SED

Student Experiment Documentation

Document ID: BX25_IRIS_SEDv4-0_22Sep17

Mission: BEXUS 25

Team Name: IRIS

Experiment Title: InfraRed albedo measurements In the Stratosphere

Team	Name	University
Student Team Leader:	Gustaf Ljungné	LTU
Team Members:	Alexander Korsfeldt Larsén	LTU
	Andreas Wallgren	LTU
	August Svensson	LTU
	Arttu Tiainen	LTU
	Edgar Martín Nieto	LTU
	Eleni Athanasiou	LTU
	François Piette	ULg
	Guillermo Ledo López	LTU
	Hampus König	LTU
	Ingo Wagner	LTU
	Lisa Jonsson	LTU
	Oriol Peláez Mercadal	LTU

Version:	Issue Date:	Document Type:	Valid from
4.0	**22 September 2017**	**EAR**	**17 December 2016**

Issued by:

The IRIS Team

Approved by:

Endorsing Professor Mathias Milz

Change Record

Version	Date	Changed chapters	Remarks
0.0	2017-01-01	New Version	Blank Document
1.0	2017-01-27	All	PDR
1.1	2017-03-23	Abstract, Chap. 1.4, 2, 3, 4, 5, 6, 8, App B Added: Chap: 4.5.1, 4.8.2.3, 4.10, 5.2.1, 5.2.2, App E, App F	PDR feedback
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
2.1	2017-06-26	Chp 2, 3.3.2, 3.5, 4.2.1, 4.3, 4.4.2, 4.5, 4.6, 4.7, 5.2.2, 6.1.1, 6.1.4, 6.3, 7.1, 7.2.2, 8.1, App B, App F	CDR feedback
3.0	2017-07-23	Chp 2.2, 4.2.1, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8.2, 4.8.3, 5.1, 5.2.2, 5.3, 6.1, 6.3, 7.1, App B, App C, App F, App G	IPR
4.0	2017-09-22	Chp 2.1, 3.3.2, 3.3.3, 4.1, 4.2.1, 4.2.2, 4.3.1, 4.3.2, 4.3.3, 4.4, 4.5, 4.6, 4.7, 4.8.2.3, 4.8.2.4, 4.8.3, 4.8.4, 4.9, 4.10, 5.1, 5.2.2, 5.3, 6.1.1, 6.1.3, 6.1.4, 6.1.5, 6.4, 7.1, 7.2.2, 7.2.4, 7.3, 7.4, App B, App C, App D, App F, App G	EAR, Pre-Campaign
5.0			Final Report

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 Experiment Acceptance Review (EAR) 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, Swedish Microwave AB, Astrosweden, FemeC, 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 I3RC.[15][16]

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 imaging 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.

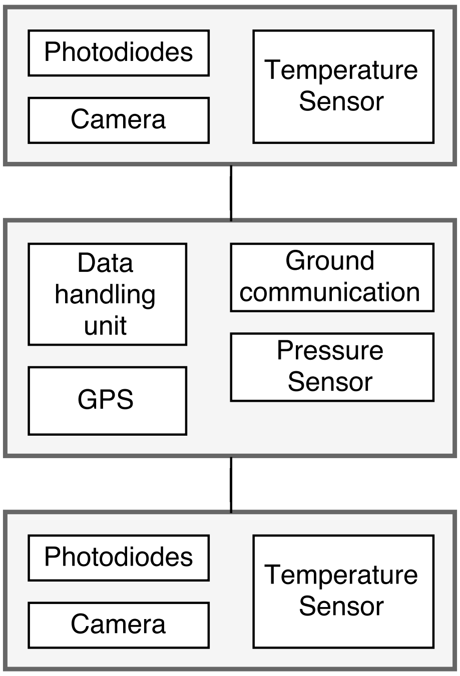


Figure 1.4.1: IRIS experiment setup

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.

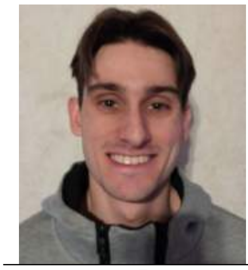
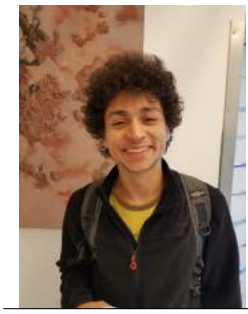
1.5 Team Details

1.5.1 Contact Point

Contact	**Contact Information**
Project Manager	Gustaf Ljungné Hagelstigen 1 98147 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.[17]

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.

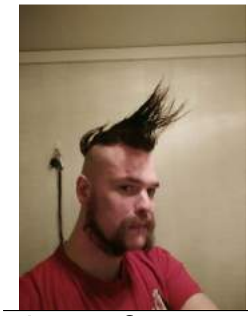
Lisa Jonsson
Head of Electronics Department

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 electronics 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 Removed, reason for requirement is to determine altitude. Moved to GPS requirement.

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 Removed, requirement moved to GPS

P.14 Removed, requirement moved to GPS

P.15 The experiment shall measure the ambient air temperature from -60 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 rate shall be below 3 seconds.

P.19 During the float phase the sampling rate shall be below 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 350 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.

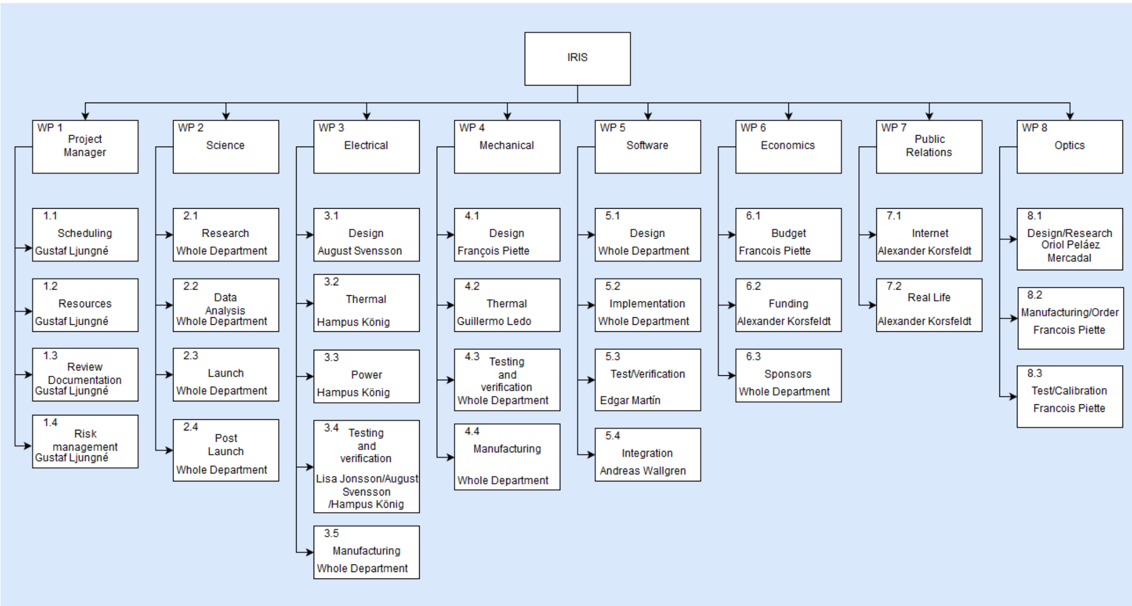


Figure 3.1.1: The WBS for IRIS

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.

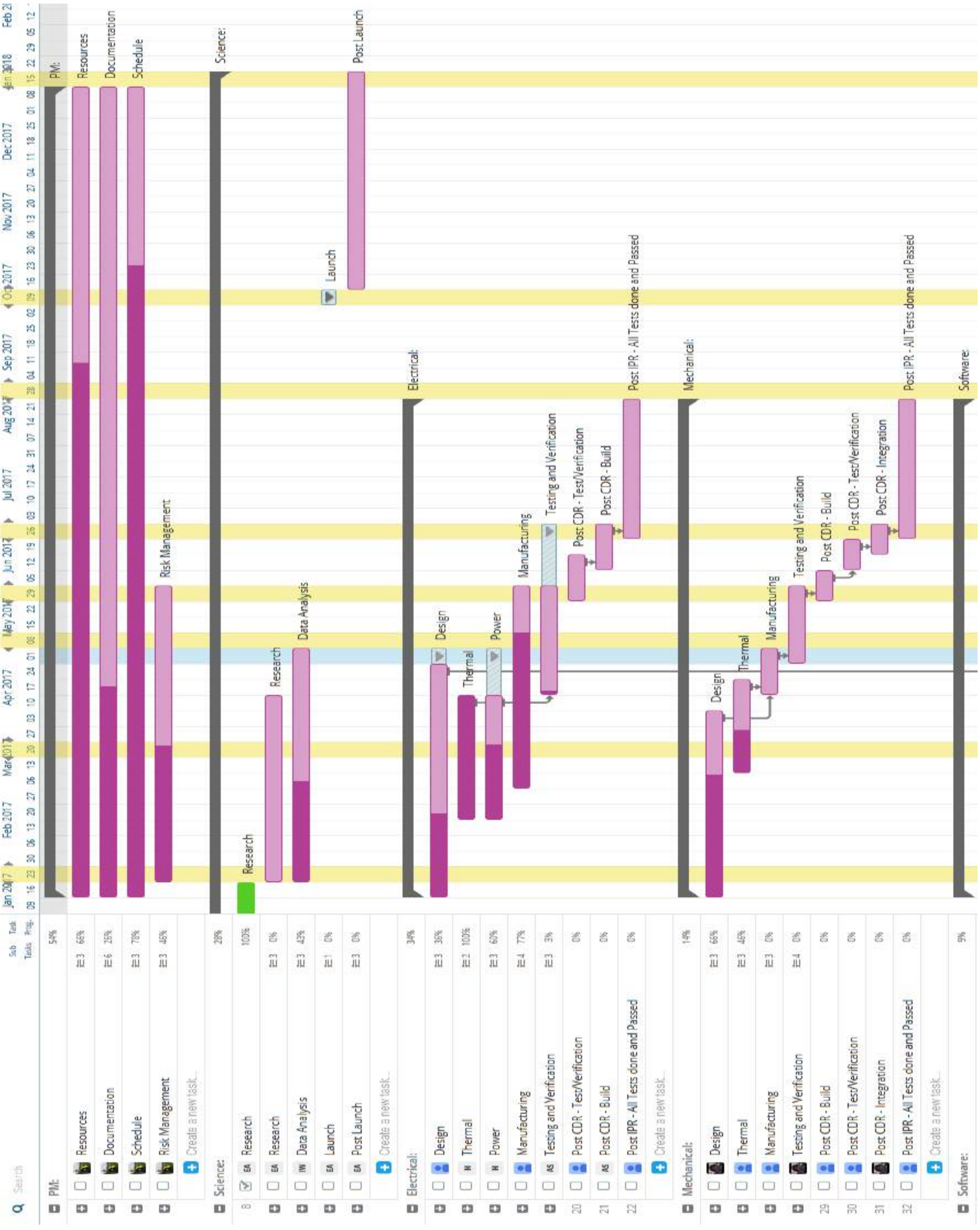


Figure 3.2.1: Gantt chart, part 1

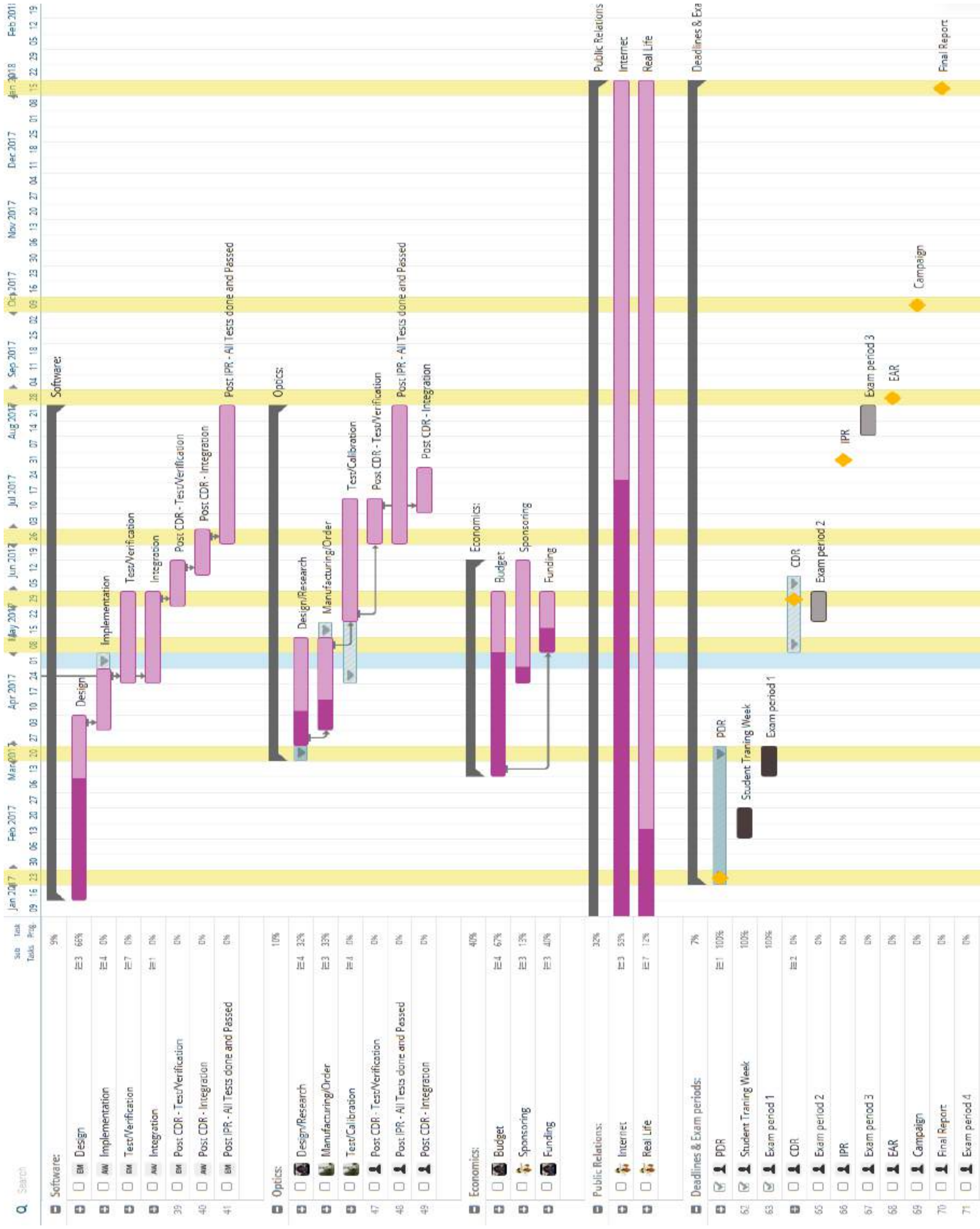


Figure 3.2.2: Gantt chart, part 2

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, updated 2017-09-22, is shown below in tab. 3.3.3. They estimation gives a good idea of where the project is financially, but due to currency conversion rates, and some pending last minute orders of spare parts, it is not yet 100% accurate.

One of the main reasons for choosing a design based on photodiodes was a belief that it would be a simple and cost efficient solution. It was later discovered that a much more complex design with expensive lenses and filters was needed, and as the design evolved the costs kept increasing.

To afford the new expenses, scholarships applications were sent to LKAB Academy and Sveriges Ingenjörer - Miljöfonden (The Swedish Association of Graduate Engineers - The Environmental Fund). A considerable amount of time was spent on discussing with these foundations, but in the end the applications did not lead anywhere.

Contacting companies, especially space and related ones, proved to be a more successful strategy of obtaining sponsorship. Requests were sent to more than 50 companies and institutions; including smaller local ones, large Swedish companies, and several companies invested in the space sector. Sponsorship deals were eventually signed by the companies Forsway, Absolicon, Swedish Microwave, and AstroSweden. In exchange for financial support, we will spread the word about the companies on our online channels and during our live presentations.

To secure even more funding, a crowdfunding campaign was launched on Generosity. This platform was chosen because they do not take any fees at all. The campaign can be found at Generosity. In addition to this, patches with the team logo was ordered and are now being sold at a small profit. This will help with the economical situation while also increasing our outreach.

Because of the large increase in expenses, all these steps were not enough to maintain a positive budget balance. Small student/project discounts negotiated with various suppliers helped alleviate the problems somewhat, but ultimately the team had to request additional funding from Luleå University of Technology.

Additional funding from LTU has meant that all the required hardware could be purchased, but at this point it is not possible to invest any more money into the Outreach Programme. The plan is still to find sponsorship for attending one larger scientific conference in 2018; or at least be able to afford sending additional team members to next the PAC Symposium where one member is already sponsored by ESA. Additional financial support from SNSB allowed IRIS to participate in the 23rd ESA PAC Symposium, held in Visby June 2017. SNSB covered expenses for travel, accommodation, and the most expensive part: participation fee. The team is also constantly looking for inexpensive ways to inform people about IRIS, BEXUS, and everything related.

All of the tests required for the mission could be performed at LTU or Esrange, and so did not incur extra costs. More information about individual components can be found in section 4.3.

Table 3.3.3: Budget estimations

Incoming/outgoing	**Amount**	**Where the money comes from/goes to**
Outgoing	€2,250	Electrical components

Outgoing	€4,600	Sensor filters and lenses
Outgoing	€1,600	Mechanical parts
Outgoing	€1,000	Manufacturing, mechanical (materials+labour)
Outgoing	€2,200	Outreach and travel costs
Incoming	€4,000	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	€400	Generosity (Crowdfunding - this is the current received amount)
Total Incoming	€12,300	
Total Outgoing	€12,150	
Total Balance	€150	

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:** Emil Forsberg **Company:** FemeC **Phone:** +46(0)703213457 **Email:** emil@femec.se
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 is 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 the IRIS outreach plan. Some articles have already been written about IRIS, and more media coverage shall be obtained during and after the launch campaign.

The team's website can be found at www.bexusiris.com. 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. Blog posts written by the various project members have been regularly published, so the website also acts as a development diary. All important documents produced by the IRIS team are 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 the IRIS website as a resource. It also contains logos with links to all of the project sponsors and stakeholders.

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 the IRIS website, a link to the article, as well as a short summary, is posted here. The team also has an Instagram account that is used to upload pictures during events and live presentations. It can be found at @bexus_iris.

More details about the Outreach Programme is found in Appendix B. This includes a list of conferences and events where IRIS was present.

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: Colour code for the risks

E	Low	Medium	High	Very High	Very High
D	Low	Low	Medium	High	Very High
C	Very Low	Low	Low	Medium	High
B	Very Low	Very Low	Low	Low	Medium
A	Very Low	Very Low	Very Low	Very Low	Low
	1	2	3	4	5

Table 3.5.3: 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	-	-	-	-	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 in each sensor box, and it has its own fisheye lens. Interior temperature sensors are included, to check that the temperature is within the safe temperature ranges of the electronics. A GPS is 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 2 M8x60 and 2 M10x60 are used to clamp the polycarbonate boom and 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 thinner clamp which are mounted on the gondola mounting rails.

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 polyamide 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 gon-

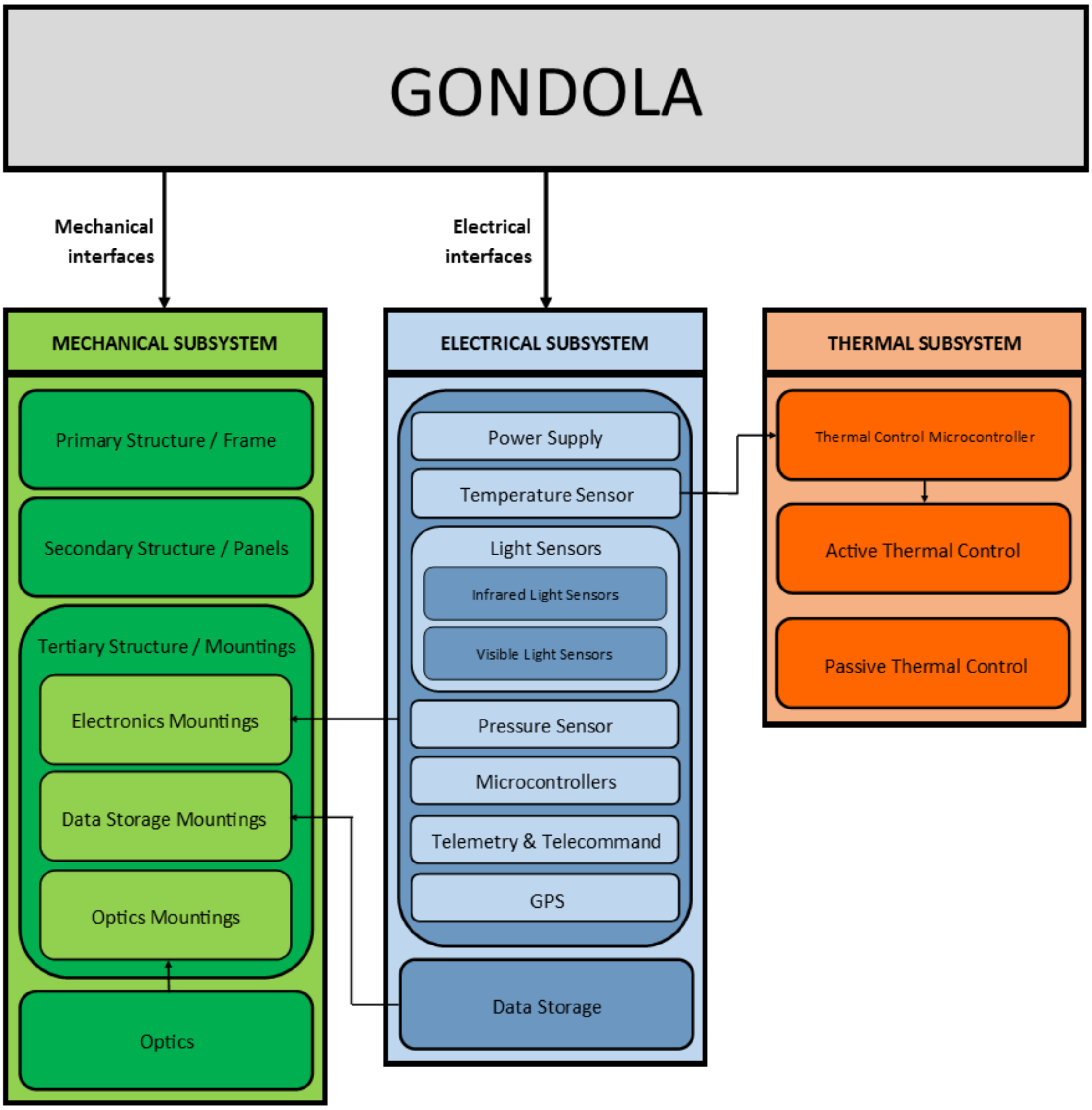


Figure 4.1.1: Subsystem diagram of the IRIS experiment.

dola rails, which allowed to reduce its height. The brain box is mounted by using the mounting rails of the gondola with M6 nuts and rubber bumpers to dampen 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	8 M8×60,8 M10×60 , 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

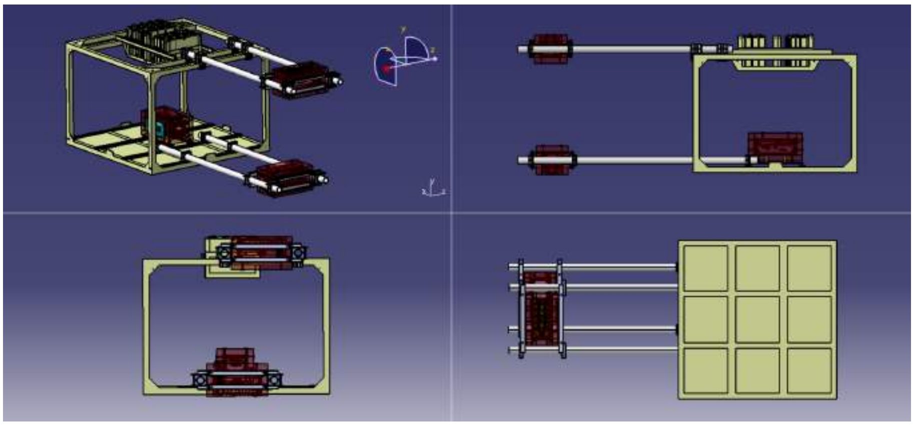


Figure 4.2.1: General view of the experiment from four different perspectives: Isometric perspective (upper left), plane xy (upper right), plane yz (lower left), and plane xz (lower right).

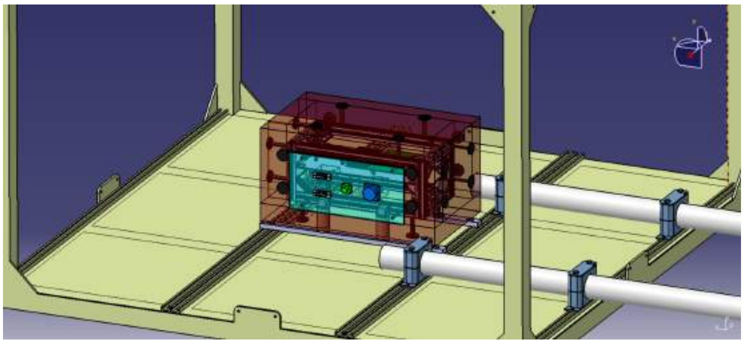


Figure 4.2.2: Top view of the "Brain" unit mounted on the gondola mounting rails.

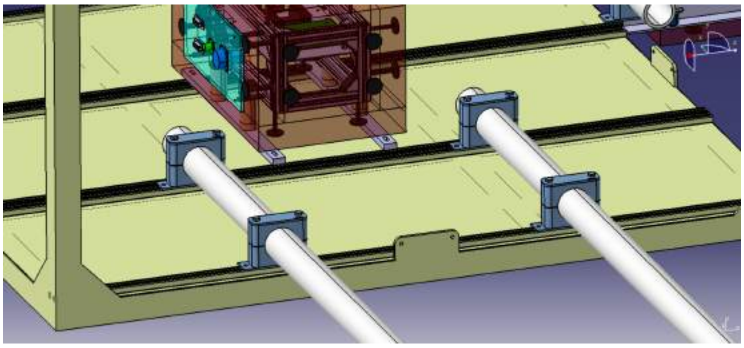


Figure 4.2.3: Top view of the lower booms mounted on the gondola mounting rails.

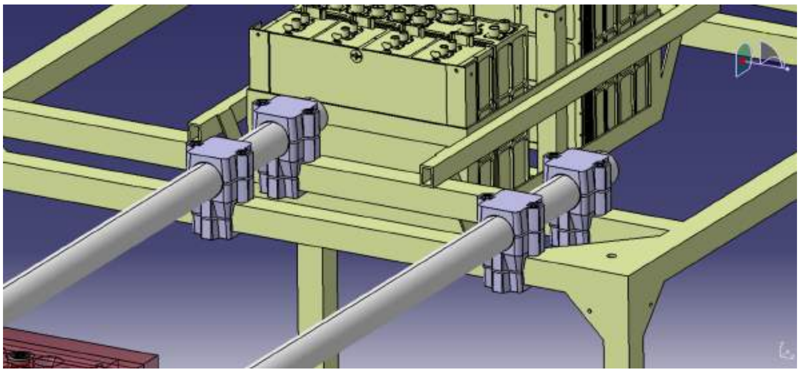


Figure 4.2.4: Top view of the upper booms mounted with clamps on the gondola frame (next to the airborne unit).

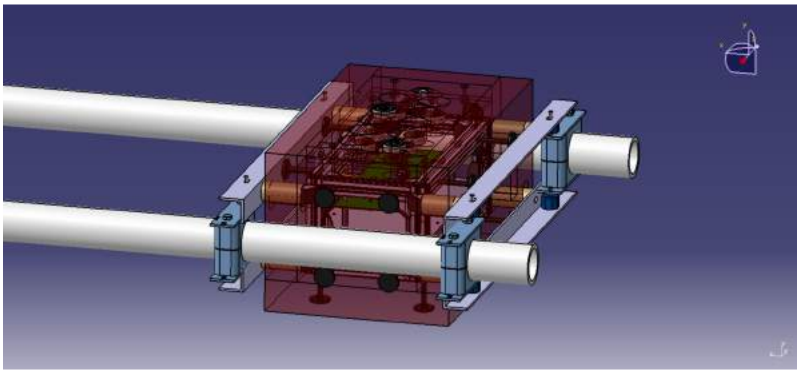


Figure 4.2.5: Top view of the sensor box mounting on the booms (upper and bottom).

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 less than 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 2A, but it requires manual override from the ground station. Otherwise there is a software implemented limit on the heaters. The expected average current draw is below 1.1A, but that is also considering all heaters running at 50% the entire flight. More likely the current draw will be less than 0.7A. 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

4.3.1 Electronics

Component	Supplier	Mass [g]	Dimensions	Amount	Cost each [EUR]	Notes	Status
Serial Camera Module μCamII	Mouser	6	32x32x21mm	2	50	Low weight, cheap	Delivered
Garmin GPS Receiver 18x-LVC	Elfa	160	⌀:85mm, H:50mm	1	110	Compact, low cost	Delivered
Photodiode FDS100 (350-1100nm)	Thorlabs	<1	⌀:10.2mm, H:3.5mm	12	14	Low cost, in stock, low delivery time	Delivered
Photodiode G12180-010A (900-1700nm)	Hamamatsu	<1	⌀:5.4mm, H:3.6mm	4	50	Large measuring range, good sensitivity	Delivered
Photodiode G12183-010K (900-2600nm)	Hamamatsu	<1	⌀:5.4mm, H:3.6mm	4	105	Large measuring range, good sensitivity	Delivered
Amplifier, LMP2022	Digikey	<1	5.0x4.0x2.0mm	20	4.2	low drift, low noise	Delivered
A/D-Converter chip, ADS1115	Digikey	<1	28x17x1.1mm	6	15	Easy to use, I^2C bus	Delivered
Watchdog Timer, TPL5010	Farnell	<1	3.0x3.0x1.0mm	1	1	Cheap, easy to use	Delivered
RS232/TTL Converter, MAX3222EEPN+	Digikey	<50	-	1	6	Easy to use, with correct conversion of signal	Delivered

Raspberry Pi 2 Model B+	Elfa	42	87x59x19mm	1	37	Easy to use, cheap	Delivered
Arduino Nano	Elfa	7	43x15mm	2	19	Easy to use, cheap	Delivered
DC/DC Converter, Traco Power, THN 15-2411WI	Farnell	15	25x25x10mm	1	35	Efficient, high current	Delivered
Heatsink, THN-HS1	Farnell	8	31x31x16.5mm	1	3.5	At high loads the DC/DC will generate alot of heat	Delivered
DC/DC Converter, Traco Power, TMR 2411	Elfa	5	22x9.2x11mm	2	12.5	Low cost, efficient	Delivered
Linear Voltage Regulator, L7805ABV	Elfa	<9	17x10x4.5mm	2	0.5	Cheap, simple design	Delivered
FTDI TTL-232R-3V3-WE	Elfa	50	⊘:5mm, L:1.8m	2	20	Easy to use signal converter + cable	Delivered
Cable, USB A to USB mini B	Digikey	< 30	L:1m	2	2	-	Delivered
Inductor, Wurth Elektronik, 7447054	Elfa	-	⊘:10.5mm, W:5.5mm	3	2	-	Delivered
Heater, Minco HK6906	Minco	3	26x36x4mm	3	38	Efficient, highly recommended	Delivered
Transistor, Vishay, IRLZ14PBF	Elfa	<2	10x15x4.5mm	3	0.5	For heater control	Delivered
Digital Thermometer, DS1631+	Digikey	-	-	11	3.5	Easy to use, I2C	Delivered

Analog Thermometer, JUMO PT1000	Elfa	<1	1x1.5x5mm	6-8	2.5	Good range, fairly simple circuit	Delivered
D-sub Cable male/female 10ft (15P)	Digikey	-	L:3050mm	2	13.8	-	Delivered
D-sub Cable male/female 15ft (15P)	Digikey	-	L:4570mm	1	13.8	Depending on box placement, longer cable might be needed	Delivered
D-sub female connector (15P)	Elfa	<7	39x12x12mm	2	1.5	-	Delivered
D-sub male connector (15P)	Elfa	<7	39x12x12mm	2	1.5	-	Delivered
PCB	ALLPCB	-	250x100 & 120x100	10	6.5	Fast delivery, low cost	Delivered
Network cable 0.15m	Elfa	-	-	1	3.5	Low cost	Delivered
Capacitor 100 nF	Elfa	1	-	15	0.1	Low cost	Delivered
Capacitor 47 μF	Elfa	1	-	10	3.5	Low cost	Delivered
Resistor 500 MOhm	Elfa	1	-	4	3	Low cost	Delivered
MicroSD card 32GB	Elfa	-	-	1	19	Low cost	Delivered
MOLEX 7-pin connector	Elfa	-	11.7x5.8	3	0.5	Low cost	Delivered

4.3.2 Optics

Component	Supplier	Mass [g]	Dimensions	Amount	Cost each [EUR]	Notes	Status
Optical Filter 440BP20**	Omega Optical	TBD	25.4x5mm	2	83	**WR**:430-450 nm, **AR**:430-450 nm, **CW**:440 $\pm$ 5 nm **FWHM**:20 $\pm$ 5 nm	Delivered
Optical Filter	Edmund Optics	TBD	12.5x5mm	2	105	**WR**:450-510* nm, **AR**:450-500 nm, **CW**:475 $\pm$ 5 nm, **FWHM**:50 $\pm$ 5 nm	Delivered
Optical Filter 560BP60 RAPID-BAND	Omega Optical	TBD	25x3.5mm	2	147	**WR**:530-590 nm, **AR**:530-590 nm, **CW**:560 $\pm$ 2 nm, **FWHM**:60 $\pm$ 4 nm	Delivered
Optical Filter FB650-40	Thorlabs	TBD	25.4x6.3mm	2	77	**WR**:630-670 nm, **AR**:630-670 nm, **CW**:650 $\pm$ 2 nm, **FWHM**:40 $\pm$ 4 nm	Delivered
Optical Filter	Edmund Optics	TBD	12.5x5mm	2	105	**WR**:850-880* nm, **AR**:850-900 nm, **CW**:875 $\pm$ 5 nm, **FWHM**:50 $\pm$ 5 nm	Delivered

Optical Filter	Edmund Optics	TBD	12.5x5mm	2	125	**WR**:1360-1380***** nm, **AR**:1350-1400 nm, **CW**:1375 ± 5 nm, **FWHM**:50 ± 5 nm	Delivered
Optical Filter	Edmund Optics	TBD	12.5x5mm	2	125	**WR**:1560-1660***** nm, **AR**:1575-1625 nm, **CW**:1600 ± 5 nm, **FWHM**:50 ± 5 nm	Delivered
Optical Filter FB2250-500	Thorlabs	2 g	25.4x6.1mm	2	295	**WR**:2000-2500 nm, **AR**:2000-2500 nm, **CW**:2250 ± 50 nm, **FWHM**:500 ± 100 nm	One Delivered, another one yet to arrive
Smartphone fisheye lenses	Amazon	48 g	TBD	10	42	TBD	First fisheye lenses received.
Fisheye lenses DSL315	Sunex	TBD	TBD	10	109	TBD	Delivered
RND Lab Suitcase	Elfa		350x230x59 [mm]	2	40		Delivered

TZ2 - Optic Tweezers with Nylon Body and Tips	Thorlabs			3	14		Delivered
SPW602 - Spanner Wrenches for SM1 series, Graduated	Thorlabs			2	50		Delivered
SPW603 - SM05 Spanner Wrench	Thorlabs			3	69		Delivered
BAG10CB - Cotton Blend Pouch for ⌀1" Optics	Thorlabs			2 (10 per pack	10		Delivered
SPW801 - Adjustable Spanner Wrench	Thorlabs			1	92		Delivered
SM05L20 - SM05 Lens Tube, 2" Thread Depth, One Retaining Ring Included	Thorlabs	20	⌀12.7 mm Optics Length 50,8 mm	2	38		Delivered
SM1A6T - Adapter with External SM1 Threads and Internal SM05 Threads	Thorlabs	10	⌀12.7 mm Optics Length 0,40 mm	20	380		Delivered
SM1L10 - SM1 Lens Tube, 1.00" Thread Depth, One Retaining Ring Included	Thorlabs	20	⌀25.4 mm Optics Length 25,4 mm	6	84		Delivered

S05LEDM - SM05-Threaded Mount for TO-18, TO-39, TO-46, or T-1 3/4 LEDs	Thorlabs	20	TO-18 Photo-diode	2	60		Delivered
SM05RR-P10 - SM05 Retaining Ring for ⊘1/2" Lens Tubes and Mounts	Thorlabs			2	68		Delivered
S1LM05 - SM1-Threaded Aluminum Mount for TO-5 Laser Diodes	Thorlabs		TO-5 Photo-diode	2	68		Delivered
SM1A33 - Adapter with External M32 x 0.75 Threads and Internal SM1 Threads	Thorlabs			4	84		Delivered
SM1A54 - Adapter with External M27 x 1.0 Threads and Internal SM1 Threads	Thorlabs			20	380		Delivered
SM1RR - SM1 Retaining Ring for ⊘1" Lens Tubes and Mounts	Thorlabs			4	20		Delivered
SM1RR - SM1 Retaining Ring for ⊘1" Lens Tubes and Mounts	Thorlabs			2	38		Delivered

SM05L10 - SM05 Lens Tube, 1" Thread Depth, One Retaining Ring Included	Thorlabs			2	28		Delivered
#45-030 - 25.0mm Dia. x -25 FL, Uncoated, Plano-Concave Lens	Edmund Optics		12	4	106		Ordered
#45-014 - 12.0mm Dia. x -12 FL, Uncoated, Plano-Concave Lens	Edmund Optics		12,7	4	100		Ordered
ACL12708U - Aspheric Condenser Lens, ∅1/2", f=8 mm, NA=0.78, Uncoated	Thorlabs		12,7	4	64		Ordered
#49-839 - 12.7mm Dia. x 12.7mm FL, Uncoated, Plano-Convex Lens	Edmund Optics		12,7	4	102		Ordered

AUKEY iPhone Lens 0.2x 238deg Ultra wide Angle Clip-on Cell Phone Camera Lenses for Samsung, Android Smartphones, iPhone	Amazon		30	4	68		Delivered
#88-282 - 5mm Dia. x 3.5mm FL, Uncoated Molded Aspheric Condenser Lens	Edmund Optics		5	2	50		Ordered

4.3.3 Mechanical

Component	Supplier	Mass [g]	Dimensions	Amount	Cost each [EUR]	Notes	Status
Nylon Standoff male-female M4	Farnell	2	Length : 38 mm Diameter : 7 mm Thread : M4	120	0.76	Spacers to mount the thermal insulation	Delivered
Nylon screw M4 - Cheese Head Slotted	Farnell	2	M4x10 mm	100	0.0635	Screw to mount the thermal insulation	Delivered

Nylon washer M4 - Natural White Nylon Penny Washers Plastic Washer	EAfixings	TBD	4.5 x 25 x 2 mm	100	0.15	Washer to mount the thermal insulation	Delivered
Bosch Rexroth Aluminium Strut 20 series	Bosch Rexroth	TBD	Profile 20×20 mm	16 of length 120 mm. 16 of length 110 mm. 16 of length 260 mm.	20	Versatile struts used to assemble the boxes and to mount various components.	Delivered
Bosch Rexroth Strut Profile Angle Bracket, strut profile 20 mm, Groove Size 6mm	Bosch Rexroth	TBD	TBD	20	40	Structural element to assemble Bosch Rexroth Struts in right angle connections. Excellent structural strength.	Delivered
Bosch Rexroth Strut Profile Sliding Element, strut profile 20 mm, Groove Size 6 m	Bosch Rexroth	TBD	20 mm	100	17	Sliding element to attach structures to the Bosch Rexroth profiles. Good strength.	Delivered

Aluminium angle section, length 1 m, EN AW-6060 T66	Femec	462 [g] (incl.package)	30 x 30 x 3 mm	5	10	See technical drawings. Angle section gives clearance to mount small bolts easily.	Delivered
Anodized Aluminium Radiator	Elfa	63 [g] (incl. Package)	65 x 50 x 20 mm	4	2.60	Radiates heat inside the box to evenly heat the PCBs.	Delivered
Emergency Blanket - Nodfilt Gold/Silver	Outnorth	70 [g]	1600 x 2100 mm	10	3.5	Covers all thermal insulation. Covers all external surface exposed to the Sun.	Delivered
Button Hex Machine Screw - M4 thread - 8mm long - pack of 50	Adafruit	TBD	M4 thread - 8 mm long	3	5	Cheap	Delivered
Aluminum Extrusion Oval T-Nut for 20x20 - M4 Thread - pack of 50	Adafruit	TBD	M4 thread - 20 series Bosch profiles	50	10	Cheap	Delivered
Aluminium plate Sensor Box	Femec	0,3 [kg]	255x145x3 [mm]	3	100	See technical drawings	Delivered
Aluminium plate Brain Box	Femec	0,2 [kg]	255x145x3 [mm]	2	100	See technical drawings	Delivered

Plexiglass plate Sensor box	Femec	0.008	60x60x2 [mm]	4		See technical drawings	Delivered
Bosch Rexroth Black Polyamide End Cap 20 series	RS-online / Bosch Rexroth	TBD	20x20xTBD [mm]	8 per box		TBD	Delivered
Bosch Rexroth Strut Profile, Angle Bracket, strut profile 20 mm, Groove Size 6mm	Bosch Rexroth		20x20x18 [mm]	4 per plate, 8 for the ceramic spacer mountings		TBD	Delivered
Hex Standoff M4, 30 mm, 148-01-355	Elfa/ S.A Bourquo Jean	3 [g]	Length: 30 [mm]	12	0.8	TBD	Delivered
Hex Standoff M4, 20 mm	Elfa/ S.A Bourquo Jean AB		Length: 20 [mm]	10	0.8	TBD	Delivered
Hex Standoff PCB M2,5	Elfa/ S.A Bourquo Jean AB	2 [g]	10x5 [mm]	10	0.5	TBD	Delivered
Aluminum tape- Silver	Elfa		75 mm x 50 m	1	2.7		Delivered
DP-6-W85 Cover Plate Type DP	Specma/STAUFF			1	0.5		Delivered
SPV-6-m-W2 Elongated Welded Plate	Specma/STAUFF			1	0.5		Delivered

AS-M6x70-W3 Bolts M6 with 70 mm length for STAUFF clamp	Specma/STAUFF			30	0.3		Delivered
STAUFF	Specma/STAUFF			14	11.4		Delivered
135-V40-B50-60-2-SW-GN135 Two-way connector clamps	Otto Ganter			5	38		Delivered
Polycarbonate Boom, 50 mm outer diameter, 40 mm inner diameter, 2000 mm length	Nordic Plastic Group	5 kg	50 mm outer diameter, 40 mm inner diameter, 2000 mm length	4	100		Delivered
Lock nuts M6-Art.Nr. 300-71-985	Bossard			100	6		Delivered
M6 washers/ Rundbricka Art.Nr. 300-72-021	Bossard			200	4		Delivered
Slotted Screw M4 x 35 mm	RS- Online		Length: 35 mm	1 (50 per bag)	20		Delivered
Slotted Screw M4 x 8 mm Art.Nr. 148-00-022	Bossard		Length: 8 mm	1	0	TBD	Delivered
M4 washers / Rundbricka Art.nr. 300-72-033	Bossard		1 (100 per pack)	3			Delivered

Slotted Screw M3 x 10 mm Art.nr 148-00-088	Bossard		Length: 10 mm, Thread: M3	100	0	TBD	Delivered
Slotted Screw M3 x 6mm Art.nr. 148-00-094	Bossard		Length: 5 mm, Thread: M3	100	0		Delivered
Lock nuts M3 - Art.nr.300-71-982	Bossard			1 (100 per pack)	3		Delivered
M3 washers/ Rundbricka Art.nr.148-00-022	Bossard			1 (100 per pack)	0		Delivered
Slotted Screw M2.5 x 10 mm	Bossard		Length: 10 mm, Thread: M2,5	1 (100 per pack)	0		Delivered
Slotted Screw M2.5 x 8 mm	Bossard		Length: 8 mm, Thread: M2.5	1 (100 per pack)	0		Delivered
Nuts M2.5- Art.nr. 148-42-621	Bossard			1 (200 per pack)	0		Delivered
M2.5 washers/ Rundbricka Art.nr. 148-00-016	Bossard			1 (200 per pack)	0		Delivered
Rubber bumper M6-Diabolo	Paulstra			8	4		Delivered

Nylon Thermal spacer bolt M3x 40 mm, connector plexiglass	S.A Bourqui Jean		Length: 40 mm, Thread: M3	4	1		Delivered
Space bolt M3 x 30 mm (1 st PCB spacer)	S.A Bourqui Jean		250x120x5 [mm]	12		TBD	Delivered
Space bolt M3 x 20 mm (2nd PCB spacer)	S.A Bourqui Jean		Length: 20 mm, Thread: M3	12	1		Delivered
Space bolt M3 x 20 mm (3rd PCB spacer)	S.A Bourqui Jean		Length: 10 mm, Thread: M3	12	1		Delivered
Spacer bolt M2.5 x 20 mm 148-01-208	S.A Bourqui Jean		Length: 20 mm, Thread: M2.5	10	1		Delivered
Superglue 20 g 180-87-264	Elfa			1	4		Delivered
Nylon M6 spacers 51 mm length	Elfa		Length: 51 mm, Thread: M6	20	3		Delivered

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

Total mass of the experiment is 21 kg.

