## Phase B

# Project, Mission, Space and Ground System Overview

Prepared by:
R. Krpoun, M. Noca, N. Scheidegger

Checked by:

Approved by:

UNINE / HES-SO / EPFL
Lausanne
Switzerland

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LMIS3

AQUA

# TEAM MEMBERS

| Subject | Student | Assistants/Professors |
|---|---|---|
| Attitude Determination and Control System | Algorithms: Basile Graf<br>Hardware : Bastien Despont, Vasko Vitanov<br>Inertia Wheel: Omar Scaglione, Gavrilo Bozovic | Philippe Muelhaupt, Denis Gillet<br>Roland Longchamp<br>Pavel Kejik, Ozge Zorlu, Radivoje Popovic<br>Christian Koechli, Yves Periard |
| Communications | Ignace Wafo | Cyril Botteron, Frédéric Chastellain, Catherine Dehollain, Pierre-André Farine, Juan Mosig, Jean-François Zürcher |
| Electrical Power System | Fabien Jordan, Jean Gubelmann | Marc Correvon, Michel Declercq, Cédric Meinen, |
| Flight Software | Adam Clément, Sylvie Rohrer | Didier Rizzotti |
| Ground Software | Benoît Cosandier, Florian George | Philippe Etique |
| Ground Station | Hui Qiu | Renato Krpoun, Juan Mosig, Jean-François Zürcher |
| Mechanisms | Jean-Paul Fuchs | Elia Deschenaux, Jacques Giovanola |
| On-board microcontroller architecture | Pierre-André Tapparel | Christophe Bianchi |
| Payload, Instruments | Raphael Jubin | Edoardo Charbon, Noémy Scheidegger, Wilfried Noell, Werner Schmutz, Herbert Shea |
| Structures and Configuration | Guillaume Röthlisberger | John Botsis, Larissa Sorensen |
| System Engineering & Mission Design | Bastien Despont, Marie Dumont, Ted Choueri | R. Krpoun, Muriel Noca, Noémy Scheidegger |
| Thermal | Oscar DelaTorre | Stefano Nebuloni, Ricardo Lima, John Thome, Thierry Ursenbacher |

# I INTRODUCTION

This document summarizes the work performed and the results achieved during the SwissCube Phase B study. About 20 students from 10 different laboratories at the EPFL, 2 laboratories at the University of Neuchâtel and 3 laboratories from the Haute Ecole Specialisée de Suisse Occidentale (HES-ARC, EIVD, HEVs) participated in this work. The Project's organization is described in the SwissCube Project Management Plan. The student work frame was semester and master projects, corresponding to ~8-12 hours per week to 40 hours per week depending on the student's year for about 4 months (November to February 2006). The students have various backgrounds including Electrical, Software, Mechanical, Material, Communication and Micro-mechanical Engineering.

This document consists of an overview of the project engineering, mission, space and ground systems. Topics include:

- Project and mission objectives,
- Requirement analysis,
- Assembly, integration and test plan,
- Mission and operations,
- Space system configuration and design,
- Ground segment.

Some sections of this report remain the same as the Phase A System Description document as no changes have been implemented since Phase A in these areas (lack of student in some areas).

The project engineering team would like to take this "optimized" space in the report to thank all students who participated, the laboratories involved and the Project Partners, RUAG Aerospace, the Swiss Space Office, Oerlikon Space AG and the CSEM who are making this whole project possible. We do warmly thank our sponsors:

| Sponsor type | Company/Institution |
|---|---|
| **Financial Contributors** | Swiss Space Office<br>RUAG-Aerospace<br>EPFL<br>La Ville du Locle |
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# II PROJECT OVERVIEW

# 1 Mission and Science Objectives

The motivation for the overall SwissCube project development is primarily educational: educate students in space technologies and space system engineering. This motivation has several impacts:

1) The project shall involve undergraduate and postgraduate students and young engineers through its whole life cycle;
2) The project cost shall be relatively small, related to a university type development;
3) Compared to an industry type space project, decisions were taken to simplify the design or design for low-cost and thus might not comply with the usual standards.

Keeping these aspects in mind, the mission and science objectives for the project are summarized in the following requirements. These requirements are the basis for the design provided in the rest of this document.

## 1.1 Mission Objective 1

The project shall design, built, and test a satellite. The success criterion is: deliver a fully tested satellite to the launch site.

This objective assumes the development of both a ground and space system.

## 1.2 Mission Objective 2

The project shall launch the satellite and communicate with it using the ground and space systems. The success criterion is: establish a radio connection with the developed ground system and download telemetry.

## 1.3 Mission Objective 3

The project shall operate a scientific or technology demonstration payload. The success criterion is: receive data from the payload and confirm operations.

The approach taken in regard to the nature of the scientific and/or technology demonstration payload is described in the next section. Note that the science requirements were defined to fit a system that is primarily designed for success of telecommunication (Mission Objective 2) and therefore represent a fine balance between the science desires and the ***capability*** of the space system.

## 1.4 Science Objectives

After discussions with several partners of the project, it was decided that the SwissCube mission should focus on the observation of the airglow phenomena. The motivation for these observations is to demonstrate the feasibility of using the airglow as basis for development of a low cost Earth Sensor (ES). A model of the airglow emissions as a function of intensity, latitude, longitude and time has been established and the objective the science mission is to collect data that will validate, or at least bring additional information to the model. The development of the Earth Sensor is a separate activity to SwissCube led by the EPFL-LMTS laboratory.

In addition, at the project level and as a technology demonstration, it was decided to develop a payload that has the most commonality/synergy as possible as the Earth Sensor. This decision impacts the design of the payload and the requirements to this effect can be found in the Project (level 2) requirements.

The nightglow is a photoluminescence of the atmosphere at night, occurring at approximately 100 km altitude (see Figure II-1). It is principally due to the recombination of the atomic oxygen, which is dissociated during the day. To study variations of the emissions as a function of time, the minimum science duration is 3 months, with an extended science mission of duration up to 1 year.

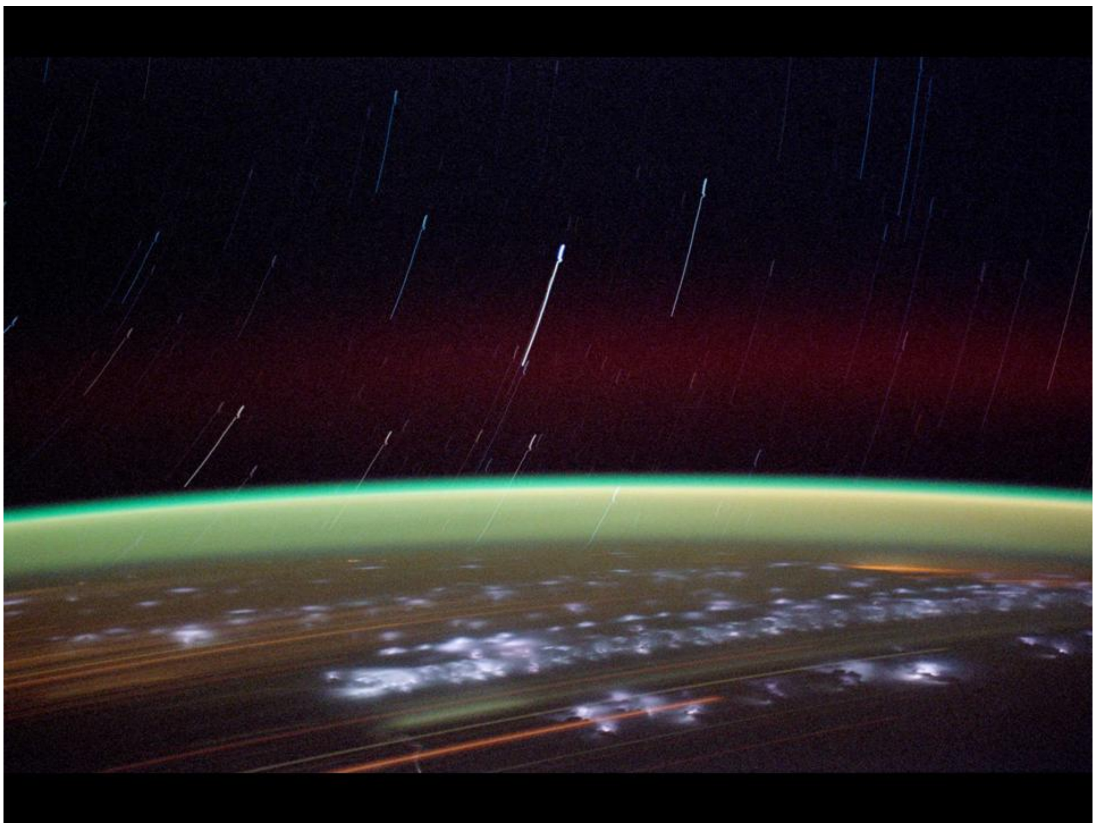


**Figure II-1: NASA Photo of the nightglow.**

At the mission level, the main science requirements are listed below. The full suite of science requirements can be found in the "SwissCube Mission, Science and Project Specifications" [1].

1_SR_02 **Primary science objective**

The primary science objective is to observe the airglow emissions both at night and during day. Both limb and zenith measurements shall be made.

*Definition of science objective.*

1_SR_03 **Science observations altitude**

The Project shall take measurements in the [50 - 120] km altitude band of the Earth's atmosphere.

*Airglow emission occurs between 50 - 120 km at day, respectively 80 - 120 km at night.*

1_SR_05 **Science observations coverage - Scoping phase**

Over the duration of the scoping phase of the science mission, a minimum of [20] images shall be taken. These images can include at least [5] limb images during day, [5] limb images at night, [5] zenith images at night and [5] during the day.

*To ensure minimum coverage for science and technology demonstration.*

1_SR_06 **Science observations coverage - Extended phase**

Over the duration of the extended phase of the science mission, the following observations shall be conducted: dayglow at latitude in the ranges [> 80°N], [40°N-50°N], [5°S-5°N], [40°S-50°S],[>80°S] and nightglow at the same ranges as the dayglow.

*The first 3 months provide a first idea of the intensities of airglow during both day and night. Observations after 3 months allow to measure variations of emission intensity depending on latitude and seasonal variations.*

1_SR_07 **Spectral range**

The project shall measure at least 1 band of emission in the spectral range of 550 – 880 nm.

*Airglow emissions occur within this wavelength band. One band shall be measured to ensure minimum science.*

1_SR_10 **Science data products**

The science data products (data needed for each observation) shall include the measurement of the airglow intensity, the position of the observed area, and the local solar time of the area of observation.

*The data shall provide the results of measurements, the local solar time and latitude of measurements. The local solar time is the local time in reference to the position of the sun.*

# 2 Project Development Assessment

## 2.1 Phase A review action items

The Preliminary Mission and System Review held on June 26, 2006 and closing Phase A for most subsystems established a list of about 240 action items. Early into Phase B the design of most subsystems was reviewed and implemented most comments. Some comments were considered but not implemented due to the change in design. Some comments are still applicable and will be carried out until assessed. The list of these action items and their status is provided in Appendix A.

## 2.2 Phase B activities

At this time in the development of the space and ground system, it is necessary to highlight the expectations at the end of the Preliminary Definition Phase (Phase B) and make an assessment of the progress of the project with respect to these expectations. The expectations listed in Table II-1 follow the definitions of the European Standards ECSS M-30-A and ECSS-10-Part1B. Table II-1 also shows the progress in terms of "Achieved" (green), "In Progress" (orange) and "Not started" (red). Although not an industry project, care is still given to follow as much as possible the standards. It is however very unlikely that project level assessments such as Reliability, Safety and Environmental Impact will be fully analyzed.

This evaluation highlights the current critical areas of the development, and the critical paths:

- At the subsystem level: flight software, beacon design and payload present the most schedule risk at this point. All three of these areas have been missing student workforce or the available workforce could not make significant progress, something that can be expected in a student project. Drastic remediation needs to be implemented, meaning special attention will be taken to insure that appropriate workforce will be available in the next semester (summer 07). However these areas remain a schedule and cost risk for the project.
- At the system level, interface documents and the fabrication plan remain to be done. Support at the system level came late in Phase B as two students agreed to help starting January of this year. These two students started updating and consolidating the project, system and subsystem specifications, the AI&V plan and end-to-end information system, but a lot remains to be done.
- As previously mentioned, it is very unlikely that a full Reliability, Safety and Environmental Impact assessment will be done. Rather, one or two semester projects will be dedicated to quality assurance and an orbital debris analysis will be done as part of the project requirements.

| PDR March 5-6, 2007 | At System | | | At Subsystem Level | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Phase B Expectations** | Launch system | Space System | Ground System | PAYLOAD | EPS | CDMS | COM Data | COM Beacon | Mechanical | ADCS HW | ADCS SW | Flight SW | Thermal | Mechanisms | G Station RF | GS SW |
| Selection of a technical solution | | | | | | | | | | | | | | | | |
| Design or technical solution | | | | | | | | | | | | | | | | |
| Confirmation of feasibility of technical solution | | | | | | | | | | | | | | | | |
| Functional/Characterization tests of components | | | | | | | | | | | | | | | | |
| Functional tests of assemblies/subsystems | | | | | | | | | | | | | | | | |
| Assessment of critical techniques or technologies | | | | | | | | | | | | | | | | |
| Assessment of pre-development work | | | | | | | | | | | | | | | | |
| Make or Buy | | | | | | | | | | | | | | | | |
| Assessment of manufacturing, production & operating cost | | | | | | | | | | | | | | | | |
| Subsystem development | | | | | | | | | | | | | | | | |
| Integration and Test | | | | | | | | | | | | | | | | |
| Operations | | | | | | | | | | | | | | | | |
| Assessment of manufacturing, production & operating schedule | | | | | | | | | | | | | | | | |
| Subsystem development | | | | | | | | | | | | | | | | |
| Integration and Test | | | | | | | | | | | | | | | | |
| Operations | | | | | | | | | | | | | | | | |
| Specifications | | | | | | | | | | | | | | | | |
| Specifications documented and reviewed | | | | | | | | | | | | | | | | |
| Specifications tree/Requirements traceability matrix | | | | | | | | | | | | | | | | |
| Start interface documents | | | | | | | | | | | | | | | | |
| Fabrication Guidelines and Plan | | | | | | | | | | | | | | | | |
| Integration and Test/Verification Plan | | | | | | | | | | | | | | | | |
| Plannification | | | | | | | | | | | | | | | | |
| Logistics requirements | | | | | | | | | | | | | | | | |
| Elaboration of Design Justification File | | | | | | | | | | | | | | | | |
| Reports | | | | | | | | | | | | | | | | |
| Assessment of Reliability and Safety | | | | | | | | | | | | | | | | |
| Assessment of environmental impact | | | | | | | | | | | | | | | | |

**Table II-1: Project assessment against Phase B expectations.**

## 2.3 Schedule and cost assessment

Quarterly reviews with the SwissCube Advisory board allow for the review of the technical, financial and schedule status of the project. In view of the project's progress, it is here proposed to the PDR board that:

1) The subsystem or system Phase B Action Items and Review Item Discrepencies shall be re-assessed by the end of June 07, corresponding to the end of the summer semester;

2) The CDR shall be moved from end of June 07 to the end of December 07 (the overall schedule can be found in the SwissCube Project Management Plan). This impacts the test plan and will be discussed in section II-4.

In addition, a grass-roots cost analysis was performed for the fabrication of the test and flight models. This analysis also included the workforce needed by the project. The estimated budget required at this point is around 600 kCHF for a flight mid-2008. Further analysis needs to be performed to verify the cost estimated for integration and tests.

# 3 Requirement Analysis

## 3.1 Status on the development of the specifications

The SwissCube specifications have been classified into levels and categories, as explained in the next section. At this point requirements are being written at 6 different levels:

- Mission and Science (Level 1)
- Project (Level 2)
- System (Level 3)
- Subsystem (Level 4)
- Assembly (Level 5)
- Sub-assembly (Level 6).

The Mission/Science and Project specifications were elaborated during Phase A and updated during phase B. The approach taken during Phase B to establish lower level requirements was to have the students of each main subsystem write the specifications for their subsystem. Additional system support at the end of Phase B started the unification and consolidation of the system level requirements. The subsystem specifications were initially written based on the analysis performed and the baseline system design and updated as further analysis was performed.

About 60% of the specification documents have been written (most of them belong to the Space System). The Project Specifications have been internally reviewed. **System and subsystem specifications have been partially reviewed.** Gaps exist in the document tree consistent with the gaps described in the previous section. Currently, each requirement identified has a parent requirement in a higher level. However, the project recognizes that the list of requirements does not yet represent the full extent of requirements that will be needed. For instance, operational requirement are still in a large part, missing.

The reader is encouraged to have a careful look at the specification documents. The driving requirements at the system and subsystem levels are highlighted in this document.

## 3.2 Specifications Documentation and Hierarchy

The SwissCube requirements are currently gathered in several Specifications documents. The highest level document includes requirements at the Mission (level 1) and Project (level 2) levels [1]. System (level 3) and subsystem (level 4) levels specifications are documented separately [2, 3, 4]. Figure II-2 shows the specification documents tree. Separate guidelines were written to facilitate the elaboration of the requirements. These guidelines include description and examples of the categories used to classify the requirements [5].

Project level requirements have an impact at least on two of the following main systems: Mission and Science, Launch System, Space System, Ground System, System Integration and Test or Mission Operations. System level requirement have an impact at least on two subsystems.

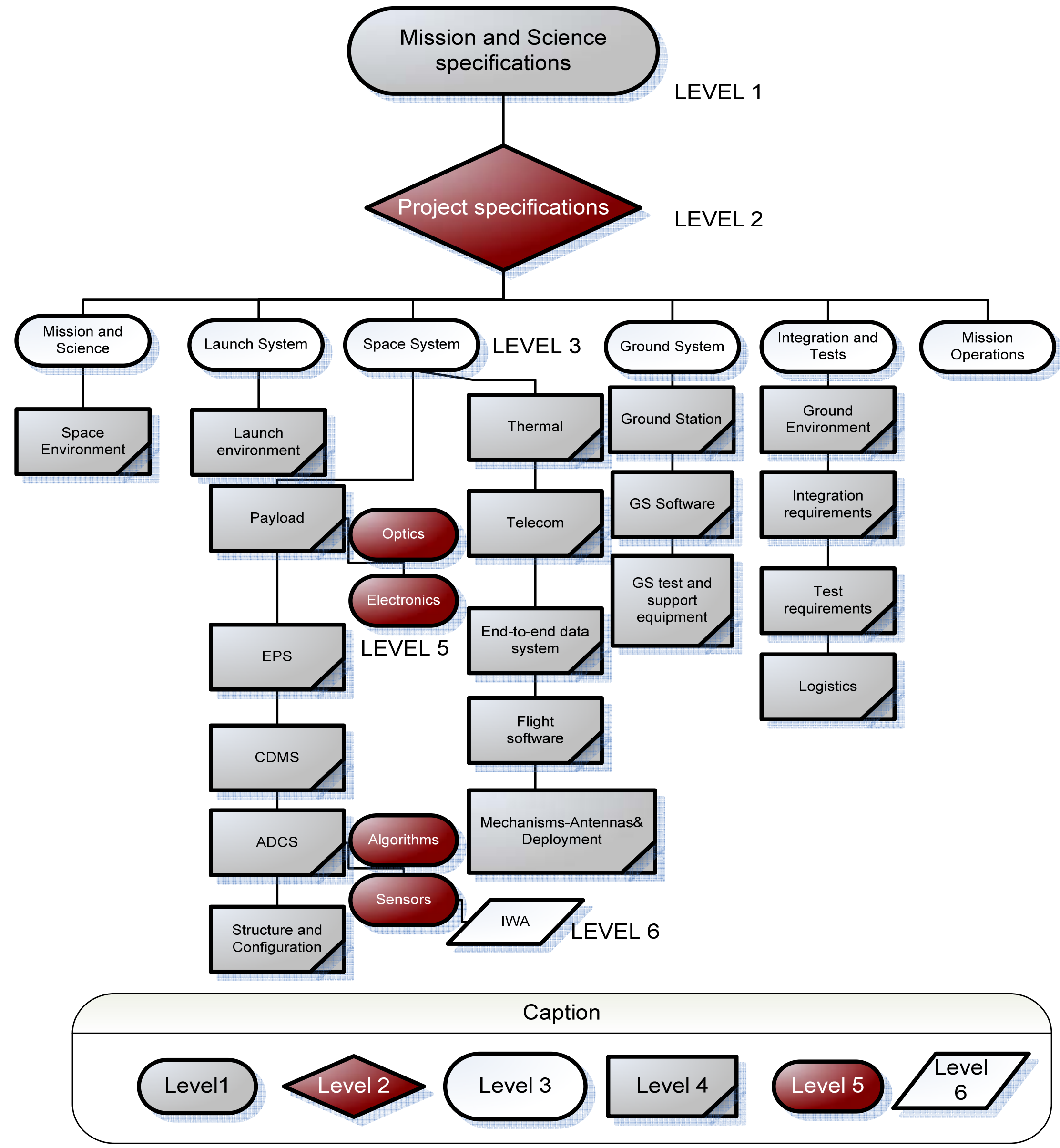



**Figure II-2: SwissCube Specification Documents Tree.**

At system and subsystem levels, the requirements are organized in categories as shown in Table II-2.

