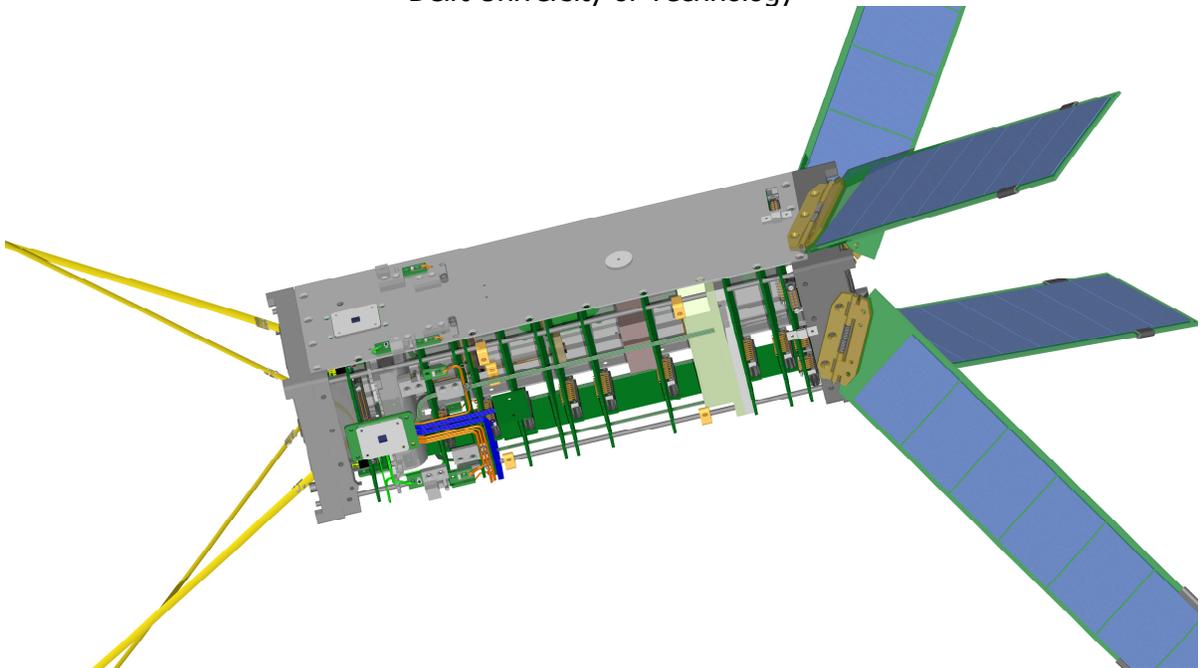


Delfi-n3Xt

Thesis Paper

Detailed design and verification of a structure and mechanisms for Delfi-n3Xt

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Preface

When I came to this faculty I wanted to learn how to design spacecraft. Later on I found astrodynamics and planetary sciences also very interesting and I decided to do the Master Space Mission Design. When I heard from a friend Tom de Groot, who was already working the Delfi-n3Xt, that I could do a thesis on designing and building a real satellite I was rapidly determined that I should work on this project, although this required a switch to the Space Systems Engineering department. The design and production of components seemed very interesting to me, so I started working as a structural and mechanical systems engineer.

I continued the work of many other students that designed the structure and mechanisms of Delfi-C3 and Delfi-n3Xt. Graduating on designing the structure and mechanisms for Delfi-n3Xt is different in many ways from a conventional thesis. First of all, there are many students working on the project simultaneously, so good teamwork is essential. Secondly, working on a project results in a lot of extra work that is not very useful for a thesis, but is necessary to finish the satellite on time. Finally the thesis is not build around a main research question, instead one gets a function. My function was to be the structural and mechanical systems engineer for Delfi-n3Xt.

The design work on the structure and mechanisms of Delfi-n3Xt is now finished and most parts were manufactured. The final assembly of the structure with all components can now be performed. I will be present regularly the coming months to help with the integration of the complete satellite.

I would like to thank my supervisor Geert Brouwer for sharing his expertise and helping with the many design issues, Jasper Bouwmeester for being always available and quickly helping with problems concerning the project, as well as the complete Delfi-n3Xt team and staff for this valuable experience.

Johan de Jong



Delft, June 6th, 2012

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Acronyms

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
PTRX	Primary Transceiver
RF	Radio Frequency
SDM	Solar cell Degradation Measurement
SLR	Standard List of References
SP	Solar Panel
STS	Structural Subsystem
STX	S-band Transmitter
TBC	To Be Confirmed
TBD	To Be Determined
TBW	To Be Written
TN	Technical Note
TOP	Top Panel
UHF	Ultra High Frequency
VHF	Very High Frequency

1 Introduction

This chapter gives an introduction into the context of this thesis paper. The Delfi-n3Xt mission, shown in section 1.2, is part of the Delfi programme which is introduced in section 1.1. The Structure and Mechanisms subsystem of Delfi-n3Xt, on which this thesis focuses, is introduced in section 1.3 together with the thesis assignment. Finally, the content and structure of this document and all attached documents is presented in section 1.4.

1.1 Delfi Programme

In order to develop a standardized space platform for academic satellite projects, the CubeSat project was started by California Polytechnique University and Stanford University in 1999. Since then, over 60 universities have joined the CubeSat project, developing nano-satellites with scientific payloads. A standard CubeSat is a 10 cm cube with a mass up to 1 kg often called a "1U" CubeSat meaning one unit. Larger CubeSats were also designed, such as a "2U" Cubesat (20x10x10 cm) and a "3U" CubeSat (30x10x10 cm). The CubeSat specification has the following goals:

- Simplification of satellite infrastructure: Makes it possible to design and produce a workable satellite at low cost.
- Encapsulation of launcher-payload interface: Takes away the prohibitive amount of managerial work that would previously be required for mating a piggyback satellite with its launcher.
- Unification among payloads and launchers: This enables quick exchanges of payloads and utilization of launch opportunities on short notice.

The Delfi programme was started by the TU Delft in 2004; to develop, build and launch CubeSats on a regular basis. The Delfi programme has three objectives: [SLR 0136]

- Educational Objective: The Delfi programme will provide students an optimal education and preparation for careers in space industry. Theoretical as well as more practical thesis's can be performed; gaining in-depth knowledge and expertise complemented with improvement of team skills, hands-on experience and management skills. The educational objective will be the main driver for Delfi projects and mission success will mostly be based on this objective.
- Technology Demonstration Objective: The technical objective is to perform testing and qualification of a miniaturization of existing space technology, integration of several components into one package or completely new technologies for space applications.
- Satellite Bus Development Objective: The development objective is to advance the nano-satellite platform for each satellite project, adding a long-term vision for the development. It will enable the TU Delft to gain more expertise, higher performance and more functionality for new payloads and scientific experiments with demanding satellite bus requirements.

Delfi-C³ is the first nano-satellite program from the TU Delft. It is currently more than 1400 days in space and is still operational. It demonstrated three payloads: four arrays of Thin Film Solar Cells (TFSC) from Dutch Space, two Autonomous Wireless Sun Sensors (AWSS) from TNO and a Radio Amateur Platform (RAP) from TU Delft. A nano-satellite spacecraft bus and a ground segment were developed for Delfi-C³. The heritage of Delfi-C³ is thoroughly used for the development of the second nano-satellite of TU Delft: Delfi-n3Xt.

1.2 Delfi-n3Xt

Delfi-n3Xt will be a three unit CubeSat with three payloads of external partners and a demonstration of an attitude determination and control system. The educational goal is to facilitate at least 20 MSc theses and 10 BSc interns. The following technology demonstrations are present in Delfi-n3Xt:

- Pre-qualification of a micro-propulsion system from TNO, TU Delft and UTwente (T³μPS)
- Scientific Radiation Experiment of Si-solar cells from DIMES.
- Qualification of a high-efficiency communications platform from ISIS BV.

Delfi-n3Xt will advance the platform by:

- Implementation of a three-axis active attitude control
- Providing high data-rate S-band transmitter
- A single-point-failure-free EPS with energy storage

1.3 Structure and Mechanisms of Delfi-n3Xt

Since too many modifications were necessary and Delfi-C³ encountered difficulties during assembly, Delfi-n3Xt uses a custom designed structure instead of a Commercial-off-the-Shelf structure as used for Delfi-C³. The mechanisms of Delfi-n3Xt consist of the antennae and solar panels which will be deployed in orbit on internal command. A preliminary design of the structure and mechanisms was already made [SLR 0604]. The objective of this thesis is a detailed design and verification of a structure and mechanisms for Delfi-n3Xt.

Thesis assignment

The thesis assignment is to perform systems engineering, detailed (re-)design and testing of the structural and mechanisms subsystems and facilitate the production of the components. The systems engineering comprises of maintaining volume and mass budgets on the entire satellite, define the placement and structural interfaces of all subsystems and perform trade-offs when required. Structural stress analysis should be performed at parts and points which deemed critical, but it is expected to be limited. Special attention should be paid to manufacturability, tolerances, handling, etc. Parts must be assembled and verified if it complies with the requirements and design and results should be reported. Since Delfi-n3Xt is heavily integrated with many payloads and subsystems, interaction is required with other system engineers and industry partners with respect to interfaces and volume.

1.4 Document structure

All project documentation for Delfi-n3Xt is organized with a Standard List of References (SLR) indicated with SLR numbers in the text. All project documentation produced by the author is attached to this document in appendices, which is the core of the thesis work. This thesis paper gives a summary of the performed work.

Chapter 2 shows the work performed on the design of the structure. Chapter 3 summarizes the redesign of the mechanisms. An overview of the evolution of the budgets and the current status are given in chapter 4. The thesis finishes with the conclusions, recommendations and lessons learned in chapter 5.

2 Design of Structural Subsystem

Delfi-n3Xt has a custom designed structure instead of a Commercial-off-the-shelf structure as used for Delfi-C³. The structure of Delfi-C³ needed modifications to the structure for accessibility and encountered difficulties during assembly, integration and testing. Therefore the structure of Delfi-n3Xt is optimized for quick integration and removal of subsystems and components. The structure is based on the design and dimensions of a three-unit CubeSat and accommodates the mounting of components onto the main support structure. The structure is designed to withstand the applied loads by the natural and induced environments to which it is exposed during its complete lifetime (manufacturing, assembly, testing, transport, launch, operations). A detailed report on the design of the structure is attached to this document [SLR 0169].

Throughout the project budgets are used for communication within the project team and with external partners on mass and volume constraints and wiring interfaces. More information about budgets can be found in chapter 4. In addition a complete design drawing was created in Catia to give a visual representation of the latest state of Delfi-n3Xt [SLR 0633]. To avoid interchanging of parts each part in Delfi-n3Xt has a unique part number and name. The structure of the part numbers is shown in the Structural Hardware Breakdown [SLR 0476].

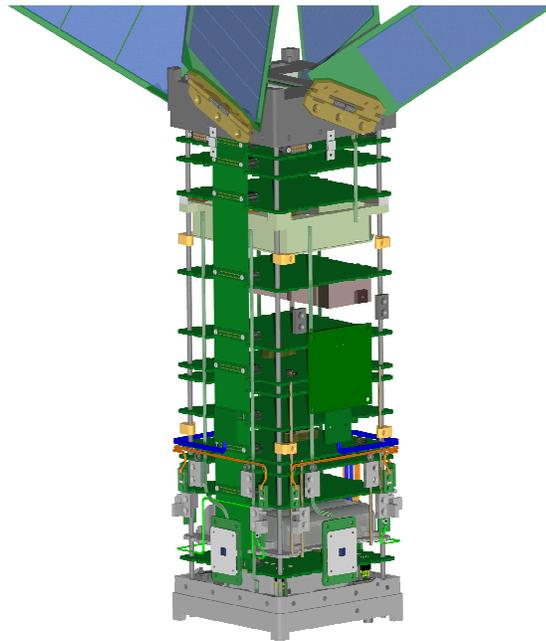


Figure 2-1: Delfi-n3Xt design drawing

The Delfi-n3Xt structural subsystem consists of a Bottom Panel (BOP), Top Panel (TOP) and an outer structure. The outer structure consists of two U-profiles of 1 mm thick aluminium sheet, connected with two connection strips. Together these components form a rigid structure which acts as the backbone of the satellite. Inside this structure there is a stack of PCBs containing all subsystems. The work performed on the structure, stack and other components is summarized below.

The solar panel configuration was changed for Delfi-n3Xt, resulting in a redesign of the complete solar panel assembly, as explained in chapter 3. Additionally, there were a lot of changes in subsystems placing and mounting, therefore all access and mounting holes on the structure were revised.

The wires between the various subsystems need to be fastened to the stack to constraint their movement due to launch vibrations. These wires are tied to the stack with a small piece of string through small holes on

little bulges on the PCBs. A standard PCB was developed with these tie-points which are used by all subsystems of Delfi-n3Xt. In this way all subsystems can change position and can also be used in future missions.

Delfi-n3Xt will have an identical sun sensor on the TOP, BOP and each side of the U-profiles. A sun sensor housing was designed as small as possible such that it can be placed in the limited space under the solar panels.

The Deployable Antenna Board (DAB) design has influence on the BOP and the Hold Down and Release Mechanism (HDRM), because both the MABs (that protrude through the BOP) and the HDRM connectors are placed on the DAB. Therefore the placement of the MABs and the connectors on the DAB was done by the author.

The subsystem PCBs are electrically connected with a flex-rigid PCB. When the final placement of all subsystems was known the required length of the flexible parts was calculated and a design drawing of the flex-rigid PCB was made.

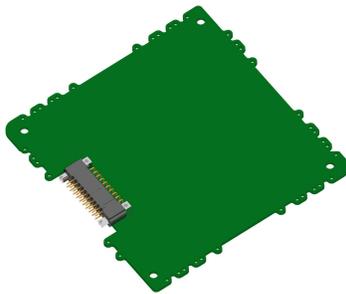


Figure 2-2: Standard PCB

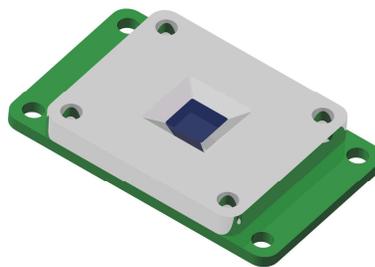


Figure 2-3: Sun Sensor

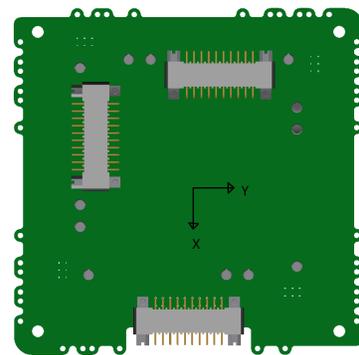


Figure 2-4: DAB

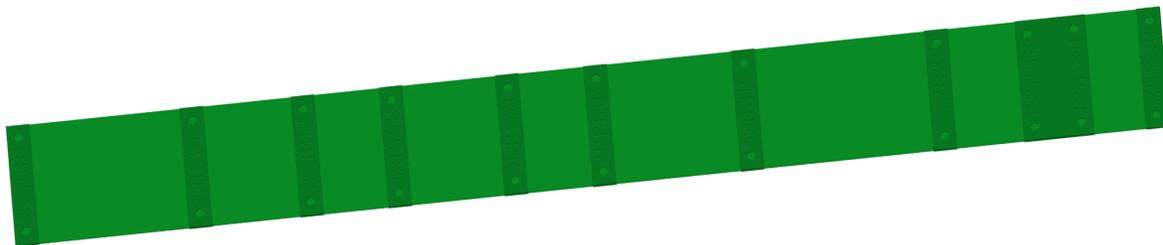


Figure 2-5: Flex-rigid PCB

2.1 Verification analysis and tests

For quasi static loading on component level a load factor of 25g was used; based on the 3σ value of random loads generated by the DNEPR launcher.

The minimal preferred margin is 2 mm between each subsystem PCB. There is a possibility that the subsystems damage each other due to bending of the PCBs during launch, therefore calculations were done for the deflection of a PCB during worst case vibration. A test was performed to validate these calculations and a comparison was made [SLR 0991]. With a design load of 25g, the deflections are 0.40 mm for a concentrated mass of 140 grams at the midpoint of the PCB and to 0.16 mm when the mass is evenly distributed. It can be concluded that the minimum margin of 2 mm between the PCB's in the stack is a safe margin and is recommended for Delfi-n3Xt and future missions.

Calculations on buckling and compression failure of the structure showed that compression failure is the critical failure mode of the structure. The critical load until compression failure will be 7.8 kN and the highest applied load during launch will be 309 N. Comparing these two loads shows that the structure can withstand

the launch loads easily. A finite element model of the complete structure was developed by [Boersma and Vielvoye, 2009]; showing that the highest loads in the structure due to static and dynamic loads were in the order of 1 MPa, which is well below the yield strength of 195 MPa. The structure has changed since then, but in a favourable way. The large holes of the MPS were replaced by smaller holes of the sun sensors and STX, increasing the strength of the structure. As both the calculations and the finite element model show that the launch loads can be easily sustained by the structure, no more strength calculations were necessary. The natural frequency of the launcher is 20 Hz. The natural frequency of Delfi-n3Xt has to be higher to avoid interference. The lateral and longitudinal natural frequencies of the structure are 483 and 833 Hz respectively, which is well above the minimum required frequency of 20 Hz in each direction.

2.2 Integration and testing

An integration plan for the complete satellite was written to ensure that the integration will be done correctly and no components will be damaged. Before the satellite can be launched, the satellite needs to undergo several tests as prove that the requirements are met. The tests that are important for the structure are the following: A geometry check is needed to ensure that the dimensions are within the specified range. A centre of mass measurement both in stowed and deployed configuration is needed to ensure that the microthruster ($T^3\mu PS$) nozzle is positioned at the centre of mass. A vibration and shock test will be performed to prove that the structure has enough strength and stiffness to survive the launch.

3 Design of Mechanical Systems

After a changed solar panel configuration, designed by Johannes Bürkle [SLR 0863], a complete redesign of the solar panel and its deployment was needed; consisting of solar panels, hinges and Hold Down and Release Mechanism (HDRM). A detailed report on the design of the mechanisms is attached to this document [SLR 0572].

3.1 Design of Solar panels

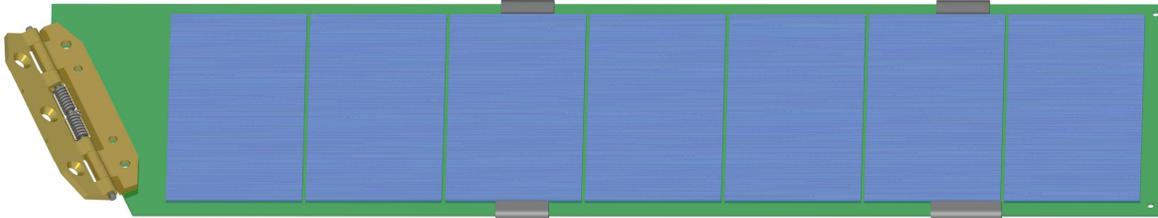


Figure 3-1: Hinge solar panel assembly

The solar panel must hold seven solar cells and a temperature sensor at each side. As the panel has solar cells on both sides, there is not much space left for wiring, therefore a PCB is chosen as solar panel substrate such that all wiring can be integrated in the PCB. The electrical design was done by Sven-Erik Haitjema [SLR 0946].

The stiffness of the PCB solar panel substrate is far lower than the original substrate of Carbon Fiber Reinforced Plastic (CFRP). Calculations on the deflections of the solar panel due to launch vibrations pointed out that the deflections were too high and the solar cells would hit the launch POD or the structure. However, there were some effects that were difficult too include in the model used for the calculations, but could increase the stiffness of the solar panel considerably. Therefore stiffness tests were performed on a solar panel without solar cells and on a solar panel with dummy cells. The result was that the solar panel with dummy cells has 40% more stiffness compared to the bare FR4 solar panel [SLR 0996]. However, this is still not enough to reduce the deflections to an acceptable level. An extra part (which is the same as at the supports near the end of the panels, see Figure 3-1) is glued to the middle of the panels (where the deflection in the largest) to protect the solar cells.



Figure 3-2: Bending test on solar panel PCB with dummy solar cells

Calculation of the natural frequency of the solar panel resulted in a natural frequency of 26 Hz, which is barely above the minimum required frequency of 20 Hz. As the accuracy of the calculations was uncertain, a test was done to give a more accurate result. From the test can be concluded that the solar panel natural frequency is 39 Hz, at a safe margin above the minimum required frequency. The calculations were inaccurate because the shape of the solar panel and the supports deviate too much from a standard case. The solar panel wires are soldered at the solar panel and attached with a connector to the EPS through a hole in the U-profiles. The wires are folded in a large S-bent under the solar panel such that there is enough wire length in deployed configuration. Special wire clips were designed to attach the wires to the solar panel and to the U-profiles, such that the wires stay in the right position and no stress develops at the connections.

3.2 Design of hinges

New hinges were needed to deploy the solar panel at the right angle. The old design with the hinge attached at the top of the TOP could not longer be used, because the new hinge must also be placed under an angle. Therefore the new hinge is attached at the side of the TOP.

The hinges of the old design were already produced in the workshop. In a first approach there was looked at redesigning only one part of the hinge, such that one part of the old design could be used, thereby saving time and costs. After a design made in Catia it became clear that this would lead to a design with too less material left for holding the hinge in the right position; making the hinge too weak and the deployment angle inaccurate.

Therefore a completely new hinge was designed. In the new design the hinge locks against the structure when fully deployed. The hinges were tested together with the dummy solar panel and HDRM. The hinges deploy very smoothly and work as intended.

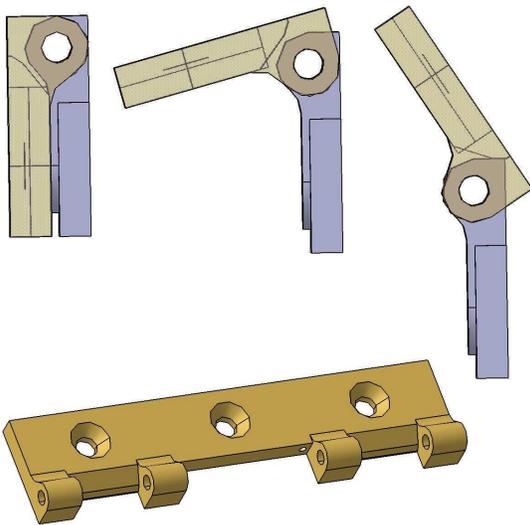


Figure 3-3: Initial redesign of hinge part

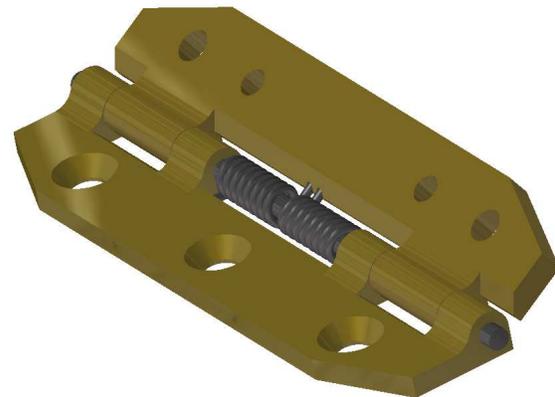


Figure 3-4: Final hinge design

3.3 Design of HDRM

The HDRM had to be redesigned because of the following reasons:

- Due to the solar cells on both sides of the solar panel, the solar panel can only be supported at the sides.
- The metal film resistors used as thermal knives in Delfi-C3 have an uneven heating of the surface of the resistors, which requires a time consuming test to locate the hot spot for each resistor. Therefore Delfi-n3Xt uses surface mounted resistors (SMD), avoiding this problem.

- The old support block leads the Dyneema wire under the support block, making the installment of the Dyneema wire difficult.

Three types of SMD resistors were tested and the one with the best performance was selected. New HDRM parts were designed in Catia and manufactured at the workshop of the TU Delft.

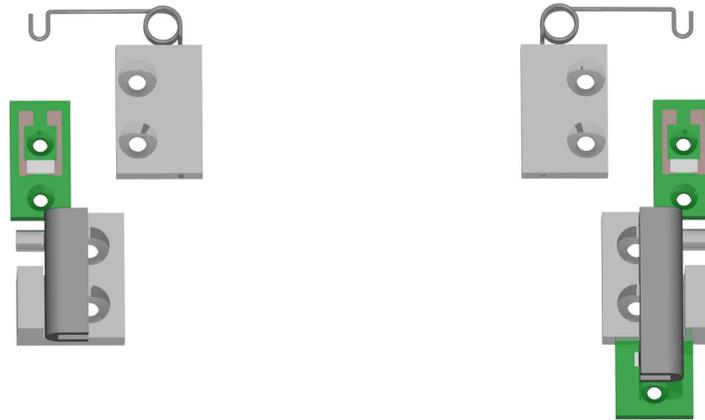


Figure 3-5: new design HDRM

3.4 Deployment tests

Since deployment of the solar panels is critical for the mission's success, the HDRM is very important for Delfi-n3Xt. Therefore the HDRM was tested at room temperature and at the lowest and highest temperature expected at the start of the mission. The result was that the solar panel deploys after three seconds at 85 °C, after five seconds at 23 °C and after five seconds at -35 °C. The deployment time is rather consistent at a given temperature. The panel deploys within the required 15 seconds with a high margin. Both resistors are tested more than 40 times and they do not show any deterioration in performance. It can be concluded that the HDRM fulfills its requirements and works as intended. The test report is attached to this document [SLR 1008].

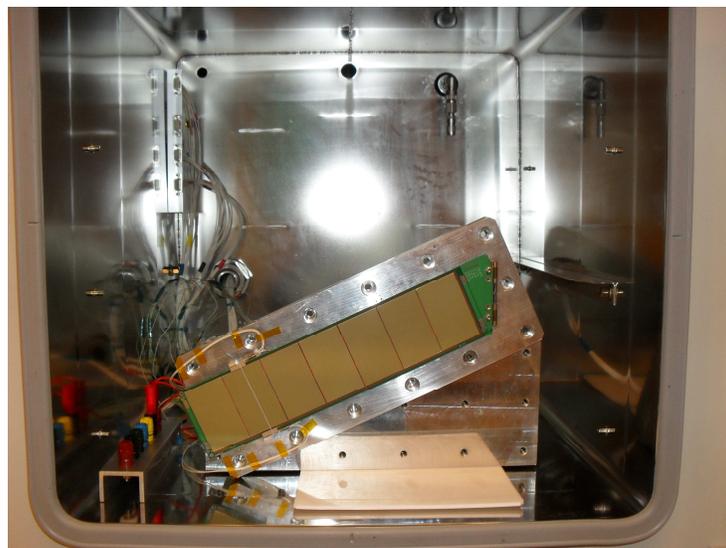


Figure 3-6: Deployment test set-up

3.5 Redesign of MABs

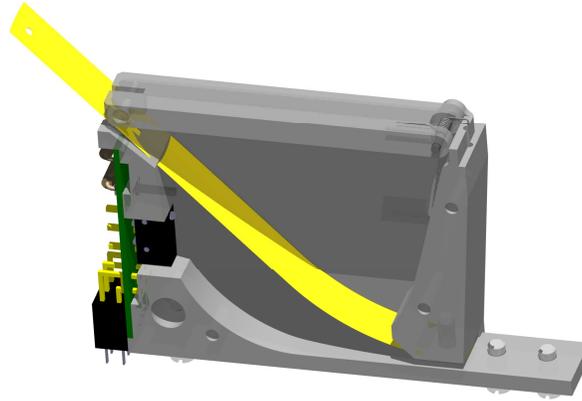


Figure 3-7: MAB

The same Modular Antenna Boxes (MABs) as used on Delfi-C3 will be used on Delfi-n3Xt. A small redesign was needed as the RF-cable attached to the old MAB is now integrated in the PCB of the antenna board. The length of the MAB is increased for placement of an extra hole for the RF-connection to the PCB. Unfortunately, the design drawings of the latest design in Catia were lost. Therefore the latest 3D-model that could be found was updated to the latest design and new drawings were made and sent to the workshop.

4 Budgets

Throughout the Delfi-n3Xt project budgets are used to monitor the available resources. As a structural and mechanical engineer I am responsible for the volume budget, mass budget and electrical wiring interface control which are explained in this chapter.

4.1 Volume budget

The volume budget is a model developed from blocks; each color represents a subsystem. The detailed shape and dimensions of these volume blocks are used for communication with the payload partners and can be found in [SLR 0303]. Throughout the project this volume budget has changed many times to include design changes. The evolution of the volume budget is shown in Appendix A. When I started with the project the latest version was version 1.3. The changes for the following versions are described below.

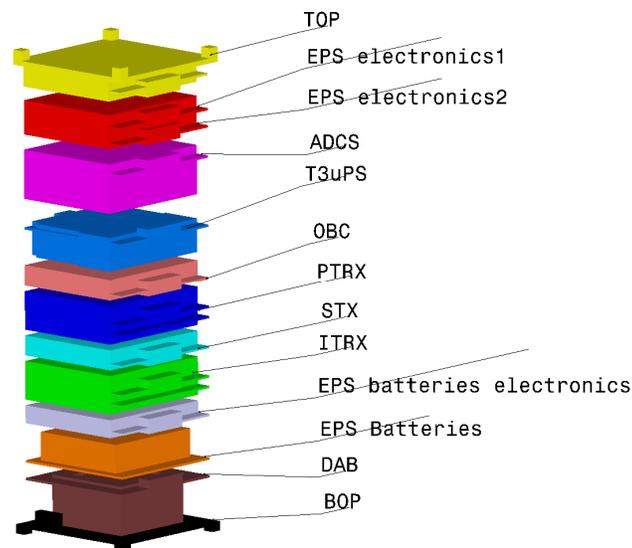


Figure 4-1: Delfi-n3Xt Volume budget

Version 2.0

The old payloads Multifunctional Particle Spectrometer (MPS) and Space Flash (SPLASH) were deleted as they were no longer payloads of Delfi-n3Xt. An extra PCB was added for the EPS as the complete EPS wouldn't fit on one PCB. The solar panel configuration was changed and the mass of the solar panels increased, therefore the Centre of Mass (CoM) shifted to a higher position in the satellite. The CoM of the satellite may not be too far from the centre of geometry of the satellite. Therefore the batteries, which are relatively heavy, were moved to the bottom of the satellite such that the CoM will be lowered. The space between each subsystem was increased to 6 mm to anticipate future problems when a volume budget of a subsystem must be slightly increased. A larger space is left over around the microthruster (T3 μ PS) to allow relocation of the microthruster when the CoM of the satellite changes.

Version 2.1

An extra PCB was added for the management of the loading and unloading of the batteries, named batteries electronics. This PCB is placed directly above the batteries, such that an electronic connection between the boards can easily be made. Therefore the batteries do not need access to the standard system bus anymore. The three radio boards (PTRX, STX and ITRX) and the OBC are shifted upwards to make room for the batteries electronics PCB.

Version 2.2

Development of the ADCS made clear that all components could be integrated on a single PCB. Therefore the ADCS electronics and the ADCS Reaction Wheels were merged into one ADCS PCB. A Test Connector Board (TCB) was implemented at the bottom of the satellite around the DAB to make a connection to the satellite for testing after full integration. The length of the solar panels was increased, therefore the test connector was now covered by a solar panel; meaning that the test connector could only be used with a deployed solar panel. This greatly limits the use of the test connector; therefore the test connector was moved to the PCB in the TOP where the DIMES experiment is placed. The test connector can now be connected at the top of the satellite with stowed solar panels, through a hole in the TOP. The TCB was deleted.

Version 2.3

The highest EPS PCB was placed such that the connectors from the solar panels could be connected to the EPS right under the TOP through a hole in the outer structure. The lower EPS PCB was placed 10.4 mm under the other PCB, such that the two PCBs can be connected with a standard Harwin connector with this height.

Version 2.4

The height of the PTRX and ITRX PCBs was increased to 27 mm such that a linear transponder can be included on both radios. The linear transponders are placed on a separate PCB with an electrical connection to the main PCB. The microthruster was placed at the current CoM. The placement of all subsystems was slightly altered such that the spacing between the PCBs was set at 4 mm. This is the latest and final version of the volume budget. With this volume budget the flex-rigid PCB for the standard system bus was made, which leaves no room for subsystem position changes.

4.2 Mass budget

The target mass of the satellite is 3 kg maximum [SLR 263]. The launch costs will increase if the mass of the satellite exceeds 3 kg, which must be avoided if possible. To monitor the design mass of the satellite throughout the project a mass budget is used. At the beginning of the project the masses of each subsystem were estimated based on the subsystem masses of Delfi-C3. During the project these estimates with their contingencies were regularly adjusted to the latest design status of each subsystem.

The latest mass budget is shown in [SLR 0018] and is attached to this document. The mass budget is shown per subsystem and per assembly. The allocated mass per subsystem or assembly equals the Current Best Estimate (CBE) plus a contingency. The contingencies are based on the design maturity of each assembly. The description of the design maturity codes is shown in the mass budget document. The mass budget per subsystem is shown in Table 4-1.

Table 4-1: Top level Mass budget

Subsystem	Current Best Estimate [g]	Allocated mass [g]
ADCS	322	345
CDHS	46	46
COMMS	387	449
EPS	934	982
MechS	122	126
STS	575	588
TCS	40	52
T ³ _μ PS	140	154
SDM	100	125
ITRX	170	187
Cable harness	51	61
Miscellaneous	40	52
<i>Total</i>	<i>2926</i>	<i>3169</i>

The history of the mass budget is shown in an added table. The information is visualized in two graphs. The first graph shows the mass budget history per subsystem. It can be seen that the mass of the payloads has

decreased over time due to omission of some heavy payloads. It can also be seen that the mass of the EPS has increased over time due to addition of two extra PCBs. The second graph shows the evolution of the total mass budget including contingencies and target mass, also shown in Figure 4-2. It shows that the total mass of the satellite and its contingencies have decreases over time, but has increased again in the latest version. This is mainly due to addition of the linear transponders on the PTRX and ITRX which add an estimated 200 grams to the satellite.

The CBE of the total satellite mass is currently 2926 grams. With contingencies added it will be 3169 grams. So there is a chance that the satellite mass will exceed 3 kg. However, there is currently much uncertainty in the estimates of the mass of the PCBs, resulting in the high contingencies. Most PCBs will be finished very soon, after which the PCBs can be weighted and the masses and contingencies can be updated in the mass budget. Then it will be clear if the satellite mass will exceed 3 kg and if measures are needed to reduce the mass of the satellite. A possible measure can be the omission of one linear transponder, reducing the satellite mass with 100 grams.

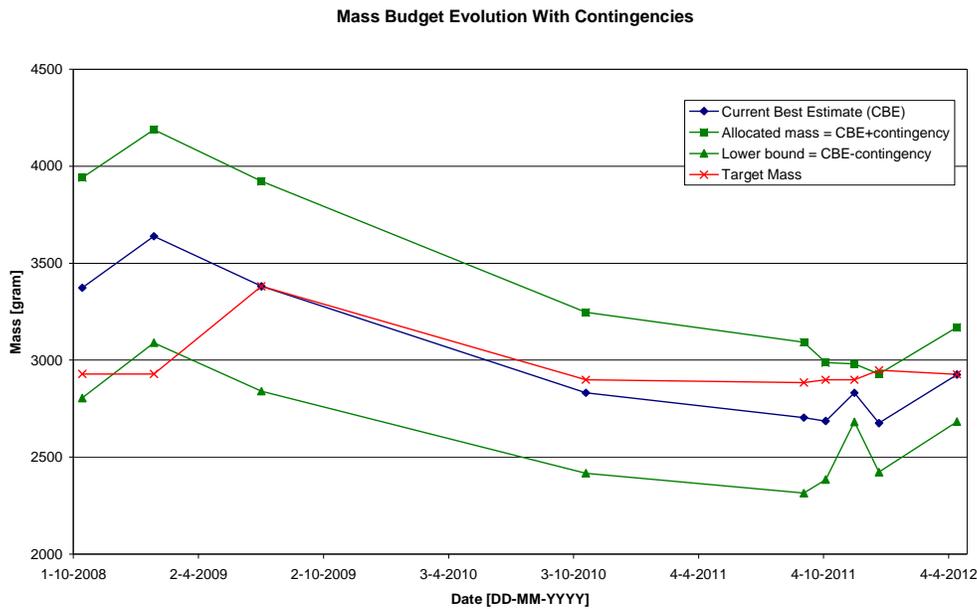


Figure 4-2: Delfi-n3Xt Mass budget evolution

4.3 Electrical Wiring Interface Control Document

The Electrical Wiring Interface Control Document defines all electrical interfaces between the various subsystems and detachable components. The pin allocation for each connector in the satellite is described to assure compatibility. The Electrical Wiring Interface Control Document [SLR 0565] is attached to this document.

5 Conclusions and recommendations

5.1 Thesis Conclusions

PCB spacing A test was performed on a subsystem PCB showing that the maximum deflection of the PCB due to launch vibrations is 0.40 mm with a concentrated mass of 140 grams at the midpoint of the PCB. It can be concluded that the minimum margin of 2 mm between the PCB's in the stack is a safe margin and is recommended for Delfi-n3Xt and future missions.

Strength structure From both calculations on compression and buckling failure and a finite element model made by [Boersma and Vielvoye, 2009] can be concluded that the launch loads can be easily be sustained by the structure.

Stiffness structure Calculations showed that the lateral and longitudinal natural frequencies of the structure are 483 and 833 Hz respectively, which is well above the minimum required frequency of 20 Hz in each direction, which is the natural frequency of the launcher.

Stiffness solar panels Bending tests were performed on a solar panel without solar cells and on a solar panel with dummy cells. The results showed that the stiffness of the solar panels is 40% higher than a bare PCB without copper layers and solar cells.

Deflection solar panels The stiffness of the solar panels is not high enough to guarantee that the solar panels will not hit the launch POD or structure during launch. Safety measures are taken to minimize the chance of damage to the solar cells.

Natural frequency solar panels A frequency test on the solar panel was performed to find the dominant vibration frequencies. The natural frequency of the solar panels is 39 Hz, at a safe margin above the minimum required frequency of 20 Hz.

HDRM The Hold Down and Release Mechanism was tested at room temperature and in a hot and cold environment. The HDRM deployed the solar panel within the required 15 seconds with a safe margin under all circumstances.

HDRM deployment resistors The deployment resistors are tested more than 40 times and they do not show any deterioration in performance.

Integration The Delfi-n3Xt is designed for easier integration by using detachable side-panels. The addition of multiple components on the side panels, such as the sun sensors, STX patch antenna and HDRM make the integration more complicated. All these components need to be electrically connected to the stack with connectors before the side-panels can be attached. Overall the integration of Delfi-n3Xt is still expected to be easier than the integration of Delfi-C3.

Volume budget The latest version of the volume budget is also the final version. With this volume budget the flex-rigid PCB for the standard system bus was made, which leaves no room for subsystem position changes.

Mass budget When contingencies are included, the satellite mass is currently above the required maximum of 3 kg. However, the weight of most subsystem PCB's is still highly uncertain and will probably be below the conservative estimates. Therefore it is expected that the final satellite mass will be below 3 kg.

5.2 Thesis Recommendations

Satellite integration When all components are manufactured the structure should be integrated as soon as possible, such that there is time for small changes if unforeseen problems arise.

Catia design The 3D model of Delfi-n3Xt made in Catia gets larger and larger while the computers on which Catia is installed can handle it barely. When more than four assemblies are opened simultaneously the screen goes black. When the complete assembly is opened it works very slowly. It is recommended to upgrade the two computers such that Catia design will be easier and faster.

Mass budget When subsystems are finished they must be weighted and the mass budget must be updated. Then the contingencies can be removed or lowered such that it is more certain that the satellite mass stays below the 3 kg. If the final satellite mass will exceed the 3 kg, corrective measures are needed. A possible measure can be the omission of one linear transponder, reducing the satellite mass with 100 grams.

5.3 Project Recommendations

Engineering model It is very unfortunate that the full engineering model of the satellite was abandoned due to time constraints. If a problem arises during integration and testing, there will be very little time to fix the problem. For future missions it is advised to produce an engineering model of the complete satellite.

Lack of students At multiple stages of the project there were too few students working on Delfi-n3Xt, which has slowed down the progress considerably. There are currently few students to finish the assembly, integration and testing on which still a lot of work needs to be done. For future projects it is recommended to have a larger team continuously.

5.4 Lessons learned

Catia design Design of parts in Catia is relatively easy and is widely covered in design courses. However, for Delfi-n3Xt much changes of parts were needed, which is more difficult; especially when the part is made by someone else. When a part is build up incorrectly, a simple change in length of the part can produce a list of complicated errors. Often it was easier to make a new part than to change the existing one. When designing a part it is important to anticipate common changes, such that they can easily be adjusted by someone else.

Workshop drawings The parts that are milled are directly produced from the delivered 3D-models. These parts can be made with very low tolerances. The drawings are primarily made as a reference and for checking the part dimensions after production. However, the parts made from plate material are handmade and have higher tolerances. Therefore, the dimensions in the drawings have to be placed at the right baseline, such that for example screw holes are properly aligned with the other parts.

Value of calculations Strength, stiffness and deflection calculations on structural parts are only accurate if the boundary conditions are simple (clamped or pinned) and the material is homogeneous and its properties are accurately known. When this is not the case accurate predictions can only be done by testing.

Graduating on a design project Working in a project team and simultaneously working on a thesis gave an extra dimension to the graduation process and gave extra challenges. It was sometimes difficult to divide my attention between finishing the satellite and finishing my thesis. It was very interesting and I learned a lot working on the Delfi team designing and building a real satellite.

List of references

In the following table all documents used from the Standard List of References (SLR) of Delfi-n3Xt are shown. Below the table all other references are given.

SLR code	Document title	Author	Version
0001	Mission Definition Report of Delfi-n3Xt	Bouwmeester, J.	1.4
0017	Delfi-n3Xt Power Budget	Bouwmeester, J.	5.03
0018	Delfi-n3Xt Mass Budget	Jong, J. P. de	4.5
0142	ADCS - Top Level Design of ADCS Subsystem	Vracking, V.	2.3
0157	ECSS Materials	-	A
0158	ECSS Structures	-	A
0159	ECSS Mechanisms	-	A
0160	Compass One, Phase A study	Scholz, A.	1
0167	Delfi-n3Xt Requirements & Configuration Item List	Bouwmeester, J.	3.34
0169	Top Level Design of Structural Subsystem	Jong, J.P. de	3.3
0181	ICD microthruster	Bouwmeester, J.	2.0
0192	Delfi-C3 Mass Budget	Graziosi, M.	2.5
0204	Interface Control Document SDM	Perez-Lebbink, L.	1.30
0263	Delfi-n3Xt – Mission Definition, Systems Overview and General Design Approach	Bouwmeester, J.	2.3
0265	EPS - Global EPS System Definition & Design Specification	Bouwmeester, J.	1.2
0269	Thesis on STS Delfi-C3	Linden, E.N. van der	1.0
0282	Delfi-n3Xt Data Budget	Groot, T.E. de	2.6
0287	CDHS - Delfi Standard System Bus	Bouwmeester, J.	2.4
0299	Dnepr User's Manual	Us, S.I.	2.0
0303	Delfi-n3Xt Volume Budget	Jong, J. P. de	2.4
0308	Design of a Universal Antenna Deployment System	Eijkhof, R. van den	1.0
0317	Systems Engineering Team Members Manual	Genbrugge, M.	1.1
0364	Systems Engineering & Technical Management Techniques	Hamann, R.J.	1.0
0373	Spacecraft Structures Lecture Notes	Wijker, J.J.	1.1
0474	Delfi-C3s electrical power system and its thin film solar cell payload	Doorn, J.H.	1.0
0484	Delfi-C3 Structures & Mechanisms	Lebbink, G.W.	1.0
0485	Design and development of Delfi-C3s deployment control system	Wezel, J.	1.0
0529	Structural Workshop Report Solar Panels	Linden, E.N. van der	2.0
0554	IsiPOD Datasheet	-	1.0
0565	Delfi-n3Xt - Electrical Wiring Interface Control Document	Jong, J.P. de	2.07
0572	MechS - Design of Mechanical Systems	Jong, J.P. de	2.3
0583	Aluminium Specification Datasheet	-	-
0597	Clifa Press-in Nuts and Studs Datasheets	-	-
0604	Thesis on Mechanical Design and Arrangement of nanosatellite Delfi-n3Xt	Go, S.Y.	1.0
0616	TCS - Analysis & Design	Alvim, D.	2.3
0632	Design of Mechanical Systems	Awchi, Y.	1.0
0633	Delfi-n3Xt - STS - Structural Drawing (CATIA)	Jong, J. P. de	5.8
0789	Inconsistent Melt Performance by 75Ohm Resistors	Vaartjes, A.A.	1.0
0863	EPS - Solar Array Configuration Analysis	Bürkle, J.F.	1.0
0872	Delfi-n3Xt Thermal Budget	Macco, C.	3.2
0931	GSE - Protection Covers Design	Kooijman, P.	2.6
0964	FR4 Glass/Epoxy Properties	-	-
0965	ISIPOD Interface Specification	Lebbink, G.W.	1.41

0991	STS - Stack PCB Deflection Test Report	Jong, J. P. de	2.0
0996	MechS - Solar Panel PCB Deflection Test Report	Jong, J. P. de	2.1
1008	Launch – Environmental Levels ISILaunch	Bolhuis, M.	1.1
1009	MechS - Solar Panel Deployment Test Report	Jong, J. P. de	1.2

Other references

ASTM, *D790-02 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*, 2002. Viewed: November 28, 2011.
<http://www.scribd.com/doc/73187063/D790-02>

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University of Washington, *Mechanics of Materials Laboratory Course Notes*, 2007. Viewed: November 22, 2011. <http://courses.washington.edu/me354a/chap3.pdf>

Ventsel, E. and Krauthammer, T. *Thin plates and Shells. Theory, Analysis and Applications*. Marcel Dekker, Inc., New York, 2001.

A Volume budget history

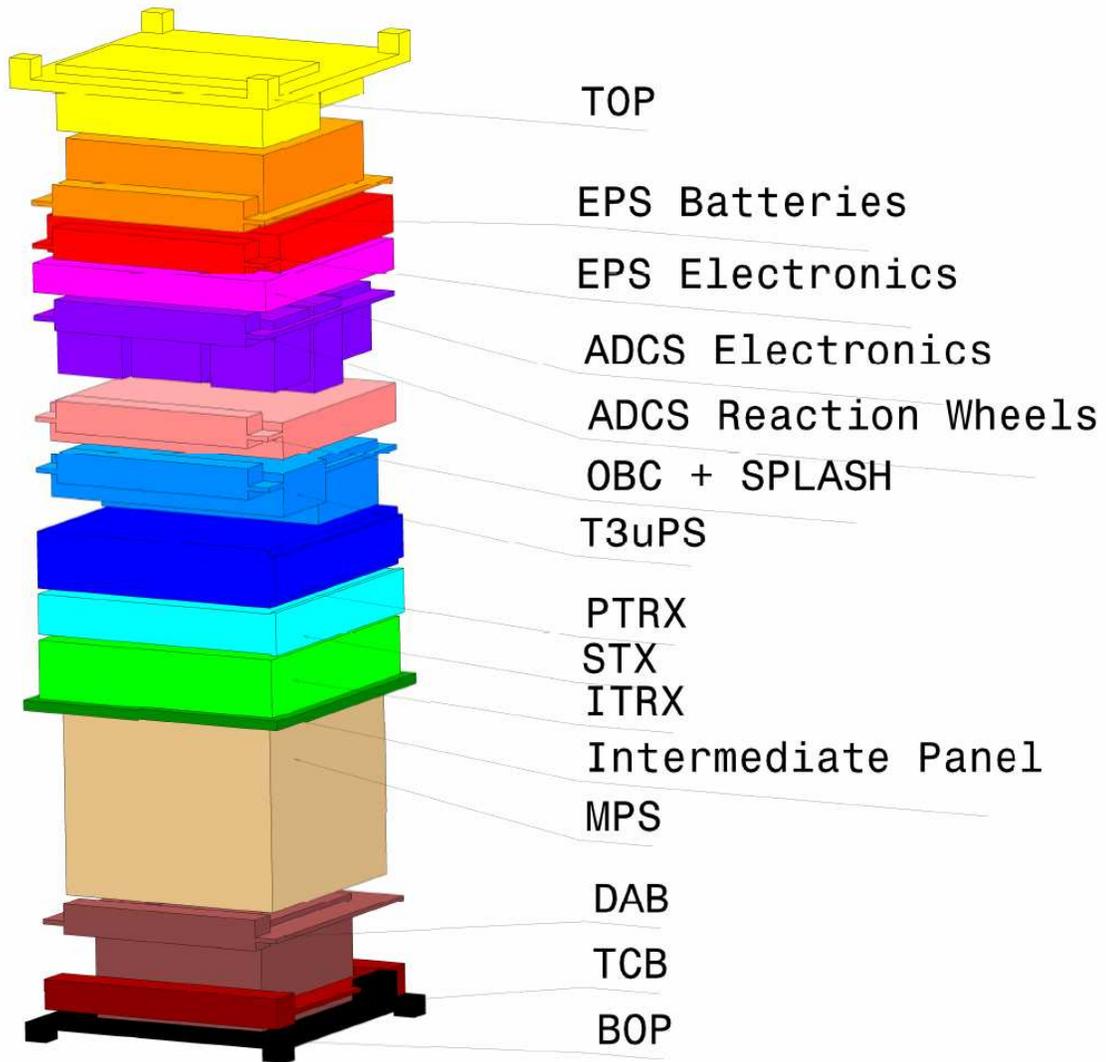


Figure A-1: Volume budget v. 1.3

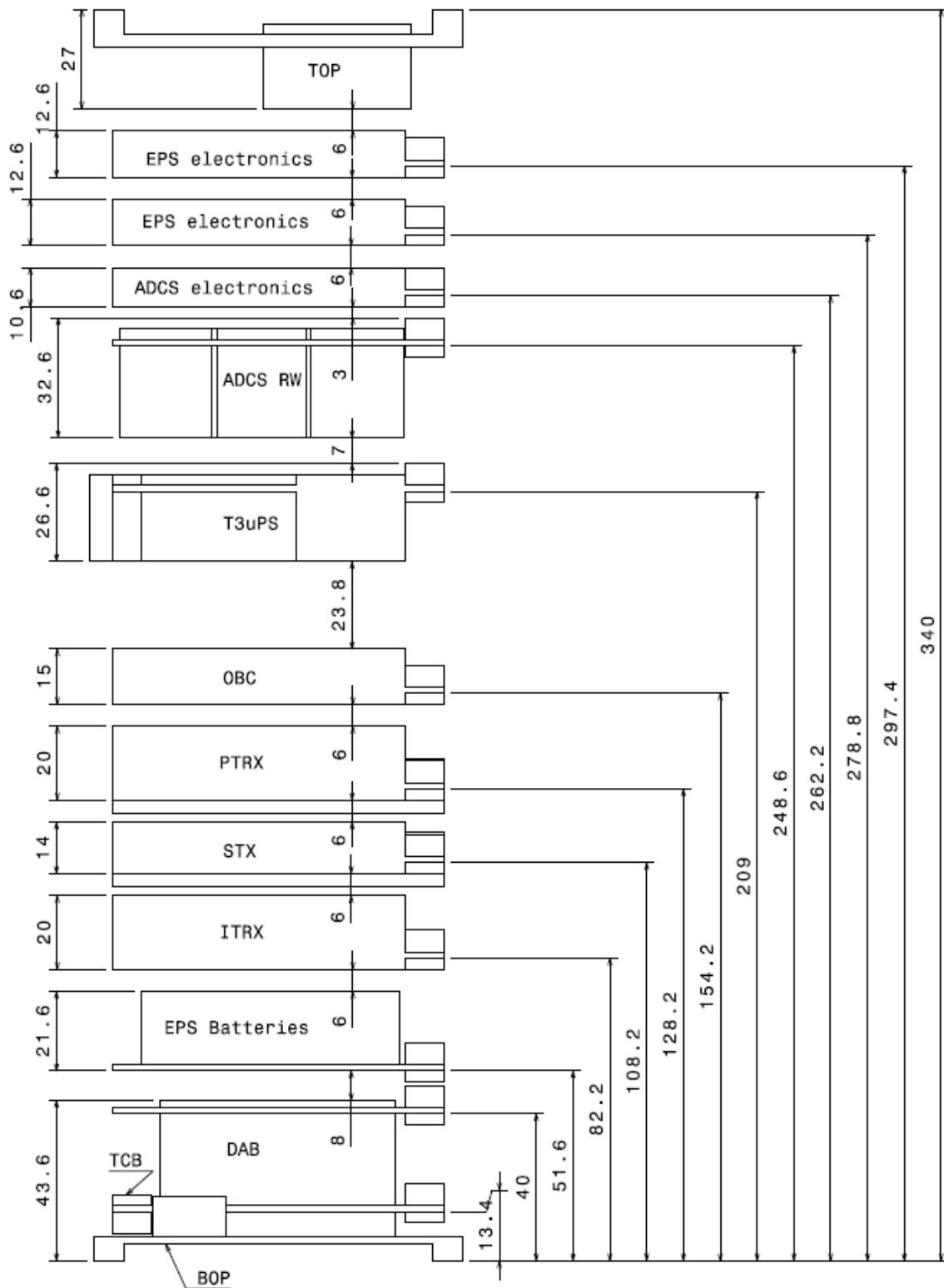


Figure A-2: Volume budget v. 2.0

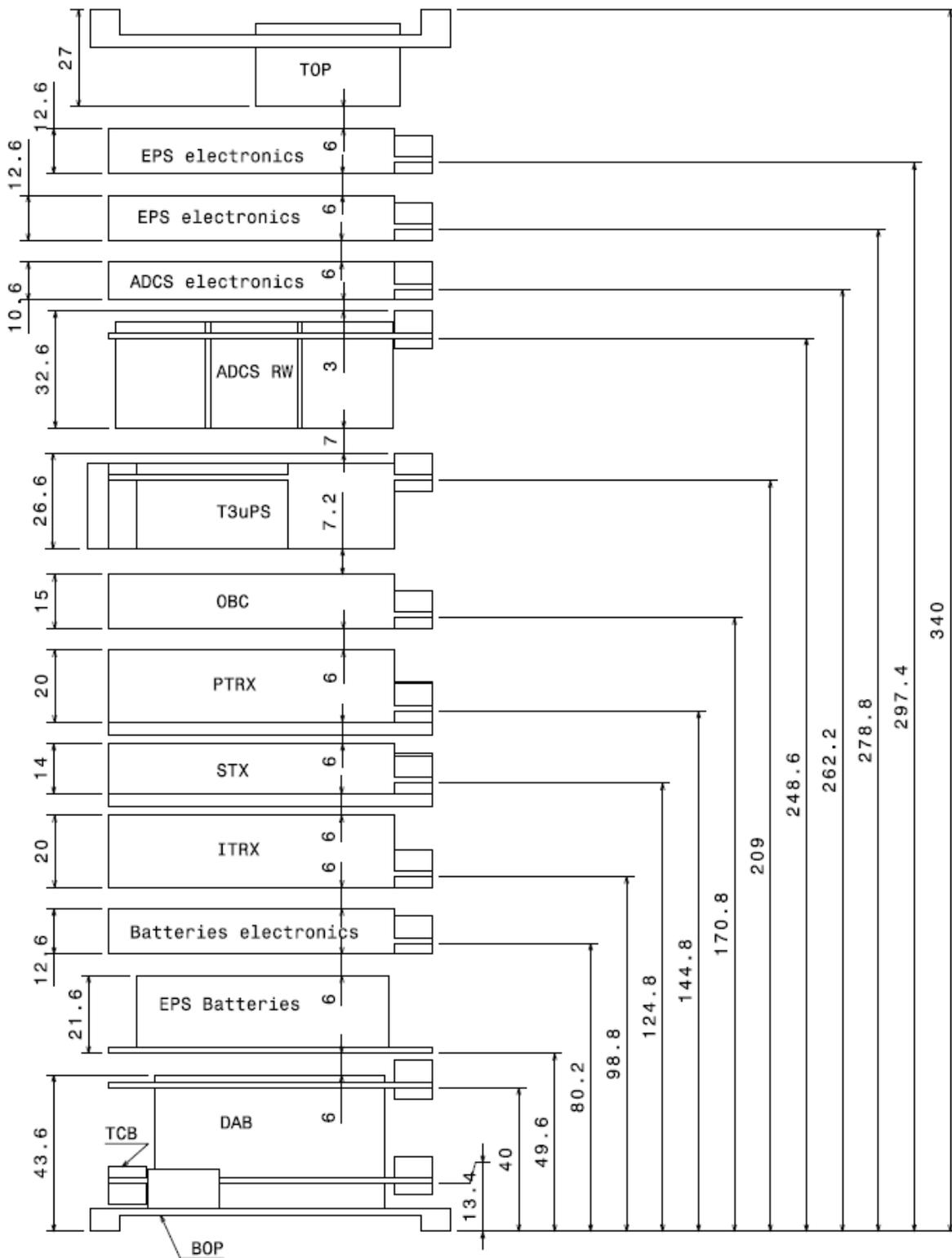


Figure A-3: Volume budget v. 2.1

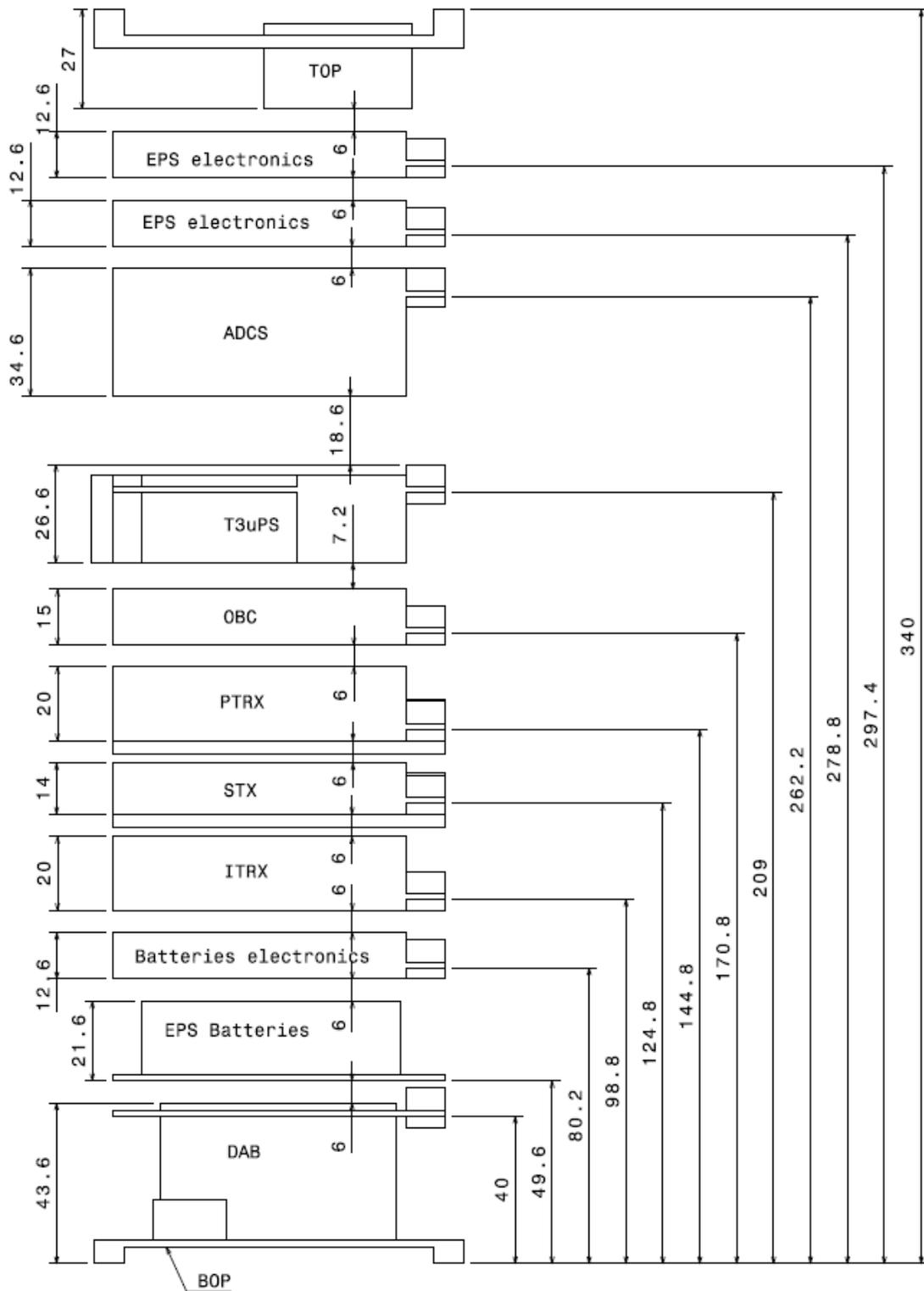


Figure A-4: Volume budget v. 2.2

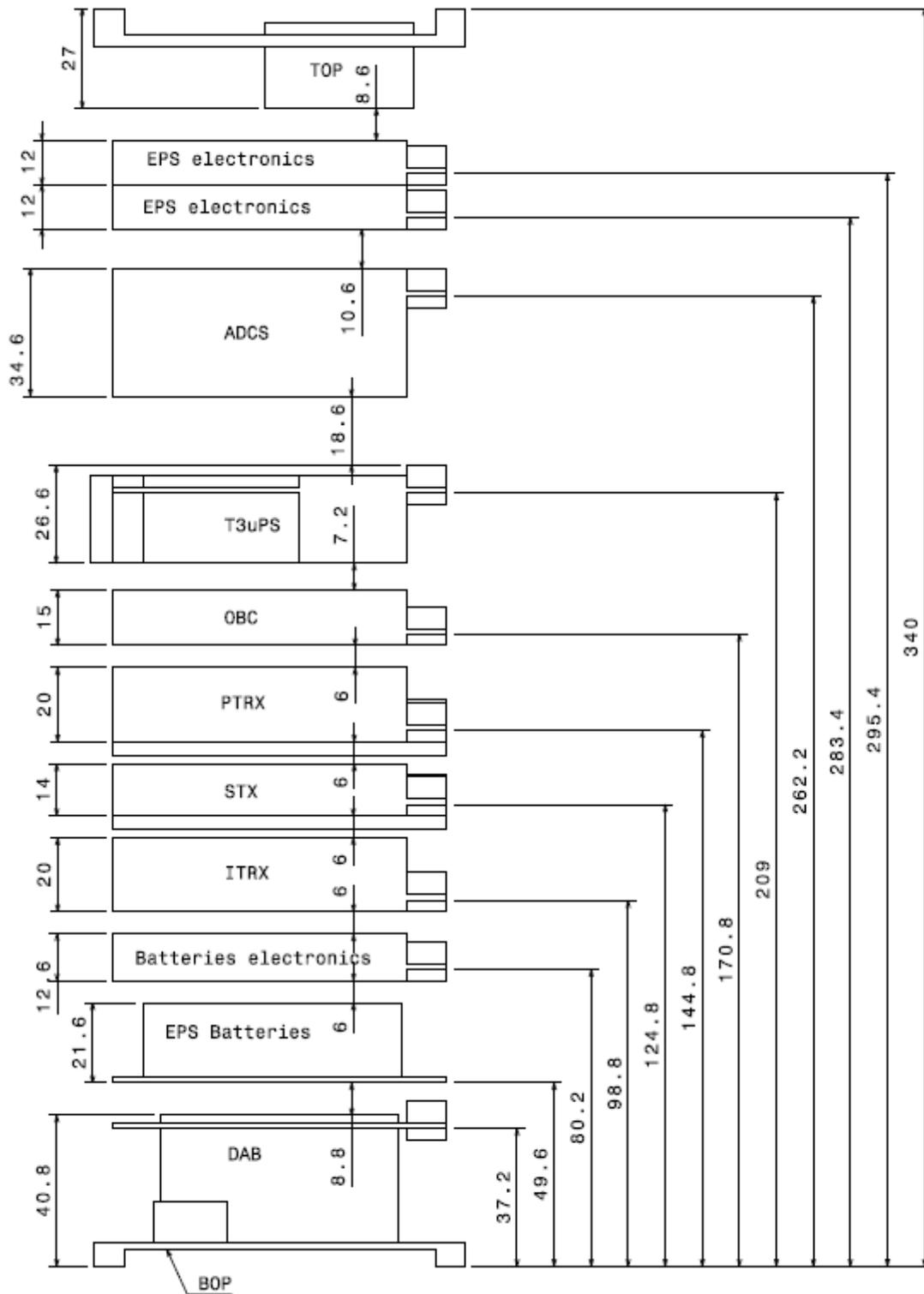


Figure A-5: Volume budget v. 2.3

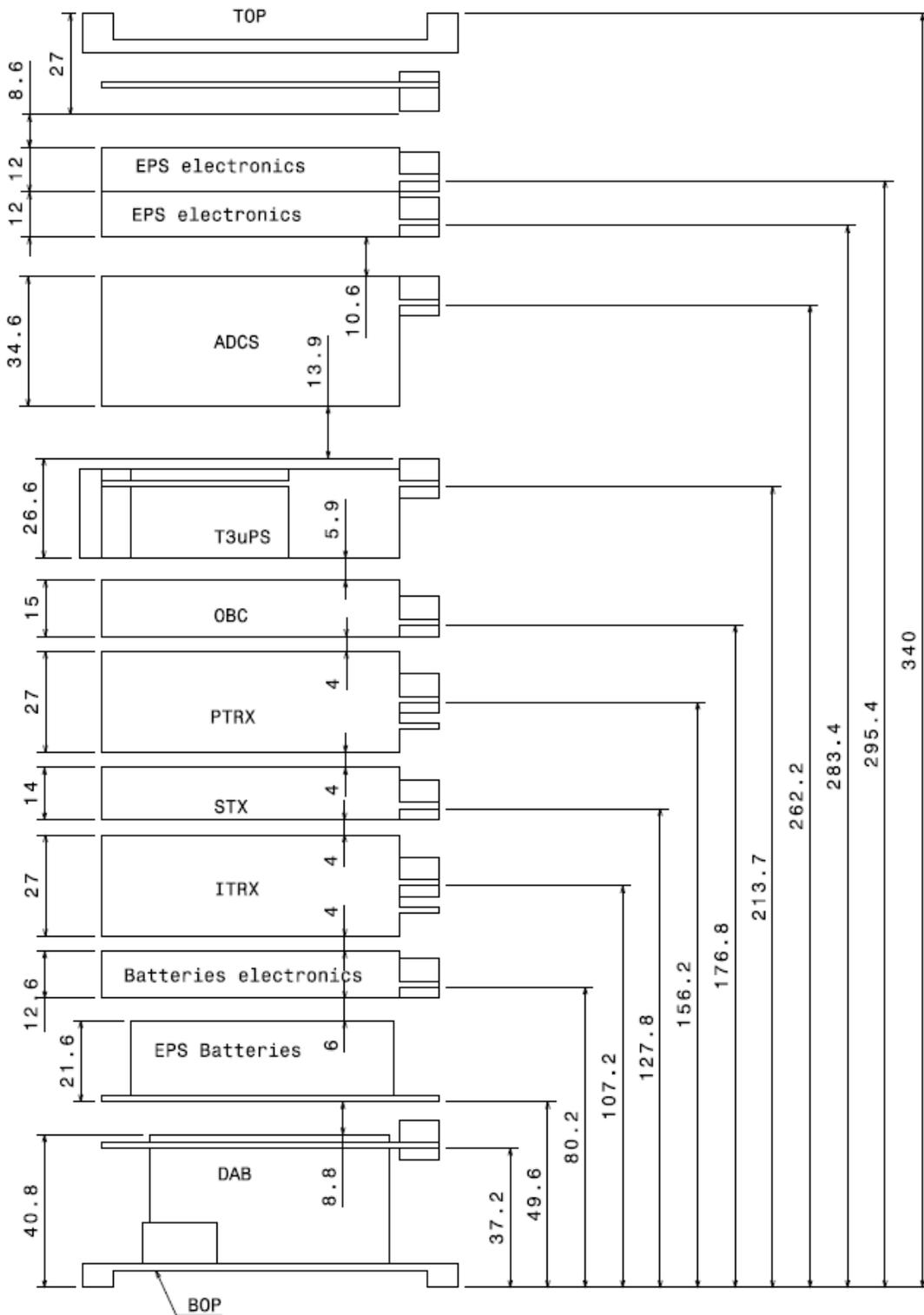


Figure A-6: Volume budget v. 2.4

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	T³μPS	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
2.2	01-07-2009	Jennifer	GB	JB		Update load case figures H9 & 10.7.1 for Natural Frequency
3.0	04-05-2011	Johan			All	Update of all design changes
3.1	19-10-2011	Johan	GB	JB	All	Document restructured Design changes updated
3.2	02-04-2012	Johan	GB		All	Document restructured Design changes updated
3.3	06-06-2012	Johan			7.3	Description of changed structure

Action Items

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

List of Used References

SLR code	Version	Data/Variable
SLR 0001	1.4	MDR Delfi-n3Xt
SLR 0017	5.03	Delfi-n3Xt Power Budget
SLR 0018	4.4	Delfi-n3Xt Mass Budget
SLR 0142	1.6	ADCS Top level TN, +/- 5 mm misalignment T ³ μPS Z-direction
SLR 0157	A	ECSS Materials
SLR 0158	A	ECSS Structures
SLR 0159	A	ECSS Mechanisms
SLR 0160	1	Compass One, Phase A study
SLR 0167	2.5	Requirement management tool Delfi-n3Xt, Requirements numbering
SLR 0181	1.0	ICD microthruster
SLR 0192	2.5	Delfi-C3 Mass Budget
SLR 0204	1.30	Interface Control Document SDM
SLR 0263	2.3	Delfi-n3Xt – Mission Definition, Systems Overview and General Design Approach
SLR 0265	1.2	EPS - Global EPS System Definition & Design Specification
SLR 0269	1.0	Delfi-C ³ STS thesis E. van der Linden
SLR 0282	2.6	Delfi-n3Xt Data Budget
SLR 0287	2.4	CDHS - Delfi Standard System Bus
SLR 0303	2.4	Delfi-n3Xt Volume Budget
SLR 0308	1.0	DC ³ antenna deployment system
SLR 0317	0.2	Systems Engineering Team Members Manual
SLR 0364	1.0	Lecture notes Systems Engineering
SLR 0373	1.1	Lecture notes Spacecraft Structures
SLR 0484	1.0	DC ³ structures and mechanisms
SLR 0525	1.0	DC ³ integration and verification
SLR 0529	2.0	Structural Workshop Report Solar Panels
SLR 0565	2.07	Delfi-n3Xt - Electrical Wiring Interface Control Document
SLR 0572	0.1	MechS TN
SLR 0583	-	Datasheet aluminium
SLR 0597	-	Clifa press nuts
SLR 0604	1.0	Thesis Jennifer Go, Mechanical Design and Arrangement of Delfi-n3Xt
SLR 0616	2.3	TCS - Analysis & Design
SLR 0633	5.8	Delfi-n3Xt - STS - Structural Drawing (CATIA)
SLR 0863	1.0	EPS - Solar Array Configuration Analysis
SLR 0872	3.0	Delfi-n3Xt Thermal Budget
SLR 0931	2.6	GSE - Protection Covers Design of Solar Panels, Sun Sensors and SDM Experiment
SLR 0965	1.41	ISIPOD Interface Specification
SLR 0991	2.0	STS - Stack PCB Deflection Test Report
SLR 1008	1.1	Launch – Environmental Levels ISILaunch

Hibbeler, R. C., 2004. *Mechanics of Materials*. Singapore: Prentice Hall.