Table 4.3.4: Sensor Box: Mass and volume

Experiment mass (in kg):	3,556
Experiment dimensions (in m):	0,511×0,23×0,19
Experiment footprint area (in m2):	0,155
Experiment volume (in m^3):	0,013
Experiment expected COG position:	x = -1,672 [m]; y = 0,521 [m]; z = 0,159 [m] for the upper sensor box. x = -1,661 [m]; y = -0,281 [m]; z = 0,008 [m] for the bottom sensor box.

Table 4.3.5: Upper Sensor Box and Booms: Mass and volume

Experiment mass (in kg):	9,763
Experiment dimensions (in m):	1,52×0,54×0,2
Experiment footprint area (in m2):	0,82
Experiment volume (in m3):	0,016
Experiment expected COG position:	x = -1,181 [m]; y = 0,51 [m]; z = 0,16 [m]

Table 4.3.6: Bottom Sensor Box and Booms: mass and volume

Experiment mass (in kg):	7,492
Experiment dimensions (in m):	1,7×0,54×0,2
Experiment footprint area (in m2):	0,918
Experiment volume (in m3):	0,016
Experiment expected COG position:	x = -1,35 [m]; y = -0,278 [m]; z = 0,008 [m]

Table 4.3.7: Central "Brain" Box mass and volume

Experiment mass (in kg):	2,606
Experiment dimensions (in m):	0,38×0,23×0,22
Experiment footprint area (in m2):	0,0874
Experiment volume (in m3):	0,013
Experiment expected COG position:	x = -0,109 [m]; y = -0,2 [m]; z = -0.015 [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.

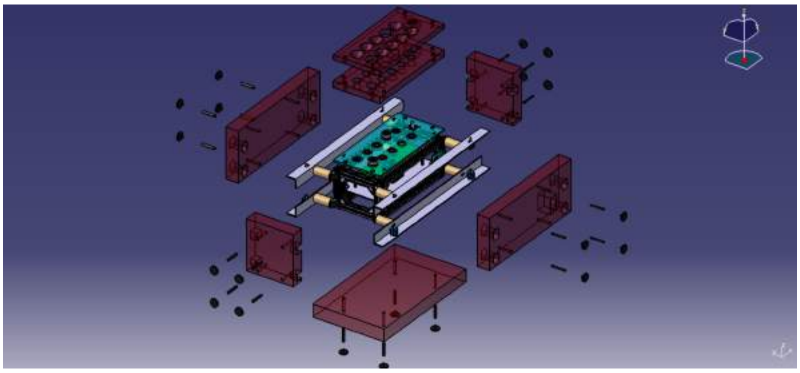


Figure 4.4.1: Exploded view of the sensor box. The red panels are those of thermal insulation.

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-. The first of these is mounted on a plexiglas plate, while the second one is mounted on an aluminium plate, as shown in fig. 4.4.2.

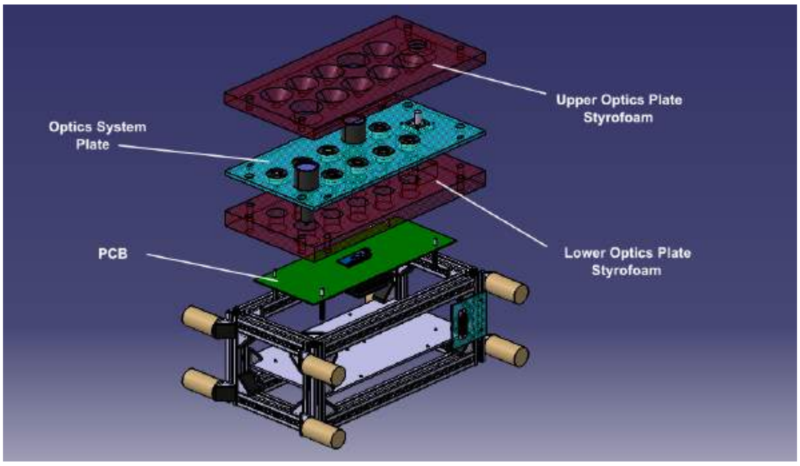


Figure 4.4.2: Exploded view of the sensor box mountings of the optical and electronics system.

The optical subsystem is composed of three different types of elements: transparent windows, filters and full optical assemblies of lenses and filters. Each of these is associated to particular photodiodes, and all of them incorporate threads that allow them to be mounted on a plexiglass plate with appropriate threaded holes, which is in turn mounted on the sensor box frame. Fig. 4.4.3 shows the section of the sensor box to better visualise the optical system mounting and thermal insulation shape

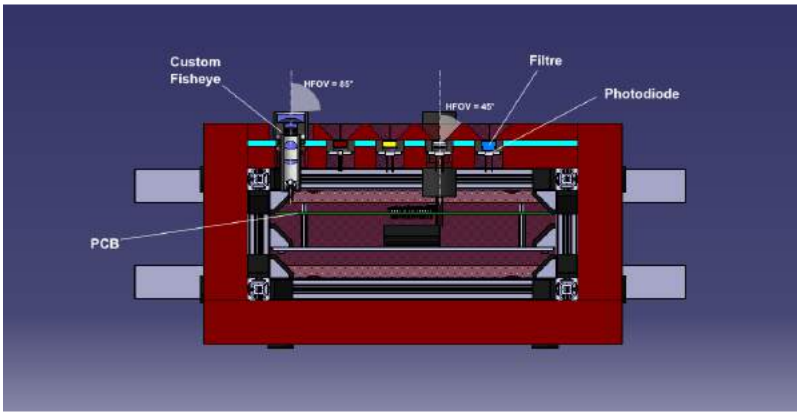


Figure 4.4.3: Exploded view of the optics subsystem mounting with an emphasis on photodiodes and filters mounting.

Because of the special characteristics of the optical systems, components off-the-shelf can not be used. Therefore, the optics plexiglass 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.

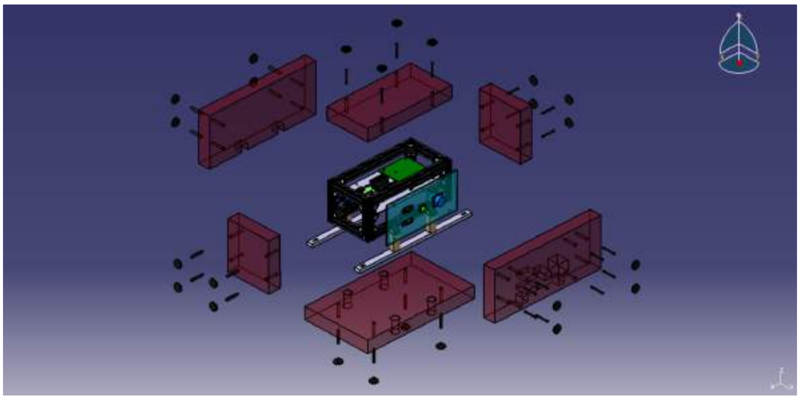


Figure 4.4.4: Exploded view of the brain box. The red panels are those of thermal insulation.

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

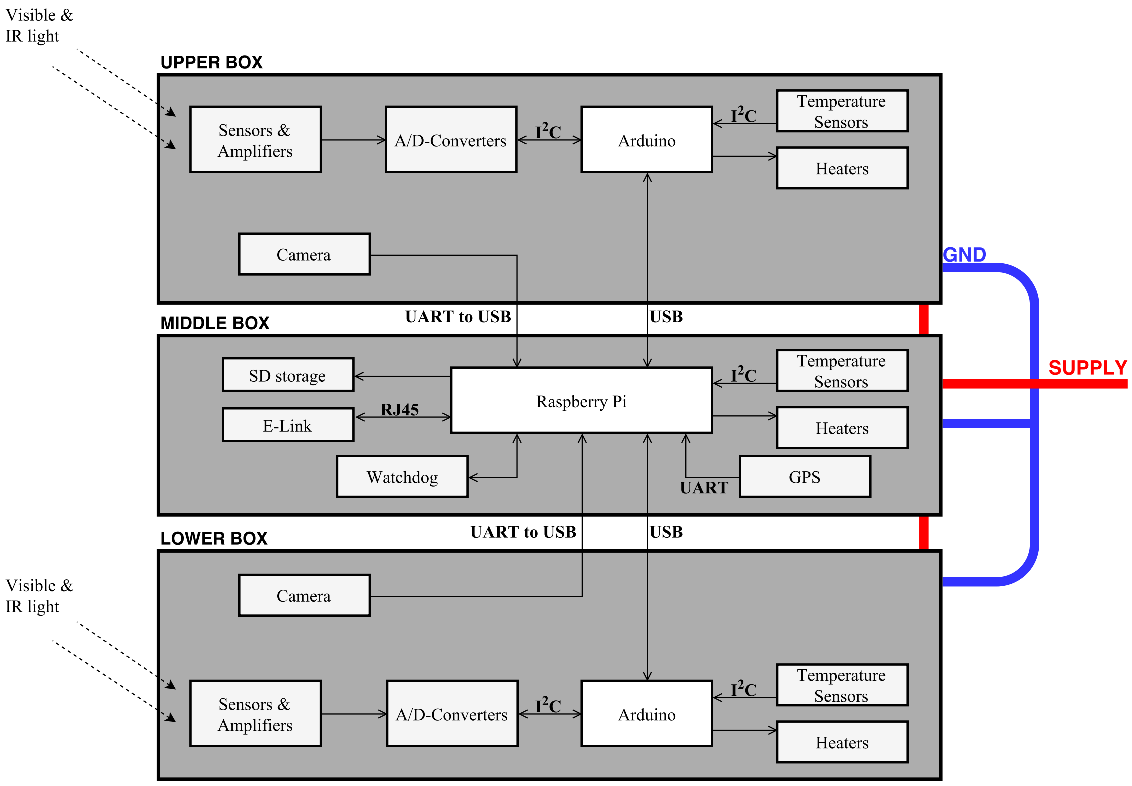


Figure 4.5.1: A block diagram of the electronics' signals and interfaces of the experiment.

Fig. 4.5.1 shows the general electrical signal diagram of the system, with interfaces. Excluding the RPi, there will be one PCB in each box, one in the upper sensor box which will measure light from above, one in the lower sensor box for the light from below, and one in the brain box next to the RPi.

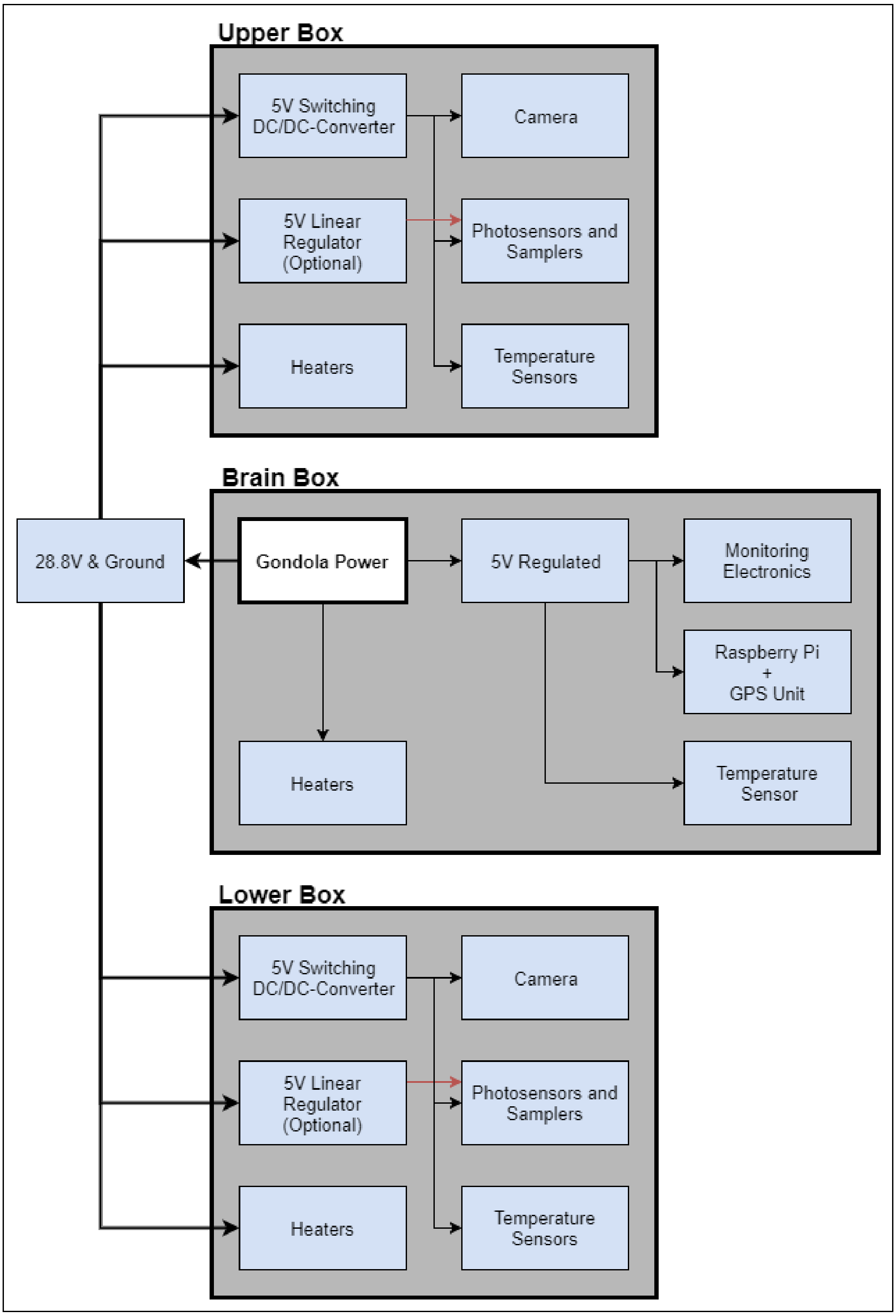


Figure 4.5.2: A block diagram of the power supply of the system.

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 all brain box electronics, such as 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. In the upper and the lower box, there is an additional regulator for the light sensors. These linear regulators are optional, and can be excluded and replaced by a connection from the normal 5 V DC/DC-converter. They are there so that the sensitive photodiode circuits can avoid the noise caused by the switching DC/DC-converter and the digital communication. The analog supply and ground are displayed in figure 4.5.3.

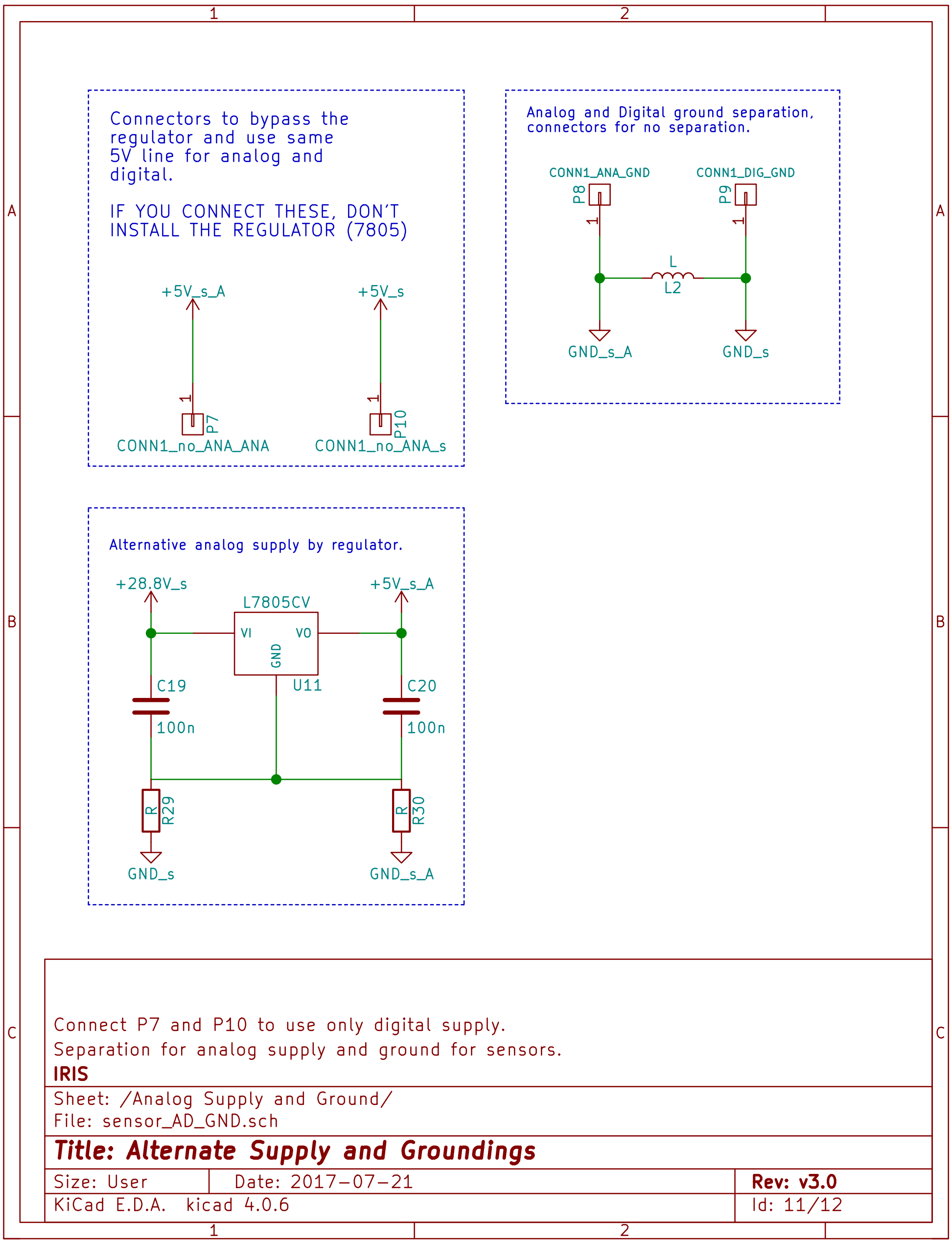


Figure 4.5.3: Linear regulator for 5 V to op-amps and ADCs. Also shows connectors for choosing supply and grounding.

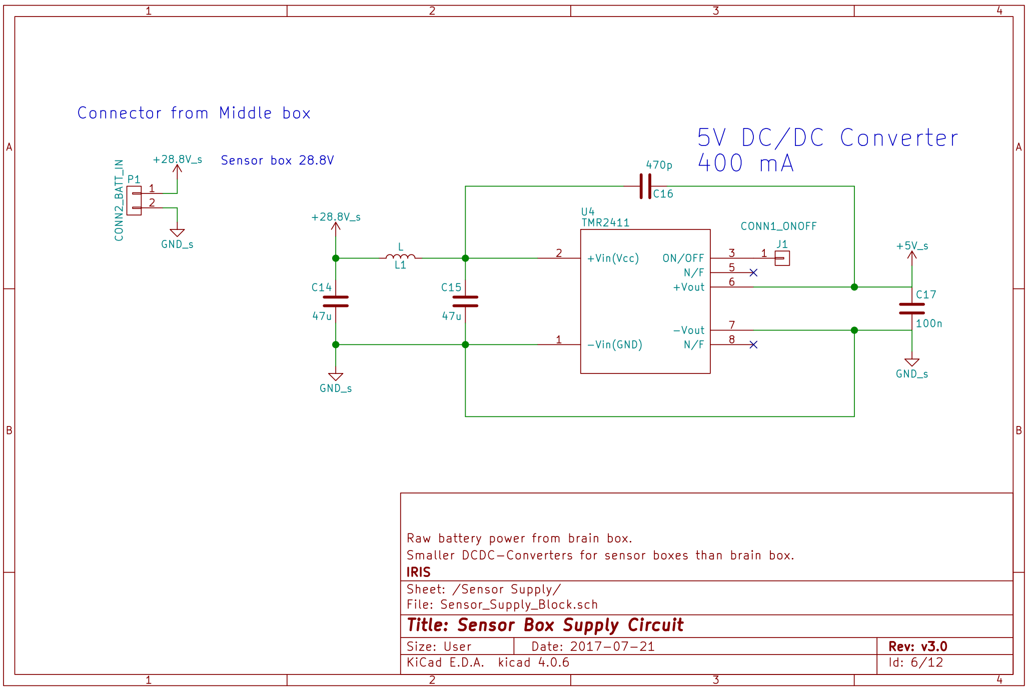


Figure 4.5.4: DC/DC-Converter for the local electronics. Sensor box gets 28.8 V from gondola via brain box.

Fig. 4.5.4 shows the 28.8 V to 5 V conversion circuit present in each box.

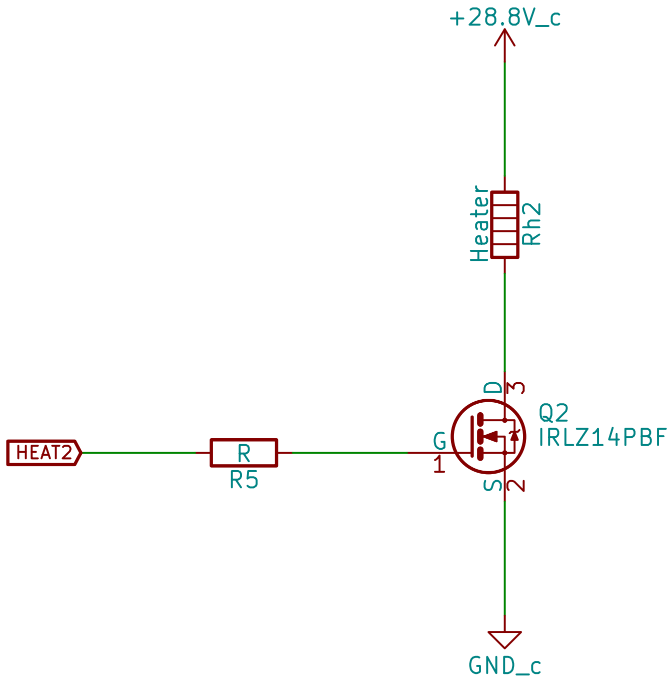


Figure 4.5.5: Simple heater circuit.

The heaters in each box are supplied with 28.8 V and are controlled by the local micro-controller through a transistor. Fig. 4.5.5 is showing a simple circuit for heating. The heater is controlled by a digital signal (*HEAT2* in the figure) from the micro controller using a transistor. The heater resistance R_h is chosen to be high enough so the power dissipated will not exceed the power budget in case of software failure.

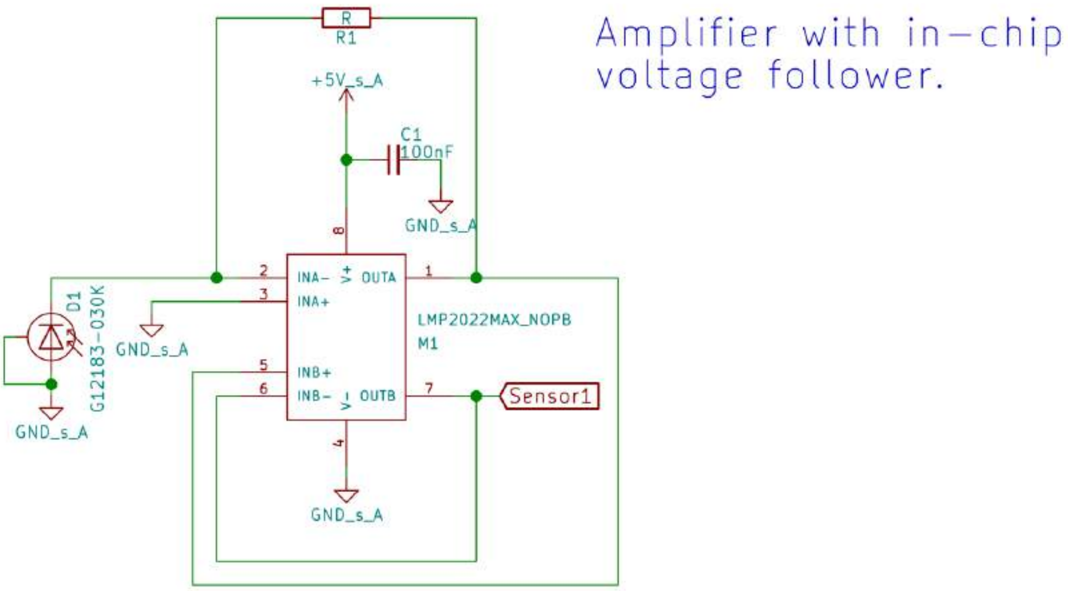


Figure 4.5.6: Photodiode amplifier circuit with voltage follower in the same chip.

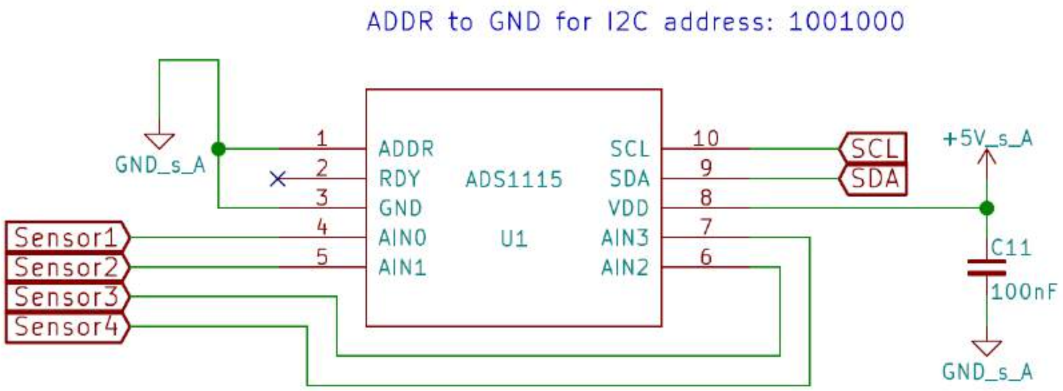


Figure 4.5.7: I^2C connection, A/D-Converters to Arduino.

Figures 4.5.6 and 4.5.7 show (in part) the sensor circuits, from photodiode, to A/D-Converter, to the I^2C interface connected to the Arduino. The `ADDR` pin determines the I2C address of the ADS1115 ADC, giving different 7-bit addresses for different connections. `GND`, `VDD` or `SCL` are used in this case. 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. Additionally, it has two inputs and outputs. This could be used to reduce the amount of devices needed by half, but in order to keep the traces of the unamplified signals as short as possible, one device per diode is still used. This also allows the implementation of a voltage follower in the same op-amp chip.

For the analysis of the photodiode data, other measurements are needed. The GPS provides position and time. Since photodiodes have changing characteristics with temperature, as most electronics does, temperature sensors are added, so that the sensor temperature can be taken into account later. These devices are shown in figure 4.5.8

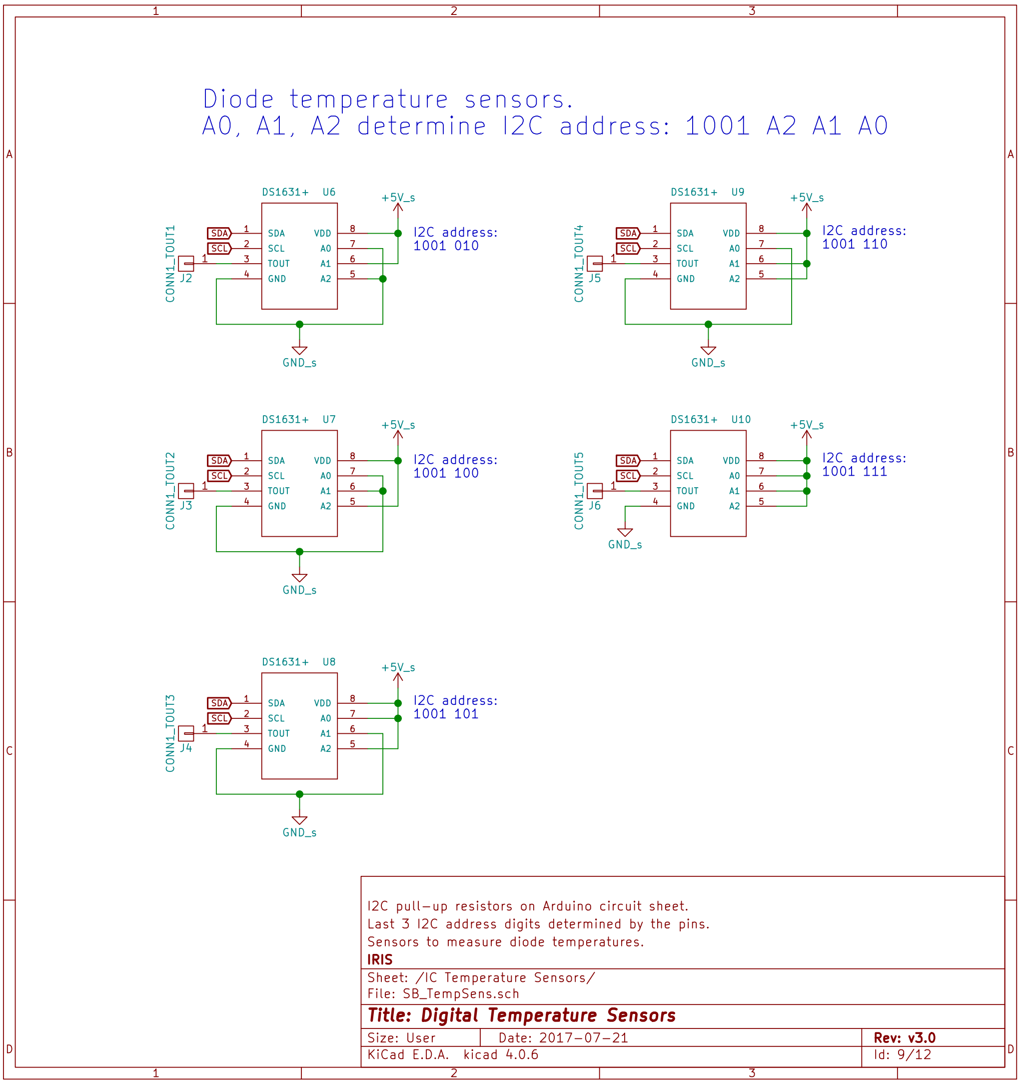


Figure 4.5.8: Temperature sensors for photodiodes in sensor box.

Every sensor is placed in between two diodes such that five are needed for ten diodes. The devices have an I^2C interface, and share this interface with the three ADCs. External temperature sensors are placed on the outside of the sensor boxes to provide data of the outside temperature. The brain box contains one inside temperature sensor, and the RPi has it's own additional temperature sensor. All of the temperature sensors inside the boxes are used for the heating systems.

All circuit schematics are added to Appendix C together with the PCB layouts, under the headings Circuit Schematics 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, μCam II	-30	85	-40	105	
2	GPS Reciever, Garmin 18x-LVC	-30	80	-40	90	
3	REMOVED	-	-	-	-	
4	Photodiode G12183-010A (900-1700nm)	-40	85	-55	125	
5	Photodiode G12183-010K (900-2600nm)	-40	85	-55	125	
6	Photodiode FDS100 (350-1100nm)	-40	100	-55	125	
7	Raspberry Pi 2 Model B+	0	70	-20	85	
8	Arduino Nano	-40	85	-40	85	
9	DC/DC Converter 5V	-40	85	-55	105	
11	Sensor Amplifier (LMP2022)	-40	125			
12	Analog/Digital converter ADS1115	-40	125			
13	Heater Control Transistor (Vishay, IRLZ14PBF)	-55	175			
14	Watchdog Timer (TPL5010)	-40	105	-65	150	
15	USB to Serial Converter Cable (FTDI TTL-232R-3V3)	-40	85			
16	Digital Thermometer, DS1631+	-55	125			
17	RS-232/TTL converter, MAX3222EEPN+	-40	85			
18	Linear Voltage Regulator, L7805ABV-DG	-40	125			
19	Passive components, resistors, capacitors etc.	-55	105			

The thermal control subsystem is divided into passive and active thermal control. The former is carried out by thermal insulation located on the outer 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 RPi 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: $-11.52\ W$

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 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 each of the 3 boxes to keep the temperature within the operating range of the electronic devices. The heaters are 16 W Polyimide Thermofoil from Minco.
Styrofoam™ thermal insulation of 4 cm thickness is also required on every side of the brain and sensor boxes. In addition, these insulation panels are covered by an emergency blanket in both their outer and inner surfaces: the purpose of the blanket is to modify the thermo-optical properties of these surfaces so that the flux of heat by radiation both incoming and outgoing these boxes is reduced. All thermal insulation panels are strapped to their respective box frames with Nylon screws and washers.

4.7 Power System

To fulfil the power needs for the project, the battery pack in the launch vehicle is needed. 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 estimate of the power for the experiment fits within these margins as stated below in tab. 4.7.1. The power budget is also able to support a possible number of heaters, which will be placed at strategic locations.

Table 4.7.1: Power consumption estimation, power summed over total component numbers, and often worst case scenarios used. A 10h flight is assumed.

ID	Component	Voltage IN [V]	Voltage out [V]	Efficiency [%]	Note
1	DC/DC Converters, 3A THN 15-2411WI	18-36	5	86	
2	DC/DC Converters, 0.4A TMR 2411	18-36	5	81	
3	Linear Voltage Regulator	<35	5	-	
ID	**Component**	**Voltage [V]**	**Current [A]**	**Power [W]**	**Total [Wh]**
4	Serial Camera Module μCam II	5	0.09	0.9	9
5	GPS Reciever Garmin 18x-LVC	5	0.11	0.55	5.5
7	Raspberry Pi 2 Model B+	5	1	5	50
8	Arduino Nano	5	0.56	2.8	28
9	Sensor Amplifier LMP2022	5	0.044	0.22	2.2
10	Analog/Digital converter ADS1115	5	0.9	0.0045	0.045
11	Watchdog Timer TPL5010	5	0.0004	0.002	0.02
12	USB to Serial Cable FTDI TTL-232R-3V3	5	0.03	0.15	1.5
13	Digital Thermometer DS1631+	5	0.01936	0.0968	0.968
14	RS-232/TTL converter MAX3222EEPN+	5	0.001	0.005	0.05
15	Analog Thermometer JUMO PT1000	5	0.006	0.03	0.3
16	Heaters, Minco HK6903	28.8	1.65	48	192
-	**Total**	-	-	-	290
-	**Total with DC/DC efficiency**	-	-	-	349
-	**Available from gondola**	-	-	-	374.4

The total consumption of power assumes that the heaters are on at 50% or less of their capacity during the full flight (calculated with 40% efficiency) During the ascend and descend phase the heaters can manually be turned of to 100% of their capacity if needed. The remaining components are always considered to be used to their full capacity which means that the Arduinos and Raspberry Pi is working at full speed during the whole flight. That is highly unlikely, but still assumed to gain some margin. Under these conditions the power consumption does not exceed the power available from batteries. If the heaters should not turn off as expected, there is a risk that the power budget is exceeded. To prevent this, the heaters can also be switched off from the ground station at any time during the flight.

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 Nano) 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.

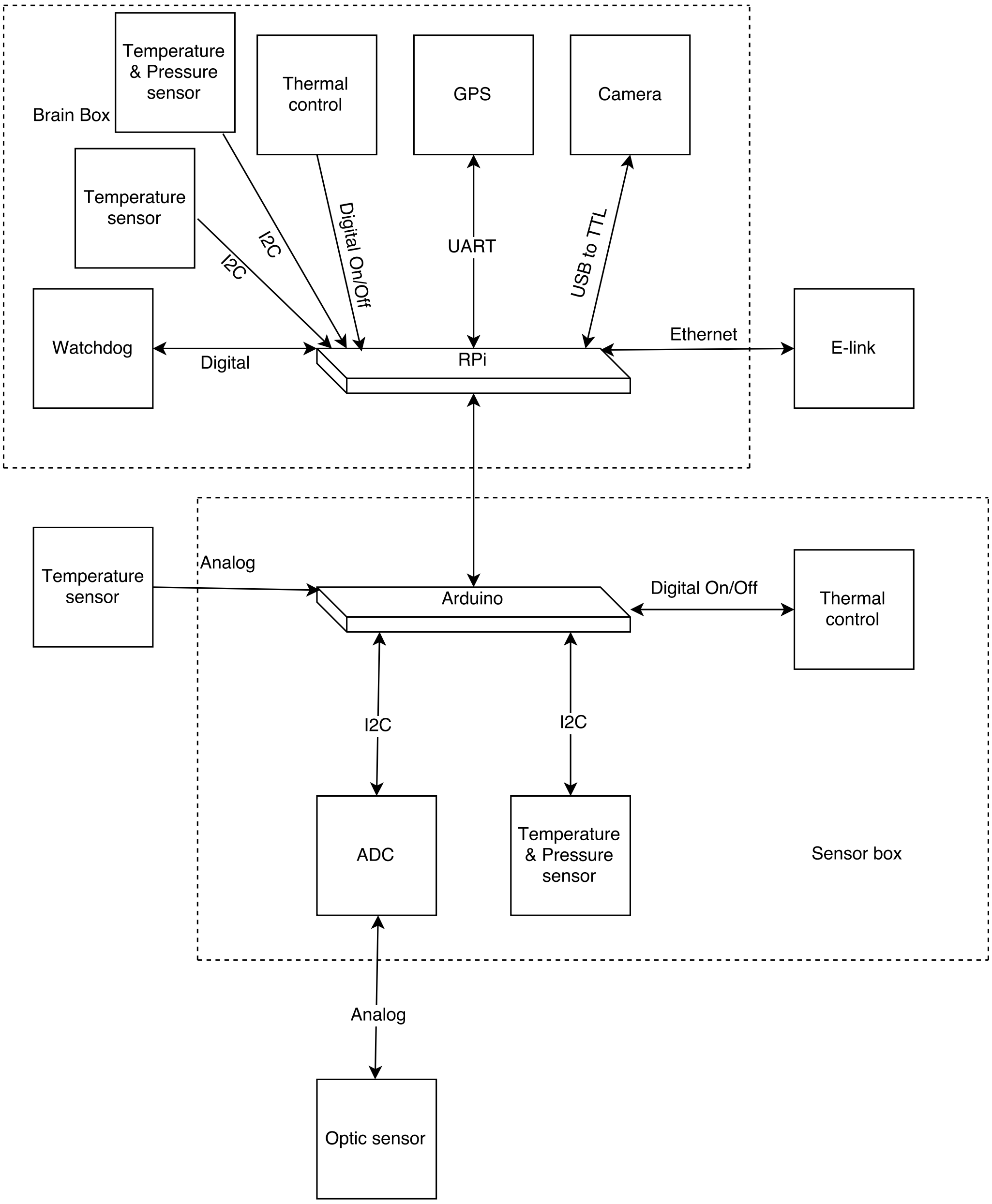


Figure 4.8.1: Process Overview Diagram

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 com-

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.

munication with ground station, and ensure a correct transmission from the sensors to the storage unit.

The communication through E-Link is performed through TCP through a SSH connection. Telemetry has a size of 750 bytes, retrieved every second by copying corresponding .txt buffers.
The telecommand functionality will be performed by sending the corresponding command through the SSH console prompt, possibly executing programs pre-stored on the Raspberry Pi.

The protocols used for packet transmission will be TCP for upling and downlink. The minimum expected bandwidth is 50 kbit/s and the maximum of 200 kbit/s. This is based on an image every ten seconds, weighting 800 kbits each, as well as constant housekeeping data download. 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. A bandwidth limiter is set in both Raspberry Pi and Ground Station system to avoid exceeding these limits.

Regarding the internal communication system, the interfaces will be serial communication and the reception of the data from the sensors is done in analogue fashion. The pressure and temperature sensor feature a serial I2C interface, and the actuation on the thermal control system will be done by switching power to the heater on/off.

The communication protocol with the off-the-shelf components using serial such as the GPS and camera is specified in the software diagram. The communication between the Arduino MCUs and RPi will be as follows in tab. 4.8.2.
The camera will be connected via USB. It was determined that USB is the simplest and best way, and, because of the external power source, the thin strip conductors on the

RPi will not cause an issue.

Table 4.8.2: 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 feature a guard when executing to avoid accidental executions.

Please refer to section 4.5 for more information on the analogue 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 about 30 kB for a 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 and 10 seconds, and the approximate flight time is around six hours. Including large marginals, power on for 10 hours, two cameras, and uninterrupted, continuous measurement yields about 8 GB of data. Choosing a 16 GB or larger storage unit is deemed necessary.

Part of 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 JPG format to store the information about the images.

4.8.2.5 Process Flow

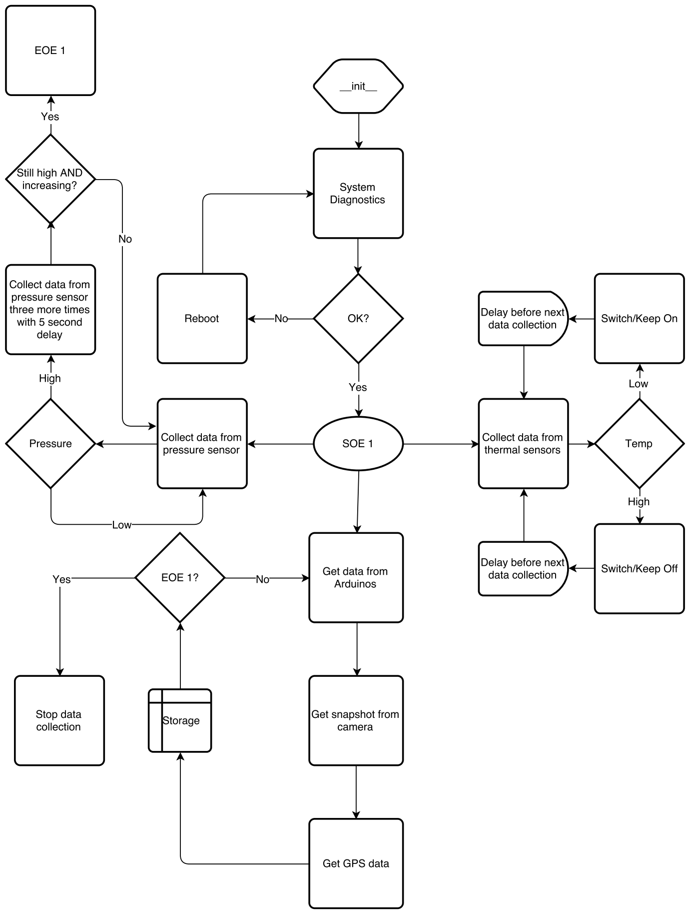


Figure 4.8.2: RPi Process Flow

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 by sending a logical 1 to the MCU's simultaneously to ensure synchronization between MCU's.
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.
- **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.
- **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.