A requirement database and friendly interface will be developed over the next semester. This tool will facilitate the verification of the requirements flow between each level.

A traceability matrix will be established along with the AI&V plan.

| Subtopic | Definition/Question | Example |
|---|---|---|

| | | |
|---|---|---|
| **Functional Requirement** | | |
| System Functions | What function does the "system" need to perform? | |
| **Mission & Performance requirements** | | |
| Modes | Modes of operation of the element | Ex. Modes ON & OFF |
| States | Possible states of the element in each mode | Ex. In mode ON the system turns between 5000 and 10000 rpm |
| H/W performance | What performances does the system exhibit in each state? | Power |
| S/W performance | | Software capacity |
| Reliability & Redundancy | What is the reliability of the system? What redundancies should be added? | |
| **Design requirements** | | |
| Constraints | Constraints are a characteristic, result or design feature which is made compulsory or has been prohibited for any reason. Constraints are generally restrictions on the choice of solution in a system. | Materials, Marking, Tribology, operational conditions, law, standards… |
| Thermal | How does the system regulate its thermal environment? Thermal design rules. | Passive or active thermal control. Heaters |
| Maintainability | Does the system need to be maintained during ground life? How? | |
| **Interface** | | |
| Structural | How does the system connect to other structural elements? | Volume, Shape, Attachment, Location |
| Thermal | | Heat generation, thermal resistance of interfaces, Heat capacity |
| Electrical | | Voltage, current, connectors (pin definition), including electrical part of data I/F |
| Data interfaces | | Data messages (content), format (protocols) |
| Physical properties | | Size, Mass, CoG, MoI |
| Other Interfaces | | |
| **Environments** | | |
| Thermal | | Qual temperature range, Operational temperature range, non-operational range, Thermal test gradients (!) |
| Static and dynamic loads | | |
| Vacuum | | |
| Radiation | | |
| **Operations** | | |
| Autonomy | | |
| Control | | |
| Failure Management | | |

**Table II-2: System and subsystem requirements categories.**

# 4 Assembly, Integration and Verification (AI&V) Plan

A separate document [6] describes the approach and plan for the SwissCube AI&V. It describes more or less in detail:

- the verification approach (consistent with the ECSS),
- the model philosophy,
- the verification matrices (still to be refined),
- the test plan as a function of the type of tests (mechanical, thermal, functional, qualification…) and as function of models (integration models, EQM…),
- the ground support equipment (still in infancy),
- the required verification documentation (tests specifications, procedures, report formats),
- the test schedule (preliminary),
- and the space system assembly procedure.

We summarize here the short term considerations for the AI&V plan.

## 4.1 Test plan

A detailed test plan flow for each subsystem has been elaborated. Figure II-3 and Figure II-4 show an example of the Phase B/C tests for the structural and EPS subsystems.

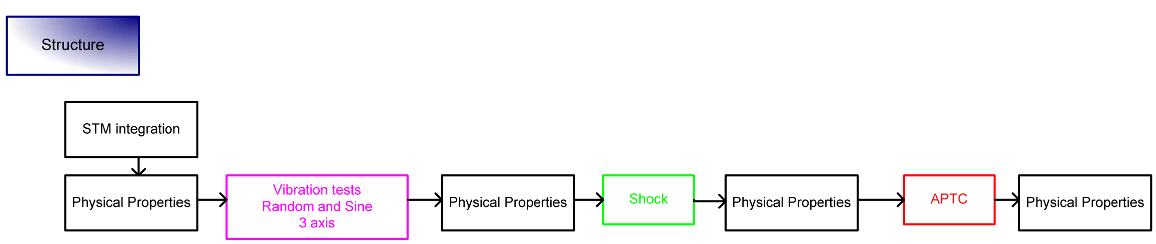
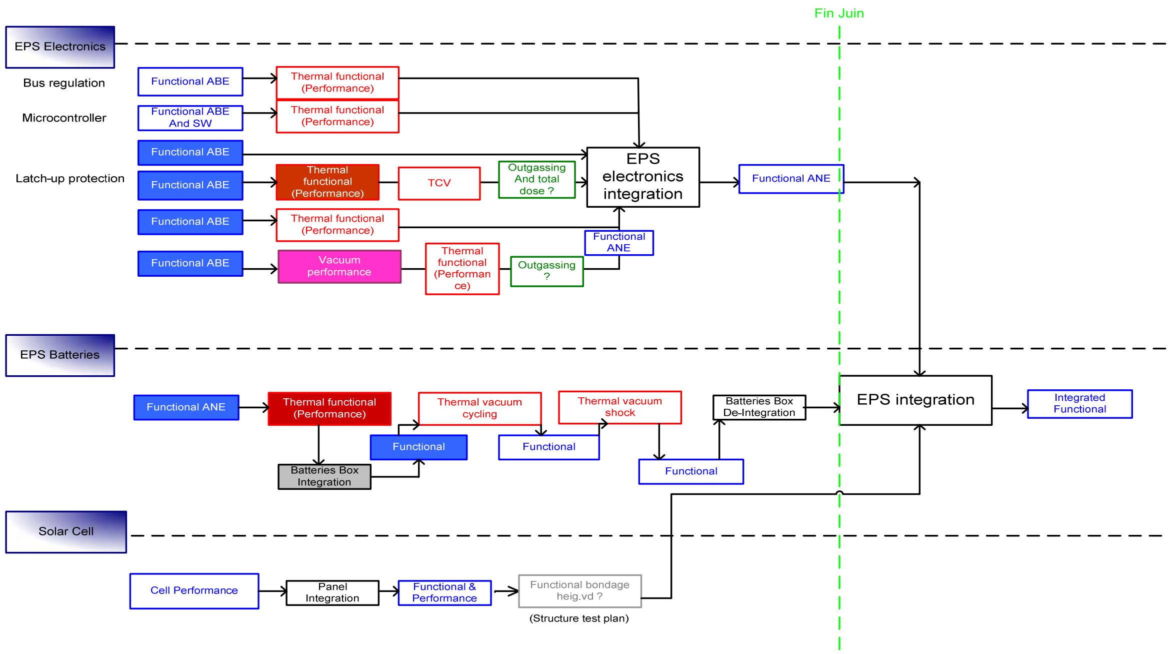



**Figure II-3: Phase B/C tests for the Structure subsystem.**

The plans have been agreed upon by most subsystems, and is being shared and reviewed with the payload and ADCS subsystems.




ABE : Ambiant Baseline Electrical
ANE: Ambiant Nominal Electrical
ISST: Integrated SubSystem Test
SW: Software
RF: Radiofrequency

TCV: Thermal cycling vaccum

**Figure II-4: Phase B/C tests for the EPS subsystem.**

## 4.2 Verification matrix

A verification matrix has been established for each model but still needs to be consolidated with the requirements at each level. Table II-3 shows an example of the verification matrix for the EQM.

| Requirement Category | Equipment Level | Instrument Level | Subsystem Level | System Level |
|---|---|---|---|---|
| **Functional** | T | T | T | T |
| **Performance** | T | T | T | T/A |
| **Composite material** | T | T | - | - |
| **Adhesive bondage** | T | T | T | - |
| **Launcher Interfaces** | - | - | - | T |
| **Ground Segment Interfaces** | T/R | - | T/R | T/R |
| **Physical Properties (mass, CoG)** | T/R | T | T | T/I |
| **Vibration** | - | - | - | T |
| **Shock** | - | - | - | T |
| **Thermal Verification** | T | - | - | T |
| **EMC/ESD** | T | - | - | - |
| **Radiation Environment** | T*/A | T* | - | - |
| **Outgassing** | T* | T | - | T |
| **Static load** | - | - | - | T |
| **Acoustic** | - | - | - | T |
| T: Test; A: Analysis; R: Review of design; I: Inspection; *: optional | | | | |

**Table II-3: Example verification matrix for the EQM.**

## 4.3 Model philosophy

The following model philosophy has been defined for the SwissCube project:

- Integration (Electrical) Model (IM)
- Satellite Structural Model (SM)
- Satellite Engineering Qualification Model (EQM)
- Satellite Flight Model (FM)
- Satellite Flight Spare (FS)

Figure II-5 shows the model flow diagram.

The current plan (deliverables) for the space subsystem models is summarized in Table II-4.

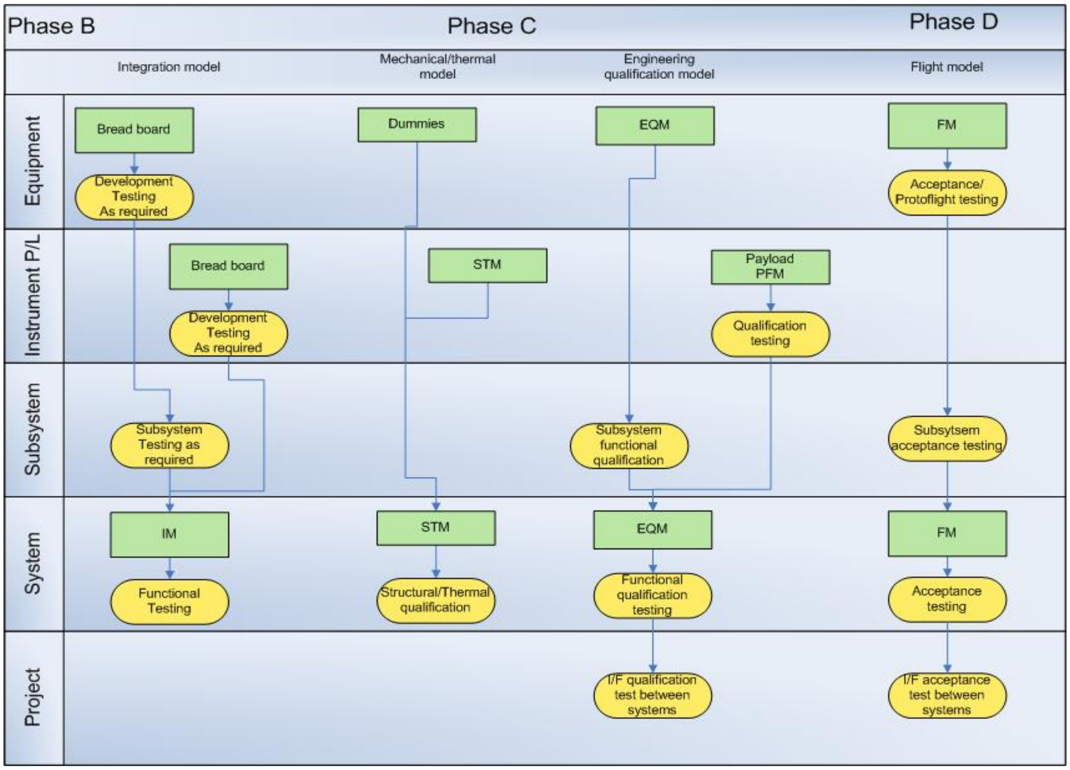



**Figure II-5: SwissCube Model Flow diagram.**

| Subsystems | PDR, March 07 | Review, June 07 | CDR, Dec.07 | AR, June 08 |
|---|---|---|---|---|
| EPS | Analogic functional | Analogic + digital (micro-controller) functional – tested prototype | EQM Board | 2 Flight Models |
| COM Beacon | | Analogic functional | EQM Board | 2 Flight Models |
| COM Data | Receiver and transmitter functional | Receiver, transmitter, micro-controller integrated functional | EQM Board | 2 Flight Models |
| CDMS | Analogic + Digital (Micro-controller) functional | EM Board | EQM Board | 2 Flight Models |
| Structure | Structural model | Structural thermal model | EQM structural and thermal | 2 Flight Models |
| Mechanisms | | Structural/functional | Integrated into EQM structural/thermal | |
| PAYLOAD | | Analogic + digital (micro-controller) functional<br>Structural model | EQM Board | 2 Flight Models |
| ADCS HW | Digital functional | Analogic + digital functional – tested prototype | EQM Board | 2 Flight Models |

**Table II-4: Deliverable models for the space subsystems.**

# III MISSION OVERVIEW

This chapter summarizes the elements related to mission design and mission planning. It also describes the assumptions and analysis regarding the space environment characterization.

# 1 Mission driving requirements

2_PR_11_01 **CubeSat Pico-satellite**

The project shall use the organizational frame and requirements of the Cubesat Standard developed by the California Polytechnic State University (Cal Poly).

*Cubesats are a standard that allows for an easier access to space and access to an experienced university community. It is assumed that the ESA VEGA launch process will be similar to the CalPoly*

2_PR_11_03 **Space to ground frequencies and protocols**

The ground to space communication link shall comply with the Amateur Radio Satellites services.

*For student satellite this is the easiest solution to implement.*

2_PR_14_02 **Launch vehicle**

The project shall be able to launch on a [DNEPR, VEGA, Rockot, Kosmos, MV-8, Indian PSLV, SOYUZ or Ariane 5] launch vehicle.

*Possible options of launcher that have been used so far for Cubesats or that are plausible solutions for the project.*

2_PR_14_04 **Launch Date**

The satellite shall be ready for launch by [6]-2008.

*Fits a reasonable development schedule and the most probable launch opportunities.*

2_PR_15_03 **Communication Availability**

The project shall provide downlink capability between the space system and the ground at every opportunity after antennas deployment.

*This requirement ensures communication capability between the space system and a ground station available and in view.*

# 2 Mission Design

SwissCube will be an auxiliary payload. The mission design will be limited to a range of possible orbits.

## 2.1 Orbit Design Drivers

There are different types of design drivers on the SwissCube orbit design, namely:

- The location of the primary ground station at EPFL requires an inclination of at least 45° to achieve reasonable pass durations. The most probable orbits that will be flown are thus sun-synchronous. However, due to orbital perturbation, the satellite will drift out of the sun-synchronous state. The drift has not yet been assessed. For the analysis, the assumption was made that the orbit would remain sun-synchronous.
- Analysis of past sun-synchronous launches showed that the most likely range for altitude heights is between [400 – 1000] km.
- The space system has no trajectory station keeping or maneuvering capability.

For the SwissCube mission other types of orbits could be considered below 1000km and above 45° inclination. Due to the enormous range of possibilities other orbits will only be studied if required by the launch provider.

2_PR_14_05 **Orbit Altitude**

The project shall operate at Earth distances between [400] and [1000] km altitudes.

*Analysis shows that for Sun-Synchronous orbits, the expected altitude range is [400-1000] km (Ref. Analyse de mission d'un satellite, N. Scheidegger)*

2_PR_14_01 **Operational orbit**

The project shall select an orbit which has an inclination above [45] degrees. For mission analysis a sun-synchronous orbit shall be considered.

*To have direct access with the Ground Segment in Switzerland. This requirement implies a very high probability of flying on a sunsynchronous orbit.*

## 2.2 Sun-synchronous Orbits (SSO)

In Sun-synchronous orbits (SSO), the nodal regression caused by the J2 (non-spherical Earth) is matched with the angular rotation of the Earth around the Sun. Thus the plane of a Sun-synchronous orbit keeps a constant angle alpha with the Earth-Sun vector (see Figure III-1). As shows Figure III-2 these orbits are almost polar and cover therefore all latitudes.

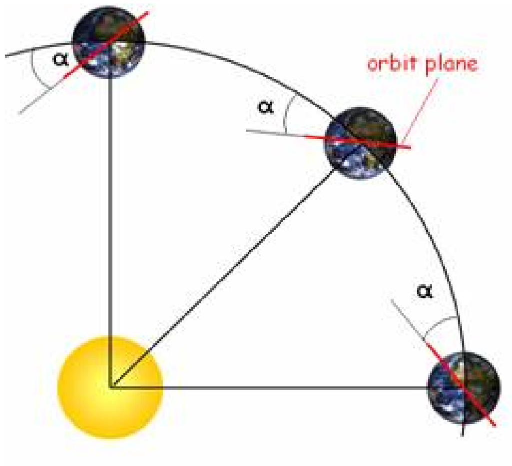



**Figure III-1: Constant Sun/Orbit plane angle alpha for sun-synchronous orbits**

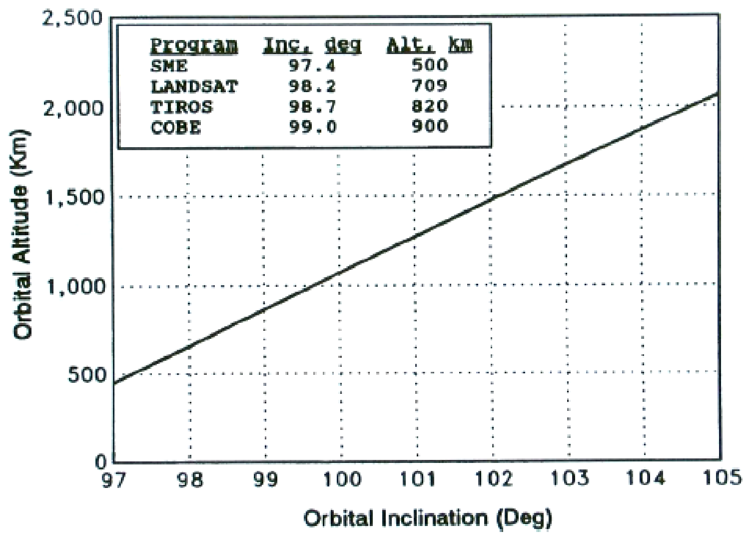



**Figure III-2: Orbital inclination and altitudes for sun-synchronous orbits**

SSO orbits are ideal for Earth observation missions since the satellite crosses the Equator always at the same local time. Further they simplify the satellite design since eclipse durations are almost constant.

### 2.2.1 Eclipse durations

The eclipse duration is an important parameter for the design of the space system. An analysis was performed that calculates the minimum, mean and maximum eclipse duration as a function of the Sun /orbit plane angle alpha and the altitude (using STK). Figure III-3 shows that:

1. For $\alpha$=0, the orbit plane coincides with the terminator, the satellite is in constant light, and there are no eclipses.

2. While eclipse duration varies between 18min and 36min for orbits with 20deg < $\alpha$ <80deg at 400km altitudes, it ranges between 22min and 34min for orbits at 1000km altitude and 40deg < $\alpha$ <80deg.

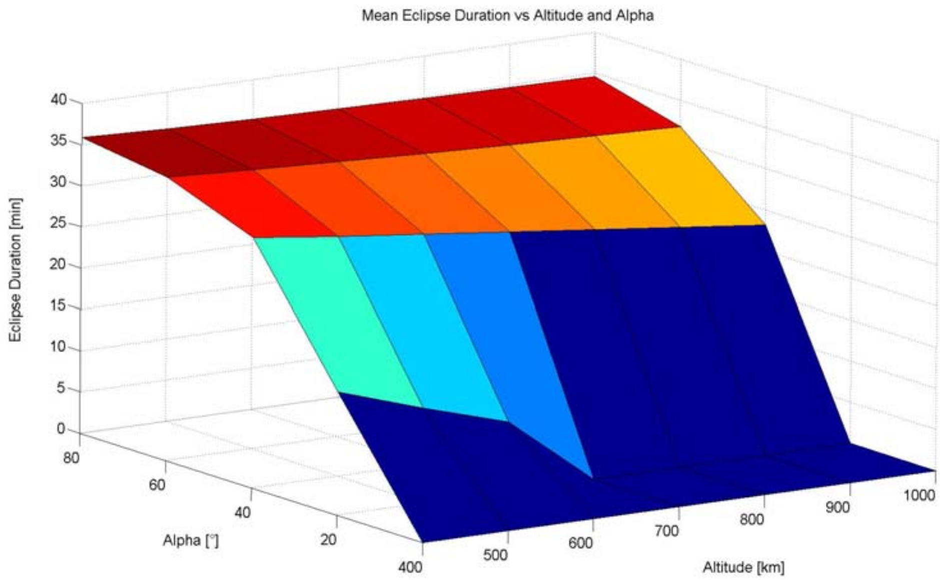



**Figure III-3: Mean eclipse duration as a function of alpha and altitude.**

### 2.2.2 Orbit disturbance, drag and lifetime

The solar cycle is expected to peak in 2011. Thus in 2008, the solar environment can be expected to be relatively high. As the solar activity influences the Earth atmospheric density profile at high altitude significantly, disturbances forces due to atmospheric drag will cause the satellite to loose altitude. The expected lifetime and analysis of the orbital disturbances remain to be done in detail.

