbers imported from CATIA


Order PCB from BOP
to TOP:
BOP
TCB
DAB
MPS
Intermediate Panel
ITRX
STX
PTRX
T3µPS
OBC + SPLASH
ADCS Wheels
ADCS electronics
EPS electronics
EPS batteries
TOP
Isometric view
Scale: 1:1

Order PCB from BOP
to TOP:
BOP
TCB
DAB
MPS
Intermediate Panel
ITRX
STX
PTRX
$T^3\mu PS$
OBC + SPLASH
ADCS Wheels
ADCS electronics
EPS electronics
EPS batteries
TOP



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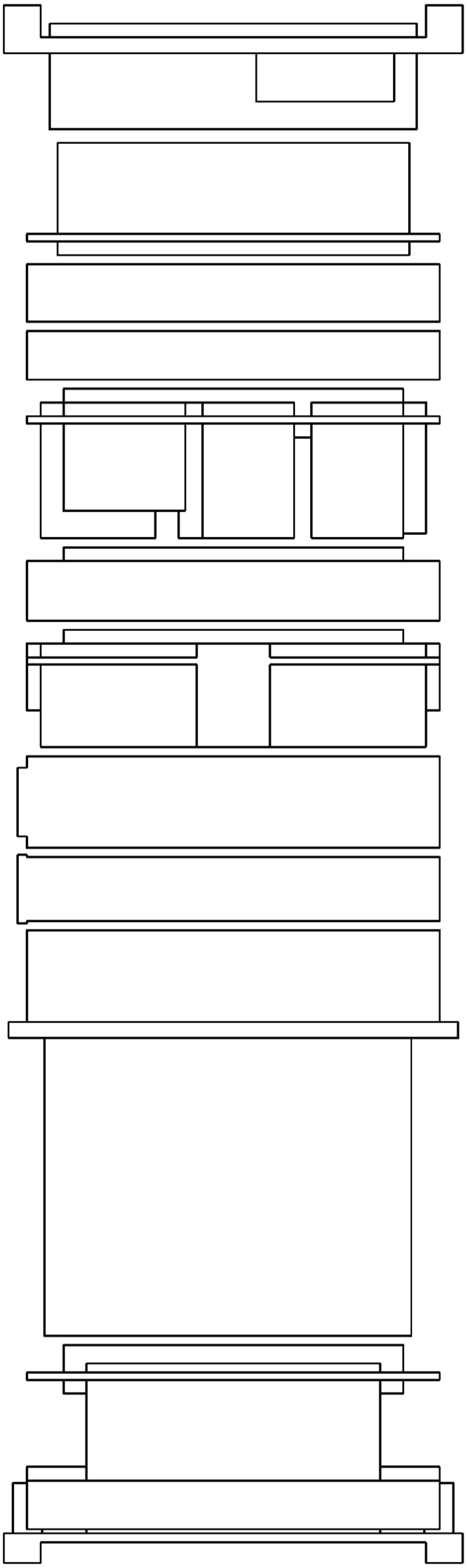
Scale: 1:1



Order PCB from BOP to TOP:

BOP
TCB
DAB
MPS
Intermediate Panel
ITRX
STX
PTRX
$T^3\mu PS$
OBC + SPLASH
ADCS Wheels
ADCS electronics
EPS electronics
EPS batteries
TOP

X- view
Scale: 1:1

Order PCB from BOP to TOP:

BOP
TCB
DAB
MPS
Intermediate Panel
ITRX
STX
PTRX
$T^3\mu PS$
OBC + SPLASH
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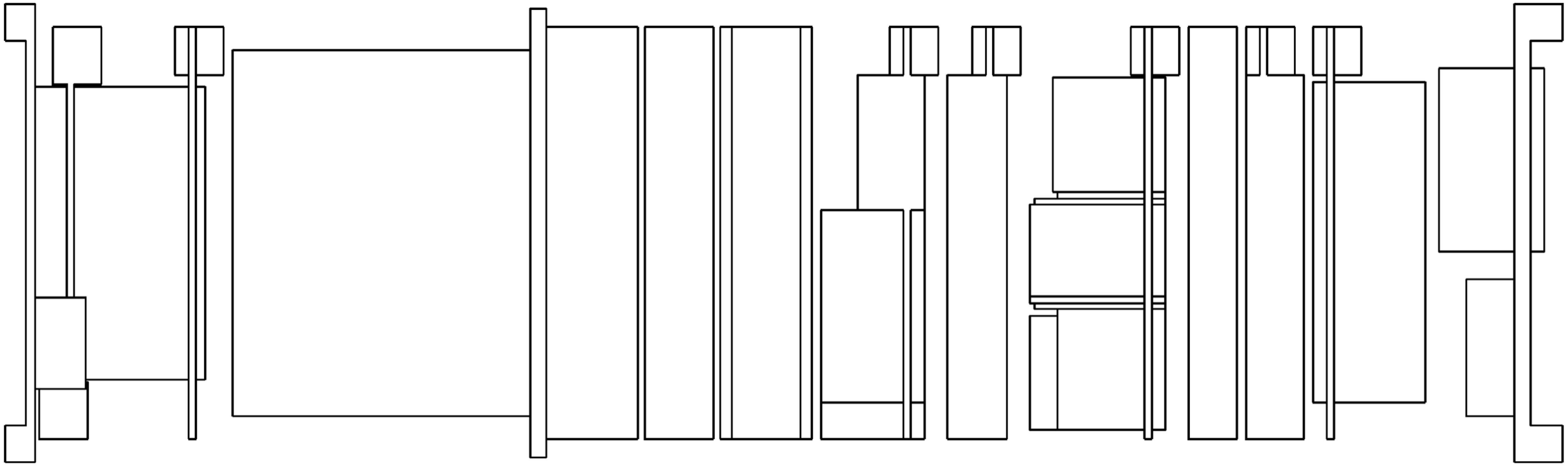
ADCS electronics
EPS electronics
EPS batteries
ICB
TOP



Y+ view
Scale: 1:1

Order PCB from BOP to TOP:

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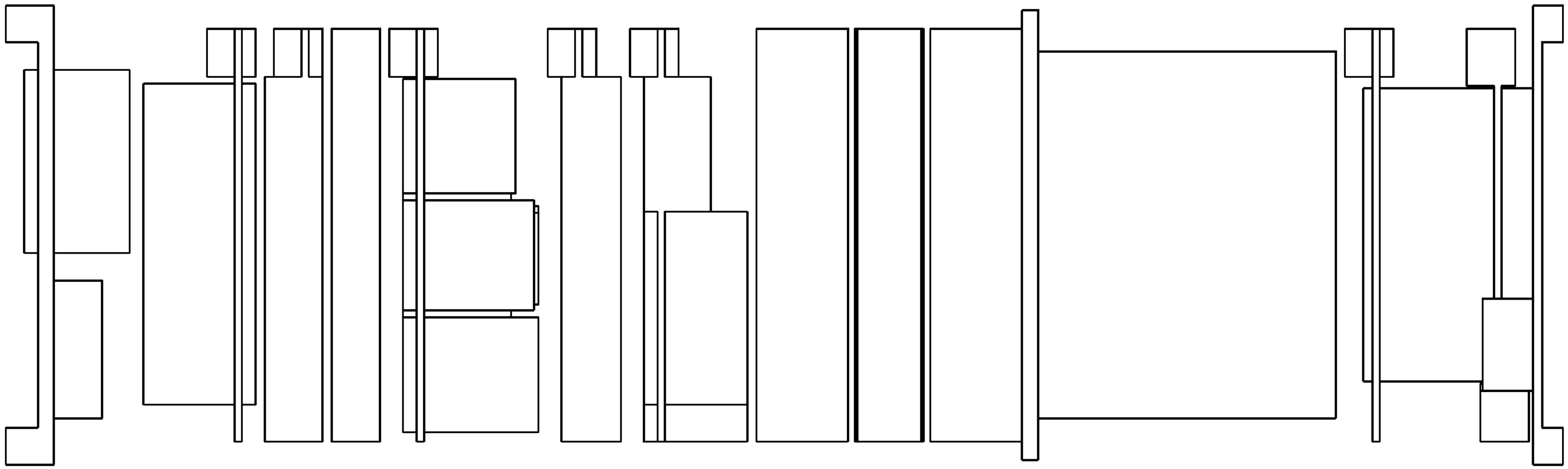
DAB
MPS
Intermediate Panel
ITRX
STX
PTRX
$T^3\mu PS$
OBC + SPLASH
ADCS Wheels
ADCS electronics
EPS electronics
EPS batteries
ICB
TOP



Y- view
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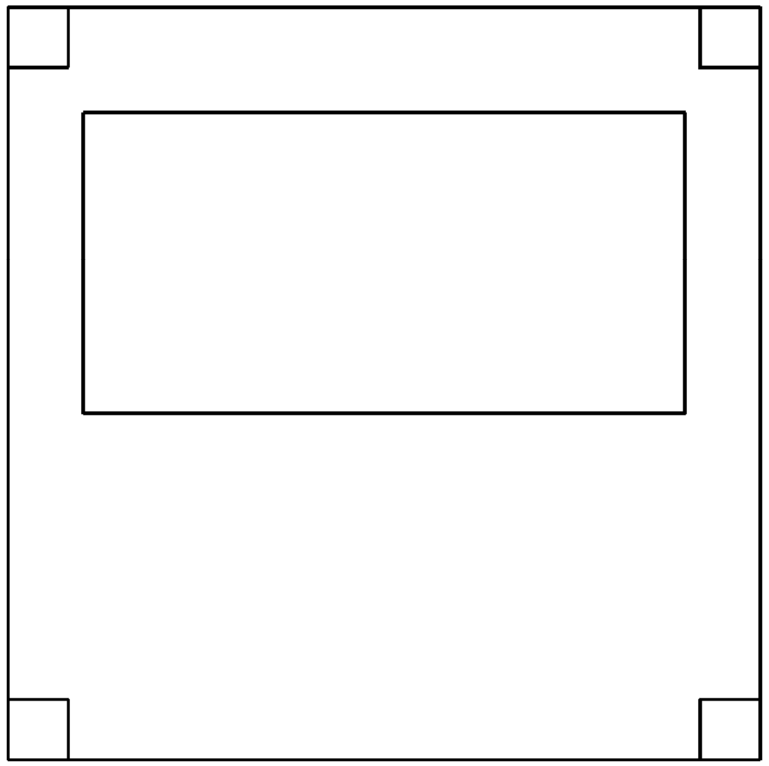
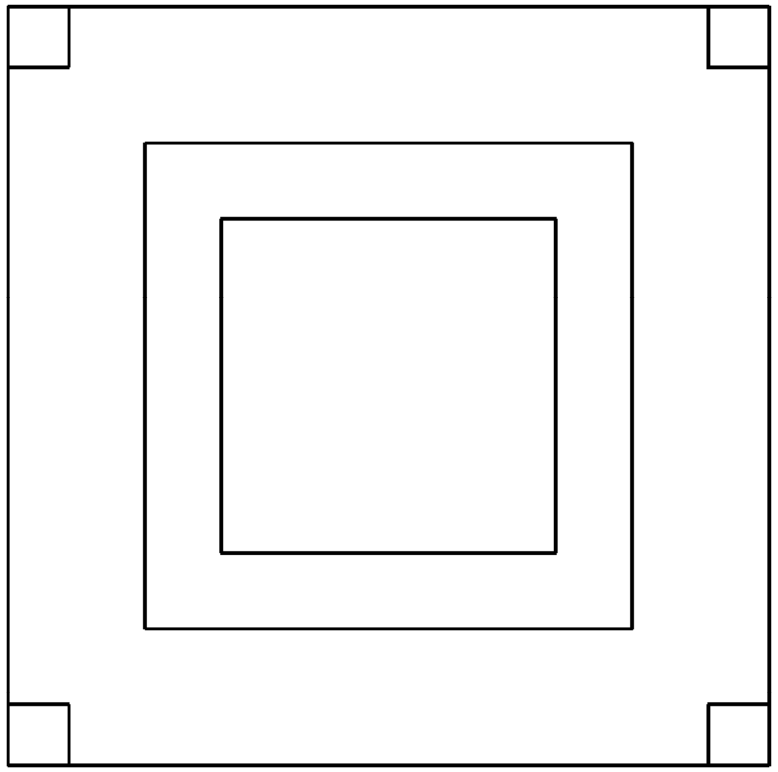


Z+ view
Scale: 1:1

Order PCB from BOP to TOP:

BOP
TCB
DAB
MPS
Intermediate Panel
ITRX
STX
PTRX
T³μPS
OBC + SPLASH
ADCS Wheels
ADCS electronics
EPS electronics
EPS batteries
TOP



Z- view
Scale: 1:1

Order PCB from BOP to TOP:

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DAB
MPS
Intermediate Panel
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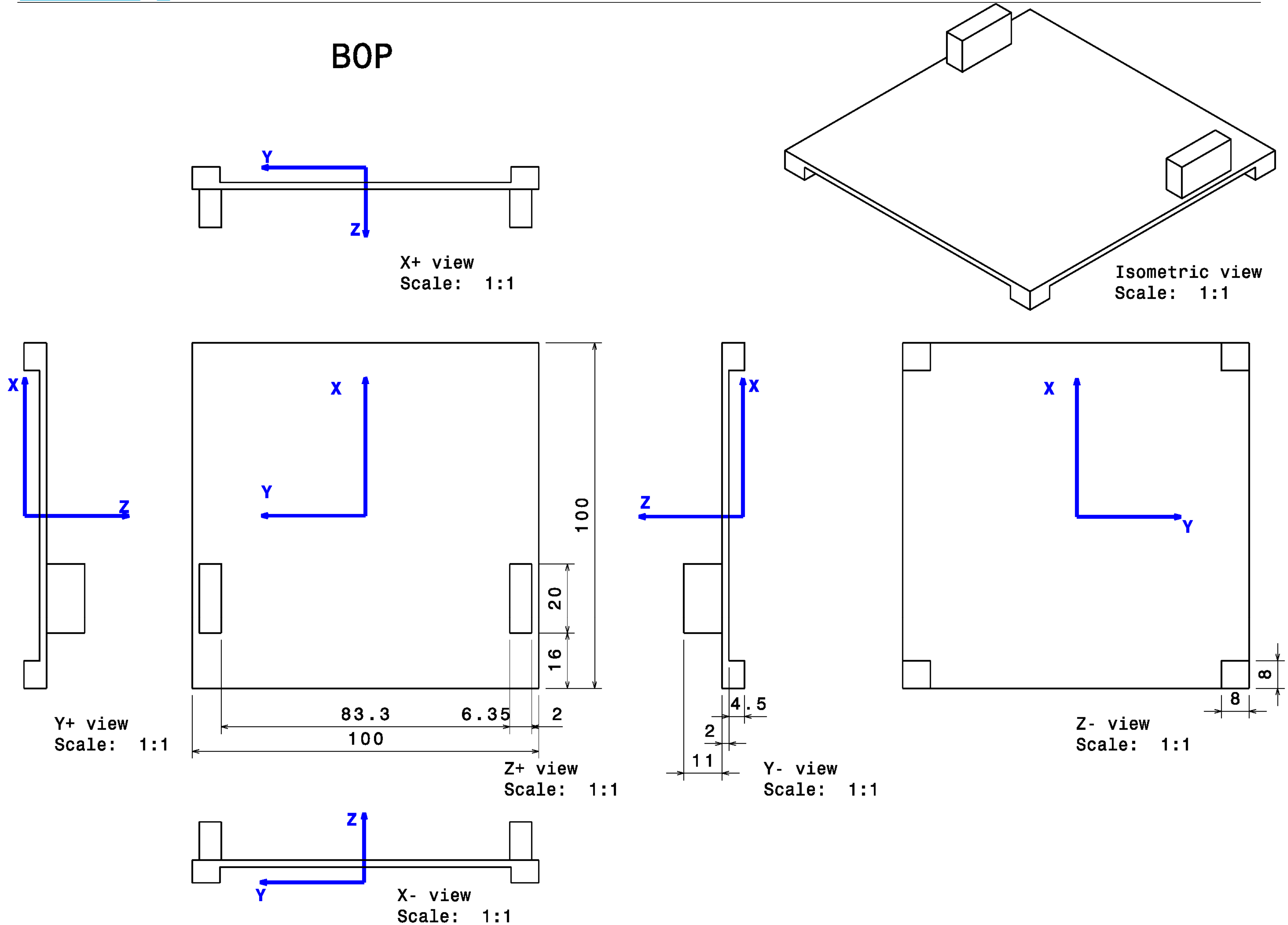
STX
PTRX
$T^3\mu PS$
OBC + SPLASH
ADCS Wheels
ADCS electronics
EPS electronics
EPS batteries
TOP

BOP


Y
Z
X+ view
Scale: 1:1
Isometric view
Scale: 1:1
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Y+ view
Scale: 1:1
X
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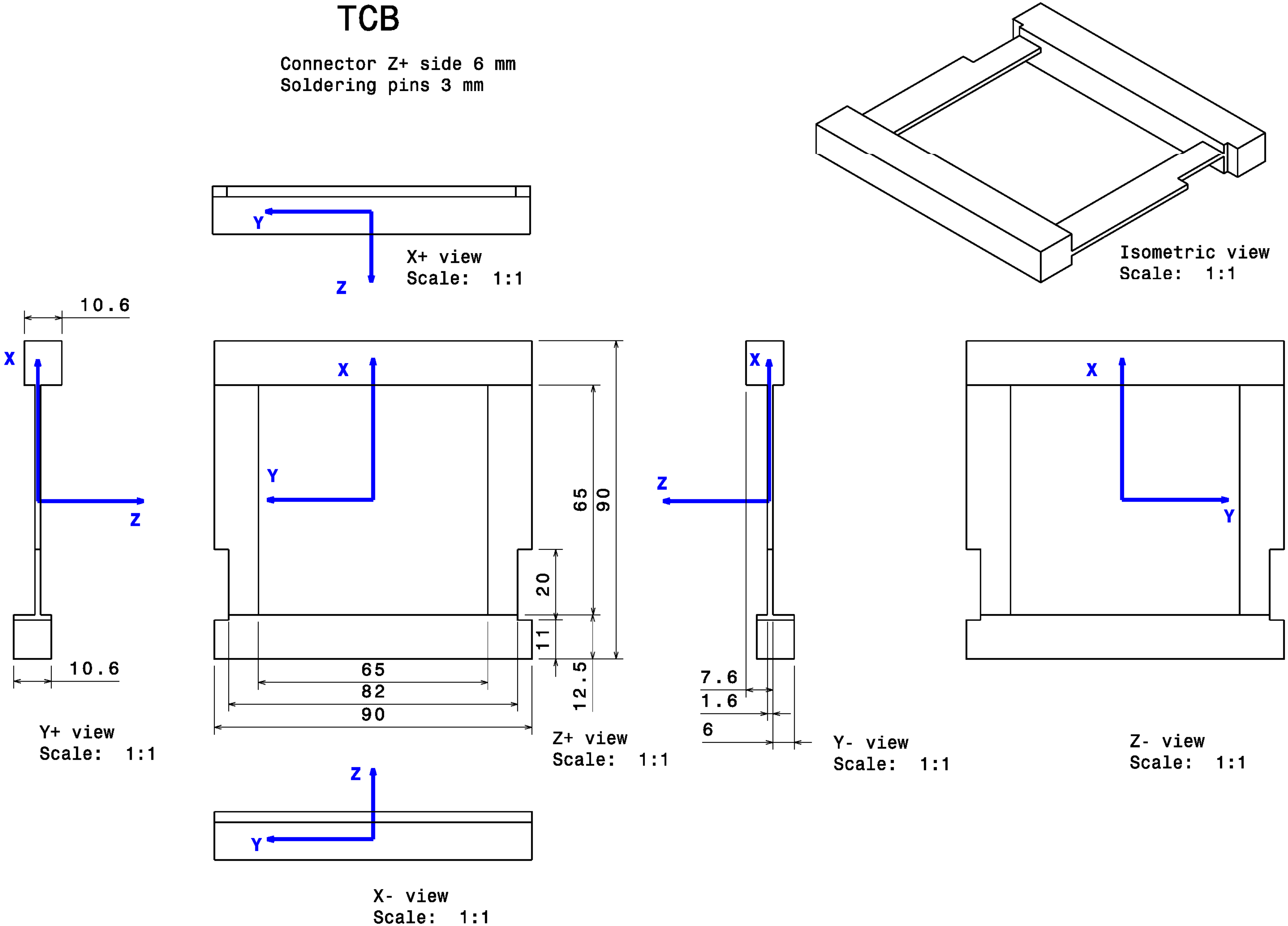
16
83.3
6.35
2
100
Z+ view
Scale: 1:1
Z
X
4.5
2
11
Y- view
Scale: 1:1
X
Y
8
8
Z- view
Scale: 1:1
Z
Y
X- view
Scale: 1:1

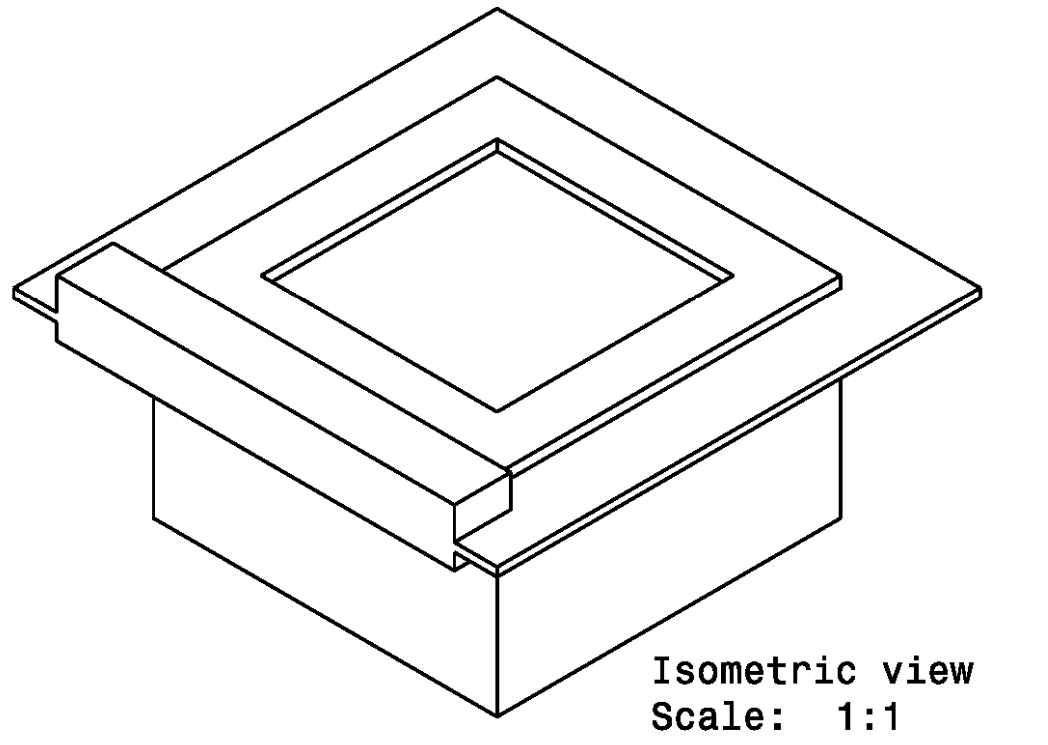
TCB

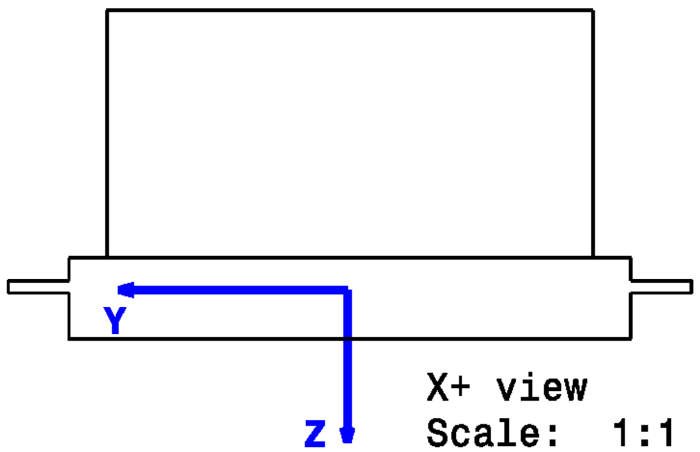
Connector Z+ side 6 mm
Soldering pins 3 mm

