SED

Student Experiment Documentation

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Team Name: IRIS

Experiment Title: InfraRed albedo measurements In the Stratosphere

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The IRIS Team

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2.0		2.2, 3.1, 3.2, 3.3, 4.1, 4.3, 4.5, 4.6, 4.7, 4.8, 5.2, 6.1, 6.2, 6.3, 7.4, 8.1, 8.2, App. C, App. E.1, E.2 Added: 5.3, App. G	CDR
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Abstract: Student Experiment Documentation of InfraRed albedo measurements In the Stratosphere for BEXUS from Luleå University of Technology.
Keywords: BEXUS, infrared, albedo, IRIS, SED - Student Experiment Documentation, LTU - Luleå University of Technology, SNSB, DLR, ESA, SSC, ZARM, Eurolaunch

Contents

Preface

This document is a part of the critical design review for the IRIS experiment. Its main purpose is to provide the reader with information on all basic knowledge about how the mission is designed and planned to perform albedo measurements from a high altitude balloon (HAB). The Student Experiment Documentation consists of the following chapters, analysed below:

- Chapter 1 - Introduction:
  This chapter explains briefly the scientific material on which this mission was based. The mission's objectives and concept is displayed. Information about the team and the team members can be found here.
- Chapter 2 - The Experiment Requirements and Constraints:
  Here, the technical functionalities are defined. These are needed to be met according to the specific requirement standards to ensure the reliability of the experiment.
- Chapter 3 - Project Planning:
  This chapter describes the schedule, the distribution of work, the available resources, the risks that have been taken into consideration and the outreach approach of the experiment.
- Chapter 4 - Experiment Description:
  This chapter clarifies the setup of the experiment, the interfaces and components, the design of the various subsystems, and the ground support equipment in need for the robustness of the experiment.
- Chapter 5 - Experiment Verification and Testing:
  This chapter displays the verification matrix and the several types of tests that will be performed in order to assure the correct operation of the experiment.
- Chapter 6 - Launch Campaign Preparation:
  In this chapter, information about the Input for the Campaign, Flight Requirement Plans, Preparation, and Test Activities at Esrange, Timeline and Countdown for the Flight, are explained along with the Post-Flight Activities
- Chapter 7 - Data Analysis:
  This chapter presents the data analysis plan, the launch campaign, results obtained, and most importantly the lessons learned from this experiment.
- Chapter 8 - Abbreviations and References:
  Contains all the abbreviations found in the document.

Information about the Experiment Review, Outreach, Additional Technology Information and Checklists are found in the Appendices in the end of the document.
The scientific terms that have been studied are emphasised in *italics*, and they are used to further comprehend the necessary scientific background for the conduction of the mission's scientific research.

This is an updated version of the first release of IRIS mission Design Document.

The REXUS/BEXUS programme is performed under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA) [1].

EuroLaunch, a cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project [2].

Suggested journals and books that have been an inspiration and give insight into the scientific background of IRIS, apart from the ones used as references in the current documentation:

- International Journal of Climatology. [3]
- International Journal of Atmospheric Sciences. [4]
- The Arctic Climate System, By Mark C. Serreze, Roger G. Barry. [5]
- The Cryosphere, An interactive open-access journal of the European Geoscience Union.[6]
- Polar meteorology, World Meteorological Organisation. [7]

Acknowledgements

This work has been generously supported by REXUS/BEXUS organisers, SNSB, DLR, ESA, SSC, ZARM, ESRANGE, Forsway, Absolicon, IRF Kiruna, our university LTU, Thomas Kuhn, Olle Persson, our endorsing professor Mathias Milz and our technical mentor Piotr Skrzypek. Our team has received support and advice from an immense number of individuals and organisations, so many in fact, that it would be impossible to mention them all without forgetting someone. Though the extents of the contributions vary greatly, they are all important for the success of our mission, and the entire team is and will be eternally grateful for everything that has been done for us. It is our sincere hope, however, that everyone who has been involved will feel a sense of pride when reading this document.

Without your support this project would not have been possible, and we will do everything in our power to make the most of this unique opportunity.

Thank you!
IRIS Team

Abstract

IRIS consists of an apparatus which aims to measure the incoming radiation from the Sun and Earth's reflection, in order to determine local albedo variations, throughout the troposphere and the stratosphere. Terms such as the red edge, Solar Zenith Angle , atmospheric extinction and clouds' microphysical properties, will be examined and are taken into consideration. The measurements will be performed by photodiodes pointing upwards and downwards, which cover the visible, the near-infrared, and infrared spectrum. A camera facing downwards will define the surface that lies directly beneath the gondola and a camera facing upwards will facilitate the observation through the determination of cloud presence. Sensors, pointing upwards and downwards, will allow the differentiation between the intensity from these two directions, and how it varies depending on the altitude.The photodiodes and the cameras will be placed respectively on the outer endpoint of each of the two booms, whose other endpoint shall be attached on the frame of the gondola. A high-altitude balloon traversing through the troposphere and the stratosphere is required for the distinguishment of the albedo variations, as other remote sensing methods are not as effective. The experiment, specially planned and designed for this mission, is taking into consideration all the requirements, constrains and risks needed to be ruminated. Thus, effectiveness of measurements is securely provided. Measuring the radiation balance of the Arctic region will aid in the development of future numerical models describing the radiative balance and the climate all over planet Earth. The supreme aim is to reduce error accumulated from remote satellite measurements.

1 Introduction

1.1 Scientific/Technical Background

The *albedo* is a non-dimensional, unit-less quantity, which indicates the quality of reflectance a surface can return. The *bond albedo* specifically, is a measure of the ratio of incident and reflected radiation. Albedo is connected directly to the heat energy budget of the planet, since the solar radiation that is not absorbed from the Earth's surface and the clouds in the atmosphere, is directly reflected into space. Thus, the long-term trend of albedo is that of cooling.
Variety and quality of the *local vegetation*, *atmospheric compositions*, type of *clouds* found throughout the troposphere and stratosphere, the *Solar Zenith Angle (SZA)* and the *wavelength* of incoming light from the Sun [8] are all factors that influence deterministically the albedo. Therefore, it is of great interest to further investigate thoroughly into how they influence the temperature equilibrium of our planet.

For the ground albedo measurements, surface type, colour and moisture and the SZA, are the most important variables to be taken into consideration.[9]
The variety and quality of vegetation is, for this reason, directly connected to the albedo. The type and healthiness of vegetation contributes to its reflectance. The *"red edge"*, consisting of wavelengths between 680-750 nm, is the spectral signature characteristic of terrestrial vegetation. This is due to the strong absorption by chlorophyll in the red region, in contrast to a strong reflectance in the near-infrared. Measurements of the red edge can provide valuable information about the chlorophyll concentration of the observed vegetation. Thereon, these measurements can be used to distinguish between living and dead plants, in order to detect and describe the anomalies of the terrestrial albedo. Previous studies have showed that the finest indicator of the level of chlorophyll contained in vegetation, is the edge of the *red edge peak*. The area of the red edge peak is useful for estimating the leaf area index. To conclude, the red edge measurements are useful, not only for the determination of the nutritional status of vegetation, but also for that of its health. [10]

Moreover, the different *types of clouds* [11] and *atmospheric compositions* influence radiation scattering through atmospheric extinction.
Clouds have a prodigious impact on the albedo, since depending on their height, temperature, thickness and composition, they play a major role to radiation scattering. This is because they consist of various droplet formations, whose size of effective radius has different scattering properties. Along with the anthropogenic aerosol particles and their absorption properties, these characteristics greatly affect the albedo and radiation scattering.

Another factor that affects the albedo is the SZA. The SZA is an indicator of radiance. It is the angle between the local zenith point and the midpoint (line of sight) of the sun. For this reason it is calculated as a function of time, day and latitude. The albedo of most surfaces depends highly on the SZA, with a general trend of increase in albedo for increasing SZA. Consequently, SZA is an essential parameter to be defined in order to correctly calculate the local albedo of an area. Snow is an exception to this case; showing almost no variation and in some cases even a decreasing albedo for larger SZA [12]. Usually, the larger the SZA is, the weaker becomes the exposure in sun's rays, because the same amount of light is spread to a larger area.

A study conducted by Steven A. Lloyd, published in 1990[13], concluded that the radiation field in the polar atmosphere is vastly different than that of lower latitudes due to several factors. The atmospheric scattering is increased for wavelengths below 340nm because of ozone depletion: ozone holes significantly affect wavelengths in the region between 280-310 nm. For smaller values of SZA, particularly below 60 degrees, surface albedo is important to consider. When this angle increases, less direct sunlight reaches the surface, but a large value of surface albedo still has some effect. All of these effects are important for estimating the rate of ozone destruction, though the most important one appears to be cloud cover.

For satellite remote sensing radiative transfer is a necessary tool. It models the sinks and sources of radiation, in other words how the intensity changes throughout the atmosphere. It specifically has terms for the absorption (transmittance), emission and scattering. It is however an empirical formula that requires assumptions, such as the local thermodynamic equilibrium (LTE). The full radiative transfer equation (RTE) in differential form is stated below:

$$\frac{dI}{ds} = -(\beta_a + \beta_s)I + \beta_a B(T) + \beta_s \int_{4\pi} P(\Omega',\Omega) I(\Omega') d\Omega'$$

Here I is the intensity, s the path through the atmosphere, β_a and β_s are the absorption and scattering coefficients, Ω is the angle, $B(T)$ the Planck function and $P(\Omega',\Omega)$ the scattering probability.[14] This equation is used by RTE models such as Futbolin and ARTS.[15][**?**]

It is important to consider that the polar regions, such as Lappland, are extremely important for the global climate, but they have not yet been studied enough. Their unstudied properties related to the modelling and parameterization of climate change are needed to analytically define in detail the parameters that influence the radiation budget. In terms of Albedo measurements, polar arctic regions have not been studied as intensely as other areas in lower latitudes. A small number of ground measurements have been performed in the past. Mostly polar orbit (PO) weather and PO imagining satellites are used to monitor the albedo and other important factors that aid the creation of climate prediction models. NOAA and CERES, NASA are two of the main researchers that assist in albedo monitoring. Hence, BEXUS provides a unique opportunity to study this otherwise remote place, since the balloon will be launched from Esrange Space Center in northern Sweden.

1.2 Mission Statement

The overall purpose of IRIS is to contribute to error elimination in remote sensing satellite measurements, by measuring the albedo (ratio of intensity between incoming and reflected outgoing radiation) and its change throughout the troposphere and the stratosphere. Specifically, in contrast to all remote sensing satellite measurements, IRIS will gather data from much thinner atmospheric layers, by the use of light sensors and a High Altitude Balloon (HAB). This process will increase the possibility of error estimation accumulated from remote sensing measurements.

1.3 Experiment Objectives

Obj.1 IRIS mission is based on the following primary scientific objectives:

- 1.1 Effective measurement of ground albedo.
- 1.2 Ratio variation of incoming radiation to outgoing reflectance throughout the troposphere and the stratosphere.
- 1.3 Estimation and elimination of accumulated error from satellite remote sensing measurements.
- 1.4 Build a simple but yet reliable experiment.

Obj.2 IRIS wishes to investigate the following secondary objectives, if conditions are met:

- 2.1 Relation of chlorophyll levels to albedo variations.
- 2.2 Comparison with PO satellite remote sensing measurements.
- 2.3 Record of variations and distinguishment between snow and/or cold cloud albedo.

1.4 Experiment Concept

IRIS will investigate the albedo for VIS, NIR and IR wavelengths and at various altitudes, above the polar circle. The mission will be carried out by an apparatus utilising light sensors and cameras mounted on a HAB.

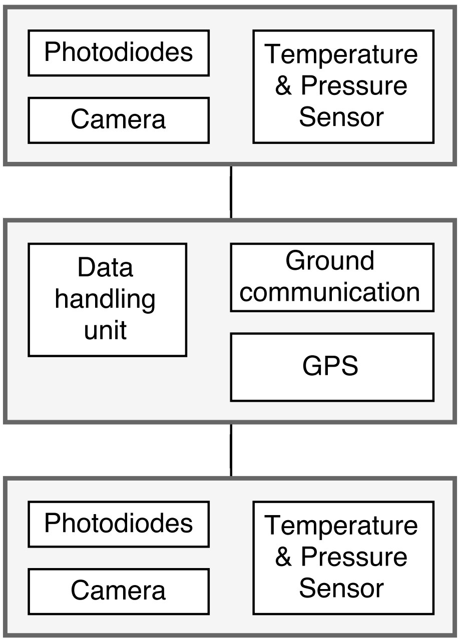


Figure 1.4.1: IRIS experiment setup

IRIS mainly consists of two sensor arrays, connected to a data storage unit. There are two separate sensor arrays, one located on the top of the gondola, looking upwards and the other one located at the bottom, looking downwards. Each array contains a number of photodiodes, which will measure the intensity of the specific wavelength bands required to conduct the scientific research. In each sensor box, there are also mounted colour cameras. The basic functional blocks are demonstrated in fig. 1.4.1.

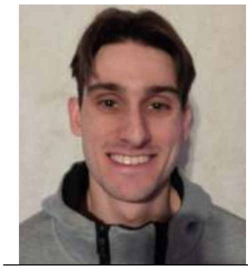
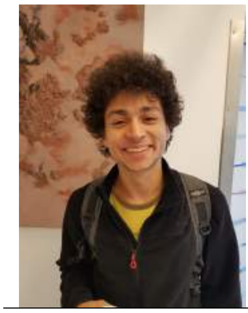
1.5 Team Details

1.5.1 Contact Point

Contact	Contact Information
Project Manager	Gustaf Ljungné Tarfalavägen 5A 98144 Kiruna, Sweden gustaf.ljungne@gmail.com +46709610679
The team	iris.bexus@gmail.com (Team email)
Contact at LTU	Associate Professor Thomas Kuhn thomas.kuhn@ltu.se Associate Professor Mathias Milz mathias.milz@ltu.se

1.5.2 Team Members

Everyone in IRIS is rewarded 15 ECTS points for the course Space Engineering Project II, P7001R by participating in BEXUS.[16]

Name and Role	Information
Gustaf Ljungné **Project Manager** 	Fourth year of M.Sc space engineering, currently working on a master in instrumentation and spacecraft design. Interests include, but are not limited to: technology, electronics, weight lifting, people skills. My role in IRIS is as the project manager. I coordinate the team and its departments.
Guillermo Ledo López **Head of Mechanical Department** 	Aerospace engineer, studying a master's degree on spacecraft design at LTU. Interested in space, physics, engineering, nature and science fiction, among others. As the head of the Mechanics department, my roles include the design of the structures and thermal control used in IRIS and the coordination of my department. I expect the heaviest workload to begin once a final configuration for the experiment has been selected and manufacturing starts.
François Piette **Mechanical Department, Optics department and Head of Economics Department** 	I am an Aerospace Engineer student from the University of Liège (ULg), and I am currently completing my degree at Luleå University of Technology as an exchange student. I have high interest in aircraft and space launchers in Europe. In the mechanical department I am mainly in charge of CAD drafts with CATIA. In the Economics department we are actively looking for grants to secure the necessary funding. Also we are trying to establish partnerships with scientific institutes in the Arctic region. I am expecting a constant increase of the workload in each step of the design.

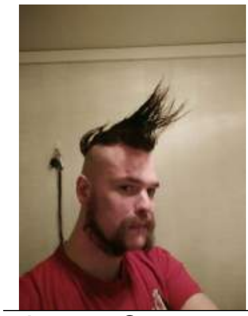
Lisa Jonsson
Head of Electronics Department

Currently studying the fourth year of MSc in space engineering with focus on instrumentation and control systems of spacecrafts and satellites. My tasks are to manage the electronic department, divide the workload between the members of the electronics team, choosing sensors and instruments according to the science department's specification and designing the electronics needed for the experiment.

Hampus König
Electronics Department

Currently in the fourth year of M.Sc in space engineering focused on instrumentation and spacecraft design. My tasks include choosing sensors according to the science department's specification and designing the electronics that are needed for the experiment.

Arttu Tiainen
Electronics Department



Currently on the second and thus last year of the MSc in spacecraft design and I did my thesis on inter-satellite link antennas. Additionally I have several years of work experience in embedded electronics design and a small consultation company. My tasks include building and programming a prototype for the measurement system and supportive and advisory tasks of the electronics design.

August Svensson
Electronics Department

Currently in the third year of a MSc in space engineering with a specialisation in spacecraft and instrumentation. My tasks involve the verification and testing of the electronics and sensors, as well as electronic design.

Edgar Martín
Head of Software Department

Aerospace engineering graduate, currently undertaking a master's program in spacecraft design. Among my interests are programming, electronics and entrepreneurship. As member and head of the software department, my tasks include system architecture design, programming and maintenance of the code, as well as internal management of the department. The expected workload is to be concentrated at the final stages, when the components from the hardware team are available.

Andreas Wallgren
Software Department

Currently thesis/final project remaining on a MSc in space engineering, with a focus on atmospheric and space physics. Relevant interests include a general fascination of mathematics; in particular information manipulation in e.g. signal processing. As a member of the software department, the task is to contribute to stable and reliable software to ensure correct data and error -handling to aid a successful mission. The bulk of the work will begin with the integration of the hardware-to-be-used. Because no system ever co-operates, the workload will be heavy and hopefully rewarding.

Eleni Athanasiou
Head of Science Department

I am an Electrical Engineer, currently studying Spacecraft Design (MSc) at LTU. I have work experience on Industrial Engineering automation control systems, and on the development and test of hardware parts for accelerator and non accelerator experiments for High Energy Physics (HEP). My general interests include: particle physics , superconductivity, cryogenics, cutting edge technology, biomedical engineering, sociology, photography and painting. For the IRIS experiment I am the Head of Science Department, and my duties consists of the following:

- Develop and analyse the scientific background and objectives of IRIS.
- Post-experiment data analysis.
- Distribution of tasks within the Science department, manage and conduct communication with the other departments, as well as with the Project manager.

Ingo Wagner **Science Department** 	BSc in Earth and Space Science, currently enrolled at LTU in a master's program in Atmospheric and Space Science. My interests in science range from oceans to space and stars with a focus on the physics. In the science department my role is the development of the scientific goal as well as the application of data analysis models. As it is the nature of these roles the workload will be focused on the beginning and end of the project.
Oriol Peláez Mercadal **Science Department and Head of Optics Department** 	Energy and Mining resource engineering graduate, studying a master's degree on Earth's atmosphere and Solar System at LTU. I like all kind of sports and technology, as well as science and everything related with space, specially the research for new horizons, either in exoplanets or close to us, like Mars or in some of our Solar System moons. I am also very interested in space mining and terraformation, which I think is a discipline that will be very important in the near future, so harvesting resources from planets and asteroids will be very significant for the next generations in order to perform interplanetary travels. My role include development of science background and data analysis. Also, I am the Head of the Optics department, which is in charge to control the optical design of the instrumentation.
Alexander Korsfeldt Larsén **Public Relations and Economics department** 	After a year in the telemarketing sector I enrolled at Luleå University of Technology, and I am now doing my fourth year in the Space Engineering Master Programme. Though my education is specialised towards electronics and instrumentation, my main task in this project is to handle most of the team's external communication. I am also responsible for our web page and our social media presence.

2 Experiment Requirements and Constraints

2.1 Functional Requirements

F.1 The experiment shall measure the intensity of visible light outside the gondola, looking towards the zenith.

F.2 The experiment shall measure the intensity of visible light outside the gondola, looking towards the nadir.

F.3 The experiment shall measure the intensity of infrared light outside the gondola, looking towards the zenith.

F.4 The experiment shall measure the intensity of infrared light outside the gondola, looking towards the nadir.

F.5 The experiment shall correlate the pressure at which the measurements were taken.

F.6 The experiment shall correlate the temperature at which the measurements were taken.

F.7 The experiment shall correlate the position at which the measurements were taken.

F.8 The experiment shall measure the position on the three axis of space with respect to the launching point.

2.2 Performance Requirements

P.1 Moved to D.28

P.2 The experiment shall measure the electromagnetic spectrum from 0.3 μm to 2.5 μm with a minimum sensitivity of 200 $mW \cdot m^{-2}$.

P.3 The experiment shall measure radiation in the wavelength range 0.43 μm to 0.45 μm with a precision of $\pm$0.005 μm.

P.4 The experiment shall measure radiation in the wavelength range 0.45 μm to 0.51 μm with a precision of $\pm$0.005 μm.

P.5 The experiment shall measure radiation in the wavelength range 0.53 μm to 0.59μm with a precision of $\pm$0.005 μm.

P.6 The experiment shall measure radiation in the wavelength range 0.63 μm to 0.67 μm with a precision of $\pm$0.005 μm.

P.7 The experiment shall measure radiation in the wavelength range 0.85 μm to 0.88 μm with a precision of $\pm$0.005 μm.

P.8 The experiment shall measure radiation in the wavelength range 1.36 μm to 1.38 μm with a precision of $\pm$0.005 μm.

P.9 The experiment shall measure radiation in the wavelength range 1.56 μm to 1.65 μm with a precision of $\pm$0.005 μm.

P.10 The experiment shall measure radiation in the wavelength range 2.00 μm to 2.50 μm with a precision of $\pm$0.005 μm.

P.11 See P.18 and P.19

P.12 The sampling delay shall not exceed 30 seconds.

P.13 The experiment shall measure the pressure from 5 to 1100 $mbar$.

P.14 The experiment shall measure the ambient absolute air pressure to make an estimation of the altitude with a minimum accuracy of ± 10 $mbar$.

P.15 The experiment shall measure the ambient air temperature from -90 to 30 $°C$.

P.16 The experiment shall measure the temperature with a minimum accuracy of ± 1 $°C$.

P.17 The experiment shall measure the position with a minimum accuracy of ± 10 m.

P.18 During the ascend phase the sampling frequency shall be 3 seconds.

P.19 During the float phase the sampling frequency shall be 10 seconds.

2.3 Design Requirements

D.1 Unnecessary requirement and has therefore been removed.

D.2 Unnecessary requirement and has therefore been removed.

D.3 Unnecessary requirement and has therefore been removed.

D.4 The experiment shall not weight more than 23 kg upon launch.

D.5 The experiment shall withstand vertical accelerations within the BEXUS launch and flight profile.

D.6 The experiment shall withstand horizontal accelerations within the BEXUS launch and flight profile.

D.7 The experiment's data storage unit should withstand shocks of up to 35 g during landing.

D.8 The experiment shall withstand vibrations related to handling and transportation before and after flight.

D.9 The experiment shall withstand pressures within the BEXUS flight profile.

D.10 Unnecessary requirement and therefore removed.

D.11 The experiment shall not be at risk of falling from the gondola during flight and launch.

D.12 Unnecessary requirement and therefore removed.

D.13 The experiment should be attached to the gondola rails.

D.14 The fastening to the gondola rails shall be carried out with rubber bumpers with volcanized M6 bolts on both sides.

D.15 The experiment shall use a sufficient number of brackets on bottom plates in order to facilitate mounting of experiments.

D.16 The experiment shall operate at temperatures within the BEXUS vehicle flight and launch profile.

D.17 Unrealistic requirement and has therefore been removed.

D.18 The replacement time of the replaceable experiment components shall be within 15 minutes.

D.19 The experiment shall use a maximum electrical energy of 275 Wh.

D.20 The experiment shall use Ethernet 10/100 Base-T with RJ45 connectors for interfacing with the provided E-link.

D.21 The experiment shall use Ethernet 10/100 Base-T with RJ45 connectors for interfacing with the ground station.

D.22 The experiment shall use a 4 pin, male, box mount receptacle MIL-C-26482P series 1 connector with an 8-4 insert arrangement as power interface.

D.23 The data storage unit shall withstand any post-landing environment within the mission profile without corruption or loss of data for at least 3 days.

D.24 Unrealistic requirement and has therefore been removed.

D.25 The experiment shall not use a downlink rate greater than 200 kbit/s.

D.26 The experiment may include sacrificial joints or other contingency plans to avoid being damaged upon landing if it protrudes from the gondola.

D.27 The position of the experiment should be selected in order to reduce "noise" interference from other experiments.

D.28 The experiment shall be able to distinguish between incoming and outgoing from Earth radiation.

D.29 The sampling time of optical instruments shall be synchronised.

2.4 Operational Requirements

O.1 The experiment sensors shall be cleaned from dust before launch.

O.2 The experiment shall accept commands from the ground station at any time.

O.3 The procedures to turn the experiment on and off should be done by connecting/disconnecting the power source.

O.4 The experiment shall perform autonomously in the event of loss of communication with the ground station.

O.5 The experiment shall be able to correctly handle aborted launch attempts during any point leading up to, including pre-flight tests, the launch.

2.5 Constraints

C.1 The E-Link data transfer rates are limited by coverage and quality of reception, imposing restrains on the uplink/downlink available rate.

C.2 Not applicable any more.

C.3 Not applicable any more.

C.4 The budget for the experiment is limited by the small number of generous companies/organisations in Sweden.

C.5 The weather conditions are to affect the experiment and its outcomes if the sky is overcast for secondary mission objectives.

C.6 Time of delivery of components is limited on the team's location, affecting manufacturing times.

3 Project Planning

This following section will explain the work distribution and expected workload for each member. It is based on when the different reviews have deadlines and what main tasks exist within the different departments.

3.1 Work Breakdown Structure (WBS)

IRIS's WBS can be seen in fig. 3.1.1. The WBS is divided into the eight departments that the team consists of, and the work packages are the main tasks in each department.

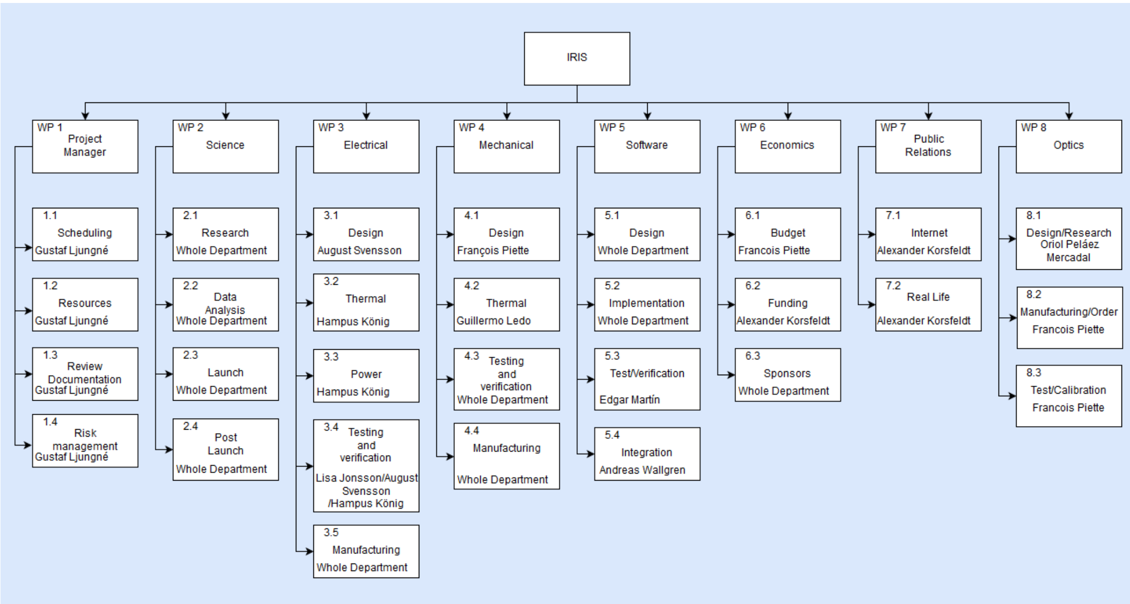


Figure 3.1.1: The WBS for IRIS

For WBS for each department see app. E.

3.2 Schedule

Fig. 3.2.1 and 3.2.2 is the estimated time and tasks distribution within the IRIS team. Included are all reviews, launch, student training week and exam periods. For more detail see app. E.

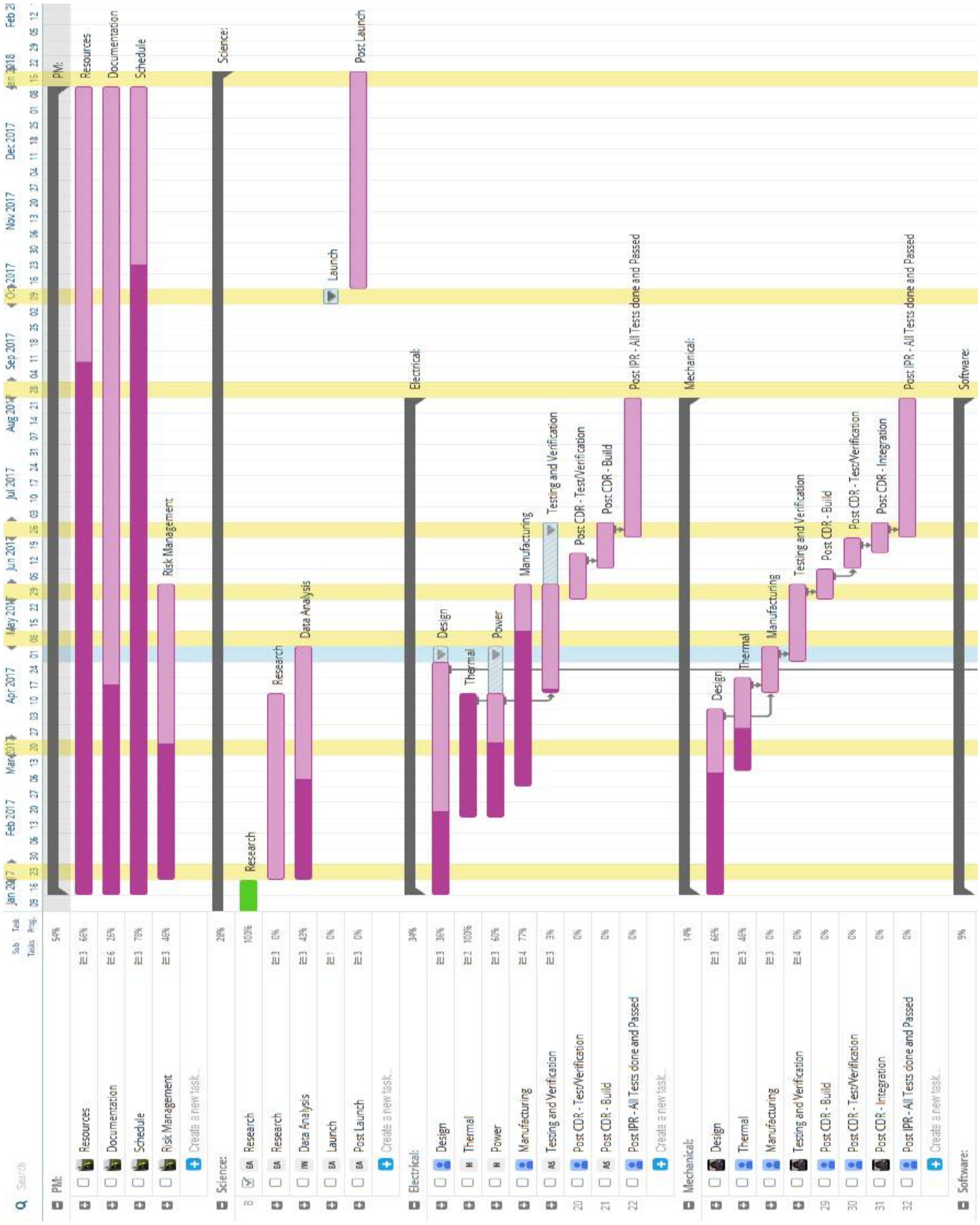


Figure 3.2.1: Gantt chart, part 1

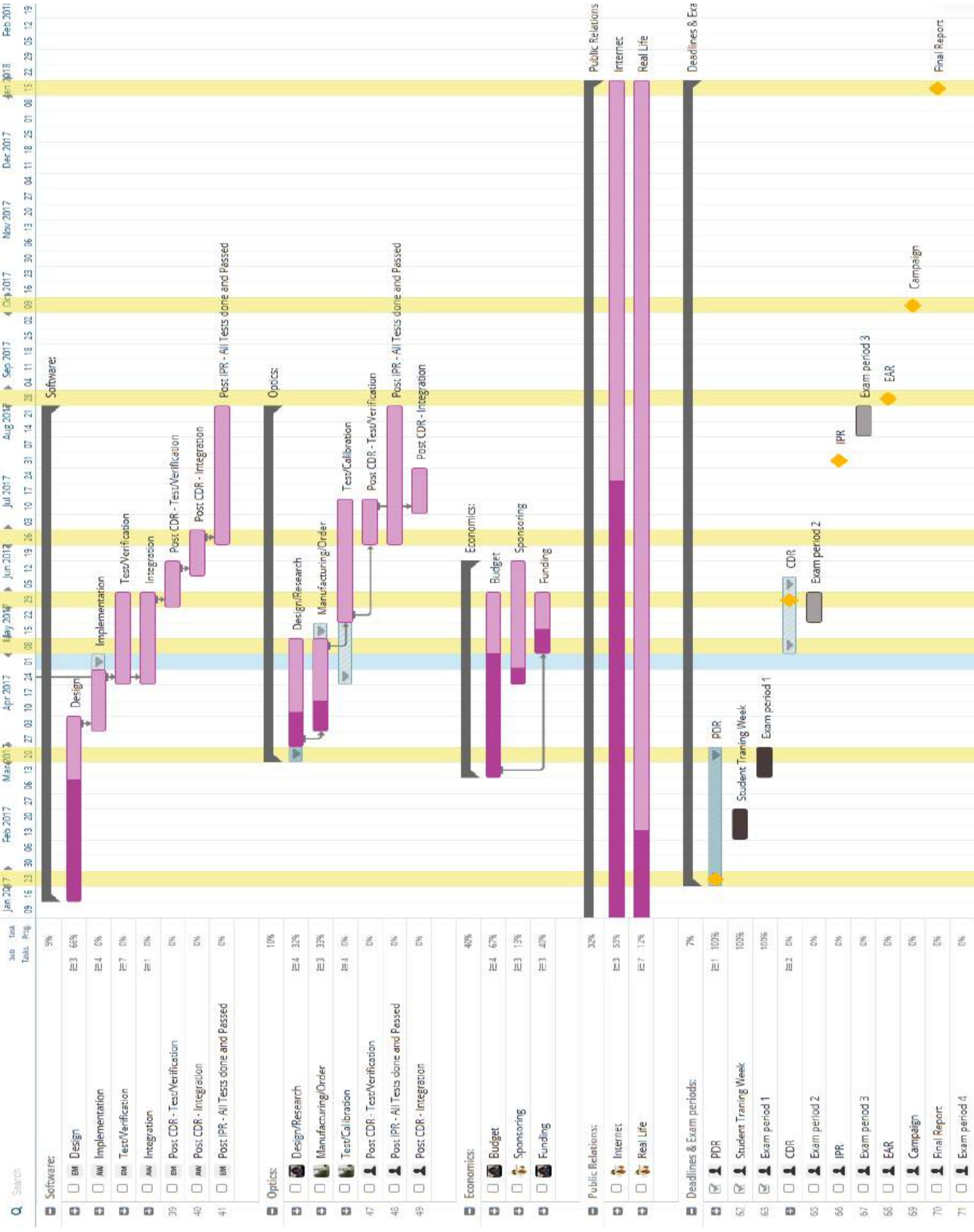


Figure 3.2.2: Gantt chart, part 2

3.3 Resources

3.3.1 Manpower

Tab. 3.3.1 and 3.3.2 show that the work hours are estimated to be distributed among the team members.

Table 3.3.1: Colour code for the work distrubution

Colour Code	Amount of time (100 % is 20h)
Red	More than 80 %
Yellow	60 to 80 %
Blue	40 to 60 %
White	Less than 40 %
Black	Not present

Table 3.3.2: Work load in hours for each team member

Month Member	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Gustaf	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow
Eleni	Red	Red	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Red	Red	Red	Red
Lisa	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow
Edgar	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow
Guillermo	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow
François	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow
Alexander	Red	Red	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Red	Red	Red	Red
Arttu	Red	Red	Red	Red	Red	Red	Yellow	Blue	Blue	Red	Red	Yellow	Yellow
Ingo	Red	Red	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Red	Red	Red	Red
Oriol	Red	Red	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Red	Red	Red	Red
Hampus	Blue	Blue	Blue	Blue	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow
August	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow
Andreas	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow

3.3.2 Budget

The current budget estimation is shown below in tab. 3.3.3. These calculations are rough, and will be updated as the design phase progresses, but they show that the total expenditures are currently higher than the secured funding. The costs for suitable lenses proved to be much higher than anticipated, and so the team is currently investigating means to obtain additional hardware funding and/or sponsorship from the manufacturers. Costs for the Outreach Programme have now been estimated; most notably this estimation includes participation for three team members in two larger conferences, namely the 23rd ESA PAC Symposium held in Visby in June 2017 and the EGU General Assembly held in Vienna in April 2018. This estimation includes all costs related to the conferences (travel, accommodation, and the most expensive part: participation fee). Also included is travel costs for individual team members to hold presentations at universities in their home countries. The team has sent applications to LKAB Academy and Sveriges Ingenjörer - Miljöfonden (The Swedish Association of Graduate Engineers - The Environmental Fund), but unfortunately it was not possible to get any funding from them. We have also sent sponsorship requests to more than 50 different companies; including smaller local ones, large Swedish companies, and several companies invested in the space sector. A positive answer was received from Forsway, who have decided to sponsor the project with 500 Euro. We have also spoken to the company Absolicon, they have promised to support us with 200 Euro. We have also been granted 1000 Euros each from the companies Swedish Microwave and AstroSweden. In return, we will spread the word about the companies on our online channels and during our live presentations.

One team member, Francois Piette, is currently working on a master thesis related to IRIS. Our hope is that this will enable us to get additional funding from our university.

To secure even more funding, a crowdfunding campaign was recently launched on Generosity. This platform was chosen because they do not take any fees at all. The campaign can be found at Generosity.
We are also currently investigating the possibility to sell patches with our team logo on it to students and other interested people. This will help with the economical situation while also potentially increasing our outreach.

The ambitious Outreach Programme that had been planned was highly dependant on this additional funding, but since the hardware proved to be more expensive than originally planned we have greatly reduced the costs of the Outreach Programme. It has also been looked into the possibility of reducing the amount of photodiodes in the design, as the optical components are the most expensive. It was however decided that it was not possible to reduce this cost without negatively affecting the scientific gains of the mission. A decision on which spare parts are required has not yet been made. For now we calculate that they will increase the total hardware costs by roughly 50 %, but our hope is that this number can be somewhat reduced. Most of the tests required for the mission can be performed at LTU, and so will not incur extra costs. Costs for the remaining tests are being investigated. More information about individual components can be found in section 4.3.

The table below shows a summary of the current budget estimation. A more detailed spreadsheet can be found here.

Table 3.3.3: Budget estimations

Incoming/outgoing	Amount	Where the money comes from/goes to
Outgoing	€1,770	Electrical components
Outgoing	€4,000	Sensor filters and lenses
Outgoing	€720	Mechanical parts

Outgoing	€750	Manufacturing, mechanical (materials+labour)
Outgoing	€3,500	Estimated cost for spare parts
Outgoing	€2,200	Outreach and travel costs
Incoming	€3,000	LTU Project Course - Hardware
Incoming	€500	LTU Project Course - Outreach
Incoming	€3,000	SNSB Hardware
Incoming	€1,700	SNSB Sponsorship for ESA PAC
Incoming	€1,000	AstroSweden
Incoming	€1,000	Swedish Microwave
Incoming	€500	Forsway
Incoming	€200	Absolicon
Incoming	€300	Generosity (Crowdfunding - this is the current received amount)
Total Incoming	€11,200	
Total Outgoing	€12,940	
Total Balance	-€1,740	

3.3.3 External Support

Table 3.3.4: External Support

Support to	Information
Whole Team	**Name:** Mathias Milz **Title:** Associate Professor **Research Area:** Atmospheric science **Relation to the Team:** Endorsing Professor **Department:** LTU, Department of Computer Science, Electrical and Space Engineering **Email:** mathias.milz@ltu.se **Phone:** +46(0)980 67541

Whole Team	**Name:** Thomas Kuhn **Title:** Associate Professor **Research Area:** Atmospheric science **Relation to the Team:** Examiner **Department:** LTU, Department of Computer Science, Electrical and Space Engineering **Email:** thomas.kuhn@ltu.se **Phone:** +46(0)980 67538
Software/Whole Team	**Name:** Piotr Skrzypek **Title:** Flight Software Systems Engineer **Research Area:** On-board software **Relation to the Team:** ESA Mentor, Software **Department:** Systems Department **Email:** Piotr.Skrzypek@esa.int **Phone:** +31715655052
Whole Team	**Name:** Olle Persson **Title:** Operations Administrator, LTU centre of excellence **Department:** LTU, Department of Computer Science, Electrical and Space Engineering **Email:** olle.persson@ltu.se **Phone:** +46(0)920 497571
Whole Team	**Name:** Victoria Barabash **Title:** Doctor **Research Area:** Atmospheric science / Physics of the upper atmosphere **Department:** LTU, Department of Computer Science, Electrical and Space Engineering, Division of Space Technology **Email:** victoria.barabash@ltu.se **Phone:** +46(0)980 67532
Software	**Name:** Anita Enmark **Title:** Doctor **Research Area:** Atmospheric science **Department:** LTU, Department of Computer Science, Electrical and Space Engineering **Email:** Anita.Enmark@ltu.se **Phone:** +46(0)980-67534

Electrical	**Name:** Soheil Sadeghi **Title:** Associate Senior Lecturer **Research Area:** Onboard space systems **Department:** LTU, Department of Computer Science, Electrical and Space Engineering, Division of Space Technology **Email:** soheil.sadeghi@ltu.se **Phone:** +46 (0)920 497574
Electrical/Mechanical	**Name:** Rita Edit Kajtar **Title:** PhD Student position **Research Area:** Atmospheric science **Department:** LTU, Department of Computer Science, Electrical and Space Engineering **Email:** rita.edit.kajtar@ltu.se **Phone:** +46 (0)920 497573
Mechanical (Manufacturing)	**Name:** Kent Johansson **Company:** Åkleby Mekaniska AB **Address:** Åkleby, Åvik 541 91 Skövde Sweden **Phone:** +46(0)500-460313 **Fax:** +46(0)500-460313 **Mobile:** +46(0)709461578 **Email:** aklebymek@telia.com
Mechanical (Manufacturing)	**Name:** Johan Ljungné **Company:** Björnasäter Smide **Address:** Stora Björnasäter 540 17 Lerdala Sweden **Email:** johan.ljungne@gmail.com **Mobile:** +46(0)709609810
Mechanical/Electrical	**Name:** Joakim Öman **Company:** SSC **Location:** Esrange Space Center **Division:** Science Services: Instrumentation **Email:** Joakim.Oman@sscspace.com
Mechanical/Electrical	**Name:** Kent Andersson **Company:** SSC **Location:** Esrange Space Center **Division:** Science Services: Instrumentation **Email:** Kent.Andersson@sscspace.com

3.4 Outreach Approach

The main idea of the IRIS Outreach Program is to focus on reaching a younger audience, e.g. university and high school students. This will be achieved through social media, the IRIS website, and by holding presentations at universities, high schools, and various events. Articles in local and national newspapers, as well as on university websites, are also part of our outreach plan. The current plan is to contact national media, including newspapers, television, and radio, once the first prototype of the experiment is completed.

The team's website can be found at https://www.bexusiris.com/. The old URL still works. The website contains all essential information about the project and the team members behind it, as well as a short description of the REXUS/BEXUS programme. Articles written by the various departments will be regularly published, so the website also acts as a blog or development diary. All important documents produced by the IRIS team will be uploaded to this site, and made available to the public. The idea is that future students participating in this programme, or a similar one, can use our site as a resource. It also contains logos with links to all of our sponsors and stakeholders. The newest feature is the weekly blog posts, written by a different team member each week. It is published every Friday afternoon together with a post on our Facebook page.

IRIS has a Facebook page, located at facebook.com/bexusiris/. News and photos are shared here in a format easily accessible. Whenever an article is posted on our website, a link to the article, as well as a short summary, will be posted here. The team also has an Instagram account that will be used to upload pictures on a regular basis. It can be found at @bexus_iris.

3.5 Risk Register

- TC – Technical/implementation
- MS – Mission (operational performance)
- SF – Safety
- VE – Vehicle
- PE – Personnel
- EN – Environmental
- OR - Outreach
- BG - Budget

Table 3.5.1: The rankings of probability (**P**) and severity (**S**)

Probability P	**Severity S**
A. Minimum – Almost impossible to occur	1. Negligible – Minimal or no impact
B. Low – Small chance to occur	2. Significant – Leads to reduced experiment performance
C. Medium – Reasonable chance to occur	3. Major – Leads to failure of subsystem or loss of flight data
D. High – Quite likely to occur	4. Critical – Leads to experiment failure or creates minor health hazards
E. Maximum – Certain to occur, maybe more than once	5. Catastrophic – Leads to termination of the REXUS and/or BEXUS programme, damage to the vehicle or injury to personnel

Table 3.5.2: Risk Register

ID	**Risk (and consequence if not obvious)**	**P**	**S**	**P × S**	**Action**
MS10	Hercules impact if the experiment protrude from the gondola	B	4	Low	Prepare spare parts of the experiment so if the launch is aborted there might be a chance to change the broken parts.
MS20	Failure of several sensors	C	2	Low	Choose appropriate sensors for the flight and thoroughly test them.
MS30	The balloon rotation will influence results on each sensors	E	1	Low	Including sensors (electronic gyro/accelerometer) to estimate rotation rate might help data analysis.
MS40	Temperature sensitive components that are essential to fulfil the mission objective might be below their operating temperature	C	3	Low	Safe mode to prevent the components to operate out of its operating temperature range.
MS50	The MCU/Central computer unit might fail, it will prevent any further collect of data	B	3	Low	Requires several tests of the robustness of the system. If it cannot be assessed, a redundant system will be required.

MS60	One flight might not be enough to achieve the scientific goals	D	2	Low	Prepare eventually for other flights with other balloons to increase data sample.
~~SF10~~	~~Mechanical failure of bolts~~	~~B~~	~~5~~	~~Medium~~	Removed because tests will be performed to confirm structure integrity
SF20	Self-loosening of bolts and nuts. Mechanical failure of bolts	A	5	Low	Redundancy to prevent the experiment to fall off. Stress calculation and testing is required.
SF30	Parts of the experiment may fall off the gondola during flight or pre-launch	A	5	Low	Redundancy to prevent the experiment to fall off.
TC10	Failure of the experiment during testing	C	3	Low	Prepare spare parts of the experiment.
TC20	Insufficient technical experience	B	3	Very Low	Laboratory equipment and external support guidance.
EN10	Full coverage of low and dense clouds will lead to one type of measurements	C	2	Low	The mission objective need to be prepare to this case.
EN20	No snow covered ground during the flight	D	2	Low	The mission objective need to be prepare to this case.
EN30	Low Sun zenith angle	D	1	Low	A low SZA is not problematic because we will still be able to measure the light being scattered from the top.
EN40	The post-landing environment conditions might corrupt or destruct the data	C	4	Medium	Testing of the data storage robustness against post-landing environmental conditions during several days.
EN50	Accumulation of dust particles on sensitive equipment, e.g. lenses or filters	C	2	Low	Accurately estimate the risk, limit unnecessary expose of sensitive equipment to environment. A protective cover of lenses can prevent the accumulation of dust.

EN60	Formation of waterdroplets on sensitive equipment, e.g. lenses	A	2	Very Low	Accurately estimate the risk, limit unnecessary expose of sensitive equipment to enviroment.
BG10	The expected budget is not met	B	3	Low	By assuring sufficient funding before critical phase or by reducing the number of costly components.
BG20	The expected budget is not met	B	3	Low	By assuring sufficient funding before critical phase or by reducing the number of costly components.
OR10	Failed outreach approach	B	1	Very Low	Adapt communication approach to each potential target groups we address.
PE10	Team members leave the team	C	2	Low	Even if people leave other team members can cover that.Files uploaded in common folders, frequent meetings and updates to understand each others' work.
PE20	Communication: team member misunderstands objectives/requirements	B	2	Low	Regular weekly meetings scheduled between the departments and get expert advice from external support. (See section 3.3.3)
PE30	University schedule overlaps with project responsibilities	C	2	Low	Proper scheduling of BEXUS and university workload. Resource Allocation.
PE40	Members lacking motivation	B	2	Very Low	Frequent talks and presentations within meetings to have a clear goal in mind.

PE50	Fail or lack of communication between members	B	2	Very Low	Frequent meetings organised, members encouraged by their team members to discuss their difficulties.
PE60	Unplanned events that will have a negative impact on the project's timeline.	C	2	Low	Enough number of team members to cover each others work - good interpersonal communication between members.

4 Experiment Description

4.1 Experiment Setup

The IRIS experiment consists of a data storage unit and two sensor arrays. One at the bottom of the gondola, pointing downwards, and the other one at the top, pointing upwards. The data storage unit is kept in a box within the central box. The main sensors needed for the experiment are light sensors in the infrared and visible wavelength spectrum, namely photodiodes. These have fisheye lenses mounted on them to expand their field of view. A camera is also included on both sensor boxes. Interior temperature sensors are included, to check that the temperature is within the safe temperature ranges of the electronics. An atmospheric pressure sensor and a GPS are also included.

Data is managed by microcontrollers and is sent both to the data storage unit and to the ground station, while the microcontroller of each box uses the internal temperature measurements to manage an active thermal control system, composed of electrical heaters. A detailed view of the subsystems that are going to form the experiment can be found in fig. 4.1.1.

4.2 Experiment Interfaces

4.2.1 Mechanical

The experiment is composed of three main units, namely the upper sensor box, the bottom sensor box and the brain box. A general view of the IRIS mechanical design can be seen on fig. 4.2.1. The upper and bottom sensor box are protruding from the gondola by using booms, while the brain box is kept inside the gondola.
Two booms are used for each sensor box to provide a stiff and stable structure. These are made of polycarbonate to ensure breaking in case of a hard landing, to avoid damage to the gondola. Each pair of booms extends 1.145 m away from the gondola frame to minimise the interference with the belts of the gondola. The upper and bottom sensor box were designed to be as symmetric as possible, in order to reduce the number of additional spare parts. However the mounting of the booms cannot be identical. For the upper booms, clamps to mount the booms on the gondola structural frame are used, as shown on fig. 4.2.4. On each clamp 4 M6x80 and 2 M6x60 are used to clamp the polycarbonate clamp on the gondola.