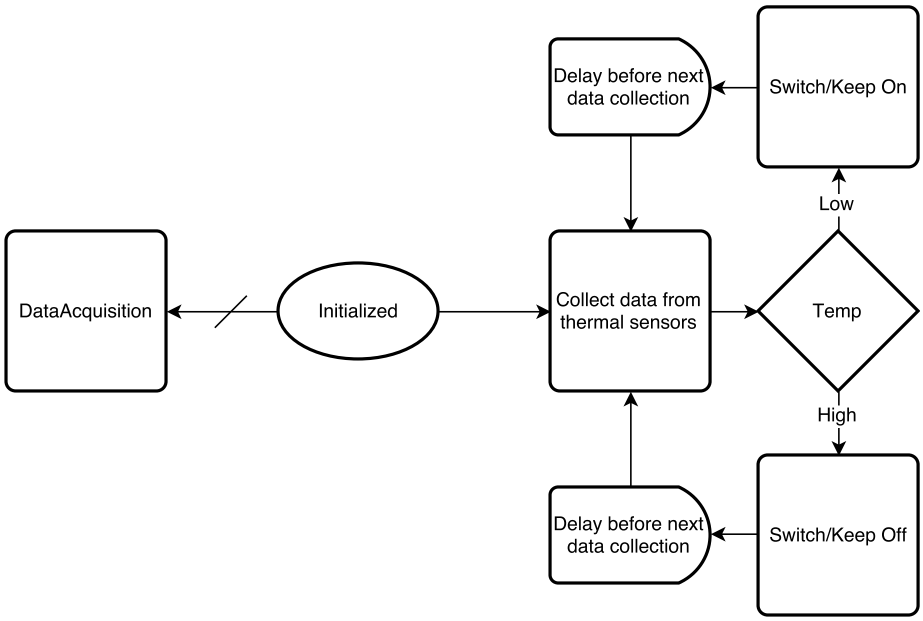


Figure 4.8.3: Sensor MCU Process Flow

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 Thermal control software

The thermal control loop can be seen to the right in fig. 4.8.3. The considerations behind choice of method are heatflux and precision. Because of the insulation, the heatflux will be fairly low and because of the high span of tolerance to temperature of the components the precision and heat supplied by a simple switch is assumed sufficient. While the core principles will be identical between the thermal control between the RPi and MCU, specifics may require slight differences. The brain box will have two internal temperature sensors. The reason is that we require higher precision in the brain box. The variable convection rates during the different flight phases encourage the use of a distributed sensor net, a huge net of two temperature sensors, to get more accurate measurements and therefore improved estimation on appropriate on/off switching.
The control loop will read the sensor(s) and determine if the temperature is too high or too low, followed by a short delay. The minimum acceptable temperature for the brainbox is set to 5°C, and -30°C for upper and lower sensor boxes.

4.8.4 Synchronization of data collection

The data coming from the upper and lower sensor box has to be collected and time stamped in order for comparions between the data sets to be fruitful. This puts a constraint on synchronization on collecting and labelling the data coming from the sensor boxes. The synchronization is made by time stamping the moment the RPi asks the MCU for data, the time stamp is coming from the GPS which includes accurate UTC timestamps. These will be logged together with the data, which is collected by the MCU from the sensors every 0.5 seconds, stored in an array and dumped to the RPi when asked.
The synchronization and camera images is not as crucial as very small changes between images are expected on time scales much larger than image capture, if the experiment status is nominal.

4.8.5 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 class-oriented language that allows for handling and representing high amounts of data. It is as well integrated with the RPi environment.

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. The ground station will feature a program in Python that will represent a time history of the temperatures of all the boxes, real time, as well as a Shell window to check experiment is running. 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 optical department is in charge of optimising the optical design 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.

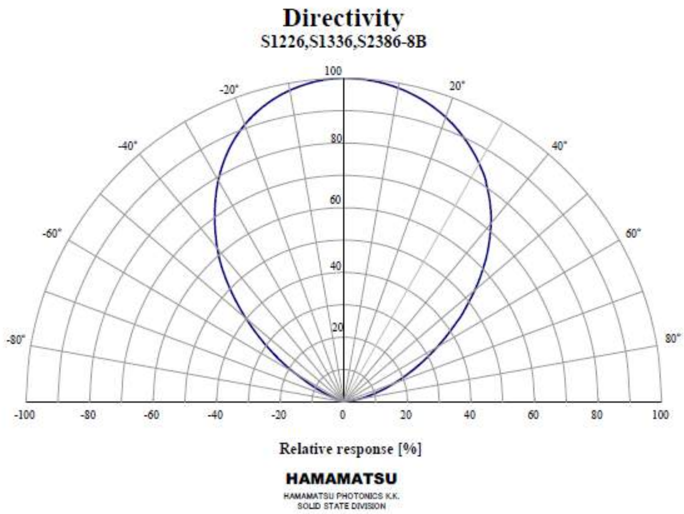


Figure 4.10.1: Directivity of Hamamatsu photodiodes

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)

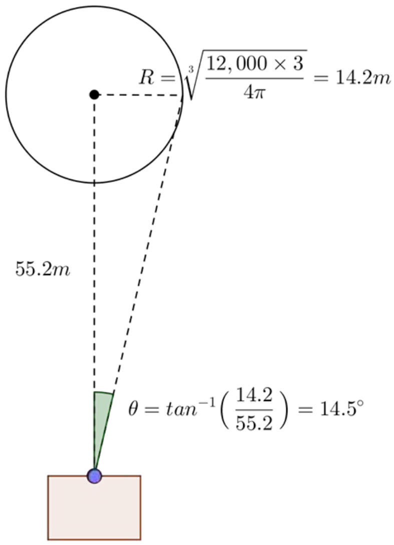


Figure 4.10.2: Visual obstruction caused by the balloon

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.

4.10.5 Custom Optics System

The following figure shows the data inserted in *Zemax OpticStudio 16.5* as an initial guess. The distance between the lenses has been selected based on the previous selection and potential opto-mechanical constraints.

	Surf:Type		Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6	Par 1(unused)	Par 2(unused)	Par 3(un
0	OBJECT	Standard ▾		Infinity	Infinity			Infinity	0.0	Infinity	0.0	0.0			
1		Standard ▾		Infinity	0.0			10.2	0.0	10.2	0.0	0.0			
2	(aper)	Standard ▾	Plano-Concave Lens 1	Infinity	3.5	N-SF11		11.0 U	0.0	12.5 U	0.0	-			
3	(aper)	Standard ▾		19.6	3.0			11.0 U	0.0	12.5	0.0	0.0			
4	(aper)	Standard ▾	Plano-Concave Lens 2	Infinity	2.2	N-SF11		5.5 U	0.0	6.0 U	0.0	-			
5	(aper)	Standard ▾		12.0	7.0			5.5 U	0.0	6.0	0.0	0.0			
6	STOP	Standard ▾		Infinity	3.0			0.5	0.0	0.5	0.0	0.0			
7	(aper)	Even Asphere ▾	Aspheric Lens 1	4.8	7.5	B270		6.3 U	0.0	6.3	-1.2	-	0.0	5.3E-04	1.1
8	(aper)	Standard ▾		-15.6	10.0			6.3 U	0.0	6.3	0.0	0.0			
9	(aper)	Standard ▾	Plano-Convex Lens 1	Infinity	4.0	N-SF11		6.3 U	0.0	6.3	0.0	-			
10	(aper)	Standard ▾		-10.0	15.0			6.3 U	0.0	6.3	0.0	0.0			
11	(aper)	Standard ▾	Plano-Convex Lens 2	2.1	1.5	LASFN9		1.2 U	0.0	1.2	0.0	-			
12	(aper)	Standard ▾		Infinity	1.0			1.2 U	0.0	1.2	0.0	0.0			
13	IMAGE	Standard ▾		Infinity	-			0.8 U	0.0	0.8	0.0	0.0			

Figure 4.10.3: Lens data of the preliminary design. Produced with *Zemax OpticStudio 16.5* Demo version.

Table 4.10.1: List of stock lenses used in the global optical system.

Product ID	**Supplier**	**FL [mm]**	R **[mm]**	**Material**	**Cost [SEK]**	Φ **[mm]**	C
#45-030	Edmund	-25	19.62	N-SF11	265	25	2.05
#45-014	Edmund	-12	9.42	N-SF11	250	12	1.98
ACL12708U	Thorlabs	8	Aspheric	Plano	B270	158	12.7
#49-839	Edmund	12	9.97	N-SF11	255	12.7	
PL1143	SurpluShed	2.5	TBD	Plano	LaSFN9	80	2.8

In Figure 4.10.4 the layout of the optical system is shown. One plano-concave lens was added to the negative lens group in order to reduce the angle of incidence on the aspheric lens. If this lens is not added the collimating beam because too wide for the filter to correcly perform. The filter is not presented in the layout on purpose. The entrance pupil aperture is 0,5 [mm] for every angle of incidence.

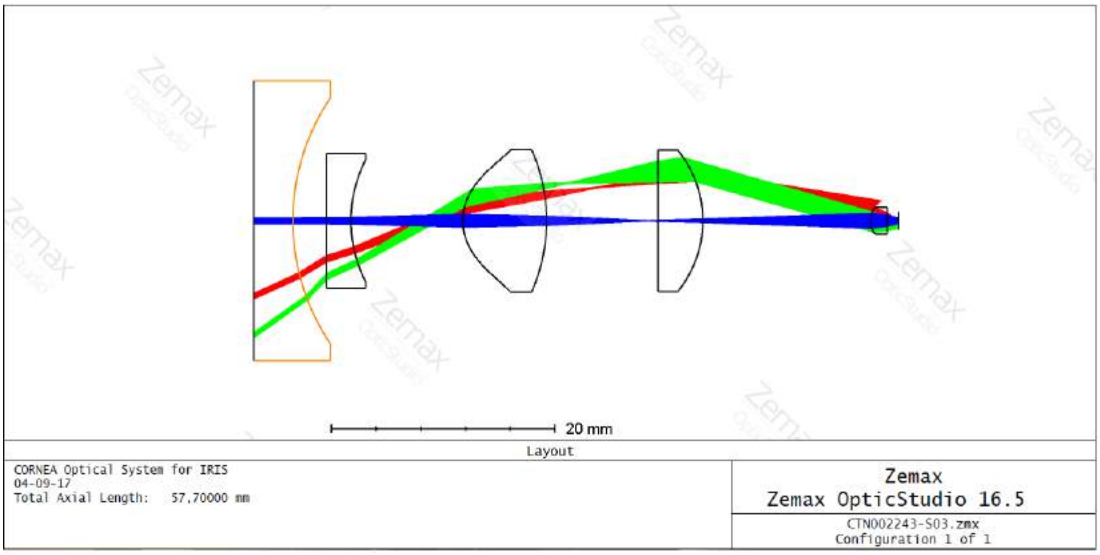


Figure 4.10.4: Layout of the preliminary design. Produced with *Zemax OpticStudio 16.5* Demo version.

4.10.6 Relative Illumination

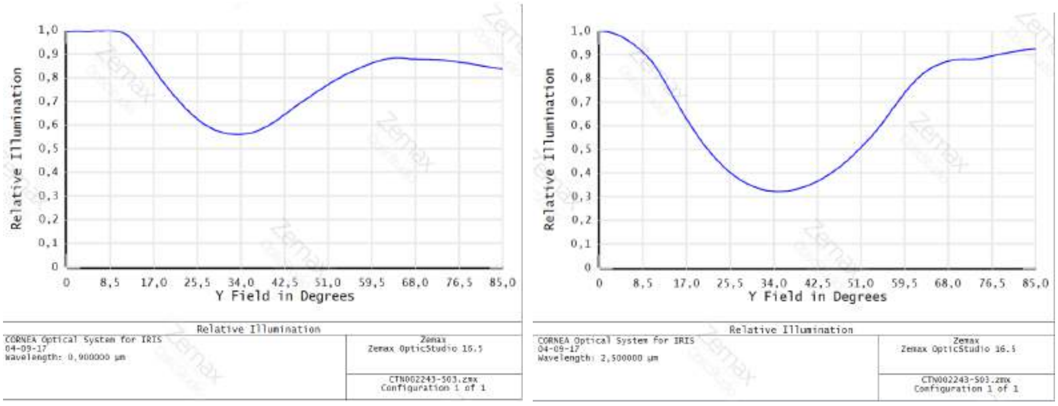


Figure 4.10.5: Relative illumination evolution with incidence angle. 900 [nm] wavelength on the left, 2500 [nm] wavelength on the right. Produced with *Zemax OpticStudio 16.5* Demo version.

In Figure 4.10.5 the relative illumination versus angle of incidence is shown. The results are only shown for the wavelength range of 900 and 2500 [nm] because it correspond to the smallest photodiode of 1 [mm] diameter. The optical system is assumed to work nominally with the bigger photodiode of 3.6x3.6 [mm] for the wavelength range of 400-1100 [nm].

4.10.7 Total Transmission

Parameters	**Transmittance** [%]
$\lambda = 900$ [nm];HFOV$= 0[°]$	$47{,}66$
$\lambda = 2500$ [nm];HFOV$= 0[°]$	$40{,}91$
$\lambda = 900$ [nm];HFOV$= 45[°]$	$47{,}36$
$\lambda = 2500$ [nm];HFOV$= 45[°]$	$40{,}28$
$\lambda = 900$ [nm];HFOV$= 85[°]$	$20{,}55$
$\lambda = 2500$ [nm];HFOV$= 85[°]$	$16{,}89$

Table 4.10.2: Total transmission of light for different AOI between 900 and 2500 [nm]. Aperture, Fresnel, coating, vignetting, and internal transmittance effects are considered.

Table 4.10.2 reveals that even though the relative illumination between 0 [°] and 85 [°] are almost identical, the transmission intensity is 4 times smaller at the steepest angle. This is a result of increase of reflection, as illustrated in the Appendix **??** where Fresnel refraction law is illustrated.

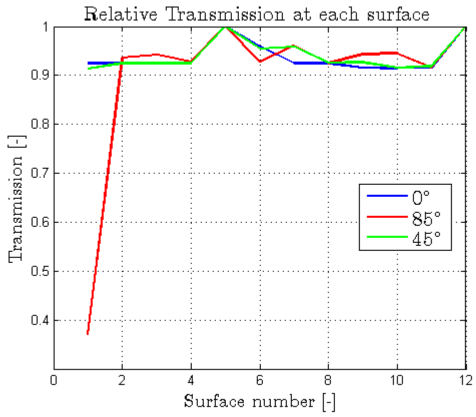


Figure 4.10.6: Relative transmission for each surface of the optical system with different angle of incidence at the entrance aperture. Results are from the numerical simulation with *Zemax OpticStudio 16.5* Demo version and transferred manually on Matlab.

In Figure 4.10.6 the relative transmission at each surface of the optical system is shown. The biggest difference between the three different angle of incidence is at the first surface of the optics system. Because the light ray is hitting the plano-concave lens at a steep angle of 85 [°] most of the light is reflected. One solution to this problem is to use negative meniscus lens. A negative meniscus lens with a curvature radius of 27 [mm] on the first surface have a transmission of 85 [%] compare to a plano concave with the same thickness and second curvature radius which have a transmission of 35 [%]. The numerical models used to estimate this transmission value with *Zemax OpticStudio 16.5* are presented in Figure 4.10.7

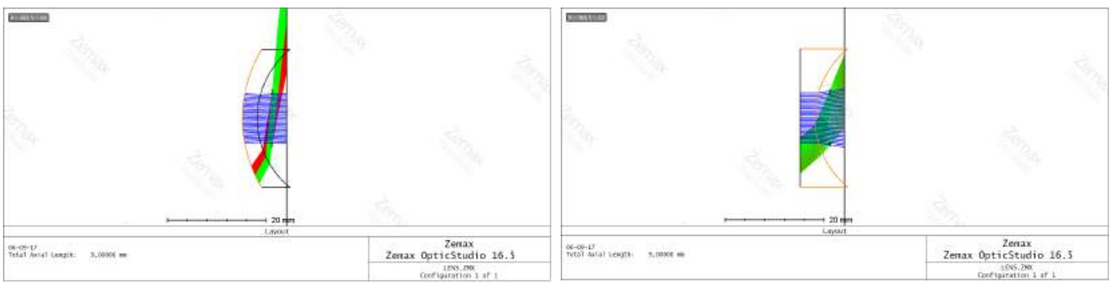


Figure 4.10.7: Transmission comparaison between a negative meniscus lens and a plano-concave lens with similar thickness and second radius of curvature. Picture generated with *Zemax OpticStudio 16.5* Demo version.

4.10.8 Collimating Group Lens Performance

Table 4.10.3: Collimating Group Lens Performance for the first initial design.

Parameter	Value
Minimum AOI $\lambda = 900$ [nm]; HFOV= $0[°]$	$0[°]$
Maximum AOI $\lambda = 900$ [nm]; HFOV= $0[°]$	$4{,}05[°]$
Minimum AOI $\lambda = 2500$ [nm]; HFOV= $0[°]$	$0[°]$
Maximum AOI $\lambda = 2500$ [nm]; HFOV= $0[°]$	$3{,}75[°]$
Minimum AOI $\lambda = 900$ [nm]; HFOV= $85[°]$	$1{,}19[°]$
Maximum AOI $\lambda = 900$ [nm]; HFOV= $85[°]$	$13{,}63[°]$
Minimum AOI $\lambda = 2500$ [nm]; HFOV= $85[°]$	$1{,}75[°]$
Maximum AOI $\lambda = 2500$ [nm]; HFOV= $85[°]$	$13{,}98[°]$
Entrance Beam Width $\lambda = 900$ [nm]; HFOV= $85[°]$	6,2 [mm]
Exit Beam Width $\lambda = 900$ [nm]; HFOV= $85[°]$	9,8 [mm]
Entrance Beam Width $\lambda = 2500$ [nm]; HFOV= $85[°]$	6,4 [mm]
Exit Beam Width $\lambda = 2500$ [nm]; HFOV= $85[°]$	10,2 [mm]

Table 4.10.3 show the performance parameters for the collimating group lens. The first parameters presents the minimum and maximum angle of incidence (AOI) for different wavelength bands and half field of view (HFOV). The AOI have a slight bigger angle than the one precised in the requirements.
The last parameters of the table show the light beam width variation between the entrance (last surface of the aspheric lens) and the exit (the first surface of the firs plano-convex lens).

4.10.9 Assembly

Due to low budget and lack of time, the team has modified the design in order to adapt it for the new circumstances. This way, currently the experiment consists in twelve FDS100 photodiodes, four G12180 and four G12183, paired with (and some of them without) filters, as shown in table 4.10.4.

4.10.10 Optics System Performance

Table 4.10.5 shows the required characterstics of our optical system.

Table 4.10.4: Optical system scheme

	Photodiode Number	Up/Down	Filter	Lens (Yes/No)
FDS100	1	U	Broadband	N
	2	D	Broadband	N
	3	U	450-510A	N
	4	D	450-510B	N
	5	U	530-590A	N
	6	D	530-590B	N
	7	U	610-690A	N
	8	D	610-690B	N
	9	U	850-890A	N
	10	D	850-890B	N
	11	U	Broadband	Y
	12	D	Broadband	Y
G121 80	1	U	1350-1400A	N
	2	D	1350-1400B	N
	3	U	1575-1625A	N
	4	D	1575-1625B	N
G121 83	1	U	broadband	N
	2	D	broadband	N
	3	U	broadband	Y
	4	D	broadband	Y

Table 4.10.5: Summarize requirements for CORNEA optical system characteristics.

Parameter	Value
Field of View (FOV)	$170[°]$
Wavelength range	$400\text{-}2500[nm]$
Min. Sensitive Area Diameter	$\phi 1[mm]$
Max. Collimated Beam	$8.5[mm]$
Min. Collimated Length	$10[mm]$
Max. Incidence Angle Filter	$10[°]$
Max. Entrance Aperture	$40[mm]$
Max. Cost per unit	1100 [SEK]

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	Removed due to reason for test implemented in GPS.	-	-	-
F.6	The experiment shall correlate the temperature at which the measurements were taken.	T	Test 2, 10	Passed
F.7	The experiment shall correlate the position at which the measurements were taken.	T	Test 10, 12	Passed

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	Moved to D.28	-	-	-
P.2	The experiment shall measure the electro-magnetic 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	See P.18 and P.19	-	-	-
P.12	The sampling delay shall not exceed 30 seconds.	A, T	Test 10	Passed, see test plan
P.13	Removed due to reason for test implemented in GPS.	-	-	-
P.14	Removed due to reason for test implemented in GPS.	-	-	-
P.15	The experiment shall measure the ambient air temperature from -60 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	Passed, see test plan
P.18	During the ascend phase the sampling frequency shall be at minimum $1/3$ Hz.	T	Test 10	To done, see test plan
P.19	During the float phase the sampling rate shall be 10 seconds.	T	Test 10	To be done, see test plan
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 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	Unnecessary requirement and has therefore been removed.	-	-	-
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	Unnecessary requirement and has therefore been removed.	-	-	-
D.13	The experiment should be attached to the gondola rails.	R	-	To be done
D.14	The fastening to the gondola rails shall be carried out with rubber bumpers with volcanized M6 bolts on both sides.	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	Unrealistic requirement and has therefore been removed.	-	-	-
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	-	Passed
D.21	The experiment shall use Ethernet 10/100 Base-T with RJ45 connectors for interfacing with the ground station.	R	-	Passed
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	-	Passed
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	Unrealistic requirement and has therefore been removed.	-	-	-
D.25	The experiment shall not use a downlink rate greater than 200 kbit/s.	A	-	Passed
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	-	Passed
D.29	The sampling time of optical instruments shall be synchronised.	T	Test 10, 11	Passed
O.1	The experiment sensors shall be cleaned 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 done by connecting/disconnecting the power source.	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	Esrange Space Center
Tested item	The whole experiment
Test level/procedure and duration	Test procedure: Use a vaccum chamber to 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	September- October
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: Use a freezer with suitable temperature range to 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: REMOVED - NOT APPLICABLE

Test number	3
Test Type	-
Test facility	-
Tested item	-
Test level/procedure and duration	-
Test campaign duration	-
Test campaign date	-
Test completed	-

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: 30-40 minutes depending on who is driving
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	Verification
Test facility	Kiruna Space Campus laboratory
Tested item	Photodiodes and filters
Test level/procedure and duration	Test procedure: 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. Test duration: ∼120 minutes
Test campaign duration	Recurrent test until and during the launch campaign.
Test campaign date	August-September
Test completed	YES

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: REMOVED, ADDED TO TEST 9

Test number	7
Test Type	-
Test facility	-
Tested item	-
Test level/procedure and duration	-
Test campaign duration	-
Test campaign date	-
Test completed	-

Table 5.2.8: Test 8: Communication between Experiment and Groundstation

Test number	8
Test Type	E-link
Test facility	Kiruna Space Campus
Tested item	RPi and Ground Station Computer
Test level/procedure and duration	Test procedure: Connect RPi and run scripts. Connect GS and run scripts. Check bandwidth limit, check correct display of data. Check correct execution of commands Test duration: 30 minutes.
Test campaign duration	N/A
Test campaign date	Late September
Test completed	NO

Table 5.2.9: 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. This is done during a simulated length of a full flight.
Test campaign duration	Two days
Test campaign date	September- October
Test completed	No

Table 5.2.10: Test 10: Data Collection test description

Test number	10
Test Type	Software
Test facility	Esrange Space Center
Tested item	Micro-controller Unit and Experiment sensors
Test level/procedure and duration	Test procedure: Subject experiment to test conditions of the thermal and pressure tests and log data 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	4th of September
Test completed	YES

Table 5.2.11: 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: Collect data for a duration of sufficient size and analyse afterwards (Data collection simulation) Test duration: 30 min.
Test campaign duration	1 day
Test campaign date	16th of September
Test completed	YES

Table 5.2.12: Test 12: GPS test description

Test number	12
Test Type	Verification
Test facility	Kiruna Space Campus Laboratory
Tested item	GPS unit
Test level/procedure and duration	Test procedure: Walk around while collecting data and control the recorded coordinates using Google Maps, if agreement{ Accept_result } Test duration: $\approx$ 1 hour.
Test campaign duration	1 day
Test campaign date	August
Test completed	YES

Table 5.2.13: 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: 20 min
Test campaign duration	1 day
Test campaign date	July-August
Test completed	NO

Table 5.2.14: 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: 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: 1 hour.
Test campaign duration	2 days
Test campaign date	September-October
Test completed	NO

Table 5.2.15: 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: 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: 2-3 days.
Test campaign duration	2-3 days
Test campaign date	September-October
Test completed	NO

Table 5.2.16: Test 16: Experiment prototype test description

Test number	16
Test Type	Electronics 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	July-August
Test completed	YES

Table 5.2.17: Test 17: Description for ripple and noise test of the analog signal chain

Test number	17
Test Type	Electrical
Test facility	Kiruna Space Campus laboratory
Tested item	Analog component chain, Pair of testdiodes, amplifier (LMP2022).
Test level/procedure and duration	Measure voltage ripple & noise of the analog sensor circuits of the system.
Test campaign duration	One day
Test campaign date	July-August
Test completed	YES

Table 5.2.18: Test 18: Description of breadboard test of electrical components

Test number	18
Test Type	Breadboard test of electrical components & subsystems
Test facility	Kiruna Space Campus laboratory
Tested item	Temperature sensor, ADC and DC/DC converters.
Test level/procedure and duration	Breadboard testing of all components to ensure measurements within the required ranges.
Test campaign duration	Two weeks
Test campaign date	July-August
Test completed	YES

5.3 Test Results

Table 5.3.1: Results for test 1: Low pressure test

Test number	1
Test Type	Low Pressure
Test facility	Esrange Space Center
Tested item	The whole experiment
Test result	No dimensional changes were found on a test piece of insulation during or after the test. The electronics of the brain box and one of the sensor boxes kept working together with no issues during and after the test. The camera was able to continue working as expected after the test. A steady state test with a full box is still needed. The optics also need to be tested in low pressure.
Test duration	One day
Test campaign date	5-6 September 2017
Test completed	Partly

Table 5.3.2: Results for test 2: Thermal test

Test number	2
Test Type	Thermal
Test facility	Esrange Space Center
Tested item	The whole experiment
Test result	Brain box, booms, clamps and camera showed no damage after the test, during which the temperature of the freezer oscillated between -65 $°C$ and -70 $°C$. Sensor boxes & optics need further testing.
Test duration	One day
Test campaign date	5-6 September 2017
Test completed	Partly

Table 5.3.3: Results for test 5: Calibration and verification

Test number	5
Test Type	Calibration and verification
Test facility	Kiruna Space Campus laboratory
Tested item	Photodiodes and filters
Test result	The response of every photodiode has been written down and each of the diodes has been paired with a filter.
Test duration	2 hours
Test campaign date	13 September 2017
Test completed	Yes

Table 5.3.4: Results for test 12: Experiment Garmin GPS.

Test number	12
Test Type	Test and verification of GPS unit
Test facility	Kiruna Space Campus laboratory
Tested item	Garmin 18x-LVC
Test result	Passed, for report see Appendix G.2.1
Test duration	One day
Test campaign date	July 2017
Test completed	Yes

Table 5.3.5: Results for test 16: Electronics prototype test

Test number	16
Test Type	Electronics prototype function test
Test facility	Kiruna Space Campus laboratory
Tested item	Prototype electronic Subsystems; the Arduino photodiode simulator, cameras, barometers, the monitoring subsystem and data storage unit. Also power system.
Test result	All parameters ok, integration of electronic subsystems successful.
Test duration	Two weeks
Test campaign date	July- September
Test completed	Yes

Table 5.3.6: Results for test 17: Analog noise.

Test number	17
Test Type	Electrical
Test facility	Kiruna Space Campus laboratory
Tested item	Analog component chain, Test diodes, amplifier (LMP2022).
Test result	Conditional Pass, some parts needs to be remade. The noise was withing reasonable limits. Some dark current must be taken into consideration during flight. Can most likely be done by software. For a better view of the test see Appendix G.2.2
Test duration	One day
Test campaign date	August 2017
Test completed	Yes

Table 5.3.7: Results for test 18: Experiment electronic test results for components.

Test number	18
Test Type	Experiment electronic, control & power subsystem test, also test of thermometer & ADC
Test facility	Kiruna Space Campus laboratory
Tested item	DC/DC converter THN 15-2411WI 15W, from *Traco Power*, DS1631+ Thermometer from Maxim Integrated, & ADC ADS1115 16bit ADC from Adafruit.
Test result	Passed, for report see Appendix G.2.3, G.2.4 & G.2.5 respectively.
Test duration	One day each
Test campaign date	June - July 2017
Test completed	Yes

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 21 kg.

Table 6.1.1: Sensor Box: Mass and volume

Experiment mass (in kg):	3,556
Experiment dimensions (in m):	0,511×0,23×0,19
Experiment footprint area (in m2):	0,155
Experiment volume (in m^3):	0,013
Experiment expected COG position:	x = -1,672 [m]; y = 0,521 [m]; z = 0,159 [m] for the upper sensor box. x = -1,661 [m]; y = -0,281 [m]; z = 0,008 [m] for the bottom sensor box.

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

Experiment mass (in kg):	9,763
Experiment dimensions (in m):	1,52×0,54×0,2
Experiment footprint area (in m2):	0,82
Experiment volume (in m3):	0,016
Experiment expected COG position:	x = -1,181 [m]; y = 0,51 [m]; z = 0,16 [m]

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

Experiment mass (in kg):	7,492
Experiment dimensions (in m):	1,7×0,54×0,2
Experiment footprint area (in m2):	0,918
Experiment volume (in m3):	0,016
Experiment expected COG position:	x = -1,35 [m]; y = -0,278 [m]; z = 0,008 [m]

Table 6.1.4: Central "Brain" Box mass and volume

Experiment mass (in kg):	2,606
Experiment dimensions (in m):	0,38×0,23×0,22
Experiment footprint area (in m2):	0,0874
Experiment volume (in m3):	0,013
Experiment expected COG position:	x = -0,109 [m]; y = -0,2 [m]; z = -0.015 [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 steel 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:	56 W
	Average power (or current) consumption:	35 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 brain box 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:

Table 6.1.7: Required Items

Item	Amount	Supplied by
Chairs	6	Esrange
Table (Workspace for 8 people)	1	Esrange
Toolbox, containing wrenches (size 7 and 10 mm), Phillips screwdriver, set of Allen keys, scissors, pliers, tweezers	1	Esrange
Cable stripper	1	IRIS
Crimping tool + Crimps	1	IRIS
Power supply with adjustable voltages	1	IRIS
Oscilloscope with probes Multimeter	1 1	IRIS IRIS
Soldering station with necessary tools for soldering	1	Esrange
Micro fiber cloth rag Bottle of glass cleaner	1 1	IRIS IRIS
Latex gloves for handling the optics	1 box	IRIS
Power strip	2	Esrange
Hot Melt Adhesive (HMA) gun and glue charges	1	IRIS

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, and to ensure the success of the experiment. As a result, launch shall take place between sunrise and noon, to maximise the amount of daylight present during the flight. The minimum mandatory 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.

In table 6.1.9 it can be seen that the irradiances for the smaller wavelengths continuously increase for larger solar elevations. However a small dip in irradiances for larger wavelengths at a solar elevation can be seen. This is due to the longer path through the atmosphere which leads to greater scattering. This dip, as well as the minimum amount of light that the photodiodes need sets the constraints for our flight window. Figure 6.1.1 shows the solar elevation, the angle of the sun above the ground as a function of daytime for several days, following the beginning of our launch campaign on the 13th of October. The necessary amount of light required by the optical system is reached at solar elevations above 3°. That means the optimal launch window would be around 9am. This assures that the sun is high enough in the sky and that the flight time is sufficiently long to collect enough data. The launch should not happen later than 11am. This will give us about 1.5h ascending time and about 2 hours of float time before the sun is below 3°elevation around 4pm again. However an early launch around 9am would be preferred as it will leave more room for delays and longer floating phase as well as longer exposure to the sun at large solar elevations above 10°. The exact times when the solar elevation reaches 3°in the morning can be seen in table 6.1.8.

Table 6.1.8: Times when the sun appears at an elevation of 3°.

Local Time	8:17	8:21	8:26	8:30	8:34	8:38	8:42	8:47
Solar elevation [°]	2.9974	2.9933	3.0626	3.0513	3.0368	3.0192	2.9984	3.0460

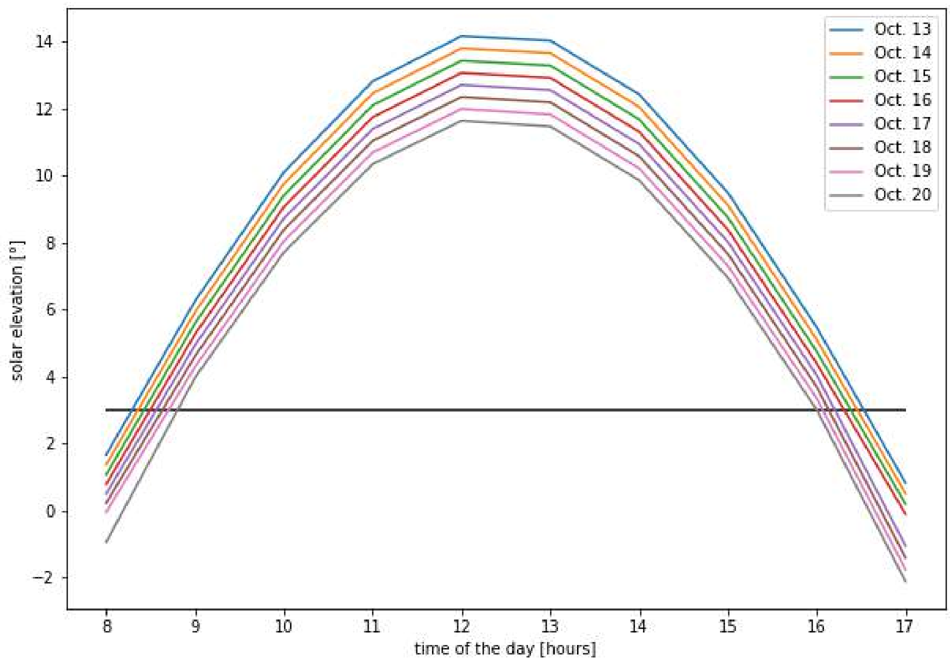


Figure 6.1.1: Solar elevation during the launch campaign.

Table 6.1.9: Expected diffuse horizontal irradiances, with values in W/m^2

Spectral bands[nm]	Solar elevation [°]							
	1	3	5	7	9	11	13	15
450-500	1.810	2.562	4.024	5.202	6.160	6.954	7.629	8.213
510-590	2.091	2.583	3.764	4.635	5.317	5.890	6.396	6.855
610-690	1.665	1.739	2.272	2.636	2.920	3.161	3.375	3.570
850-900	0.491	0.415	0.495	0.542	0.576	0.603	0.627	0.648
1575-1625	0.032	0.024	0.027	0.029	0.031	0.032	0.033	0.034

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	Department
30 min	Power test of the system	Electrical
30 min	Check data acquisition	Electrical, Software & Science
TBD	Communication Test	Software
TBD	Cleaning of sensors	Optics
TBD	Calibration of sensors	Optics
TBD	Flight Simulation	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 E-link. It will stop recording data when it is at 3000 m 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.

The experiment will shut down automatically at the specified altitude, or by command prior to that point if considered necessary by the science team. The shutdown command shall be designed and programmed to be executed in such way to prevent any unexpected shut down.

Tab. 6.3.1 summarises the most important moments on countdown and during flight. Note that this is only a 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+∼4H00	Check reception of shutdown

6.4 Post-Flight Activities

After the recovery team tracks and reaches the gondola, it is required for them follow these steps.

- Disconnect the power cable from the power supply.
- Dismount the brain box and the two sensor boxes.
- Return the brain box and the two sensor boxes and to the lab.

Next, two members of the IRIS team will take the apparatus from the ESRANGE and return it to LTU university. The boxes will be disassembled and the conditions of electronic boards shall be checked. The SD card will be retrieved. If the data file stored is not corrupted, the first step towards the data analysis shall be to try to correlate the data from the camera to those of the photodiodes. This would work as the first validation of our data.
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 [16] 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 improvement of 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.
It is in the nature of all kind of measurements that several types of errors are going to be inherently present and influence the quality of the data, as the true value of the measurement is never known. A very good calibration of the two optical systems is required to assure the data quality. Though by itself it is not enough, it is a very important step to eliminate a systematic error in the measurements. Since the measurements are continuously taken the precision of the measurements is expected to be at acceptable levels. The measurement accuracy is however a much more complicated factor which should be calculated and added on the final data.

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.

Another apparent possibility is that the sensors placed on the bottom boom array might be exposed to direct sunlight. This would be caused from severe unbalancing of the gondola due to atmospheric pressure variations and the forces applied from the speed of the gondola. Since two cameras are used, one placed on each boom, it shall be easily detected when the sun will shine onto the camera. Furthermore, a second step to ensure data quality shall be applied. During the data evaluation and since the ratio of incoming to outgoing radiation will be measured, a code that checks the results shall be applied. When both values from up and down sensors are suddenly equal due to direct sunlight exposure, the measurement shall not be taken into account.

An other error to occur will be caused by the water concentrated on the top of the lenses. This would be created due to condensation caused by temperature and pressure differences. This will influence the values of the IR bands.

In addition, the balloon has a diameter of approximately 30 meters when it is fully inflated. The properties of the material of the balloon will influence the absorption and scattering of light. Taking a sample of the balloon and analyzing its spectrometric behaviour would be extremely beneficial for the quality of the data.

As for instrumental error added to the measurements, thermal noise in the diodes and the electrical noise in the circuits shall calculated and taken into consideration.

Finally, there is also a possibility of interference from nearby experiments, but this possibility, appears to be extremely low.

7.2 Launch Campaign

7.2.1 Flight preparation activities during launch campaign.

During launch campaign, a number of 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 30 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 more analytically in a later version of the SED after the testing of all ordered equipment that is required for the correct function of the experiment.
From calculations and some from some tests performed by optics and electronics, appears to be an apparent possibility that one optical band might not receive enough data, due to the very low power intensity of the band itself. For this case, the situation is examined and a possible step to be taken is the removal of the filter from the optic tube,

in order to assure better quality data. From the mechanical tests and simulations, there is no apparent possibility of malfunction or failure. From the software point of view there is no apparent possibility of malfunction or failure.
The total power consumption should be around 32 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 keeping the interior of the sensor box within the operating temperature ranges of all its components, and that the boom does not heat up beyond around 60 °C in the warmest case. In addition, thermal testing of brain box, sensor box, booms and clamps showed that the boxes can keep their internal temperatures within operating ranges in the coldest case, while the boom and its clamps can keep their functionality. However, due to technical problems, no more simulations could be done, which would otherwise provide more information about the thermal behaviour of the experiment, especially in the warmest case. According to hand calculations, one heater (max. operating power: 16 W at ascent descent phase, average operating power: 8 W) should be active in each box. This would result in a maximum power consumption 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 steel 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.
A checklist of the process needed to be followed by the Recovery Team on how the experiment shall be treated can be found in Appendix D.

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.
IRIS has already participated in the 23rd ESA Symposium on European Rocket and Balloon Programmes and Related Research which took place on June 2017, under the title: *ALBEDO MEASUREMENT USING PHOTODIODES ON A HIGH-ALTITUDE BALLOON*. During the conference the scientific goals, and design of the experiment were presented. It is of great interest to present the post flight condition of the experiment, along with the results and the complete data analysis in the following ESA Symposium on European Rocket and Balloon Programs and Related Research and also in the 2018 European Geosciences Union (EGU) General Assembly.

7.4 Lessons Learned

7.4.1 Special Experiences and Problems

Table 7.4.1: Special Experiences and Problems

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	• Changes in the design can lead to vastly increased costs. Our final hardware costs were more than 10 times higher than what we had originally planned. • Frequently changing the design can make it difficult to keep track of all the components and their associated costs. Prices are given in different currencies (dollars, euros, SEK), which further complicates things.

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. • When working with components that have lots of pins (i.e. 18-DIP packages) It's a good idea to use sockets for the components until the finalised product is to be assembled.

Mechanical	• For the Selection Workshop, a design based on one sensor box held to the gondola by a boom was presented. The feedback received recommended to not use booms and instead attach these boxes directly to the gondola. After this feedback was implemented and a new design according to it was presented at PDR stage, new feedback was received that recommended the use of aluminium booms, contradicting the previous feedback and invalidating the new design. Following this PDR feedback, another design was proposed for CDR, but this one was also deemed in need of change by the panel, namely from aluminium booms to poly carbonate ones. These continuous changes had the effect of greatly delaying progress in terms of freezing and optimising the design, generating CAD models and manufacturing drafts, running thermal and mechanical simulations, ordering components and integrating the experiment. As a result, at IPR stage, progress was severely behind schedule, and critical problems related to the mounting of the optics system were only detected at this stage. • Rexroth profile-based structures are highly versatile, although prone to misalignment and jamming during assembly, increasing the time it takes to assemble structures and doing modifications. • Styrofoam is a very effective thermal insulator and can easily be shaped with a hot wire foam cutter, but it is also easy to accidentally break it or make errors during machining due to how soft the materials is.
Optics	
Project Management	• Define the mission statement and objectives early • The Ljungné stress factor: $\frac{1}{R+1}$, where R is number om kilometers away from the project lab. R=0 leads to 100% stress.

Public Relations	• Attending conferences can be very expensive, and funding should be secured at an early stage. • Frequent posts on social media, combined with an attractive website, is a very cost efficient solution.
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	• Never use a RPi • Always start the project with integration in mind • Always ask for a Piotr. • Syntax highlight is pretty dope, will save you some time. And that sneaky parenthesis will not hide anymore. • Simple is better: Make a copy of files from time to time and forget about GitHub. Also applicable for text editors and interpreters.

7.4.2 Identified Problems and Mistakes

Table 7.4.2: Problems and Mistakes

Department	What has been learned
General	•
Economics	• Discovering one month before launch that more components are needed is not optimal. A more thorough analysis on what exact hardware is needed should be done at an early stage to avoid surprises. This also improves the chances of selecting the most cost efficient design. • It was extremely difficult to estimate how much of the budget should be allocated to spare parts. Some components are cheap and available with fast shipping, and these do not pose much of a problem. Others have to be customised for the experiment, and this means that they are both expensive, difficult and time consuming to replace. Having extras is definitely desirable in case a critical component is involved in an accident, but having one or multiple extras of everything is incredibly expensive.

Electronics	• It is easy to set a pin that should be GND to a floating potential instead, which can make all kind of signals go weird.
Mechanical	• The work load related to both mechanical and thermal design was probably too excessive for just 2 team members, of which 1 was also required for optics design. • Cabling brought unexpected problems into the design -mainly interference- that required design modifications during integration, such as additional machining of aluminium plates and styrofoam insulation.
Optics	
Project Management	• Having a Facebook group to relay information dumps • Follow through to make sure each department have their own weekly meetings • As project manager do not underestimate the importance of a project manager • Have a better and clearer team structure
Public Relations	• Always have someone check your website for bugs. • Be prepared that a discussion over mail or phone can take a long time to finalise.
Science	• TBD (after Data Analysis)

Software	• Make sure 3 times that you hit the "save" button. And then once more. • Hardware is unreliable. Make a copy of your work. You can, they can not.

7.4.3 Possible Improvements

Table 7.4.3: Improvements

Department	**What has been learned**
General	•
Economics	• Opening a bank account for the project, instead of going through the University, would have made it easier to keep track of all incomes and expenses. • Finding more sponsors earlier on, even though the economy looked fine at that point, would have helped us later on.
Electronics	• Order a first PCB early, that allows second order which has had all the problems not noticeable until it is tested, fixed.
Mechanical	• It could had been convenient to have an additional team member within the Mechanical department due to the work load related to this department. Separating thermal design into a new department, as was done with optics, could had been convenient as well, for the same reasons.
Optics	

Project Management	• Only using one management software to relay information (delete or do not use a Facebook group) • Work more with software like Asana and Gantt charts
Public Relations	• Reaching out to someone highly skilled in optics at an early stage would have allowed us to validate our thoughts and ideas for the design. We could have realised earlier on that our design would not be as cost efficient as originally planned.
Science	• Investigate into other bands, such as NUV, for more optimal error correction in satellite remote systems
Software	• Set up a good workbench/procedure before going directly hands on with your experiment. Will improve work rate and availability of resources.