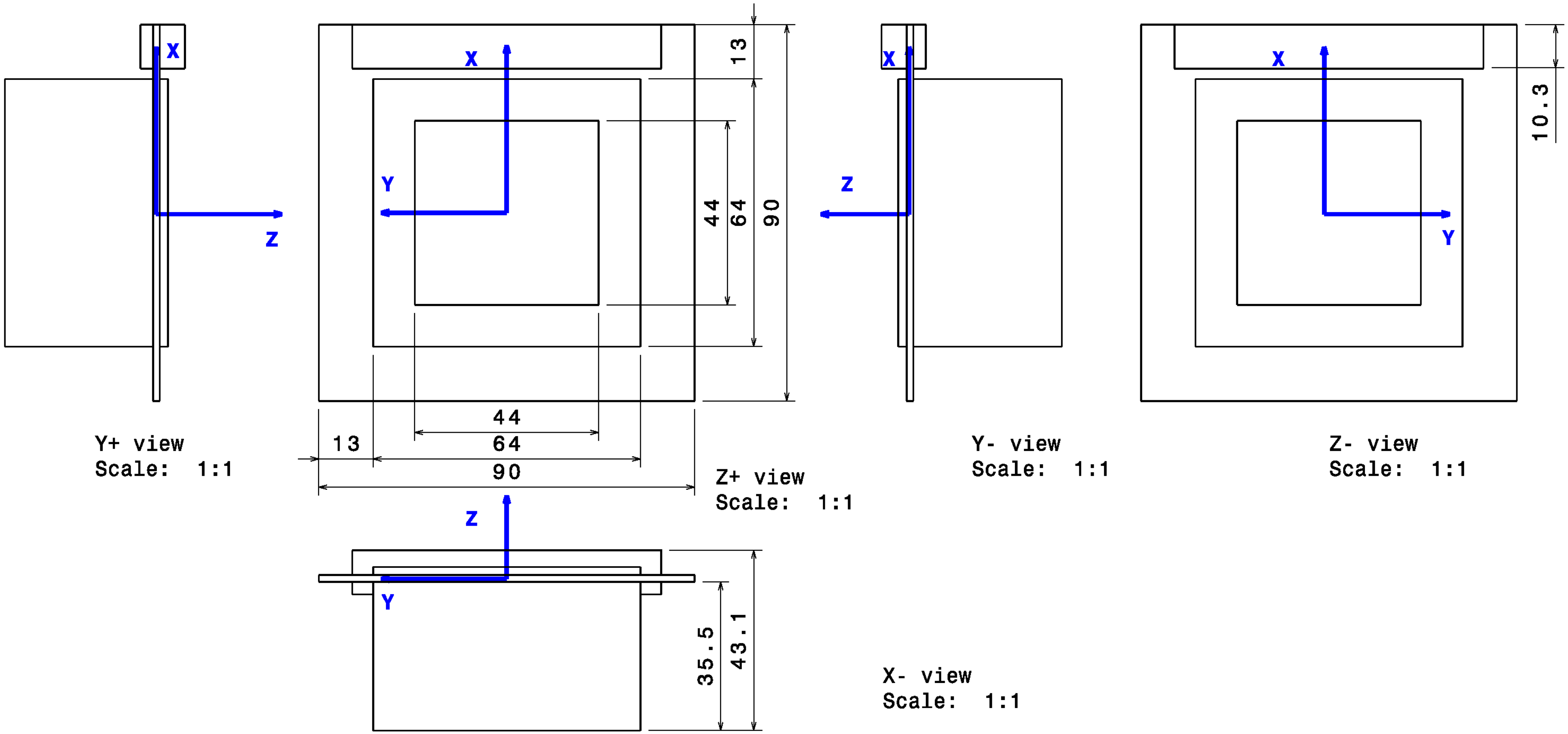


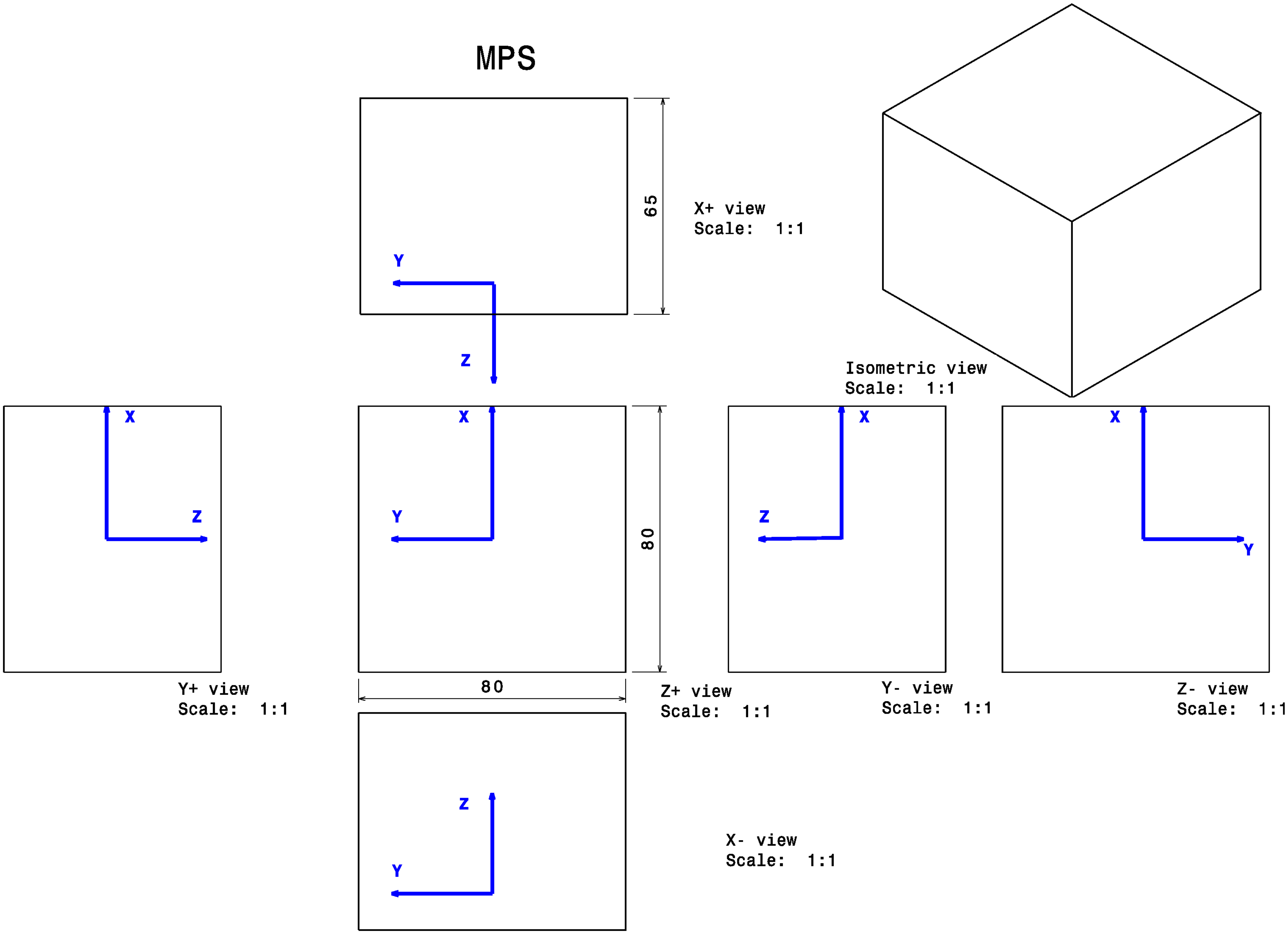
DAB

PCB board 90mm x 90 mm x 1.6 mm
Connector Z+ side 6 mm
Soldering pins 3 mm








MPS
65
X+ view
Scale: 1:1
Y
Z
Isometric view
Scale: 1:1
X
Z
Y
80
80
Y+ view
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Z+ view
Scale: 1:1
Y- view
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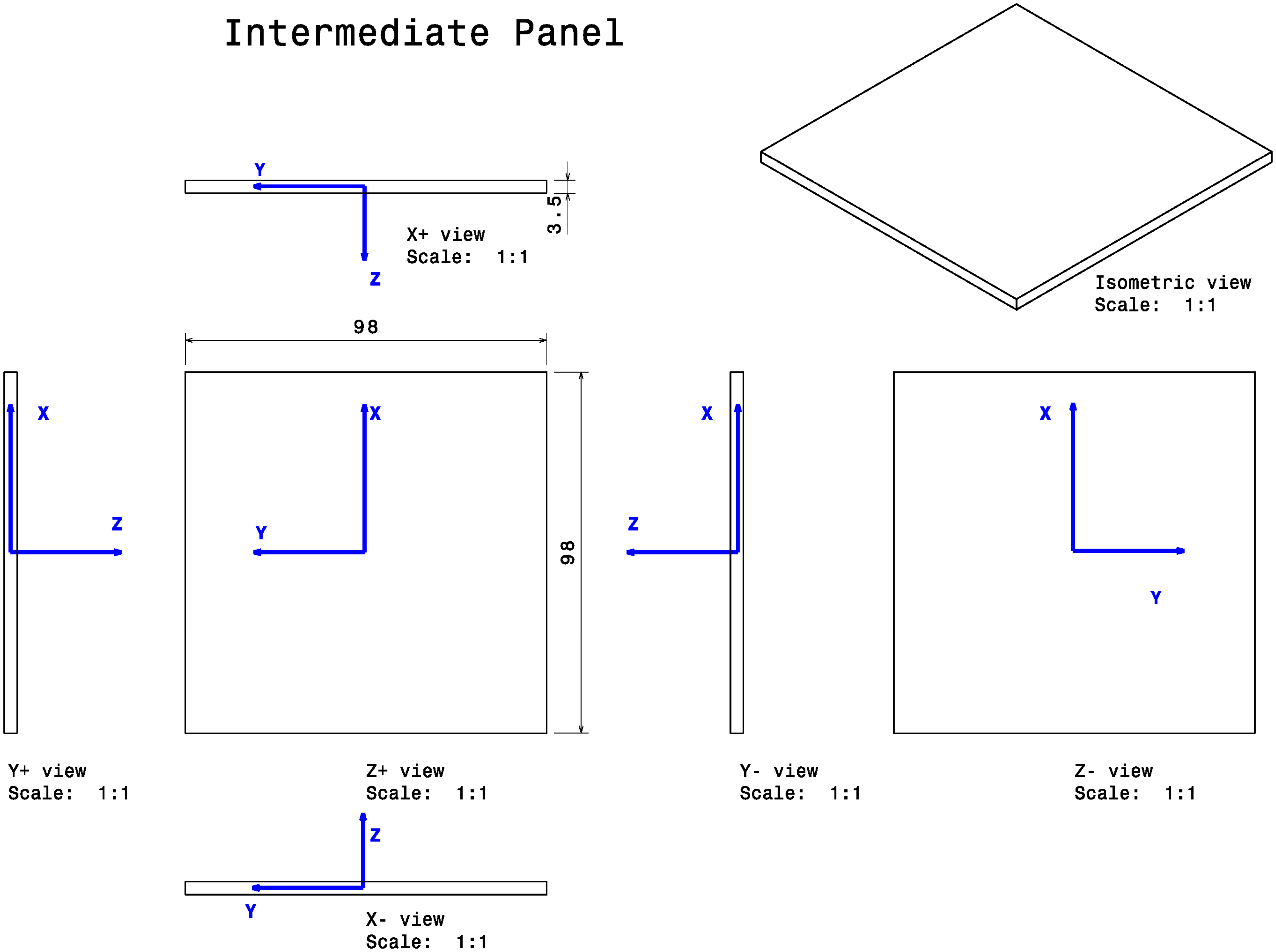
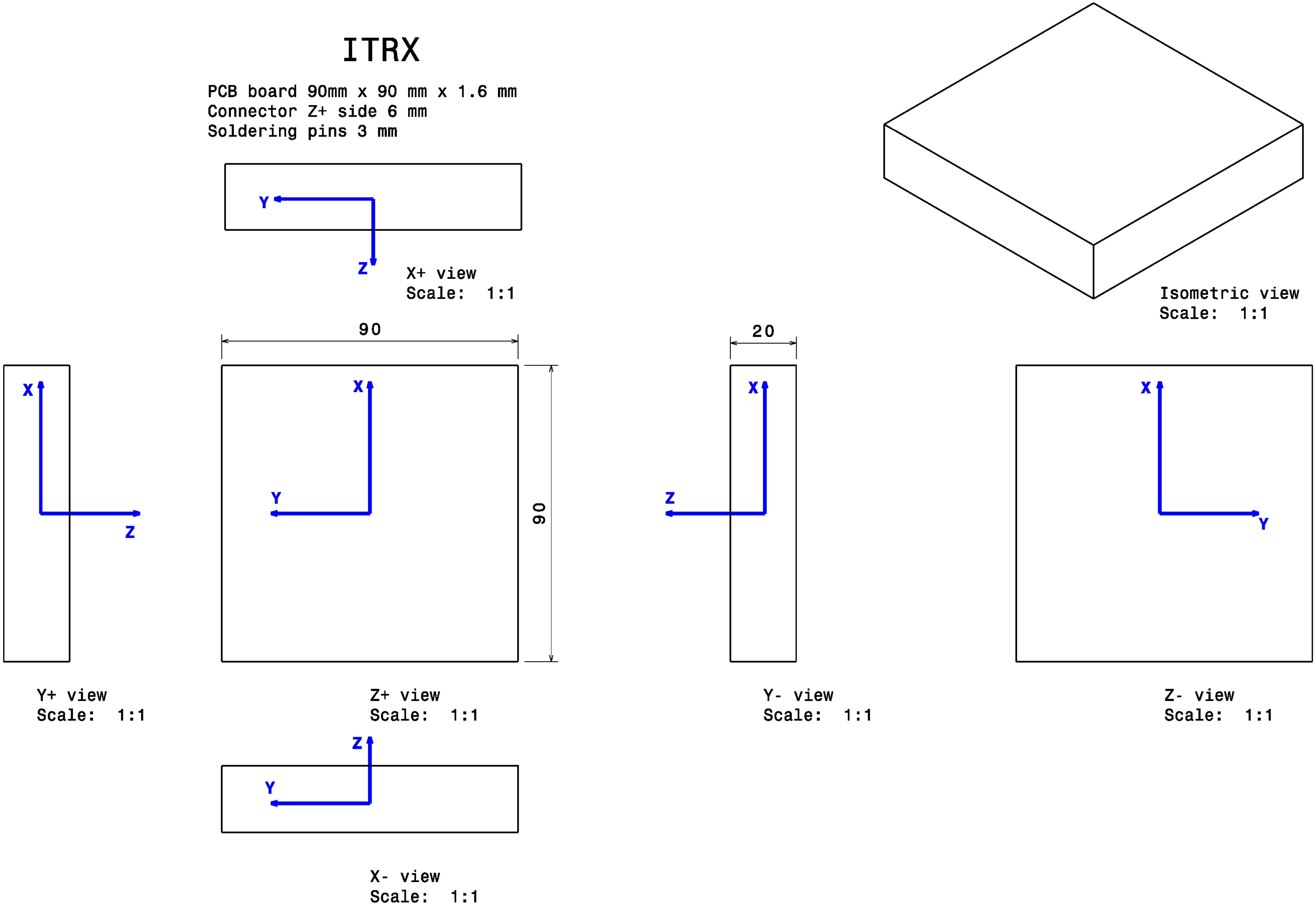
Z- view
Scale: 1:1
X- view
Scale: 1:1

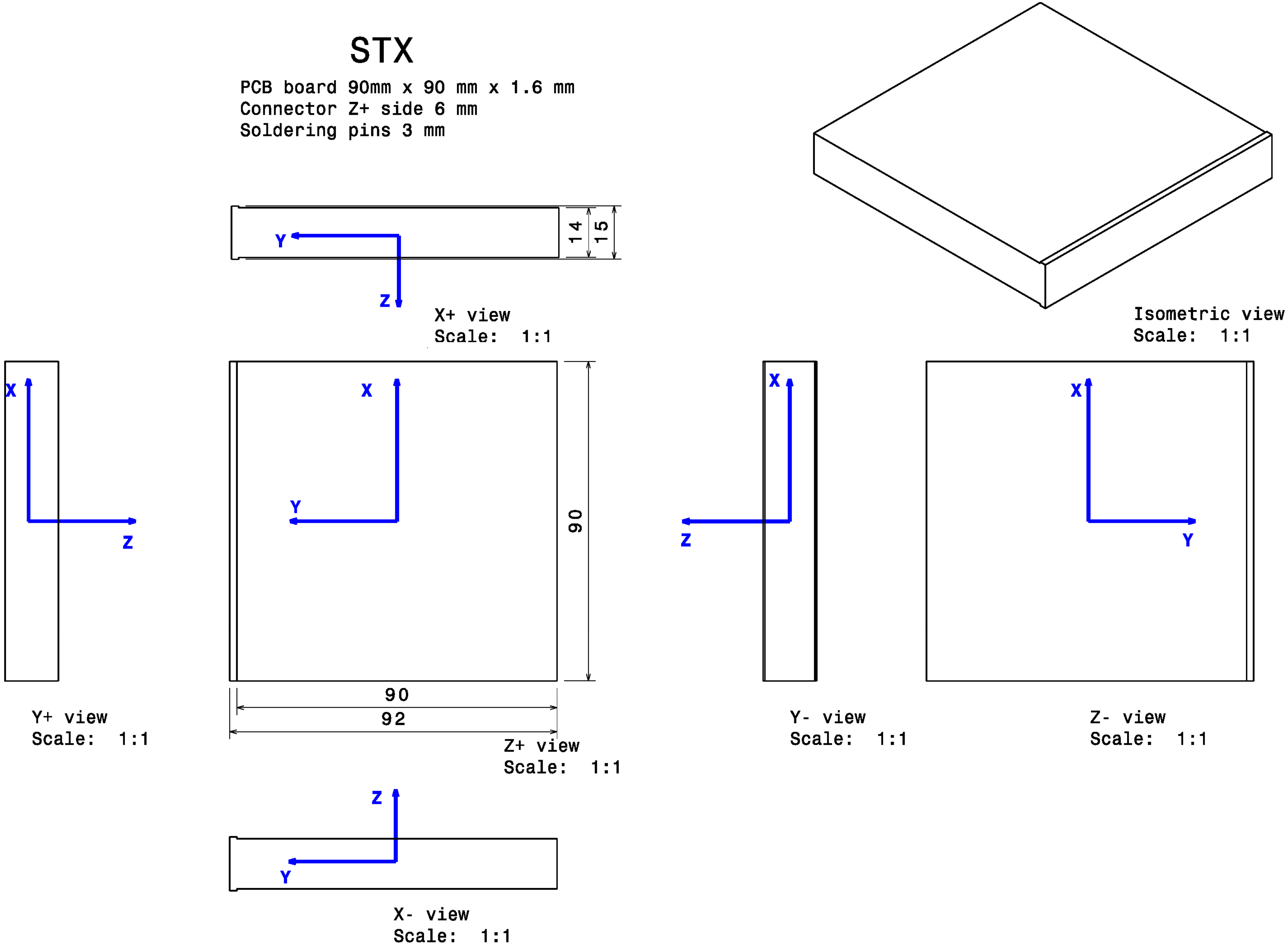
Intermediate Panel




ITRX
PCB board 90mm x 90 mm x 1.6 mm
Connector Z+ side 6 mm
Soldering pins 3 mm
X+ view
Scale: 1:1
Isometric view
Scale: 1:1
90
90
20
Y+ view
Scale: 1:1
Z+ view
Scale: 1:1
Y- view
Scale: 1:1
Z- view
Scale: 1:1
X- view
Scale: 1:1
X
Y
Z

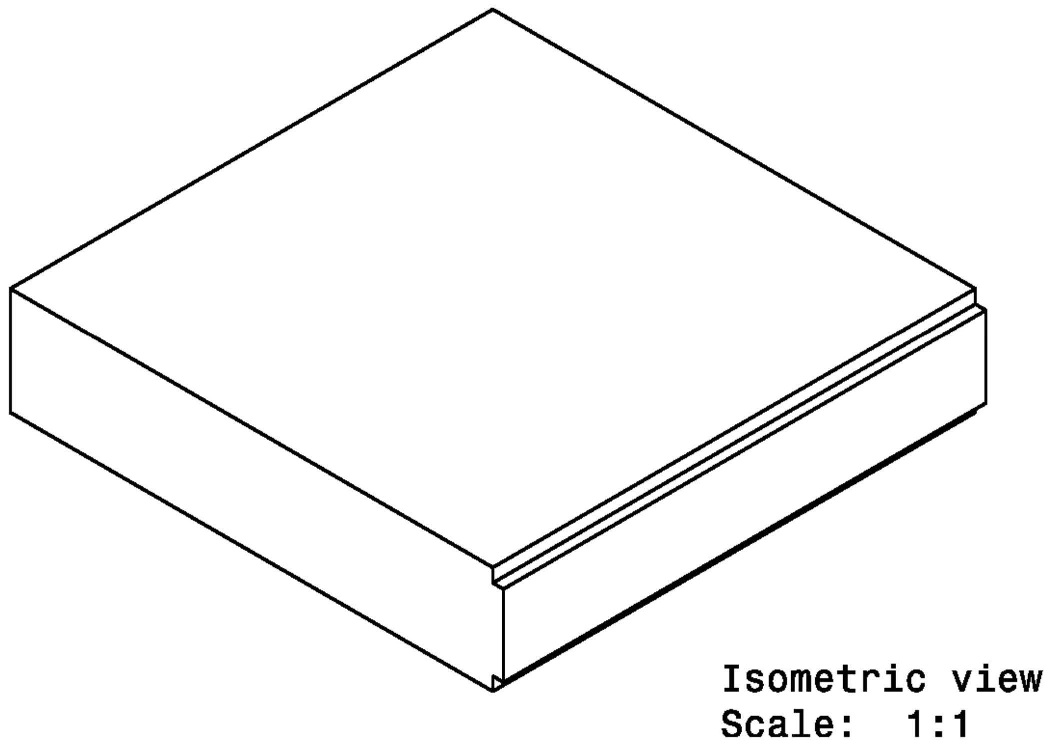
STX

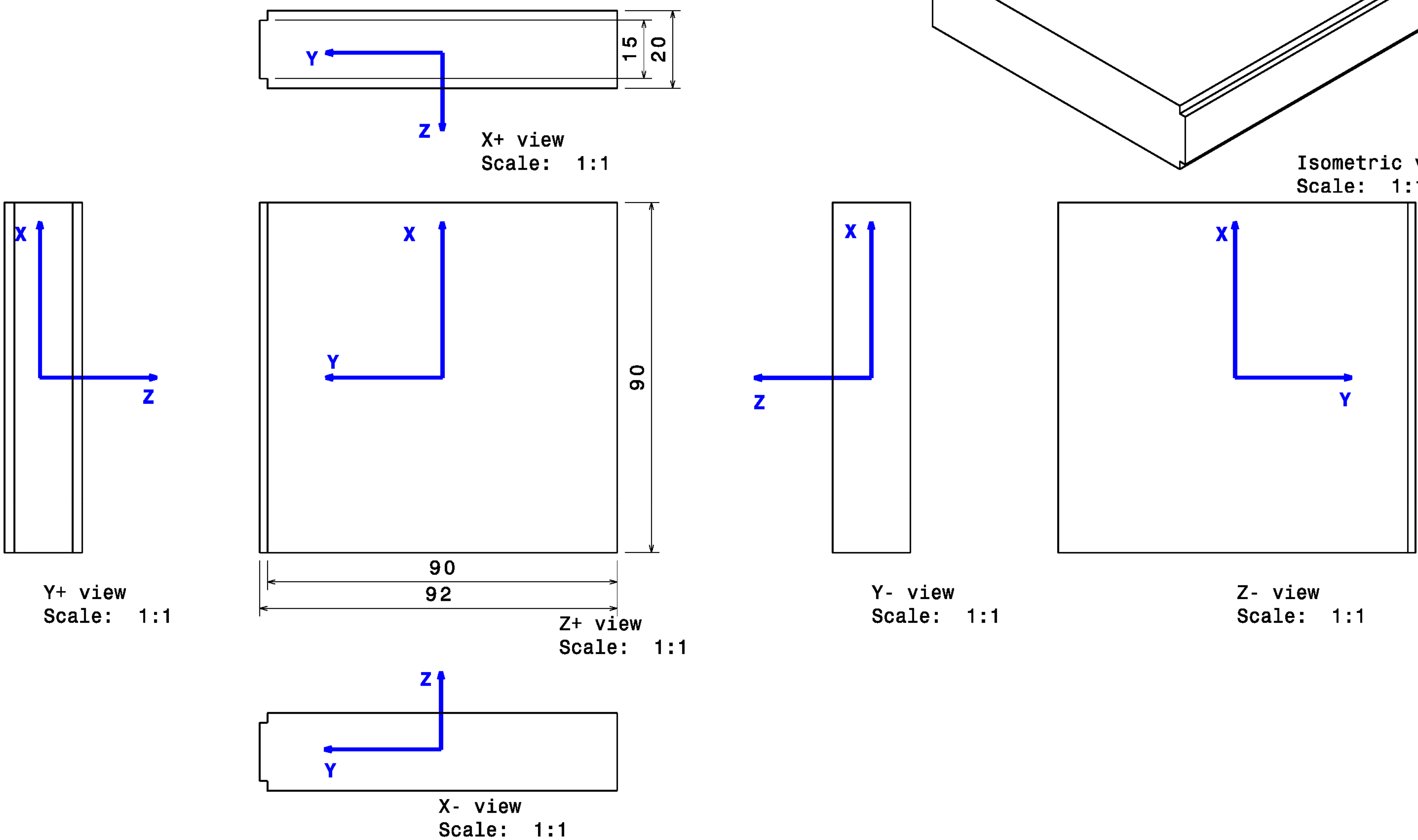
PCB board 90mm x 90 mm x 1.6 mm
Connector Z+ side 6 mm
Soldering pins 3 mm



PTRX

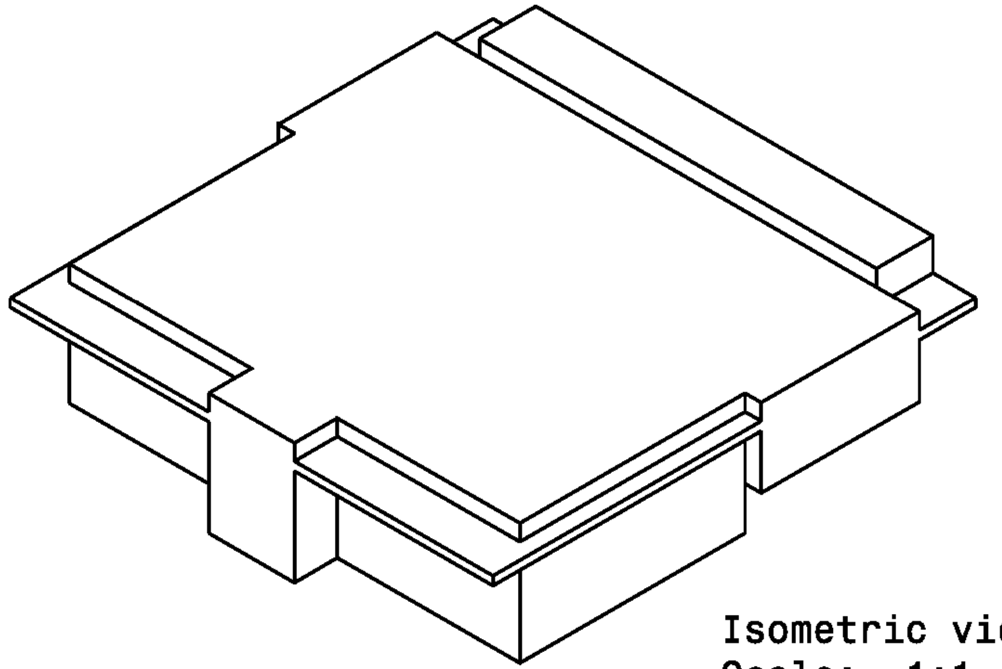
PCB board 90mm x 90 mm x 1.6 mm
Connector Z+ side 6 mm
Soldering pins 3 mm