For the bottom booms similar clamps are used to mount them on the mounting rails, as shown on fig. 4.2.3. Compare to the upper boom clamp, the bottom boom use a smaller

The sensor box mounted on each of the upper and bottom booms have an identical mounting on each. As shown on fig. 4.2.5, clamp parts used in the bottom polycarbonate clamp are used to mount the sensor box to the boom. 8 M6x15 with rubber bumpers are used to mount the sensor box to the clamp system.

The brain unit has been designed to be large enough in order to mount it on the gondola rails, which allowed to reduce its height. The brain box is mounted by using the mount-

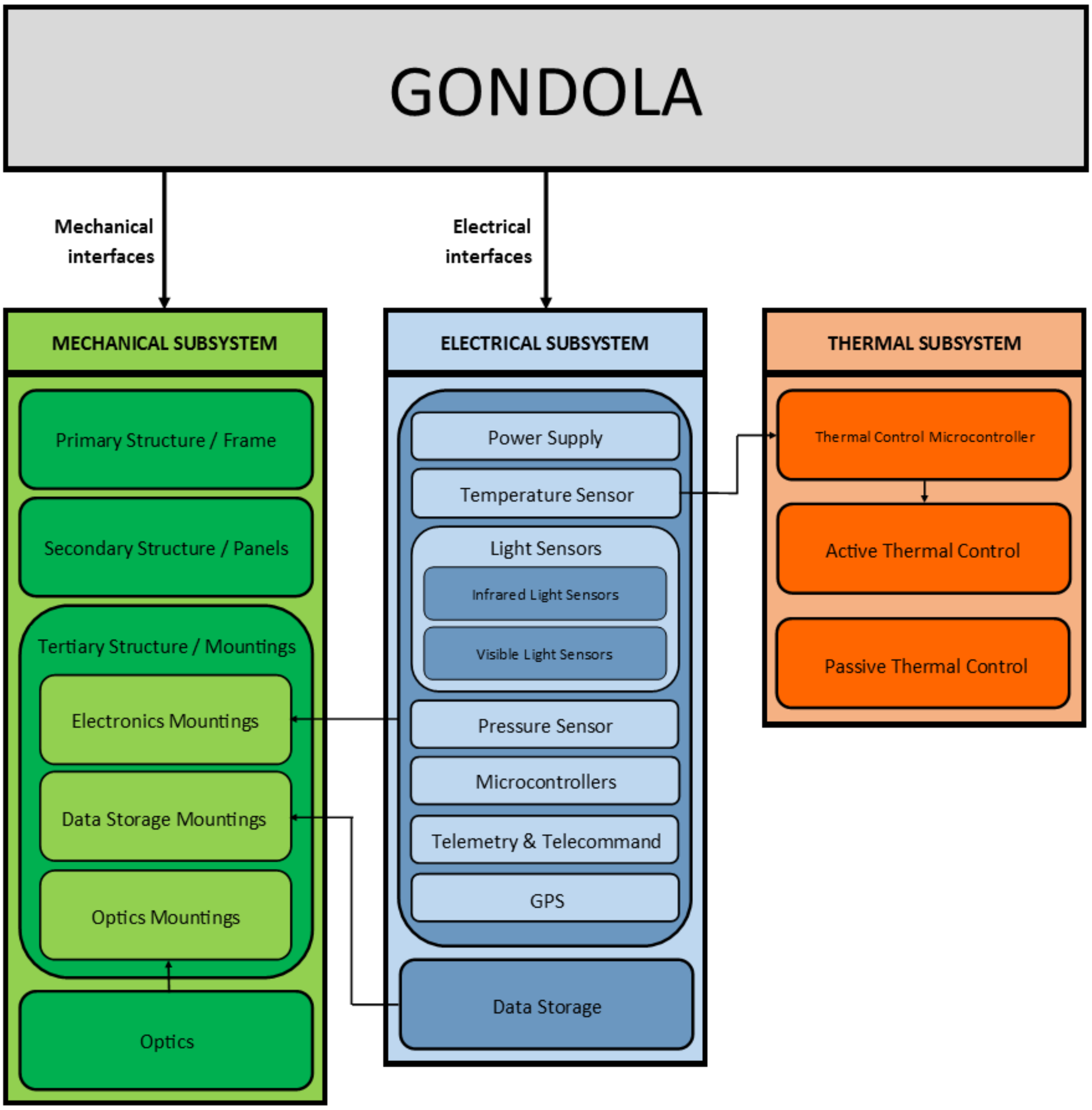


Figure 4.1.1: Subsystem diagram of the IRIS experiment.

ing rails of the gondola with M6×23 bolts, as shown on fig.4.2.2.Additionaly rubber bumpers are used to damp vibration and to reduce conduction from the heat bridge with the gondola.

Static load and shock tests will be conducted to check whether the chosen nuts and bolts meet the requirements stated in section 2.3.

∗ *ISO identifiers for the bolts and nuts used in the design will be added on the next SED version (3.0).*

Table 4.2.1: Bolts, nuts and washers used to mount the bottom, upper and brain box on the gondola.

Box	**Bolts**	**Nuts**	**Washers**
Upper Sensor Box	16 M6×80, 8 M6×60	24 M6	32 M6
Bottom Sensor Box	8 M6×23, 8 M6×60	16 M6	16 M6
Brain Box	4 M6×23	4 M6	4 M6

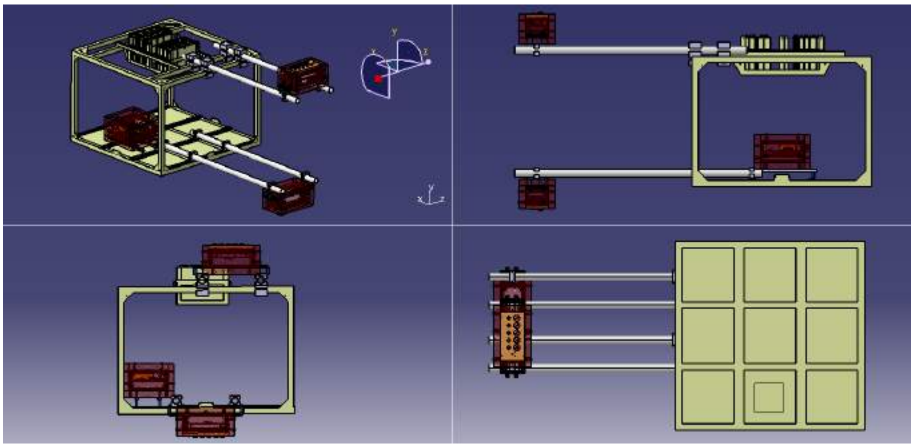


Figure 4.2.1: General view of the experiment from four different perspectives: Isometric perspective (upper left), plane xy (upper right), plane yz (lower left), and plane xz (lower right).

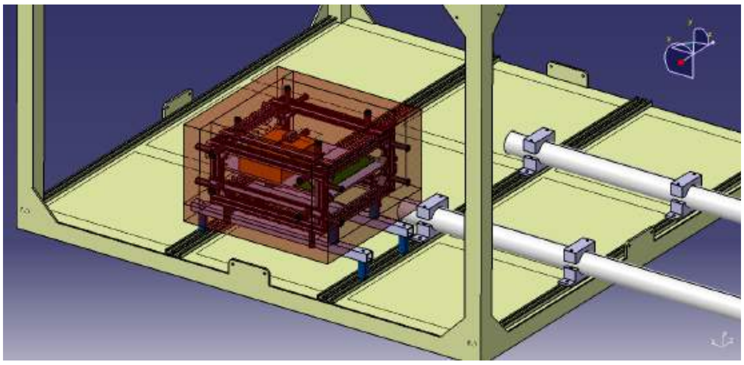


Figure 4.2.2: Top view of the "Brain" unit mounted on the gondola mounting rails.

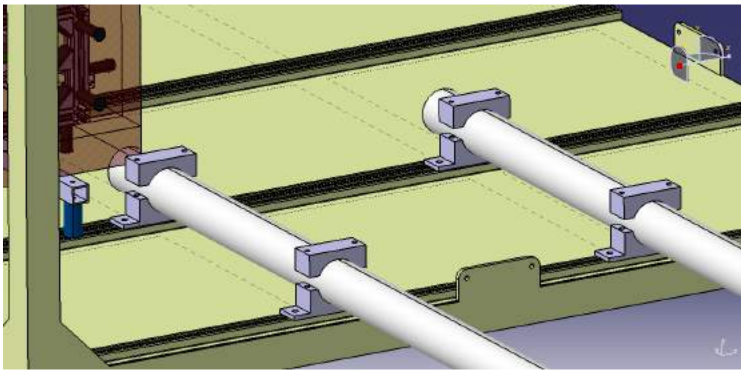


Figure 4.2.3: Top view of the lower booms mounted on the gondola mounting rails.

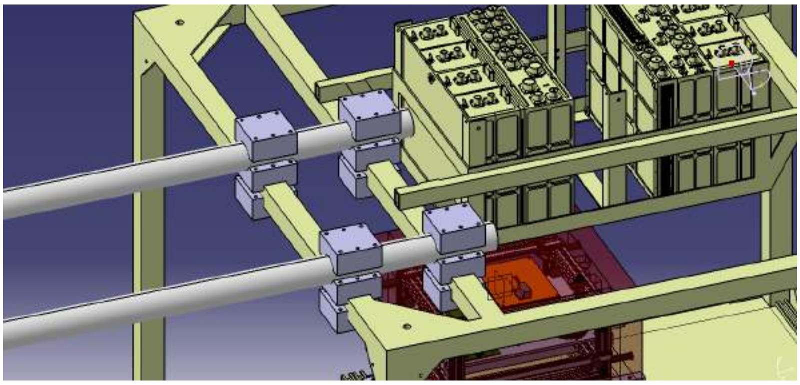


Figure 4.2.4: Top view of the upper booms mounted with clamps on the gondola frame (next to the airborne unit).

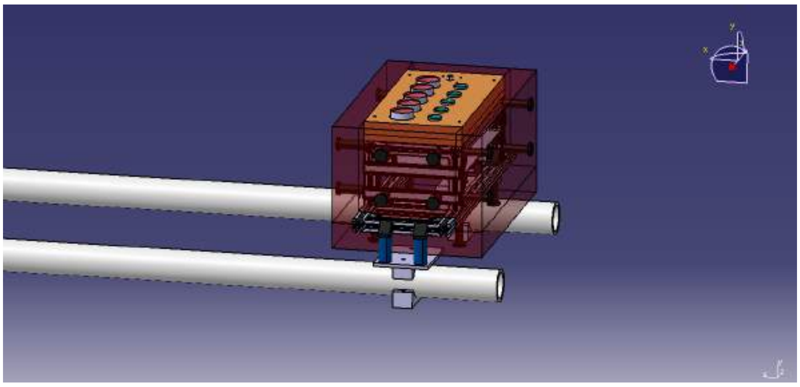


Figure 4.2.5: Top view of the sensor box mounting on the booms (upper and bottom).

4.2.2 Electrical

According to the BEXUS User Manual, an Ethernet protocol shall be used in this experiment, and the connector shall be an Amphenol RJF21B with a standard RJ45 connector.

The transfer rates are expected to be 200 kbps nominal and 200 kbps peak downlink. The expected uplink rates will just be command strings, not greater than 256 bytes per request. For more information about transfer rates, please refer to section 4.8.2.3.

The experiment uses the provided 28.8 V/1 mA (13 Ah) battery pack consisting of eight SAFT LSH20 batteries in series, where each battery has got a built-in 5 A fuse (not changeable) for protection, and the combined recommended continuous maximum current draw is 1.8 A. The expected max current is 1.24 A and the expected average current draw is 0.62 A. The connector to the battery which will provide power to the IRIS experiment shall be a 4" male, box mount receptacle MIL – C-26482P series 1 connector with an 8-4 insert arrangement (MS3112E8-4P) as specified in the BEXUS User Manual.

4.3 Experiment Components

Component	Supplier	Mass	Dimensions	Amount	Cost	Notes	Status
Serial Camera Module 4D Systems		6 g	32x32x21 mm (varies with focus)	2	100 EUR (total)	Low weight, cheap	Delivered
Garmin GPS Receiver 18x-LVC		160 g	diameter: 85 mm, height: 50 mm	1	110 EUR	Compact, cheap	Delivered
Barometric Pressure Sensor MS5607-02BA03		< 5 g	5.0x3.0x1.0 mm	4	84 EUR (total)	High resolution, large measuring range	Delivered
Photodiode G12183-030K Longwave		< 1 g	9.4x22.4mm	8	100 EUR (total)	Large measuring range	Not ordered
Photodiode S1336-8BK		< 1 g	14.1x20.2mm	12	100 EUR (total)	Large measuring range	Not ordered
Op-amp LMP2022		< 1 g	4.0x4.0x2.0 mm (approx.)	10	2.5 EUR	low drift, low noise	Delivered
A/D-Converter ADS1115		< 1 g	3.1x5.1x1.1 mm (approx.)	6	6.3 EUR		Delivered
Watchdog Timer TPL5010		< 1 g	3.0x3.0x1.0 mm (approx.)	1	0.8 EUR		Delivered
Raspberry Pi 2 Model B+		42 g	85x56x1.4 mm (without considering USB ports, etc.)	1	25 EUR	Easy to use, cheap	Delivered
Arduino Nano		7 g	18x45 mm	2	25 EUR	Easy to use, cheap	Delivered

DC/DC Converter 15W 18-36Vin 5Vout 300-3000mA		15 g	25x25x10 mm	3	30 EUR	Low consumption of supply current	Ordered
FTDI TTL-232R-3V3		50 g	1.8 m, 5 mm ⊘	2	16.6 EUR (each)	-	Delivered
PSCC TCK-050		10 g	11x8.8 mm	3	4.1 EUR (each)	-	Not ordered
STEGO 01602.0-03 PTC HEATER		20g	30x12.5 x12.5 mm	4	39 EUR (each) +extra for delivery	-	Not ordered
BSS138 transistor		< 1 g	3x2.5x1.2 mm	4	0.2 EUR (each)	-	Not ordered
OSTOQ PCB-connectors		3 g	12x8.5xXX mm	21	1 EUR (each)	Dimensions vary with pins	Not ordered
OSTTJ PCB-connectors		3 g	12x8.5xXX mm	21	1 EUR (each)	Dimensions vary with pins	Not ordered
STAUBLI 61 ⊘1.0 mm Wire		10 g/m	5 m	1	19 EUR	Large temperature range	Not ordered
Optical Filter 440BP20**	Omega Optical	TBD	25.4x5mm	2	$98.80	**WR**:430-450 nm, **AR**:430-450 nm, **CW**:440 ± 5 nm **FWHM**:20 ± 5 nm	Not ordered

Optical Filter	Edmund Optics	TBD	12.5x5mm	2	$125.00	**WR**:450-510* nm, **AR**:450-500 nm, **CW**:475 ± 5 nm, **FWHM**:50 ± 5 nm	Not ordered
Optical Filter 560BP60 RAPID-BAND	Omega Optical	TBD	25x3.5mm	2	$175.00	**WR**:530-590 nm, **AR**:530-590 nm, **CW**:560 ± 2 nm, **FWHM**:60 ± 4 nm	Not ordered
Optical Filter FB650-40	Thorlabs	TBD	25.4x6.3mm	2	$91.50	**WR**:630-670 nm, **AR**:630-670 nm, **CW**:650 ± 2 nm, **FWHM**:40 ± 4 nm	Not ordered
Optical Filter	Edmund Optics	TBD	12.5x5mm	2	$125.00	**WR**:850-880* nm, **AR**:850-900 nm, **CW**:875 ± 5 nm, **FWHM**:50 ± 5 nm	Not ordered
Optical Filter	Edmund Optics	TBD	12.5x5mm	2	$149.00	**WR**:1360-1380* nm, **AR**:1350-1400 nm, **CW**:1375 ± 5 nm, **FWHM**:50 ± 5 nm	Not ordered

Optical Filter	Edmund Optics	TBD	12.5x5mm	2	$149.00	**WR**:1560-1660* nm, **AR**:1575-1625 nm, **CW**:1600 $\pm$ 5 nm, **FWHM**:50 $\pm$ 5 nm	Not ordered
Optical Filter FB2250-500	Thorlabs	2 g	25.4x6.1mm	2	2,808.00 SEK	**WR**:2000-2500 nm, **AR**:2000-2500 nm, **CW**:2250 $\pm$ 50 nm, **FWHM**:500 $\pm$ 100 nm	Not ordered
Smartphone fisheye lenses	Amazon	48 g	TBD	5	$ 50	TBD	First fisheye lenses received.
Fisheye lenses DSL315	Sunex	TBD	TBD	5	$ 129	TBD	Not ordered
Aluminium rough-cast plate	Alfer/Elfa	TBD	200x250x0.8 mm	TBD	77.20 SEK	...	Not ordered
Aluminium perforated plate (round-holes)	Alfer/Elfa	Mass	200x250x1.5 mm	TBD	204 SEK	...	Not ordered
Mounting plate Aluminium	Pentair Schroff/Elfa	Mass	84x220x2 mm	TBD	179 SEK	...	Not ordered
Mounting plate Aluminium	Pentair Schroff/Elfa	Mass	84x280x2 mm	TBD	193 SEK	...	Not ordered

Mounting plate Aluminium	Pentair Schroff/Elfa	Mass	84x460x2 mm	TBD	256 SEK	...	Not ordered
Mounting plate Aluminium	Pentair Schroff/Elfa	Mass	84x400x2 mm	TBD	187 SEK	...	Not ordered
Mounting plate Aluminium	Pentair Schroff/Elfa	Mass	84x340x2 mm	TBD	218 SEK	...	Not ordered
Sheet aluminium, blank	Alfer/Elfa	Mass	500x250x0.3 mm	TBD	33.10 SEK	High Priority	Not ordered
Sheet aluminium, blank	Alfer/Elfa	Mass	500x250x0.5 mm	TBD	50.60 SEK	High Priority	Not ordered
Sheet aluminium, blank	Alfer/Elfa	Mass	500x250x0.8 mm	TBD	57.60 SEK	High Priority	Not ordered
Bosch Rexroth 20 series, 300mm	Bosch	0.4 kg/m	20x20x300 mm	4	20 Euro per 3000mm	...	Not ordered
Bosch Rexroth 20 series, 260mm	Bosch	0.4 kg/m	20x20x260 mm	8	20 Euro per 3000mm	...	Not ordered
Bosch Rexroth 20 series, 220mm	Bosch	0.4 kg/m	20x20x220 mm	4	20 Euro per 3000mm	...	Not ordered
Bosch Rexroth 20 series, 110mm	Bosch	0.4 kg/m	20x20x110 mm	8	20 Euro per 3000mm	...	Not ordered
Bosch Rexroth 20 series, 100mm	Bosch	0.4 kg/m	20x20x100 mm	4	20 Euro per 3000mm	...	Not ordered

Bosch Rexroth 20 series, 80mm	Bosch	0.4 kg/m	20x20x80 mm	8	20 Euro per 3000mm	...	Not ordered
Watertight box	Hammond Manufacturing /Digikey	224 g	119 x 94 x 34mm	1	100 SEK	...	Not ordered
Styrofoam XPS insulation	Byggmax	TBD	2500 x 600 x 12 mm	TBD	379 SEK each	...	Not ordered
Bosch Rexroth Strut Profile Angle Bracket	RS-Online	TBD	Strut profile 20 mm, Groove Size 6mm	100	2.34 Euro each	...	Not ordered
Nylon Screw M4	RS-Online	TBD	Length 6 mm, thread pitch 0.7	100	2.06	...	Not ordered
Bosch Rexroth Strut Profile T-Slot Nut	RS-Online	TBD	M4 Thread strut profile 20 mm, Groove Size 6mm	100	0.7 Euro each	...	Not ordered
Nylon Hex Spacer Standoff	Elfa	TBD	M4 Thread 40 mm male-female	100	5 SEK each	...	Not ordered

Explanations: **WR** = Wanted Range, **AR** = Actual Range, **CW** = Center Wavelength,
***** = Exact range not found

Total mass of the experiment is $22{,}556$ kg.

Table 4.3.2: Sensor Box: Mass and volume

Experiment mass (in kg):	2,773
Experiment dimensions (in m):	0,511×0,23×0,19
Experiment footprint area (in m2):	0,1
Experiment volume (in m^3):	0,012
Experiment expected COG position:	x = -1,661 [m]; y = 0,661 [m]; z = 0,171 [m] for the bottom sensor box. x = -1,661 [m]; y = -0,417 [m]; z = 0,001 [m] for the upper sensor box.

Table 4.3.3: Upper Sensor Box and Booms: Mass and volume

Experiment mass (in kg):	11,798
Experiment dimensions (in m):	1,42×0,467×0,333
Experiment footprint area (in m2):	0,663
Experiment volume (in m3):	0,016
Experiment expected COG position:	x = -0,959 [m]; y = 0,538 [m]; z = 0,172 [m]

Table 4.3.4: Bottom Sensor Box and Booms: mass and volume

Experiment mass (in kg):	6,746
Experiment dimensions (in m):	1,6×0,457×0,265
Experiment footprint area (in m2):	0,731
Experiment volume (in m3):	0,015
Experiment expected COG position:	x = -1,244 [m]; y = -0,333 [m]; z = 0,001 [m]

Table 4.3.5: Central "Brain" Box mass and volume

Experiment mass (in kg):	4,012
Experiment dimensions (in m):	0,361×0,34×0,28
Experiment footprint area (in m2):	0.123
Experiment volume (in m3):	0,019
Experiment expected COG position:	x = -0,054 [m]; y = -0,148 [m]; z = -0.38 [m]

4.4 Mechanical Design

4.4.1 Sensor Box

The sensor box design is identical for the upper and bottom parts. In tab. 6.1.1, the two respective centers of gravity of the sensor boxes without the booms are shown. The frame structure of each sensor box is made of Rexroth 20x20mm aluminium profiles. Angle brackets are used inside each sensor box to mount a plate for the corresponding electronic components, as shown in fig. 4.4.1.

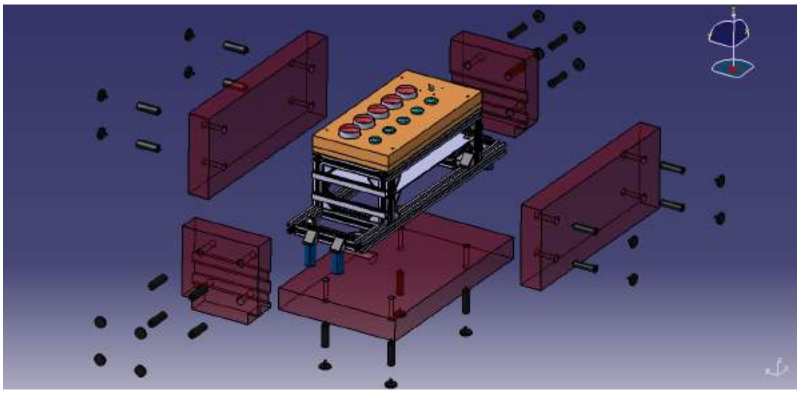


Figure 4.4.1: Exploded view of the sensor box. The red panels are those of thermal insulation.

The sensor box is mainly composed of two subsystems: the optical subsystem—composed of photodiodes, filters and lenses- and the electronic subsystem—in charge of sending the photodiodes signal to the brain unit-. Each of these subsystems are mounted on aluminium plates, as shown in fig. 4.4.2.

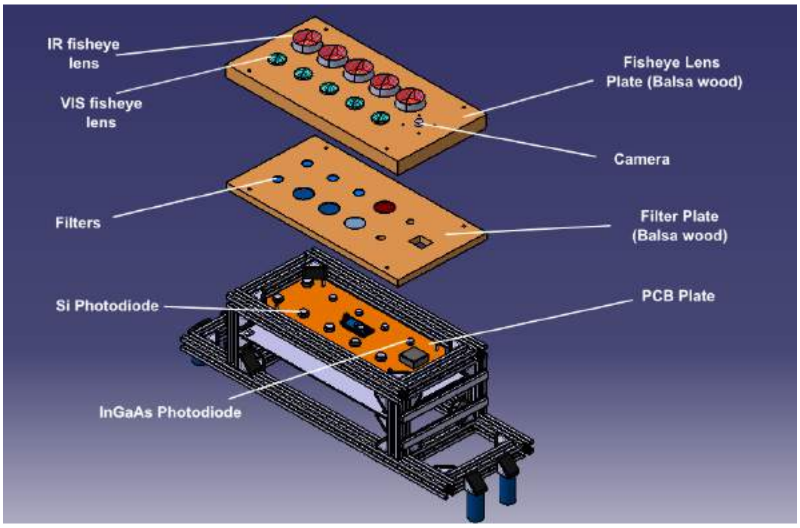


Figure 4.4.2: Exploded view of the sensor box mountings of the optical and electronics system.

The optical subsystem is assembled together by using several layers of aluminium plates to constraint the photodiodes and filters. For each of these optical components, a lower plate is used as a support for the component, and an upper plate is then placed on top of it for holding it in place. Fig. 4.4.3 shows how this mounting procedure can be accomplished.

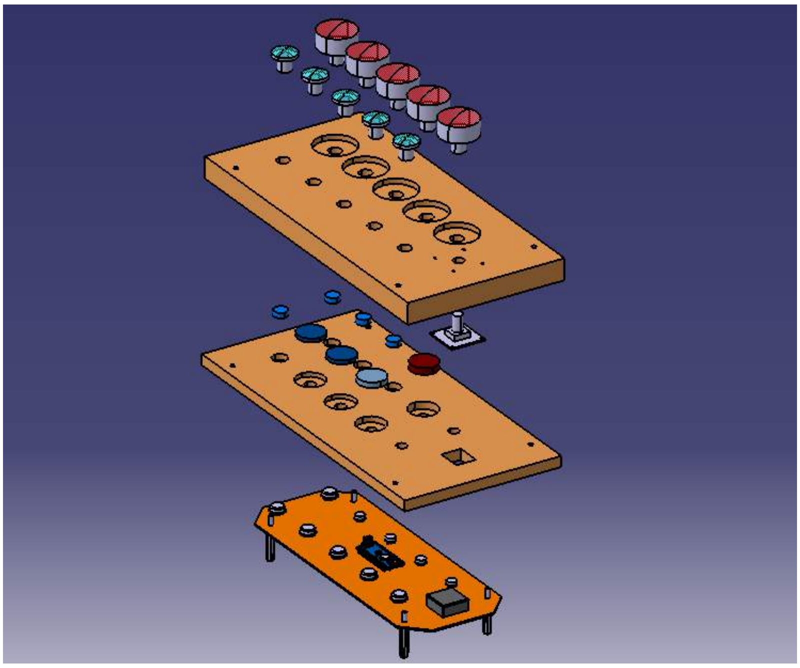


Figure 4.4.3: Exploded view of the optics subsystem mounting with an emphasis on photodiodes and filters mounting.

Because of the special characteristics of the optical systems, components off-the-shelf cannot be used. Therefore, the optics plate must be manufactured. All other components in the sensor box are almost completely off-the-shelf components.

4.4.2 Brain Box

The brain box of IRIS is the central processing unit where data is handled and stored. The brain box is mainly composed of the computer unit, GPS sensor and electronics system.

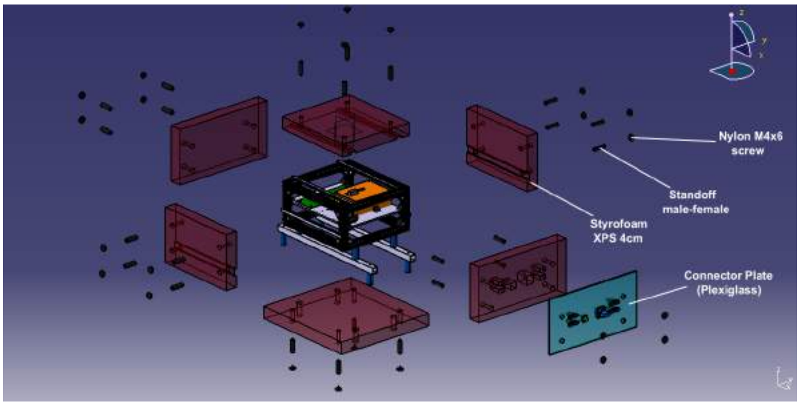


Figure 4.4.4: Exploded view of the brain box. The red panels are those of thermal insulation.

During the thermal analysis of the brain box, the high operating temperature of the Raspberry Pi had to be coped with. At the same time it was intended to design the data storage unit to be able to keep data safe in case of contact with water, in case the landing conditions are harmful. Therefore, it was concluded that isolating the Raspberry Pi with the data storage unit in a thermally insulated box inside the Brain box could solve the problem. As it can be seen in tab. 4.6.1, the RPi is the only component that have to be in positive Celsius to operate correctly. Thus, this component requires additional thermal insulation, while it is unnecessary to increase the insulation of the brain box. Due to the importance of this unit, it is sealed inside its own box.

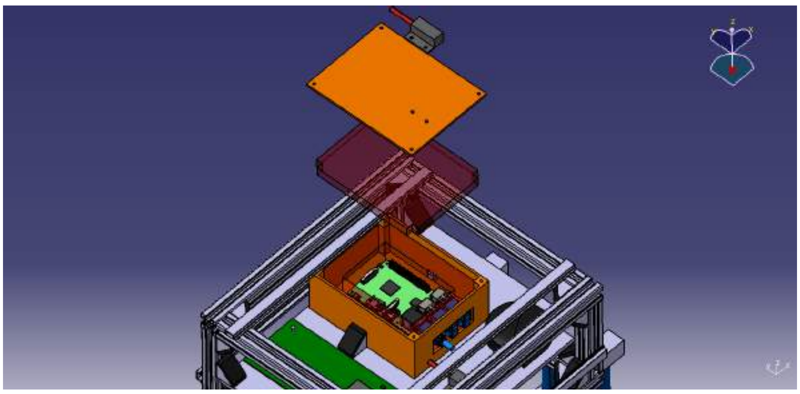


Figure 4.4.5: Detail of Raspberry Pi and Data Storage Unit robust, thermally insulated and watertight box. The holes on the box represent where the watertight cable adaptors will be mounted.

Beams and plates used on the experiment are created in aluminium alloys (Al). Additional nuts and bolts for attaching some of these elements together—as well as the equipment to the structure—are made of steel.

4.5 Electronics Design

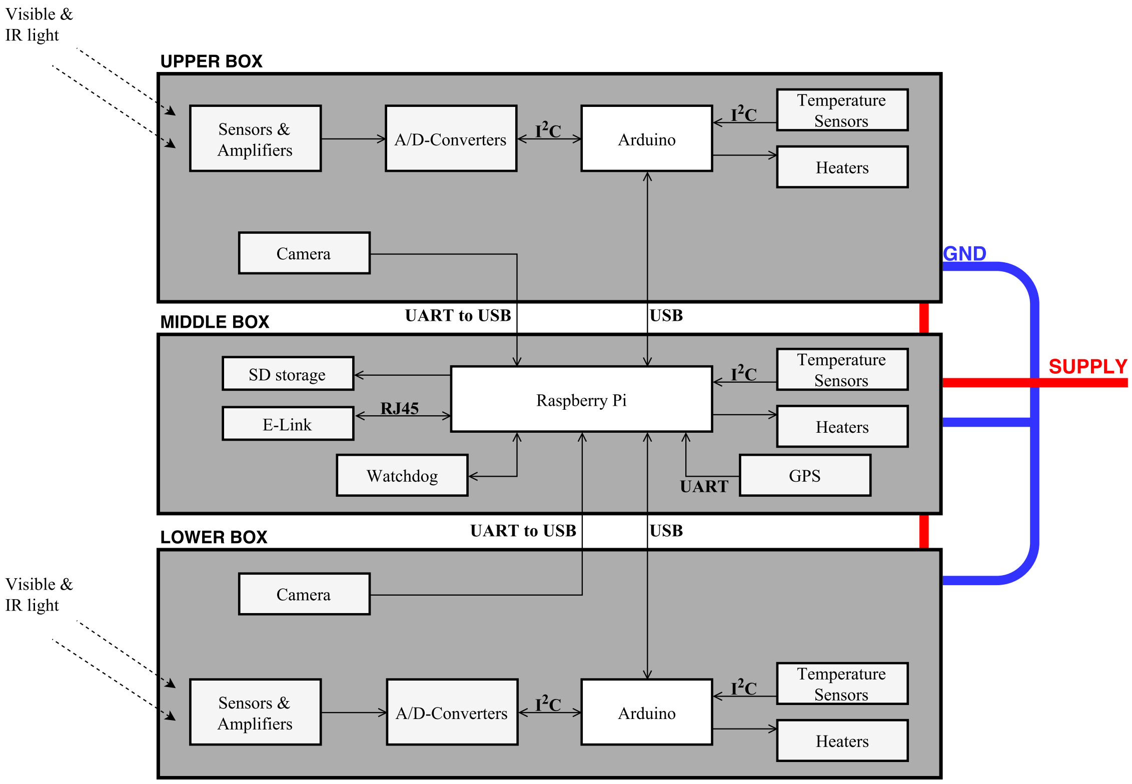


Figure 4.5.1: A block diagram of the electronics' signals and interfaces of the experiment.

Fig. 4.5.1 shows the general electrical signal diagram of the system, with interfaces.

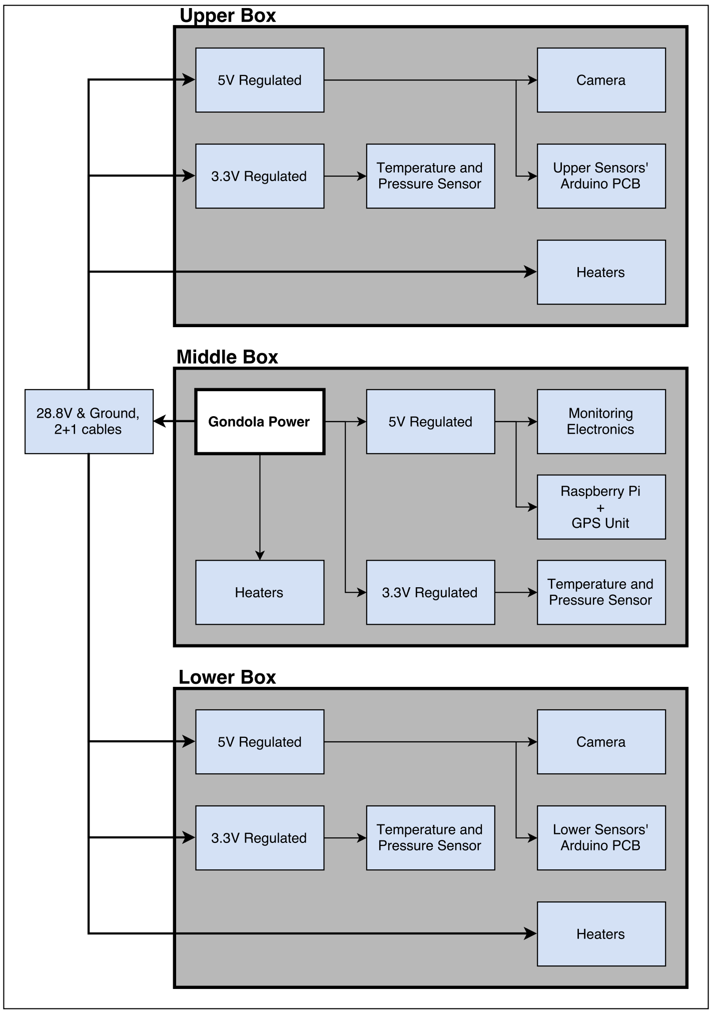


Figure 4.5.2: A block diagram of the power supply of the system.

Fig. 4.5.2 shows the power supply diagram of the experiment. The gondola's 28.8 V power is connected to the middle box inside the gondola. In the middle box, the regulated 5 V powers the Raspberry Pi and the external watchdog timer. From the middle box, 28.8 V is fed to the upper and the lower boxes, where the voltages are regulated inside to power the electronics. Fig. 4.5.3 shows the 28.8 to 5 and 3.3 V conversion circuit present in each box.

The heaters in each box are supplied with 28.8 V and are controlled by the local micro-controller through a FET.

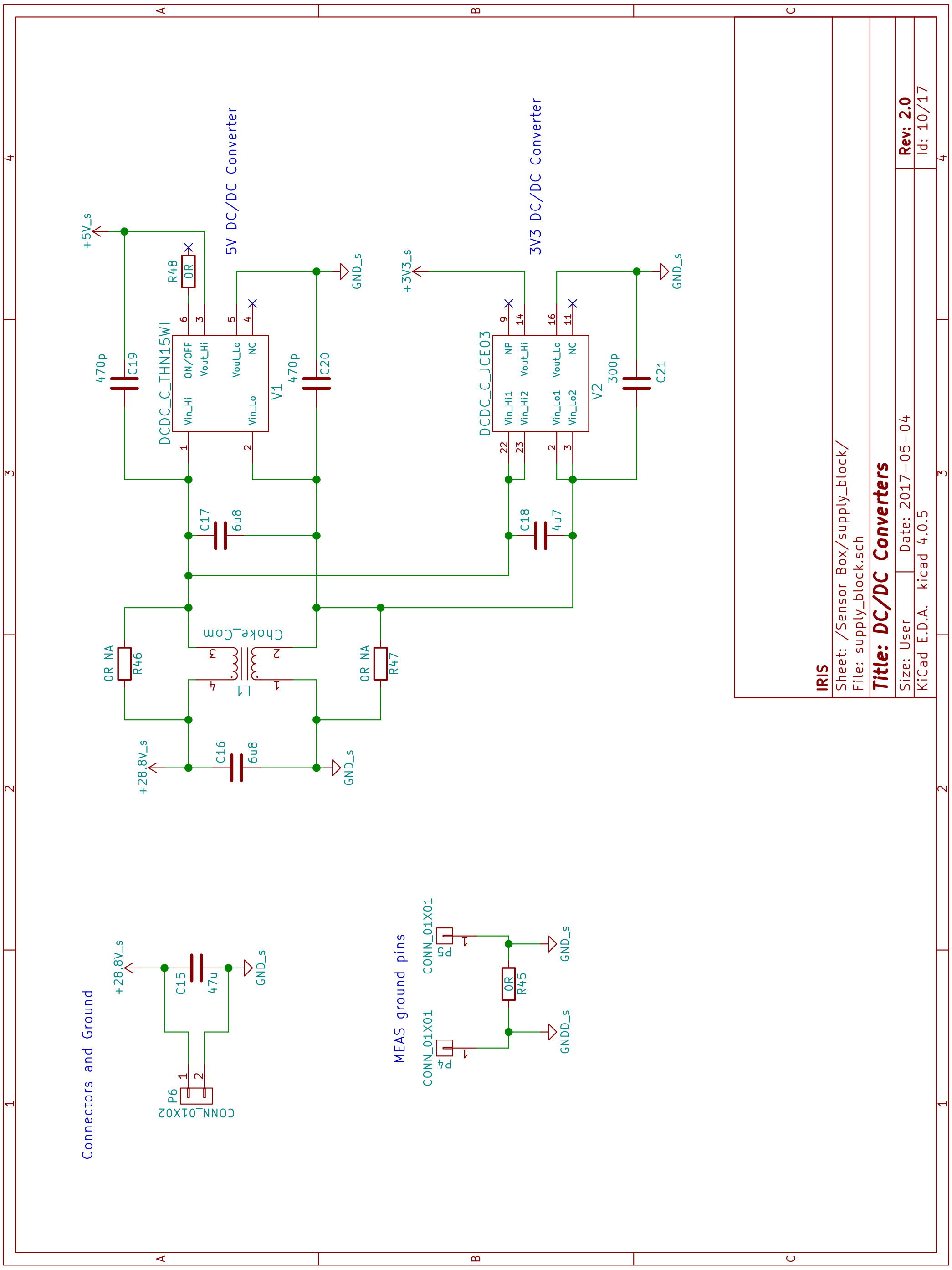


Figure 4.5.3: DC/DC-Converters for the local electronics. Sensor box gets 28.8 V from gondola via middle (brain) box.

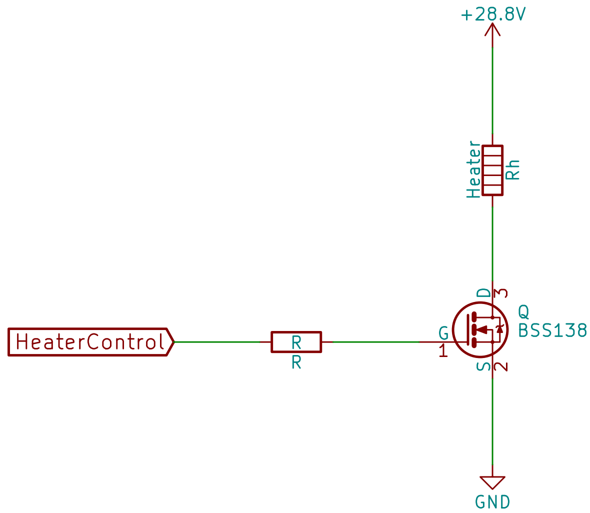


Figure 4.5.4: Simple heater circuit.

Fig. 4.5.4 is showing a simple circuit for heating. The heater is controlled by a PWM signal *HeaterControl* from the microcontroller using a transistor. The heater resistance R_h shall be chosen to be high enough so the power dissipated will not exceed the power budget in case of software failure.

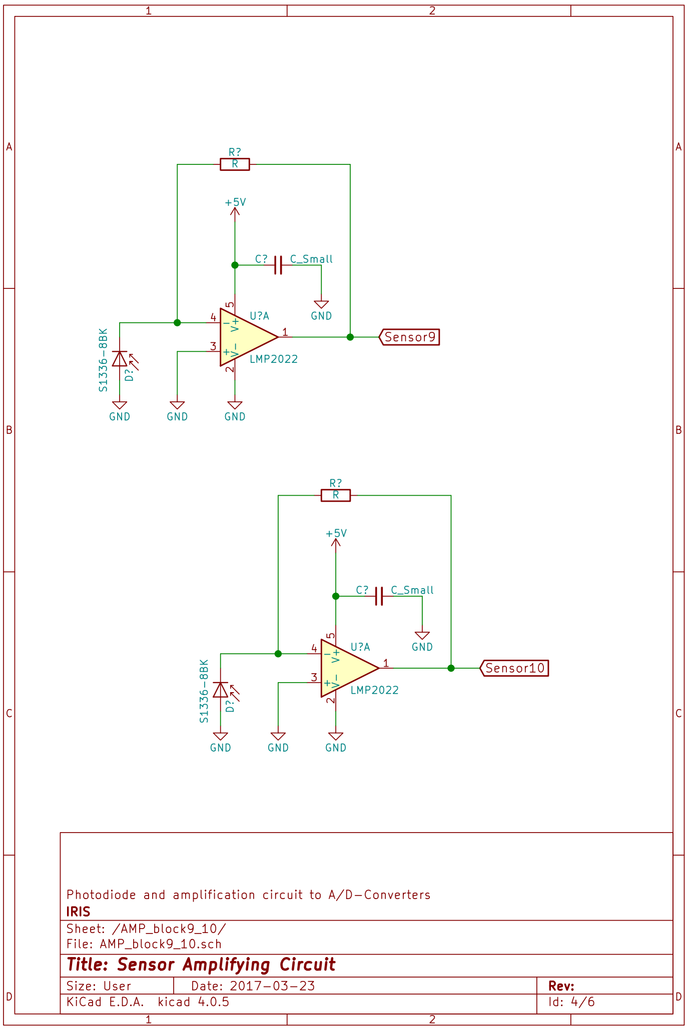


Figure 4.5.5: Photodiode amplifier circuit.

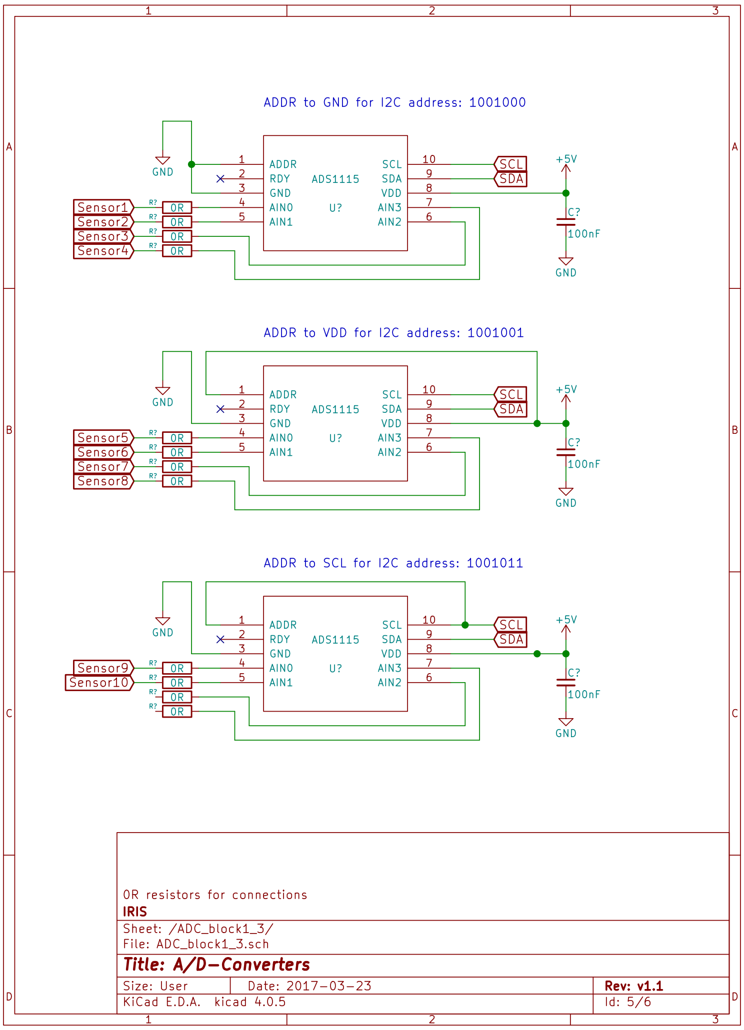


Figure 4.5.6: I2C connection, A/D-Converters to Arduino.

Figures 4.5.5 and 4.5.6 show (in part) the sensor circuits, from photodiode, to A/D-Converter, to the I^2C interface connected to the Arduino. The zero ohm resistors in fig. 4.5.6 are there to make it easier during assembly, if some complications arise, and unexpected connections are needed. The `ADDR` pin determines the I2C address of the ADS1115 ADC, giving different 7-bit addresses for different connections: `GND`, `VDD` or `SCL`. The 16-bit ADS1115 ADC has pins for four single-ended analog inputs, with built-in multiplexing.

The LMP2022 is used in the amplifying circuit. It is a low-noise, low-drift op amp, for precision and for the rough thermal environment.

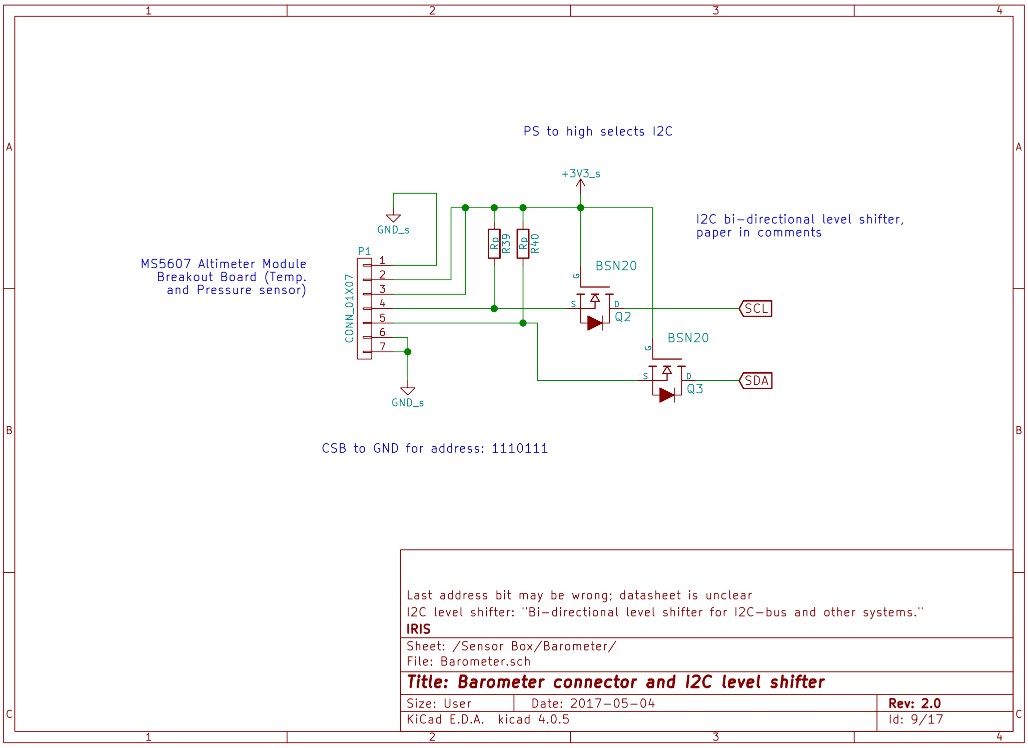


Figure 4.5.7: I^{2}C connection from barometer.

The barometer used for pressure measurements includes a temperature sensor which will be used for the heating systems. The barometer chip uses 3.3 V logic levels which differs from those of the Arduinos. This is solved using the circuit in figure 4.5.7. The transistors allow for write and read of the barometer (bi-directional). [17]

The complete circuits are added to Appendix C together with the PCB layouts, under the headings Electronics Circuits and PCB Layouts, respectively.

4.6 Thermal Design

Tab. 4.6.1 shows the expected operating maximum and minimum temperature of each component, as well as their longevity temperature range.