Boersma, L.S. and Vielvoye, R.H., 2009. *Finite Element model of Delfi-n3Xt*. Bonus assignment Spacecraft Structures, TU Delft.

eFunda, Inc., 2012. URL: <http://www.efunda.com/materials/alloys/aluminium>

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
OBC	On-Board Computer
PCB	Printed Circuit Board
PTRX	Primary Transceiver
RF	Radio Frequency
SDM	Solar cell Degradation Measurement
SLR	Standard List of References
SP	Solar Panel
STS	Structural Subsystem
STX	S-band Transmitter
TBC	To Be Confirmed
TBD	To Be Determined
TBW	To Be Written
TN	Technical Note
TOP	Top Panel
UHF	Ultra High Frequency
VHF	Very High Frequency

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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. The preliminary design is made by Jennifer Go [SLR 0604]. This design is altered due to changing subsystems and a new solar panel configuration designed by Johannes Bürkle [SLR 0863]. This document reflects the latest design of the Delfi-n3Xt structure.

2 Mission Need Definition

The mission need definition for the STS has been deduced from top level requirement SAT.2.4-F.01 for Delfi-n3Xt [SLR 0263]:

The STS shall be based on the design and dimensions of 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-C³ 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-C³ 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-C³ 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.

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-C³ for more accessibility to the structure, but with the COTS structure used, the solution was not advantageous enough [SLR 0269].

Cable harness for Delfi-n3Xt

The cabling from the outside to the inside structure of Delfi-C³ 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.

Flight model for Delfi-n3Xt

Delfi-C³ 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]. An engineering model of the structure is produced and is currently located in the clean room. The engineering model is made to notice manufacturing problems early in the design process and to have a first physical model of Delfi-n3Xt.

Handling of Delfi-n3Xt

The Mechanical Ground Support Equipment (MGSE) as developed for Delfi-C³ worked very well. Delfi-n3Xt will make use of the available MGSE as much as possible. Modifications and additions will be made if needed.

Integration and assembly for Delfi-n3Xt

As Delfi-C³ Delfi-n3Xt will use a modular concept, meaning all components to be developed and tested separately and integrated in the end.

PCB-layout for Delfi-n3Xt

Delfi-C³ 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]. The configuration tree focusing on STS is shown on **Error! Reference source not found.** 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-C³, 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 complete list of requirements for the satellite and its subsystems can be found in [SLR 0167]. This chapter explains the requirements for the STS.

4.1 Top Level Requirements

Table 4-1: Constraints for all Delfi-n3Xt systems

Category	Req. #	Requirement
CONSTRAINT	SAT-C.01	All satellite systems shall comply with the mass budget, as given in [SLR 0018].
CONSTRAINT	SAT-C.02	All satellite systems shall comply with the volume budget, as given in [SLR 0303].
CONSTRAINT	SAT-C.03	All satellite systems shall comply with the power budget, as given in [SLR 0017].
CONSTRAINT	SAT-C.04	All satellite systems shall comply with the data budget, as given in [SLR 0282].
CONSTRAINT	SAT-C.05	All satellite systems shall comply with power and data bus interfaces, as specified in [SLR0287] and [SLR0565].
CONSTRAINT	SAT-C.06	All satellite systems shall be able to withstand the launch environment [SLR 1008].
CONSTRAINT	SAT-C.07	All satellite systems shall be able to withstand the space environment [SLR 1008].
CONSTRAINT	SAT-C.08	All satellite systems shall comply with the thermal budget, as given in [SLR0872] and to vacuum conditions without outgassing or structural degradation.

These constraints apply for all Delfi-n3Xt systems and are explained in [SLR0263].

4.2 Functional requirements

Table 4-2: Functional requirements

Category	Req. #	Requirement
FUNCTIONAL	SAT.2.4-F.01	The STS shall be based on the design and dimensions of a three-unit CubeSat.
FUNCTIONAL	SAT.2.4-F.02	The STS shall enable the quick integration and removal of subsystems and components.
FUNCTIONAL	SAT.2.4-F.03	The STS shall accommodate for the mounting of components onto the main support structure.
FUNCTIONAL	SAT.2.4-F.04	The STS shall be designed to withstand applied loads by the natural and induced environments to which it is exposed during its complete lifetime (manufacturing, assembly, testing, transport, launch, operations).

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 (SAT.2.4-F.01). Delfi-n3Xt shall be launched, making use of an ISIPOD deployer. From the mission statement the requirement SAT.2.4-F.01 has been flown down, which states that the STS of Delfi-n3Xt is based on the design of a three-unit CubeSat [SLR 0263].

An important function of the structure is the integration with other subsystems (SAT.2.4-F.02). The STS has to allow easy integration and removal of subsystems while on ground. In this way adjustments can be made and subsystems can be tested separately. The structure shall accommodate the mounting of components

(SAT.2.4-F.03). In the design of the STS should be taken into account that subsystems need to be fastened, while not interfering with volume requirements. Furthermore, STS should withstand the loads induced during its complete lifetime (SAT.2.4-F.07).

4.3 General Requirements

Table 4-3: General requirements

Category	Req. #	Requirement
GENERAL	SAT.2.4-G.01	All items identically numbered shall be designed to be interchangeable in function and dimension.

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-G.02).

4.4 Constraints

Table 4-4: Constraints

Category	Req. #	Requirement
CONSTRAINT	SAT.2.4-C.01	The STS, including solar panels, shall fit into an ISIPOD deployment canister [SLR 0965].
CONSTRAINT	SAT.2.4-C.02	The STS, excluding solar panels, shall fit within an envelope of 100 mm x 100 mm x 340.5 mm.

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.2.4-C.01 and SAT.2.4-C.02.

4.5 Performance requirements

Table 4-5: Performance requirements

Category	Req. #	Requirement
PERFORMANCE	SAT.2.4-P.01	The STS shall have stiffness, such that the natural frequencies of the STS are at least 20 Hz in each direction, as defined in the ISIS launch requirements [SLR 1008].

The performance requirements are set such that the STS does not fail during mission life time. The rocket which launches the satellite induces vibrations which the satellite must be able to endure. This leads to requirement SAT.2.4-P.01.

4.6 Interface requirements

Table 4-6: Interface requirements

Category	Req. #	Requirement
CONSTRAINT	SAT.2.4-I.01	The structure shall provide mechanical interfaces to the subsystems.

To be able to fit all subsystems in the imposed volume, the interfaces between the subsystems need to be accurately defined (SAT.2.4-I.01). This is done in separate interface control documents (ICD's) for the external partners: T³μPS [SLR 0181], ITRX [SLR 0192] and SDM [SLR 0204]. All other subsystems have to apply to the volume budget.

4.7 Payload requirements

For assembly, integration and modularity reasons it is convenient for the Solar cell Degradation Measurement (SDM) to have its own housing. This simplifies integration work for Delfi-n3Xt and makes handling of the payload easier.

The payload $T^3\mu\text{PS}$ requires an outlet for the valve. 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 has been set for the positioning of $T^3\mu\text{PS}$ 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 $T^3\mu\text{PS}$ goes through the Centre of Mass (CoM) with a total vector misalignment of +/- 5 mm in Z-direction as specified in [SLR 0142].

5 Design

To assure that all payloads and subsystems of Delfi-n3Xt fit in a three-unit CubeSat a volume budget and verification drawings have been made for the entire satellite. 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 5.1; the design drawing is discussed in paragraph 5.3. The coordinate system used is shown in Figure 5-1.

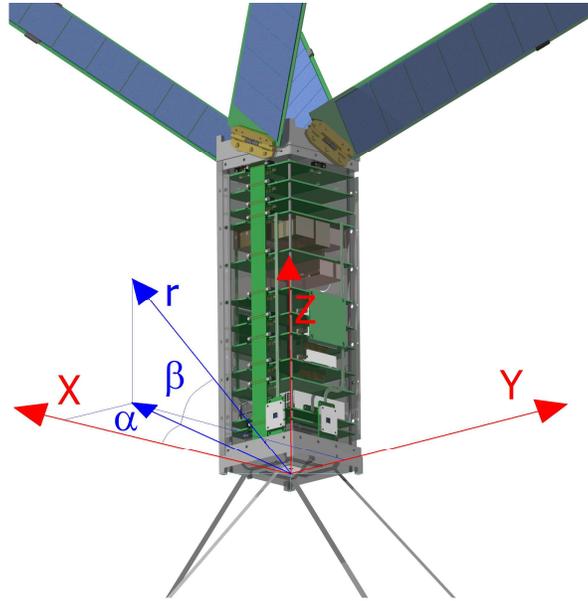


Figure 5-1: Delfi-n3Xt body fixed reference frame

5.1 Volume budget

The volume budget is a simple model developed from blocks (Figure 5-2). The detailed shape and dimensions per subsystem can be found in [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 standard PCB including a Harwin connector (Figure 6-6) and a specified height above and beneath the PCB. The heights are derived from the height of components specified by payload partners, of similar subsystems used on Delfi-C³ and data provided by the subsystem engineers.

The volume budget fits in a three-unit CubeSat, shown in Figure 5-2. With an even distribution of the empty space the margin between subsystems is 6 mm. If more volume is required for a subsystem the responsible subsystem engineer must discuss the problem as soon as possible with the structural engineer to find a suitable solution.

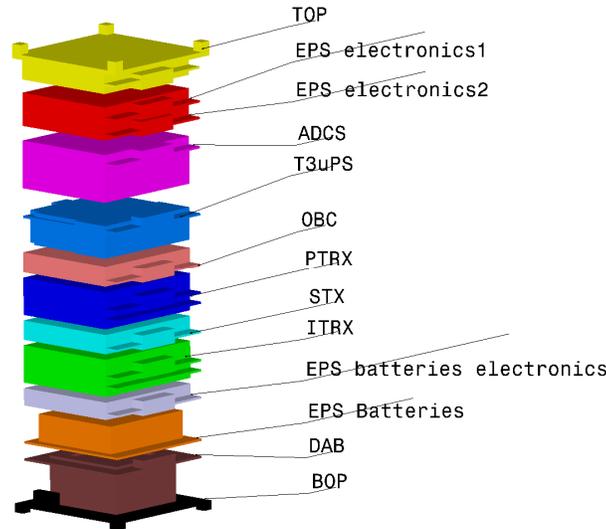


Figure 5-2: Delfi-n3Xt Volume budget

5.2 Placement of subsystems

Most subsystems require a specific placement in the satellite due to constraints of the subsystem or the whole satellite:

ADCS

A sun sensor is needed on each side of the satellite. Therefore, one sun sensor is placed in the TOP, one in the BOP and four on the U-profiles. The sun sensors on the U-profiles are preferred to be as low on the satellite as possible, to minimize reflections from the solar panels. The ADCS-PCB, with integrated reaction wheels, magnetorquers and magnetometers, has no placement requirements with respect to the z-axis.

COMMS

The Modular Antenna Boxes (MAB's) on the Deployable Antenna Board (DAB) are placed at the bottom of the satellite to avoid interference with the solar panels. The COMMS-PCB's have no strict placement requirements. They are positioned as low as possible on the satellite, such that the RF-wires to the DAB are as short as possible. The STX PCB is placed between the PTRX and the ITRX, to avoid interference between the two radios. The STX patch antenna is placed on the Y⁺-side of the satellite such that the attitude changes are minimal when switching between sun pointing, thruster pointing and STX-pointing. The STX patch is placed as low as possible on the satellite, to avoid reflections from the solar panels, right above the HDRM and temperature sensor board. The STX patch must be connected to the STX PCB through the STX-hole in the U-profile before the U-profiles installed.

EPS

The EPS electronics must as close as possible to the solar panels, such that the solar panel connectors can be easily connected to an EPS board when the satellite is fully assembled. The two EPS boards are kept together such that an electronic connection between the boards can easily be made. For these reasons the EPS electronics PCB's are placed right under the TOP. The batteries and batteries electronics are placed low in the satellites as explained below.

HDRM

The HDRM is placed low on the satellite to make the maximum deflections of the solar panels as low as possible.

OBC

The OBC has no placement requirements and is therefore placed on the last available spot in the middle of the satellite.

Payload T³μPS

The T³μPS must be in the center of mass when the solar panels are deployed. It is desirable to keep the center of mass around the center of the satellite, such that the position of the thruster can be easily adjusted to the center of mass of the finished satellite. The subsystems with the highest mass are the solar panels and the batteries. Therefore the batteries are placed in the bottom of the satellite to counteract the weight of the solar panels. The batteries electronics board is placed next to the batteries such that a simple connection can be made.

Payload SDM

The TOP is pointed towards the sun during sun-pointing mode, therefore the SDM is placed on a PCB below a hole in the TOP.

5.3 Design drawing

The design drawing (Figure 5-3) is used to give a visual representation of the latest state of Delfi-n3Xt. With the model it can easily be checked if all subsystems and payloads still fit nicely together. The model is constantly changing with the latest updates of the subsystems.

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 are included in the mass budget [SLR 0018]. In appendix A renderings of the Catia model can be found. In the coming paragraphs the different subsystems are discussed.

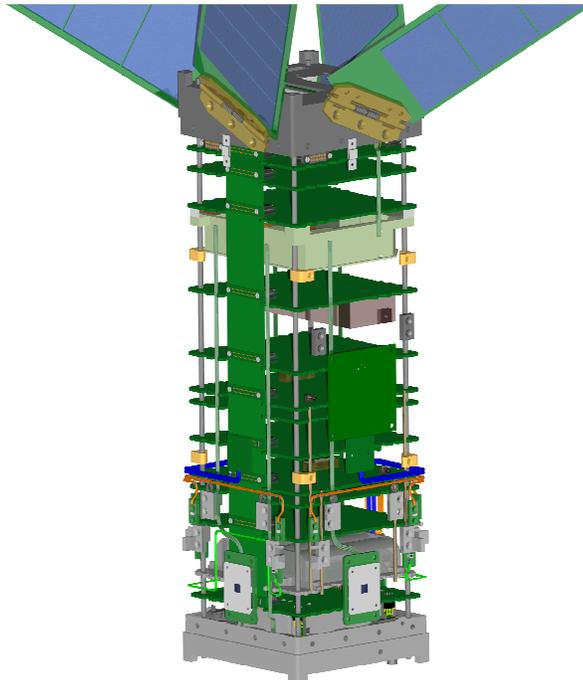


Figure 5-3: Delfi-n3Xt design drawing

5.3.1 Stack

The core of the satellite is a stack of PCB's fastened on threaded rods. A standard PCB is developed for all subsystems which allows for mounting of components. Details of the standard PCB can be found in section 6.6. The PCB's are electrically connected through a flex-rigid PCB (see section 6.9).

5.3.2 BOP

The Bottom Panel (BOP) is a rigid aluminium block to form a rigid structure together with the TOP and U-panels. The bottom plate provides openings for the kill switches and the MABs. For redundancy two kill switches 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 section 6.1.

5.3.3 DAB

The Delfi-C³ MABs are reused in Delfi-n3Xt. The four MABs of Delfi-n3Xt are fastened on the Deployment and Antenna Board (DAB) and go through the BOP. The DAB further facilitates the circuitry for phasing of the antennas and circuitry for the hold down and release mechanisms.

5.3.4 Communications boards

Delfi-n3Xt has three communication boards: ITRX, PTRX and STX (see also [SLR 0014]). The ITRX PCB will be very similar, if not identical, to the PTRX PCB; but to avoid confusion they will still be named separately. For communication Delfi-n3Xt is equipped with five antennas.

- Four antennas are connected on the antenna board and deployed through the BOP.
- One S-band antenna patch is implemented on the Y⁺-side of Delfi-n3Xt. The patch has a size of 50 mm x 50 mm x 1.6 mm.

To reduce the height of the communication boards smaller coax connectors have been chosen. The PTRX and ITRX use cooling blocks that are positioned on the PCB's inside its volume budget. An extra PCB is placed right under the main PCB of both the ITRX and the PTRX with a linear transponder. These PCB's are only connected to the main board with a Harwin connector and have no connection to the standard system bus.

5.3.5 Microthruster

To minimise the disturbance torques, caused by the microthruster, the thrust vector of the microthruster should go through the CoM. A CoM calculation was done with the latest mass budget [SLR 0018] and the microthruster is now fixed at its current location. As not all masses are known with great accuracy, it could be possible that the thruster has an offset to the CoM in the final assembled satellite. The CoM of the satellite will then be tuned to the thruster position by adding small weights at the TOP or BOP. The weight of the microthruster is a maximum of 140 g. For the nozzle a cut-out in the structure must be made. More information about the microthruster can be found in [SLR 0181].

5.3.6 ADCS

In the design drawing three reaction wheels, three magnetorquers and two magnetometers have been taken into account in accordance with [SLR 0142]. On top of the ADCS board an aluminium bracket is placed to mount the reaction wheels. On top of this a bracket of Polyoxymethylene (POM) is placed for mounting of the magnetorquers.

5.3.7 EPS

The EPS consists a batteries board and three electronics PCB's. The solar panels are considered as a separate system. Two PCB's are used for the maximum power point trackers and bus regulation and one for the

battery charging/discharging electronics [SLR 0265]. The batteries are mounted with an aluminium frame to the stack. A power connection with the solar panels is made on four sides of one of the electronics PCB's.

5.3.8 TOP

The Top Panel (TOP) has three openings; one opening for the DIMES SDM experiment, one opening for the sun sensor and one for the test connector. The TOP has support feet similar to the ones for Delfi-C³ to protect the satellite during launch. Furthermore the SPs are attached to the sides of the TOP. The SDM experiment is placed on a separate PCB in the stack which falls inside the TOP. A more detailed description of the TOP can be found in section 6.2.

5.3.9 Structure

The outer structure of the satellite is formed by 2 unsymmetrical U-profiles and two connection strips. The shapes are fastened with bolts and nuts at several places of the structure. The 2 U-profiles 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.

For launch, the solar panels are fastened to the outside of the structure. These are held down by the hold down and release mechanisms (HDRM's), which are placed on the outer structure. A more detailed description of the outer structure can be found in chapter 6. More details about the HDRM can be found in [SLR 0572].

5.3.10 Solar Panels

The satellite has four solar panels for power generation. The solar panels are attached to the sides of the TOP. The dimensions of a SP are 71 x 3.3 x 315 mm. The panels provide space for an array of seven solar cells on each side. Twelve wires are soldered to the solar panels which are connected to the EPS electronics board with a twelve pin Harwin connector. More information on the solar panels can be found in [SLR 572].

6 Design Details

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 0633]. Figure 6-1 shows the various elements of the STS. Additionally, the design of the standard PCB, sun sensors and flex-rigid PCB is also shown in this chapter.

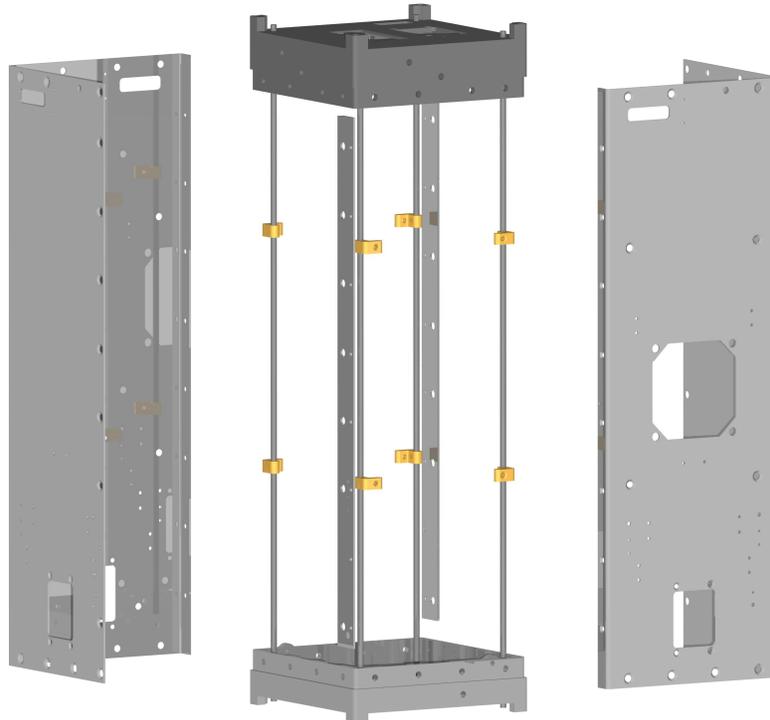


Figure 6-1: Elements of STS

6.1 BOP

Functions of the BOP are protection of components, adding stiffness to the satellite and acting as fastening point for components. To comply with these functions the BOP is designed as panel with raised sides on support feet.

The BOP (Figure 6-2) is situated on the Z-side of the satellite. The panel provides openings for four MABs, a sun sensor, and two kill switches. The opening for the MAB is rectangular 43 mm x 10 mm. This creates a spacing of 0.5 mm on each side of the MAB, needed for easy integration. The position of the openings is dependent on the fastening of the MABs on the DAB.

For the sun sensor a hole of 28x 24 mm is implemented with four holes with M2 Thread, centered between the MAB's.

For the kill switches two holes of 6 mm diameter are foreseen. The BOP is altered at the places of the kill switches for a secure mounting. The kill switch is attached with an M2.5 torxhead bolt into the BOP.

Further four holes are implemented for the fastening of the PCB-

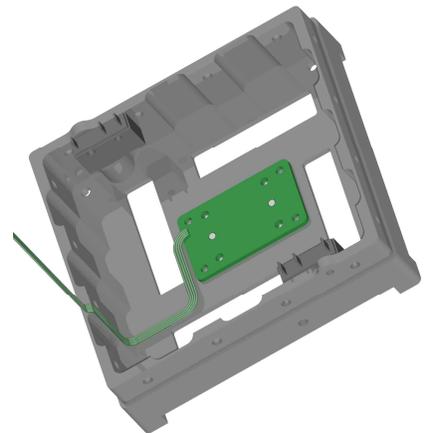


Figure 6-2: BOP with sun sensor and kill switches

stack. The threaded M3 rods of the stack are fastened with nuts. The head height of the M3 nut is 2.4 mm. Including 0.5 mm for an M3 washer and approximately 0.6 mm for the protrusion of the rod, this adds up to a height of 3.5 mm. To make sure nothing gets damaged or touches the POD besides the support feet, the support feet are chosen to be 4.5 mm.

The support feet have an inside rounding for tooling for the nut. 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-C³, such that the same MGSE can be used.

The X- and Y-sides of the BOP have two thicknesses. The upper part is 1 mm thinner than the lower part, so when the side panels are attached the side panels are flush with the lower part of the BOP. 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).

6.2 TOP

Functions of the TOP are similar to the BOP: protection of components, adding stiffness to the satellite and acting as fastening point for components. With similar functions to comply with, the design of the TOP (Figure 6-3) is comparable to the BOP, a panel with raised sides on support feet. Differences are in the details.

The top plate is situated on the Z⁺-side of the satellite. There are three openings in the TOP; one for SDM one for the test connector and one for a sun sensor. For the SDM experiment a hole of 18x 44 mm is made with chamfered sides to avoid reflections. A hole of 20x 9 mm is implemented for the connection of a test connector to the satellite. The hole for the sun sensor is identical as on the BOP. For attachment of the protection cover on the TOP, for both the SDM and the sun sensor, five holes with M2 thread are used.

As for the BOP (section 6.1) 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 nut. 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-C³.

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).

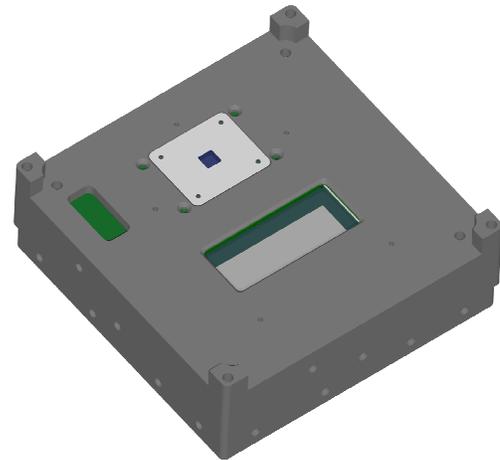


Figure 6-3: TOP with sun sensor and SDM

6.3 Outer Structure

The function of the outer structure is protection of subsystems and providing fastening for components. Further the outer structure needs to comply with the requirements as stated in paragraph 4.2.

To comply with the requirements, as design has been chosen two U-profiles fastened to each other by connection strips (see Figure 6-4). 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. 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 an outlet for the microthruster, a hole of 48 x 48 mm for the STX patch antenna and four holes for the sun sensors. The STX patch is positioned on the Y⁺ side. The hole for the microthruster must still be drilled, now that the final location is known.

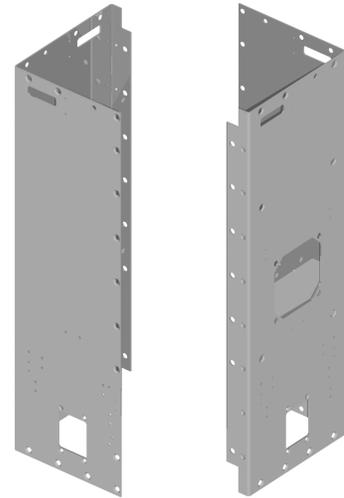


Figure 6-4: Outer structure

6.4 Midplane Standoffs

The midplane standoffs are used to connect the stack to the outer structure, such that the stack does not hit the outer structure due to launch vibrations. The midplane standoffs are small structural items, on one side constraint to the outer structure with a bolt. The standoffs are placed on each side at one third and at tow thirds of the satellite. 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 6-5: midplane standoff

6.5 Materials

The STS comprises several milled parts and several sheets. Milled parts are BOP, 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 6-1.

Table 6-1: Overview materials for STS parts

Part	Material	Surface Treatment
BOP	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 supplier and workshop staff. 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.

6.6 Standard PCB

A detailed drawing of the standard PCB (Figure 6-6) can be found in [SLR 633]. The standard PCB has a dimension of 90 x 90 mm, tie points excluded. In all corners an area of 8 x 8 mm is reserved for the mounting of the PCB in the stack. At the X⁺-side 19 mm is reserved for the Delfi Standard System Bus (DSSB).

At the X⁺-side an indent of 5 x 34 mm is made, such that the flex-rigid PCB that connects all PCB's in the stack falls completely within the 90 x 90 mm. Without an indent the pins in the flex-rigid PCB could make contact with the outer structure, causing a short circuit. Another advantage of the indent is that the sun sensor at the X⁺-side can now be placed in front of the flex-rigid PCB, at the same position as the sun sensors at the other sides.

Some wires between different subsystems, such as the wires from the sun sensors to the ADCS board and the RF cables from the communication boards to the DAB, have to be fixed to the stack to constrain the movement due to launch vibrations. A simple and effective way to do this is to tie these wires with a small piece of string through small holes in the PCBs. We don't want to decrease the available space for components on the PCB's. Therefore it was decided to place the holes on little bulges at the edges of the PCB. These bulges have a width of 2.5 mm, leaving 1.5 mm space between the PCB and the outer structure. There are spaces of 4 mm for small cable harnesses, for example the one used for the sun sensors. There are spaces of 2 mm for RF cables and other single cables. The mid-sections are left free for the sun sensors. Two corners are also free of tie points for the connection strips. There is room for extra cables to accommodate design changes. In this way the same subsystems can also be used on future missions.

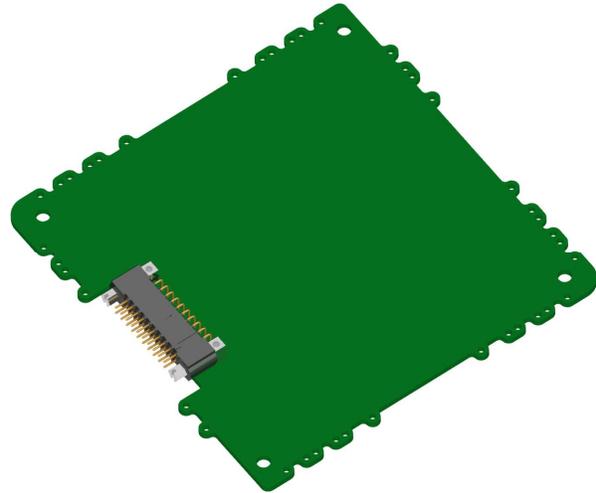


Figure 6-6: Standard PCB

6.7 Sun sensor housing

Delfi-n3Xt will have an identical sun sensor on the TOP, BOP and each side of the U-profiles. On the U-profiles is very little space for the sun sensors. On the inside of the satellite is 4 mm between the PCB stack and the U-profile. On the outside is a space of 3.65 mm between the solar panel and the U-profile. The sensor housing is designed such that it fits in this limited space. The sun sensor is shown in Figure 6-7. The sensor housing has size of 26.5 x 22.5 x 3 mm, therefore a hole of 27 x 23 is made on each side of the outer structure to accommodate these sensors. The wall thickness is 1 mm, therefore the sensor housing is 2 mm above the U-profiles; leaving 1.65 mm between the sun sensor and the solar panel. The PCB with sensor and electronics (the green part in Figure 6-7) is placed on the inside of the U-profile and has a thickness of 1.55 mm. This leaves 2.45 mm between the sensor-PCB and the PCB-stack. The sensor-PCB and housing are fastened with M 2.5 countersunk torx head bolts. The sun sensors are connected to the ADCS electronics board with four electronic wires per sun sensor. These wires are also drawn in the Catia model to ensure that it does not interfere with other components.

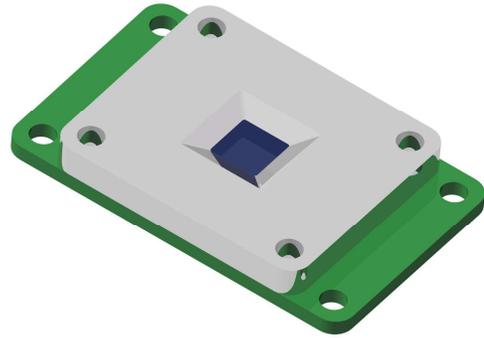


Figure 6-7: Sun Sensor

6.8 DAB

The DAB design has influence on the BOP and the HDRM, because both the MABs (that protrude through the BOP) and the HDRM connectors are placed on the DAB. Therefore the placement of the MABs and the connectors on the DAB was done by the author (see Figure 6-8).

The MABs are placed in a “square” configuration for an optimal antenna configuration. The relative position of the antennas cannot be changed, but the placement of four antennas together can be changed. At the X⁺ side of the DAB a 20 pins connector is placed for the standard system bus, which position cannot be changed. Therefore the MABs are shifted 4 mm towards the X⁻ side, such that the connector and the MAB do not interfere. At the Y⁺ side of the DAB the RF-connectors are placed for connections to the radios. This leaves only the Y⁻ side and the X⁻ side for the HDRM connectors.

In the original design of the U-profiles the X⁺ side and the Y⁺ side were combined in one U-profile and the X⁻ side and the Y⁻ side were combined in the other U-profile. This would result in a problem during integration, because then both HDRM connectors are placed behind a single U-profile. In this case the connector from one U-profile can be covered by the other U-profile, such that integration is only possible in one particular sequence. For Delfi-n3Xt it is very desirable that each U-profile can be assembled independently from the other U-profile, to simplify integration and testing. Therefore the U-profiles were changed such that the X⁺ side and the Y⁻ side are combined in one U-profile with a connector at the Y⁻ side and the X⁻ and the Y⁺ side are combined in the other U-profile with a connector at the X⁻ side.

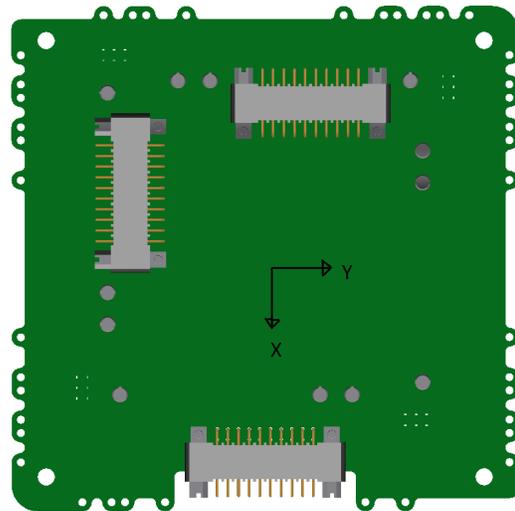


Figure 6-8: DAB

6.9 Flex-rigid PCB

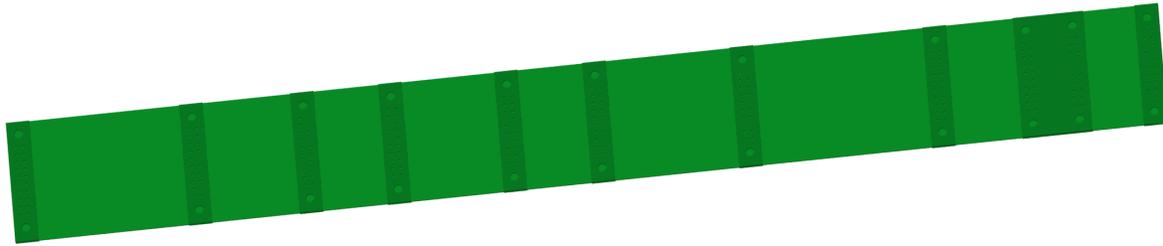


Figure 6-9: Flex-rigid PCB

The subsystem PCBs are electrically connected with a flex-rigid PCB. Rigid parts of 6x32 mm are used to connect the flex-rigid PCB to the connectors. An M2 screw is placed through the holes of these parts to make a firm connection to the subsystems. The screws from the connectors can not be used, because they are not long enough when a PCB of 1.6 mm is added. Between these rigid parts there are flexible parts with some extra length, such that these parts bent 4 mm to the inside of the stack. In this way it is ensured that no stresses can develop on the solder joints. To calculate the extra length needed a simple model of the flex is used with two straight lines as shown in Figure 6-10. The length of the flex part can be calculated by using Pythagoras' theorem:

$$L_{flex} = 2 \cdot \sqrt{(L/2)^2 + 4^2} \tag{6.1}$$

The resulting flex lengths are shown in Table 6-2. The minimum extra length is set to 1 mm such that the flexible parts are never under tension even with small PCB mounting inaccuracies in the order of 0.1 mm. The aluminium structure has a thermal expansion coefficient of $23 \cdot 10^{-6} \text{ m/Km}$. When assuming that the PCBs in the stack deform with the structure, the difference in length for the largest flex part with a temperature difference of 70 K will be:

$$\delta = 23 \cdot 10^{-6} \cdot 42.5 \cdot 70 = 0.07 \text{ [mm]} \tag{6.2}$$

Therefore the 1 mm extra length is also sufficient to account for thermal expansion and compression. The drawing of the flex-rigid PCB can be found in the design drawings [SLR 0633].

Table 6-2 : Length of Flex parts

Length between connectors [mm]	Length of flexible part [mm]	Extra length [mm]
10,5	13,2	2,7
15,2	17,2	2,0
42,5	43,5	1,0
30,9	31,9	1,0
14,6	16,6	2,0
22,4	23,8	1,4
14,6	16,6	2,0
21	22,5	1,5
37,5	38,5	1,0

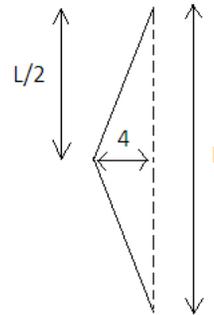


Figure 6-10: Model used to calculate length of flex parts

7 Verification analysis and tests

In this chapter it is verified that 2 mm is a safe margin between subsystems and that the structure can withstand the launch loads.

7.1 Launch loads

For the random vibration on component level, a quasi static launch load of 65g was used, which is based on the calculations done by Jennifer Go [SLR 0604]. This load factor is rather high and resulted in too large deflections of the solar panels.

A load factor of 25g is a more realistic value for quasi static loading on component level, based on a structural workshop report from Delfi-C3 [SLR 0529]. In this report the root mean square value of random loads during launch is calculated using the Power Spectral Density curve from the DNEPR launcher. This resulted in a load of 8.36g. The design loads for all components will then be the 3σ value: 25g. A design load of 25g will now be used for all components.

7.2 PCB deflection

To have a decent model for the margin between the different subsystems, calculations have been done for the deflection of a PCB during worst case vibration. A test was performed to validate these calculations and a comparison was made [SLR 0991]. A PCB has been taken, since the majority of subsystems make use of a PCB to fasten components. A minimal margin between subsystems is preferable for Delfi-n3Xt, such that there is much space available for subsystems. The minimal preferred margin is 2 mm between each subsystem.

The results were the following: with an applied load of 89.3 N at the center of the PCB, which represents a PCB of 140 grams under a quasi static load of 65g, the deflection is 1.15 mm in the calculations and 1.05 mm in the test.

There are two reasons for the difference between these values. The first one is inaccuracies in the model used for the calculations, especially the assumed boundary conditions which were not fully representable for the real PCB. The second reason is that the PCB has copper layers at the outside of the PCB. Copper has a higher modulus of elasticity than FR4 (117 GPa versus 17.5 GPa); therefore the copper layers increase the stiffness of the PCB. However, the difference is small and therefore the model can be used for other calculations. In the case of a distributed load on the PCB, which is the case for most PCB's because its mass is evenly distributed, the deformation is only 0.42 mm.

With a design load of 25g, the deflections reduce to 0.40 mm for a concentrated load at the midpoint of the PCB and to 0.16 mm when the mass is evenly distributed.

It can be concluded that the deformations of the PCB's in the stack due to launch vibrations are very small even for the PCB's with heavy components in the middle of the PCB. The minimum margin of 2 mm between the PCB's (with components) in the stack is a safe margin and is recommended for Delfi-n3Xt and future missions.

7.3 Verification outer structure

The TOP and BOP are very rigid aluminium blocks and their deformation due to launch loads can be neglected. However, the outer structure is made of thin aluminium sheet and could possibly fail under high launch loads. Therefore calculations are made to prove that the structure does not fail due to buckling and that that the natural frequency is high enough to avoid resonance.

7.3.1 Buckling and compression strength

When making a verification calculation for the STS, it can crudely be analysed as a square hollow tube of width $b=100$ mm, length $L=340.5$ mm and wall thickness $t=1$ mm. The tube is loaded under compression; therefore buckling or compression failure is the critical failure mode. The outer structure can be modelled as an ideal column with clamped supports, because the satellite is clamped inside the launch POD. The maximum load the structure can take until buckling will be [Hibbeler, 2004]:

$$P_{cr} = \frac{4\pi^2 EI}{L^2} \quad (7.1)$$

Where the moment of inertia will be:

$$I = \frac{1}{12}(b^4 - (b-2t)^4) = \frac{1}{12}(0.1^4 - (0.1 - 2 \cdot 0.001)^4) = 6.5 \cdot 10^{-7} \text{ [m}^4\text{]} \quad (7.2)$$

With the modulus of elasticity $E=70$ GPa for aluminium, the critical load will be:

$$P_{cr} = \frac{4 \cdot \pi^2 \cdot 70 \cdot 10^9 \cdot 6.5 \cdot 10^{-7}}{0.34^2} = 15.2 \text{ [MN]} \quad (7.3)$$

With a yield strength of 195 MPa for aluminium 5083 [eFunda Inc., 2012]; the critical load until compression failure will be:

$$F = \sigma \cdot A = 195 \cdot 10^6 \cdot 40 \cdot 10^{-6} = 7.8 \text{ [kN]} \quad (7.4)$$

So the critical failure case will be compression failure, not buckling. With the highest load of 10.5g during launch [SLR 1008] and a satellite of 3 kg, the maximum load will be:

$$P_L = 3 \cdot 10.5g = 3 \cdot 10.5 \cdot 9.81 = 309 \text{ [N]} \quad (7.5)$$

Comparing these two loads shows that the structure can withstand the launch loads easily. The real structure is somewhat weaker, because it is made out of two parts and there are some holes added. However, the difference between the loads is so large that the real structure can still withstand the loads easily.

A finite element model of the complete structure was developed by [Boersma and Vielvoye, 2009]. The structure has changed since then, but the strength of the structure has increased since the large holes of the MPS were replaced by smaller holes of the sun sensors and STX. The conclusion of this analysis was that the highest loads in the structure due to static and dynamic loads were in the order of 1 MPa, which is well below the yield strength of 195 MPa.

As both the calculations above and the finite element model show that the launch loads can be easily sustained by the structure, no more strength calculations are necessary.

7.3.2 Natural frequency

The lateral and longitudinal natural frequencies are calculated for the structure with the formulas given in [SLR 0373]. The lateral natural frequency with a clamped-clamped structure will be:

$$f_b = \frac{1}{2\pi} \sqrt{\frac{24EI}{ML^3}} = \frac{1}{2\pi} \sqrt{\frac{24 \cdot 70 \cdot 10^9 \cdot 6.5 \cdot 10^{-7}}{3 \cdot 0.3405^3}} = 483 \text{ [Hz]} \quad (7.6)$$

With the cross sectional area A taken as $4bt$; the longitudinal natural frequency will be:

$$f_l = \frac{1}{2\pi} \sqrt{\frac{EA}{ML}} = \frac{1}{2\pi} \sqrt{\frac{70 \cdot 10^9 \cdot 4 \cdot 0.1 \cdot 0.001}{3 \cdot 0.3405}} = 833 \text{ [Hz]} \quad (7.7)$$

The stiffness of the satellite is far higher than the minimum stiffness requirement of 20 Hz in each direction (SAT.2.4-P.01, see section 4.5). These formulas assume the mass of the entire satellite is uniformly distributed over the STS. When the mass decreases, the natural frequency increases. Also taking a more complicated model only increases the cross sectional area or the moment of inertia, further increasing the natural frequency.

8 Interfaces

Since the structure 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 can be found in the ICD's for the external partners: T³μPS [SLR 0181], ITRX [SLR 0192] and SDM [SLR 0204]. All other subsystems have to apply to the volume budget. Some subsystems (or components) that are not placed in the stack, such as the HDRM, sun sensors and solar panels are not mentioned in the volume budget and are therefore mentioned here.

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.
- 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, TOP and connection strips need to be revised.
- Hinges -> the placement of fastening holes in the BOP and the solar panels need to be revised.
- HDRM -> the placement of holes in the U-profiles need to be revised.

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

8.2 Subsystem location changes

Changes of subsystems in Z-direction have influence on placement and fastening. The fastening holes for the connection strips must be between PCB's from the stack to avoid interference.

Change in Z-direction for:

- 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.
- Sun sensors -> the location of the holes in the U-profiles for the sun sensors need to be revised.
- STX -> the location of the hole in the U-profile for the STX needs to be revised.
- EPS electronics -> the location of the holes in the U-profiles for the solar panel wires need to be revised.

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.

9 Integration plan

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.

First some sub-assemblies can be made before total assembly:

- A sun sensor and two kill switches can be fastened to the BOP. The sun sensor must be covered with a protection cover.
- A sun sensor can be fastened to the TOP. The protection cover for the sun sensor and SDM cover can be installed.
- The U-profiles can be integrated with HDRMs and all wires must be taped to the inside of the U-profiles.
- The solar panels can be fastened to the hinges.

The assembly starts at the middle of the threaded rods to minimize the length that the nuts have to travel. The stack is loosely built up from the PTRX to the BOP; the exact location is not yet important. Afterwards the subsystems are secured in their right location from BOP to PTRX. The total assembly has to take place in this order:

1. Assemble the threaded rods to the PTRX.
2. Build the stack up from PTRX to BOP.
3. Attach the stack to the BOP and make sure that the subsystems are fastened exactly at their location from BOP to PTRX.
4. Build the stack further up until the SDM experiment.
5. Install the flex-rigid PCB.
6. Assemble the TOP to the stack.
7. Connect all six sun sensors to the ADCS board; the wires must be fastened to the tie points on the PCB's in the stack.
8. Connect the STX patch antenna to the STX PCB through the STX hole, then screw the U-profile to the BOP and TOP, leaving open the X⁺-side.
9. Screw the STX patch to the U-profile
10. Screw the sun sensors to the structure and attach protection covers.
11. Fasten the second U-profile.
12. Fasten the remaining sun sensors to the U-profiles and install the protection covers.
13. Assemble the solar panel assembly with the TOP. Connect the solar panel cables to the EPS board. Screw a wire clip to the structure to hold the cables in the right position. Fold in the solar panels and hold them with the HDRMs.
14. Place the solar panel protection covers.

10 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.

10.1 Mechanical testing

As can be read in paragraph 4.7 T³_{μPS} 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-C³ can be found for:

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

10.2 Vibration and shock tests

Before launch the satellite needs to undergo a vibration and a shock test. These tests will be performed with the satellite in the ISIS Test Pod. Of importance for the STS is to show that the STS is correctly designed and has enough strength and stiffness to fulfil the mission lifetime.

10.3 Thermal vacuum test

A thermal vacuum test will be performed simulating the space environment with hot-cold cycles. With the temperature sensors in the satellite a temperature profile of the satellite can be created to validate the thermal model [SLR 0616]. In addition the subsystems are tested in a hot and a cold environment.

11 Mechanical Ground Support Equipment

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-C³ (DC3). Where needed adaptations to the designs are proposed. The MGSE has been subdivided into three categories:

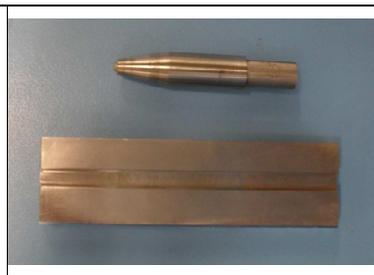
- manufacturing tools (Section 11.1),
- Assembly, Integration, Verification and Testing (AIVT) tools (Section 11.2), and
- protection covers (Section 11.3).

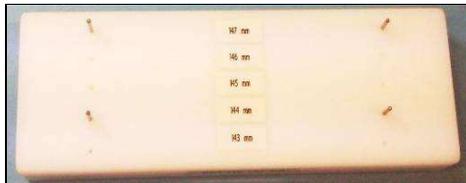
11.1 Manufacturing Tools

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 11-1 shows the manufacturing tools foreseen for Delfi-n3Xt. Figure 11-1 to Figure 11-5 give an overview of the manufacturing tools developed for Delfi-C³, which are going to be used for Delfi-n3Xt. For Delfi-n3Xt a different press nuts are used and a new press nut tool has been made.

Table 11-1: Overview Manufacturing Tools

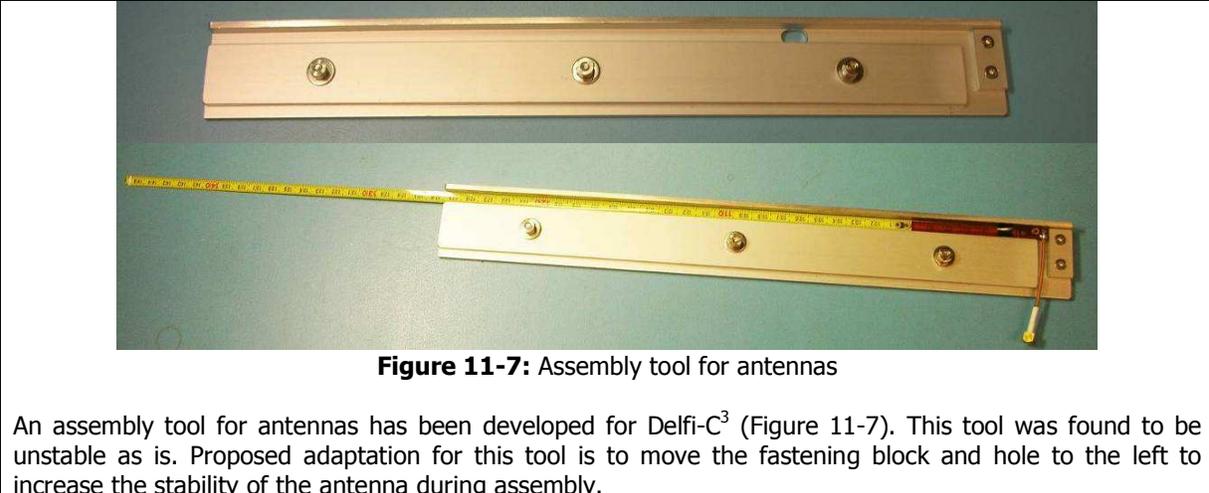
Tool	Inherit DC3 Modification	
Solar panel Deployment Spring (Figure 11-1)	Yes	Adjust to increased deployment angle
Press nut instalment (Figure 11-2)	No	Press with adjustable pressure level needed [SLR 0597]
Wire length hold down system (Figure 11-3)	Yes	No
Antenna winding (Figure 11-4)	Yes	No
MAB instalment (Figure 11-5)	Yes	No
Antenna drill jig (Figure 11-6)	Yes	No
Antenna assembly (Figure 11-7)	Yes	Move fastening block and hole

	<p>The springs in Delfi-C³ have been handmade with a manufacturing tool (Figure 11-1). This tool can be used for Delfi-n3Xt without adaptations.</p> <p>Figure 11-1: Solar panel deployment spring tool</p>	<p>A new tool for instalment of press nuts has been made for Delfi-n3Xt (Figure 11-2). This tool must be inserted into a press bench.</p> <p>Figure 11-2: Press nut instalment tool</p>	
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	<p>This tool (Figure 11-3) has been developed to get the correct wire length needed for the hold down system of Delfi-C³. This tool can be used without further adaptations for Delfi-n3Xt.</p> <p>Figure 11-3: Wire length tool for hold down system</p>
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	<p>The wind tool (Figure 11-4) was developed for Delfi-C³ to roll the MAB antennas easily [SLR 0308]. A similar tool will be used for Delfi-n3Xt.</p> <p>Figure 11-4: Wind tool for MABs</p>	<p>The MAB instalment tool (Figure 11-5) has been developed for Delfi-C³ to easily integrate the antenna in the MAB [SLR 0308]. This tool will be reused for Delfi-n3Xt without further adaptation.</p> <p>Figure 11-5: MAB instalment tool</p>	
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<p>A drilling tool (Figure 11-6) has been developed for the antennas of Delfi-C³ [SLR 0308]. This tool can be reused for Delfi-n3Xt without adaptations.</p>	 <p>Figure 11-6: Drill jig for antennas</p>
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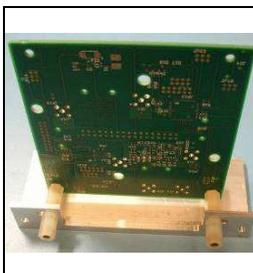
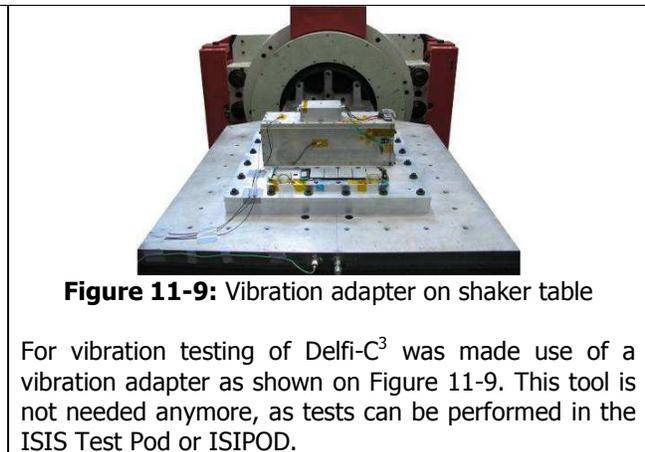
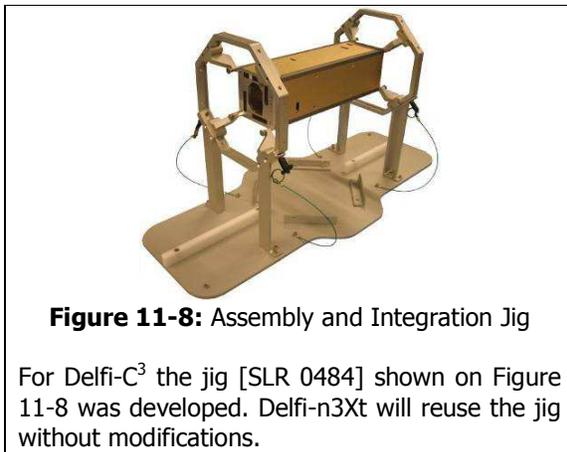
 <p>Figure 11-7: Assembly tool for antennas</p> <p>An assembly tool for antennas has been developed for Delfi-C³ (Figure 11-7). This tool was found to be unstable as is. Proposed adaptation for this tool is to move the fastening block and hole to the left to increase the stability of the antenna during assembly.</p>
--

11.2 AIVT Tools

Delfi-n3Xt is the same size as Delfi-C³. Most of the AIVT tools of Delfi-C³ 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 11-2 gives an overview of the AIVT tools and what level of modification is necessary. Figure 11-8 to Figure 11-12 show which AIVT tools of Delfi-C³ will be reused for Delfi-n3Xt. It is not sure if the vibration adapter can be changed to fit Delfi-n3Xt (TBD).

Table 11-2: Overview AIVT

Tool	Inherit DC3 Modification	
Jig (Figure 11-8)	Yes	No
Vibration adapter (Figure 11-9)	No	Use ISIPOD instead
PCB stands (Figure 11-10)	Yes	No
Handling tool (Figure 11-11)	Yes	No
Grounding tool (Figure 11-12)	No	Facilitate grounding point on satellite for fastening by a bolt



For testing of PCBs a PCB stand (Figure 11-10) was developed [SLR 0484] for Delfi-C³. Delfi-n3Xt will reuse the stands without modifications.

For Delfi-C³ a handling tool (Figure 11-11) for putting the satellite in the CubeSat deployer was developed [SLR 0484]. This tool can be reused for Delfi-n3Xt without making adjustments.

Figure 11-11: Handling tool



To ensure comparable test conditions at different locations and to avoid short-circuits the satellite needs to be electrically grounded. Delfi-C³ made use of a clip for grounding. Delfi-n3Xt will make use of bolts for grounding as shown on Figure 11-12. A hole for grounding has been implemented in the BOP.

11.3 Protection Covers

Protection covers function to protect fragile components from damage, contamination and make handling during AIVT-phases easier. Elements of Delfi-C³ for which protection covers were developed (see [SLR 0484] for more information) are the solar cells and Sun sensor. Since Delfi-n3Xt is equipped with more solar cells and different sensors and components needing covers, the covers of Delfi-C³ cannot be reused and new covers were developed by Patrick Kooijman [SLR 0931].

11.4 Facilities

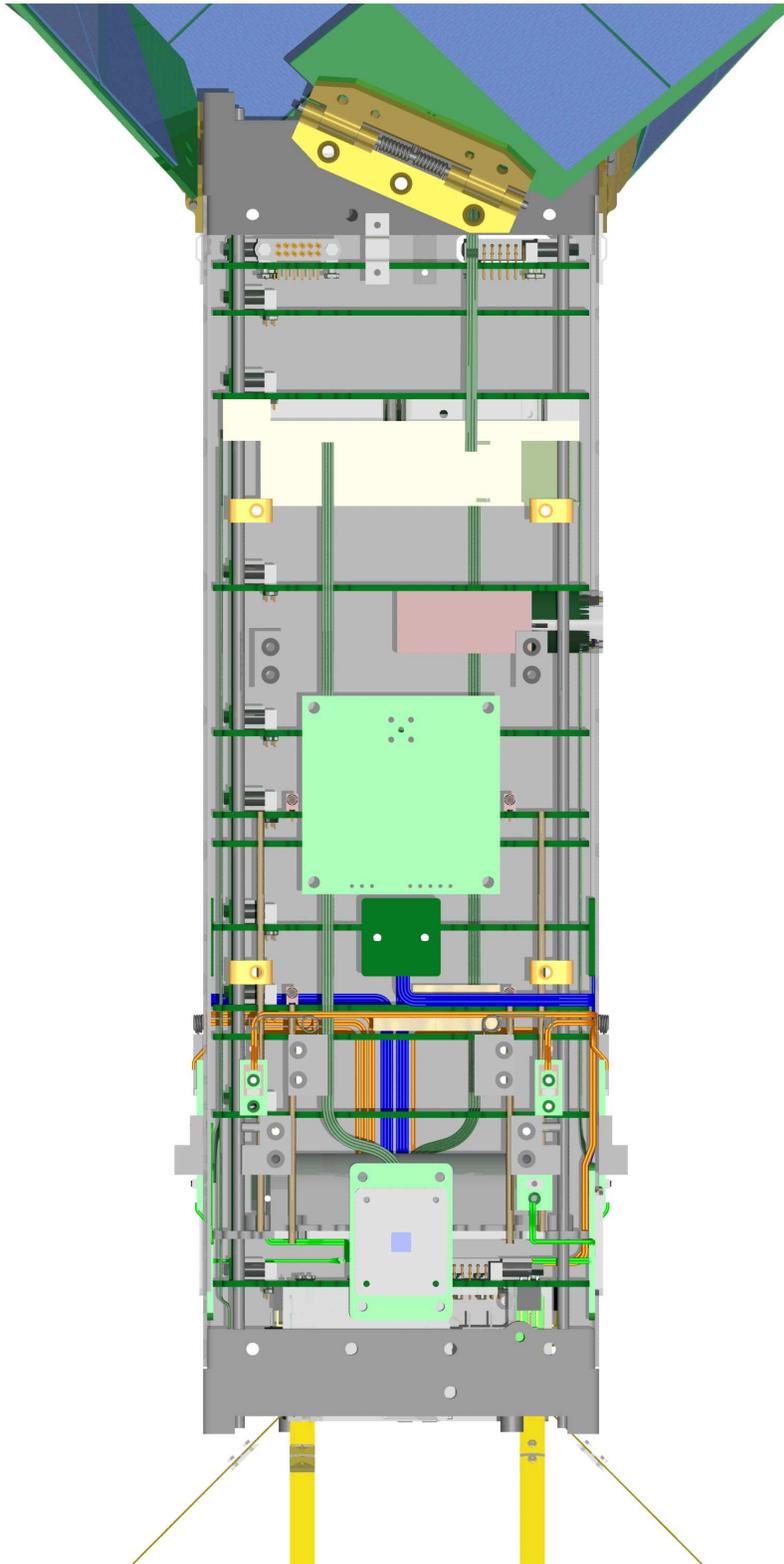
Baseline for AIVT is working in cleanroom of the Faculty of Aerospace Engineering in Delft. The cleanliness of the cleanroom is class 100.000. When other facilities are needed for e.g. tests, the cleanliness level for these facilities needs to be taken into account.

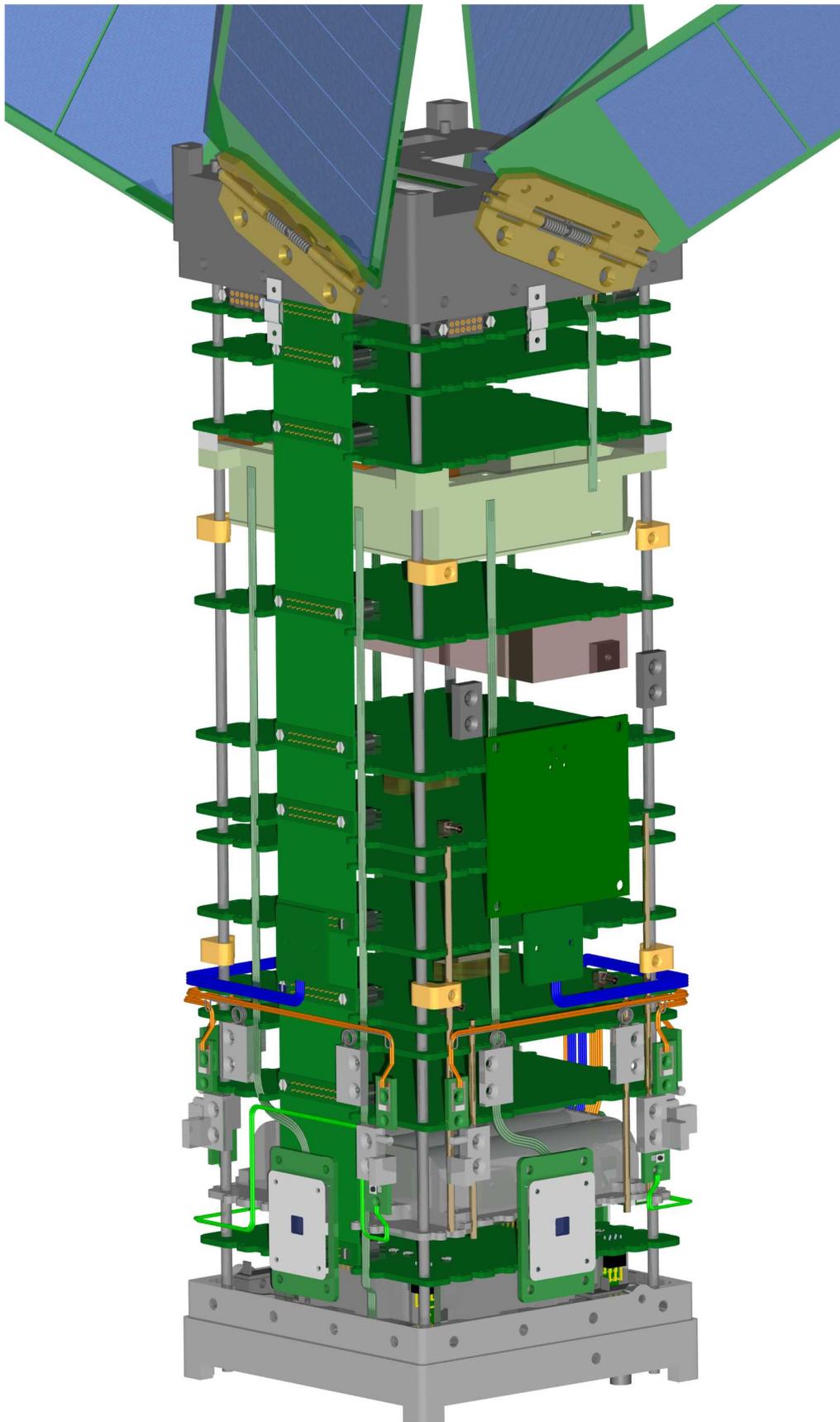
12 Next Steps

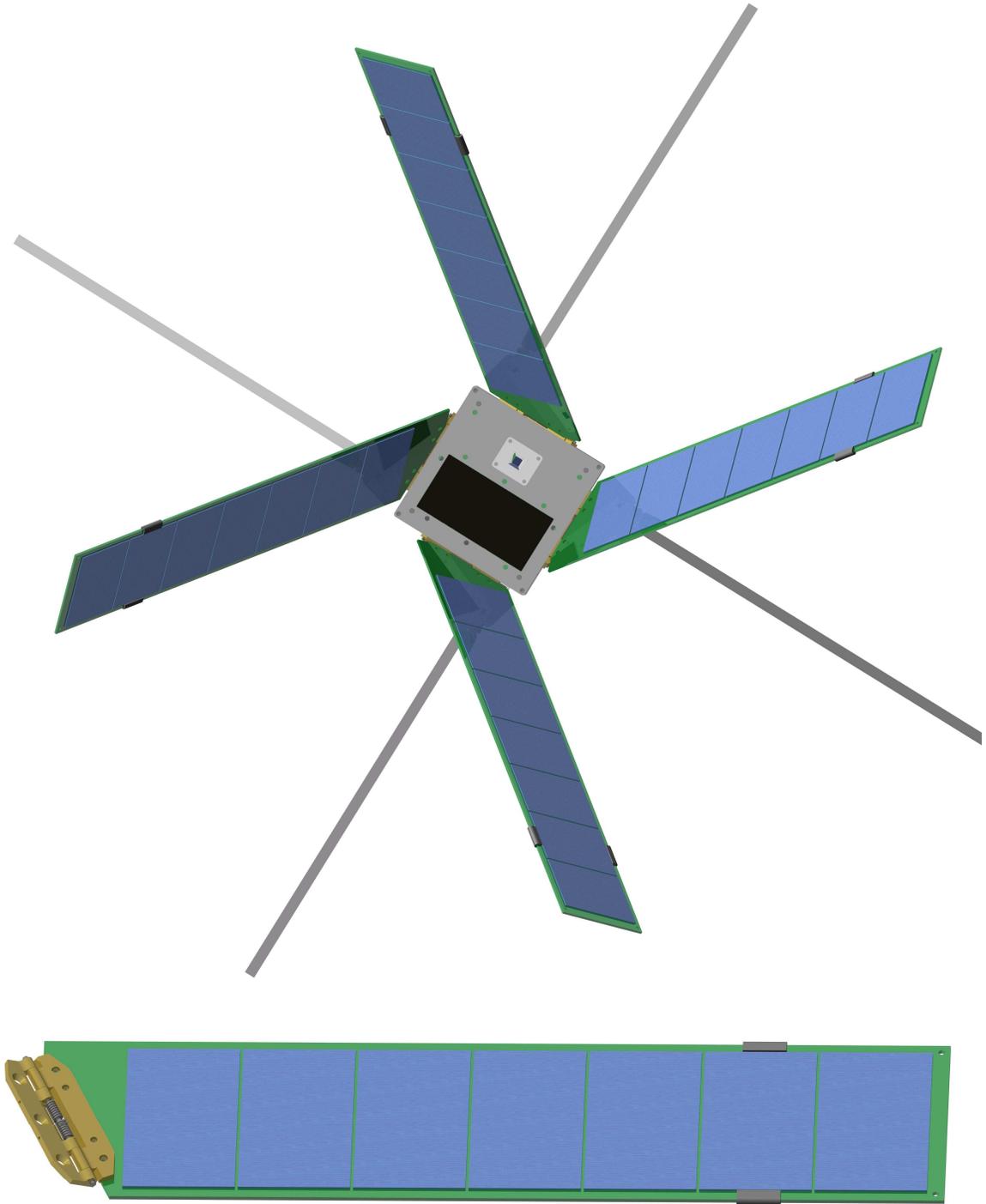
Future steps with respect to the structural subsystems are:

- Production of all parts
- Integration of complete structure. It must be checked if the integration works as intended.
- Now that the location of the microthruster is known, the hole for the thruster can be drilled.
- Perform mechanical tests, vibration and shock test and thermal vacuum test of complete satellite.