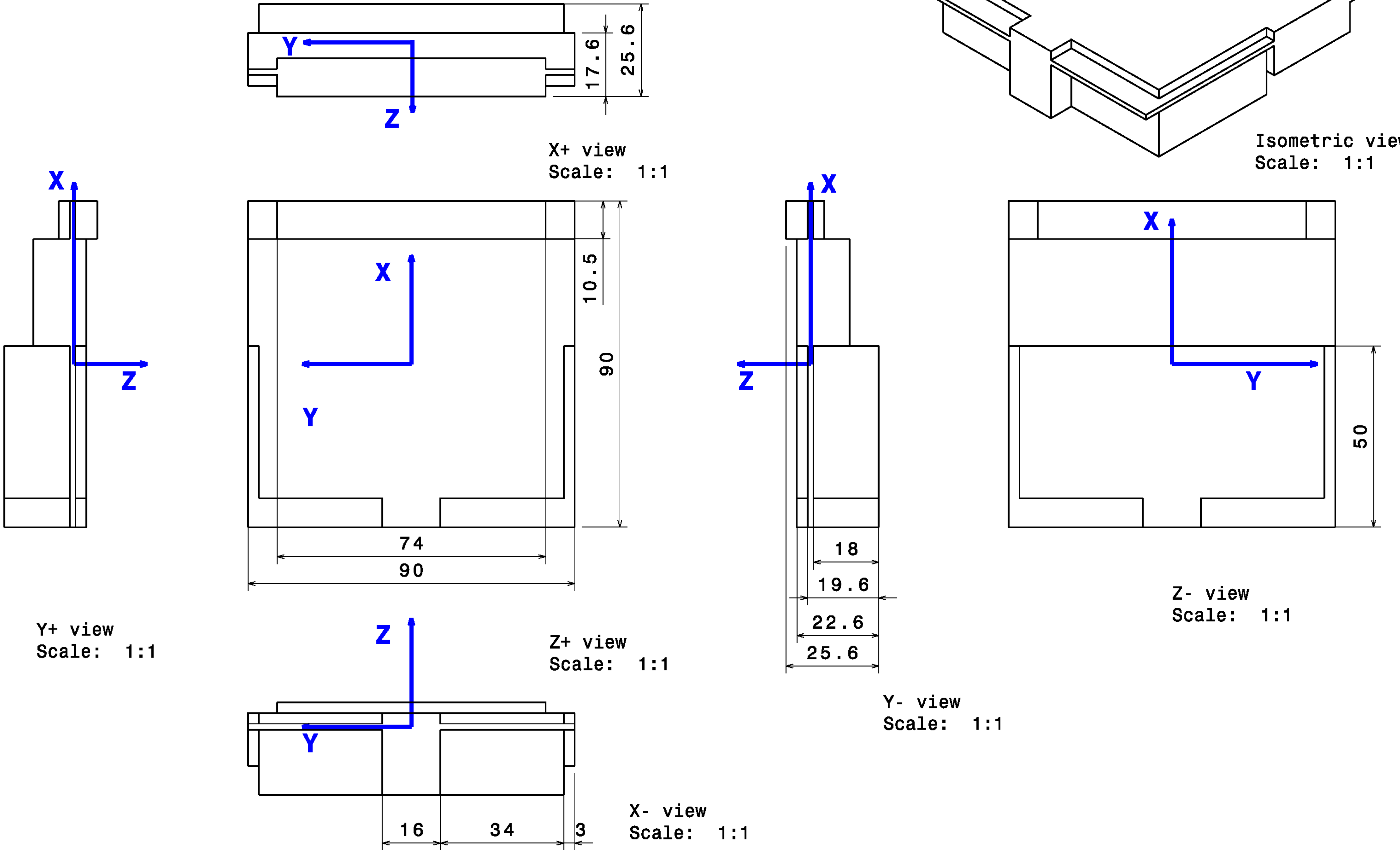




$T^3\mu PS$

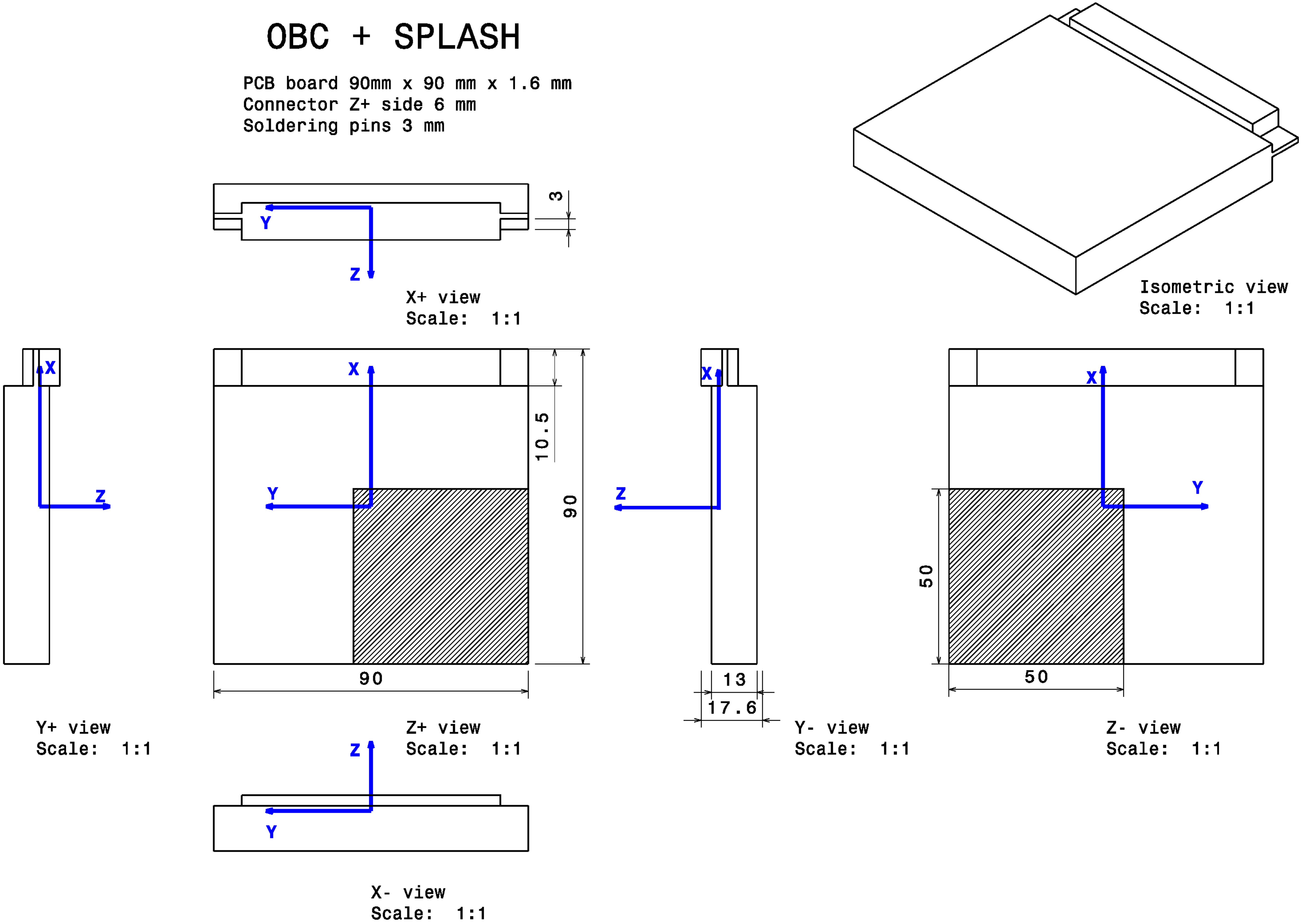
PCB board 90mm x 90 mm x 1.6 mm
Connector Z+ side 6 mm
Soldering pins 3 mm





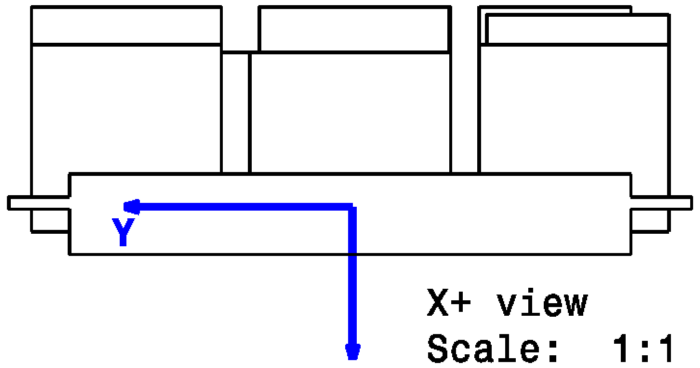
OBC + SPLASH

PCB board 90mm x 90 mm x 1.6 mm
Connector Z+ side 6 mm
Soldering pins 3 mm

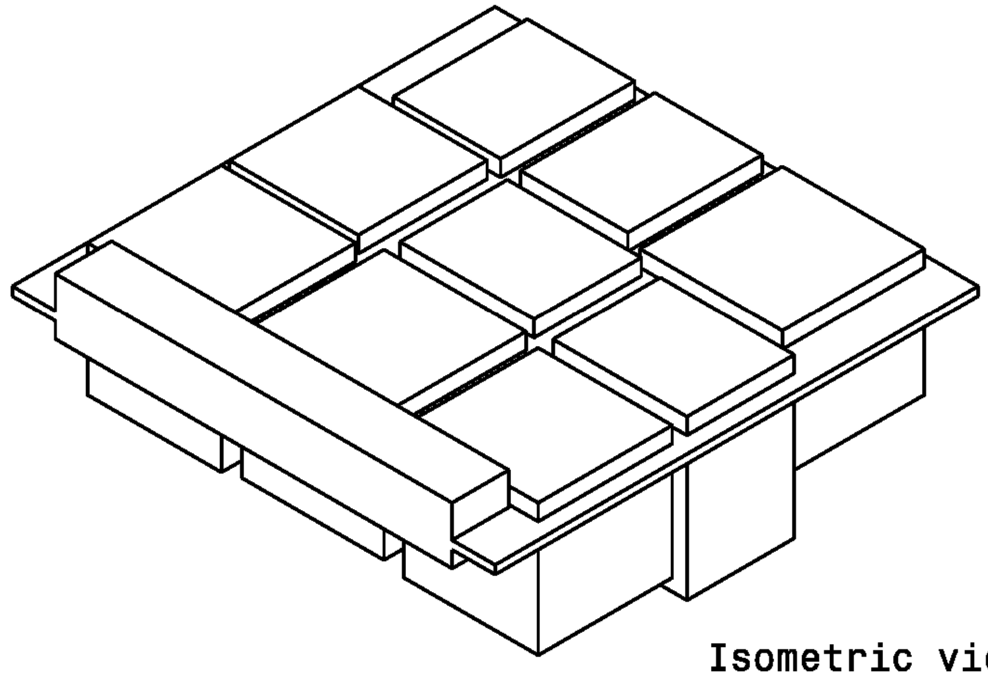


ADCS Wheels

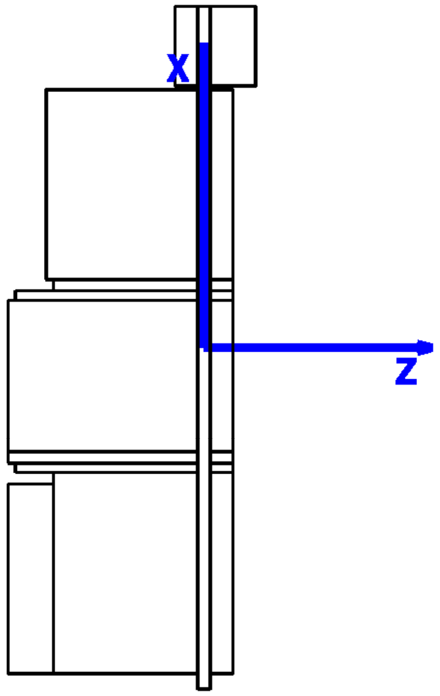
PCB board 90mm x 90 mm x 1.6 mm
Connector Z+ side 6 mm
Soldering pins 3 mm



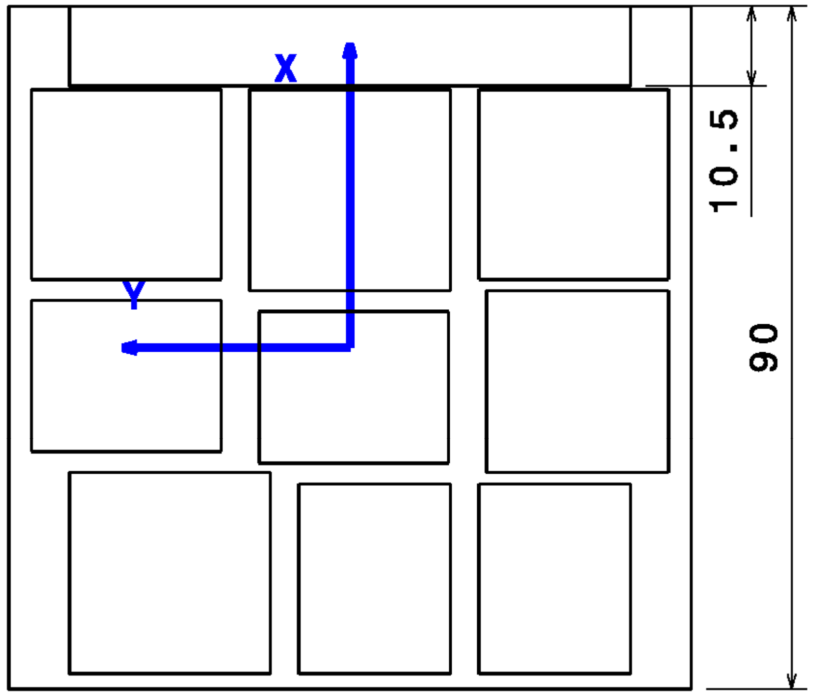
X+ view
Scale: 1:1



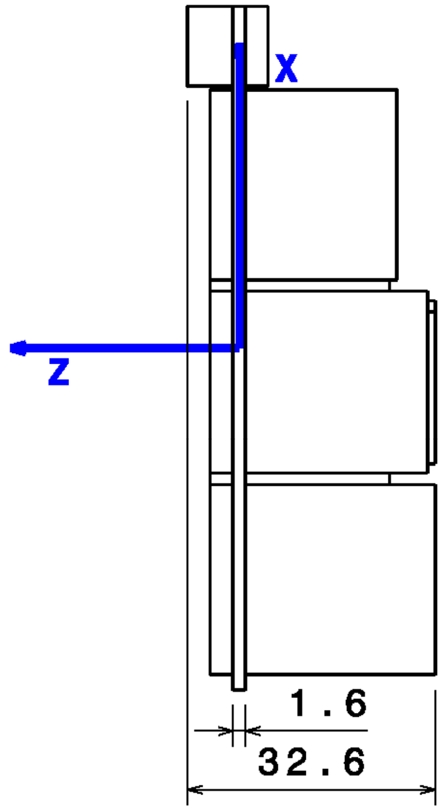
Isometric view
Scale: 1:1



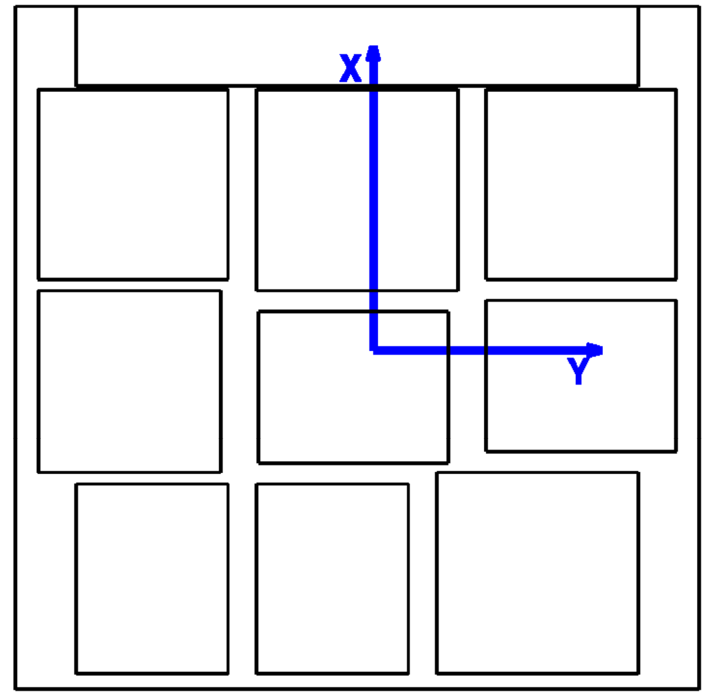
Y+ view
Scale: 1:1



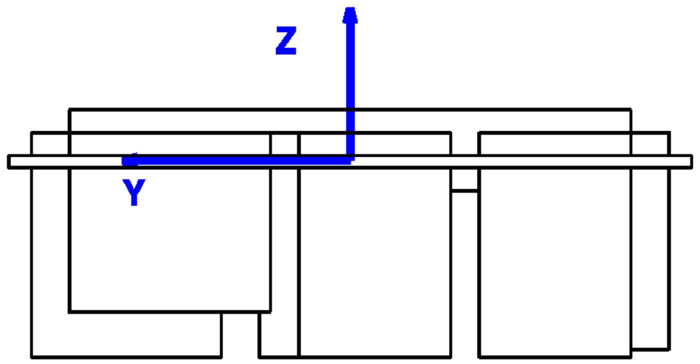
Z+ view
Scale: 1:1



Y- view
Scale: 1:1



Z- view
Scale: 1:1

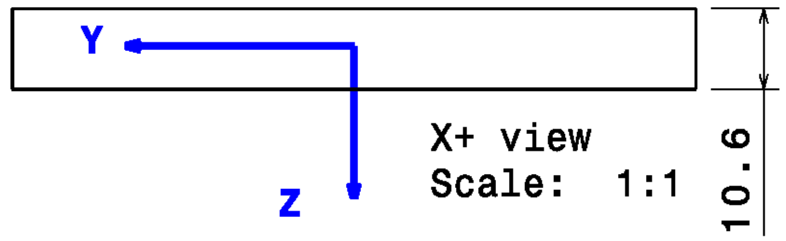


X- view
Scale: 1:1

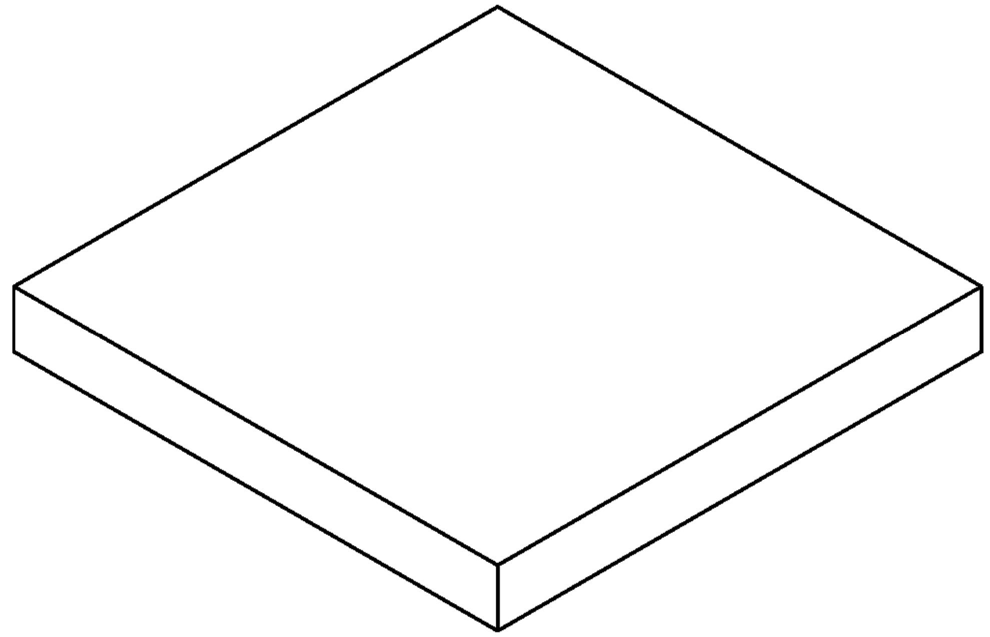
NOTE: This layout is a possible layout for 6 reaction wheels, 2 magnetometers and 1 gyro [SLR 0142 vs 1.4].
The configuration of this board varies on a week to week basis and/or information is inconsistent.
This board is not up-to-date. Volume is a block of 90 mm x 90 mm x 32.6 mm.

ADCS Electronics

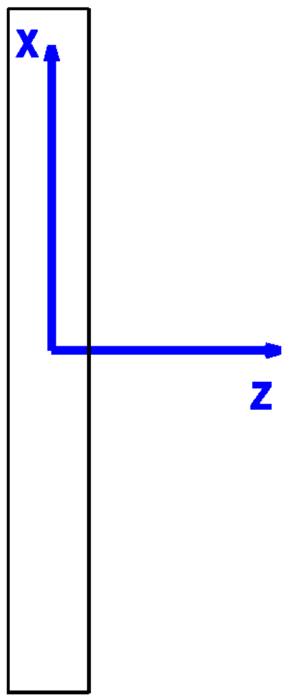
PCB board 90mm x 90 mm x 1.6 mm
Connector Z+ side 6 mm
Soldering pins 3 mm