Table 4.6.1: Component thermal range table

ID	Component	Operating T($^{\circ}C$)		Survivable ($^{\circ}C$)		Comments
		Min	Max	Min	Max	
1	Serial Camera Module	-30	85	-40	105	
2	GPS Reciever	-30	80	-40	90	
3	Barometer	-40	85	-40	125	
4	Photodiode G12183-030K Longwave	-40	85	-55	125	
5	Photodiode S1336-8BK	-40	100	-55	125	
6	Raspberry Pi Model B+	0	70	-20	85	
7	Arduino Nano	-40	85	-40	85	
8	DC/DC Converter 5V	-40	85	-55	105	
9	DC/DC Converter 3.3V	-40	85	-50	125	
10	Sensor Amplifier (LMP2022)	-40	125			
11	AD Converter ADS1115	-40	125			
12	Heater Control Transistor (BSS138)	-55	150			
16	Watchdog Timer (TPL5010)	-40	105	-65	150	
13	USB to Serial Converter Cable (FTDI TTL-232R-5V) (USB-end connector)	-40	85			
14	I2C level shifter transistor BSN20	-55	150	-55	150	

The thermal control subsystem is divided into passive and active thermal control. The former is carried out by thermal insulation located on the inner side of the boxes containing the equipment. Active thermal control is accomplished by the use of heaters, which are controlled by the respective microcontroller in the upper and lower boxes and the Raspberry in the central box. Temperature measurements from the interior thermometers are used to ensure that all the electrical components are working within their operating ranges.

In order to design the active thermal control system, it was necessary to approximate the heat losses with only the passive thermal control system. Three cases with different assumptions were considered, from worst to best-case scenario. The results of this analysis can be found in app. F. At the end of the analysis, it was concluded that the middle-case scenario was the most realistic estimation.
This analysis provides the following results for thermal power balance on each box:

- Upper Sensor Box: $63.63\ W$

- Lower Sensor Box: $63.63\ W$

- Central "Brain" Box: $-11.52\ W$

- Central RPi Box: $-4.312\ W$

These results shows that if during the flight the Sun is present, a reflective surface or paint layer will be needed to prevent the sensor box to heat up. However, the worst-case scenario also showed us that heating within the sensor box might be needed if the Sun is not present during the whole flight.

Based on these thermal calculations, one heater is needed in the upper box, one in the central box, one in the lower box and one in the Raspberry Pi box to keep the temperature within the operating range of the electronic devices. The heaters are small 8 W PTC (Positive Temperature Coefficient) heating elements.

Styrofoam™ foam thermal insulation of 10 cm thickness is also required on every side of the brain and sensor boxes. For the side of each box that is covered by an aluminium plate -meant for housing the various electrical sockets- this insulation is split in two layers: a 3 cm thickness one on the outside and a 7 cm one on the inside of said plate. All thermal insulation panels are strapped to their respective box frames with Nylon screws.

4.7 Power System

To fulfil the power needs for the project, a battery pack is available for use. The pack is stated to be able to provide 28.8 V/1 mA and has 13 Ah. One other constraint that must be considered is the 1.8 A continuous use of current as stated in the BEXUS user manual. With these constraints well defined, the list of components can be added, and determined in case additional power will be required. The first estimate of the power for the experiment seems to fit within these margins as stated below in tab. 4.7.1. The power budget will also be able to support a possible number of heaters, which will be placed at strategic locations, if they are considered necessary after the problem areas have been identified.

Table 4.7.1: Power consumption estimation, (wattages summed over total component numbers)

ID	Component	Voltage [V]	Current [mA]	Power [W]	Total [Wh]
1	Serial Camera Module	5	90	0.90	9
2	GPS Receiver	5	90	0.45	4.5
3	Temp. and Pressure sensor	3.3	0.0014	0.014	0.14
4	Photodiode G12183-030K Longwave	5	N/A	N/A	N/A
5	Photodiode S1336-8BK	5	N/A	N/A	N/A
6	Raspberry Pi 2 Model B	5	600	3	30
7	Arduino Nano	5	2×19	0.19	1.9
8	Watchdog Circuit	-	-	-	-
9	A/D-Converters	5	0.15	0.005	0.05
10	Sensor Op-amp	5	1.1	0.11	1.1
11	DC/DC Converters, 5V	-	-	1.19	11.9
12	DC/DC Converters, 3.3V	-	-	0.004	0.04
13	Heaters	28.8	1111	32	320
14	**Total**	N/A	N/A	38	379
15	**Available from gondola**	N/A	N/A	N/A	374.4

The total consumption of power assumes that the heaters are on 100 % of the time full power and the consumption does exceed the power available from batteries. But this scenario is not likely, an estimation is that the heaters is on 50 % of the time full power, in this scenario the total power consumption does not exceed the power available from the gondola.

4.8 Software Design

4.8.1 Purpose

The software will be responsible for monitoring, housekeeping and data handling of the experiment IRIS. A monitoring and housekeeping subsystem will be designed, and environmental experiment data shall be stored and a portion transmitted to a ground station to aid a successful mission.

4.8.2 Design

4.8.2.1 Process overview

The system has been designed to fulfil three main functions: handling measured data, telemetry for sending back data to ground, and monitoring and housekeeping internal systems.

Most of the measured data is to be stored on an internal memory in the form of a SD-card. Some data from the camera uses the downlink during the early parts of the mission, specifically the ascent, to utilise the larger downlink rates and ease constraints on the memory budget and reduce the risk of experiment result returning NULL. The central hub and coordinator will be a SOC, in particular a Raspberry Pi (RPi). The RPi shall be responsible for data handling, data storage, telemetry and talking to the MCU:s (Arduino) that relay data from the sensors to the RPi.

There will be a total of two MCU's. The two MCU's will be responsible for data collection and thermal monitoring and control in their respective box.
The process, including interfaces, is described graphically in fig. 4.8.1.

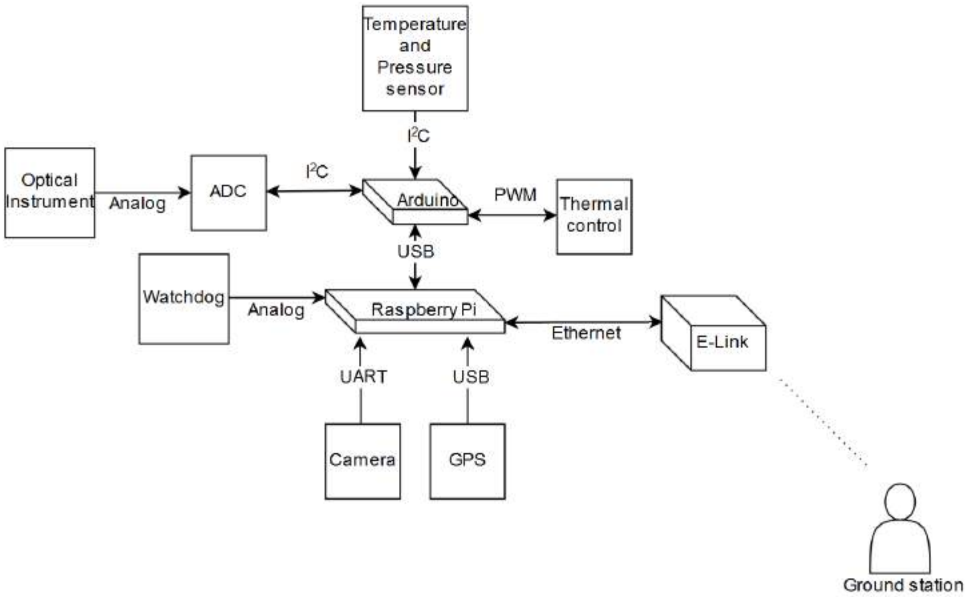


Figure 4.8.1: Process Overview Diagram

4.8.2.2 General safety related concepts

All components that can, shall include individual failsafes in form of rebooting schemes, in case of unsuspected events. The RPi will also be connected to an external watchdog. Some of the possible failure modes are described in tab. 4.8.1.

4.8.2.3 Interfaces

The platform interfaces between components can be seen in tab. 4.8.1, and Ethernet Base 10/100 for communicating with the E-Link. The module shall be able to transmit part of the data gathered and stored, operate autonomously in the event of loss of communication with ground station, and ensure a correct transmission from the sensors to the storage unit.

The telemetry sent via the E-link has a TBD size, and every packet will feature a

Table 4.8.1: General safety concerns

Topic	Possible errors and safety concerns	Mitigation measures
Initialization	- Any of the connected devices through UART does not initialize. ADC or storage fails to start.	- If the Ethernet interface with the E-link is initialized but no other interface is, a critical failure message will be sent. One restart attempt will happen after that. - Each component that fails to intiate will go to rebooting procedure.
Data storage	- Possible corruption or loss of data	- Shut down the system before touchdown, disconnect power from the storage unit to avoid damage. - Be wary of using FAT, the allocation table has been known to corrupt or wrongly allocate files after unexpected power off. - Use journaling.
Heaters	- Temperature inside the experiment boxes is under/over the thresholds before lift-off.	- Monitor temperature on the experiment before lift-off will be monitored and action will be taken.
Sensors performance	- Any malfunction in sensors is detected.	- Readings will continue to be taken, but a flag/message indicating faulty measurements will be added.
E-link connection	- Connection is lost or not working.	- The system will continue to work with pre-stored conditions for loss of communications. - Data transmission will be halted until connection is recovered.
Test	- The system has rebooted, or dedicated command has been received.	- During test mode little data will be stored and testing telemetry will be sent through the command link for troubleshooting. It will be determined by the number of tasks to be performed.

header and terminator. Tab. 4.8.2 depicts the packet design for the telemetry data.

Table 4.8.2: Telemetry and telecommand messages

Name	MID	DATA	STAT	CHK
Description	Message ID	Transmitted message	Status	Checksum
Size	2 bytes	1-16 bytes	1 byte	2 bytes
Use	States the nature of the message and its length	The data transmitted	Gives telemetry data or mode of operation	Checks errors of the message

The telecommand functionality will follow the same packet distribution as the telemetry design, but featuring a fixed 1 byte transmitted data section for the command.

The protocols used for packet transmission will be UDP for upling and downlink. The minimum expected bandwidth is 100 kbit/s and the maximum of 200 kbit/s. This is based on an image every ten seconds, weighting 800 kbits each. The uplink of commands is expected to be sporadic messages for command, minimum of 0 kbps, nominal of 20 bytes and peak of 50 bytes. This is based on the protocols to be used.

Regarding the internal communication system, the interfaces will be serial communication and the reception of the data from the sensors is done in analog fashion. The pressure and temperature sensor feature a serial I2C interface, and the actuation on the thermal control system will be done using PWM signals.

The communication protocol with the off-the-shelf components using serial such as the GPS and camera is TBD. However, for the communication between the Arduino MCUs and RPi the communication will be as follows in tab. 4.8.3.

Because the camera will have a UART interface it is necessary to make sure that it is sufficiently fast. It was determined that the UART will be fast enough. The reason for this choice over USB was that the camera came with UART interface and to limit the number of USBs as much as possible connected to the RPi which may have power issues when multiple USB's are connected, because of the thin strip-conductors within the RPi.

Table 4.8.3: Inner communication packet design

Name	SYNC	MID	VAL	STAT	PAR
Description	Synchronization	Message ID	Transmitted value	Status	Parity bit
Size	16 bits	8 bits	8-12 bits	1 bit	1 bit
Use	Used to identify and synchronize the beginning of the message	States procedence of the message and the sensor generating the value	The value transmitted	States the calibration of the sensor	Checks errors of the message

To avoid corrupt data on transmission, a checksum in larger and a parity bit in short messages is included. Critical messages (such as commanded shut down from ground) will be sent twice for the experiment not to be blocked by these.

Please refer to section 4.5 for more information on the analog interfaces.

4.8.2.4 Data acquisition and storage

The RPi used in the experiment has an inbuilt microSD card slot. This is used to store the boot information for the board's software and the data gathered by the sensors. The estimated amount of data from the sensors is two bytes from each of the photodiodes, and between 400 and 800 kB for the single camera reading. Position, temperature and pressure readings are also considered a total amount of 1 kB.

The experiment shall take measurements with a delay of between 3 seconds, and the approximate flight time is around six hours. Therefore, the expected amount of data generated is 4 GB, which can be solved with one 8 GB microSD card.

Part or the complete of the data will be sent back to the ground station. The station features a fully capable computer that integrates enough storage capacity for the data that has been sent.

The data files to be used for this purpose are txt files generated as a CSV file to store the sensor data, and JPEG format to store the information about the images.

4.8.2.5 Process Flow

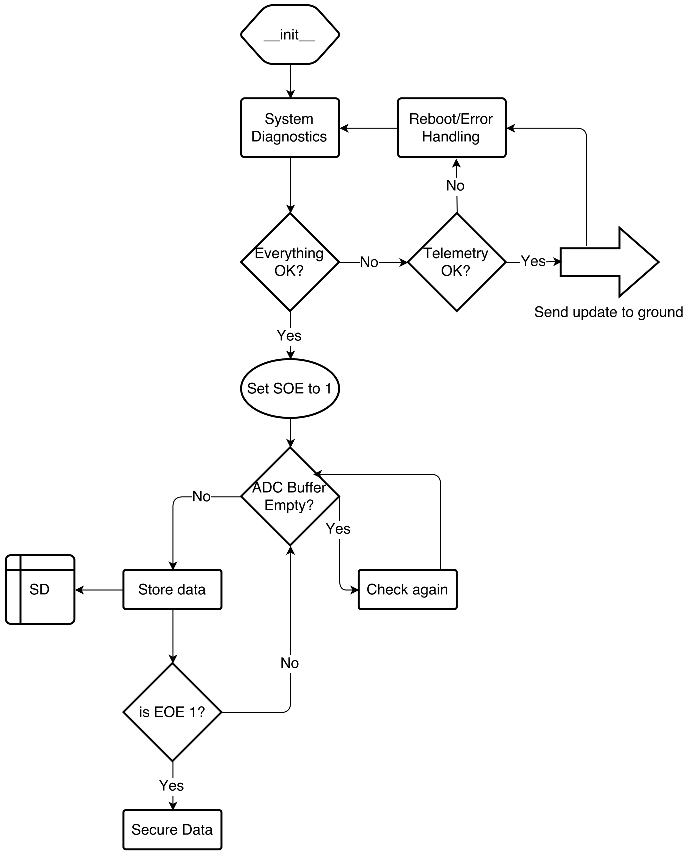


Figure 4.8.2: RPi Process Flow

The SOC is initialized according to its boot procedure by applying power, which then initializes all objects. The monitoring object is initialized on both of the Arduino MCU's and is responsible for individual thermal control and data collection. The watchdog will be initiated and updated by the SOC regularily if everything is nominal. If everything checks out, SOE will be set to 1 and data collection can start. The sensor object will start generating data, which will fill the buffer of the MCU's interfaced with the external sensors. The ADC will be continuously measured by the MCU, and the SOC will ask the MCU's for available data.
The data will be buffered on the RPi USB interface buffer before being stored in the SD card. It is not expected that this buffers are filled up, as the processing speed is way larger than the data transmission rate

4.8.2.6 Modularization and pseudo code

The system software architecture can be divided into three different modules with different functions. This functions are data acquisition, system monitoring and housekeeping and data handling and storage.

The data acquisition module will be in charge of reading the sensors. It will be programmed in Arduino IDE. The main objects included in this module will be:

- **Data gathering:** Will provide the functions to other objects to make a readout of the sensors.
- **Serial Interface:** Will be in charge of handling the requests from the serial interface and send the relevant information.
- **Calibration:** Will provide a function to calibrate the sensors, and will return the values associated with them.
- **Mode:** Will store the information about the mode of operation and will decide which actions are taken by the rest of the module.
- **Initialization:** Will be the first object to take action, initializing all the other objects and checking that they are functioning correctly.

The second module will be in charge of monitoring all the other modules, ensuring that they work correctly and taking action when they do not perform as intended. It will also be in charge of controlling the environment and will relay the information of internal housekeeping to the main unit. The main objects of the module will be:

- **Data gathering:** Will provide the functions to other objects to make a readout of the sensors.
- **Serial Interface:** Will be in charge of handling the requests from the serial interface and send the relevant information.
- **Actuator:** Will be in charge or providing the control mechanism for the thermal resistance to heat the module in case temperature runs out of limits.
- **Monitoring:** Will check all the subsystems and will set the modes of operation of them.
- **Error control:** Will set the modes of operation of the subsystems in function of the errors reported. Will also shut down the main computer when the flight is about to end.
- **Initialization:** Will initialize all the objects and will check that all the other modules have started correctly.

Finally, the third module is the main system data handling and storage. It will also provide the interface to the E-Link, allowing to communicate with the ground station. It will run an operating system based on Linux, and the code will be programmed in Python. The main objects of this module are:

- **Data collection:** Will communicate with other modules to ask for the values of the sensors.

- **Mode:** Will hold the mode of operation for the actions that have to be taken. Will also execute the shutdown command when commanded by the monitoring module.
- **Data storing:** Will handle the files to store the values and will provide the function to other objects.
- **System inialization:** Will initialize all the interfaces and objects.
- **Ethernet interface:** Will provide the functions necessary to communicate through the E-link and will generate the package to be sent.
- **Serial interface:** Will provide the functions to handle communications through the Serial interfaces.

It is still to be determined which of the modules should include an I2C connection object to provide the handling of the interfaces to the sensors.

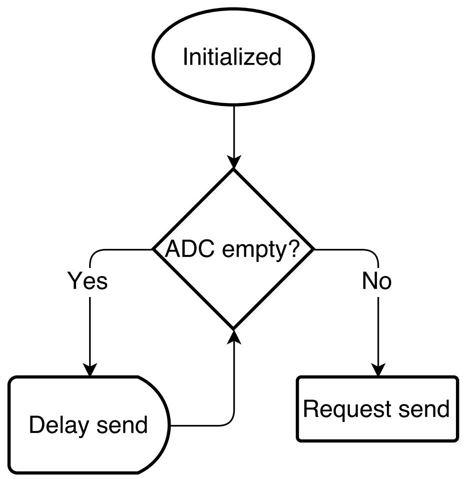


Figure 4.8.3: Sensor MCU Process Flow

The initialization signal from the SOC lets the MCU know it's OK to start collecting analogue data, which will be fed from the sensors, converted to digital and sent to the SOC.

4.8.3 Implementation

The languages to implement the code are Arduino and Python. Arduino is an IDE based on C++ with custom built functions, that verifies, compiles and uploads the code to the Arduino-compatible boards (based on Atmel controllers). However, it can be programmed outside this environment with Atmel studio and the output runfile uploaded to the controllers without using the environment.

Regarding Python, it is included as part of Anaconda IDE. It is an interpreted language that allows for handling and representing high amounts of data. It is as well integrated with the RPi environment. The possible libraries to be included would be Ethernet handling libraries, as well as for creating and storing text files and images.

4.9 Ground Support Equipment

The ground support equipment will consist of a computer with an Ethernet interface connected to the ground station to receive the data. It is still TBD if the ground station will use Python or Matlab to provide a GUI to evaluate images in real time. The data will be simultaneously stored in the hard drive for further analysis in case of failing to recover the main data.

The GUI will consist of a window displaying the last image received from the camera, together with a history curve of the measurements read by all the sensors. Data of position will be displayed on a virtual map, while pressure and temperature reading will be displayed as normal linear data.

4.10 Optics Design

The department of Optics is in charge of optimising the optical components to obtain data. The aim is to improve the design of photodiodes, filters and fisheye lenses to improve the quality of the obtained data.

4.10.1 Photodiodes

The photodiodes are the main components of the optics, so they absorb the photons and, thanks to that, it is possible to measure the intensity of light of a determined region. On the photodiodes, the filters and the fisheye lenses will be added in order to meet the requirements of the experiment.

Since the field of view of the photodiodes is relatively narrow, it would be of an advantage to enlarge it.

As it is shown in fig. 4.10.1, the photodiodes have a certain directivity. This shows how the response varies, depending on the incident angle of the light.

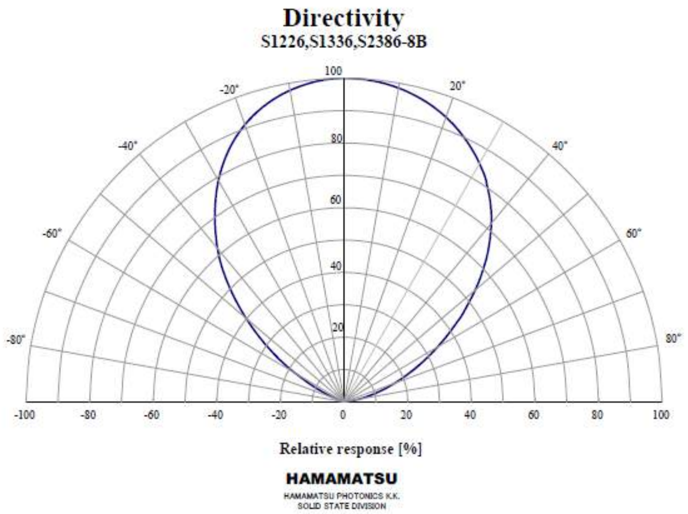


Figure 4.10.1: Directivity of Hamamatsu photodiodes

The main reason why the fisheye lenses are necessary is because it is intended to gather the rays of light in the most perpendicular way possible.

4.10.2 Filters

Special filters are required to maintain high data quality precision. The reason for this is that the experiment requires differentiation between the intensities for several ranges of the electromagnetic spectrum.

4.10.3 Lenses

Increasing the Field of View (FoV) of the photodiodes will provide a greater accuracy of data collection from a larger surface range. The need for lenses was considered necessary and through calculations it does not add any fallacious measurements caused by the SZA and the FoV of the sensors. However, the team handles different options to choose the proper lens:

- **Commercial fish-eye lenses:** Within a big range of prices, from cheap ones (mobile phone lenses) to expensive ones (some of them not affordable), in the case of the professional lenses or for a very specific aim. The price of these lenses is very high because the device itself has inside multiple lenses and mirrors, with high manufacturing cost, contrary to the custom made lenses.
- **Custom made lenses:** It consists of a single glass lens, since the experiment does not need to correct image, just gather a certain quantity of light. Thanks to that,

even being customized, the costs can be lower, depending on which manufacturer is chosen.

4.10.4 Interferences

It is important to take into account that the field of view of the photodiodes will be partly obstructed by the parts that hold the balloon (for instance the four belts going out from the gondola and the wire they hold) and the balloon itself. Some calculations have been done to approximate the angle that will be covered by the balloon. (Fig.4.10.2)

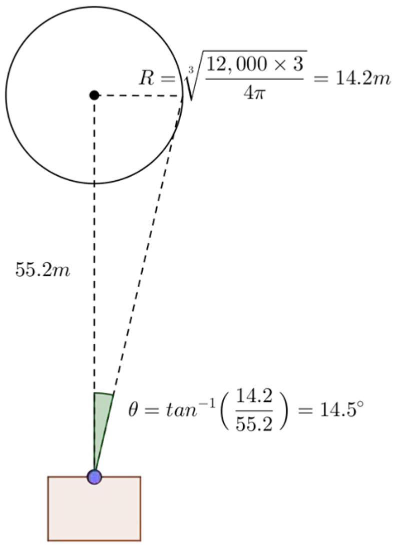


Figure 4.10.2: Visual obstruction caused by the balloon

The mechanical department has designed two booms, one for each photodiode array facing upwards and downwards, in order to reduce the obstruction that would be caused by placing the sensors directly outside of the gondola. Therefore, the booms, each of the length of 1 meter, shall considerably reduce the obstructions to an acceptable minimum.

5 Experiment Verification and Testing

5.1 Verification Matrix

- I - Verification by inspection
- R - Verification by review-of-design
- A - Verification by analysis or similarity
- T - Verification by test

Table 5.1.1: Verification Matrix

ID	Requirement text	Verification	Test number	Status
F.1	The experiment shall measure the intensity of visible light outside the gondola, looking towards the zenith.	R	-	To be done
F.2	The experiment shall measure the intensity of visible light outside the gondola, looking towards the nadir.	R	-	To be done
F.3	The experiment shall measure the intensity of infrared light outside the gondola, looking towards the zenith.	R	-	To be done
F.4	The experiment shall measure the intensity of infrared light outside the gondola, looking towards the nadir.	R	-	To be done
F.5	The experiment shall correlate the pressure at which the measurements were taken.	T	Test 1, 10	To be done
F.6	The experiment shall correlate the temperature at which the measurements were taken.	T	Test 2, 10	To be done
F.7	The experiment shall correlate the position at which the measurements were taken.	T	Test 10, 12	To be done

F.8	The experiment shall measure the position on the three axis of space with respect to the launching point.	T	Test 12	To be done
~~P.1~~	~~The experiment shall be able to distinguish between incoming and outgoing from Earth radiation.~~	~~R~~	-	~~To be done~~
P.2	The experiment shall measure the electromagnetic spectrum from 0.3 μm to 2.5 μm with a minimum sensitivity of 200 $mW \cdot m^{-2}$	R, T	Test 5	To be done, see test plan
P.3 to P.10	The experiment shall measure radiation in the wavelength range 0.43 μm to 0.45 μm, 0.45 μm to 0.51 μm, 0.53 μm to 0.59 μm, 0.63 μm to 0.67 μm, 0.85 μm to 0.88 μm, 1.36 μm to 1.38 μm, 1.56 μm to 1.65 μm, 2.00 μm to 2.50 μm with a precision of $\pm$0.005 μm.	R, T	Test 5	To be done, see test plan
~~P.11~~	~~The sampling rate of the experiment shall be between 5 and 10 seconds.~~	~~A, T~~	~~Test 10~~	~~To be done, see test plan~~
P.12	The sampling delay shall not exceed 30 seconds.	A, T	Test 10	To be done, see test plan
P.13	The experiment shall measure the pressure from 5 to 1100 $mbar$.	R, T	Test 1,10	To be done, see test plan

P.14	The experiment shall measure the pressure with a minimum accuracy of 10 $mbar$.	R, T	Test 1,10	To be done, see test plan
P.15	The experiment shall measure the temperature from -90 to 30 $°C$.	R, T	Test 2, 10	To be done, see test plan
P.16	The experiment shall measure the temperature with a minimum accuracy of ± 1 $°C$.	R, T	Test 2, 10	To be done, see test plan
P.17	The experiment shall measure the position with a minimum accuracy of ± 10 m.	R, T	Test 10, 12	To be done, see test plan
P.18	During the ascend phase the sampling frequency shall be 3 seconds.	T	Test 10	To done, see test plan
P.19	During the float phase the sampling frequency shall be 10 seconds.	T	Test 10	To be done, see test plan
~~D.1~~	~~The experiment shall not include components that could prove to be dangerous for people.~~	~~R~~	-	~~To be done~~
~~D.2~~	~~The experiment shall not include components that disturb or harm the launch vehicle.~~	~~R~~	-	~~To be done~~
~~D.3~~	~~The experiment shall not include components that disturb or harm other experiments.~~	~~R~~	-	~~To be done~~
D.4	The experiment shall not weigh more than 23 kg upon launch.	R, A, T	Test 13	To be done, see test plan

D.5	The experiment shall withstand vertical accelerations within the BEXUS flight and launch profile.	A, T	Test 6	To be done, see test plan
D.6	The experiment shall withstand horizontal accelerations within the BEXUS launch and flight profile.	A, T	Test 6	To be done, see test plan
D.7	The experiment's data storage unit should withstand shocks of up to 35 g during landing.	A, T	Test 6	To be done, see test plan
D.8	The experiment shall withstand vibrations related to handling and transportation before and after flight.	A, T	Test 4	To be done, see test plan
D.9	The experiment shall withstand pressures within the BEXUS flight profile.	R, T	Test 1	To be done, see test plan
~~D.10~~	~~The experiment shall withstand temperatures within the BEXUS flight profile.~~	~~R, T~~	~~Test 2~~	~~To be done, see test plan~~
D.11	The experiment shall not be at risk of falling from the gondola during flight and launch.	R, T	Tests 4, 6	To be done, see test plan
~~D.12~~	~~The experiment shall not slide or translate inside the during flight and launch~~.	R, A	-	To be done
D.13	The experiment should be attached to the gondola rails if possible.	R	-	To be done
D.14	The fastening to the gondola rails shall be carried out with M6 bolts with 23 mm thread length.	R	-	To be done

D.15	The experiment shall use a sufficient number of brackets on bottom plates in order to facilitate mounting of experiments.	R	-	To be done
D.16	The experiment shall operate at temperatures within the BEXUS vehicle flight and launch profile.	R, T	Test 2	To be done, see test plan
~~D.17~~	~~All experiment critical components shall be accessible within 2 minutes.~~	~~R, T~~	~~Test 14~~	~~To be done, see test plan~~
D.18	The replacement time of the replaceable components shall be within 15 minutes.	R, T	Test 14	To be done, see test plan
D.19	The experiment shall use a maximum electrical energy of 275 Wh.	R, A, T	Tests 7, 9, 17 ,18	To be done, see test plan
D.20	The experiment shall use Ethernet 10/100 Base-T with RJ45 connectors for interfacing with the provided E-link.	R	-	To be done
D.21	The experiment shall use Ethernet 10/100 Base-T with RJ45 connectors for interfacing with the ground station.	R	-	To be done
D.22	The experiment shall use a 4 pin, male, box mount receptacle MIL-C-26482P series 1 connector with an 8-4 insert arrangement as power interface.	R	-	To be done

D.23	The data storage unit shall withstand any post-landing environment within the mission profile without corruption or loss of data for at least 3 days.	R, T	Test 15	To be done, see test plan
~~D.24~~	~~The experiment shall be able to handle two aborted launches.~~	~~R~~	-	~~To be done~~
D.25	The experiment shall not use a downlink rate greater than 200 kbit/s.	A	-	To be done
D.26	The experiment may include sacrificial joints or other contingency plans to avoid being damaged upon landing if it protrudes from the gondola.	T	Test 6	To be done
D.27	The position of the experiment should be selected in order to reduce "noise" interference from other experiments.	R	-	To be done
D.28	The experiment shall be able to distinguish between incoming and outgoing from Earth radiation.	R	-	To be done
D.29	The sampling time of optical instruments shall be synchronized.	T	Test 10, 11	To be done
O.1	The experiment sensors shall be clean from dust before launch.	I, T	Test 5	To be done, see test plan
O.2	The experiment shall accept commands from the ground station at any time.	A, T	Test 3	To be done, see test plan

O.3	The procedures to turn the experiment on and off should be kept simple.	T	Test 14	Try the power on / power off system.
O.4	The experiment shall perform autonomously in the event of loss of communication with the ground station.	R, T	Tests 3, 8	To be done, see test plan
O.5	The experiment shall be able to correctly handle aborted launch attempts during any point leading up to, including pre-flight tests, the launch.	R, T	Test 8	To be done, see test plan

5.2 Test Plan

The test ordering follows a system where the test considered most time consuming in case of failure are prioritised. The tests were graded using High, Medium and Low classifications to illustrate the time it takes to be able to redo the test.

Test classification interpretation key:

- High:
  - Tests that require substantial external help or facilities, may cause difficulties in booking times.
  - Tests that may break non-spare components that that may take a long time to re-order.
  - Re-test availability time on the order of weeks to months
- Medium:
  - Tests that require internal co-ordination or may break critical components that takes not insignificant time replacing.
  - Re-test availability time on the order of days
- Low:
  - Tests that can be performed individually by single departments, non-invasive tests.
  - Re-test availability time on the order of hours

5.2.1 Test classification

Tests within a certain classification are initially considered equally important to prioritise, but will include a number for sake of reference.

High Priority

- Test 1: Low Pressure Test
- Test 2: Thermal Test
- Test 3: E-link Test
- Test 4: Vibration Test

Medium Priority

- Test 5: Photodiodes Calibration Test
- Test 6: Shock Test
- Test 7: Power Test
- Test 8: Autonomy Test
- Test 9: Experiment Electronic and Power Subsystem Test

Low Priority

- Test 10: Data Collection Test
- Test 11: Data Collection Synchronisation Test
- Test 12: GPS verification Test
- Test 13: Weight Verification
- Test 14: Experiment Assembly and Disassembly Test
- Test 15: Data Storage Unit Robustness Test
- Test 16: Experiment Prototype Test
- Test 17: Description for ripple and noise test of entire electrical system
- Test 18: Description of breadboard test of electrical components

5.2.2 Test description

Table 5.2.1: Test 1: Low pressure test description

Test number	1
Test Type	Low Pressure
Test facility	TBD (Esrange Space Center TBC)
Tested item	The whole experiment
Test level/procedure and duration	Test procedure: TBD (reproduce pressure similar to stratospheric pressure at 30 km. Verify that all subsystems are operational and reliable) Test duration: 5 hours.
Test campaign duration	3 days (1 day build-up, 1 day verification, 1 day testing)
Test campaign date	July-August
Test completed	NO

Table 5.2.2: Test 2: Thermal test description

Test number	2
Test Type	Thermal
Test facility	Esrange Space Center
Tested item	The whole experiment
Test level/procedure and duration	Test procedure: TBD (reproduce temperature of -80°C to verify that all subsystems are operational and reliable. Test of the active/passive thermal control unit). Test duration: 5 hours.
Test campaign duration	3 days (1 day build-up, 1 day verification, 1 day testing)
Test campaign date	July-August
Test completed	NO

Table 5.2.3: Test 3: E-link test description

Test number	3
Test Type	E-link
Test facility	TBD (Kiruna Space Campus or Esrange Space Center)
Tested item	TBD
Test level/procedure and duration	Test procedure: TBD Test duration: TBD
Test campaign duration	TBD
Test campaign date	TBD
Test completed	NO

Table 5.2.4: Test 4: Vibration test description

Test number	4
Test Type	Vibration
Test facility	Kiruna Space Campus
Tested item	The whole experiment
Test level/procedure and duration	Test procedure: Put the running experiment in a car and drive to Esrange Test duration: 5 hours (typical BEXUS flight duration)
Test campaign duration	2 days (1 day build-up, 1 day testing)
Test campaign date	July-August
Test completed	NO

Table 5.2.5: Test 5: Photodiodes Calibration test description

Test number	5
Test Type	Calibration and Verification
Test facility	Kiruna Space Campus laboratory
Tested item	Photodiodes, lenses and filters
Test level/procedure and duration	Test procedure: TBD (A given object, with well-known electromagnetic spectrum response, is used to examine the accuracy of the photodiodes, the functionality of the lenses and filters, determine the influence of dusts on the sensors). Test duration: TBD (∼10 minutes)
Test campaign duration	Recurrent test until and during the launch campaign.
Test campaign date	April
Test completed	NO

Table 5.2.6: Test 6: Shock test description

Test number	6
Test Type	Shock
Test facility	Kiruna Space Campus laboratory
Tested item	The mechanical structure alone first and secondly the whole experiment.
Test level/procedure and duration	Test procedure: Test by dropping mechanical frame from a height. Test duration: Less than a minute
Test campaign duration	4 days
Test campaign date	July-August
Test completed	NO

Table 5.2.7: Test 7: Power test description

Test number	7
Test Type	Power
Test facility	5 Kiruna Space Campus
Tested item	All the components using electronic power.
Test level/procedure and duration	Test procedure: TBD Test duration: TBD (7 hours, to reproduce pre-flight and flight conditions).
Test campaign duration	2 days (1 day build-up, 1 day testing).
Test campaign date	July-August
Test completed	NO

Table 5.2.8: Test 8: Autonomy test description

Test number	8
Test Type	E-link
Test facility	TBD (Kiruna Space Campus or Esrange Space Center)
Tested item	TBD
Test level/procedure and duration	Test procedure: TBD Test duration: TBD.
Test campaign duration	TBD
Test campaign date	TBD
Test completed	NO

Table 5.2.9: ~~Test 9: Experiment electronic and power subsystem test description~~

Test number	9
Test Type	Experiment electronic, control & power subsystem test
Test facility	Kiruna Space Campus laboratory
Tested item	Electronic Subsystems; the upper and lower Arduino photodiode circuits, cameras, barometers, heaters, the monitoring subsystem and data storage unit. Also power system.
Test level/procedure and duration	Basic testing of all components on breadboard, subsystems and all electronic subsystems together. Checking all parameters.
Test campaign duration	Two weeks
Test campaign date	April - May 2017
Test completed	NO

Table 5.2.10: Test 9: Experiment electronic test description

Test number	9
Test Type	Electrical
Test facility	Kiruna Space Campus laboratory
Tested item	Entire electrical system
Test level/procedure and duration	Measure peak current, average current & power consumption of the system.
Test campaign duration	Two days
Test campaign date	June-July 2017
Test completed	NO

Table 5.2.11: Test 10: Data Collection test description

Test number	10
Test Type	Software
Test facility	Kiruna Space Campus laboratory
Tested item	Micro-controller Unit and Experiment sensors
Test level/procedure and duration	Test procedure: TBD Test duration: 5 hours. Based on previous BEXUS flight durations.
Test campaign duration	2 days (1 day build-up, 1 day testing)
Test campaign date	June
Test completed	NO

Table 5.2.12: Test 11: Data Collection Synchronisation Test

Test number	11
Test Type	Calibration and Verification
Test facility	Kiruna Space Campus Laboratory
Tested item	Data collection
Test level/procedure and duration	Test procedure: TBD (Data collection simulation) Test duration: TBD ($<$ 30 min).
Test campaign duration	1 day
Test campaign date	April
Test completed	NO

Table 5.2.13: Test 12: GPS test description

Test number	12
Test Type	~~Calibration and~~ Verification
Test facility	Kiruna Space Campus Laboratory
Tested item	GPS unit
Test level/procedure and duration	Test procedure: TBD (Drive a car or climb a building to verify the GPS accuracy) Test duration: TBD (30 min).
Test campaign duration	1 day
Test campaign date	April
Test completed	NO

Table 5.2.14: Test 13: Weight verification test description

Test number	13
Test Type	Weight Verification
Test facility	Kiruna Space Campus laboratory
Tested item	The whole experiment
Test level/procedure and duration	Test procedure: Measure the weight of the brain box, sensor boxes and booms Test duration: TBD (1 min)
Test campaign duration	1 day
Test campaign date	July-August
Test completed	NO

Table 5.2.15: Test 14: Assembly & Disassembly test description

Test number	14
Test Type	Assembly and Disassembly
Test facility	Kiruna Space Campus
Tested item	The whole experiment.
Test level/procedure and duration	Test procedure: TBD (All components are placed on a table, a chronometer is used to determine the time necessary to assemble the experiment. After assembly, the chronometer is restarted to calculate the time necessary to disassemble and replace components). Test duration: TBD (1 hour).
Test campaign duration	2 days
Test campaign date	July-August
Test completed	NO

Table 5.2.16: Test 15: Data storage unit robustness test description

Test number	15
Test Type	Robustness
Test facility	Kiruna Space Campus laboratory
Tested item	Data Storage Unit
Test level/procedure and duration	Test procedure: TBD (The data storage unit will be tested in various conditions to assure its resistance for post-landing environmental conditions. Example: put data storage in water, soil, snow,etc. Verify mechanical resistance of the data storage. Determine if sacrificial joints might be needed.) Test duration: TBD (2-3 days).
Test campaign duration	1 month
Test campaign date	April
Test completed	NO

Table 5.2.17: Test 16: Experiment prototype test description

Test number	16
Test Type	Experiment prototype function test
Test facility	Off-site
Tested item	Prototype electronic Subsystems; the Arduino photodiode simulator, cameras, barometers, the monitoring subsystem and data storage unit. Also power system.
Test level/procedure and duration	Basic testing of all components on breadboard, subsystems and all electronic subsystems together. Checking all parameters.
Test campaign duration	Week
Test campaign date	April - May 2017
Test completed	NO

Table 5.2.18: Test 17: Description for ripple and noise test of entire electrical system

Test number	17
Test Type	Electrical
Test facility	Kiruna Space Campus laboratory
Tested item	Entire electrical system
Test level/procedure and duration	Measure voltage ripple & noise of the system.
Test campaign duration	Two days
Test campaign date	June-July 2017
Test completed	NO

Table 5.2.19: Test 18: Description of breadboard test of electrical components

Test number	18
Test Type	Breadboard test of electrical components
Test facility	Kiruna Space Campus laboratory
Tested item	Pressure & temperature sensor, ADC, GPS, photo diodes and DC/DC converters.
Test level/procedure and duration	Breadboard testing of all components to ensure measurements within the required ranges. Checking all parameters.
Test campaign duration	Two weeks
Test campaign date	May 2017
Test completed	NO

5.3 Test Results

Table 5.3.1: Results for test 18: Experiment electronic test results for 3.3 V DC/DC converter.

Test number	18
Test Type	Experiment electronic, control & power subsystem test
Test facility	Kiruna Space Campus laboratory
Tested item	JCE03 DC/DC Converter 3W $V_{in} = 36$ V, $V_{out} = 3.3$ V, 300-3000 A
Test result	High & low frequency noise obtained in output voltage, the cause can be faulty grounding or need of an extra capacitor to eliminate noise. For complete test report see Appendix G.1.1.
Test duration	Two days
Test campaign date	2-4 May 2017
Test status	Started, needs further testing

Table 5.3.2: Results for test 18: Experiment electronic test results for 5 V DC/DC converter.

Test number	18
Test Type	Experiment electronic, control & power subsystem test
Test facility	Kiruna Space Campus laboratory
Tested item	DC/DC converter THN 15-2411WI 15W 9-36 $V_{in}V$, $V_{out} = 5$, from *Traco Power*
Test result	TBD For complete test report see Appendix G.1.2.
Test duration	One day
Test campaign date	May 2017
Test status	Not started

6 Launch Campaign Preparation

6.1 Input for the Campaign/Flight Requirements Plans

6.1.1 Dimensions and Mass

Total mass of the experiment is currently 22,556 kg.

Table 6.1.1: Sensor Box: Mass and volume

Experiment mass (in kg):	2,773
Experiment dimensions (in m):	0,511×0,23×0,19
Experiment footprint area (in m2):	0,1
Experiment volume (in m^3):	0,012
Experiment expected COG position:	x = -1,661 [m]; y = 0,661 [m]; z = 0,171 [m] for the bottom sensor box. x = -1,661 [m]; y = -0,417 [m]; z = 0,001 [m] for the upper sensor box.

Table 6.1.2: Upper Sensor Box and Booms: Mass and volume

Experiment mass (in kg):	11,798
Experiment dimensions (in m):	1,42×0,467×0,333
Experiment footprint area (in m2):	0,663
Experiment volume (in m3):	0,016
Experiment expected COG position:	x = -0,959 [m]; y = 0,538 [m]; z = 0,172 [m]

Table 6.1.3: Bottom Sensor Box and Booms: mass and volume

Experiment mass (in kg):	6,746
Experiment dimensions (in m):	1,6×0,457×0,265
Experiment footprint area (in m2):	0,731
Experiment volume (in m3):	0,015
Experiment expected COG position:	x = -1,244 [m]; y = -0,333 [m]; z = 0,001 [m]

Table 6.1.4: Central "Brain" Box mass and volume

Experiment mass (in kg):	4,012
Experiment dimensions (in m):	0,361×0,34×0,28
Experiment footprint area (in m2):	0.123
Experiment volume (in m3):	0,019
Experiment expected COG position:	x = -0,054 [m]; y = -0,148 [m]; z = -0.38 [m]

6.1.2 Safety Risks

Table 6.1.5: Safety Risks for the flight and preparation

Risk	Characteristics	Mitigation
Sensor Boxes falling off	The sensor boxes mounted on the booms outside the gondola can fall or break off.	The booms will be attached securely to the gondola. Additionally, they will be made from materials that can break easily in case of a rough landing. The sensors will be secured to the gondola frame with metallic cables, so that they do not fly away too far from the gondola.

6.1.3 Electrical Interfaces

Please refer to tab. 6.1.6 for information on the electrical interfaces with the gondola.

Table 6.1.6: Electrical interfaces applicable to BEXUS.

BEXUS Electrical Interfaces	
E-Link Interface: E-Link required? Yes	
Number of E-Link interfaces:	1
Data rate - downlink:	200 kbit/s
Data rate – uplink:	1 kbit/s
Interface type (RS-232, Ethernet):	Ethernet
Power system: Gondola power required? Yes	
Peak power (or current) consumption:	38 W
Average power (or current) consumption:	22 W
Power system: Experiment includes batteries? No	
Type of batteries:	
Number of batteries:	
Capacity (1 battery):	Ah
Voltage (1 battery):	V

6.1.4 Launch Site Requirements

The IRIS team will require a working space to mount the sensor boxes on the booms, and these on the gondola frame. It will also be needed to mount the RPi box inside the brain box, and this one on the gondola rails. It will be required to electrically connect the boxes together and to the gondola electrical interfaces (refer to section 4.2.2), calibrate the sensors and clean all optics material and finally, for the after flight dismount the experiment from the gondola. To prepare all necessary steps for launching, as well as the post launch activities, the following items will be required:

- Six (6) chairs
- One (1) table (Workspace for 13 people)
- One (1) table for hardware assembly ($\sim 4m^2$)
- One (1) toolbox, containing wrenches (size TBD), Phillips screwdriver
- One (1) power supply with adjustable voltages
- One (1) oscilloscope with two (2) probes
- One (1) multimeter
- One (1) soldering station with necessary tools for soldering
- One (1) microfiber cloth rag
- One (1) bottle of glass cleaner
- Power strip (15 outlets)

6.1.5 Flight Requirements

The ascend phase will provide the first interesting interval of measurements. During the float phase the albedo value is expected to stabilize. Longer floating times are going to give more accurate results. But a minimum time of 1 hour should be enough to ensure the success of the experiment. Nevertheless a longer time at the maximum altitude would be preferred.

In case of cloud-cover the IRIS experiment needs to be able to take measurements from above the clouds. Thus, float altitude should be at least high enough for the gondola to raise above the clouds that may be present at the day of launch. Most clouds, like cirrus clouds, are located in the troposphere, below the expected floating altitude of the HAB [11]. Nevertheless cloud cover poses no problem for the scientific goals of the mission.

IRIS requires daylight in order to obtain the intended scientific data. As a result, launch should take place between sunrise and noon, to maximise the amount of daylight present during the flight. The minimum daylight time required should be during the ascend and 1 hour during the float time. If the flight is during the night the team cannot guarantee to collect any meaningful data.

6.1.6 Accommodation Requirements

The booms carrying the sensor boxes shall be attached the upper gondola frame and its lower mounting rails respectively. They shall also be located on the same side of the gondola, as they can only be mounted on these locations due to the mechanical design of the experiment. Refer to section 4.2.1 for a sketch of the correct placement of the sensor boxes.

Both sensor boxes shall remain uncovered during the whole flight, but they may be covered before and after flight if it is deemed necessary for handling the gondola by the launch and recovery crews.

6.2 Preparation and Test Activities at Esrange

Table 6.2.1: Test and preparation activities at Esrange.

Time	**Activity**	**People**
TBD	Power test of the system	Electrical
TBD	Check data acquisition	Electrical, Software & Science
TBD	Communication Test	Software
TBD	Cleaning of sensors	Optics
TBD	Calibration of sensors	Science
TBD	Flight Simulations	All
All days	Take pictures for the outreach	Everyone

6.3 Timeline for Countdown and Flight

A late access window is describing the very last activities preformed right before the launch. As part of the late access window before the launch the cover of the lenses shall be removed.

The experiment shall start measuring data before the launch. This will be activated by a command send through the link. It will stop recording data when it is at 10000 ft from ground prior to touchdown, to avoid data loss. The experiment, however, will be switched on prior to the restriction of access, or will be active at any time if power is correctly provided.

When the balloon reaches cruise altitude the experiment may need to switch the frequency at which the data is either gathered or sent to ground. For this, a command will be sent from the ground station. The experiment will however shut down automatically at the specified altitude, or by command prior to that point if considered necessary by the science team or due to low battery readings. The shutdown command shall be designed and programmed to be executed in such way to prevent any unexpected shut down.

Tab. 6.3.1 summarizes the most important moments on countdown and during flight. Note that this is only a first estimation and may suffer changes in the future.

Table 6.3.1: Experiment timeline during countdown and flight

Time	Action
T-4H	Experiment check-outs, ground
T-2H30	Experiment check-outs, mounted
T-1H30	late access, remove sensor covers
T-1H00	Experiment check-outs and start recording, through E-Link
T+0	LO
T+∼83	Command to reduce acquisition rate
T+∼4H	Check reception of shutdown

6.4 Post-Flight Activities

The SD Memory card needs to be retrieved to save the full data collected during the flight. As IRIS team is based in Kiruna, receiving the data from Esrange should not pose any difficulties.

Afterwards the science team will start analysing the data, providing preliminary results for the post-flight meeting and later a full analysis for the final report. Scientific publications are also planed as well as possible presentations at conferences such as EGU - general assembly.

7 Data Analysis and Results

7.1 Data Analysis Plan

The data from the sensors will be used to compute the irradiances that comes in from the sun and that is reflected from the surface and lower part of the atmosphere. By comparing the two values the bond albedo can be calculated.
The measurements during the ascend phase will give the change of the albedo along the (increasing) height.

A model for radiative transfer (RT) in the atmosphere shall be used. The model, suitably chosen to support the wavelengths measured (e.g.'FUTBOLIN' [15], DART [18] or I3RC [19] will be used to cast the various radiative components that are coming in onto the surface as well as the outgoing reflected flux, at the according radiation conditions. These RT models are important for satellite measurements as they are used for the retrieval of the data. By comparing the measured values with the model results, both the model and the in-situ measurements can be evaluated. If the obtained measurements and the modelled values are in disagreement, further data analysis could reveal where the error is located and eventually contribute to the improvement the model. An improved radiative transfer model will help to improve the accuracy of satellite measurement evaluation.

The non-homogeneity of the several types of soil, causes distortions, thus it is hard to distinguish between the represented data, obtained from the satellite measurements. That is because the homogeneity of the ground is directly connected with the variability of the ground topography. The more homogeneous the ground is the less variable is the ground topography, providing more compatibility between the in-situ and the remote sensing measurements. For this reason Bidirectional Reflectance Distribution Function (BRDF) models are used to simulate more effectively the observed surface and eliminate the data drift of the performed measurements.
For the error analysis many factors have to be taken into account, from the movement of the gondola and the position of the sun in the sky to the potential shadows cast by cables and possibly other experiments.

It is possible that the sun in October, in northern Sweden, is very low on the horizon and therefore it will not directly contribute to the sensors mounted on the top array. Nevertheless, this should not be a problem as a lot of radiation is scattered in the atmosphere. The measurement should reflect the true flux coming from the top and the flux from the bottom.

7.2 Launch Campaign

7.2.1 Flight preparation activities during launch campaign.

During launch campaign the following launch preparations activities shall be performed, in order to ensure a secure and infallible experiment.
Refer to Appendix D with checklists.