## 2.3 Mission Operation Considerations

### 2.3.1 Time in view of a ground station

The time in view analysis aims at estimating the access frequency and duration with the ground station. The following analysis assumes a single ground station located in Lausanne. Time in view duration was computed with respect to the altitude, the elevation angle $\varepsilon$ and $\alpha$-angle. Figure III-4 shows the mean access time as a function of altitude for a minimum elevation of 10°. Mean access times between 5 and 10 minutes can be expected.

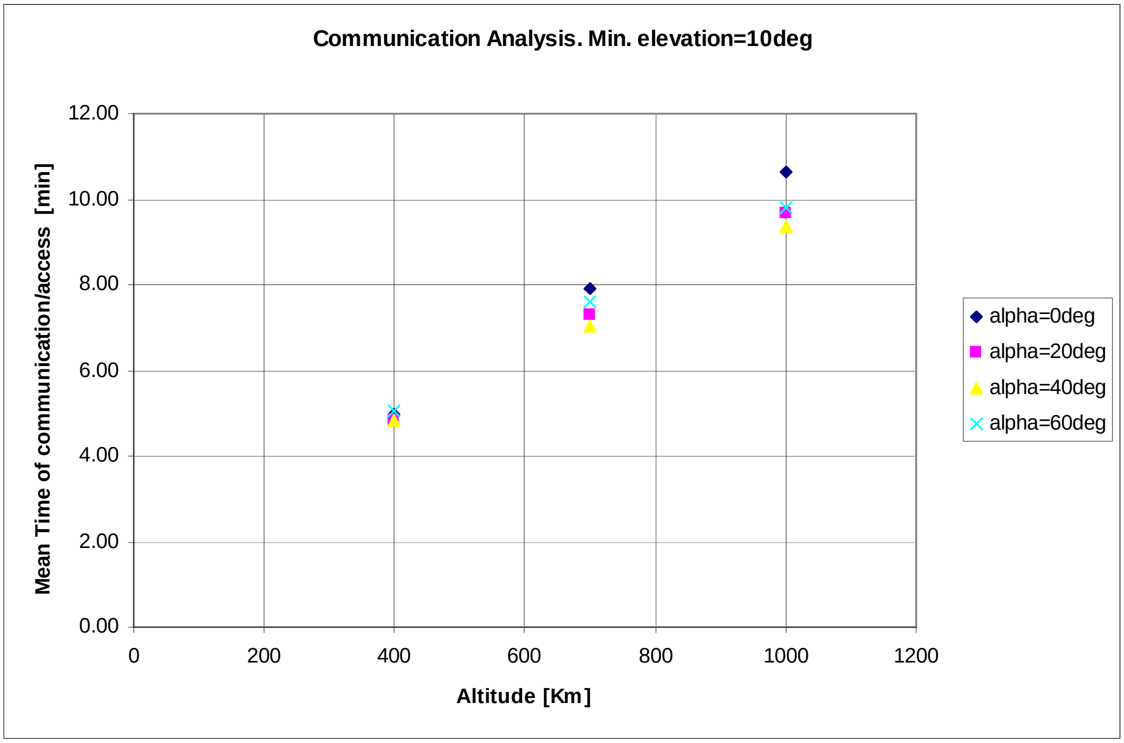



**Figure III-4: Mean access time as a function of altitude for 10° min. elevation.**

### 2.3.2 Sample timelines

Based on the analyses of the precedent section, it is possible to establish a time plan over a fixed period ranging from one (typical) day to the whole mission duration. Timelines offer an overview of the mission course and help design a schedule for the different tasks such as maintenance, scientific measurement, data exchange, etc.

Sample timelines presented in Figure III-5 and Figure III-6 span over the periods of one day for an altitude of 400 km and $\alpha$=20 deg and a second one at an altitude of 1000 km and $\alpha$=60 deg.

<u>Case1: Altitude=400 km, $\alpha$=20 deg</u>

This orbit has an average eclipse time of 18min with a frequency of 15 eclipses per day. For communicating there are at most five possible passes with the maximum possible duration (time in view) equal to 8 minutes per pass. The number of passes and their duration decrease under the $\varepsilon_{min}$ constraints.

<u>Case2: Altitude=1000 km, $\alpha$=60 deg</u>

In contrast to the first orbit this one has an average eclipse duration of 31min and 14 eclipses per day. Since the altitude is higher there are more and longer possible access windows. In fact there are 8 possible communication windows with pass durations of at most 12 min.

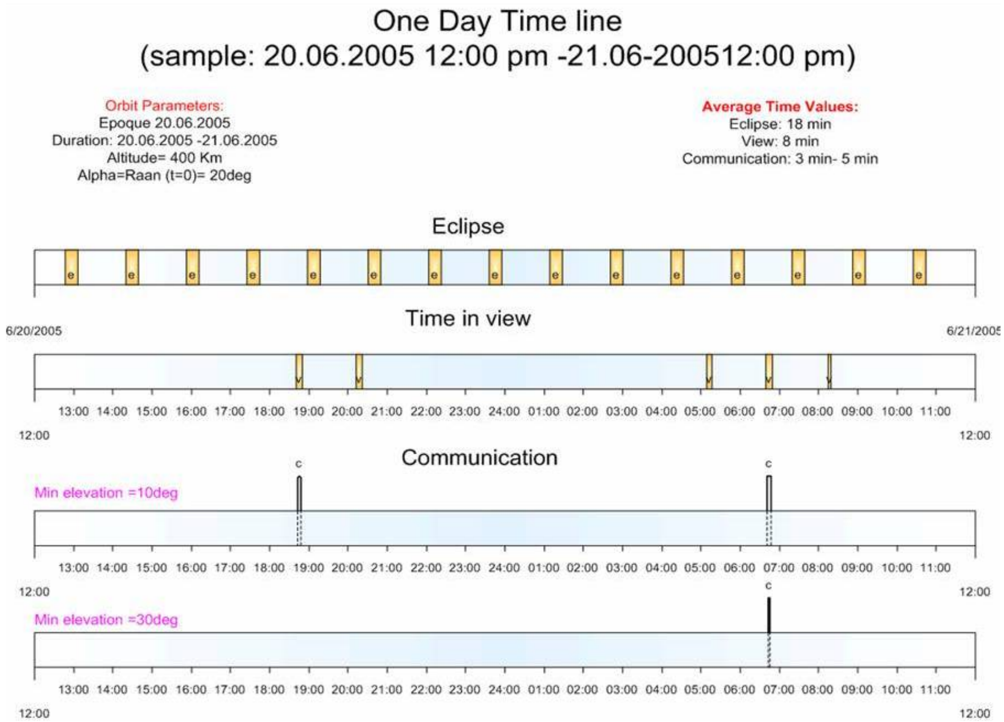



**Figure III-5: Sample timeline for 400 km, $\alpha$ = 20 deg.**

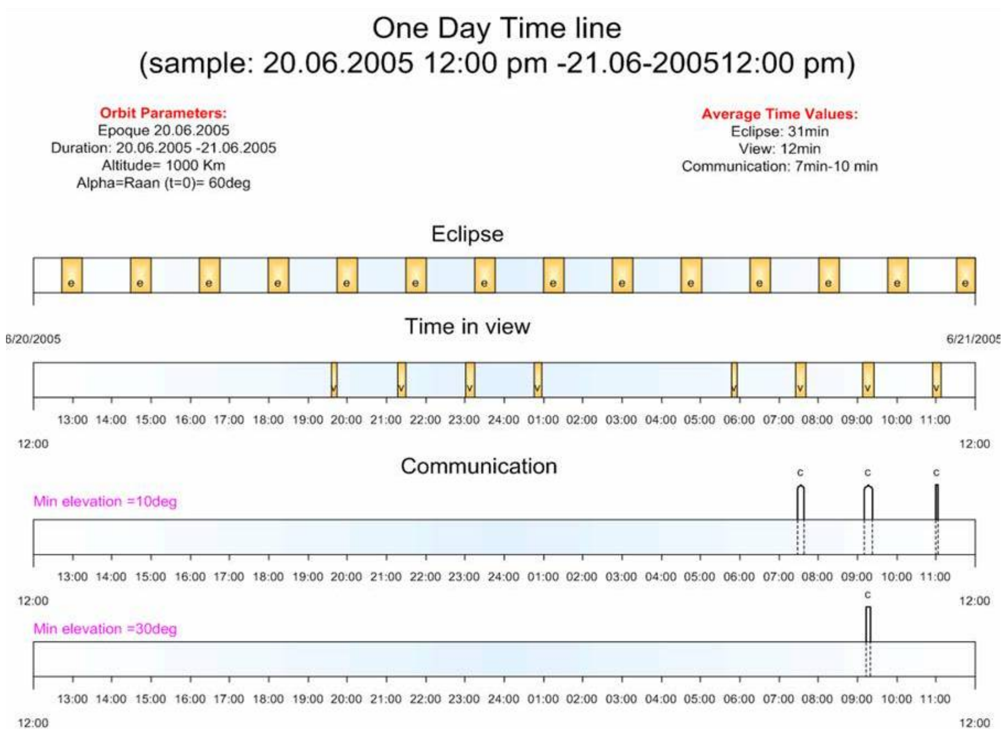



**Figure III-6: Sample timeline for 1000 km, $\alpha$ = 60 deg.**

# 3 Mission Environments

The space environment is far from benign in its effects on space systems. Understanding of the space environment and its interactions is the first step in mitigating these effects. For typical Earth missions, several types of environments should be evaluated, such as:

- Neutral atmosphere: primarily responsible for drag, glow and oxygen erosion;
- Magnetic and electric fields: responsible for magnetic torques and induced electric fields;
- UV/EUV radiation: responsible for photoelectrons and long term changes in material properties;
- IR radiation: driver for thermal effects;
- Plasma/Ionosphere: responsible for wake effects and solar array arcing;
- Plasmasheet: primary region for satellite charging;
- Auroral zone;
- Radiation Belts;
- Particulate environment (debris and micrometeorids).

The principal interactions of concern are then: cumulative radiation effects; single event upsets; latch up; surface and internal charging; surface degradation and erosion; contamination; glow; space debris and micrometeroid impacts. Themal effects and torques were taken into account and were included in the space system design.

Although each interaction should be assessed, a few have been considered so far in the design of the space system. Given the relatively short mission duration, the major concerns assessed so far for SwissCube are listed below. A debris and meteorid assessment remains to be done (as included in the requirements).

## 3.1 Cumulative Radiation Effects

Table III-1 summarizes the trapped radiation dose cumulated for 4 months and 1 year behind 40 mils of Al (1mm) for maximum and minimum solar activity. The analysis assumes a spherical shell shield configuration. The analysis was done using the ESA Spenvis Tool.

| Configuration | Cumulated Dose (krad[Si], 1 mm Al, Solar Max) | Cumulated Dose (krad[Si], 1 mm Al, Solar Min) |
|---|---|---|
| 400 km 4 months | 0.9 | 0.5 |
| 400 km 1 year | 4 | 2 |
| 1000 km 4 months | 5 | 4 |
| 1000 km 1 year | 22 | 15 |

**Table III-1: Trapped radiation cumulated dose worst and best cases behind Aluminum.**

According to the current design, the side panels of the satellite will be made of carbon composites. The thicknesses of carbon composite in discussion is an 8 ply, corresponding to 0.8 mm. Assuming a density for the carbon composite of 1.8 g/cm3, the equivalent cumulated dose behind the carbon panel is summarized in Table III-2.

| **Configuration** | **Cumulated Dose (krad[Si], 0.8 mm CC, Solar Max)** | **Cumulated Dose (krad[Si], 0.8 mm CC, Solar Min)** |
|---|---|---|
| 400 km 4 months | 2 | 1 |
| 400 km 1 year | 10 | 5 |
| 1000 km 4 months | 21 | 11 |
| 1000 km 1 year | 82 | 44 |

**Table III-2: Trapped radiation dose worst and best cases behind Carbon Composite.**

Further analysis needs to be done to confirm the dose and the effects on the PCB components. However, the cumulated dose for solar minima (as expected in 2008) and the required 4 months of operation is sufficiently small (between 1 and 11 krads) to confirm that COTS can be used without major shielding.

## 3.2 Single Event Upsets

SEUs will be mitigated by hardware and software design practices.

## 3.3 Latch-up

A separate latch-up protection circuit has been designed and will be implemented in each electronic subsystem.

# 4 Launch Vehicle

The launch interface for a CubeSat is defined by the Calpoly Design Specifications [7]. CubeSats are not attached to a separation ring as do "classical" satellites but are placed inside a closed pod. Once in orbit the pod's lid is opened and the CubeSats inside are released. The fundamental goal of the design is therefore to fit the interface requirements of the CubeSat launch pod. This standardization allows for SwissCube to be placed on virtually any launcher capable of carrying the CubeSat launch pod.

## 4.1 Candidate Launch Vehicles

CubeSats have been launched from many different launchers the list hereafter includes a non exhaustive list:

- STS-113, Cape Canaveral, November 2001
- Rockot, Plesetsk, June 2003
- Kosmos-3M, Plesetsk, Octobre 2005
- M-V-8, Uchinoura, February 2006
- Dnepr, Baikonour, Summer 2006

The most plausible options identified so far for launch in 2008 are the following:

1) **VEGA Maiden Flight and demonstration flights**

   The VEGA maiden flight will launch in 2008, with a launch date soon to be released. Following the maiden flight, a series of 5 qualification flights is planned in a sequence of one every 6 months. It is assumed that the same structure as the CalPoly P-POD will be used if Cubesats are to be launched on VEGA, as expected. Launch is also expected to be free (or close to).

2) **CalPoly launch services**

   CalPoly offers about one launch per year. The project registered to the “interested list” for flight on DNEPR late 2008. Launch cost are about 50000 CHF.

3) **KAP on Ariane 5 or Soyouz**

   The Kaiser-Threde Arianespace Platform (KAP) is an experimental platform for in-orbit demonstration and/or verification of technology and scientific experiments. Arianespace as launcher authority as well as ESA and DLR are supporting KAP as future auxiliary payload for Technology In-Orbit Demonstration. A first flight opportunity will occur on Ariane 5 in 2008. It is unclear if Cubesats will be accepted on that flight. Another opportunity is on Soyuz (launched from Baikonur Cosmodrome) mid-2008, but details still need to be provided. To launch Cubesats, the KAP would most probably be equipped with the “Single PicoSat Launcher” (SPL) developed by Astro Feinwerktechnik, Berlin, Germany (see Figure III-7). Interfaces are expected to be similar to the P-POD, but still need to be defined.

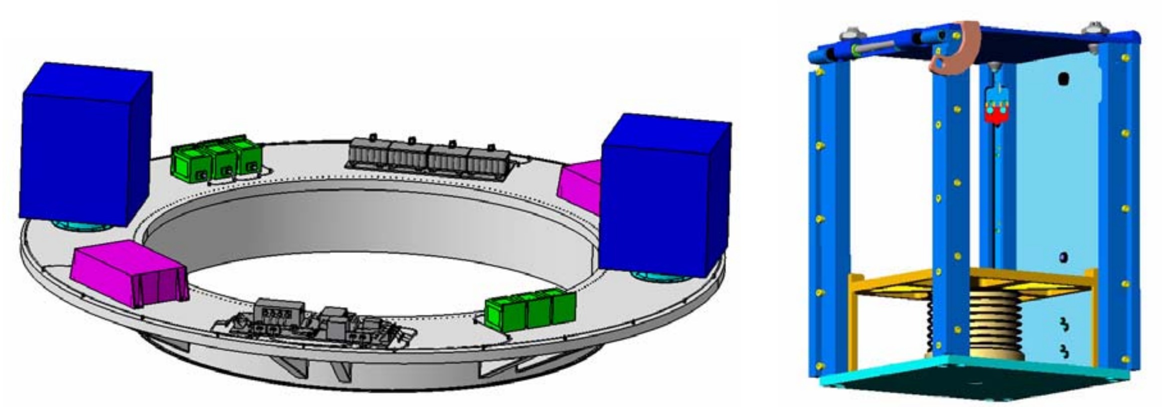


**Figure III-7: KAP on Ariane 5 (in green) and Single PicoSat launcher from Astro Feinwerktechnik.**

## 4.2 Launch environments

The launch environments are defined according to the specifications given in Calpoly Design Specifications [7] and the chosen launcher. The launch environment specification document [8] summarizes the launch environment for several launch vehicles. SwissCube should be compatible with any of the launch vehicles listed above; therefore the most stringent launch environments shall be met. Those environments are specified by the various launch providers.

## 4.3 Accommodation & Mechanical Interface

Mechanical interface between the satellite and the launcher is achieved through the P-POD or T-POD launcher.

**Figure III-8: P-POD during Rokot launch campaign .**

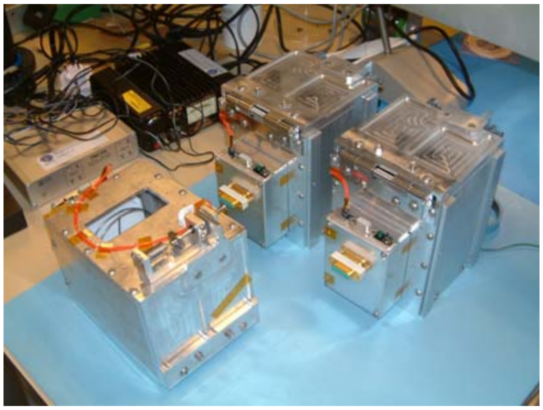
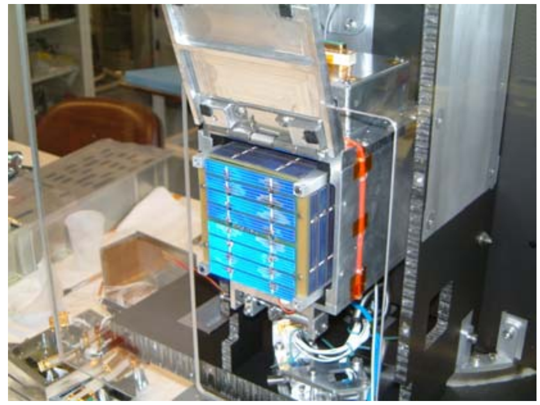



**Figure III-9: T-POD's during integration of SSETI-Express.**

## 4.4 Electrical Interface

2_PR_31_01 **Ground electrical interface**

During ground operations an umbilical link to the satellite will be available through the Cubesat's launch pod's access port.

*Calpoly spec.*

2_PR_31_02 **Launch electrical interface**

During launch there will be no electrical interfaces to the launch vehicle.

*Calpoly requirements*

2_PR_15_07 **Space System maintenance after launcher integration**

The space system shall be capable of being stored inside the P-POD without maintenance for at least [7] days.

*Ensure autonomy of the satellite once integrated on the launch vehicule.*

# 5 Mission Timeline

## 5.1 Timeline Drivers

The following external parameters will influence the mission timeline:

- Orbital parameters.
- Ground stations location.
- Cal Poly CubeSat requirements.

The drivers above will influence the system performance parameters. Hereafter the major mission phases will be defined.

## 5.2 Mission Phases

The following paragraph summarizes the various phases after final satellite acceptance until the disposal of the satellite.

### 5.2.1 Pre-Launch

In the pre-launch phase the final launch site tests are performed and the satellite is prepared for launch. Activities include the charging of batteries and the check-out of the satellites subsystems. This action will be performed while the satellite is already integrated into its launch pod.

### 5.2.2 Launch and early operations (LEOP)

LEOP phase will start after satellite separation from its launch container. It will include the following:

- 15 minutes transmission and antenna deployment dead time.
- Switch-on and antenna deployment.
- Initial satellite acquisition (RF Beacon).
- Validation of the correct operation environment on-board the satellite.
- Validation of the space-ground data link (RF Transceiver).

This phase will end once the validation steps above have been performed. This phase will be terminated within [4] days after ejection from the launch container.

### 5.2.3 Commissioning phase

During satellite commissioning the on-board systems of the SwissCube satellite will be tested and their operational performances confirmed. The results will be used to correct and calibrate the on-ground satellite models. Commissioning will end after the validation of all systems and will be terminated within [20] days after ejection from the launch container.

### 5.2.4 Nominal phase

During nominal phase SwissCube will be fully operational and shall perform the defined science program. This phase will be over 3 months after the end of the commissioning phase.