A Delfi-n3Xt Renderings







MechS – Design of Mechanical Systems

Description: The design of mechanical systems for the Delfi-n3Xt including hinges, solar panel and hold down and release mechanism.

Subsystem(s) involved:	ADCS	CDHS	COMMS	EPS	MechS	STS	TCS	ITRX	MPS	T³μPS	SDM	Splash	GSE	GSN	Launch
				x	x	x									

Revision Record and Authorization

Issue	Date	Author / Editor	Reviewer checked	PM approved	Affected Section(s)	Description of change
0.1	27-03-2009	Y. Awchi				
0.3	08-05-2009	Y. Awchi				
1.0	17-06-2009	Y. Awchi	GB	JB		
2.0	16-05-2011	J.P. de Jong			2.7	Redesign hinge
					3.9	Redesign HDRM
					Appendix A	SMD resistor test
					Appendix B	Design drawings
2.1	19-10-2011	J.P. de Jong			all	General update to latest project status
2.2	14-04-2012	J.P. de Jong	GB		all	General update to latest project status
2.3	06-06-2012	J.P. de Jong			6.2.1	Description clarified

Action Items

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

List of Used References

SLR code	Version	Data/Variable
0554	1.0	ISI-POD dimensions
0632	1.0	Design of Mechanical Systems
0633	5.3	Delfi-n3Xt - STS - Structural Drawing (CATIA)
0789	1.0	Inconsistent Melt Performance by 750hm Resistors
0474	1.0	Delfi-C3s electrical power system and its thin film solar cell payload
0863	1.0	EPS - Solar Array Configuration Analysis
0964	-	FR4 Glass/Epoxy Properties
0299	2.0	Dnepr User's Manual
0485	1.0	Design and development of Delfi-C3s deployment control system

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1 Introduction

This document contains the development of several mechanical parts of the Delfi-n3Xt.

The most important group for this document is that of the solar panel assembly, consisting of the hinge, Hold Down and Release Mechanism (HDRM), deployment sensor and solar panel. The requirements for these systems are set up in chapter 2. The design of the new hinges is shown in chapter 3. Chapter 4 covers the redesign of all HDRM parts from Delfi-C3 and the position and the wiring of the HDRM. In chapter 5 the type and position of a sensor is discussed, that has to confirm the deployment of the solar panel. In chapter 6 an analysis of the solar panel is made to see if the solar panel has enough stiffness and has a natural frequency that is high enough to survive the launch vibrations. The results of solar panel deployment tests are discussed in chapter 7.

The Modular Antenna Boxes (MABs) (chapter 8) is a group which has limited amount of work due to use of almost the same MABs as on the Delfi-C³. The document finishes with the conclusions and recommendations (chapter 9) and next steps (chapter 10).

1.1 Goals

For this technical note goals can be set for the solar panel assembly which consist of four parts:

- the hinge system
- hold down and release mechanism
- deployment sensor
- Solar panel

For each part the goals are as follows:

Hinge system

Design a hinge system which will fix the solar panel at 147 degrees. The hinge must be small enough to fit inside the envelope which is set by the launch canister.

- Set requirements for the hinge system
- Make a trade-off to find the best concept
- Calculate whether the hinge is able to withstand the possible loads
- Design the hinge using CATIA
- Write a test plan for the hinge
- Produce the hinge

HDRM

- Redesign the hold down and release mechanism. The mechanism must be able to hold down the panel during launch and to release it after deployment from the canister.
 - Set requirements for the HDRM
 - Investigate the bottlenecks
 - Find the required solutions
 - Set the HDRM wiring route

Deployment sensor

- Investigate whether the deployment sensing system of the Delfi-C³ can be improved by using a different sensor type.
 - Set requirements for the sensor
 - Investigate possibilities
 - Set the wiring route

Solar panel

- Design a solar cell substrate which can hold 7 solar cells of 39 x 66 mm. The substrate must be able to situate the necessary provisions of the cells.
 - Set requirements for the substrate
 - Make detail design
 - Calculate whether it withstand the possible loads

2 Requirements

Requirements for the mechanical systems of Delfi-n3Xt have been set up. The numbering of the requirements has been done using the system explained in [SLR 0317]. The complete list of requirements for the satellite and its subsystems can be found in [SLR 0167]. This chapter explains the requirements for the mechanical systems.

2.1 Top Level Requirements

Table 2-1: Constraints for all Delfi-n3Xt systems

Category	Req. #	Requirement
CONSTRAINT	SAT-C.01	All satellite systems shall comply with the mass budget, as given in [SLR 0018].
CONSTRAINT	SAT-C.02	All satellite systems shall comply with the volume budget, as given in [SLR 0303].
CONSTRAINT	SAT-C.03	All satellite systems shall comply with the power budget, as given in [SLR 0017].
CONSTRAINT	SAT-C.04	All satellite systems shall comply with the data budget, as given in [SLR 0282].
CONSTRAINT	SAT-C.05	All satellite systems shall comply with power and data bus interfaces, as specified in [SLR0287] and [SLR0565].
CONSTRAINT	SAT-C.06	All satellite systems shall be able to withstand the launch environment [SLR 1008].
CONSTRAINT	SAT-C.07	All satellite systems shall be able to withstand the space environment [SLR 1008].
CONSTRAINT	SAT-C.08	All satellite systems shall comply with the thermal budget, as given in [SLR0872] and to vacuum conditions without outgassing or structural degradation.

These constraints apply for all Delfi-n3Xt systems and are explained in [SLR 0263].

2.2 Functional requirements

Table 2-2: Functional requirements

Category	Req. #	Requirement
FUNCTIONAL	SAT.2.7.1-F.01	The hinge must deploy the SP after separation from the POD and fix the SP at 147 degrees.
FUNCTIONAL	SAT.2.7.2-F.01	The HDRM must keep the panel down until separation from the POD and allow the panel to deploy after separation.
FUNCTIONAL	SAT.2.7.3-F.01	The deployment sensor must report deployment status after separation from the POD.
FUNCTIONAL	SAT.2.7.3-F.02	The deployment sensor must be able to work on 12V.
FUNCTIONAL	SAT.2.7.4-F.01	The solar panel must provide space for 7 solar cells on each side of the panel.
FUNCTIONAL	SAT.2.7.4-F.02	The solar panel must provide attachment points for MGSE to protect the cells.

The solar panel together with the hinge, HDRM and deployment sensor form one integrated system that holds the solar panel in place during launch and deploys the solar panel after separation from the POD. The function of each part is covered in these requirements.

2.3 General Requirements

Table 2-3: General requirements

Category	Req. #	Requirement
GENERAL	SAT.2.7-G.01	All items identically numbered shall be designed to be interchangeable in function and dimension.

In the design of the mechanical systems, for simplicity and transparency during assembly and integration, holds that identically numbered items are interchangeable in both function and dimension.

2.4 Constraints

Table 2-4: Constraints

Category	Req. #	Requirement
CONSTRAINT	SAT.2.7-C.01	The total package of hinge, solar panel and HDRM must be fitted in the red area in Figure 2-1.

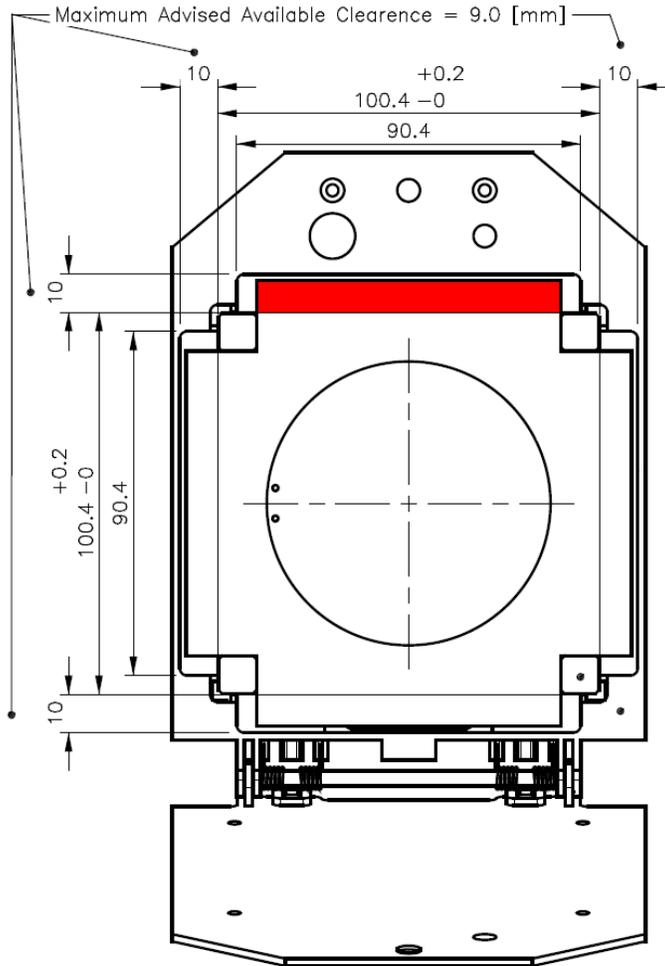


Figure 2-1: ISI-POD

3 Hinges

In this chapter the design of the hinges of Delfi-n3Xt will be discussed. The hinge is based on a previous design shown in appendix B.

A redesign of the hinges is made as a consequence of the new solar panel configuration. The hinge now deploys at an angle of 147 degrees instead of the old 90 degrees. First it was considered to change only the structure leaf, such that the old hinges already in stock could be altered to the new design at minimal costs (Figure 3-1). However, too little material was left to block the hinge in the deployed position. This could result in an inaccurate deployment angle due to deformation of the material or manufacturing tolerances. Therefore it was decided to change both leafs of the hinge.

Much work is already performed on an optimal hinge design; therefore the new design is very similar to the old one. The new design is shown in Figure 3-2. The dimensions can be found in the design drawings [SLR 0633].

The thickness of the structure leaf is increased to 2 mm, to make sure that the bolts can be completely countersunk. The total thickness of the hinge has increased to 4.5 mm, such that the highest parts on the outside of the structure are 8.6 mm. The maximum allowable height of parts on the outside of the structure is 9 mm for the ISI-POD.

The hinge was tested many times during the deployment tests described in chapter 7. During these test the hinge worked as intended.

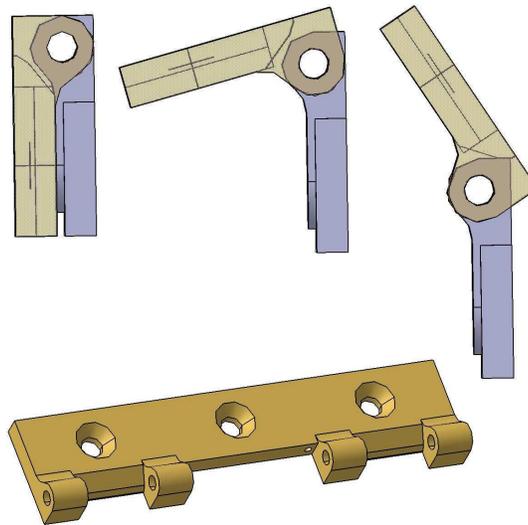


Figure 3-1: Changed structure leaf

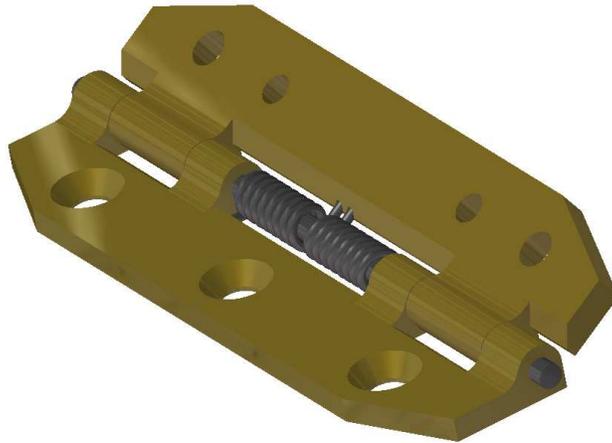


Figure 3-2: New hinge design

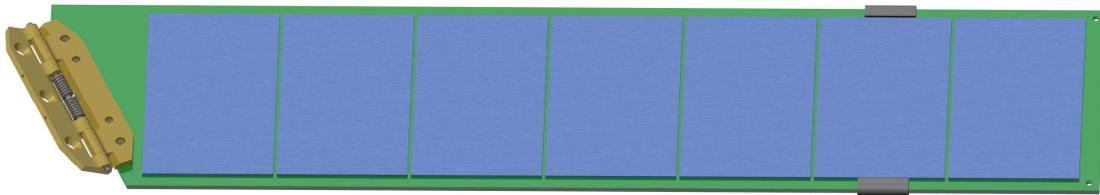


Figure 3-3: Hinge solar panel assembly

4 Hold Down and Release Mechanism

In this chapter the adaptations of the design of the Hold Down and Release Mechanism (HDRM) are discussed. On the Delfi-n3Xt 4 HDRMs on each side of the satellite ensure that the 4 panels are held down and released according to the OnBoard Computer (OBC) signals.

The complete Hold Down and Release Mechanism (HDRM) was already devised for the Delfi-C³. The baseline design was done by an InHolland University student; however the old design could not be used for the Delfi-n3Xt as it is and was redesigned. The redesign is necessary for several reasons, amongst them different panel size and layout. Further on in this chapter those redesign points will be described.

The SP will be held down with a Dyneema wire, a product of DSM, which has a tensile strength of 2.6 GPa. This material is not heat resistant which allow sthe easy cutting of the wire with a "hot knife"; in this case a resistor. The wire also requires a mechanism to keep it tensioned and in contact with the hot knife.

4.1 Concept

Figure 4-1 illustrated the Delfi-C³ design. The Dyneema wire, which is not drawn in the previous picture, runs over the structure surface. It starts with a knot around the spring eye, and then it runs over the resistor and under the clamp. After these parts it goes thogh an opening over the panel, this opening being situated behind the solar cells. This means that the Dyneema does not run over any critical surface, however on the Delfi-n3Xt panel there will be no transition without critical surfaces.

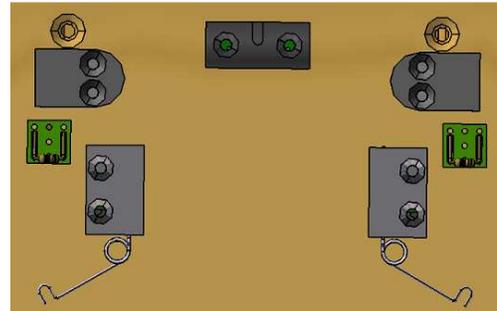


Figure 4-1: Delfi-C³ HDRM

4.2 Redesign

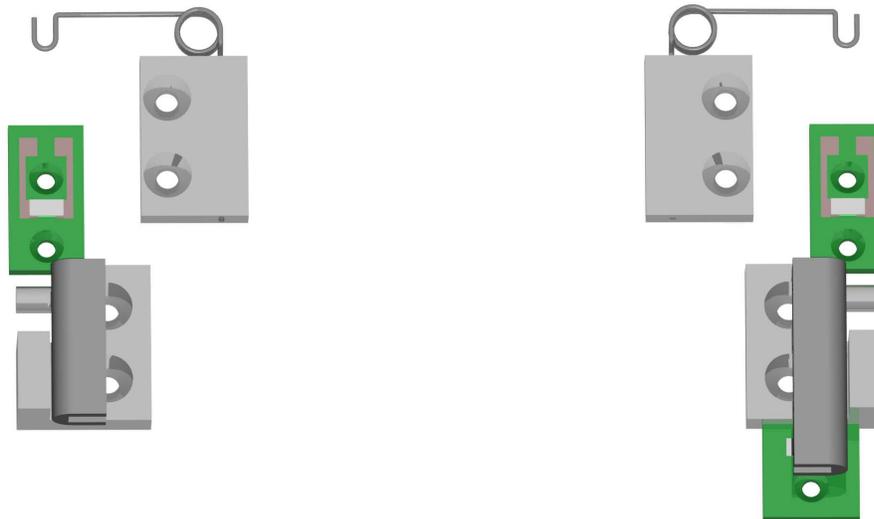


Figure 4-2: new design HDRM

The Hold Down and Release Mechanism (HDRM) is redesigned to accommodate the new solar panels. The solar panel has now cells on both sides, so the panel can only be held down at the sides. Because the there is

no room on the panel surface to let the Dyneema wire run over it, a crossing solution is necessary. This means that the wire must be raised above the panel surface so that it cannot damage the solar cells. In a previous design a grommet was used that was placed in an indent in the solar panels. A new design of the grommet is made that does not weaken the solar panel. The support blocks act now also as position blocks, so a position block is no longer needed. The new design is shown in Figure 4-2. The design drawings of the HDRM together with solar panel can be seen in [SLR 0633].

4.3 HDRM parts

4.3.1 Support blocks

The support blocks are changed for the new grommets and changed height of the hinges. The blocks fix the position of the solar panel, so a position block used in the old design is no longer needed. The round part guides the support wire over the resistor. The left and right support blocks are made of aluminium to give the round part sufficient strength. A separate block is designed to protect the solar cells from hitting the STX patch antenna. These blocks are only installed at the Y⁺ side of the satellite where the STX patch antenna is placed. The parts are fixed on the outer structure with M2 countersunk bolts.

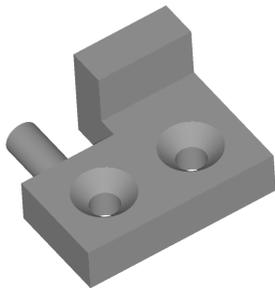


Figure 4-3: Support block left

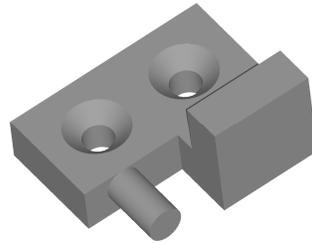


Figure 4-4: Support block right

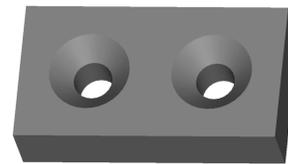


Figure 4-5: Support block STX

4.3.2 Spring blocks

The springs are needed to tension the Dyneema wire, with this tensioning needed because the Dyneema stretches when it is kept tensioned for a long time. Due to degradation of the Dyneema when stored for a long time under tension, the panel would then no longer be held down against the structure until launch. The Delfi-C³ design of the spring and its support does not need any redesign and can be used for the Delfi-n3Xt, this because it worked flawlessly and the design is still applicable. These parts are also fastened with M2 countersunk bolts.



Figure 4-6: Spring with support clockwise

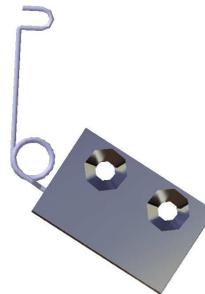


Figure 4-7: Spring with support counter clockwise

4.3.3 Resistor pcb

The metal film resistors used in Delfi-C³ have an uneven heating of the surface of the resistors, a hotspot. [SLR 0789] A test set-up was made to locate the hotspot on a resistor. Unfortunately, this test has to be done for each resistor, which is very time consuming. A surface mounted resistor (SMD) could possibly avoid this problem, if it has no hotspot. New tests were performed to show that the SMD resistors have the same or better performance than the metal film resistors and that they have an even surface heating. SMD resistors have been considered for Delfi-C³. They were not selected because too much heat was conducted to PCB because of its relative large surface mounted area, increasing the melt time. [SLR 0485] The heat conducted to the PCB and the structure is minimized by keeping the soldering pads as small as possible and by using a relatively thick circuit board of 1.6 mm. Three types of SMD resistors have been tested, the test results are shown in appendix A. The 75 Ohm resistor with a power rating of 125 mW is selected because it has the best performance.

The PCB design is very simple. The PCB contains two solder pads to mount the resistor, two solder pads to solder the wires on, a connection between the pads and two holes for M 1.6 screws.

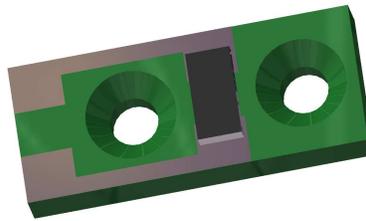


Figure 4-8: Resistor pcb

4.3.4 Hold down guide

For the old design of the grommet it was necessary to make an indent in the solar panel at both sides, which weakens the solar panel considerably. For the new design (Figure 4-9) no indent is needed. It is now no longer a grommet, so the name is changed to Hold down guide. The hold down guide together with the support blocks provides a rigid support for the solar panel. Two extra hold down guides are added at each panel at the midpoint between the hinge and support blocks; where the deflection is the largest. In case of large deflections the hold down guide will hit the structure or the POD first, protecting the solar cells.

A longer hold down guide was designed to make a solid base for the deployment switch. The hold down guide leads over the deployment switch, pressing it in when the solar panel is in stowed configuration.

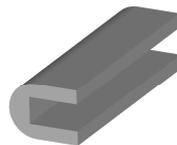


Figure 4-9: Hold down guide short

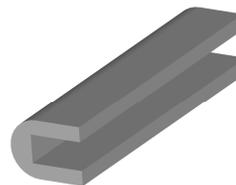


Figure 4-10: Hold down guide long

4.4 Position of HDRM

The question as to where to locate the HDRM depends on two issues. The first one is the positioning of the Dyneema wire. The best position for the Dyneema wire is at 57 mm from the end of the panel (see section 6.2), because that case the deflections will be minimal. The second issue is the positioning of the S-band patch and the sun sensor. The sun sensor where placed as low as possible on the satellite to reduce the reflections from the solar panels as much as possible. The S-band patch can be placed higher on the satellite and is therefore placed above the HDRM. The next picture gives an overview of the parts situated on the Y⁺ side of the Delfi-n3Xt.

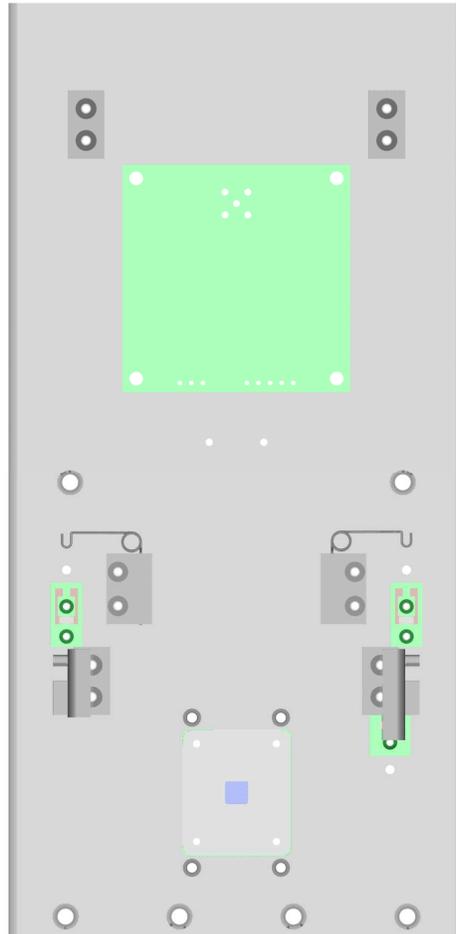


Figure 4-11: HDRM assembly overview

4.5 Dyneema pretension

To ensure that the panel will not move too much during the launch pretension must be applied on the Dyneema wire. A simple test showed that the pretension is 3.0 N when the springs from the springblocks are stressed to the configuration shown in Figure 4-2.

For the pretension calculation a maximum static load of 10.5g is assumed [SLR 1008]. The equivalent static loads due to vibrations are higher (see section 6.2.1), but these are dynamic loads with a very short duration, which will not lead to deployment of the solar panel. It can now be calculated what tension in the dyneema will be necessary to hold the panel down. A simple drawing of the situation is shown in Figure 4-12. At the hinge the panel can rotate (point A) and the hinge exerts a moment M_H of 0.1 Nm on the panel (known from testing). The panel is held down by the force F_{Hr} , acting at 57 mm from the end of the panel (see section 6.2); $L_2=303-57=246$ mm. The Force resulting from the accelerating panel is denoted by F_G , acting at the CoM of the panel $L_1=303/2=152$ mm. The force F_H will then be:

$$\Sigma M_A = M_H + F_G \cdot L_1 - F_P \cdot L_2 = 0$$

$$F_P = \frac{M_H + F_G \cdot L_1}{L_2} = \frac{M_H + (m \cdot g \cdot n) L_1}{L_2} = \frac{0.1 + (0.093 \cdot 9.81 \cdot 10.5) 0.152}{0.246} = 6.3 \text{ [N]} \quad (4.1)$$

The panel is held down with the Dyneema wire at both sides of the panel, so the tension in the wire is half the force: 3.2 N. This is slightly higher than the 3.0 N that the current spring blocks generate. However, if the maximum load of 10.5g will be achieved the panel will deploy only for a very small amount. The force in the springs will then increase to 3.2 N and balance the load. The maximum load of 10.5g is unlikely to occur and if it occurs the limited deployment of the solar panel will be no problem. Therefore it can be concluded that the springs are strong enough to hold down the solar panels during launch.

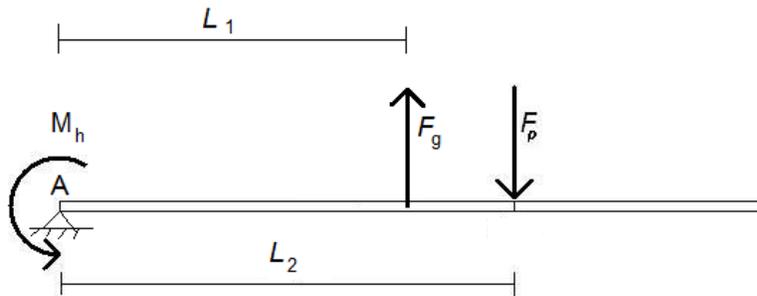


Figure 4-12: Forces acting on solar panel

4.6 HDRM wiring

The HDRM wiring is rather complex because there are many wires that must be placed at the limited space at the inside of the U-profiles. In this section the placement of the HDRM wiring is thought out. The HDRM wiring consists of 2 power lines per resistor and two wires for the deployment sensor. In addition there are 4 wires from a temperature sensor that are combined on the same connector. As there are 2 resistors on each side, 10 wires should be connected per side. Wires of 2 sides can be combined together in one bundle because the use of U-shaped panel for the outer structure.

Those wires will run down to the Deployable Antenna Board (DAB) which also controls the MABs. Integrating the HDRM control on the DAB is ideal because the DAB is placed almost on the lowest part near the BOP. Since the HDRM is placed on the bottom part, the wire lengths do not need to be that long which is an advantage. Regarding the HDRM wiring position there are two options: let the wires run on the outer side of the structure and lead them inside near the DAB or lead the wires first inside and then run down to the DAB. When the wires from two sides are combined, the wires have to cross the corner of the satellite. This cannot be done on the outside of the structure, because the corners have to be clear for the guiderails of the deployment pod. Therefore the wires have to cross the corner at the inside of the structure.

It is not desirable to have the two resistors from one panel on the same connector for redundancy, because in case of a connector failure the panel cannot deploy. Therefore it is better to combine one resistor from the X⁺-side, one resistor from the Y⁺-side and a deployment sensor in one 6 pin connector and the two redundant resistors with the second deployment resistor in a second connector. The same holds for the X⁻side and the Y⁻side.

However, there is only place for connectors on the Y⁻ and the X⁻ side of the satellite, as the X⁺ side is reserved for the DSSB and the Y⁺ side for the RF connectors. There is not enough space on one side for two Harwin connectors with 10 pins; therefore one connector of 20 pins is used. This removes the connector redundancy, but a connector failure is assumed to be very unlikely; as the DSSB also uses a single connector per subsystem.

There are already holes in the structure at the height of the DAB for the sun sensors. These holes can also be used to attach the connectors from the HDRM to the DAB, so no extra big holes are needed in the structure.

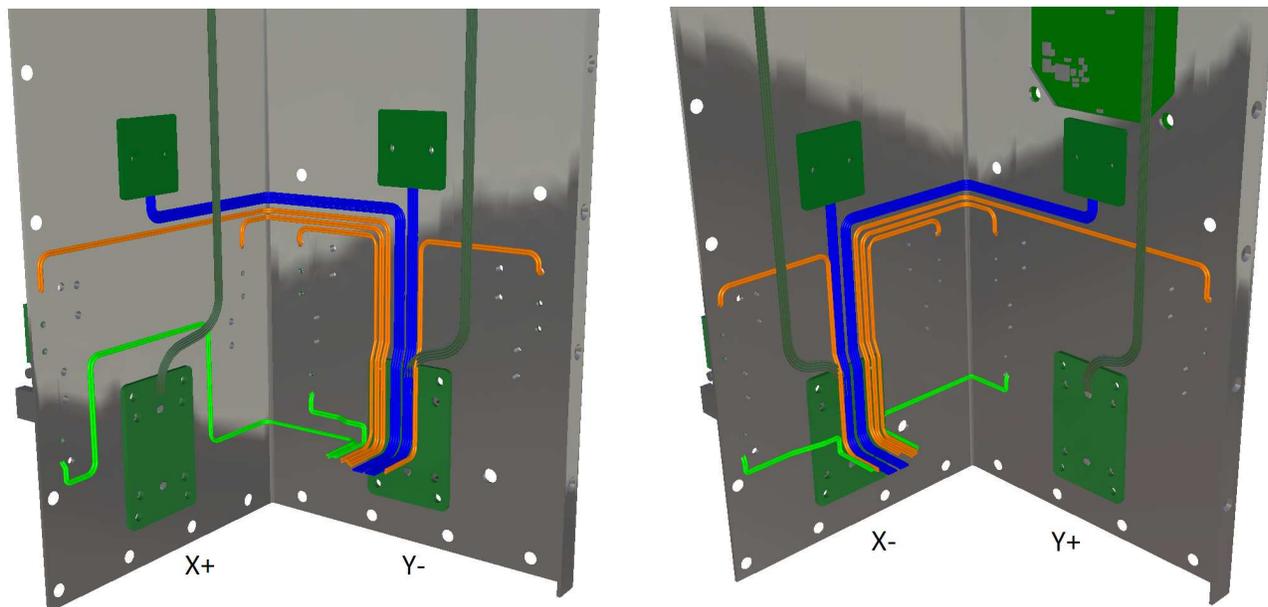


Figure 4-13: HDRM wiring: the orange wires lead to the deployment resistors, the light green wires to the deployment switches and the blue wires to the temperature sensors.

5 Deployment Sensor

To be able to know whether the panels are deployed, deployment sensors are placed near the HDRM assembly. The HDRM holds the panel down until deployment. It is however necessary to know whether the panel is actually deployed or not. When a successful deployment is performed at the first try, then there are no further problems. But there is a problem when the deployment is not completed due an unknown reason, one of those could be that the Dyneema wire will not be burned completely through. This means that the panel will partly or not at all.

To prevent such problems there is some feedback needed on deployment, confirmation of deployment can be done by a tact switch. This switch is pressed down when the panel is not deployed; when the Dyneema is burned through, and the panel is released, it also releases the tact switch. The tact switch gives a positive deployment signal to the Command and Data Handling System (CDHS), completing the deployment cycle.

When at the first try a negative deployment signal is sent to the CDHS, the CDHS reacts by sending a second deployment signal to the HDRM. A second attempt to burn the Dyneema will then be preformed, this second attempt is done with the redundant resistor.

Partly deployment of the panel is hard to detect and requires more or other sensors.

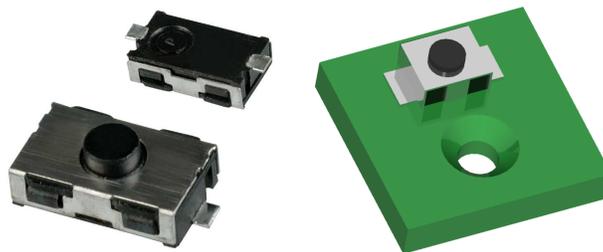


Figure 5-1: Tact switch Figure 5-2: Tact switch pcb

5.1 Sensor type

To sense whether the panel is deployed there are several sensors available on the market. A small research on the internet results in the following options:

- Optic sensors: sensing light
- Load cells: sensing load applied on the cell
- Piezoelectric sensors: sensing applied stress on material
- Motion sensors: sensing motion
- Tact switches: sensing applied force

A closer look at the sensor properties shows that not all sensors do satisfy the requirements; some sensors are too big to fit inside the envelope while other sensors are unreliable or too expensive. The tact switch which was also used for the Delfi-C³ does comply with the requirements. This is obvious as it was used before. The small size, reliability and the fact that they are cheap are big advantages of the tact switches. Experience with the Delfi-C³ also has a big impact on the choice; deployment and confirmation of deployment without problems. So the conclusion is that tact switches are the best option to use on the Delfi-n3Xt.

5.2 Switch position

To be able to operate the switch without false signals, it has to be placed on a position where the panel does not deflect due to external forces. To satisfy that there are 2 options for the position of the tact switch. One option is to place it near the hinge; the other option is to place it near the HDRM. At those points almost no deflection is occurring.

The difference between the 2 positions is the wire length. Placing the switch near the HDRM means a reduction of approximately 200 mm of wire length; another advantage is that the wire can be integrated within the HDRM bundle.

One can conclude that those advantages give the optimum position for the switch; near the HDRM. There are solar cells on both sides of the solar panel; therefore the switch cannot be placed in the middle of the panel, as it would then touch the solar cells. The hold down guide is made longer on one side and the deployment switch is placed right below. This creates the right height difference such that the switch is fully pressed when the solar panel is in stowed position.

5.3 Sensor wiring

The 2 wires of each sensor can be integrated in the HDRM bundle as mentioned earlier on. The exact location of those wires can be obtained from section 4.6.

6 Solar panels

To gain power solar cells are used on Delfi-n3Xt. The cells are acquired from Dutch Space and have a size of 38.46 x 63.22 x 0.7 mm [SLR 474]. In between the cells there is 1 mm room spared for strips which connect the cells together. The cells are supported on a panel, which is a PCB made of FR4. The solar panel geometry is changed to achieve the desired solar panel configuration designed by Johannes Bürkle [SLR 0863]. A PCB is chosen to reduce the amount of wires on the solar panel, because there is not much space for the wires with cells on both sides of the panel. The solar cells and temperature sensors can now be directly connected to the PCB, so there are no wires needed in the length of the panel.

At the triangular part of the panel, which is free of cells, wires are soldered to the panel which are connected to the EPS PCB with a Harwin connector.

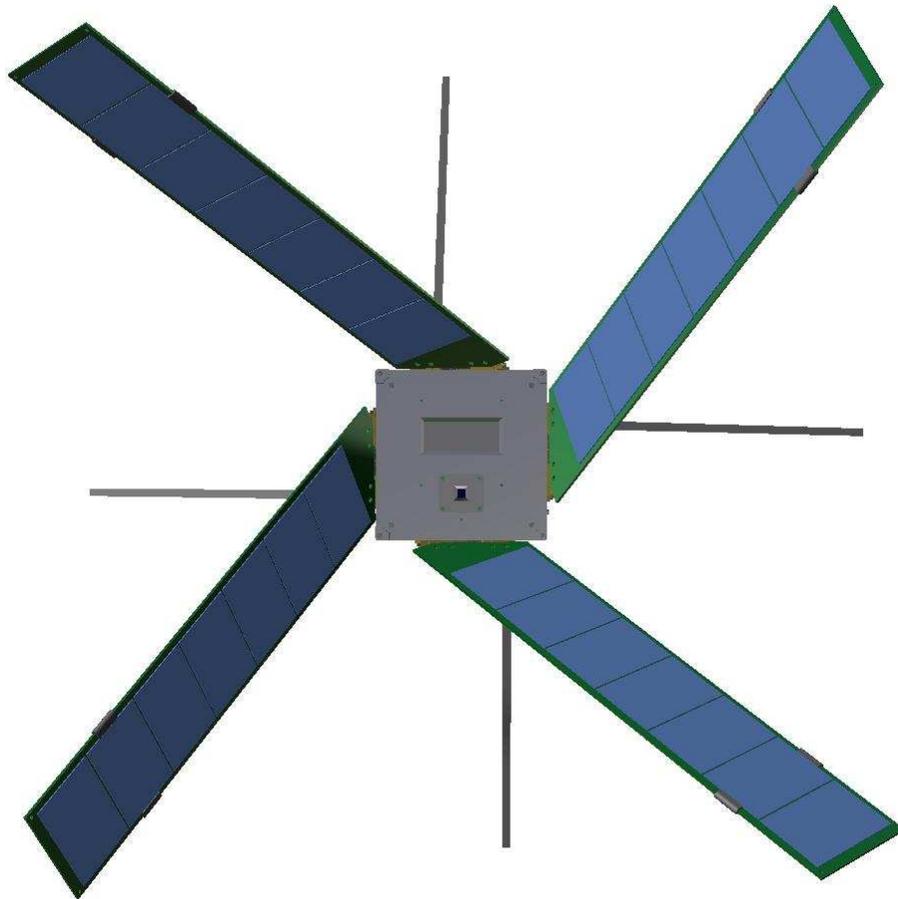


Figure 6-1: 4 solar panels

6.1 Design

The design of the solar panel with all relevant dimensions is shown in the design drawings [SLR 0633]. The solar panel has a total length of 315 mm. 275 mm is used for the 7 solar cells with a spacing of 1 mm. At the end of the panel 6 mm is left for the connection of the cells to the panel and two protection bolts. Those bolts are redundant parts which will protect the panel because the bolts will hit the satellite structure first in case of excessive deflection. The protection bolts are M2 bolts fastened with nuts. At the remaining 34 mm the hinge and the wires are attached. The width of the panel is 71 mm and the together with the HDRM the width increases to 80 mm. This leaves 10 mm at each side for the guide rails of the POD.

6.2 Solar panel deflection

The SP is made of CFRP which will deflect due to the launch acceleration loads. In case of excessive deflection the panel may hit the POD structure or the outer structure which can damage the cells. So the amount of deflection is important and must be calculated. The load case can be illustrated as follows:

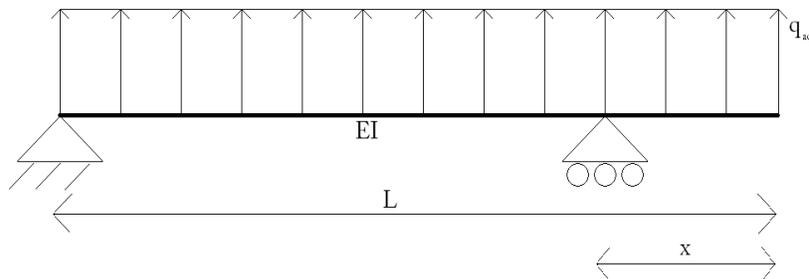


Figure 6-2: Panel Free Body Diagram

Where L is the length of the panel, q_{acc} is the distributed load induced by launch accelerations and x is the position where the panel is hold down with a Dyneema wire. The resulting deflection is shown in the following figure:

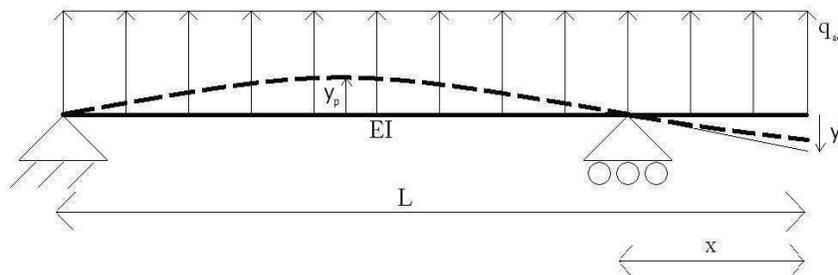


Figure 6-3: Deflection of panel

The maximum deflections occur at the midpoint between the supports and at the end of the cantilever part. For the calculation of the deflection of the y_p , the cantilever part can be replaced by a moment:

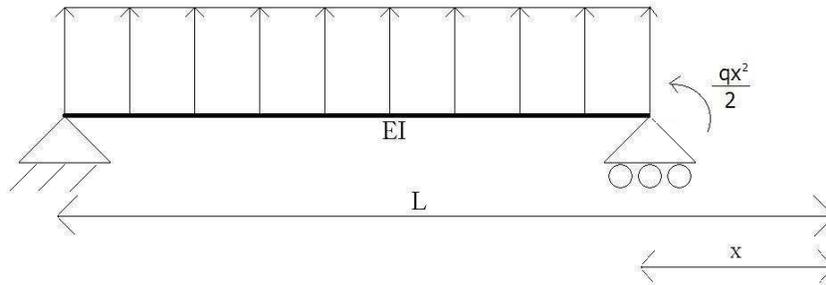


Figure 6-4: Free body diagram mid section

Now the mid plane deflection is given by:

$$y_p = \frac{5q(L-x)^4}{384EI} - \frac{qx^2(L-x)^2}{16EI} \tag{6.1}$$

Where p is a point on the panel with the position:

$$p = \frac{L-x}{2} \tag{6.2}$$

The end cantilever deflection is:

$$y_a = -\frac{qx^4}{8EI} + \theta x = -\frac{qx^4}{8EI} + \frac{qx(L-x)^3}{24EI} + \frac{qx^3(L-x)}{6EI} \tag{6.3}$$

Where point a is the free end of the panel and θ is the rotation at the roller support.

The properties of the solar panel used for the calculations are shown in table 5.1.

Table 6.1: Solar panel properties (CFRP)

Length	303 mm
Width	71 mm
Thickness	1.6 mm
Modulus of Elasticity	100 GPa
Density	1600 kg/m ³ (CFRP)
Mass	30 g

The distributed load q is calculated with a random vibration load factor of 65 g, which is used for all parts in the satellite. This results in a distributed load of:

$$q = \frac{F}{L} = \frac{m \cdot a}{L} = \frac{0.03 \cdot (65 \cdot 9.81)}{303} = 0.06 \text{ [N/mm]} \tag{6.4}$$

The area moment of inertia of the rectangular cross section of the solar panel is given by:

$$I = \frac{1}{12} t^3 \cdot b = \frac{1}{12} \cdot 1.6^3 \cdot 71 = 24.23 \text{ [mm}^4\text{]} \tag{6.5}$$

The deflections were already calculated by Yusuf Awchi [SLR 632], but unfortunately not correct. In equation (6.1) the last term representing the moment from the cantilever part was not included. In equation (6.3) the last two terms, representing the initial rotation of the cantilever beam due to the deflection of the mid section, were not included. In Figure 6-5 the results from both calculations are shown. The optimum solution is where both the mid deflection and the end deflection are minimal. Yusuf Awchi concluded that the optimum solution was 110 mm with a deflection of 0,5 mm. With the correct calculations the optimum is at 57 mm with a maximum deflection of 1 mm at the endpoint and the midpoint.

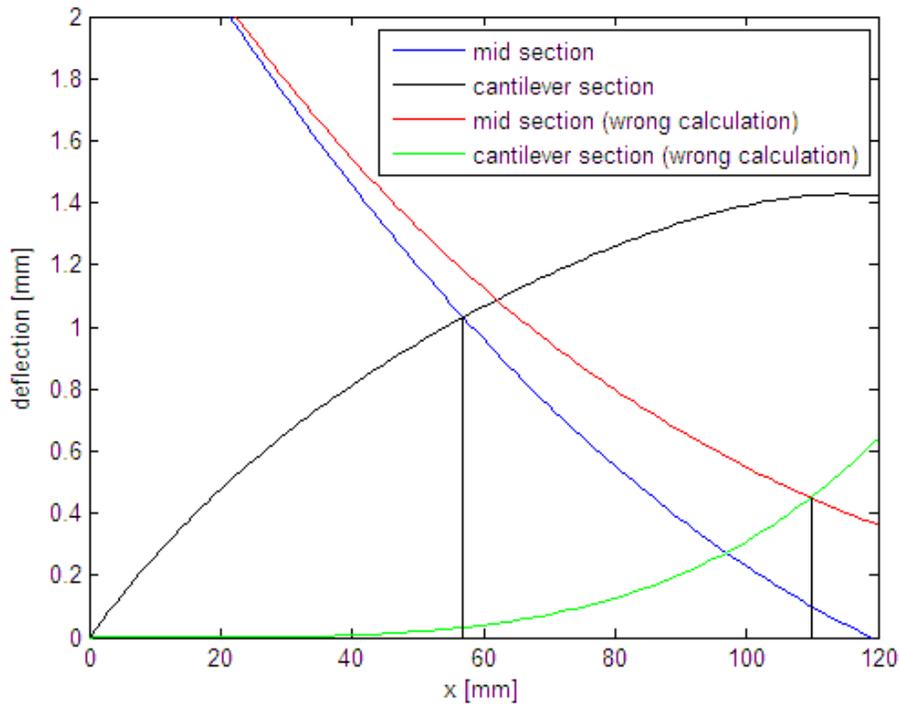


Figure 6-5: Dyneema position vs deflection

An example calculation for the maximum deflection is shown below:

$$y_p = y_a = \frac{5 \cdot 0.06 \cdot (303 - 57)^4}{384 \cdot 100 \cdot 10^3 \cdot 24.23} - \frac{0.06 \cdot 57^2 (303 - 57)^2}{2 \cdot 16 \cdot 100 \cdot 10^3 \cdot 24.23} = 1.03 \text{ [mm]} \tag{6.6}$$

6.2.1 Solar panel of FR4

After design changes the solar panel has changed to a double sided solar cells and a panel of FR4 (which stands for Flame Retardant 4 which is a material commonly used for PCBs). This has consequences for the deflection of the panel, because this changes the modulus of elasticity and the distributed load due to the increased weight. However, the optimal Dyneema position does not change; because the deflections are all linearly dependent on the changing parameters (see equation (6.1) and (6.3)). Therefore only the deflection at the optimal point of 57 mm is recalculated with the new parameters. The properties of the solar panel made from FR4 [SLR 0964] that are used for the calculations are shown in Table 6.2. Additionally, the random vibration load factor was recalculated using Miles' equation.

Preliminary calculations with the new panel resulted in deflections that were too high. However, there are several reasons why the deflection will be far smaller in reality:

- The solar cells will make the panel stiffer. The addition of the solar cells increases the thickness of the panel considerably, thereby increasing the area moment of inertia. However, the stiffness of the panel with cells is very difficult to calculate because the cells have empty spaces between them and are glued with a flexible adhesive to the panel. Therefore it would be very useful to measure the influence of the cells on the panel stiffness. As soon as one panel with cells is produced the stiffness will be measured and compared with a panel without cells. The result can then be used for a more accurate calculation of the maximum deflection.
- The solar cell adhesive will have a damping effect on the vibrating motion of the panel. Again the effect will be difficult to calculate and a future vibration test can give more insight.
- The hinge is not a perfect pin support. The hinge can open when the panel deforms as shown in Figure 6-2, but it cannot close further in case of the opposite deflection. Furthermore, the hinge is placed skewed on the satellite, which leads to a complex two dimensional deformation of the panel due to the launch loads. (For the calculations the length between the supports is measured at the middle of the panel.) The exact result will also be difficult to calculate. The support will be somewhat in between a clamped and a pinned support, which will lead to smaller deflections.
- The copper wiring inside the PCB will increase its stiffness.

The combined effect is unknown and difficult if not impossible to calculate. Therefore the following tests were performed:

- A stiffness test of the panel without solar cells;
- A stiffness test of the panel with solar cells;

The results of the tests are the following: the solar panel PCB without dummy cells is 26% stiffer compared to the bare FR4 panel due to the copper layers inside the PCB. The solar panel PCB with dummy cells is 12% stiffer compared to the panel without cells. This increase is relatively low, because the solar cells are not mechanically coupled to each other. The combined effect of the copper layers and the solar cells increases the bending stiffness of the panel 40% compared to a bare FR4 panel. The complete test report can be found in [SLR 0996].

Table 6.2: Solar panel substrate properties (FR4)

Length	315 mm
Width	71 mm
Thickness	1.6 mm
Modulus of Elasticity	24.5 GPa
Density	1900 kg/m ³ (FR4)
Mass	82 g
Mass including cells	133 g

With the new properties of the solar panel, the random vibration load factor can be calculated by using Miles' equation, which is based upon statistical analyses of induced acceleration spectra with a 3σ distribution. Miles' Equation determines a load factor by assuming that the fundamental (first system) mode in each orthogonal direction will provide the primary response:

$$g_{rms} = 3 \sqrt{\frac{\pi}{2} \cdot f_n \cdot Q \cdot W_{xx}(f_n)} \quad (6.7)$$

Where f_n is the system natural frequency, Q is the amplification factor and W_{xx} is the power spectral density depending on frequency. The natural frequency of the solar panel is 39 Hz (see section 6.3). The amplification factor is taken as 10, which should be used if no test data is available. The power spectral density is 0.07 g²/Hz at 20-80 Hz; which is extracted from the environmental levels provided by ISILaunch [SLR 1008]. This will result in an equivalent static load factor of:

$$g_{rms} = 3\sqrt{\frac{\pi}{2} \cdot 39 \cdot 10 \cdot 0.07} = 19.6 \text{ [g]} \quad (6.8)$$

This will result in a distributed load on the solar panel:

$$q = \frac{F}{L} = \frac{m \cdot a}{L} = \frac{0.133 \cdot (19.6 \cdot 9.81)}{315} = 8.12 \cdot 10^{-2} \text{ [N/mm]} \quad (6.9)$$

With the new panel the maximum deflection due to vibrations will be:

$$y_{pDynamic} = y_{aDynamic} = \frac{5 \cdot 8.12 \cdot 10^{-2} \cdot (315 - 57)^4}{384 \cdot 24.5 \cdot 10^3 \cdot 24.23} - \frac{8.12 \cdot 10^{-2} \cdot 57^2 (315 - 57)^2}{16 \cdot 24.5 \cdot 10^3 \cdot 24.23} = 6.97 \text{ [mm]} \quad (6.10)$$

The maximum static acceleration is 10.5 g [SLR 1008]. As the above calculations have a linear relation with the load factor, the maximum deflection due to the 10.5 g static load will be:

$$y_{pStatic} = y_{aStatic} = 6.97 \cdot \frac{10.5}{19.6} = 3.73 \text{ [mm]} \quad (6.11)$$

Both deflections are too high, since the distance between the solar panel and the structure is 3.65 mm and the distance between the solar panel and the POD is 3.05 mm (see technical drawings [SLR 0633]). Therefore it is possible that the solar panel will hit the POD and structure.

The value due to the dynamic loads is obtained by using 3σ value of Miles' equation, which gives a conservative estimate of the maximum loads due to random vibration. It is still the question if the panel will actually hit the outer structure or launch POD and if it hits it with enough force to damage the solar cells. This can only be answered by a random vibration test as more detailed calculations, even finite element models, are not accurate enough to guarantee that the solar cells stay intact.

As an extra safety measure a small piece of hold down guide will be added to the solar panels at the point of maximum deflection. In case of the excessive deflection this piece will hit the POD or the structure first; protecting the solar cells. At the end of the panel there are already bolts that protect the cells in case of accidental deployment in the POD. These will also protect the solar cells at the end of the panel against too large deflections.

The final vibration test of the complete satellite in the ISIPOD has to prove that the solar cells will not be damaged by excessive deflections of the solar panel.

6.3 Natural frequency

To avoid resonance, the natural frequency needs to be higher than 20 Hz; which is the frequency of the launcher [SLR 1008]. The natural frequency is given by:

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \quad (6.12)$$

Where the stiffness k can be obtained from the deflection formula (eq. 6.1):

$$y_p = \frac{5q(L-x)^4}{384EI} - \frac{qx^2(L-x)^2}{16EI} = \frac{qL}{k} \rightarrow k = \frac{L}{\frac{5(L-x)^4}{384EI} - \frac{x^2(L-x)^2}{16EI}} \quad (6.13)$$

$$k = \frac{0.315}{\frac{5(0.315 - 0.057)^4}{384 \cdot 24.5 \cdot 10^9 \cdot 2.4 \cdot 10^{-11}} - \frac{0.057^2}{2} (0.315 - 0.057)^2} = 3.53 \cdot 10^3 \text{ [N/m]} \quad (6.14)$$

The natural frequency will then be:

$$f = \frac{1}{2\pi} \sqrt{\frac{3.53 \cdot 10^3}{0.133}} = 26 \text{ [Hz]} \quad (6.15)$$

So the natural frequency is higher than the required minimum, although it is relatively low due to its high mass and low stiffness.

6.3.1 Frequency test

The calculated natural frequency is very close to the minimum required frequency. The calculations may not be very accurate because the boundary conditions are very complicated. (The assumed boundary conditions are the same as used for the deflection calculations and are shown in Figure 6-2.) Therefore a test was performed to acquire the natural frequency of the solar panel for comparison with the calculations.

Test set-up and procedure

The test was performed at 3ME with the help of Maarten van der Seijs, who has experience with the equipment. The same test set-up as for the deployment tests was used; consisting of a heavy aluminium block, the HDRM, hinge and integrated solar panel (see Figure 6-6). The velocity of the solar panel was measured with a Laser Doppler Velocimeter, which was connected to a spectrum analyzer. The panel was excited by hitting the aluminium support block with an impact hammer; which was also connected to the spectrum analyzer to measure the magnitude of the impact. The velocity of the panel was measured at the small reflecting part of each solar cell (clearly visible in Figure 6-6). The complete test set-up with the dummy solar panel is shown in Figure 6-7. Firstly the set-up was placed on a piece of rubber to exclude the vibrations of the table from the results. The piece of rubber was later removed, because it made the set-up vibrate at a low frequency; around the frequency which we wanted to measure. The vibrations of the table were no problem, because they were at a far higher frequency beyond the measured range.

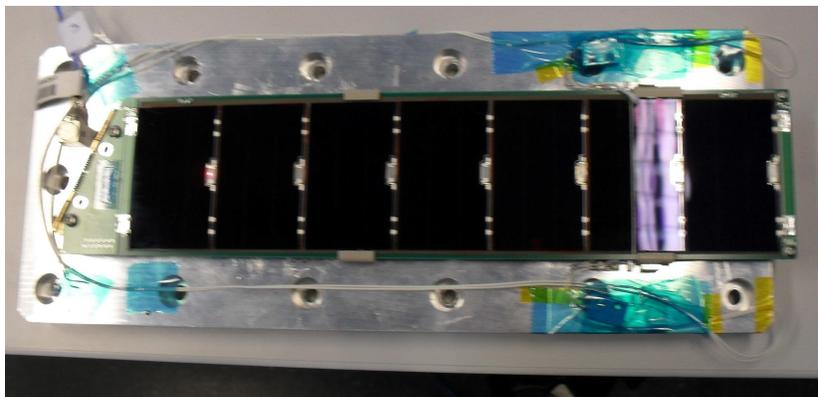


Figure 6-6: Frequency test set-up with real panel

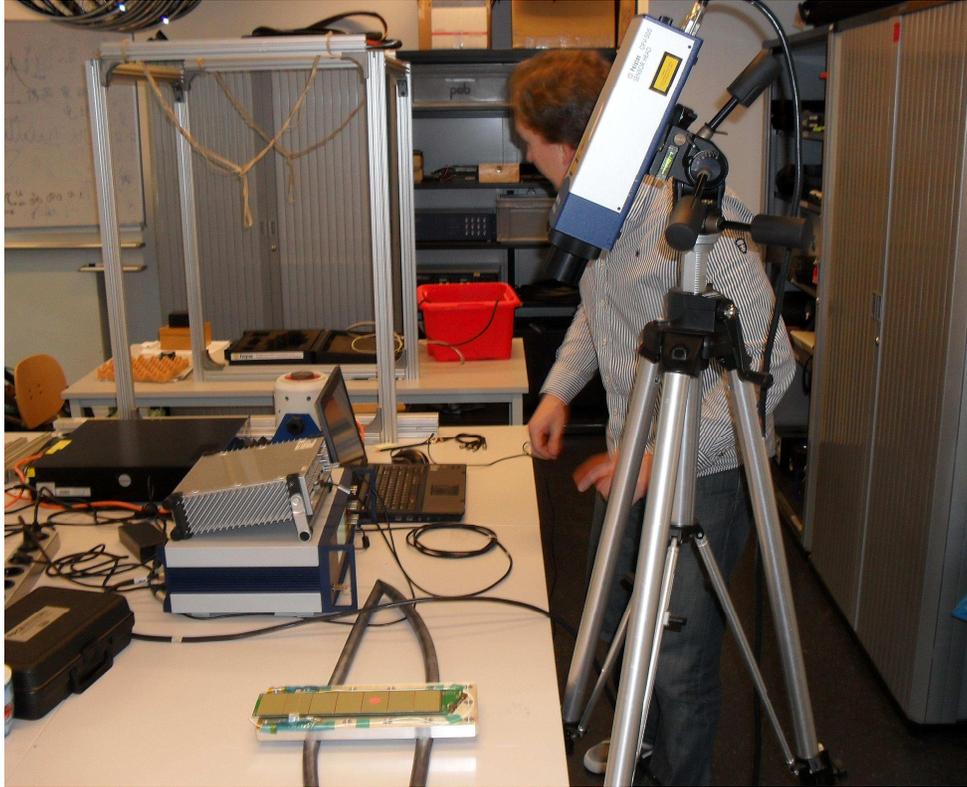


Figure 6-7: Frequency test set-up with dummy panel

Test results

The resulting Frequency Response Functions are shown in Figure 6-8. It is clearly visible that the highest response is at 39 Hz. The corresponding mode shape is visualized in Figure 6-9. This corresponds to the expected deflection as shown in Figure 6-3, so this is indeed the natural frequency. There is smaller peak visible at 22.5 Hz. This is a rigid body mode where the panel does not bend; instead it vibrates in its supports.

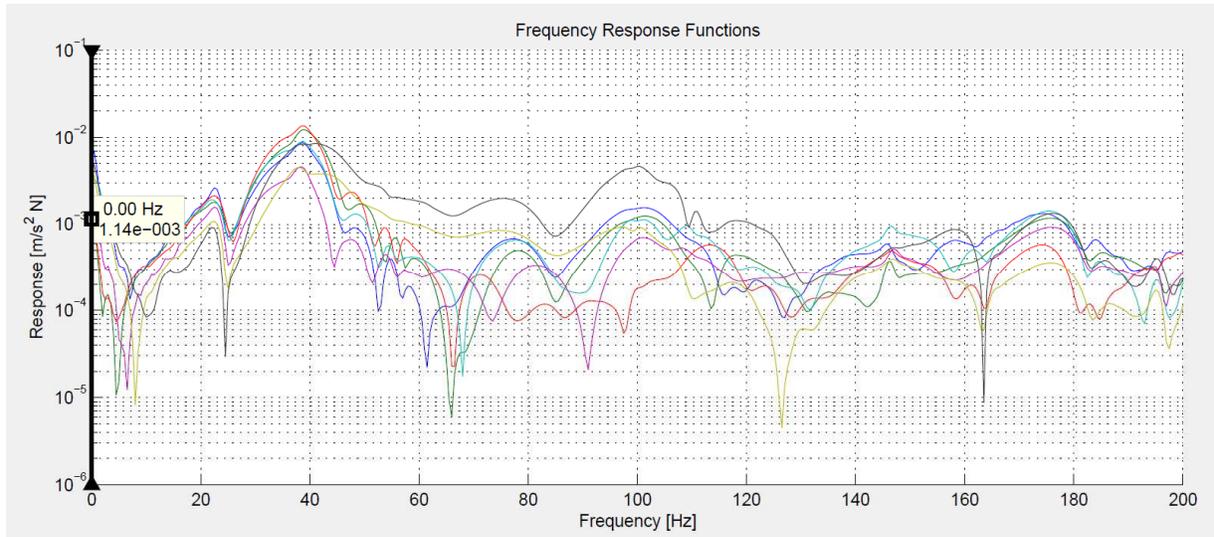


Figure 6-8: Frequency Response Functions of each point

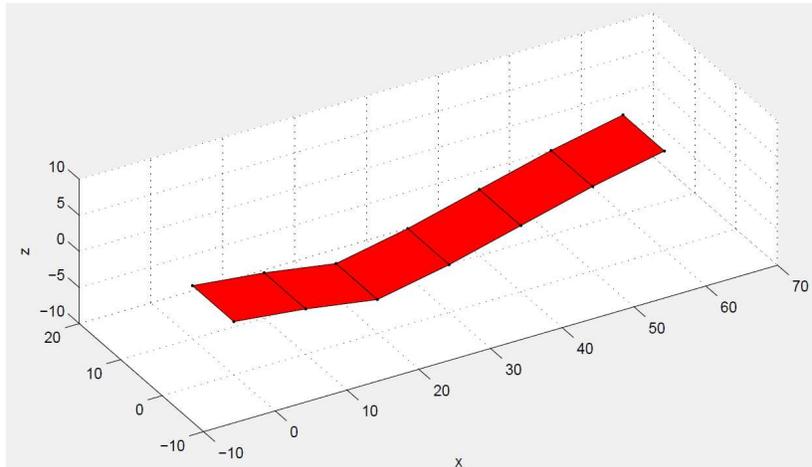


Figure 6-9: Dominant mode shape at 39 Hz

Conclusion

The natural frequency of the solar panels is 39 Hz, which is more than the minimum required of 20 Hz. This result differs from the calculated 26 Hz. The supports of the solar panel deviate too much from a standard case, such that eq. (6.15) gives an inaccurate result. For accurate predictions calculations with a finite element model are needed.

7 Deployment tests

The new hinge design was sent to the workshop and manufactured. A model of the solar panel was made for deployment tests. The panel is milled out of a sheet of FR4 material, which is the same material as will be used on the real panel. For the solar cells aluminum mass dummies are used with the same mass as a real solar cell. The solar cells have a mass of 2g and dimensions of 63.22 and 38.46 mm [SLR 0474]. The aluminum has a density of 2650 kg/m³. This results in an aluminum thickness of:

$$V = \frac{m}{\rho} = \frac{2 \cdot 10^{-3}}{2650} = 7.55 \cdot 10^{-7} \text{ [m}^3\text{]} \quad (7.1)$$
$$t = \frac{V}{w \cdot h} = \frac{7.55 \cdot 10^{-7}}{63.22 \cdot 10^{-3} \cdot 38.46 \cdot 10^{-3}} = 3.10 \cdot 10^{-4} \text{ [m]}$$

An aluminum sheet of 0.3 mm was used to produce the mass dummies. The dummies were glued on the panel with silicone kit.

Deployment tests were performed in a hot and a cold case to qualify both the hinge and the HDRM. The solar panel deploys after three seconds at 85 °C, after five seconds at room temperature and after five seconds at -34 °C. The deployment time is rather consistent. The solar panel deploys within the required 15 seconds with a high margin. Both resistors are tested more than 40 times and they do not show any deterioration in performance. It can be concluded that the HDRM and hinges fulfill their requirements and work as intended. See [SLR 1009] for the complete test report.

8 MAB redesign

The same Modular Antenna Boxes (MABs) of Delfi-C3 will be used on Delfi-n3Xt with one small adjustment. The Delfi-C3 MAB has a coax cable that connects the MAB to the Deployable Antenna Board (DAB). The Delfi-n3Xt MAB has an extra bolt that connects the MAB directly to the DAB. In this way there is more design freedom for the DAB layout.

Unfortunately, there were only Catia files of an old model of the Delfi-C3 MAB. These files were updated to the latest design and an extra hole was added. The new design is shown in Figure 8-1. The new drawings are shown in the design drawings [SLR 0633].

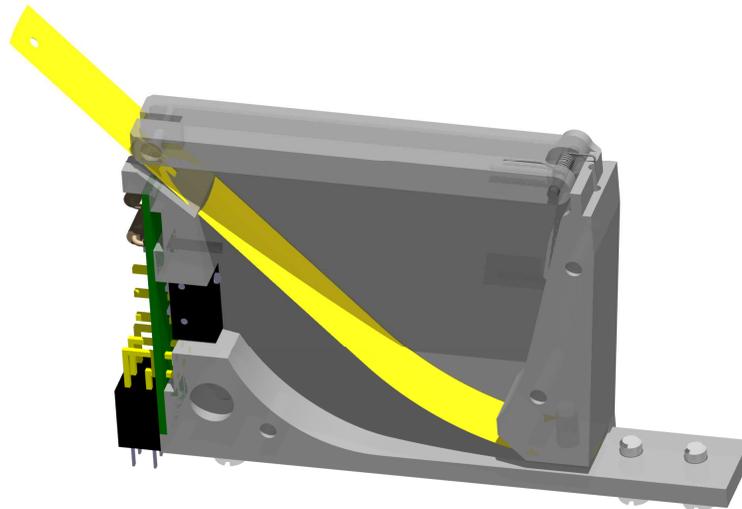


Figure 8-1: MAB

The drawings were sent to the workshop and the parts were produced. A complete list of all components needed for the MABs was made, which is also included in the assembly drawing. The parts that are not available must be ordered. The hotspots on the burn-through resistors must be found with a special test which was designed for Delfi-C3. Then the MABs can be assembled and tested. Logs will be kept from each MAB such that the status of each MAB is clear for all people involved in assembly and testing.

9 Conclusions & Recommendations

The complete solar panel assembly including hinge, HDRM and deployment sensor was redesigned for the new solar panel configuration.

From stiffness tests with the solar panel pcb including dummy cells can be concluded that the solar panel is 40% stiffer than the bare pcb. However, the deflections of the solar panel are still too large; therefore it is possible that the solar panel will hit the POD or the structure during launch. As a safety measure special parts are added at the points of maximum deflection to protect the solar cells. Calculation of the natural frequency of the solar panel shows that it is higher than the minimum required natural frequency.