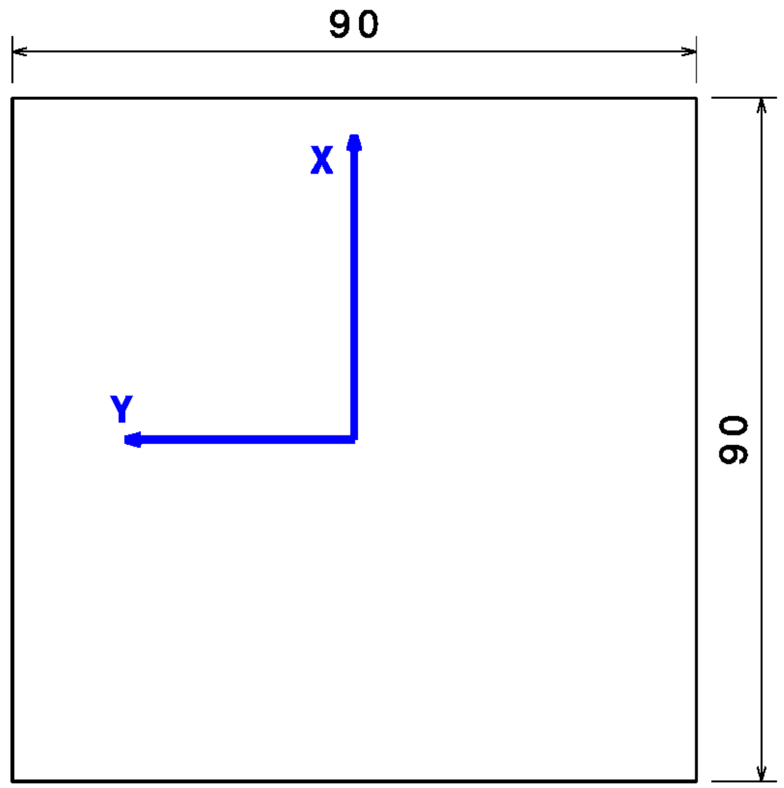
X+ view
Scale: 1:1



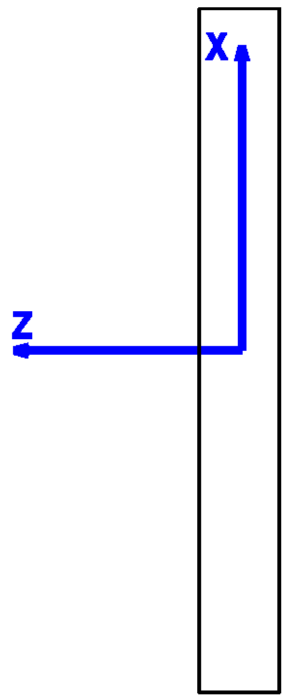
Isometric view
Scale: 1:1



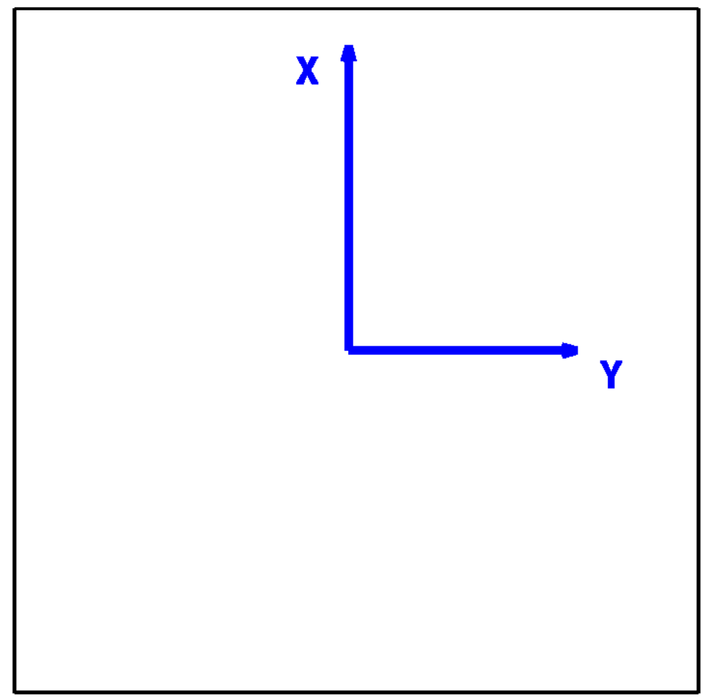
Y+ view
Scale: 1:1



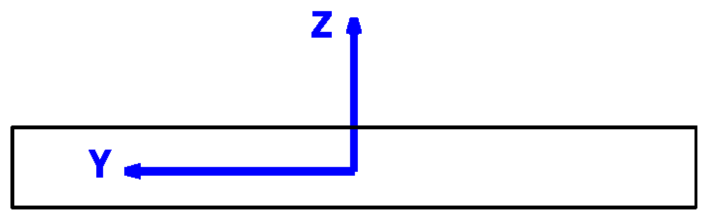
Z+ view
Scale: 1:1



Y- view
Scale: 1:1



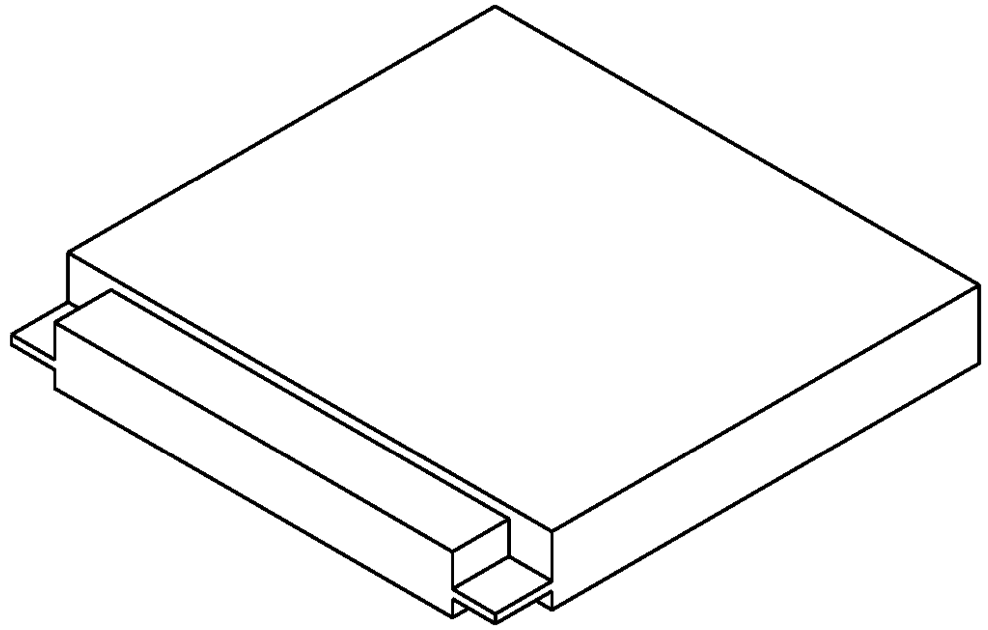
Z- view
Scale: 1:1



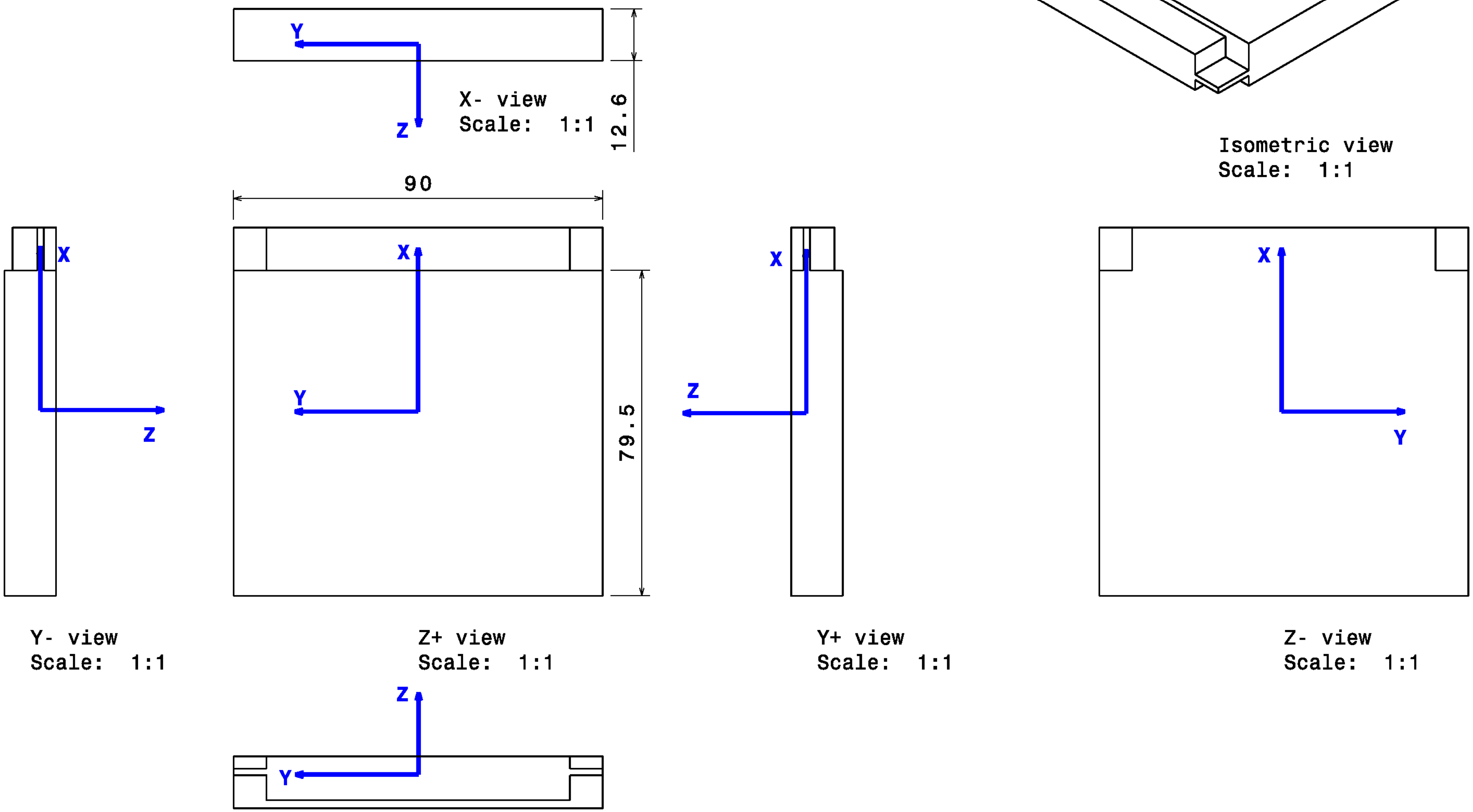
X- view
Scale: 1:1

EPS Electronics

PCB board 90mm x 90 mm x 1.6 mm
Connector Z+ side 6 mm
Soldering pins 3 mm



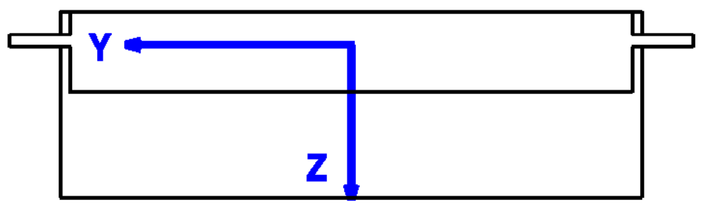
Isometric view
Scale: 1:1



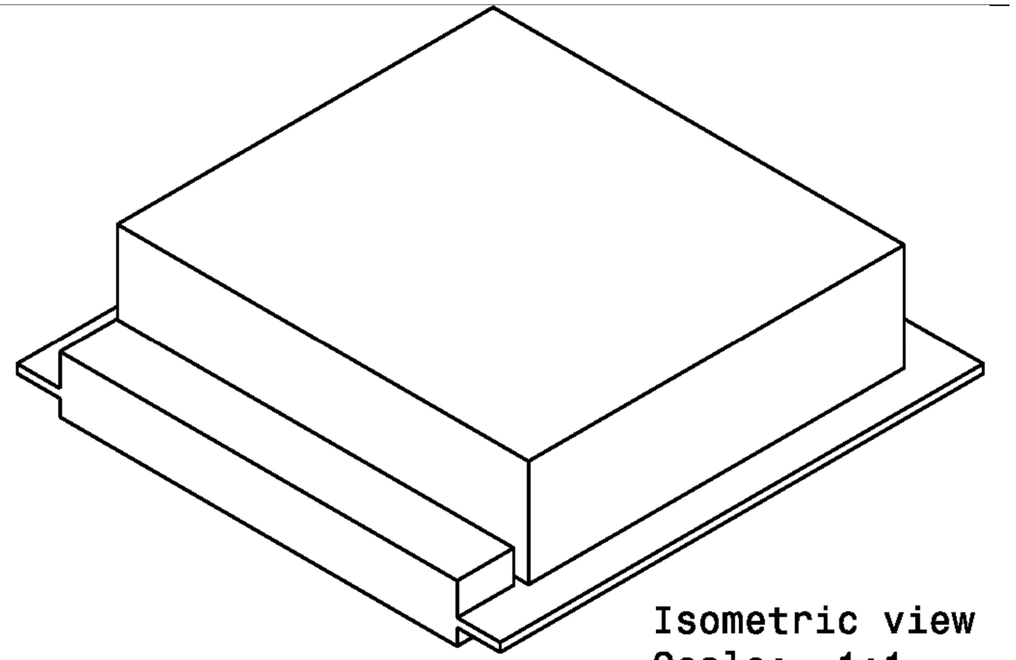
X+ view
Scale: 1:1

EPS Batteries

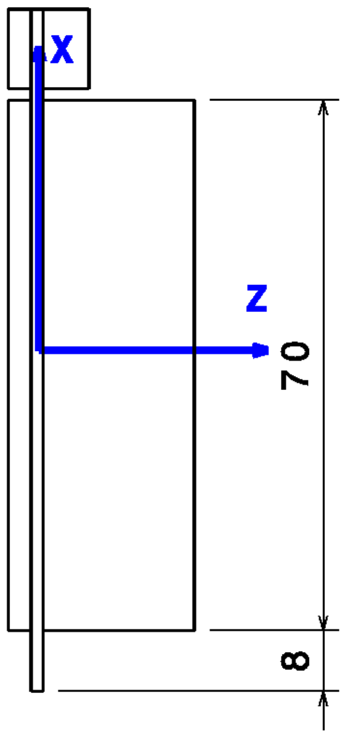
PCB board 90mm x 90 mm x 1.6 mm
Connector Z+ side 6 mm
Soldering pins 3 mm



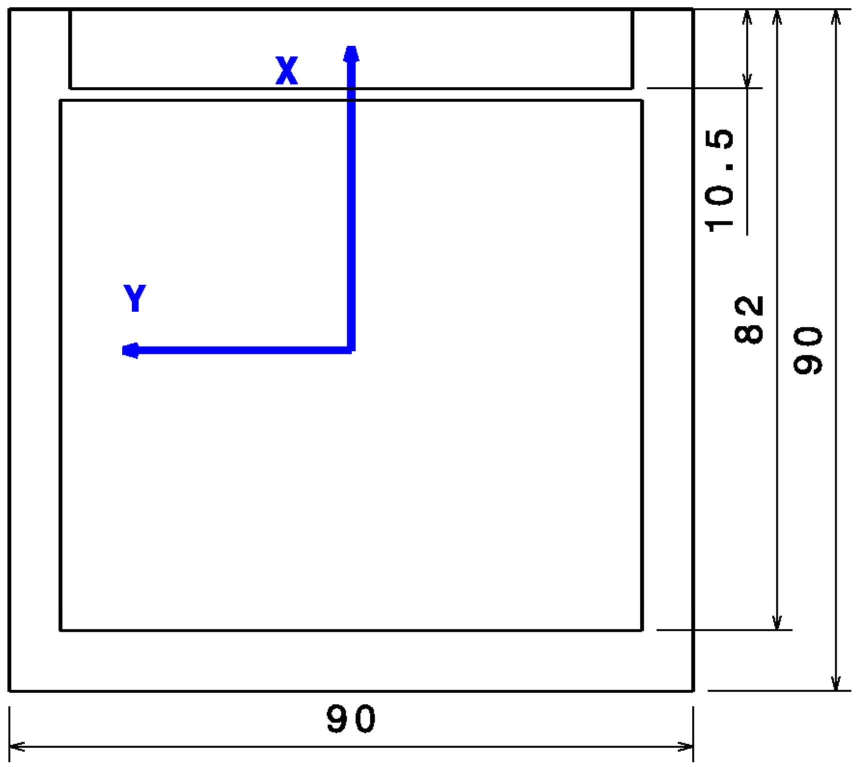
X+ view
Scale: 1:1



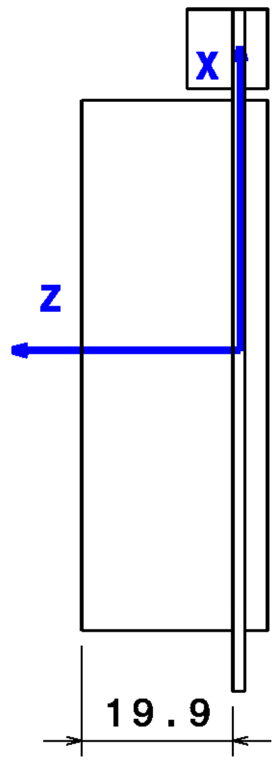
Isometric view
Scale: 1:1



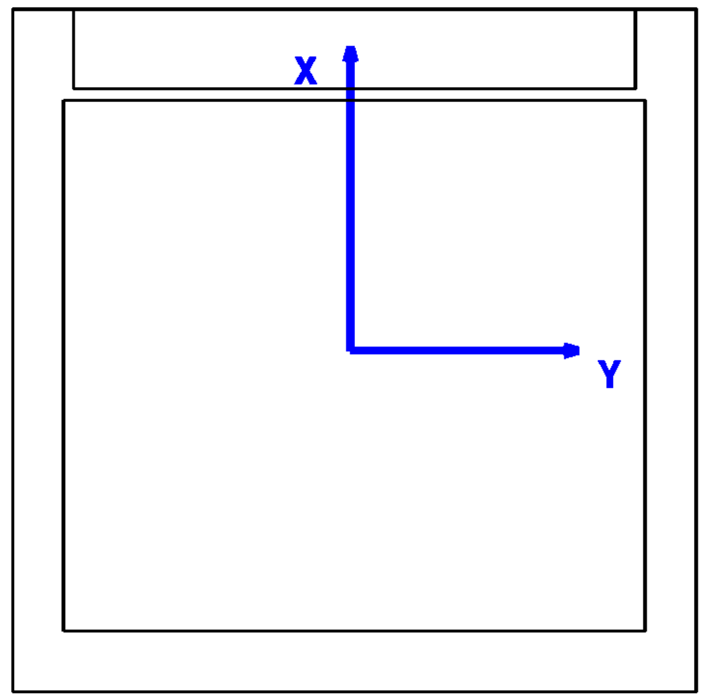
Y+ view
Scale: 1:1



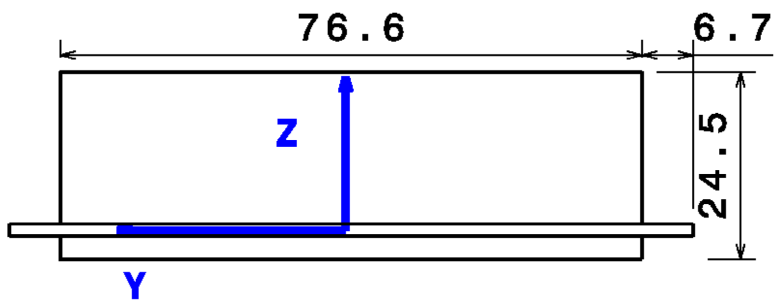
Z+ view
Scale: 1:1



Y- view
Scale: 1:1

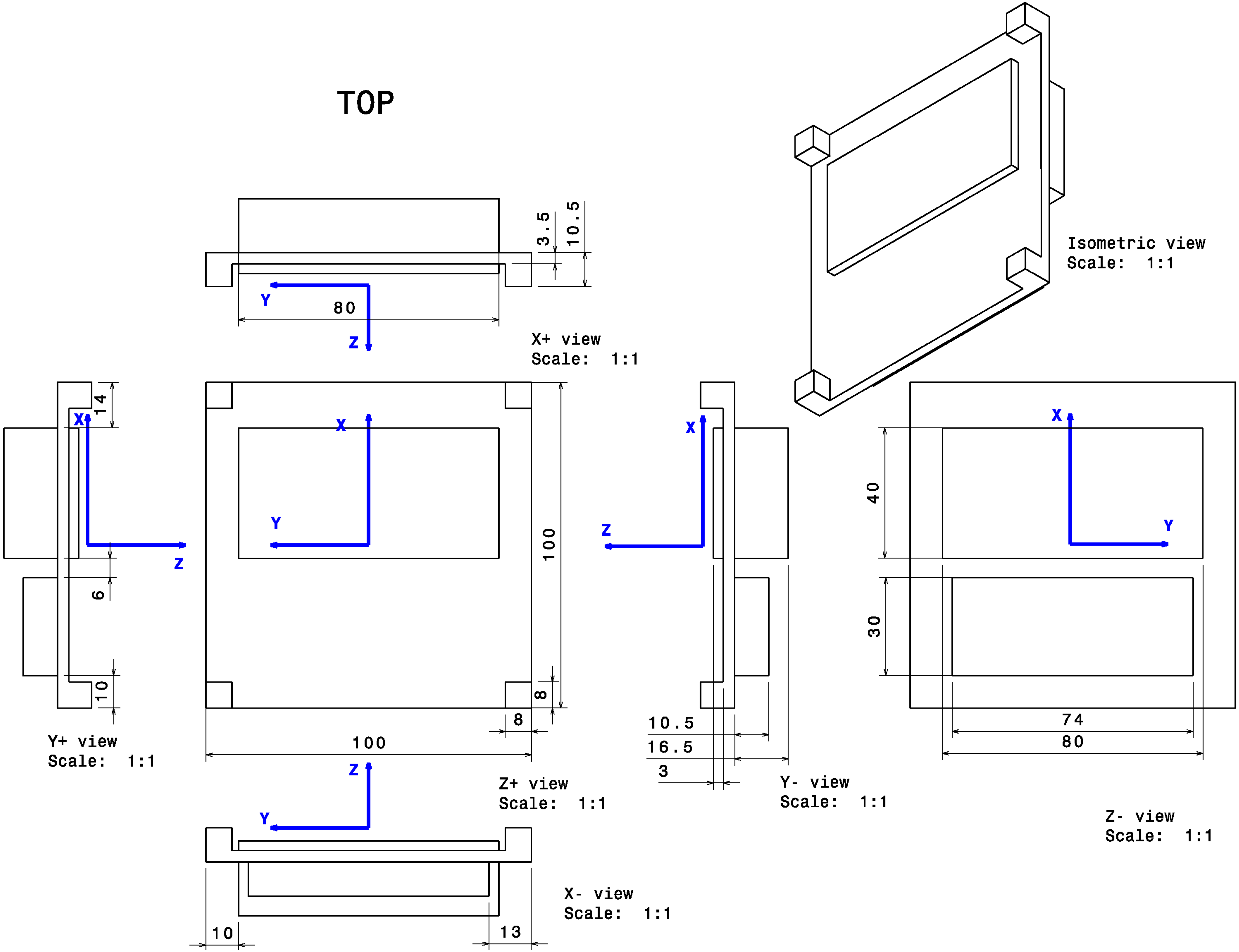


Z- view
Scale: 1:1



X- view
Scale: 1:1

TOP



Isometric view
Scale: 1:1
X+ view
Scale: 1:1
3.5
10.5
80
Y
Z
Y+ view
Scale: 1:1
14
6
10
X
Z
Z+ view
Scale: 1:1
100
100
8
8
X
Y
Y- view
Scale: 1:1
10.5
16.5
3
X
Z
Z- view
Scale: 1:1
40
30
74
80
X
Y
X- view
Scale: 1:1
10
13
Z
Y

Appendix E Mechanical and structural ICD

Description: Interfaces and restricted envelopes of STS on other subsystems on mechanical and structural level.

Subsystem(s) involved:

ADCS	CDHS	COMMS	EPS	MechS	STS	TCS	ITRX	MPS	$T^3\mu PS$	SDM	Splash	GSE	GSN	Launch
X	X	X	X	X	X	X	X	X	X	X	X	X		X

Revision Record and Authorization

Issue	Date	Author / Editor	Reviewer checked	PM approved	Affected Section(s)	Description of change
0.1	03-2009	Jennifer Go	Mattias			All
1.0	04-2009	Jennifer Go	Mattias, Geert			all
1.1	05-2009	Jennifer Go				Change in CI tree

Action Items

TBW	TBD	TBC	Applicable Section(s)	Description of action item

List of Used References

SLR code	Version	Data/Variable
SLR 0141	0.2	Coordinate system
SLR 0028	11.0	P-POD specifications and limitations
SLR 0169	2.0	Drawings version 4.0
SLR 0167	2.3	Requirements numbering
SLR 0325	1.4	Configuration Tree
SLR 0539	1.0	T-POD ICD
SLR 0554		ISIPOD specifications
SLR 0572		MechS TN

Abbreviations

ADCS EB	Attitude Determination and Control Subsystem, Electronics Board
ADCS PD	Attitude Determination and Control Subsystem, PhotoDiodes
ADCS RW	Attitude Determination and Control Subsystem, Reaction Wheels
ADCS SS	Attitude Determination and Control Subsystem, Sun Sensor
BOP	Bottom Panel
CDHS	Command and Data Handling Subsystem
COMMS	Communication Subsystem
EPS	Electrical Power Subsystem
EPS BAT	Electrical Power Subsystem, Batteries
EPS EB	Electrical Power Subsystem, Electronics Board
GSE	Ground Support Equipment
GSN	Ground Support Network
ICB	InterConnect Board
IP	Intermediate Panel
ISIPOD	Innovative Solutions In Space Picosatellite Orbital Deployer
ISIS	Innovative Solutions In Space
ITRX	ISIS Transceiver
MechS	Mechanical Subsystem
MGSE	Mechanical Ground Support Equipment
MPS	Multifunctional Particle Spectrometer
OBC	On-Board Computer
P-POD	Poly-Picosatellite Orbital Deployer
PCB	Printed Circuit Board
POD	Picosatellite Orbital Deployer
PTRX	Primary Transceiver
RF	Radio Frequency
SDM	Solar cell Degradation Measurement
SLR	Standard List of References
SPLASH	SPace fLASH
STS	Structural Subsystem
STS OS	Structural Subsystem, Outer Structure
STX	S-band Transmitter
T^3µPS	TNO, TU Delft and UTwente Micro Propulsion System
TCB	Test Connector Board
TCS	Thermal Control Subsystem
TOP	Top Panel
VHF	Very High Frequency
VHF AB	Very High Frequency Antenna Board
XPOD	eXperimental Push Out Deployer

Table of Contents

1 Introduction

This technical note describes the interfaces and restricted envelopes of the Structural Subsystem (STS), with an additional chapter about the Picosatellite Orbital Deployer (POD), for every subsystem. Restrictions are enforced from mechanical aspects, e.g. guide rails from the launch deployer, and from the design of the STS. For every subsystem it is important to take the limitations into account for a smooth overall integration. More information about the design of the STS can be found in SLR 0169.

Table 1.1: Interface table

BOP	TCB	VHF AB	IP	STX	PTRX	ADCS RW	ADCS EB	OBC	EPS EB	EPS BAT	ICB	TOP	ADCS SS	STS OS	MechS	ADCS PD	ITRX	MPS	T^{3}µPS	SDM	Splash	MGSE

At the beginning of every chapter the interfaces of STS parts with other subsections are shown (Table 1.1). For Table 1.1 subsystems have been subdivided into subsections. The Attitude Determination and Control Subsystem (ADCS) has as subsections the Reaction Wheels (RW) board, an Electronics Board (EB), a Sun Sensor (SS) package at the Z^+-side of the satellite and PhotoDiodes (PD). The Communication Subsystem (COMMS) includes as subsections the Very High Frequencies (VHF) Antenna Board (AB), the S-band Transmitter (STX), the Primary Transceiver (PTRX) and the InterConnect Board (ICB). Subsections of the Electrical Power Subsystem (EPS) are the Test Connector Board (TCB) including the kill switches, an EB and Batteries (BAT). The STS has been subdivided in the Bottom Panel (BOP), the Intermediate Panel (IP), the Top Panel (TOP) and the Outer Structure (OS).

Figure 1.1 shows the configuration tree [SLR 0325] for the STS. Interfaces with the first level of the STS-branch are dealt in this Technical Note (TN). Besides the first level, also interfaces with the Rods and PCBs are part of this document. Additional information about the configuration items of the STS-branch can be found in SLR 0169.
Chapter 2 starts with the coordinate system as is used in this document.
Chapter 3 deals with the POD, which is configuration item LOS.2 [SLR 0325].
The remaining chapters attend to the interfaces of the STS configuration items in the order as shown on Figure 1.1.

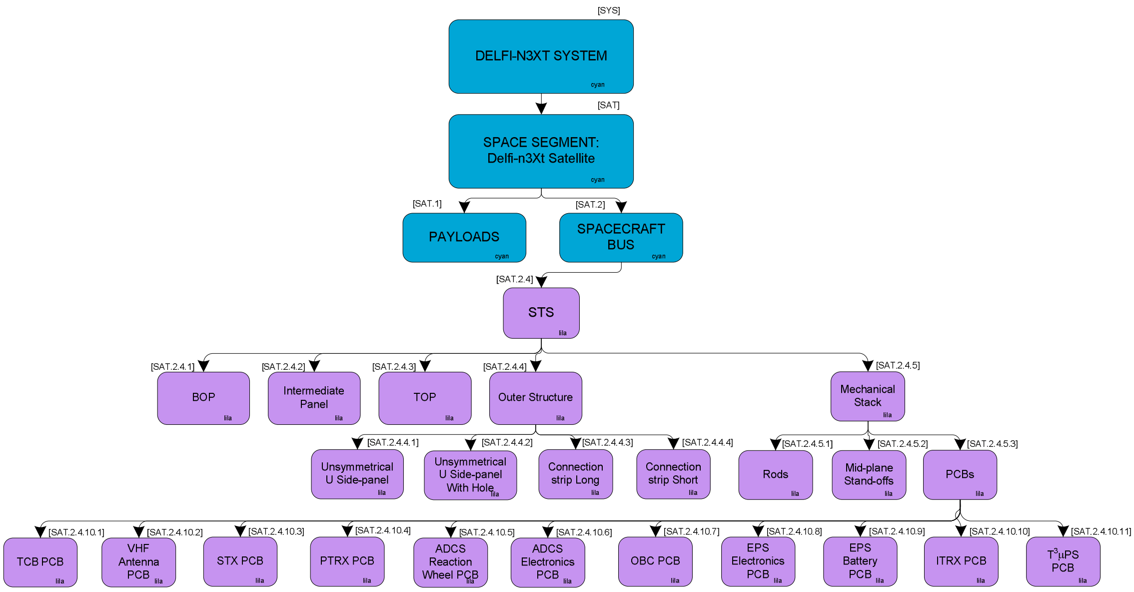


Figure 1.1: STS configuration tree (entire tree can be found in SLR 0325)
Cyan: Delfi-n3Xt colour, Lila: STS colour

2 Coordinate system

Subsection(s) involved:

BOP	TCB	VHF AB	IP	STX	PTRX	ADCS RW	ADCS EB	OBC	EPS EB	EPS BAT	ICB	TOP	ADCS SS	STS OS	MechS	ADCS PD	ITRX	MPS	$T^3\mu PS$	SDM	Splash	MGSE
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

The satellite makes use of the body fixed coordinate system as defined in [SLR 0141].
The coordinate system on subsystem level is defined on a similar way as the satellite coordinate system and is shown on Figure 2.1. As the satellite coordinate system, on local level also holds:

- X^+-side is reserved for the power and data bus connector with the connectors located on the Z^+-side of the PCB.
- Y^+-side is reserved for radio frequency connectors (if applicable) of which the connector is put on the Z^+-side of the PCB.

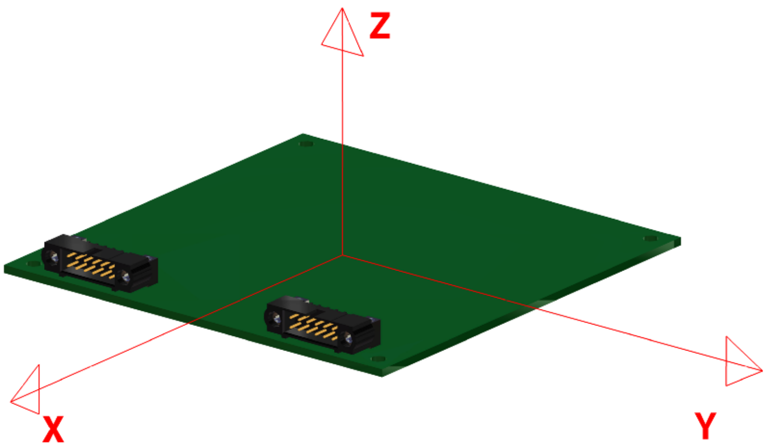


Figure 2.1: Z^+-view PCB

3 POD

Subsection(s) involved:

BOP	TCB	VHF AB	IP	STX	PTRX	ADCS RW	ADCS EB	OBC	EPS EB	EPS BAT	ICB	TOP	ADCS SS	STS OS	MechS	ADCS PD	ITRX	MPS	T^{3}µPS	SDM	Splash	MGSE
x												x		x	x							x

For the protection of the CubeSat during transportation and launch a POD will be used. Since Delfi-n3Xt is a three-unit CubeSat, STS volume requirements are 100 mm x 100 mm x 340.5 mm as can be found in SLR 0167. In addition restrictions on all outer structural parts are set by the POD. The POD makes use of a guide rail for getting the CubeSat in and out of the POD. The rails are smooth and it is not allowed to obstruct them. The walls and rails of the POD are not to be used to constrain deployables [SLR 0028].
Three possible deployers for Delfi-n3Xt are Poly-Picosatellite Orbital Deployer (P-POD), eXperimental Push Out Deployer (XPOD) and Innovative Solutions In Space Picosatellite Orbital Deployer (ISIPOD). The volume for deployables for the different deployers is (L x W x H):
P-POD: 340.5 x 87.7 x 8.5 [mm] [SLR 0028]
XPOD: 340.5 x 87.7 x 12.5 [mm] [SLR 0539]
ISIPOD: 340.5 x 90.4 x 10.0 [mm] [SLR 0554]
With L the length of the satellite in launch direction, W the available width between the guide rails and H the distance between the structure of the CubeSat without deployables and the POD side wall (see also Figure 3.1).
Taking into account the restriction that the rails need to be smooth leaves the following maximum volumes for deployables (L x W x H):
P-POD: 340.5 x 83.0 x 6.5 [mm] [SLR 0028]
XPOD: 340.5 x 87.0 x 11.5 [mm] [SLR 0539]
ISIPOD: 340.5 x 90.0 x 9.0 [mm] [SLR 0554]
These values have been taken in accordance with the deployer user manuals and/or the maximum expected clearances needed for deflection of the solar panels [SLR 0572] and play of the satellite within the deployer.

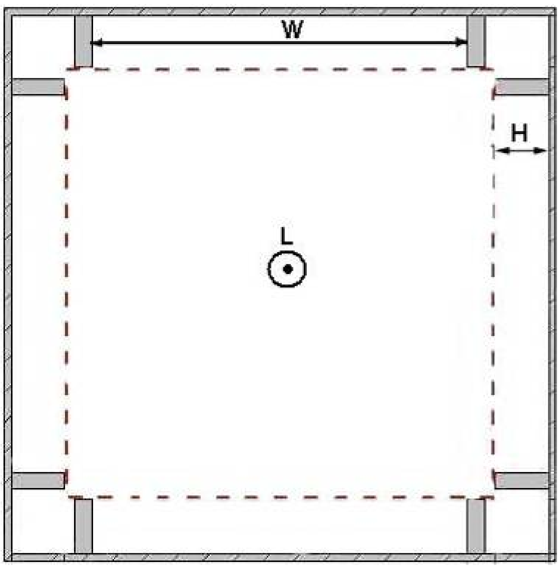


Figure 3.1: Definition of length, width and height for POD

4 BOP

Subsection(s) involved:

BOP	TCB	VHF AB	IP	STX	PTRX	ADCS RW	ADCS EB	OBC	EPS EB	EPS BAT	ICB	TOP	ADCS SS	STS OS	MechS	ADCS PD	ITRX	MPS	$T^3\mu PS$	SDM	Splash	MGSE
x	x	x												x		x						x

The BOP is on the Z^--side of the satellite. In Z-direction the BOP provides holes for Modular Antenna Boxes (MABs), kill switches, photodiodes and bolts, which support the TCB and the VHF AB. Further support feet are put on the BOP to protect fragile components during launch. This way the components are not in direct contact with the CubeSat deployer. The deployer might otherwise damage components during launch. Figure 4.1 shows the restricted or reserved areas as hatched. This is valid for both the Z^+- as the Z^--side of the BOP. Some holes are still subject to change, as are the location for holes of the kill switches. A more detailed description about the design of the BOP can be found in SLR 0169.