### 5.2.5 Extended phase & disposal

If the satellite is still operational after this phase the mission will be extended. No active disposal is foreseen. Science operations will be performed as long as possible and subsystem degradation will be monitored up to a mission critical failure, or up to [1] year, whichever comes first.

### 5.2.6 Recovery phases

For each phase possible failure scenarios and recovery plans will be elaborated. The recovery plans for the nominal and extended phases will be identical.

## 5.3 LEOP Tentative Mission Timelines

This paragraph will present a tentative mission timeline for LEOP for the various launch site options and highlight subtleties that might occur for the various launch sites.

For this study a participation in a ground station network is assumed with stations in Stanford, (USA), Tokyo (Japan) and Lausanne (Switzerland).

The final launch site will have an impact on the satellites early operation scenarios. The following have been considered for a 400 km altitude SSO launch towards north. A launch during daylight is assumed.

- CSG Kourou
- Baikonour
- Plesetsk

### 5.3.1 CSG Kourou

One option is to launch from the Centre Spatial Guyanais (CSG) in Kourou. A reference ground track for a SSO orbit is given in Figure III-10.

From a mission point of view the launcher performance and launch site will affect how soon after injection the satellite will be acquired by a SwissCube partner ground station. Taking into account that for a daytime SSO launch towards North the ascending part of the orbit will occur at daylight whereas the descending at night.

A tentative timeline for a CSG Kourou launch is given in Table III-3. The assumption is a 10° minimum elevation angle. The first pass over the Lausanne ground station occurs only 7:20 hours into the mission. This will have impact on the design and shows the necessity of several partner ground stations and radio amateur surveillance of the satellite.

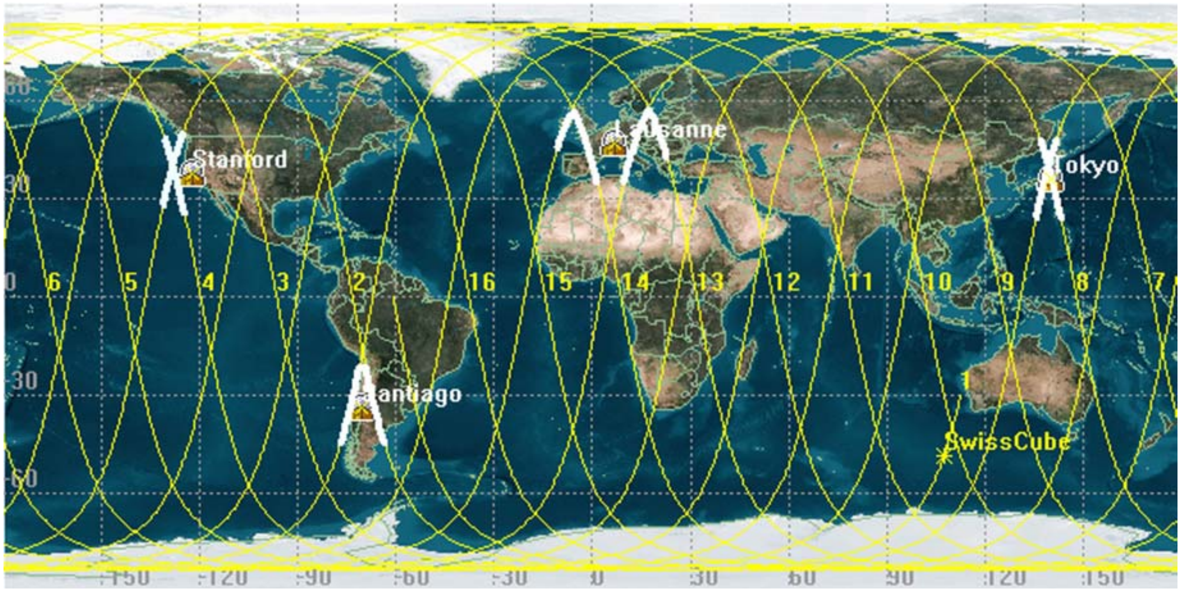



**Figure III-10: Satellite ground track after injection by Vega from CSG Kourou.**

| Orbital time | Location | Ascending Descending | Event |
|---|---|---|---|
| 0:00 | West Australia | | Satellite injection |
| 0:15 | Antarctica | | Antenna deployment and beacon turned-on |
| 0:37 | Argentina/Chile | A | First landfall, possible radio amateur contacts |
| 3:50 | Stanford | A | GSN pass (355 sec) |
| 7:20 | Lausanne | D | First main GS satellite pass (355 sec) |
| 9:55 | Lausanne | D | Second main GS satellite pass (170 sec) |
| 10:00 | Tokyo | A | GSN pass (374 sec) |
| 16:30 | Stanford | D | GSN pass (341 sec) |
| 17:40 | Lausanne | A | Third main GS satellite pass (233 sec) |
| 19:20 | Lausanne | A | Fourth main GS satellite pass (336 sec) |

**Table III-3: Tentative timeline for SSO launch from CSG Kourou.**

### 5.3.2 Baïkonour Cosmodrome

As for Kourou a tentative timeline was established for the Baïkonour Cosmodrome situated in Kazakhstan. For this option the launch would be most likely with a Dnepr launch vehicle [9]. For the present simulation a 98° Sun-synchronous launch has been assumed.

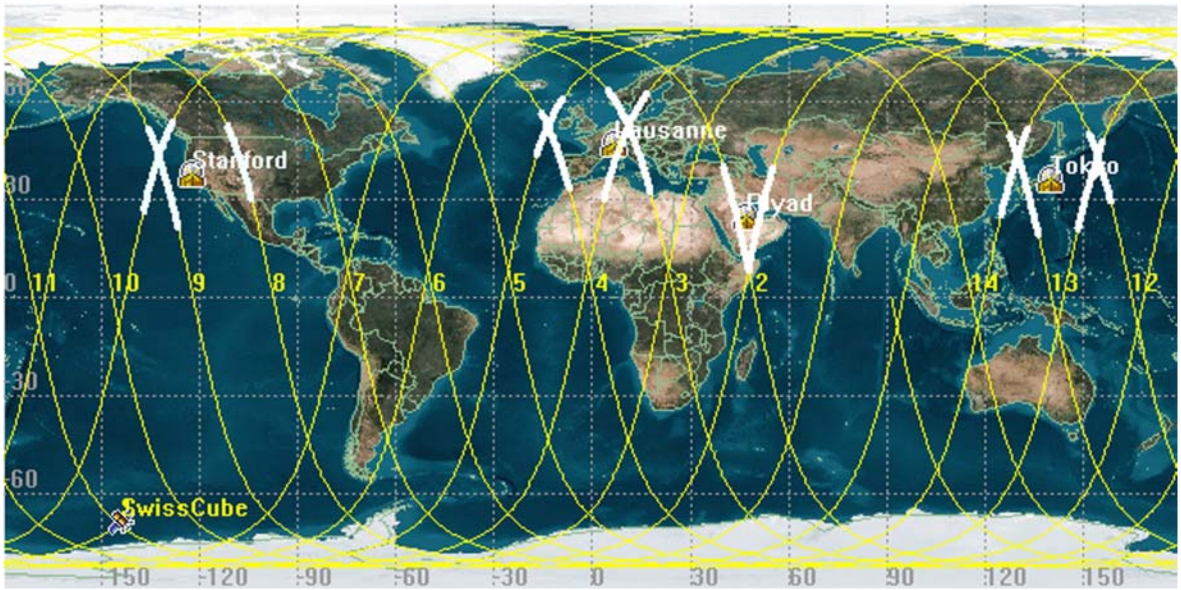



**Figure III-11: Satellite ground track after injection by Dnepr from Baikonour Cosmodrome.**

| Orbital time | Location | Ascending Descending | Event |
|---|---|---|---|
| 0:00 | Around Antarctica | | Satellite injection |
| 0:15 | Indian ocean | A | Antenna deployment and beacon turned-on |
| 0:33 | Yemen/Somalia | A | First landfall, possible radio amateur contacts |
| 1:04 | Stanford | D | GSN pass (457 sec) |
| 2:16 | Lausanne | A | First main GS satellite pass (525 sec) |
| 3:54 | Lausanne | A | Second main GS satellite pass (386 sec) |
| 6:00 | Tokyo | D | GSN pass (446 sec) |
| 7:36 | Tokyo | D | GSN pass (446 sec) |
| … | | | |
| 15:42 | Lausanne | D | Third main GS satellite pass (544 sec) |
| 17:20 | Lausanne | D | Fourth main GS satellite pas (291 sec) |

**Table III-4: Tentative timeline for a 98° SSO launch from Baïkonour Cosmodrome.**

#### 5.3.3 Plesetsk Cosmodrome

The third assessed launch site has been the Plesetsk Cosmodrome situated in northern Russia. Two CubeSat launches have been carried one with a Kosmos-3M and the other with a Rockot [10] launcher.

Rockot places the satellites and the upper stage first into a 96.1° parking orbit. The satellites are then placed into their  final orbit using the Breeze upper stage. At this stage it is therefore not possible to predict any LEOP.

For Kosmos an analysis for a 98° Sun-synchronous launch has been carried out. Due to the geographic proximity to Baïkonour the results are very similar.

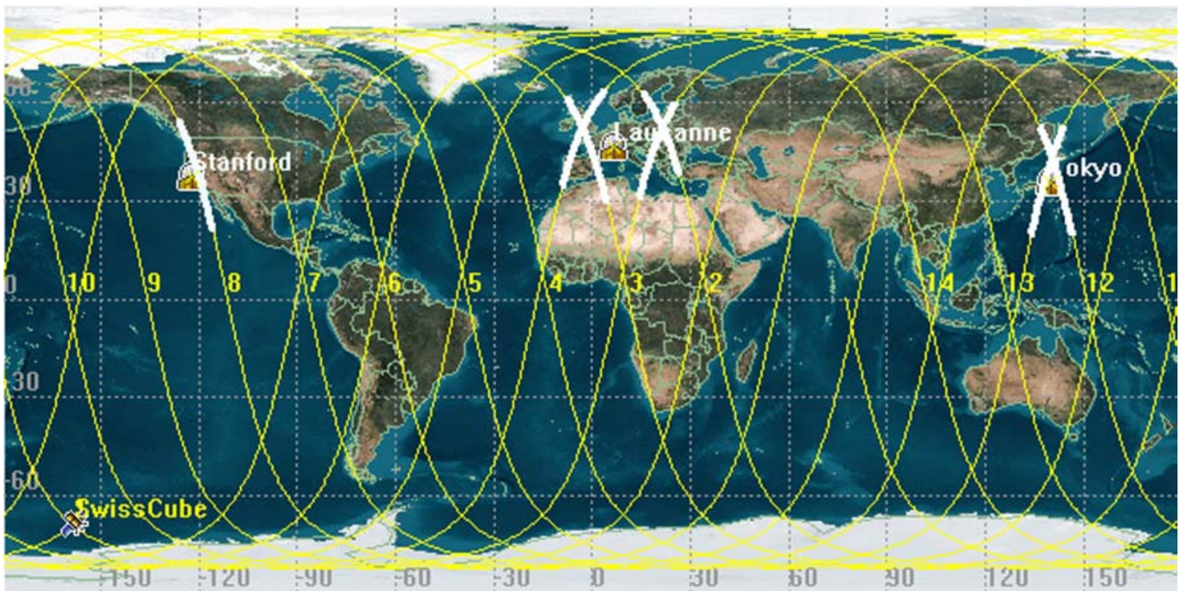



**Table III-5: Tentative timeline for a 98° SSO launch from Plesetsk Cosmodrome.**

#### 5.3.4 Conclusion

From the carried out analyses it can be concluded that first ground contact with the principal ground station might occur more than 7 hours after satellite injection. This assumes a good knowledge of the orbital parameters of the satellites, which might not be true for a CubeSat launch. The following recommendations/requirements should be taken into account during the system design:

- Capability to perform autonomous operations after injection for at least [48] hours.
- Emission of a status signal (beacon) easily receivable by the amateur radio community.
- Work with partner ground stations to decrease LEOP duration.

# 6 Operations and Data Flow

## 6.1 Operations

SwissCube operations will be performed by a team of students. They will be trained by means of a satellite operations system. Operation scenarios will be elaborated and trained by using one of the two SwissCube test benches. The following scenarios will be considered:

- Satellite commissioning
- Nominal satellite operations
- Fault handling.

Training sessions will be performed in an operative environment. This will include real-time simulations where the operations team will try to resolve a system failure by fault assessment and debugging.

## 6.2 Space & Ground Data System

Design Drivers

The small data rate between space and ground (1.2 kbits/sec) requires the elaboration of a "light" data exchange protocol. Further the design should consider the distributed system architecture of SwissCube.

Approach

For telecommand and telemetry exchange with SwissCube and mission control a packet service have been elaborated, inspired by the CCSDS [11, 12] and the ESA Packet Utilization Standard [13].

**Telemetry** data will be generated by the various on-board applications. SwissCube foresees a distributed TM processing where each subsystem/payload will be able to generate TM and route it through the RF system directly to the ground station or it might be buffered in the satellite's CDMS for later retrieval. All telemetry will be stored and processed at mission control for analysis and display.

**Telecommand** packet data generated at the Mission Operations centre will be uplinked to SwissCube, received by the RF receiver and directly routed to the destination subsystem or placed in the CDMS scheduler.

For the RF ground-to-space data link, the AX.25 has been selected. The end-to-end packet protocol is defined in [14].

## 6.3 Link Budget

To generate the link budget, the "AMSAT/IARU Annotated Link Model System" by Jan. A. King was used.

### 6.3.1 Downlink 437.5 MHz (Data)

The following assumptions were made [15]:

- For the slant range a worst case orbital altitude of 1000 km was assumed with a minimum elevation of 10°.
- A transmit power of 1.0 Watts has been assumed with an antenna gain of 3dBi on the satellite side (power amplifier 50% efficient).
- The downlink antenna being a dipole there is a theoretical zero in the axis of the antenna. For the antenna pointing loss, 3dB were assumed.
- The satellite's antennas being linearly polarized a circular polarization was assumed on ground, the worst case loss is 3dB.
- The chosen modulation scheme is FSK: For a bit error rate of $10^{-5}$ an Eb/No of 13.8dB is required. This modulation may change in view of recent development and will offer better performances.
- Maximum data rate is 1'200 bit/sec.
- A stack with 4 Yagis for downlink is assumed at the ground station yielding a conservative gain of 19dBi.

### 6.3.2 Uplink 145.8 MHz (Data)

The same assumptions were made for the Uplink with the following exceptions:

- Transmitted power: 20W.
- Double Yagi stack: 15.4 dBi.
- On the satellite side, a monopole with a gain of 2.3 dBi was assumed.

Table III-6 summarizes the generated TM/TC budget. For a 400 km the path losses decrease by about 6dB. The budgets show close to 10 dB margin, but further refinements need to be done in this area.

| SwissCube Project Downlink Telemetry Budget | | |
|---|---|---|
| *Parameter:* | *Value:* | *Units:* |
| ***Spacecraft:*** | | |
| Spacecraft Transmitter Power Output: | 1.0 | watts |
| In dBW: | 0.00 | dBW |
| In dBm: | 30.0 | dBm |
| Spacecraft Total Transmission Line Losses: | 0.4 | dB |
| Spacecraft Antenna Gain: | 3.7 | dBi |
| Spacecraft EIRP: | 3.3 | dBW |
| ***Downlink Path:*** | | |
| Spacecraft Antenna Pointing Loss: | 0.1 | dB |
| S/C-to-Ground Antenna Polarization Loss: | 3.0 | dB |
| Path Loss: | 155.4 | dB |
| Atmospheric Loss: | 1.1 | dB |
| Ionospheric Loss: | 0.4 | dB |
| Rain Loss: | 0.0 | dB |
| Isotropic Signal Level at Ground Station: | -156.8 | dBW |
| ***Ground Station (EbNo Method):*** | | |
| ***------- Eb/No Method -------*** | | |
| Ground Station Antenna Pointing Loss: | 0.6 | dB |
| Ground Station Antenna Gain: | 19.0 | dBi |
| Ground Station Total Transmission Line Losses: | 1.8 | dB |
| Ground Station Effective Noise Temperature: | 1494 | K |
| Ground Station Figure of Merrit (G/T): | -14.6 | dB/K |
| G.S. Signal-to-Noise Power Density (S/No): | 56.6 | dBHz |
| System Desired Data Rate: | 1200 | bps |
| In dBHz: | 30.8 | dBHz |
| Telemetry System Eb/No for the Downlink: | 25.8 | dB |
| Demodulation Method Seleted: | Non-Coherent FSK | |
| Forward Error Correction Coding Used: | None | |
| System Allowed or Specified Bit-Error-Rate: | 1.0E-04 | |
| Demodulator Implementation Loss: | 1 | dB |
| Telemetry System Required Eb/No: | 13.4 | dB |
| Eb/No Threshold: | 14.4 | dB |
| **System Link Margin:** | **11.4** | dB |
| ***Ground Station Alternative Signal Analysis Method (SNR Computation):*** | | |
| ***---------- SNR Method ------------*** | | |
| Ground Station Antenna Pointing Loss: | 0.6 | dB |
| Ground Station Antenna Gain: | 19.0 | dBi |
| Ground Station Total Transmission Line Losses: | 1.8 | dB |
| Ground Station Effective Noise Temperature: | 1494 | K |
| Ground Station Figure of Merrit (G/T): | -14.6 | dB/K |
| Signal Power at Ground Station LNA Input: | -140.3 | dBW |
| Ground Station Receiver Bandwidth (B): | 1,600 | Hz |
| G.S. Receiver Noise Power (Pn = kTB) | -164.8 | dBW |
| Signal-to-Noise Power Ratio at G.S. Rcvr: | 24.6 | dB |
| Analog or Digital System Required S/N: | 14.8 | dB |
| System Link Margin | **9.8** | dB |

| SwissCube Project Uplink Command Budget (NOTE:) | | |
|---|---|---|
| *Parameter:* | *Value:* | *Units:* |
| ***Ground Station:*** | | |
| Ground Station Transmitter Power Output: | 20.0 | watts |
| In dBW: | 13.0 | dBW |
| In dBm: | 43.0 | dBm |
| Ground Stn. Total Transmission Line Losses: | 6.0 | dB |
| Antenna Gain: | 15.4 | dBi |
| Ground Station EIRP: | 22.4 | dBW |
| ***Uplink Path:*** | | |
| Ground Station Antenna Pointing Loss: | 0.5 | dB |
| Gnd-to-S/C Antenna Polarization Losses: | 3.0 | dB |
| Path Loss: | 145.8 | dB |
| Atmospheric Losses: | 1.1 | dB |
| Ionospheric Losses: | 0.7 | dB |
| Rain Losses: | 0.0 | dB |
| Isotropic Signal Level at Spacecraft: | -128.7 | dBW |
| ***Spacecraft (Eb/No Method):*** | | |
| ***------- Eb/No Method -------*** | | |
| Spacecraft Antenna Pointing Loss: | 7.6 | dB |
| Spacecraft Antenna Gain: | 2.3 | dBi |
| Spacecraft Total Transmission Line Losses: | 1.8 | dB |
| Spacecraft Effective Noise Temperature: | 257 | K |
| Spacecraft Figure of Merrit (G/T): | -23.6 | dB/K |
| S/C Signal-to-Noise Power Density (S/No): | 83.9 | dBHz |
| System Desired Data Rate: | 1200 | bps |
| In dBHz: | 30.8 | dBHz |
| Command System Eb/No: | 53.1 | dB |
| Demodulation Method Seleted: | Non-Coherent FSK | |
| Forward Error Correction Coding Used: | None | |
| System Allowed or Specified Bit-Error-Rate: | 1.0E-04 | |
| Demodulator Implementation Loss: | 1.0 | dB |
| Telemetry System Required Eb/No: | 13.4 | dB |
| Eb/No Threshold: | 14.4 | dB |
| **System Link Margin:** | **38.7** | dB |
| ***Spacecraft Alternative Signal Analysis Method (SNR Computation):*** | | |
| ***---------- SNR Method ------------*** | | |
| Spacecraft Antenna Pointing Loss: | 7.6 | dB |
| Spacecraft Antenna Gain: | 2.3 | dBi |
| Spacecraft Total Transmission Line Losses: | 1.8 | dB |
| Spacecraft Effective Noise Temperature: | 257 | K |
| Spacecraft Figure of Merrit (G/T): | -23.6 | dB/K |
| Signal Power at Spacecraft LNA Input: | -135.8 | dBW |
| Spacecraft Receiver Bandwidth: | 3,000 | Hz |
| Spacecraft Receiver Noise Power (Pn = kTB) | -169.7 | dBW |
| Signal-to-Noise Power Ratio at G.S. Rcvr: | 33.9 | dB |
| Analog or Digital System Required S/N: | 15.8 | dB |
| System Link Margin | **18.1** | dB |

**Table III-6: Link Budget for the SwissCube TM/TC link**

### 6.3.3 Downlink (Beacon)

Again, the Beacon link budget used the "AMSAT/IARU Annotated Link Model System" by Jan. A. King. This budget assumes 0.075 W of RF transmitted power and a spacecraft antenna gain of 3.7 dBi (analytically calculated during Phase A). This budget takes into account of different losses in transmission lines and the misalignment of the antennas.