Deployment tests in a hot and a cold environment showed that the solar panel deploys within 3 to 5 seconds. The solar panel deploys within the required 15 seconds with a high margin. Both resistors are tested more than 40 times and they do not show any deterioration in performance. From these deployment tests can be concluded that the complete solar panel assembly including hinges and HDRM fulfills their requirements and work as intended.

10 Next Steps

- A vibration test of the complete satellite in the ISIPOD. This test has to prove that the solar cells will not be damaged by excessive deflections of the solar panel.
- Assembly and testing of MAB's

A SMD resistor test report

In this test three types of resistors were tested in room temperature. Two 75 Ohm resistors with power ratings of 125 mW and 250 mW and a 100 Ohm resistor with a 250 mW power rating. The resistors are connected to a 12V power source, which is used throughout the satellite. For the 75 Ohm resistors this results in a current of:

$$I = \frac{U}{R} = \frac{12V}{75\Omega} = 160 \text{ mA}$$

Power used:

$$P = U \cdot I = 12 \cdot 0.16 = 1.92 \text{ W}$$

For the 100 Ohm resistor the results are:

$$I = \frac{U}{R} = \frac{12V}{100\Omega} = 120 \text{ mA}$$

$$P = U \cdot I = 12 \cdot 0.12 = 1.44 \text{ W}$$

A test set-up is made and the dyneema wire is put under tension with a bottle of water of 1 kg. This may not be exactly the same tension as acquired with springs of the hold down and release system. However, this will not influence the test result, as only a limited tension is needed to push the dyneema wire onto the resistor and pull the wire away when it melts. The time it takes to melt the wire after the current is applied is measured with a stopwatch. The results are shown in Table A.1.

Table A.1: Dyneema burn through time for several resistors [s]

Resistor (Power rating)	100 Ω (250 mW)	75 Ω (250 mW)	75 Ω (125 mW)
Test 1	21	8	5
Test 2	18	7	5
Test 3	18	6	5
Test 4	16	6	5
Test 5	19	6	5

During the test it was noticed that the bottom side of the PCB became very hot. This PCB is mounted on the aluminium structure of the satellite, so it could be that a lot of heat is conducted to the structure, increasing the melt time of the dyneema wire. Therefore, a second test setup is made with the PCB mounted on an aluminium sheet of 80x80x1.6 mm. The 100 Ohm resistor is not tested again, because the burn through time is unacceptably long even without the aluminium sheet. The results are shown in Table A.2.

Table A.2: Dyneema burn through time with aluminium sheet [s]

Resistor (Power rating)	75 Ω (250 mW)	75 Ω (125 mW)
Test 1	7	7
Test 2	7	6
Test 3	8	7
Test 4	8	6
Test 5	7	7

The burn through time increases 1-2 seconds with the aluminium sheet, but stays well below the acceptable limit of 15 seconds. The 75 Ohm resistor with the 125 mW power rating is selected because it has the best performance. Additional tests need to be performed with lower temperature.

B Hinge design history

A previous design was made by Y. Awchi [SLR 0632]. A redesign of the Delfi-C³ hinge was considered, but this was not possible because the hinge position was changed from the top to the side of the cube. New concepts were made, a trade-off was made between various concepts and the block hinge was selected. Strength calculations were done and a test plan was developed. The result is shown in Figure B-2.

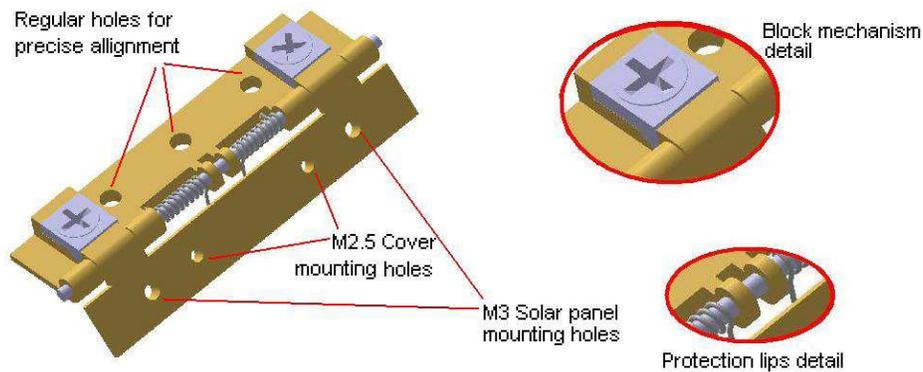


Figure B-1: Delfi-C³ hinge



Figure B-2: Old hinge design

Delfi-n3Xt Mass Budget

Revision Record and Authorization

Issue	Date	Author / Editor	Reviewed	PM approved	Affected Section(s)	Description of change
0	mei-08	Lisero			ALL	Initialization of document (v1.0)
1.0	20-5-2008	Lisero			ALL	Addition of MDR mass estimates of payloads
1,1	21-5-2008	Lisero			ALL	Change of maturity (contingency) percentages and wording
2.0	8-9-2008	Lisero			ALL	Update of estimates on all elements. Current status of PDR.
2,2	14-10-2008	Lisero			ALL	Complete revision of structure and mass estimates.
2,3	27-1-2009	Lisero			ALL	Update of estimates on solar panels
3,0	30-6-2009	Jennifer			all	Revision of entire mass budget, addition several columns
3,1	3-7-2009	Jennifer			history	added mass budget evolution
4.0	21-10-2010	Johan			payloads, STS, MechS, SP	MPS and SPLASH deleted, changes in STS, MechS and SP due to changed solar panel configuration.
4.1	5-9-2011	Johan			ADCS	ADCS reorganised, ADCS electronics PCB deleted, STX PCB set to 65 g, magnetotorquer mass changed
4.2	7-10-2011	Johan			ADCS	updated masses and contingencies
4.3	18-10-2011	Johan			EPS	added batteries electronics pcb target mass of complete satellite added
4.4	24-10-2011	Johan			ITRX, PTRX	set to 100g maturity B
4.5	16-4-2012	Johan			ITRX, PTRX all Mass budet	set to 170g including linear transponder maturities updated CoM in Z direction added for microthruster

CI-number [SLR 0325]	Drawing number [SLR 0476]	Subsystem Part	Sub-Part	Amount	Unit mass [gram]	Current Best Estimate [gram]	Maturity	Contingency [percent]	Allocated mass [gram]	Target mass [gram]	SLR CBE	CoM (Z+)
Breakdown according to Subsystems, then assemblies												
SAT.2.2		DNX-41-000 ADCS					322		345	322		256,8
SAT.2.2.2.1	DNX-41-300	Magnetorquer assembly		1	83,51	83,5	A	0	83,5		142	
SAT.2.4.5.3.5	DNX-41-201	ADCS PCB		1	65	65,0	D	10	71,5		142	
SAT.2.2.1.1	DNX-41-700	Magnetometers		2	1	2,0	A	0	2,0		142	
SAT.2.2.2.2	DNX-41-200	Reaction Wheel assembly		1	81,3	81,3	D	10	89,4		142	
SAT.2.2.1.2	DNX-41-500	Sun sensors		6	15	90,0	D	10	99,0		596	
SAT.2.6		DNX-46-000 CDHS					46		46	46		177,8
SAT.2.6.2	DNX-46-002	OBC		1	45,8	45,8	A	0	45,8		192	
SAT.2.3		DNX-42-000 COMMS					387		449	387		
SAT.2.7.2	DNX-44-200	MABs		4	16	64,0	A	0	64,0		192	23,8
SAT.2.7.1	DNX-44-102	DAB		1	47,6	47,6	F	30	61,9		192	23,8
SAT.2.3.1	DNX-42-100	PTRX		1	170	170,0	D	10	187,0		192	151,4
SAT.2.3.3.2		S-patch antenna		1	40	40,0	F	30	52,0		387	162
SAT.2.3.2	DNX-42-200	STX PCB		1	65	65,0	F	30	84,5		192	128,8
SAT.2.1		DNX-43-000 EPS					934		982	934		
SAT.2.1.1	DNX-43-200	Battery Board		1	270	270,0	B	2	275,4			59,6
SAT.2.1.1.4	DNX-43-202		housing	1	85	85,0	B	2	86,7		19	
SAT.2.1.1.1	DNX-43-201		Batteries	4	46	184,0	B	2	187,7		19	
		Batteries electronics		1	57,5	57,5	E	25	71,9		192	81,2
SAT.2.1.3	DNX-43-102	Electronics PCB		2	57,5	115,0	E	25	143,8		192	290,6
SAT.2.1.2	DNX-20-000	Solar panel substrate (FR4 1.6 mm)		4	82	328,0	A	0	328,0		169	412,3
SAT.2.1.2	DNX-20-000	Solar panel cells		56	3,6	164,0	A	0	164,0		474	417,5
SAT.2.7		MechS					122		126	122		
SAT.2.7.3.3	DNX-21-000	Deployment hinge		4	26,6	106,4	A	0	106,4		600	324,3
SAT.2.7.3.1	DNX-15-000	Hold down mechanisms		4	4	16,0	E	25	20,0		192	91
SAT.2.4		DNX-10-000 STS					575		588	575		
SAT.2.4.1	DNX-11-000	BOP		1	107	107,0	C	5	112,4		600	15,1
SAT.2.4.4	DNX-14-000	Unsymmetrical U's		1	307	307,0	A	0	307,0		600	167,9
SAT.2.4.3	DNX-13-000	TOP		1	161	161,0	C	5	169,1		600	220,6
		Connection strips		2	11	22,0	A	0	22,0		600	167,3
		Midplane standoffs		8	1,38	11,0	A	0	11,0		192	292,5
		Rods		4	19	76,0	B	2	77,5		192	168,8
SAT.2.5		DNX-70-000 TCS					40		52	40		
		Thermal control tape		1	40	40	F	30	52			170
SAT.1.2	DNX-63-000	T ³ _μ PS		1	140	140	D	10	154	140	181	213,7
SAT.1.3	DNX-61-000	SDM		1	100	100	E	25	125	100	204	218,8
SAT.1.1	DNX-64-000	ITRX		1	170	170	D	10	187	170	182	104,7
	DNX-50-000	Cable harness				51			61	51		
		Flex-rigid PCB		1	25	25	F	30	32,5			180,8
		Coax cables		5	4	20,0	D	10	22,0			84,7
		HDRM wiring		4	1,5	6,0	D	10	6,6			70
DNX-80-000		Miscellaneous					40		52	40		170
		nuts/bolts/etc for STS		1	40,25	40,3	F	30	52,3			
Total mass						2926			3169	2927		214,0

Design Maturity Description	Maturity code	Contingency [%]
Flight hardware	A	0
Actual qualification hardware	B	2
Released drawing	C	5
Pre-released drawing (equivalent to minor modification)	D	10
Circuit estimate (equivalent to major modification)	E	25
Conceptual estimate (based on sketches, descriptions, experience)	F	30

Current Best Estimate	Amount x Unit mass (column F*G)
Actual mass	Current best estimate + contingency
Target mass	Target mass for the subsystem

Mass budget, history

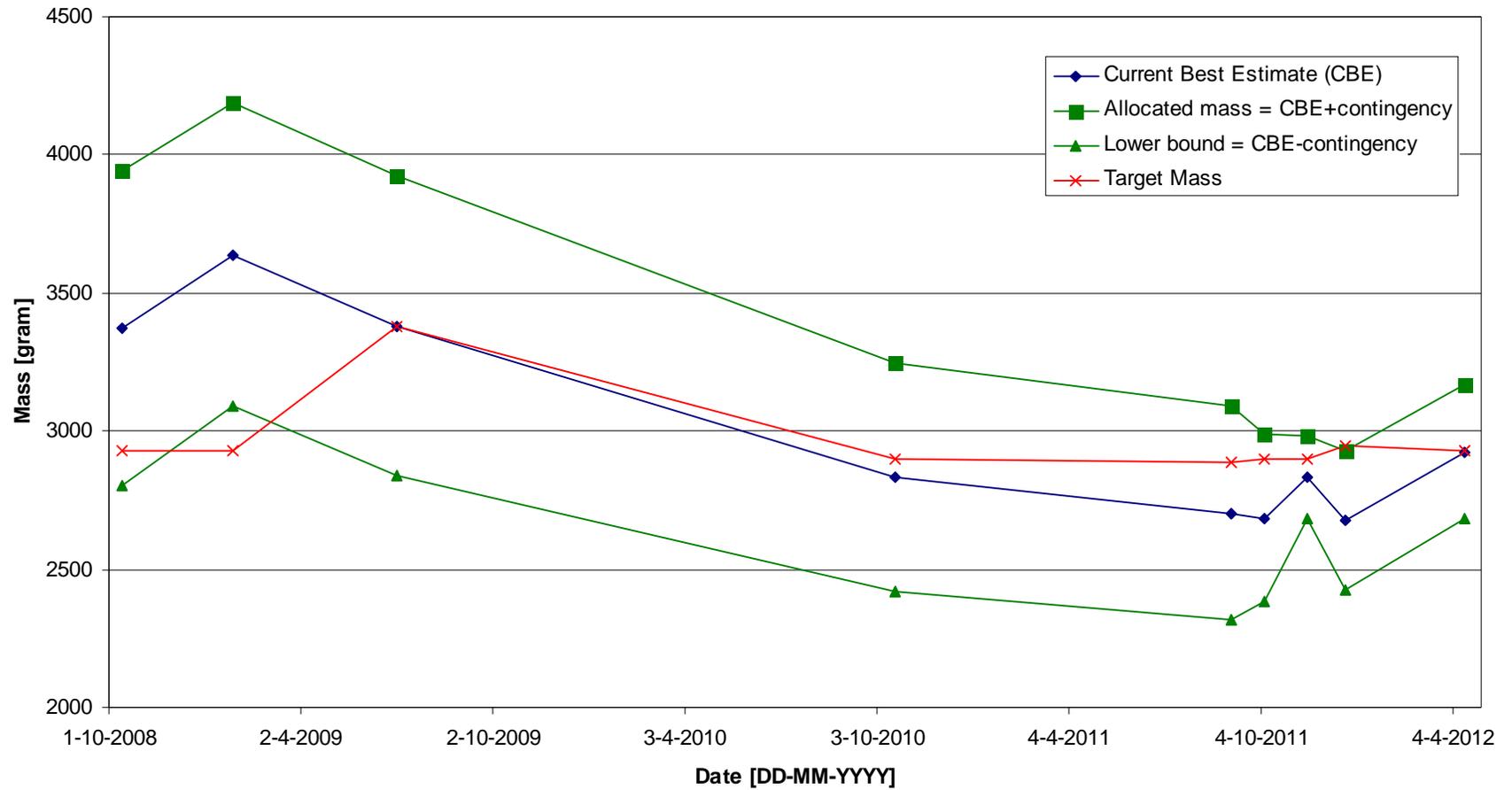
Subsystem	Allocated Mass								
Version	14-10-2008	27-1-2009	3-7-2009	21-10-2010	5-9-2011	7-10-2011	18-11-2011	24-12-2011	16-4-2012
ADCS	464,4	464,4	476	476	399	346	346	346	345
CDHS	97,8	97,8	61	61	61	61	61	61	46
COMMS	558,1	550,28	448	448	372	388	388	364	449
EPS	520,2	682,5	739	870	870	816	888	888	982
MechS	124,5	159,4	189	150	150	134	134	134	126
STS	759	779	695	633	633	633	588	588	588
TCS	52	52	52	52	52	52	52	52	52
Payloads	1068,6	1107,3	1112	411	557	557	411	381	466
Cables + Misc.	295,7	294,7	152	146	146	146	113	113	113
Total	3940,3	4187,4	3922	3246	3093	2987	2982	2929	3169

Subsystem	CBE	CBE	CBE	CBE	CBE	CBE	CBE	CBE	CBE
Version	14-10-2008	27-1-2009	3-7-2009	21-10-2010	5-9-2011	7-10-2011	18-11-2011	24-12-2011	16-4-2012
ADCS	387	387	414	414	344	323	323	323	322
CDHS	85	85	49	49	49	49	49	49	46
COMMS	485,3	478,3	386	386	328	340	340	317	387
EPS	468,4	609,5	661	752	752	756	814	814	934
MechS	111,1	140,6	180	140	140	128	128	128	122
STS	630	700	632	575	575	575	575	575	575
TCS	40	40	40	40	40	40	40	40	40
Payloads	945	912,8	899	360	476	476	360	340	410
Cables + Misc.	220,8	285,3	120	116	116	116	91	91	91
Total	3372,6	3638,5	3381	2832	2704	2686	2832	2676	2926

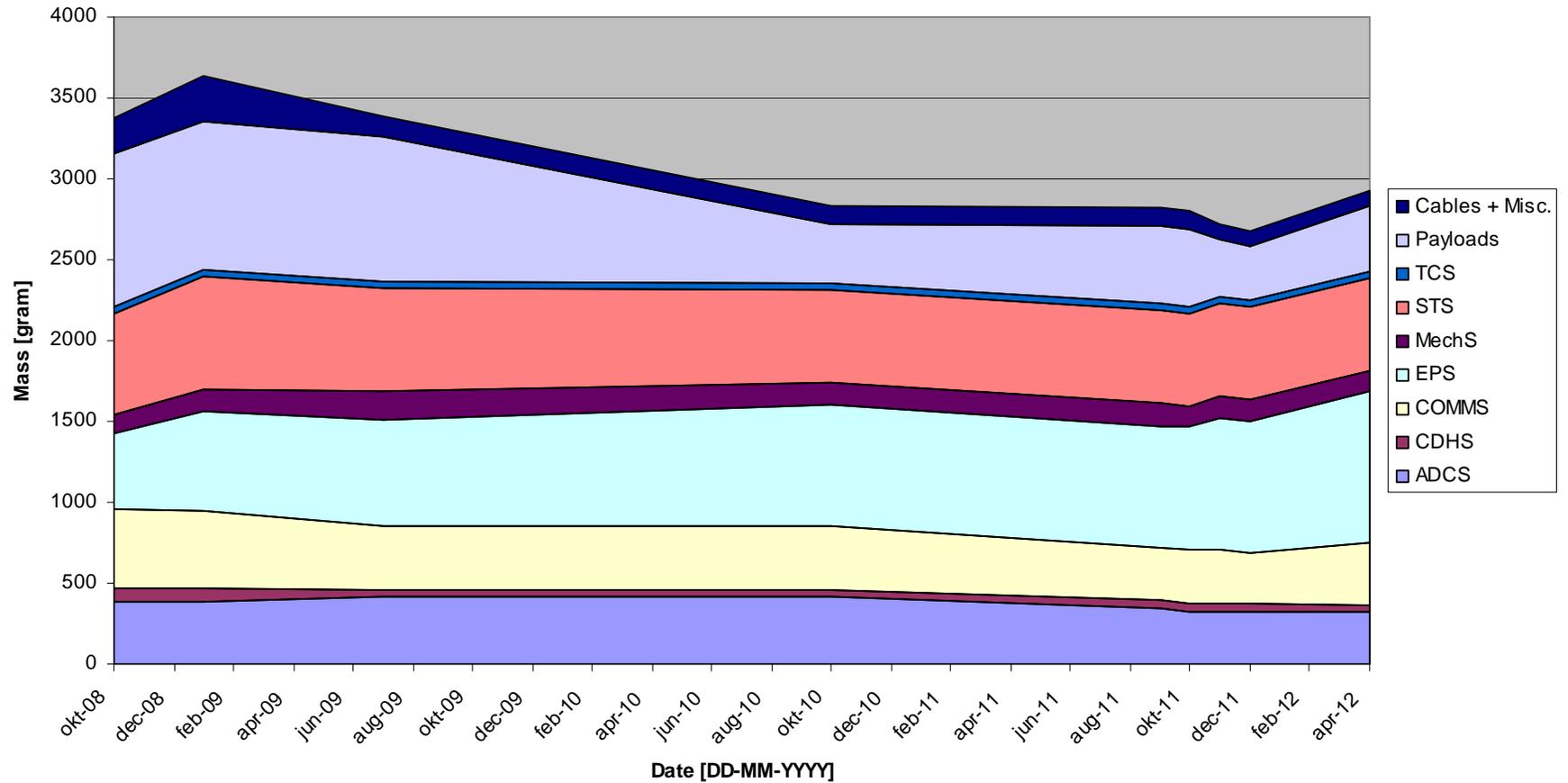
Subsystem	Target Mass	Target Mass	Target Mass	Target Mass	Target Mass	Target Mass	Target Mass	Target Mass	Target Mass
Version	14-10-2008	27-1-2009	3-7-2009	21-10-2010	5-9-2011	7-10-2011	18-11-2011	24-12-2011	16-4-2012
ADCS	309,6	309,6	414	414	400	414	414	414	322
CDHS	72,3	72,3	49	49	49	49	49	49	46
COMMS	407	407	386	386	386	386	386	386	387
EPS	383,3	383,3	661	751	751	751	751	800	934
MechS	115	115	180	152	152	152	152	152	122
STS	621	621	632	627	633	627	627	627	575
TCS	40	40	40	40	40	40	40	40	40
Payloads	741,9	741,9	899	360	476	476	360	360	410
Cables + Misc.	239,6	239,6	120	120	120	120	120	120	91
Total	2929,7	2929,7	3381	2899	2885	2899	2899	2948	2927

Subsystem	CBE-cont.	CBE-cont.	CBE-cont.	CBE-cont.	CBE-cont.	CBE-cont.	CBE-cont.	CBE-cont.	CBE-cont.
Version	14-10-2008	27-1-2009	3-7-2009	21-10-2010	5-9-2011	7-10-2011	18-11-2011	24-12-2011	16-4-2012
ADCS	309,6	309,6	352	352	289	300	300	300	299
CDHS	72,2	72,2	37	37	37	37	37	37	46
COMMS	412,5	406,32	324	324	284	292	292	270	325
EPS	416,6	536,5	583	634	634	696	740	740	886
MechS	97,7	121,8	171	130	130	122	122	122	118
STS	501	621	569	517	517	517	562	562	562
TCS	28	28	28	28	28	28	28	28	28
Payloads	821,4	718,3	686	309	395	395	309	299	354
Cables + Misc.	145,9	275,9	88	86	86	86	69	69	69
Total	2804,9	3089,6	2840	2418	2315	2385	2682	2423	2683

Mass Budget Evolution With Contingencies

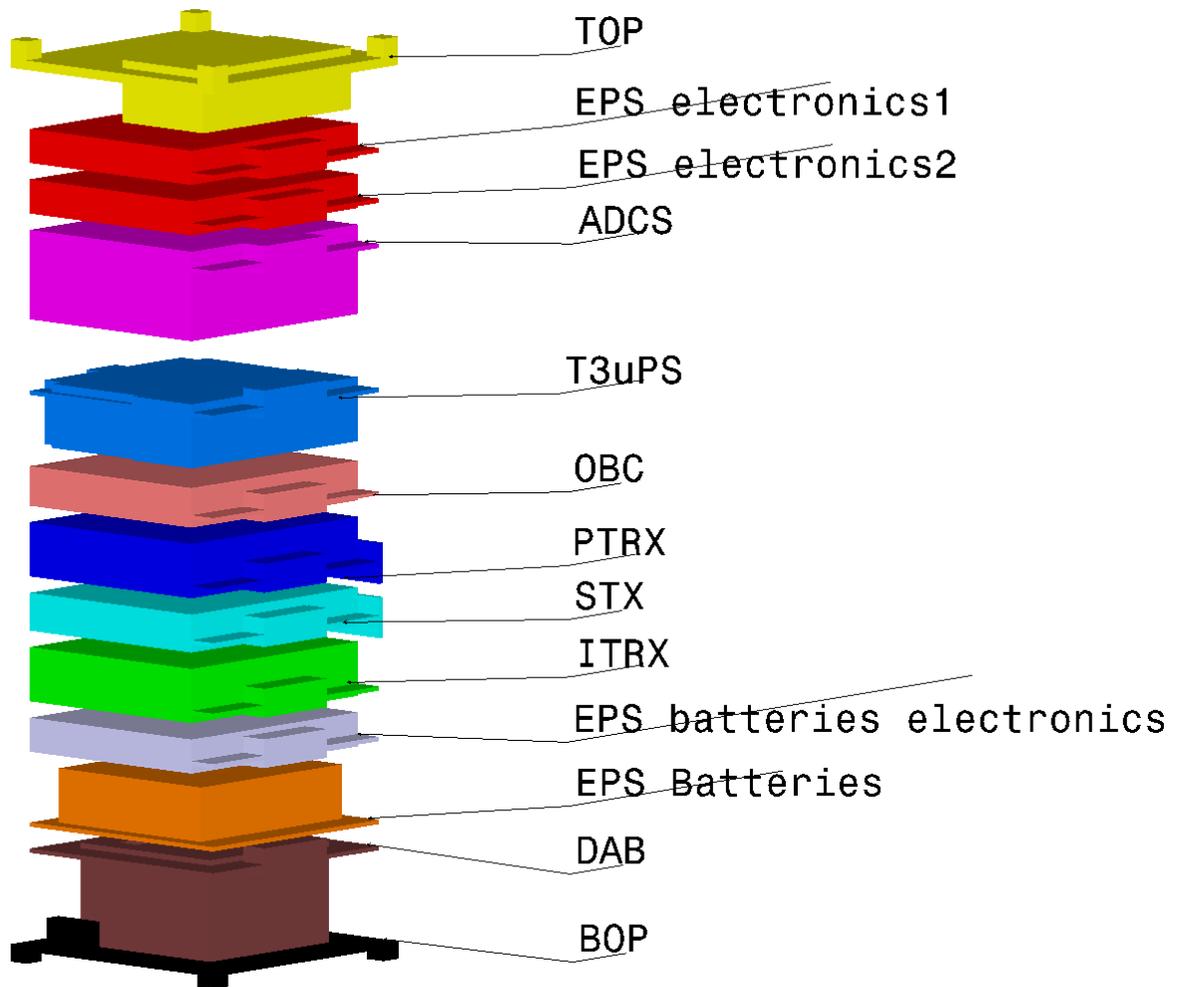


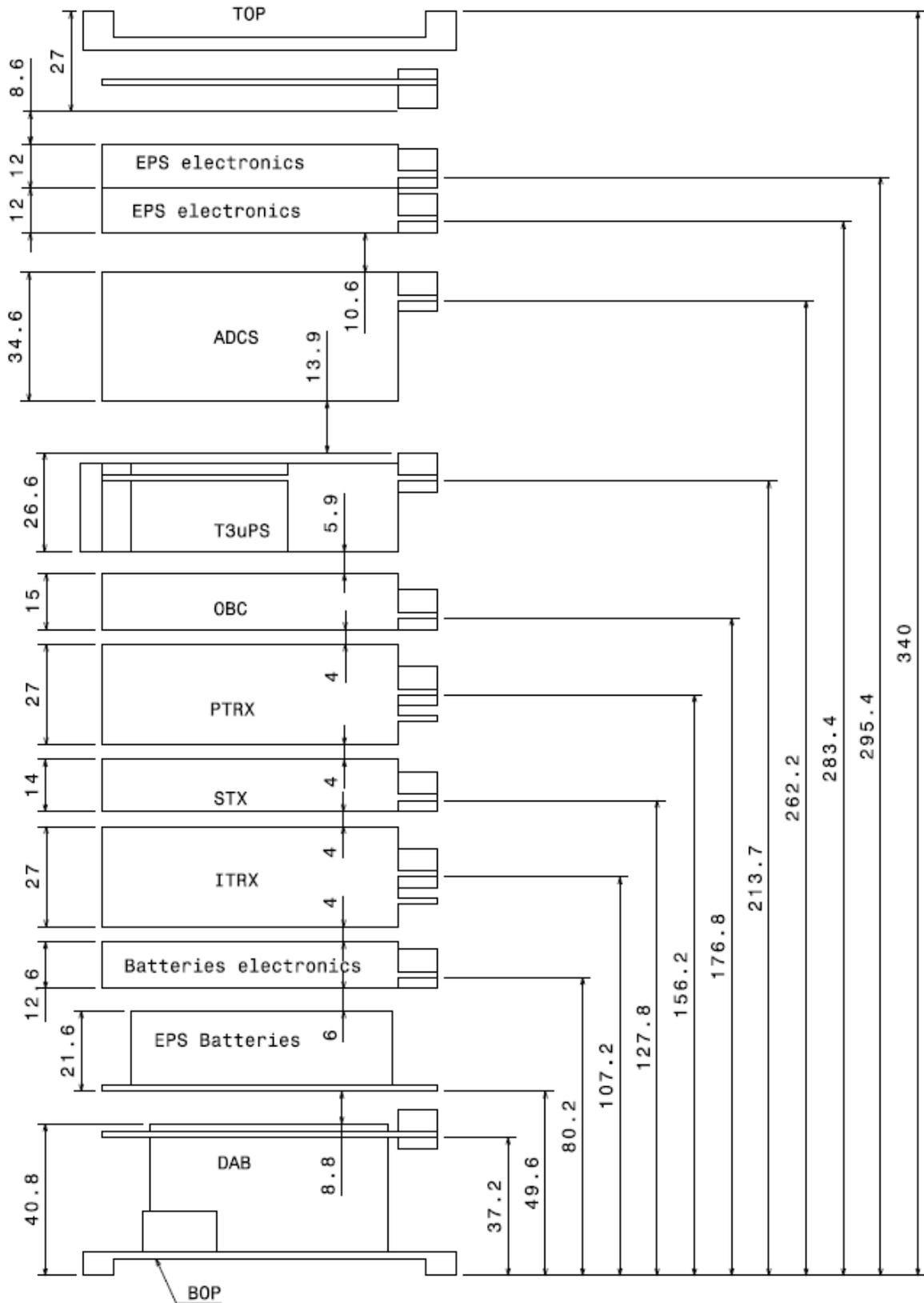
Mass Budget History Per Subsystem



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
2	30-11-2010	Johan			All	MPS and SPLASH deleted, extra EPS PCB added, order of subsystems changed, new solar panel configuration, updated masses and volumes
2,1	12-5-2011	Johan				batteries electronics added
2,2	12-12-2011	Johan				ADCS reaction wheels and electronics merged into one PCB, TCB deleted
2,3	26-1-2012	Johan				EPS placement changed
2,4	21-3-2012	Johan			All	PTRX and ITRX volume changed to 27 mm. ITRX, STX, PTRX, OBC and thruster moved up to create even spacing





Z-direction	budget	comments	Reference SLR
BOP	(6,5)	feet + thickness BOP	
DAB	40,8	from BOP Z+ without connector	
Batteries	21,6	without connector	
Batteries electronics	12,6		
ITRX	27		182
STX	14		
PTRX	27		
T ³ μPS	26,6	incl connector	181
OBC	15		
ADCS	34,6	incl connector	
EPS 1	12		
EPS 2	12		
TOP	27	incl SDM	
offset	69,8		
total height	340		

maximum height satellite 340.5 mm

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

Status	Date: 1-6-2012			Responsible	QUANTITIES						DIMENSIONS [mm]				MAIT INFORMATION							
	(Sub)System	Drawing number	Drawing Name		FM1	FM2	Spare	Total	Order	In stock	Length	Width	Diameter	Thickness	Type	USA norm	NL norm	Werkstoffnr.	Surface treatment	Material supplier	Material ordered	Product status
0	SATELLITE	DNX-00-000	Delfi-n3Xt SATELLITE ASSEMBLY																			
		DNX-00-000	Delfi-n3Xt SATELLITE ASSEMBLY solar panels fold out																			
		DNX-00-001	Reference coordinate system Delfi-n3Xt																			
		DNX-00-002	Delfi-n3Xt SATELLITE ASSEMBLY solar panels fold in																			
		DNX-00-003	Delfi-n3Xt SATELLITE ASSEMBLY without TOP, BOP and DAB																			
1	STRUCTURE	DNX-10-000	STRUCTURE ASSEMBLY																			
		DNX-11-000	Bottom Panel Assembly																			
		DNX-11-001	Bottom Panel		1	1	1	3			110	110		35	Aluminium	6082	51ST	3.2315.72	Alodine 1500	Salomons	delivered	
		DNX-11-004	Kill switch assembly		1	1	1	3														
		DNX-11-005	Kill switch		1	1	1	3														
		DNX-11-006	Over travel kit		1	1	1	3														
		DNX-11-007	Spring pin		1	1	1	3														
		DNX-13-000	Top Panel Assembly																			
		DNX-13-001	Top Panel		1	1	1	3			110	110		40	Aluminium	6082	51ST	3.2315.72	Alodine 1500	Salomons	delivered	
		DNX-14-000	Body Assembly																			
		DNX-14-001	U-profile Y-X+		1	1	1	3			400	250		1	Aluminium	5083	D54S	3.3547.08	Alodine 1500	Salomons	delivered	
		DNX-14-002	Connection strip		2	2	2	6			400	15		1	Aluminium	5083	D54S	3.3547.08	Alodine 1500	Salomons	delivered	
		DNX-14-003	U-profile Y+X-		1	1	1	3			400	250		1	Aluminium	5083	D54S	3.3547.08	Alodine 1500	Salomons	delivered	
		DNX-15-000	HDRM - Assembly																			
		DNX-15-100	HDRM - Deployment Resistor Assembly		8	8	8	24							---							
		DNX-15-101	HDRM - Support right		4	4	4	12														
	design as DC3	DNX-15-102	HDRM - Release spring block		8	8	8	24	24	25					Aluminium	5083	D54S	3.3547.08	Alodine 1500	Salomons	delivered	surface treatment open
	design as DC3	DNX-15-103	HDRM - Release spring - clockwise		4	4	4	12	20	20					Stainless steel	AISI 301				Tevema	delivered	delivered
	design as DC3	DNX-15-104	HDRM - Release spring - counterclockwise		4	4	4	12	20	20					Stainless steel	AISI 301				Tevema	delivered	delivered
		DNX-15-105	HDRM - Support left		4	4	4	12														
		DNX-15-106	HDRM - Resistor PCB		8	8	8	24														
		DNX-15-107	HDRM - Resistor		8	8	8	24														
	design as DC3	DNX-15-108	HDRM - Release rope - L = ???		4	4	40	48							Dyneema					DSM	available	
		DNX-15-109	HDRM - Support block SP STX		2	2	2	6														
		DNX-15-200	HDRM - Deployment Confirmation Assembly		4	4	4	12							---							
	design as DC3	DNX-15-201	HDRM - Tact switch PCB		4	4	4	12														
		DNX-15-202	HDRM - Tact switch		4	4	4	12														
2	SOLAR PANELS	DNX-20-000	SOLAR PANEL ASSEMBLY																			
		DNX-21-000	SPA - Hinge Assembly																			
		DNX-21-001	SPA - Hinge blade structure		4	4	0	8	-	12					Brass	Rg7		2.1090.03		Salomons	delivered	assembly open
		DNX-21-002	SPA - Hinge blade solar panel		4	4	0	8	-	12					Brass	Rg7		2.1090.03		Salomons	delivered	assembly open
		DNX-21-003	SPA - Axle		4	4	4	12	-	13	60				Stainless steel	AISI 301				Salomons	delivered	assembly open
		DNX-21-004	SPA - Deployment spring - left		4	4	4	12	material						0.8-1.0	Stainless steel	AISI 301			Tevema	delivered	
		DNX-21-005	SPA - Deployment spring - right		4	4	4	12	material						0.8-1.0	Stainless steel	AISI 301			Tevema	delivered	
		DNX-22-000	SPA - Substrate Assembly		4	-	2	6							---							
		DNX-22-001	SPA - Substrate		4	-	2	6							CFRP							
		DNX-22-002	SPA - Hold-down guide		8	-	2	10							Vespel or PEEK							
		DNX-22-003	SPA - Solar Cell String (7 TEC cells per string)		4	-	2	6							GaAs cell					Dutch Space		
3	STACK	DNX-30-000	STACK ASSEMBLY																			
		DNX-30-000	STACK ASSEMBLY		1	1		2														
		DNX-30-001	Threaded Rod		4	4	4	12	16						Stainless steel	AISI 304	A2-50			JEVEKA	delivered	
		DNX-30-002	Mid plane stand-off		8	8	8	24	30						Aluminium	5083	D54S	3.3547.08	Alodine 1500	Salomons	delivered	
		DNX-30-003	Distance bush Top Panel/Battery board - L = ?? mm		4	4	4	12	16						4	0,5	Stainless steel	AISI 304			Salomons	delivered
		DNX-30-004	Distance bush Battery board/EPS - L = ?? mm		4	4	4	12	16						4	0,5	Stainless steel	AISI 304			Salomons	delivered
		DNX-30-005	Distance bush EPS/ADCS electronics - L = ?? mm		4	4	4	12	16						4	0,5	Stainless steel	AISI 304			Salomons	delivered

Status	Date: 1-6-2012		Respon- sible	QUANTITIES						DIMENSIONS [mm]				MAIT INFORMATION							
	(Sub)System	Drawing number		Drawing Name	FM1	FM2	Spare	Total	Order	In stock	Length	Width	Dia- meter	Thick- ness	Type	USA norm	NL norm	Werk- stoffnr.	Surface treatment	Material supplier	Material ordered
		DNX-30-006	Distance bush ADCS electronics/ADCS reation wheels - L = ?? mm	4	4	4	12	16				4	0,5	Stainless steel	AISI 304				Salomons	delivered	
		DNX-30-007	Distance bush ADCS reation wheels/Microthruster - L = ?? mm	4	4	4	12	16				4	0,5	Stainless steel	AISI 304				Salomons	delivered	
		DNX-30-008	Distance bush Microthruster/PTRX - L = ?? mm	4	4	4	12	16				4	0,5	Stainless steel	AISI 304				Salomons	delivered	
		DNX-30-009	Distance bush PTRX/STX - L = ?? mm	4	4	4	12	16				4	0,5	Stainless steel	AISI 304				Salomons	delivered	
		DNX-30-010	Distance bush STX/ITRX - L = ?? mm	4	4	4	12	16				4	0,5	Stainless steel	AISI 304				Salomons	delivered	
		DNX-30-011	Distance bush ITRX/Intermediate panel - L = ?? mm	4	4	4	12	16				4	0,5	Stainless steel	AISI 304				Salomons	delivered	
		DNX-30-012	reserved																		
		DNX-30-013	Distance bush DAB/TCB - L = ?? mm	4	4	4	12	16				4	0,5	Stainless steel	AISI 304				Salomons	delivered	
		DNX-30-014	Distance bush TCB/Bottom panel- L = ?? mm	4	4	4	12	16				4	0,5	Stainless steel	AISI 304				Salomons	delivered	
		DNX-30-100	Flex rigid PCB standard system bus	1																	
		DNX-31-000	Standard PCB																		
		DNX-32-000	TCS PCB	4	4	4	12														
4	SUB-SYSTEMS	DNX-40-000	SUB-SYSTEMS ASSEMBLY																		
		DNX-41-000	ADCS - ATTITUDE DETERMINATION and CONTROL SYSTEM																		
		DNX-41-100	ADCS - PCB Assembly	1	1	1	3							---							
		DNX-41-101	ADCS Electrical Diagram											---							
		DNX-41-102	ADCS - PCB	1	1	2	4	10						FR4					Cyner		
		DNX-41-200	ADCS - Reaction Wheels Assembly	1	1	1	3														
		DNX-41-201	ADCS - RW PCB	1	1	2	4	10						FR4					Cyner		
		DNX-41-202	ADCS - RW Flywheel - high	1	1	2	4	5													
		DNX-41-203	ADCS - RW bracket	1	1	2	4	5													
		DNX-41-204	ADCS - RW Flywheel - medium	1	1	2	4														
		DNX-41-205	ADCS - RW Flywheel - low	1	1	2	4														
		DNX-41-300	ADCS - Magnetorquer assembly	1	1	1	3							---							
		DNX-41-301	ADCS - X-axis torquer																		
		DNX-41-302	ADCS - Y-axis torquer																		
		DNX-41-303	ADCS - Z-axis torquer																		
		DNX-41-304	ADCS - Clamp blocks																		
		DNX-41-305	ADCS - X- and Y-torquer flange A																		
		DNX-41-306	ADCS - X- and Y-torquer flange B																		
		DNX-41-500	ADCS - Sun Sensor Assembly																		
		DNX-41-502	ADCS - Sensor PCB																		
		DNX-41-503	ADCS - Sensor housing																		
		DNX-41-504	ADCS - Sensor																		
		DNX-41-505	ADCS - Sensor positioning part																		
		DNX-42-000	COMMS - COMMUNICATION SUBSYSTEM																		
		DNX-42-100	PTRX Assembly				0							---							
		DNX-42-101	PTRX Electrical Diagram				0							---							
		DNX-42-102	PTRX - PCB	1	1	4	6	10						FR4					Cyner		
		DNX-42-200	STX Assembly				0							---							
		DNX-42-201	STX - Electrical Diagram				0							---							
		DNX-42-202	STX - PCB	1	1	4	6	10						FR4					Cyner		
		DNX-42-204	STX - Patch PCB																		
		DNX-43-000	EPS - ELECTRONIC POWER SUBSYSTEM	SystematIC			0														
		DNX-43-100	EPS - Assembly	SystematIC	1	1	2	4						---							
		DNX-43-101	EPS - Electrical Diagram	SystematIC			0							---							
		DNX-43-102	EPS - PCB	SystematIC	1	1	4	6	10					FR4					Cyner		

Status	Date: 1-6-2012		Responsible	QUANTITIES						DIMENSIONS [mm]				MAIT INFORMATION								
	(Sub)System	Drawing number		Drawing Name	FM1	FM2	Spare	Total	Order	In stock	Length	Width	Diameter	Thickness	Type	USA norm	NL norm	Werkstoffnr.	Surface treatment	Material supplier	Material ordered	Product status
		DNX-43-103	EPS - second PCB																			
		DNX-43-200	EPS - Battery Board Assembly				0								---							
		DNX-43-201	EPS - Electrical Diagram												---							
		DNX-43-202	EPS - Battery Bracket		1	1	4	6	10						FR4					Cyner		
		DNX-43-203	EPS - Battery Bracket Lid	TUD				0														
		DNX-43-204	EPS - Battery																			
		DNX-43-300	EPS - Batteries electronics PCB																			
		DNX-43-301	EPS - Wire clip lower part																			
		DNX-43-302	EPS - Wire clip upper part																			
		DNX-43-303	EPS - Wire clip SP																			
		DNX-44-200	DAB - Deployment and Antenna Board Assembly	TUD																		
	design as DC3, adapted	DNX-44-201	MAB - Assembly		4	4	6	14														
	design as DC3	DNX-44-202	MAB - Antenna assembly		4	4	6	14														
	design as DC3	DNX-44-203	MAB - Antenna inner part		4	4	6	14							Spring steel					Stanley	available	
		DNX-44-204	MAB - Antenna outer part		4	4	6	14							Spring steel					Stanley	available	
		DNX-44-205	MAB - Nut M1		4	4	6	14														
		DNX-44-206	MAB - Bolt M1-6mm		4	4	6	14														
		DNX-44-207	MAB - Connector		4	4	6	14														
	design as DC3, adapted	DNX-44-208	MAB - Box		4	4	6	14							Makrolon					Wientjes		
	design as DC3	DNX-44-209	MAB - Front cover		4	4	6	14							Makrolon					Wientjes		
	design as DC3	DNX-44-210	MAB - Lid without sword		4	4	6	14							Makrolon					Wientjes		
	design as DC3	DNX-44-211	MAB - Lid spring		4	4	6	14							Stainless steel							
	design as DC3	DNX-44-212	MAB - Axle 1x8mm		4	4	6	14							Stainless steel							
	design as DC3	DNX-44-213	MAB - ICB		4	4	6	14														
		DNX-44-214	MAB - Resistor		4	4	6	14														
		DNX-44-215	MAB - TAC switch		4	4	6	14														
		DNX-44-216	MAB - Bolt M2x8mm		4	4	6	14														
		DNX-44-217	MAB - Isolation ring		4	4	6	14														
		DNX-44-218	MAB - Dyneema wire		4	4	6	14							Dyneema					Goedkoper vi	available	
		DNX-46-000	OBC - ON-BOARD COMPUTER	TUD				0														
		DNX-46-001	OBC - Electrical Diagram					0														
		DNX-46-002	OBC - PCB		1	1	4	6	10													
6	PAYLOADS	DNX-60-000	PAYLOAD ASSEMBLIES																			
		DNX-61-000	SDM - SOLAR CELL EXPERIMENT ASSEMBLY	DIMES	1	1	?	2														
		DNX-61-001	SDM - Electrical Diagram	DIMES																		
		DNX-61-002	SDM - PCB	DIMES																		
		DNX-61-003	SDM - Aluminium plate	DIMES																		
		DNX-61-004	SDM - Solar cell glass	DIMES																		
		DNX-61-005	SDM - Plate with cells	DIMES																		
		DNX-61-006	SDM - Self clinching nut	DIMES																		
		DNX-61-007	SDM - Rubber ring	DIMES																		
		DNX-63-000	MICRO-PROPULSION ASSEMBLY	TNO	1	1	?	2														
		DNX-63-001	MPA - Electrical Diagram																			
		DNX-63-002	MPA - PCB																			
		DNX-63-003	MPA - Microthruster																			
		DNX-63-004	MPA - Nozzle																			
		DNX-64-000	ITRX ASSEMBLY	ISIS	1	1	?	2														
		DNX-64-001	ITRX - Electrical Diagram	ISIS																		
		DNX-64-002	ITRX - PCB	ISIS																		
		DNX-64-003	ITRX - Cooling Fin	ISIS																		

Status	Date: 1-6-2012		Drawing Name	Respon- sible	QUANTITIES						DIMENSIONS [mm]				MAIT INFORMATION						
	(Sub)System	Drawing number			FM1	FM2	Spare	Total	Order	In stock	Length	Width	Dia- meter	Thick- ness	Type	USA norm	NL norm	Werk- stoffnr.	Surface treatment	Material supplier	Material ordered
7	THERMAL CONTROL	DNX-70-000	THERMAL CONTROL ASSEMBLY																		
		DNX-71-000	THERMAL CONTROL ASSEMBLY	TUD	1	1	TBD	2													
8	MISCELLANEOUS	DNX-80-000	MISCELLANEOUS ASSEMBLIES, PARTS																		
9	GSE	DNX-90-000	GROUND SUPPORT EQUIPMENT																		
		DNX-91-000	MECHANICAL GROUND SUPPORT EQUIPMENT																		
		DNX-91-100	TOP - Protection Cover		1	1	1	3													
		DNX-91-300	n3xt - Handling Tool		1	1	0	2													
		DNX-91-900	Miscellaneous																		
		DNX-91-901	RW test PCB		1																
		DNX-91-902	RW mass dummy		2																
		DNX-91-903	Flywheel Assembly Support Base		1																
		DNX-91-904	Flywheel Disassembly Support Base		1																
		DNX-91-905	Flywheel Assembly Distance Plate		1																
		DNX-91-906	Satellite Support Station Base																		
		DNX-91-907	Satellite Support Station Bracket																		
		DNX-92-000	ELECTRICAL GROUND SUPPORT EQUIPMENT																		
	From DC3		MAB Circuit test cable		1	0	0	1													available
			Pin-savers TBD pins		1			1													
			Break-out box - type 1, TBD pins		1			1													
			Break-out box - type 2, TBD pins		1			1													
			S/C power supply line		1	1		2													
			S/C electrical grounding cable		1	1		2													
			S/C test cable		1	1		2													
		DNX-93-000	TOOLS																		
	from DC3		MAB Antenna assembly tool					0													available
	from DC3		MAB Antenna drill jig																		available
	from DC3		Hinge spring manufacturing tool					0													available
			Press nut installation tool																		
	from DC3		Release cord jig																		available
	from DC3		Resistor hot spot tool																		available
			Drill jig - outside <TBD>																		new design
	from DC3		PCB stand - small																		available
	from DC3		PCB stand - large																		available
*	SHOWMODEL		Drawings																		
			Bottom panel											Aluminium							delivered
			Top panel											Aluminium							delivered
*	POD		ISIPOD Drawings																		
																		ISIS			open

(CANDIDATE) PARTS

Item	Product	Material	Size	Length	Supplier code	Specification	Material code	Supplier	Manufacturer	Remarks
	Nut	Stainless steel	M1	n/a		DIN 934	AISI 304	Jeveka		
	Nut	Stainless steel	M2	n/a		DIN 934	AISI 304	Jeveka		
	Nut	Stainless steel	M2.5	n/a		DIN 934	AISI 304	Jeveka		
	Nut	Stainless steel	M3	n/a		DIN 934	AISI 304	Jeveka		
	Washer for M1	Stainless steel	dia 1.1 X 3	n/a		DIN 125A	AISI 304	Jeveka		
	Washer for M2	Stainless steel	dia 2.2 X 5	n/a		DIN 125A	AISI 304	Jeveka		
	Washer for M2.5	Stainless steel	dia 2.7 X 6	n/a		DIN 125A	AISI 304	Jeveka		
	Washer for M3 cylinder head	Stainless steel	dia 3.2 X 6	n/a		DIN 433	AISI 304	Jeveka		
	Springwasher for M3	Stainless steel	dia 3.1 X 5.6	n/a		DIN 7980	AISI 304	Jeveka		
	Screw, slitted, countersunk	Stainless steel	M1			DIN 963	AISI 304	Jeveka		for antenna connection
	Screw, slitted, cylinder head	Stainless steel	M1			ISO 1207	AISI 304	Jeveka		
	Screw, Philips, countersunk	Stainless steel	M1.6			DIN 965	AISI 304	Jeveka		
	Screw, Philips, cylinder head	Stainless steel	M1.6			DIN 7985	AISI 304	Jeveka		
	Screw, Torx, countersunk	Stainless steel	M2			ISO 14581	AISI 304	Jeveka		
	Screw, Torx, countersunk	Stainless steel	M2.5			ISO 14581	AISI 304	Jeveka		
	Screw, Torx, countersunk	Stainless steel	M3			ISO 14581	AISI 304	Jeveka		
	Screw, Torx, cylinder head	Stainless steel	M2			ISO 14583	AISI 304	Jeveka		
	Screw, Torx, cylinder head	Stainless steel	M2.5			ISO 14583	AISI 304	Jeveka		
	Screw, Torx, cylinder head	Stainless steel	M3			ISO 14583	AISI 304	Jeveka		
	Threaded rod	Stainless steel	M3			DIN976	AISI 304	Jeveka		
	Helicoil	Bronze	M2.5	1D	546000449			VIBA	Bolhoff	
	Helicoil	Bronze	M2.5	1.5D	546000360			VIBA	Bolhoff	
	Helicoil	Bronze	M3	1D	41301030003			VIBA	Bolhoff	
	Helicoil	Bronze	M3	1.5D	41301030045			VIBA	Bolhoff	
	Pressnut " anchor mini"	Brass	M2.5		724 000 025 800			Gebrema	Kerb Konus	hole in sheet dia. 4.2
	Pressnut " anchor mini"	Brass	M3		724 000 030 800			Gebrema	Kerb Konus	hole in sheet dia. 4.2

(CANDIDATE) ELECTRICAL PARTS

Item	Product	Style	Type / partnumber	Material	Specification	Supplier	Manufacturer	Remarks
	PCB		FR4			Cyner	Cyner	
	Shrink sleeve		RT876				Tyco (Raychem)	
	connector	male					Harwin	
	connector	female					Harwin	
	connector	pinheader					Harwin	
	socket, small bore						Harwin	goldized
	socket, large bore						Harwin	goldized
	pin male, small bore						Harwin	goldized
	pin male, large bore						Harwin	goldized

(CANDIDATE) MATERIALS

Item	Product	Materiaal / Type / partnumber	Material USA norm	EN/NL norm	Werkstoffnr.	Manufacturer / Supplier	Remarks
METALS							
	Plate	Aluminium alloy	6082	51ST	3.2315.72	Salomons Metalen, Groningen	TOP, BOT, intermediate panel
	Sheet	Aluminium alloy	5083	D54S	3.3547.08	Salomons Metalen, Groningen	outside panel
	Foil	Aluminium alloy					for window of MPS
	platstaf	Bronze	Rq7	CH493K	2.1090.03	Salomons Metalen, Groningen	
	Capillaire buis, dia 4.5 X 0.5	Stainless steel non-magnetic	AISI 304		1,4301	Salomons Metalen, Groningen	
	Rod, dia 2 mm	Stainless steel non-magnetic	AISI 304			Salomons Metalen, Groningen	passing h9; for hinge
	Spring wire	Stainless steel	AISI			Tevema	wire dia. 0.8 0.9 1.0 mm
PLASTICS							
	GFRP	FR4					
	CFRP	M55					solar panel substrate
	plastic	PEEK					
	plastic	Vespel SP1				Du Pont	max. 315 Deg C
	plastic	Vespel SP3				Du Pont	graphite filled
	packing material	Choterm				Chomerics	high thermal conductivity
		Makrolon				Wientjes	MAB's, MGSE
ADHESIVES and TAPES							
	Adhesive, epoxy	EC2216 B/A				3M	max. 80 deg C full load; max. 120 deg C
	Adhesive, epoxy	EA 934 B/A				Henkel Corporation Aerospace Group	up to 180 deg C
	Adhesive, acrylic transferfilm	Y966				3M	max 180 deg C
	Adhesive, silicone	RTV 566 B/A				GE	primer needed
	Adhesive, silicone	RTV S-691				Wacker Chemie AG http://www.wacker.com	primer needed; solar cells
	Thermal control tape	Teflon, silverised, SSM, 5 mil (=125 micrometer)				Misc.	max 300 deg C
	Thermal control tape	Kapton, aluminised, frontside				Misc.	max 260 deg C
	Tape	Kapton				Permacell, Brands	General use; max. 180 deg C
PAINT							
	black paint	Electrodag				Acheson	
MISCELLANEOUS							
	Surface treatment	Alodine 1500				Henkel Corporation Aerospace Group	
		Primer for RTV 566					
		Primer for S-691					

Change Log

Date	Version	Author	Reviewed by	Description of Change
27-3-2009	0,01	J. Bouwmeester	SG, AT	First draft
30-02-2009	0,02	J. Bouwmeester		Added solar panels, changed system bus to 18 pins (16 pins not standard)
19-5-2009	0,03	J. Bouwmeester	SL	Removed kill switch pins from main system bus, added 2 series of batteries and added test connectors
20-5-2009	0,04	J. Bouwmeester		Removed ICB, Antenna Board changed to DAP (Deployment, Antenna & Phasing board)
26-10-2010	0,05	J. Bouwmeester	LB	Updated standard system bus wiring and connector.
19-4-2011	1,00	J. Bouwmeester	PB	Updated standard system bus pin-out.
2-5-2011	1,01	J. Bouwmeester	PB	Corrected name pin 20 DSSB.
30-8-2011	2,00	J. Bouwmeester	LB	Complete update, to start baselining all wiring interfaces, location and side.
31-8-2011	2,01	J. Bouwmeester	PB	Added solar panel deployment mechanisms wiring.
2-9-2011	2,02	J. Bouwmeester		Added sun sensor pin definition, added thermal sensors
13-9-2011	2,03	J.P. de Jong		Added pin definition STX
	2,04	J.P. de Jong		Added pin definition DAB
	2,05	J.P. de Jong		Changed pin definition DAB to 20 pins connectors
	2,06	J.P. de Jong		Changed pin definition DAB
	2,07	J.P. de Jong		Added pin definition EPS

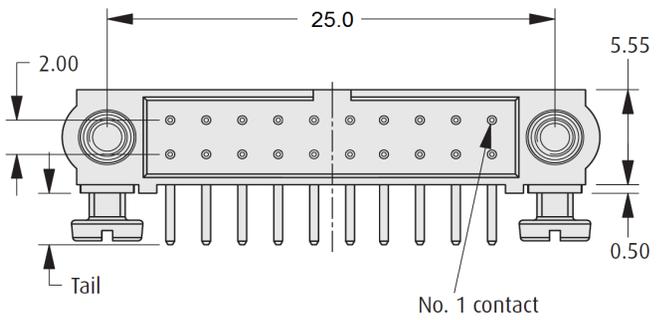
Electrical Wiring Interface Overview

Wiring Interface	Acronym	From	To	Description
Delfi Standard System Bus	DSSB	Full stack, X+	Full stack, X+	data and bus power distribution
Pin	Allocation			
1	RSVA_RHS	N/A	N/A	reserved for future developments
2	RSVB_RHS	N/A	N/A	reserved for future developments
3	GND	EPS	Full stack	satellite ground
4	SDA_RHS	OBC	Full stack	I ² C data line, right hand side
5	+12VDC	EPS	Full stack	regulated +12 V bus
6	GND	EPS	Full stack	satellite ground
7	SCL_RHS	OBC	Full stack	I ² C clock line, right hand side
8	VARV_RHS	EPS	BS & T3μPS	variable voltage bus, right hand side
9	GND	EPS	Full stack	satellite ground
10	+12VDC	EPS	Full stack	regulated +12 V bus
11	+12VDC	EPS	Full stack	regulated +12 V bus
12	GND	EPS	Full stack	satellite ground
13	VARV_LHS	EPS	BS & T3μPS	variable voltage bus, left hand side
14	SCL_LHS	OBC	Full stack	I ² C clock line, left hand side
15	GND	EPS	Full stack	satellite ground
16	12VDC	EPS	Full stack	regulated +12 V bus
17	SDA_LHS	OBC	Full stack	I ² C data line, left hand side
18	GND	EPS	Full stack	satellite ground
19	RSVB_LHS	N/A	N/A	reserved for future developments
20	RSVA_LHS	N/A	N/A	reserved for future developments
Radio Frequency Links	COMMS_RF			RF cables between radios and antenna board
ITRX	ITRX_VHF	ITRX, Y+	DAB, Y+	VHF signal from ITRX
	ITRX_UHF	ITRX, Y+	DAB, Y+	UHF signal to ITRX
PTRX	PTRX_VHF	PTRX, Y+	DAB, Y+	VHF signal from PTRX
	PTRX_UHF	PTRX, Y+	DAB, Y+	UHF signal to PTRX
Sun Sensors	SS			data and power from ADCS to
Sun Sensor X+	SS_X+	SS, X+	ADCS, TBD	
Pin	Allocation			
1	SDA_ADCS			

2	3.3VDC			
3	GND			
4	SCL_ADCS			
Sun Sensor X-	SS_X-	SS, X-	ADCS, TBD	See SS_X+ for pin definition
Sun Sensor Y+	SS_Y+	SS, Y+	ADCS, TBD	See SS_X+ for pin definition
Sun Sensor Y-	SS_Y-	SS, Y-	ADCS, TBD	See SS_X+ for pin definition
Sun Sensor Z+	SS_Z+	SS, Z+/TBD	ADCS, TBD	See SS_X+ for pin definition
Sun Sensor Z-	SS_Z-	SS, Z-/TBD	ADCS, TBD	See SS_X+ for pin definition
Solar Panels	SP			
Solar Panel X+	SP_X+	SP, X+	EPS1_X+	
Pin	Allocation			
1	S1-1+	SP, X+	EPS1_X+	S1+ primary
2	S1-2+	SP, X+	EPS1_X+	S2+ secondary
3	T2-	SP, X+	EPS1_X+	T2-
4	S2-1+	SP, X+	EPS1_X+	S2+ primary
5	T2+	SP, X+	EPS1_X+	T2+
6	S2-2+	SP, X+	EPS1_X+	S2+ secondary
7	S1-2-	SP, X+	EPS1_X+	S1- secondary
8	T1-	SP, X+	EPS1_X+	T1-
9	S1-1-	SP, X+	EPS1_X+	S1- primary
10	T1+	SP, X+	EPS1_X+	T1+
11	S2-2-	SP, X+	EPS1_X+	S2- secondary
12	S2-1-	SP, X+	EPS1_X+	S2- primary
Solar Panel X-	SP_X-	SP, X-	EPS1_X-	idem
Solar Panel Y+	SP_Y+	SP, Y+	EPS1_Y+	idem
Solar Panel Y-	SP_Y-	SP, Y-	EPS1_Y-	idem
Panel Deployment Mechanism	DEP			
Panel Deployment X+& Y-	DEP_X+Y-			
Pin	Allocation			
1		Switch	DAB	Deployment switch X+
2		Switch	DAB	
3		Switch	DAB	Deployment switch Y-
4		Switch	DAB	
5	positive	ResistorB Y-	DAB	ResistorB Y-
6	negative	ResistorB Y-	DAB	
7	positive	ResistorA X+	DAB	ResistorB X+

8	negative	ResistorA X+	DAB		
9	positive	ResistorB X+	DAB	ResistorB X+	
10	negative	ResistorB X+	DAB		
11	SDA	temp. sensor	DAB	temp. sensor X+	
12	3.3V	temp. sensor	DAB		
13	GND	temp. sensor	DAB		
14	SCL	temp. sensor	DAB		
15	SDA	temp. sensor	DAB	temp. sensor Y-	
16	3.3V	temp. sensor	DAB		
17	GND	temp. sensor	DAB		
18	SCL	temp. sensor	DAB		
19	positive	ResistorA Y-	DAB	ResistorA Y-	
20	negative	ResistorA Y-	DAB		
Panel Deployment X- & Y+		DEP_X-Y+			
Pin	Allocation				
1		Switch	DAB	Deployment switch X-	
2		Switch	DAB		
3	positive	ResistorB X-	DAB	ResistorB X-	
4	negative	ResistorB X-	DAB		
5	SDA	temp. sensor	DAB	temp. sensor X-	
6	3.3V	temp. sensor	DAB		
7	GND	temp. sensor	DAB		
8	SCL	temp. sensor	DAB		
9	SDA	temp. sensor	DAB	temp. sensor Y+	
10	3.3V	temp. sensor	DAB		
11	GND	temp. sensor	DAB		
12	SCL	temp. sensor	DAB		
13	positive	ResistorA Y+	DAB	ResistorA Y+	
14	negative	ResistorA Y+	DAB		
15	positive	ResistorB Y+	DAB	ResistorB Y+	
16	negative	ResistorB Y+	DAB		
17	positive	ResistorA X-	DAB	ResistorA X-	
18	negative	ResistorA X-	DAB		
19		Switch	DAB	Deployment switch Y+	
20		Switch	DAB		
S-band Tx - STX I/F Board		STX S/S - STX I/F	STX S/S, Y+	STX I/F, Y+	cables from STX patch to STX PCB

1	GND			
2	SCL			
3	SDA			
4	Vcc (unused)			
5	12VDC			
Battery System - G-EPS		BS		
Battery box - electronics				
Connector 1: M80- 5400842				
Pin	Allocation			
1	positive	Battery 1	Batt. Elec.	
2	negative	Battery 1	Batt. Elec.	
3		Battery 2	Batt. Elec.	
4		Battery 2	Batt. Elec.	
5		Sensor Batt 1	Batt. Elec.	
6		Sensor Batt 1	Batt. Elec.	
7		Sensor Batt 2	Batt. Elec.	
8		Sensor Batt 2	Batt. Elec.	
Connector 2: M80- 5400842				
Battery System - Kill Switch		TBD	TBD	TBD
Thermal Sensors		TS	TBD	TBD



PCB Deflection Test Report

Description: In this document the calculated deflection is compared with the PCB deflection test result.

Subsystem(s) involved:	ADCS	CDHS	COMMS	EPS	MechS	STS	TCS	ITRX	MPS	T³μPS	SDM	Splash	GSE	GSN	Launch
						X									

Revision Record and Authorization

Issue	Date	Author / Editor	Reviewer checked	PM approved	Affected Section(s)	Description of change
1.0	14-11-2011	J.P. de Jong				Initiation of document
2.0	21-11-2011	J.P. de Jong				Test plan and procedure included
2.1	27-4-2012	J.P. de Jong	Luca Guadagni			Minor changes for clarity

Action Items

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

List of Used References

SLR code	Version	Data/Variable
0169	3.1	Maximum load factor for components: 65g Minimum margin between PCB's in the stack: 2mm
0018	4.3	Weight of T ³ μPS: 140g
0964	-	Stiffness of FR4: 18.6 GPa LW; 16.5 GPa CW

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1 Introduction

The launcher of Delfi-n3Xt will induce launch vibrations on the satellite and all its components. The PCB's in the stack will deflect, so a margin between the subsystems is required to avoid interference. The objective of the test is to validate the deflection calculations of the midpoint of the PCB's in the stack due to launch vibrations. The deflection of the PCB at worst case vibration was calculated and the minimum margin was set to 2 mm [SLR 0169]. A deflection test has to validate that this is a safe margin. In this document the PCB deflection test result is compared with the deflection calculations.

The test set-up is shown in chapter 2. The required resources are given in chapter 3 and the test procedure is shown in chapter 4. In chapter 5 the deflection of the PCB is calculated for both a concentrated and a distributed load. The test results are shown in chapter 6. A comparison between these results and the conclusions are given in chapter 7.

2 Test Set-up

In order to get a comparable test result a standard PCB will be mounted into the GEERTSAT in the same way as it will be mounted in the stack of Delfi-n3Xt. The Generic Essentially Empty Reusable Test Satellite (GEERTSAT) is a single cube test satellite for testing components or subsystems of Delfi-n3Xt. A gradually increasing static load will be applied by a tensile test bench at the midpoint of the PCB. The applied load and deflection will be monitored and stored on the computer.

The load must be applied by a loading nose with a small surface area to get a point load. To avoid excessive indentation, or failure due to stress concentration directly under the loading nose, the surface area of the loading nose may not be too small. An M6 bolt head will be used to apply the load, which is small enough to assume a point load and large enough to avoid indentation.

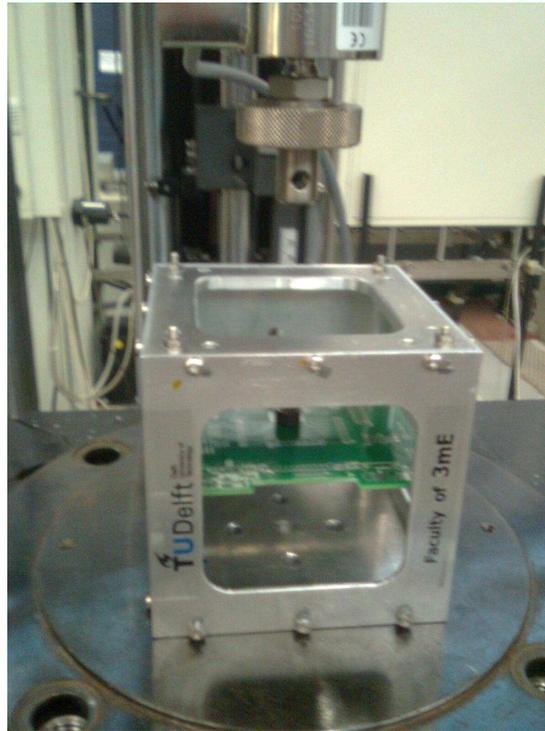


Figure 2-1: Test set-up

3 Resources

3.1 Human resources

The test bench may only be used by trained personnel. An appointment must be made to perform the test.

3.2 Test Equipment

- Tensile test bench
- Loading nose of appropriate size (M6 bolt)
- GEERTSAT with integrated PCB
- Camera

4 Test Procedure

- Place the GEERTSAT on the test bench.
- Place the bolt on the PCB.
- Align the bolt with the centre of the PCB and the loading nose.
- Set the maximum applied force and the parameters to measure on the computer.
- Let the test bench apply the pre-load of 1 N (this is the point where the loading nose just touches the bolt and the measurements begins.)
- Check the alignment of the bolt with the centre of the PCB.
- Let the bench apply the load and start the measurement.
- Save the resulting graph.