7.2.2 Flight performance

Concerning the flight performance of the apparatus, the following factors shall be taken into account. The data generated is expected to be in the form of voltage levels, transduced from light intensity. This will be stored in several CSV files, together with the altitude at which the measurements were taken, the position data from the GPS and ambient conditions from pressure and temperature sensors. Camera readings will be stored in jpg files, with an expected output of 100 kB per image. The total amount of data is TBD.

There is a number of possible failures and malfunctions during the flight performance. These are TBD in a later version of the SED after the testing of all ordered equipment that is required for the correct function of the experiment.

The power consumption should be around 30 W. However, the total power consumption is mainly based on the thermal simulations. It varies according to the altitude and the environment conditions that are mandatory for the correct operation of each of the boxes. As shown on appendix F, thermal transient simulations seem to imply that the insulation is capable of avoiding heat losses in all cases, although only radiative and conductive transfers are represented on them. Opposed to this, hand calculations had showed that heat losses should be expected in the most representative cases. According to these, at least one 8 W heater should be active on each box: this would result in a maximum power consumption of this system of 32 W.

7.2.3 Recovery

For the recovery of the apparatus a GPS mechanism already provided on the gondola shall be used. The brain box is not expected to be damaged from the fall. Some operational units could be reused. The two booms that are mounted on the gondola could be detached during descend, either from the speed, either from tree branches, or from the crash. For this reason, apart from the mounting on the gondola an additional connection will be performed, between the gondola and the sensor boxes, using a safety metallic wire. In this way, if the mounting of the booms or the booms themselves fail, the booms should remain attached, hanging from the gondola, and this action prevents their loss and therefore the loss of the sensor boxes. Permanent damage of the optics lenses is expected and therefore could not be reused.

7.2.4 Post flight activities

After the gondola is recovered the experimental apparatus will be returned to IRIS. The main units brain box with all the contained material shall be opened and the status of all included devices will be checked. The first data evaluation shall be to check if the storage of all data taken during the flight has been successful. If data is successfully acquired, the data analysis procedure to meet the scientific objectives will follow.

7.3 Results

There will be three measurement periods during the flight: the ascent, the float phase and the descent.

During ascent the albedo is expected to vary significantly, because some radiation is absorbed by water vapour in the troposphere. This absorption does not apply for the VIS wavelength spectrum. In the case of clouds or haze much light in the VIS spectrum will be scattered. Therefore, the incident radiation at the top is expected to increase with altitude. In the case of cloud coverage the albedo is expected to increase, as clouds have a high reflectance.
While the balloon is floating the albedo is expected to stabilise, only varying when passing over possible water bodies, such as lakes and rivers or when passing over single clouds.
The measurements during the descent phase should resemble those during the ascent phase.
One expected outcome of the subsequent analysis should be to find a better relation with the albedo throughout changing altitude, contributing to the correction of the errors in the satellite measurements.

This can be achieved by comparing and contrasting the data from both methodologies and calculating the error made from the remote sensing satellites, which measurements are less accurate than the HAB used in this project, as the data in the HAB case is gathered in-situ.
In addition, by using a high altitude balloon, a higher accuracy BRDF model can be calculated, since the angle depended on focal length and altitude has a larger number of obtained values in-between and it therefore contributes to a more accurate integration.

7.4 Lessons Learned

Table 7.4.1: Lessons learned

Department	**What has been learned**
General	• Things always take more time and cost more than expected. Even if you are told beforehand that it will you never quite understand it until you have experienced it. • Communication in between departments and their members must be thorough when trying to reach design conclusions. Design concepts are often more intricate than imagined by each separate member and therefore ambiguity can arise and result in two or more different designs. • You will start drinking coffee
Economics	

Electronics	• It is easy to underestimate the level of interaction between the experiment designs; small but necessary changes might bring larger changes in related designs by consequence. • Some of these small necessary changes are not noticed until design moves into a later stage, like PCB tracing. Therefore, looking forward early might be beneficial even though the previous stage of design is not finished. • One does not simply order surface mounted components for testing on a breadboard.
Mechanical	
Optics	
Project Management	• Define the mission statement and objectives early •
Public Relations	

Science	• It is important to design the scientific requirements in such a way that flexibility in terms of budget and technical requirements is maintained. • Getting familiar with data analysis for atmospheric physics is more demanding and complex than it seems. • Do not underestimate the integration time that will be needed for data analysis. • It is very important in terms of efficiency to distribute tasks within the science group clearly and keep good communication with the other departments. • It is more efficient to write down the tasks when are done, rather than setting goals. • Distribution of information and study materials from each person should be organised separately in the department folder. This way it is easier to find the correct piece of information when needed and at the same time the work of each person is monitored.
Software	

8 Abbreviations and References

8.1 Abbreviations

AR	Actual Range
ADC	Analog-to-digital converter
DART	Discrete Anisotropic Radiative Transfer
BEXUS	Balloon Experiment for University Students
BRDF	Bidirectional Reflectance Distribution Function
CAD	Computer Aided Design
CATIA	Computer Aided Three-dimensional Interactive Application
CERES	Clouds and the Earth's Radiant Energy System
CW	Center Wavelength
COG	center of gravity
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ECTS	Europeant Credit Transfer System
EM	Electromagnetic
EOE	End of Experiment
EGU	European Geosciences Union
ESA	European Space Agency
ESRANGE	European Space and Sounding Rocket Range
EXIST	Examination of Infrasound in the Stratosphere and Troposphere
FET	Field-Effect Transistor
FoV	Field of View
FUTBOLIN	Full Transfer by Ordinary LINe-by-line methods
GPS	Global Positioning System
HAB	High Altitude Balloon
HEP	High Energy Physics
I2C	Inter-Integrated Circuit
I3RC	International Comparison of 3-Dimensional Radiative Transfer Codes
IDE	Integrated Software Environment
IR	Infrared part of the EM spectrum
IRIS	InfraRed albedo measurements In the Stratosphere
LKAB	Luossavaara-Kiirunavaara Aktiebolag
LTE	Local Thermodynamic Equilibrium
LTU	Luleå University of Technology

MCU	Micro Controller Unit
MORABA	Mobile Rocket Base
MSc	Master of Science
NASA	National Aeronautics and Space Administration
NIR	Near-Infrared part of the EM spectrum
NOAA	National Oceanographic and Atmospheric Administration
PIT	Prototype Instrument Project
PCB	Printed Circuit Board
PDR	Preliminary Desing Review
PO	Polar Orbit
PWM	Pulse-Width Modulation
REXUS	Rocket Experiment for University Students
RJ45	Registered Jack 45
RPi	Raspberry Pi
RT	Radiative Transfer
RTE	Radiative Transfer Equation
SAFT	Société des Accumulateurs Fixes et de Traction
SD	Secure Digital (Storage)
SED	Student Experiment Documentation
SNSB	Swedish National Space Board
SOC	System On Chip
SOE	Start of experiment
SSC	Swedish Space Corporation
SZA	Solar Zenith Angle
TBC	To Be Confirmed
TBD	To Be Determined
TCP	Transmission Control Protocol
UART	Universal Asynchronous Receiver Transmitter
UDP	User Datagram Protocol
ULg	University of Liège
VIS	Visible part of the EM spectrum
WR	Wanted Range
WBS	Work Breakdown Structure
ZARM	Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation

8.2 References

References

[1] REXUS/BEXUS Organizers. *RXBX_SED_guidelines_v5-2*, December 17, 2015.

[2] EuroLaunch. *BEXUS User Manual V7*, December 8, 2016.

[3] International journal of climatology.

[4] International journal of atmospheric sciences.

[5] Mark C. Serreze and Roger G. Barry. *The Arctic Climate System*. Series: Cambridge Atmospheric and Space Science Series. Cambridge University Press, 1 edition, 2005.

[6] The cryosphere, an interactive open access journal of the european geoscience union.

[7] John Turner. Polar meteorology, understanding global impacts, 2007.

[8] Ann R. Webb, I. M. Stromberg, H. Li, and L. M. Bartlett. Airborne spectral measurements of surface reflectivity at ultraviolet and visible wavelengths. *Journal of Geophysical Research: Atmospheres*, pages 4945–4948, 2000.

[9] Fanglin Yang et al. Dependence of land surface albedo on solar zenith angle: Observations and model parameterization. *Journal of Applied Meteorology and Climatology*, 47:2963–2982, 2008.

[10] I. Filella and J. Penuelas. The red edge position and shape as indicators of plant chlorophyll content, biomass and hydric status., 1994.

[11] WMO. *manual on the observation of clouds and other meteors*. WMO, 3 edition, 1975.

[12] V. Ray Taylor and Larry L. Stowe. Reflectance characteristics of uniform earth and cloud surfaces derived from nimbus-7 erb. *Journal of Geophysical Research: Atmospheres*, 89:4987–4996, 1984.

[13] Donald E. Anderson and Steven A. Lloyd. Polar twilight uv-visible radiation field: Perturbations due to multiple scattering, ozone depletion, stratospheric clouds, and surface albedo. *Journal of Geophysical Research: Atmospheres*, 95:7429–7434, 1990.

[14] Gareth Rees. *Physical Principles of Remote Sensing*. Cambridge University Press, New York, 2012.

[15] F. J. Martin-Torres and M. G. Mlynczak. FUTBOLIN (full transfer by ordinary line-by-line methods): A new radiative transfer code for atmospheric calculations in the visible and infrared, 05/2005.

[16] Luleå University of Technology. Space engineering project ii.

[17] Herman Schutte. Bi-directional level shifter for i2c-bus and other systems., 1997.

[18] Original author: Jean-Philippe GASTELLU. DART,discrete anisotropic radiative transfer.

[19] I3RC, international comparison of 3-dimensional radiative transfer codes, 1990.

[20] Nea Kuusinen et al. *Boreal forest albedo and its spatial and temporal variation*. PhD thesis, University of Helsinki, 2014.

[21] Michael M Loranty, Scott J Goetz, and Pieter SA Beck. Tundra vegetation effects on pan-arctic albedo, 2011.

[22] K. A. Nicoll and R. G. Harrison. Balloon-borne disposable radiometer for cloud detection, 2012.

[23] R. G. Harrison, G. J. Marlton, P. D. Williams, and K. A. Nicoll. Coordinated weather balloon solar radiation measurements during a solar eclipse, 2016.

[24] NASA. U.S. Standard Atmosphere Supplements, 1966.

A Experiment Reviews

A.1 PDR

REXUS / BEXUS

Experiment Preliminary Design Review

Flight: BEXUS 25

Payload Manager: TBD

Experiment: **IRIS**

Location: DLR, MORABA **Date:** 21 Feb 2017

1. Review Board members

Koen DeBeule (ESA)
Alexander Kinnaird (ESA)
Armelle Frenea-Schmidt (ESA) – Minutes
Stefan Krämer (SSC) – Chair
Jianning Li (SSC)
Maria Snäll (SSC)
Simon Mawn (ZARM)
Dieter Bischoff (ZARM)

2. Experiment Team members

Lisa Cornelia Jonsson (Electrical)
Nils Johan Alexander Korsfeldt Larsén (outreach)
Ingo Wagner (science)
Edgar Martin Nieto (software)
François Jean-Philippe Piette (mechanics)

3. General Comments

- **Presentation**
  - You have a lot of electronics schematics which is good, add also ones for mechanics
- **SED**
  - Abstract with a lot of acronyms so try to limit them in order to be more accessible
  - Be sure that your acronyms list is exhaustive (add also ESA, ZARM…)

4. Panel Comments and Recommendations

- **Requirements and constraints** (SED chapter 2)
  - Globally, good work
  - Sometimes, you can combine your requirements

  Design requirements
  - You have a lot of design requirements, remove the obvious like D12: " The experiment shall not slide or translate inside the gondola during flight and launch"
  - D10 and D16 are the same requirements
  - D17 and D18 are impossible, reword these two requirements
  - D24 seems very strict and is not really necessary (focus on what is critical: temperature range, power max…)
  - You need to synchronize the photodiodes and the cameras, add a requirement for that

  Performance requirements
  - P1 "The experiment shall be able to distinguish between incoming and outgoing from Earth radiation" is a design requirement
  - P11 and P12: you must know exactly what do you want because it is a main driver for your design

software – Show the different requirements for the different phases

- P11 and P12: it is very important for your software responsible to know exactly what do you want, clarify by speaking in terms of acquisition frequency
- P15 and P16 are not easily achievable, the accuracy of +/-0.5°C is difficult to reach with the conditions required previously

Constraints

- C2: you are allowed but you need a safe line to prevent any free falling parts
- C3: BEXUS accommodation session during the training week

▪ **Mechanics** (SED chapter 4.4)
  - Detail the design of housing of the sensor box and for the data storage (off-the-shelf or manufactured?)
  - Top box seems big and very close to the E-link. SSC devices could cover your experiment, the belt could be in the field of view for example, may consider to push the experiment a little bit
  - Why your box is so close to your sensors? You can have a better field of you if you push it a little bit in order to avoid interferences with the belt
  - **Easier configuration could be to use a boom (BEXUS Accommodation Session) in order to avoid landing on them**
  - **For the lower part, be careful, it could be crushed by the gondola during the landing. To use a boom could enable you to be more flexible which can help you to recover the experiment**
  - **Detail the fixation of your boxes in the next version of your SED**

▪ **Electronics and data management** (SED chapter 4.5)
  - Interfaces: the serial or Ethernet connection is not decided yet (preliminary design : software slide), you need to decide
  - Block diagram in your presentation is better than the on your SED, update your SED
  - Power distribution was not clear on the SED, improve it
  - Heater control: adapt the voltage, not 24V
  - On page 48, on the figure you have photodiode and you use a relay: what kind of relay (electric, mechanic)?
  - Very low current on mechanical relay could be difficult to have a good contact so bad idea – Ask in experts sessions
  - Photodiode outputs: select an IDG406 analog device use for analog/analog signals, it is an analog multiplexer from FARELL adapted for low current
    Information: photodiode goes to single amplifier, a good buffer OP177 and then switch inside a multiplexer because photodiode is very sensitive for a super accuracy
  - Different photodiodes because of different ranges
  - Another solution with external converter 16 bits in order to avoid using external multiplexer, it could simplify your design because a multiplexer is complex
  - Data rates 200 Kbits ok, max 800 Kbits when there is a peak, have to coordinate with other teams because the peak is a lot – the bandwidth is limited, don't forget that you share with the other teams
  - Specify how many images you need in what time or frequency of this, specify when you need your picture for the flight scheduling
  - Power consumption is pretty low, are you sure? Take into account also your heaters on your power budget

▪ **Thermal** (SED chapter 4.6)
  - Add the conduction, it is the main driver for your thermal design
  - Outside minimum will be higher than the expected one, no insulation for the moment? (minimum temperature in your calculation -90°C is really low, maybe too low)
  - The expected temperatures:
    - Inside will be around -40°C depending on the canvas covers of the gondola
    - Outside You can expect -80°C on the shadow side and depending on material and colours the sun will heat up surfaces
  - Ensure that a piece of metal make the contact when you use your heater
  - Assembling of the clamps, screws are good conductors
  - Calculations based on worst cases and best cases and after you try to be between

- The message: "Each box shows three of its sides to the sun…" is not correct at all, because of the canvas covers and the structure and interior of the gondola
- By the attachment and chosen material for the housings you will have very good heat conductors where the setup will lose lot of energy by

- **Software** (SED chapter 4.8)
  - You have a complex software… try to simplify
  - You are using Arduinos and Raspberry Pi but you need to present how they communicate and how you store the data. Clarify the process from the sensor to the Arduino and then to the Raspberry Pi and to the ground station
  - Define the communication interface especially the analog interface

- **Verification and testing** (SED chapter 5)
  - You use too much inspection! Sometimes consider testing
  - Analyse for D12 is impossible
  - Shall be clean from dust – Inspection yes but Test impossible
  - O3 : analysis is impossible, you need to test
  - MS20: not sure how the action relates to the risk, this is not a well described or useful risk
  - In some cases the risk scenario needs more explanation like SF10 mechanical failure of bolts (leading to detachment of experiment during flight?)
  - Not much discussion around non-technical risks, consider risk management (budget, time, resources…)
  - Test 5 – detail your calibrations, verification of the GPS yes, calibration no p66
  - Test 11 – e link test? Could be done at Esrange if someone is available
  - Be very careful with shock tests: do not destroy your experiment before campaign!
  - Vacuum test facilities – source these now, determine the maximum size and requirements for the test facility (not sure Esrange have a test chamber big enough for the whole experiment), also think about data feed through/read out during the test (if required).
  - Think about the logical order of the testing (i.e. do things in the order they will experienced during flight), but also how far you have to 'roll back' if a test is failed or a design change is needed

- **Safety and risk analysis** (SED chapter 3.5)
  - Having spare parts of the experiment is not a risk
  - More explanation on the technical risks, add also risk management
  - Budget risk has a too big severity
  - Risk that something could fall off the gondola, add this risk in chapter 6

- **Launch and operations** (SED chapter 6)
  - Prepare ''remove before flights'' and covers, prepare a check list, consider late access facility to remove this cap in order to keep sensor clean – has to be requested in chapter 6

- **Organisation, project planning & outreach** (SED chapters 3.1, 3.2, 3.3 & 3.4)

  Resources
  - A lot of team members, probably got all required skills covered, but a good chance to optimise the project (resource allocation)
  - You need someone to really made the interface between all the sub systems, improve the system engineering in order that each has its inputs to work well, improve technical communication inside your team

  WBS
  - Missing system level activities, don't neglect this, whole system design, system budgets management, interface management, whole experiment AIV, system testing

  Schedule
  - Really good start, especially with mapping exams etc.
  - Next step is to build up more detailed Gantts for the upcoming phase
  - Good resource planning, but now try and map this to the required man hours for the WPs

  Budget
  - Provide the total of the 'outgoing' and the total of the 'incoming' to get a quick look at the expected project costs

- Don’t neglect testing costs and travel costs
- This is a good summary budget, but be sure to have a working spread sheet in the team listing your materials, order status, order details, costs…

Outreach

- Great to have a focus on a particular audience, but look back to the training week and think about all your stakeholders and how they need to be communicated with
- Great website
- Try to develop the outreach plan to include traditional media, and plan some key points for press releases, think about the build-up to key events (i.e. the campaign) and then the follow up

5. Internal Panel Discussion

- Summary of main actions for the experiment team
  - Decide and detail the interface between your boxes and the gondola
  - Detail your power distribution unit
  - Decide your electrical interface
  - Improve your power consumption calculation

- **PDR Result: Conditional Pass**

- Next SED version due: yes

- **SEDv1-1 on 21 Mars 2017**

- **SEDv2-0 on 10 May 2017**

A.2 CDR

BEXUS
Experiment Critical Design Review

Flight:	**BEXUS 25**		
Payload Manager:	TBC		
Experiment:	IRIS		
Location:	ESA ESTEC, Noordwijk, The Netherlands		**Date: 31 May 2017**

1. Review Board members

Alexander Kinnaird (ESA)
Armelle Frenea-Schmidt (ESA) – Minutes
Stefan Krämer (SSC) – Chair
Maria Snäll (SSC)
Koen DeBeule (ESA)
Piotr Skrzypek (ESA)
Hanno Ertel (ESA)
Katharina Schüttauf (DLR)
Dieter Bischoff (ZARM)
Marion Engert (ZARM)
Simon Mawn (ZARM)

2. Experiment Team members

Gustaf Axel LJUNGNE
Francois Jean-Philippe PIETTE
August Karl SVENSSON
Andreas Johm WALLGREN

3. General Comments

- **Presentation**
  - Your presentation was fine and you present all the aspects
  - You said ''Remove before flight switch'' but in fact ''cap'' or ''pin'' is more often used so just used the right word

- **SED**
  - Little bit light for a CDR
  - In your components table you still have a lot of TBD which is not a CDR level
  - Presentation brings more information than the SED
  - P56-57 you have two figures (4.5.2 and 4.5.3) but one is not applicable anymore so delete this one
  - Delete also the requirements which are not applicable anymore because it could be confusing
  - Sun will shines into the measurements with a big field of view, is it a problem? Even if you performed calculation, you can have some roll because of the mass even if it could be equilibrated with SUNBYTE. However, add a requirement about centre of mass of the gondola to balance the mass of the gondola on the chapter 6 and consider to move your booms along the gondola

4. Panel Comments and Recommendations

- **Requirements and constraints** (SED chapter 2)
  - Updates are fine
  - C4 – budget, it is a constraint but write it down in a way that it is easy to understand (in what extent it could be grave for you)
  - Not ideal wording sometimes, for example ‘’simple’’ or ‘’clean’’, these words are quite ambiguous. Try to clarify
  - P14 & P15 - you have requirements for pressure and temperature but which pressure, which temperature ? air pressure and air temperature ? Clarify
  - D13 – ‘’should… if possible’’ is a ‘’could’’ but it means it not a priority
  - Your sensor box is water tight but there is no requirements explaining that it is necessary, it can impact your design so add a requirement
  - D14 - “The fastening to the gondola rails shall be carried out with M6 bolts…” – not really, for vibration damping we offer rubber bumpers with volcanized M6 bolts on both sides (contact ZARM)

- **Mechanics** (SED chapter 4.2.1 & 4.4)
  - It could be good to have a sacrificed material for the boom like polycarbonate because during the landing, if the gondola lands on one of your booms, the gondola will be bent and damaged however a gondola has to be reusable. Polycarbonate can break that is why it could be better, it can save your box and the gondola
  - How to mount it? Ask an Expert session – Stefan or Dieter
  - Moreover, the only constraint for your booms is the mass of your box that is why it could be feasible with polycarbonate
  - Contact Dieter for the clamps
  - Interfaces to the gondola up and down: please provide long holes on one side of the clamps and of the main box which will be attached on the rails (because of bigger tolerances of the rails)
  - For your risks SF20 and SF30, use locking nuts or Loctite (for example)
  - Consider to make the safety wire (and electronic cables) longer in order to follow the frame of your experiment
  - Moreover, all components mounted outside of the gondola have to be linked by the safety line
  - Water tight box COTS so it can become a pressure vessel… so test it if air tight, place a sponge inside
  - There is an interface issue with E-link on the upper boom, maybe decrease or increase the distance between the booms
  - Never use through holes in Bosch profiles, use a nut
  - Clamps design is fine, the inside has to be smaller than the Bosch profile because you can have movement of the profile inside the clamp which is bad because you cancel the clamp effect
  - Drawings – good in general but please find here some advices from Dieter:
    - You reduced the title blocks to the things you need – it is fine but not standard;
    - In the overviews give overall dimensions, the specified ones will be given in the single part drawings or the list of parts (for the case of a length of a BOSCH profile f.ex);
    - Add middle lines for symmetrical parts which allows you to give centred dimensions;
    - Dimensions on visible lines, corners or edges only. Very often you took hided lines or the beginning of a radius which is not good;
    - Do not place the dimensions on the frame of the drawing sheet, because important information could be covered/hided by this;
    - Give x- and y- coordinates to the centre of a drilling. And in case of more of the same drillings in a row: Give x- and y- coordinates of the first one and follow with relations (distances) of the others;
    - Give overall dimensions of any part and not only the details of the preparation (see “Filter Upper Plate”…);
    - Specify the used material (missing in Thermal Insulation parts);
    - Look again over the drawing sheets to ensure that no dimension is missing (diameter for the both drillings in the lateral thermal insulation f.ex.);
    - On the brain socket plate you are going to assemble connectors with fixed threads. For those give the diameter of the centre hole and relate the outer drilling for the

screw for fixation;

- If you look at the sensor box, you have diode and filter and it might affect the field of view so if you want to have the full field of view don't have a cylindrical but consider a conic hole

- **Electronics and data management** (SED chapter 4.2.2, 4.2.3, 4.5, 4.7, 4.9)
  - Good power and good data rate, ok for SSC
  - Communication line – USB for the moment and 1.1 or 2.0 necessarily ? Cable will be outside and your USB also so try to have the cable inside and try to make sure that USB is not completely exposed to the environment - But v1.1 can be longer cables and you don't have a big data rate so you can use 4.2 or 4.5
  - Have good quality cables, test a lot and shield them
  - Power distribution unit is on each box but no schematics or drawings, part of the appendix

- **Thermal** (SED chapter 4.2.4 & 4.6)
  - Good calculations
  - Estimate the air flow on ground (actually, you can count on convection properties on ground only. It will not be possible to establish an air flow of 5m/s during float time because of low pressure environment)
  - There is no simulation software for sun radiations so you have to calculate by hands
  - P174 – aluminium is a good conductor but after a while, the temperatures inside and outside the box will be the same so add some plastic material
  - How will you mount insulation? Taped for the moment, good but not the main one, you can use plastic screws in nylon in the aluminium profiles to attach the thermal insulation
  - Use aluminium tape and not black colours
  - Styrofoam – be sure that it is ok in low pressure
  - Looking at the sensor box you will produce a big heat bridge to the side where the sensor board is mounted. The panel is conducted to the inner rack out of aluminium which means that the loss of heat will be really big. What about a board out of plastic material such as PEEK which is stable and almost resistant to big temperature range?
  - Brain box is good but use thermal spacer – contact Dieter also for comments on calculations
  - Regarding the calculation of the heat flow through the boxes You put aluminium around the cover. This means after a while the temperature in between aluminium and Styrofoam will be equal than the outer temperature because of the conducting properties of aluminium. An outer layer out of plastic material would be better (PE, PU…)
  - Sensor box & heater – you can have the other case, shadow side so perform this case because it will be the coldest condition for your heaters, In October when we will launch BEXUS the sun is just little height than the horizon. For the considerations (middle case) for the calculation of the radiation by the sun this means You will have one surface directly or two surfaces at 45° or nothing if the boxes are in the shadow of the gondola

- **Software** (SED chapter 4.8)
  - Usually system is powered on by SSC through the battery, a remove before flight is good if you have something to protect not just to switch on
  - Data transmitting – everyone wants to transmit pictures! So add calculations about data you want to transmit especially from the camera (kbits), SSC has limitation of 2 Mbits/s
  - Process flow chart - how often you want to have data from sensors – 1 every 3s, question about buffering. Store in the Arduino and then Raspberry ? Or store in the Raspberry ? Clarify this and test these different scenarios
  - Thermal control loop is missing, also add it in the process flow

- **Verification and testing** (SED chapter 5)
  - Do you really need an E-link test before the campaign? Actually, the main problem with E-link will be when all experiments will be mounted together on the gondola and it will be tested during the BEXUS campaign
  - Vibrations during 5 hours is super long, safety factor of 5 is little bit high
  - For landing shock, don't use the real module but a test one
  - Perform test vibrations and then in vacuum
  - Good to prioritize your tests, calibration of the photo diodes test is really good

- **Safety and risk analysis** (SED chapter 3.5)
  - MS10 – risk ok, low risk, but you can't repair during flight
  - Update your risk register when you have mitigated it, the medium ones should be lower now

and you can have more risks now because your design is quite complete
- Miss risk for budget
- If you delete a risk, explain why

- **Launch and operations** (SED chapter 6)
  - Mass has been doubled from the PDR – you have to tell that and not surprised us in the SED
  - So your requirements is not respected 8kg ! ^^
  - Risk of the sensor box falling off
  - Power ok
  - Requirements are ok but 13 chairs is too much
  - Oscilloscope is ok (from ZARM)
  - When it is too specific, provide your own materiel
  - Start to capture data before LO to be sure that it is working
  - Chapter 6 – you have a lot of TC and make it clear that it is manually
  - If your storage is on the water, are the data corrupted? Test it, but the chance to land on water is low

- **Organisation, project planning & outreach** (SED chapters 3.1, 3.2, 3.3 & 3.4)
  - More consideration on your WBS and Gantt Chart especially for testing
  - You can reduce travel costs with outreach activities
  - Countdown is a great idea but maybe also add the date

- **Questions from the team**
  - Single ground point, they want to have several grounding points, sometimes the manufacturer of sensors has specifications and advices if the component has to be isolated completely or grounded
  - Because you have long cable, use a single ground point in your brain box
  - You can have a jumper between your mechanical ground and the electronics one
  - You can use Linux process in order to protect your system but it is more difficult to share your data

5. Internal Panel Discussion

- **Summary of main actions for the experiment team**
  - Mechanics: consider to use polycarbonate for the structure of the boom
  - You have also a conflict with E-link, modify the length between the two parts of the boom
  - Improve your thermal design
  - Improve your project management especially the test plan (schedule)
  - Consider removing the 'water rightness' of the box,

- CDR Result: **Conditional Pass**

- Next SED version due: **SED v2-1 on 26 June 2017**
  SED v3-0 on 23 July 2017

A.3 IPR

TBD

A.4 EAR

TBD

B Outreach and Media Coverage

The team's website can be found at: www.bexusiris.com.

IRIS has a Facebook page, located at: facebook.com/bexusiris/.

Our Instagram account is found at: @bexus_iris.

An article about IRIS, as well as our sister project EXIST, was published by the Atmospheric Science Group at Luleå University of Technology. It could be found here: atmospheres.research.ltu.se
This article has been removed due to maintenance work on the Atmospheric Science Group's webpage.

Atmospheric Science Group
Luleå University of Technology

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SEARCH

Two new LTU's projects selected for REXUS/BEXUS programme

December 21, 2016 / News

Two new experiments proposed by student teams from Luleå University of Technology (LTU) were selected to be launched within the REXUS/BEXUS programme during a workshop held at European Space research and Technology Centre (ESTEC, in Noordwijk, The Netherlands). The projects are *EXamination of InfraSound in the Stratosphere and Troposphere* (EXIST), and *infraRed albedo measurements in Stratosphere* (IRIS) and, in particular, they will be included in the BX 24/25 balloon campaigns, adding up to three the LTU's projects accepted in the programme together with the SALACIA experiment, which will be launched next march on board the 21 REXUS rocket. The acceptance marks the beginning of the long process of development of the initial idea and the construction of the correspondent instruments.

Figure B.0.1: Article about IRIS and EXIST

A 20 minute presentation, with an additional 10 minutes for questions, was held for participants of the Space Instruments R7013R course at Luleå University of Technology. The presentation took place on 2016-12-16. Information about the course can be found at this link.

On 2017-01-28 IRIS took part in the Space Day 2017, an event organised at Folkets Hus in central Kiruna. Here we presented our project to the general public of Kiruna, sharing a booth with EXIST and the REXUS team SALACIA.

Another article, based on an interview of members from both IRIS and EXIST, was written by LTU's Communicator Linda Alfredsson. It was published on the university webpage 2017-02-24 and is available in both Swedish and English. Link

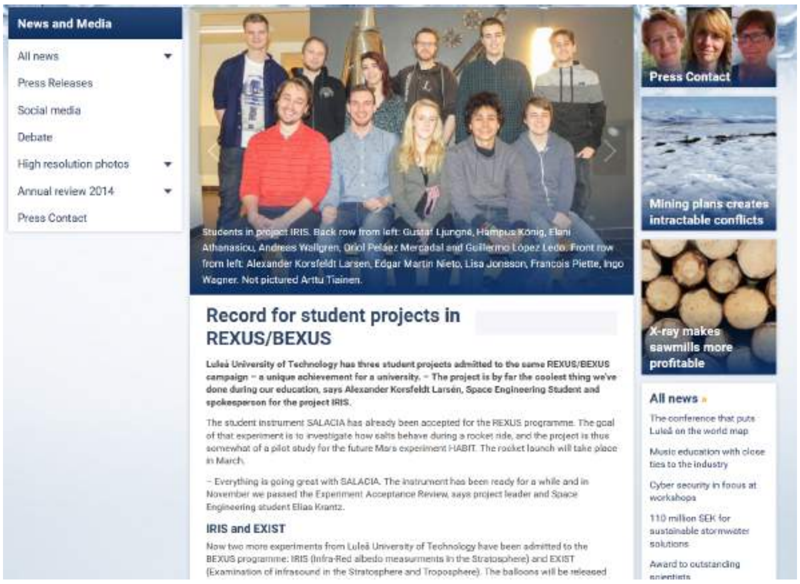


Figure B.0.2: Interview published on the LTU website.

A radio interview was aired on the Swedish radio station P4 Norrbotten on 2017-03-05. Link.

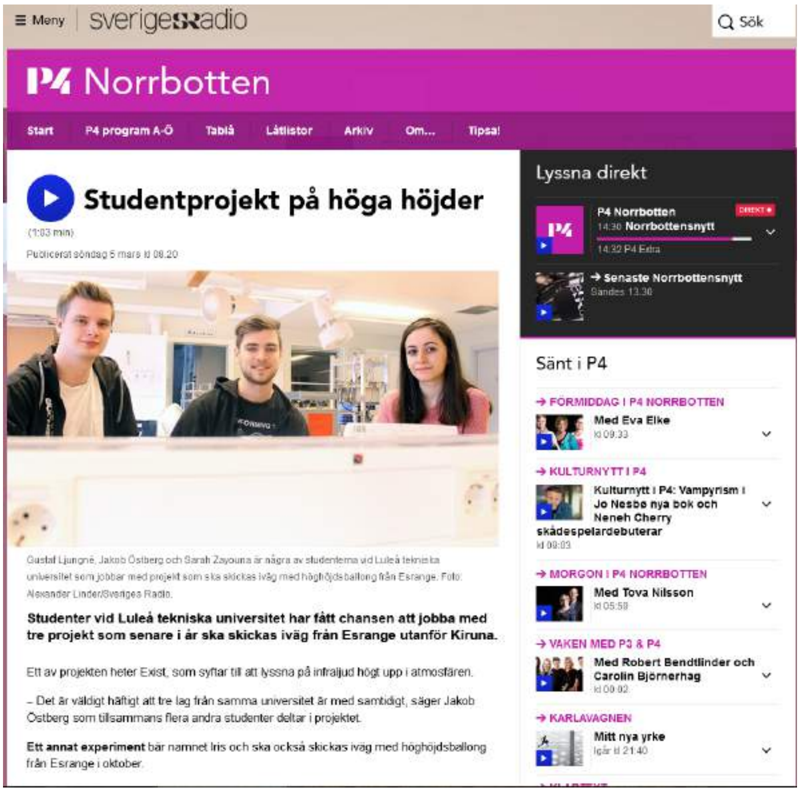


Figure B.0.3: Interview on the radio station P4 Norrbotten

On 2017-03-22 a short presentation was held together with EXIST for politicians from the county council of Norrbotten, Sweden. We told them about the REXUS/BEXUS programme and about the scientific goals of our experiments. Emphasisis was also put on why we think it is so important to have programmes like this available for students.

On 2017-05-05, a brief presentation of the IRIS project was given in a short commercial break during a lecture in R7021R Space Communication. Course information

IRIS attended Rymdforum 2017, a conference held in Kiruna May 8-10. This granted us an opportunity to demonstrate our project and meet representatives from various space companies, space agencies, and the Swedish government. A poster was created for this event. It will be used for similar events in the future, and at other times will be placed in a visible location at Space Campus.

Two members from the team were sent to the 23rd ESA PAC Symposium held in Visby June 11-15. This helped get word out about the IRIS Project and REXUS/BEXUS in general, while also giving valuable experience to the team. The trip was financed with the help of the Swedish National Space Board.
The IRIS logo, fig. B.0.4, was created with the aid of Martin Tomasson, a student at Chalmers University of Technology, Göteborg. In addition to a balloon the logo shows incoming light, with the colours of the EU flag, being reflected as the flags of every nation represented in the IRIS project. These countries are Sweden, Belgium, Finland, Spain, Greece, Bulgaria, and Germany.

Figure B.0.4: The IRIS Project logo

In the middle of March, 2017, we received hoodies with our team logo on them that we purchased from T&S Reklam tsreklam.se. The company sponsored 50 % of the cost in exchange for us providing links to their websites in posts on our webpage and Facebookpage. A picture of the hoodies is shown in fig. B.0.5 below.

Figure B.0.5: The IRIS Team Hoodies

C Additional Technical Information

C.1 Electronics Diagrams

Following are the circuit diagrams used in the experiment. All diagrams are made with KiCAD.

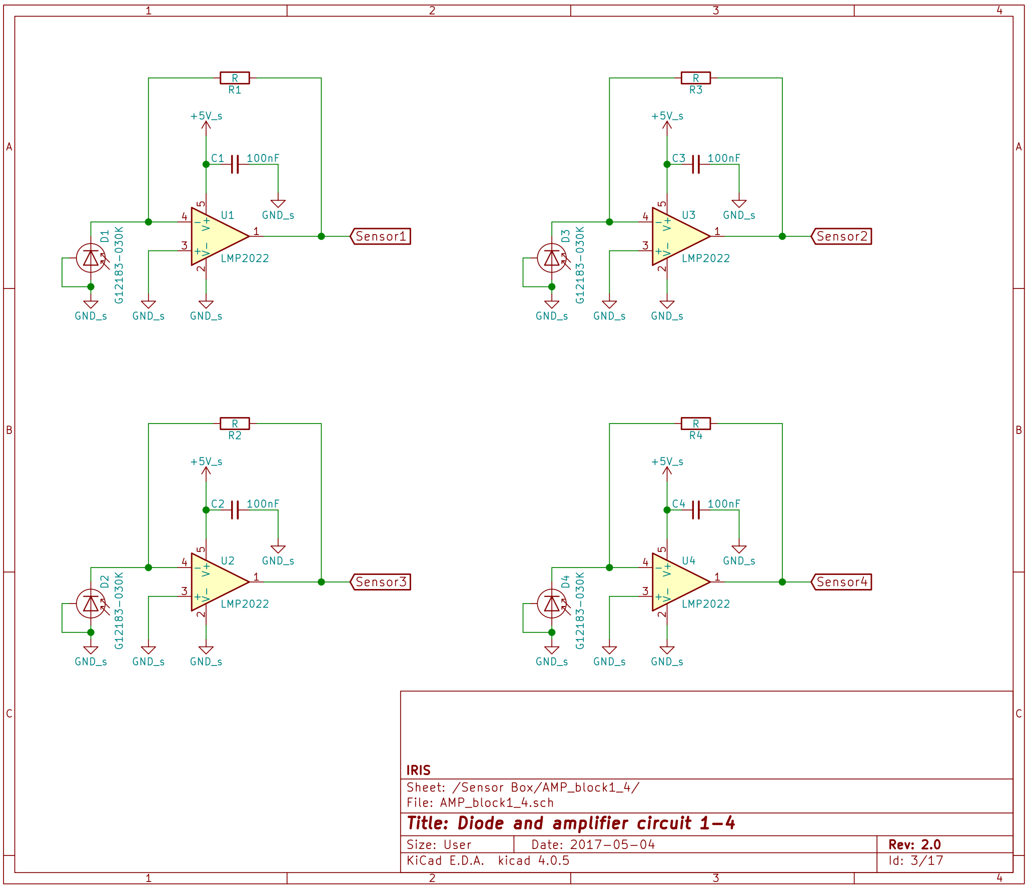


Figure C.1.1: Amplifier circuits with photo diodes, connected to first ADC.

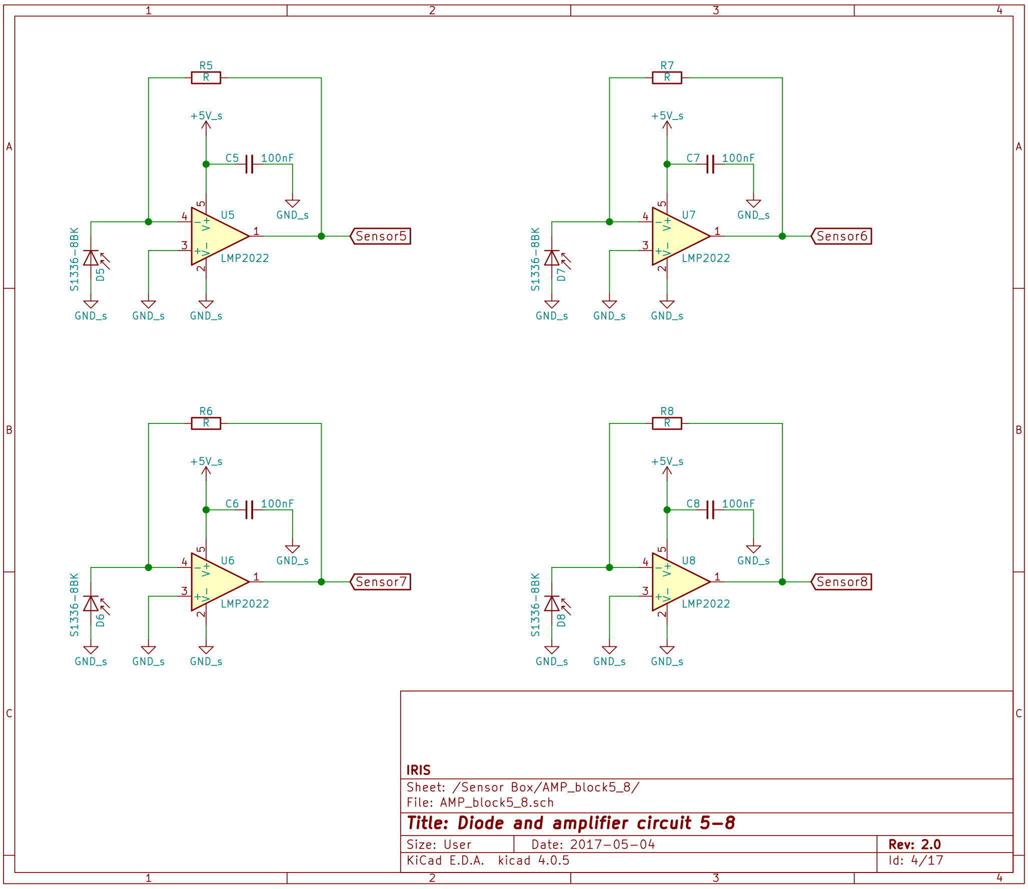


Figure C.1.2: Amplifier circuits with photo diodes, connected to second ADC.

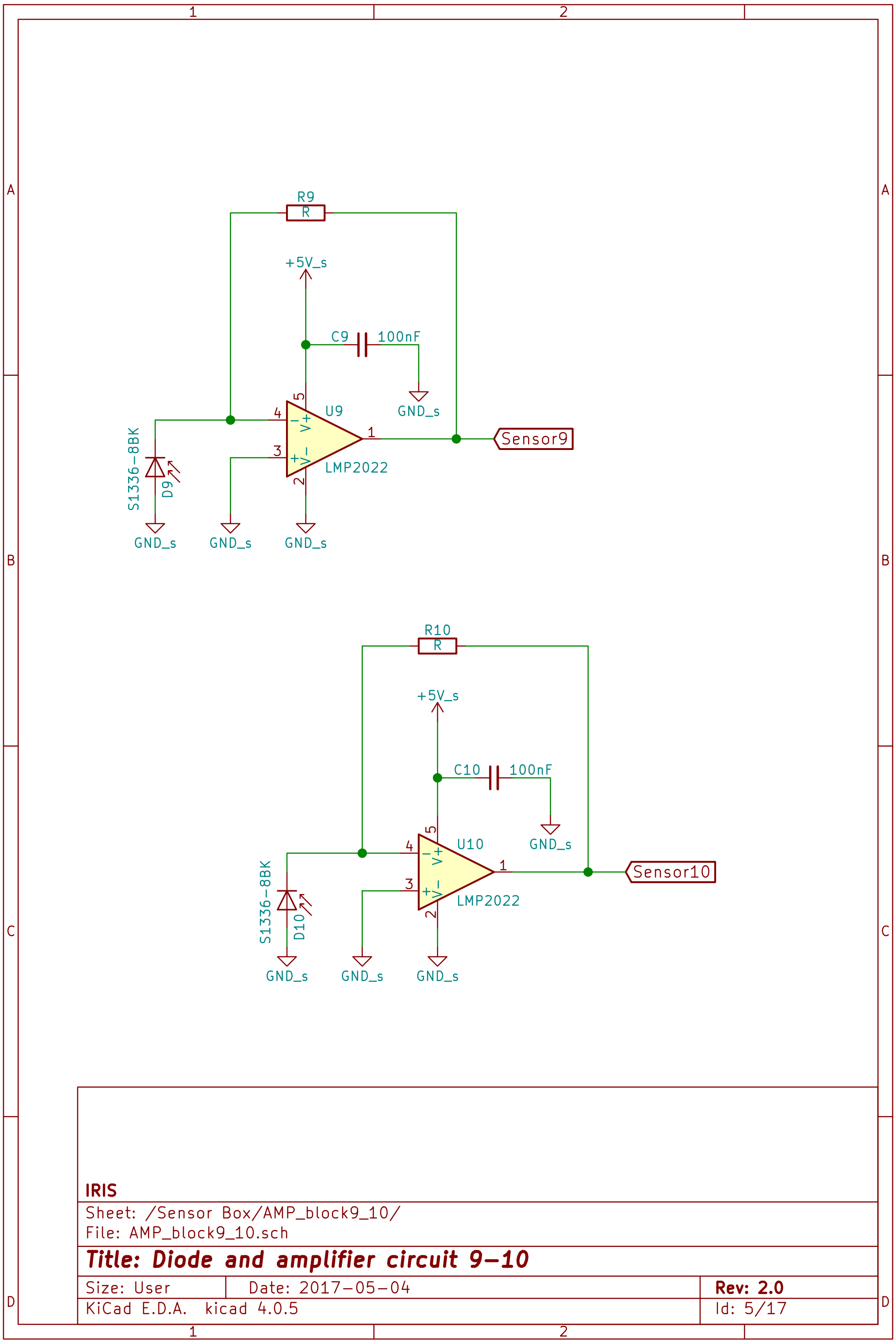


Figure C.1.3: Amplifier circuits with photo diodes, connected to third ADC.

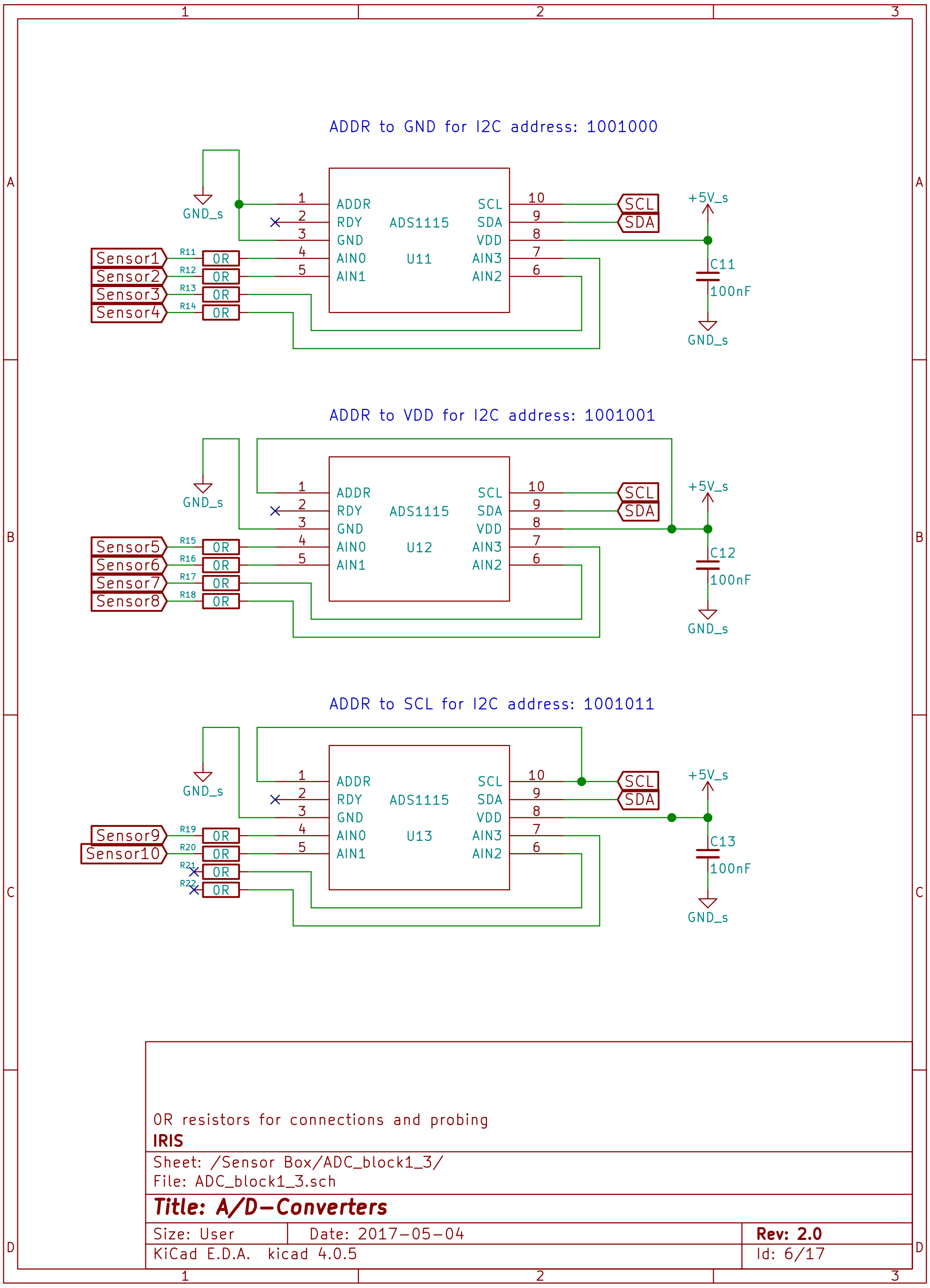


Figure C.1.4: A/D-Converters, connected to the I²C interface of an Arduino Nano.