The beacon modulation assumed here is the 400 bit PSK modulation with FEC on top, as advised by a few AMSAT radio-amateurs. The coding gain and improvement in robustness is significant compared to the regular Morse code, and it became the standard mode for all future AMSAT projects. Also software decoders for this format (PC soundcard connected to HF receiver) are widely spread in the hamradio community. This modulation scheme still needs to be implemented.

**SwissCube Project**
**Downlink Telemetry Budget**

| *Parameter:* | *Value:* | *Units:* |
|---|---|---|
| ***Spacecraft:*** | | |
| Spacecraft Transmitter Power Output: | 0.1 | watts |
| In dBW: | -11.2 | dBW |
| In dBm: | 18.8 | dBm |
| Spacecraft Total Transmission Line Losses: | 0.4 | dB |
| Spacecraft Antenna Gain: | 3.7 | dBi |
| Spacecraft EIRP: | -8.0 | dBW |
| ***Downlink Path:*** | | |
| Spacecraft Antenna Pointing Loss: | 0.1 | dB |
| S/C-to-Ground Antenna Polarization Loss: | 3.0 | dB |
| Path Loss: | 155.4 | dB |
| Atmospheric Loss: | 1.1 | dB |
| Ionospheric Loss: | 0.4 | dB |
| Rain Loss: | 0.0 | dB |
| Isotropic Signal Level at Ground Station: | -168.0 | dBW |
| ***Ground Station (EbNo Method):*** | | |
| ***------- Eb/No Method -------*** | | |
| Ground Station Antenna Pointing Loss: | 0.6 | dB |
| Ground Station Antenna Gain: | 19.0 | dBi |
| Ground Station Total Transmission Line Losses: | 1.8 | dB |
| Ground Station Effective Noise Temperature: | 1494 | K |
| Ground Station Figure of Merrit (G/T): | -14.6 | dB/K |
| G.S. Signal-to-Noise Power Density (S/No): | 45.3 | dBHz |
| System Desired Data Rate: | 1200 | bps |
| In dBHz: | 30.8 | dBHz |
| Telemetry System Eb/No for the Downlink: | 14.6 | dB |
| Demodulation Method Seleted: | PSK/FEC Code | |
| Forward Error Correction Coding Used: | 400 bit PSK modulation with FEC on to | |
| System Allowed or Specified Bit-Error-Rate: | 1.0E-02 | |
| Demodulator Implementation Loss: | 1 | dB |
| Telemetry System Required Eb/No: | 2 | dB |
| Eb/No Threshold: | 3 | dB |
| **System Link Margin:** | **11.6** | dB |

**Figure III-12: link budget**

The budget with an emitted power of 20 dBm is well-balanced because the link margin is higher than 10 dB.

# IV SPACE SYSTEM DESIGN

# 1 Overview

The current space system design is the result of a few concept iterations. The first steps in defining the system were to establish system and subsystem trade-off options, done during Phase A. The result of this phase was a first baseline which served as input for Phase B and served also to readjust performance requirements of the space segment.

Preliminary functional analysis was performed showing two major threads, namely:

- Communications
- Science

Table IV-1 shows the criticality of different on-board functions. A compromise between robustness and redundancy has been chosen. Figure IV-1 shows the reliability block diagram of the satellites most critical functions, i.e. downlink of information.

| Criticality | Function | Criteria |
|---|---|---|
| High | Downlink | Satisfies primary mission objective |
| Medium | Uplink | Required for satellite operation & debugging |
| Low | Platform & payload functions | Required for secondary mission objective |

**Table IV-1: Mission critical function of the space system**

Basic reliability considerations start with EPS for which partial redundancy and robustness have been implemented to maximize reliability. Redundancy is achieved by having separated batteries, charge and discharge circuits and solar cells. Robustness is achieved by the simplicity of the system that does not require any programmable controller.

The basic beacon signal can be generated by a hardware source[1] which allows identifying the satellite from ground, this mode will be operated in case of EPS microcontroller failure. A more complex beacon signal can be generated by the EPS microcontroller; this signal can include status parameters of the satellite, such as bus voltages and temperatures. A hardware switch selects between both signals.

In case of a failure within the RF Beacon part a second, more complex option will be available to communicate with the satellite. This can be done using the satellites receiver and transmitter system.

The RF switch, used for downlink, still remains as single point of failure, redundancy or robustness options shall be investigated for this component.

[1] The generated signal does not include any variable parameters. It will probably just contain the satellite name and a mode identifier.

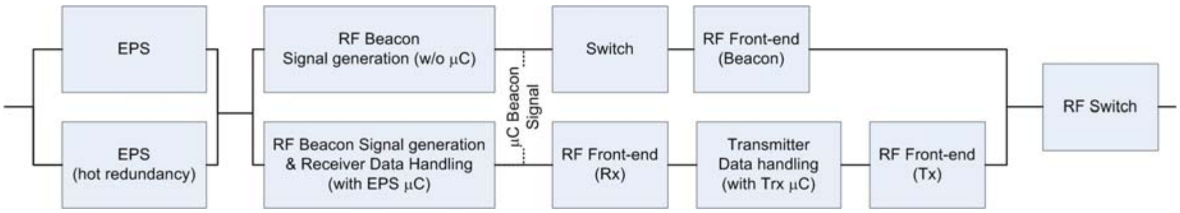



**Figure IV-1: Critical function reliability block diagram.**

## 1.1 Satellite Reference Point (SRP) and Frame (SRF)

The reference frame is provided in Figure IV-2. In this right handed frame the payload aperture is oriented towards +X. The Z axis is parallel to the structure rails with the motherboard perpendicular to +Z. The satellite reference point is in the geometrical center of the "cube".

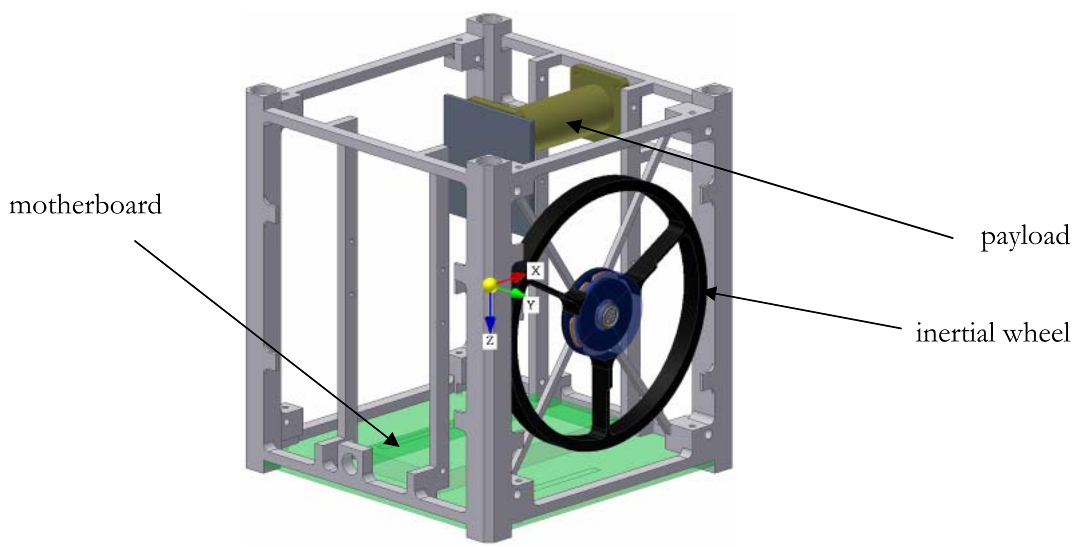



**Figure IV-2: Satellite reference frame**

# 2 System Level Trade-offs

The trade-offs performed at the system level are summarized below and presented in a general point of view. The subsystem trade-offs are detailed in the corresponding reports.

## 2.1 Communication

The major trade-off for the ground-space RF link(s) is the choice between a single frequency radio system and a multi-frequency one. Simplex radio requires the satellite transmitter and receiver to operate at the same frequency. The satellite can either send or receive data and has to switch between these modes during a pass. Three major issues have been raised in [Ref 13] that strongly urges to avoid simplex radio on a satellite.

The first involves possible failure modes of the transmitter. Cycling the transmitter on/off leads, due to low efficiency and high powers used, to a significant lifetime degradation of the power carrying components in the transmitter and might cause premature failure of transistors bond wires.

A second aspect is that regulations require that all satellite operations in space have positive control of transmissions at all times[2]. In this case a radio switching between emission/reception might not be considered as being capable to immediately end radio transmissions. This is particularly true if the system is blocked in a continuous transmission state.

A final concern is satellite safety where "denial of service" attacks could easily be performed when using a simplex radio.

For the three reasons above it was decided to design the RF system for UHF (435MHz) downlink and VHF uplink (145MHz). This uplink/downlink choice is based on the fact that UHF is not a primary radio amateur band and is mainly used by coastal RADAR that could jam the uplink signal.

It is further recommended to limit transmission bandwidth to a minimum. For early operations it was decided to use a continuous low power beacon and a data transceiver, that both can be shutdown.

The SwissCube team has been in contact with Graham Shirville member of the IARU Satellite Advisory Panel who has given a go-ahead for the chosen communication system layout.

## 2.2 Bus Topology and Controller Functions

Figure IV-3 shows a simplified schema of the information flow between the various subsystems (functions). CDMS as the main data source/sink is identified. The CDMS provides various services to the other subsystems and contains the on-board scheduler. A peripheral information connection exists between the RF receiver and the EPS allowing for recovery in case of the failure of the CDMS system.

[2] "Space stations shall be fitted with devices to ensure immediate cessation of their radio emission by telecommand, whenever such cessation is required under the provisions of these Regulations." [ITU Radio Regulations]

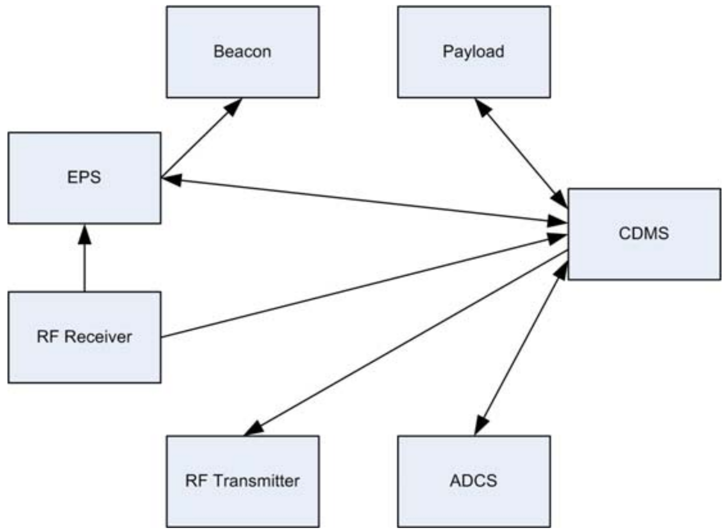



**Figure IV-3: Information flow between the different subsystems**

From this dataflow diagram different possible bus can be identified. Figure IV-4 shows two basic options. The payload is always considered as an independent component. This option offers the possibility to adapt to the payload requirements very easily.

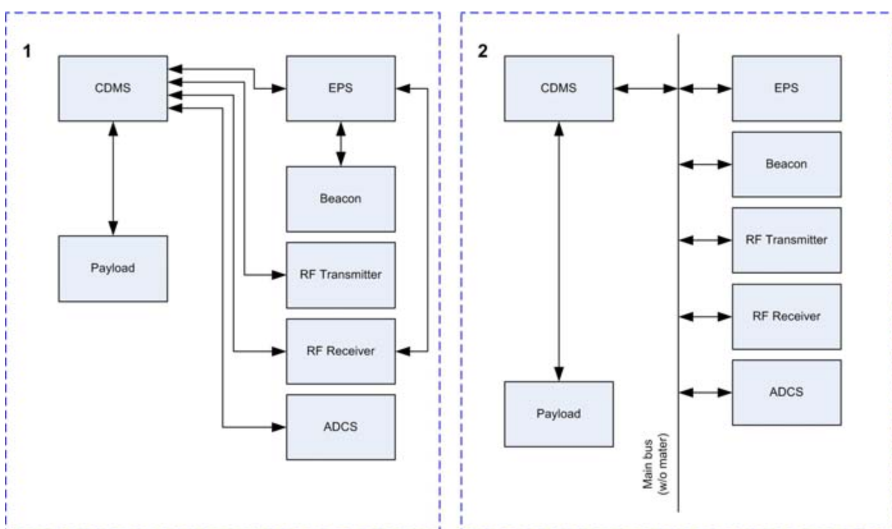



**Figure IV-4: Bus topology dedicated vs. distributed bus.**

The dedicated bus option seems to be the more complex in terms of cabling inside the satellite. Further it requires many dedicated data ports on the controller and in case of failure of the CDMS the subsystems become inaccessible.

Figure IV-5 shows the baseline bus layout which is based on a distributed bus system. To simplify data exchange between EPS, RF Transmitter and Beacon these three functions will be combined within a microcontroller.

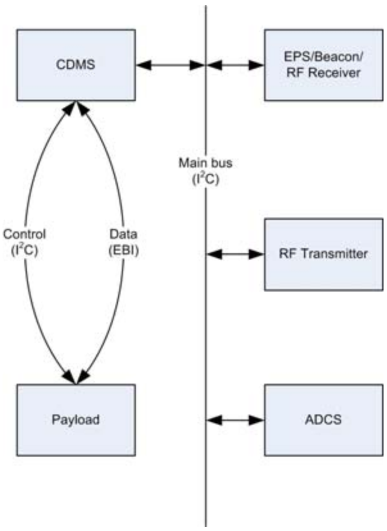



**Figure IV-5: Baseline bus layout.**

## 2.3 Data Bus Trade-offs

Several options for the on-board data busses exist like the RS family, I2C, CAN, etc. They can be sorted in 2 categories, the differential busses and the non differential. Differential busses, like the CAN, offer the advantage to be more robust to perturbations but their consumption is bigger.

Depending on the function on the bus different trade-off criteria have been established. For the main satellite bus the reliability criteria was heavily weighted. The trade-off is summarized in [16].

## 2.4 Structure and Configuration

The CubeSat standards offer the possibility to build double or triple CubeSats. A double satellite is just twice as long than a normal one. Because our scientific mission will occur during an eclipse we need a lot of power. A double CubeSat offer more than twice the solar array surface. It also has more weight capacity and space to place additional batteries. The biggest disadvantage of the double is its launch price, twice the price of a single one. One of our objectives is to try to fulfill the mission requirements with a single CubeSat.

The primary structure can be built in different ways, from the monoblock structure (one piece) to "IKEA kit" structure with a large number of pieces. The monoblock structure offers the advantage to weight less because there are less connecting parts like screws but it has the disadvantage that it is more difficult to insert the boards in it.

The internal configuration depends mainly on the choice of the payload placement and how to arrange the boards around it.

# 3 System Block Diagrams

## 3.1 Product Tree

The analysis of the required functionalities of the space system have led to the product tree, arranged by subsystem, shown in Figure IV-6.

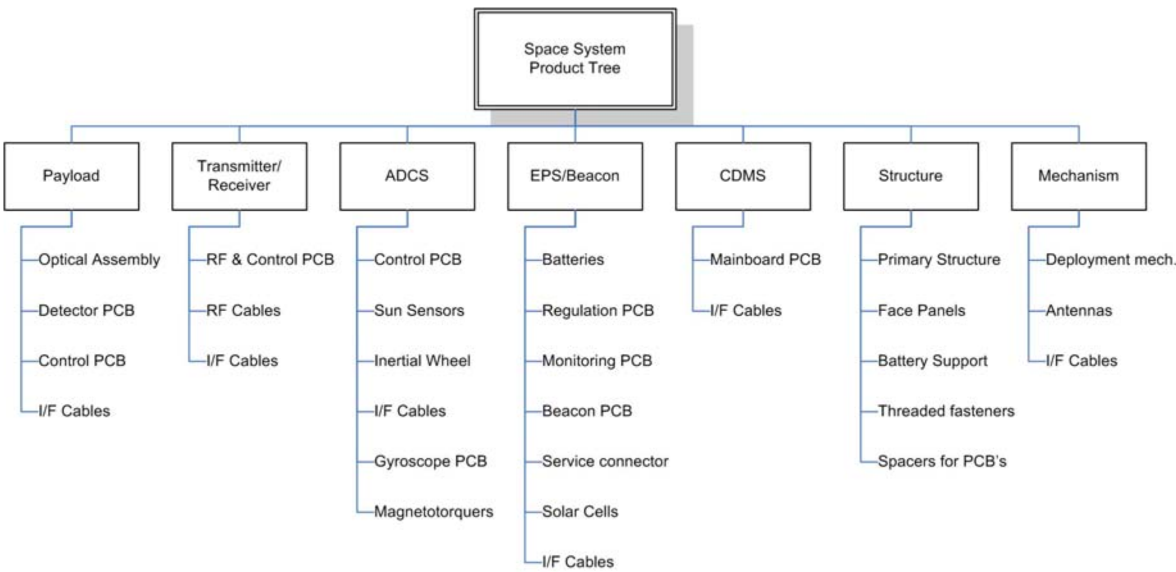



**Figure IV-6 Space System Product Tree**

## 3.2 Electrical Block Diagram

Figure IV-7 shows the electrical block diagram of the satellite. For a detailed version please consult the reference [17]. To simplify the electrical lines having identical functions have been regrouped.

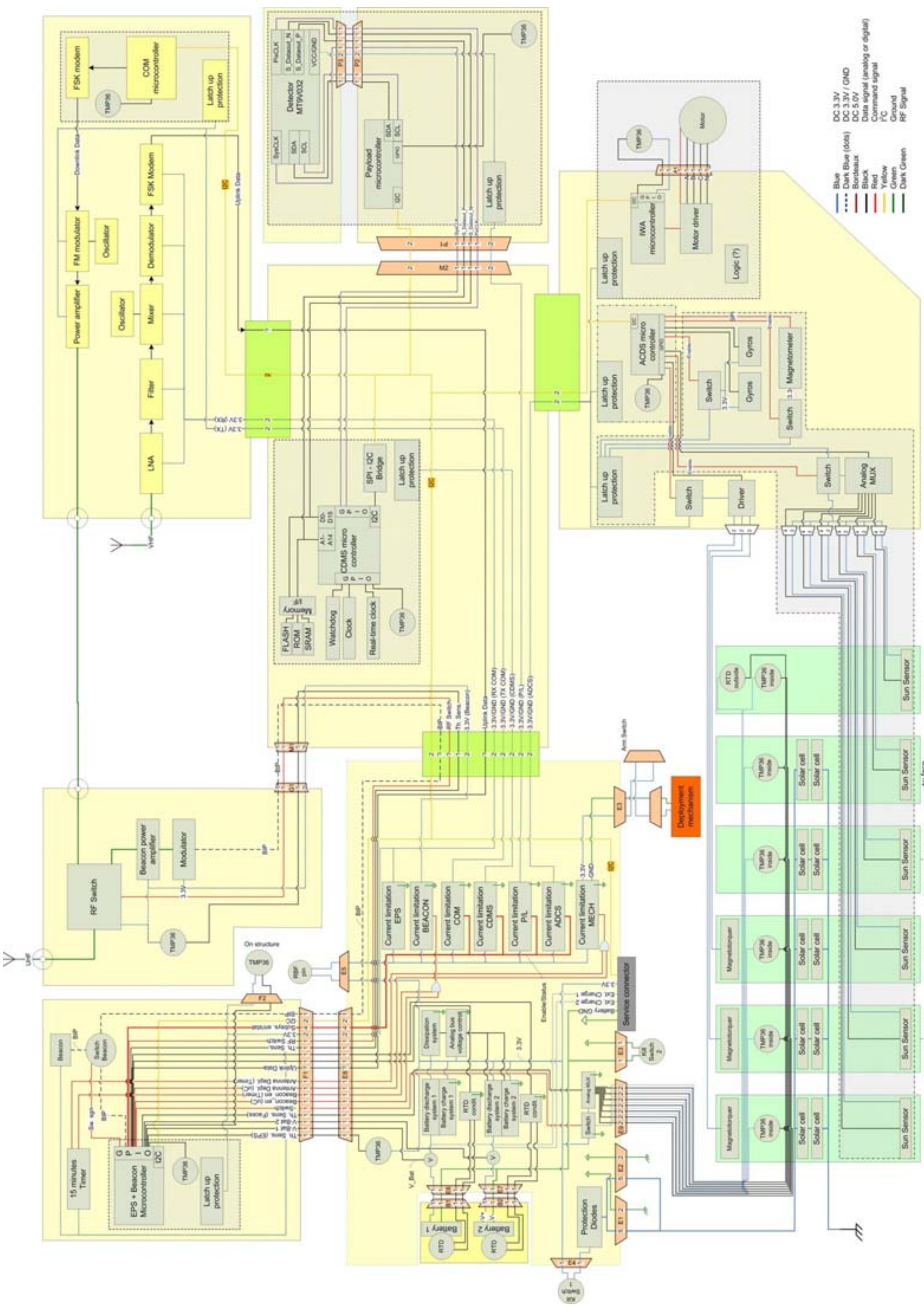


**Figure IV-7: Electrical Block Diagram**

# 4 System Budgets

## 4.1 Mass Budget

The CubeSat specifications state a 1kg maximum mass allocation. The mass budget is based on the work done during Phase A. It was updated during the whole Phase B. Just as a reminder a CubeSat shall weight less than 1 kilogram. After Phase A, the overall mass of the SwissCube was 913 grams. It means a margin of about 10%. During Phase B it was possible to refine the estimation made before, because structural models of the hardware were available. Table IV-2 presents the mass allocation of each subsystem. Actually the satellite weights 814 grams, which means a margin of about 20%.

| Subsystem | Mass [g] |
|---|---|
| Structure & Configuration | 263 |
| EPS | 188 |
| ADCS | 114 |
| CDMS | 33 |
| Payload | 47 |
| COM | 45 |
| Mechanism & antenna | 20 |
| Thermal | 4 |
| Cabling | 100 |
| Total | 814 |

**Table IV-2: Subsystem mass budget.**

## 4.2 Power Budget

The actual power budget is based on the work done during phase A and B. The establishment of the power budget is done using many assumptions. The worst case in term of orbit duration is considered and a 30 % margin is book kept.