5 Calculation of deflection

The bending of the PCB will be calculated with the aid of small deflection plate bending theory for thin rectangular plates. A relation between the applied load and the deflection can be obtained by solving the governing differential equation of the deflections for thin plate bending ^[1]:

$$\frac{\partial^4 w}{\partial x^4} + 2 \frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{p}{D} \quad (5.1)$$

Where x and y are the in-plane directions, w is the normal component of the displacement vector (the deflection) and p is the lateral distributed load. D is the flexural rigidity of the plate:

$$D = \frac{Eh^3}{12(1-\nu^2)} \quad (5.2)$$

Where E , h and ν are the modulus of elasticity, plate thickness and Poisson's ratio respectively.

For a solution of the differential equation boundary equations are needed that represent the supports of the plate. The PCB is clamped at its corners through holes with bolts and nuts. The bolts itself can also deflect. This results in very complicated boundary conditions that are not governed in textbooks on thin plate bending. A finite element analysis may be the only reasonable option in order to achieve very accurate results. However, this will cost a lot of time and is not very valuable for the defi-n3Xt project.

The supports that can easily be calculated are the simply supported, clamped and free edge supports. For these calculations it is assumed that all four edges are simply supported, which comes the closest to the actual situation. This differs from the real supports in two ways:

- In the real case the plate edges are allowed to bend between the point supports; leading to a larger deflection than in the calculations.
- In the real case the corners are clamped; leading to a smaller deflection than in the calculations.

These two deviations from the real case have an opposite effect on the deflection of the PCB and are expected to be small, such that the calculations can be used for comparison with the test results.

To find a solution on the bending of simply supported plates Navier's method is used, which involves a double series solution. For a concentrated load in the middle of the square panel the maximum deflection will be:

$$w_{\max} = \frac{4Pa^2}{\pi^4 D} \sum_{m=1,3,\dots}^{\infty} \sum_{n=1,3,\dots}^{\infty} \frac{1}{(m^2 + n^2)^2} \quad (5.3)$$

Where a is the width of the plate. The series converges rapidly to 0.2822, resulting in the final equation:

$$w_{\max} = 0.01159 \frac{Pa^2}{D} \quad (5.4)$$

The load on the PCB is a quasi static load induced by vibrations of the launcher. The maximum expected launch load is 65g for components [SLR 0604]. The heaviest PCB in the stack is the T³_μPS, which has a weight of 140g [SLR 0018]. With the acceleration of gravity of 9.81 m/s² this results in a load of:

$$P = m \cdot n \cdot g = 0.14 \cdot 65 \cdot 9.81 = 89.3 \text{ [N]} \quad (5.5)$$

The PCB is made of FR4 material which has a modulus of elasticity of 18.6 GPa in the lengthwise direction and 16.5 GPa perpendicular to the lengthwise direction [SLR 0964] For these calculations it is assumed that the modulus of elasticity is 17.5 GPa in all directions. The same holds for the poisson's ratio which is 0.136 in lengthwise direction and 0.118 in crosswise direction. A poisson's ration of 0.127 is assumed. With a PCB thickness of 1.6 mm, a plate width of 82 mm (which is the length between the supports) and a force of 89.3 N; this gives the following results for the flexural rigidity and the maximum deflection:

$$D = \frac{17.5 \cdot 10^9 (1.6 \cdot 10^{-3})^3}{12(1-0.127^2)} = 6.07 \text{ [Nm]} \quad (5.6)$$

$$w_{\max_c} = 0.01159 \frac{89.3 \cdot (82 \cdot 10^{-3})^2}{6.07} = 1.15 \text{ [mm]} \quad (5.7)$$

For most of the PCB's in the stack the mass is approximately evenly distributed over the surface. The quasi-static loads from the launch vibrations can than be modelled as a distributed load on the surface of the PCB. In this case the deflection is given by the following equation:

$$w_{\max_D} = \frac{16p_0a^4}{\pi^6 D} \sum_{m=1,3,\dots}^{\infty} \sum_{n=1,3,\dots}^{\infty} \frac{1}{m \cdot n (m^2 + n^2)^2} \quad (5.8)$$

The series converges rapidly to 0.2580, resulting in the equation:

$$w_{\max} = 0.00429 \frac{p_0 a^4}{D} \quad (5.9)$$

When using the same load of 89.3 N, distributed over the PCB surface, the distributed load will be:

$$p_0 = \frac{P}{a^2} = \frac{89.3}{(82 \cdot 10^{-3})^2} = 1.33 \cdot 10^4 \text{ [N/m}^2\text{]} \quad (5.10)$$

With this distributed load the deflection will be:

$$w_{\max_D} = 0.00429 \frac{1.33 \cdot 10^4 (82 \cdot 10^{-3})^4}{6.07} = 0.42 \text{ [mm]} \quad (5.11)$$

6 Test results

In Figure 6.1 the stress-strain curve of the PCB bending test is shown. A linear relation between the strain or deflection and the applied load or stress is expected from thin plate bending theory for small deflections (see equation (5.4)). The first part of the graph, until 0.8 mm deflection, shows a deviation from the linear relation. This is due to small displacements of the PCB on its support or displacement of the bolt on which the load is applied. From a deflection of 0.8 mm to 1.3 mm the PCB has fully set and the relation is perfectly linear. This part will be used to calculate the relation between load and deflection and is a measure for the stiffness of the PCB. As can be seen from Figure 6.1, the deflection is 0.8 mm with an applied load of 57.5 N and 1.3 mm with 100 N. So the slope of the graph equals:

$$d = \frac{100 - 57.5}{1.3 - 0.8} = 85 \text{ [N/mm]} \tag{6.1}$$

To compare the test to the calculated values, the same load must be used. With a load of 89.3 N the deflection will be:

$$w_{\max} = \frac{P}{d} = \frac{89.3}{85} = 1.05 \text{ [mm]} \tag{6.2}$$

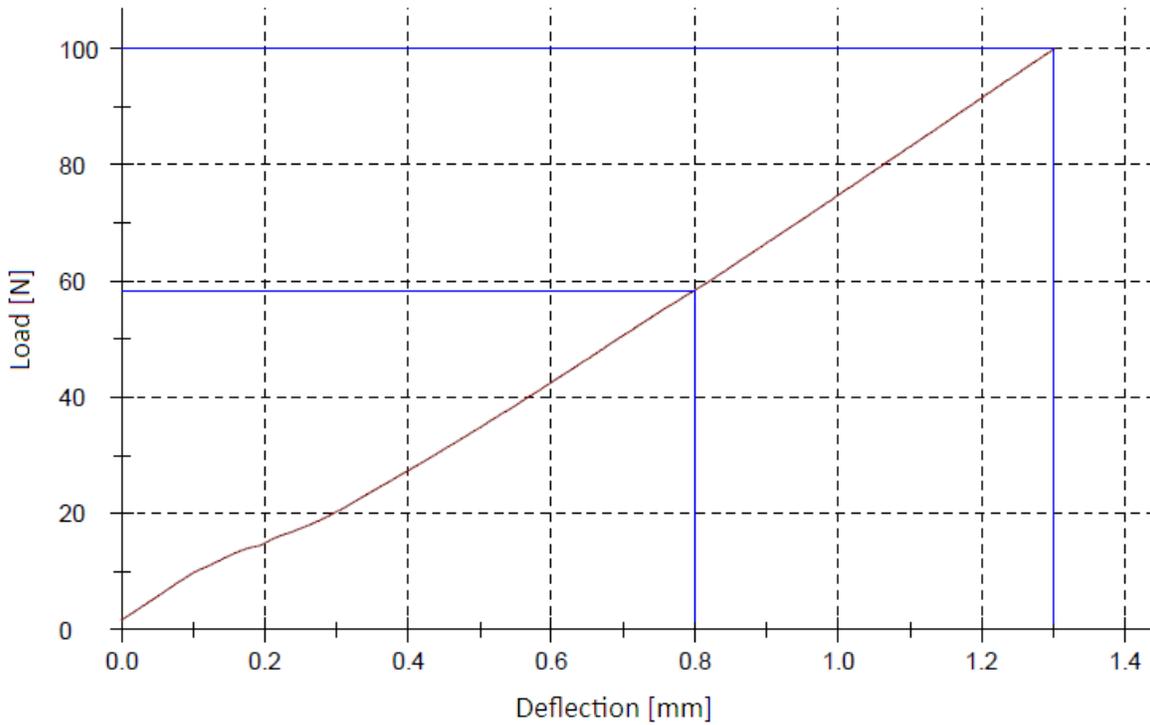


Figure 6.1: Deflection-Load curve

7 Conclusions and recommendations

With an applied load of 89.3 N at the center of the PCB, which represents a PCB of 140g under a quasi static load of 65g, the deflection is 1.15 mm in the calculations and 1.05 mm in the test.

There are two reasons for the difference between these values. The first one is inaccuracies in the model used for the calculations, especially the assumed boundary conditions explained in chapter 5. The second reason is that the PCB has copper layers at the outside of the PCB. Copper has a higher modulus of elasticity than FR4 (117 GPa versus 17.5 GPa); therefore the copper layers increase the stiffness of the PCB. However, the difference is small and therefore the model can be used for other calculations.

In the case of a distributed load on the PCB, which is the case for most PCB's because its mass is evenly distributed, the deformation is only 0.42 mm.

It can be concluded that the deformations of the PCB's in the stack due to launch vibrations are very small even for the PCB's with heavy components in the middle of the PCB. The minimum margin of 2 mm between the PCB's (with components) in the stack is a safe margin and is recommended for Delfi-n3Xt and future missions.

List of References

- [1] Ventsel, E. and Krauthammer, T. *Thin plates and Shells. Theory, Analysis and Applications*. Marcel Dekker, Inc., New York, 2001.

Solar panel PCB Deflection Test Report

Description: In this document the calculated deflection is compared with the solar panel PCB deflection test results.

Subsystem(s) involved:	ADCS	CDHS	COMMS	EPS	MechS	STS	TCS	ITRX	MPS	T³μPS	SDM	Splash	GSE	GSN	Launch
					X										

Revision Record and Authorization

Issue	Date	Author / Editor	Reviewer checked	PM approved	Affected Section(s)	Description of change
1.0	21-11-2011	J.P. de Jong				Initiation of document
2.0	8-12-2011	J.P. de Jong				Tests with dummy cells added
2.1	27-4-2012	J.P. de Jong	Luca Guadagni			Minor changes for clarity

Action Items

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

List of Used References

SLR code	Version	Data/Variable
0169	3.1	Thickness of solar panel PCB: 1.6 mm
0964	-	Stiffness of FR4: 18.6 GPa LW; 16.5 GPa CW

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1 Introduction

The solar panel substrate has changed from CFRP to a PCB made from FR4, such that the electrical wires can be integrated in the PCB and all electrical components can be directly soldered onto the panel. However FR4 has a modulus of elasticity of 17.5 GPa [SLR 0964] compared to 100 GPa for CFRP [SRL 0169]. This means that the panel has a lot less bending stiffness, which could possibly lead to large deflections during launch vibrations.

The solar panel PCB is not entirely made of FR4, there are also copper layers inside the PCB. Copper has a high flexural modulus (117 GPa), therefore it is expected that the copper layers will increase the stiffness of the PCB considerably. Therefore bending tests are performed such that the bending stiffness of the panel can be calculated.

The addition of the solar cells on the panel will also increase the stiffness. Therefore the tests will be repeated for the panel with dummy solar cells. The dummy cells are made of aluminium of 0.3 mm thickness, such that a cell weights 2g; the same as the real cells. The real solar cells are made of aluminium and glass. Both aluminium and glass have a modulus of elasticity of about 70 GPa, so aluminium dummy cells are well suited for the bending tests.

The dummy cells are glued on the panel by Fons van Wijk from DutchSpace with the same method and adhesive as the real solar cells.

In chapter 2 is explained which theory is used for both three- and four point bending and the corresponding equations are derived. The test set-up is shown in chapter 3, the resources required in chapter 4 and the test procedure in chapter 5. The test results are shown in chapter 6; the corresponding bending stiffness is calculated for each method and the results are compared. Chapter 7 states the conclusions and recommendations.

2 Theory

The bending stiffness EI of the solar panel PCB will be calculated, which is the product of the modulus of elasticity E and the second moment of area I of the PCB. Only the modulus of elasticity is not useful in this case, because the PCB is made out of multiple layers of different materials.

The schematics of the test set-up for three- and four-point loading are shown in Figure 2.1 and Figure 2.2 respectively, together with the resulting shear force and bending moments. Both a three- and a four-point bending test will be performed, because the stress induced by the applied force is different, which could lead to different results. In the tree-point test the shear force is uniform over the entire length between the supports and changes sign in the middle of the beam. The moment increases linearly from zero at the supports to a maximum under the loading point. In four-point bending the shear force between the loading points is zero and the bending moment is constant between the loading points. Therefore the specimen is subjected to a pure bending moment over a large part of the beam, which gives a more accurate result when calculating the maximum stress. However, for the calculation of the bending stiffness both load cases are suitable.

The bending stiffness can be calculated by using the Euler-Bernoulli beam theory. This theory is only valid for small deflections. Therefore the initial linear part of the force-deflection curves will be used for calculating the bending stiffness; where the deflections are small. It is assumed that shear deflection can be neglected. Therefore the Span to thickness ratio S/h must be large enough. $S/h=160$ is selected; which is a standard ratio for these tests. With this ratio almost the complete length of the panel is used, such that the effect of the separate cells is also included in the test. With a thickness of the panel of 1.6 mm [SLR 0169] the span will be 256 mm. The panel has a length of 315 mm, so there is enough space left for the supports. The results of both a three- and a four-point flexure test are compared. The results should be similar and is a measure for the accuracy of the tests and applicability of the model used for the calculations.

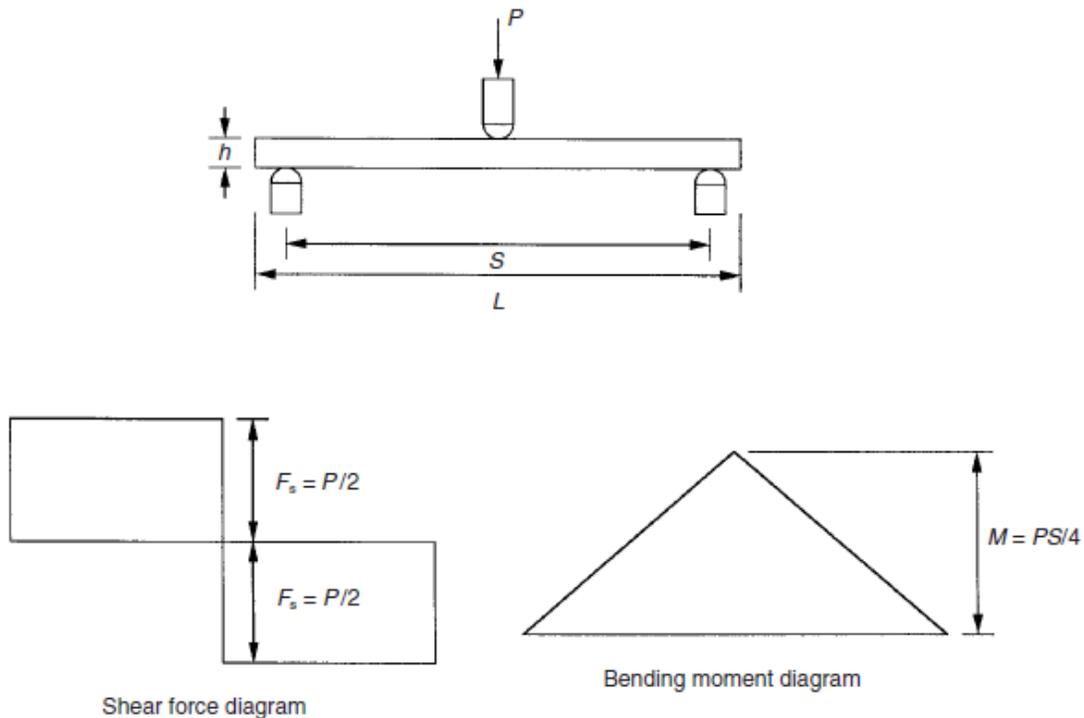


Figure 2.1: Three point bending test with shear force and bending moment diagrams ^[1]

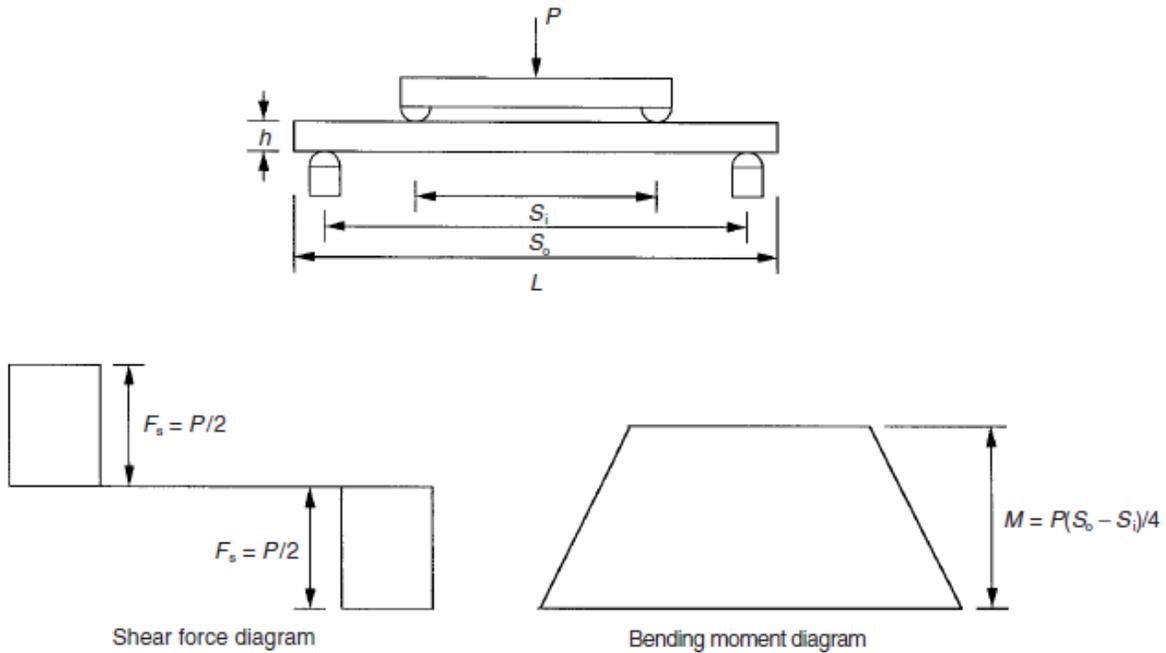


Figure 2.2: Four point bending test with shear force and bending moment diagrams [1]

2.1 Three-point bending

For small deflections the maximum deflection at the midpoint of the beam is given by:

$$\delta_{\max} = \frac{PS^3}{48EI} \tag{2.1}$$

Where P is the applied load, S is the distance between the supports, E is the modulus of elasticity and I is the area moment of inertia. Rewriting gives the bending stiffness EI for three point bending:

$$EI_{3p} = \frac{PS^3}{48\delta_{\max}} = \frac{S^3 m_{3p}}{48} \tag{2.2}$$

Where $m_{3p} = P/\delta_{\max}$ can be obtained from the initial linear part of the force-deflection curve.

2.2 Four-point bending

The deflection of a simply supported beam with an off-centered load, as shown in Figure 2.3, is given by:

$$\delta = \frac{Pbx}{6EIS} [S^2 - b^2 - x^2] \quad \text{for } 0 \leq x \leq a \tag{2.3}$$

Where x is measured from the left support to the right.

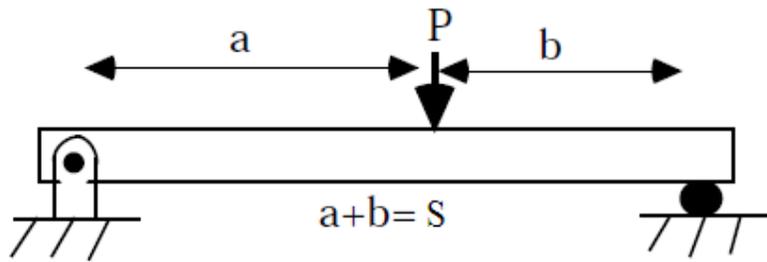


Figure 2.3: Four point bending test with shear force and bending moment diagrams ^[2]

With the four point bending test which will be performed, the test bench applies a load of $P/2$ at $x = S/4$ and at $x = 3S/4$. The test bench measures the movement of the load points in vertical direction. Therefore the deflection must be calculated at $x = S/4$ or at $x = 3S/4$ and not at the midpoint of the panel. For the deflection of the panel at $x = S/4$ caused by the load at $x = S/4$ equation (2.3) can be used with $b = 3S/4$:

$$\delta_{x=S/4, b=3S/4} = \frac{P/2 \cdot 3S/4 \cdot S/4}{6EIS} \left[S^2 - (3S/4)^2 - (S/4)^2 \right] = \frac{3}{512} \frac{PS^3}{EI} \quad (2.4)$$

The deflection of the panel at $x = S/4$ caused by the load at $x = 3S/4$ (with $b = S/4$) will be:

$$\delta_{x=S/4, b=S/4} = \frac{P/2 \cdot S/4 \cdot S/4}{6EIS} \left[S^2 - (S/4)^2 - (S/4)^2 \right] = \frac{7}{1536} \frac{PS^3}{EI} \quad (2.5)$$

For the total deflection the principle of superposition can be used. Superposition can be used because the deflections are small and shear deformation can be neglected. Therefore the total deflection at $x = S/4$ will be:

$$\delta_{x=S/4} = \frac{3}{512} \frac{PS^3}{EI} + \frac{7}{1536} \frac{PS^3}{EI} = \frac{PS^3}{96EI} \quad (2.6)$$

Rewriting gives the following result for the bending stiffness:

$$EI_{4p} = \frac{PS^3}{96\delta_{x=S/4}} = \frac{S^3 m_{4p}}{96} \quad (2.7)$$

$m_{4p} = P/\delta_{x=S/4}$ can be obtained from the initial linear part of the force-deflection curve.

3 Test set-up

The test set-ups for three- and four point loading is shown in the Figure 3-1 and Figure 3-2 respectively. For both the three- and the four point bending test the same support is used. The support must be set to 256 mm. For the three-point bending test a single loading nose is attached to test bench. For the four-point bending test a two point loading nose with a separation of 128 mm is attached to the test bench. The loading nose must be accurately aligned with the midpoint between the supports. The applied force and deflection will be monitored and stored on the computer.



Figure 3-1: Test set-up three point bending

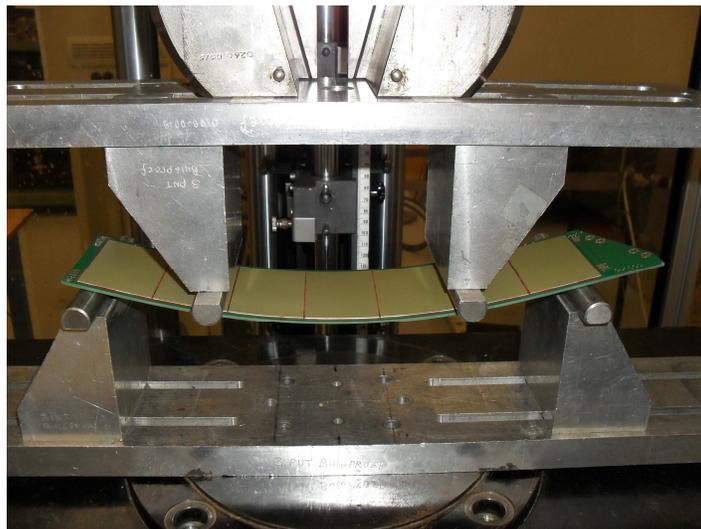


Figure 3-2: Test set-up four point bending

4 Resources

4.1 Human resources

The test bench may only be used by trained personnel. An appointment must be made to perform the test. The tests without dummy cells were performed in cooperation with Bob de Vogel. The tests with dummy cells were performed with Berthil Grashof.

4.2 Test Equipment

- Tensile test bench
- Support for both three- and four-point bending
- Loading nose for three-point bending
- Loading nose for four-point bending
- Solar panel PCB
- Ruler
- Camera

5 Test Procedure

- Place the support on the test bench.
- Attach the loading nose to the test bench.
- Place the solar panel on the support.
- Align the middle of the loading nose with the middle between the supports.
- Set the maximum applied deflection (30 mm for three-point bending, 20 mm for four-point bending) and the parameters to measure on the computer (only applied force and deflection).
- Let the test bench apply the pre-load of 1 N (this is the point where the loading nose just touches the bolt and the measurements begin.)
- Check the alignment of the loading point(s) and support.
- Let the bench apply the load and start the measurement. The load is gradually increased over time from the preload to the maximum load.
- Make some pictures
- Save the resulting graph.

6 Test results

The force-displacement curves from the tests are shown in Figure 6-1. Lines are added that coincide with the first linear part of the curves.

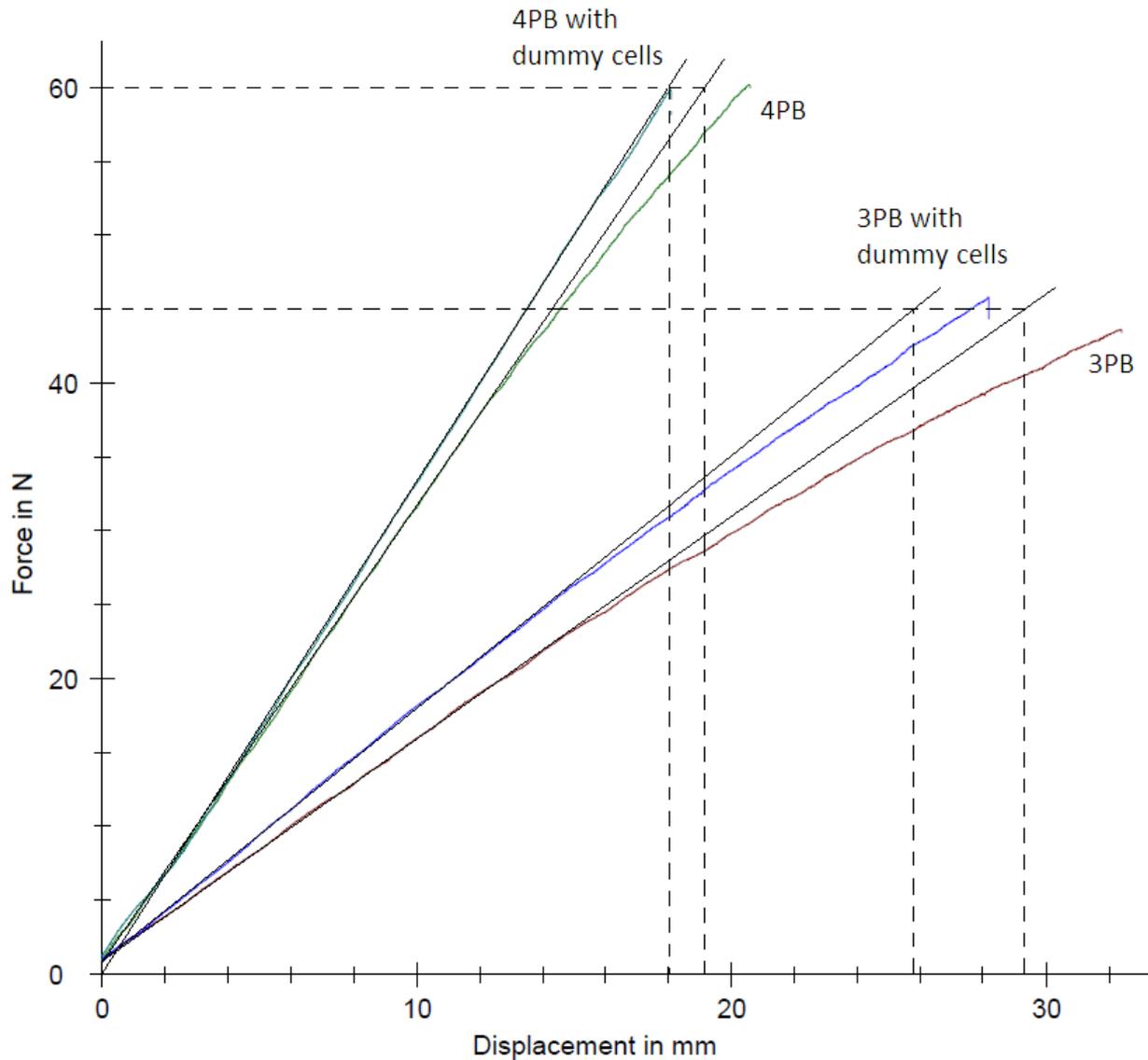


Figure 6-1: Force-Displacement curve of three-point bending (3PB) and four-point bending (4PB) for the solar panel with and without dummy solar cells

6.1 Solar panel without dummy cells

The slopes of the curves in Figure 6-1 represent the ratios m_{3p} and m_{4p} from equations (2.2) and (2.7):

$$m_{3p} = \frac{P}{\delta_{\max}} = \frac{45-1}{29.4} = 1.497 \text{ [N/mm]} \quad (6.1)$$

$$m_{4p} = \frac{P}{\delta_{x=L/4}} = \frac{60-0.5}{19.1} = 3.115 \text{ [N/mm]} \quad (6.2)$$

Now the modulus of elasticity can be calculated with equations (2.2) and (2.7):

$$EI_{3p} = \frac{S^3 m_{3p}}{48} = \frac{256^3 \cdot 1.497}{48} = 5.23 \cdot 10^5 \text{ [Nmm}^2\text{]} \quad (6.3)$$

$$EI_{4p} = \frac{S^3 m_{4p}}{96} = \frac{256^3 \cdot 3.115}{96} = 5.44 \cdot 10^5 \text{ [Nmm}^2\text{]} \quad (6.4)$$

This difference between the two test methods equals:

$$\Delta_{3p/4p} = \frac{5.44 \cdot 10^5 - 5.23 \cdot 10^5}{5.23 \cdot 10^5} \cdot 100\% = 4\% \quad (6.5)$$

So the four point bending test gives a 4% higher result compared to the three point test.

For comparison of these results with a panel made entirely of FR4 material the bending stiffness of such a panel must first be calculated.

The modulus of elasticity of FR4 without copper layers is between 16.5 GPa in crosswise direction and 18.6 GPa in the length of manufacturing [SLR 0964]. The solar panel PCB has no direction of manufacturing; therefore it is assumed that the modulus of elasticity is 17.5 GPa in all directions.

The area moment of inertia for a rectangular cross-section is given by:

$$I = \frac{1}{12} b h^3 \quad (6.6)$$

Where b is the beam width and h is the beam height. With a panel width of 71 mm and a panel thickness of 1.6 mm the moment of inertia will be:

$$I = \frac{1}{12} \cdot 71 \cdot 1.6^3 = 24.2 \text{ [mm}^4\text{]} \quad (6.7)$$

The bending stiffness will then be:

$$EI = 17.5 \cdot 10^3 \cdot 24.2 = 4.24 \cdot 10^5 \text{ [Nmm}^2\text{]} \quad (6.8)$$

When comparing this with the average of the test results ($5.34 \cdot 10^5 \text{ Nmm}^2$); the difference is:

$$\Delta_{PCB/FR4} = \frac{5.34 \cdot 10^5 - 4.24 \cdot 10^5}{4.24 \cdot 10^5} \cdot 100\% = 26\% \quad (6.9)$$

So the solar panel PCB without dummy cells is 26% stiffer compared to the bare FR4 panel.

6.2 Solar panel with dummy cells

The same test was repeated with the solar panel with added dummy solar cells:

$$m_{3p-dc} = \frac{P}{\delta_{\max}} = \frac{45-1}{19.1} = 1.746 \text{ [N/mm]} \quad (6.10)$$

$$m_{4p-dc} = \frac{P}{\delta_{x=L/4}} = \frac{60-0}{18} = 3.333 \text{ [N/mm]} \quad (6.11)$$

$$EI_{3p-dc} = \frac{S^3 m_{3p-dc}}{48} = \frac{256^3 \cdot 1.746}{48} = 6.10 \cdot 10^5 \text{ [Nmm}^2\text{]} \quad (6.12)$$

$$EI_{4p-dc} = \frac{S^3 m_{4p-dc}}{96} = \frac{256^3 \cdot 3.333}{96} = 5.83 \cdot 10^5 \text{ [Nmm}^2\text{]} \quad (6.13)$$

This difference between the two test methods equals:

$$\Delta_{3p/4p} = \frac{6.10 \cdot 10^5 - 5.83 \cdot 10^5}{6.10 \cdot 10^5} \cdot 100\% = 5\% \quad (6.14)$$

In this case the four point bending test gives a 5% lower stiffness than the three point test. The average of the test results ($5.96 \cdot 10^5 \text{ Nmm}^2$) compared to the panel without dummy cells will be:

$$\Delta_{PCB_{-dc}/PCB} = \frac{5.96 \cdot 10^5 - 5.83 \cdot 10^5}{5.83 \cdot 10^5} \cdot 100\% = 12\% \quad (6.15)$$

So the solar panel PCB with dummy cells is 12% stiffer compared to the panel without cells. The average of the test results ($5.96 \cdot 10^5 \text{ Nmm}^2$) compared to the bare FR 4 panel will be:

$$\Delta_{PCB_{-dc}/PCB} = \frac{5.96 \cdot 10^5 - 4.24 \cdot 10^5}{4.24 \cdot 10^5} \cdot 100\% = 40\% \quad (6.16)$$

So the solar panel PCB with dummy cells is 40% stiffer compared to the bare FR4 panel.

The stiffness increase is relatively low, because the solar cells are not mechanically coupled to each other. When the panel bends the spacing between the solar cells can increase or decrease due to the elasticity of the adhesive. Therefore the cells do not take up tension and compression forces from the solar panel, so the solar cells cannot be modelled as additional continuous layers glued to the solar panel. The cells do resist the bending of the solar panel over the entire length; therefore the cells can be modelled as continuous layers mechanically decoupled from the solar panel. The added stiffness will then be the bending stiffness of this layer of solar cells:

$$EI_{cells} = E \frac{1}{12} bh^3 = 70 \cdot 10^3 \frac{1}{12} \cdot 70 \cdot 0.3^2 = 3.73 \cdot 10^4 \quad (6.17)$$

Solar cells on both sides will have a stiffness increase compared to the panel without cells of:

$$\Delta_{PCB_{dc}/FR4} = \frac{2 \cdot 3.73 \cdot 10^4}{5.83 \cdot 10^5} \cdot 100\% = 14\% \quad (6.18)$$

This is a similar result as the 12% from the test results.

7 Conclusions and recommendations

7.1 Solar panel without dummy cells

The four point bending test resulted in a 4% higher stiffness compared to the three point test. The 4% difference between the two test methods is probably caused by inaccuracies in the test set-up. Changing the length between the supports and the loading points was difficult to do accurately, because it was fastened with large bolts on sliding support with large tolerances. The alignment of the loading nose with the support introduces a second inaccuracy. In the equations used the support span is raised to the power three, so a small inaccuracy in the support span results in a considerable error. 4% Difference is reasonable, therefore the results can be used for further calculations. For future bending test it is recommended to measure the support- and loading span as accurate as possible.

The solar panel PCB without dummy cells is 26% stiffer compared to the bare FR4 panel. A reason for the stiffness increase is that the solar panel PCB has copper layers inside the PCB. Copper has a higher modulus of elasticity than FR4 (117 GPa versus 17.5 GPa); therefore the copper layers increase the stiffness of the PCB. It can be concluded that the added copper layers have a high influence on the stiffness of the PCB.

7.2 Solar panel with dummy cells

For these tests the support span and loading point alignment was measured very accurately. With these tests the difference between the three- and four point bending was 5%, but now the four point test resulted in a lower stiffness than the three point test. It is unknown which test is more accurate, therefore the average of the two test is used for further calculations.

The solar panel PCB with dummy cells is 12% stiffer compared to the panel without cells. This increase is relatively low, because the solar cells are not mechanically coupled to each other.

The combined effect of the copper layers and the solar cells increases the bending stiffness of the panel 40% compared to a bare FR4 panel. This information will be used to calculate the deflection of the solar panel due to launch vibrations.

List of References

- [1] Hodgkinson, J. M. *Mechanical testing of advanced fibre composites*. Woodhead Publishing Ltd and CRC Press LLC, 2000.
- [2] University of Washington, *Mechanics of Materials Laboratory Course Notes*, 2007. Viewed: November 22, 2011. <http://courses.washington.edu/me354a/chap3.pdf>
- [3] ASTM, *D790-02 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*, 2002. Viewed: November 28, 2011. <http://www.scribd.com/doc/73187063/D790-02>

Solar panel Deployment Test Report

Description: This document describes the test set-up, procedure and results of the solar panel deployment test at room temperature, hot and cold case.

Subsystem(s) involved:	ADCS	CDHS	COMMS	EPS	MechS	STS	TCS	ITRX	MPS	T³μPS	SDM	Splash	GSE	GSN	Launch
					X										

Revision Record and Authorization

Issue	Date	Author / Editor	Reviewer checked	PM approved	Affected Section(s)	Description of change
1.0	23-12-2011	J.P. de Jong				Initiation of document
1.1	9-1-2012	J.P. de Jong				Overloading test added
1.2	27-4-2012	J.P. de Jong	Luca Guadagni			Minor changes for clarity

Action Items

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

List of Used References

SLR code	Version	Data/Variable
0616	2.3	Temperature range HDRM: -70°C<T<85°C
0522	1.0	Dyneema wire must melt within 15 s

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6	CONCLUSIONS AND RECOMMENDATIONS	142

1 Introduction

Since the deployment of the solar panels is critical for the missions success; the Hold Down and Release Mechanism (HDRM) is very important for Delfi-n3Xt. Several tests are performed to prove that the deployment mechanism is consistent and reliable at all possible circumstances and deploys within 15 seconds [SLR 0522]. The most extreme temperatures at which the HDRM must work is $-70\text{ }^{\circ}\text{C}$ at the coldest $85\text{ }^{\circ}\text{C}$ as the hottest [SLR 0616]. The climate rooms at the Delft Aerospace Structures and Materials Laboratory (DASML) that are easily available go to a minimum of $-40\text{ }^{\circ}\text{C}$. Therefore the low temperature test is performed at $-40\text{ }^{\circ}\text{C}$; which is cold enough to prove trouble-free deployment at cold temperatures. The hot temperature test is performed at $85\text{ }^{\circ}\text{C}$ in the vacuum oven at the cleanroom at the TU Delft.

It is possible that the performance of the resistors declines after the many deployments that will be performed during the integration and testing phase of the complete satellite. The satellite software applies a voltage of 12V on the resistor for 15 seconds. The overloading test is performed to simulate these deployments. Firstly a test at room temperature is performed as a reference. After the hot and cold temperature tests an overloading test will be performed. Afterwards a second test at room temperature will be performed to verify any variations in deployment time.

The pre-tension of the Dyneema wire was measured to be 3N.

2 Test set-up

For the deployment tests a special test set-up was made with all the parts of the Hold Down and Release Mechanism (HDRM), a hinge and a solar panel PCB with dummy cells. The support is made of aluminium blocks that can also be used for future vibration and shock tests. The solar panel with dummy cells has the same mass as the flight panel. The hinge axis is placed vertical, such that gravity has a minimal influence on the deployment. A thermocouple is placed next to the deployment resistor on the aluminium block to measure the temperature of the test set-up. The test set-up in the oven in the cleanroom is shown in Figure 2-1.

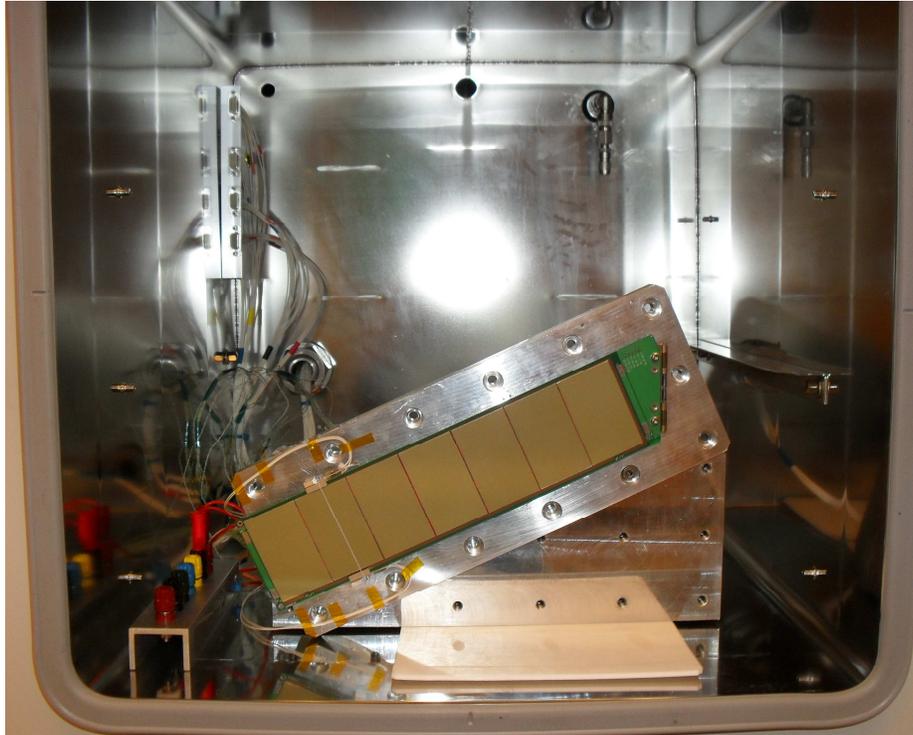


Figure 2-1: Test set-up

3 Test Equipment

- Test set-up complete with HDRM, solar panel and hinge
- 48 Dyneema wires made with special wire length tool
- Tweezers to install Dyneema wires
- Power source and electric cables
- Vacuum oven in cleanroom
- Climate chamber at the DASML
- Camera to make pictures
- Stopwatch to measure time

4 Test Procedure

Test procedure deployment tests

- Install a Dyneema wire on the test set-up
- Check the temperature
- Apply a 12V voltage and start stopwatch at the same time
- Stop the stopwatch when the Dyneema wire is melted and the panel deploys
- Turn the power off
- Write down the result
- Repeat eight times for each resistor

Test procedure overloading test

- Apply a 12V voltage for 15 seconds
- Let the resistor cool down for 15 seconds
- Repeat sixteen times for each resistor

5 Test results

Table 5-1 shows the deployment test results at room temperature for both the left and the right resistor (with the positive Z axis being the upward direction). There are two resistors in the HDRM for redundancy; the second resistor is used when deployment of with the first failed. The average time until deployment is five seconds for both resistors without much variation.

Table 5-1: Deployment time at room temperature (23 °C)

Test number [-]	Deployment time, left resistor [s]	Deployment time, right resistor [s]
1	6.8	4.0
2	4.5	4.7
3	5.1	5.1
4	5.0	5.1
5	5.0	4.7
6	3.9	5.1
7	6.1	4.4
8	4.9	4.1
average	5.2	4.7

Table 5-2 shows the results for the tests at 85 °C performed in the vacuum oven of the cleanroom. There were two cases in which the deployment took much longer than the average. The reason for this is that the knot in the dyneema wire was above a screw in the resistor pcb. Therefore the wire was lifted slightly above the resistor, such that it took a lot longer to melt the wire. This situation must be avoided in the flight model. This can be achieved by making the knot small enough, such that it does get onto the resistor pcb. However it is good to see that even with the Dyneema not installed correctly, the wire still melts within seven seconds. For the average of the test these two cases are not used, shown by a strikethrough in Table 5-2. The average of the tests will than be about three seconds for both resistors.

Table 5-2: Deployment time at 85 °C

Test number [-]	Deployment time, left resistor [s]	Deployment time, right resistor [s]
1	2.9	4.4
2	2.7	2.8
3	3.3	2.5
4	2.9	7.1
5	5.7	2.6
6	3.2	2.8
7	3.5	2.5
8	2.8	2.5
average	3.0	2.9

Table 5-3 and Table 5-4 show the results of the tests at low temperatures performed in a climate chamber at the DASML. It was planned to perform the tests at -40 °C, but the coldest temperature the climate chamber could achieve was -40 °C; so it took very long to cool from -30 °C to -40 °C. Therefore the tests are performed at slightly higher temperature, reducing the time between tests considerably. The temperature is measured with the built-in thermometer from the climate chamber and a thermocouple at the aluminium support close to the HDRM resistor. The thermocouple is used because the aluminium support block has a delay in temperature because of its high heat capacity. The average deployment time is five seconds for both resistors; which is the same as the tests at room temperature.

Table 5-3: Deployment time at low temperatures, left resistor

Test number [-]	Temperature climate chamber [°C]	Temperature thermo-couple [°C]	Deployment time [s]
1	-40	-40	7.0
2	-35	-36	4.8
3	-30	-33	5.8
4	-30	-31	5.0
5	-37	-32	5.3
6	-31	-30	5.7
7	-39	-34	4.5
8	-33	-32	4.4
average	-34	-34	5.3

Table 5-4: Deployment time at low temperatures, right resistor

Test number [-]	Temperature climate chamber [°C]	Temperature thermo-couple [°C]	Deployment time [s]
1	-30	-30	4.5
2	-36	-30	4.4
3	-32	-29	3.8
4	-30	-28	5.1
5	-34	-28	6.3
6	-29	-27	5.0
7	-26	-26	5.3
8	-25	-25	4.0
average	-30	-28	4.8

After these tests each resistor was tested sixteen times at room temperature without Dyeema wire; such that each resistor was tested 40 times in total. The resistance of the resistor had not changed and remains 75 Ohms. Each resistor was tested eight times again to see if the deployment time has changed after 40 tests. The results are shown in Table 5-5. The results are very similar to the results of the first tests; so it can be concluded that the deployment time does not change after 40 deployments.

Table 5-5: Deployment time at room temperature (23 °C) after 40 tests

Test number [-]	Deployment time, left resistor [s]	Deployment time, right resistor [s]
1	4.9	3.8
2	5.3	6.7
3	5.0	5.1
4	7.0	5.8
5	3.7	3.7
6	4.3	4.3
7	3.7	4.6
8	3.7	3.3
average	4.7	4.7

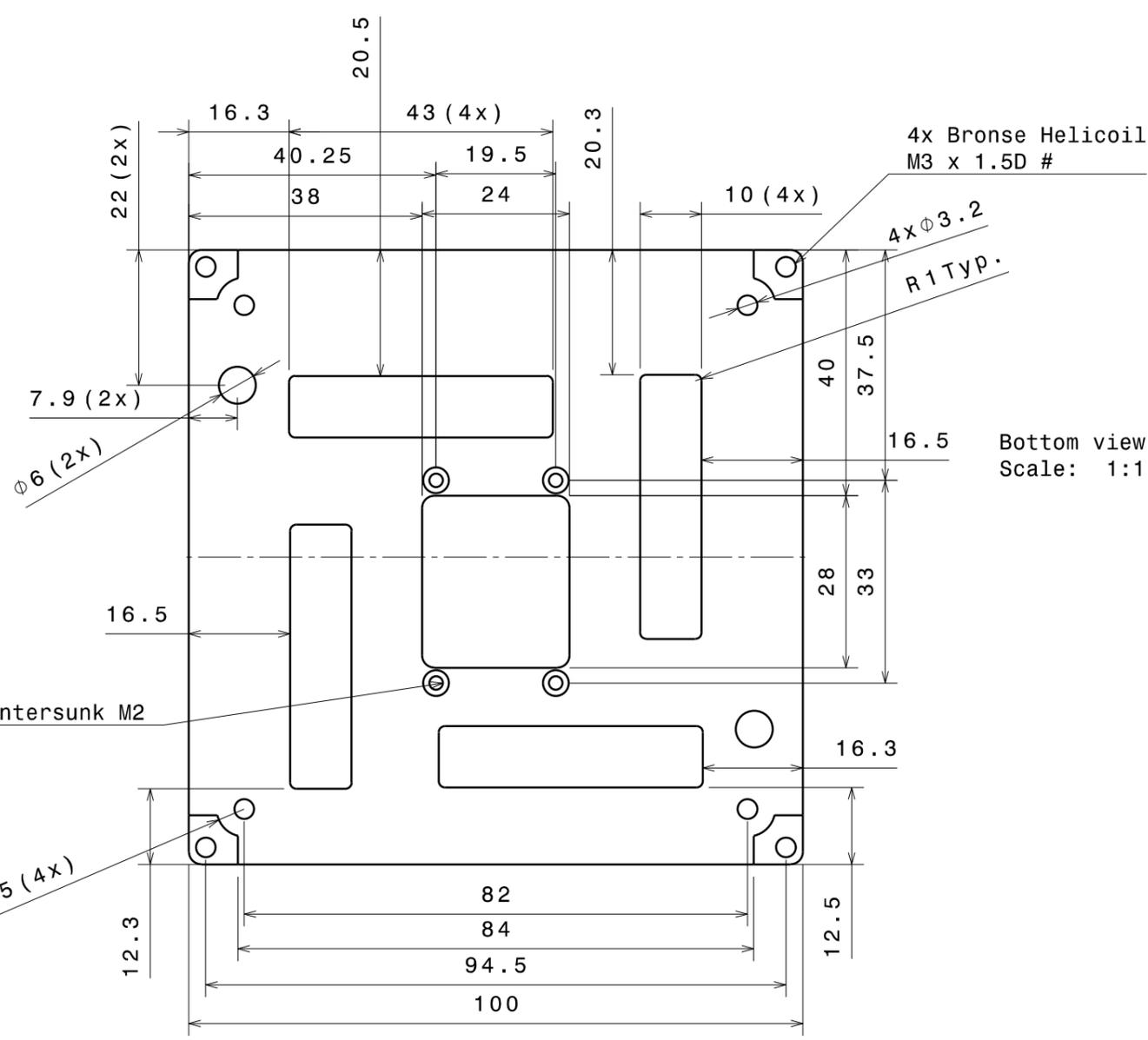
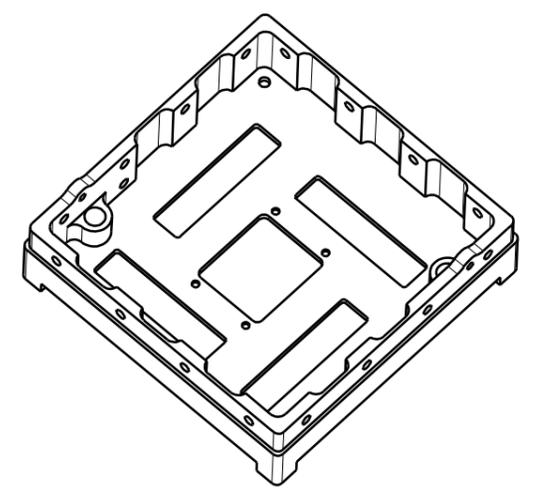
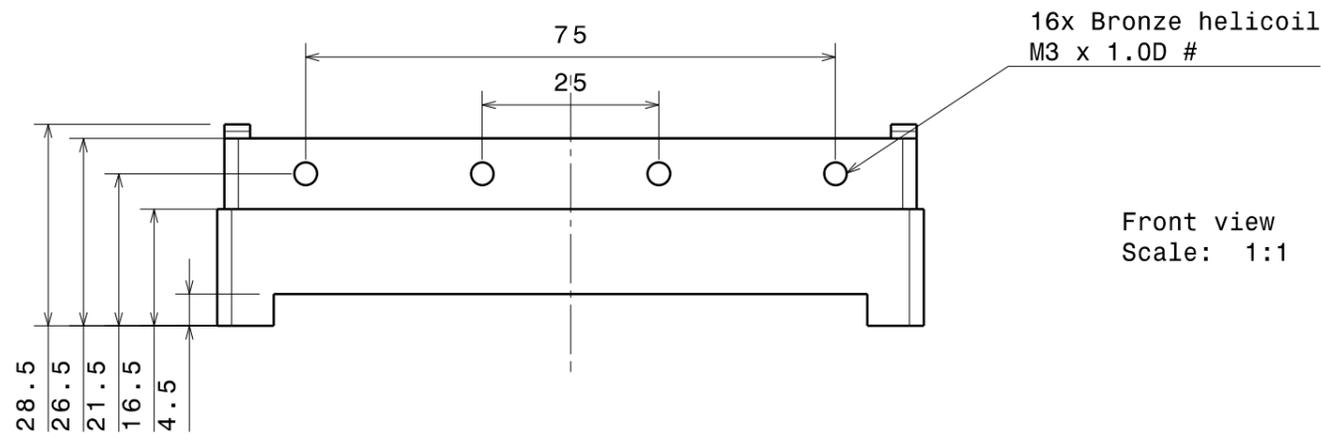
6 Conclusions and recommendations

The solar panel deploys after three seconds at high temperatures, after five seconds at room temperature and after five seconds at low temperatures. The deployment time is rather consistent. It can be seen from the results in chapter 5 that the panel deploys within the required 15 seconds with a high margin. Both resistors are tested more than 40 times and they do not show any deterioration in performance. It can be concluded that the HDRM fulfills its requirements and works as intended.

It is recommended that the knot in the Dyneema wire is made small enough, such that it does not rest on the resistor PCB and raise the wire above the resistor.

Contents

DNX-11-001 BOP
DNX-13-001 TOP
DNX-14-000 Integrated U-panels (with STX position)
DNX-14-001 U-profile Y-X+
DNX-14-002 Connection strip
DNX-14-003 U-profile Y+X-
DNX-15-100 HDRM Resistor PCB
DNX-15-101 HDRM Support left
DNX-15-106 HDRM Support right
DNX-15-109 HDRM Support block SP STX
DNX-15-200 Tact switch assembly
DNX-20-000 Solar panel assembly v.1
DNX-20-000 Solar panel assembly v.2
DNX-21-000 Hinge assembly
DNX-21-001 Hinge leaf structure
DNX-21-002 Hinge leaf solar panel
DNX-22-001 Solar panel substrate
DNX-22-002 Hold down guide
DNX-22-005 Hold down guide long
DNX-30-002 Midplane stand-off
DNX-30-100 Flex-rigid PCB
DNX-31-000 Standard PCB [1.0]
DNX-31-000 Standard PCB [4.0]
DNX-41-500 ADCS Sun sensor assembly
DNX-41-503 ADCS Sun sensor housing [3.0]
DNX-41-503 Sun sensor positioning part
DNX-43-103 EPS electronics assembly
DNX-43-300 EPS Wire clips
DNX-44-200 DAB Assembly
DNX-44-200 DAB Wiring schematic
DNX-44-201 MAB Assembly
DNX-44-208 MAB Box
DNX-44-209 MAB Front cover
DNX-44-210 MAB Lid
DNX-44-217 MAB Isolation ring



Install Helicoil after surface treatment

Project contact: 015-2785326	Surface treatment	Alodine 1500
Order no.	Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges	Roundings	R1, unless specified otherwise
Dimensions in mm	Process	Milling
	Material	Aluminium 6082 (51ST 3.2315.72)

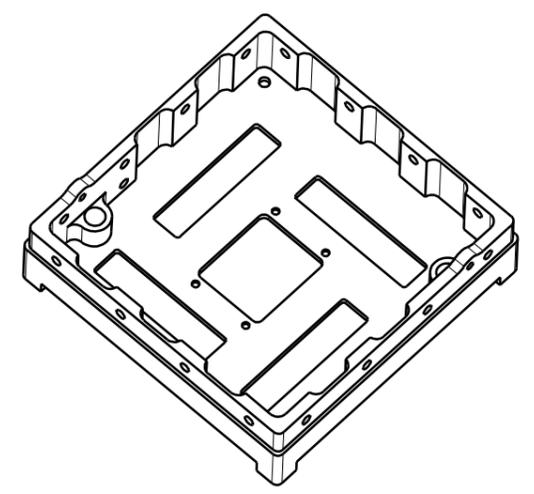
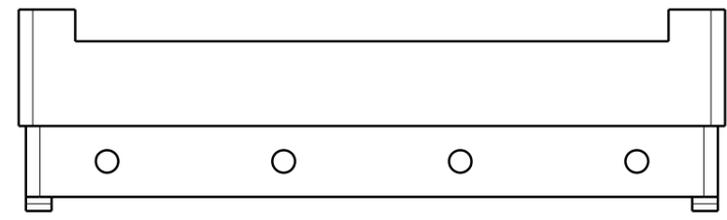
DESIGNED BY: J P. de Jong DATE: 22/02/2012	<h1>Bottom Panel</h1>	I	-
CHECKED BY: G.F. Brouwer DATE: 22/02/2012		H	-
SIZE A3	<h2>Delfi-n3Xt</h2>	G	-
SCALE 1:1		F	-
WEIGHT (kg) 0.11	DNX-11-001	E	-
DRAWING NUMBER DNX-11-001		D	-
SHEET 1/2	1/2	C	-
		B	22/02-2012
		A	13/02/2009

Valid for all sides

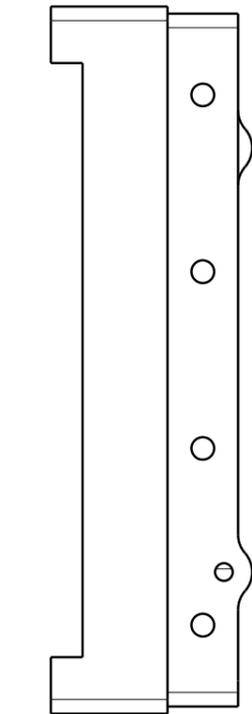
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H G F E D C B A

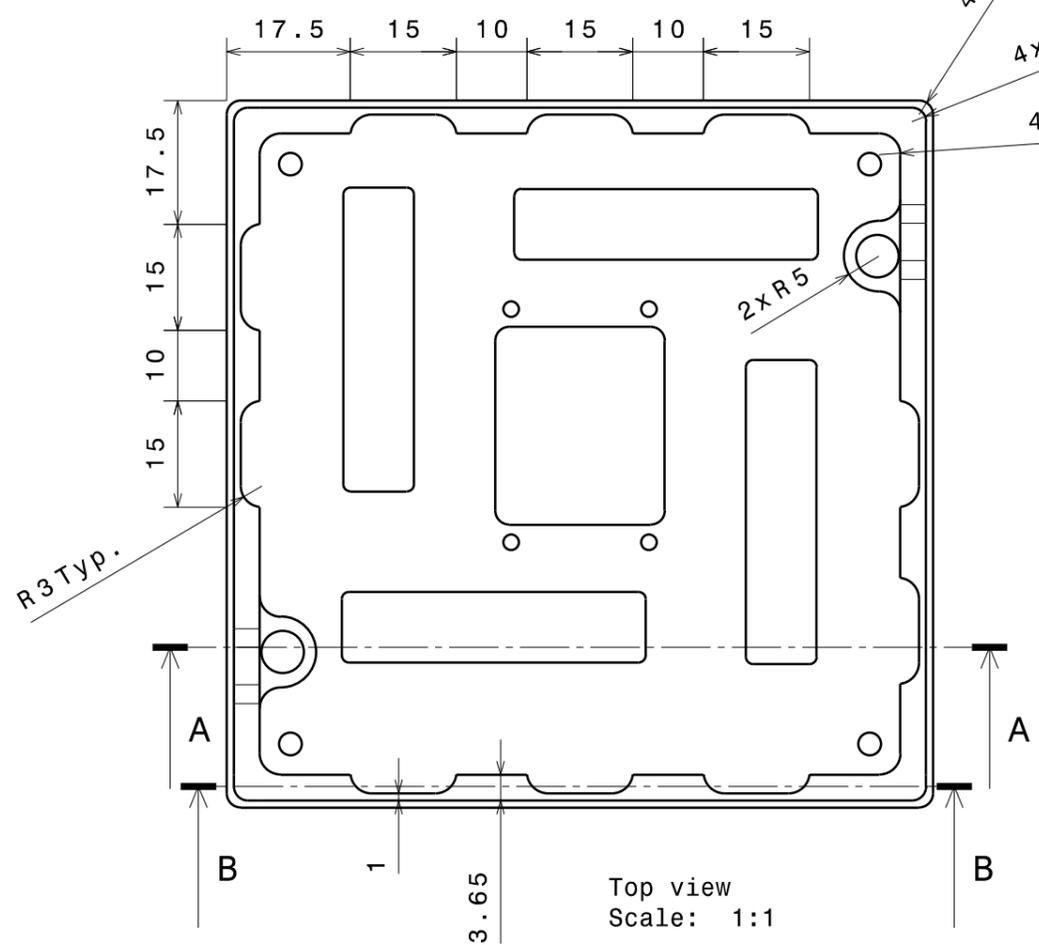
Rear view
Scale: 1:1



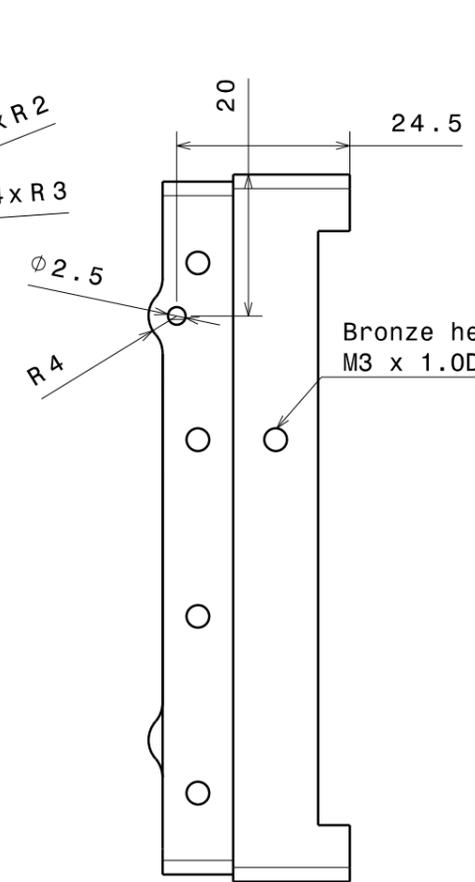
Isometric view
Scale: 1:2



Left View
Scale: 1:1

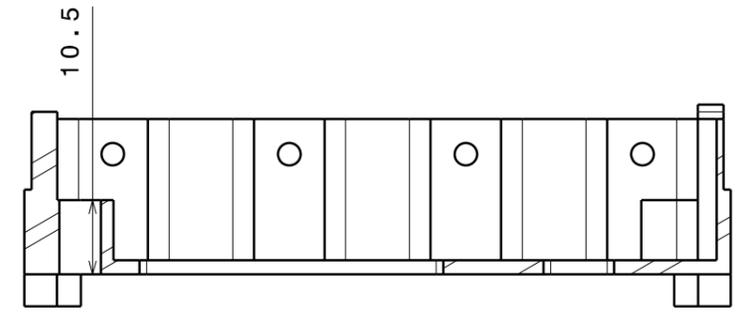


Top view
Scale: 1:1

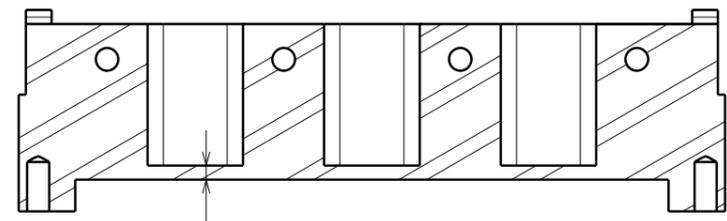


Right View
Scale: 1:1

Bronze helicoil
M3 x 1.0D #



Section view A-A
Scale: 1:1



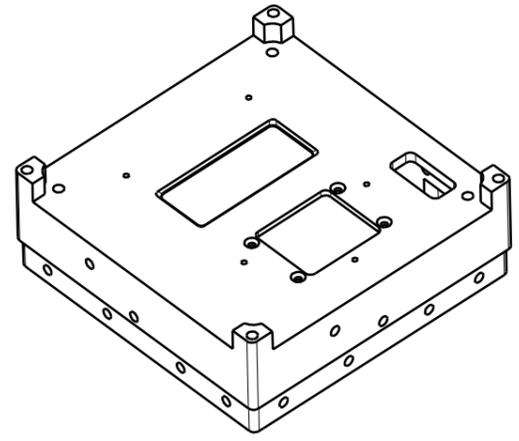
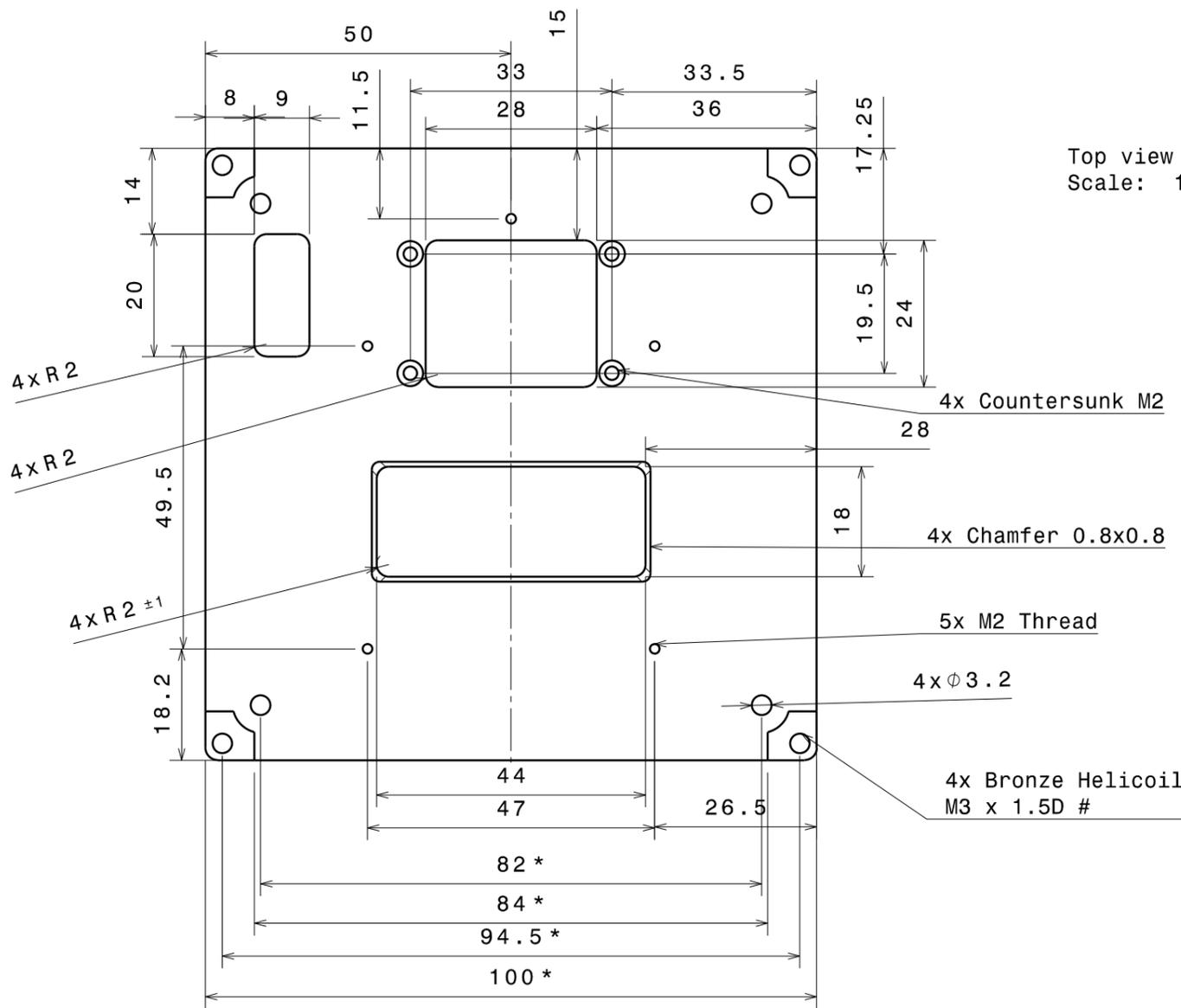
Section view B-B
Scale: 1:1