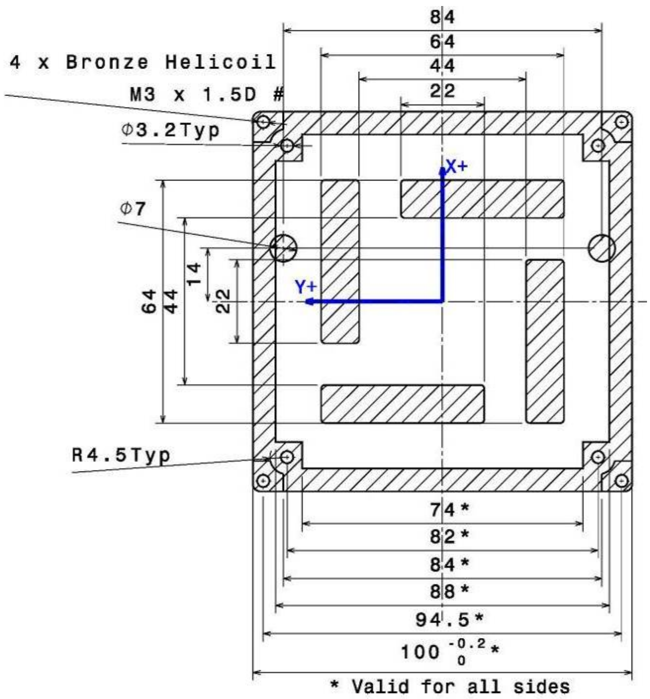


Figure 4.1: BOP layout Z-view

The sides of the BOP are raised. Figure 4.2 shows a cross-section of the BOP. As shown on Figure 4.2 the thickness of the side walls varies. The thinner part of the sides overlaps with the outer structure (Chapter 7) and provides holes to connect the outer structure to the BOP. These holes are symmetrically placed on all four sides with dimensions as shown on Figure 4.3. On the X^--side of the BOP, on the thicker part, openings for test connectors are implemented (Figure 4.3). On the Y-sides a hole for grounding has been taken into account on the thicker part of the BOP as shown on Figure 4.2.

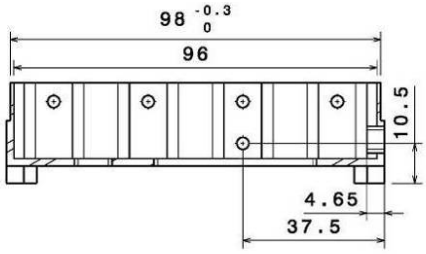


Figure 4.2: BOP cross-section

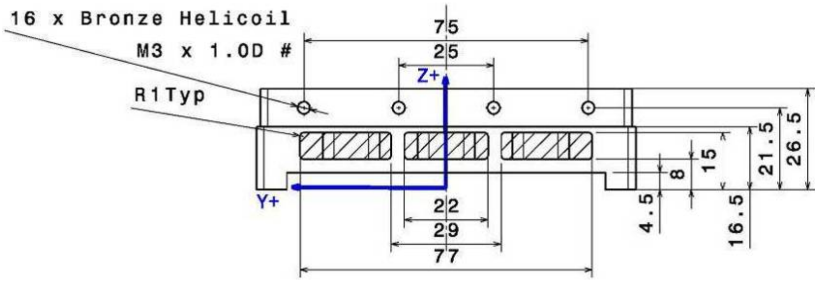


Figure 4.3: X⁻-side BOP layout

Figure 4.1, Figure 4.3 and Figure 4.2 can also be found in Appendix A.

As said, bolts are used to support the TCB and VHF AB. These bolts should therefore be long enough for the support of these sections. At this moment 40 mm long M3 bolts are foreseen. The correct offset of the components will be given by using busses and spacers (see also Chapter 8).

Interfaces which need to be observed are the placement, location and opening dimensions of the kill switches, MABs, photodiodes and test connectors. If one of these changes, modifications to the BOP are necessary.

5 Intermediate Panel

Subsection(s) involved:

BOP	TCB	VHF AB	IP	STX	PTRX	ADCS RW	ADCS EB	OBC	EPS EB	EPS BAT	ICB	TOP	ADCS SS	STS OS	MechS	ADCS PD	ITRX	MPS	T³µPS	SDM	Splash	MGSE
			x	x	x				x					x	x		x	x				x

On about a third of the total height an intermediate panel is placed. This panel provides holes for the long rods of the stack and provides structural support for the Multifunctional Particle Spectrometer (MPS). The frame is fastened to the outer structure of the satellite. Figure 5.1 shows the restricted areas as hatched. This is valid for both the Z^+ as the Z^--side of the intermediate panel. A more detailed description about the design of the intermediate panel can be found in SLR 0169.

On the X^+-side of the intermediate panel two openings for the power and data bus connectors are implemented; on the Y^+-side openings for the RF connectors are implemented plus an opening for the battery connector.

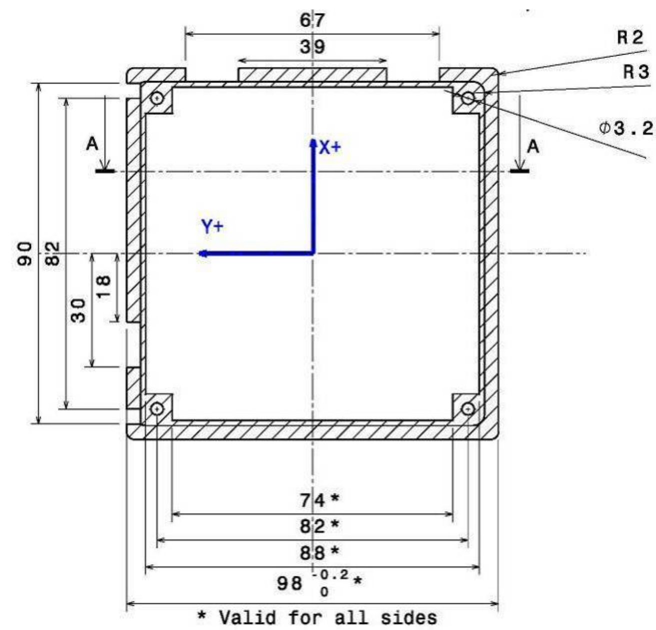


Figure 5.1: Intermediate Panel layout Z-view

Figure 5.2 shows one of the sides of the intermediate panel (valid for all sides). The sides are fastened to the outer structure on four points as shown.

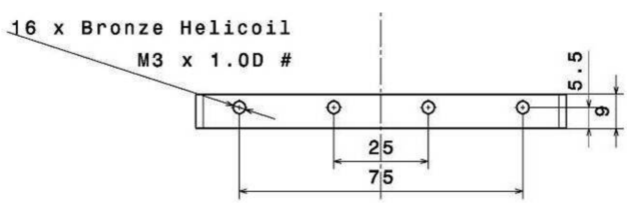


Figure 5.2: Intermediate Panel side layout

The thicknesses of the panel are shown on Figure 5.3. These values are valid for the entire panel.

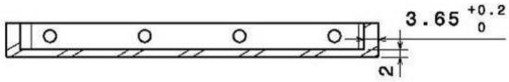


Figure 5.3: Intermediate Panel cross-section

Figure 5.1, Figure 5.2 and Figure 5.3 can also be found in Appendix B.

Interfaces which need to be observed are the placement, location and opening dimensions of the power and databus connectors, RF connectors and fastening for the MPS. If one of these changes, modifications to the intermediate panel are necessary. At this moment the thickness of the plate in XY-direction is 2 mm, this means that at this moment the MPS cannot make use of helicoils for fastening. If the MPS requires helicoils, adaptations to the intermediate panel need to be implemented, if possible.

6 TOP

Subsection(s) involved:

BOP	TCB	VHF AB	IP	STX	PTRX	ADCS RW	ADCS EB	OBC	EPS EB	EPS BAT	ICB	TOP	ADCS SS	STS OS	MechS	ADCS PD	ITRX	MPS	T^3µPS	SDM	Splash	MGSE
												x	x	x	x	x				x		x

The TOP is on the Z^+-side of the satellite. The Z-direction of the TOP provides holes for the Solar Degradation Measurement (SDM) payload of Dimes, a Sun sensor and the long rods. Also support feet are put on the TOP as on the BOP (chapter 3). Figure 6.1 shows the restricted or reserved areas as hatched. This is valid for both the Z^+ as the Z^--side of the TOP. A more detailed description about the design of the TOP can be found in SLR 0169.

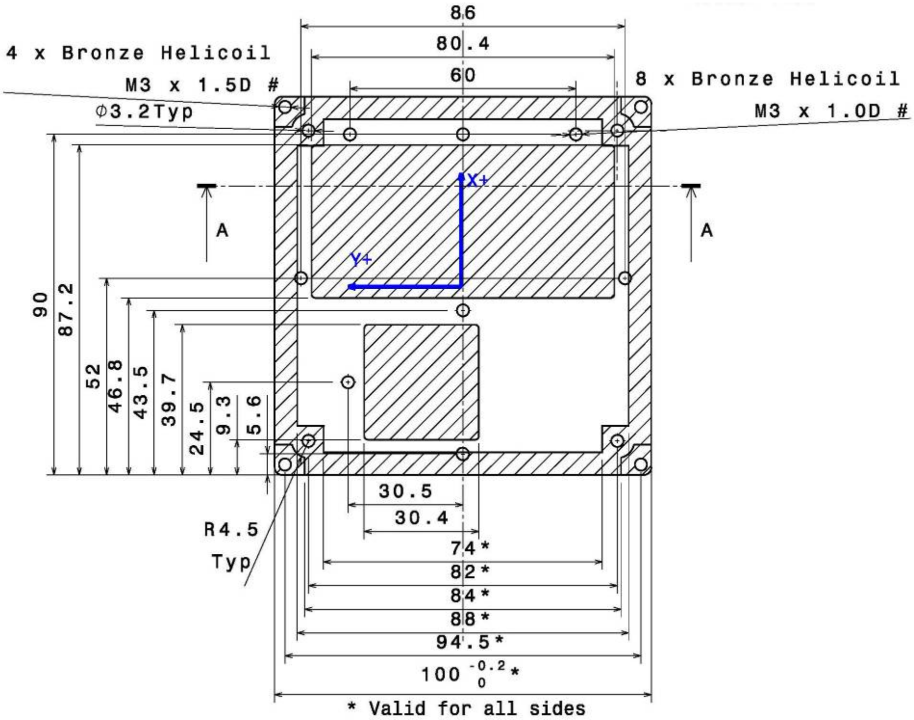


Figure 6.1: TOP layout Z-view

The sides of the TOP, as on the BOP, are raised. Again holds that the thinner part of the sides overlaps with the outer structure and that the TOP provides holes to connect the outer structure. The thicker part of the sides supports the hinges of the solar panels and two bolts for grounding are taken into account on the X-sides with dimensions as shown on Figure 6.2 . Figure 6.2 shows the wall thicknesses of the TOP, valid for all sides. Figure 6.3 shows one of the sides of the TOP; this is also valid for all sides.

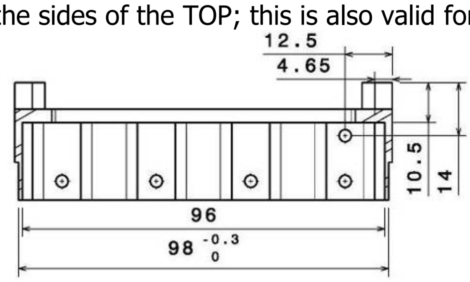


Figure 6.2: TOP cross-section

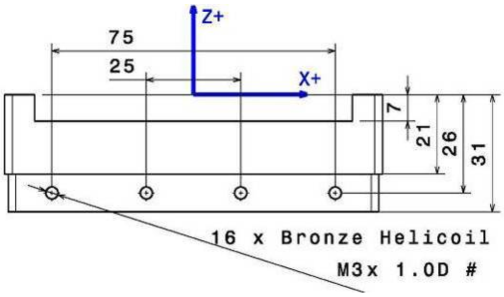


Figure 6.3: TOP side dimension

Figure 6.1, Figure 6.3 and Figure 6.2 can also be found in Appendix C.

Interfaces which need to be observed are the placement, location and opening dimensions of the SDM and the Sun sensor. If one of these changes, modifications to the TOP are necessary.

7 Outer structure

Subsection(s) involved:

BOP	TCB	VHF AB	IP	STX	PTRX	ADCS RW	ADCS EB	OBC	EPS EB	EPS BAT	ICB	TOP	ADCS SS	STS OS	MechS	ADCS PD	ITRX	MPS	$T^3\mu PS$	SDM	Splash	MGSE
x			x	x								x		x	x	x		x	x			x

The outer structure is formed by two U-profiles [SLR 0169]. The profiles are fastened to each other by means of connection strips. The profiles, moreover, are connected to the TOP, BOP and intermediate panel, and provide fastening for the midplane standoffs, see SLR 0169.
Hold down & release mechanisms are put on the outer structure to support and hold down the solar panels until their deployment. Also S-patch antennas are fastened on the outer structure. For the mechanisms and antennas the restriction of rail clearances as stated in Chapter 3 need to be considered.
Interfaces exist between the outer structure and two of the payloads, namely $T^3\mu PS$ and MPS. $T^3\mu PS$ requires an outlet (SAT.2.4.4.2.REQ.P.000) for the thruster; MPS requires a window of 300 micron thickness (SAT.2.4.REQ.I.006). When $T^3\mu PS$ and MPS are relocated with respect to orientation or Z-location, the location of the openings in the outer structure needs to be revised as well.

Interfaces which need to be observed further are the placement, location and opening dimensions of the hold down and release mechanisms and the S-patch antennas. If one of these changes, modifications to the outer structure are necessary.

8 Rods

Subsection(s) involved:

BOP	TCB	VHF AB	IP	STX	PTRX	ADCS RW	ADCS EB	OBC	EPS EB	EPS BAT	ICB	TOP	ADCS SS	STS OS	MechS	ADCS PD	ITRX	MPS	$T^3\mu$PS	SDM	Splash	MGSE
			x	x	x	x	x	x	x	x	x	x		x			x	x	x	x	x	x

The satellite makes use of threaded rods. The rods run from run from the intermediate panel to the TOP. The rods are M3 in diameter. The length of the rods is determined by the distance between the intermediate panel and the TOP, taking into account the fastening of the rods at the TOP and intermediate panel with a nut and some tolerance. Additionally the rods are supported by midplane standoffs [SLR 0169] which are fastened to the outer structure of the satellite.
Busses and spacers (Figure 8.1) will be used to give the various sections the correct offset. The spacers are placed at the Z^+- and Z^--side of the PCBs and are 6 mm in diameter (this has been taken into account in the area for restriction in Figure 9.1).

Figure 8.1: Washer, distance bush and threaded rod

9 Printed Circuit Board

Subsection(s) involved:

BOP	TCB	VHF AB	IP	STX	PTRX	ADCS RW	ADCS EB	OBC	EPS EB	EPS BAT	ICB	TOP	ADCS SS	STS OS	MechS	ADCS PD	ITRX	MPS	T^3µPS	SDM	Splash	MGSE
	x	x		x	x	x	x	x	x	x	x			x			x		x		x	x

First the standard for PCBs is given, afterwards custom PCBs are regarded.

9.1 Standard PCB

The standard PCB has been defined as having the following dimensions: 90 mm x 90 mm x 1.6 mm. There are holes on every corner to let the rods through. Figure 9.1 shows the restricted areas as hatched (can also be found in Appendix D). The restrictions are valid for both sides of the PCB. The restrictions include the area with holes for the rods and space for the power and data bus connector. Room for Radio Frequency (RF) cables has been reserved on the Y^+-side; subsystems using RF connectors on their PCB should take this into account when designing.

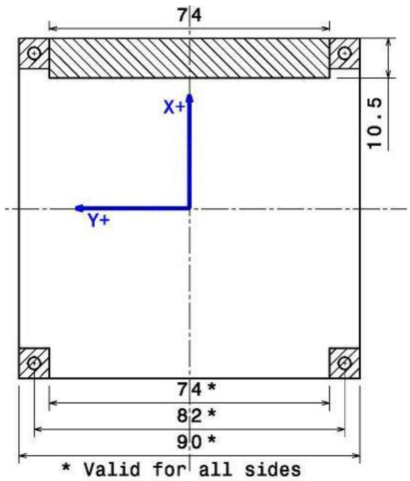


Figure 9.1: PCB layout Z-view

Between the standard PCB and the outer structure is a spacing of 4 mm. This spacing is reserved for wiring and magnetorquers. General components may not overlap the PCB, unless in agreement.

9.2 TCB

The TCB has custom dimensions. The TCB is placed as a board around the VHF antenna board. The outer dimensions are similar to the standard PCB (90 mm x 90 mm x 1.6 mm) and restrictions for the rod holes hold as on the standard PCBs, however an opening large enough to let all four antenna boxes through is implemented. Further a gap for two kill switches needs to be considered. A possible layout for this board is shown on Figure 9.2.
The TCB houses the test connectors, and has an interface with the BOP (Chapter 4) for connection of the test connectors.

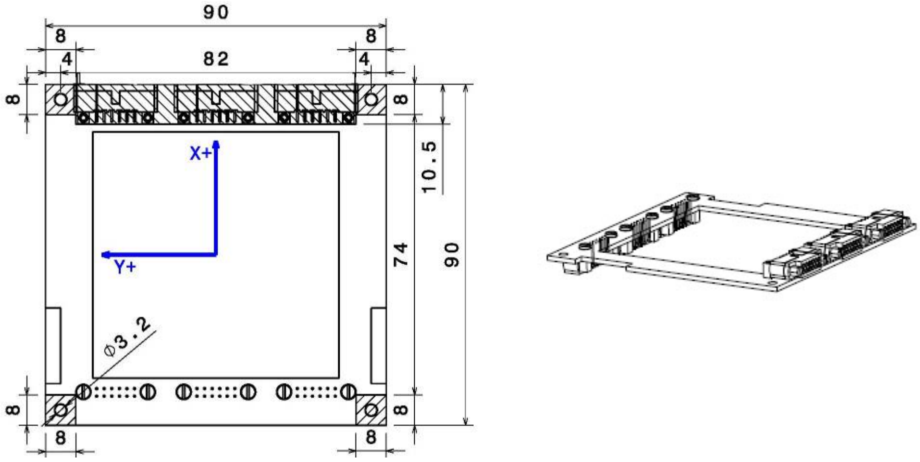
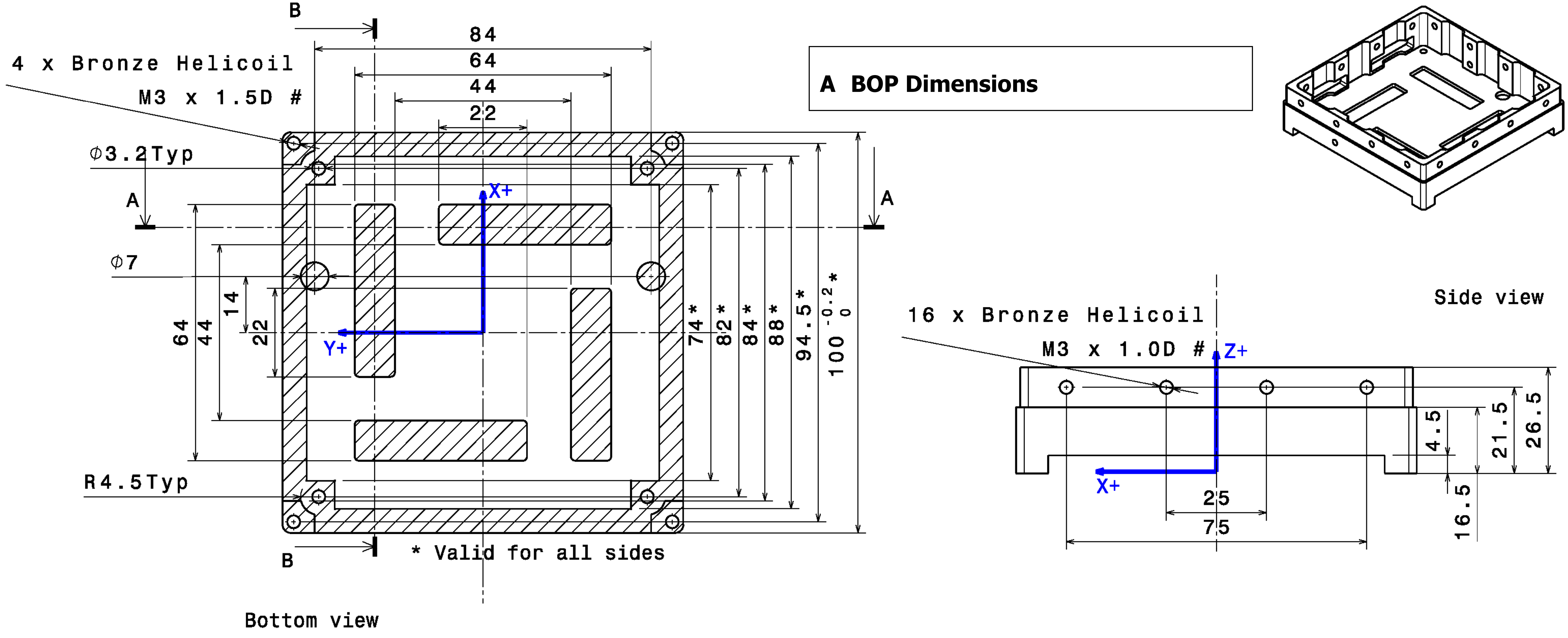
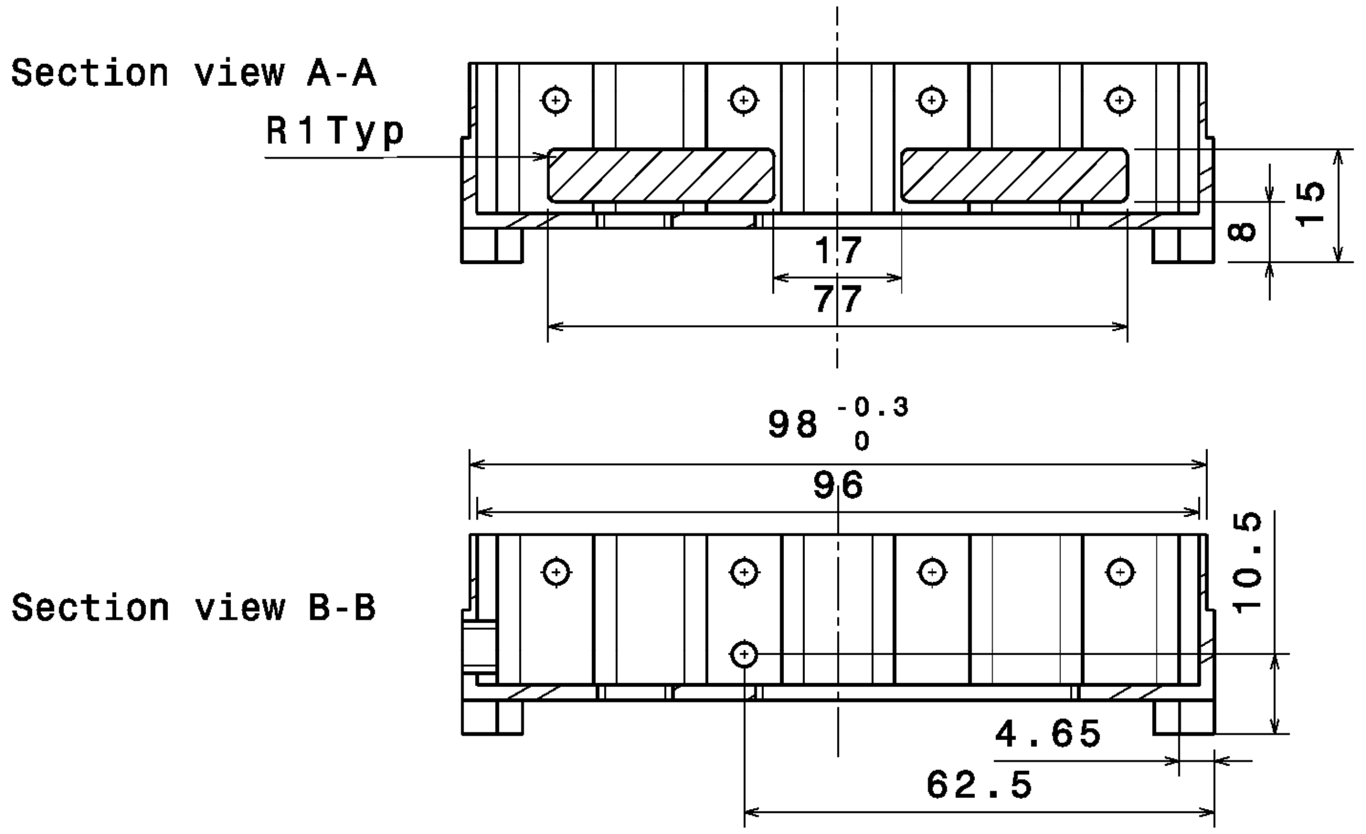