8 Abbreviations and References

8.1 Abbreviations

AR	Actual Range
ADC	Analog-to-digital converter
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
DART	Discrete Anisotropic Radiative Transfer
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
ISA	International Standard Atmosphere
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

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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

1. REVIEW

Flight: BEXUS

Experiment: IRIS

Review location: LTU Rymdcampus / Kiruna, Sweden

Date: 04th August 2017

Review Board Members

1. Stefan Krämer (SSC)
2. Piotr Skzrypek (ESA)
3. Giovanni Chirulli (ESA)

Experiment Team Members

Gustaf Ljungné	Eleni Athanassiou
Ingo Wagner	Francois Piette
Andreas Wallgren	Guillermo Lopez
August Svensson	

2. GENERAL COMMENTS

2.1. Presentation

- Good Presentation by different team members. Presentation of status and problems.

2.2. SED

- No comments

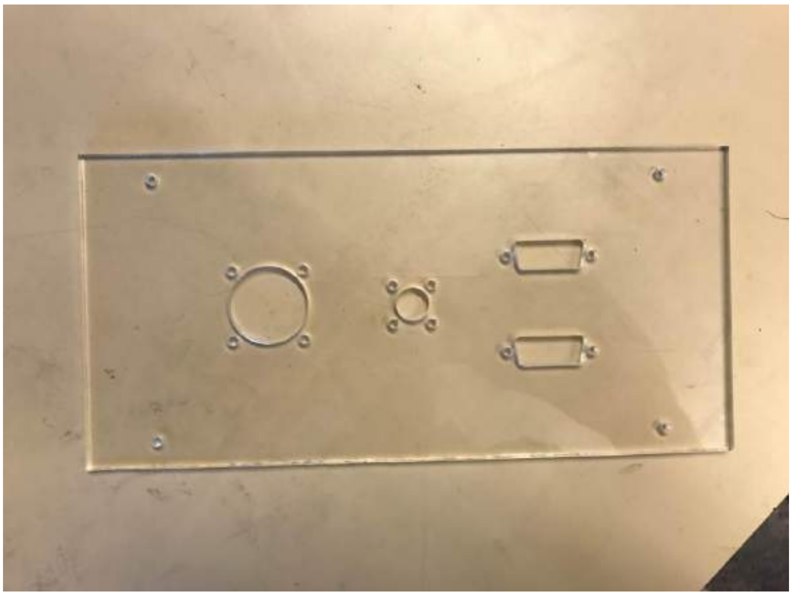
2.3. Hardware

- Mechanical
    - Bosch Profiles for sensor boxes just arrived
    - Booms are not ordered yet
    - Many mechanical parts not ordered yet
    - Problem with alignment of optical parts in current design
- Electrical
    - PCBs for sensor box and brain box are in house
    - Several components for PCB integration are not yet ordered – PCBs are not soldered and tested yet

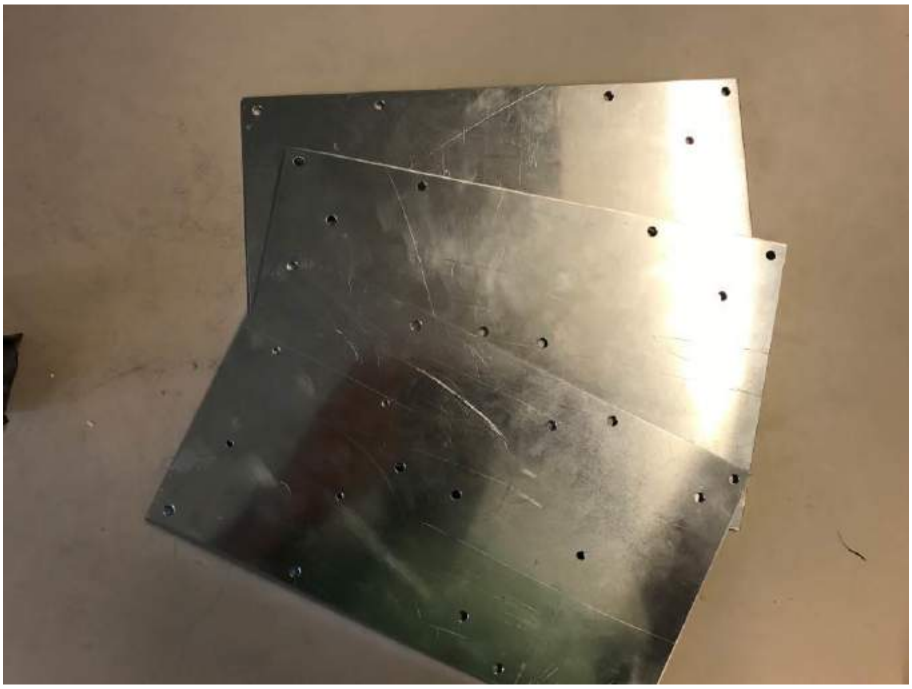
- Optical
  - All filters except one are already in house
  - Photo diodes are just available for testing – flight hardware not yet ordered
  - Lenses for testing are just enough for testing – flight hardware has to be ordered.

3. PHOTOGRAPHS

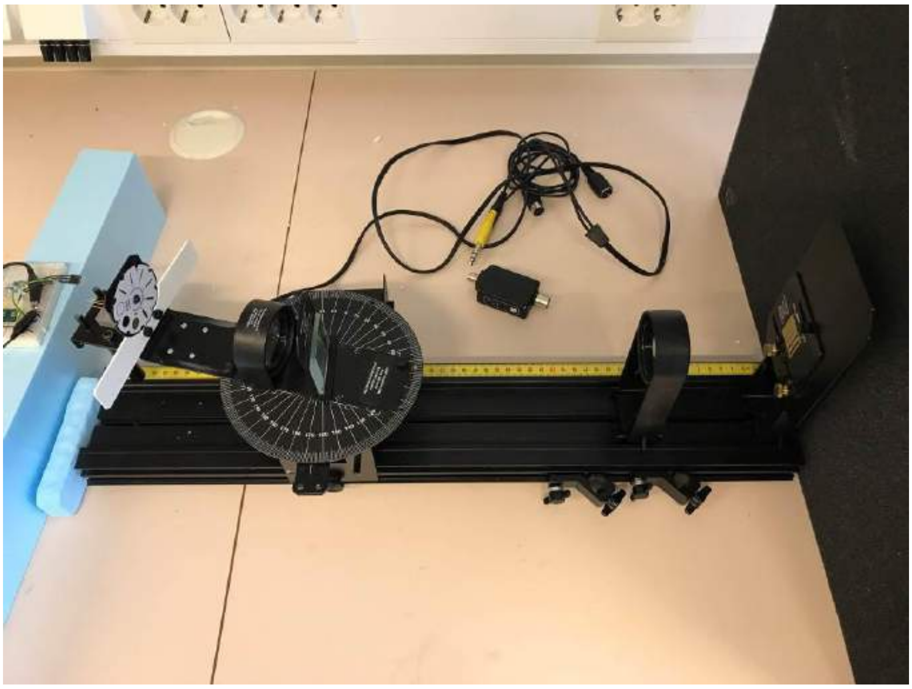
Picture 1: Structural profiles for sensor boxes



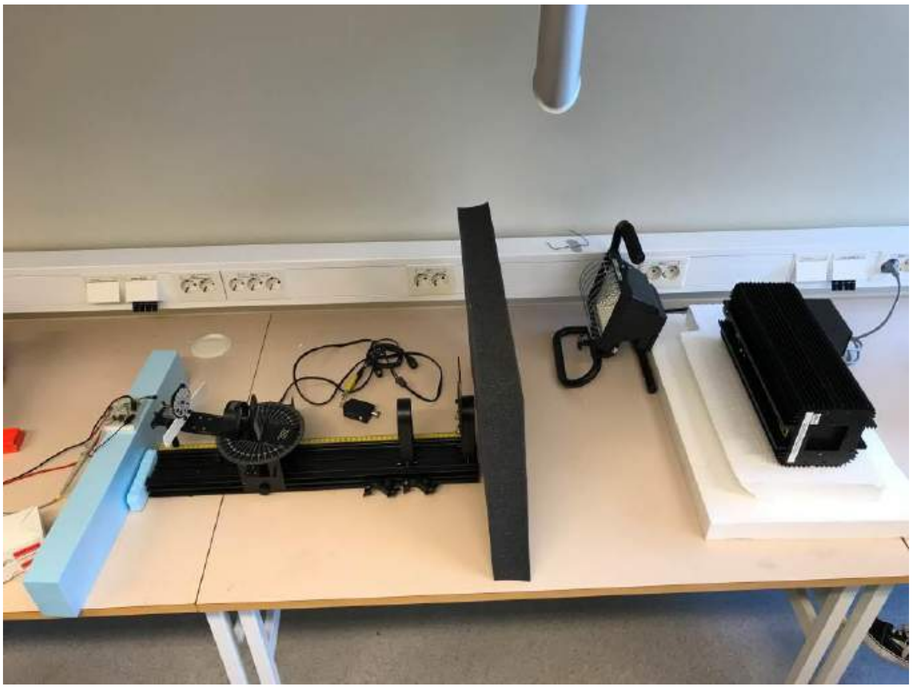
Picture 2: front plate of brain box



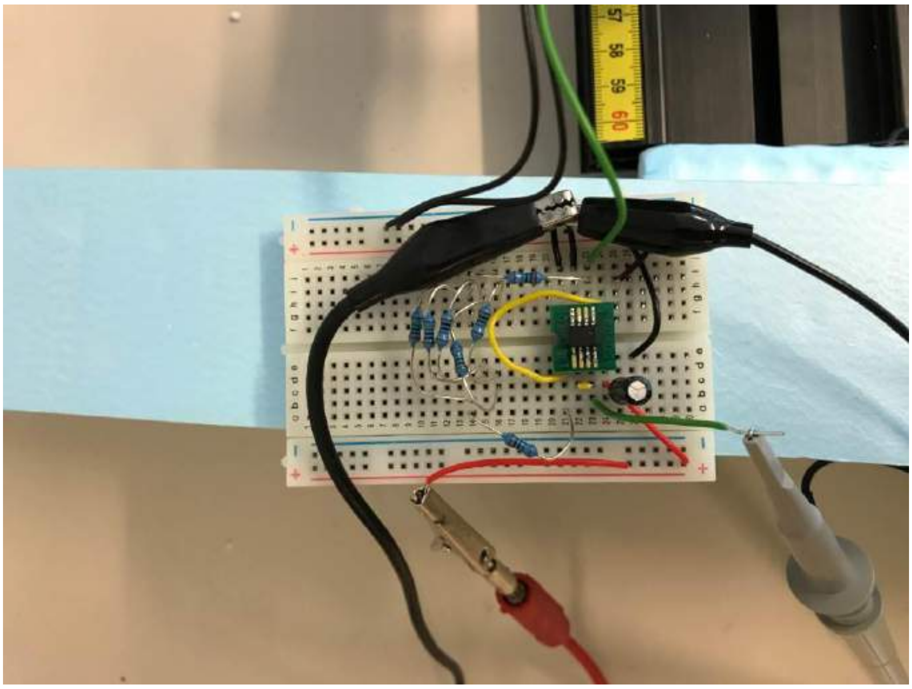
Picture 3: Mounting plates for sensor boxes



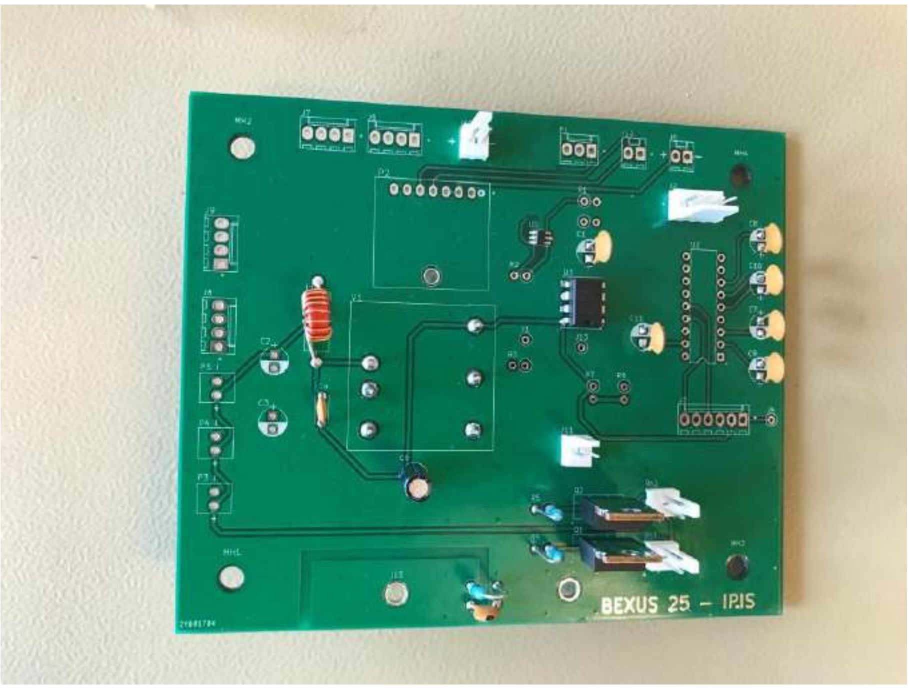
Picture 4: Optical Bench with setup to test the photodiodes and optical filters



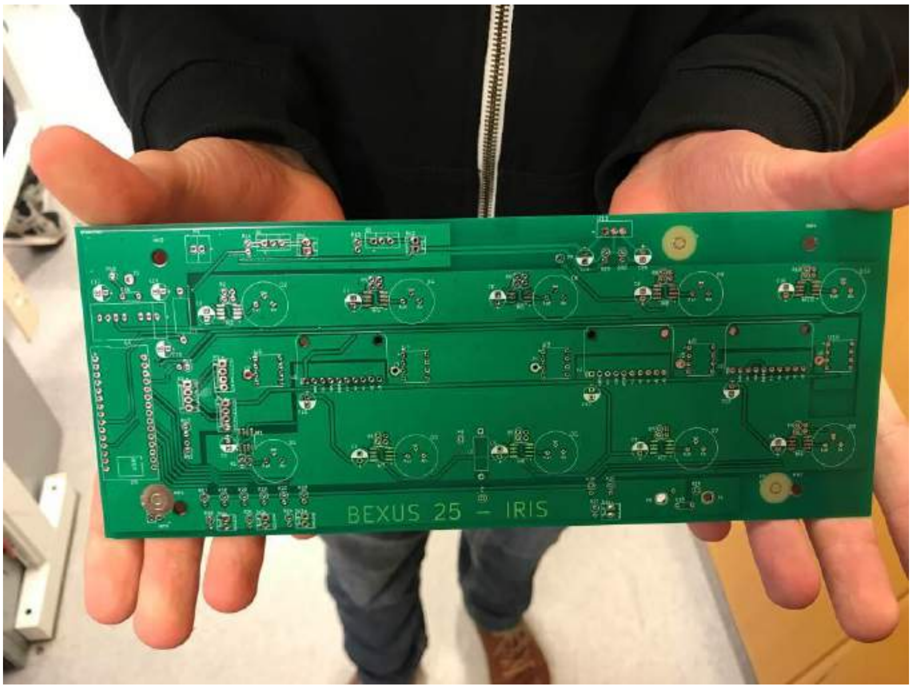
Picture 5: Full test setup on the optical bench



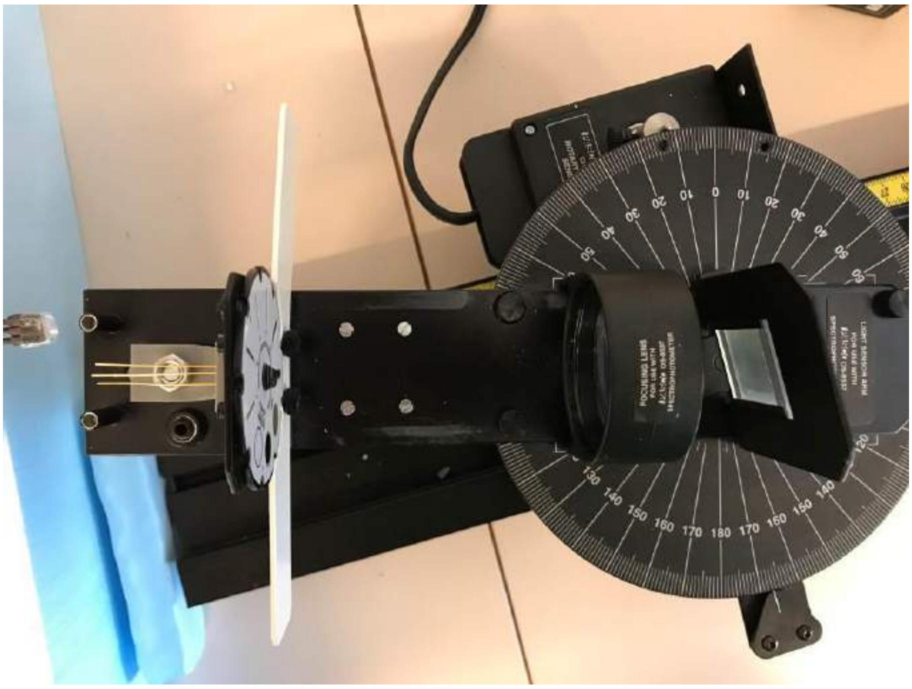
Picture 6: Filter on breadboard



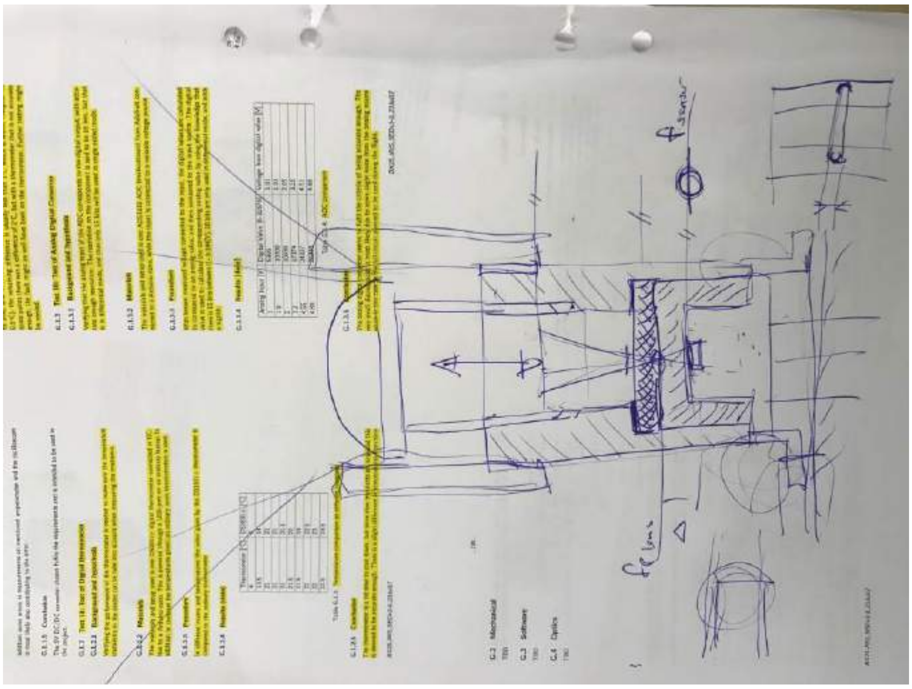
Picture 7: IRIS Power PCB



Picture 8: IRIS Sensor PCB for photodiodes



Picture 9: Detail of test setup with photodiode



Picture 10: Sketch for optical path of Lens, filter and photodiode

4. REVIEW BOARD COMMENTS AND RECOMMENDATIONS

4.1. Science

- **Alignment of optical path between Photodiode, Filter and lens is not secured. There is a huge concern that with the current design, there is no scientific data.**
- The design of the mounting of the optical components has to be changed to ensure a sufficient alignment.
- Tilting of gondola might affect the incident angle at the fish eye lens. Consider adding an adjustable baffle which can be adapted and fixated during launch campaign, when COG of gondola does not change anymore.

4.2. Requirements and constraints (SED chapter 2)

- No comments

4.3. Mechanics (SED chapter 4.2.1 & 4.4)

- Consider the design of an optical tubus for each sensor, test with rapid prototyping and order parts asap.
- Update the position of the "brain box" in the SED after the decision during interface discussion
- Update the drawings according to standards for the parts which are still to be manufactured

4.4. Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5 & 4.7)

- Solder PCBs and test them. Bring hardware into the loop for S/W development and testing.

4.5. Thermal (SED chapter 4.2.4 & 4.6)

- Thermal hardware is not existing, order insulation material asap
- Thermal simulation software will be provided by Giovanni
- New analysis with help of provided software and evaluate the result by comparing with thermal requirements of system components
- Implement thermal algorithm for heater
- Order the heaters

4.6. Software (SED chapter 4.8)

- Proceed with integration and testing
- Communication via Ethernet not established yet
- Camera processing to be finished
- Ground software to be finished
- Integration of brain box with sensor boxes

4.7. Verification and testing (SED chapter 5)

- Don´t underestimate the time required for testing
- Diagnose the source of the unexpected signal in test setup
- Update test plan with internal deadlines and dedicated dates
- Organise testing (Thermal / Vacuum) at Esrange
- Consider building a “dark room” / box around test setup to avoid unwanted stray light of undefined sources

4.8. Safety and risk analysis (SED chapter 3.4)

- No comments

4.9. Launch and operations (SED chapter 6)

- Define your required launch window more in detail
- Check again for BYO items in 6.1.4

4.10. Organisation, project planning & outreach (SED chapters 3.1, 3.2 & 3.3)

- By now financial situation OK, still 1600€ left. Design change of optical setup might affect budget -> increased manufacturing costs

4.11. End-to-end Test

- End to end test not yet possible. Test setup of optical components on an optical bench was presented

5. FINAL REMARKS

5.1. Summary of main actions for the experiment team

- **Re-Design the alignment system for filters and lenses** (Alignment of optical path between Photodiode, Filter and lens is not secured. There is a huge concern that with the current design, there is no scientific data)
- Order missing components ASAP!
- Solder and Integrate PCBs and test their function

5.2. Summary of main actions for the organisers

- Thermal software by Giovanni
- Review of new optical setup before manufacturing - Stefan

5.3. IPR Result: pass / conditional pass / fail

- **Conditional pass**

5.4. Next SED version due

- **Please provide SED v4-0 before the 22nd September**

6. INTEGRATION PROGRESS REVIEW – IPR

Experiment documentation must be submitted at least five working days (the exact date will be announced) before the review (SED version 3). The input for the Campaign / Flight Requirement Plans should be updated if applicable. The IPR will generally take place at the location of the students' university, normally with the visit of one expert.

The experiment should have reached a certain status before performing the IPR:

- The experiment design should be completely frozen
- The majority of the hardware should have been fabricated
- Flight models of any PCB should have been produced or should be in production
- The majority of the software should be functional
- The majority of the verification and testing phase should have been completed

The experiment should be ready for service system simulator testing (requiring experiment hardware, electronics, software and ground segment to be at development level as minimum)

Content of IPR:

- General assessment of experiment status
- Photographic documentation of experiment integration status, with comments were necessary
- Discussion of any open design decisions if applicable
- Discussion of review items still to be closed
- Discussion of potential or newly identified review item discrepancies
- Discussion of components or material still to be ordered or received by the team
- Clarification of any technical queries directed towards the visiting expert
- Communication and functional testing (Service system simulator testing and E-link testing for REXUS and BEXUS respectively)

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 its 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 web page.


Atmospheric Science Group
Luleå University of Technology
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

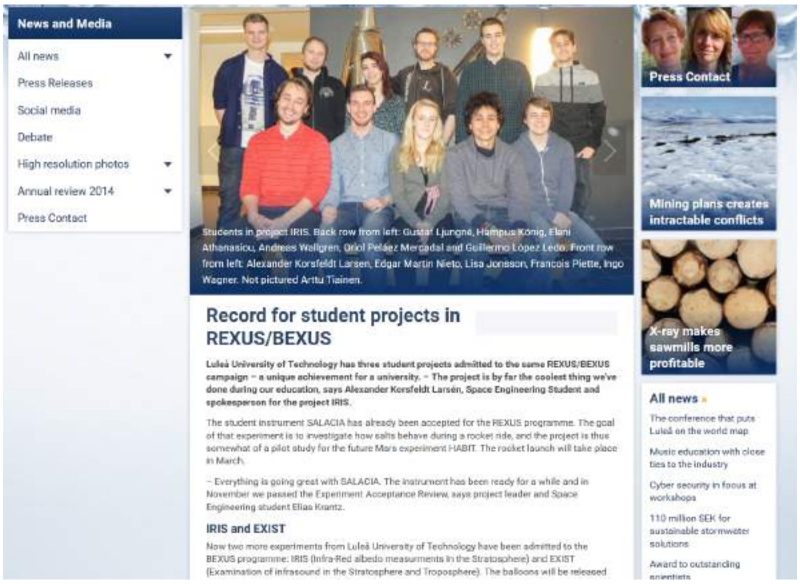


Figure B.0.2: Interview published on the LTU website.

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

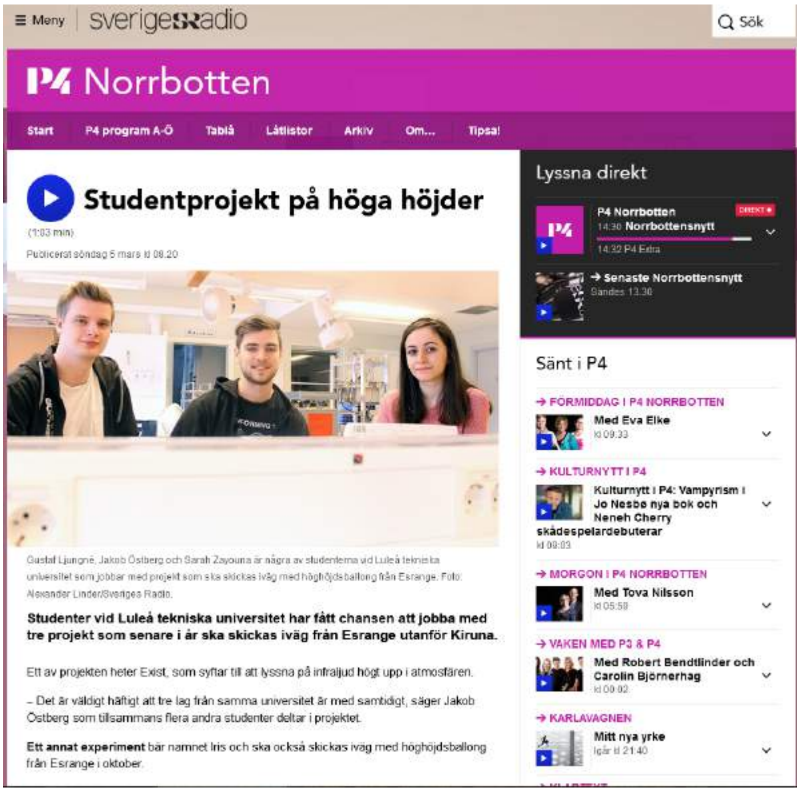


Figure B.0.3: Interview on the radio station P4 Norrbotten

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.

On Monday 22nd of July, a presentation was held together with the BEXUS team EXIST about the two experiments and the REXUS/BEXUS Programme in general. The presentation was performed at Esrange Space Center for participants of the Space Research School organized by Astronomisk Ungdom (Astronomical Youth).

Inspired by the Previous BEXUS team OSCAR, IRIS will arrange a competition, where the winners will have their favorite quote engraved on a plexi-glass plate mounted on the experiment. The winners have now been selected, and the plexi-glass plate is under production.

The next event that IRIS will take part in is called LiftOff, a job fair for space companies scheduled to take place at Space Campus on October 4-5th. A presentation will be held, and we will showcase what we can of the experiment. We will also sell patches with the IRIS logo.

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.

I.R.I.S.
BEXUS 24/25

Figure B.0.4: The IRIS Project logo

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

Figure B.0.5: The IRIS Team Hoodies

In August, 2017 the team received patches with the team logo from mera.se. The company sponsored 12 % of the cost in exchange for IRIS providing links to their website in posts on the project web page and Facebook page. A picture of the patches is shown in fig. B.0.6 below.

Figure B.0.6: The IRIS Patch 1.0

C Additional Technical Information

C.1 Circuit Schematics

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

C.1.1 Brain Box Schematics

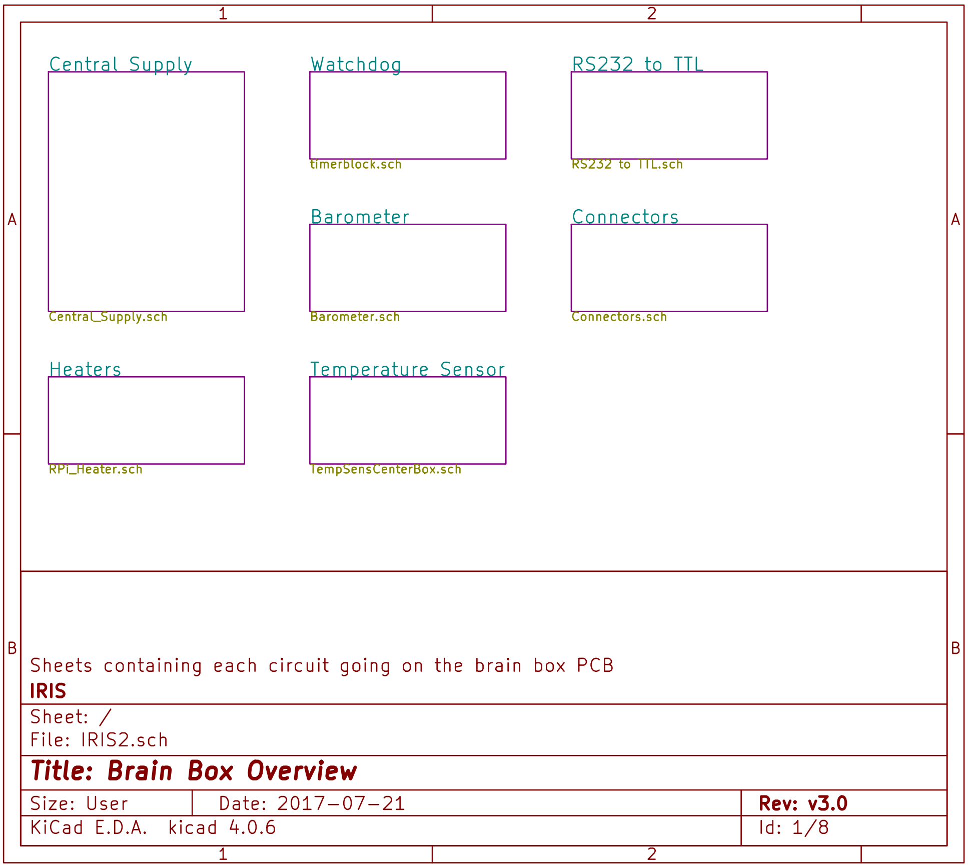


Figure C.1.1: Overview of the brain box electrical subsystems. These blocks are circuits, which are shown below.

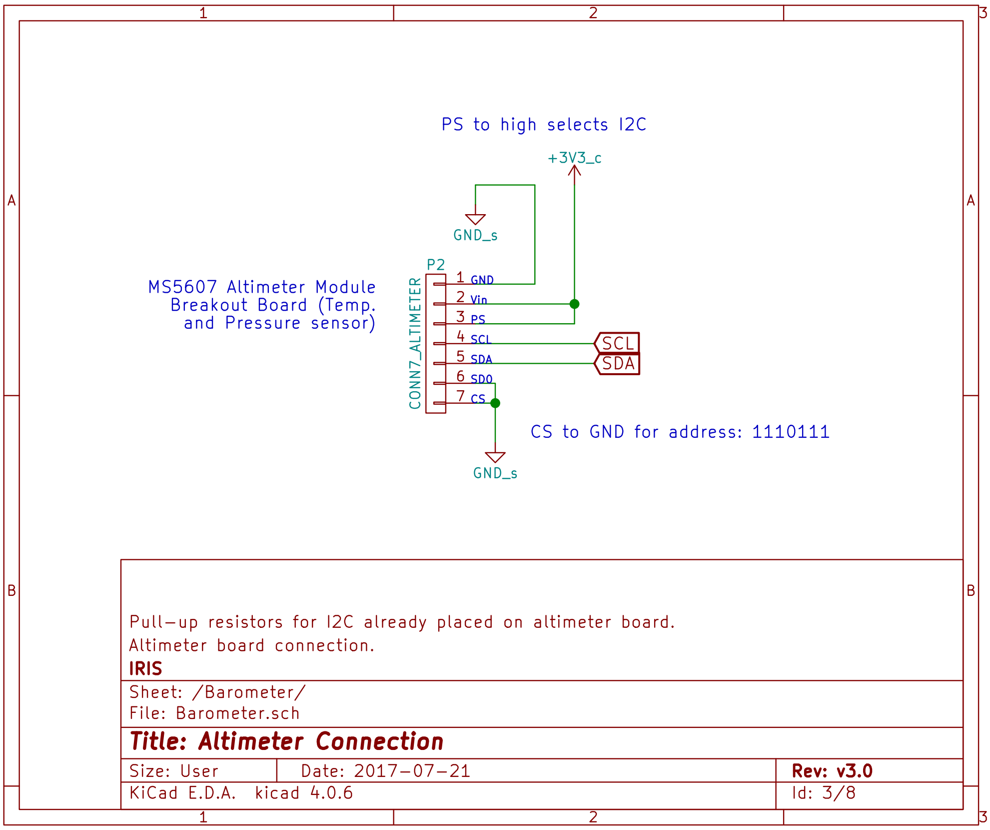


Figure C.1.2: The altimeter has a separate board. This circuit shows its connection between the boards.

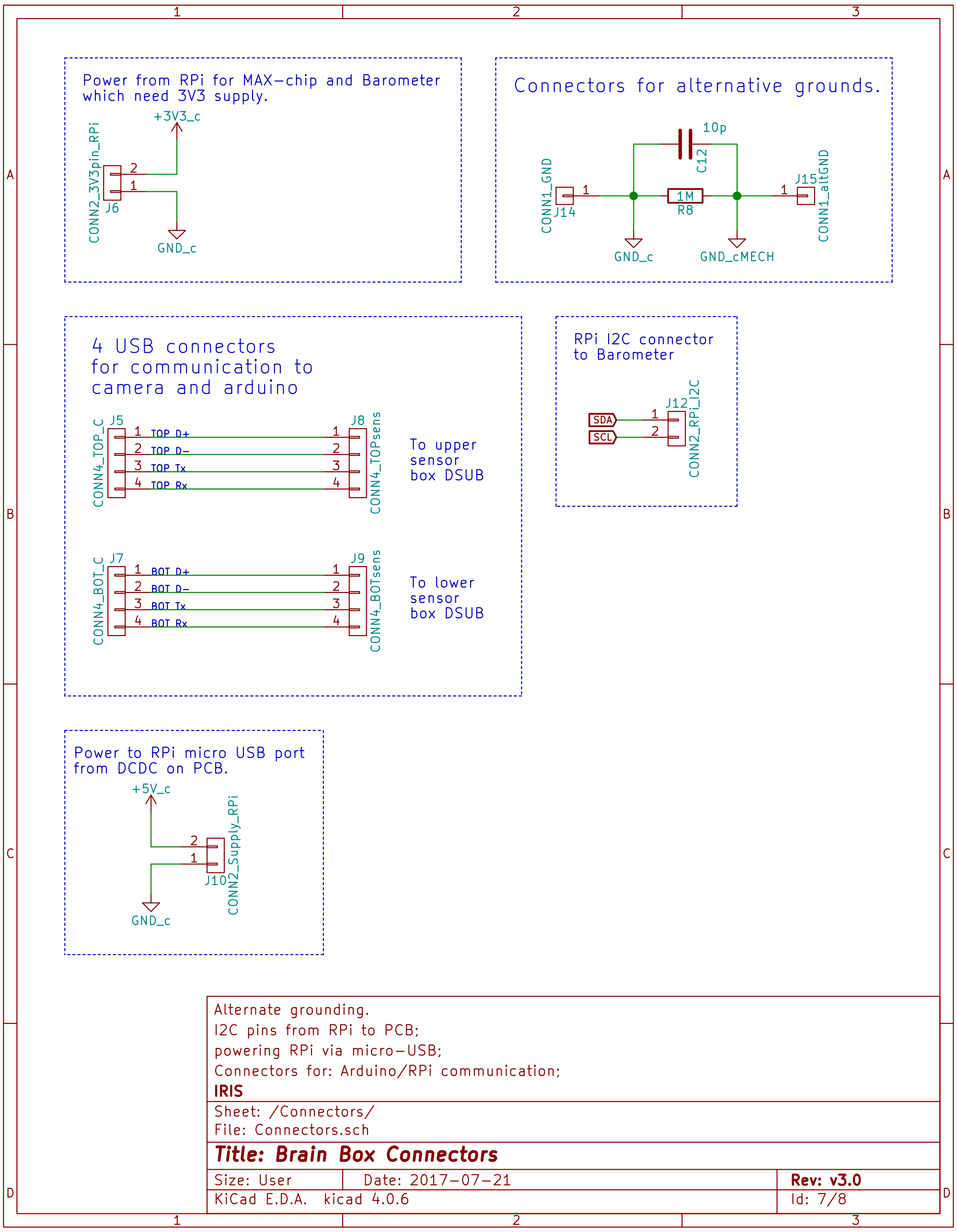


Figure C.1.3: Various connectors in the brain box. Description below.

In the upper left, is the connection from the RPi 3.3 V pin, which powers the TTL-to-RS232 converter MAX-chip. In the upper right, is the connection with the alternate ground, that can be attached to off-board mechanical grounding. Middle left shows the data-lines on which the communication between boxes takes place; the camera UART lines *Tx*, *Rx*, and the Arduino USB lines *D+*, *D-*. Middle right shows the I^2C lines of the RPi connecting with the PCB. Finally, at the bottom, is the connector from the PCB 5 V line to power the RPi (through the micro USB to benefit from this port's internal regulation).

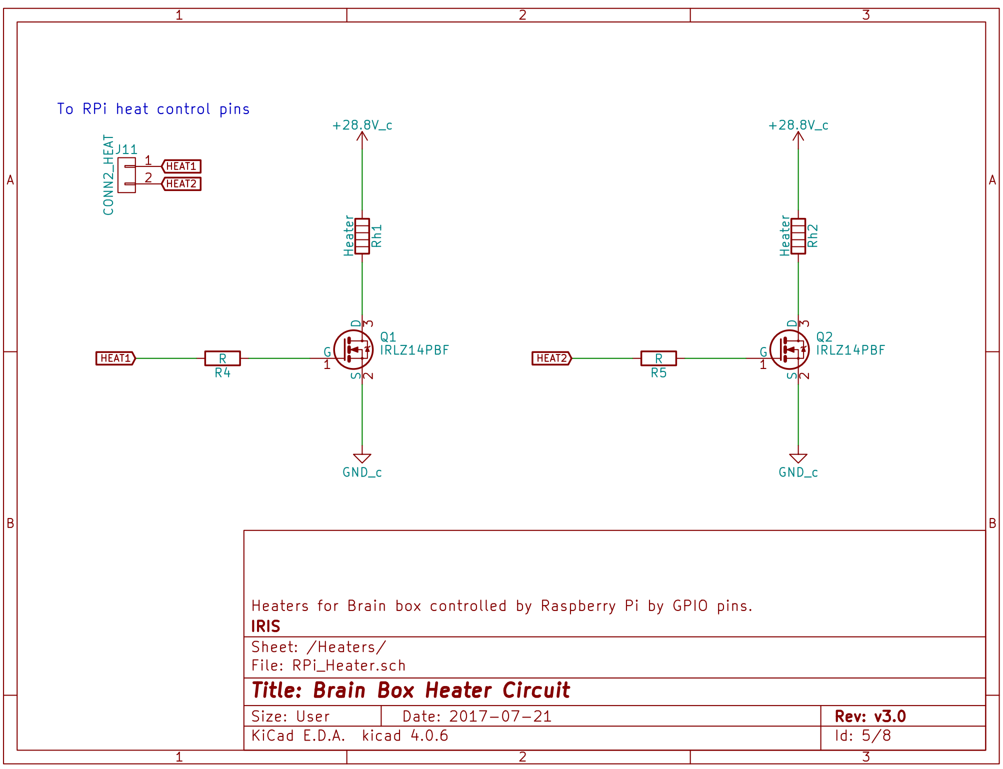


Figure C.1.4: Brain box heaters controlled by Raspberry Pi and fed power from battery.

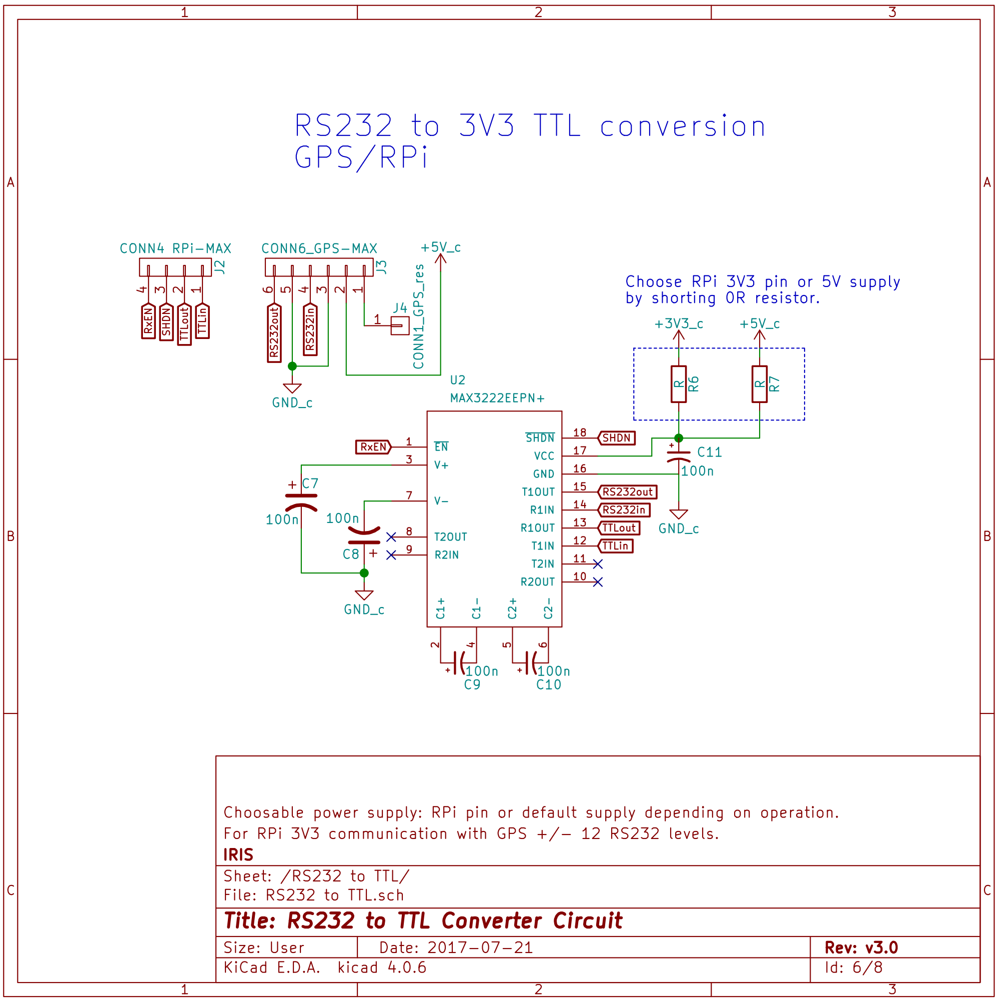


Figure C.1.5: MAX-chip circuit for RPi-to-GPS communication.