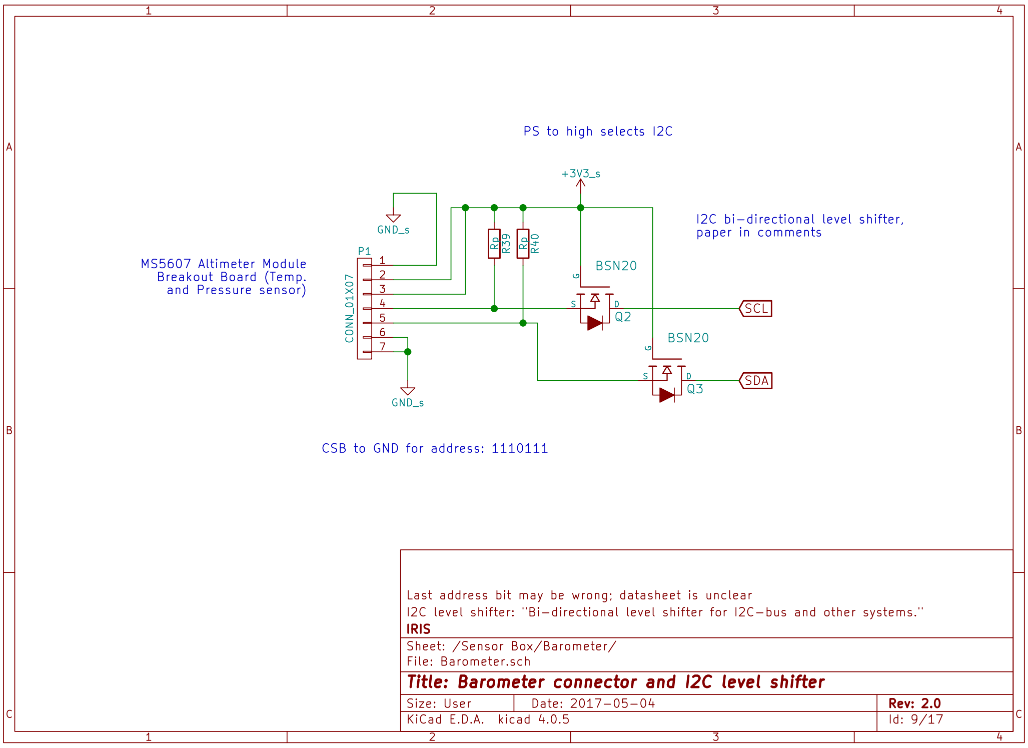


Figure C.1.5: Barometer with temperature sensor, connector to I^{2}C interface.

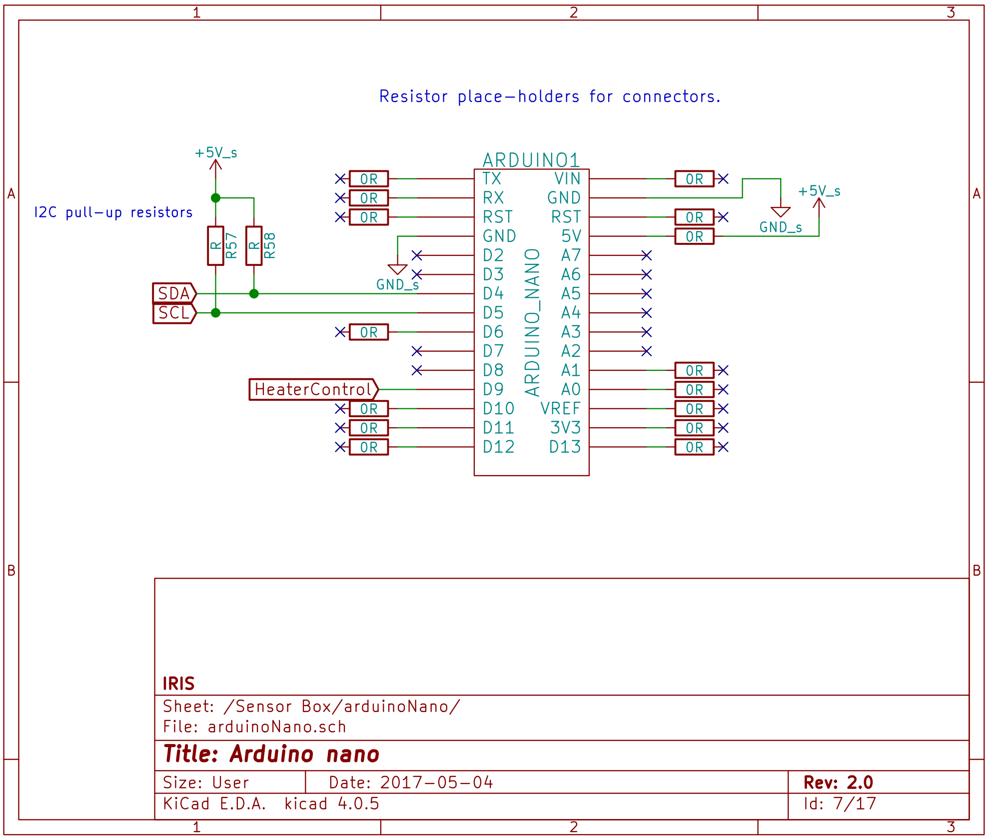


Figure C.1.6: Arduino Nano with I^{2}C pull-up resistors.

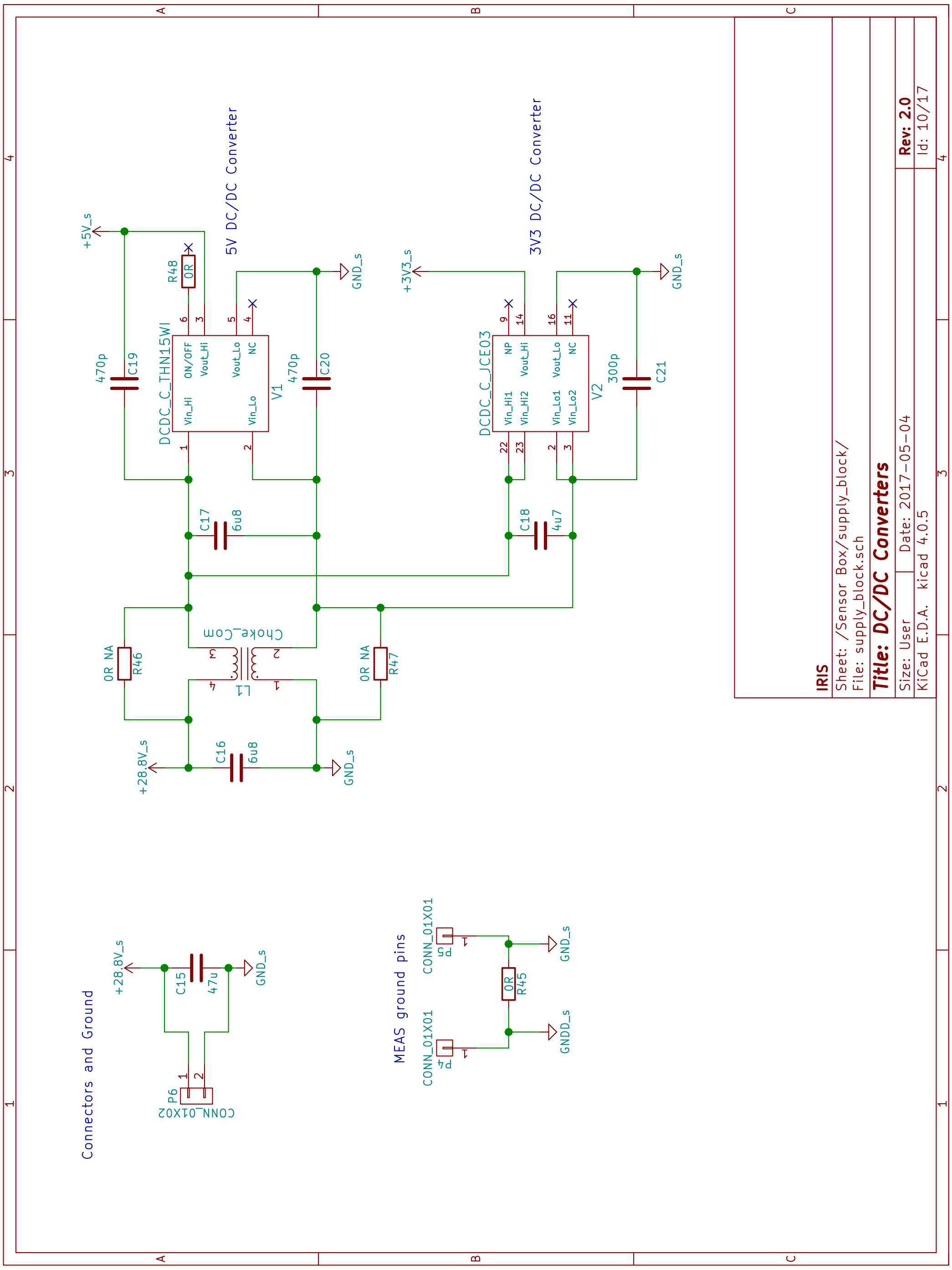


Figure C.1.7: DC/DC-Converters for the local electronics. Sensor box gets 28.8 V from gondola via middle (brain) box.

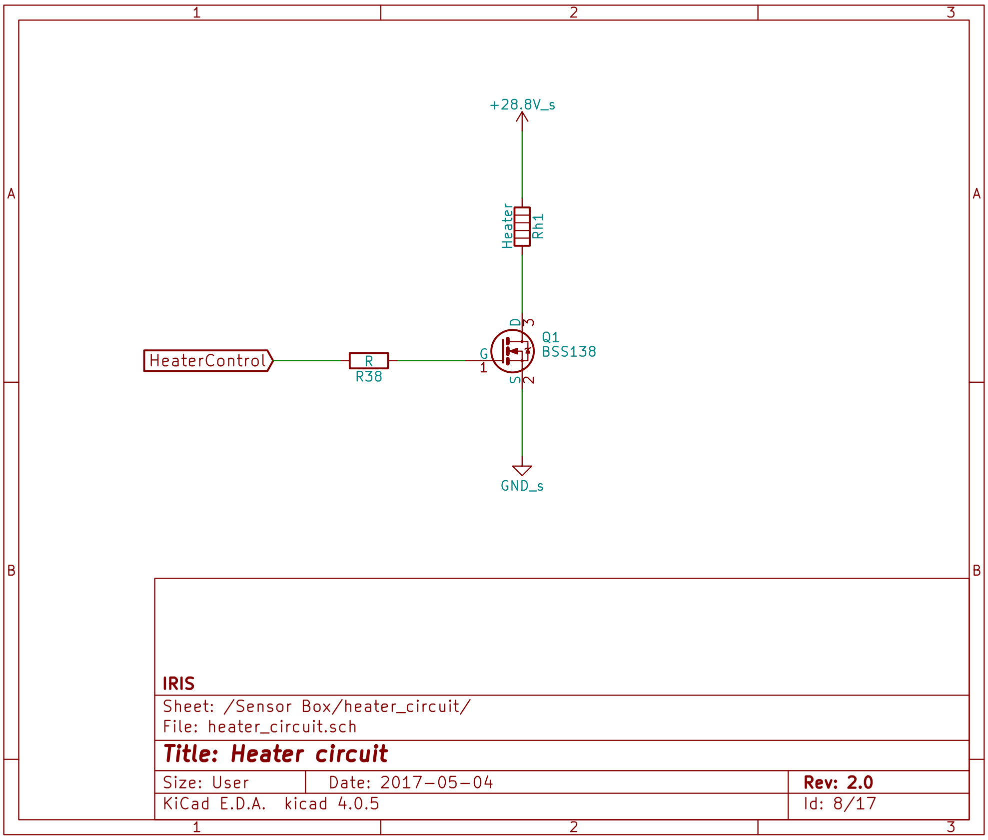


Figure C.1.8: PWM-controlled heaters connected to local Arduino.

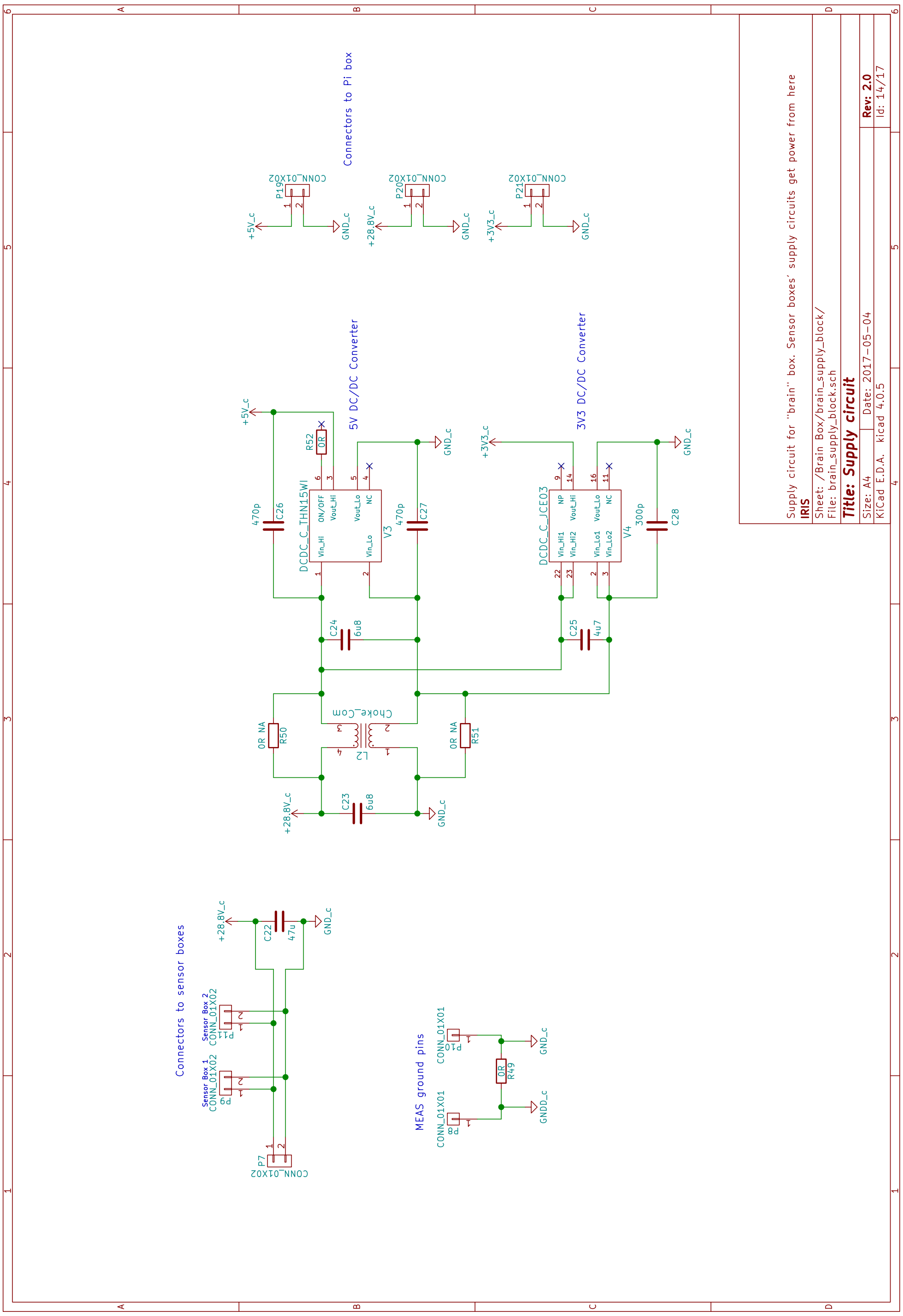


Figure C.1.9: DC/DC-Converters for the local electronics in the brain box, along with connectors for gondola source and to other boxes.

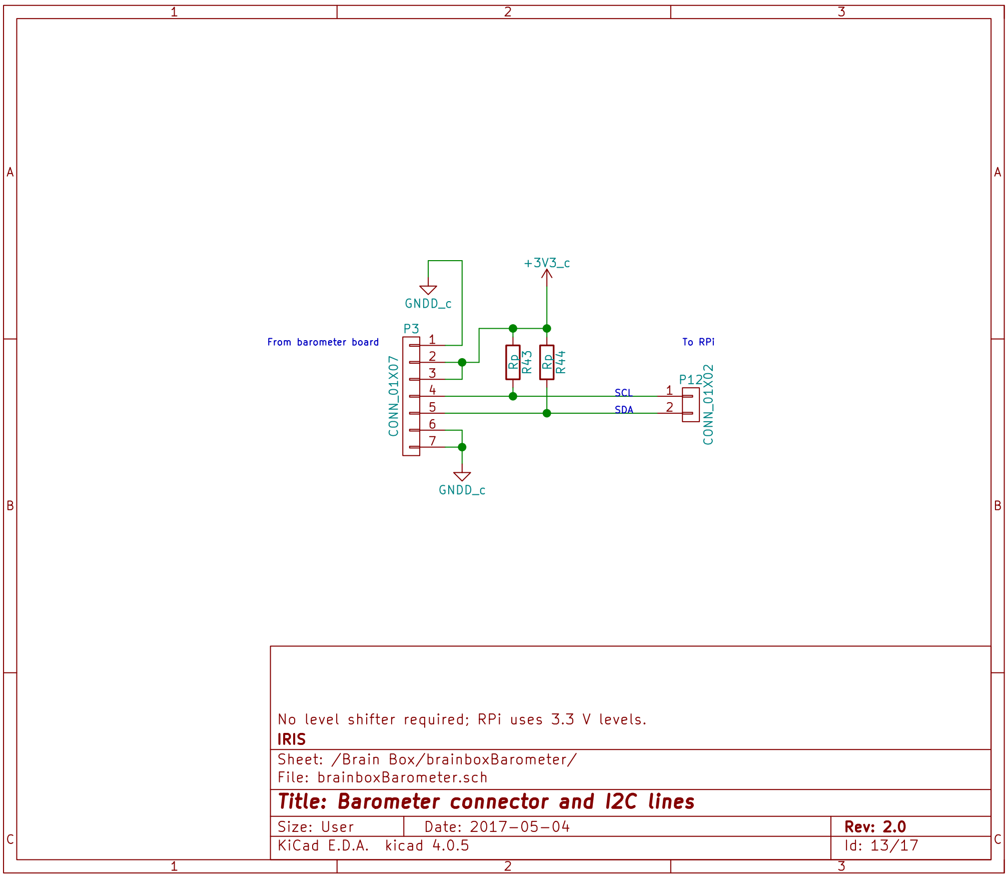


Figure C.1.10: Barometer with temperature sensor, connector to I^{2}C interface of the RPi.

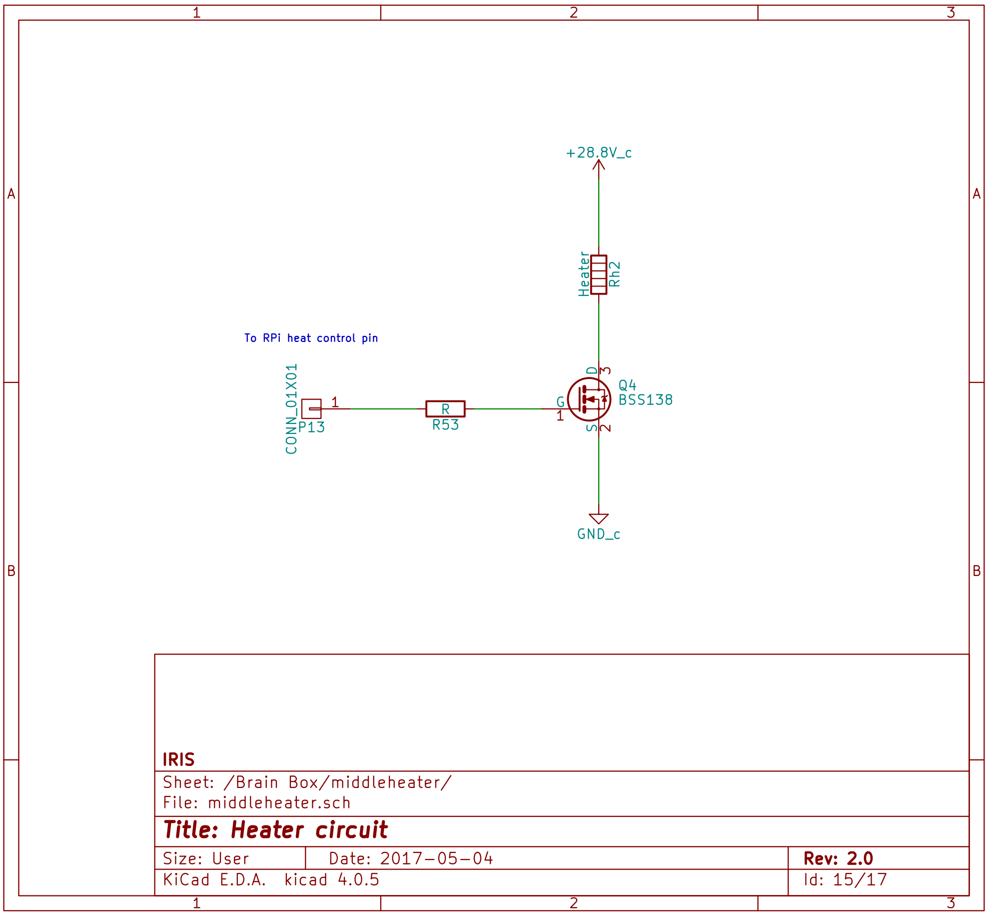


Figure C.1.11: PWM-controlled heater for the brain box connected to RPi.

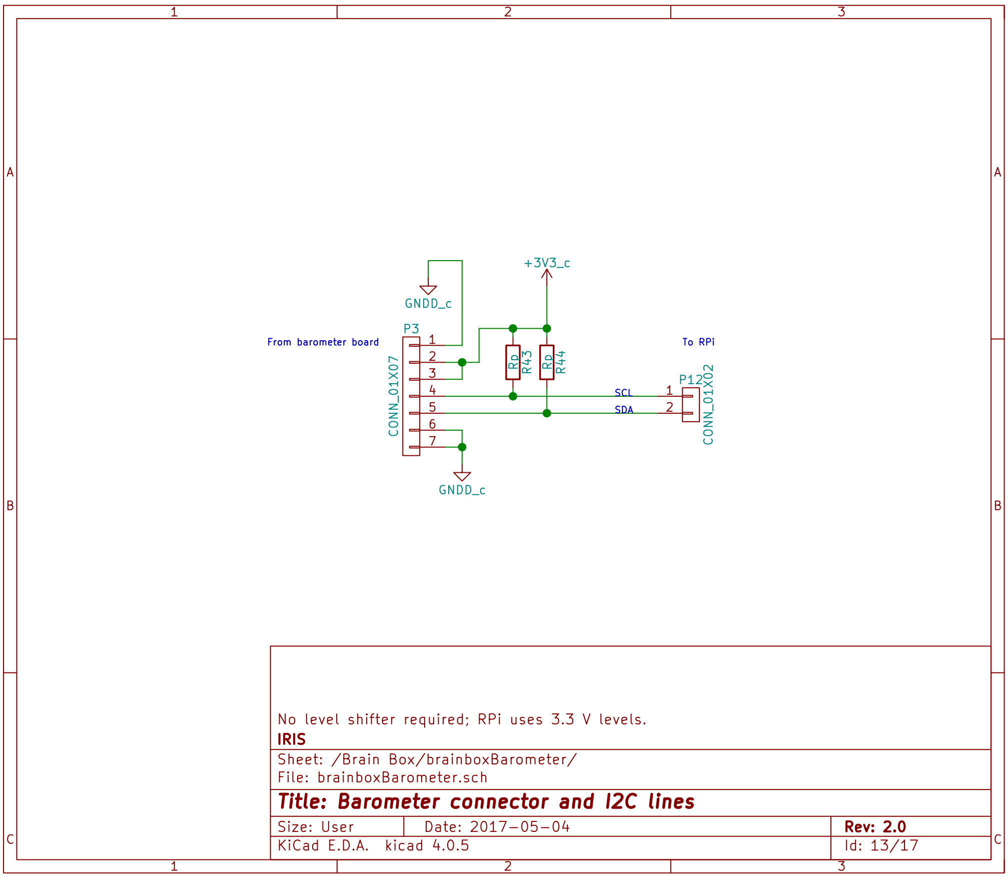


Figure C.1.12: Barometer with temperature sensor, connector to I^{2}C interface of the RPi.

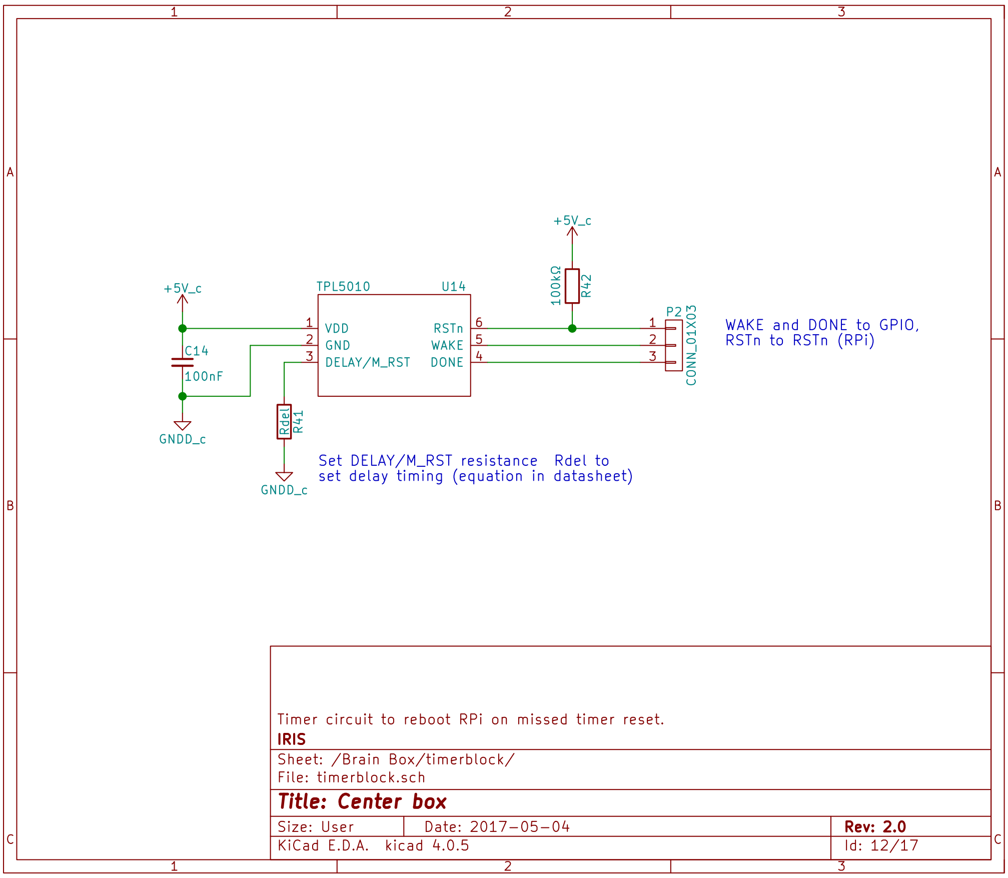


Figure C.1.13: Timer chip circuit to act as a primitive watchdog for the RPi RESET-pin, in case it freezes.

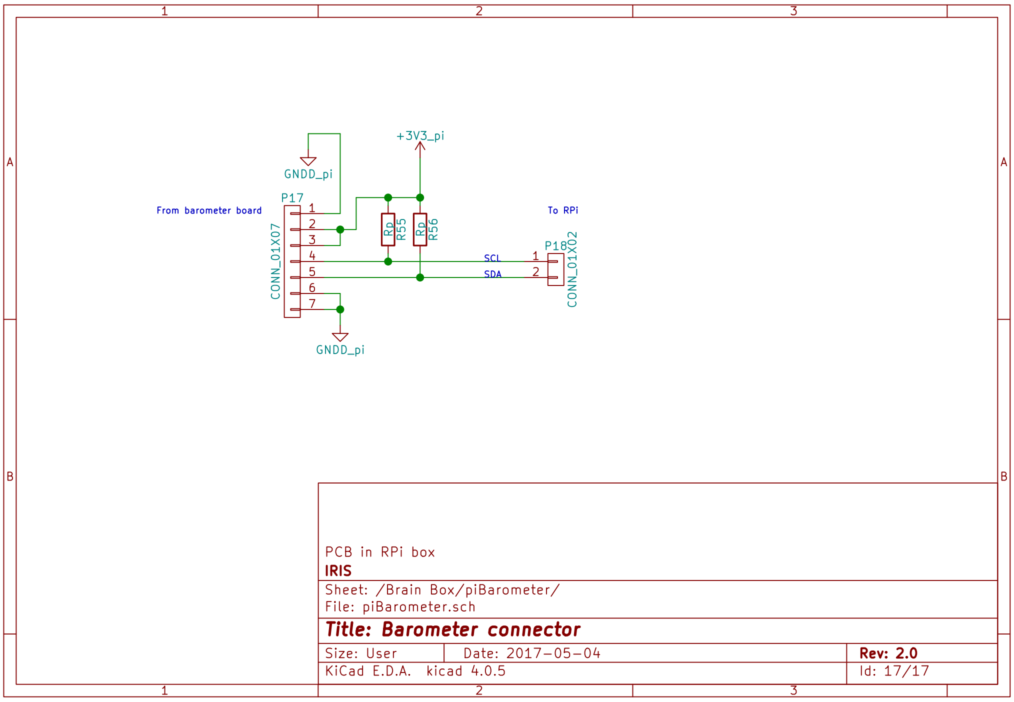


Figure C.1.14: Barometer with temperature sensor inside water-proof box, connector to I^{2}C interface of the RPi.

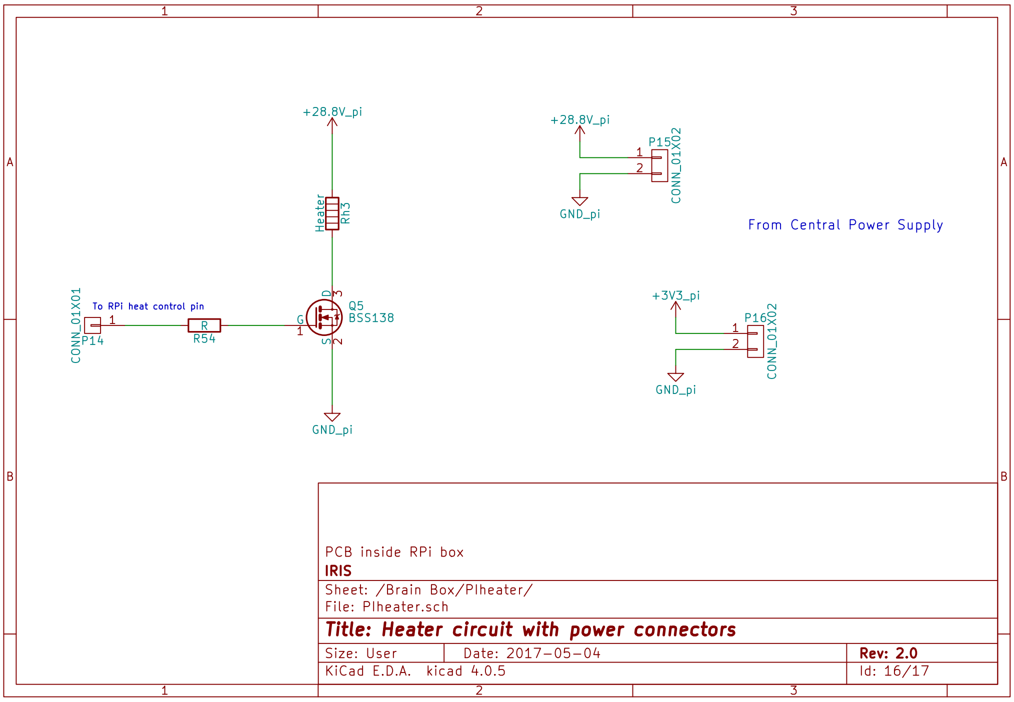


Figure C.1.15: PWM-controlled heater for the water-proof box containing the RPi.

C.2 PCB Layouts

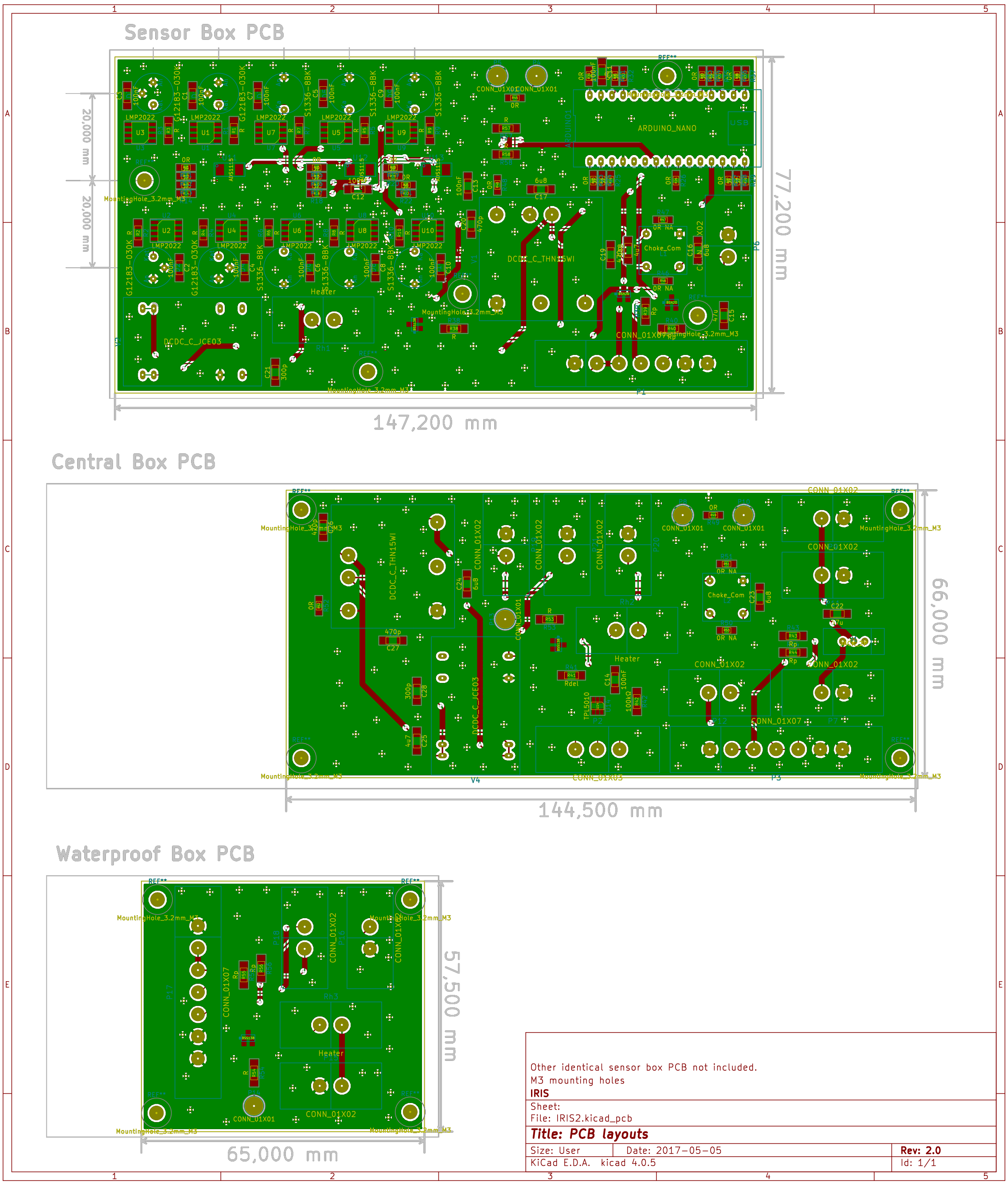
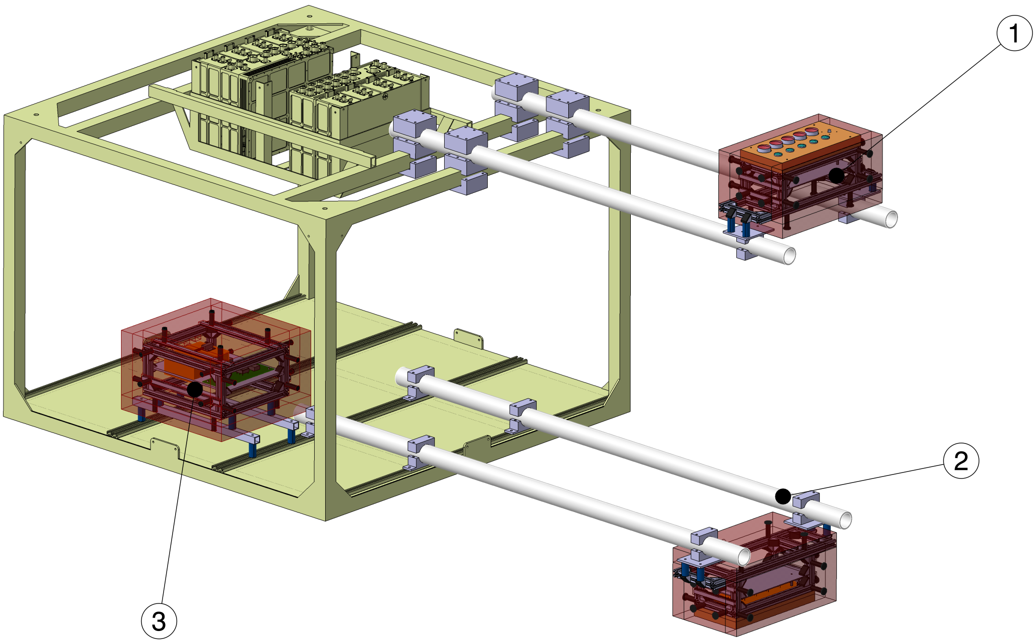


Figure C.2.1: PCB layouts of the three different designs.

The tiny ADS1115 chips in figure C.2.1 are going to be replaced with their break-board counterpart, effectively changing the mounting from surface-mounted to through-hole mounting.

C.3 Manufacturing drafts

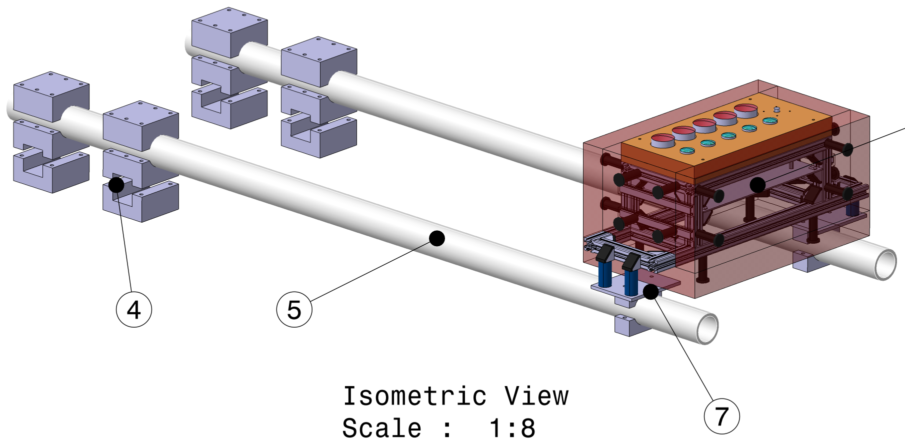
The following are the drafts that are to be used to manufacture the mechanical components of the experiment.



Isometric View
Scale : 1:14

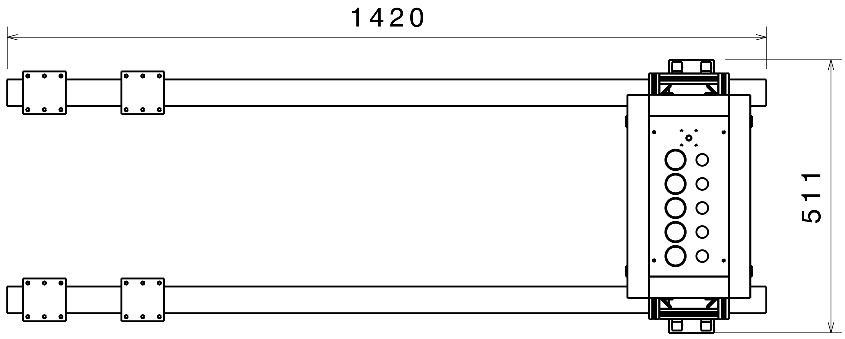
Item N°	Title
1	Upper Sensor Box
2	Lower Sensor Box
3	Brain Box

Title IRIS v2.1		**Author** IRIS - BX25
Bolts /	**Item N°** /	**Material** /
Nuts /	**Scale** 1:14	**Dimensions [mm]** /
Washers /	**Weight [kg]** 22.5	**Sheet** 1/?

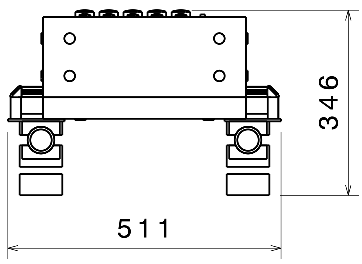


Isometric View
Scale : 1:8

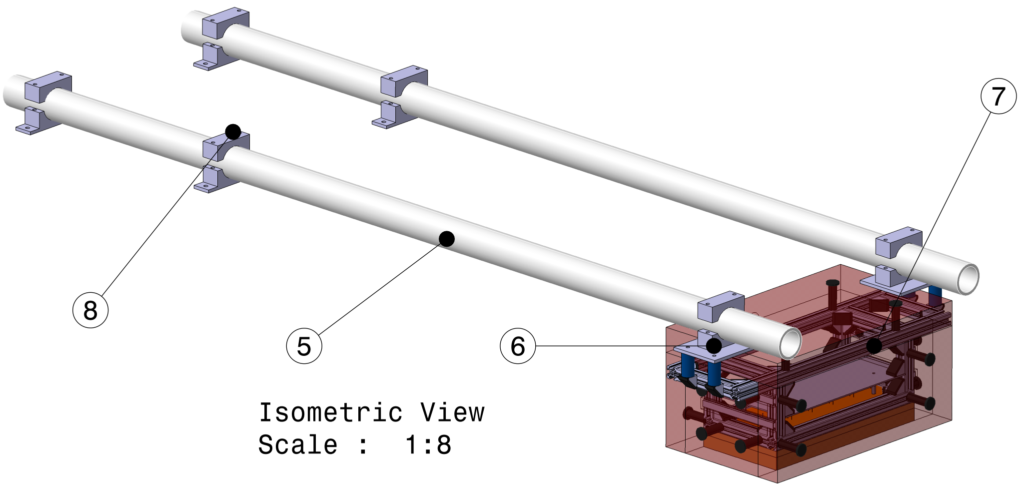
Item N°	Title
4	Gondola-boom mounting (clamp-clamp)
5	Polycarbonate Boom
6	Sensor Box
7	Sensor-Boom mounting



Upper View
Scale : 1:10

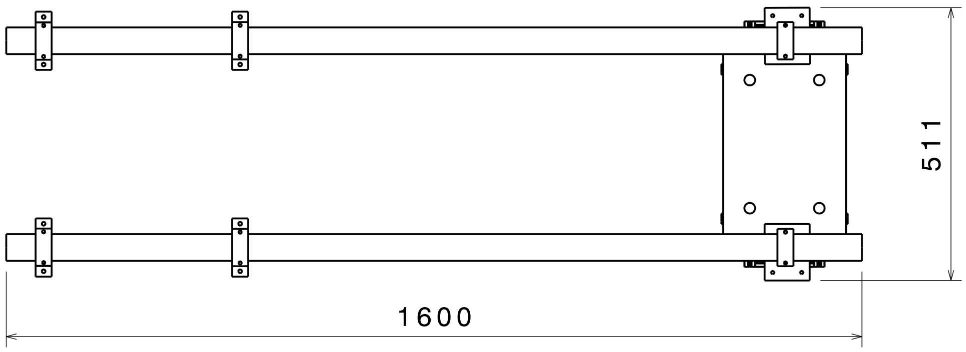


Front View
Scale : 1:10

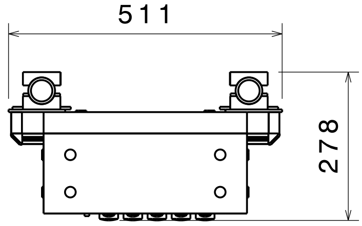


Isometric View
Scale : 1:8

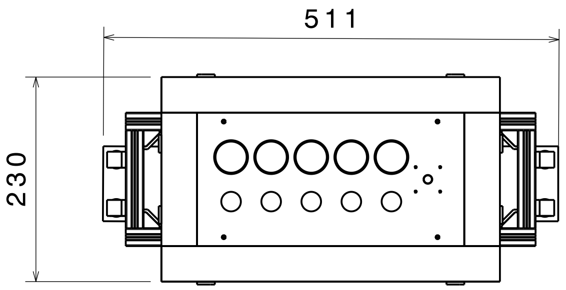
Item N°	Title
5	Polycarbonate Boom
6	Sensor-Boom mounting
7	Sensor Box
8	Lower Gondola-Boom mounting



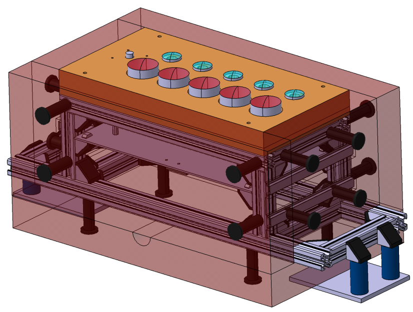
Front View
Scale : 1:10



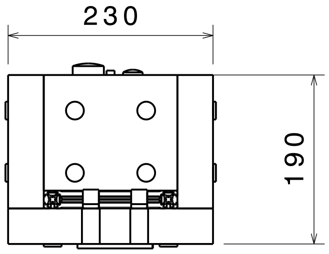
Front View
Scale : 1:10



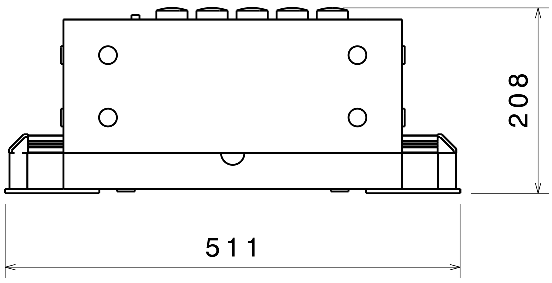
Upper View
Scale : 1:6



Isometric View
Scale : 1:6

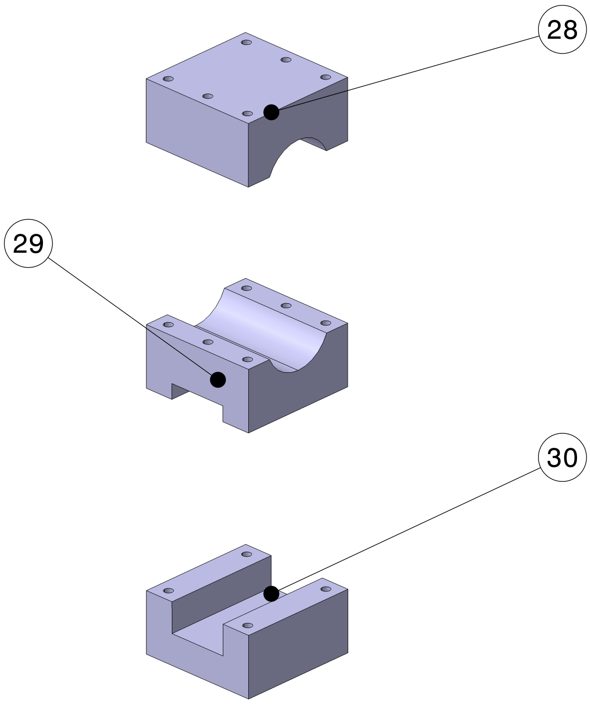


Side View
Scale : 1:6



Front View
Scale : 1:6

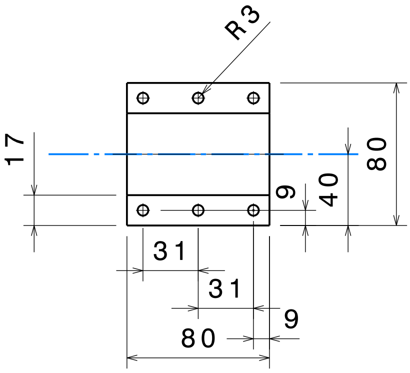
Title Sensor Box		**Author** IRIS - BX25
Bolts /	**Item N°** /	**Material** /
Nuts /	**Scale** 1:6	**Dimensions [mm]** 511x230x190
Washers /	**Weight [kg]** 2.8	**Sheet** 4/?



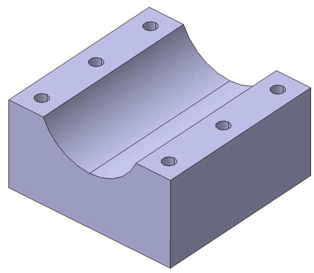
Isometric View
Scale : 1:3

Item N°	Title
28	Boom Clamp Upper Part
29	Boom-Gondola Clamp
30	Gondola Clamp Lower Part

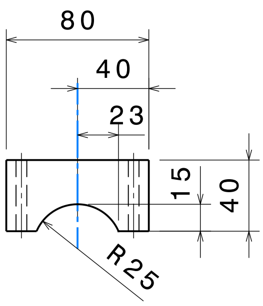
Title Gondola-Boom Clamp parts		**Author** IRIS - BX25
Bolts 4 M6x90 2 M6x60	**Item N°** /	**Material** Aluminium
Nuts 6 M6	**Scale** 1:3	**Dimensions [mm]** 153x80x80
Washers 12 M6	**Weight [kg]** 1.55	**Sheet** 5/?



Bottom View
Scale : 1:3

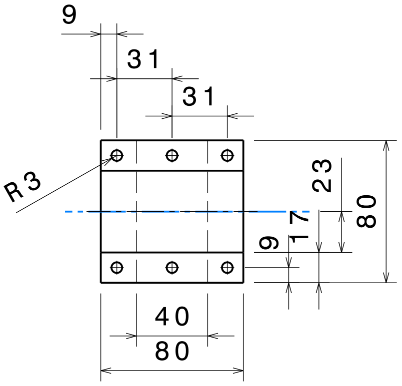


Vue isométrique
Echelle : 1:2

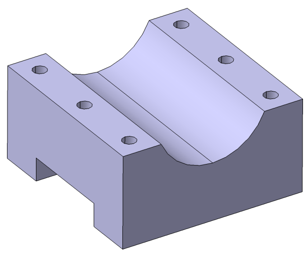


Front View
Scale : 1:3

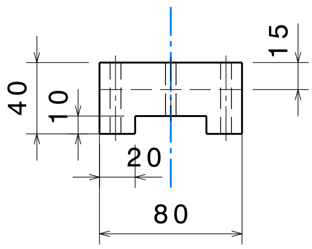
Title Boom Clamp Upper Part		**Author** IRIS - BX25
Bolts 4 M6x90 2 M6x60	**Item N°** 28	**Material** Aluminium
Nuts 6 M6	**Scale** 1:2 and 1:3	**Dimensions [mm]** 80x80x40
Washers 12 M6	**Weight [kg]** 0.564	**Sheet** 6/?