## 4.3 Assumptions

To calculate the total amount of energy (mWh) needed for one orbit around the Earth, assumptions were made. Some of them come from the projects requirements and others will define new system requirements. These assumptions are listed below.

- One orbit is 92.6 minutes long, 36 minutes in eclipse and 56.6 minutes in daylight. This is the worst case because this is the longest eclipse duration and it corresponds to an altitude of 400 km.
- Science takes pictures during the eclipse and when possible also during day time
- RF reception is always on
- The beacon sends a 15 seconds long message every 30 seconds
- ADCS Magnetotorquers are always in use and need 50 mW each on average

- ADCS controller and sensors are always on
- EPS is on all the time (eclipse and daylight)
- RF Data transmission sends 7.5 minutes long data message
- Payload picture capture is 10 seconds long
- The energy taken from the battery generate 10% losses

The power, in watts, needed by each subsystem is presented in Table IV-3.

| **Loads** | | | |
|---|---|---|---|
| *Subsystem* | Value | Unit | Remark |
| EPS | 30 | mW | |
| | | | |
| Payload | 450 | mW | |
| CDMS | 150 | mW | |
| Beacon | 150 | mW | |
| ADCS control | 30 | mW | |
| ADCS sensor | 60 | mW | |
| ADCS Magnetotorquers | 150 | mW | |
| ADCS wheel | 85 | mW | |
| Main RF control & receiver | 90 | mW | |
| Main RF transmitter | 2000 | mW | |
| | | | |
| **Generation** | | | |
| Produced power (mean) | 1744 | mW | |
| | | | |
| **Other Parameters** | | | |
| | | | |
| Eclipse duration | 0.6 | | Altitude 400km |
| Daylight duration | 0.94 | | |
| | | | |
| Transmission duration | 0.13 | h | |
| | | | |
| Margin | 30% | | |
| | | | |
| Battery discharging losses | 10% | | |
| Battery charging losses | 10% | | |

**Table IV-3: Power required per subsystem.**

## 4.4 Power production profile

The mean power production over the worst case orbit (400 km) was calculated using the STK simulator and Simulink. The incidence angle on each face is calculated with Simulink/MatLab taking different vectors from STK. With a basic model of the SwissCube, the incidence angle of the solar rays on each satellite face can be computed. The results of each face are summed the power production profile over the orbit can be determined. The average over the orbit is taken and so the power production. Figure IV-8 shows the power production in function of time.

The solar cells of the model have a limit angle of 20 degrees. It means that if the solar ray it the side panel with an angle below 20 degrees, no power will be produced.

The produced power is constant on one face, +y or –y depending of the kind of orbit. The peaks correspond to the illumination of the four other faces.

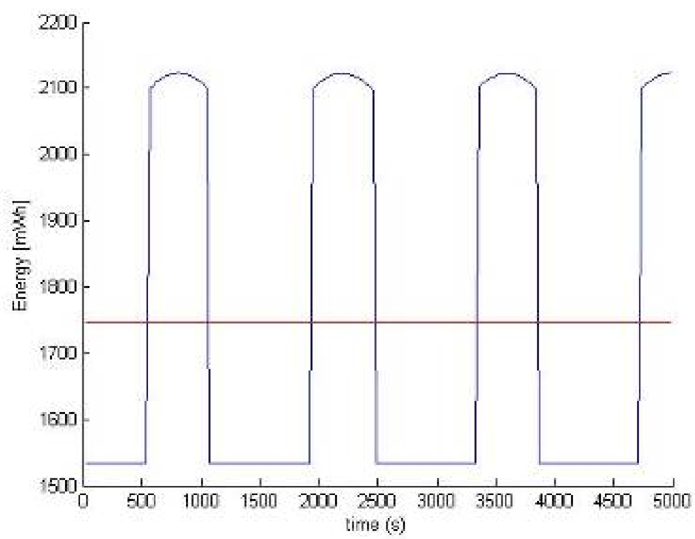



**Figure IV-8: Power production in function of time with mean value.**

## 4.5 Power modes

Once the satellite is in function which is corresponding to the nominal mode of the operational modes, there are 8 different possible power consumption states, 4 during daylight and 4 during the eclipse. In each part of the orbit the satellite can be transmitting or not and taking pictures or not. The different states are listed in Table IV-4 with their corresponding energy consumption.

| | | |
|---|---|---|
| DTS | Daylight WITH transmission and WITH science | 1090 mWh |
| DTnS | Daylight WITH transmission but WITHOUT science | 1088 mWh |
| DnTS | Daylight WITHOUT transmission but WITH science | 789 mWh |
| DnTnS | Daylight WITHOUT transmission and WITHOUT science | 787 mWh |
| ETS | Eclipse WITH transmission and WITH science | 1021 mWh |
| ETnS | Eclipse WITH transmission but WITHOUT science | 1020 mWh |
| EnTS | Eclipse WITHOUT transmission but WITH science | 559 mWh |
| EnTnS | Eclipse WITHOUT transmission and WITHOUT science | 558 mWh |

**Table IV-4: Power Modes**

In order to have to have power modes for complete orbits, the different cases above have to be combined. The combination gives 16 (4x4) different power states. Table IV-5 shows the sum of the divers states (unit mWh).

| | ETS | ETnS | EnTS | EnTnS |
|---|---|---|---|---|
| DTS | 2'266 | 2'265 | 1'884 | 1'883 |
| DTnS | 2'265 | 2'264 | 1'883 | 1'882 |
| DnTS | 1'923 | 1'921 | 1'541 | 1'539 |
| DnTnS | 1'921 | 1'920 | 1'539 | 1'538 |

**Table IV-5: Power consumption combinations.**

## 4.6 Consumption scenario

The 16 different combinations are list in Table IV-6. Once the satellite is in nominal mode of operation, it will be in one of these power consumption combinations. At an altitude of 400 kilometers, the satellite will orbit about 15 times around the Earth. It will have three opportunities to communicate with the ground segment (assumption that only one ground station is used for communication). The assumed scenario is that the satellite will take pictures once a day that the communication will be established three times a day and that during the remaining eleven orbits, no science and no transmission will occur. The energy consumed for each orbit is summed, so the total consumption per day is known. As it is to be seen in Table IV-6 the total power consumed power in one day is less than the total amount of produced energy during the fifteen orbits.

| Phase | Number of orbits | Energy/phase | Energy |
|---|---|---|---|
| DTS ETS | | 2'266 | 0 |
| DTS ETnS | | 2'265 | 0 |
| DTS EnTS | | 1'923 | 0 |
| DTS EnTnS | | 1'921 | 0 |
| DTnS ETS | | 2'265 | 0 |
| DTnS ETnS | | 2'264 | 0 |
| DTnS EnTS | | 1'921 | 0 |
| DTnS EnTnS | 3 | 1'920 | 5'759 |
| DnTS ETS | | 1'884 | 0 |
| DnTS ETnS | | 1'883 | 0 |
| DnTS EnTS | | 1'541 | 0 |
| DnTS EnTnS | | 1'539 | 0 |
| DnTnS ETS | | 1'883 | 0 |
| DnTnS ETnS | | 1'882 | 0 |
| DnTnS EnTS | 1 | 1'539 | 1'539 |
| DnTnS EnTnS | 11 | 1'538 | 16'916 |
| | | | |
| Total | | | 24'215 |
| | | | |
| Power production | 15 | 1'639 | 24'590 |

**Table IV-6: Scenario**

## 4.7 Data Budget

So far no data budget has been established, an overview of all signals can be found in [18].

# 5 Science Instrument

## 5.1 Design Drivers

### 5.1.1 Functional requirements

The payload of the SwissCube satellite will be a technology demonstrator of a novel Earth sensor (ES). It shall satisfy the following conditions:

- The payload observes the nightglow band of 762 nm, with a resolution of at least 10 nm.
- The payload has the spatial resolution of [0.3]° and a FOV of [20]°.
- The payload shall survive a sun pointing attitude, with a permanent damage or performance degradation of less than [20]% for an exposure time of at least 10h.
- The payload is able to perform the science mission with the sun no closer than [30] ° from the sensor boresight.

### 5.1.2 Operational requirements

In a first phase airglow emissions shall be observed at different regions and under different angles of observation. These measurements will provide a first idea of expected minimum, maximum and mean intensities of airglow emissions during both day and night. Furthermore, it will allow analyzing background radiation due to scattered sun- or moonlight. The first observation phase shall last 3 months. During this period, 20 images of the airglow shall be taken.

In a second phase only observations of airglow emissions at limb between 50 and 120 km shall be carried out. Since they constitute the basis for a new low-cost Earth Sensor, their variation in intensity has to be studied more carefully. Hence, the variation of emission intensity depending on latitude can be observed over a longer period. The duration of this second phase will be determined by the lifetime of the satellite.

### 5.1.3 Physical constraints

Since there will not be enough place to attach all the required electronic components of the payload subsystem to the optical system, the payload's electronics shall consist of a headboard, including the detector which is attached to the optical system, and a mainboard on a second PCB, housing the power supply, and other components required to successfully operate the detector and communicate with the CDMS subsystem. The space which has been attributed to the payload has a volume of [30 (length) x 30 (height) x 70 (depth)] $mm^3$ for the optical system and the headboard, and a volume of [70 (length) x 30 (height) x 20 (depth)] $mm^3$ for the mainboard. The total mass of the payload shall be less than [60] g.

The payload shall be turned on only if science observations have to be carried out and consume at maximum [450] mW (peak power) during [10]s once all four days.

### 5.1.4 Technical description of the payload

The payload consists of two main elements:

- a detector and its corresponding electronic circuit, which detect incoming photons and generate a digital output proportional to the local light intensity. The electronic circuit provides the required power and control signals for the detector and interfaces with the CDMS or the ground station.
- an optical system used to magnify and image a selected line of the airglow on the detector

#### 5.1.4.1 Detector and control electronics

The payload of the SwissCube satellite is the prototype of the ES currently developed at LMTS. Since this ES instrument will be based on a SPAD-array[3], it would be best to use this same detector for the prototype in order to provide a more realistic characterization of the ES concept. However, it might be difficult to adapt such a novel solution to the low-power and low-mass specifications of the SwissCube project and the control electronics will not be ready in time to be launched with SwissCube. Therefore, a solution, like the use of commercial CMOS-detectors or CCDs, has been studied and designed.

Analysis shows clearly that the performances of a CMOS detector are closer to those of a SPAD-array. Thus, it is this type of sensor which will be used.

The most interesting options are the KODAK KAC-9619 and the MICRON MT9V032. Both detectors are highly sensitive CMOS detectors, with similar power requirements and a similar size as a SPAD-array, if a Binning of 4 x 4 pixels is applied. However, the Dark Count Rate (DCR), the Fill-Factor (FF) and the Photon Detection Probability (PDP) are significantly higher for the CMOS sensors. Nevertheless, they will be able to detect similar photon fluxes as a SPAD-array.

The characteristics of the three detectors are summarized in Table IV-7. The photon flux has been calculated for the worst case, hence for a telescope aperture of 8 mm and a FOV of 0.156°/pixel for a pixel pitch of 30 µm (giving a total FOV of 20° for a SPAD-array with 128 x 128 pixels). Since the MICRON MT9V032 is smaller and cheaper than the KODAK KAC-9619 and has nevertheless a similar performance, it is the most interesting option.

[3] SPAD – Single Photon Avalanche Diode

| Performance | Unit | MT9V032 | KAC -9619 | SPAD |
|---|---|---|---|---|
| Array size | pixels | 188 x 120 † | 162 x 122 † | 128 x 128 |
| Pixel pitch | µm | 24 x 24† | 30 x 30† | 30 x 30 |
| Total FOV | ° | 23.5 x 15 | 25.3 x 19 | 20 x 20 |
| Dynamic range | dB | 100 | 110 | 140 |
| Fill-factor | % | 20 | 47 | 15 |
| Photon Detection Probability | % | 45 | 27 | 5 |
| Dark Counts (25°) | Hz | 4000 | 3500 | 25 |
| Power consumption | mW | 320 | 170 | ? |
| Required integration time | s | < 0.2 | < 0.2 | < 0.2 |
| Detector performances at night for limb measurements | | | | |
| Minimum photon flux * | photons pixel $^{-1}$ s $^{-1}$ | 340 † | 760 † | 50 |
| Mean photon flux * | photons pixel $^{-1}$ s $^{-1}$ | 860 † | 2 k † | 100 |
| Maximum photon flux * | photons pixel $^{-1}$ s $^{-1}$ | 3 k † | 6 k † | 340 |
| Detector performances at day for limb measurements | | | | |
| Minimum photon flux * | photons pixel $^{-1}$ s $^{-1}$ | 70 k † | 150 k † | 9 k |
| Mean photon flux * | photons pixel $^{-1}$ s $^{-1}$ | 170 k † | 380 k † | 22 k |
| Maximum photon flux * | photons pixel $^{-1}$ s $^{-1}$ | 310 k † | 680 k † | 40 k |

† including Binning of 4 x 4 pixels

* including FF and PDP

**Table IV-7: Characterization of the two detectors.**

### 5.1.5 Electronic circuit

The electronic circuit consists of two PCBs: a headboard measuring [30 (length) x 30 (height) x 20 (depth)] $mm^3$, which is attached to the optical system and bears the detector; and a mainboard, measuring [70 (length) x 30 (height) x 20 (depth)] $mm^3$ and housing the power supply and other components required to successfully operate the detector and communicate with the CDMS subsystem.

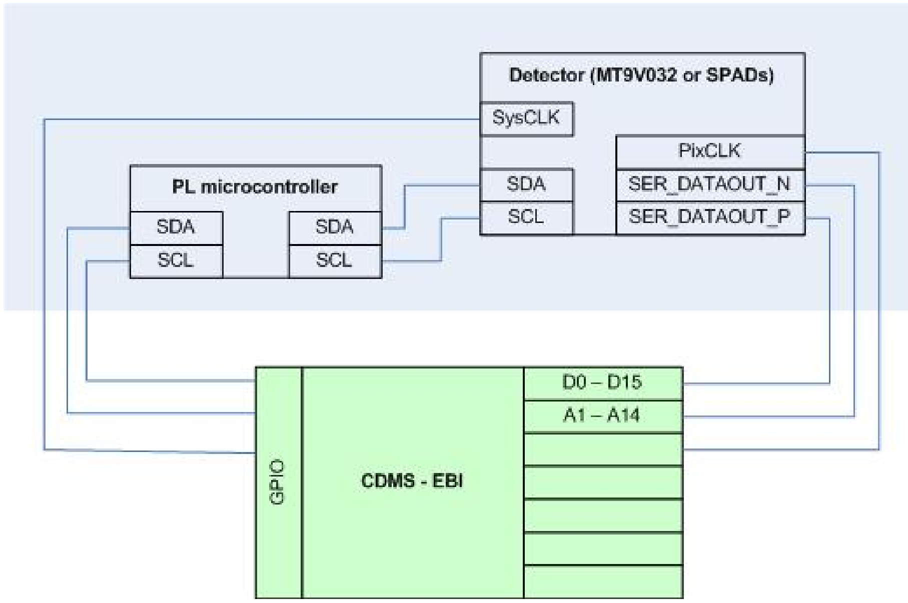



**Figure IV-9: Software interface between CDMS and Payload.**

The block diagram of the electronic circuit is shown in Figure IV-9. The microcontroller is only used to interface the detector with the CDMS and does not read or compress the science data. Nevertheless, it is required to guarantee a standard software interface between CDMS and the payload, no matter which detector type will be used on the final satellite and to allow a direct communication between the ground station and the payload subsystem.

The read-out of both detectors[4] needs a high frequency (> 13 MHz) and can not be done with a small microcontroller. Thus, we will use the microcontroller of the CDMS to read the science data, compress it if necessary and store it aboard the satellite until transfer to the ground station.

A successful procedure to take an image consists of the following steps:

- CDMS sends a message to EPS to turn on the payload subsystem
- EPS turns on the payload subsystem and sends an acknowledgement to CDMS
- CDMS sends a command to the payload microcontroller to initialize the detector
- Payload microcontroller initializes the detector according to the received parameters (integration time, binning factor, DCR suppression factor, …) and sends an acknowledgement to CDMS for successful initialization of the detector
- CDMS sends a command to the payload microcontroller to capture an image
- Payload microcontroller triggers the image capturing, formats the scientific data in a 10 bit format and sends a message to CDMS to start the lecture of the science data
- CDMS reads the science data, compresses it if necessary and stores it in a memory until transfer to the ground station
- CDMS sends a message to EPS to turn off the payload subsystem
- EPS turns off the payload subsystem and sends an acknowledgement to CDMS

[4] SPAD-array or CMOS detector.

Recovery plans have to be elaborated for all possible failure scenarios during this procedure.

The required size of the memory depends on the chosen detector array and the compression of the data. There are basically two configurations:

- A CMOS detector of 752 x 480 pixels with 10bits/pixel which will be compressed during lecture by Binning of 4 x 4 pixels. Thus the image has a size of 226 kbits.
- A SPAD-array of 128 x 128 pixels with 10bits/pixel giving an uncompressed image of 164 kbits.

Thus, the required memory for scientific data will not exceed 1.2 Mbits, even without compression.

## 5.2 Optical system

The optical system shall provide a total Field of View of at least [20] ° and a minimum resolution of [0.3] °/pixel. The targeted detector pixel pitch is 30 µm and requires a focal length of about [6] mm. In order to relax the complexity of the optical system (and to minimize the dimensions of the optical system), the aperture has to be as small as possible. However, a larger aperture would be preferred, since a higher photon flux would increase the SNR and provide more reliable measurements. A good compromise between the complexity of the optical system and a maximum aperture is reached for an aperture of 8 mm.

The detailed design of the optical system has not been done, yet. Preliminary analyses show however, that the use of several lenses is required.

**For further details please refer to the following report:**

- Payload system engineering [19]

# 6 Platform Subsystems

## 6.1 Structure and Configuration

### 6.1.1 Overview

The purpose of the structural subsystem is to provide a simple study structure that will survive launch loads and provide a suitable environment for the operation of all subsystems throughout all phases of the mission life. The structure shall also provide easy access for integration and satellite check-out. Moreover the structural subsystem shall carry, support, and mechanically align the satellite equipment.

Structural design shall aim for simple load paths, a maximization in the use of conventional materials, simplified interfaces and easy integration. Due to the size of the satellite and small expense budget, this was done with the philosophy of maximizing usable interior space, while minimizing the complexity and cost of the design.