Install Helicoil after surface treatment

DESIGNED BY: J.P. de Jong	<h1>Bottom Panel</h1>		I	-
DATE: 22/02/2012			H	-
CHECKED BY: G.F. Brouwer	<h1>Delfi-n3Xt</h1>		G	-
DATE: 22/02/2012			F	-
SIZE: A3		E	-	
SCALE: 1:1		D	-	
WEIGHT (kg): 0.11	DRAWING NUMBER: DNX-11-001	C	-	
	SHEET: 2/2	B	22/02/2012	
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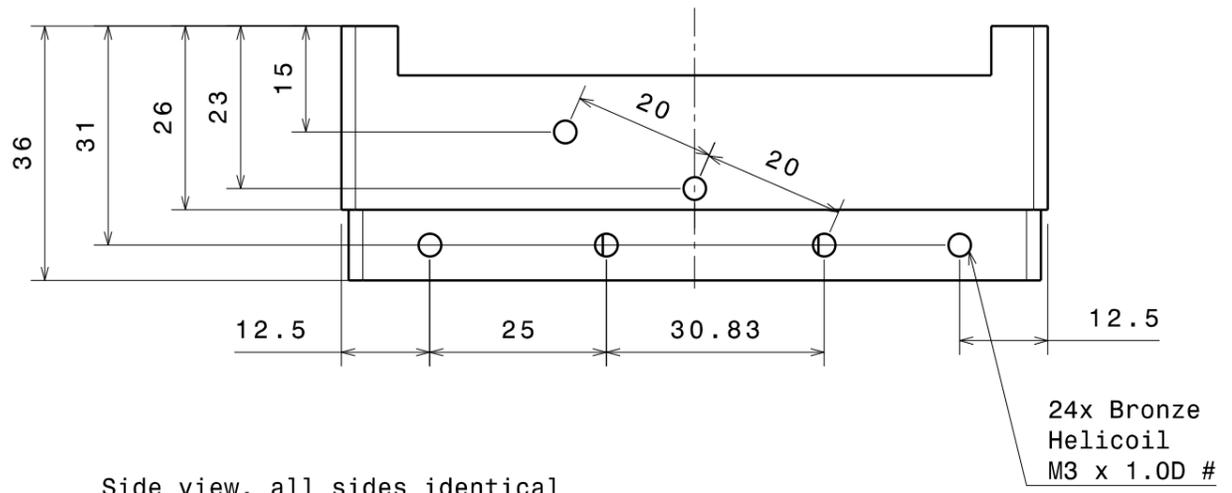
H G F E D C B A

H G F E D C B A



*Valid for all sides

Install Helicoil after surface treatment

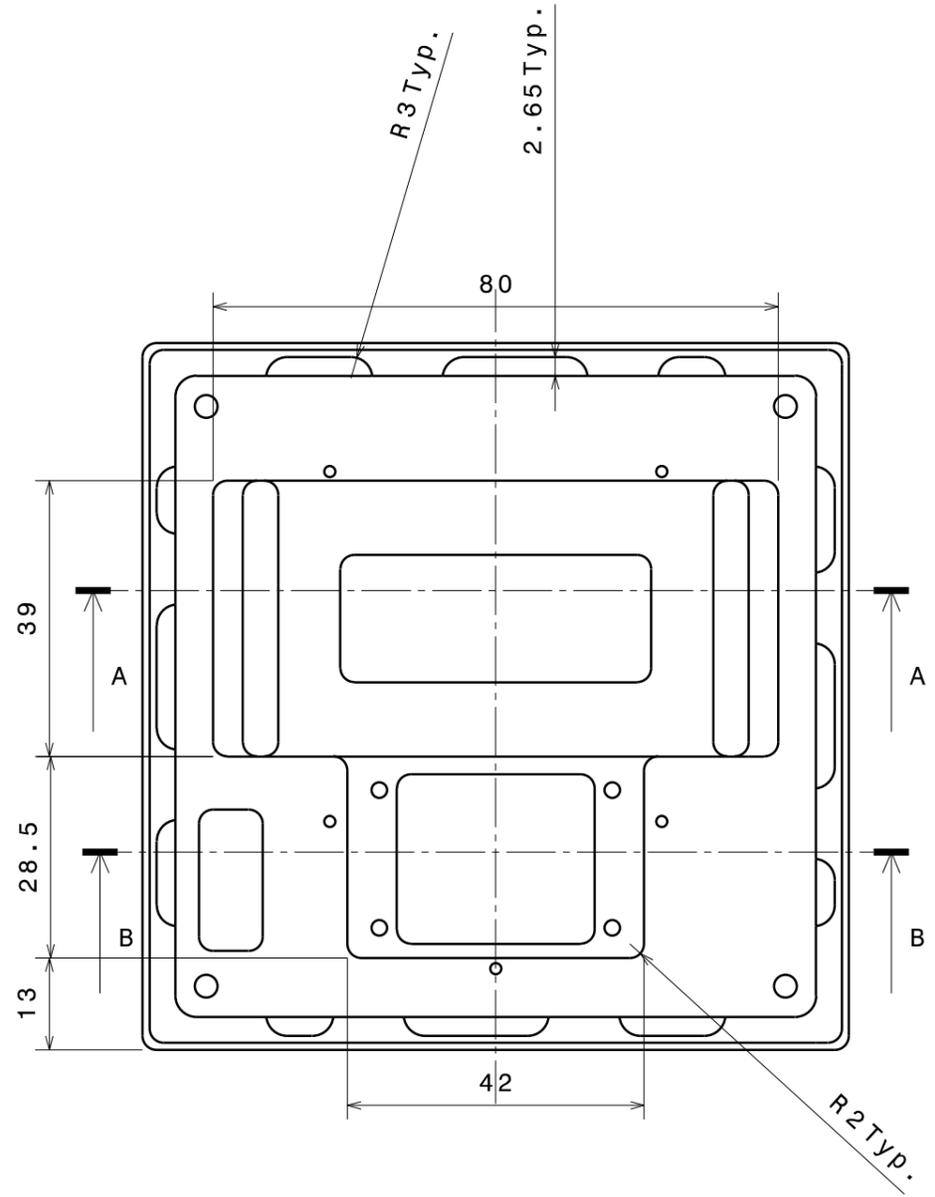


Project contact: 015-2785326	Surface treatment	Alodine 1500
Order no.	Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges	Roundings	R2, unless specified otherwise
Dimensions in mm	Process	Milling
	Material	Aluminium 6082 (51ST 3.2315.72)

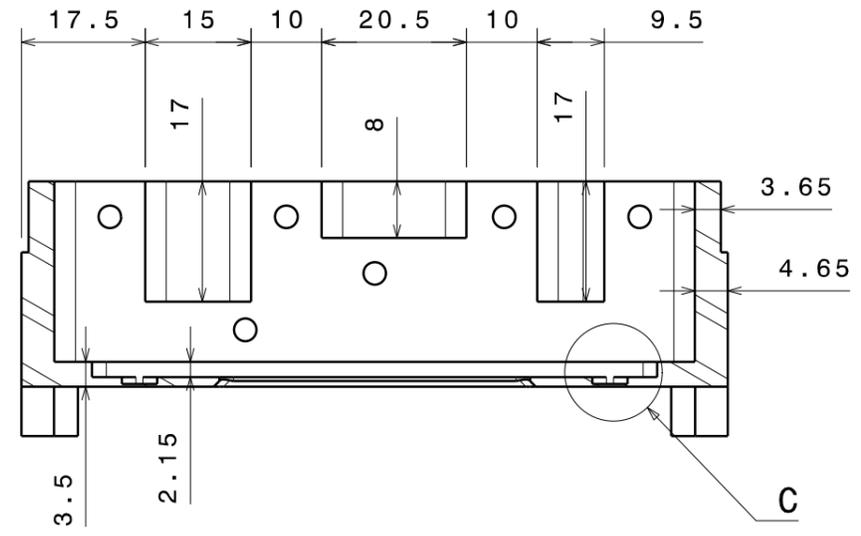
DESIGNED BY: J.P. de Jong DATE: 22/02/2012	<h1>Top Panel</h1>	I	-
CHECKED BY: G.F. Brouwer DATE: 22/02/2012		H	-
SIZE A3	<h1>Delfi-n3Xt</h1>	G	-
SCALE 1:1		F	-
WEIGHT (kg) 0.123	DNX-13-001	E	-
DRAWING NUMBER DNX-13-001		D	-
SHEET 1/2	1/2	C	-
		B	22/02/2012
		A	13/02/2009

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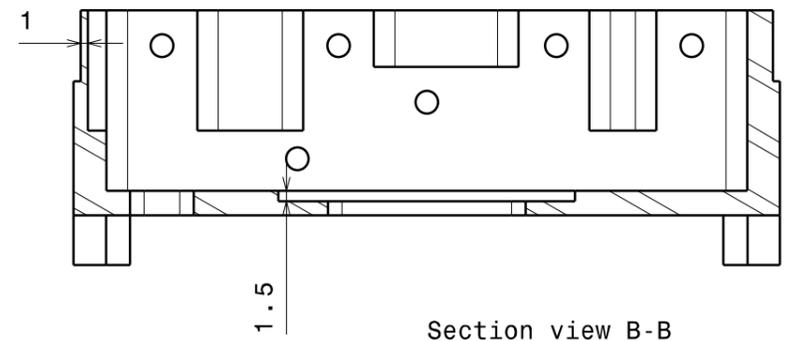
H G F E D C B A



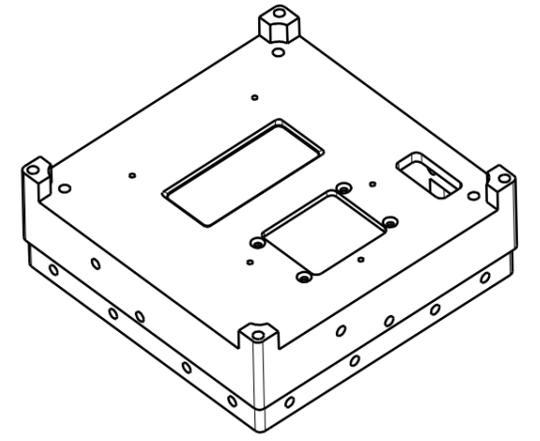
Bottom View
Scale: 1:1



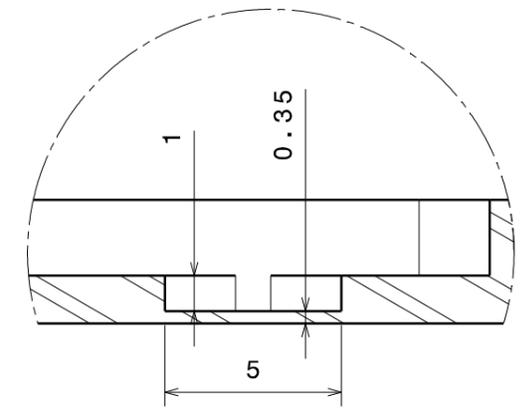
Section view A-A
Scale: 1:1



Section view B-B
Scale: 1:1



Isometric view
Scale: 1:2



Detail C
Scale: 5:1

DESIGNED BY: J.P. de Jong		<h1>Top Panel</h1>		I	-
DATE: 22/02/2012				H	-
CHECKED BY: G.F. Brouwer		<h1>Delfi-n3Xt</h1>		G	-
DATE: 22/02/2012				F	-
SIZE: A3		<h1>DNX-13-001</h1>		E	-
SCALE: 1:1				WEIGHT (kg): 0.123	D
DRAWING NUMBER: DNX-13-001		SHEET: 2/2		C	-
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				A	13/02/2009

H G F E D C B A

4

3

2

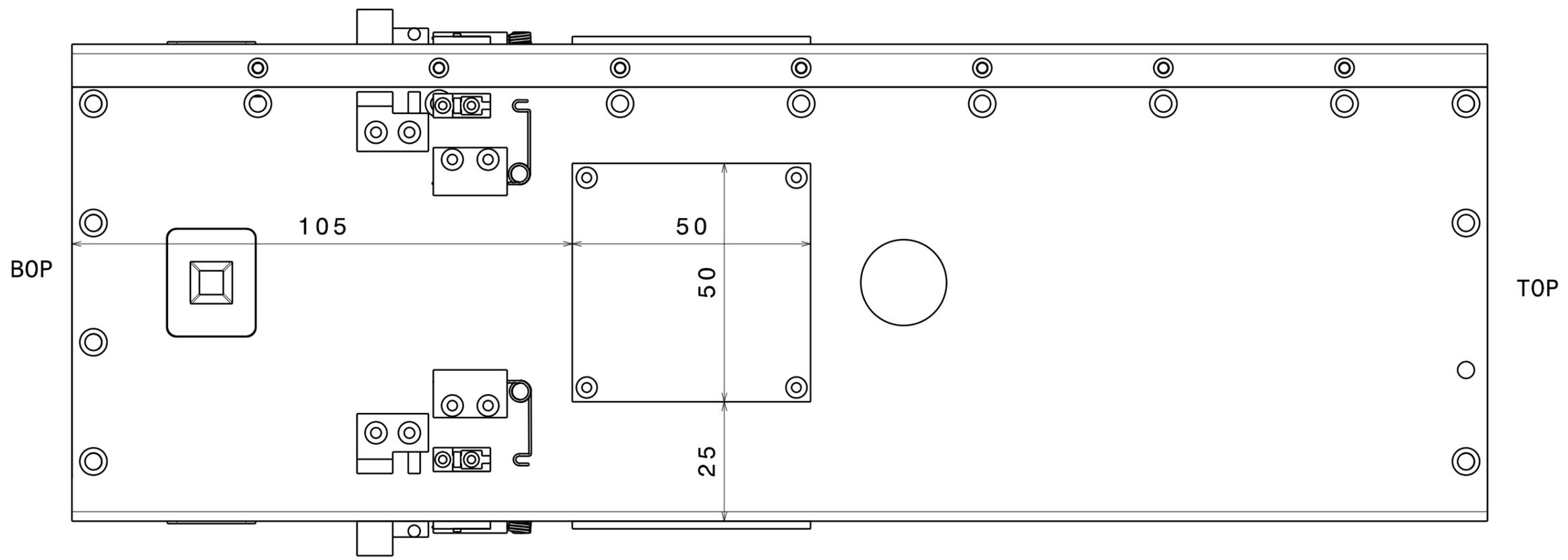
1

4

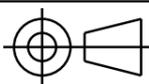
3

2

1

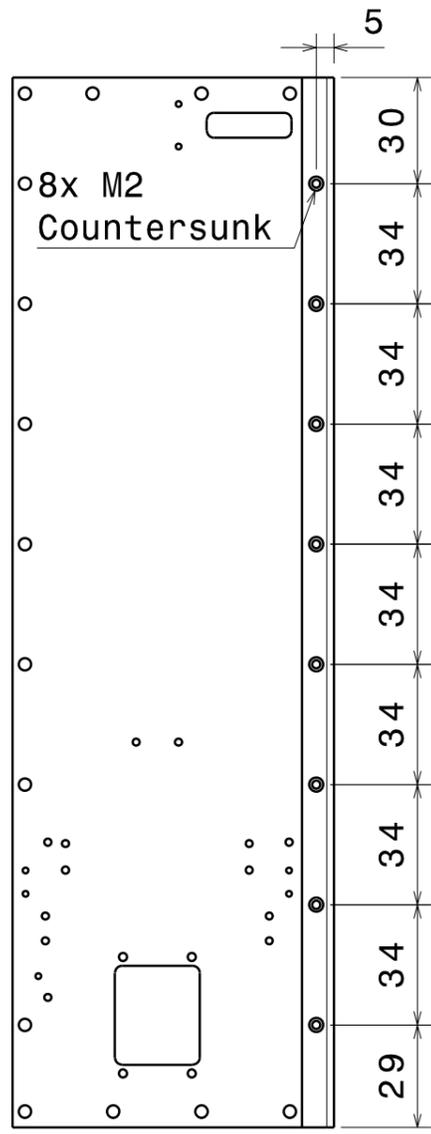


Front view
Scale: 1:1

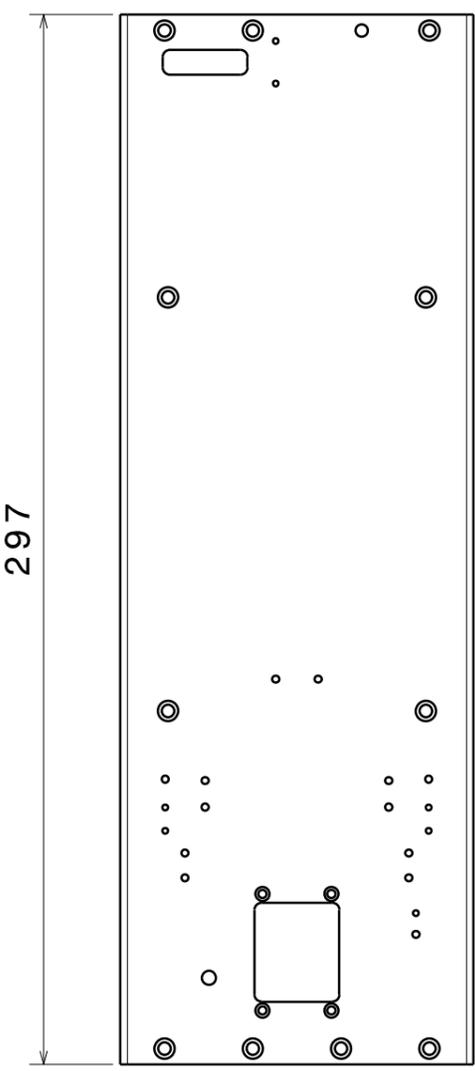
Project contact: 015-2785326		Surface treatment	None			
Order no.		Tolerances	± 0.1 mm, unless specified otherwise			
Remove sharp edges		Roundings	R2, unless specified otherwise			
Dimensions in mm		Process	Milling			
		Material	-			
DESIGNED BY: J.P. de Jong DATE: 7/12/2010		<h1>Integrated U panels</h1>			I	-
CHECKED BY: G.F. Brouwer DATE: -					H	-
SIZE A3		<h1>Delfi-n3Xt</h1>			G	-
SCALE 1:1	WEIGHT (kg) -				E	-
DRAWING NUMBER DNX-14-000		SHEET 1/1			D	-
					C	
					B	
					A	7/12/2010

H G F E D C B A

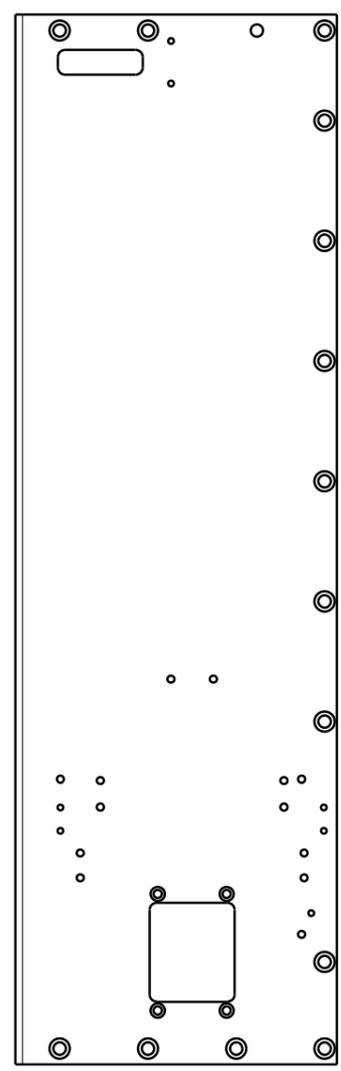
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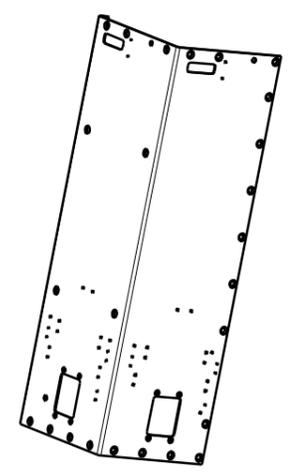
Left view
Scale: 1:2



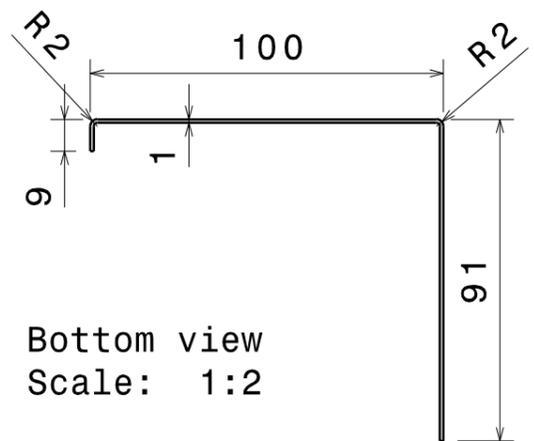
Front view
Scale: 1:2



Right view
Scale: 1:2



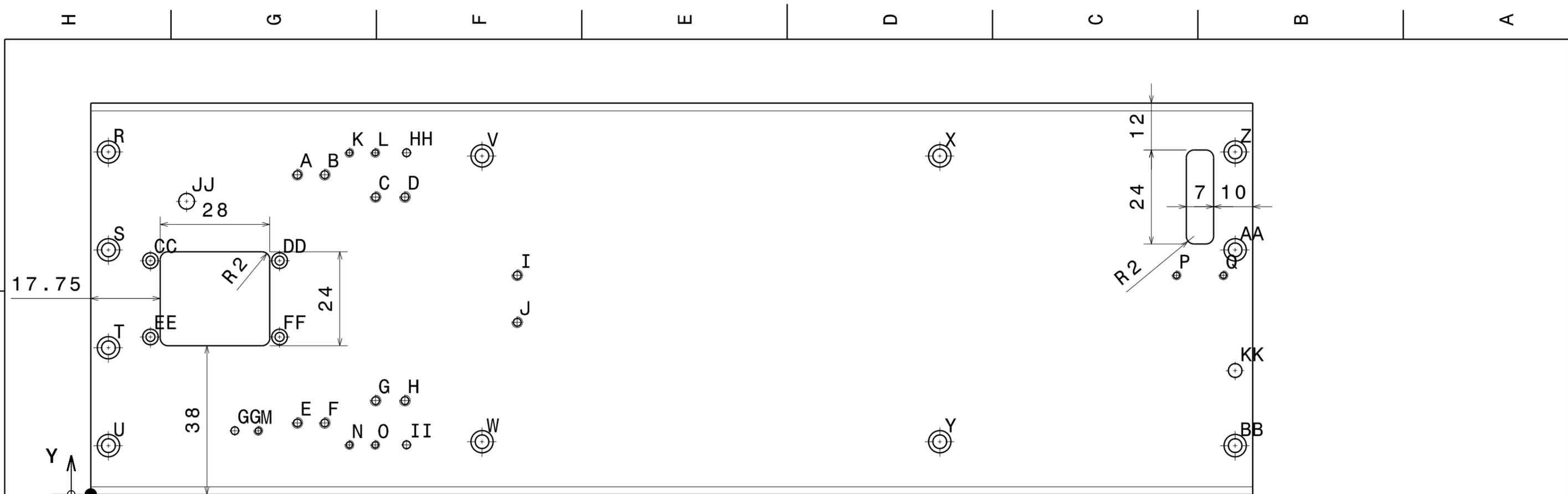
Isometric view
Scale: 1:5



Bottom view
Scale: 1:2

Project contact: 015-2785326		Surface treatment	None	
Order no.		Tolerances	± 0.1 mm, unless specified otherwise	
Remove sharp edges		Roundings	R2, unless specified otherwise	
Dimensions in mm		Process	Bending	
DESIGNED BY: J.P. de Jong DATE: 25/1/2012		Material	Aluminium 5083	
CHECKED BY: G.F. Brouwer DATE: 31/1/2012		U-profile Y-X+		
SIZE A3				
SCALE 1:1	WEIGHT (kg) 0.151	DRAWING NUMBER DNX-14-001	SHEET 1/3	
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I	-
H	-
G	-
F	-
E	-
D	-
C	-
B	25-1-2012
A	13-2-2009



Front view (Y-)
Scale: 1:1

X = 0mm
Y = 0mm

M1.6 Thread

REF.	X	Y	Diameter
K	66,1	87,3	1,25
L	72,7	87,3	1,25
M	42,8	16,3	1,25
N	66,1	12,7	1,25
O	72,7	12,7	1,25
P	277,5	56	1,25
Q	289,5	56	1,25

M2 Countersunk

REF.	X	Y	Diameter
CC	15,25	59,75	2,3
DD	48,25	59,75	2,3
EE	15,25	40,25	2,3
FF	48,25	40,25	2,3

REF.	X	Y	Diameter
GG	36,8	16,3	2
HH	80,7	87,3	2
II	80,7	12,7	2

M3 Countersunk

REF.	X	Y	Diameter
R	4,5	87,5	3,5
S	4,5	62,5	3,5
T	4,5	37,5	3,5
U	4,5	12,5	3,5
V	100	86,5	3,5
W	100	13,5	3,5
X	217	86,5	3,5
Y	217	13,5	3,5
Z	292,5	87,5	3,5
AA	292,5	62,5	3,5
BB	292,5	12,5	3,5

M2 Thread

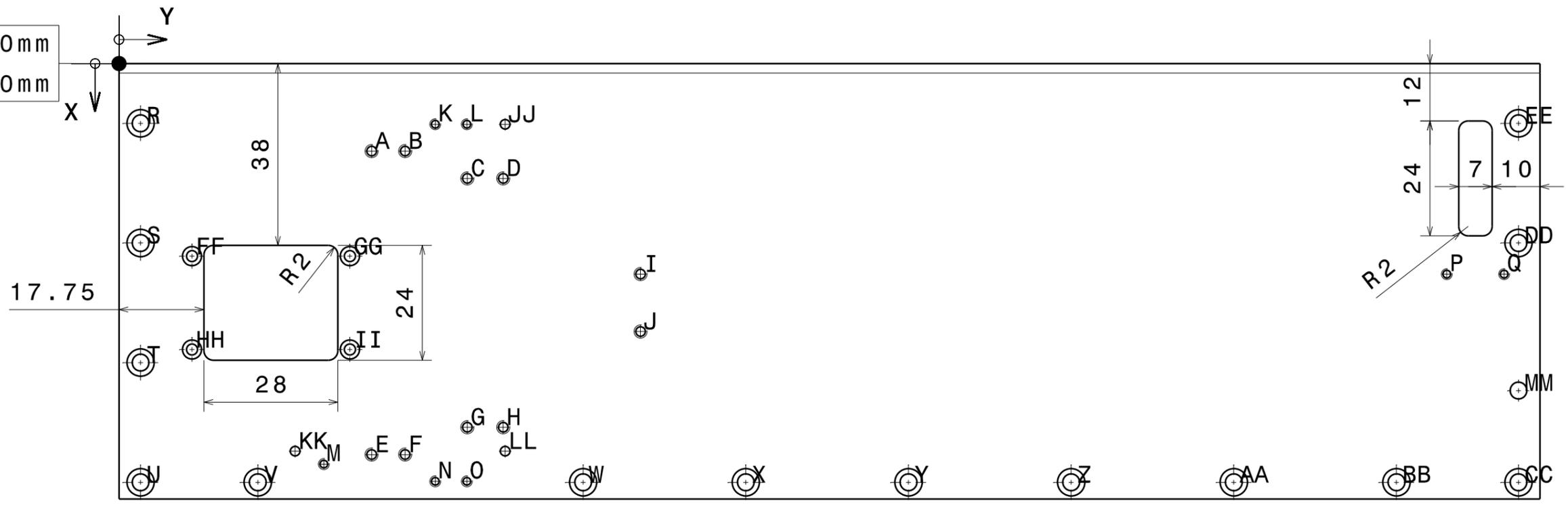
REF.	X	Y	Diameter
A	52,8	81,7	1,6
B	59,8	81,7	1,6
C	72,8	76	1,6
D	80,3	76	1,6
E	52,8	18,3	1,6
F	59,8	18,3	1,6
G	72,8	24	1,6
H	80,3	24	1,6
I	109	56	1,6
J	109	44	1,6

REF.	X	Y	Diameter
JJ	24,5	74,9	4

REF.	X	Y	Diameter
KK	292,5	31,67	3,5

DESIGNED BY: J.P. de Jong	<h1>U-profile Y-X+</h1>	I	-
DATE: 25/1/2012		H	-
CHECKED BY: G.F. Brouwer	<h1>Delfi-n3Xt</h1>	G	-
DATE: 31/1/2012		F	-
SIZE: A3		E	-
SCALE: 1:1		D	-
WEIGHT (kg): 0.151	DRAWING NUMBER: DNX-14-001	C	-
	SHEET: 2/3	B	25-1-2012
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X = 0mm
Y = 0mm



Front view (X+)
Scale: 1:1

M3 Countersunk

REF.	X	Y	Diameter
R	12,5	4,5	3,5
S	37,5	4,5	3,5
T	62,5	4,5	3,5
U	87,5	4,5	3,5
V	87,5	29	3,5
W	87,5	97	3,5
X	87,5	131	3,5
Y	87,5	165	3,5
Z	87,5	199	3,5
AA	87,5	233	3,5
BB	87,5	267	3,5
CC	87,5	292,5	3,5
DD	37,5	292,5	3,5
EE	12,5	292,5	3,5

M2 Thread

REF.	X	Y	Diameter
A	18,3	52,8	1,6
B	18,3	59,8	1,6
C	24	72,8	1,6
D	24	80,3	1,6
E	81,7	52,8	1,6
F	81,7	59,8	1,6
G	76	72,8	1,6
H	76	80,3	1,6
I	44	109	1,6
J	56	109	1,6

M1.6 Thread

REF.	X	Y	Diameter
K	12,7	66,1	1,25
L	12,7	72,7	1,25
M	83,7	42,8	1,25
N	87,3	66,1	1,25
O	87,3	72,7	1,25
P	44	277,5	1,25
Q	44	289,5	1,25

M2 Countersunk

REF.	X	Y	Diameter
FF	40,25	15,25	2,3
GG	40,25	48,25	2,3
HH	59,75	15,25	2,3
II	59,75	48,25	2,3

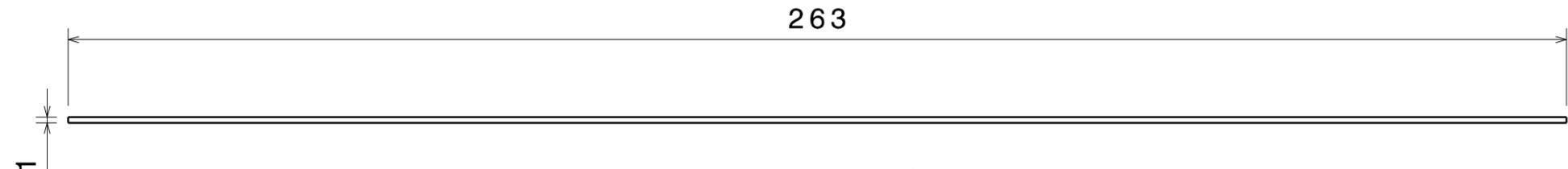
REF.	X	Y	Diameter
JJ	12,7	80,7	2
KK	81	36,8	2
LL	81	80,7	2

REF.	X	Y	Diameter
MM	68,33	292,5	3,5

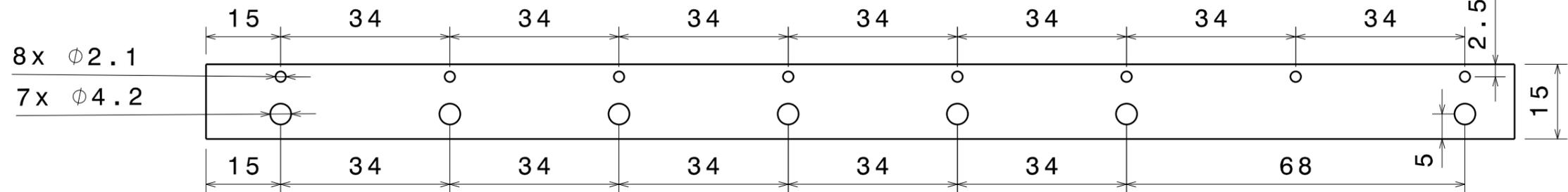
DESIGNED BY: J.P. de Jong	<h1>U-profile Y-X+</h1>	I	-
DATE: 25/1/2012		H	-
CHECKED BY: G.F. Brouwer	<h1>Delfi-n3Xt</h1>	G	-
DATE: 31/1/2012		F	-
SIZE: A3		E	-
SCALE: 1:1		D	-
WEIGHT (kg): 0.151	DRAWING NUMBER: DNX-14-001	C	-
SHEET: 3/3		B	25-1-2012
		A	13-2-2009

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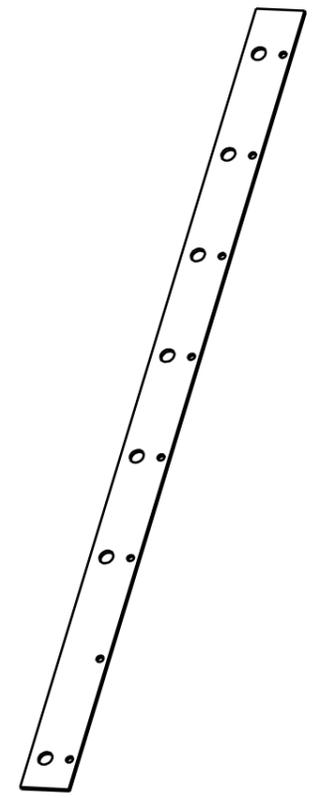
H G F E D C B A



Top view
Scale: 1:1



Front view
Scale: 1:1



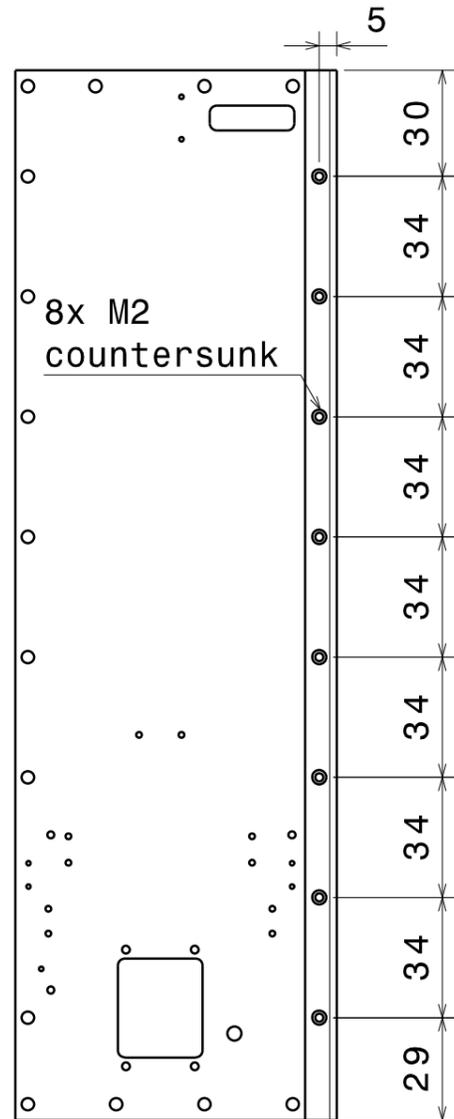
Isometric view
Scale: 1:2

Project contact: 015-2785326		Surface treatment	None	
Order no.		Tolerances	± 0.1 mm, unless specified otherwise	
Remove sharp edges		Roundings	R2, unless specified otherwise	
Dimensions in mm		Process	Cutting	
DESIGNED BY: J.P. de Jong DATE: 26/1/2012		Material	Aluminium 5083	
CHECKED BY: G.F. Brouwer DATE: 31/1/2012		<h1>Connection strip</h1>		
SIZE A3				
SCALE 1:1	WEIGHT (kg) 0.010	DRAWING NUMBER DNX-14-002	SHEET 1/1	
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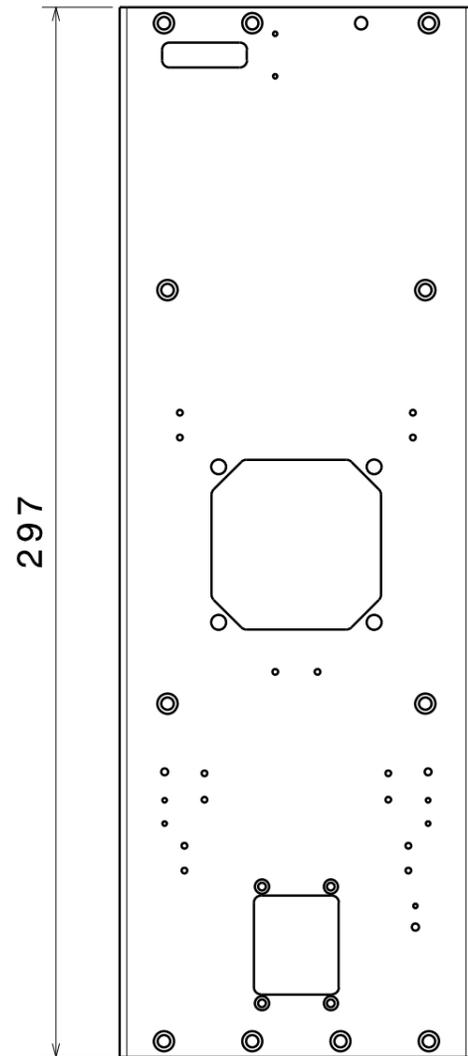
I	—
H	—
G	—
F	—
E	—
D	—
C	—
B	26-1-2012
A	13-2-2009

H G B A

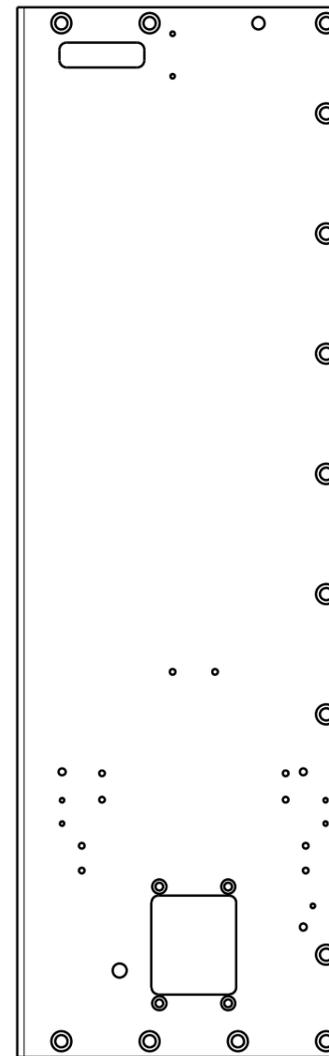
H G F E D C B A



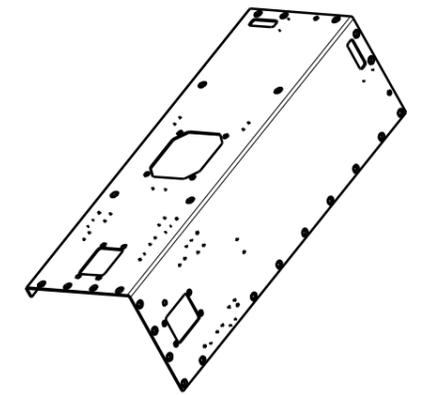
Left view (X+)
Scale: 1:2



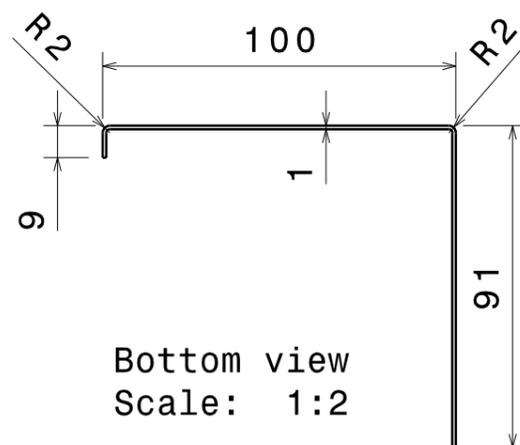
Front view (Y+)
Scale: 1:2



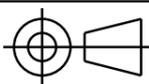
Right view (X-)
Scale: 1:2



Isometric view
Scale: 1:5



Bottom view
Scale: 1:2

Project contact: 015-2785326		Surface treatment	None	
Order no.		Tolerances	± 0.1 mm, unless specified otherwise	
Remove sharp edges		Roundings	R2, unless specified otherwise	
Dimensions in mm		Process	Bending	
DESIGNED BY: J.P. de Jong DATE: 25/1/2012		Material	Aluminium 5083	
CHECKED BY: G.F. Brouwer DATE: 31/1/2012		U-profile Y+X-		
SIZE A3				
SCALE 1:1	WEIGHT (kg) 0.146	DRAWING NUMBER DNX-14-003	SHEET 1/3	I —
				H —
				G —
				F —
				E —
				D —
				C —
				B 25-1-2012
				A 13-2-2009

H G F E D C B A

4

3

2

1

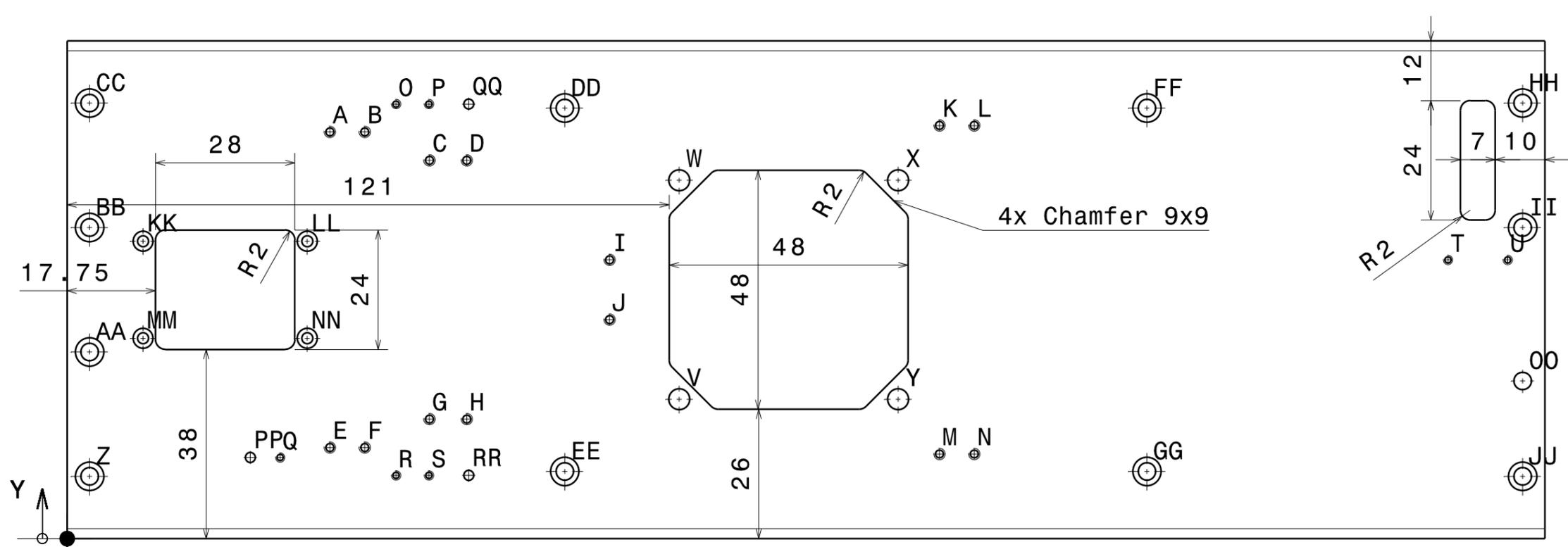
4

3

2

1

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Front view (Y+)
Scale: 1:1

X = 0mm
Y = 0mm

M3 Countersunk

REF.	X	Y	Diameter
Z	4,5	12,5	3,5
AA	4,5	37,5	3,5
BB	4,5	62,5	3,5
CC	4,5	87,5	3,5
DD	100	86,5	3,5
EE	100	13,5	3,5
FF	217	86,5	3,5
GG	217	13,5	3,5
HH	292,5	87,5	3,5
II	292,5	62,5	3,5
JJ	292,5	12,5	3,5

M2 Thread

REF.	X	Y	Diameter
A	52,8	81,7	1,6
B	59,8	81,7	1,6
C	72,8	76	1,6
D	80,3	76	1,6
E	52,8	18,3	1,6
F	59,8	18,3	1,6
G	72,8	24	1,6
H	80,3	24	1,6
I	109	56	1,6
J	109	44	1,6
K	175,3	83	1,6
L	182,3	83	1,6
M	175,3	17	1,6
N	182,3	17	1,6

M1.6 Thread

REF.	X	Y	Diameter
O	66,1	87,3	1,25
P	72,7	87,3	1,25
Q	42,8	16,3	1,25
R	66,1	12,7	1,25
S	72,7	12,7	1,25
T	277,5	56	1,25
U	289,5	56	1,25

M2 Countersunk

REF.	X	Y	Diameter
KK	15,25	59,75	2,2
LL	48,25	59,75	2,2
MM	15,25	40,25	2,2
NN	48,25	40,25	2,2

REF.	X	Y	Diameter
00	292,5	31,67	3,5

REF.	X	Y	Diameter
V	123	28	4,2
W	123	72	4,2
X	167	72	4,2
Y	167	28	4,2

REF.	X	Y	Diameter
PP	36,8	16,3	2
QQ	80,7	87,3	2
RR	80,7	12,7	2

DESIGNED BY: J.P. de Jong	U-profile Y+X-	I	-
DATE: 25/1/2012		H	-
CHECKED BY: G.F. Brouwer	Delfi-n3Xt	G	-
DATE: 31/1/2012		F	-
SIZE: A3	DRAWING NUMBER: DNX-14-003	E	-
SCALE: 1:1		D	-
WEIGHT (kg): 0.146	SHEET: 2/3	C	-
DRAWING NUMBER: DNX-14-003		B	25-1-2012
		A	13-2-2009

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4

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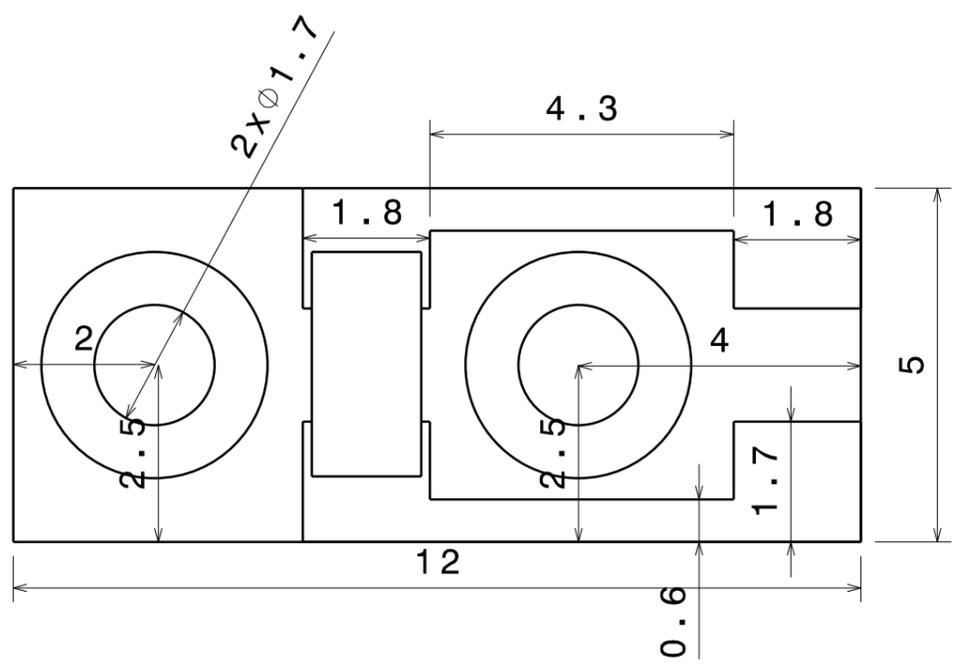
1

4

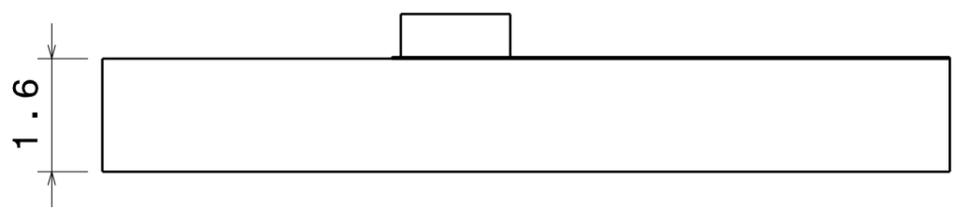
3

2

1



Top view
Scale: 10:1



Front view
Scale: 10:1

Project contact: 015-2785326	Surface treatment	None
	Tolerances	± 0.1 mm, unless specified otherwise
Order no.	Roundings	R2, unless specified otherwise
Remove sharp edges	Process	Milling
Dimensions in mm	Material	FR4

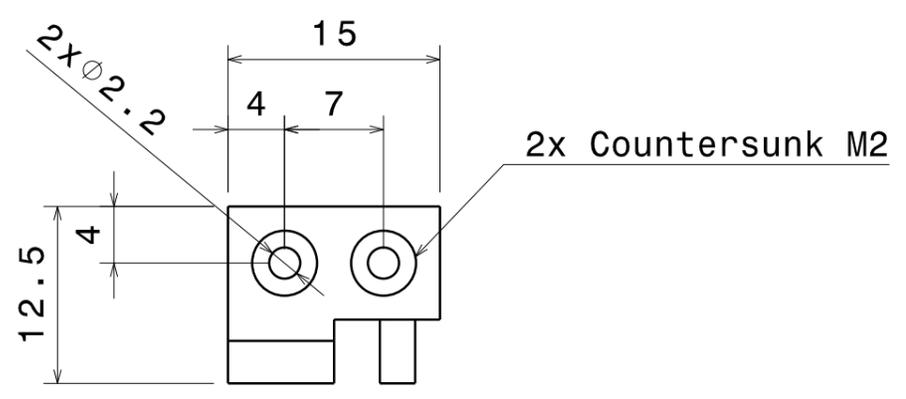
DESIGNED BY: J.P. de Jong	HDRS Resistor PCB		I	-
DATE: 30/11/2010			H	-
CHECKED BY: -			G	-
DATE: -	Delfi-n3Xt		F	-
SIZE A3			E	-
SCALE 1:1			D	-
WEIGHT (kg) -	DRAWING NUMBER DNX-15-100	SHEET 1/1	C	
			B	
			A	30/11/2010

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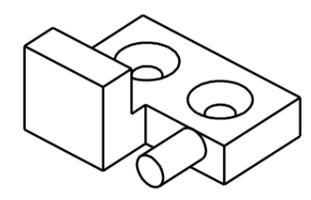
H G F E D C B A

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4

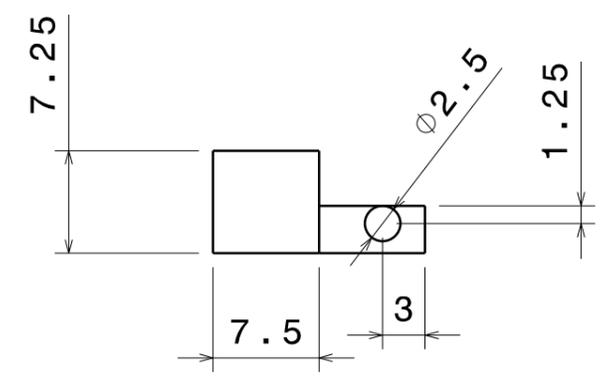


Top view

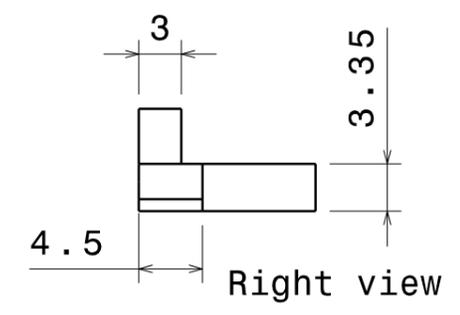


3

3



Front view



Right view

2

2

Project contact: 015-2785326		Surface treatment	Blank anodised			
Order no. L10 L10901		Tolerances	± 0.1 mm, unless specified otherwise			
Remove sharp edges		Roundings	R2, unless specified otherwise			
Dimensions in mm		Process	Milling			
DESIGNED BY: J.P. de Jong DATE: 29-10-2010		Material	Aluminium 6082 (51ST 3.2315.72)			
CHECKED BY: G.F. Brouwer DATE: 29-10-2010		<h1>Support Left</h1>			I	-
SIZE A3					<h1>Delfi-n3Xt</h1>	
SCALE 2:1		<h1>DNX-15-101</h1>				
WEIGHT (kg) 0.002					<h1>1/1</h1>	
DRAWING NUMBER		<h1>29-10-2010</h1>				
SHEET					<h1>1/1</h1>	
DRAFTING NUMBER		<h1>1/1</h1>				
SHEET					<h1>1/1</h1>	
DRAWING NUMBER		<h1>1/1</h1>				
SHEET					<h1>1/1</h1>	

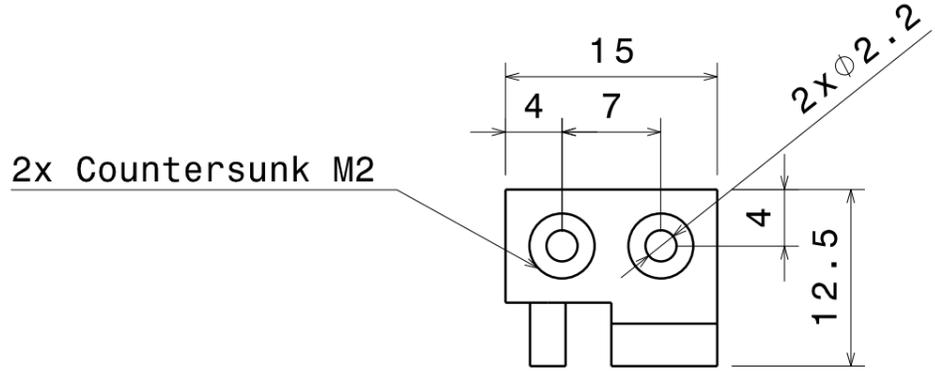
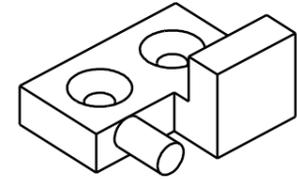
H G F E D C B A

1

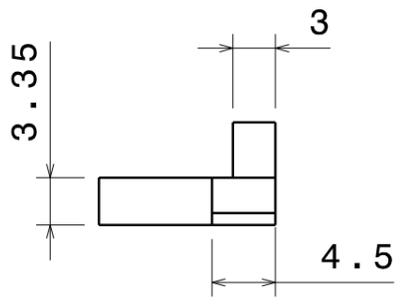
1

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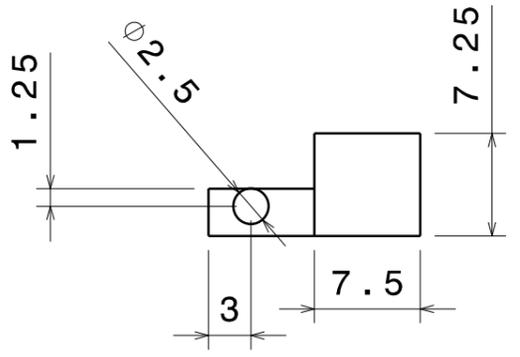
H G F E D C B A



Top view



Left view



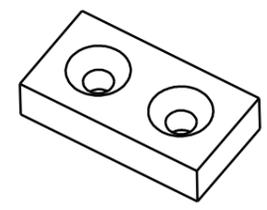
Front view

Project contact: 015-2785326		Surface treatment	Blank anodised			
Order no. L10 L10901		Tolerances	± 0.1 mm, unless specified otherwise			
Remove sharp edges		Roundings	R2, unless specified otherwise			
Dimensions in mm		Process	Milling			
DESIGNED BY: J.P. de Jong DATE: 01/11/2010		Material	Aluminium 6082 (51ST 3.2315.72)			
CHECKED BY: G.F. Brouwer DATE: 01/11/2010		<h1>Support Right</h1>			I	-
SIZE A3					<h1>Delfi-n3Xt</h1>	
SCALE 2:1	WEIGHT (kg) 0.002	DRAWING NUMBER DNX-15-106		G		
		SHEET 1/1		F	-	
				E	-	
				D	-	
				C	-	
				B	-	
				A	01/11/2010	

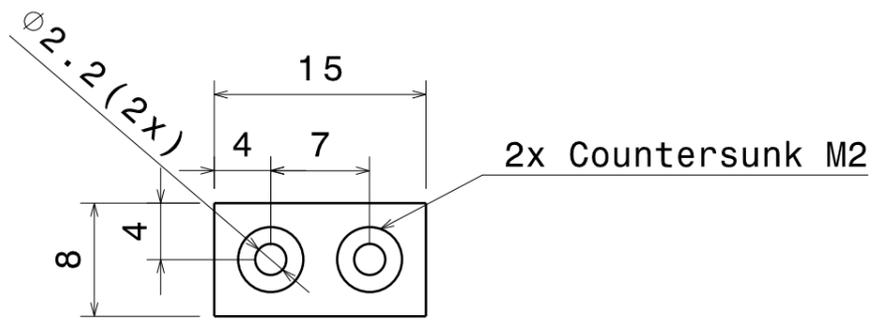
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H G F E D C B A

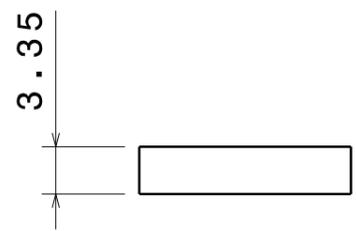
H G F E D C B A



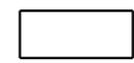
Isometric view



Top view



Front view



Right view

Project contact: 015-2785326		Surface treatment	None			
Order no.		Tolerances	± 0.1 mm, unless specified otherwise			
Remove sharp edges		Roundings	R2, unless specified otherwise			
Dimensions in mm		Process	Milling			
		Material	PEEK			
DESIGNED BY: J.P. de Jong		Support block SP STX			I	-
DATE: 28/2/2012					H	-
CHECKED BY: G.F. Brouwer		Delfi-n3Xt			G	-
DATE: -					F	-
SIZE A3					E	-
SCALE 1:1	WEIGHT (kg) 0.001	DRAWING NUMBER DNX-15-109			D	-
		SHEET 1/1			C	-
					B	-
					A	28-02-2012

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H G B A

H G F E D C B A

4

4

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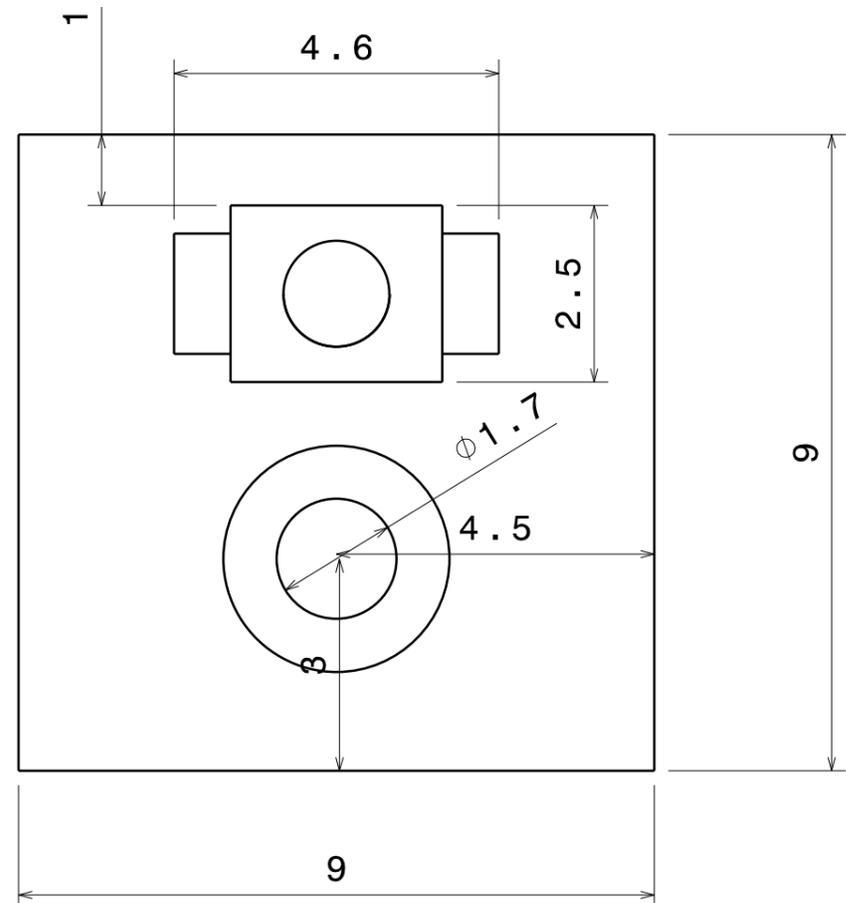
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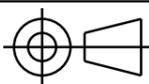
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1

1

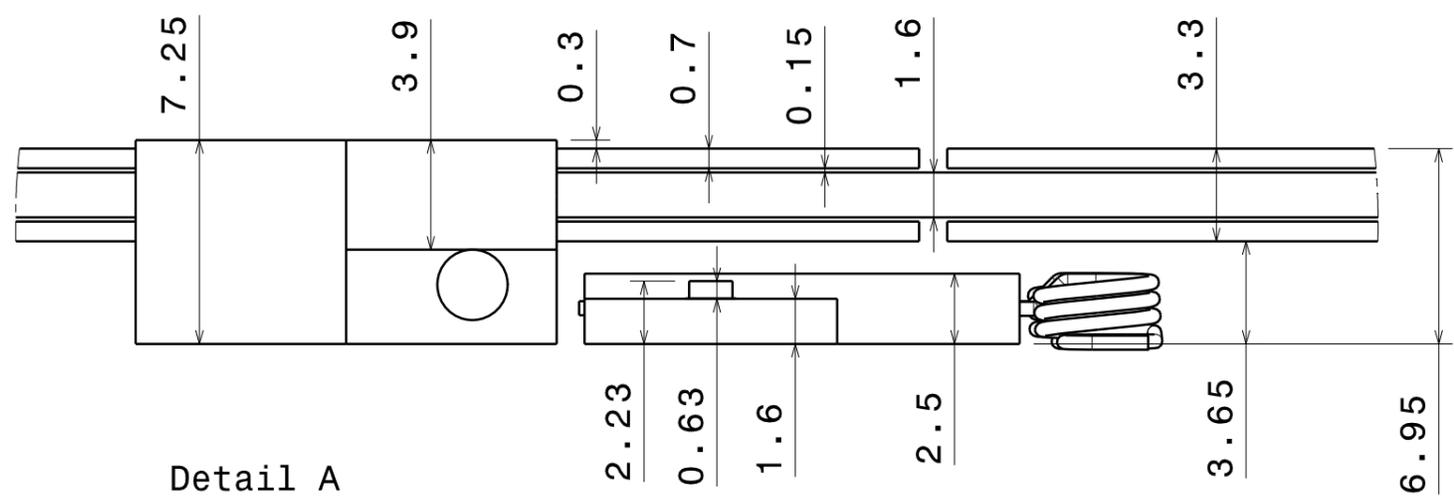


Front view
Scale: 10:1

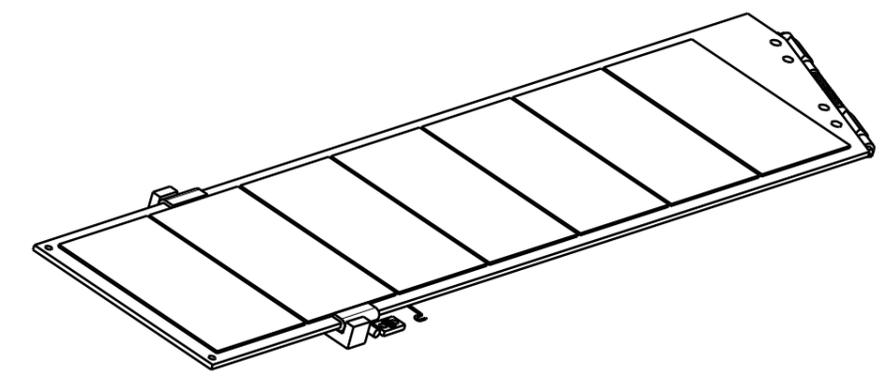
DESIGNED BY: J.P. de Jong		Tact switch assembly		I	-
DATE: 26-1-2012				H	-
CHECKED BY:		Delfi-n3Xt		G	-
DATE:				F	-
SIZE A3		DRAWING NUMBER DNX-15-200		E	-
SCALE 1:1	WEIGHT (kg) -			D	-
		SHEET 1/1		C	
				B	
				A	26-1-2012

H G B A

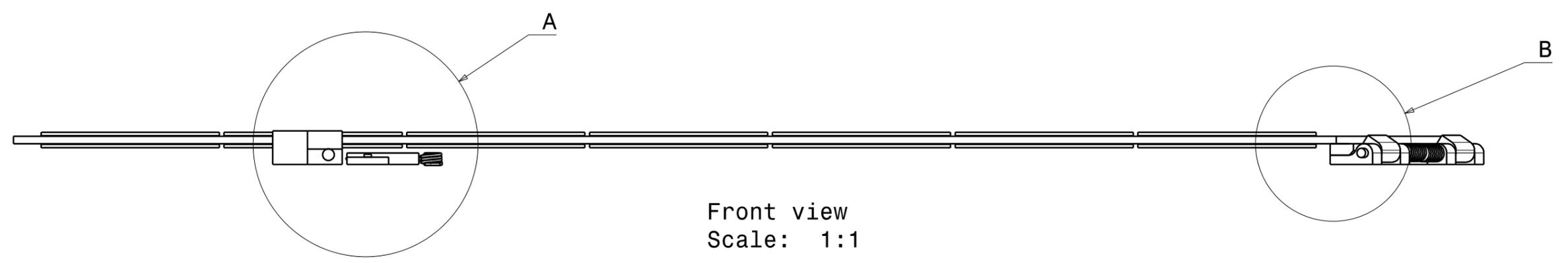
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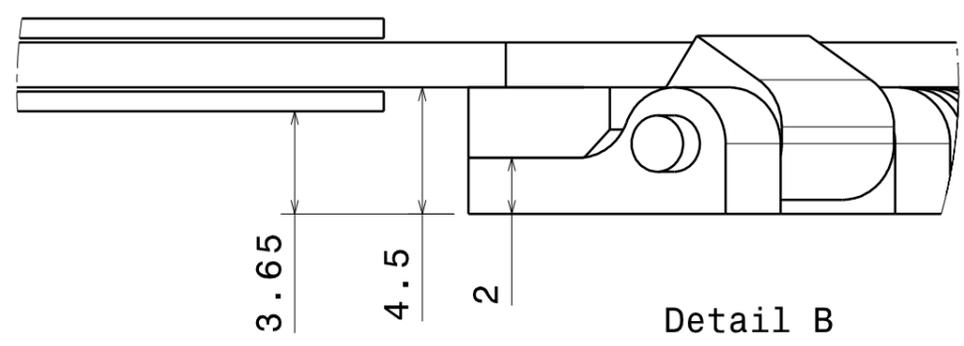
Detail A
Scale: 4:1