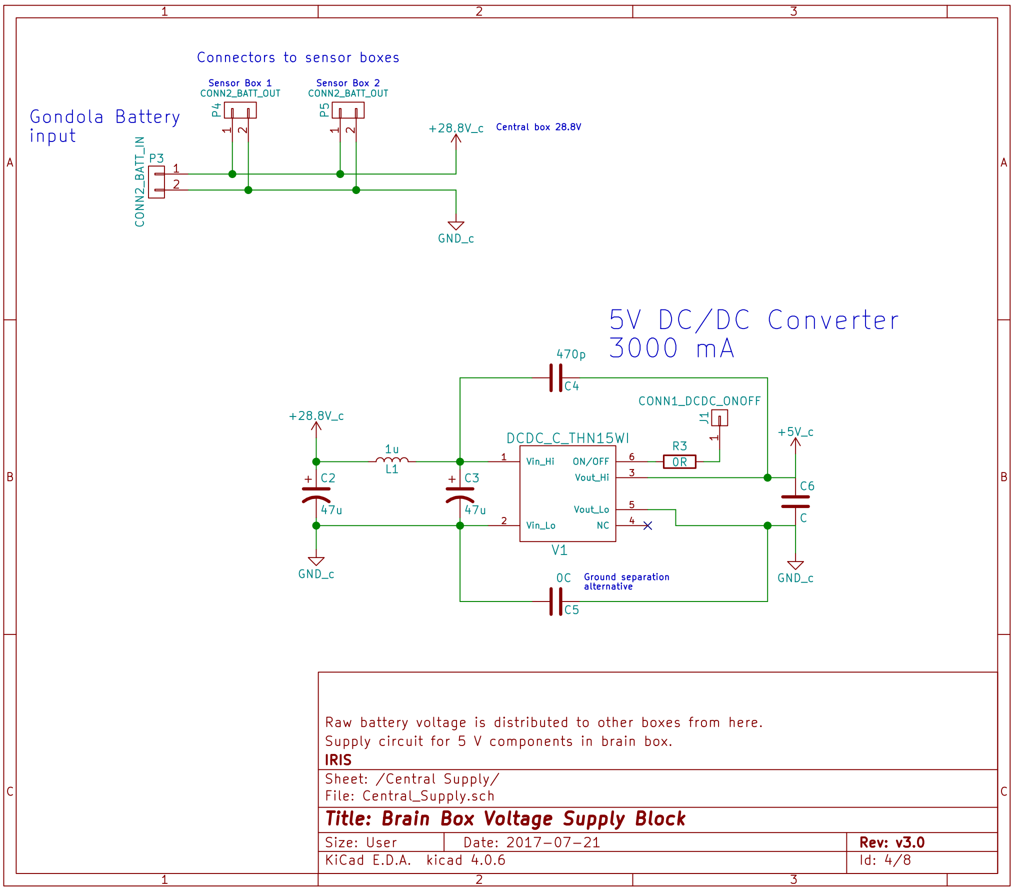


Figure C.1.6: Battery 28.8 V distributed to sensor boxes and regulated for 5 V in brain box.

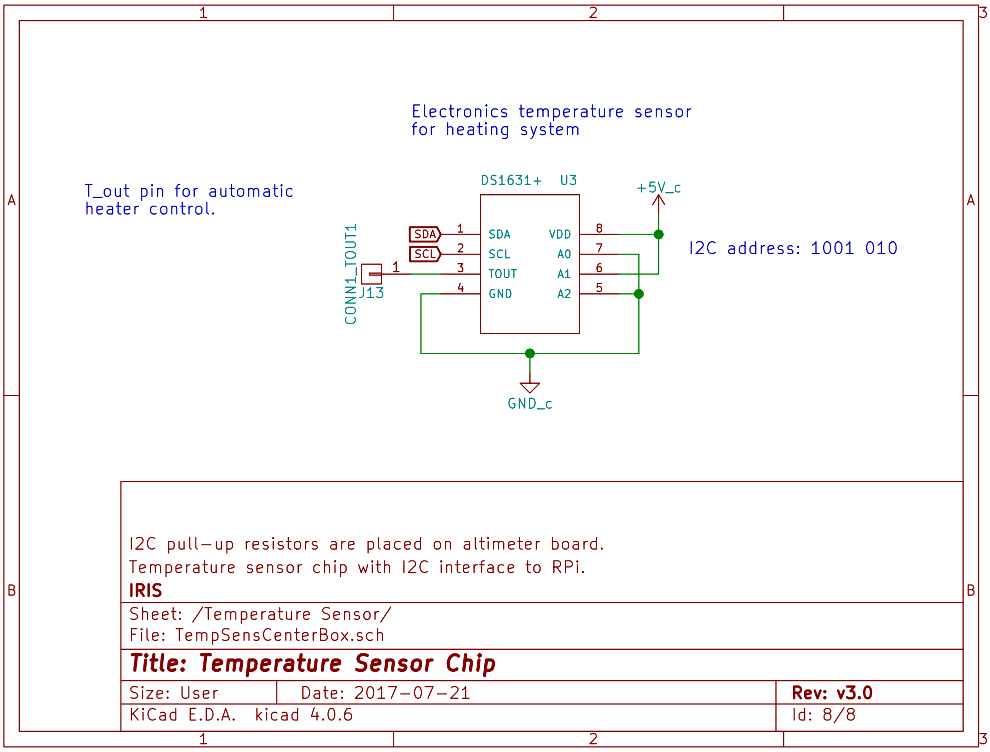


Figure C.1.7: Temperature sensor chip for monitoring of electronics and heating in the brain box.

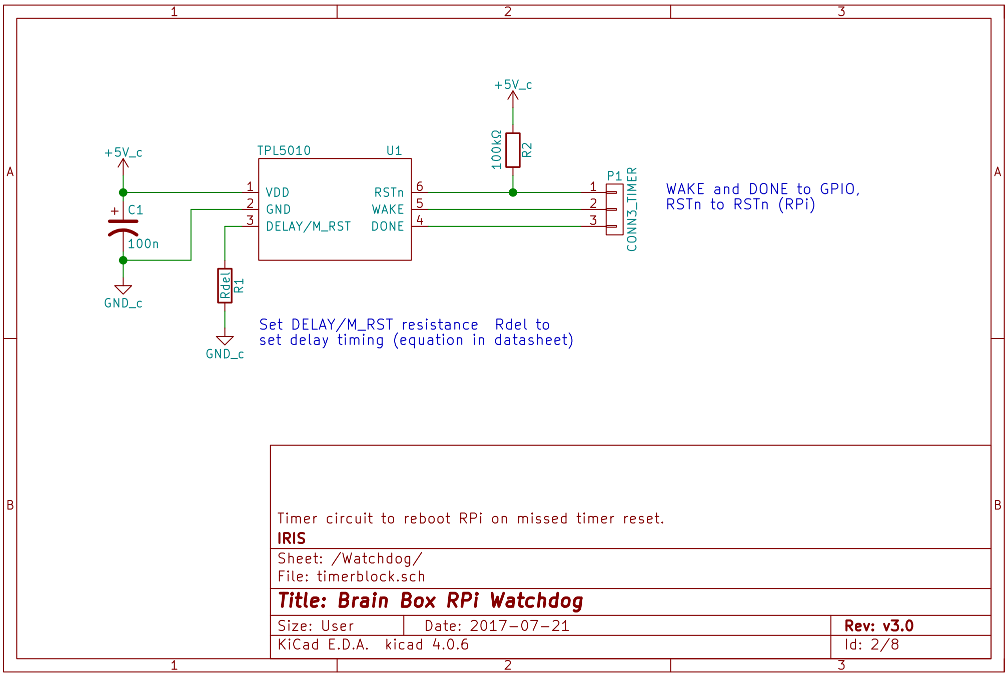


Figure C.1.8: Watchdog timer circuit. R_{del} sets delay timer.

C.1.2 Sensor Box Schematics

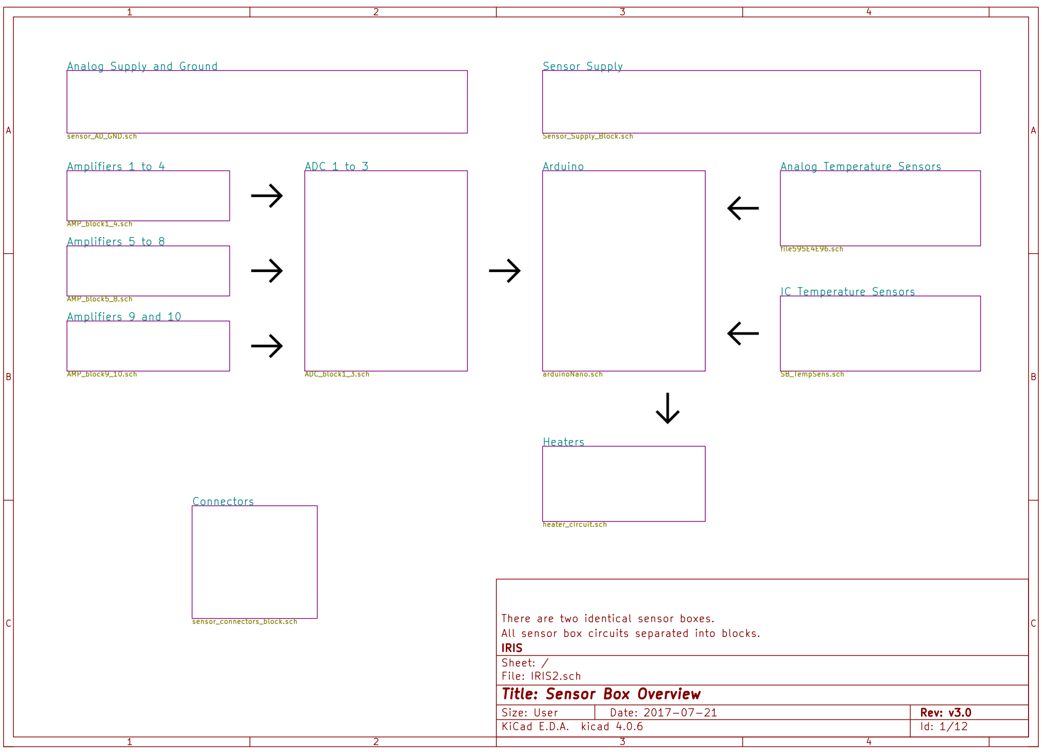


Figure C.1.9: Overview of the sensor box electrical subsystems. These blocks are circuits, which are shown below. Arrows describe a general flow of signals.

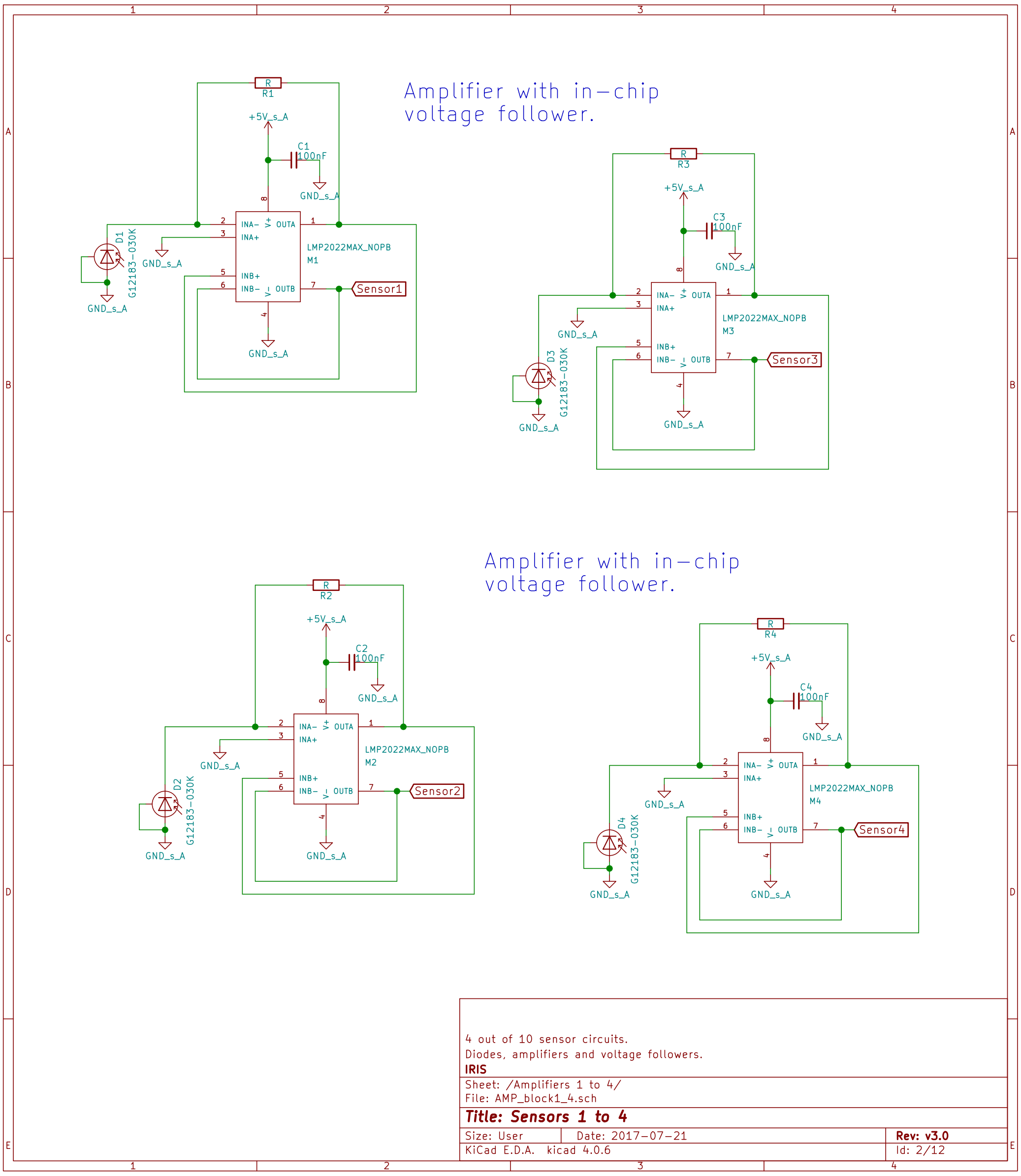


Figure C.1.10: Photodiode and amplifier circuits. Op-amps used are dual-input, so second input/output is used as a voltage follower.

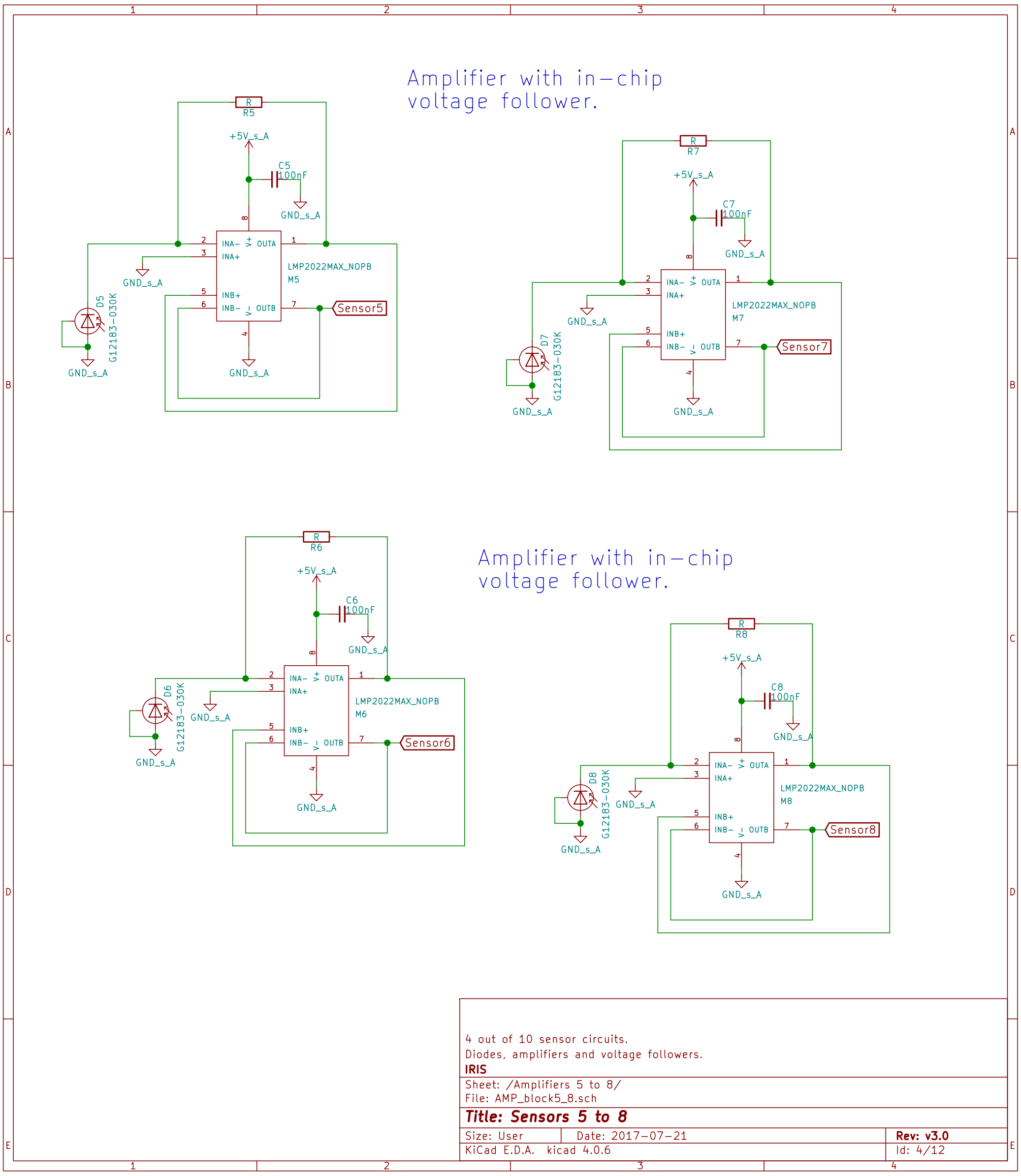


Figure C.1.11: Next four amplifiers.

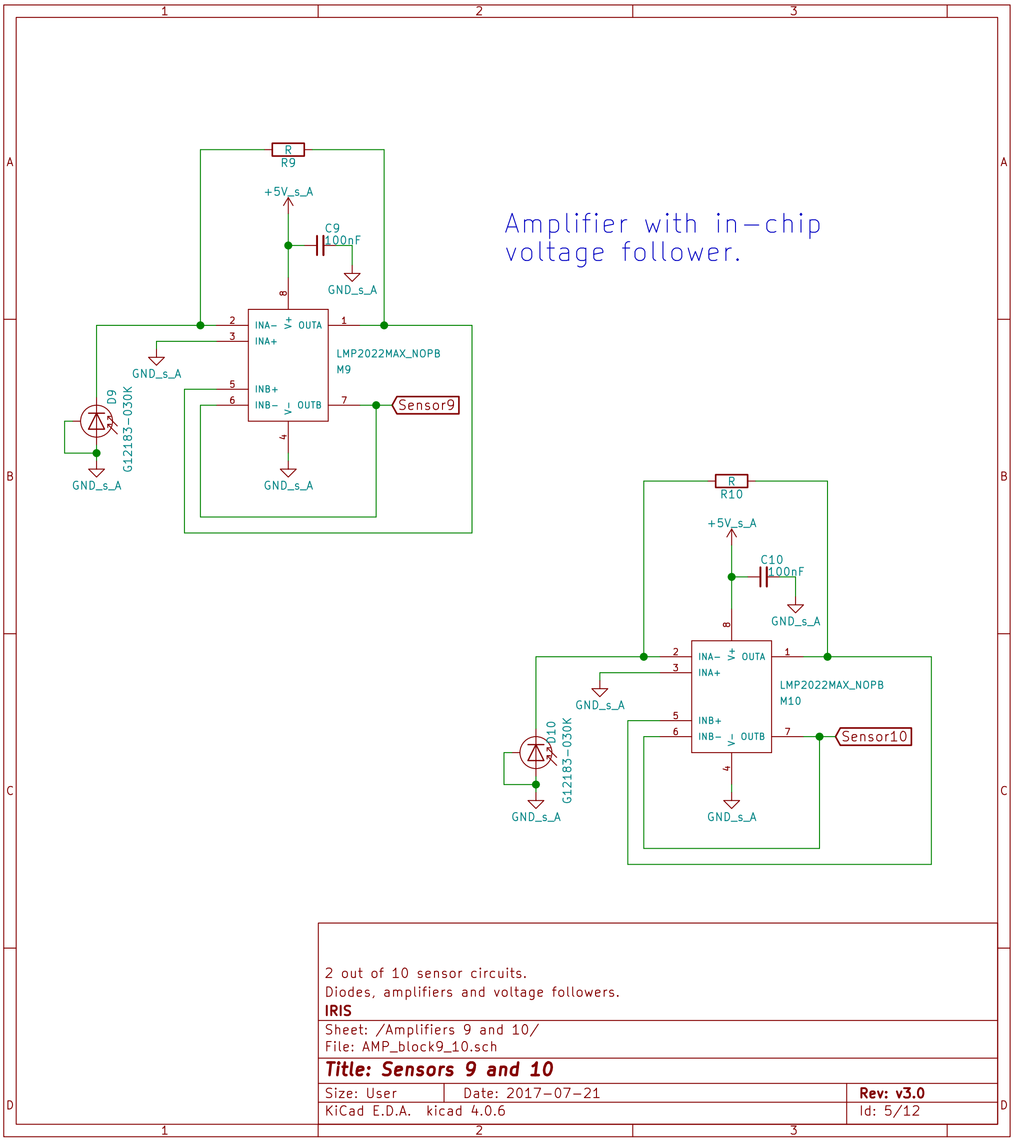


Figure C.1.12: Last two out of the ten amplifiers.

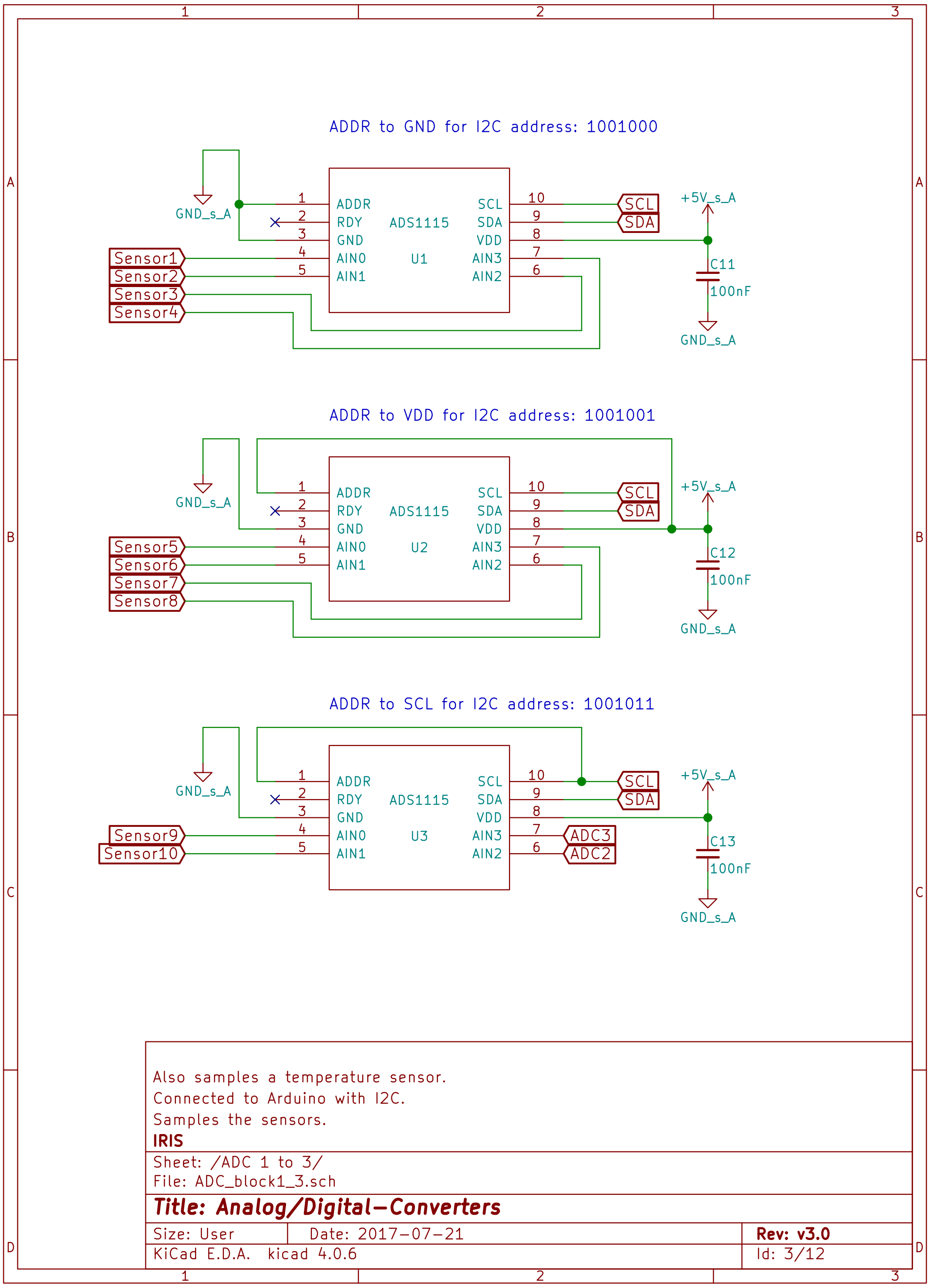


Figure C.1.13: I^{2}C ADCs which sample the sensors seen in the above figures. *ADC2* and *ADC3* on the bottom-most device sample the outside temperature through a thermistor.

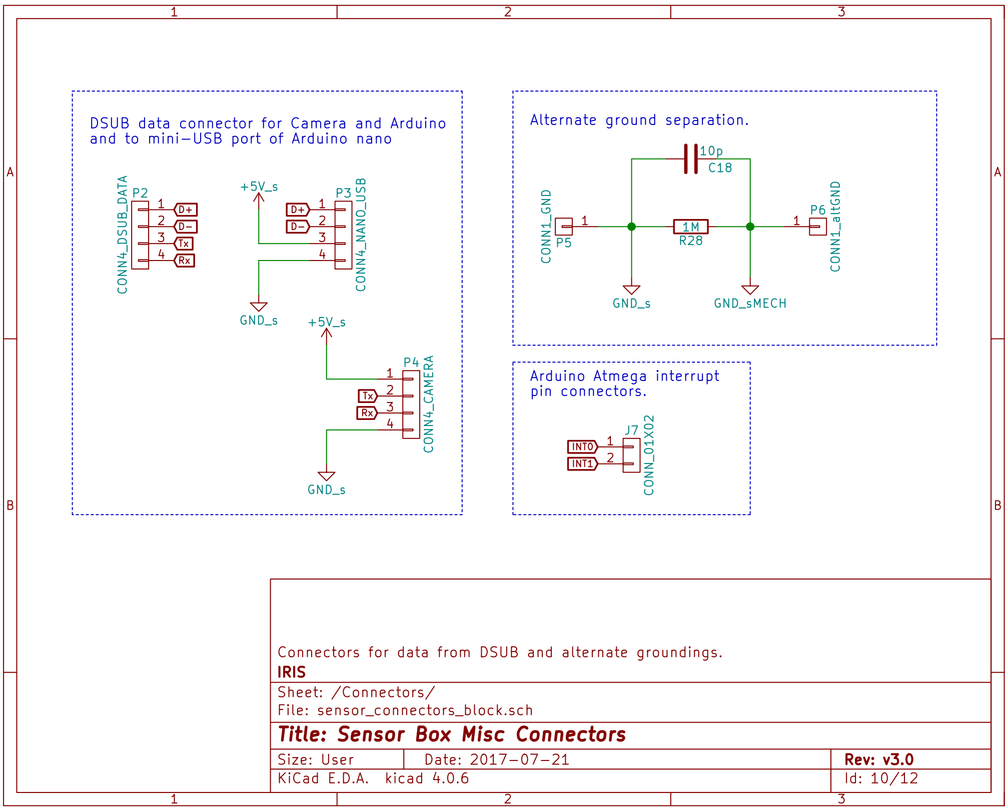


Figure C.1.14: Various connectors for the sensor boxes' PCBs. Description below.

In figure C.1.14, the left block contains the data-lines from the brain box, to the Arduino Nano. The top-right block contains the connectors and connections for alternate grounding. The bottom-right block shows the connectors for the Arduino's microcontroller external interrupt pins.

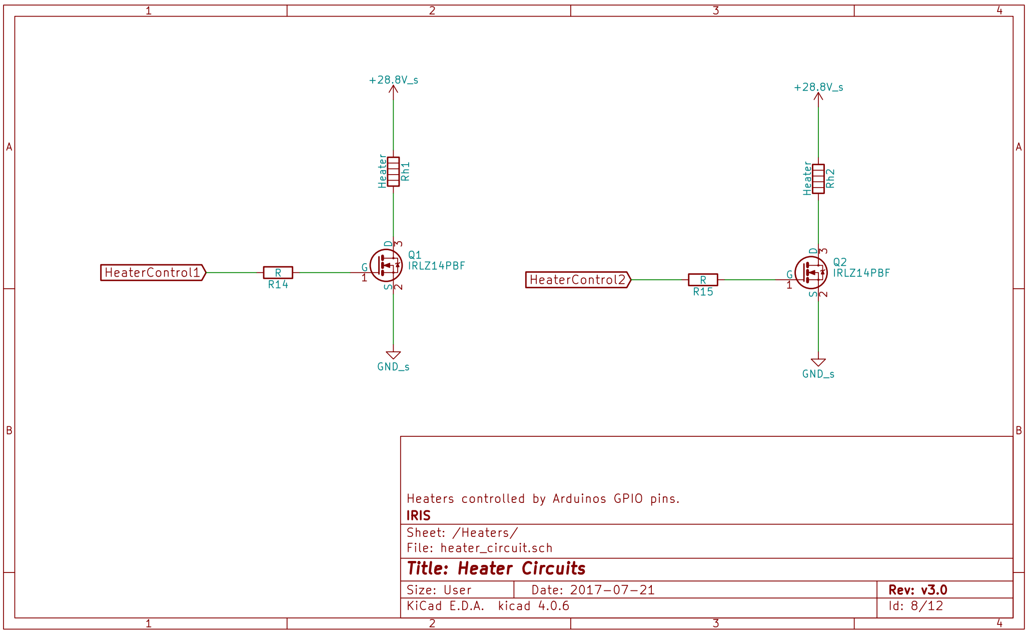


Figure C.1.15: Brain box heaters controlled by Raspberry Pi and fed power from battery.

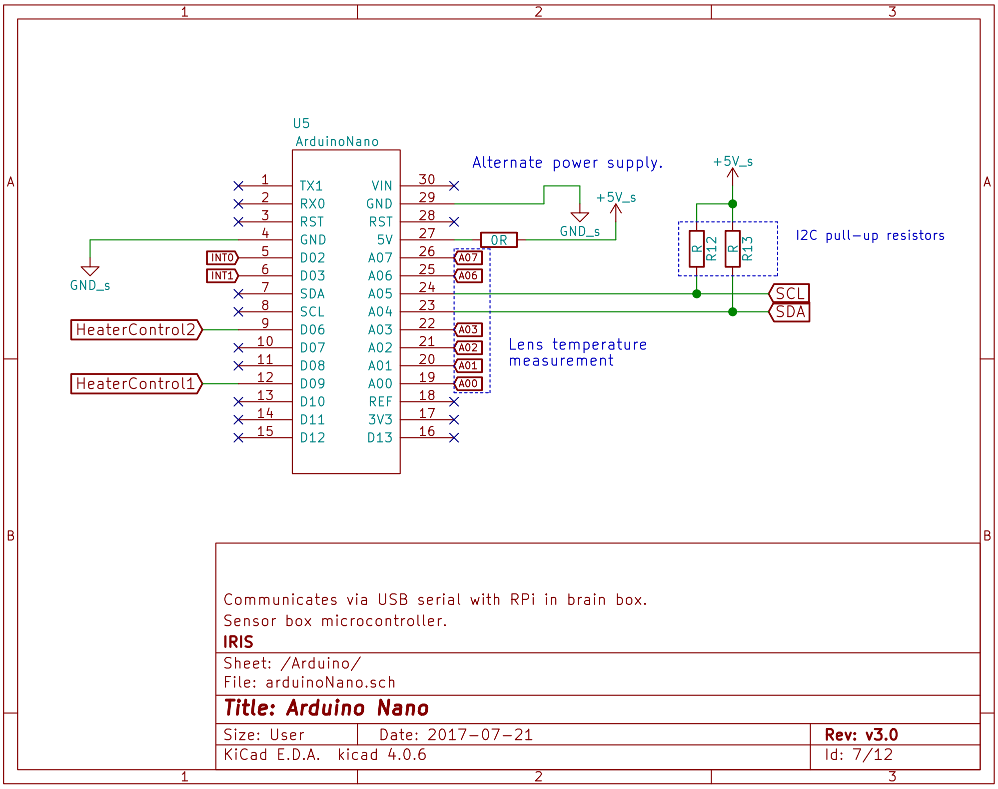


Figure C.1.16: Arduino nano connection with the board. It is soldered directly on to the board. Shown above are heater connections, I^2C pull-up resistors, and inputs from the analog temperature sensors that measure the lens temperatures.

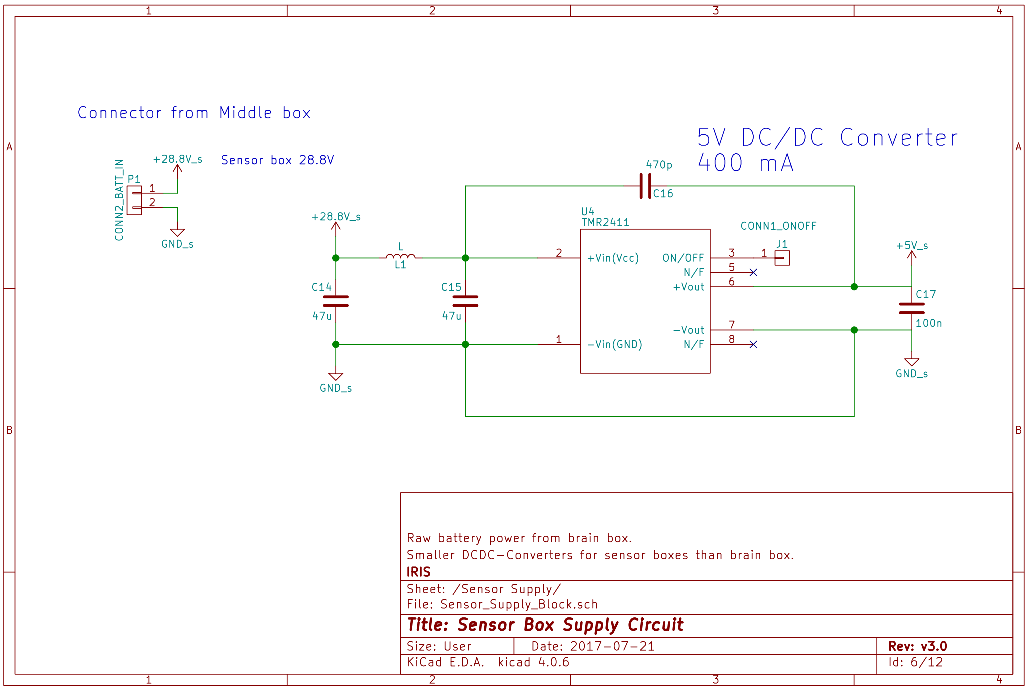


Figure C.1.17: Digital supply source: a DC/DC-Converter that is smaller than the brain box one. Sensor boxes require less power.

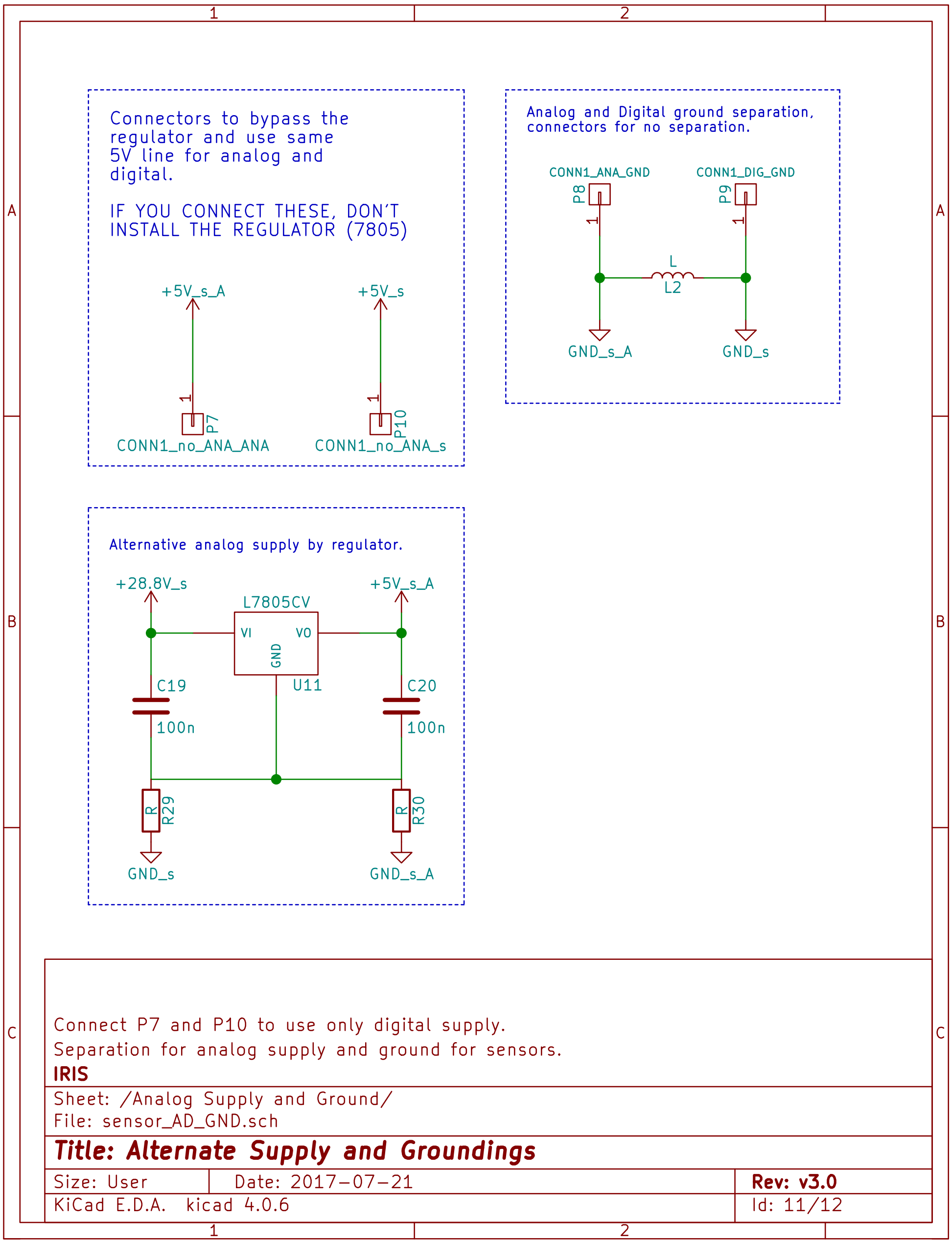


Figure C.1.18: Circuits relating to the boxes' analog supply and ground. Provides choice for various grounding schemes and also whether or not separate analog supply should be used at all.

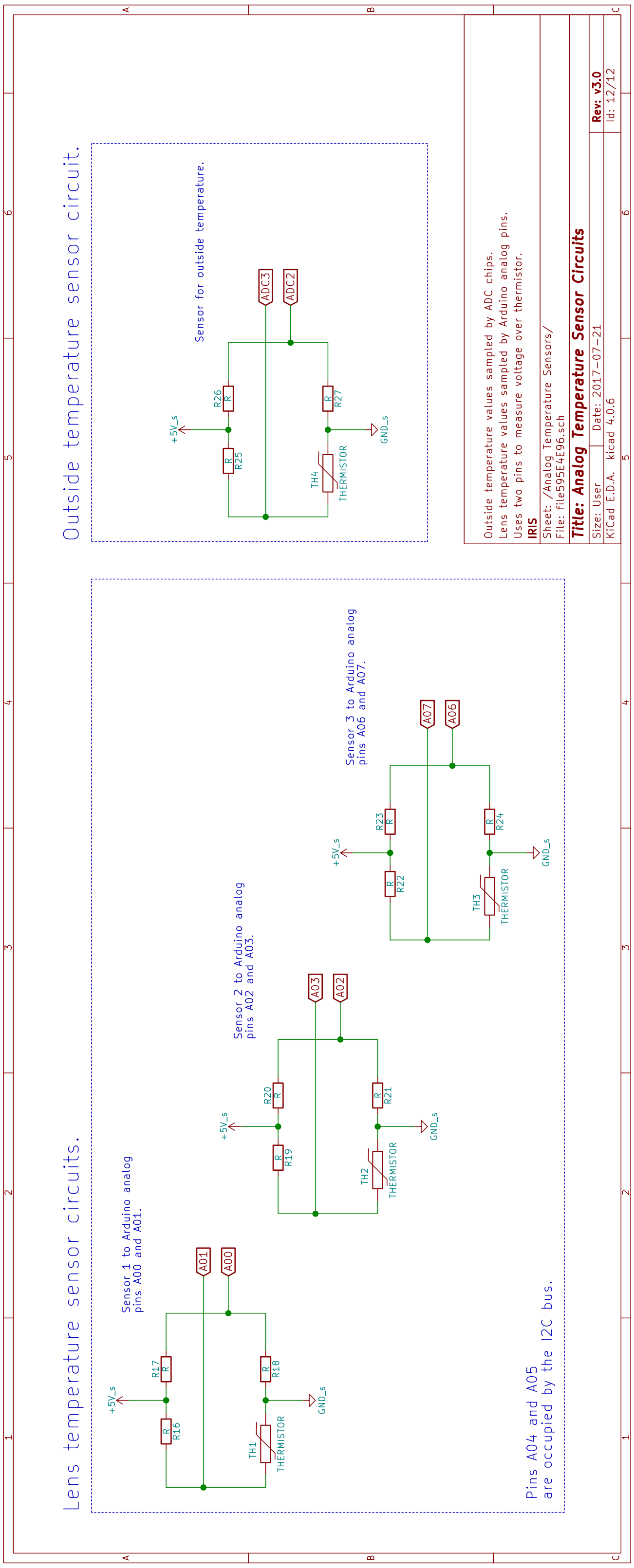


Figure C.1.19: Analog temperature sensor bridges. Analog devices are needed due to the low temperatures that are to be measured. These measure lens and outside temperatures.