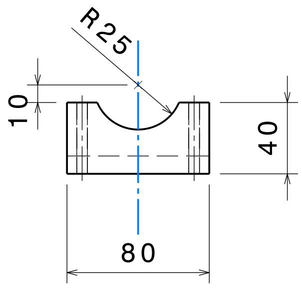
Top View
Scale : 1:3



Isometric View
Scale : 1:2

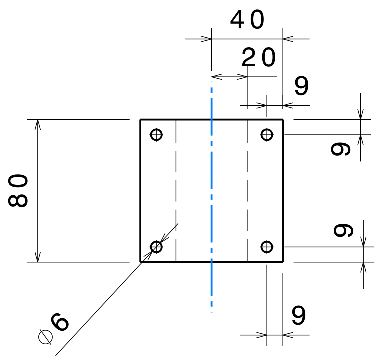


Front View
Scale: 1:3

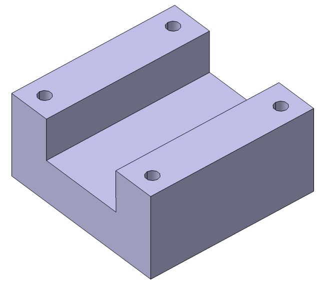


Side View
Scale: 1:3

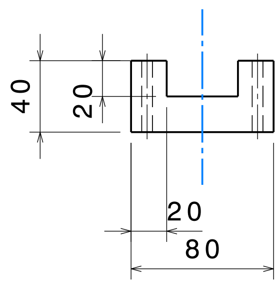
Title Boom-Gondola Clamp		**Author** IRIS - BX25
Bolts 4 M6x90 2 M6x60	**Item N°** 29	**Material** Aluminium
Nuts 4 M6	**Scale** 1:2 and 1:3	**Dimensions [mm]** 80x80x40
Washers 12 M6	**Weight [kg]** 0.48	**Sheet** 7/?



Bottom View
Scale: 1:3

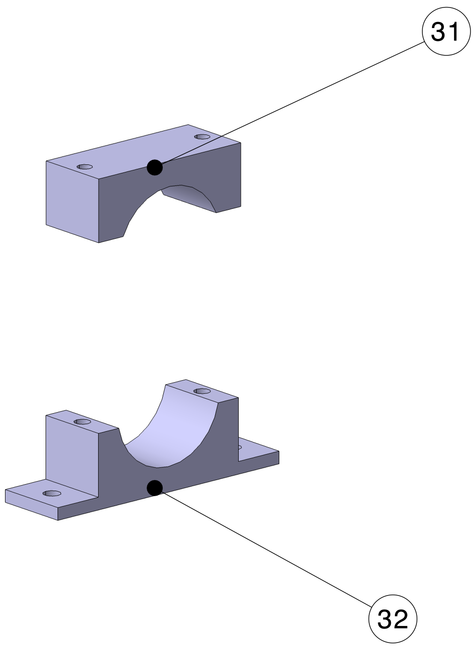


Isometric View
Scale : 1:2



Front View
Scale: 1:3

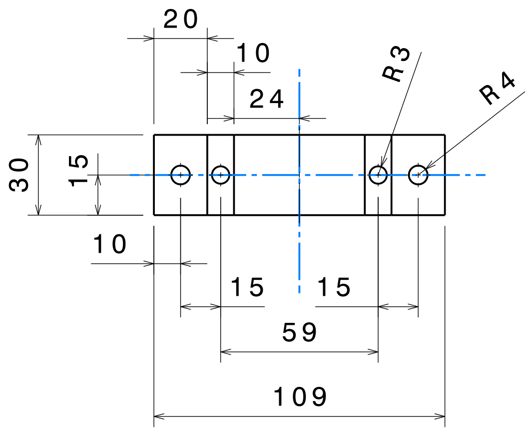
Title Gondola Clamp Lower Part		**Author** IRIS - BX25
Bolts 4 M6x90	**Item N°** 30	**Material** Aluminium
Nuts 4 M6	**Scale** 1:2 and 1:3	**Dimensions [mm]** 80x80x40
Washers 8 M6	**Weight [kg]** 0.506	**Sheet** 8/?



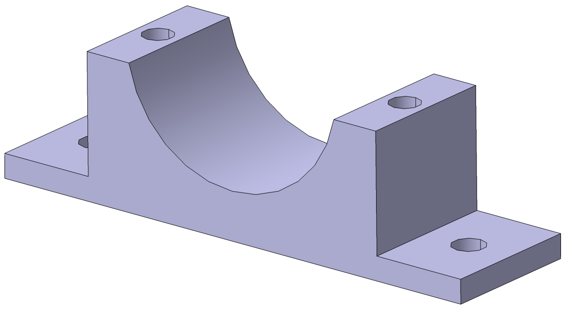
Isometric View
Scale : 1:2

Item N°	Title
31	Sensor-Boom Clamp
32	Rail-Boom Clamp Lower Part

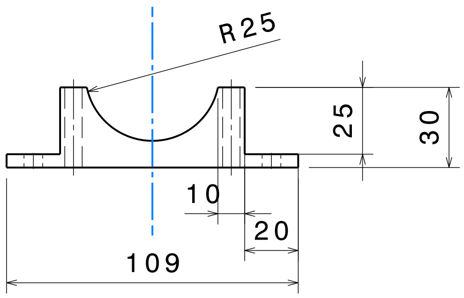
Title Lower Gondola-Boom mounting		**Author** IRIS - BX25
Bolts 2 M6x60 2 M6x23	**Item N°** 8	**Material** Aluminium
Nuts 2 M6	**Scale** 1:2	**Dimensions [mm]** 110x70x30
Washers 4 M6	**Weight [kg]** 0.113	**Sheet** 9/?



Top View
Scale : 1:2

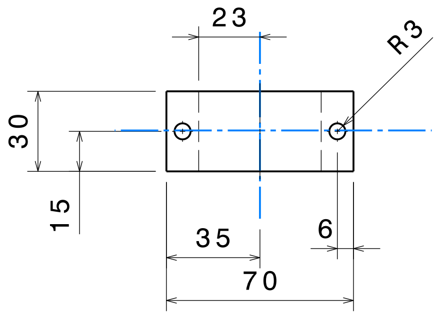


Isometric View
Scale : 1:1

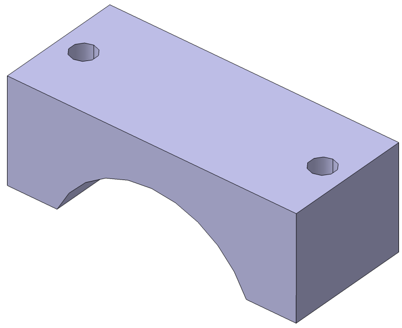


Front View
Scale : 1:2

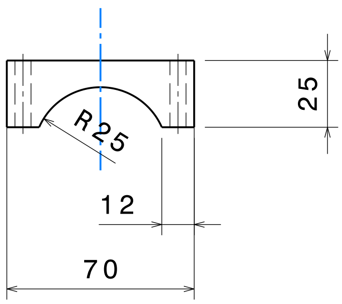
Title Rail-Boom Clamp Lower Part		**Author** IRIS - BX25
Bolts 2 M6x60 2 M6x23	**Item N°** 32	**Material** Aluminium
Nuts 2 M6	**Scale** 1:1 and 1:2	**Dimensions [mm]** 110x30x30
Washers 6 M6	**Weight [kg]** 0.118	**Sheet** 10/?



Top View
Scale : 1:2

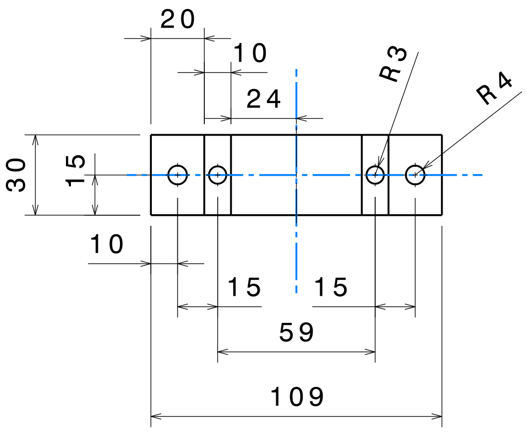


Isometric View
Scale : 1:1

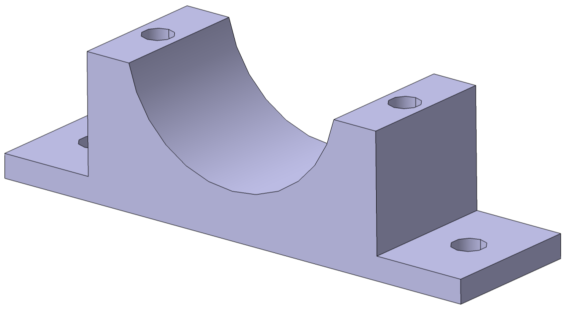


Front View
Scale : 1:2

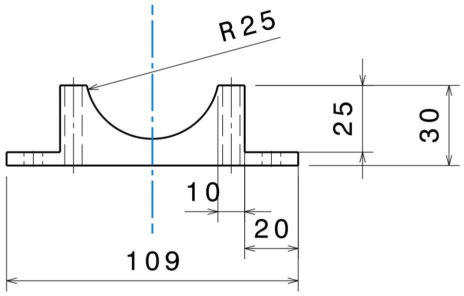
Title Sensor-Boom Clamp		**Author** IRIS - BX25
Bolts 2 M6x60	**Item N°** 31	**Material** Aluminium
Nuts /	**Scale** 1:1 and 1:2	**Dimensions [mm]** 70x30x25
Washers 2 M6	**Weight [kg]** 0.098	**Sheet** 10/?



Top View
Scale : 1:2

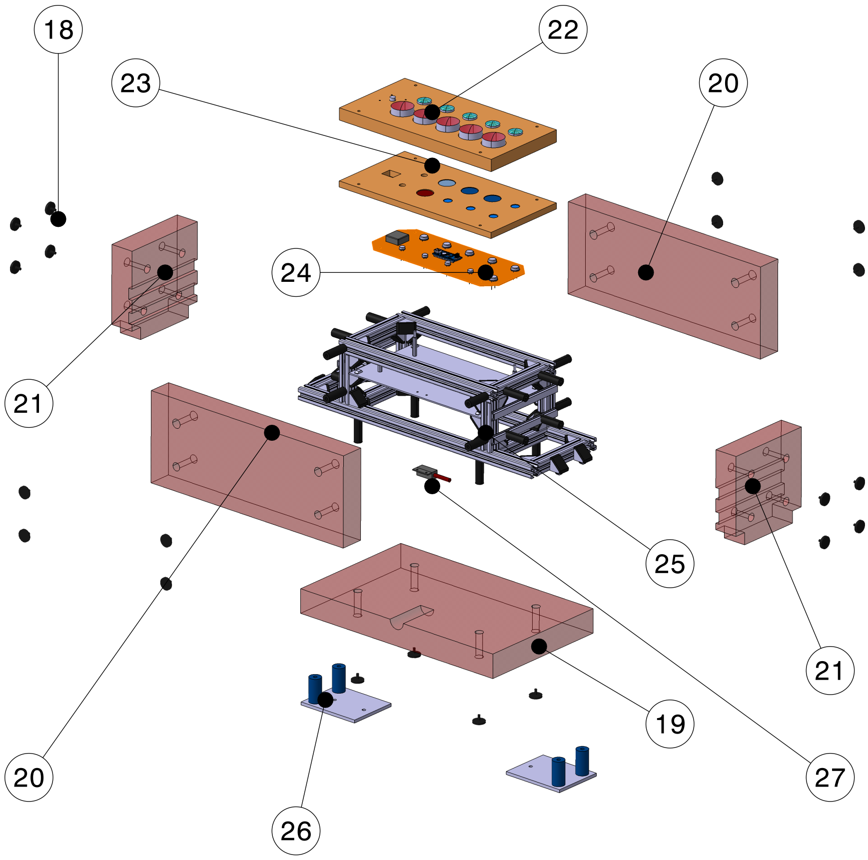


Isometric View
Scale : 1:1



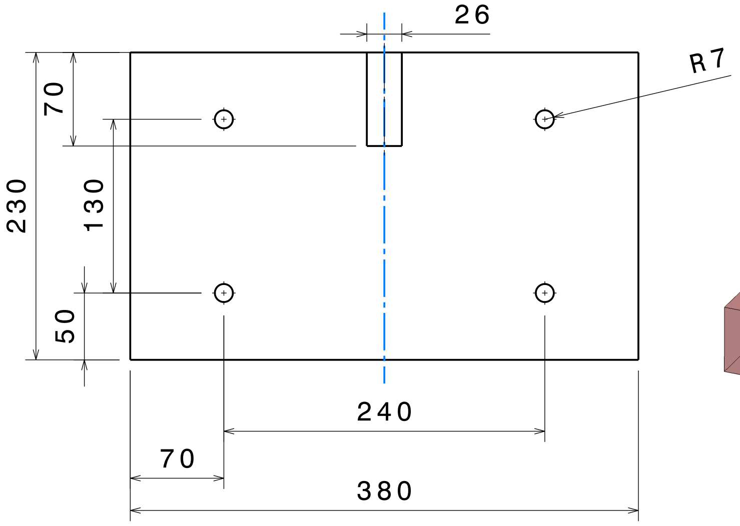
Front View
Scale : 1:2

Title Rail-Boom Clamp Lower Part		**Author** IRIS - BX25
Bolts 2 M6x60 2 M6x23	**Item N°** 32	**Material** Aluminium
Nuts 2 M6	**Scale** 1:1 and 1:2	**Dimensions [mm]** 110x30x30
Washers 6 M6	**Weight [kg]** 0.118	**Sheet** 11/?

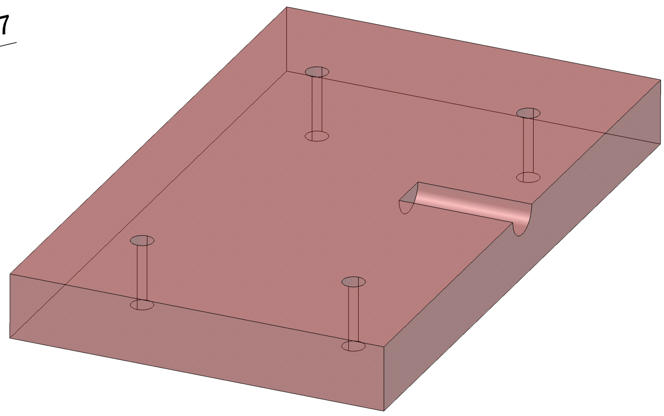


Isometric View
Scale : 1:8

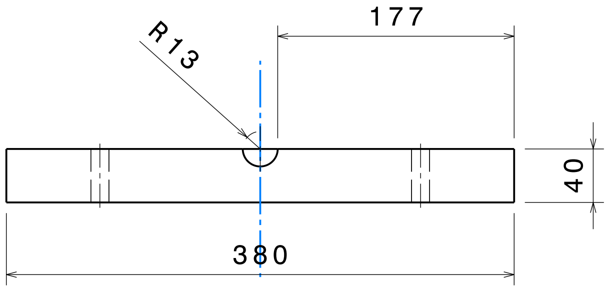
Item N°	Title
18	Nylon Screw M4
19	Thermal Insulation Lower Side
20	Thermal Insulation Longitudinal Side
21	Thermal Insulation Lateral Side
22	Fisheye Lens Plate
23	Filter Plate
24	Photodiode PCB
25	Structural Frame
26	Sensor-Boom mountings
27	Heater



Front View
Scale : 1:4

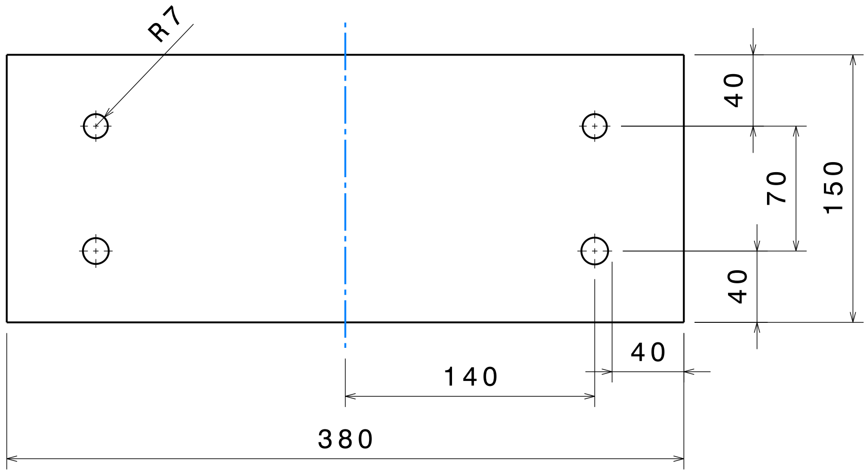


Isometric View
Scale : 1:3

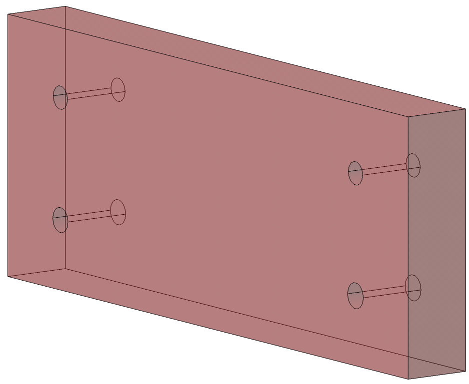


Side View
Scale : 1:4

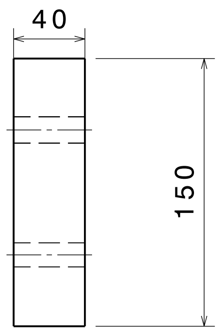
Title Thermal Insulation Lower Side		**Author** IRIS - BX25
Bolts 4 M4 Nylon	**Item N°** 19	**Material** Styrofoam XPS
Nuts /	**Scale** 1:3 and 1:4	**Dimensions [mm]** 380x230x40
Washers /	**Weight [kg]** 0.138	**Sheet** 13/?



Front View
Scale : 1:3

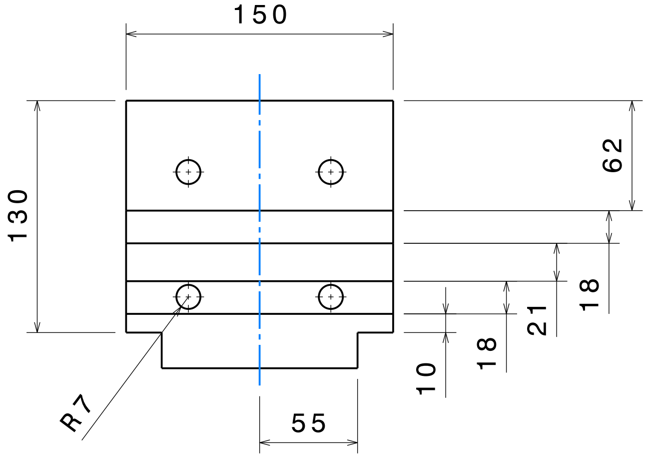


Isometric View
Scale : 1:3

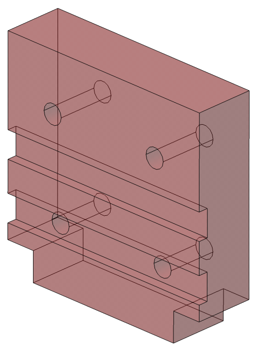


Side View
Scale : 1:3

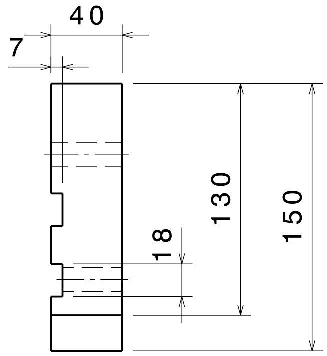
Title Thermal Insulation Longitudinal Side		**Author** IRIS - BX25
Bolts 4 M4 Nylon	**Item N°** 20	**Material** Styrofoam XPS
Nuts /	**Scale** 1:3	**Dimensions [mm]** 380x150x40
Washers /	**Weight [kg]** 0.09	**Sheet** 14/?



Front View
Scale : 1:3

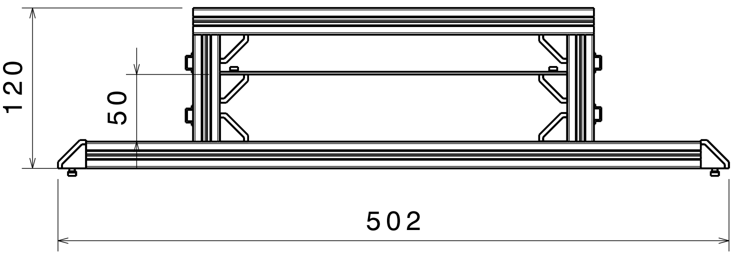


Isometric View
Scale : 1:3

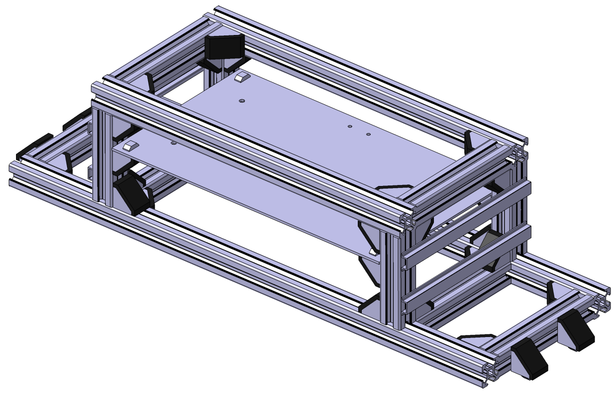


Side View
Scale : 1:3

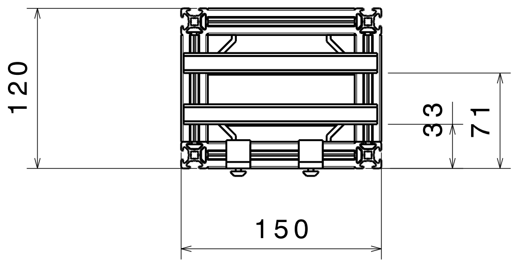
Title Thermal Insulation Lateral Side		**Author** IRIS - BX25
Bolts 4 M4 Nylon	**Item N°** 21	**Material** Styrofoam XPS
Nuts /	**Scale** 1:3	**Dimensions [mm]** 150x150x40
Washers /	**Weight [kg]** 0.032	**Sheet** 15/?



Front View
Scale : 1:4

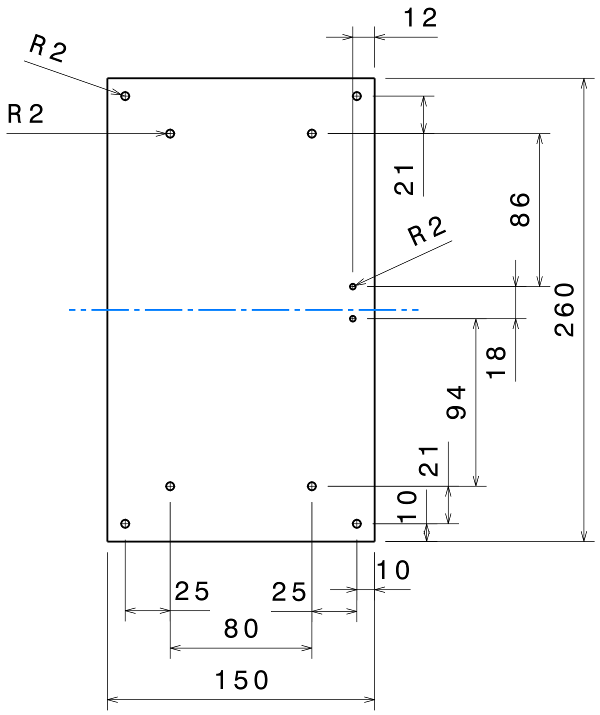


Isometric View
Scale : 1:4

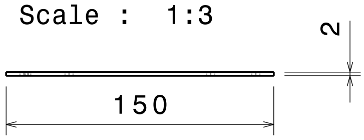


Side View
Scale : 1:4

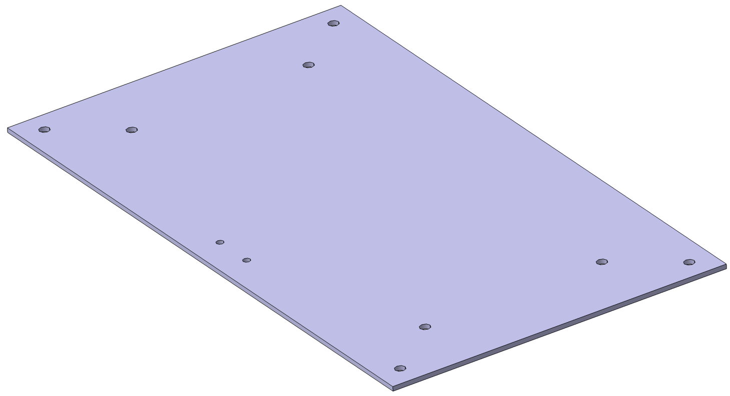
Title Sensor Box Structural Frame		**Author** IRIS - BX25
Bolts /	**Item N°** 25	**Material** Aluminium
Nuts /	**Scale** 1:4	**Dimensions [mm]** 502x150x120
Washers /	**Weight [kg]** 1.438	**Sheet** 16/?



Front View
Scale : 1:3

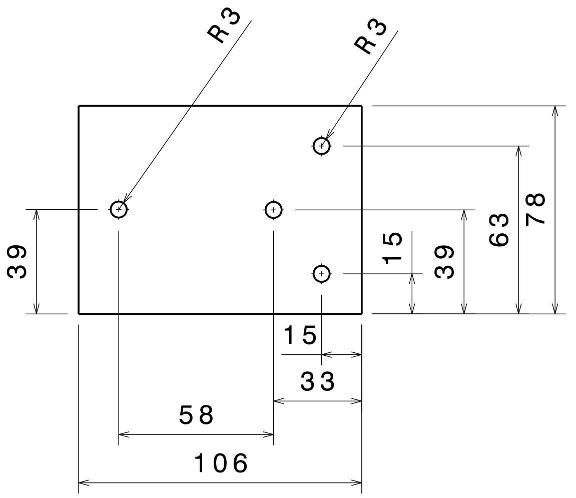


Side View
Scale : 1:3

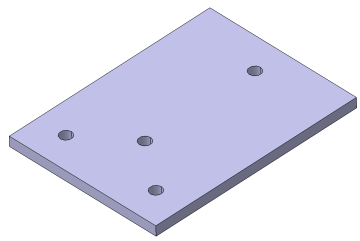


Isometric View
Scale : 1:2

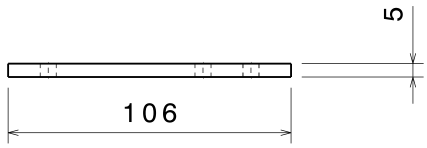
Title Sensor Box Electronics Plate		**Author** IRIS - BX25
Bolts 4 M4x10 4 M4 Hex Standoff 2 M3x10	**Item N°** /	**Material** Aluminium
Nuts 8 M4 2 M3	**Scale** 1:2 and 1:3	**Dimensions [mm]** **260x150x2**
Washers 8 M4 8 M3	**Weight [kg]** 0.211	**Sheet** 17/?



Front View
Scale : 1:2

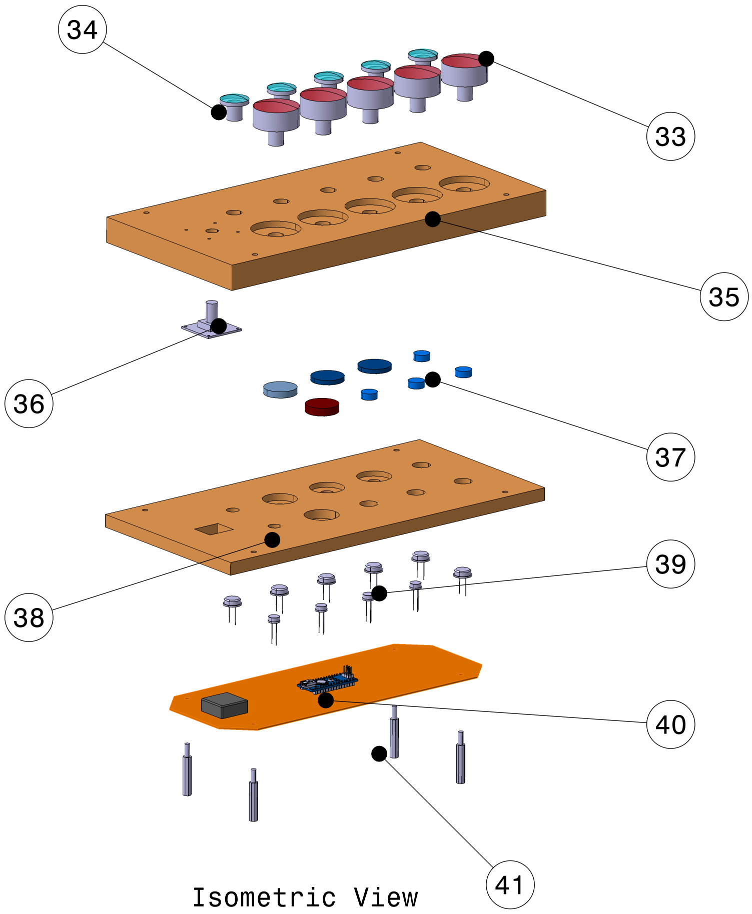


Isometric View
Scale : 1:2



Side View
Scale : 1:2

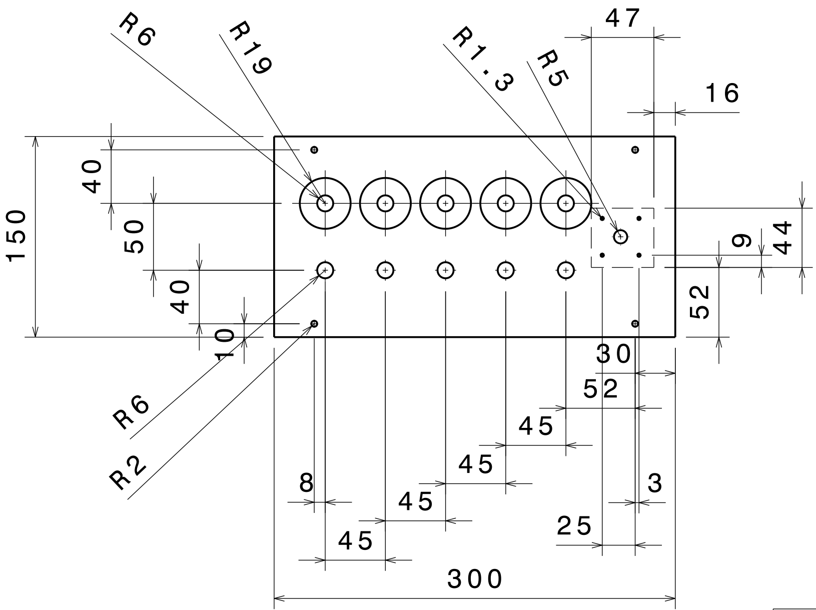
Title Sensor-Boom Mounting Plate		**Author** IRIS - BX25
Bolts 2 M6x60 2 M6x20	**Item N°** /	**Material** Aluminium
Nuts 2 M6	**Scale** 1:2	**Dimensions [mm]** 106x78x5
Washers 4 M6	**Weight [kg]** 0.11	**Sheet** 18/?



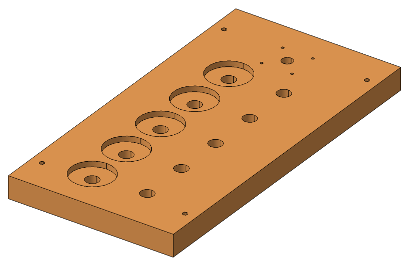
Isometric View
Scale : 1:4

Item N°	Title
33	NIR Fisheye
34	VIS Fisheye
35	Balsa Wood Fisheye Plate
36	Camera uCam
37	Filters
38	Balsa Wood Filter Plate
39	Si and InGaAs Photodiodes
40	Phototdiodes PCB
41	Hex M4 Standoff Male-Female

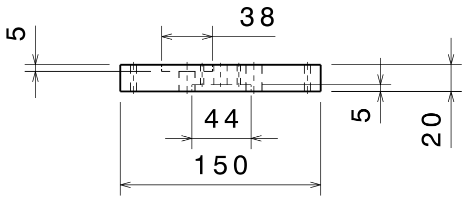
D C B A



Front View
Scale : 1:4



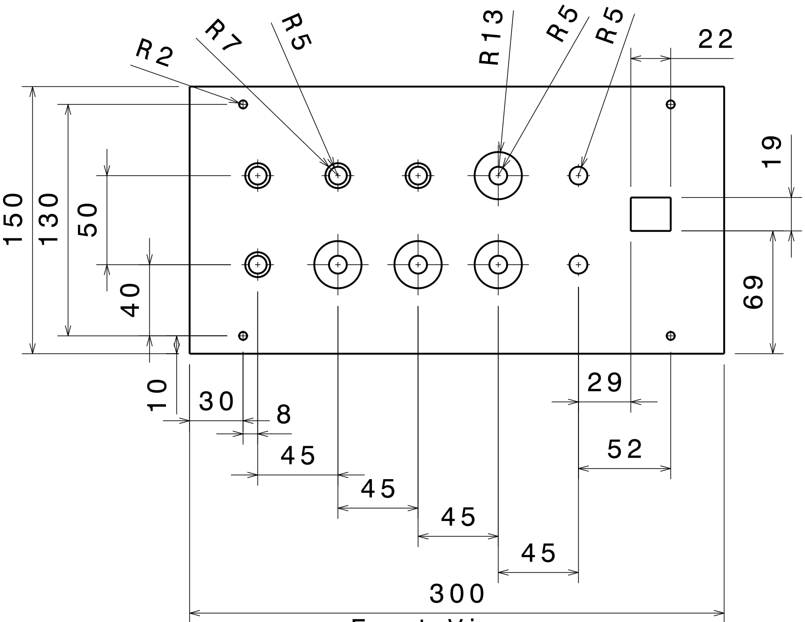
Isometric View
Scale : 1:4



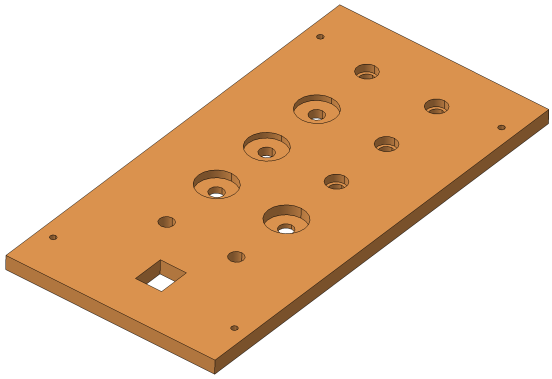
Side View
Scale : 1:4

Title		**Author**
Balsa Wood Fisheye Plate		IRIS - BX25
Bolts 4 M4x40	**Item N°** 35	**Material** Balsa Wood
Nuts /	**Scale** 1:4	**Dimensions [mm]** 300x150x20
Washers /	**Weight [kg]** 0.302	**Sheet** 20/?

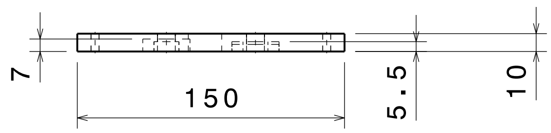
D A



Front View
Scale : 1:3

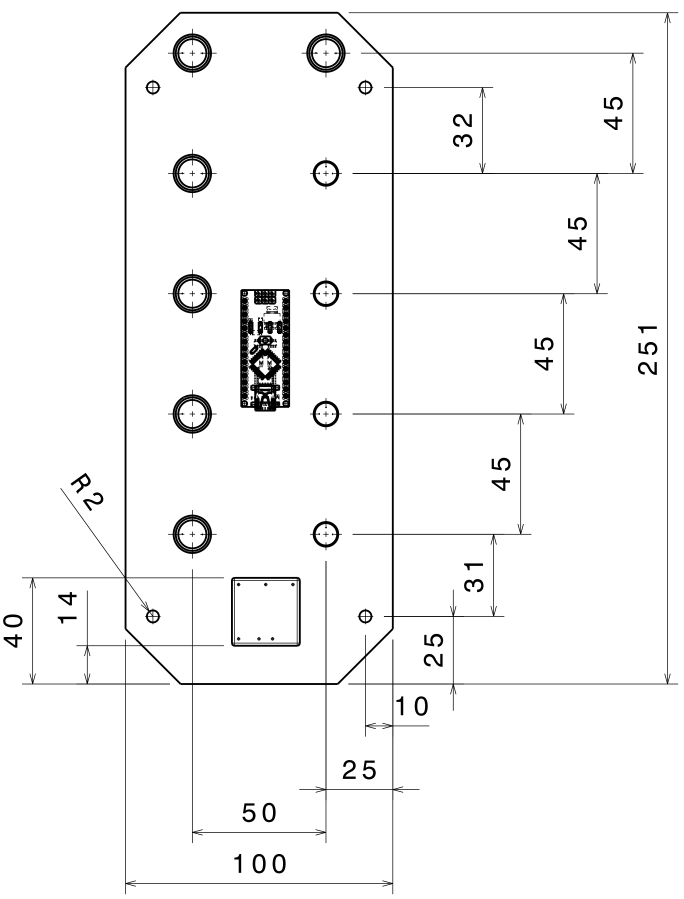


Isometric View
Scale : 1:3

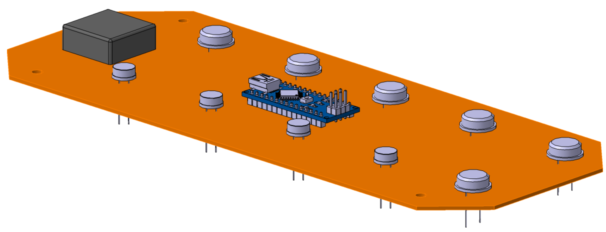


Side View
Scale : 1:3

Title Balsa Wood Filter Plate		**Author** IRIS - BX25
Bolts 4 M4x40	**Item N°** 38	**Material** Balsa Wood
Nuts /	**Scale** 1:3	**Dimensions [mm]** 300x150x10
Washers /	**Weight [kg]** 0.149	**Sheet** 21/?

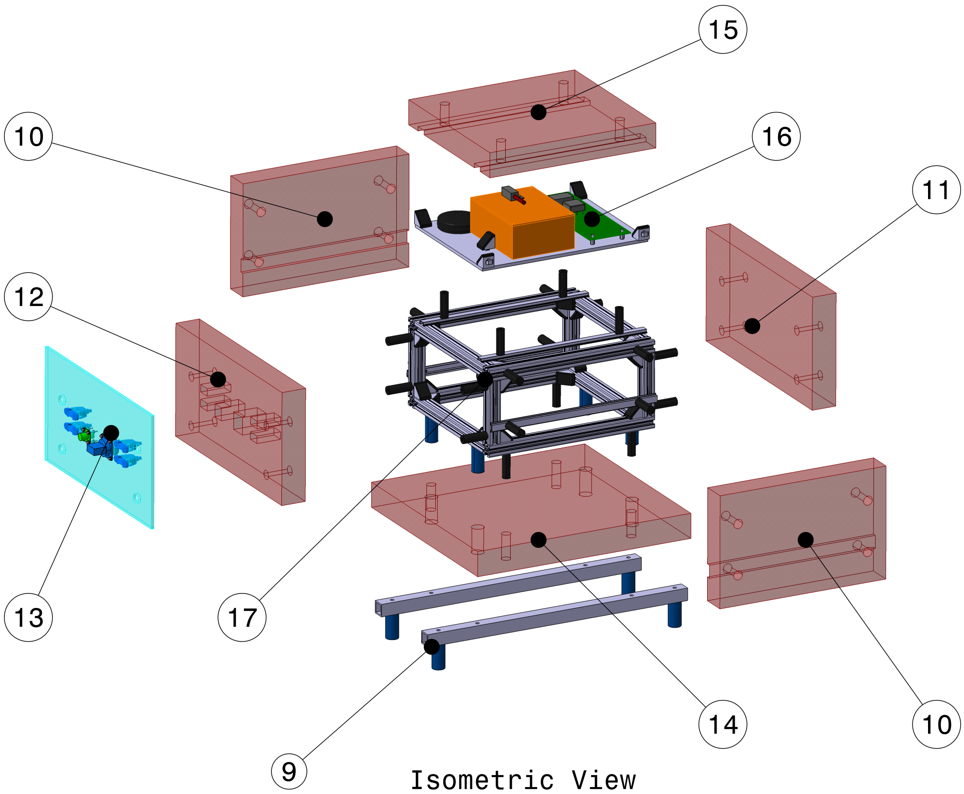


Front View
Scale : 1:2



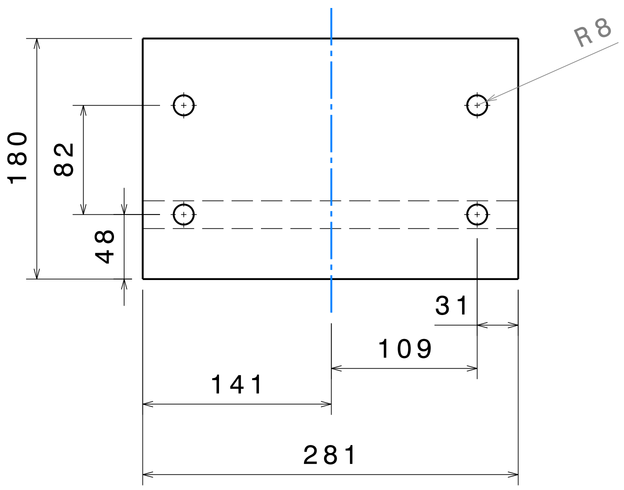
Isometric View
Scale : 1:2

Title Photodiodes PCB		**Author** IRIS - BX25
Bolts /	**Item N°** 40	**Material** /
Nuts /	**Scale** 1:2	**Dimensions [mm]** 250x100x2
Washers /	**Weight [kg]** 0.043	**Sheet** 22/?

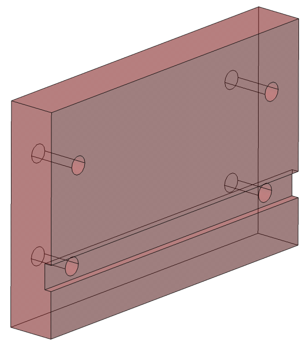


Isometric View
Scale : 1:8

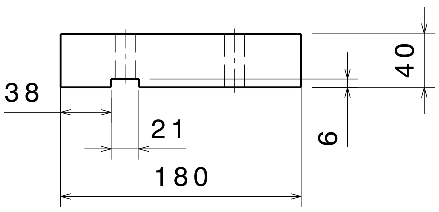
Item N°	Title
9	Brain-Gondola mountings
10	Thermal Insulation Lateral Side
11	Thermal Insulation Longitudinal Side
12	Thermal Insulation Connector Side
13	Connector Plate
14	Thermal Insulation Lower Side
15	Thermal Insulation Upper Side
16	Electronics Plate
17	Structural Frame



Front View
Scale : 1:4

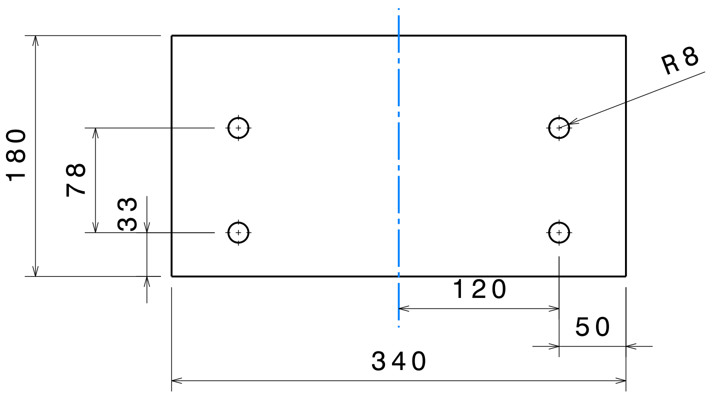


Isometric View
Scale : 1:4

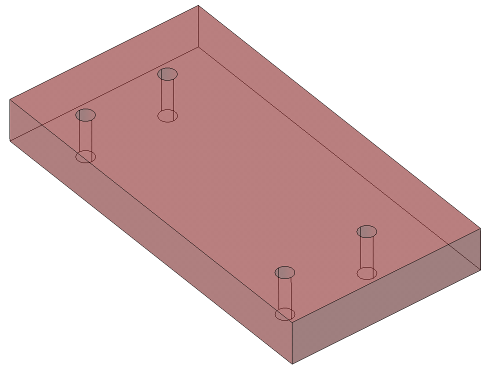


Side View
Scale : 1:4

Title Thermal Insulation Lateral Side		**Author** IRIS - BX25
Bolts 4 M4 Nylon	**Item N°** 10	**Material** Styrofoam XPS
Nuts /	**Scale** 1:4	**Dimensions [mm]** 281x180x40
Washers /	**Weight [kg]** 0.078	**Sheet** 25/?



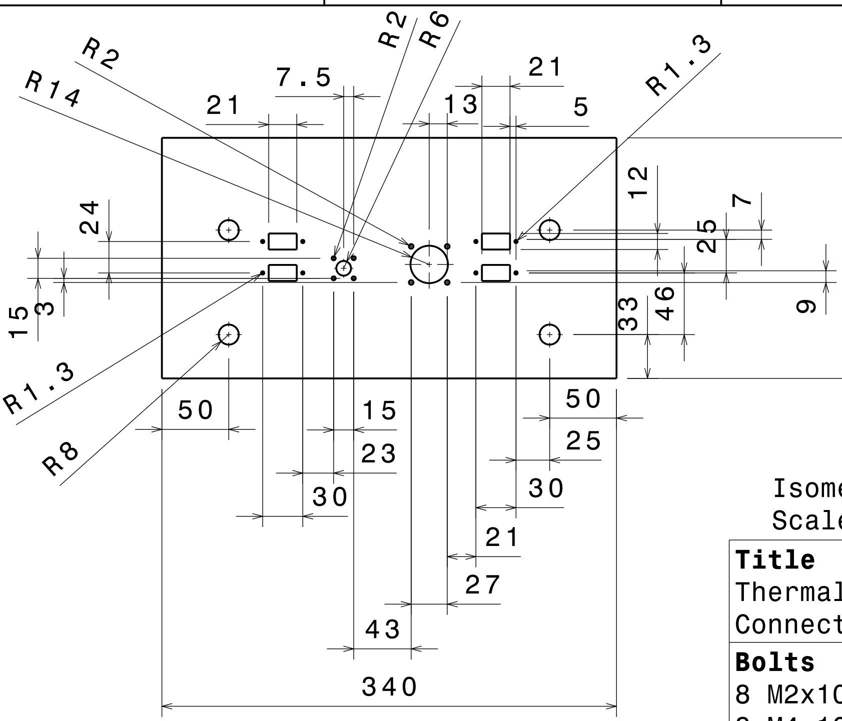
Front View
Scale : 1:4



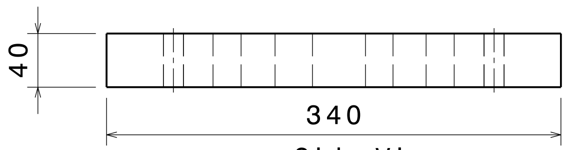
Isometric View
Scale : 1:4

Side View
Scale : 1:4

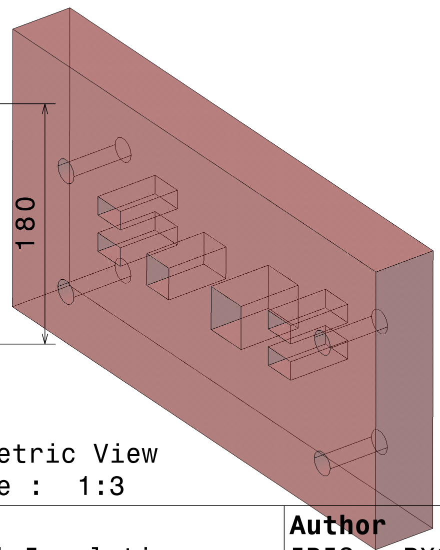
Title Thermal Insulation Longitudinal Side		**Author** IRIS - BX25
Bolts 4 M4 Nylon	**Item N°** 11	**Material** Styrofoam XPS
Nuts /	**Scale** 1:4	**Dimensions [mm]** 340x180x40
Washers /	**Weight [kg]** 0.097	**Sheet** 26/?



Front View
Scale : 1:4

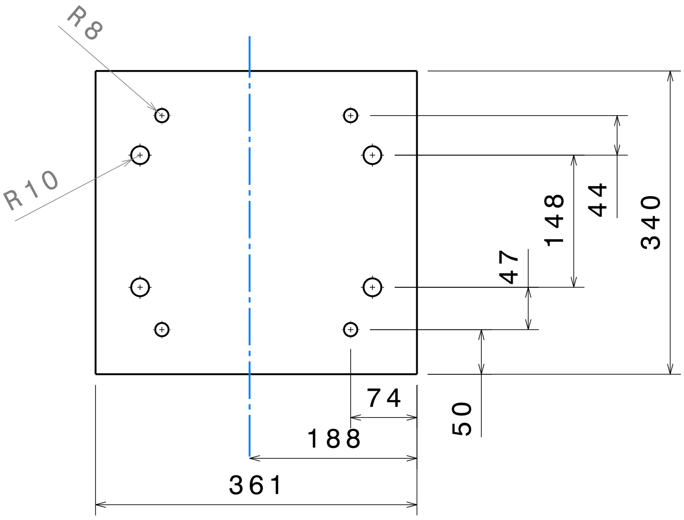


Side View
Scale : 1:4

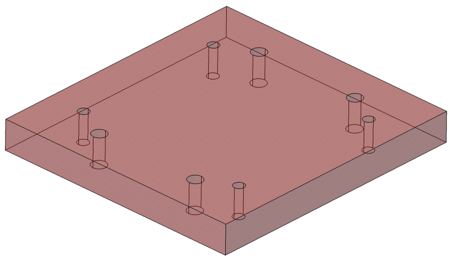


Isometric View
Scale : 1:3

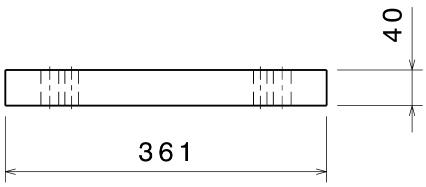
Title Thermal Insulation Connector Side		**Author** IRIS - BX25
Bolts 8 M2x10 8 M4x10 4 M4 Nylon	**Item N°** 12	**Material** Styrofoam XPS
Nuts 8 M2 8 M4	**Scale** 1:3 and 1:4	**Dimensions [mm]** 340x180x40
Washers 16 M2 16 M4	**Weight [kg]** 0.112	**Sheet** 27/?