Isometric view
Scale: 1:2



Front view
Scale: 1:1

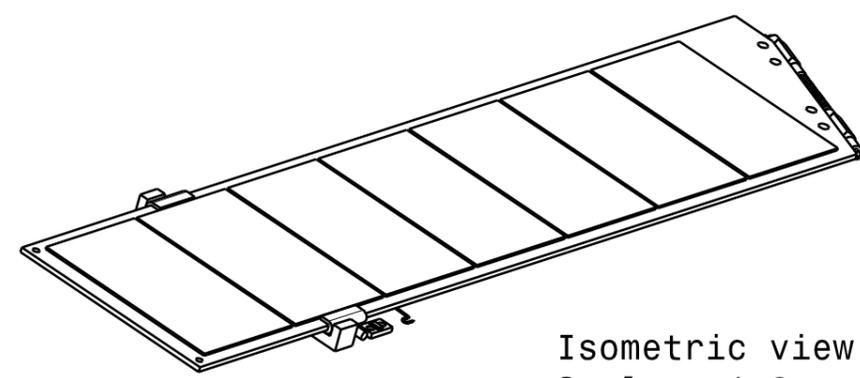


Detail B
Scale: 4:1

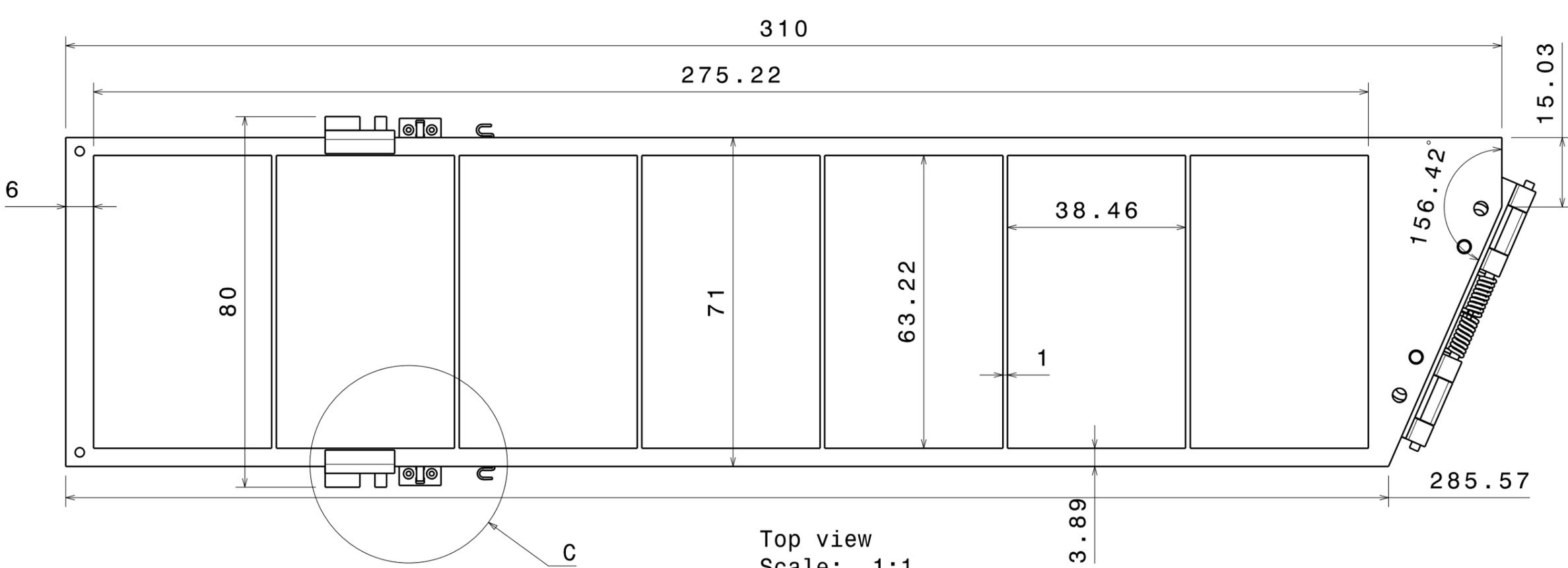
DESIGNED BY: J.P. de Jong	Solar panel assembly	I	-
DATE: 5/11/2010		H	-
CHECKED BY: G.F. Brouwer	Delfi-n3Xt	G	-
DATE: 9/11/2010		F	-
SIZE A3	DRAWING NUMBER DNX-20-000	E	-
SCALE 1:1		D	-
WEIGHT (kg) -	SHEET 1/3	C	-
		B	-
		A	5/11/2010

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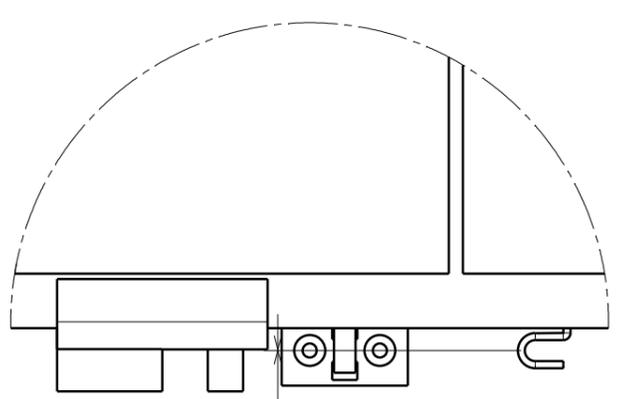
H G F E D C B A



Isometric view
Scale: 1:2



Top view
Scale: 1:1



Detail C
Scale: 2:1

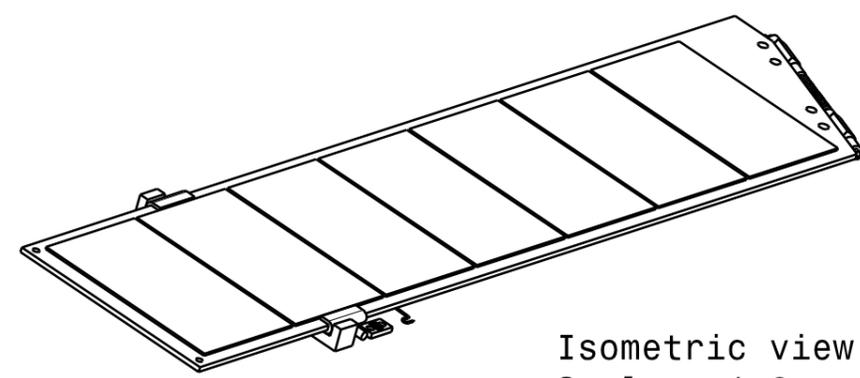
DESIGNED BY: J.P. de Jong	Solar panel assembly		I	-
DATE: 5/11/2010			H	-
CHECKED BY: G.F. Brouwer	Delfi-n3Xt		G	-
DATE: 9/11/2010			F	-
SIZE: A3		DNX-20-000	E	-
SCALE: 1:1	WEIGHT (kg): -		D	-
DRAWING NUMBER: DNX-20-000		2/3	C	-
SHEET: 2/3			B	-
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H G B A

H G F E D C B A

4

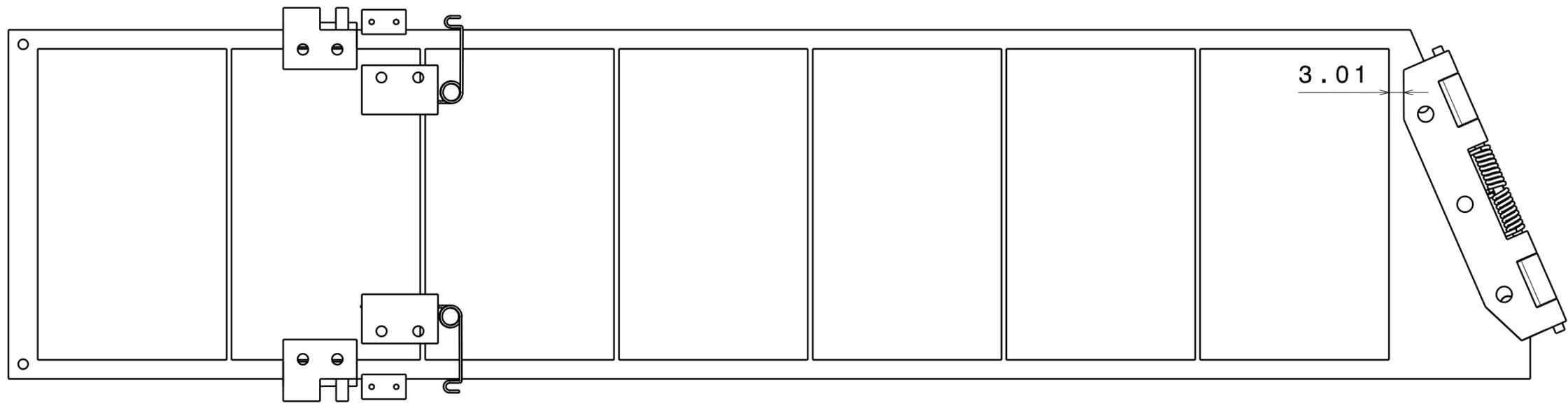
4



Isometric view
Scale: 1:2

3

3



Bottom view
Scale: 1:1

2

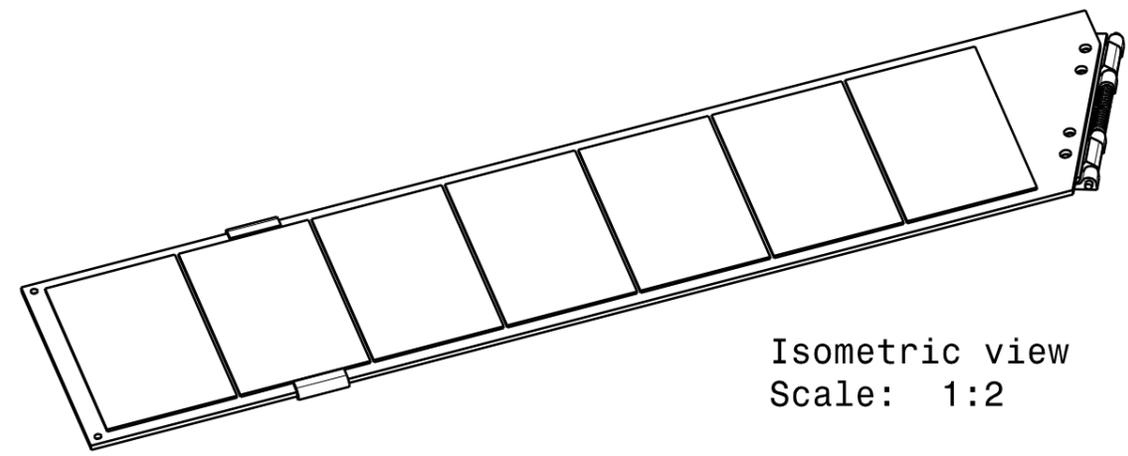
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1

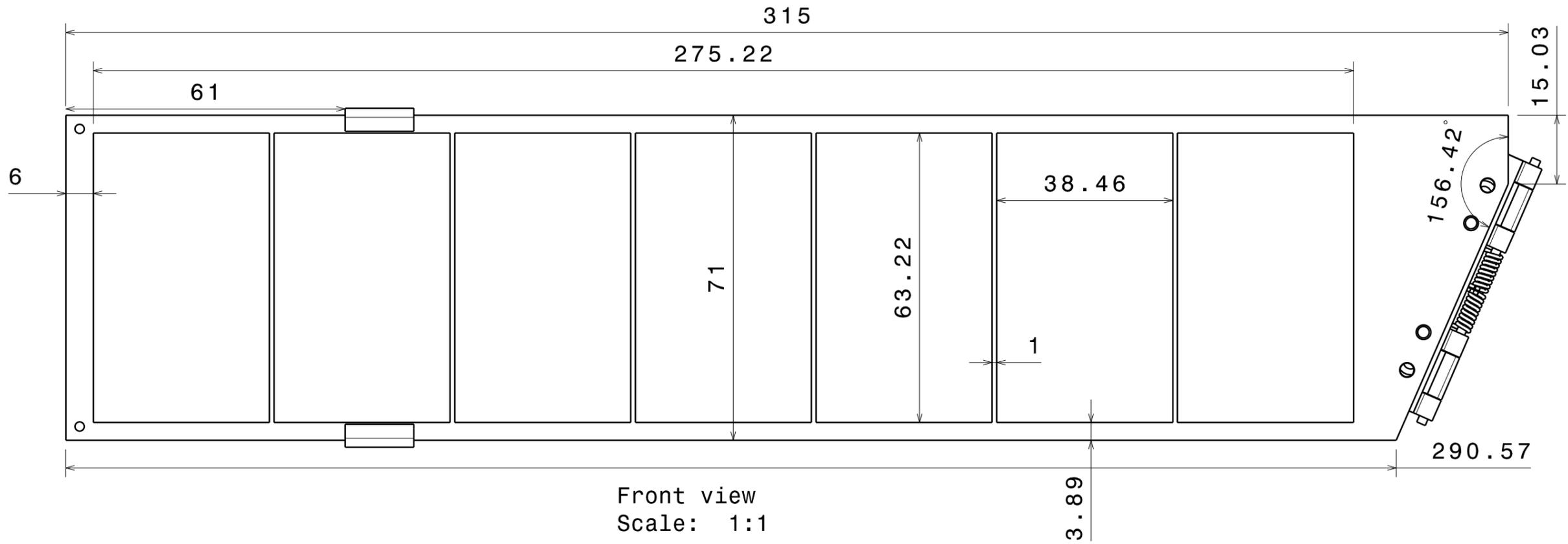
1

DESIGNED BY: J.P. de Jong		<h1>Solar panel assembly</h1>		I	-
DATE: 5/11/2010				H	-
CHECKED BY: G.F. Brouwer		<h2>Delfi-n3Xt</h2>		G	-
DATE: 9/11/2010				F	-
SIZE A3		<h3>DNX-20-000</h3>		E	-
SCALE 1:1	WEIGHT (kg) -			D	-
DRAWING NUMBER		<h3>3/3</h3>		C	-
SHEET				B	-
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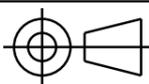
H G B A



Isometric view
Scale: 1:2

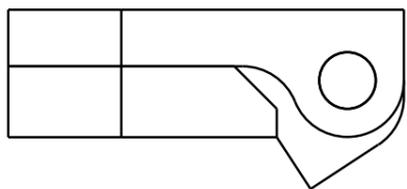


Front view
Scale: 1:1

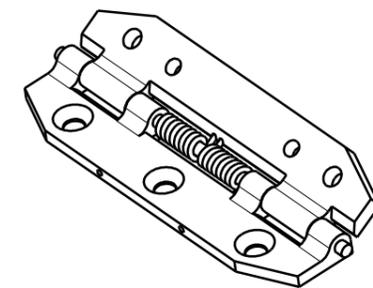
DESIGNED BY: J.P. de Jong		Solar Panel Assembly		I	-
DATE: 5/11/2010				H	-
CHECKED BY: G.F. Brouwer		Delfi-n3Xt		G	-
DATE: 9/11/2010				F	-
SIZE A3		DNX-20-000		E	-
SCALE 1:1	WEIGHT (kg) -			D	-
DRAWING NUMBER			C	-	
SHEET			B	18/10/2011	
			A	5/11/2010	

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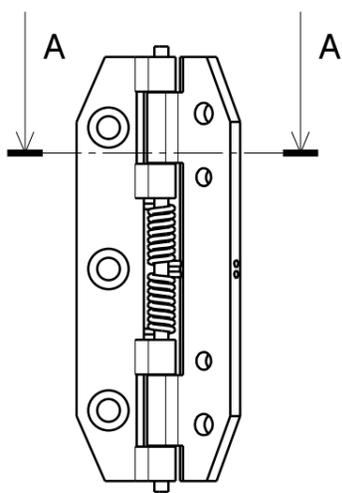
H G F E D C B A



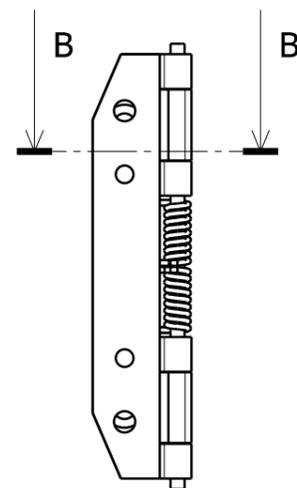
Top view
Scale: 4:1



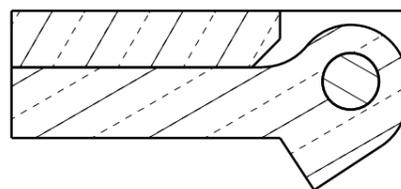
Isometric view open
Scale: 1:1



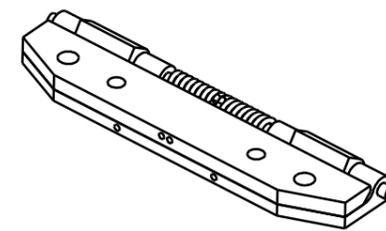
Front view open



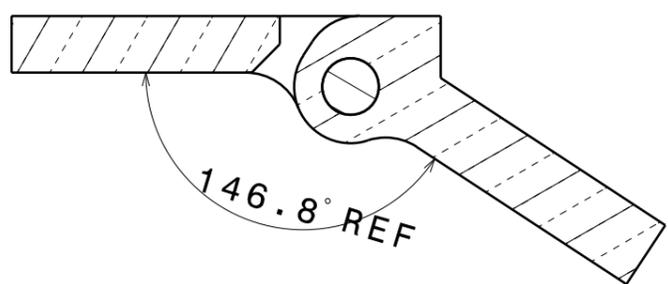
Front view closed



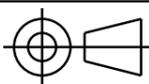
Section view B-B
Scale: 4:1



Isometric view closed



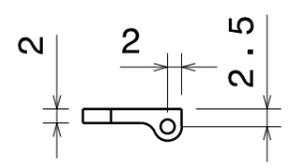
Section view A-A
Scale: 4:1

Project contact: 015-2785326		Surface treatment	None	
Order no. L10 L10901		Tolerances	± 0.1 mm, unless specified otherwise	
Remove sharp edges		Roundings	R2, unless specified otherwise	
Dimensions in mm		Process	Milling	
DESIGNED BY: J.P. de Jong DATE: 1/11/2010		Material	Bronze RG 7	
CHECKED BY: G.F. Brouwer DATE: 1/11/2010		<h1>Hinge Assembly</h1>		
SIZE A3				
SCALE 1:1	WEIGHT (kg) 0.012	DRAWING NUMBER DNX-21-000	SHEET 1/1	
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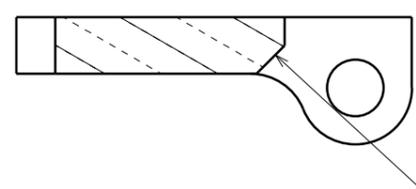
I	-
H	-
G	-
F	-
E	-
D	-
C	-
B	1/11/2010
A	1/4/2009

H G F E D C B A

H G F E D C B A

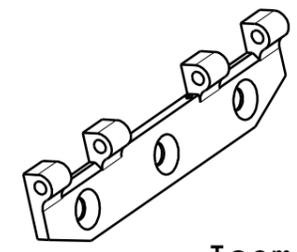


Top view

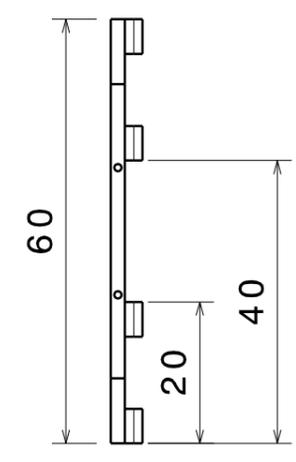


Chamfer 1x1

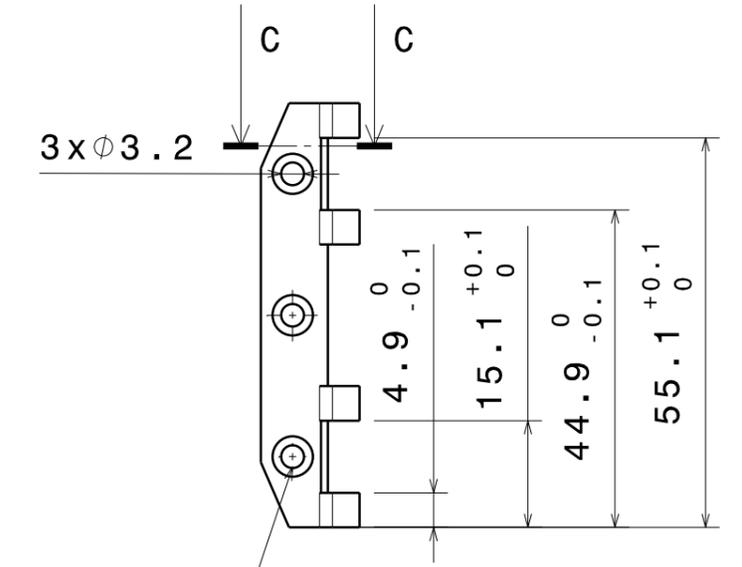
Section view C-C
Scale: 4:1



Isometric view

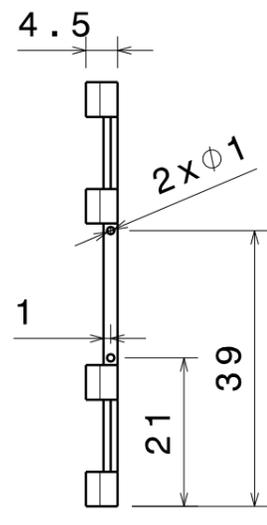


Left view

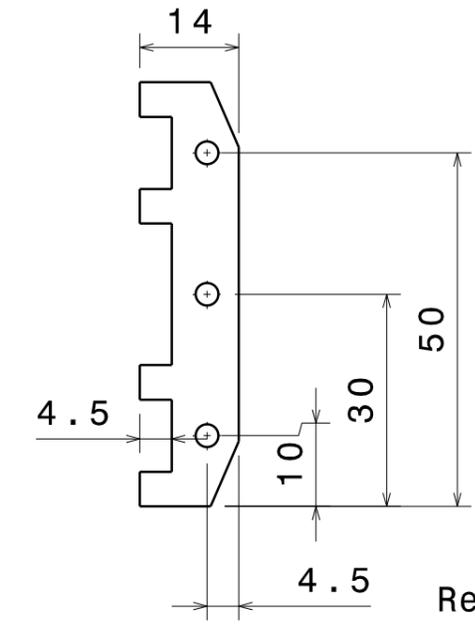


3x Countersunk M3

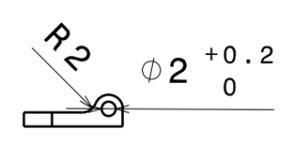
Front view



Right view



Rear view



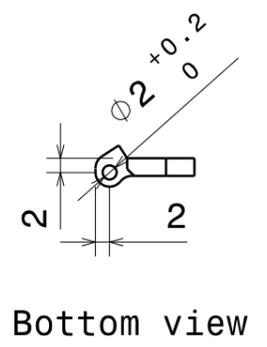
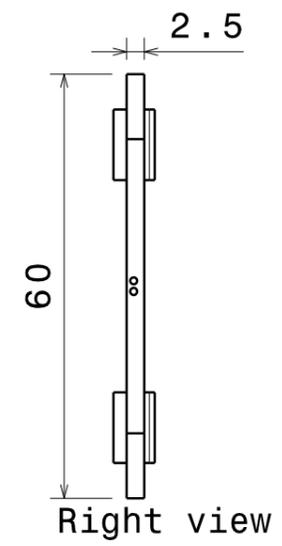
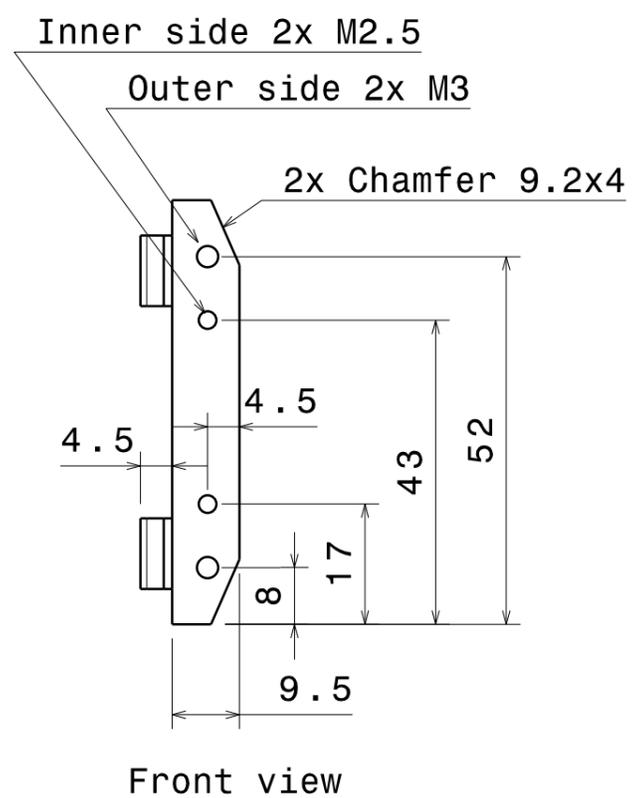
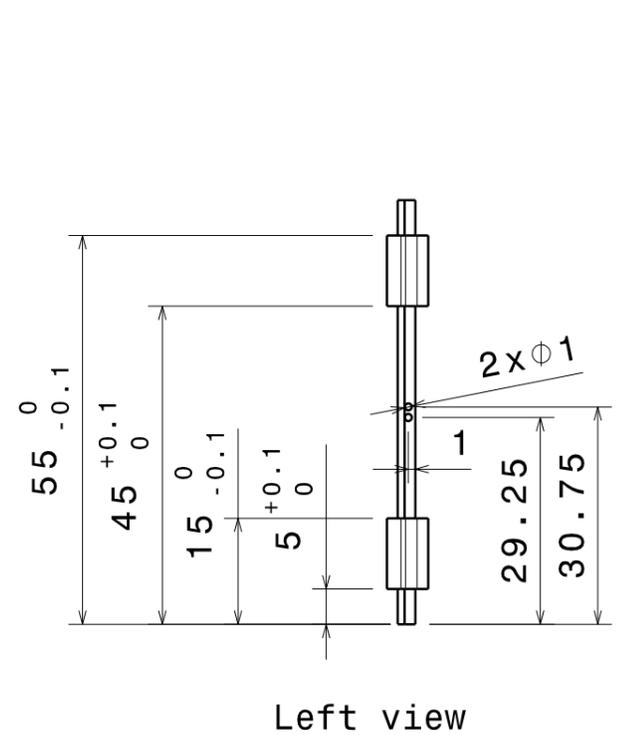
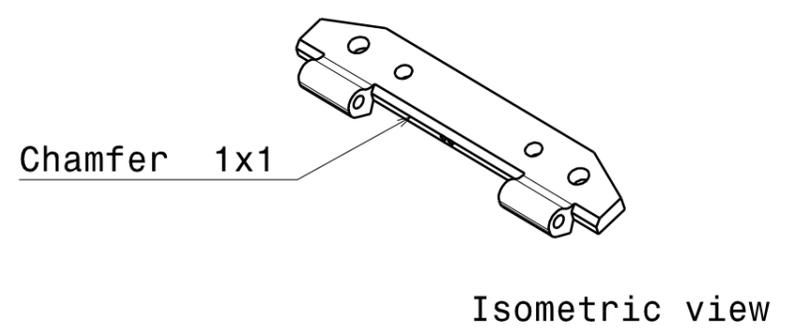
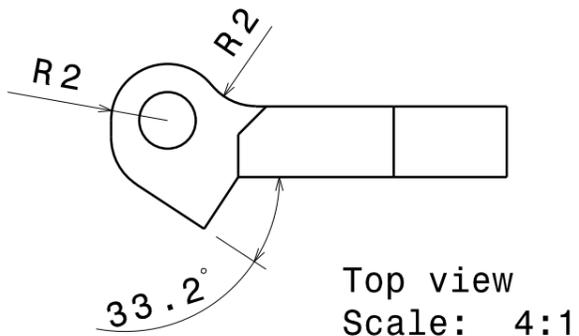
Bottom view

Project contact: 015-2785326		Surface treatment	None
Order no. L10 L10901		Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges		Roundings	R2, unless specified otherwise
Dimensions in mm		Process	Milling
		Material	Bronze RG 7
DESIGNED BY: J.P. de Jong DATE: 1/11/2010		<h1>Hinge leaf structure</h1>	
CHECKED BY: G.F. Brouwer DATE: 9/11/2010			
SIZE A3		<h2>Delfi-n3Xt</h2>	
SCALE 1:1	WEIGHT (kg) 0,016	DRAWING NUMBER DNX-21-001	SHEET 1/1
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I	-
H	-
G	-
F	-
E	-
D	-
C	1/11/2010
B	3/4/2009
A	1/4/2009

H G B A

H G F E D C B A



Project contact: 015-2785326	Surface treatment	None
Order no. L10 L10901	Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges	Roundings	R2, unless specified otherwise
Dimensions in mm	Process	Milling
DESIGNED BY: J.P. de Jong DATE: 1/11/2010	Material	Bronze RG 7
CHECKED BY: G.F. Brouwer DATE: 9/11/2010	Hinge leaf Solar Panel	
SIZE A3		
SCALE 1:1	WEIGHT (kg) 0,012	DRAWING NUMBER DNX-21-002
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4
3
2
1

4
3
2
1

H G B A

H G F E D C B A

4

3

2

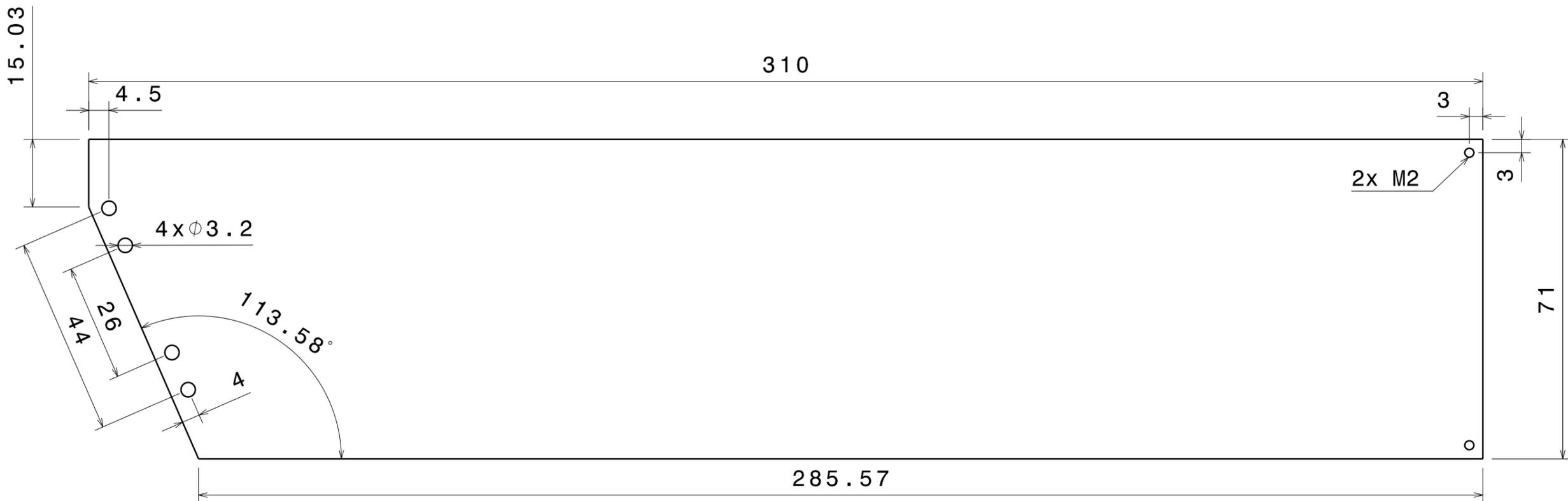
1

4

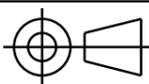
3

2

1



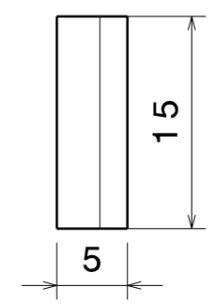
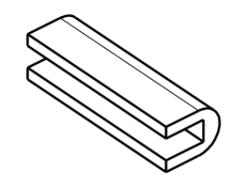
Top view
Scale: 1:1

Project contact: 015-2785326		Surface treatment	None		
Order no.		Tolerances	± 0.1 mm, unless specified otherwise		
Remove sharp edges		Roundings	R2, unless specified otherwise		
Dimensions in mm		Process	Milling		
DESIGNED BY: J.P. de Jong		Material	RF4		
DATE: 30/11/2010		SPA Substrate			
CHECKED BY: G.F. Brouwer					
DATE: -		Delfi-n3Xt			
SIZE A3					
SCALE 1:1	WEIGHT (kg) -	DRAWING NUMBER DNX-22-001	SHEET 1/1	I	-
				H	-
				G	-
				F	-
				E	-
				D	-
				C	-
				B	-
				A	30/11/2010

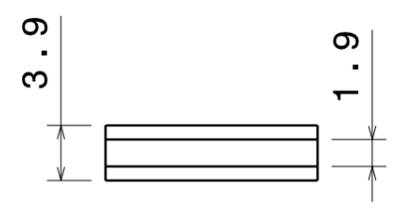
H G F E D C B A

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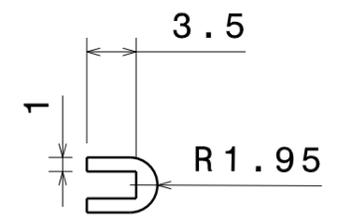
H G F E D C B A



Top view



Left view

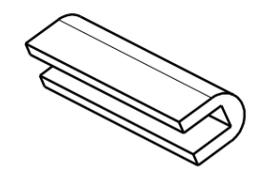


Front view

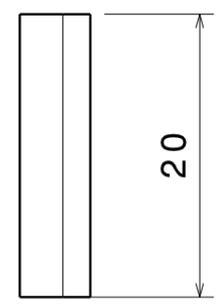
Project contact: 015-2785326		Surface treatment	None			
Order no. L10 L10901		Tolerances	± 0.1 mm, unless specified otherwise			
Remove sharp edges		Roundings	R2, unless specified otherwise			
Dimensions in mm		Process	Milling			
		Material	PEEK			
DESIGNED BY: J.P. de Jong DATE: 01/11/2010		<h1>Hold Down Guide</h1>			I	-
CHECKED BY: G.F. Brouwer DATE: 01/11/2010					H	-
SIZE A3		<h1>Delfi-n3Xt</h1>			G	-
SCALE 2:1	WEIGHT (kg) 0.00023				E	-
DRAWING NUMBER DNX-22-002		<h1>1/1</h1>			D	-
SHEET 1/1					C	-
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					A	01/11/2010

H G B A

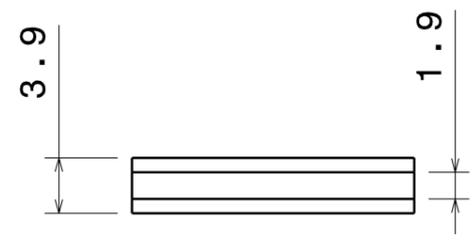
H G F E D C B A



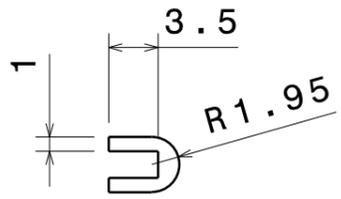
Isometric view
Scale: 2:1



Top view



Left view



Front view

Project contact: 015-2785326	Surface treatment	None
Order no. L10 L10901	Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges	Roundings	R2, unless specified otherwise
Dimensions in mm	Process	Milling
	Material	PEEK

DESIGNED BY:
J.P. de Jong
DATE:
28/2/2012
CHECKED BY:
G.F. Brouwer
DATE:
-

**Hold Down Guide
long**

I	-
H	-
G	-
F	-
E	-
D	-
C	-
B	-
A	28/02/2012

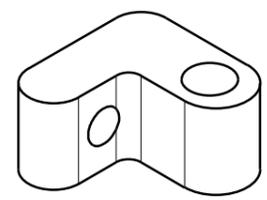
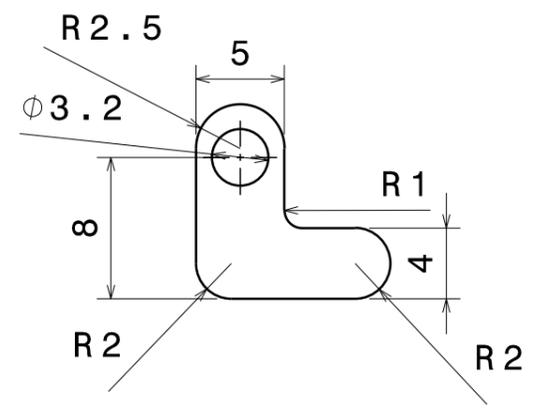
SIZE A3		Delfi-n3Xt	
SCALE 2:1	WEIGHT (kg) 0.00023	DRAWING NUMBER DNX-22-005	SHEET 1/1

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H G B A

H G F E D C B A

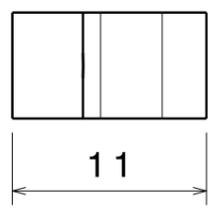
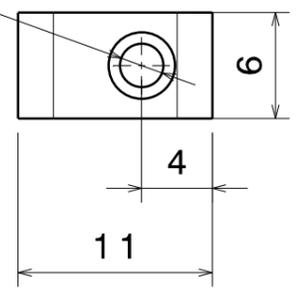
Top view



Front view

Right view

Bronze Helicoil
M3 x 1.0D #



Install Helicoil after surface treatment

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

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

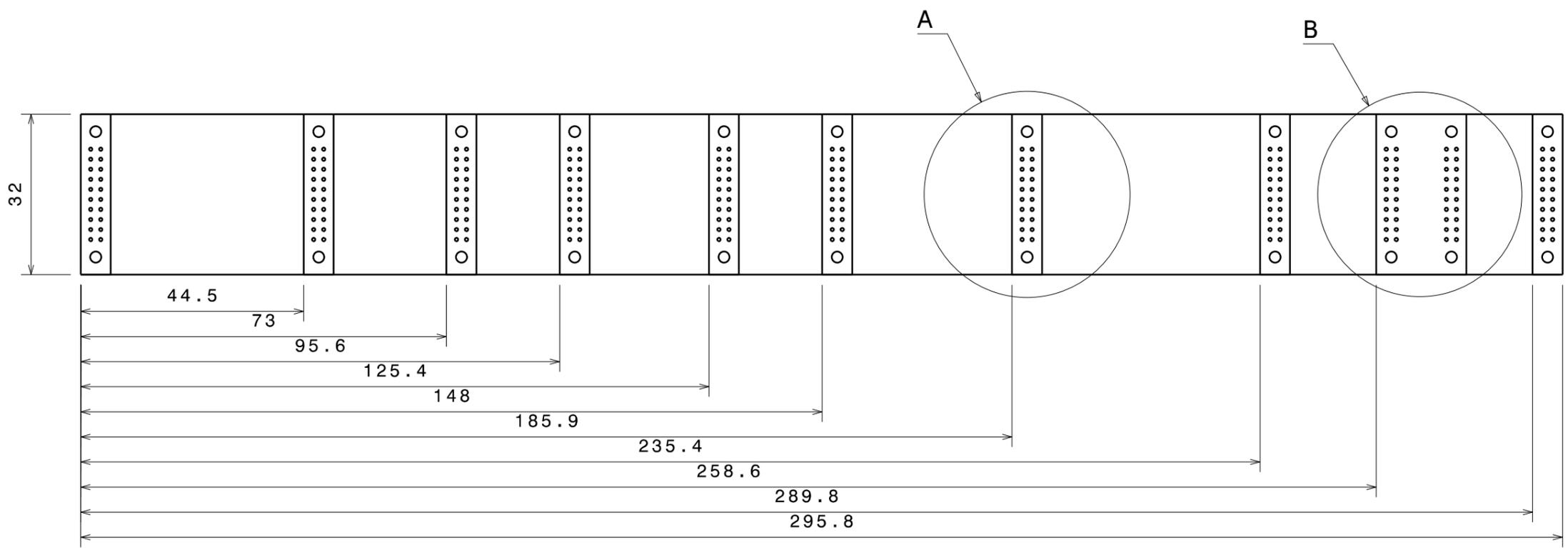
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H G F E D C B A

H G F E D C B A

4

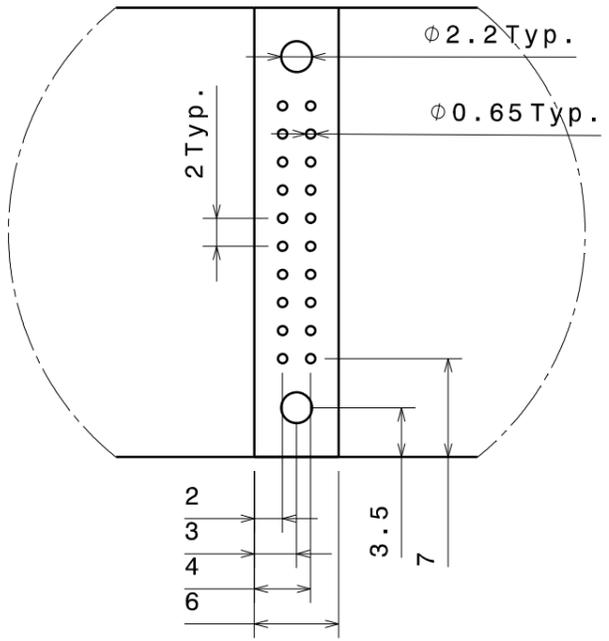
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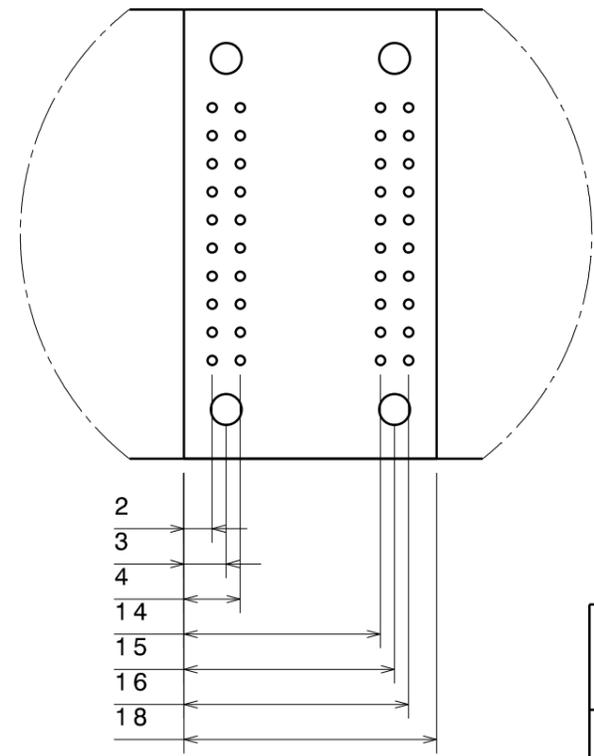
Front view
Scale: 1:1

3

3



Detail A
Scale: 2:1



Detail B
Scale: 2:1

2

2

1

1

DESIGNED BY: J.P. de Jong	Flex-rigid PCB		I	-	
DATE: 22/03/2012			H	-	
CHECKED BY: -	Delfi-n3Xt		G	-	
DATE: -			F	-	
SIZE: A3		DNX-30-100		E	-
SCALE: 1:1				WEIGHT (kg): -	DRAWING NUMBER: DNX-30-100
		SHEET: 1/1	C	-	
			B	22-03-2012	
			A	21-03-2012	

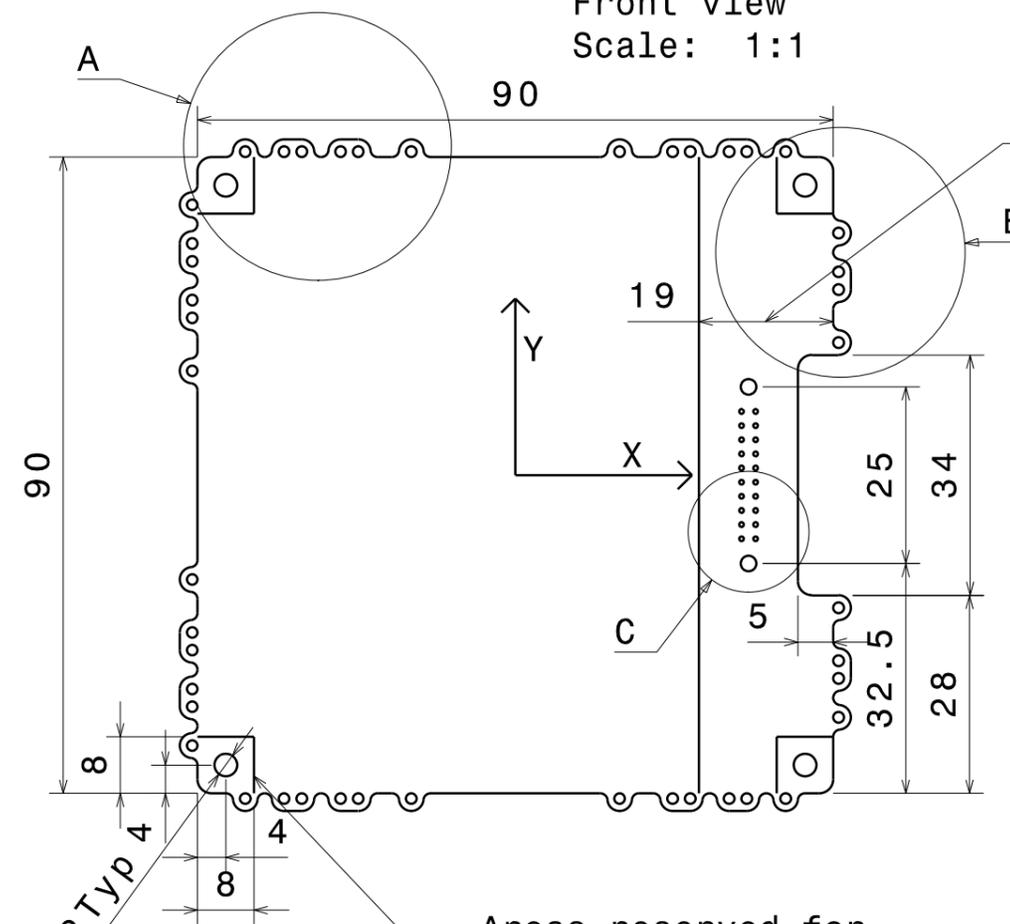
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H G B A

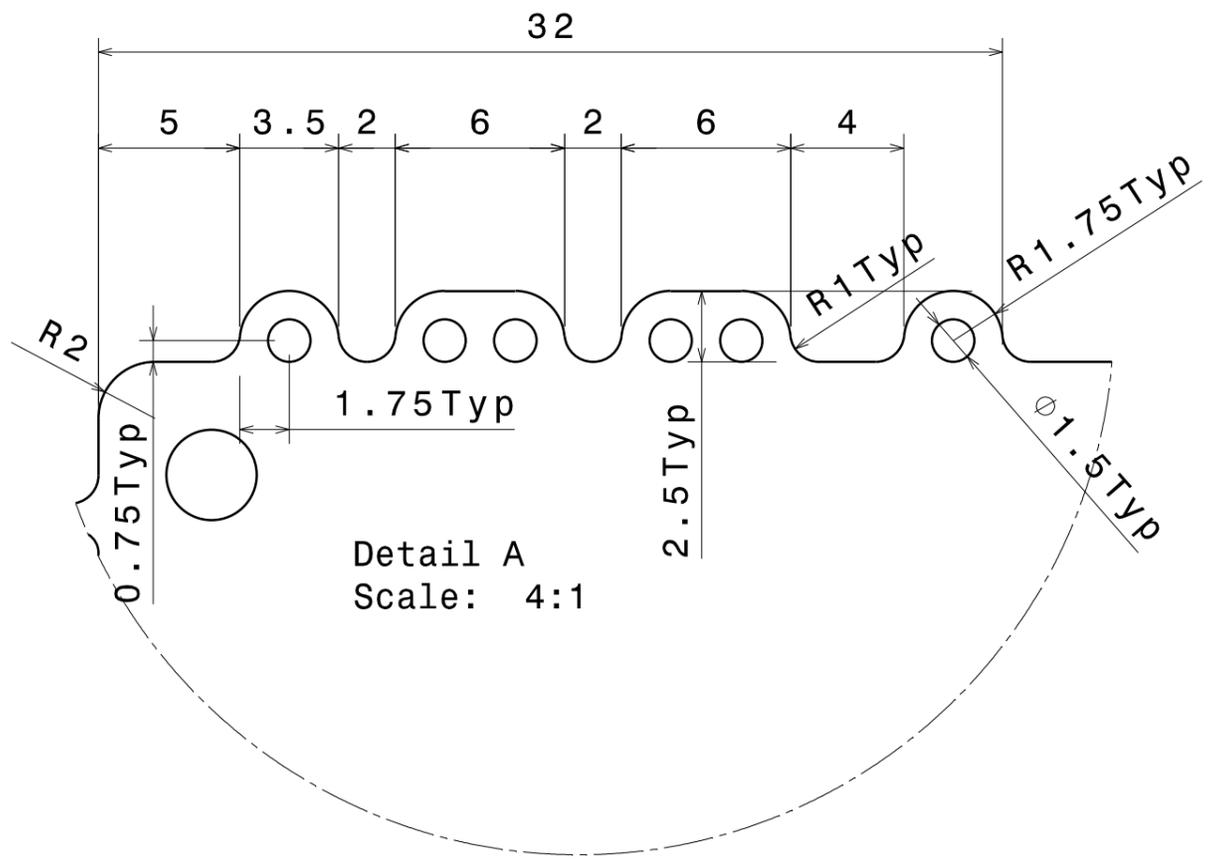
H G F E D C B A

Front view
Scale: 1:1

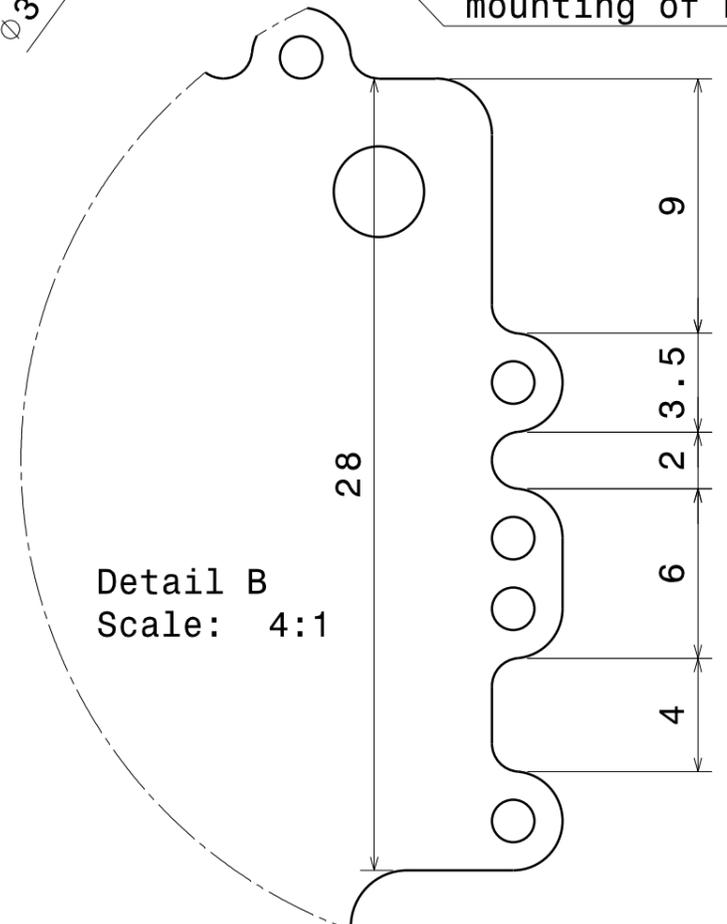
Area reserved for Delfi
Standard System Bus



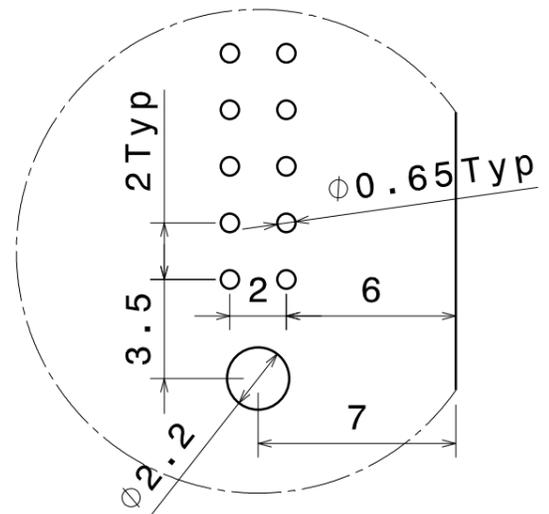
Areas reserved for
mounting of PCB



Detail A
Scale: 4:1



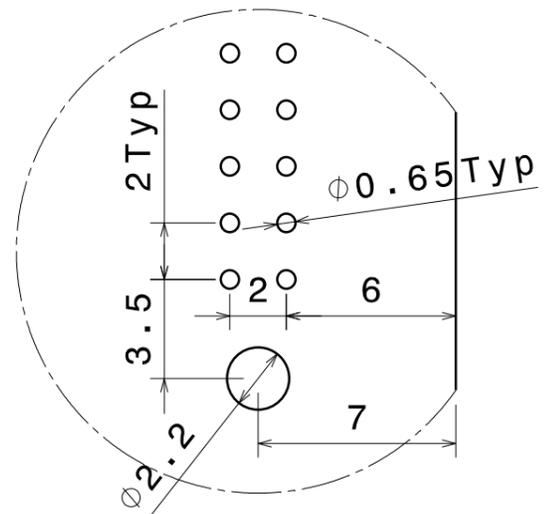
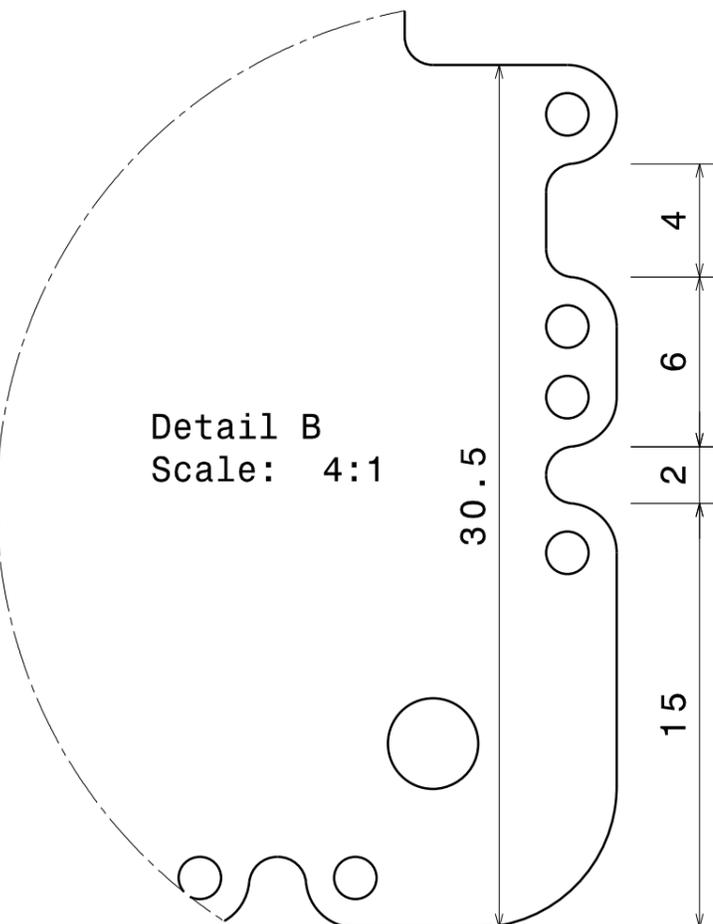
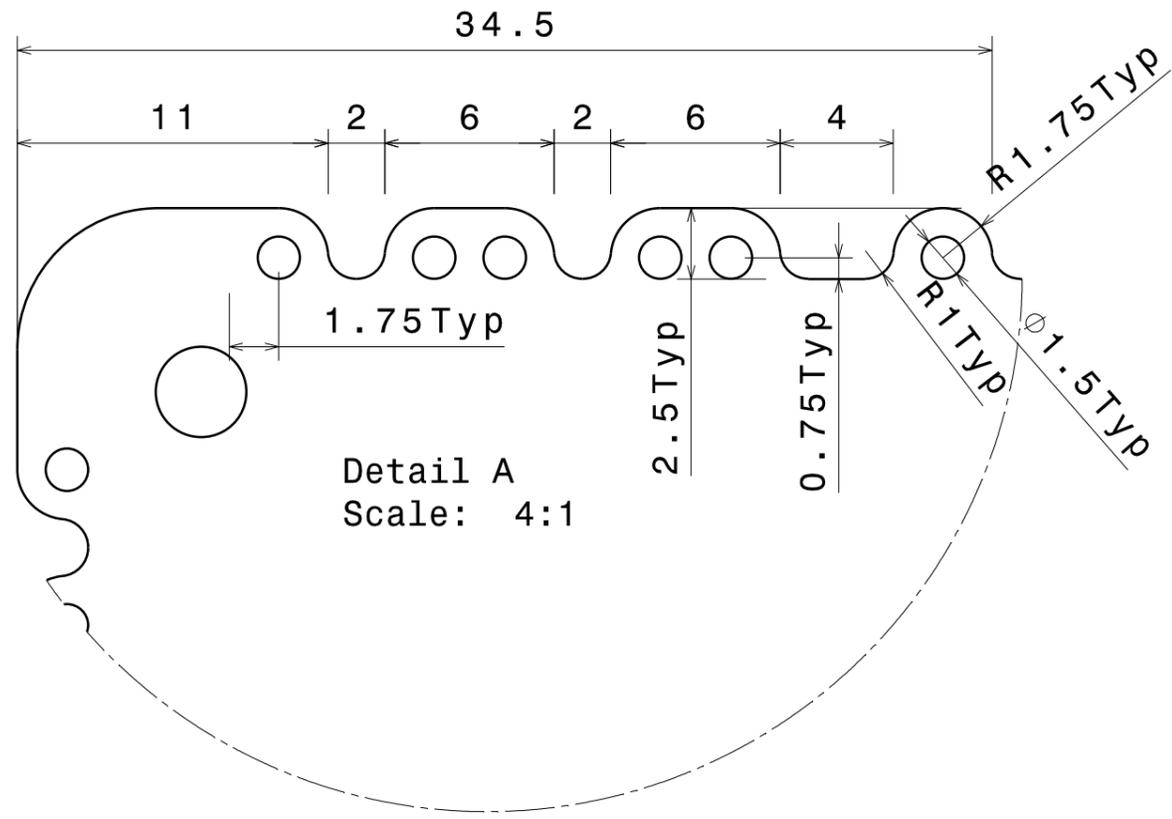
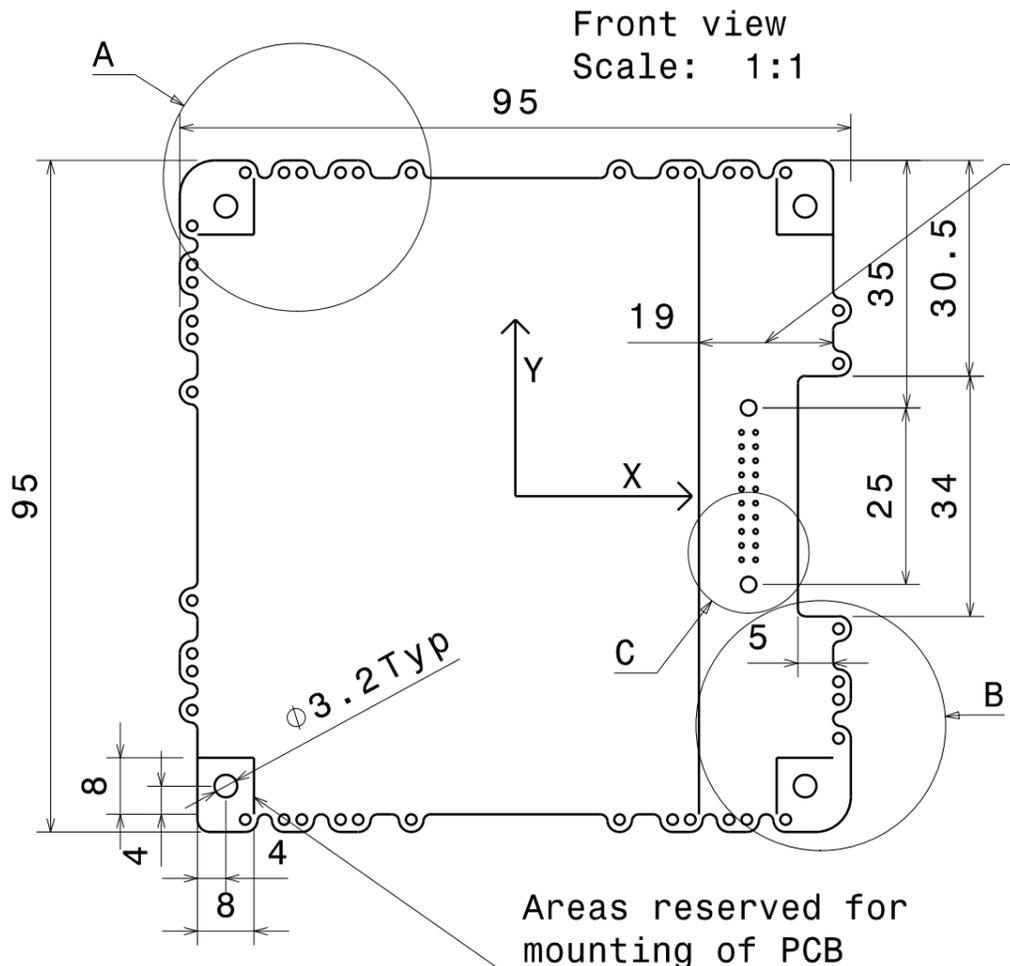
Detail B
Scale: 4:1



Detail C Harwin connector
Scale: 4:1

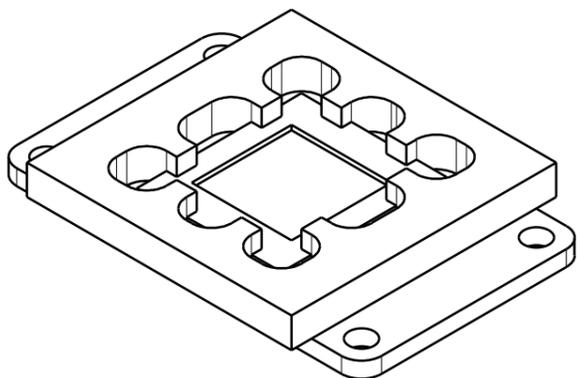
Project contact: 015-2785326	Surface treatment	None
Order no.	Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges	Roundings	-
Dimensions in mm	Process	-
DESIGNED BY: J.P. de Jong	MATERIAL	RF4
DATE: 6-9-2011	<h1>Standard PCB</h1>	
CHECKED BY: G.F. Brouwer		
DATE: 13-9-2011	<h1>Delfi-n3Xt</h1>	
SIZE: A3		
SCALE: 1:1	WEIGHT (kg): -	DRAWING NUMBER: DNX-31-000
		SHEET: 1/1
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H G B A

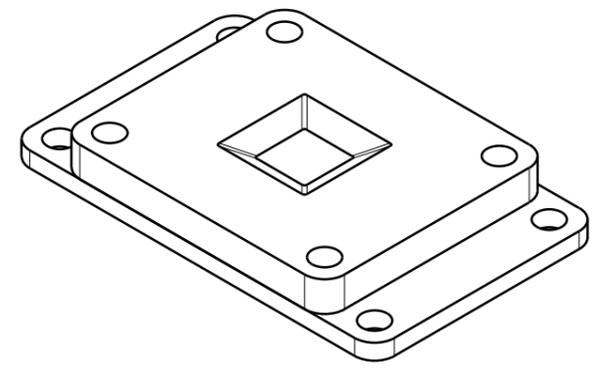


Project contact: 015-2785326	Surface treatment	None																			
Order no.	Tolerances	$\pm 0.1 \text{ mm}$, unless specified otherwise																			
Remove sharp edges	Roundings	-																			
Dimensions in mm	Process	-																			
DESIGNED BY: J.P. de Jong DATE: 2-12-2011	Material	RF4																			
CHECKED BY: G.F. Brouwer DATE: 13-9-2011	Standard PCB																				
SIZE A3			Delfi-n3Xt																		
SCALE 1:1	WEIGHT (kg) -	DRAWING NUMBER DNX-31-000			SHEET 1/1																
<small>All rights reserved. Disclosure to third parties of this document or any part thereof, or the use of any information contained therein for purposes other than provided for by this document, is not permitted, except prior and express written permission of Delft University of Technology.</small>			<table border="1"> <tr><td>I</td><td>-</td></tr> <tr><td>H</td><td>-</td></tr> <tr><td>G</td><td>-</td></tr> <tr><td>F</td><td>-</td></tr> <tr><td>E</td><td>-</td></tr> <tr><td>D</td><td>2-12-2011</td></tr> <tr><td>C</td><td>30-11-2011</td></tr> <tr><td>B</td><td>29-11-2011</td></tr> <tr><td>A</td><td>6-9-2011</td></tr> </table>	I	-	H	-	G	-	F	-	E	-	D	2-12-2011	C	30-11-2011	B	29-11-2011	A	6-9-2011
I	-																				
H	-																				
G	-																				
F	-																				
E	-																				
D	2-12-2011																				
C	30-11-2011																				
B	29-11-2011																				
A	6-9-2011																				