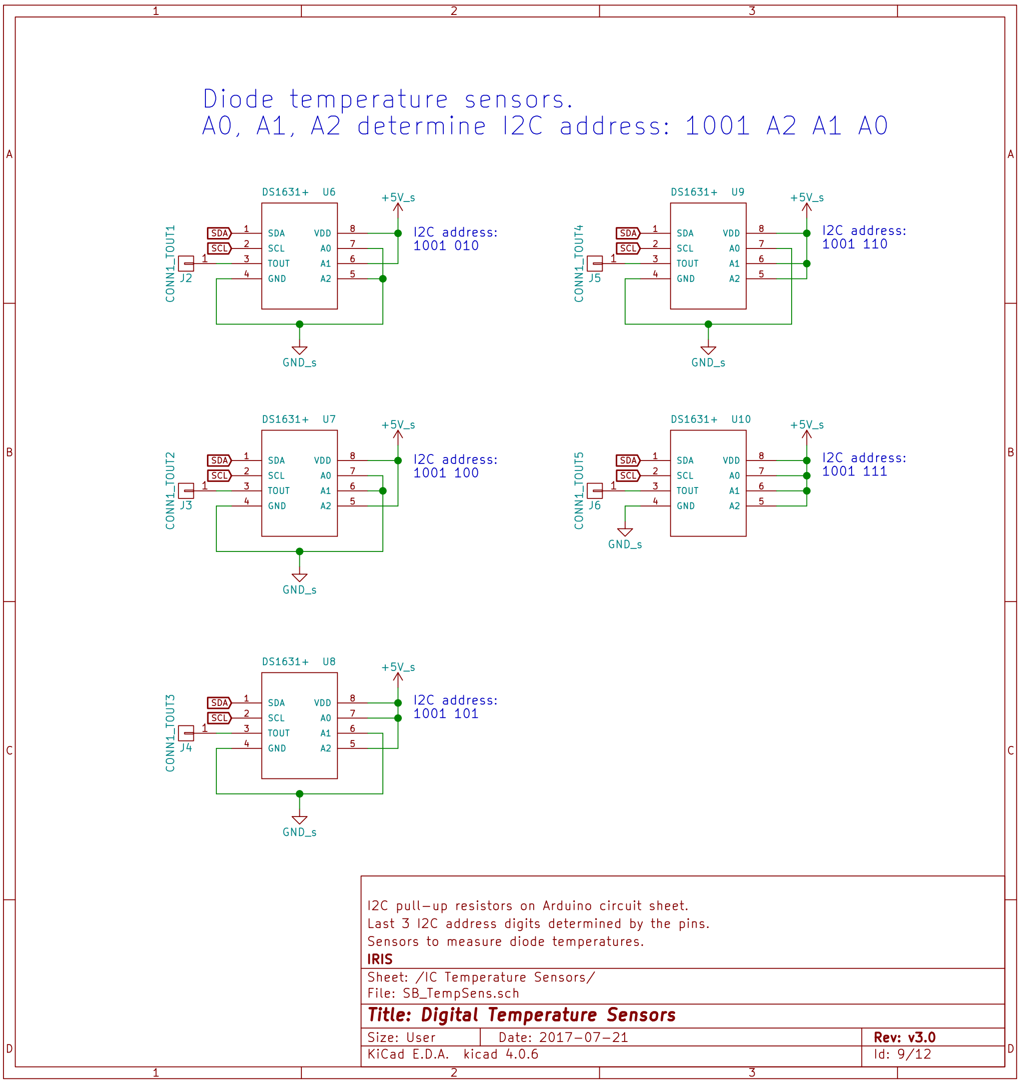


Figure C.1.20: Temperature sensors to measure diode temperatures. One sensor per two diodes. Also there to make sure the electronics are within their operating temperatures.

C.2 PCB Layouts

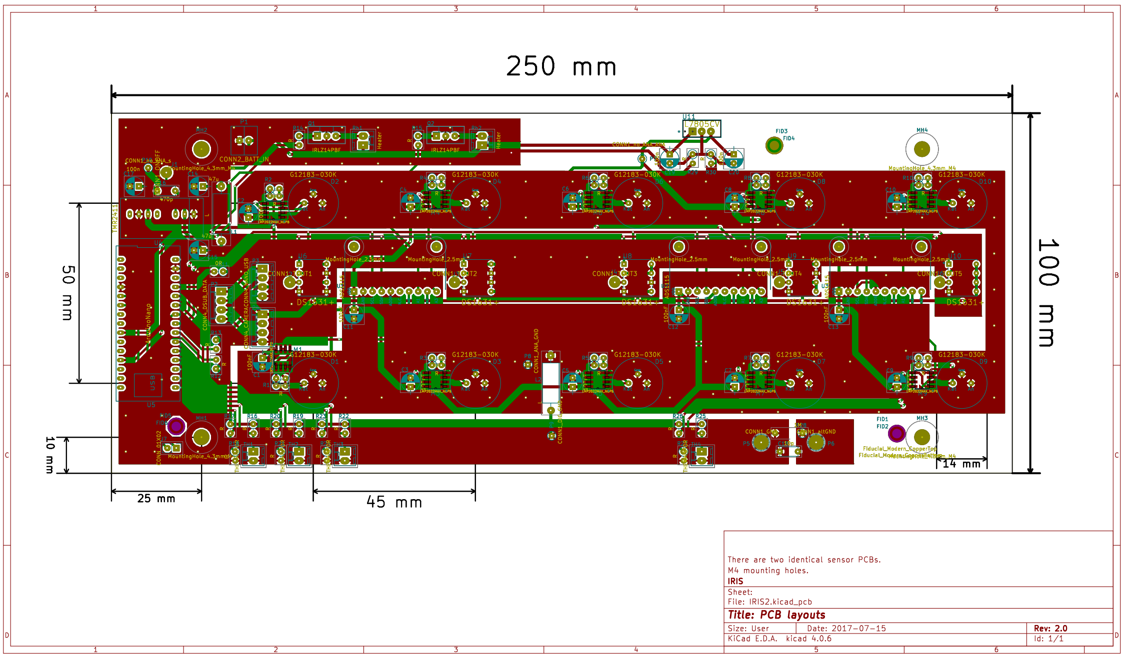


Figure C.2.1: Sensor box PCB. Description below.

The sensor box PCB layout is shown above in figure C.2.1. The mounting holes are M4, 4.3 mm diameter, they are symmetrically placed in each corner. The 10 diodes are shown to be placed in two rows of five; 50 mm between rows and 45 mm between diodes in each row.

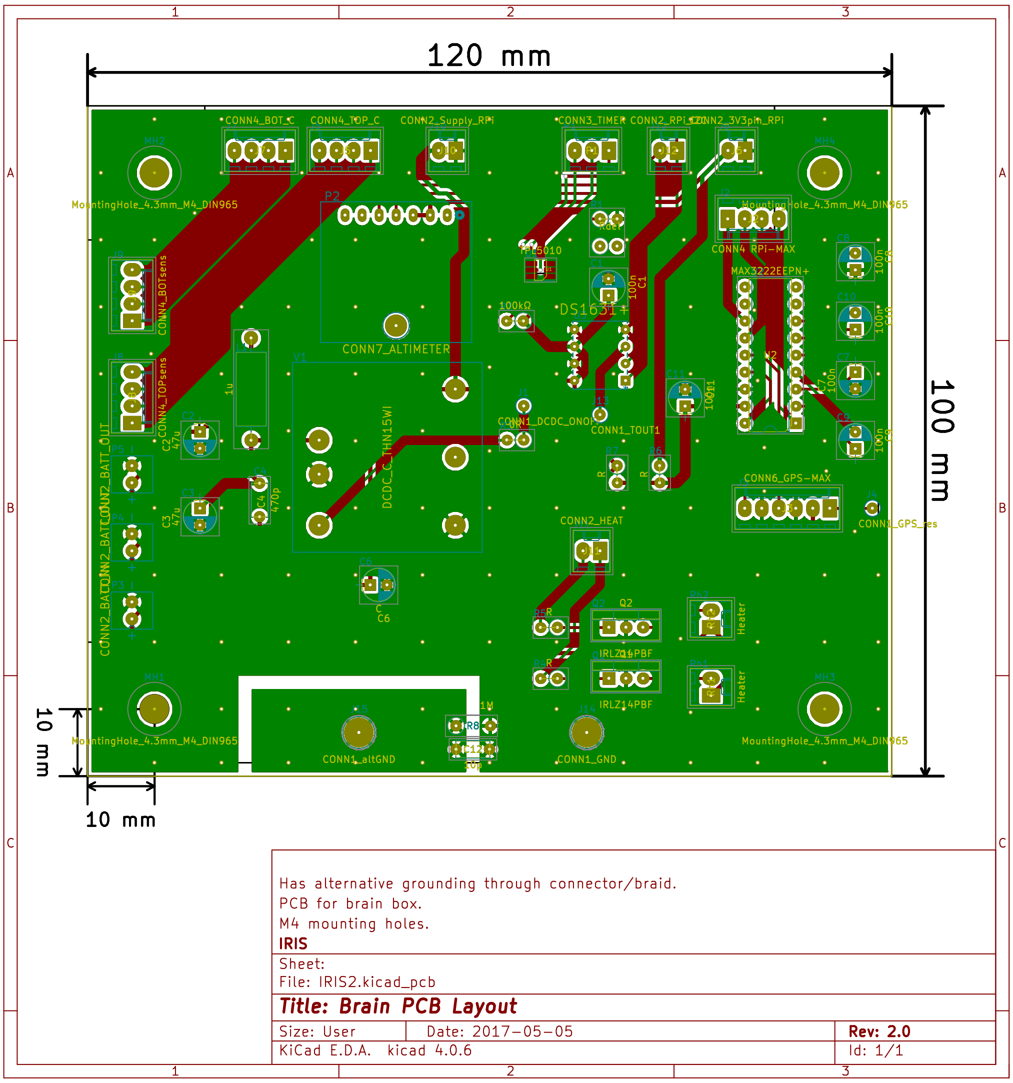
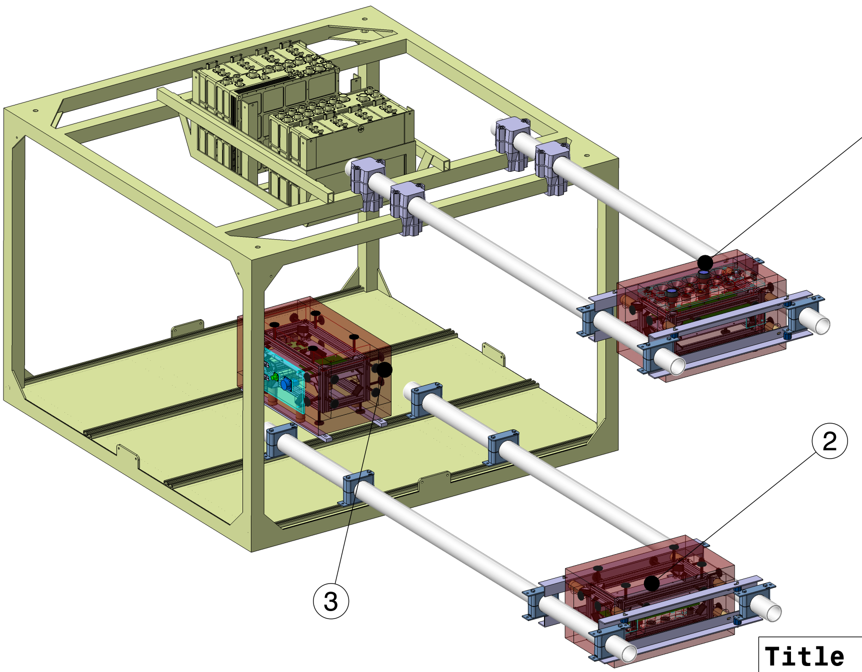


Figure C.2.2: Brain box PCB. Description below.

The brain box PCB layout is shown in figure C.2.2 Mounting holes are the same as for the sensor boxes' PCBs: M4, 4.3 mm diameter. The Raspberry Pi is mounted by itself, off-board, and is connected to the PCB only indirectly by wires and connectors.

C.3 Manufacturing drafts

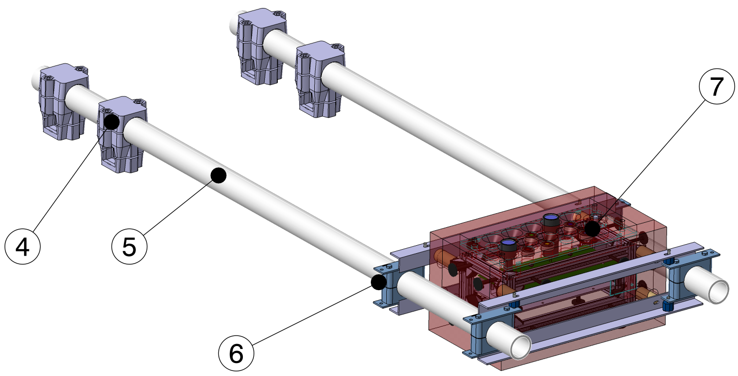
The following are the drafts that are to be used to manufacture the mechanical components of the experiment.



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

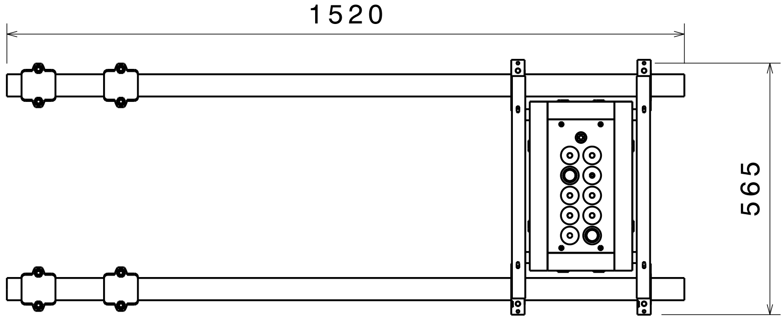
Isometric View
Scale : 1:14

Title IRIS v4.0		Author IRIS - BX25
Bolts /	**Item N°** /	**Material** /
Nuts /	**Scale** 1:14	**Dimensions [mm]** /
Washers /	**Weight [kg]** 21.0	**Sheet** 1/18

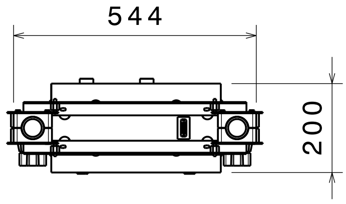


Isometric View
Scale : 1:10

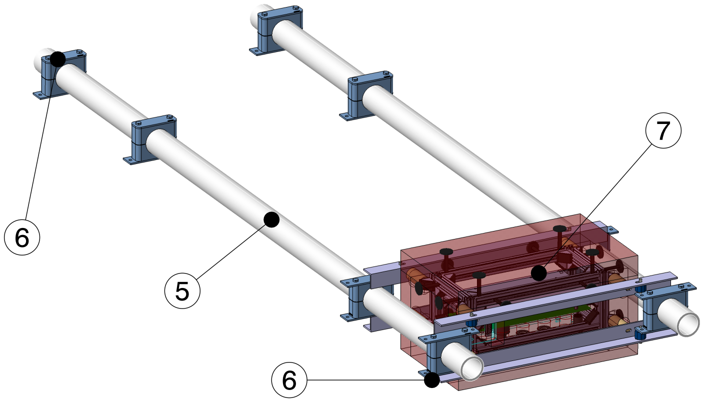
Item N°	Title
4	Two-way connector clamp GN135-V40-B50
5	Polycarbonate Boom 50/40mm
6	STAUFF Clamp 650,8-PA
7	Sensor box



Upper View
Scale : 1:12

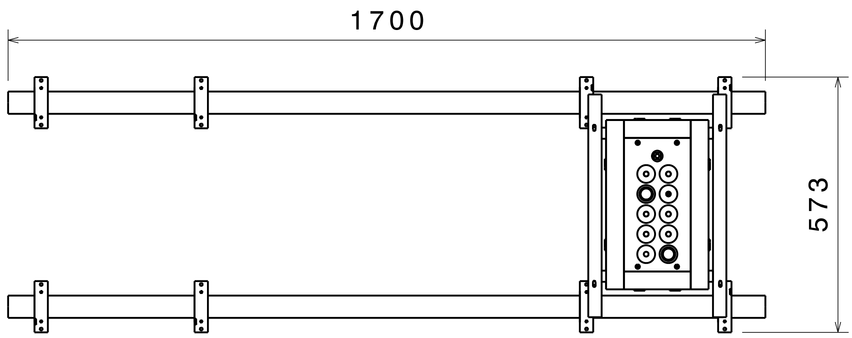


Side View
Scale : 1:12

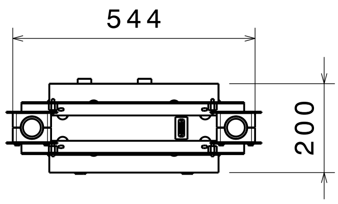


Isometric View
Scale : 1:10

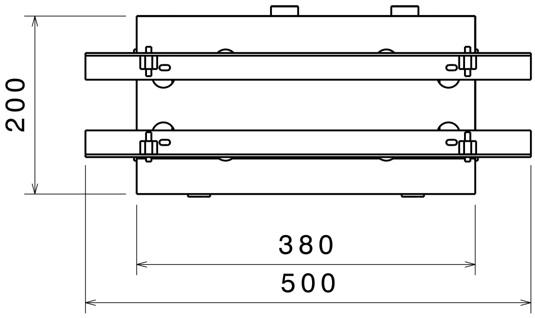
Item N°	Title
5	Polycarbonate Boom 50/40mm
6	STAUFF Clamp 650,8-PA
7	Sensor Box



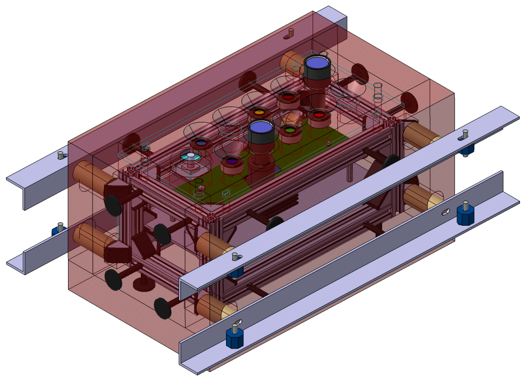
Upper View
Scale : 1:12



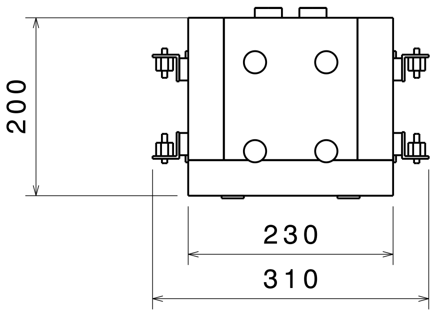
Side View
Scale : 1:12



Front View
Scale : 1:6

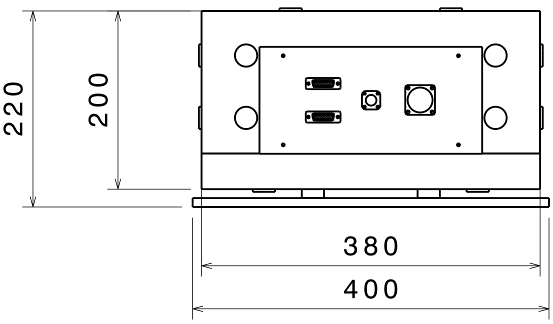


Isometric View
Scale : 1:6

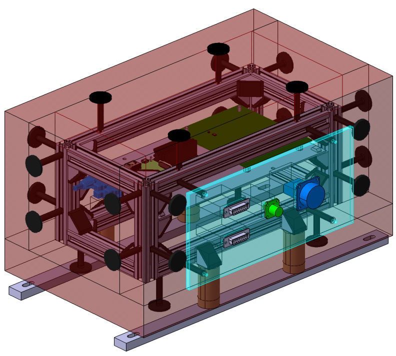


Side View
Scale : 1:6

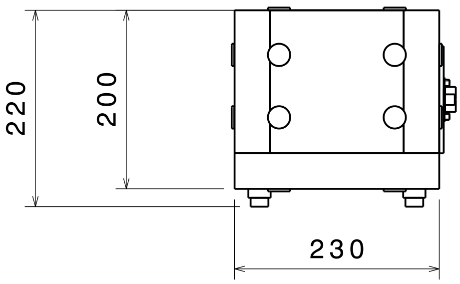
Title Sensor Box		**Author** IRIS - BX25
Bolts /	**Item N°** /	**Material** /
Nuts /	**Scale** 1:6	**Dimensions [mm]** 500x330x200
Washers /	**Weight [kg]** 3.556	**Sheet** 4/?8



Front View
Scale : 1:6

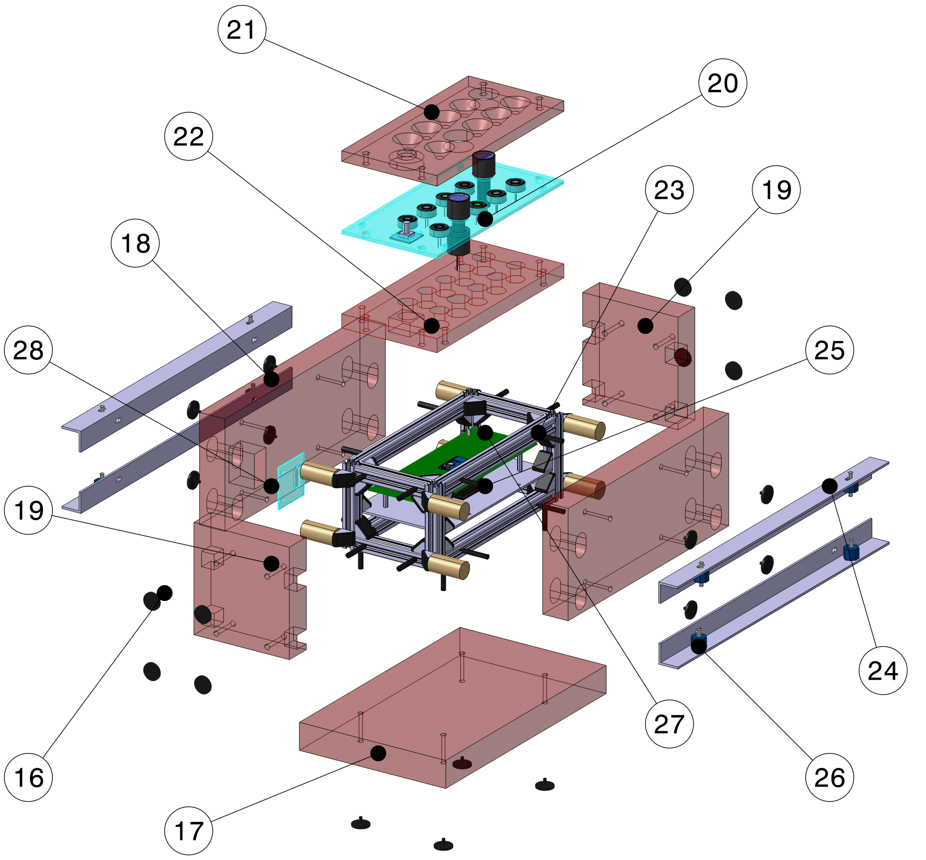


Isometric View
Scale : 1:6



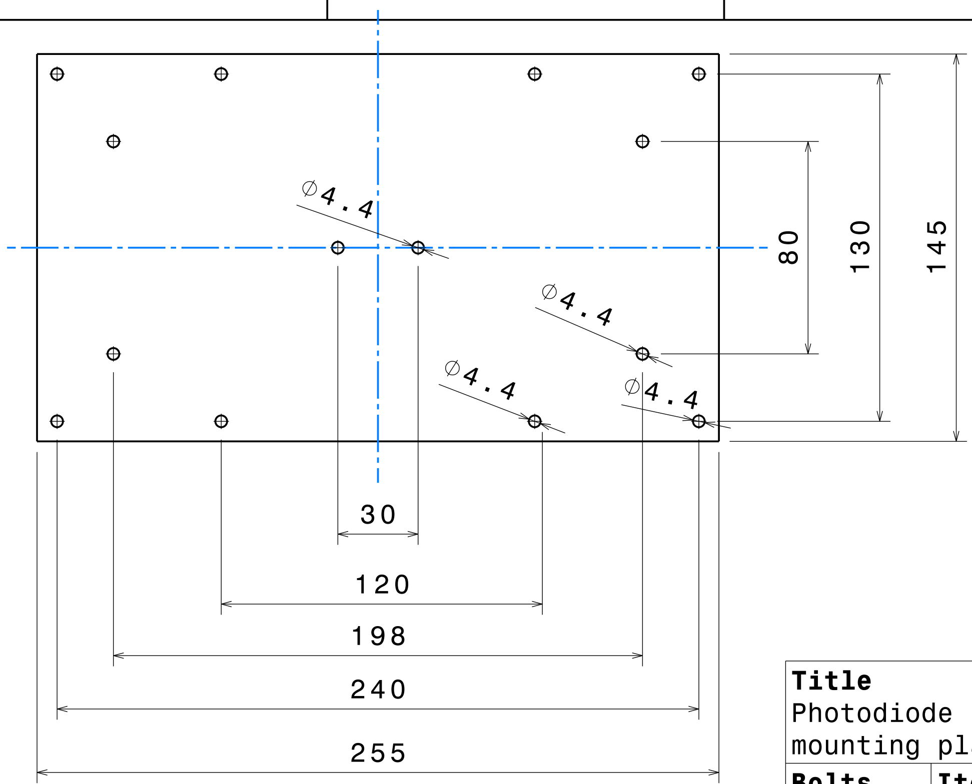
Side View
Scale : 1:6

Title Brain Box		**Author** IRIS - BX25
Bolts /	**Item N°** 3	**Material** /
Nuts /	**Scale** 1:6	**Dimensions [mm]** 380x230x220
Washers /	**Weight [kg]** 2.606	**Sheet** 5/18

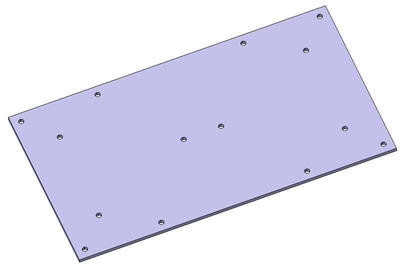


Item N°	Title
16	Nylon Screw M4
17	Styrofoam Bottom Side
18	Styrofoam D-Sub Side
19	Styrofoam Lateral Side
20	Optics Plate
21	Styrofoam Upper Optics
22	Styrofoam Lower Optics
23	Structural Frame
24	Angle section beam
25	Radiator
26	Rubber bumper
27	PCB
28	D-sub plexiglass

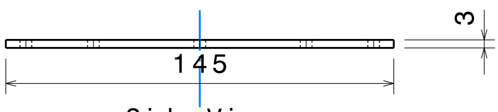
Isometric View
Scale: 1:7



Front View
Scale : 1:2

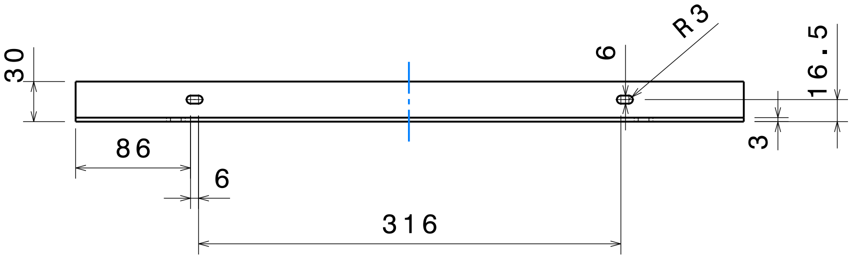


Isometric View
Scale : 1:4

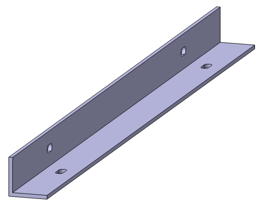


Side View
Scale : 1:2

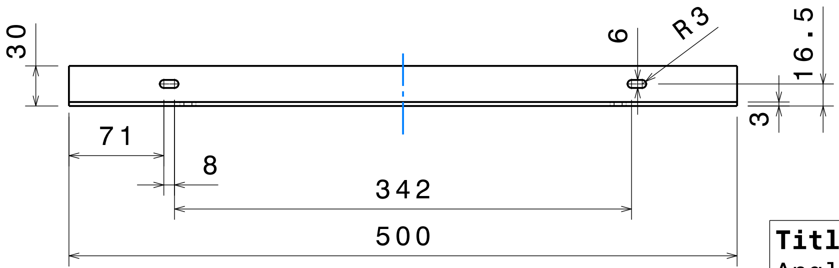
Title Photodiode PCB mounting plate		**Author** IRIS - BX25
Bolts 16 M4	**Item N°** /	**Material** Aluminium
Nuts 16 M4	**Scale** 1:2	**Dimensions [mm]** 255x145x3
Washers 32 M4	**Weight [kg]** 0.299	**Sheet** 7/18



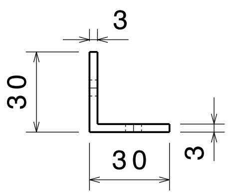
Longitudinal View 1
Scale : 1:4



Isometric View
Scale : 1:4

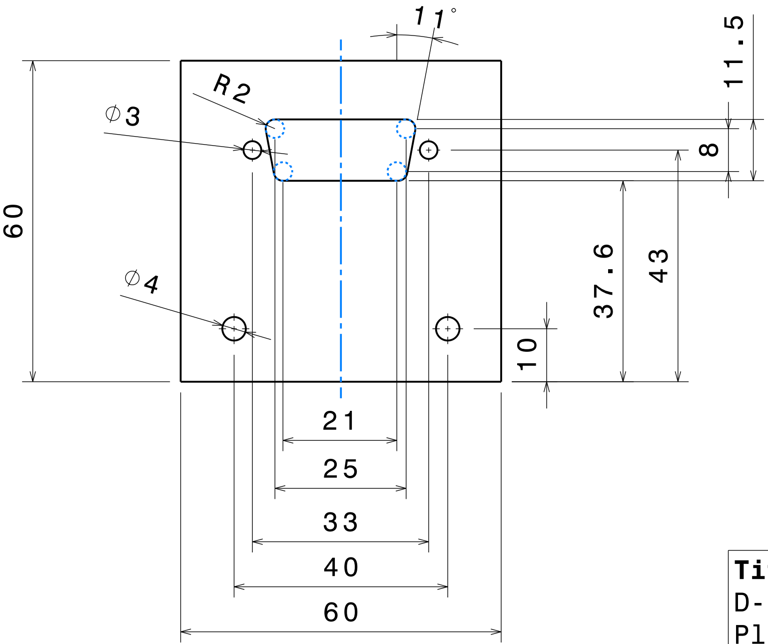


Longitudinal View 2
Scale : 1:4

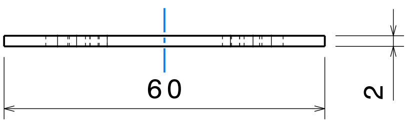


Profile View
Scale : 1:2

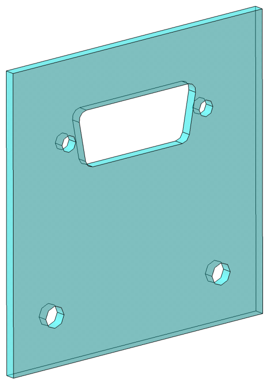
Title Angle section beam		**Author** IRIS - BX25
Bolts 4 M4x20 2 M6x20	**Item N°** 24	**Material** Aluminium
Nuts 4 M4 2 M6	**Scale** 1:2 and 1:4	**Dimensions [mm]** 500x30x30
Washers 8 M4 4 M6	**Weight [kg]** 0.229	**Sheet** 8/18



Front View
Scale : 1:1

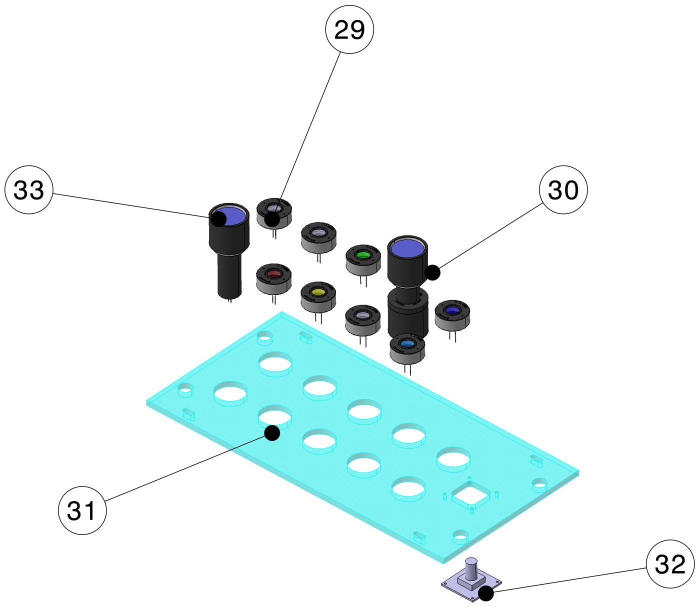


Side View
Scale : 1:1



Isometric View
Scale : 1:1

Title D-sub 15 connector Plate		**Author** IRIS - BX25
Bolts 2 M3 2 M4	**Item N°** 28	**Material** Plexiglass
Nuts 2 M3 2 M4	**Scale** 1:1	**Dimensions [mm]** 60x60x2
Washers 4 M3 2 M4	**Weight [kg]** 0.008	**Sheet** 9/18

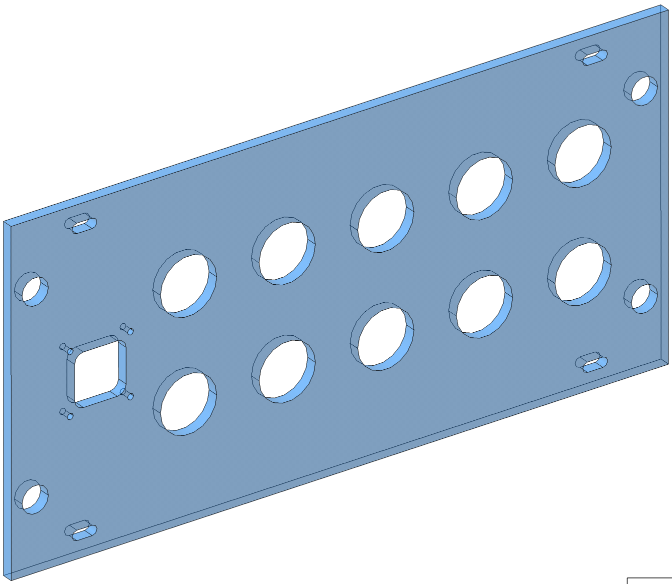


Item N°	Title
29	Filter-Photodiode Optomechanics
30	VIS Fisheye Lens
31	Optics Plexiglass Plate
32	Camera uCam
33	NIR Fisheye Lens

Isometric View
Scale : 1:4

D C B A

4 3 2 1

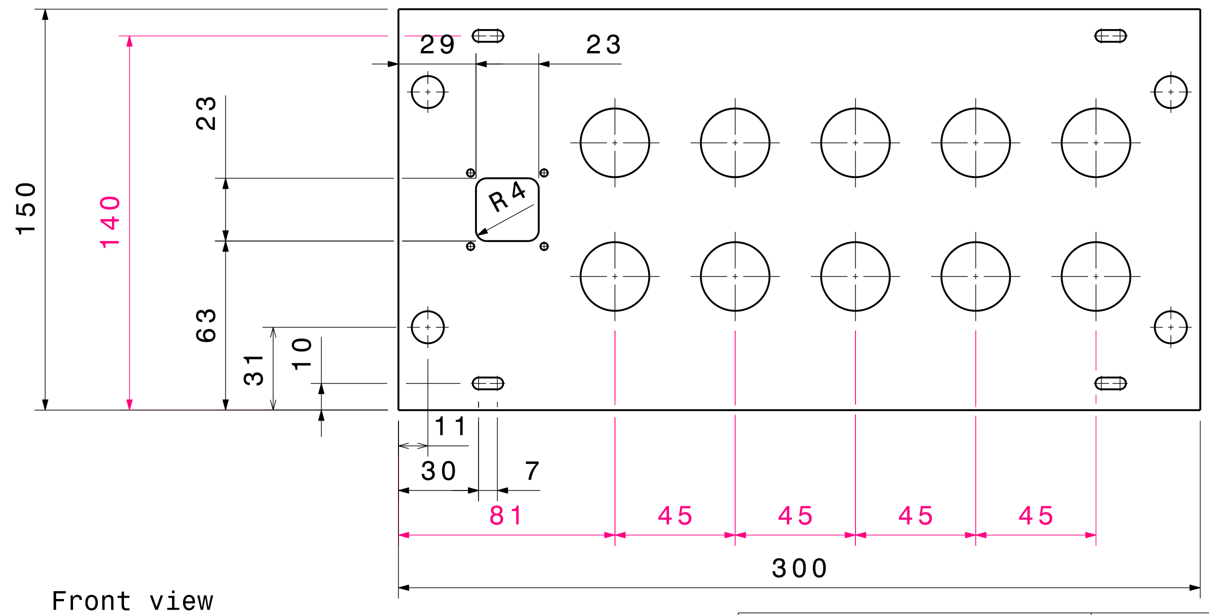


Isometric view
Scale 1:2

Title **Optics plate**		Author IRIS - BX25
Bolts /	**Item N°** 31	**Material** White opaque plexglass
Nuts /	**Scale** 1:2	**Dimensions** **300x150x5 [mm]**
Washers /	**Weight** 0.23 [kg]	**Sheet** 11/18

4 3 2 1

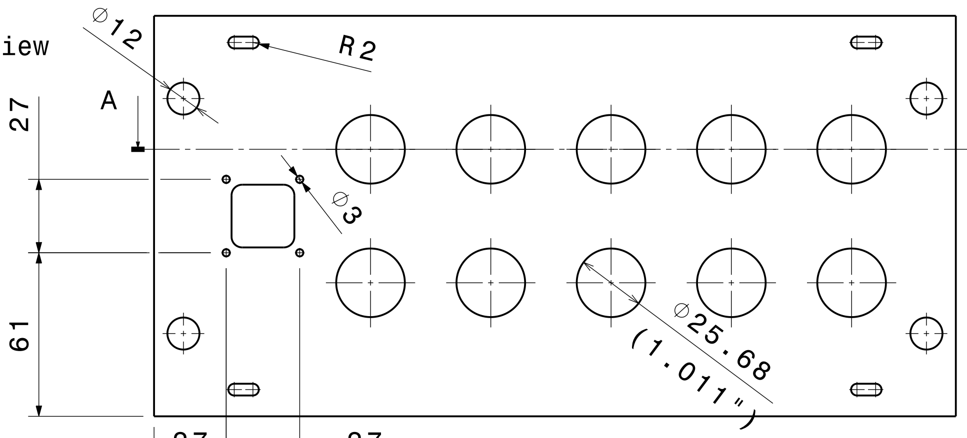
D A



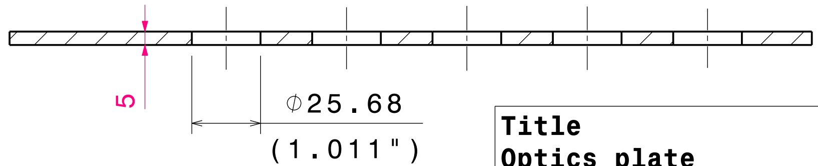
Front view

Title **Optics plate**		**Author** IRIS - BX25
Bolts /	**Item N°** 31	**Material** White opaque plexglass
Nuts /	**Scale** 1:2	**Dimensions** /
Washers /	**Weight** 0.23 [kg]	**Sheet** 12/18

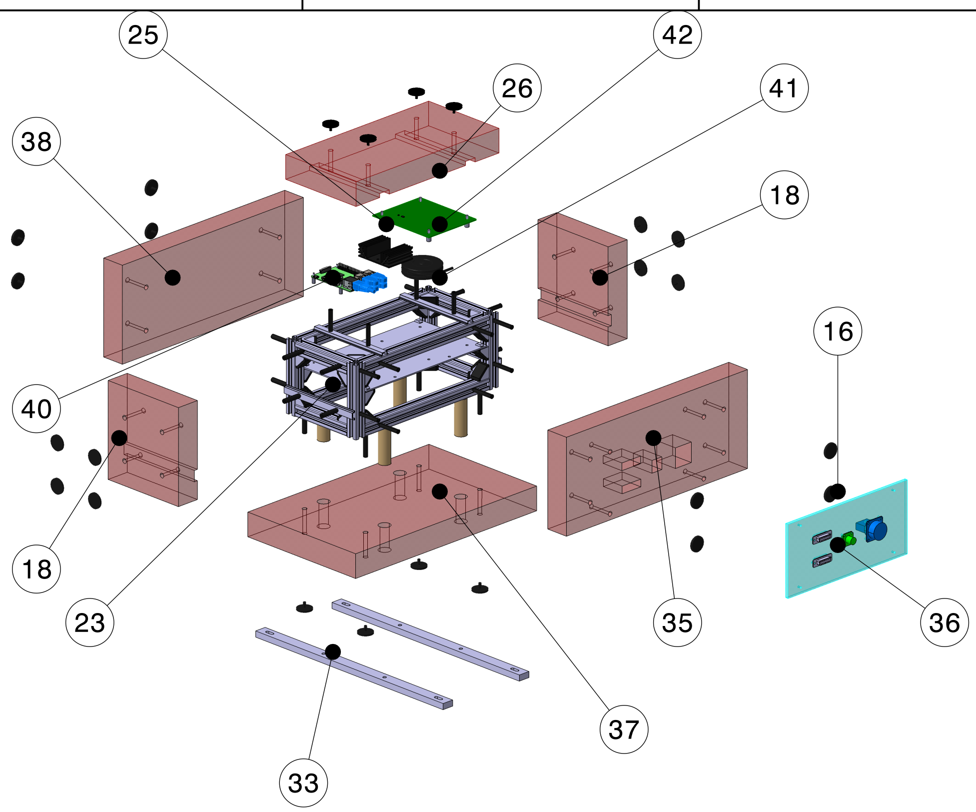
Front view



Section view A-A

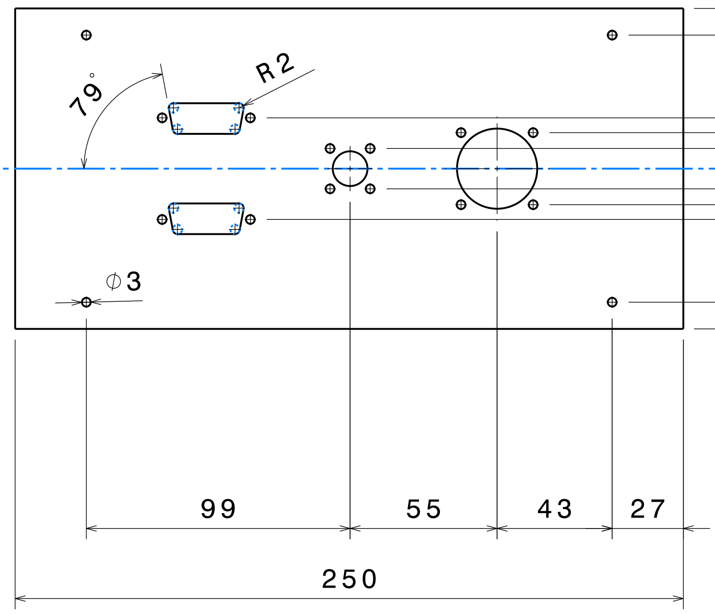


Title **Optics plate**		**Author** IRIS - BX25
Bolts /	**Item N°** 31	**Material** White opaque plexglass
Nuts /	**Scale** 1:2	**Dimensions** /
Washers /	**Weight** 0.23 [kg]	**Sheet** 13/18

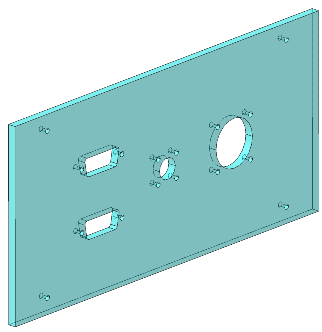


Item N°	Title
33	Rectangular beam
34	Styrofoam Longitudinal Side
35	Styrofoam Connector Side
36	Connector Plate
37	Styrofoam Lower Side
38	Styrofoam Upper Side
39	Electronics Plate
40	RPi Model B
41	GPS
42	PCB
16	Nylon Screw M4
18	Styrofoam Lateral Side
23	Structural Frame
25	Radiator