Front View
Scale : 1:6

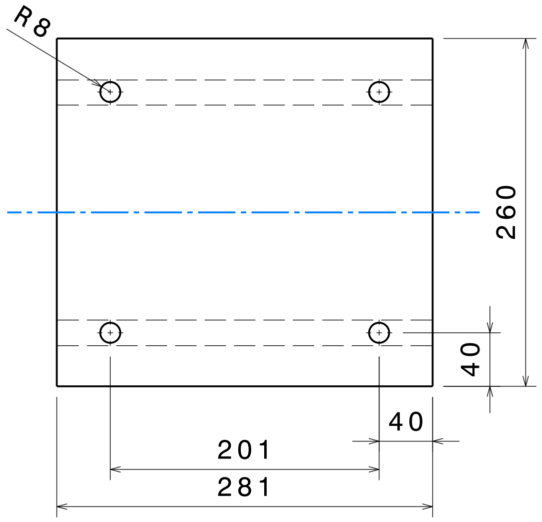


Isometric View
Scale : 1:6

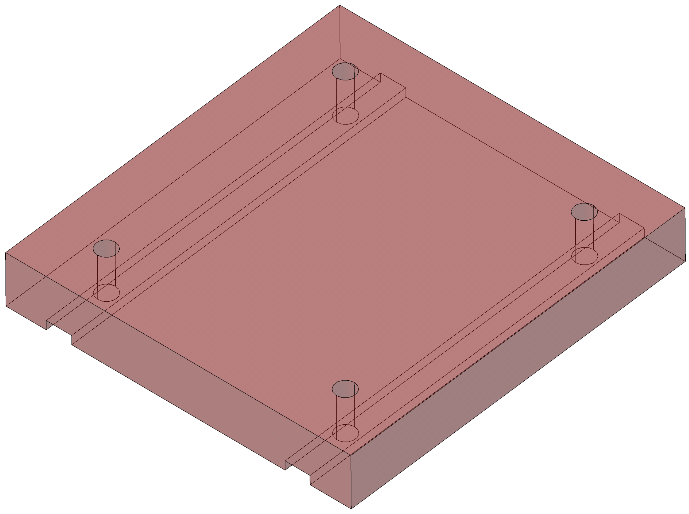


Side View
Scale : 1:6

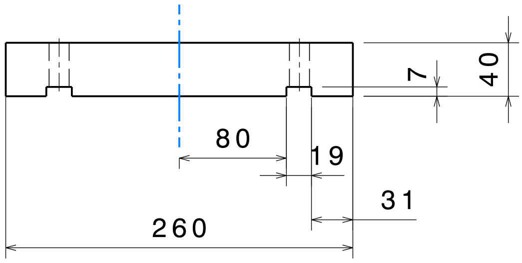
Title Thermal Insulation Lower Side		**Author** IRIS - BX25
Bolts 4 M4 Nylon	**Item N°** 14	**Material** Styrofoam XPS
Nuts /	**Scale** 1:6	**Dimensions [mm]** 361x340x40
Washers /	**Weight [kg]** 0.193	**Sheet** 28/?



Front View
Scale : 1:4

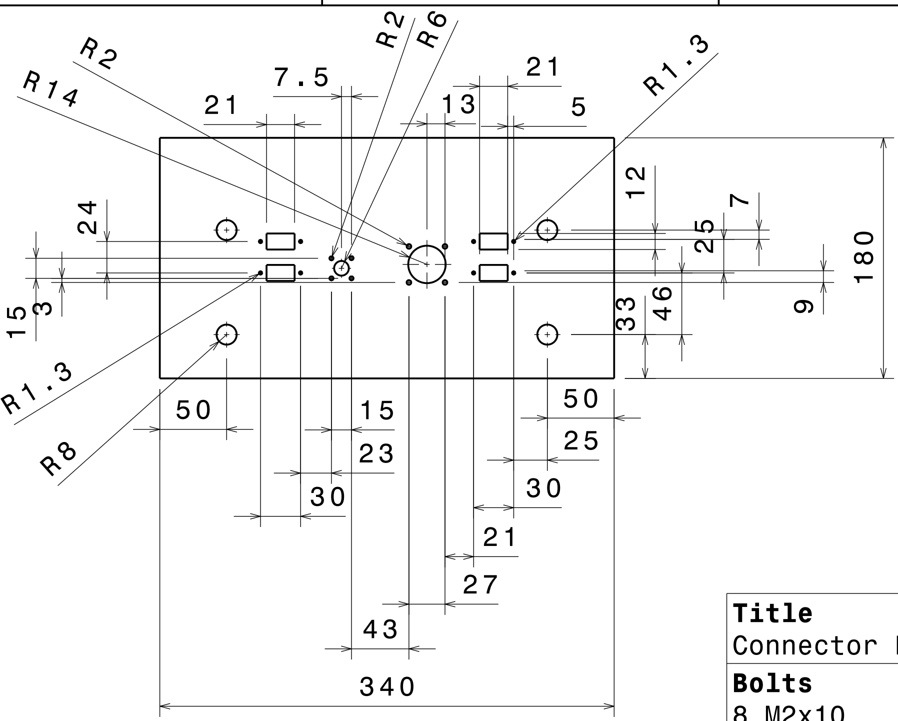


Isometric View
Scale : 1:3

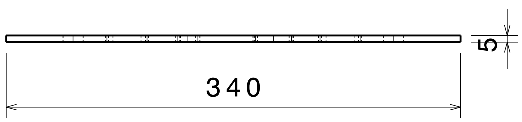


Side View
Scale : 1:4

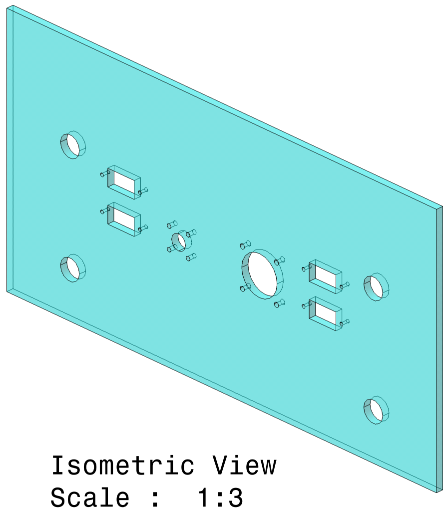
Title Thermal Insulation Upper Side		**Author** IRIS - BX25
Bolts 4 M4 Nylon	**Item N°** 15	**Material** Styrofoam XPS
Nuts /	**Scale** 1:3 and 1:4	**Dimensions [mm]** 281x260x40
Washers /	**Weight [kg]** 0.113	**Sheet** 29/?



Front View
Scale : 1:4

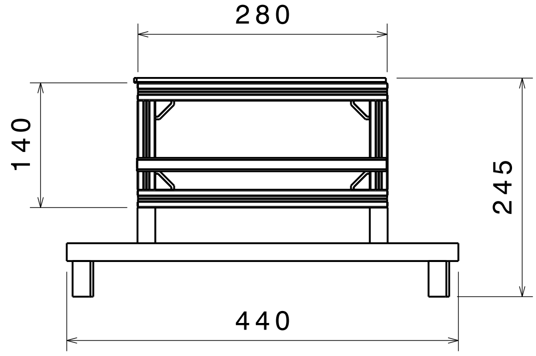


Side View
Scale : 1:4

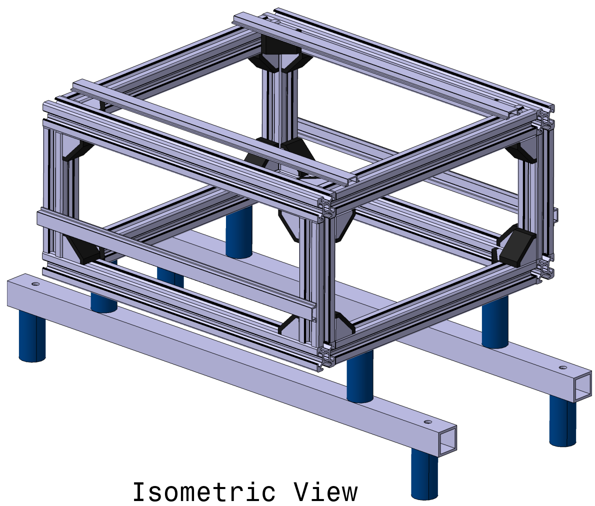


Isometric View
Scale : 1:3

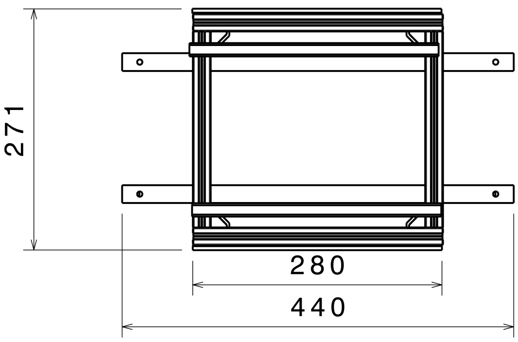
Title		Author
Connector Plate		IRIS - BX25
Bolts 8 M2x10 8 M4x10 4 M4 Nylon	**Item N°** 13	**Material** Plexiglass
Nuts 8 M2 8 M4	**Scale** 1:3 and 1:4	**Dimensions [mm]** 340x180x5
Washers 16 M2 16 M4	**Weight [kg]** 0.352	**Sheet** 30/?



Front View
Scale : 1:6

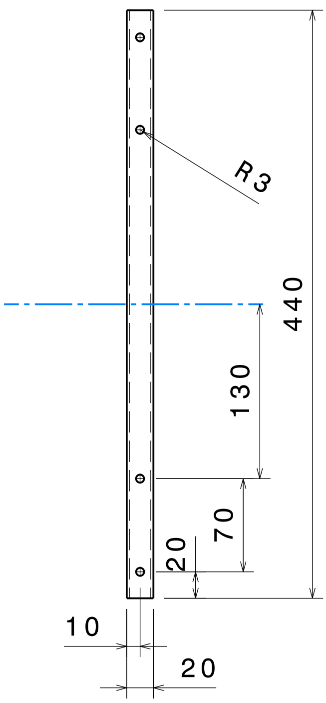


Isometric View
Scale : 1:4

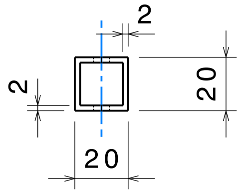


Top View
Scale : 1:6

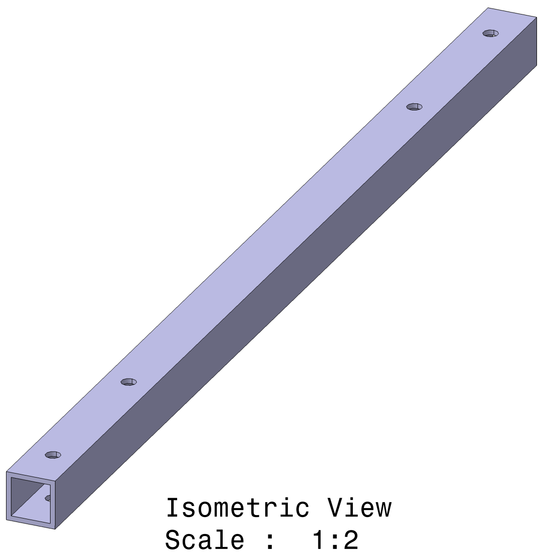
Title Brain Structural Frame		**Author** IRIS - BX25
Bolts /	**Item N°** 17	**Material** /
Nuts /	**Scale** 1:4 and 1:6	**Dimensions [mm]** 440x271x245
Washers /	**Weight [kg]** 0.748	**Sheet** 31/?



Top View
Scale : 1:4

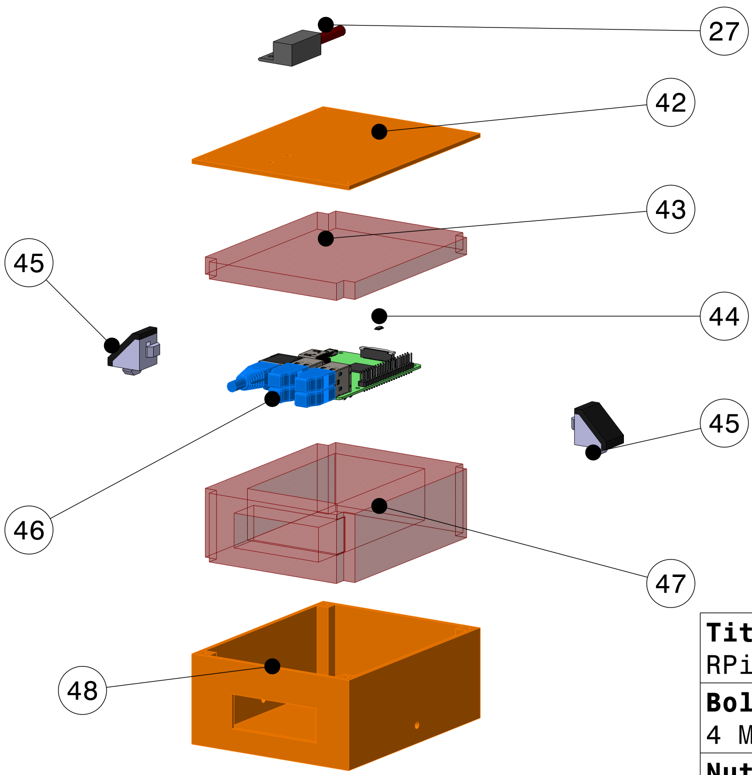


Front View
Scale : 1:2



Isometric View
Scale : 1:2

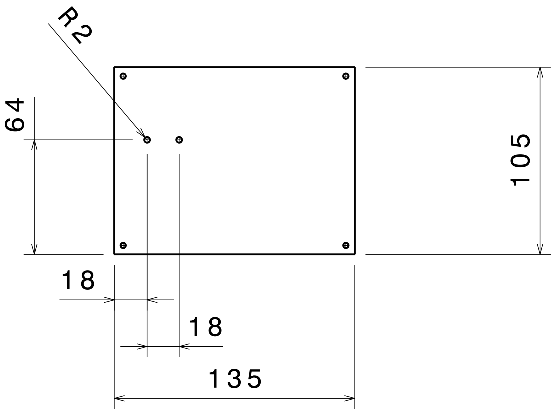
Title Mounting Square Beam Brain Box		**Author** IRIS - BX25
Bolts 2 M6x23 2 M6x30	**Item N°** 9	**Material** Aluminium
Nuts 2 M6	**Scale** 1:2 and 1:4	**Dimensions [mm]** 440x20x20
Washers 6 M6	**Weight [kg]** 0.17	**Sheet** 32/?



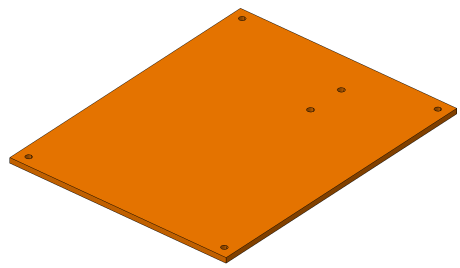
Isometric View
Scale : 1:3

Item N°	Title
27	Heater
42	Rpi Closure Plate
43	RPi Upper Thermal Insulation
44	Pressure and temperature sensor
45	Gusset 20 series
46	RPi Model 2+
47	RPi Lower Thermal Insulation
48	Metallic Box

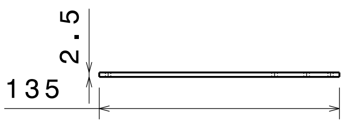
Title RPi Box		**Author** IRIS - BX25
Bolts 4 M?	**Item N°** /	**Material** /
Nuts /	**Scale** 1:3	**Dimensions [mm]** /
Washers /	**Weight [kg]**	**Sheet** 33/?



Front View
Scale : 1:3

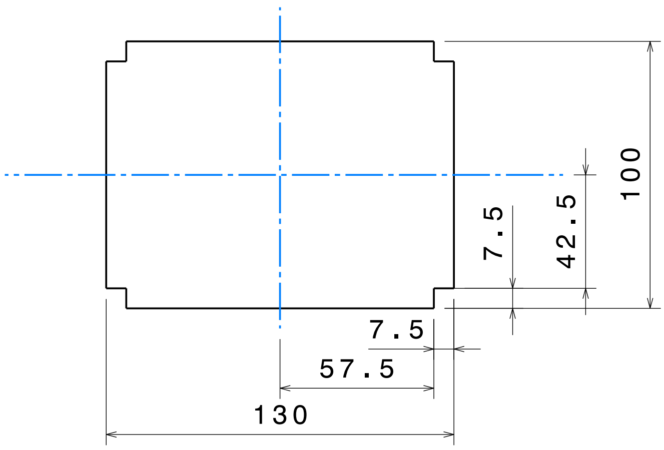


Isometric View
Scale : 1:2

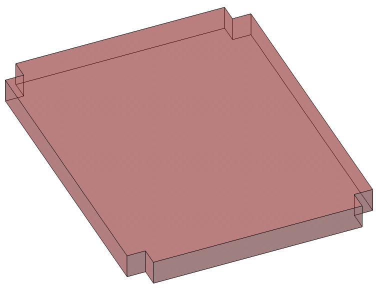


Side View
Scale : 1:3

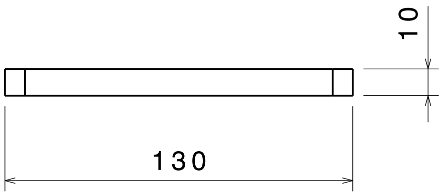
Title RPi Closure Plate		**Author** IRIS - BX25
Bolts 2 M3x10 4 M3x30	**Item N°** 42	**Material** Aluminium
Nuts 2 M3	**Scale** 1:2 and 1:3	**Dimensions [mm]** 135x105x2.5
Washers 8 M3	**Weight [kg]** 0,096	**Sheet** 34/?



Front View
Scale : 1:2

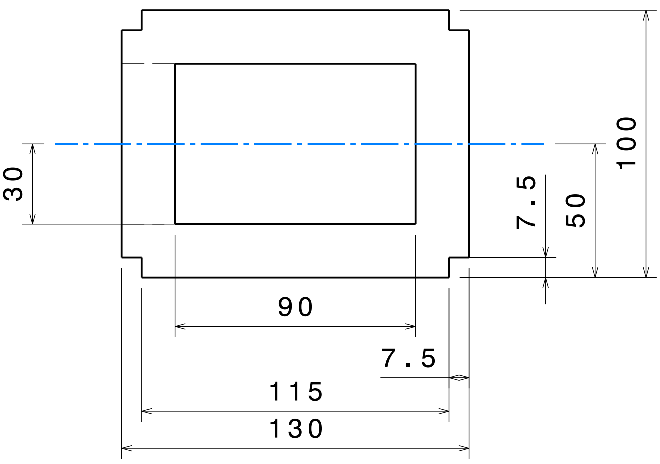


Isometric View
Scale : 1:2

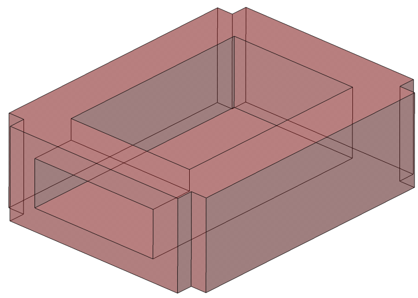


Side View
Scale : 1:2

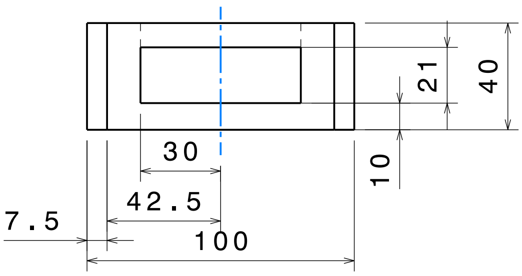
Title RPi Upper Thermal Insulation		**Author** IRIS - BX25
Bolts /	**Item N°** 43	**Material** Styrofoam XPS
Nuts /	**Scale** 1:2	**Dimensions [mm]** 130x100x10
Washers /	**Weight [kg]** 0.006	**Sheet** 34/?



Top View
Scale : 1:2

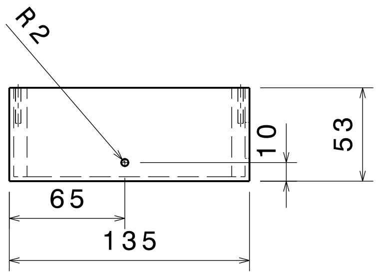


Isometric View
Scale : 1:2

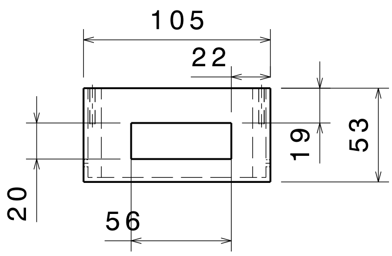


Front View
Scale : 1:2

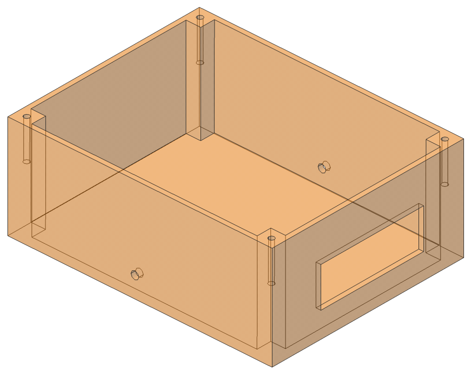
Title RPi Lower Thermal Insulation		**Author** IRIS - BX25
Bolts /	**Item N°** 47	**Material** Styrofoam XPS
Nuts /	**Scale** 1:2	**Dimensions [mm]** 130x100x40
Washers /	**Weight [kg]** 0.017	**Sheet** 35/?



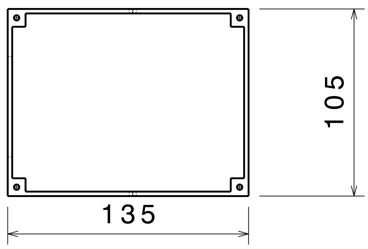
Side View
Scale : 1:3



Front View
Scale : 1:3



Isometric View
Scale : 1:2



Top View
Scale : 1:3

Title Metallic Box RPi		**Author** IRIS - BX25
Bolts 4 M4x20	**Item N°** 48	**Material** /
Nuts 2 M4	**Scale** 1:2 and 1:3	**Dimensions [mm]** 135x105x53
Washers /	**Weight [kg]** 0.276	**Sheet** 36/?

D Checklists

- Remove cover from the photodiodes
- Remove cover from the cameras
- Close brain box by placing its top thermal insulation lid

~~TBD~~

E WBS and Gantt Chart

This appendix contains the WBS and Gantt chart for each department in the IRIS team.