Figure 9.2: Possible layout for TCB



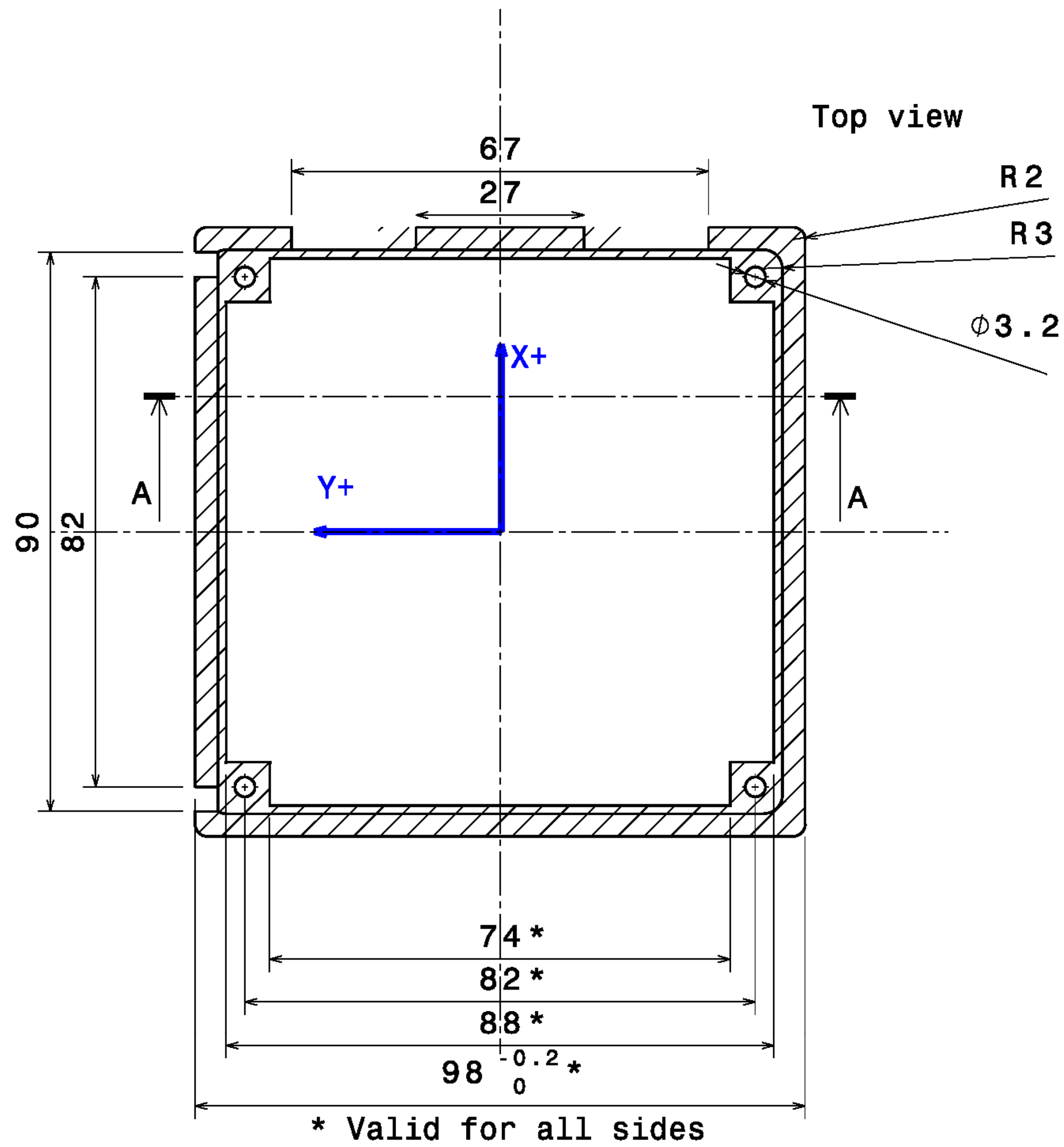


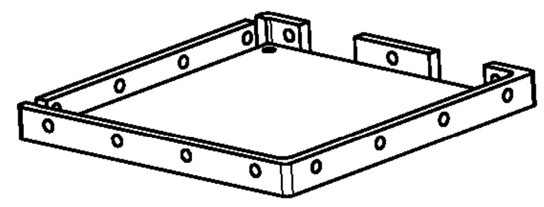
Hatched areas are restricted from use
Install Helicoil after surface treatment

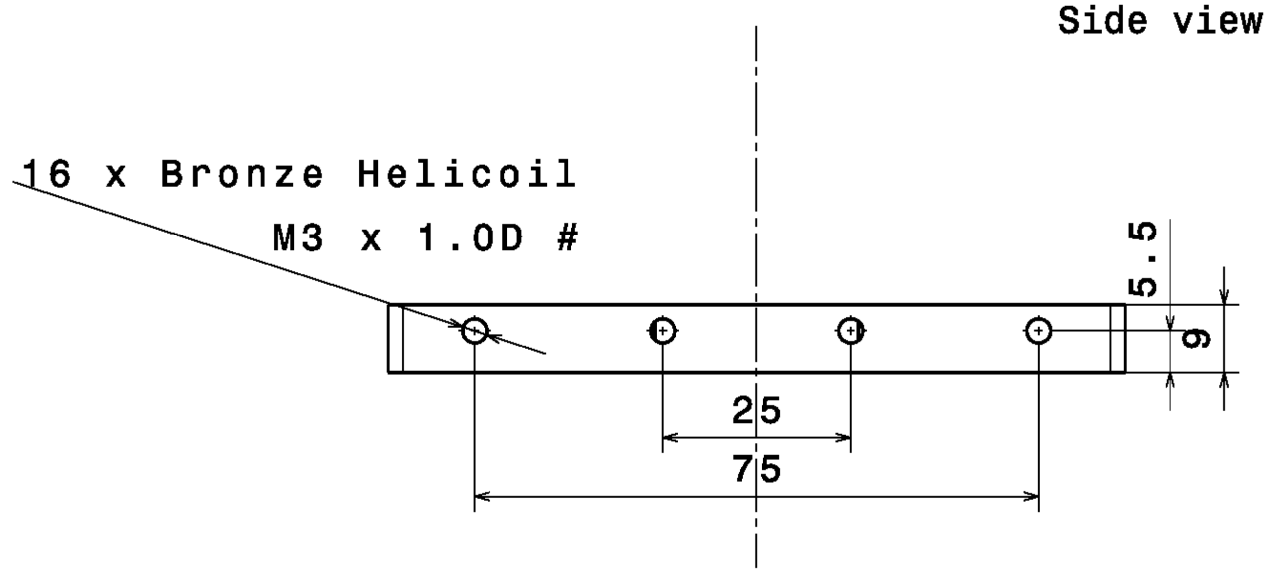
Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Milling
Dimensions in mm	Material	Aluminium 6082 (51ST 3.2315.72)

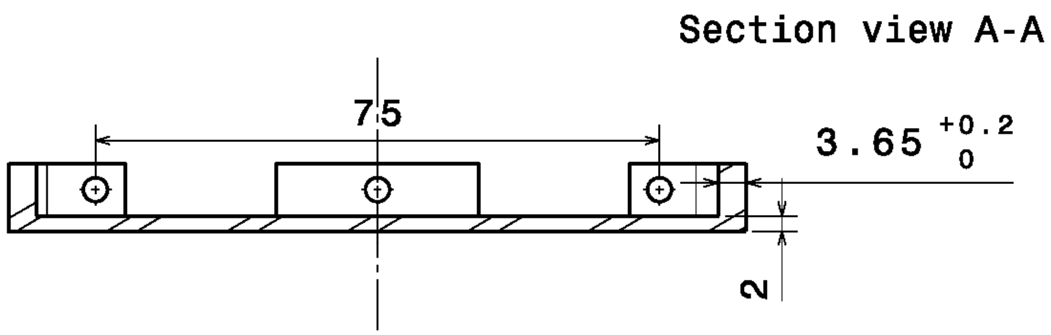
DESIGNED BY: Jennifer Go DATE: 13/02/2009	Bottom Panel		I	_
			H	_
CHECKED BY: G.F. Brouwer DATE: 13/02/2009			G	_
			F	_
SIZE	Delfi-n3Xt		E	_
			D	_
SCALE 1:1	WEIGHT (kg) 0.104	DRAWING NUMBER DNX-11-001	SHEET 1/1	C _
			B	_
			A	13/02/2009

B Intermediate Panel Dimensions









Hatched areas are restricted from use
Install Helicoil after surface treatment

Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Milling
Dimensions in mm	Material	Aluminium 6082 (51ST 3.2315.72)

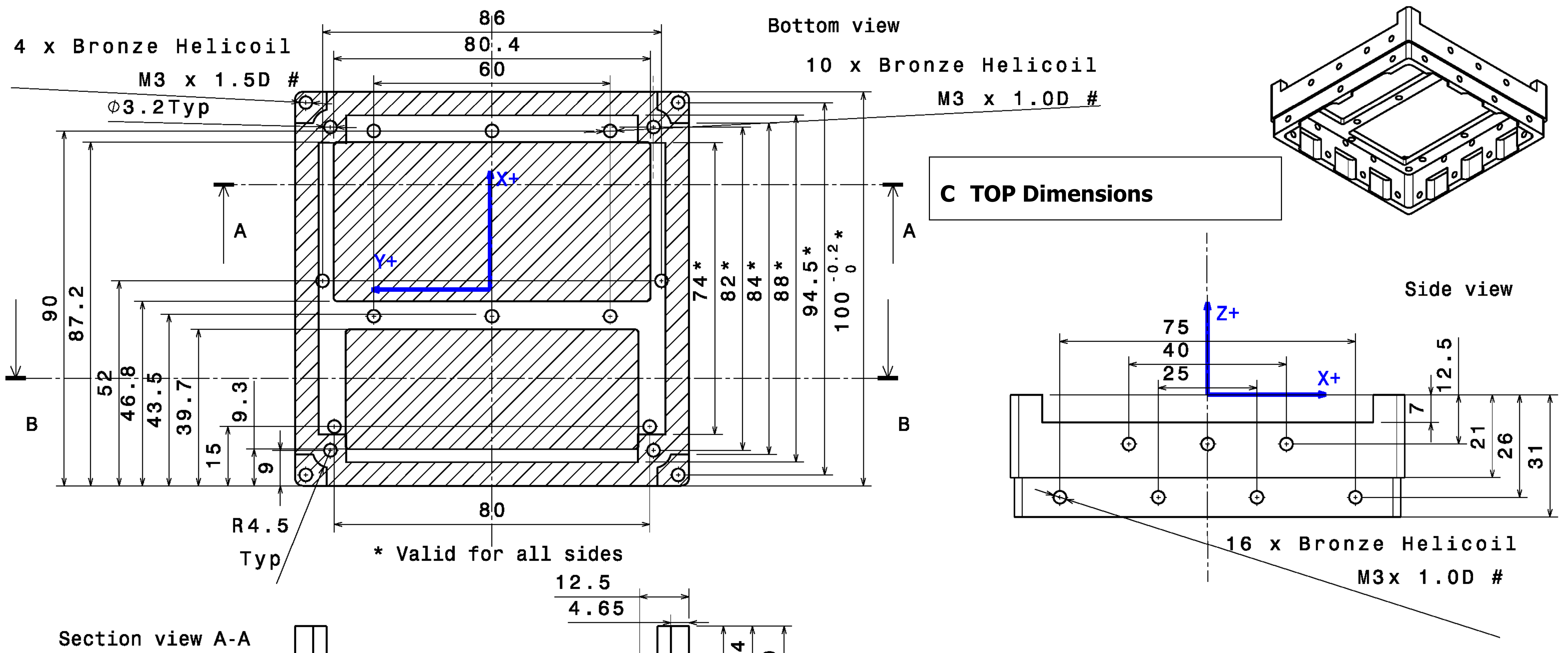
DESIGNED BY: Jennifer Go
DATE: 13/02/2009
CHECKED BY: G.F. Brouwer
DATE: 13/02/2009

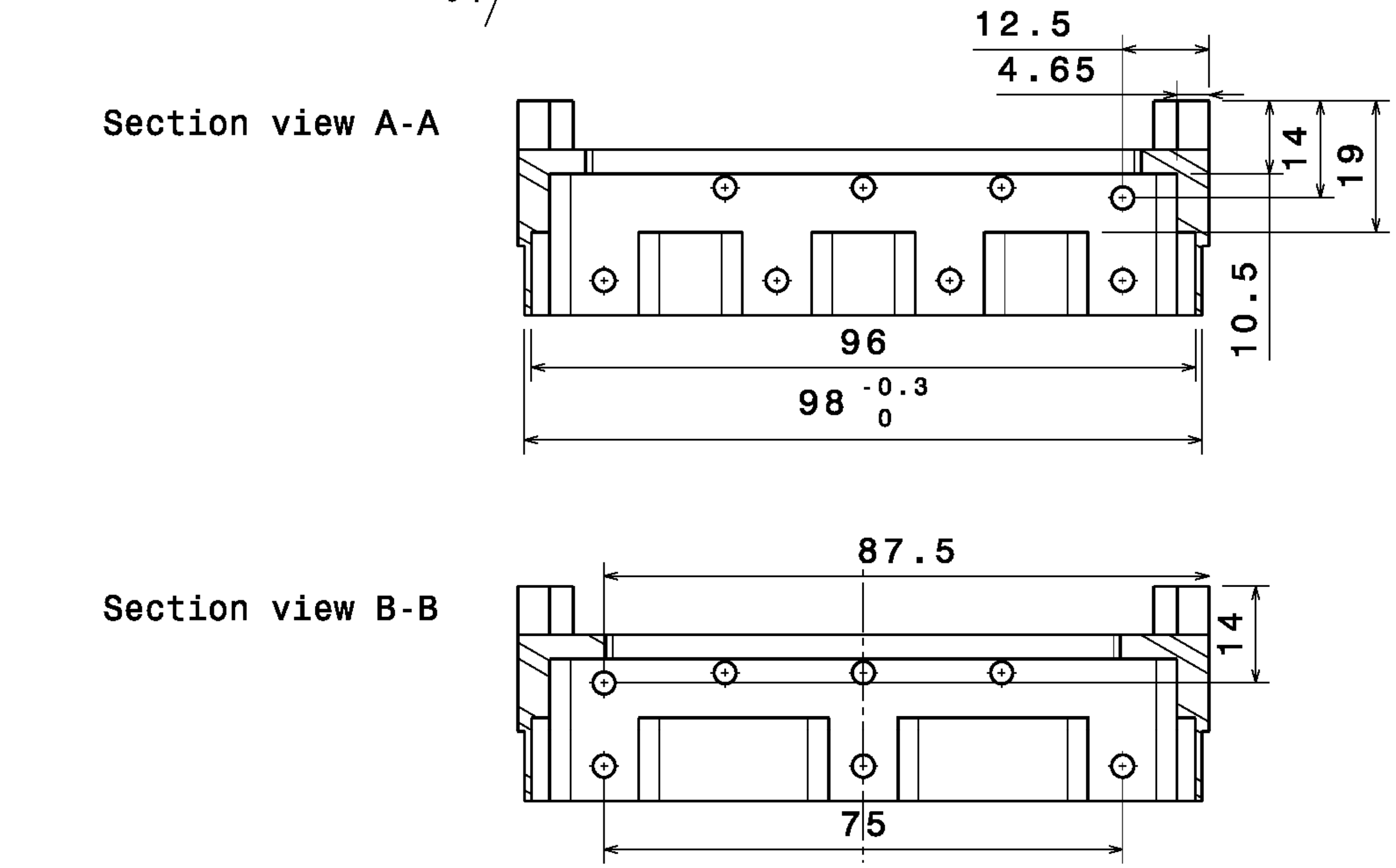
Intermediate Panel

Delfi-n3Xt

SIZE	SCALE	WEIGHT (kg)	DRAWING NUMBER	SHEET
A3	1:1	0.075	DNX-12-001	1/1

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	13/02/2009





Hatched areas are restricted from use

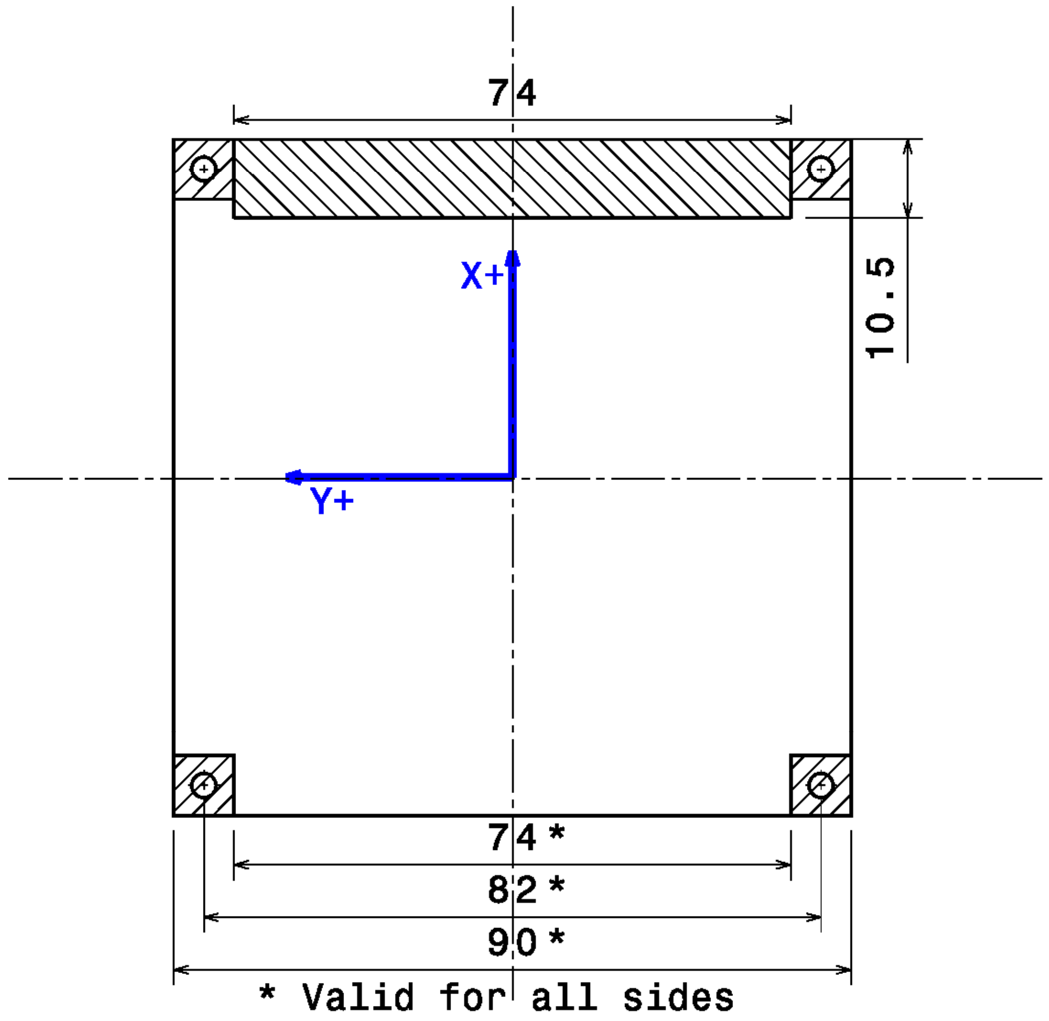
Install Helicoil after surface treatment

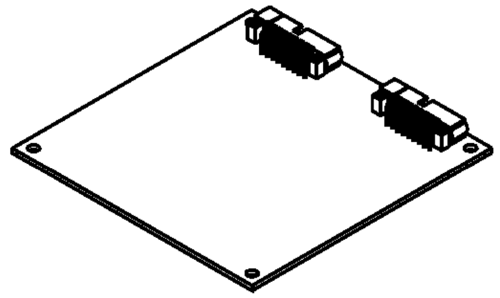
Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Milling
Dimensions in mm	Material	Aluminium 6082 (51ST 3.2315.72)

DESIGNED BY: Jennifer Go DATE: 13/02/2009	Top Panel		I	_
CHECKED BY: G.F. Brouwer DATE: 13/02/2009			H	_
SIZE	Delfi-n3Xt		G	_
SCALE 1:1	WEIGHT (kg) 0.123	DRAWING NUMBER DNX-13-001	SHEET 1/1	

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	13/02/2009

D PCB Layout





Front view
Scale: 1:1

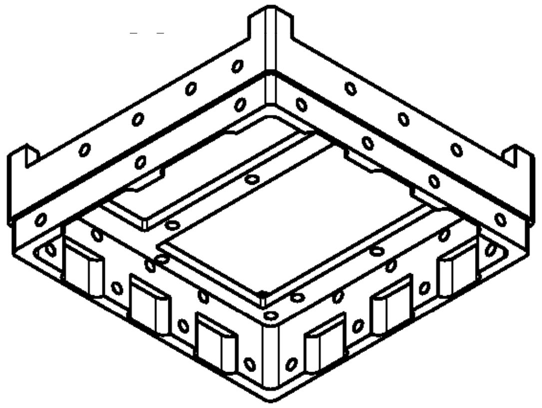
This drawing is our property.
It can't be reproduced
or communicated without
our written agreement.

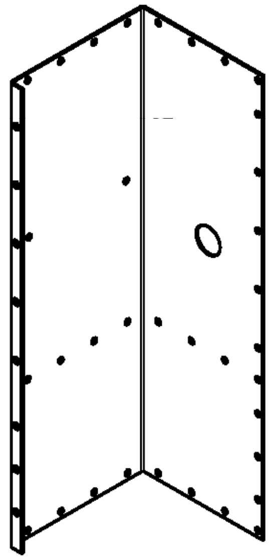
Delfi-n3Xt

DRAWN BY: Jennifer Go	DATE: 29-10-2008	PCB layout	
CHECKED BY: XXX	DATE: xxx	SIZE: A3	DRAWING NUMBER: PCB met rods	REV: X
DESIGNED BY: XXX	DATE: xxx	SCALE: 1:1	WEIGHT(kg): 0,02	SHEET: 1/1

Appendix F STS – Technical Drawings for Structure

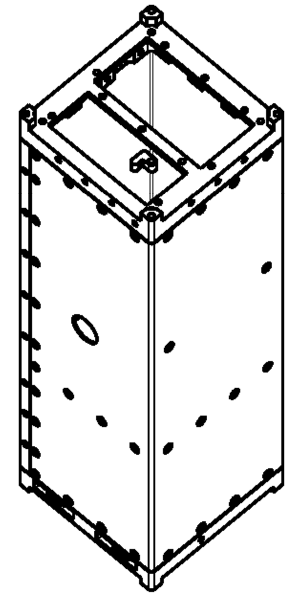
Top Panel



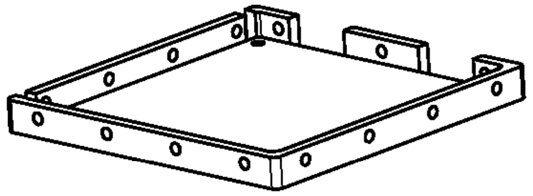


Unsymmetrical U with hole

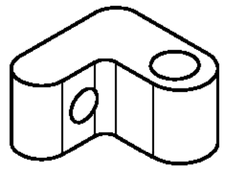
Connection Strip Long



Isometric view

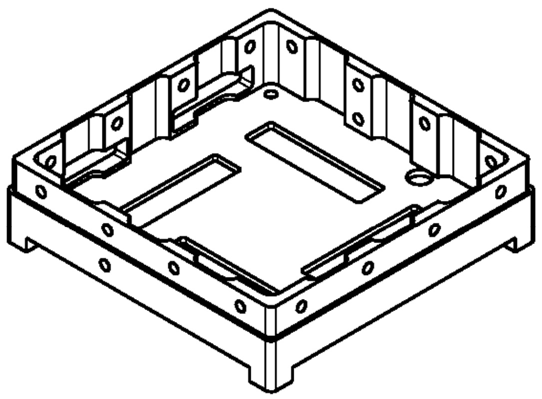


Intermediate Panel

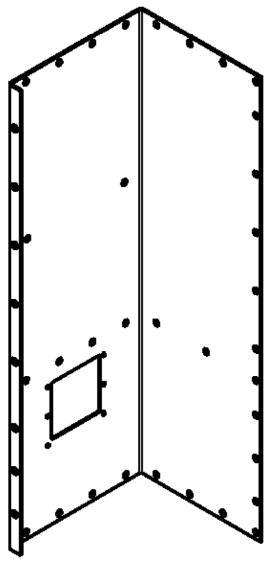


Midplane Stand-off

Connection Strip Short



Bottom Panel



Unsymmetrical U

Part Number	Part Name	Qty	Rev
DNX-11-001	Bottom Panel	1	A
DNX-12-001	Intermediate Panel	1	A
DNX-13-001	Top Panel	1	A
DNX-14-001	Unsymmetrical U	1	A
DNX-14-002	Connection Strip Long	2	A
DNX-14-003	Unsymmetrical U with hole	1	A
DNX-14-004	Connection Strip Short	2	A
DNX-30-002	Midplane Standoff	4	A
EC2216 B/A	Epoxy Adhesive		
Clifa-M 500 000 030.800	Press nut	16	
DIN 963-M3x4-A2-70 DIN 963-M2.5x4-A2-70	Screw M3 or M2.5	84	
DIN 963-M2x4-A2-70	Screw M2	16	
DIN 934-M2-A2-70	Nut M2	16	
41301030003	Helicoil M3 x 1.0D	60	
41301030045	Helicoil M3 x 1.5D	8	

Project contact: 015-2785326
Order no. L10 L10502
Remove sharp edges
Dimensions in mm

DESIGNED BY: Jennifer Go
DATE: 13/02/2009
CHECKED BY: G.F. Brouwer
DATE: 13/02/2009