Isometric View
Scale : 1:8

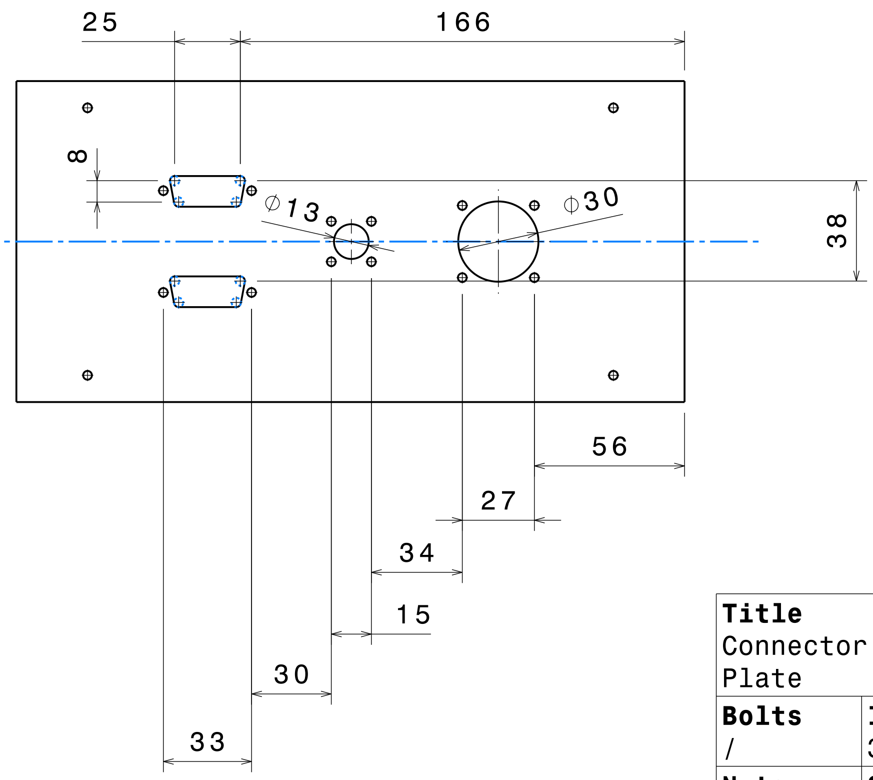


Front View
Scale : 1:2

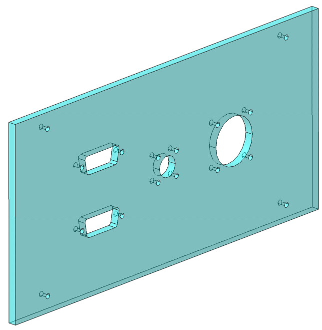


Isometric View
Scale : 1:3

Title		**Author**
Connector Plexiglass Plate		IRIS - BX25
Bolts	**Item N°**	**Material**
/	36	Plexiglass
Nuts	**Scale**	**Dimensions [mm]**
/	1:2	250x120x5
Washers	**Weight [kg]**	**Sheet**
/	0.171	15/18

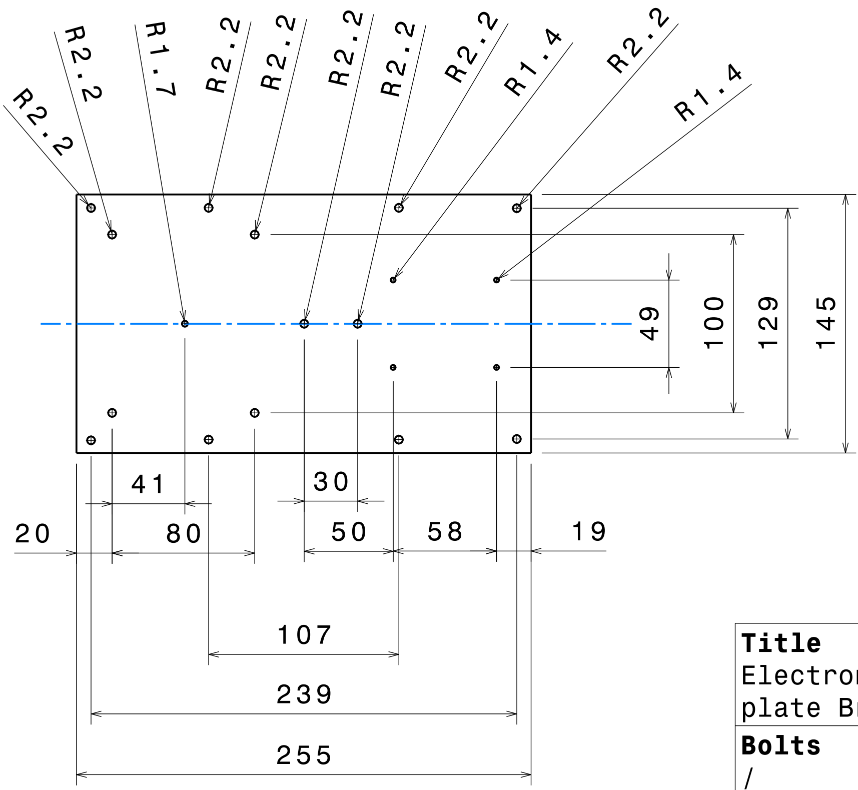


Front View
Scale : 1:2

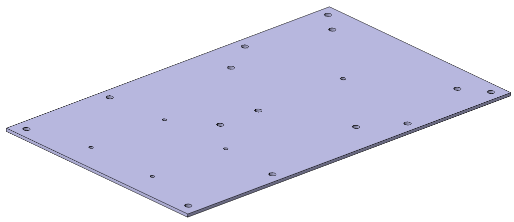


Isometric View
Scale : 1:3

Title		**Author**
Connector Plexiglass Plate		IRIS - BX25
Bolts /	**Item N°** 36	**Material** Plexiglass
Nuts /	**Scale** 1:2	**Dimensions [mm]** 250x120x5
Washers /	**Weight [kg]** 0.171	**Sheet** 16/18

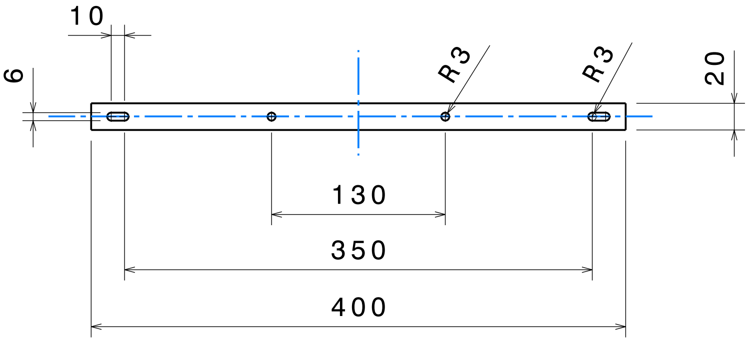


Front View
Scale : 1:3

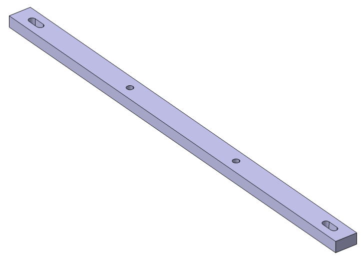


Isometric View
Scale : 1:3

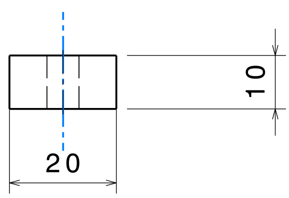
Title Electronics mounting plate Brain		**Author** IRIS - BX25
Bolts /	**Item N°** /	**Material** Aluminium
Nuts /	**Scale** 1:3	**Dimensions [mm]** 255x145x3
Washers /	**Weight [kg]** 0.199	**Sheet** 17/18



Longitudinal View
Scale : 1:4



Isometric View
Scale : 1:4



Profile View
Scale : 1:1

Title Rectangular beam Brain mounting		**Author** IRIS - BX25
Bolts 4 M6	**Item N°** 29	**Material** Aluminium
Nuts 4 M6	**Scale** 1:1 and 1:4	**Dimensions [mm]** 400x20x10
Washers 4 M6	**Weight [kg]** 0.21	**Sheet** 18/18

D Checklists

Table D.0.1: Everything shall be checked in the same order as mention below

Time	**Done by**	**Description**	**If done, mark with X**
Pre launch	IRIS Optics Department	Remove cover from the upper camera on lower box. Take picture	
Pre launch	IRIS Optics Department	Remove cover from the lower camera on lower box. Take picture	
Pre launch	IRIS Software Department	Check all processes are running. (PID)	
Pre launch	IRIS Software Department	Check that camera takes pictures and stores them.	
Pre launch	IRIS Software Department	Check interfaces are up.	
PPre launch	IRIS Software Department	Check SSH and E-Link connection.	
Pre launch	IRIS Software Department	Check GPS is up and running.	
Pre launch	IRIS Software Department	Check files are created.	
Pre launch	IRIS Software Department	Check bandwith limiter is set.	
Post Landing	Recovery team	Collect Brain box (inside gondola)	
Post Landing	Recovery team	If possible, retrieve upper sensor box (outside gondola)	
Post Landing	Recovery team	If possible, retrieve lower sensor box (outside gondola)	

E WBS and Gantt Chart

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

E.1 WBS

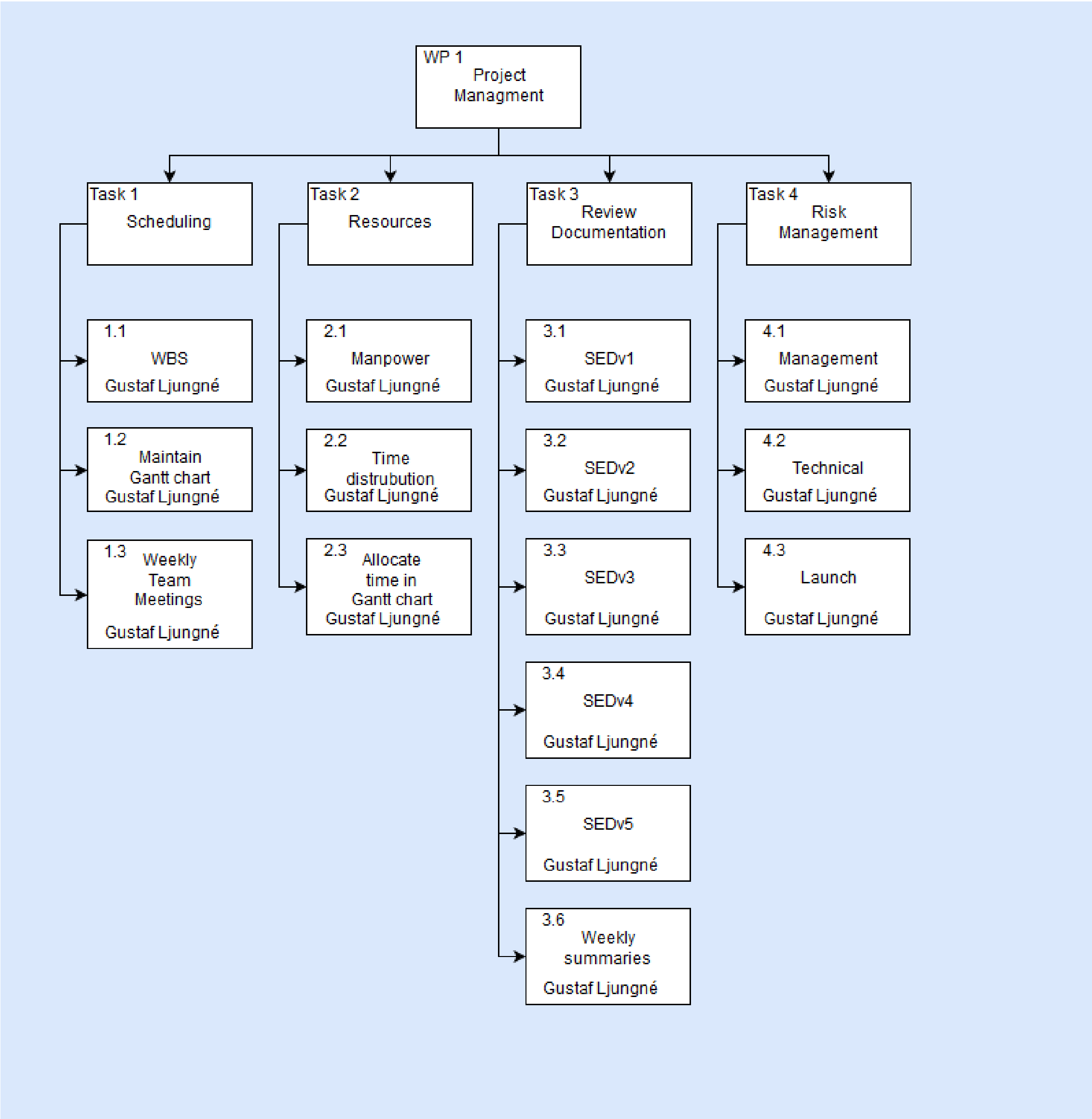


Figure E.1.1: WBS - Project Manager

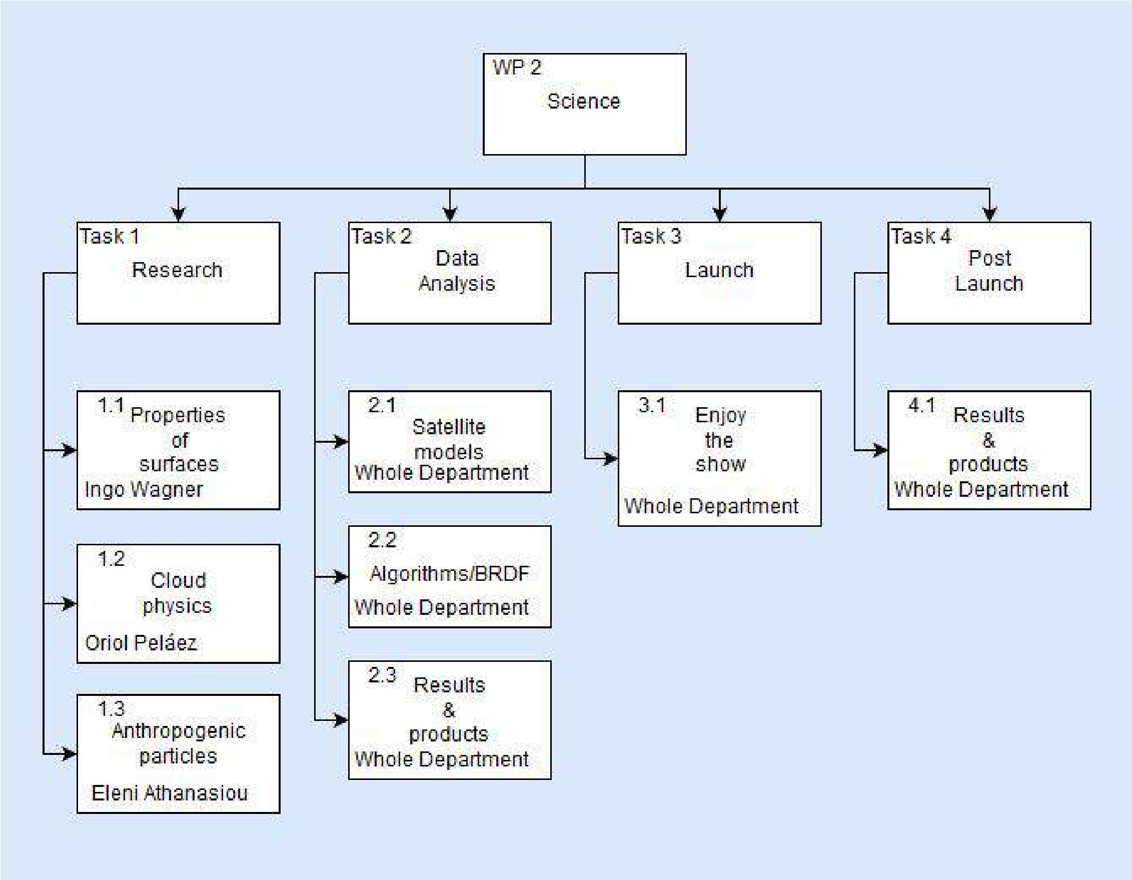


Figure E.1.2: WBS - Science

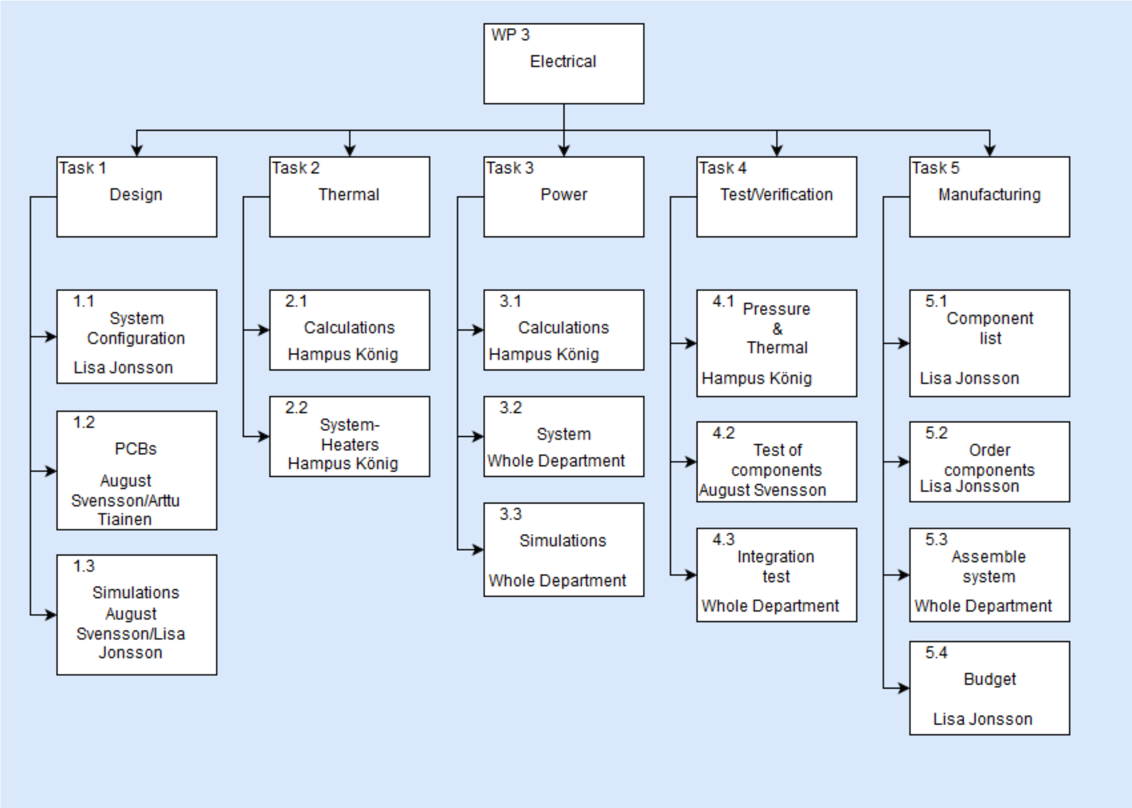


Figure E.1.3: WBS - Electrical

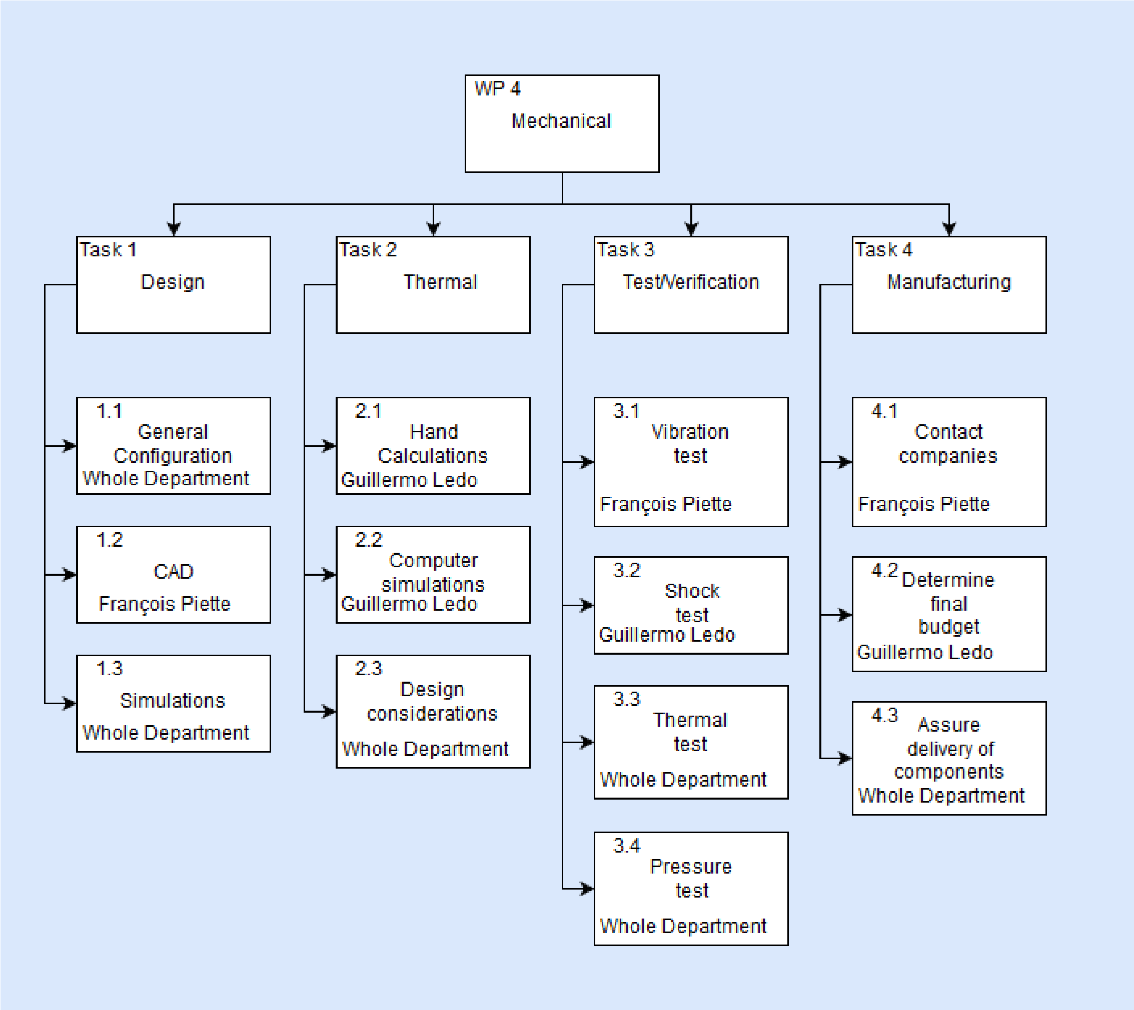


Figure E.1.4: WBS - Mechanical

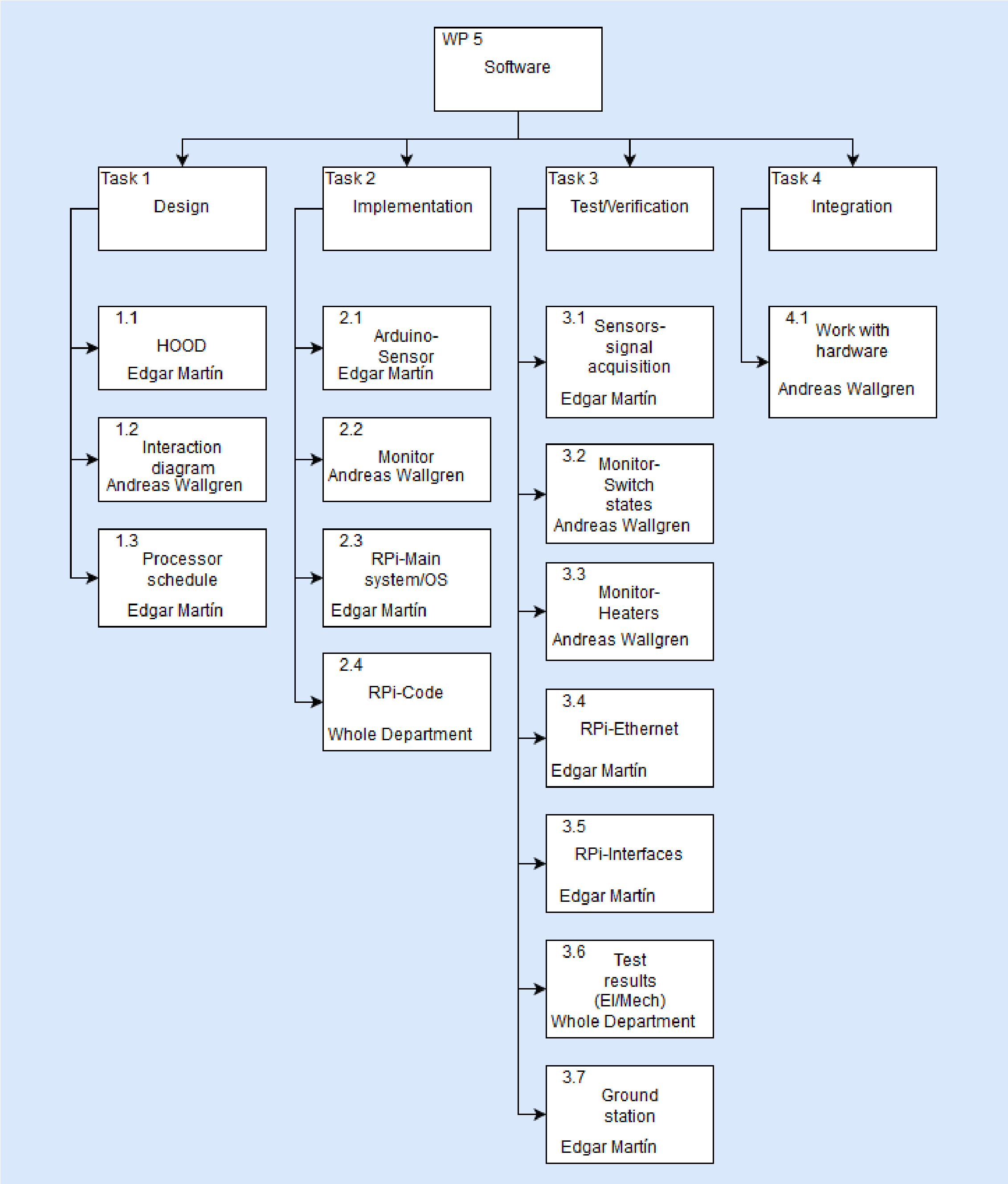


Figure E.1.5: WBS - Software

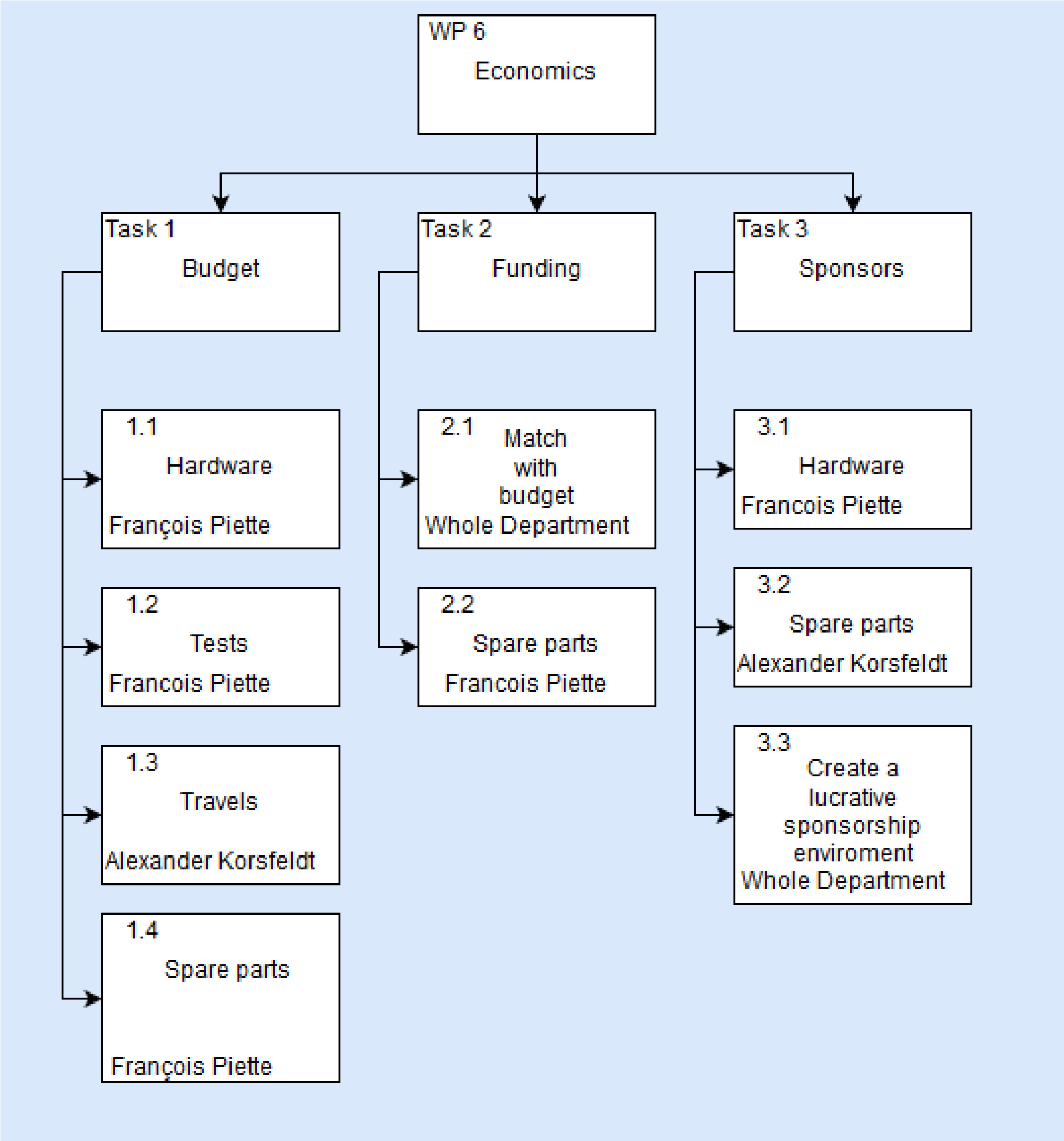


Figure E.1.6: WBS - Economics

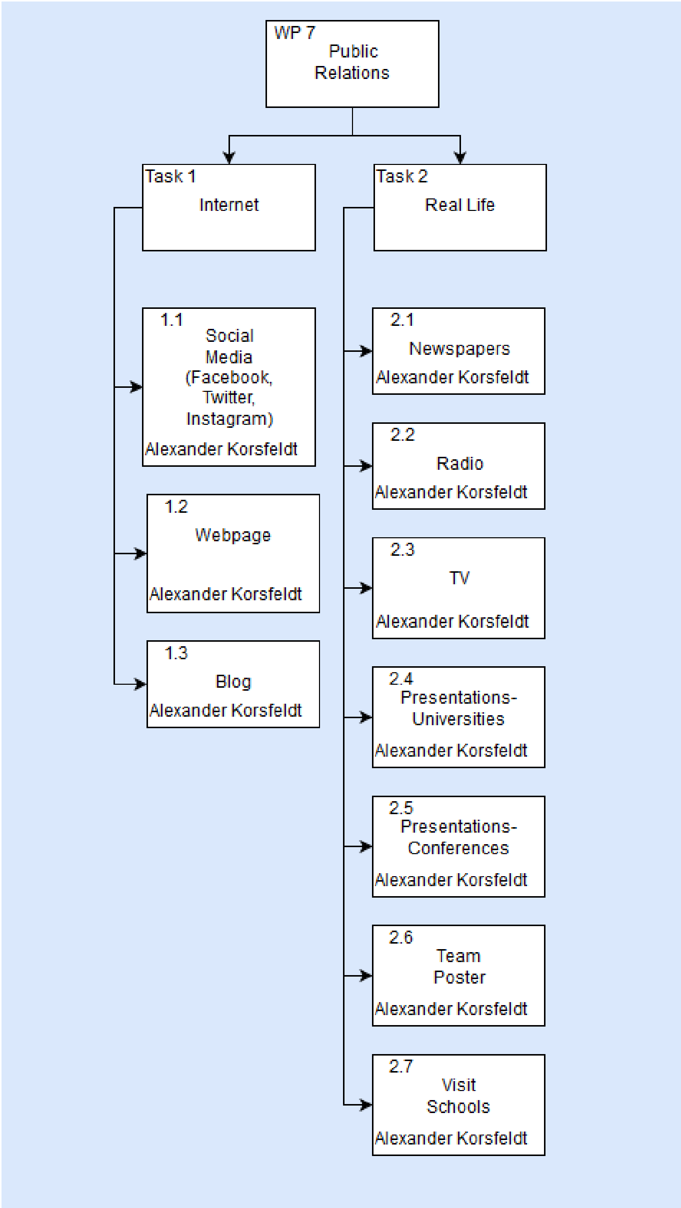


Figure E.1.7: WBS - Public Relations

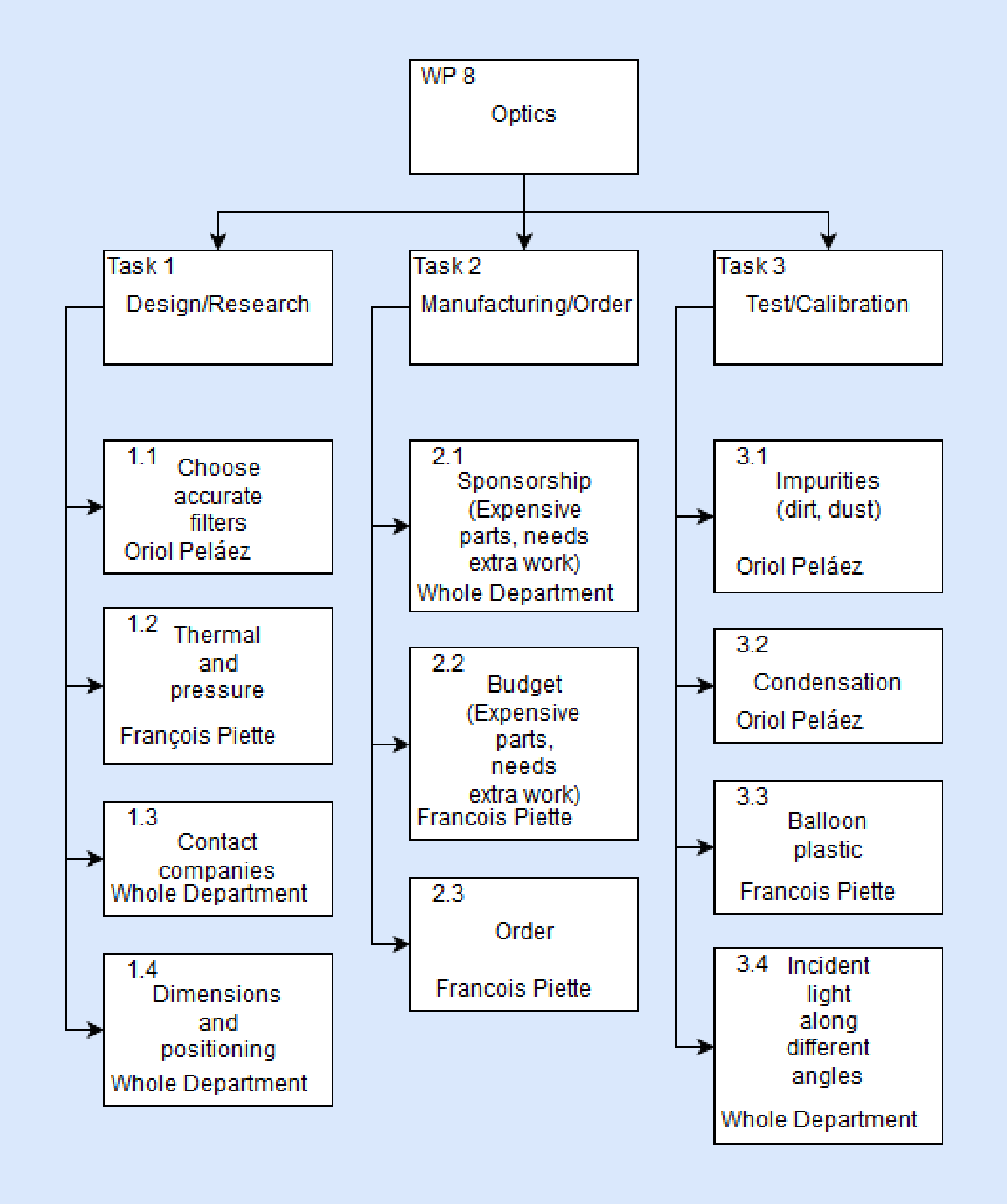


Figure E.1.8: WBS - Optics

E.2 Gantt Chart

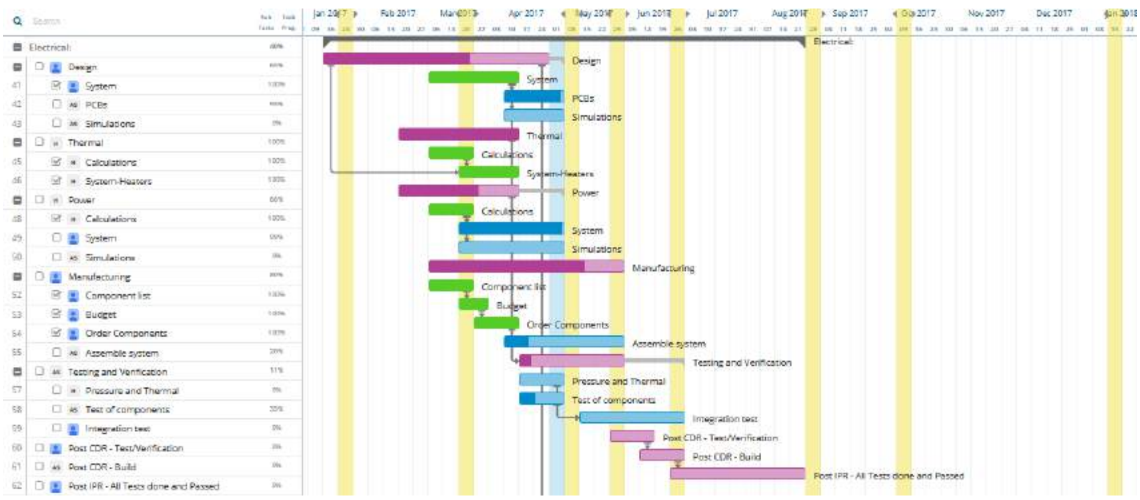


Figure E.2.1: Gantt - Electrical

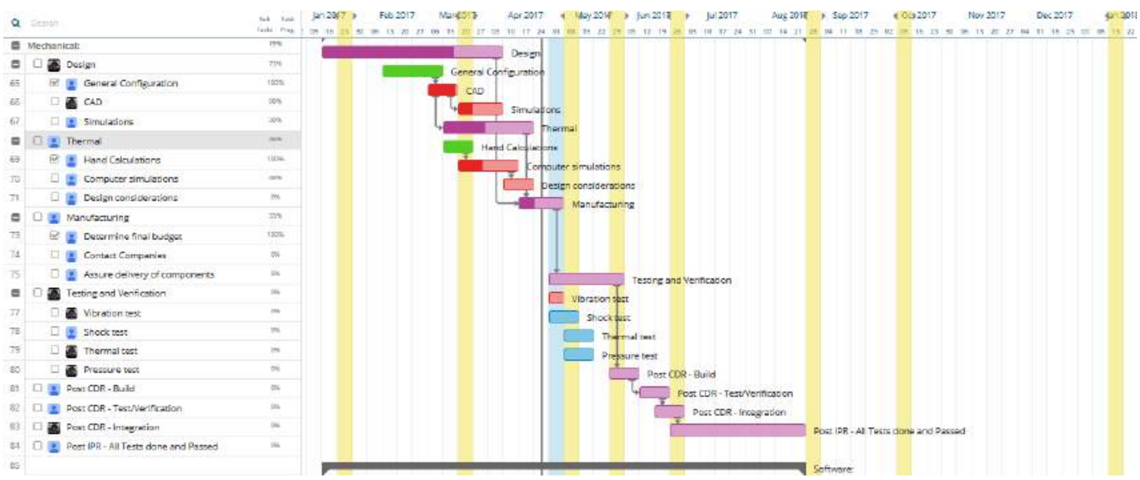


Figure E.2.2: Gantt - Mechanical

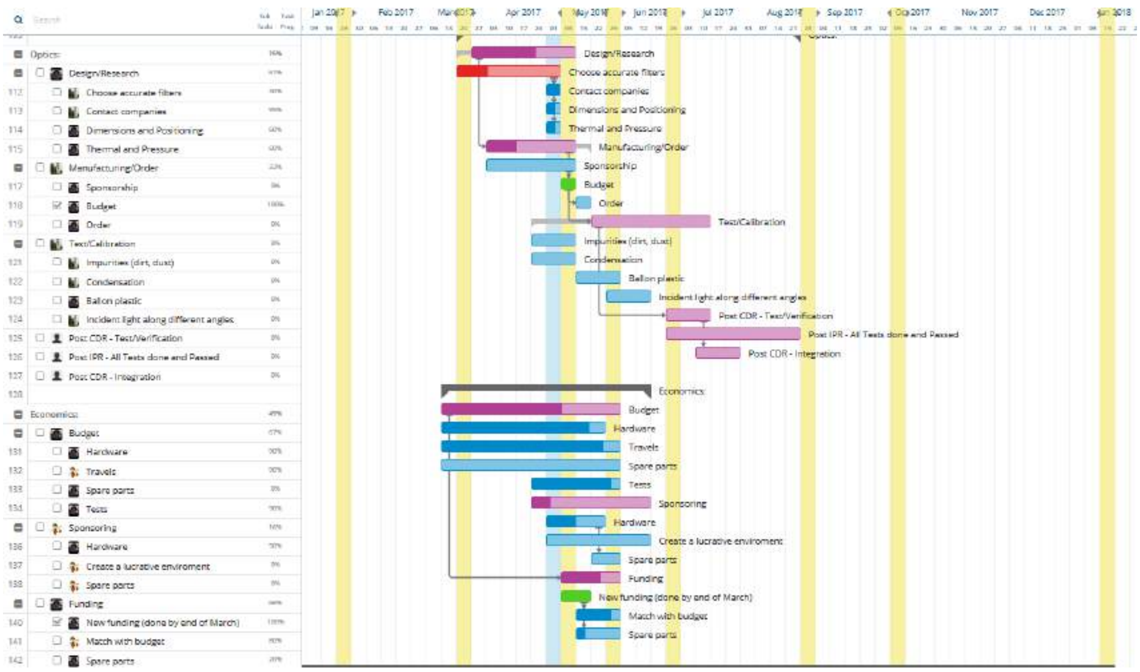


Figure E.2.3: Gantt - Optical and Economics

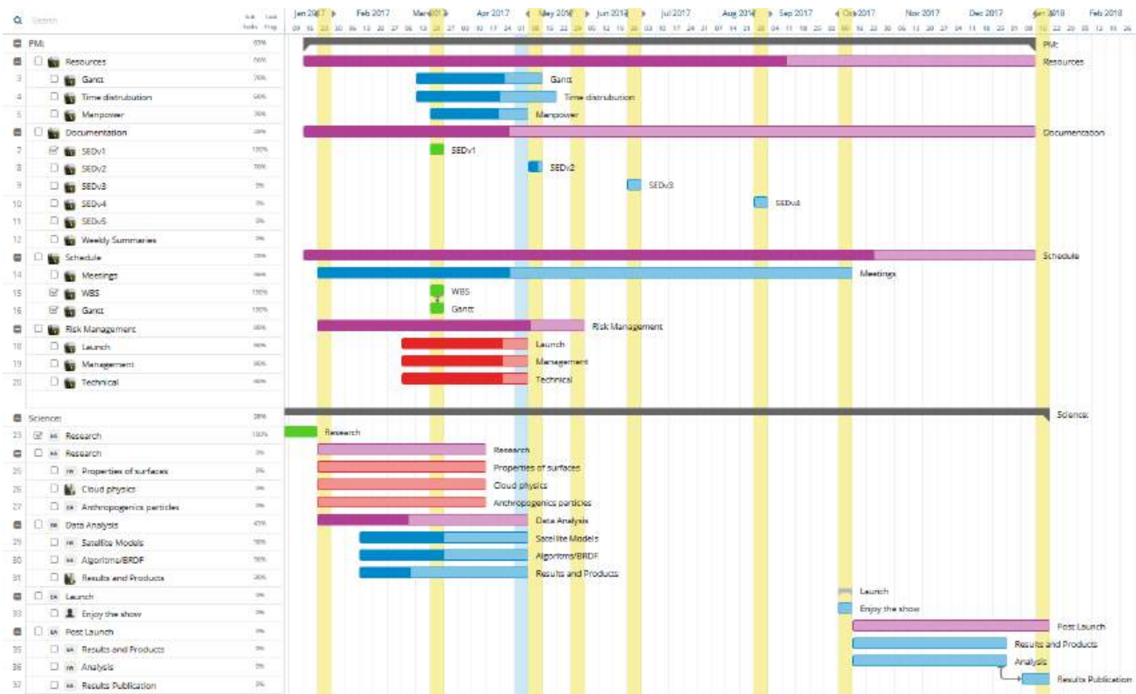


Figure E.2.4: Gantt - Project Management and Science

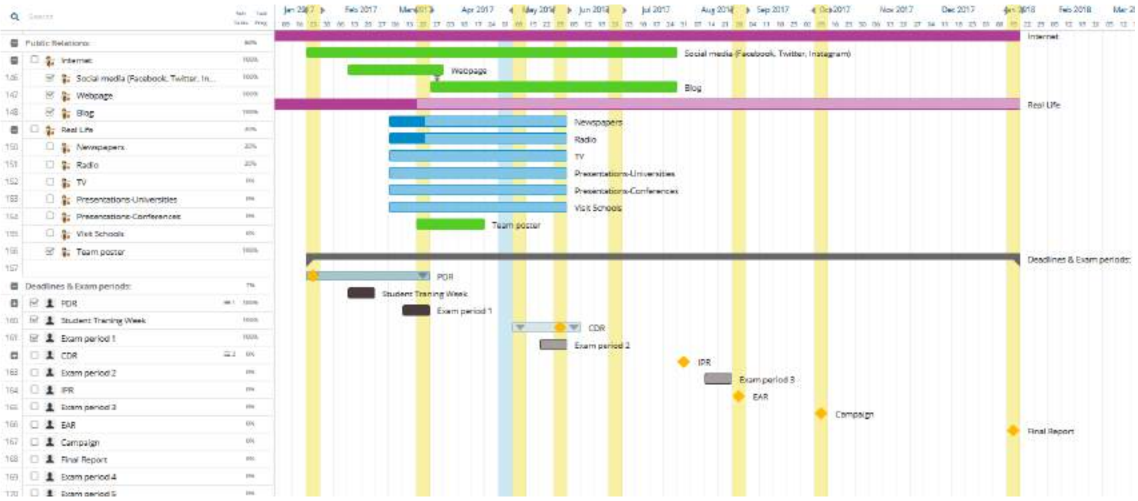


Figure E.2.5: Gantt - Public Relations and Exams/deadlines

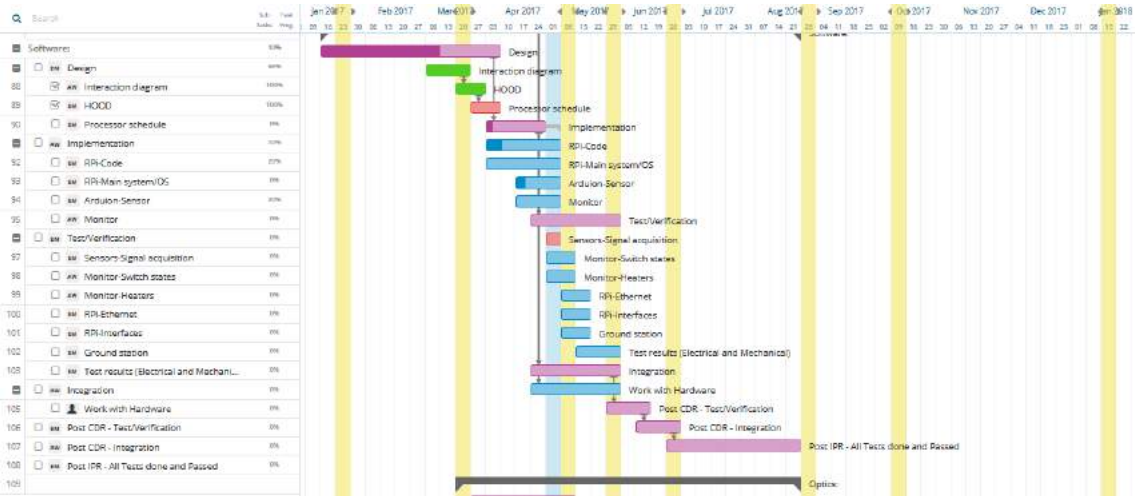


Figure E.2.6: Gantt - Software

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).