E.1 WBS

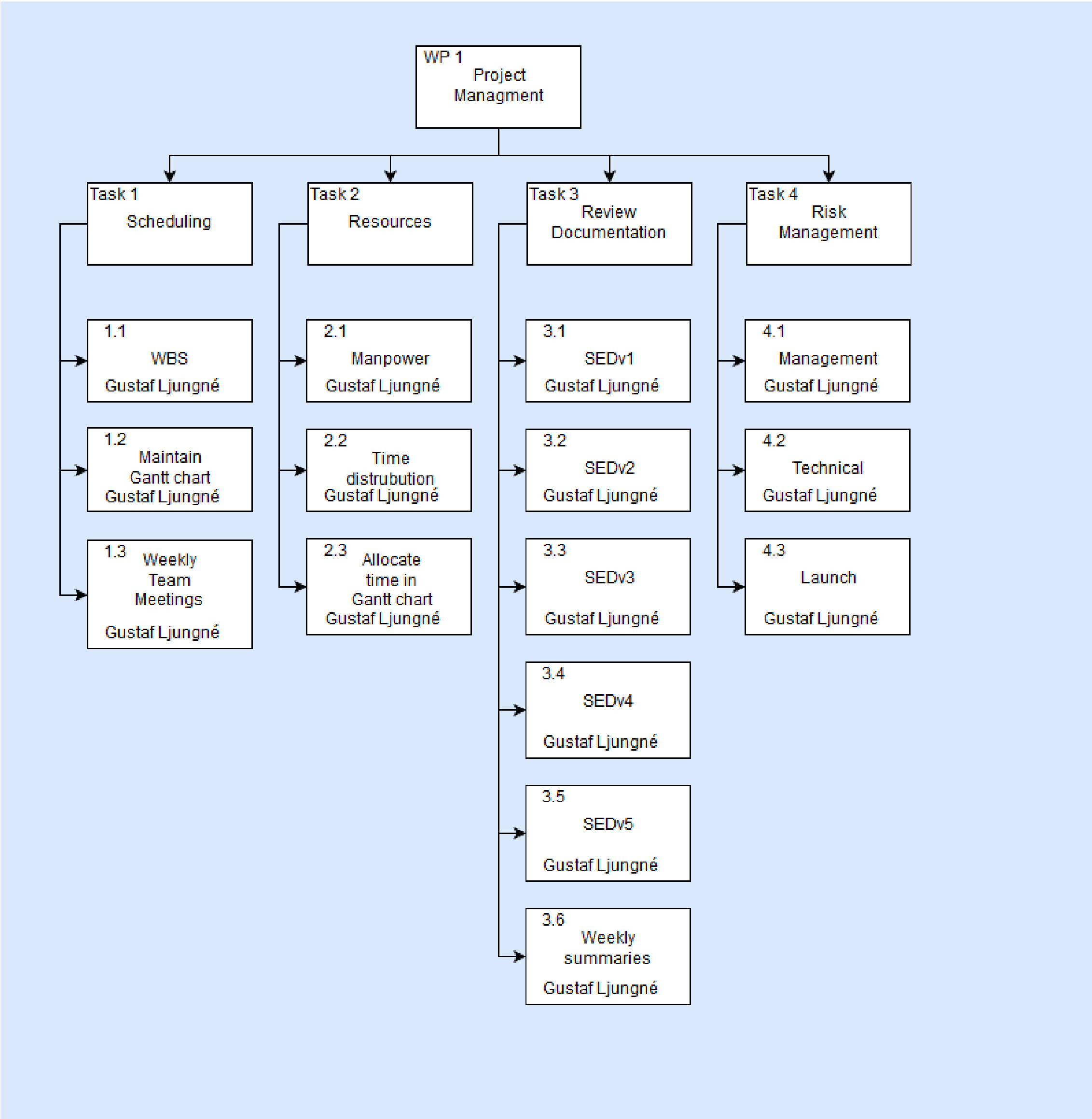


Figure E.1.1: WBS - Project Manager

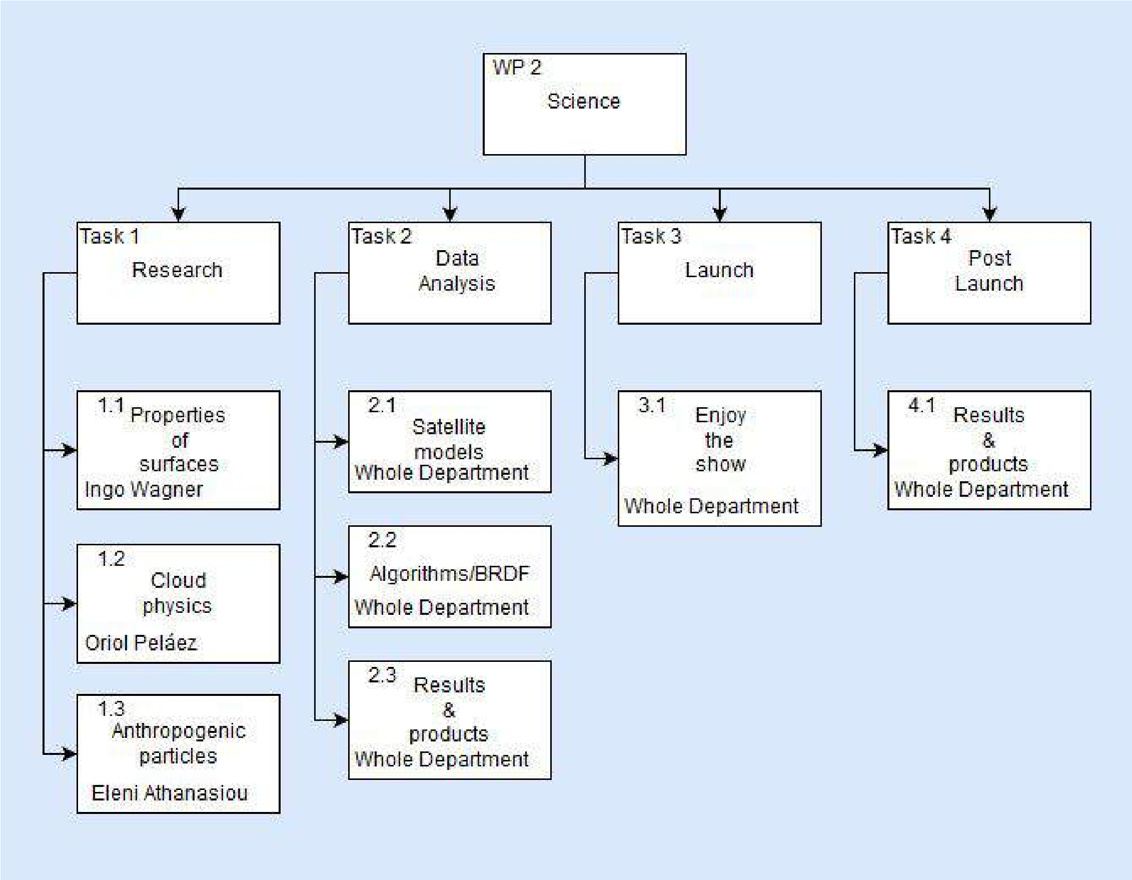


Figure E.1.2: WBS - Science

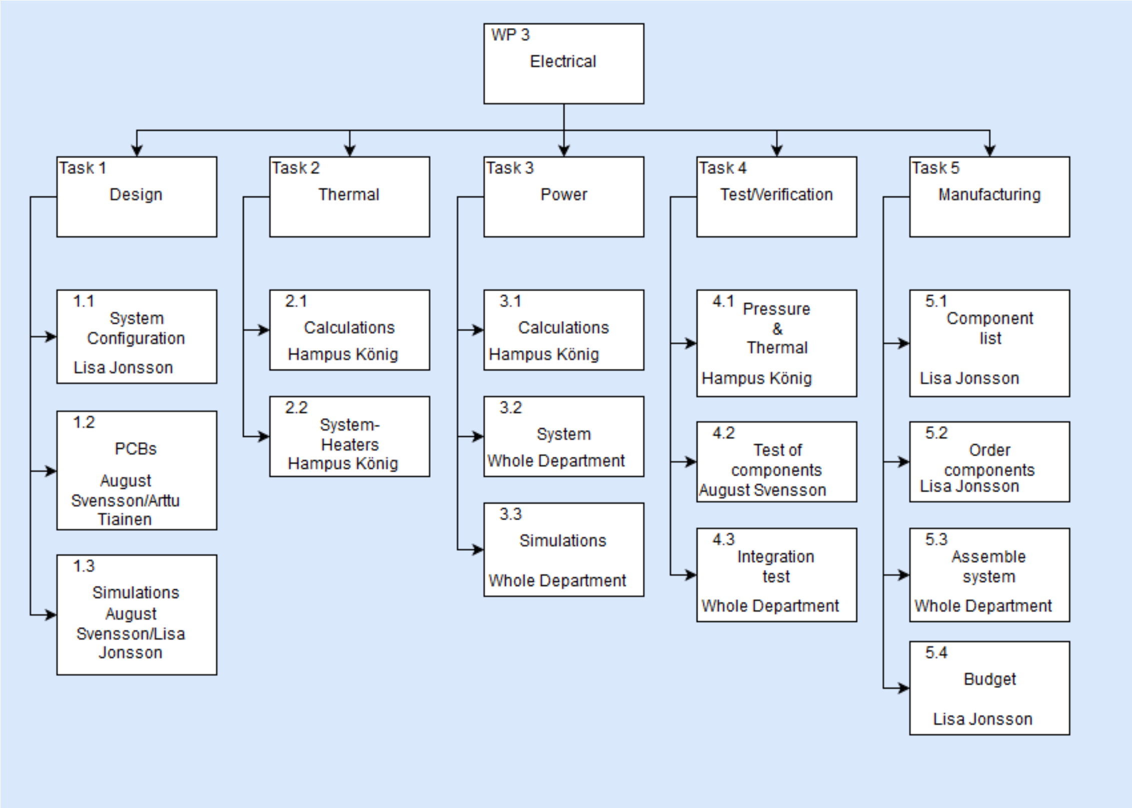


Figure E.1.3: WBS - Electrical

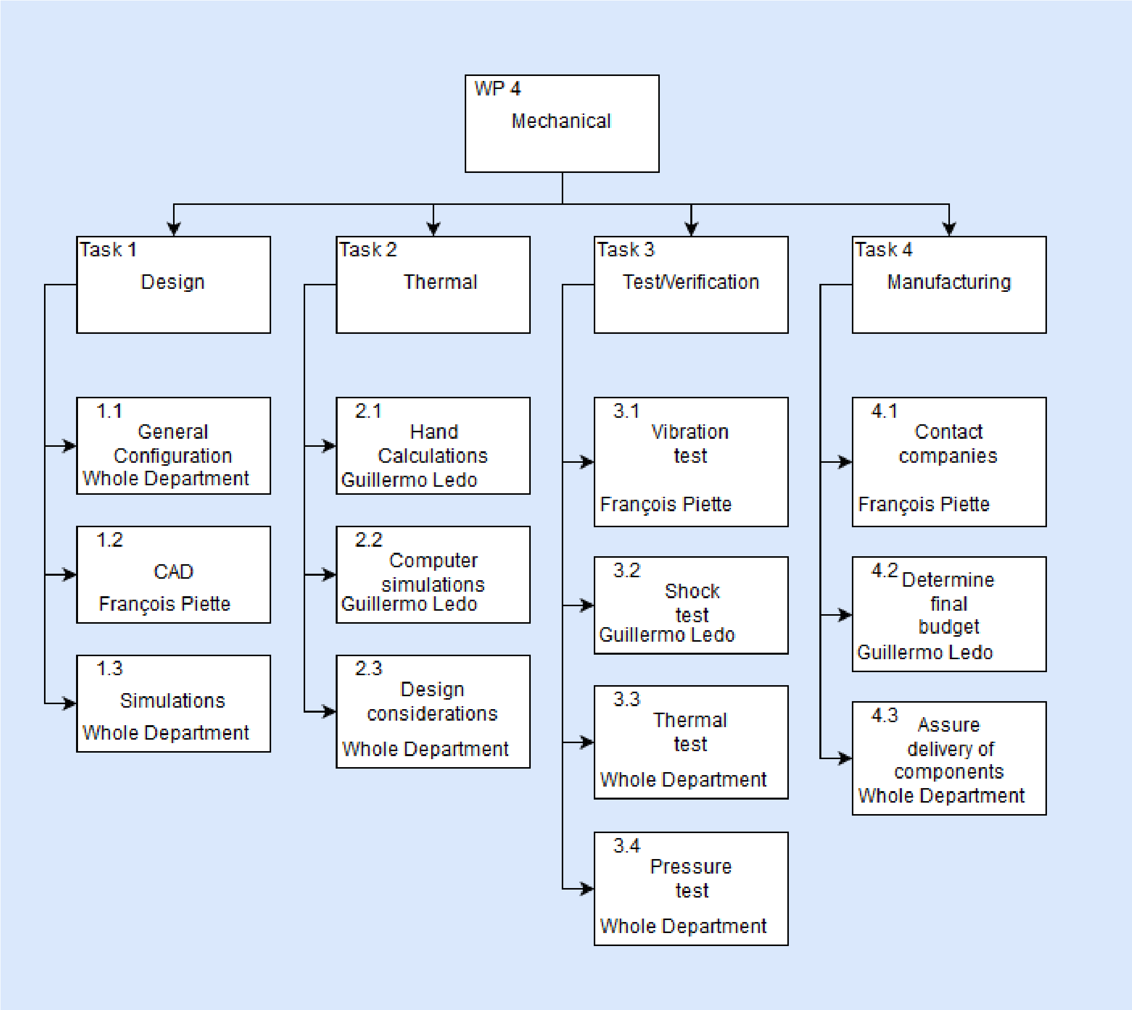


Figure E.1.4: WBS - Mechanical

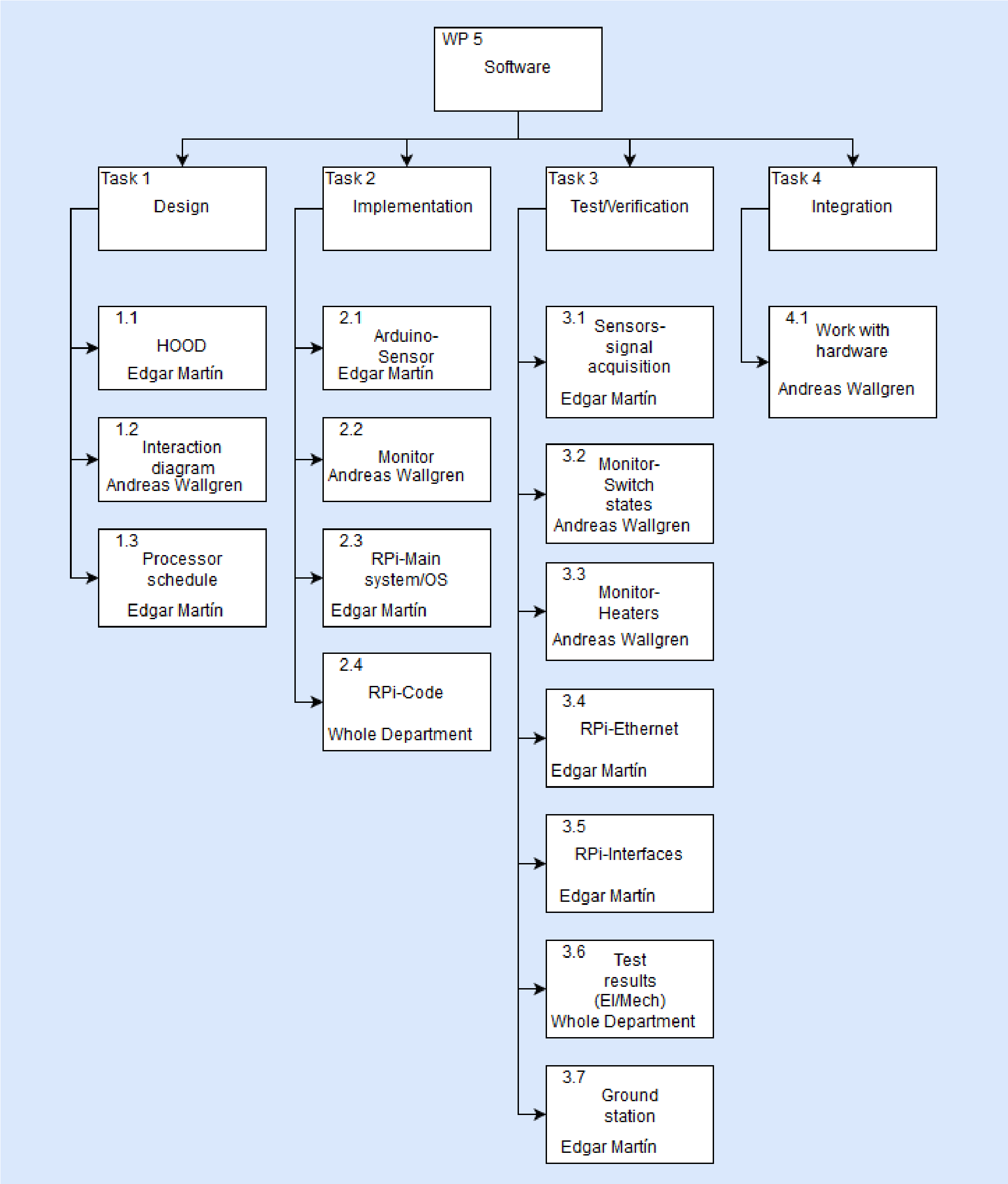


Figure E.1.5: WBS - Software

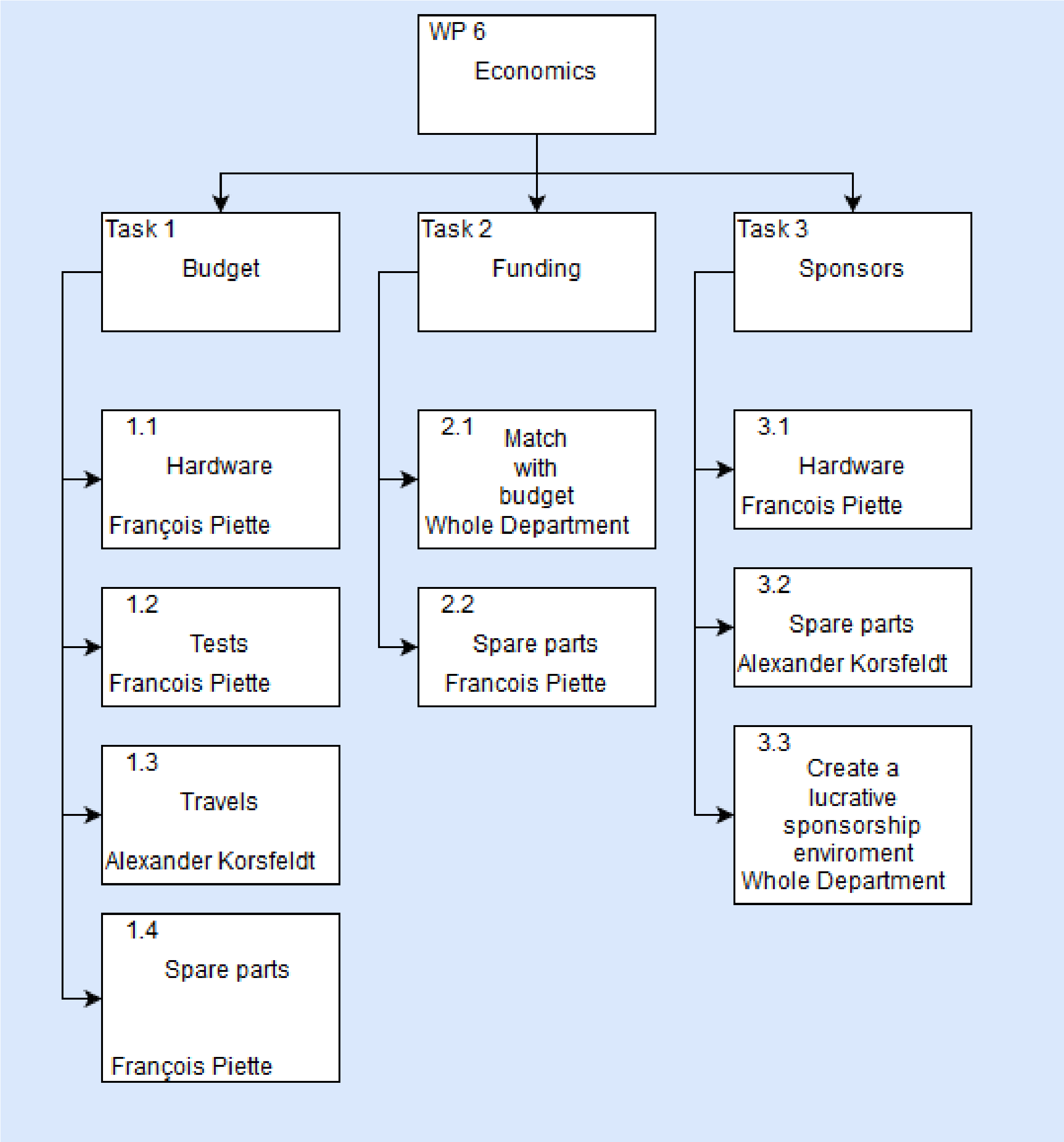


Figure E.1.6: WBS - Economics

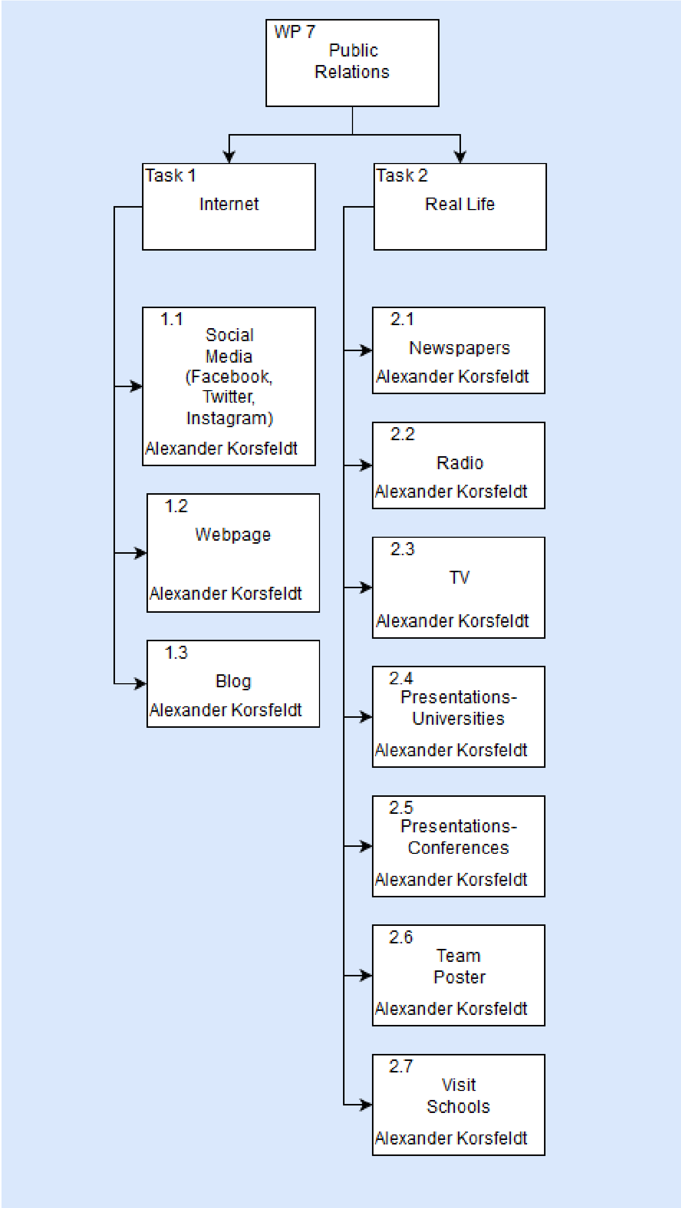


Figure E.1.7: WBS - Public Relations

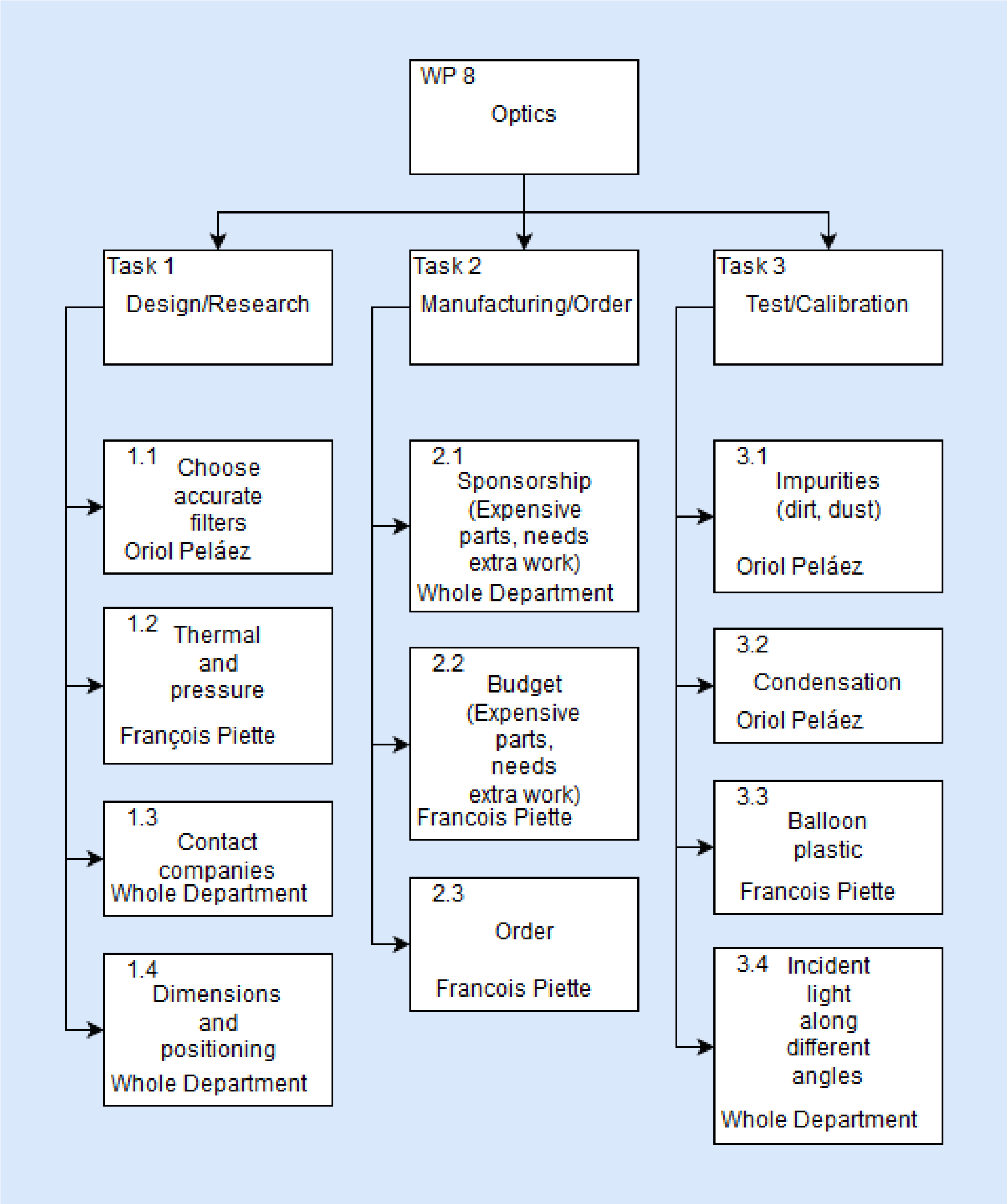


Figure E.1.8: WBS - Optics

E.2 Gantt Chart

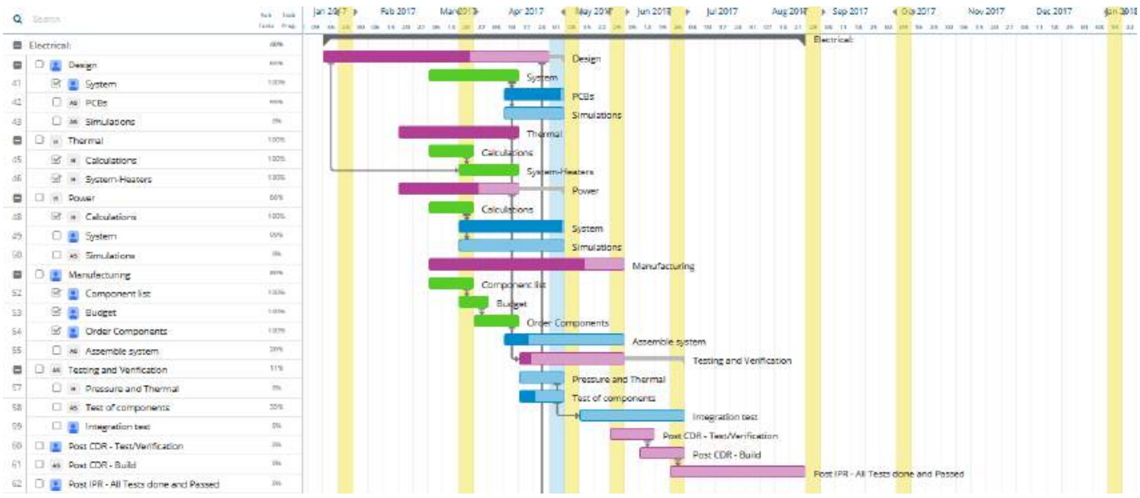


Figure E.2.1: Gantt - Electrical

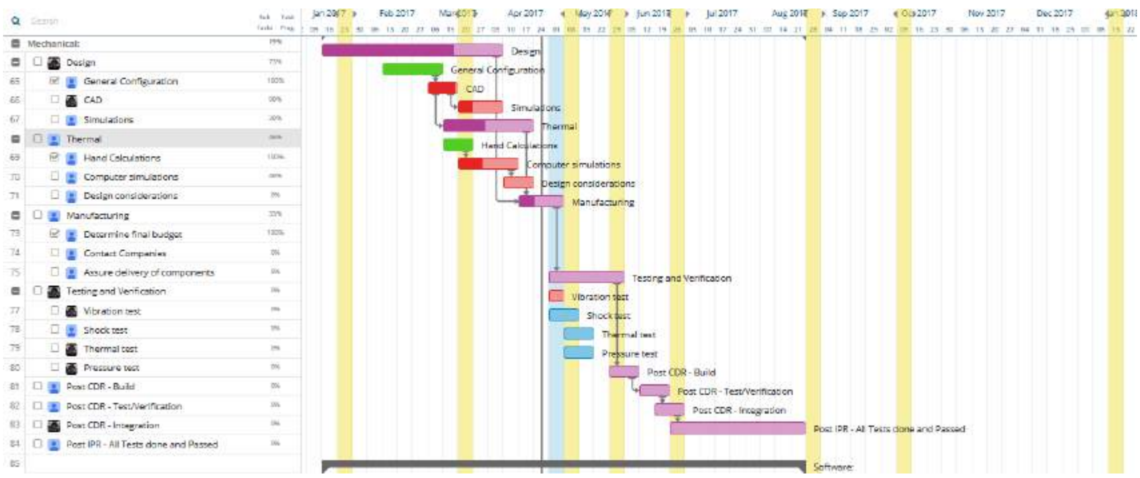


Figure E.2.2: Gantt - Mechanical

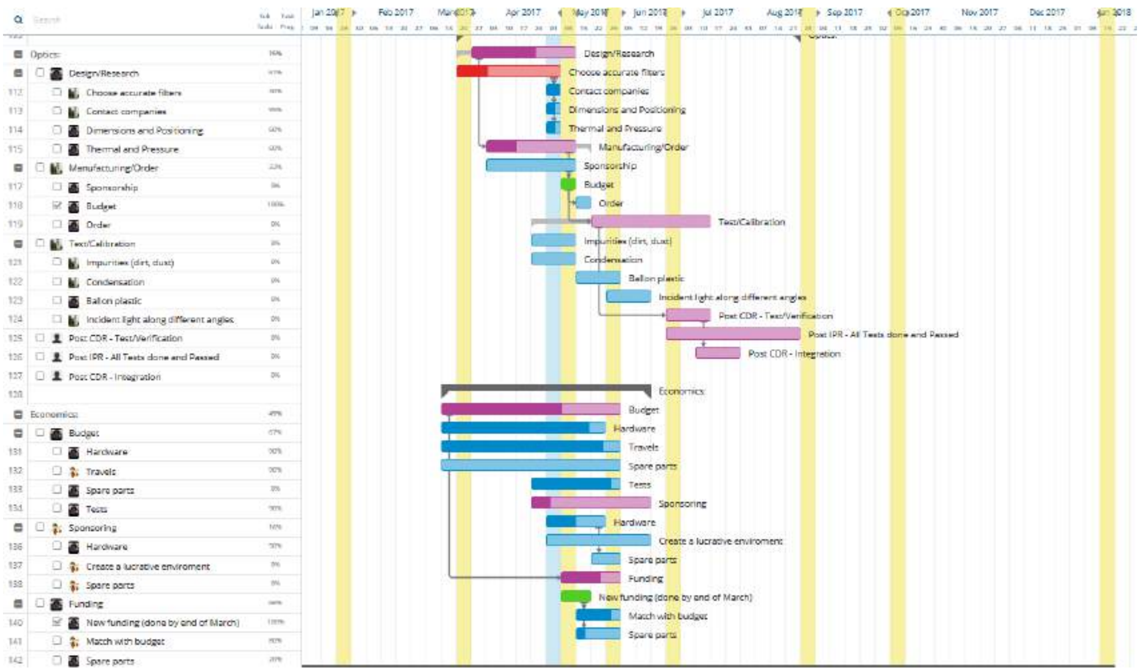


Figure E.2.3: Gantt - Optical and Economics

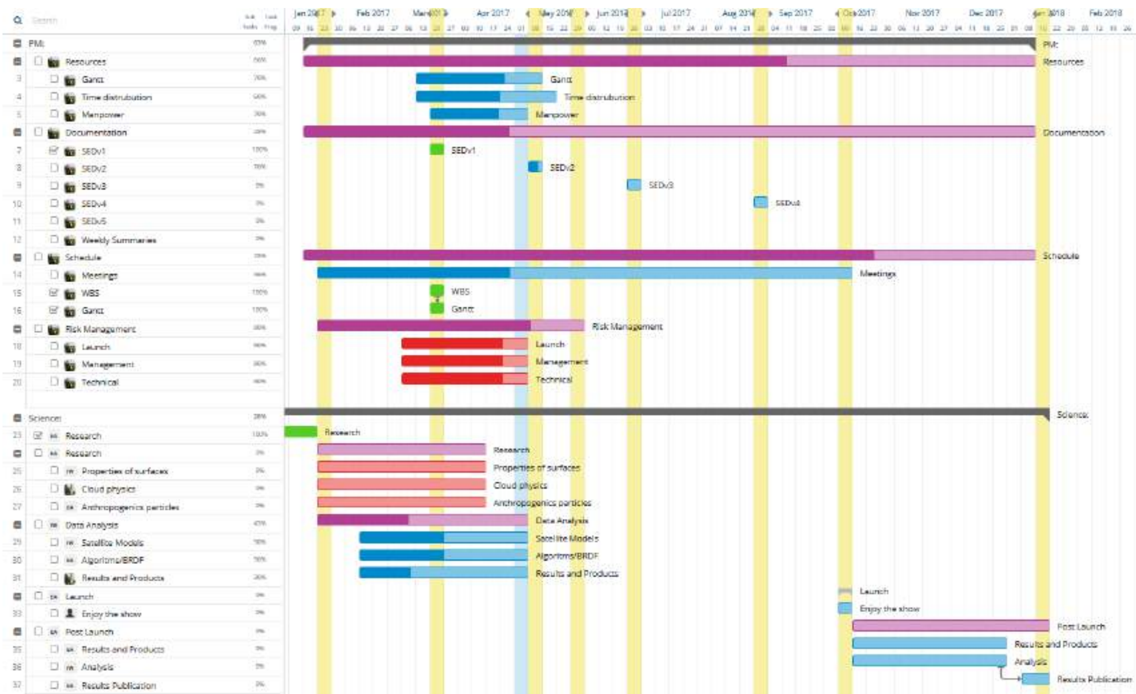


Figure E.2.4: Gantt - Project Management and Science

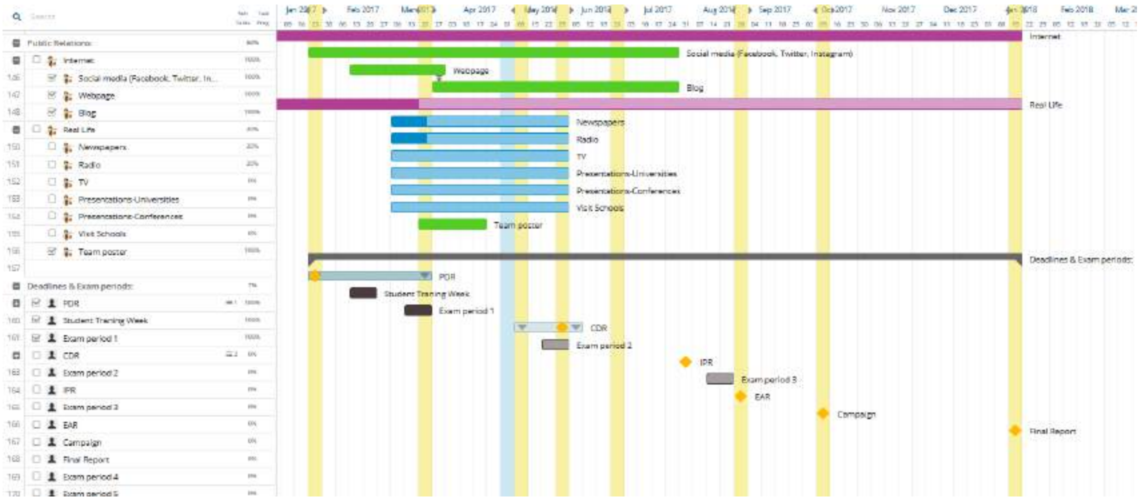


Figure E.2.5: Gantt - Public Relations and Exams/deadlines

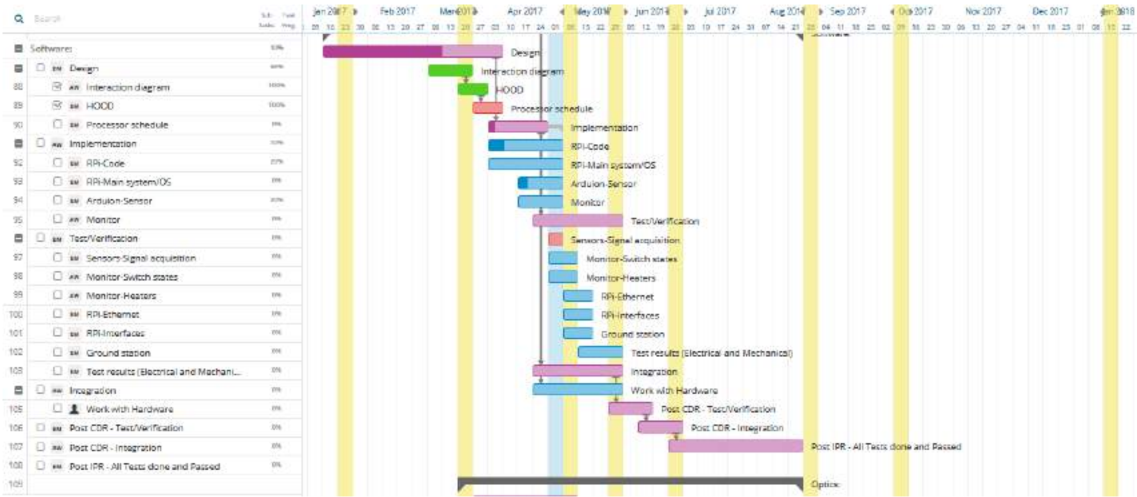


Figure E.2.6: Gantt - Software

F Thermal analysis

In this appendix the method used to estimate the heat budget is presented. Three cases with different assumptions have been considered, starting from a worst-case scenario, followed by a middle-case scenario and finally a best-case scenario. The following assumptions were chosen for each cases:

Table F.0.1: The three thermal cases considered for the heat budget estimation.

	Assumptions
Worst-case scenario	• No power heat dissipation • Two cases for solar radiation: on one surface perpendicularly, and on two surfaces with an angle of 45° for the sensor box. No solar radiation for the brain box. • Maximum conduction area (external surface of the boxes).
Middle case	• 50% power heat dissipation. • Two cases for solar radiation: on one surface perpendicularly, and on two surfaces with an angle of 45° for the sensor box. No solar radiation for the brain box. • Maximum conduction area (external surface of the boxes).
Best case	• 50% power heat dissipation • Two cases for solar radiation: on one surface perpendicularly, and on two surfaces with an angle of 45° for the sensor box. No solar radiation for the brain box. • ~~Free convection.~~ • Minimum conduction area (angle brackets+contact with booms).

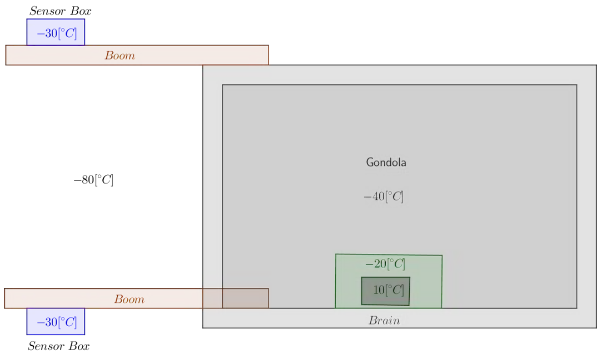


Figure F.0.1: Optimal temperature considered during the estimation of the heat budget.

In each case the same optimal temperature inside the boxes have been assumed, as shown on Fig. F.0.1. These values were selected based on the operating temperature of the components, presented in section 4.6. A safety margin of 10°C was been selected to assure the good behaviour of the electronic components.

In the following section the process used to estimate the heat budget of the middle-case scenario is presented. The estimation process of the other two cases can be deduced from the method presented. The heat budget is calculated for the four boxes: the upper and bottom sensor boxes, the brain box and the Raspberry Pi box (located inside the brain box). The heat budget for the upper and bottom sensor boxes are the same and therefore they are presented as one single box budget.

F.1 Heat Outputs

F.1.1 Conduction

To estimate the loss of heat by conduction the following equation is to be solved:

$$Q = \frac{A\Delta T}{\sum R} \tag{1}$$

Where Q is the heat $[W]$, A is the area in contact $[m^2]$, ΔT is the difference of temperature between the inside and the outside environment $[K]$ and R is the thermal resistance, defined as:

$$R = \frac{L}{k} \tag{2}$$

Where L is the characteristic length $[m]$ and k is the thermal conductivity $[Wm^{-1}K^{-1}]$. The characteristic length is usually the dimension parallel to the heat flow direction. Often the characteristic length is the thickness of the structure. On Fig. F.1.1 the general configuration of IRIS boxes is represented: it is shown that the characteristic length is

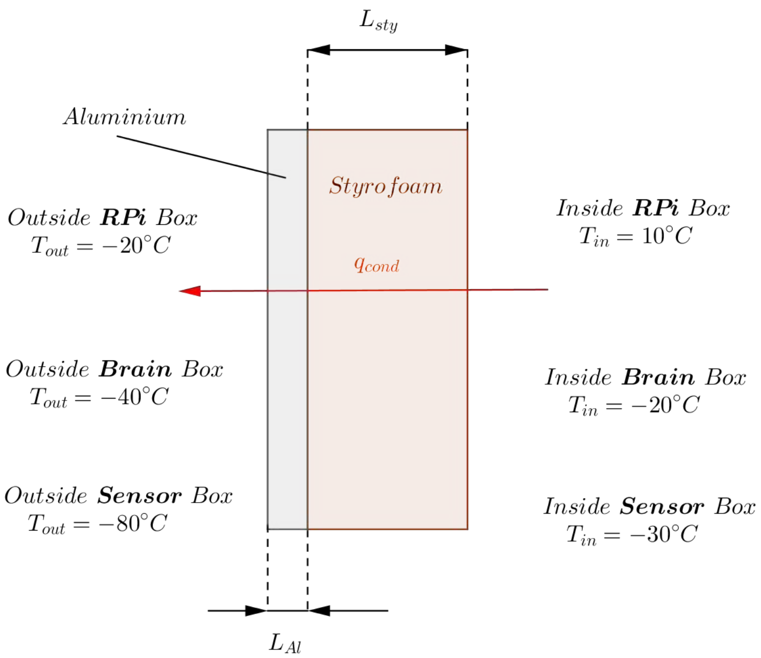


Figure F.1.1: Conduction conditions for the Sensor, Brain and Raspberry Pi box.

the thickness of the material and is parallel to the heat flow.

For each box, it is assumed that conduction has similar parameters on each face. This simplifies the estimation by using the total area of the box in Eq. 1.

The thermal conductivity of Styrofoam-brand foam is estimated to be $0.035\ Wm^{-1}K^{-1}$, and the conductivity of aluminium is estimated to be $130\ Wm^{-1}K^{-1}$. Using this data, it is now possible to estimate the heat losses by conduction for each box.

	$L\ [m]$	$R\ [KW^{-1}]$	$A\ [m^2]$	ΔT	$Q\ [W]$
Sensor Box	$L_{Al} = 0.02$; $L_{sty} = 0.04$	$R_{Al} = 1.538 \times 10^{-4}$; $R_{sty} = 1.1428$	0.238	50	10.41
Brain Box	$L_{Al} = 0.02$; $L_{sty} = 0.04$	$R_{Al} = 1.538 \times 10^{-4}$; $R_{sty} = 1.1428$	0.4108	20	7.188
RPi Box	$L_{Al} = 0.0025$; $L_{sty} = 0.02$	$R_{Al} = 1.923 \times 10^{-5}$; $R_{sty} = 0.571$	0.054	30	2.835

Table F.1.1: Conduction Heat Budget Estimation for the middle case scenario.

Conduction losses for the brain box can be reduced by mounting it on a plate with thermal spacers, and separating this one from the gondola rails with rubber bumpers, as shown in figure F.1.2.

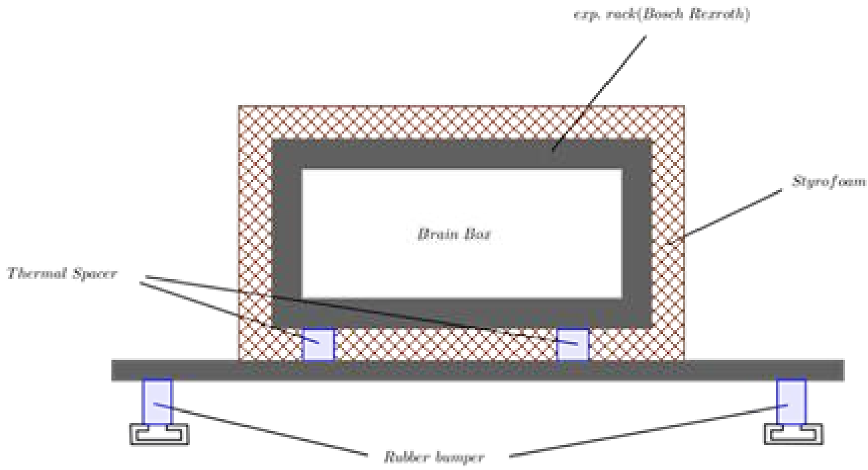


Figure F.1.2: Sketch of the modifications on the brain box mounting on the gondola rails, with the objective of reducing conduction losses.

F.1.2 Convection

To estimate the loss of heat by convection, the following equation is to be solved:

$$Q = hA\Delta T \tag{3}$$

where h is the convective heat transfer coefficient, A is the area, and ΔT is the difference of temperature between the fluid and the wall.

The temperature of the wall is unknown but it can be estimated as the average between the inside and the outside temperatures:

$$T_w = \frac{T_{in} + T_{out}}{2} \tag{4}$$

The wall temperature of each box is represented on fig. F.1.3. By knowing the wall temperature it is possible to calculate the difference of temperature for each box.

Based on the data presented in the document "*U.S. Standard Atmosphere Supplements, 1966*" by NASA, the properties of the air at stratospheric altitude can be estimated. Properties of air were measured at latitude of $60°$ at an altitude of 25 km at a temperature of $-45\ °C$ (page 134), and similar data were measured at a latitude of $70°$ and an altitude of 25 km at a temperature of $-76\ °C$ (page 140). Therefore the following properties for the air in the stratosphere are known:

	$k\ [Wm^{-1}K^{-1}]$	$\rho\ [kgm^{-3}]$	$\mu\ [kgm^{-1}s^{-1}]$	$C_p\ [Jkg^{-1}K^{-1}]$
$T = -40°C$	0.02047	4.205×10^{-2}	1.484×10^{-5}	1000
$T = -80°C$	0.01785	3.233×10^{-2}	1.312×10^{-5}	1000

Table F.1.2: Air properties from an altitude of 25 km at high latitude with an atmospheric temperature of -45 $[°C]$ and -76 $[°C]$.

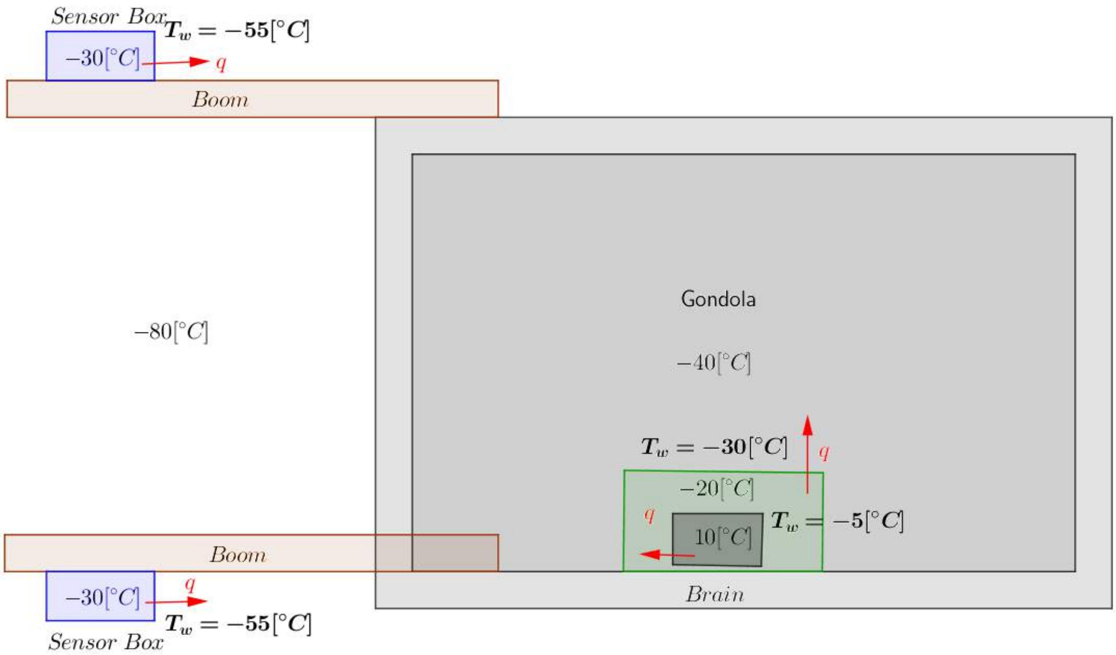


Figure F.1.3: Wall temperature estimation for the sensor, Brain and Raspberry Pi boxes.

This data allows to determine useful thermodynamic properties that will be used in subsequent steps:

	ν $[m^2s^{-1}]$	α $[m^2s^{-1}]$	β $[K^{-1}]$	Pr [-]
$T = -40°C$	3.529×10^{-4}	4.868×10^{-4}	0.0043	0.725
$T = -80°C$	0.01785	3.233×10^{-2}	1.312×10^{-5}	0.735

Table F.1.3: Thermodynamic air properties based on the data on tab. F.1.2.

The most complex part about convection is to estimate the convective heat transfer coefficient, h. By using the air properties presented previously, it is possible to empirically estimate this parameter for free and forced convection. The two methods will be presented shortly in the following subsection. Generally the convective heat transfer coefficient is estimated by using an empirical law to calculate the Nusselt number, which is linked to the heat transfer coefficient by the following equation:

$$Nu = \frac{hL}{k} \tag{5}$$

where h is the convective heat transfer coefficient, L is the characteristic length and k is the thermal conductivity of the fluid. The characteristic length for vertical plates in free convection corresponds to the dimension which is parallel to gravity. For horizontal plates the following formula is generally used:

$$L = \frac{Area}{Perimeter} \tag{6}$$

For free convection the following characteristics lengths are considered:

	$L\ [m]$
Sensor Box: Vertical Plate	0.132
Sensor Box: Horizontal Plate	0.055
Brain Box: Vertical Plate	0.16
Brain Box: Horizontal Plate	0.079
RPi Box: Vertical Plate	0.055
RPi Box: Horizontal Plate	0.027

Table F.1.4: Characteristic lengths for free convection.

The characteristic length for forced convection can be considered to be the length in the direction of the flow. For forced convection along the longest length of the sensor box, the following characteristic lengths are considered:

	$L\ [m]$
Sensor Box: Vertical Plate	0.32
Sensor Box: Horizontal Plate	0.0333

Table F.1.5: Characteristic lengths for forced convection.

N.B. : The Brain and RPi box are not considered for forced convection because they are inside the gondola.

Free Convection

For free convection, the Nusselt number is a function of the Rayleigh and Prandtl number and therefore it is necessary to first calculate them. However, the Rayleigh number requires to calculate the Grashof number. The Grashof and Prandlt number can be estimated based on the properties of the fluid:

$$Gr = \frac{g\beta(T_w - T_{inf})L^3}{\nu^2} \tag{7}$$

$$Pr = \frac{\nu}{\alpha} = \frac{c_p\mu}{k} \tag{8}$$

where g is the gravity, β is the thermal expansion coefficient, T_w is the wall temperature, T_{inf} is the temperature of the fluid, L is the characteristic length and ν is the kinematic viscosity.

After calculating the Grashof and Prandtl numbers, the Rayleigh number can be obtained:

$$Ra = GrPr \tag{9}$$

Based on the Rayleigh number range, different empirical formulae exist for calculating the Nusselt number. Also, the Nusselt empirical law depends on the orientation of the plate. Therefore, different equations for horizontal and vertical plates must be used.

The empirical law used for free convection at a vertical wall for this case is:

$$Nu = 0.68 + \frac{0.67Ra^{1/4}}{[1 + (\frac{0.492}{Pr})^{9/16}]^{4/9}} \tag{10}$$

For horizontal plates the following equation is used:

$$Nu = 0.59Ra^{1/4} \tag{11}$$

Finally, it is possible to estimate the convective heat coefficient for the brain and RPi boxes:

	Gr [-]	Ra [-]	Nu [-]	h $[Wm^{-2}K^{-1}]$	q $[W]$	q_{tot} $[W]$
Brain: Vertical Plate 1	13846.41	10038.14	5.847	0.748	0.437	0.874
Brain: Vertical Plate 2	13846.41	10038.14	5.847	0.748	0.335	0.67
Brain: Horizontal Plate	1680.97	1218.64	3.49	0.901	0.921	1.842
Brain: **Total**						3.385
RPi: Vertical Plate 1	754.91	547.28	3.176	1.23	0.129	0.258
RPi: Vertical Plate 2	754.91	547.28	3.176	1.23	0.11	0.22
RPi: Horizontal Plate	100.106	72.57	1.72	1.3	0.274	0.548
RPi: **Total**						1.026

Table F.1.6: Free convection heat budget estimation for the Brain and Raspberry Pi boxes.

Forced Convection

For the forced convection the Reynolds number of the flow around the boxes has to be estimated first. In this special case, the flow speed is assumed to be 5m/s. First the Reynolds number has to be calculated:

$$Re = \frac{u\rho L}{\mu} \tag{12}$$

Where u is the velocity of the flow, ρ is the density, L is the characteristic length, and μ is the dynamic viscosity. By calculating the Reynolds number the Nusselt number can be calculated:

$$Nu = 0.664Re^{1/2}Pr^{1/3} \tag{13}$$

Finally it is possible to estimate the convective heat coefficient to determine the heat budget with forced convection :

	Re [-]	Nu [-]	h $[Wm^{-2}K^{-1}]$	q $[W]$	q_{tot} $[W]$
Sensor : Vertical Plate 1	1626.36	24.17	3.27	3.451	6.902
Sensor : Vertical Plate 2	1626.36	24.17	3.27	1.833	3.666
Sensor : Horizontal Plate	683.93	15.67	5.04	6.854	13.708
Sensor : **Total**					24.276

Table F.1.7: Forced convection with a flow velocity $v = 5m/s$ heat budget estimation for the Sensor box.

As of version 2.1 of this document, convection outside the boxes during the float phase has been considered non-important for all boxes and cases due to low atmospheric density and relative speeds at the float altitudes. It is however still considered for the analysis of early ascent phase and late descent phase, as at these altitudes atmospheric density is high enough to increase this effect to noticeable levels.

F.1.3 Radiation

Radiation losses are caused by the tendency of warm bodies to emit radiation. The emissivity of Styrofoam-brand foam is 0.6. Even though it is currently not possible for the IRIS team to estimate the emissivity of this foam at stratospheric temperatures, this value provides a good estimate of the radiation balance with its environment.

The Stefan-Boltzmann law for grey bodies can be used to estimate the radiation heat balance:

$$Q = \epsilon A \sigma (T_{in}^4 - T_{out}^4) \tag{14}$$

Where ϵ is the emissivity, σ is the Boltzmann constant, T_{in} is the temperature of the body emitting radiation within the body of interest, T_{out} is the temperature of the box and A is the area of the box.

For the sensor boxes, the radiation input is assumed to be zero: even though some emitted thermal radiation from the gondola will warm them, this is considered negligeable. The brain box within the gondola will be subject to emitted radiation inside the gondola, as shown on Fig. F.1.4.

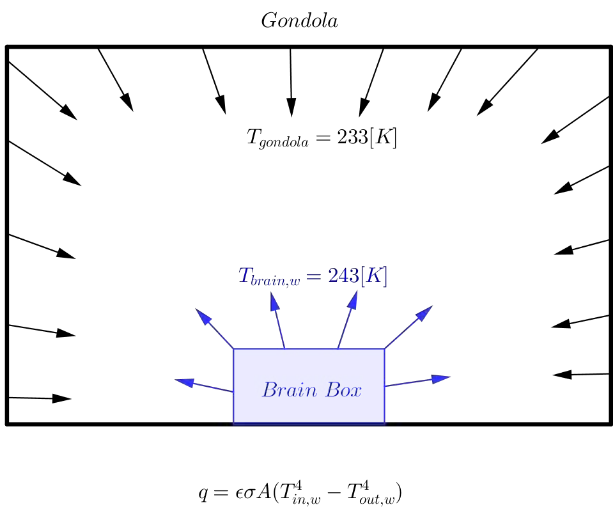


Figure F.1.4: Radiation field of the brain box inside the gondola.

Introducing the value $\sigma = 5.67 \times 10^{-8}\ \frac{W}{m^2 K^4}$ and the emissivity of Styrofoam-brand foam, the following radiation losses are obtained:

- Sensor box: 17.26 W
- Brain box: 7.54 W
- RPi box: 1.95 W

F.2 Heat Inputs

F.2.1 Heat Power Dissipation

Without any kind of active thermal control, the electronic devices in each of the boxes are the only source of heat from inside. In order to estimate how much heat is being generated by each component, a 50% power efficiency is assumed for all of them, meaning that 50% of the electric power consumed by each component is being converted into heat. Notice that in the worst-case scenario all electronic devices are assumed to be not working, which means they would be producing no heat at all.

Therefore, calculating the heat power dissipation for each box is reduced to first identify which components are present on each box and how much electric power they consume; these values can be found on Tab. 4.6.1. After applying a 50% efficiency to the power consumption of every component, the resulting heat power dissipations are summed for the components present on each box. The result is the heat input in the form of heat power dissipation for each box:

- Sensor box: 0.9 W
- Brain box: 0.784 W
- RPi box: 1.5 W

F.2.2 Solar Radiation

The heat transfered to a surface by incident electromagnetic radiation can be calculated from the following equation:

$$Q = AIcos(\theta) \tag{15}$$

where Q $[W]$ is the absorbed heat, A $[m^2]$ is the exposed area, I $[Wm^{-2}]$ is the solar irradiance, and θ is the angle of incidence of the incoming photons on the surface and is equal to zero in the case of perpendicular incidence.

Solar irradiance has an approximate value of $I = 1362\ \frac{W}{m^2}$ at one astronomical unit from the Sun. As stated in Tab. F.0.1, only the sensor boxes are considered to be receiving solar radiation in all cases. For the middle-case in particular, solar radiation is assumed to hit three different surfaces of each sensor box at an average angle of $\theta = 45°$: this is intended to represent the possible rotations of the gondola during the flight.

By calculating the exposed area A for both sensor boxes -which is the same due to both having the same dimensions and being attached to the gondola in a very similar position-and making use of the aforementioned values of irradiance and incidence angle, equation 15 can be then used to obtain the heat input from the solar radiation, which has a value of $Q = 114.7$ W.

F.3 Heat Budget

Once both heat inputs and outputs are calculated as shown in the previous sections, the heat budget can be calculated by substracting the heat outputs to the heat inputs. The results for the middle-case scenario are shown on Tab. F.3.1.

	Conduction	Convection	Radiation	Power Dissipation	Solar Irradiance	**Total**
Sensor Box	10.418	24.278	17.26	0.9	114.68	63.63
Brain Box	2.835	3.385	7.54	0.784	0	-11.52
RPi Box	7.18	1.026	1.95	1.5	0	-4.312

Table F.3.1: Heat budget estimation for the middle case scenario. All values are given in Watts.

F.4 Verification of results

The results obtained previously are verified with computer simulations. These have been realised with the aid of LISA, a Finite Element Analysis (FEA) free software. Thermal steady states are solved with this program for each of the four boxes of the experiment, for the three stated cases.

Due to the limitations of the software, only simplified models of each box could and conductive heat transfer could be used: because of this, sensor boxes could be considered to be always under shadow. For each box, only its thermal insulation was modelled, as a single piece with no holes and with their nominal dimensions. Volume meshes were used. Figures F.4.1 to F.4.3 show the meshes used.

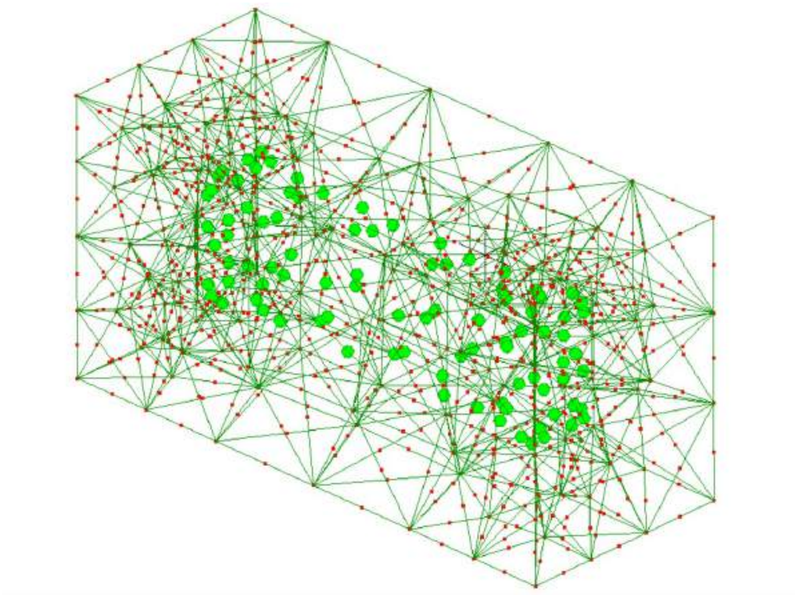


Figure F.4.1: Mesh used on the sensor box model. Red dots are nodes, while green dots represent heat dissipation boundary conditions.

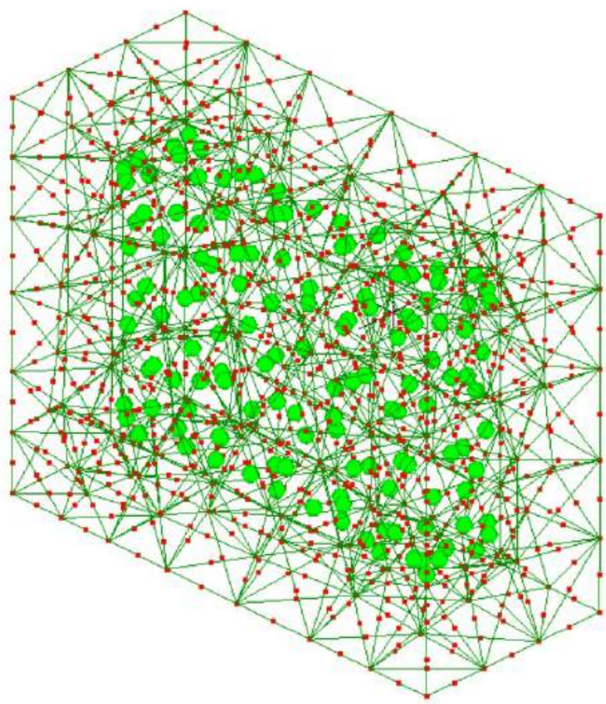


Figure F.4.2: Mesh used on the brain box model. Red dots are nodes, while green dots represent heat dissipation boundary conditions.

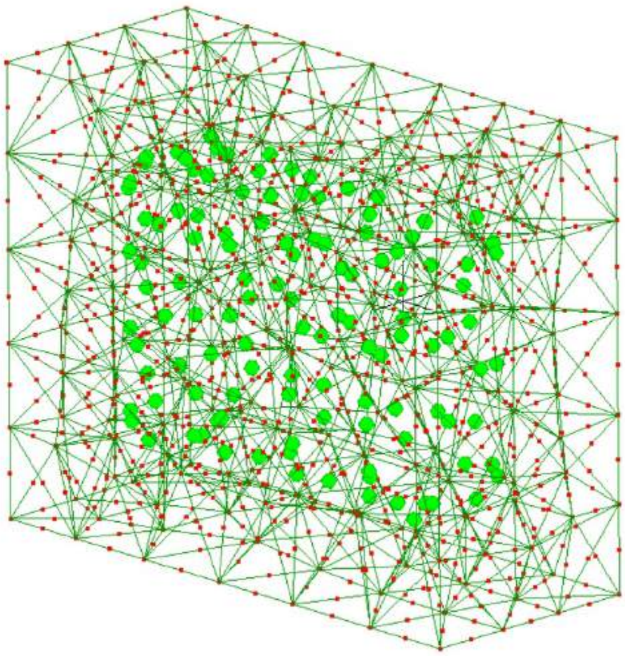


Figure F.4.3: Mesh used on the RPi box model. Red dots are nodes, while green dots represent heat dissipation boundary conditions.

Table F.4.1 shows the temperatures of each wall of each of the boxes of the experiment, while table F.4.2 shows the heat fluxes set on each of their interior walls.

Table F.4.1: Initial temperatures of the various boxes of the experiment.

Box	**Interior wall temperature ($^{\circ}C$)**	**Exterior wall temperature ($^{\circ}C$)**
Sensor box	-55	-80
Brain box	-15	-40
RPi box	+10	-30

Table F.4.2: Heat fluxes on each of the interior walls of the boxes.

Box	**Worst case, heaters inactive (W)**	**Worst case, heaters active (W)**	**Middle and best cases (W)**
Sensor box	0	1.333	1.483
Brain box	0	1.333	2.153
RPi box	0	1.333	1.583

Solving both the steady state and transient analyses showed that the interior walls of all boxes were able to keep their stated temperature in all cases, as shown in pictures F.4.4 to F.4.6. Therefore, the results obtained with analytical methods -and thus the thermal design- can be considered to be correct, although it is to be kept in mind that radiative and convective transfers were not considered on these simulations.

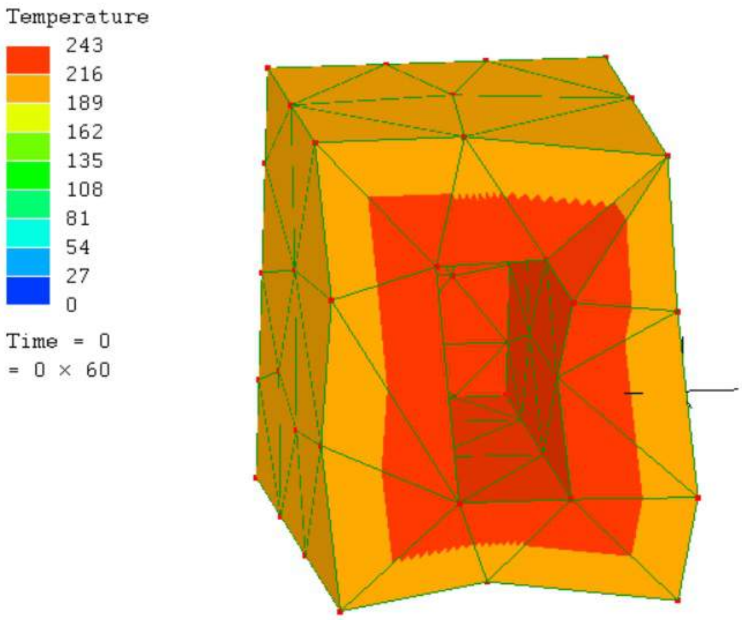


Figure F.4.4: Cut-away temperature distribution of the sensor box for the middle case. Other cases showed very similar, if not identical, results.

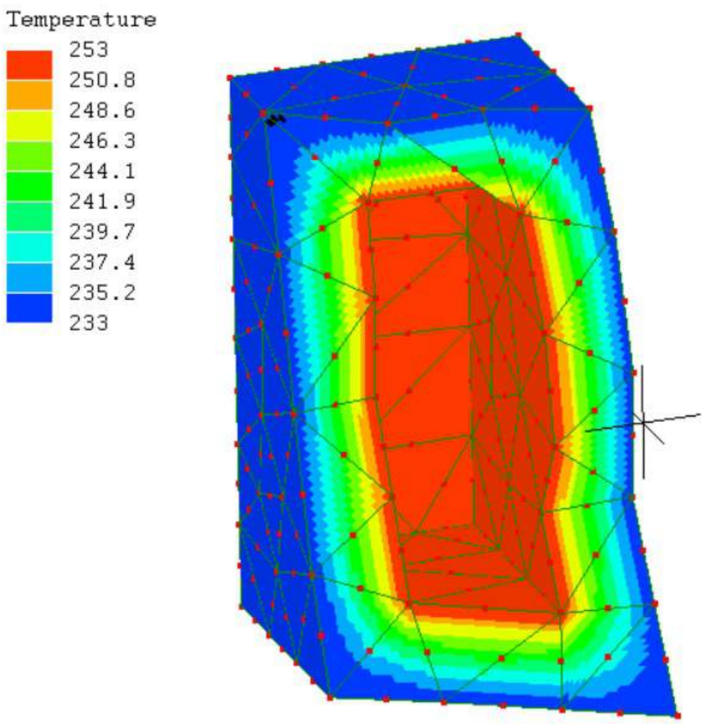


Figure F.4.5: Cut-away temperature distribution of the brain box for the middle case. Other cases showed very similar, if not identical, results.

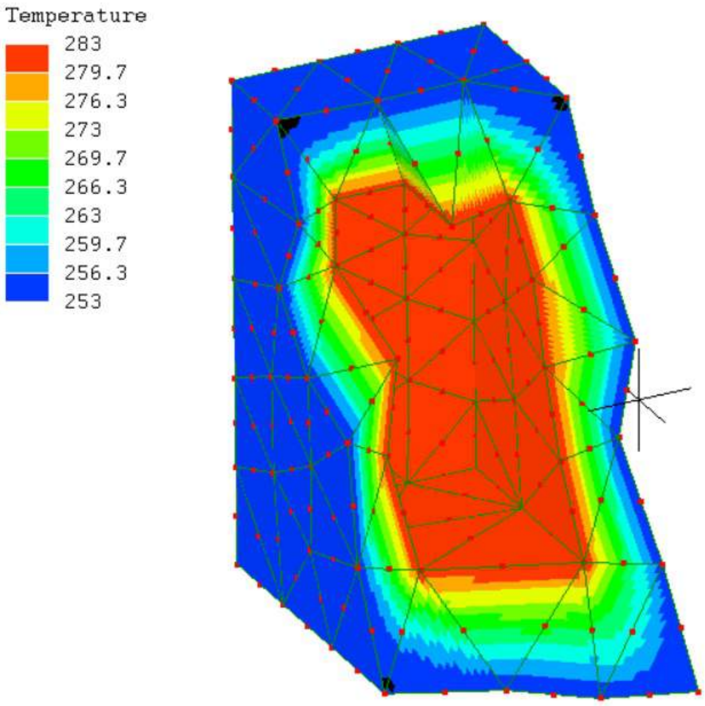


Figure F.4.6: Cut-away temperature distribution of the RPi box for the middle case. Other cases showed very similar, if not identical, results.

G Test results

G.1 Electronics

G.1.1 Test 18: Test of 5 V DC/DC converter

G.1.1.1 Background and hypothesis

Verifying the performance of the DC/DC converter is necessary to ensure a high quality power supply system of the project. The component should be tested to ensure it meets the system requirements. In this test different parameters of the DC/DC converter THN 15-2411WI (15 W, 9–36 V_{in}, 5 V_{out}) by *Traco Power* are measured and compared to expected values from manufacturer data sheet.

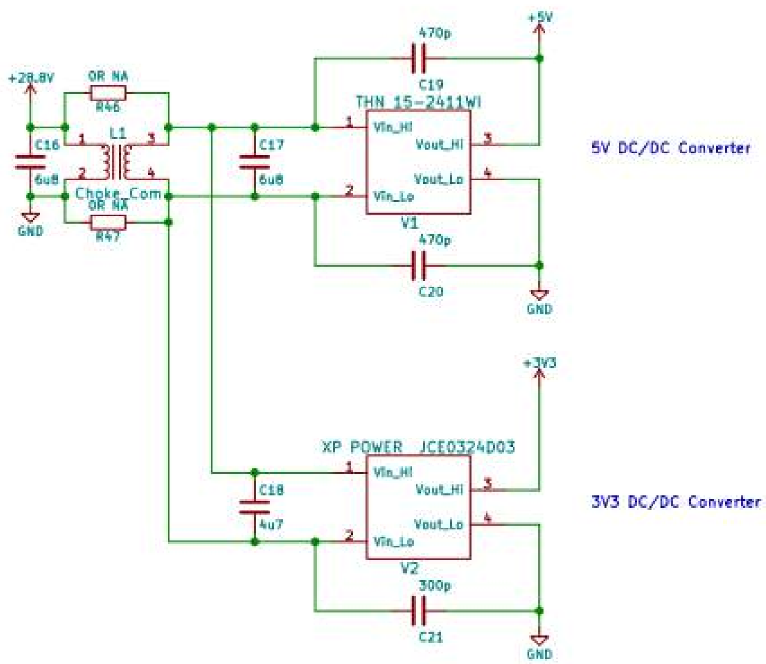


Figure G.1.1: The circuit of the power supply.

Parameter	From Datasheet	Unit	Comment
Turn-on input voltage	9	V	
Turn-off input voltage	8	V	
Start-up time	30	ms	
Shut down time	N/A	ms	
Line regulation	0.2	%	
Load regulation	0.2	%	
Efficiency	86	%	
Output ripple	75	mV pk-pk	With external capacitor

Table G.1.1: Expected values for different parameters of the converter.

Table G.1.1 shows the expected values for different parameters of the DC/DC converter, some parameters could not be found in the data sheet but they need to be measured.

G.1.1.2 Materials

- 5V DC/DC Converter THN 15-2411WI, *Traco Power*
- Capacitors: 2 $\times$ 470 pF, 2 $\times$ 6.8 μF
- Resistor: Load 1:$\approx 2\Omega$ power resistor, Load 2:$\approx 3.5\Omega$ power resistor
- Inductor
- Breadboard
- Oscilloscope
- Power source

G.1.1.3 Procedure

Figure G.1.1 shows the complete circuit of the power supply, but in this test only the 5 V converter part is tested. This circuit is connected up on a breadboard, a power supply is used to simulate the battery voltage of 28.8 V.

To complete the testing a load resistor of varying sizes are used during the testing and is inserted between V_{out-Hi} and V_{out-Lo}.

G.1.1.4 Results (data)

Parameter	From Datasheet	Measured	Unit	Comment
Turn-on input voltage	9	8,7	V	
Turn-off input voltage	8	8.3	V	
Start-up time	30	20	ms	
Shut down time	N/A	N/A	ms	
Line regulation	0.2	0.02	%	
Load regulation	0.2	0.15	%	
Efficiency	86	80.5	%	Note 1
Output ripple	75	<75	mV pk-pk	

Table G.1.2: Expected and measured values for different parameters of the converter.

Note 1: The difference has several reasons, most likely are measuring errors and losses in the equipment used. Some small losses in the amperemeters and the breadboard in addition some errors in measurements on mentioned amperemeter and the oscilloscope is most likely also contributing to the error.

G.1.1.5 Conclusion

The 5V DC/DC converter chosen fulfils the requirements and is intended to be used in the project.

G.2 Mechanical

TBD

G.3 Software

TBD

G.4 Optics

TBD