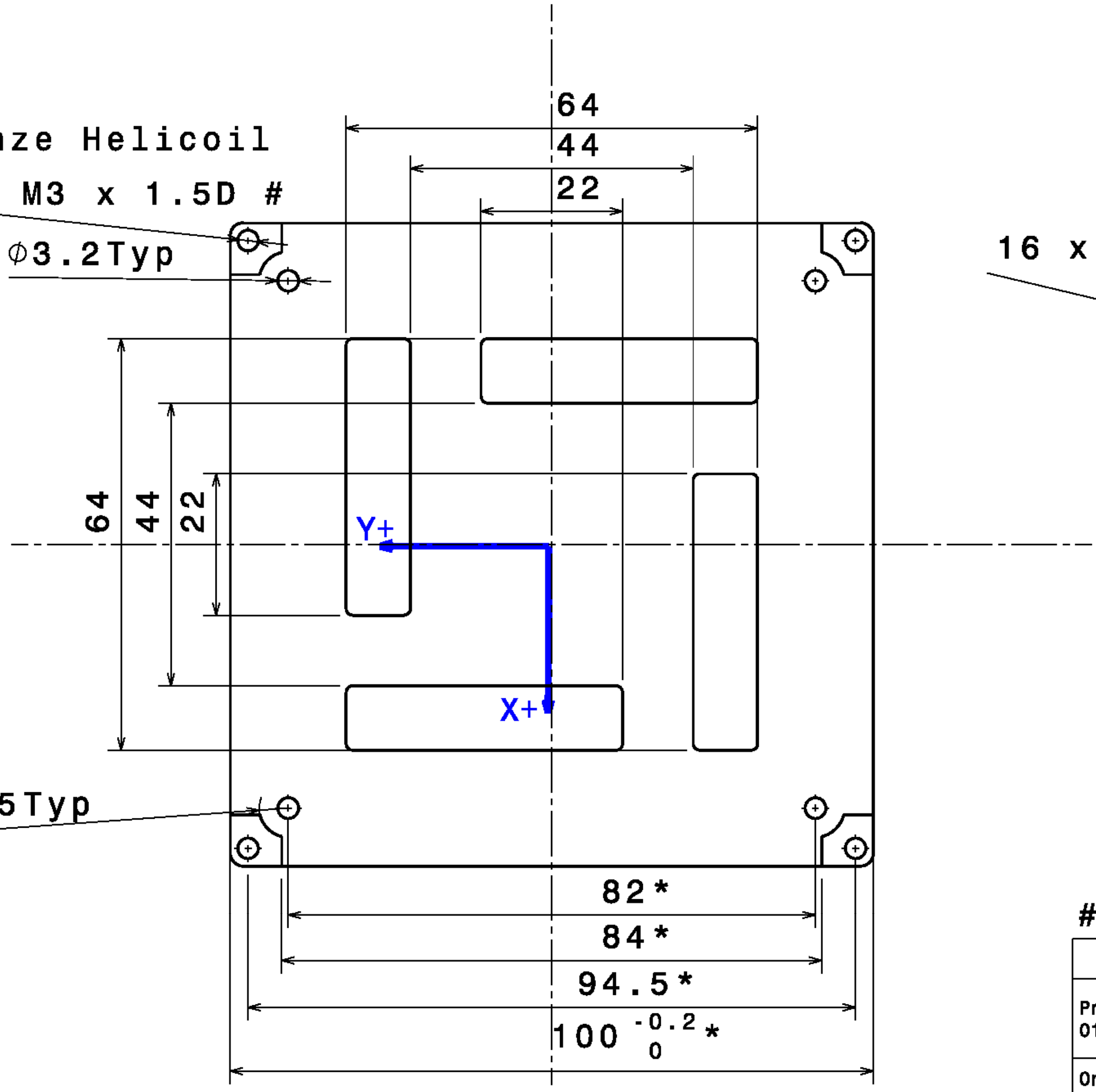
Structure Assembly

Delfi-n3Xt

SIZE	SCALE	WEIGHT (kg)	DRAWING NUMBER	SHEET
A3	1:1	0.658	DNX-10-000	1/1

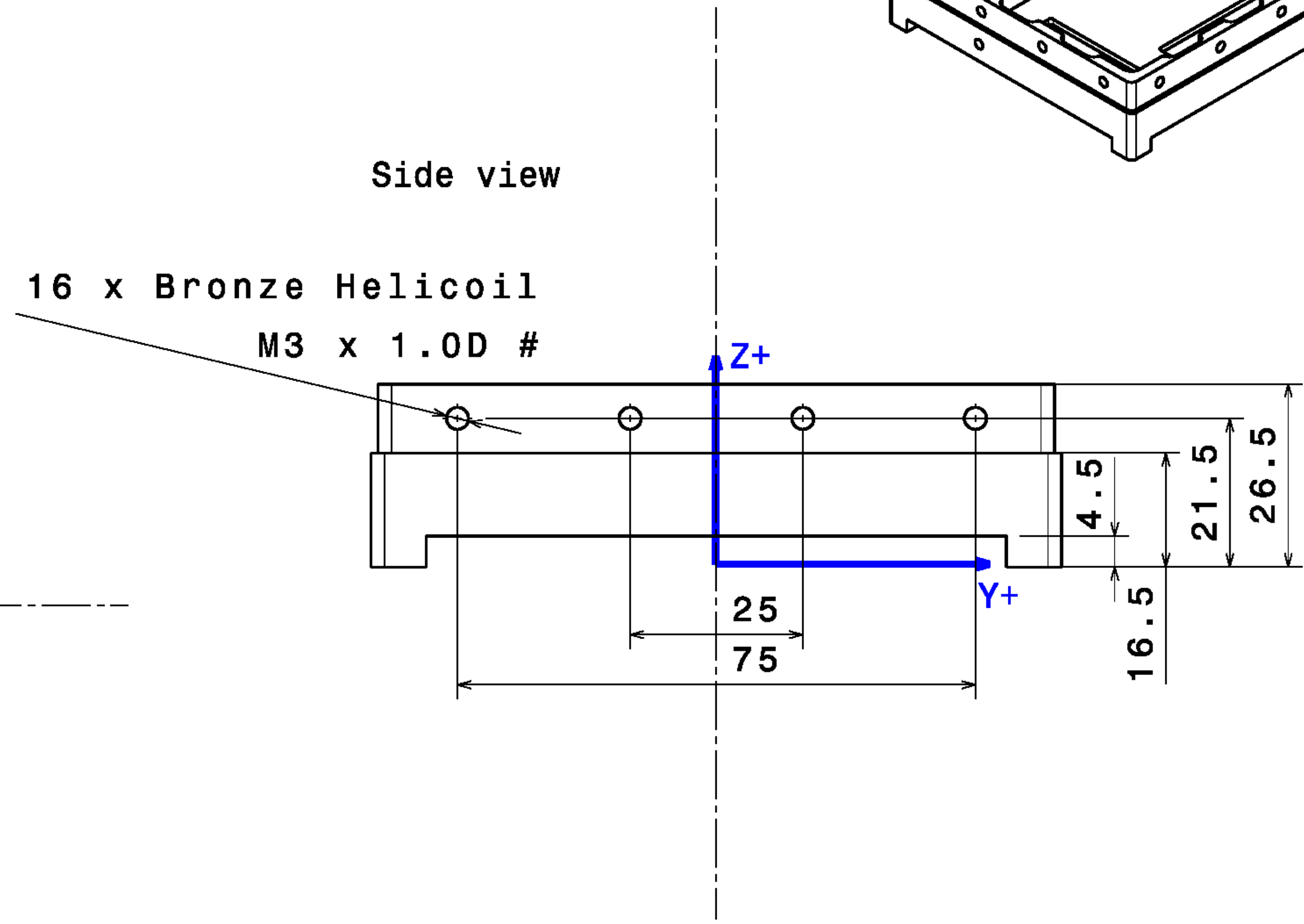
Rev	
I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	13/02/2009

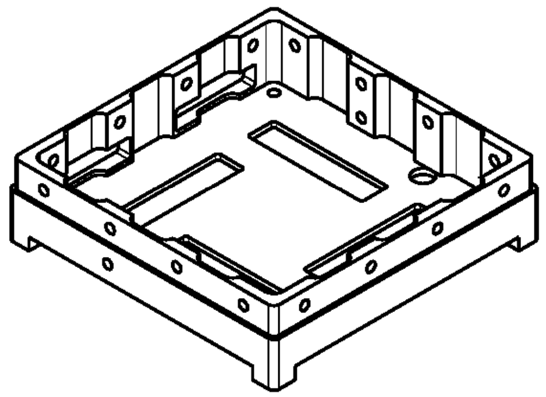
Bottom view



* Valid for all sides

Side view





Install Helicoil after surface treatment

Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Milling
Dimensions in mm	Material	Aluminium 6082 (51ST 3.2315.72)

DESIGNED BY: Jennifer Go
DATE: 13/02/2009
CHECKED BY: G.F. Brouwer
DATE: 13/02/2009

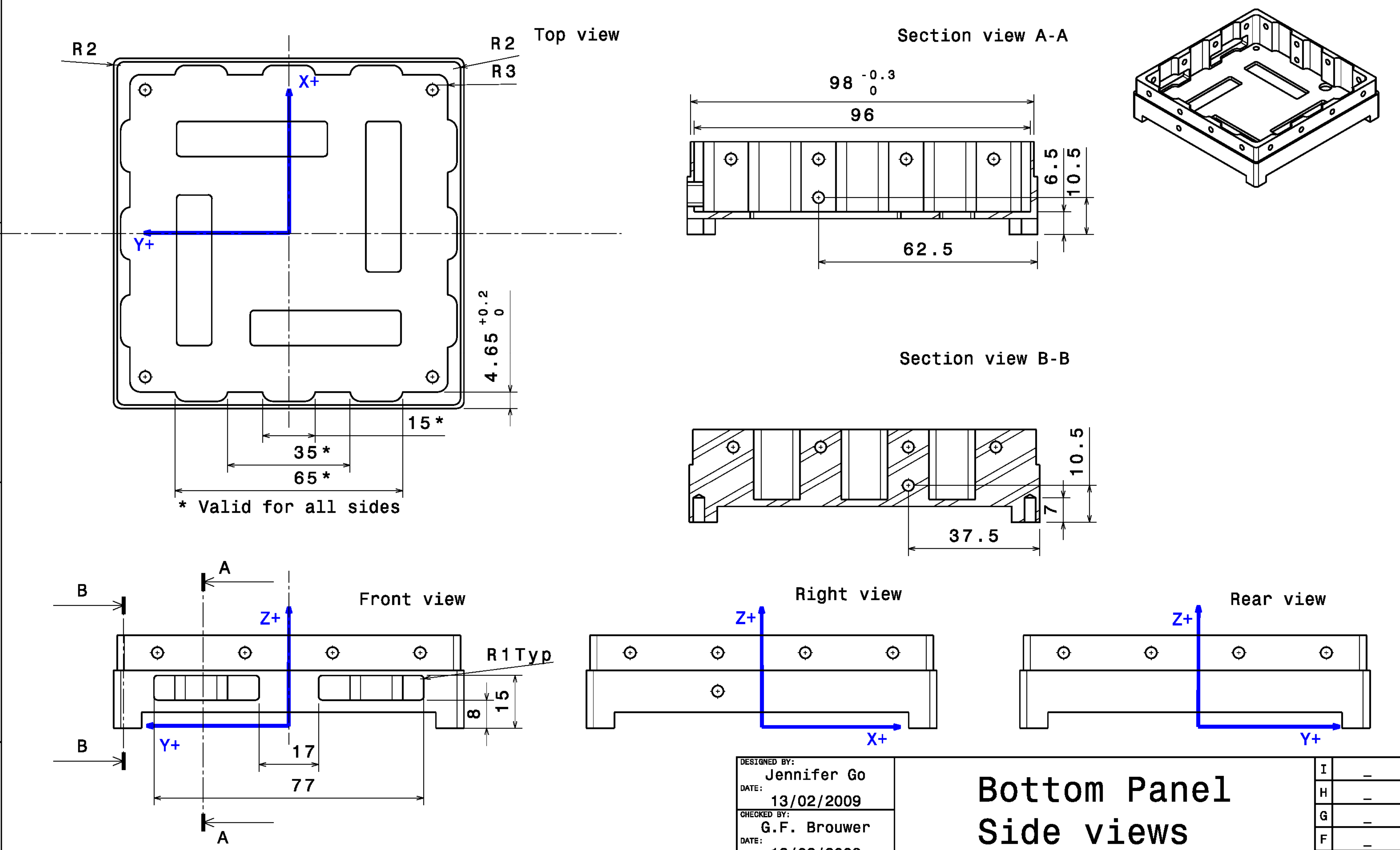
Bottom Panel

SIZE: A3

Delfi-n3Xt

SCALE	WEIGHT (kg)	DRAWING NUMBER	SHEET
1:1	0.104	DNX-11-001	1/2

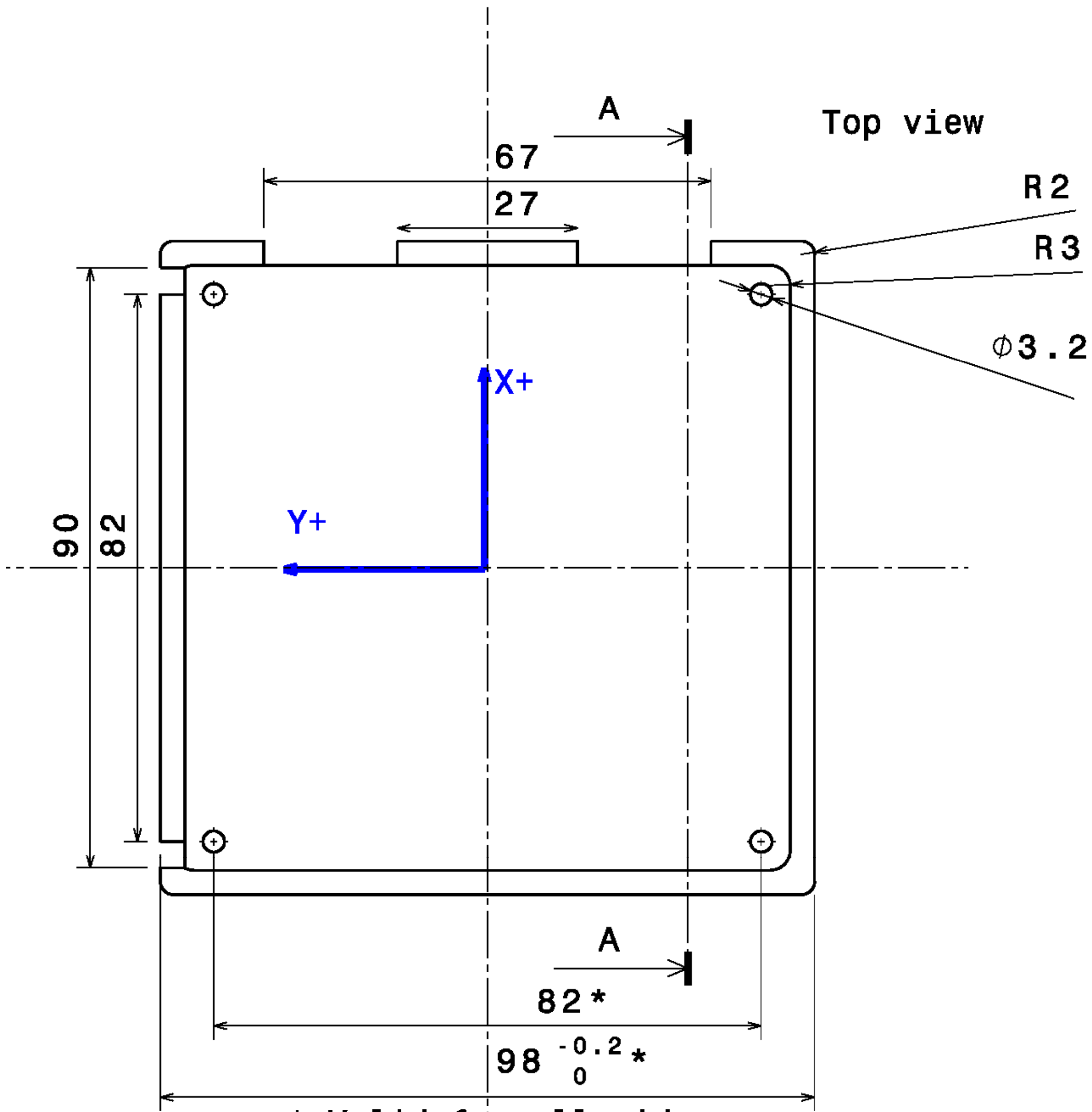
I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	13/02/2009



DESIGNED BY: Jennifer Go DATE: 13/02/2009 CHECKED BY: G.F. Brouwer DATE: 13/02/2009	Bottom Panel Side views
SIZE A3	Delfi-n3Xt
SCALE 1:1 · WEIGHT (kg) 0.104	DRAWING NUMBER DNX-11-001 · SHEET 2/2

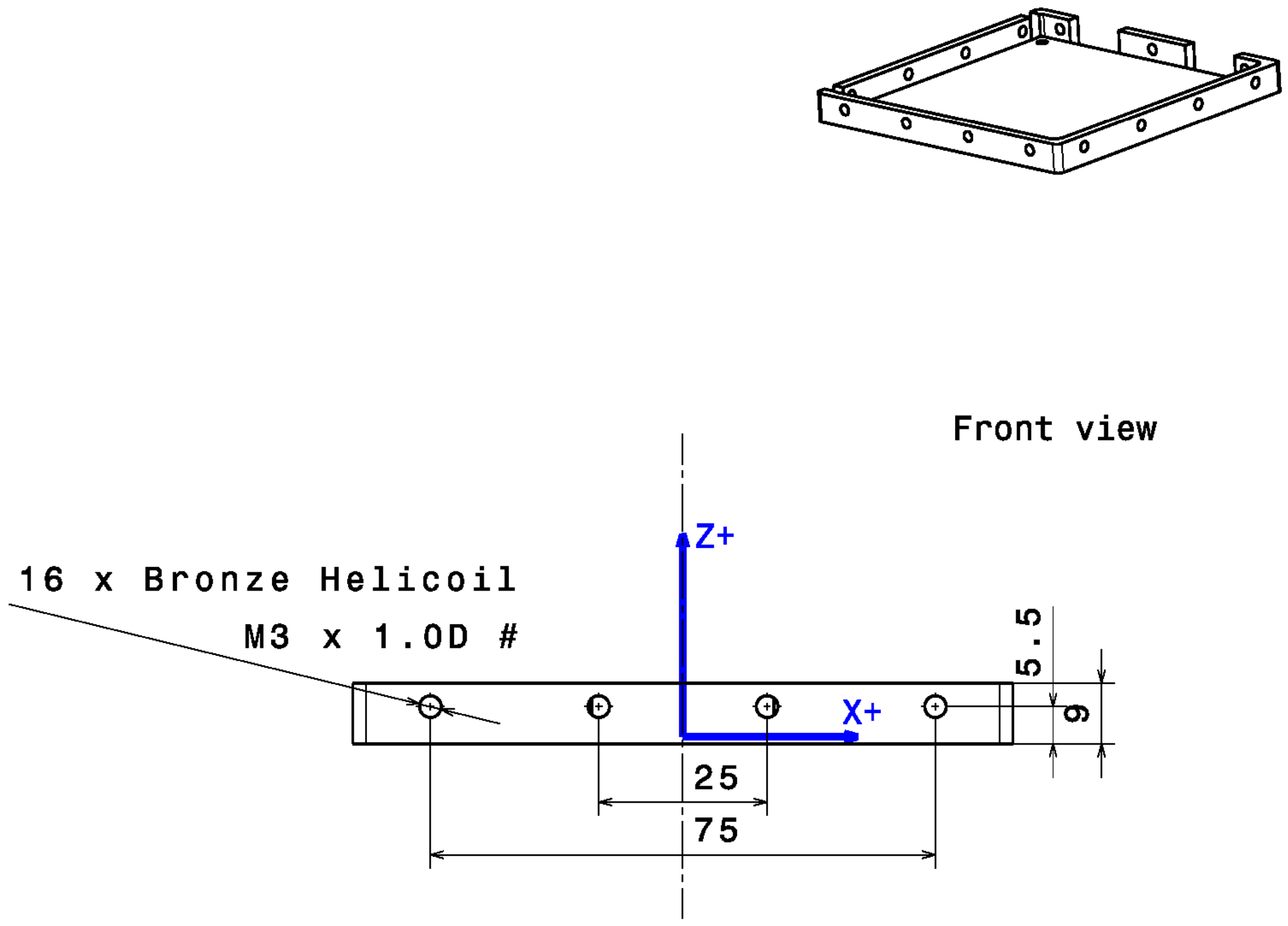
I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	13/02/2009

Top view

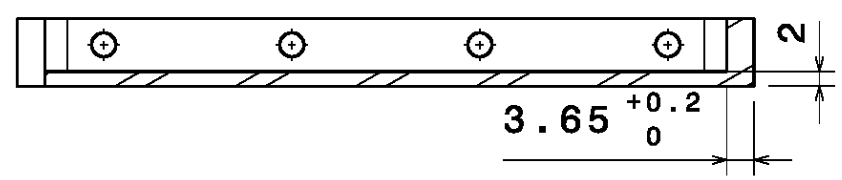


* Valid for all sides

Front view



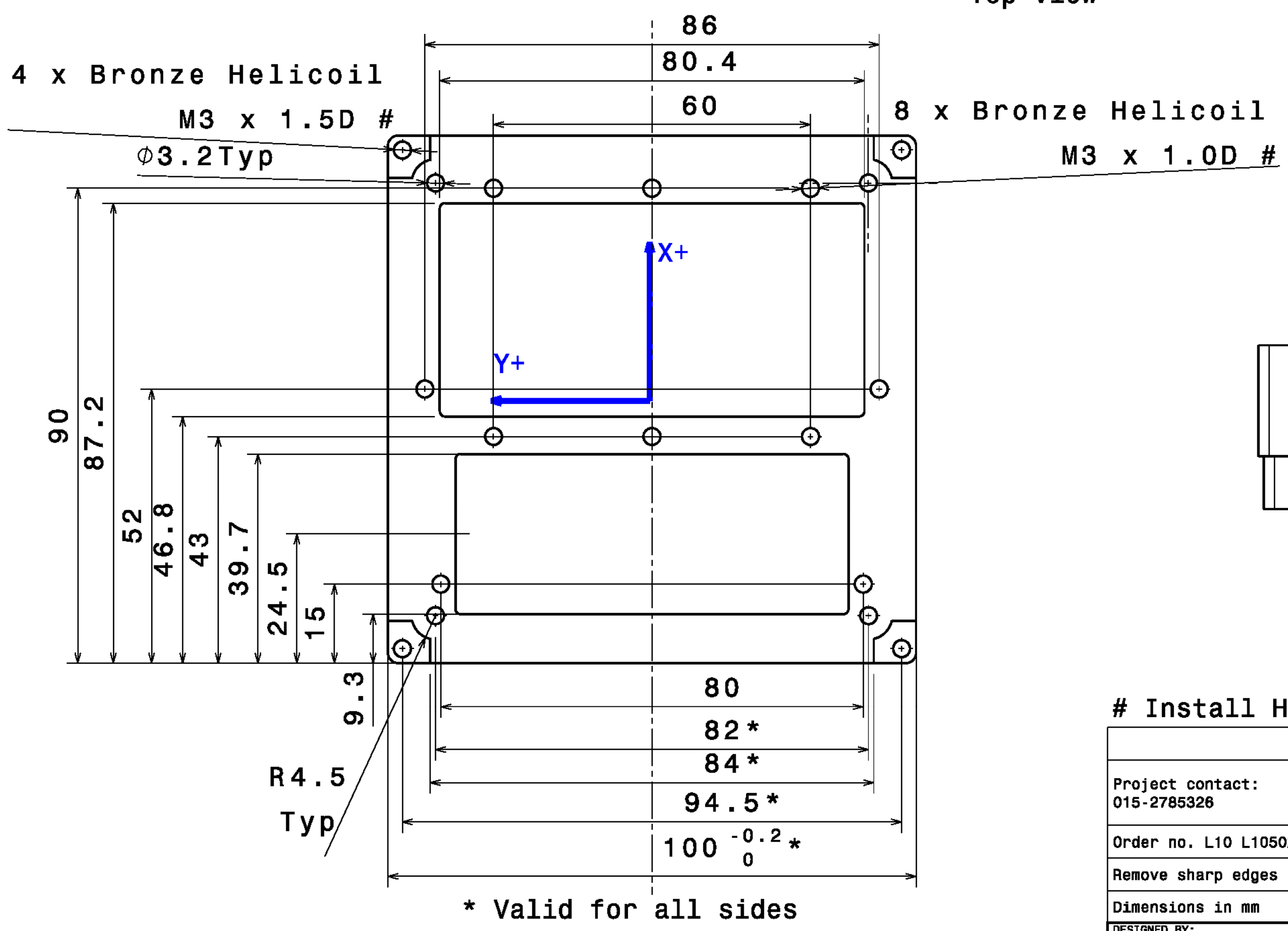
Section view A-A

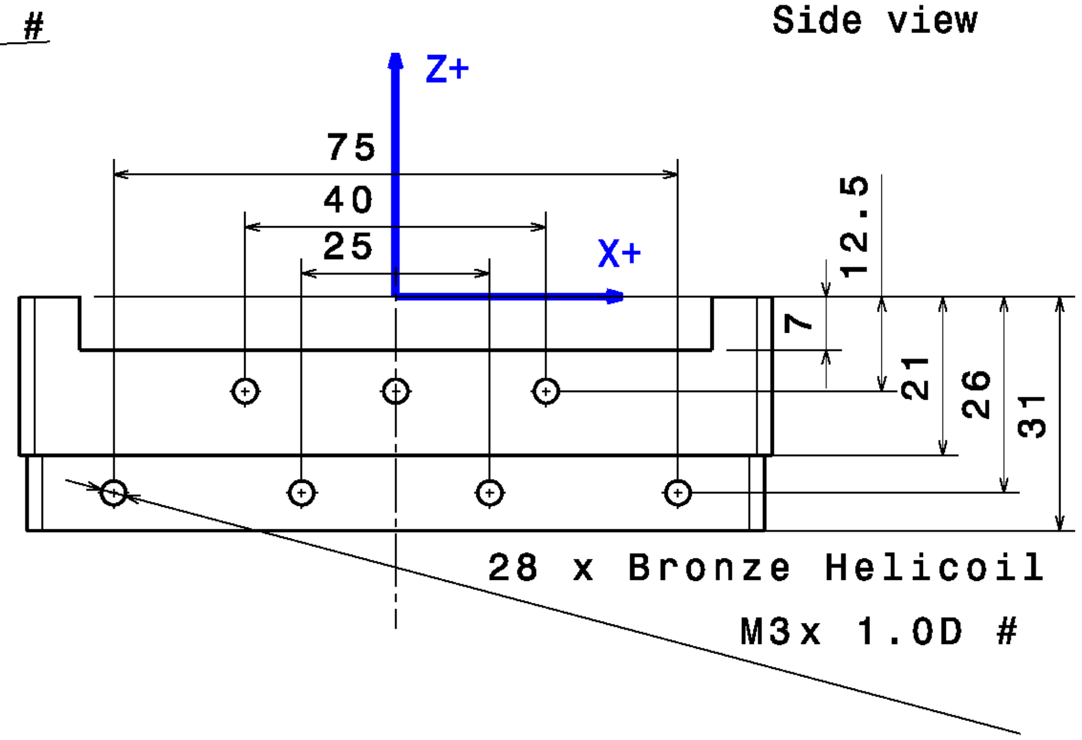


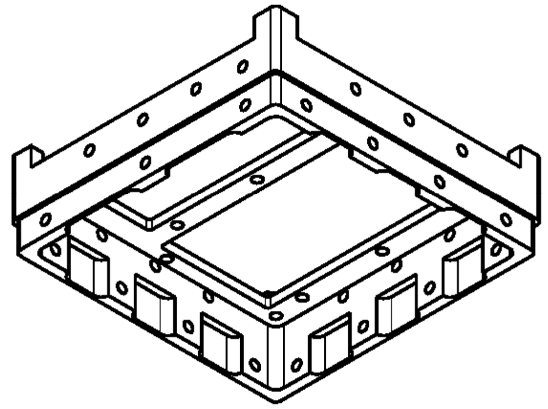
Install Helicoil after surface treatment

Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Milling
Dimensions in mm	Material	Aluminium 6082 (51ST 3.2315.72)

DESIGNED BY: Jennifer Go DATE: 13/02/2009 CHECKED BY: G.F. Brouwer DATE: 13/02/2009	Intermediate Panel			I _ H _ G _ F _ E _
SIZE A3		Delfi-n3Xt		D _ C _
SCALE 1:1	WEIGHT (kg) 0.075	DRAWING NUMBER DNX-12-001	SHEET 1/1	B _ A 13/02/2009