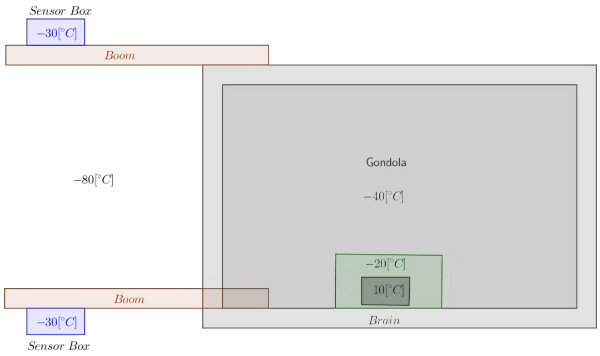


Figure F.0.1: Optimal temperature considered during the estimation of the heat budget.

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

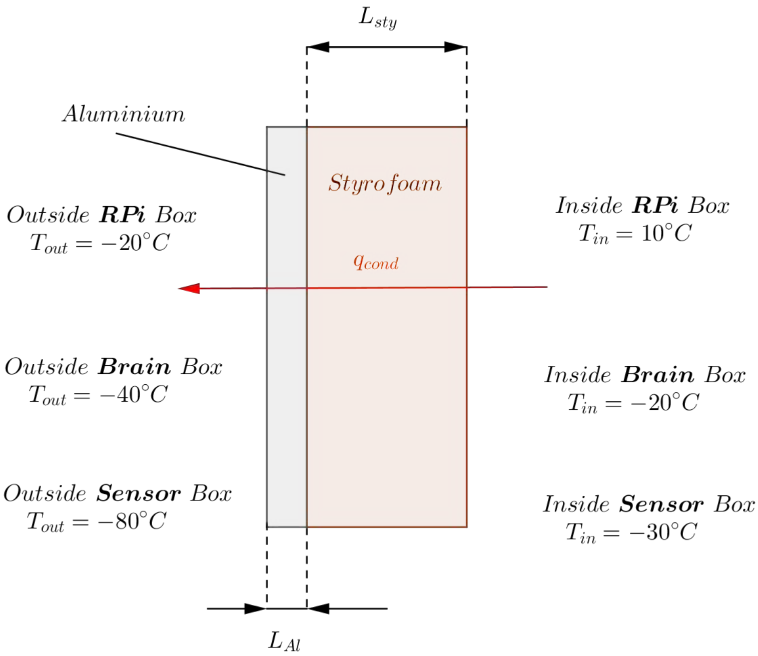


Figure F.1.1: Conduction conditions for the Sensor, Brain and Raspberry Pi box.

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.

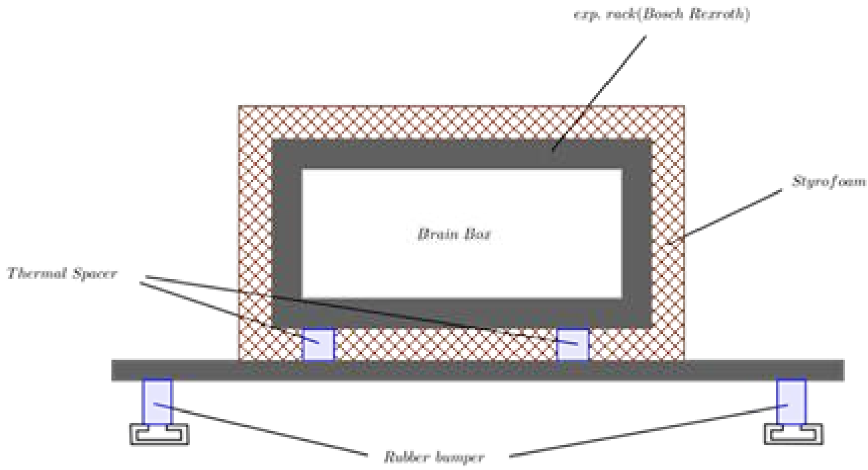


Figure F.1.2: Sketch of the modifications on the brain box mounting on the gondola rails, with the objective of reducing conduction losses.

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 $[°C]$.

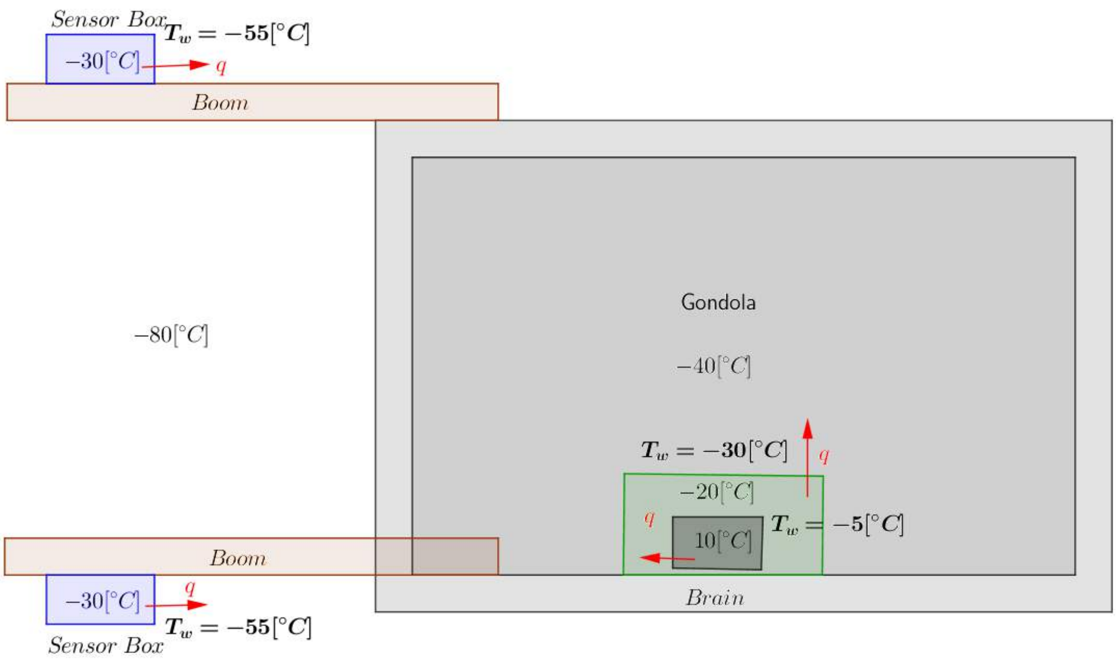


Figure F.1.3: Wall temperature estimation for the sensor, Brain and Raspberry Pi boxes.

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

	$\nu\ [m^2s^{-1}]$	$\alpha\ [m^2s^{-1}]$	$\beta\ [K^{-1}]$	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:

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

For horizontal plates the following equation is used:

$$Nu = 0.59Ra^{1/4} \quad (11)$$

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:

$$Re = \frac{u\rho L}{\mu} \quad (12)$$

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:

$$Nu = 0.664Re^{1/2}Pr^{1/3} \quad (13)$$

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.

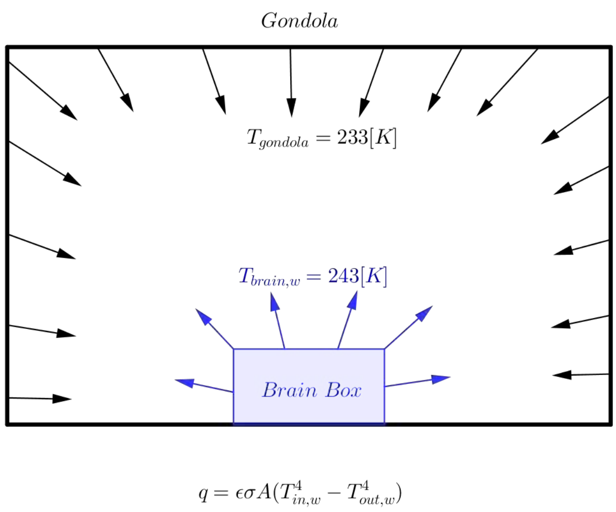


Figure F.1.4: Radiation field of the brain box inside the gondola.

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. The first round of simulations was realised with the aid of LISA, a Finite Element Analysis (FEA) free software. Thermal steady states were solved with this program for each of the four boxes of the experiment, for the two stated cases. The second round of simulations were performed with Siemens NX, with the intent of running both thermal and structural simulations for the booms, and thermal ones for the boxes.

F.4.1 LISA simulations

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.

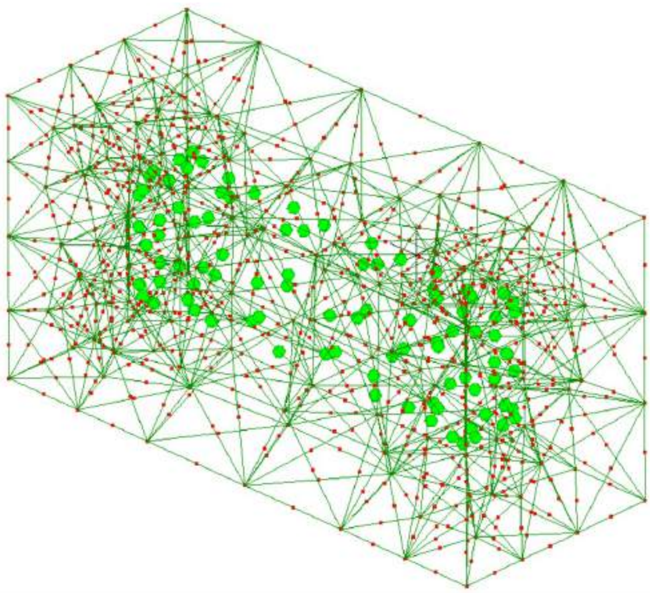


Figure F.4.1: Mesh used on the sensor box model. Red dots are nodes, while green dots represent heat dissipation boundary conditions.

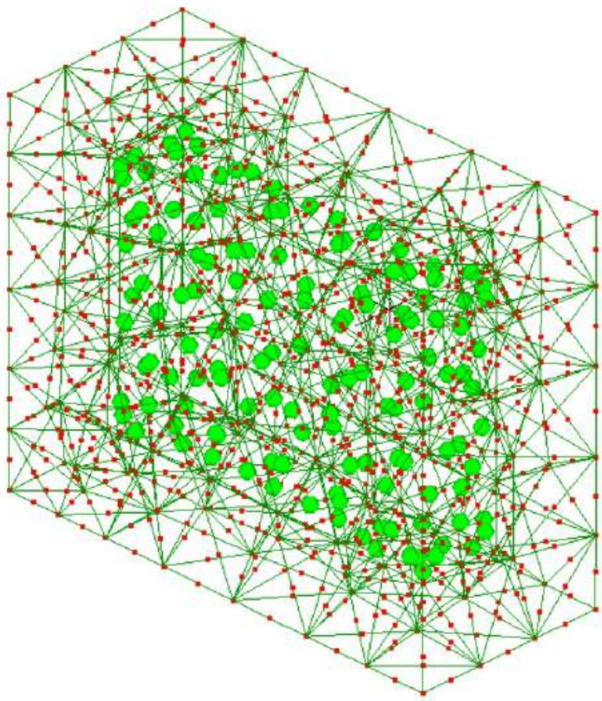


Figure F.4.2: Mesh used on the brain box model. Red dots are nodes, while green dots represent heat dissipation boundary conditions.

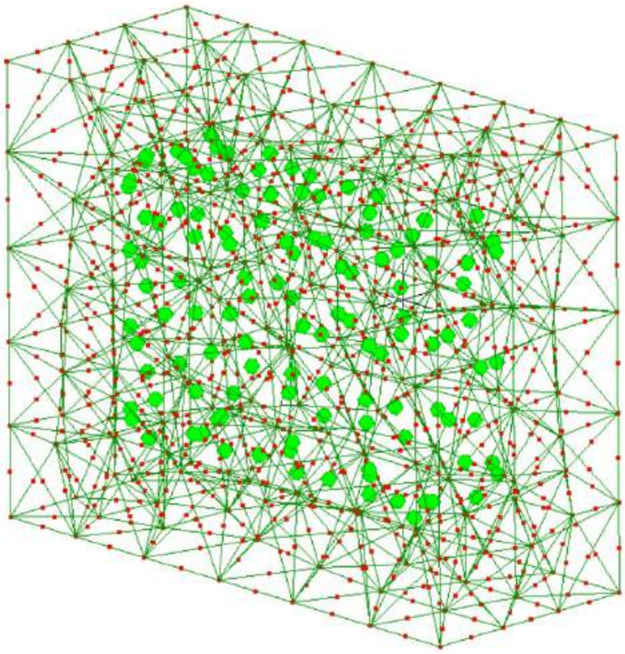


Figure F.4.3: Mesh used on the RPi box model. Red dots are nodes, while green dots represent heat dissipation boundary conditions.

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.

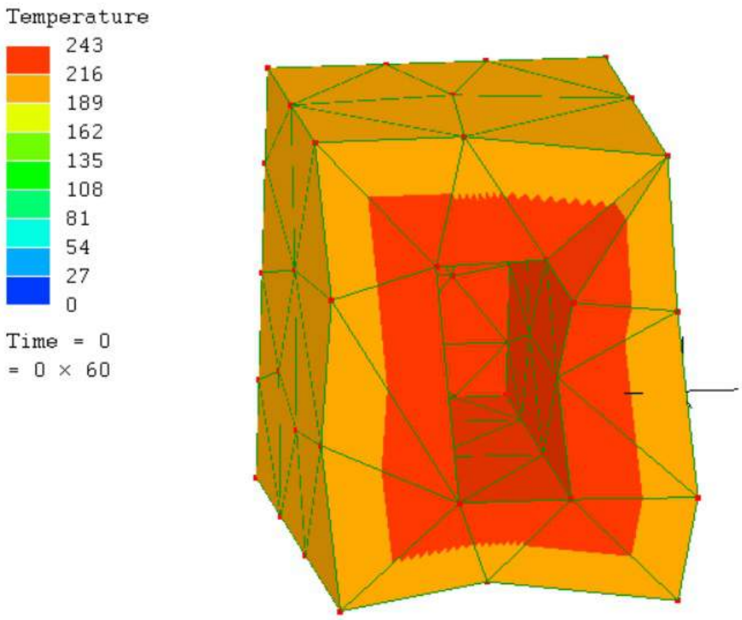


Figure F.4.4: Cut-away temperature distribution of the sensor box for the middle case. Other cases showed very similar, if not identical, results.

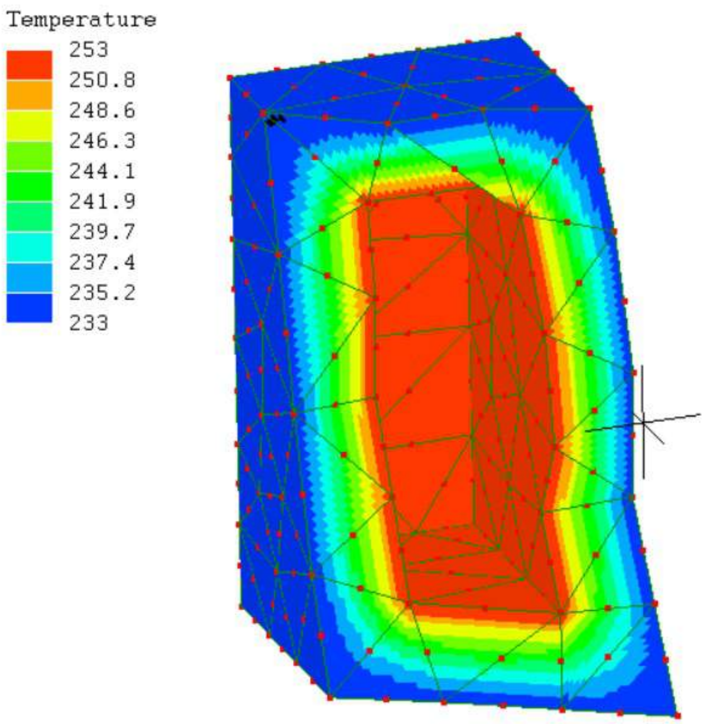


Figure F.4.5: Cut-away temperature distribution of the brain box for the middle case. Other cases showed very similar, if not identical, results.

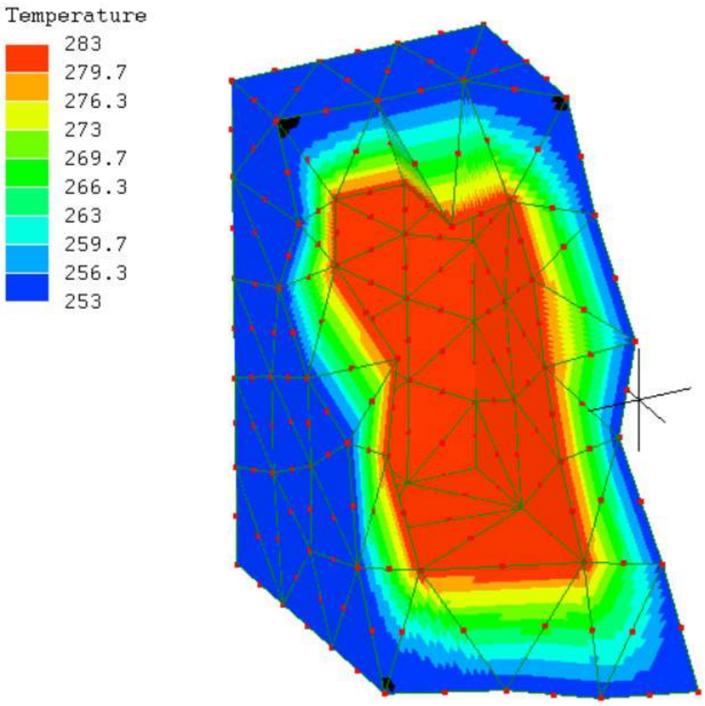


Figure F.4.6: Cut-away temperature distribution of the RPi box for the middle case. Other cases showed very similar, if not identical, results.

F.4.2 Siemens NX simulations

The simulation plan for this software consisted on solving the warmest and coldest thermal cases for brain box, sensor box and upper boom (as this one is held by clamps made of aluminium, which has very different thermal behaviour than the polycarbonate of the boom) and then use the thermal simulation results of the boom as data for running an structural behaviour simulation of it. All cases would be solved as transient analysis with the duration of a full flight, with the following assumptions:

- Total duration of the flight: 20,000 seconds
- Times of ascent phase: 0 to 7,000 seconds
- Times of float phase: 7,000 to 14,000 seconds
- Times of descent phase 14,000 to 20,000 seconds
- Altitude of float phase: 25 km
- Atmosphere model: International Standard Atmosphere (ISA)
- Values of convection coefficient: provided by Peeters, measured during the flight of their experiment

Unfortunately, numerous problems arose during the set-up of these simulations, particularly with that of the latest, more complex versions. These problems, related to the computers that were being used -a network of computers available to students located at Kiruna campus and connected to the main Luleå campus (Luleå University of Technology)-, caused simulations to fail to the point no more time was available to try to run them on different computers.

For this reason, the results shown here correspond to earlier versions of the thermal simulations of the boom and the sensor box, which while less accurate, can provide an idea of the thermal behaviour of these components of the experiment.

For the boom, different meshes were used for the areas covered by the clamps and those which were not, so that the different conditions for these -pressure of the clamps, heat conduction with them, lack of sunlight- could be represented. The results obtained, shown in figure F.4.7, show that the boom would reach a maximum temperature of around 42 °C in the center of the areas exposed to the Sun; a temperature far below the glass transition temperature of polycarbonate (147 °C).

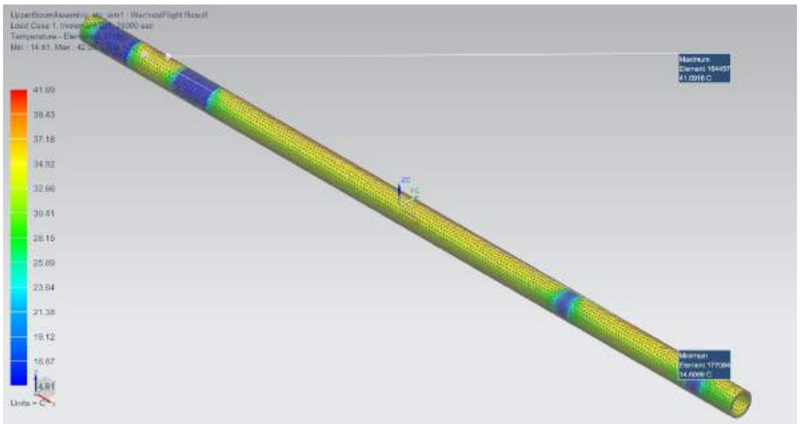


Figure F.4.7: Upper boom in the moment of maximum temperature, which corresponds to the instant of landing

For the sensor box, its model was simplified into 3 solid bodies: insulation, structure, and PCB. Each of these was modelled with its own material and mesh. The thermo-optical properties of the insulation (namely solar absorptivity and IR emissivity) were set to be those of the emergency blanket, so that its effects are represented in the model. As shown in figures F.4.8 and F.4.9, the simulation of the warmest case showed that the interior of the box would reach a maximum of around 20 °C, which would mean the internal components would keep their temperatures within safe limits.

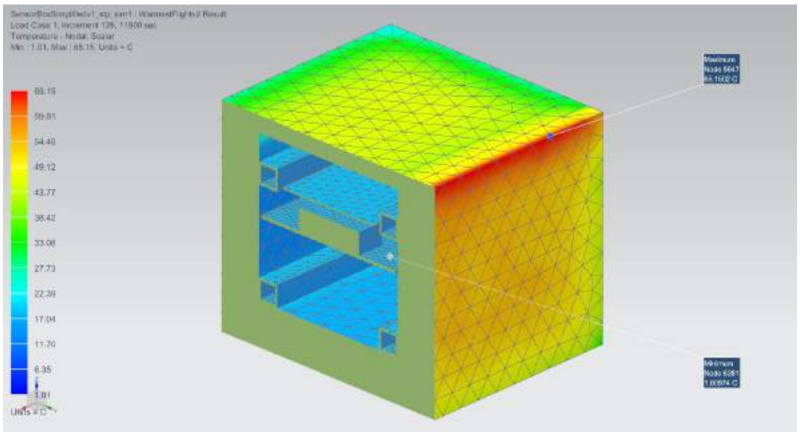


Figure F.4.8: Section view of the sensor box in the moment of maximum temperature, which roughly corresponds to the instant of cut-off

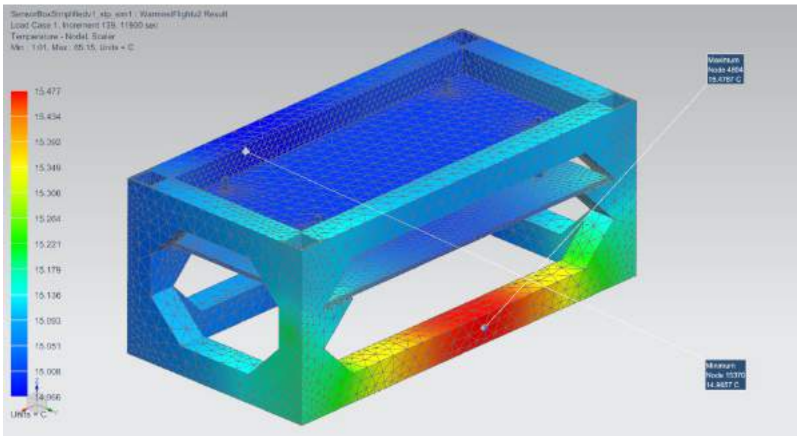


Figure F.4.9: Frame and PCB of the sensor box in the moment of maximum temperature, which roughly corresponds to the instant of cut-off

G Test results

G.1 General

Below shows a report written after vacuum and thermal test were performed at Esrange space center.

1 Background

To see that the IRIS experiment will survive in the BEXUS flight profile tests are needed. Two of them are thermal and vacuum tests. These are going to be done at Esrange space center. The purpose of these tests is the determine if the IRIS experiment can survive a low pressure environment as well as low temperature environment for a prolonged time.

2 Approach

2.1 Attendees

Table 2.1.1: Planned attendees from IRIS

Name	Department	Days Attending
Gustaf Ljungné	Project Manager	Tuesday, Wednesday
Hampus König	Electronics, Software	Tuesday
Guillermo Ledo López	Mechanical, Thermal	Tuesday, Wednesday
Andreas Wallgren	Software	Tuesday, Wednesday
Edgar Martín	Software	Tuesday
Lisa Jonsson	Electronics	Tuesday, Wednesday

2.2 Equipment brought by IRIS

2.2.1 Test Equipment

- Power Supply
- Tool box
- Multimeter

2.2.2 Experiment Parts

- 2 sensor PCB:s
- 1 brain PCB
- 2 Sensor boxes
- 1 brain box
- Insulation for the 3 boxes
- Test piece of the boom
- Test piece of insulation

2.3 Equipment supplied by Esrange

- 1 vacuum chamber
- 1 freezer (With temperature range down to -70^{o} C)

3 Risk Assessment

- XPS-500-SL-A-N polystyrene might expand/deform in vacuum. Test will be performed

4 Schedule

Table 4.0.1: Check box meaning

Complete	Incomplete	Needs further tests
X	-	+

4.1 Tuesday 5th of September

4.1.1 Morning

Table 4.1.1: Test Plan, first morning

Time	Activity	Result	Done
0745-0815	Arrival at Esrange and receive guest passes		X
0815-0900	Vacuum test setup		X
0900-1000	Initial vacuum test	• Insulation - Worked well • Running electronics and software worked	X
1000-1100	Evaluation, further tests needed?	The camera needs to be tested as well. No need to test the electronics and insulation more.	+
1100-1200	Lunch		X

4.1.2 Afternoon

Table 4.1.2: Test Plan, first afternoon

Time	Activity	Result	Done
1200-1300	Thermal test setup	Insulation for the boxes not done. Could only test the booms with the smaller clamps	+
1300-1400	Initial thermal test	Clamps did not budge under stress after having been in -45^{o}C for 2.6 h	X
1400-1500	Evaluation, further tests needed?	Further tests needs to be done on the full system, will be done tomorrow.	X
1500-1600	Changes to be made before Wednesday tests and clean up of work stations	Finish the complete boxes and bring the newly received big clamps. Test overnight with the clamps at -70^o	X

4.2 Wednesday 6th of September

4.2.1 Morning

Table 4.2.1: Test Plan, second morning

Time	Activity	Result	Done
0745-0815	Arrival at Esrange and receive guest passes		X
0815-0915	Depending on Tuesday's results. If they were successful, the plan is the do a combined thermal and vacuum test. Otherwise repeat the vacuum test.	Camera and boom tested in vacuum.	X
0915-1000	Further vacuum test	A steady state test with a full box is needed. Furthermore, the optics when ordered and received need both vacuum and thermal tests.	+
1000-1100	Evaluation, further tests needed?	Yes	+
1100-1200	Lunch		X

4.2.2 Afternoon

Table 4.2.2: Test Plan, second afternoon

Time	Activity	Result	Done
1200-1330	If all tests are done, evaluate results. Otherwise perform the required extra tests	Thermal test with two boxes.	X
1330-1500	Evaluation and discussion about results	The brain box had no problems heating itself a the set limit of 5^{o}C (freezer set at -70^{o}C. The sensor box did not start heating itself and the test had to be terminated when the lowest temperature in the sensor box was reached.	+
1500-1600	Clean up of work stations		X

5 Results

Table 5.0.1: Some various freezer tests

Hardware Start/End	Time	Temperature (Freezer) [^{o}C]	Result
Small clamps + boom, start	14.18, Tuesday	-45	Worked as planned
Small clamps + booms, end	09.03, Wednesday	-65	Worked as planned
Big clamps + boom, start	08.05, Wednesday	-66	Worked as planned
Big clamps + boom, end	15.27, Wednesday	-70	Worked as planned
Camera, start	15.35, Wednesday	-70	Worked as planned
Camera, end	16.36, Wednesday	-68	Worked as planned

Figure 5.0.1: The big clamps before freezer test

Figure 5.0.2: Small clamps and boom piece after freezer test

Figure 5.0.3: Brain box in the freezer pre-test

Figure 5.0.4: Electrical system running in vacuum chamber

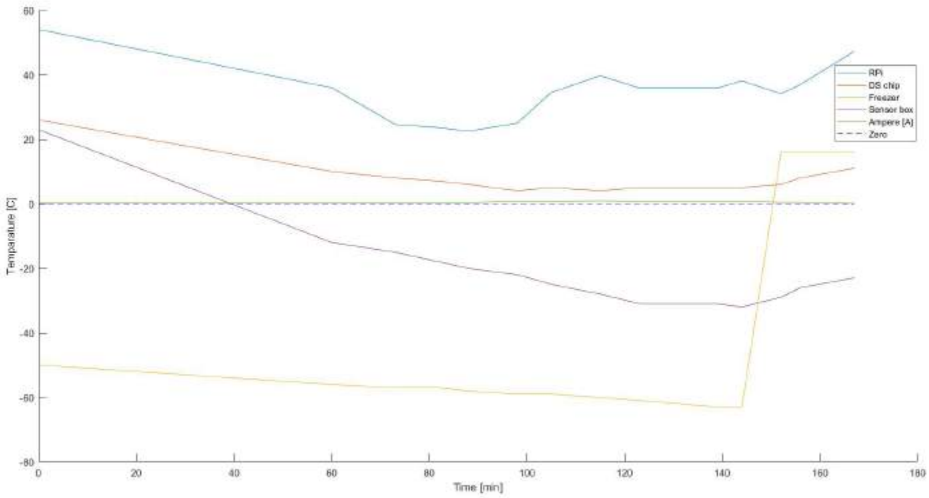


Figure 5.0.5: Results of the freezer tests for the brain box and one sensor box

The plot in fig. 5.0.5 show the temperature from the different sensors inside the two boxes. The heater inside the brain box worked fine and kept the temperature at the set limit. The sensor box on the other hand had a software error that cause the heater to remain shut off and therefore the test had to be terminated early.

6 Evaluation and Discussion

Further testing is needed to verify that the heaters actually work as planned. Also the optical systems need to tested in both a low pressure environment as well as a freezer environment.

The insulation for the 2 tested boxes worked as planned and when the software error for the sensors boxes is fixed there is no need to test them in the freezer again. Just verify that the heaters start.

G.2 Electronics

G.2.1 Test 12: Test of Garmin GPS

G.2.1.1 Background and hypothesis

Verifying the performance of the GPS is needed to verify the location of the balloon during the full flight. It also gives us a time stamp used to synchronise the measurements.

G.2.1.2 Materials

- *Garmin 18x-LVC*
- Arduino Nano
- Breadboard
- Wires
- Laptop
- MAX233 chip for signal adjustment

G.2.1.3 Procedure

The components used was to connect the GPS by a MAX233 chip, into the Arduino, and that in turn was connected to the Laptop of choice. The full system was easy to carry, and powered from the laptop battery. To see if the location given by the GPS was correct, two comparisons was made. One Android Smartphone with google Maps was used, along with a webpage where the possibility to point/click on a map gave the location. In the following table the is shown

G.2.1.4 Results (data)

Table G.2.1: GPS results

Test ID	Device	Latitude	Longitude	Altitude
1	Garmin	67.840454	20.412874	401.4
	Phone	67.8404789	20.4128129	-
	Webpage	67.8405053	20.4127693	402.2
2	Garmin	67.840843	20.409465	413
	Phone	67.84083	20.40937	390
	Webpage	67.8408654	20.4096687	401.144
3	Garmin	67.841934	20.408927	394.8
	Phone	67.84186	20.40899	382
	Webpage	67.8419297	20.4091644	399.028
4	Garmin	67.842964	20.411050	390.8
	Phone	67.84294	20.41092	380
	Webpage	67.8429453	20.4109561	396.086

A quick look on the table above seems to indicate that the GPS is accurate enough. However, due to how longitude/latitude works, the distance can be quite big even with a small difference. The calculations showed that depending on which device the GPS was compared to the difference in location could differ up to 9.97m. This is still within the GPS specifications and is considered within limits. The altitude could also differ up to about 23m at most (test 2). The remaining tests had a difference up to about 10m at most, and is considered accurate enough for this flight. One error that could explain some discrepancies is that the position on the webpage could not be accurately chosen.

G.2.1.5 Conclusion

The GPS will provide accurate positioning for the experiment.

G.2.2 Test 17: Test of analog component chain

G.2.2.1 Background and hypothesis

Determining the amount of noise induced into the analog part of the experiment must be done to know how much of the signal can be accounted for because of outer sources or from the electronics.

G.2.2.2 Materials

- Sensorbox PCB with mounted components
- Oscilloscope
- Power source

G.2.2.3 Procedure

By analysing the signal out after the amplifier it is determined how much noise that the chain has. Compare this noise to the amount of noise when the diode is fully covered, or desoldered, and the effect of the analog chain can be determined. This should also be affected by the amplification factor of each analog chain.

G.2.2.4 Conclusion

The difference in noise (ripple) between the two tests are very small, however, with new information regarding the amplification factor needed this test needs to be remade with focus on the chain that has the highest amplification since the amplification also affect the noise before the amplifier. Also some lesser dark current (a signal from the diode with it covered) was also noted.

G.2.3 Test 18: Test of 5 V DC/DC converter

G.2.3.1 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.

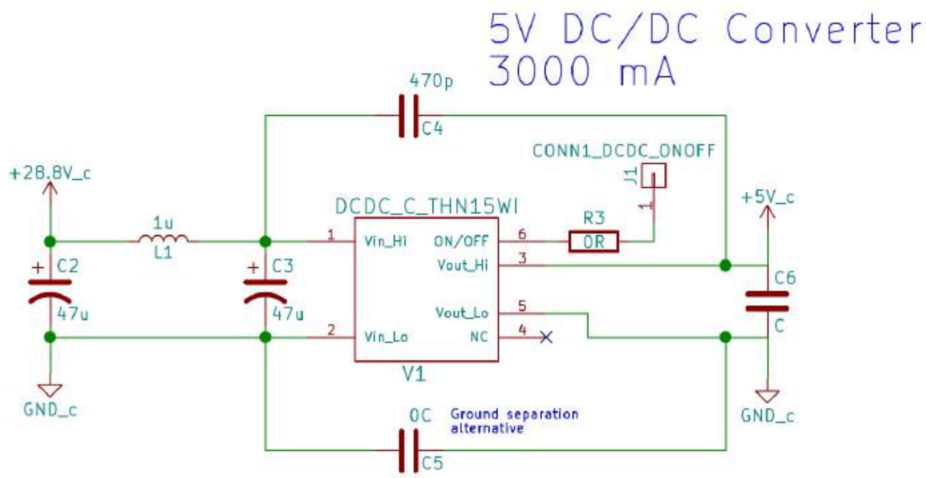


Figure G.2.1: The circuit of the power supply.

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.2.2: Expected values for different parameters of the converter.

Table G.2.2 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.2.3.2 Materials

- 5V DC/DC Converter THN 15-2411WI, *Traco Power*
- Capacitors: 2 × 470 pF, 2 × 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.2.3.3 Procedure

Figure G.2.1 shows the complete circuit of the power supply. 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.2.3.4 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.2.3: 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.2.3.5 Conclusion

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

G.2.4 Test 18: Test of Digital thermometer

G.2.4.1 Background and hypothesis

Verifying the performance of the thermometer is needed to make sure the temperature transients in the diodes can be take into account when measuring the irradiance.

G.2.4.2 Materials

The materials and setup used is one DS1631+ digital thermometer connected vi I2C-bus to a Arduino nano. This is powered through a USB-port on an ordinary laptop. In addition to compare the temperatures given, an ordinary room thermometers is used.

G.2.4.3 Procedure

In different rooms and temperatures the value given by the DS1631+ thermometer is compared to the ordinary thermometer

G.2.4.4 Results (data)

Thermometer [°C]	DS1631+ [°C]
4	6
13.5	14
21	21
21	21
21	21.5
21.5	22
21.5	23
22	22.5
22	23
22.5	23.5

Table G.2.4: Temperature comparison at different locations

G.2.4.5 Conclusion

The thermometer is a bit slow to cool down, but since slow transients are expected this is deemed to be accurate enough. There is a slight difference in temperatures from time to time, and while some might be because of the rounded temperature (resolution is 0.5°C), the remaining difference is usually less than 1°C which is within margins. At some points there was a difference of 2°C, but with a thermometer that is not accurate enough, the fault might as well have been on the thermometer. Further testing might be needed.

G.2.5 Test 18: Test of Analog Digital Converter

le relsih

G.2.5.1 Background and hypothesis

Verifying that the analog input of the ADC corresponds to the digital output, with accurate enough resolution. The resolution on the component is said to be 16 bits, but that is in differential mode, and thus only 15 bits will be used in single ended mode.

G.2.5.2 Materials

The materials and setup used is one ADS1115 ADC breakoutboard from Adafruit connected to a Arduino nano, while the input is connected to a variable voltage source

G.2.5.3 Procedure

With known measured voltage connected to the input, the digital values are calculated to correspond to an analog value, and then compared to the input source. The digital value is used to calculate the corresponding analog value by using the knowledge that there is 15 bits between 0 - 6.144[V]. 16 bits are only used in differential mode, and adds a signbit.

G.2.5.4 Results (data)

Analog Input [V]	Digital Value [0-32676]	Voltage from digital value [V]
1	5395	1.01
1.9	10300	1.93
2	10935	2.05
3.2	17374	3.25
4.55	24027	4.51
4.86	25930	4.86

Table G.2.5: ADC comparison

G.2.5.5 Conclusion

The analog digital converter seems to fulfil the criteria of being accurate enough. The very small discrepancies is most likely due to some slight noise from the analog source which in this case as the full circuit planned to be used during the flight.

G.3 Mechanical

Thermal testing of the brain box, sensor box and clamped boom was realized within the freezer provided by the Esrange center. These elements were subject to temperatures of around -66 °C for roughly 2 hours. During the test, the brain box was able to keep its internal temperature within the safety limits of the Raspberry Pi. The sensor box gradually decreased its temperature from the ambient 10 °C to -43 °C during this time, although its heater was not working due to a software bug and its insulation plates were faulty. The clamps showed no deterioration in their capacity to safely hold the boom after the test.

The internal electronics of both boxes were tested in the provided vacuum chamber at around 20 MPa, for several hours, along with the camera and a test piece of thermal insulation. All these components successfully passed the test, showing no degradation, deformation or inability to perform their purposes during or after the test.

Additional testing will be realized on September 29th, 2017, once integration has been completed for the whole experiment.

G.4 Software

The parts of the experiment considered here are communication, data collection, data storage, and response of the heaters. Further tests will be performed at Esrange 2017-09-29.

G.4.1 Procedure

The the complete system run for an extended ($\tilde{1}$ h) period of time while monitoring system health. Analysis of the results post completion of the test.

G.4.1.1 Communication - Results

The communication between in particular the RPi and the MCU was deemed successful in the Esrange test-facilities. The system was tested seperately under low pressure conditions (20 mbar lowest) and down to -63°C.

G.4.1.2 Data Collection

Data collection was succesful with no missed information or measurements.

G.4.1.3 Data Storage

Data Storage is the next step to data collection and communication. It requires the communication to work, to then be able to store the data sent by the MCU's. This was deemed succesful, where no data was dropped.

G.4.1.4 Heater response

The heaters worked perfectly on the RPi who kept a steady state temperature of $\sim$5°C in the brain box. The arduinos has a preknown bug in the heating, which will be tested at the next visit to Esrange, date seen above.

G.5 Optics

TBD