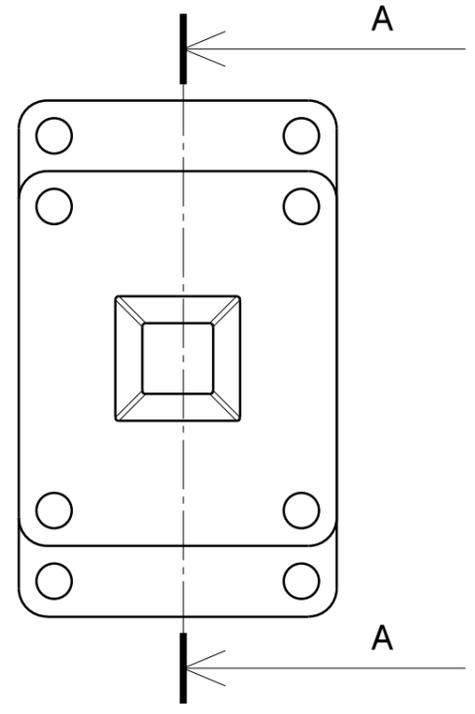
H G F E D C B A



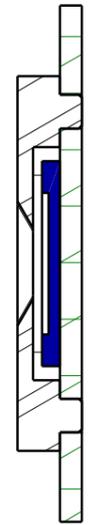
Isometric view
Scale: 2:1



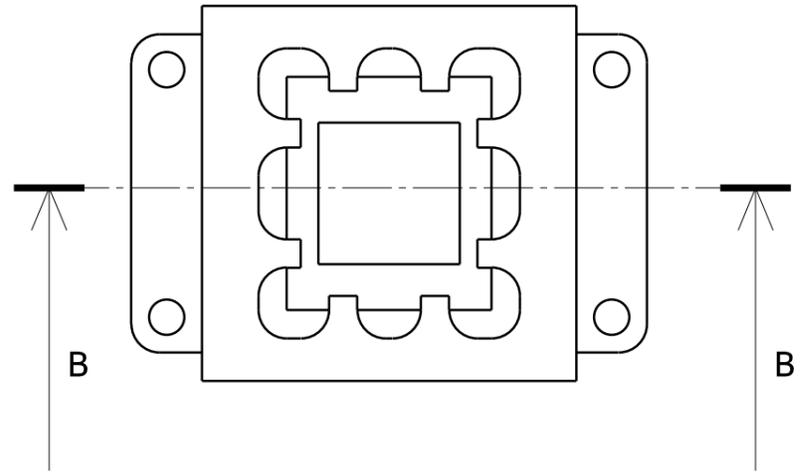
Isometric view
Scale: 2:1



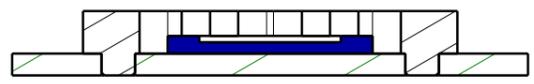
Front view
Scale: 2:1



Section view A-A
Scale: 2:1



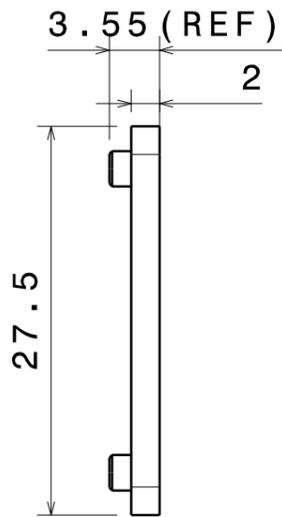
Front view
Scale: 2:1



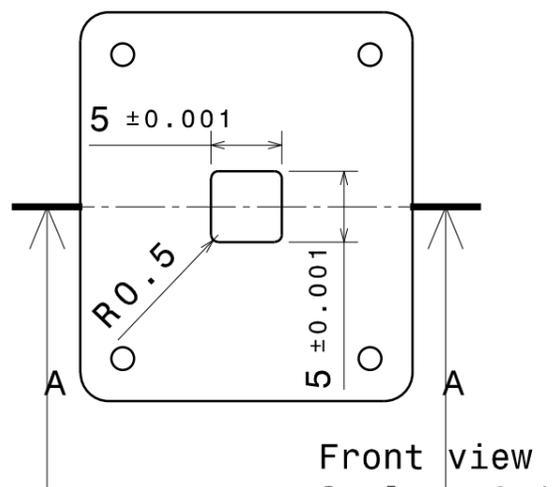
Section view B-B
Scale: 2:1

Project contact: 015-2785326		Surface treatment	None
Order no.		Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges		Roundings	R2, unless specified otherwise
Dimensions in mm		Process	Milling
DESIGNED BY: J.P. de Jong DATE: 7/12/2010		Material	-
CHECKED BY: G.F. Brouwer DATE: -		<h1>Sun Sensor Assembly</h1>	
SIZE A3			
SCALE 1:1	WEIGHT (kg) -	DRAWING NUMBER DNX-41-500	SHEET 1/1
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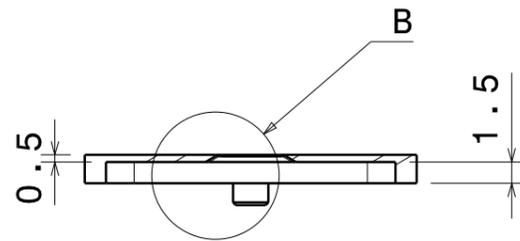
H G F E D C B A



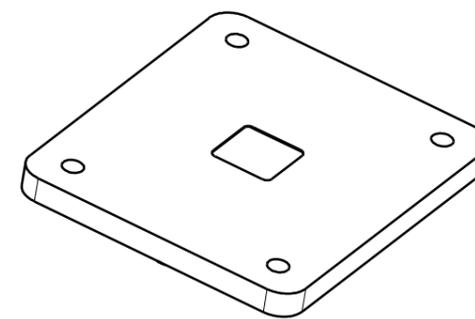
Left view
Scale: 2:1



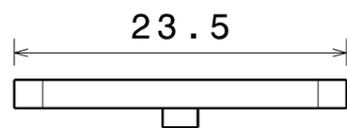
Front view
Scale: 2:1



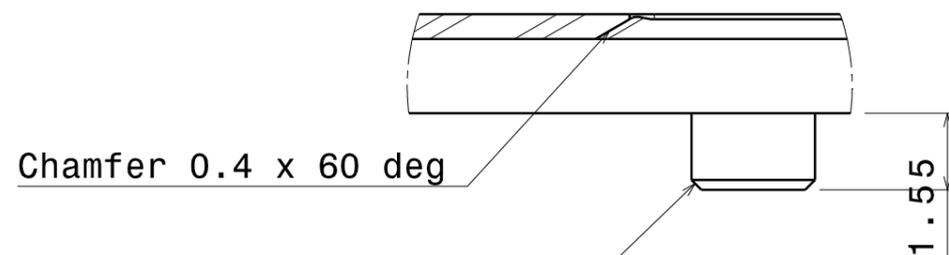
Section view A-A
Scale: 2:1



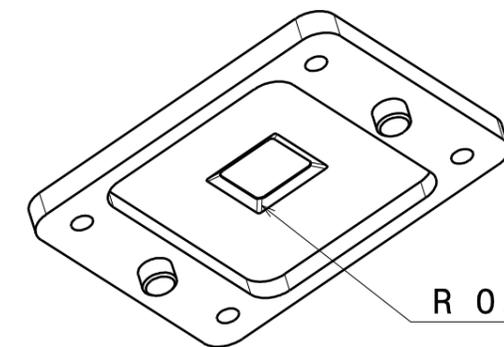
Isometric view
Scale: 2:1



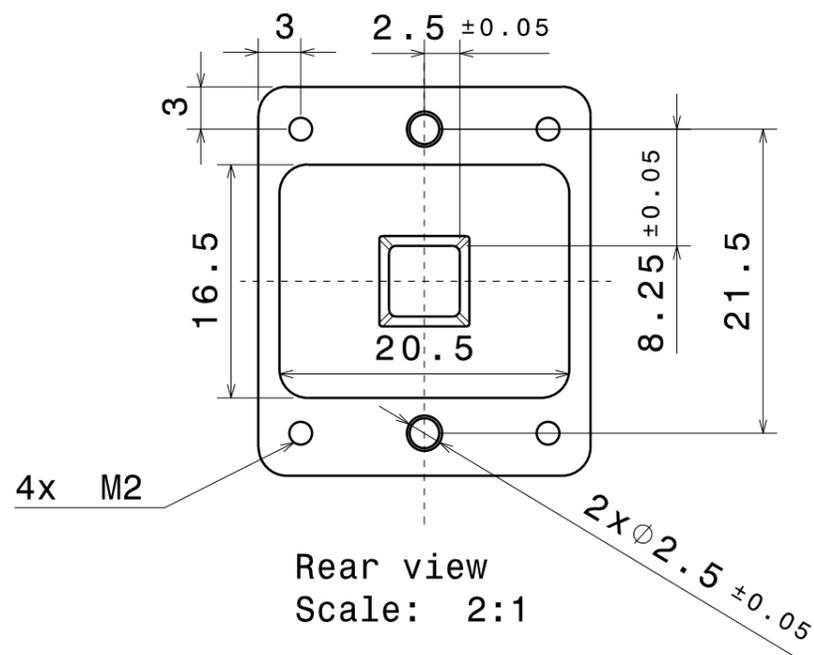
Bottom view
Scale: 2:1



Detail B
Scale: 7:1



Isometric view
Scale: 2:1

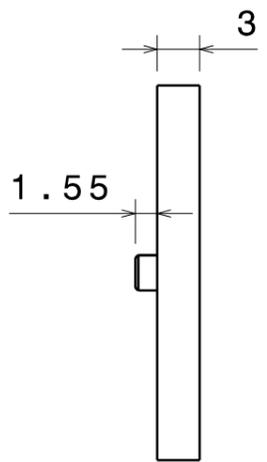


Rear view
Scale: 2:1

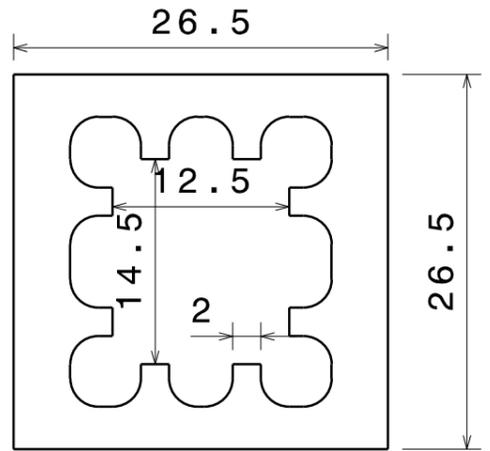
Project contact: 015-2785326	Surface treatment	None
Order no.	Tolerances	± 0.1 mm, unless specified otherwise
	Roundings	R2, unless specified otherwise
	Process	Milling
Dimensions in mm	Material	PEEK (Black)
DESIGNED BY: J.P. de Jong DATE: 6/12/2011	<h1>Sun sensor housing</h1>	
CHECKED BY: G.F. Brouwer DATE: 6/12/2011		
SIZE A3	<h1>Delfi-n3Xt</h1>	
SCALE 2:1	WEIGHT (kg) 0.002	DRAWING NUMBER DNX-41-503
		SHEET 1/1

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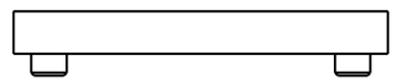
H G F E D C B A



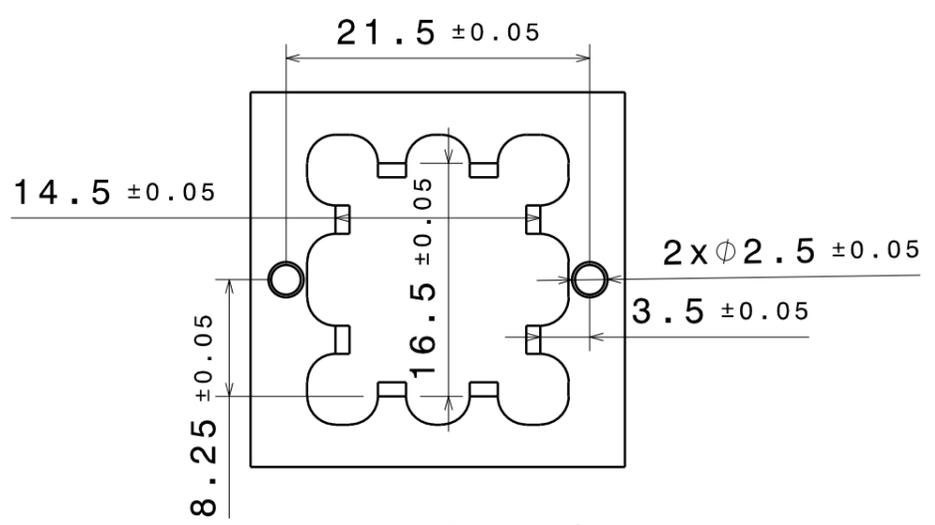
Left view
Scale: 2:1



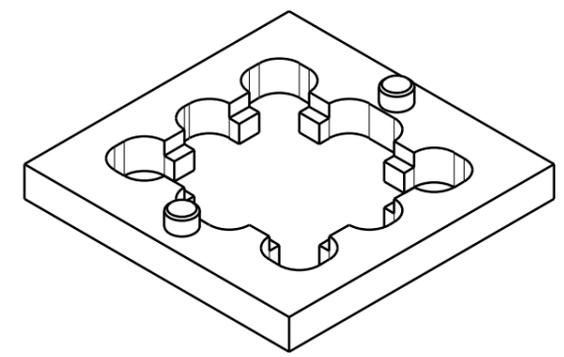
Front view
Scale: 2:1



Bottom view
Scale: 2:1



Rear view
Scale: 2:1



Isometric view
Scale: 2:1

Project contact: 015-2785326	Surface treatment	None
Order no.	Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges	Roundings	R2, unless specified otherwise
Dimensions in mm	Process	Milling
	Material	Steel

DESIGNED BY:
J.P. de Jong
DATE:
7/12/2010
CHECKED BY:
G.F. Brouwer
DATE:
-

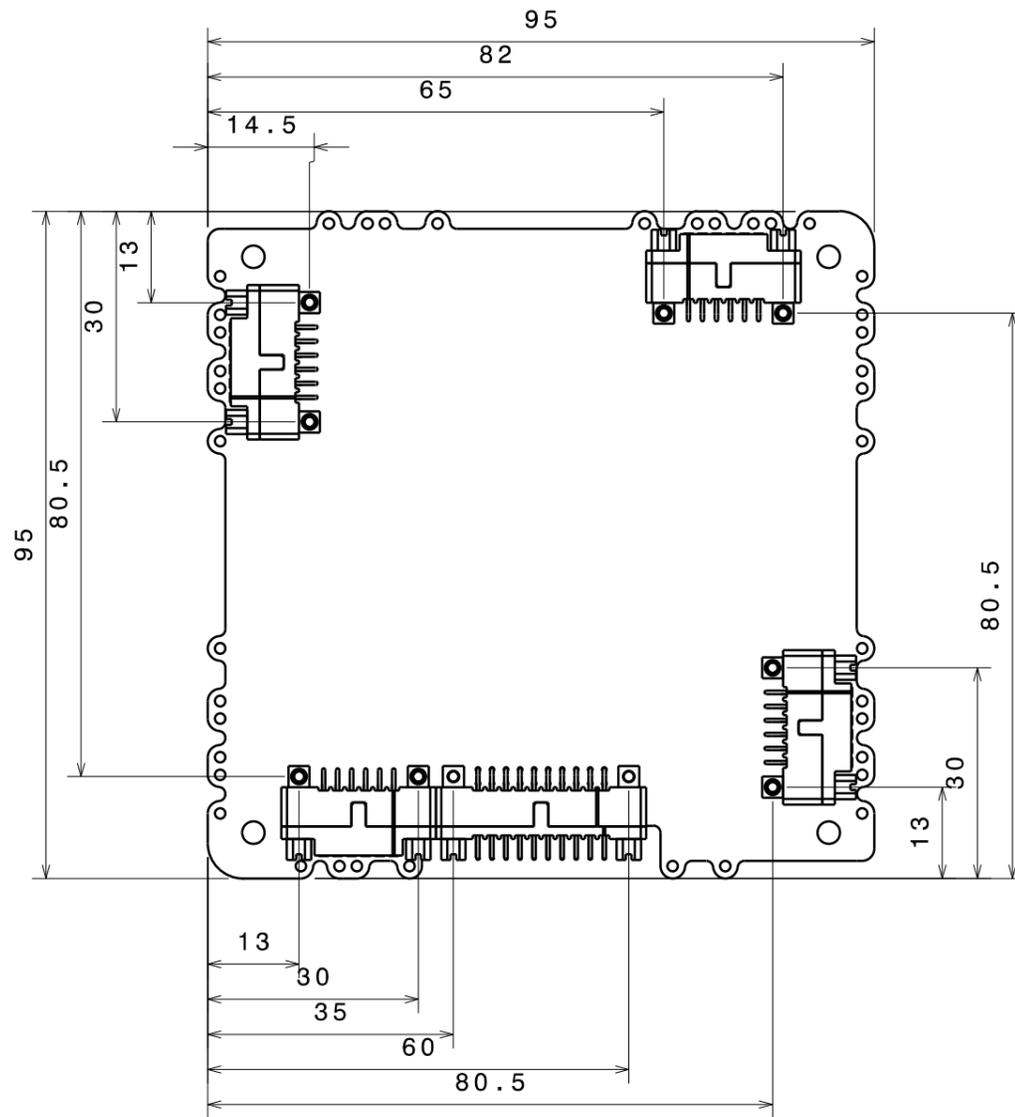
Sensor positioning part

SIZE A3		Delfi-n3Xt	
SCALE 2:1	WEIGHT (kg) 0.012	DRAWING NUMBER DNX-41-505	SHEET 1/1

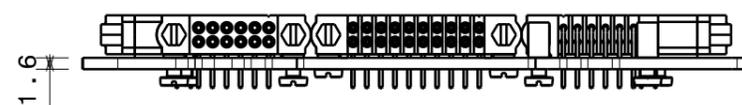
I	-
H	-
G	-
F	-
E	-
D	-
C	-
B	-
A	7/12/2010

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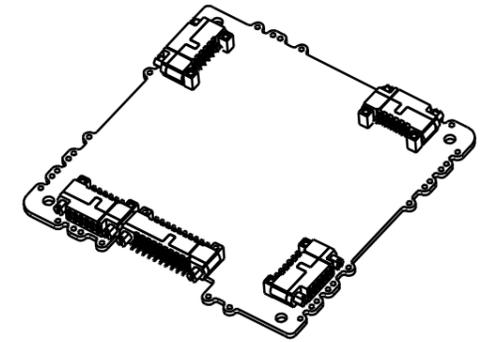
H G F E D C B A



Top view
Scale: 1:1



Front view
Scale: 1:1

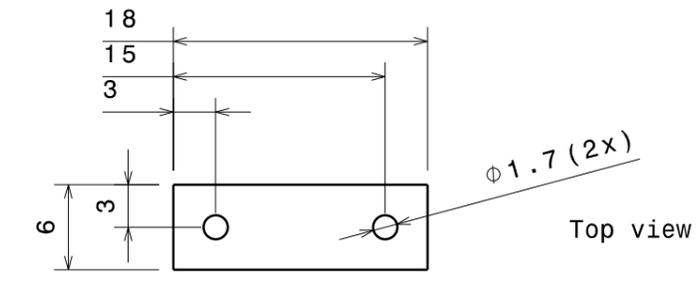


Isometric view
Scale: 1:2

DESIGNED BY: J.P. de Jong		<h1>EPS Electronics 1</h1>	I	-
DATE: 27/3/2012			H	-
CHECKED BY: -		<h1>Delfi-n3Xt</h1>	G	-
DATE: -			F	-
SIZE: A3		DNX-43-103	E	-
SCALE: 1:1	WEIGHT (kg): -		D	-
DRAWING NUMBER: DNX-43-103		1/1	C	-
SHEET: 1/1			B	-
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H G F E D C B A

DNX 43-301

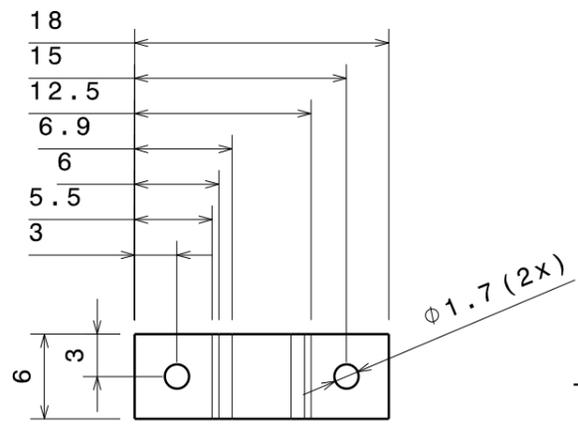


Top view

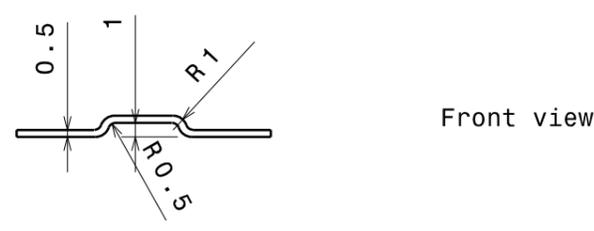


Front view

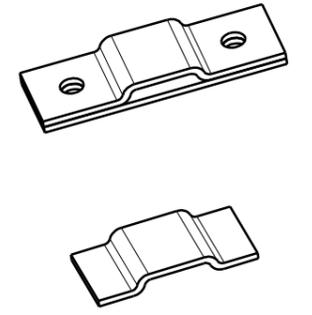
DNX 43-302



Top view

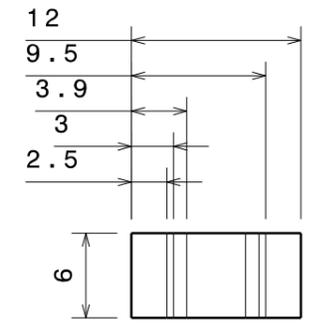


Front view

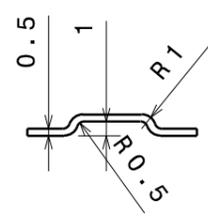


Isometric view

DNX 43-303



Top view



Front view

Project contact: 015-2785326	Surface treatment	None
Order no.	Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges	Roundings	R2, unless specified otherwise
Dimensions in mm	Process	Bending
	Material	Aluminum

DESIGNED BY:
J.P. de Jong
DATE:
28/2/2012

CHECKED BY:
G.F. Brouwer
DATE:
-

EPS wire clips

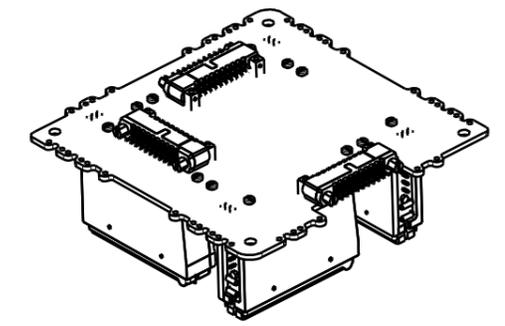
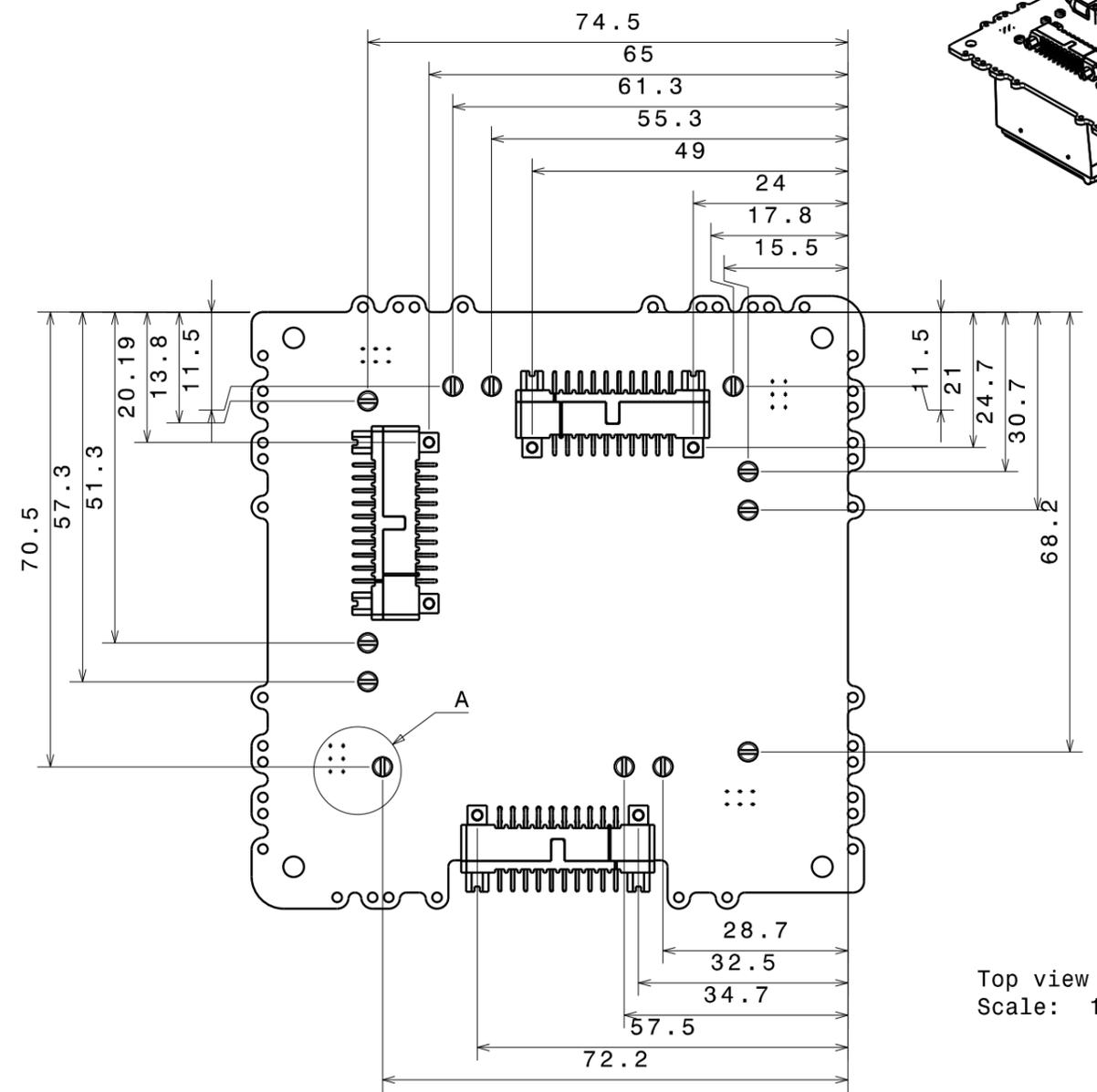
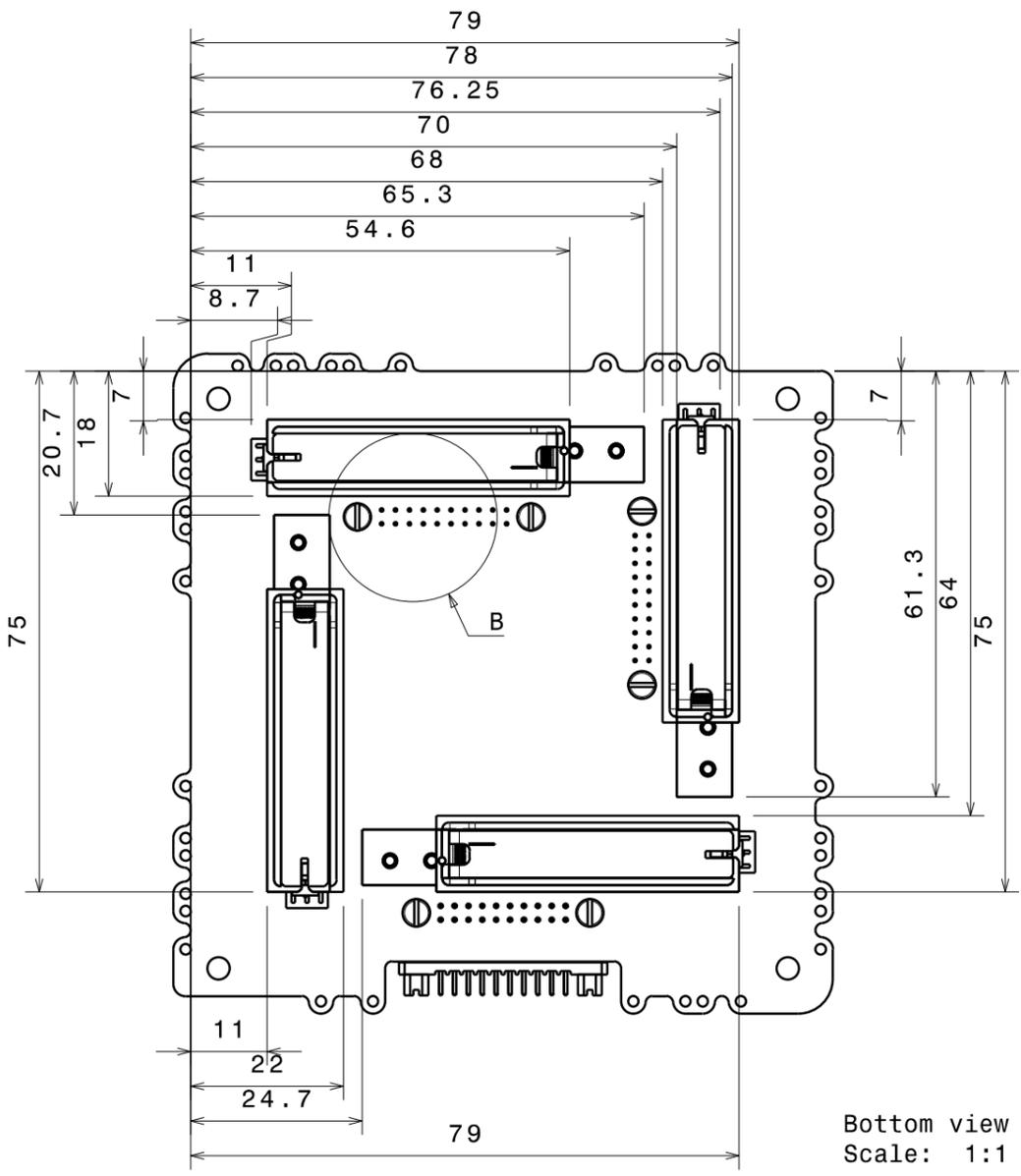
Delfi-n3Xt

SIZE A3		DRAWING NUMBER DNX-43-301 DNX-43-302 DNX-43-303	SHEET 1/1
SCALE 2:1	WEIGHT (kg) 0.001		

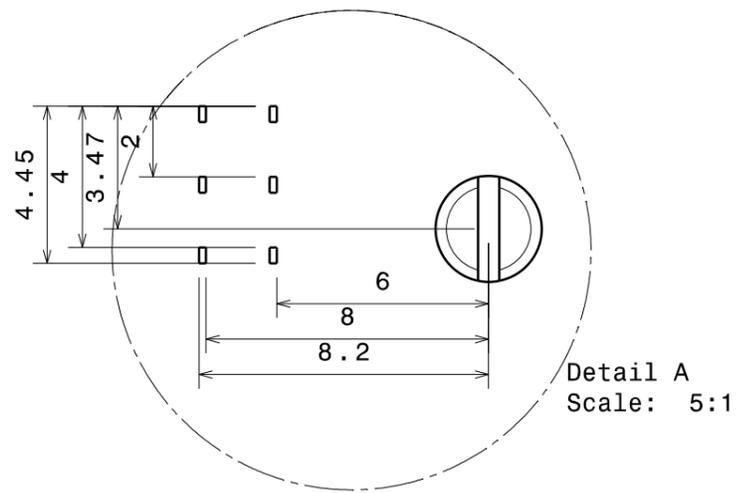
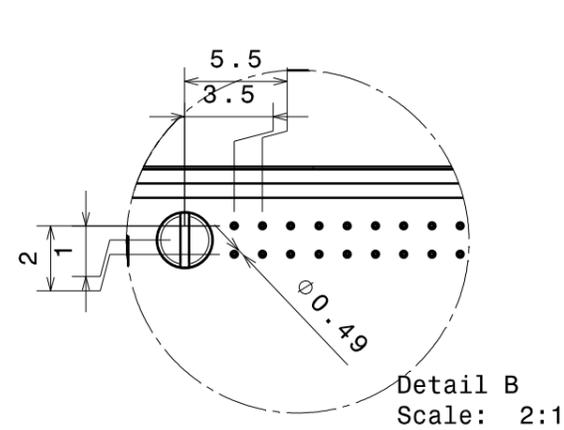
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F	-
E	-
D	-
C	-
B	-
A	28-02-2012

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H G B A



Isometric view
Scale: 1:2



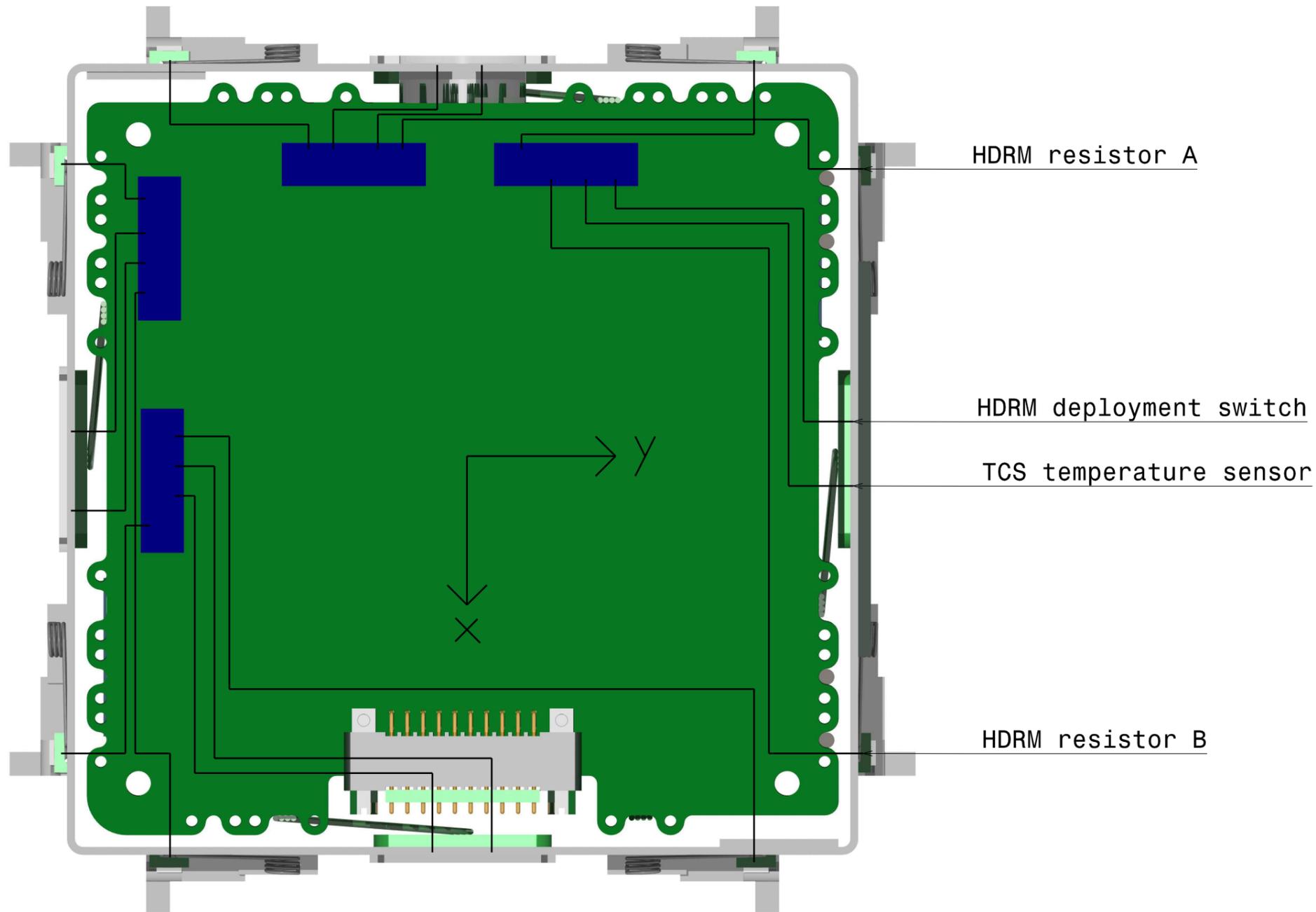
DESIGNED BY: J.P. de Jong	DAB assembly		I	-
DATE: 28/2/2011			H	-
CHECKED BY: G.F. Brouwer	Delfi-n3Xt		G	-
DATE: -			F	-
SIZE: A3		DNX-44-200	E	28-02-2012
SCALE: 1:1			D	24-02-2012
WEIGHT (kg): -	DRAWING NUMBER: DNX-44-200	SHEET: 1/1	C	13-02-2011
			B	20-12-2011
			A	13-12-2011

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H G F E D C B A

4

4



3

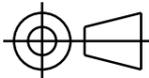
3

2

2

1

1

DESIGNED BY: J.P. de Jong		DAB wiring schematic		I	-
DATE: 2/12/2011				H	-
CHECKED BY:		Delfi-n3Xt		G	-
DATE:				F	-
SIZE A3		DRAWING NUMBER DNX-44-200		E	-
SCALE -	WEIGHT (kg) -			D	-
		SHEET 1/1		C	
				B	
				A	2-12-2011

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H G B A

H G F E D C B A

Antenna outer part

Antenna parts connected with
2x Bolt countersunk M1x3
+ plastic rings

Axle+spring

Lid

Bolt countersunk
M1x6

3x Bolt countersunk M2x5

2x Resistor

Antenna inner part
+ Flex pcb antenna

Bolt countersunk
M1x4

Box

Power PCB

Switch

Male power
connector

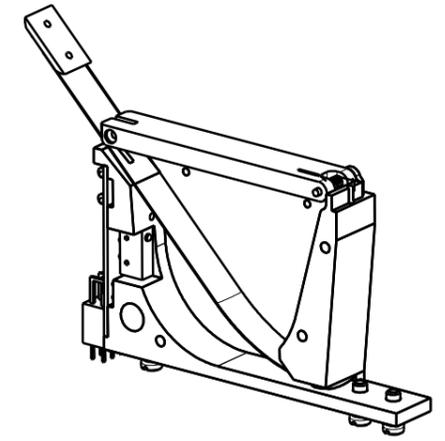
Cylinder

3x Bolt Domehead M2x10

Bolt Domehead M2x6

Front view
Scale: 2:1

Isometric view
Scale: 1:1



Qty	Part Name	Drawing Number
1	Box	DNX-44-208
1	Front cover	DNX-44-209
1	Lid	DNX-44-210
1	Lid spring	
1	Axle 1x8mm	
1	Power PCB	
2	Resistor	Multicomp MF1275
1	Male power connector	Harwin ...
1	Switch	
1	Antenna long part	
1	Antenna inner part	
1	Flex pcb antenna	
1	Bolt countersunk M1x6	Slot
1	Cylinder	
2	Bolt countersuk M1x3	Slot
2	Nut M1	
2	Washer M1	
2	Plastic ring M1	
2	Bolt Domehead M2x10	Torx
6	Washer M2	
2	Nut M2	
1	Dyneema wire	
3	Bolt countersunk M2x5	Torx
1	Bolt Domehead M2x6	Torx
1	Bolt countersunk M1x4	Slot

DESIGNED BY: J.P. de Jong	MAB assembly
DATE: 3-4-2012	
CHECKED BY: G.F. Brouwer	Delfi-n3Xt
DATE: -	
SIZE A3	
SCALE 1:1	WEIGHT (kg) 0.019
DRAWING NUMBER DNX-44-201	
SHEET 1 / 1	

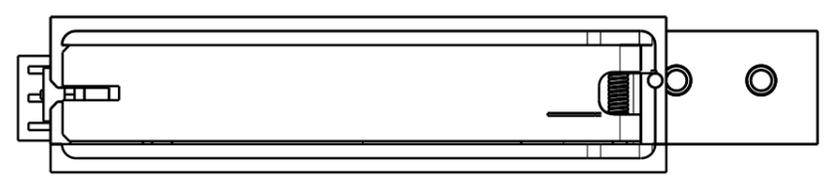
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D	-
C	03-04-2012
B	28-02-2012
A	24-02-2012

H G B A

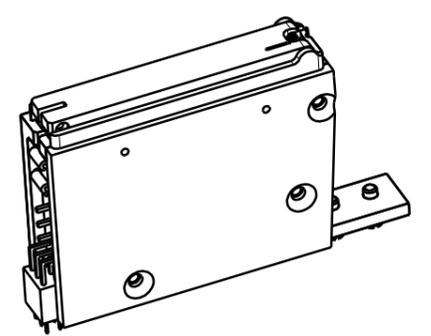
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H G F E D C B A

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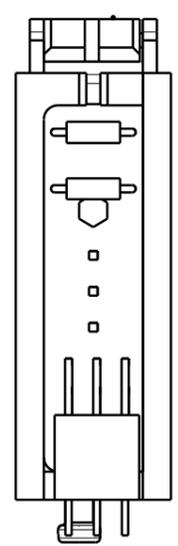


Top view
Scale: 2:1

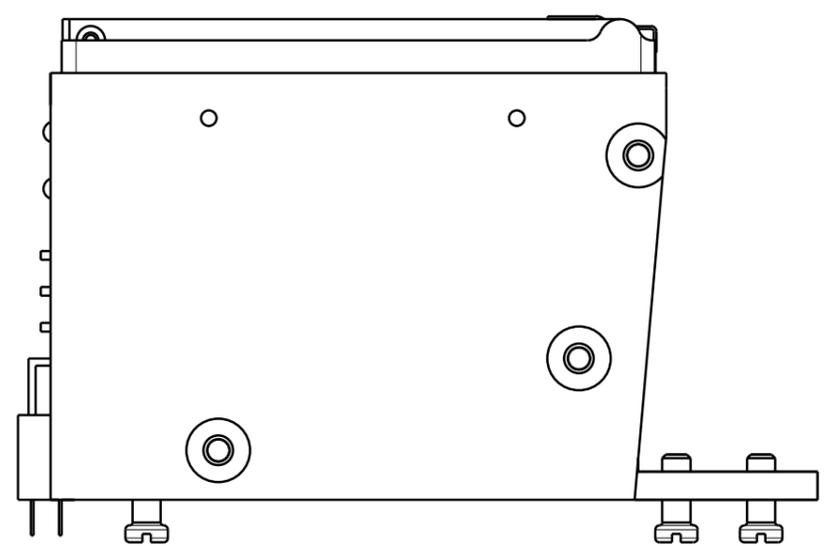


Isometric view
Scale: 1:1

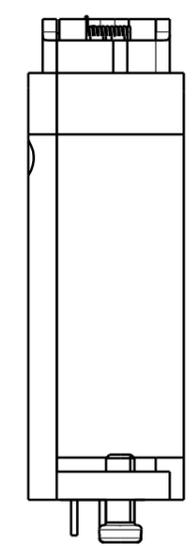
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Left view
Scale: 2:1

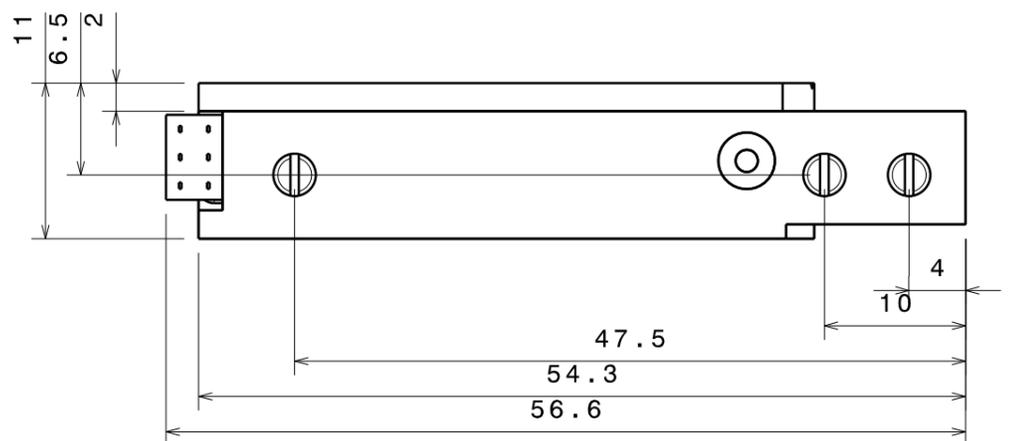


Front view
Scale: 2:1



Right view
Scale: 2:1

2



Bottom view
Scale: 2:1

1

DESIGNED BY: J.P. de Jong		MAB assembly		I	-
DATE: 28-2-2012				H	-
CHECKED BY: G.F. Brouwer		Delfi-n3Xt		G	-
DATE: -				F	-
SIZE: A3		DNX-44-201		E	-
SCALE: 1:1				WEIGHT (kg): 0.019	D
DRAWING NUMBER: DNX-44-201		SHEET: 1/1		C	-
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				A	24-02-2012

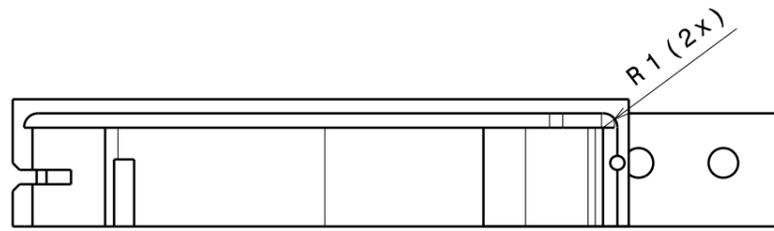
H G F E D C B A

4

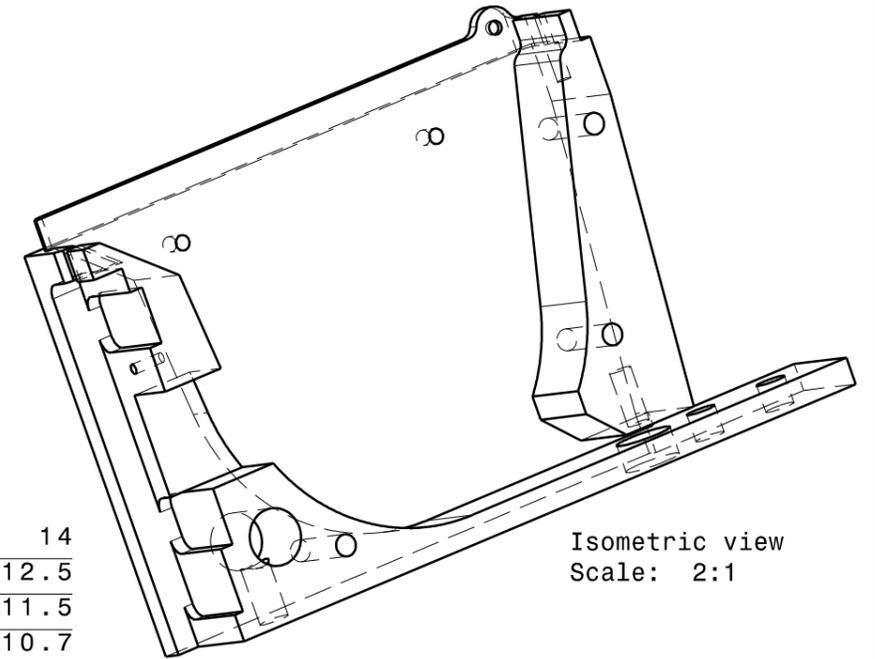
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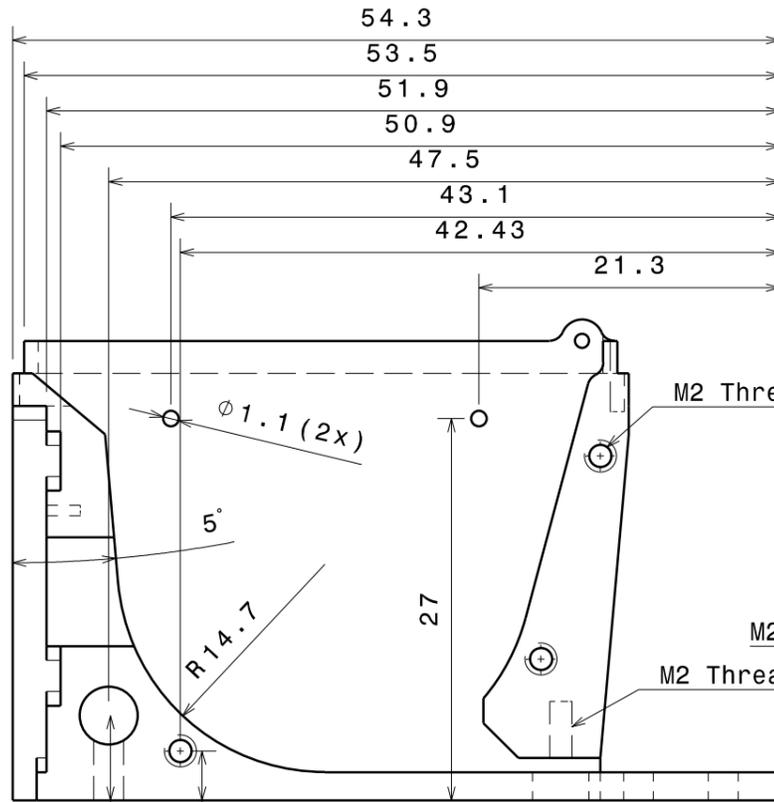
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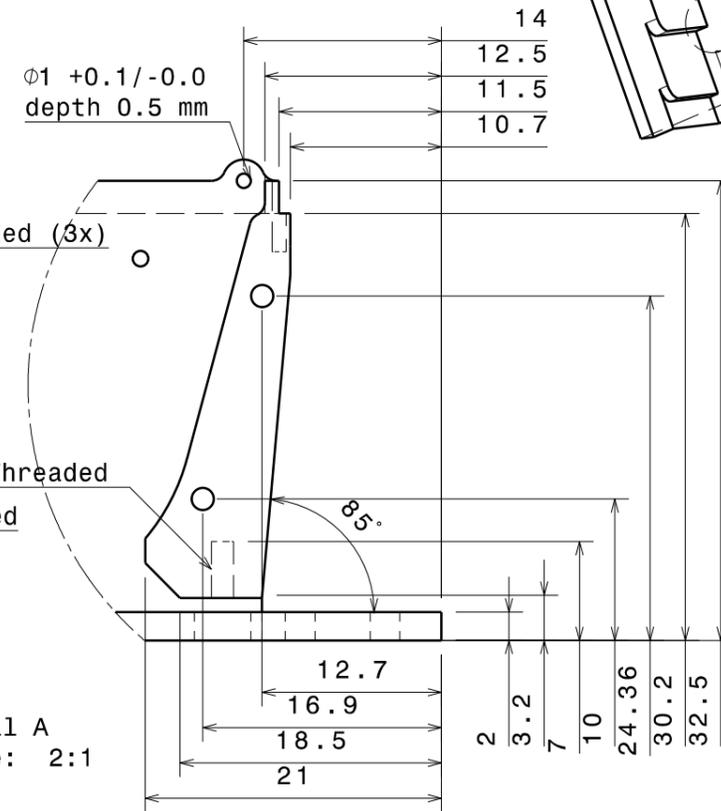
Top view
Scale: 2:1



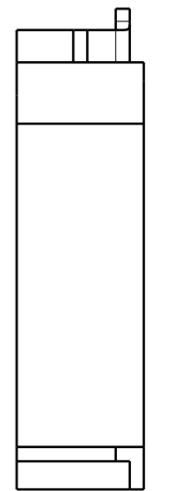
Isometric view
Scale: 2:1



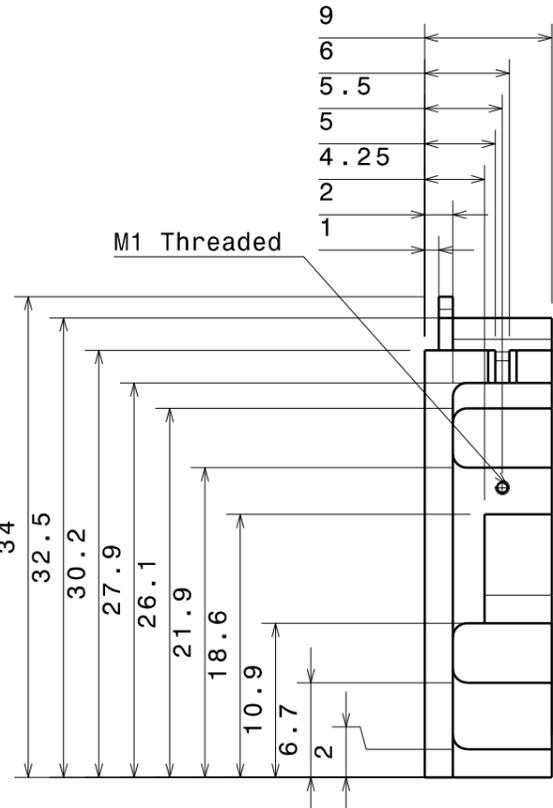
Front view
Scale: 2:1



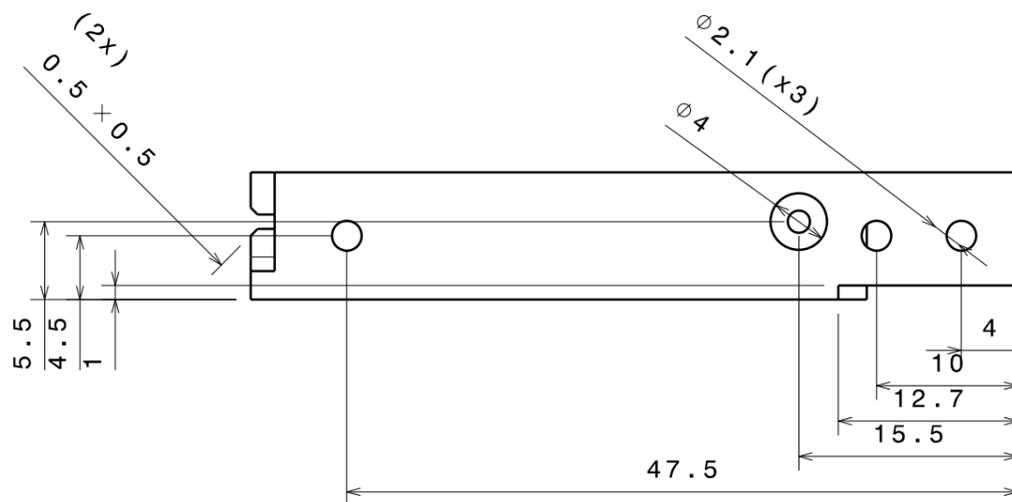
Detail A
Scale: 2:1



Right view
Scale: 2:1



Left view
Scale: 2:1



Bottom view
Scale: 2:1

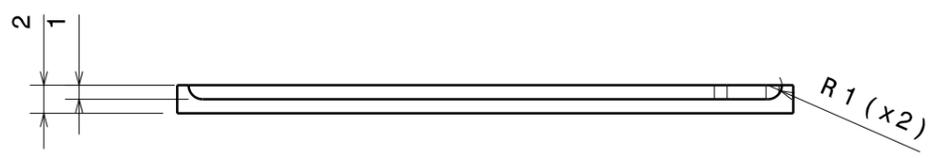
Project contact: 015-2785326	Surface treatment None	
Order no.	Tolerances ± 0.1 mm, unless specified otherwise	
Remove sharp edges	Roundings R1, unless specified otherwise	
Dimensions in mm	Process Milling	
	Material Makrolon	
DESIGNED BY: J.P. de Jong	<h1>MAB Box</h1>	
DATE: 28/02/2012		
CHECKED BY: G.F. Brouwer		
DATE: -		
SIZE A3	<h1>Delfi-n3Xt</h1>	
SCALE 1:1	WEIGHT (kg) 0.007	DRAWING NUMBER DNX-44-208
		SHEET 1/1
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C	23-02-2012
B	09-05-2007
A	07-01-2007

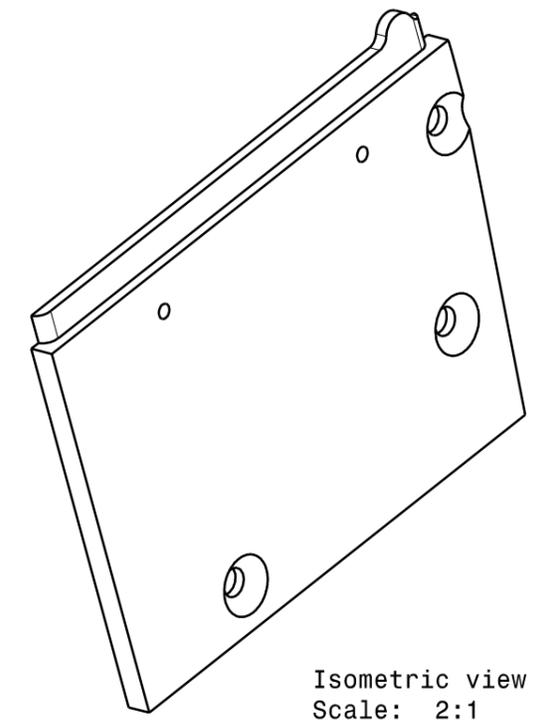
H G F E D C B A

4

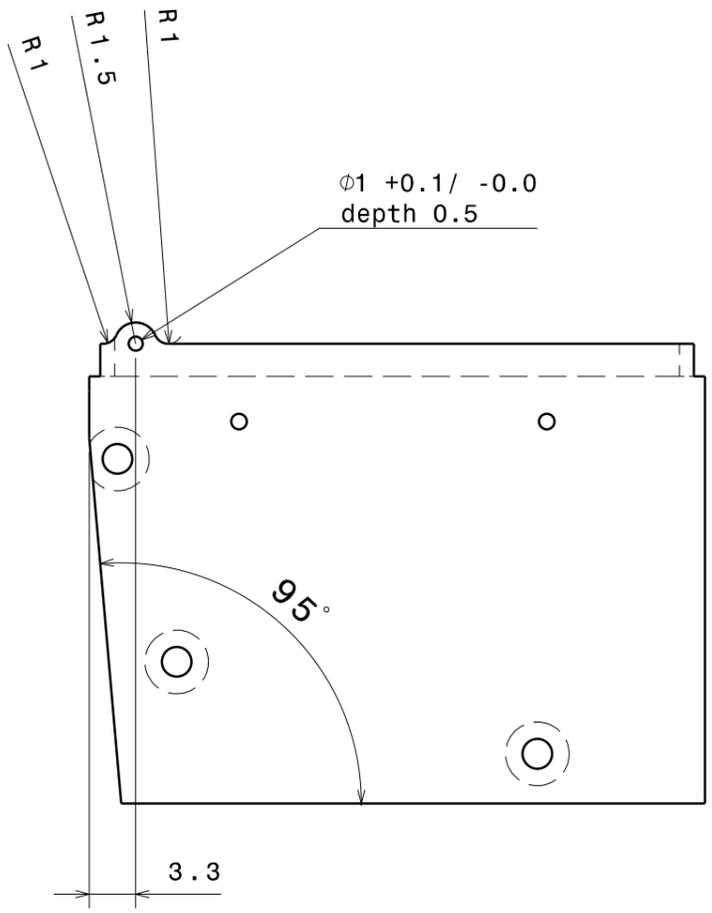
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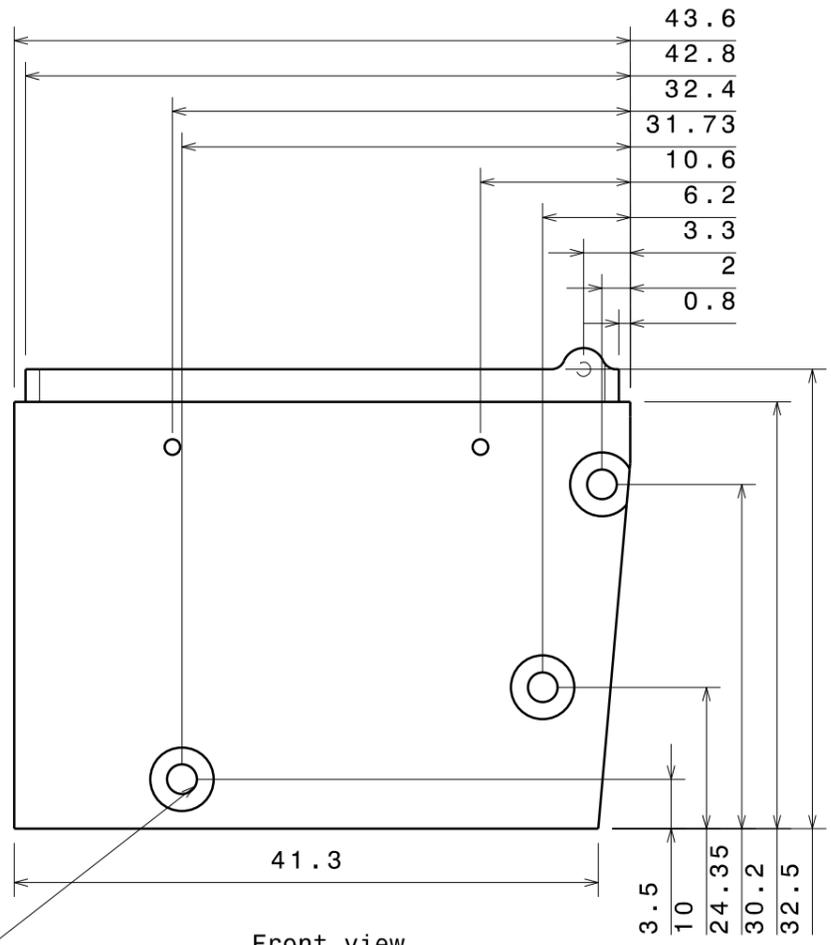
Top view
Scale: 2:1



Isometric view
Scale: 2:1



Rear view
Scale: 2:1



Front view
Scale: 2:1

M2 countersunk (3x)

Project contact: 015-2785326		Surface treatment	None
Order no.		Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges		Roundings	R1, unless specified otherwise
Dimensions in mm		Process	Milling
DESIGNED BY: J.P. de Jong		Material	Makrolon
DATE: 24/2/2012		<h1>MAB Front cover</h1>	
CHECKED BY: G.F. Brouwer			
DATE: -		<h1>Delfi-n3Xt</h1>	
SIZE A3			
SCALE 1:1	WEIGHT (kg) 0.003	DRAWING NUMBER DNX-44-209	SHEET 1/1
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C	22-05-2007
B	09-05-2007
A	08-01-2007

2

2

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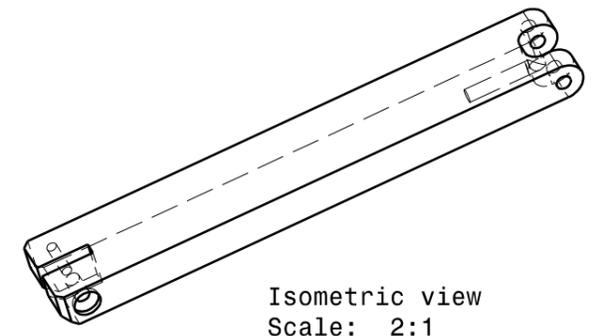
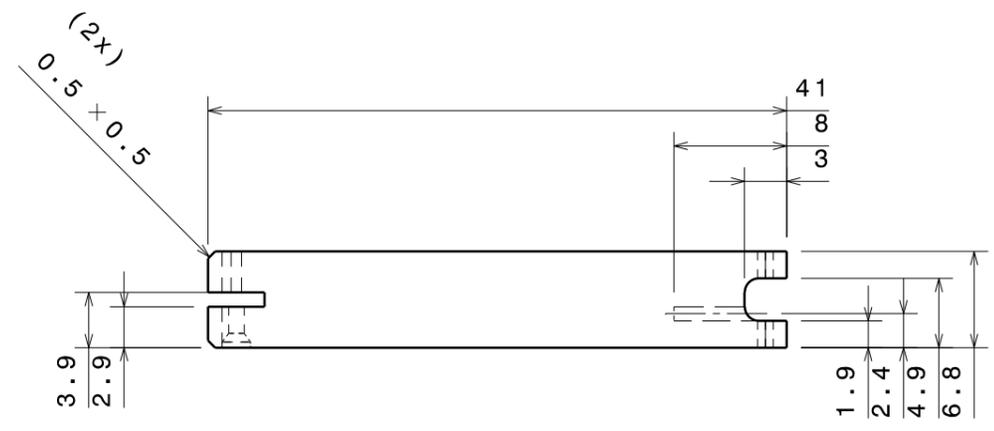
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H G F E D C B A

H G F E D C B A

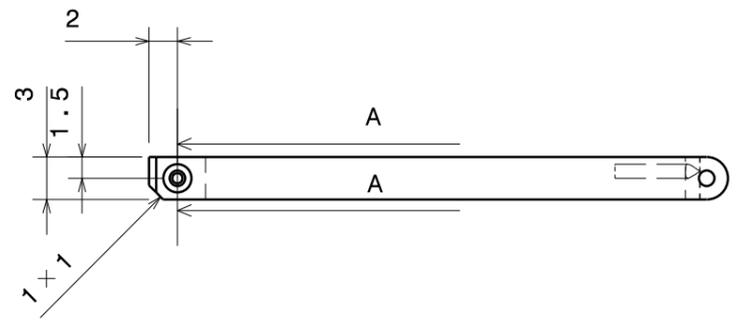
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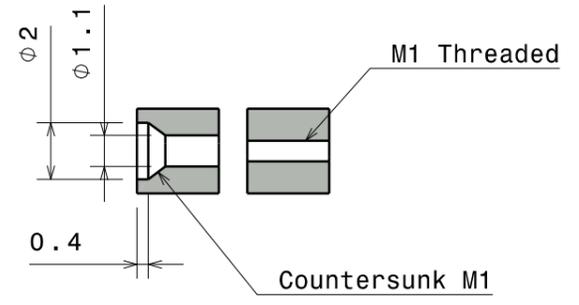
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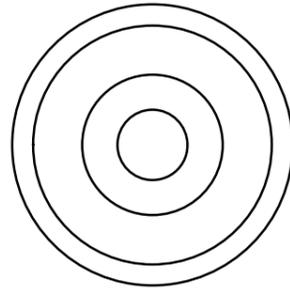
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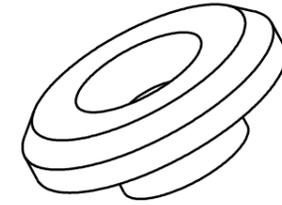
H G F E D C B A

Project contact: 015-2785326		Surface treatment	None
Order no.		Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges		Roundings	R1, unless specified otherwise
Dimensions in mm		Process	Milling
		Material	Makrolon
DESIGNED BY: J.P. de Jong		MAB Lid	
DATE: 24/2/2012			
CHECKED BY: G.F. Brouwer		Delfi-n3Xt	
DATE: -			
SIZE A3		DNX-44-210	
SCALE 1:1	WEIGHT (kg) 0.001		
DRAWING NUMBER		SHEET	
		1 / 1	
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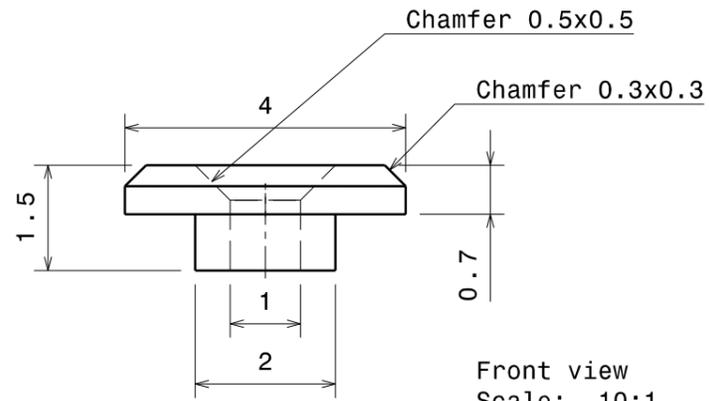
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B	09-05-2007
A	10-01-2007



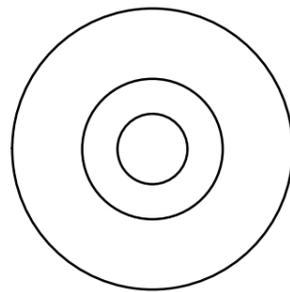
Top view
Scale: 10:1



Isometric view
Scale: 10:1



Front view
Scale: 10:1



Bottom view
Scale: 10:1

Project contact: 015-2785326		Surface treatment	None
Order no.		Tolerances	± 0.1 mm, unless specified otherwise
Remove sharp edges		Roundings	R2, unless specified otherwise
Dimensions in mm		Process	Milling
		Material	PEEK
DESIGNED BY: J.P. de Jong		<h1>MAB Isolation Ring</h1>	
DATE: 18/4/2012			
CHECKED BY: -			
DATE: -		<h1>Delfi-n3Xt</h1>	
SIZE A3			
SCALE 10:1	WEIGHT (kg) -	DRAWING NUMBER DNX-44-217	SHEET 1/1
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