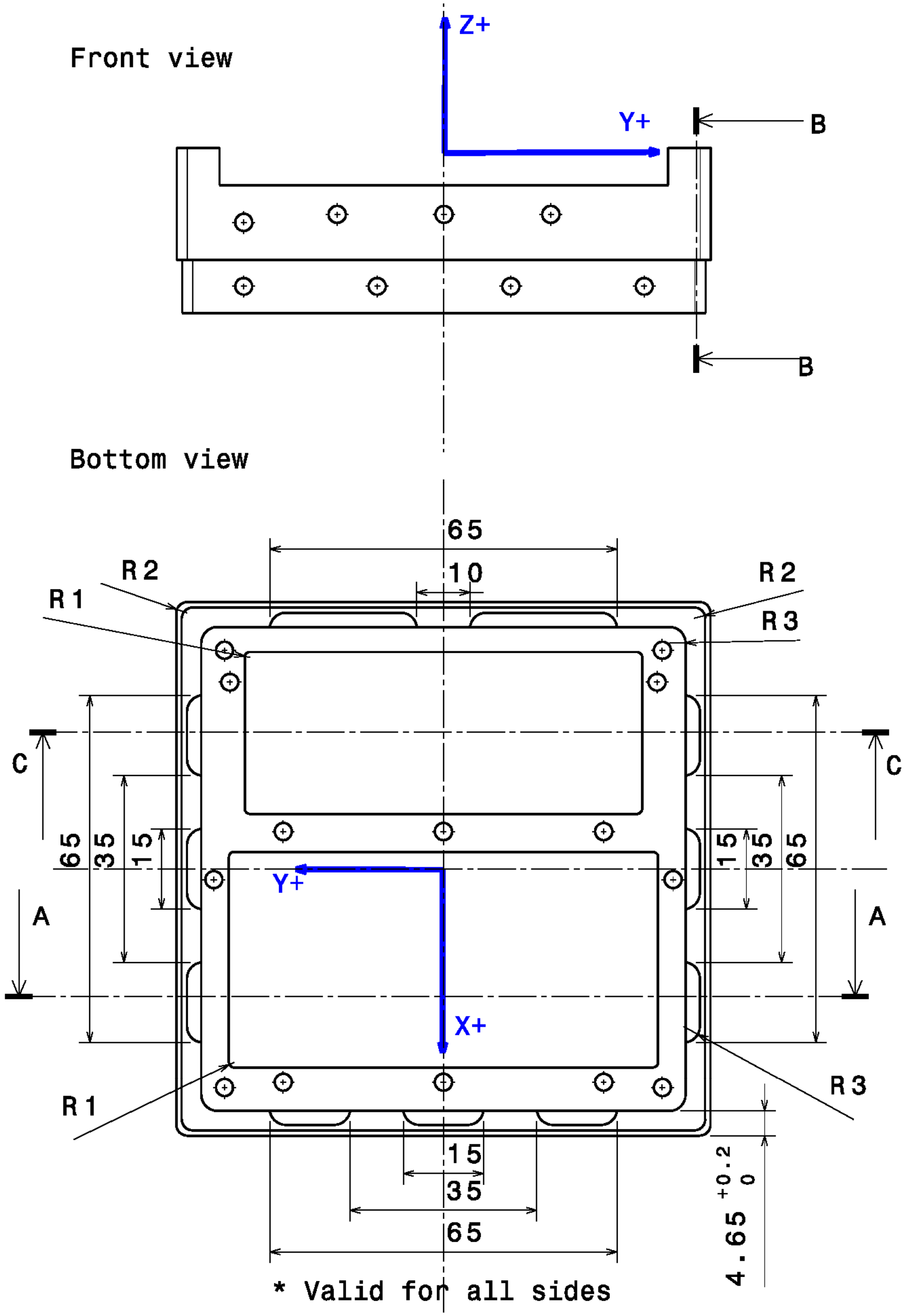


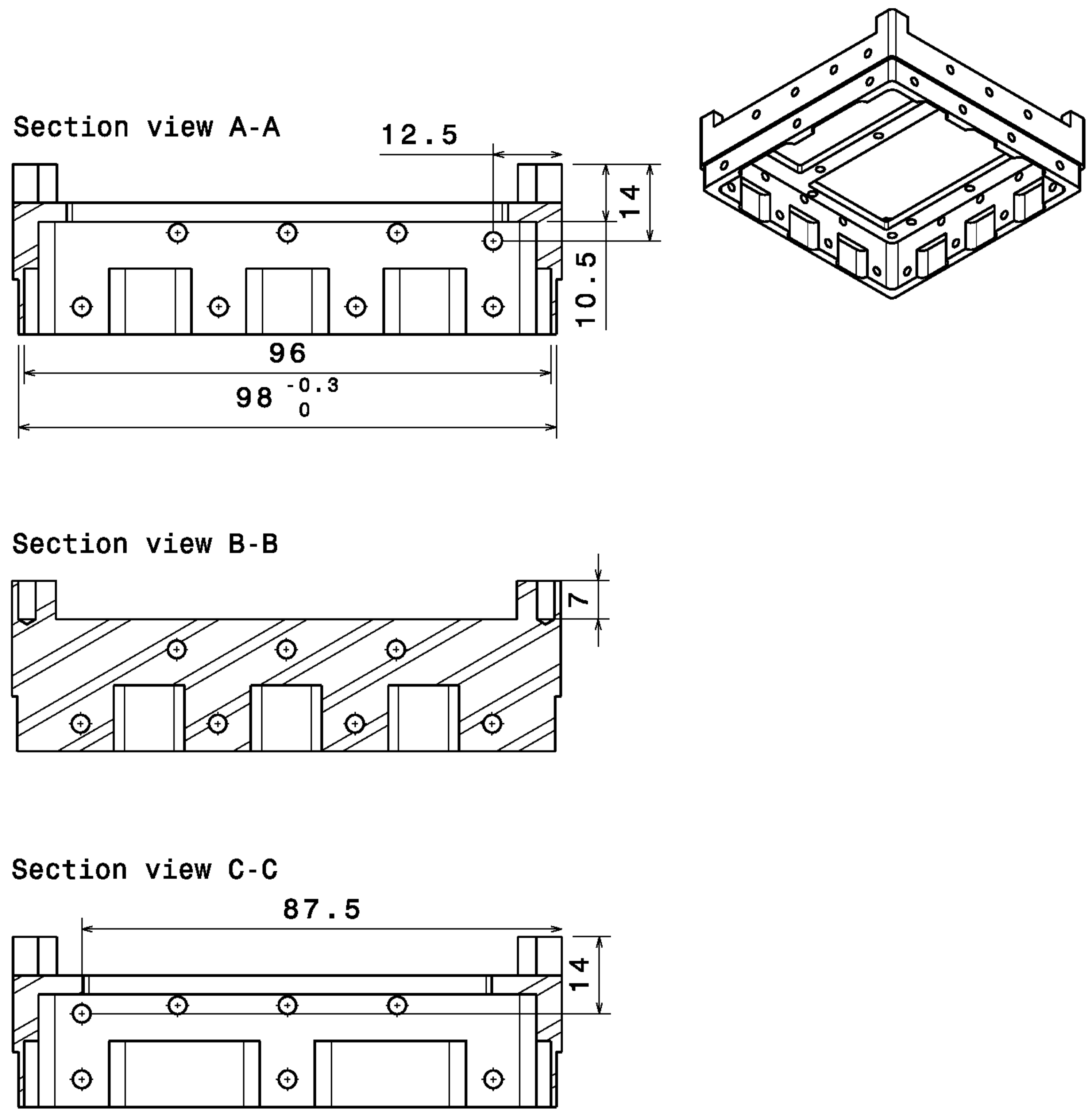


Install Helicoil after surface treatment

Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Milling
Dimensions in mm	Material	Aluminium 6082 (51ST 3.2315.72)

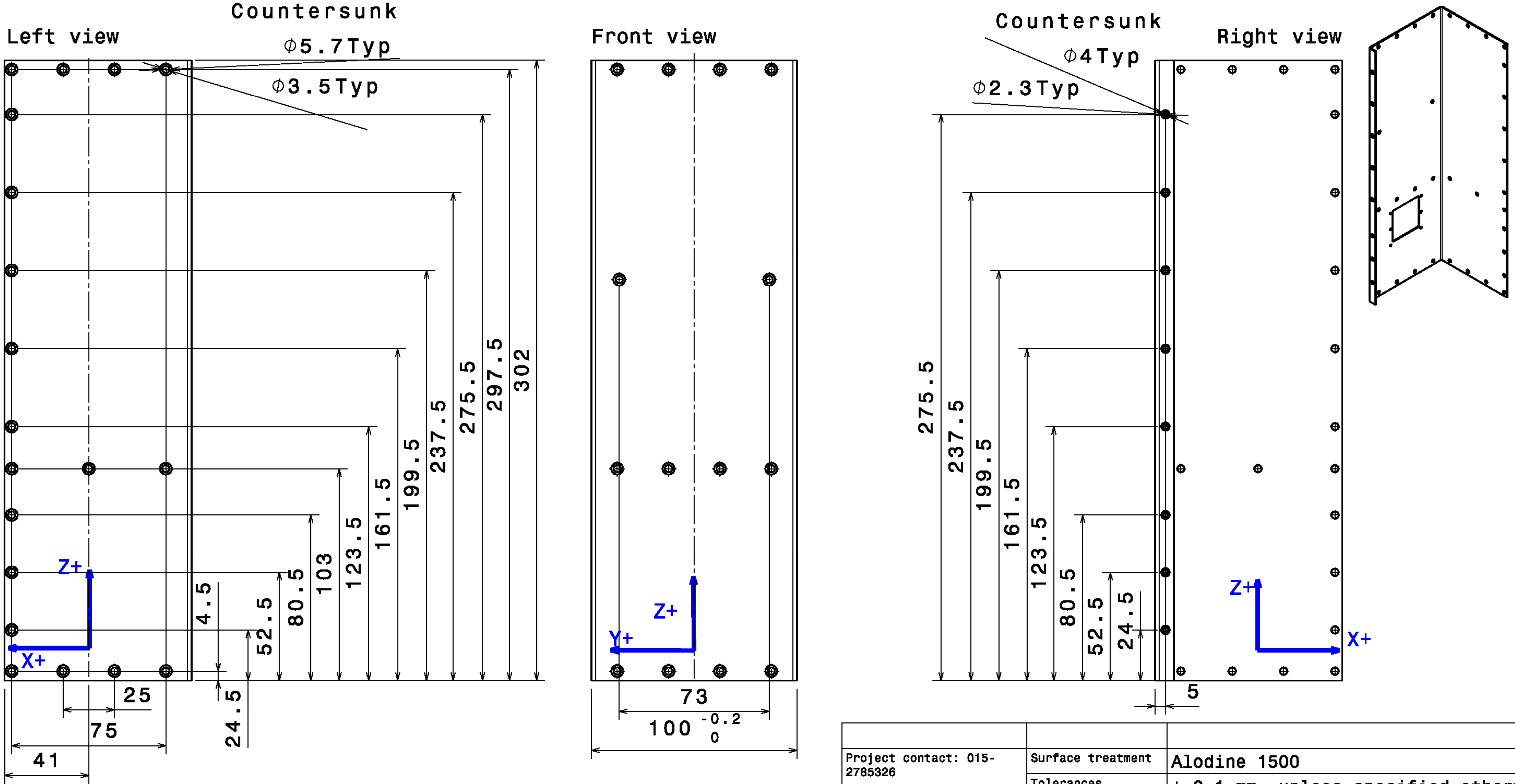
DESIGNED BY: Jennifer Go DATE: 13/02/2009		Top Panel	I	_
			H	_
CHECKED BY: G.F. Brouwer DATE: 13/02/2009			G	_
			F	_
SIZE A3		Delfi-n3Xt	E	_
			D	_
SCALE 1:1	WEIGHT (kg) 0.123	DRAWING NUMBER DNX-13-001 / SHEET 1/2	C	_
			B	_
			A	13/02/2009

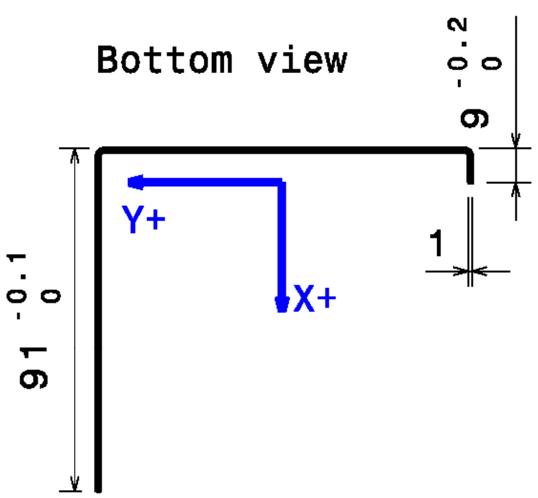




DESIGNED BY: Jennifer Go DATE: 13/02/2009 CHECKED BY: G.F. Brouwer DATE: 13/02/2009	Top Panel Side Views		
SIZE A3		Delfi-n3Xt	
SCALE 1:1	WEIGHT (kg) 0.123	DRAWING NUMBER DNX-13-001	SHEET 2/2

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	13/02/2009





Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Bending
Dimensions in mm	Material	Aluminium 5083 (D54S 3.3547.08)

DESIGNED BY: Jennifer Go
DATE: 13/02/2009
CHECKED BY: G.F. Brouwer
DATE: 13/02/2009

Unsymmetrical U

Delfi-n3Xt

SIZE		DRAWING NUMBER	SHEET
A3			
SCALE: 1:2	WEIGHT (kg): 0.166	DNX-14-001	1/1

Rev	
I	_
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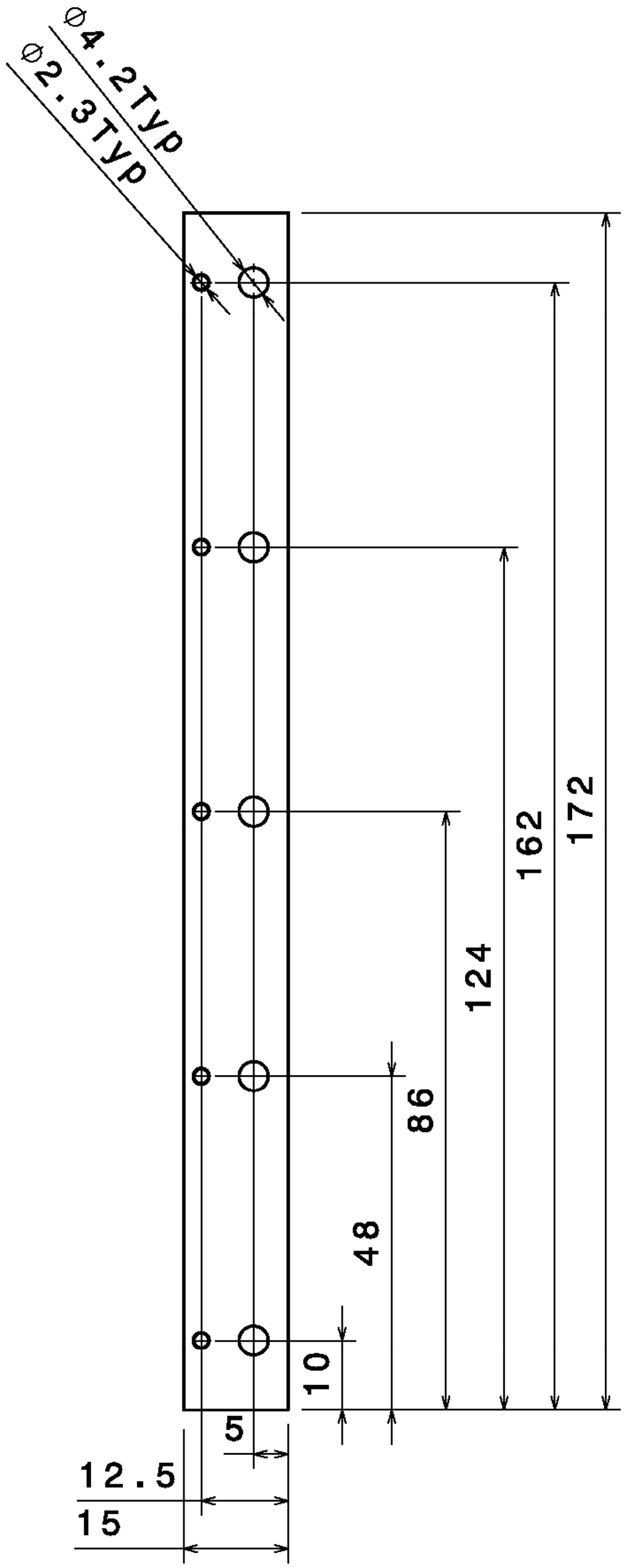
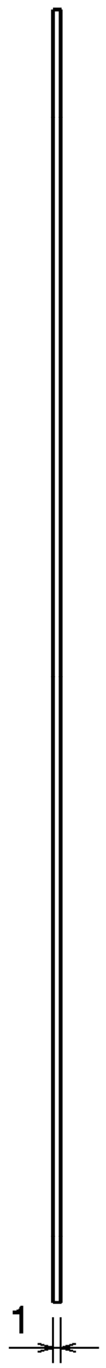
A	13/02/2009

Front view



Right view



Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Bending
Dimensions in mm	Material	Aluminium 5083 (D54S 3.3547.08)

DESIGNED BY: Jennifer Go DATE: 13/02/2009	Connection Strip Long		I _
CHECKED BY: G.F. Brouwer DATE: 13/02/2009			H _
SIZE A3		Delfi-n3Xt	G _
SCALE 1:1	WEIGHT (kg) 0.008	DRAWING NUMBER DNX-14-002	SHEET 1/1

Revision	
I	_
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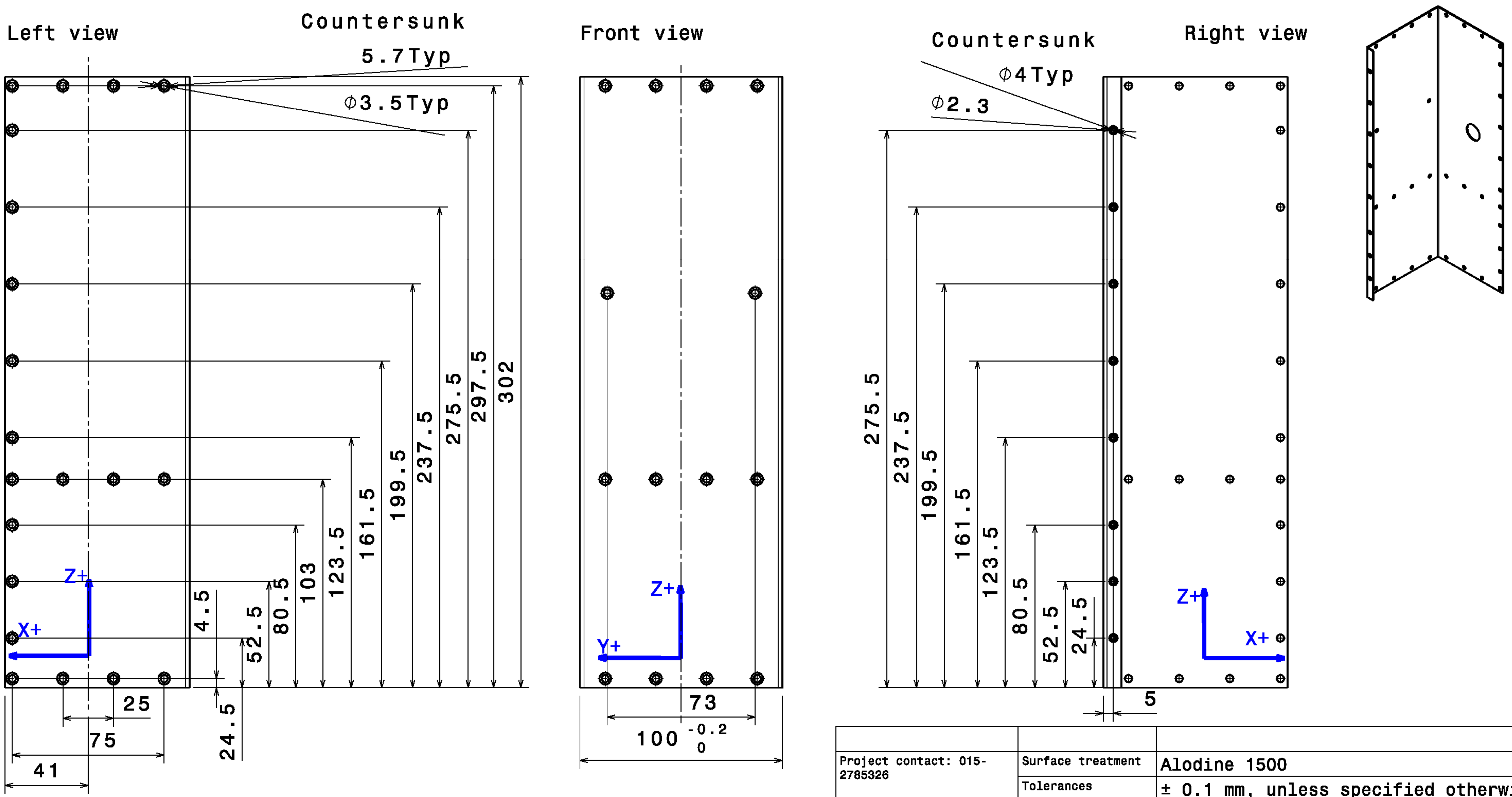
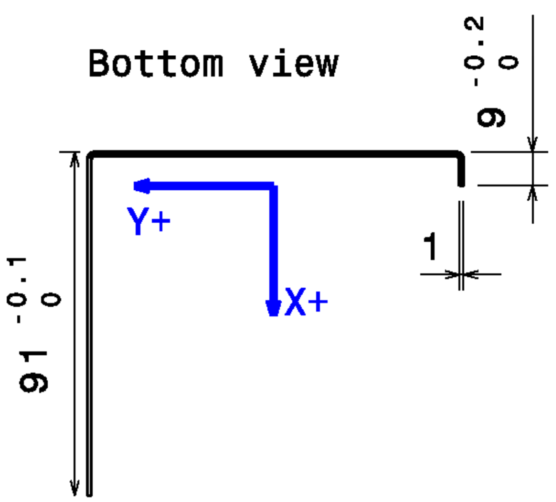
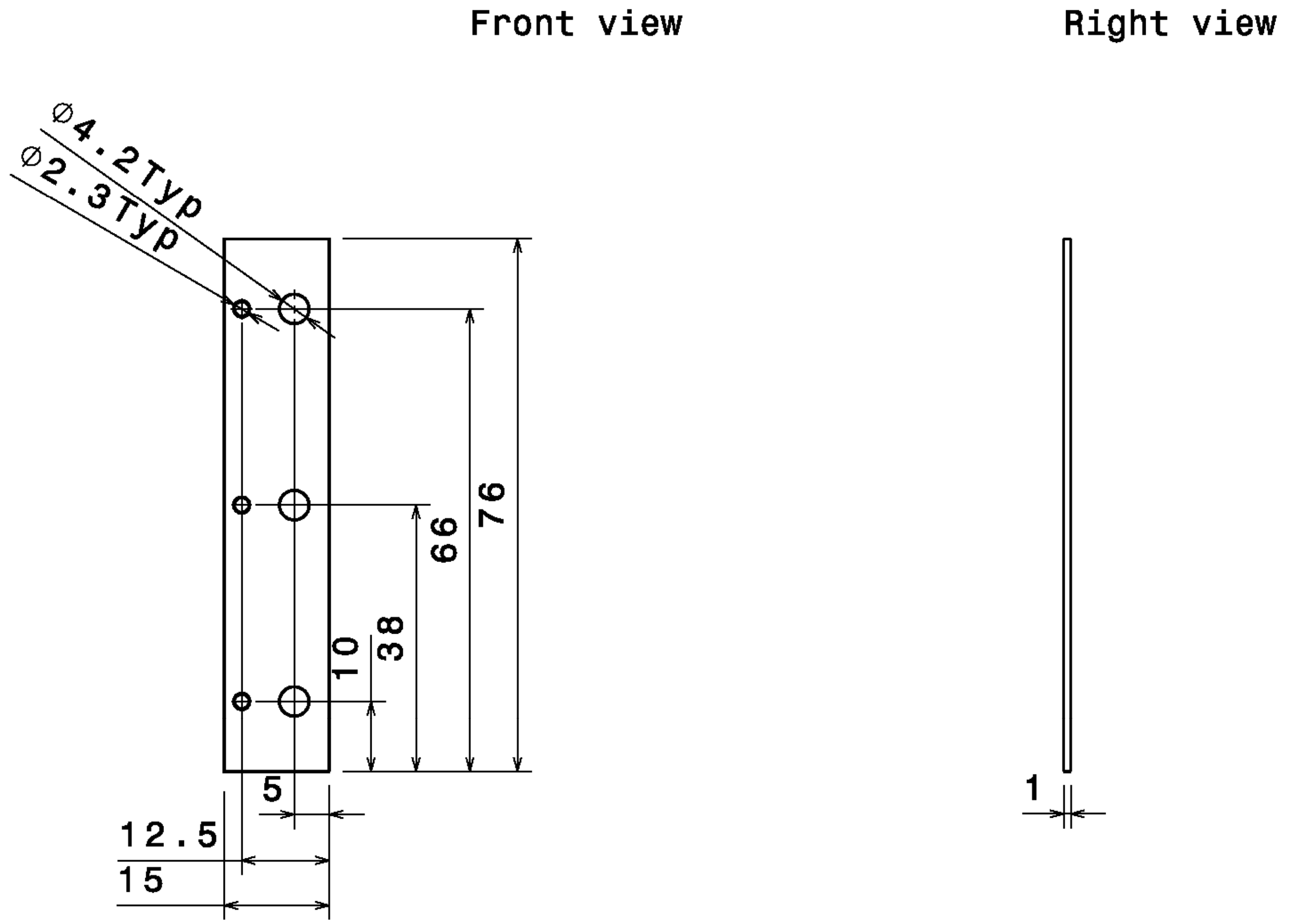
A	13/02/2009

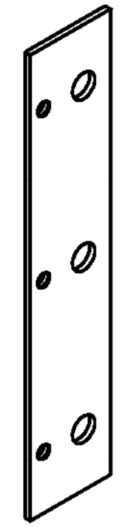




Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Bending
Dimensions in mm	Material	Aluminium 5083 (D54S 3.3547.08)

DESIGNED BY: Jennifer Go DATE: 13/02/2009		Unsymmetrical U with hole		I _ / H _ / G _
CHECKED BY: G.F. Brouwer DATE: 13/02/2009				F _ / E _
SIZE A3		Delfi-n3Xt		D _ / C _
SCALE 1:2	WEIGHT (kg) 0.165	DRAWING NUMBER DNX-14-003	SHEET 1/1	B _ / A 13/02/2009





Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Bending
Dimensions in mm	Material	Aluminium 5083 (D54S 3.3547.08)

DESIGNED BY: Jennifer Go
DATE: 13/02/2009
CHECKED BY: G.F. Brouwer
DATE: 13/02/2009

Connection Strip Short

SIZE: A3

Delfi-n3Xt

SCALE: 1:1
WEIGHT (kg): 0.003
DRAWING NUMBER: DNX-14-004
SHEET: 1/1

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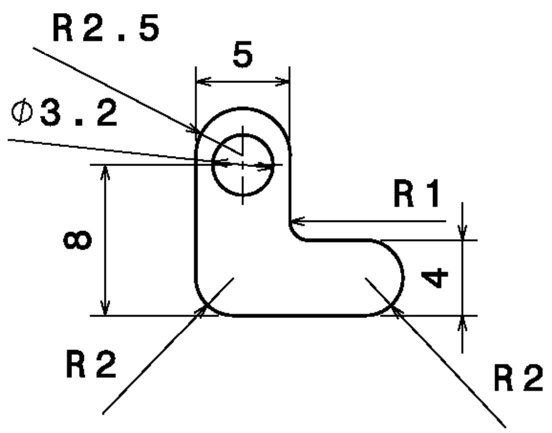
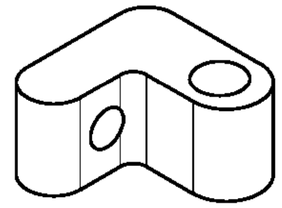
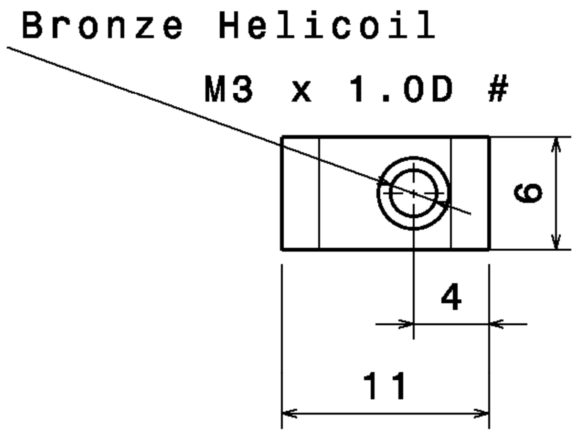
A	13/02/2009

Top view

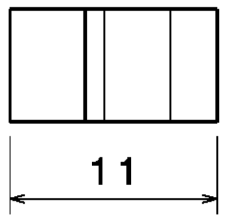




Front view



Right view



Install Helicoil after surface treatment

Project contact: 015-2785326	Surface treatment	Alodine 1500
	Tolerances	± 0.1 mm, unless specified otherwise
Order no. L10 L10502	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Milling
Dimensions in mm	Material	Aluminium 6082 (51ST 3.2315.72)

DESIGNED BY: Jennifer Go DATE: 13/02/2009 CHECKED BY: G.F. Brouwer DATE: 13/02/2009	Midplane Standoff		
SIZE A3		Delfi-n3Xt	
SCALE 20:1	WEIGHT (kg) 0.001	DRAWING NUMBER DNX-30-002	SHEET 1/1

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A	13/02/2009