The structural has been given a mass allocation which is a target for the overall design.

### 6.1.2 Principal design drivers

The proposed SwissCube structure has to be compatible with the CubeSat standard, including access ports and deployment switches. The configuration has to accommodate all platform elements, the optics payload and the antenna mechanism.

### 6.1.3 Baseline design

Different frame options were studied during the early phases of the design. A "monoblock" approach was selected based on weight constraints and structural strength considerations.

The payload and platform elements are inserted into the primary structure, shown in Figure IV-10. The structure will be made out of either AL-7075-T73 or Al-6061-T6 as required in [7]. For the external panels the baseline foresees a reinforced composite of carbon fibers in an epoxy resin matrix.

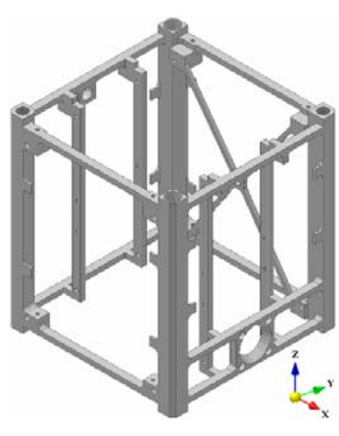



**Figure IV-10: A. SwissCube primary structure**

Figure IV-11 shows the layout of all components forming the satellite. The satellite configuration combines three major assemblies:

- Primary structure with attached side and solar panels
- Payload assembly
- Printed circuit board stack connected to a common motherboard

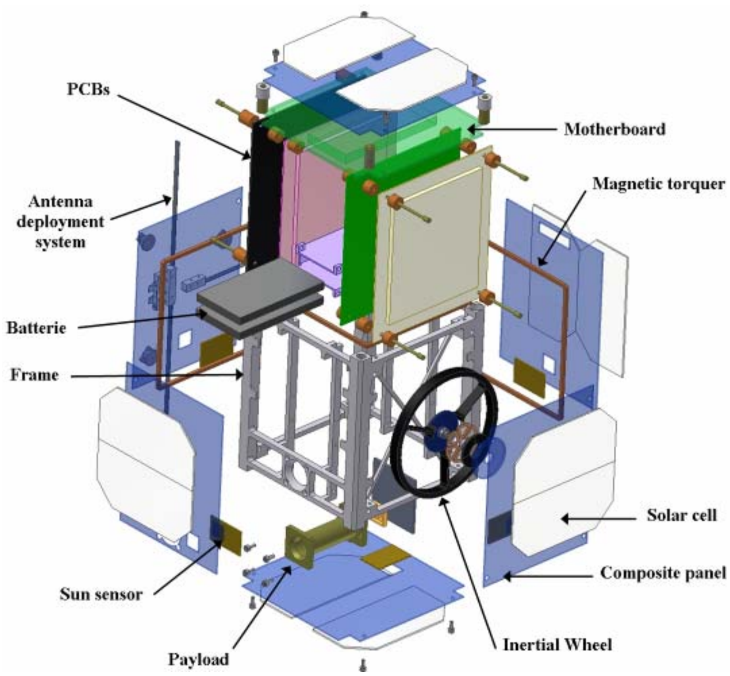



**Figure IV-11: SwissCube configuration.**

### 6.1.4 Satellite assembly

An overview of the satellite assembly procedure is given in Figure IV-12. Elements will either be threaded or glued onto the structure. The preferred fixation method is by threaded fasteners, this should allow disassembly. Some components such as side panels will be glued.

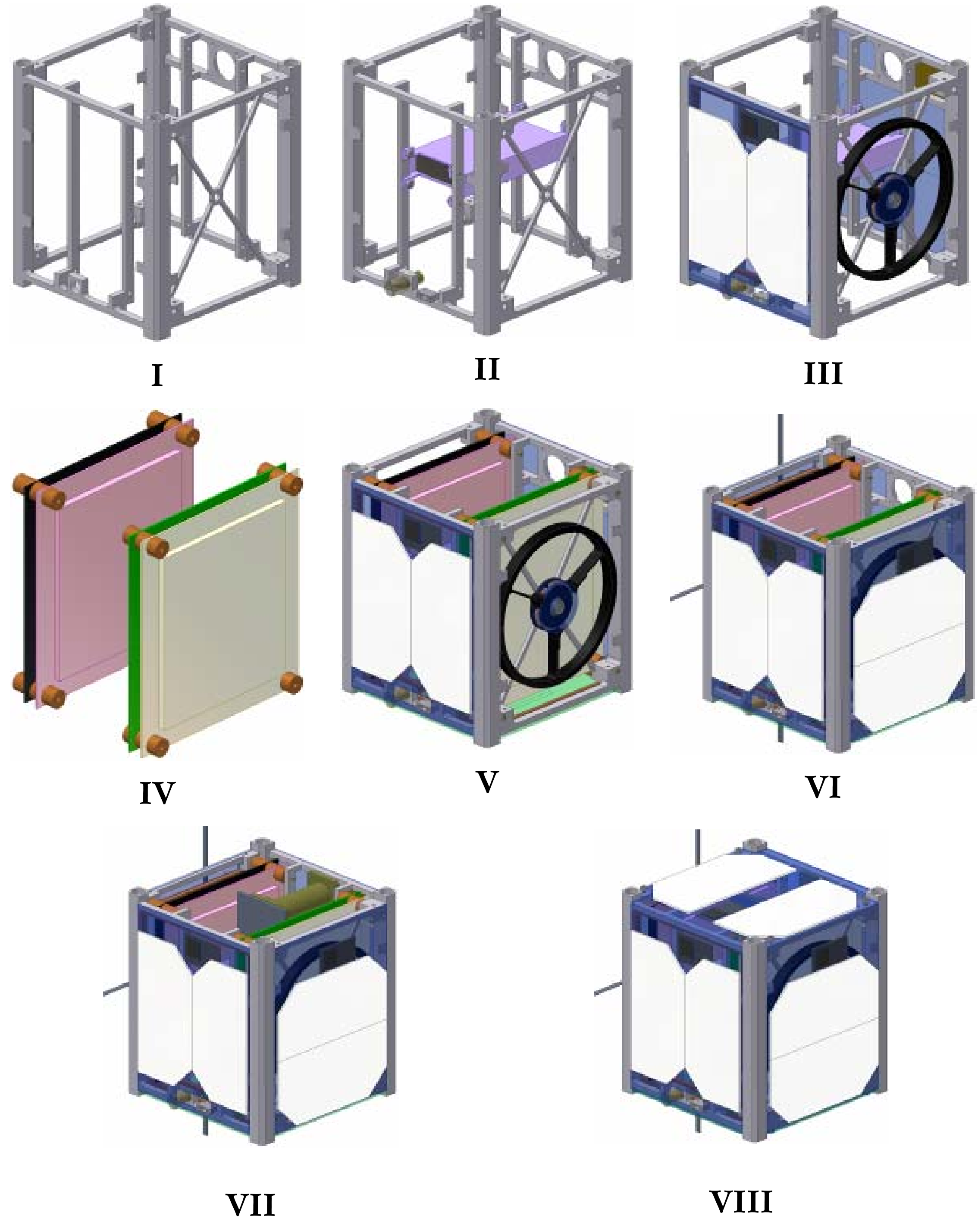



**Figure IV-12: SwissCube assembly procedure**

### 6.1.5 Structural Analysis

To validate the selected structure and configuration baseline static and dynamic analysis were performed. Further the physical and inertial properties of the satellite were determined through the CAD model.

#### 6.1.5.1 Physical and inertial properties of the satellite

Table IV-8 and Table IV-9 give the center of gravity and the inertial properties of the SwissCube with respect to the satellites reference point and frame.

| **Center of Gravity** | |
|---|---|
| Axis | Value [mm] |
| $X_c$ | -1.01 |
| $Y_c$ | -1.54 |
| $Z_c$ | 1.64 |

**Table IV-8 Center of mass**

| **Physical moments of inertia** | |
|---|---|
| | Value [kg mm²] |
| $I_{xx}$ | 1580 |
| $I_{yy}$ | 1510 |
| $I_{zz}$ | 1410 |

| **Principal moments of inertia** | |
|---|---|
| | Value [kg mm²] |
| $I_1$ | 1580 |
| $I_2$ | 1500 |
| $I_3$ | 1400 |

| **Rotation XYZ/principal** | |
|---|---|
| | Value [deg] |
| $R_x$ | -0.09 |
| $R_y$ | 7.6 |
| $R_z$ | 10 |

**Table IV-9 Inertial properties.**

#### 6.1.5.2 Static analysis

The worst case static load of 7.5g was identified for SwissCube on the Dnepr launcher. Including a factor of safety of 1.25, a worst case acceleration of 10g has been considered for the analysis. The determined margin of safety for the whole satellite is a factor of 29, the weakest points being the inertial wheel suspensions.

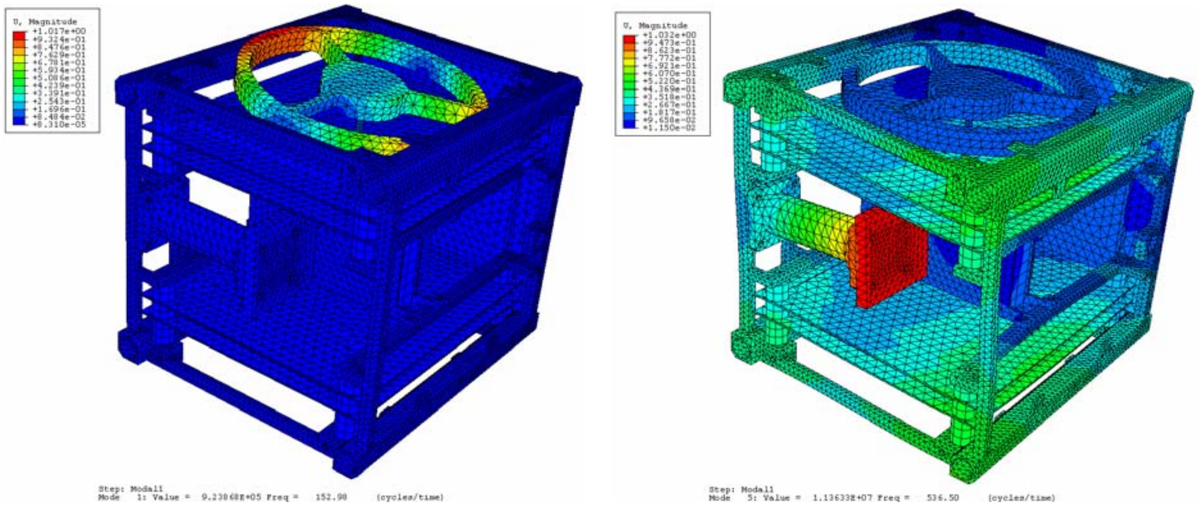
#### 6.1.5.3 Modal analysis

Modal analysis has been performed with simplified model of the satellite using the Abaqus software.

| Mode | Frequency [Hz] | Zone of interest |
|---|---|---|
| 1 | 153 | Wheel attachment crossbars |
| 2 | 158 | Wheel attachment crossbars |
| 3 | 175 | Wheel attachment crossbars |
| 4 | 189 | Wheel attachment crossbars |
| 5 | 537 | Monobloc frame (payload attachment) |
| 6 | 634 | Monobloc frame (battery box attachment) |
| 7 | 685 | PCBs stack & Payload attachment |
| 8 | 698 | PCBs stack & Payload attachment |
| 9 | 713 | PCBs stack & Payload attachment |
| 10 | 778 | PCBs stack |
| 11 | 808 | PCBs stack & monobloc frame |
| 12 | 953 | Monobloc frame |
| 13 | 997 | Monobloc frame |
| 14 | 1112 | Monobloc frame |

**Table IV-10: Natural frequencies of the satellite**

The first four modes are due to the wheel attachment crossbars as summarized in Table IV-10. The first vibration mode of the primary structure (monobloc) is situated around 537Hz. These two modes of vibration are illustrated in Figure IV-13.



(a) (b)

**Figure IV-13: Modes of vibration. (a) 1st mode at 153Hz (b) 5th mode 537Hz.**

### 6.1.6 Structural Tests

Sinusoidal and random vibration tests were conducted using the testpod. The first show that the structure survives the qualification spectra. The modal analysis is unfortunately non conclusive because of a gap between the rails of the testpod and the ones of the structural model. The consequence to this is that the satellite is not well constrained and hits against the testpod rails.

**For further details please refer to the following report:**

- Structure and Configuration [20]

## 6.2 Thermal Management

### 6.2.1 Mathematical model and analysis

For SwissCube a passive thermal management approach has been selected, i.e. no active thermal components, such as heaters will be implemented.

A first study using an analytical model was performed during phase A [Ref 21], this study was complemented by a FEM study. The current FEM study has been done around two models:

- *Structural-thermal model* – includes frame, external panels, thermal glue, solar cells and internal PCBs.
- *Battery-thermal model* – focused on battery study and internal radiation effects. This model includes a model of thermal properties of stand-by, charging and discharging modes of the battery.

The following environmental conditions were taken into account:

- Sun emissions
- Albedo effect
- Earth emissions
- Sunlight and eclipse times
- Sun vector-function

### 6.2.2 Results

#### 6.2.2.1 Structural-thermal model

Three orbital altitudes were considered for the simulations, i.e. 400km, 700km and 1000km. The results are presented in Figure IV-14. A decrease in maximum and minimum temperature can be observed for increasing orbital height. The model does not take into consideration the variation of Earths radiation intensities for the different altitudes.

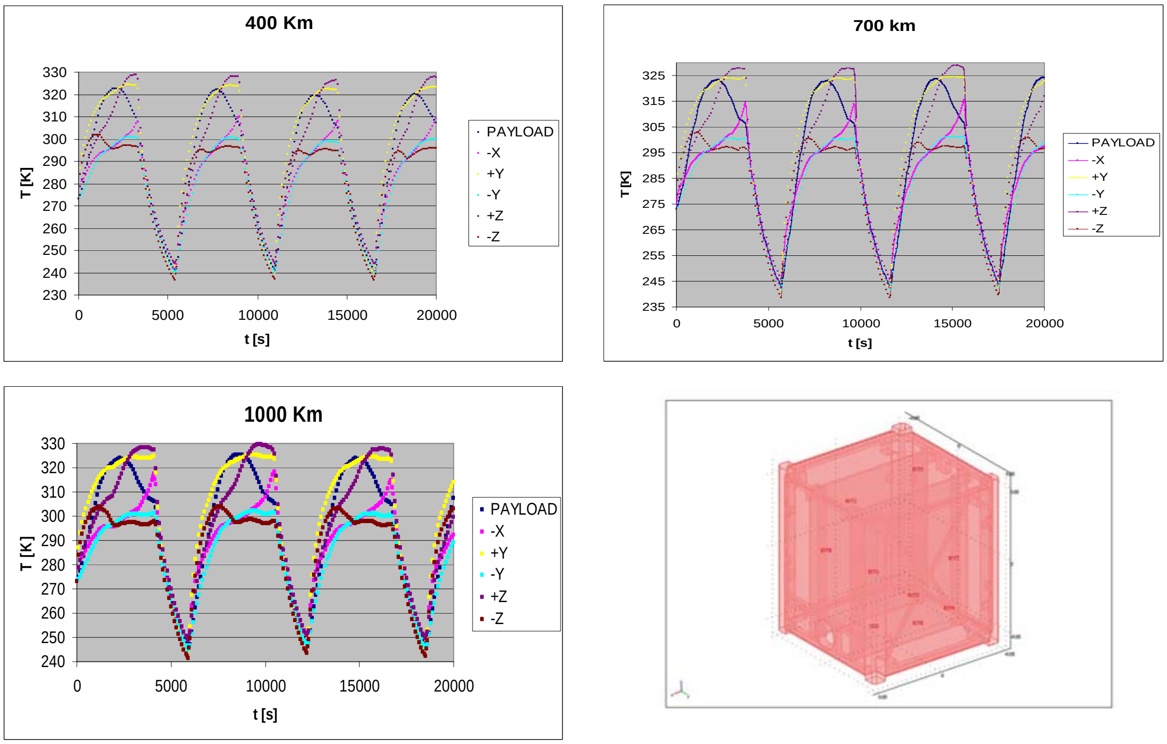



**Figure IV-14: Simulation results for the thermal-structural model.**

### 6.2.2.2 Battery model

For the battery model it was assumed that the battery is thermally isolated in the center of the satellite. The goal of this simulation was to determine the radiative behavior of the battery depending on its operational state and the mean temperature of the walls of the satellite. The results show that with the assumed electrical efficiency during charge and discharge, the heat generation of the battery keeps it within the desired range, provided that the battery be thermally isolated (by conduction). The design should tend to minimize thermal conduction leaks from the battery package to the structural frame.

Table IV-11 summarizes the thermal design parameters for satellite components. In addition a **maximum thermal gradient of 30°C** should be taken into account.

| Parameter | Analysis Results [°C] | |
|---|---|---|
| | Internal | External |
| Minimum Temperature | - 20 | - 30 |
| Maximum Temperature | + 24 | + 37 |

**Table IV-11: Satellite thermal environment design values.**

**For further information please consult the following report:**

- Thermal Management [21]

## 6.3 Mechanisms

### 6.3.1 Design drivers

The used antennas will have a length of up to 2 meters. During the take off, the satellite shall not exceed the dimensions specified by Cal Poly. Therefore a system to deploy the antennas is needed.

The first requirement of the deployment system is high reliability. This has to be achieved with several other constraints like mass, volume and power consumption. The mass for the antenna system is budgeted to 25g. The used volume in the interior of the satellite has to be kept as small as possible and it shall not protrude out of the face of the cube more than 6.5mm. In addition to that, the system has to fulfill all the compatibility criteria for space applications.

### 6.3.2 Baseline design

Figure IV-15 shows the trade-off tree for the mechanisms subsystem. A non magnetic Beryllium copper antenna is used to avoid magnetic perturbations of ADCS, further to increase the antennas rigidity a "v" shaped cross section will be used. As release mechanism a melting wire will be used. Figure IV-16 shows a prototype drawing of the deployed antenna system.

The current baseline foresees an angle for the dipole antenna of 120°; this design feature guarantees a better coverage than a solution with a 180° angle. During launch the antennas are wrapped around three contact points and fixed by the deployment mechanism.

**For the further information please consult the following report:**

- Antenna Deployment Mechanism [22]

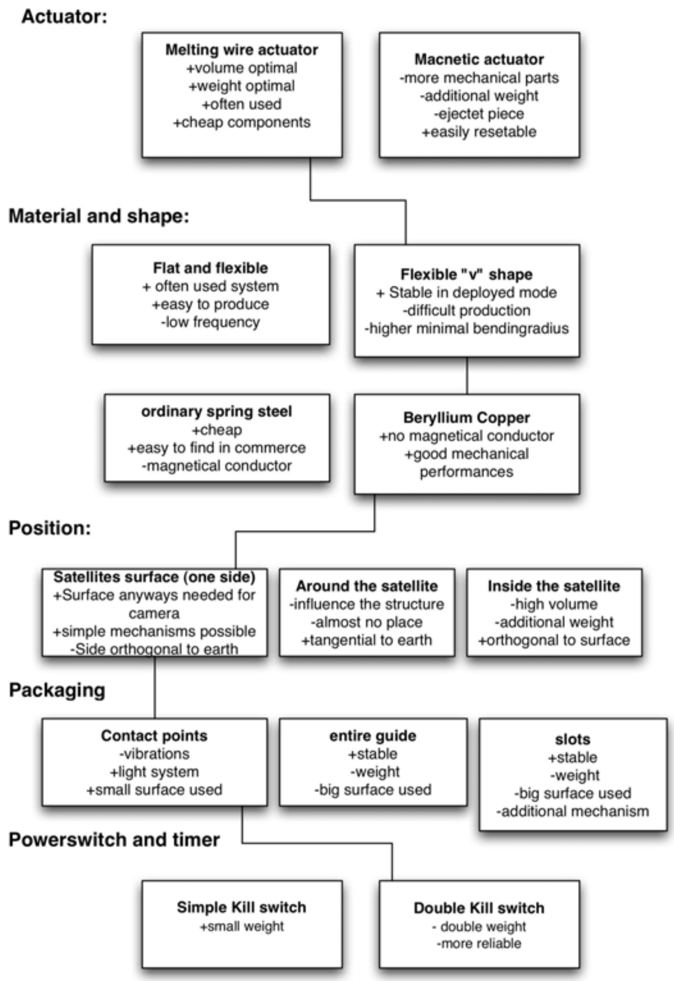



**Figure IV-15: Trade-off tree for the antenna deployment mechanism**

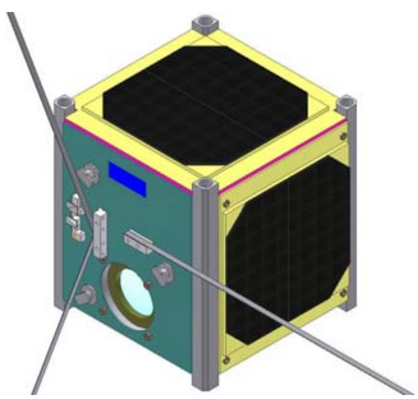


**Figure IV-16: Drawing the antenna baseline design**

## 6.4 Attitude Determination and Control

### 6.4.1 Design drivers

ADCS design is driven by the payload pointing requirements which have to be satisfied, namely:

- Pointing stability: 3°/s
- Pointing accuracy: 10°

Nominal attitude shall be Earth center pointing.

### 6.4.2 Disturbances

In order to have precise dimensioning requirements, a disturbances analysis was made. The analysis completes and refines the one done during Phase A.

The disturbances the satellite is subjected to are mainly due to four sources of torques on low-altitude Earth orbits. They are gravity-gradient effects, magnetic fields, disturbance by solar radiation and aerodynamic torques. The torques are categorized as secular and cyclic. Cyclic torques vary in a sinusoidal manner during an orbit and secular accumulate with time and don't average out over an orbit. For an Earth-oriented spacecraft, gravity-gradient and aerodynamic torques are secular and solar radiation and magnetic field cyclic.

The disturbances torques were separately calculated in the very worst case for every altitude between 400 kilometers and 1000 kilometers with a step of 100 kilometers. For the worst case each parameter was taken at its maximal value. For this reason no margin was added at this point. The major disturbance factor is aerodynamic up to 600km, higher the magnetic field becomes more important. The summarized results can be seen in Figure IV-17 and Table IV-12.

For the dimensioning of the actuators, twice the worst case was taken. The worst case happens at the altitude of 400 km. The torque that the actuators shall produce is 2x3.6e-7=**7.2e-7 Nm.** For example, the torque used for the actuators dimensioning is twelve times greater than the disturbance torque at the altitude of 700 km.

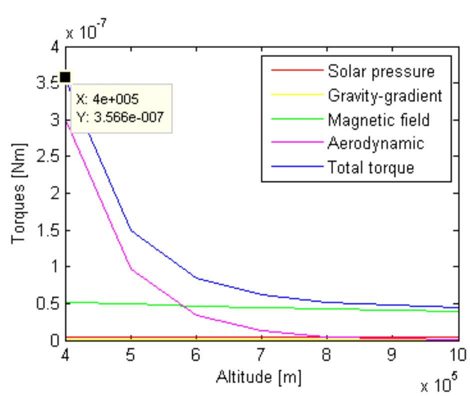



**Figure IV-17: Disturbances in function of altitude.**

| Altitude [km] | Solar pressure [Nm] | Gravity-gradient [Nm] | Magnetic field [Nm] | Aerodynamic [Nm] | Total torque [Nm] |
|---|---|---|---|---|---|
| 400 | 3.6e-9 | 3.6e-10 | 5.1e-8 | 3.0e-7 | **3.6e-7** |
| 500 | 3.6e-9 | 3.4e-10 | 4.9e-8 | 9.7e-8 | **1.5e-7** |
| 600 | 3.6e-9 | 3.3e-10 | 4.7e-8 | 3.5e-8 | **8.6e-8** |
| 700 | 3.6e-9 | 3.2e-10 | 4.5e-8 | 1.3e-8 | **6.2e-8** |
| 800 | 3.6e-9 | 3.0e-10 | 4.3e-8 | 5.2e-9 | **5.2e-8** |
| 900 | 3.6e-9 | 2.9e-10 | 4.1e-8 | 2.2e-9 | **4.7e-8** |
| 1000 | 3.6e-9 | 2.8e-10 | 3.9e-8 | 8.9e-10 | **4.4e-8** |

**Table IV-12: Analysis results for disturbances.**

### 6.4.3 Attitude modes

The Attitude Determination and Control System (ADCS) will be responsible to acquire the satellites current orientation and to influence, if required, its attitude.

Three distinctive modes of operation might be defined for the satellite's attitude. They are summarized in Table IV-13.

| **Mode** | **Timeline** |
|---|---|
| Unstabilised | Separation from the P-Pod, rotation at 0.1 $rad\ s^{-1}$ |
| | Start ADCS system, antenna deployment |
| Detumbling | Begin de-tumbling control algorithm |
| | Receive data from ground station with orbital and position parameters |
| Transitional | Begin attitude determination |
| Nominal (Science) | When de-tumbling controller has reached equilibrium begin nominal control |

**Table IV-13: ADCS Mode Summary**

### 6.4.4 Attitude Control Algorithm

#### 6.4.4.1 Reference Frames

For the derivation of the dynamic model of the satellite three different reference frames were defined an inertial one (IRF), fixed to the Earth, an orbital one (ORF), fixed to the orbit with the positive x-direction pointing in the direction of displacement and a positive z-direction pointing toward the center of the Earth. The last one is the body-fixed referential (SRF) which coincides with the ORF when the satellite has the desired nominal orientation (cf. Figure IV-18).

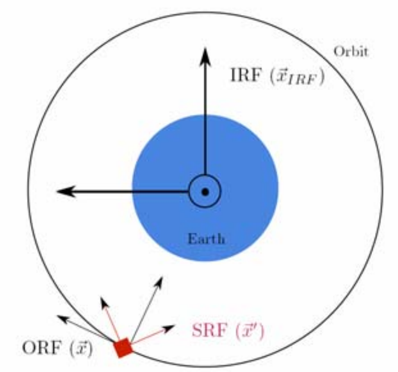



**Figure IV-18: Reference Frames**

#### 6.4.4.2 Control Algorithm Design

The appropriate control algorithms for science operations are currently being investigated. During the Phase B study three models of the satellite were created and validated these models are:

- Inertial quaternion based;
- Non-inertial quaternion based;
- Non-inertial Euler angles based.

The conclusion of the study is that one single reaction wheel is of limited interest for the project. Therefore the study was limited to magnetotorquers only. The conclusion of this study has shown that full magnetic actuation is theoretically feasible, but not capable to reject the amount of environmental predicted perturbations.

These results require will require a full review of the satellites attitude control concept and the science objectives during the next phase. A possible solution is to have a passive or no stabilization system and perform analysis of acquired images on board to identify "relevant" images.

#### 6.4.4.3 Attitude Determination

No work has been performed with respect to the attitude determination system.

### 6.4.5 Attitude control and determination hardware

#### 6.4.5.1 Baseline design

The current design was based on the ADCS results obtained during phase A. Figure IV-19 shows the possible determination and control systems, the selected ones are grayed out.

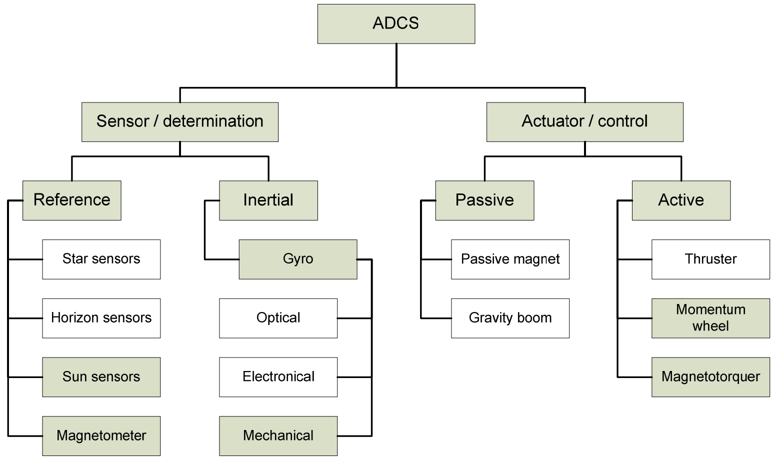



**Figure IV-19: ADCS hardware trade-off.**

During daylight, the three kinds of sensors are used, gyroscopes, sun sensors and magnetometers. According to preliminary calculations, the solar panels do not offer enough accuracy to be used as sensors therefore dedicated sun-sensors will be used.

During the eclipse, the sun sensors will become useless. The magnetometers and the gyroscopes will still be used. Due to drift, the gyroscopes will probably need to be recalibrated. It will be done by using the sun sensors during daylight.

Two different types of actuators are planned to be used. An inertial/momentum wheel has been developed to be tested on the SwissCube. The main actuators are three perpendicular coils, called magnetotorquers.

**For further details please refer to the following report:**

- Control Algorithm Design and Validation: [23]
- Characterization and tests of an integrated 3D compass for the attitude control of SwissCube satellite: [24]
- ADCS Hardware report [25]
- ADCS Phase A report [26]

## 6.5 Electrical Power Subsystem

### 6.5.1 Design drivers and functional overview

The satellites Electrical Power System's task is to provide power to the various subsystems as required by the mission timeline. It will ensure power generation by means of solar cells, energy storage in batteries and regulate the power distribution to the various subsystems.

The 3 main SwissCube electrical loads are:

- Electrical Power System (converters and linear regulators)
- Attitude Control and Determination System (magnetotorquers, motors, …)
- Communication System (RF transmitter, …)

The payload will take measurements during the eclipse but its operation does not consume a lot of energy. The power conditioning shall include a latch-up mitigation circuit to protect the different subsystems against "Single Event Latch-up" (SEL).

### 6.5.2 Architectures

Two main architectures have been studied for EPS, the first one including a maximum power point tracking (MPPT) system the second one without. The best layout for the architecture using MPPT is shown in Figure IV-20. This design contains a maximum redundancy in case of battery or solar cell breakdown. In this case the microcontroller represents a single point of failure and its failure would cause the loss of the mission. The only solution for this would therefore be to create a redundant system with two microcontrollers where each one controls a battery and 5 solar cells.

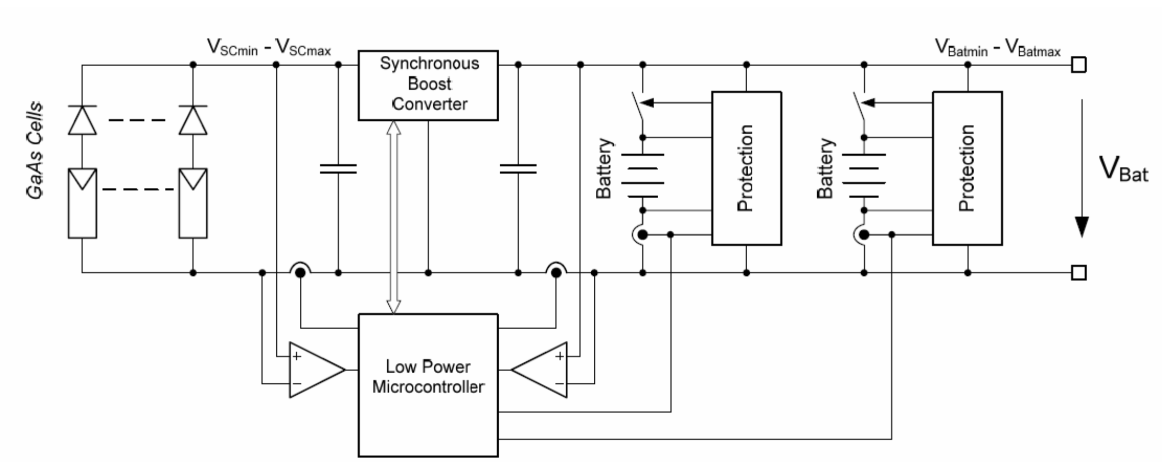



**Figure IV-20: EPS architecture with MPPT, the batteries and solar cells are connected in parallel.**

A second approach is to use a fixed working point of the solar cell characteristics. Major advantage is that the control of the bus can be done by an analogue circuit, as shown in Figure IV-21, further charge and discharge circuits are redundant, i.e. the loss of one battery will not cause a mission critical failure.

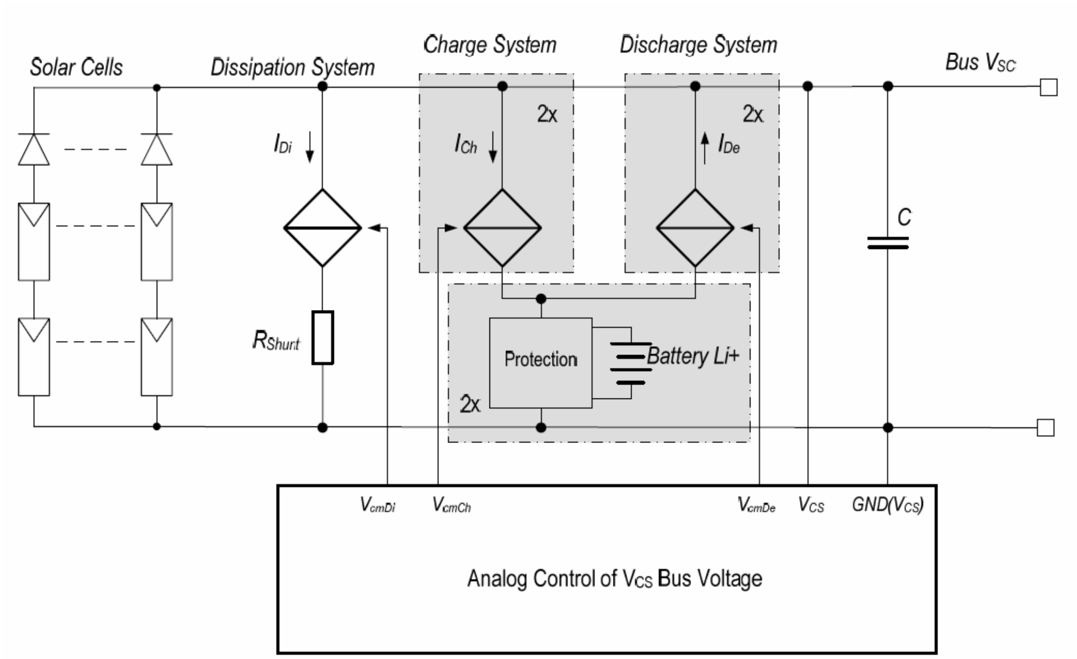



**Figure IV-21: EPS architecture without MPPT**

This concept has further the advantage that the 100% of the energy can be directly transmitted to the users and does not need any microcontroller to operate. To validate this concept and to show, that the power losses due to a missing MPPT can be kept low an analytical model of the solar cells was created which will be discussed hereafter.

### 6.5.3 Analyses

The satellites small size and power requirements require the use of the most efficient solar cells on the market. GaAs based solar cells have the potential to reach efficiencies greater than 30%. Currently cells with up to 28% efficiency are available. To carry out the electrical power calculation we have initially considered the following cell type: RWE3G-ID2/150-8040[5] which has an average efficiency of 26.6 % (BOL@28°).

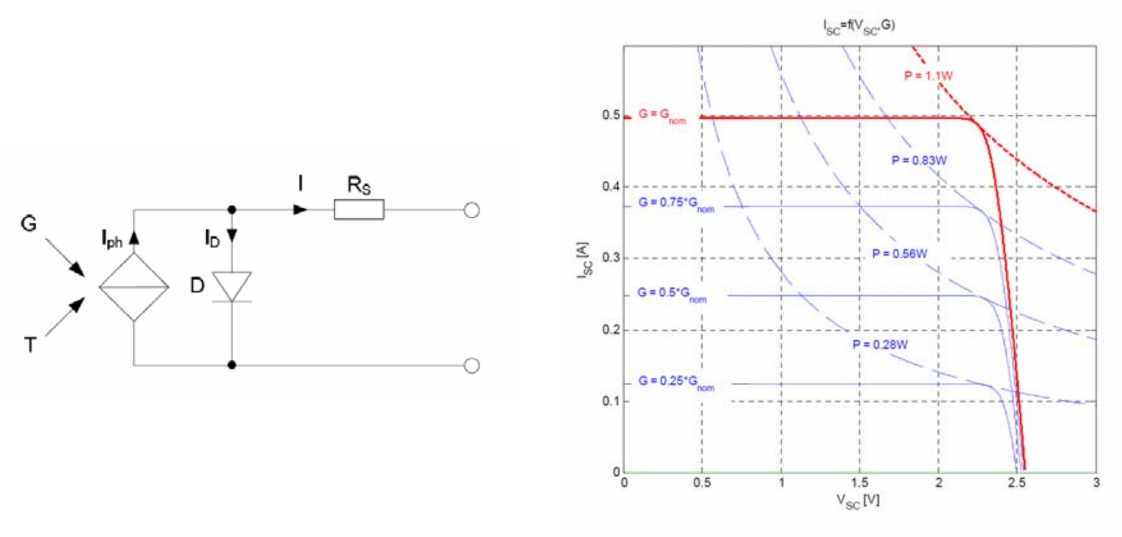
To confirm the required power values and to size EPS components a power generation study was carried out. Following points were considered.

- Cell degradation factors, EOL values, efficiency 20.1%.
- Simulations performed for 28°C.
- Satellite configuration, solar cells on five faces.
- Limit angle of total reflection of 20°.
- Earth Albedo: 30%

The obtained power generation during sunlight is: [2.85]W and the average energy accumulated during one orbit [2.69]Wh.

[5] The company RWE has been renamed to AZUR SPACE Solar Power GmbH and the cell type used for our considerations has been replaced by the type: GAGET2-ID2/160-8040

In addition, to analyze the behavior of the solar cell with respect to insolation and temperature an analytical model of the cell behavior has been created.




(a) (b)

**Figure IV-22: Solar cell model. (a) simplified electrical model of the solar cell (b) I-V characteristics as a function of the insolation ($G_{norm}$ = 1350W/m², T=25°)**

From the model it can be concluded that that for any insolation and temperature range the MPP does not fall below 2V. Preliminary measurements conducted with an incandescent light of 2000W placed over the cells have given a first confirmation of the model. Currently further measurements with a "solar simulator" are being performed to further validate the model.

### 6.5.4 Batteries

Currently Lithium-Ion Polymer batteries are considered for the mission. Their major advantage over Lithium-Ion cells being a higher energy density. The baseline design foresees the use of two PoLiFlex batteries from VARTA[6]. So far bulging has been a major issue with Li-Poly, recent tests at ESA [27] have shown that the PoLiFlex series, in comparison to other Li-Poly batteries, do not suffer from this problem. They further are radiation tolerant and conserve their charge under vacuum conditions.

The chosen DOD for our system is 15% if both batteries are operational and 30% in the case of one operational unit. The low DOD has been chosen to increase life expectancy of the battery. To simplify the electronics it has been decided to work with a constant charge current.

[6] Investigated models include VARTA PoLiFlex PLF503759 and PLF423566

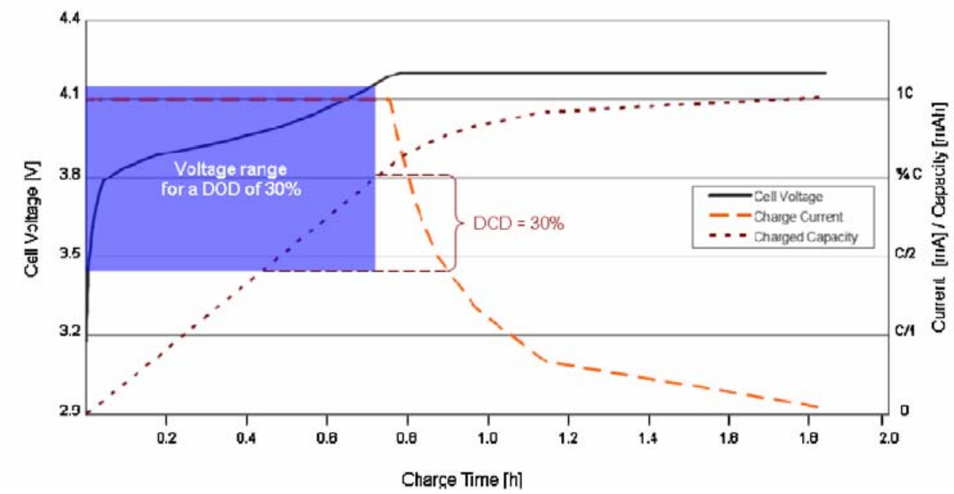



**Figure IV-23: Typical charge profile (1C, 20°C) with the defined voltage range for the application.**

### 6.5.5 Baseline design

Based on the considerations presented above a baseline design without MPPT was chosen (Figure IV-24). The current limiters serve also as switches for the supply of the different subsystems (refer to [17] for updated version). The sole purpose of the microcontroller is to monitor data and allow the exchange of data with the other systems.

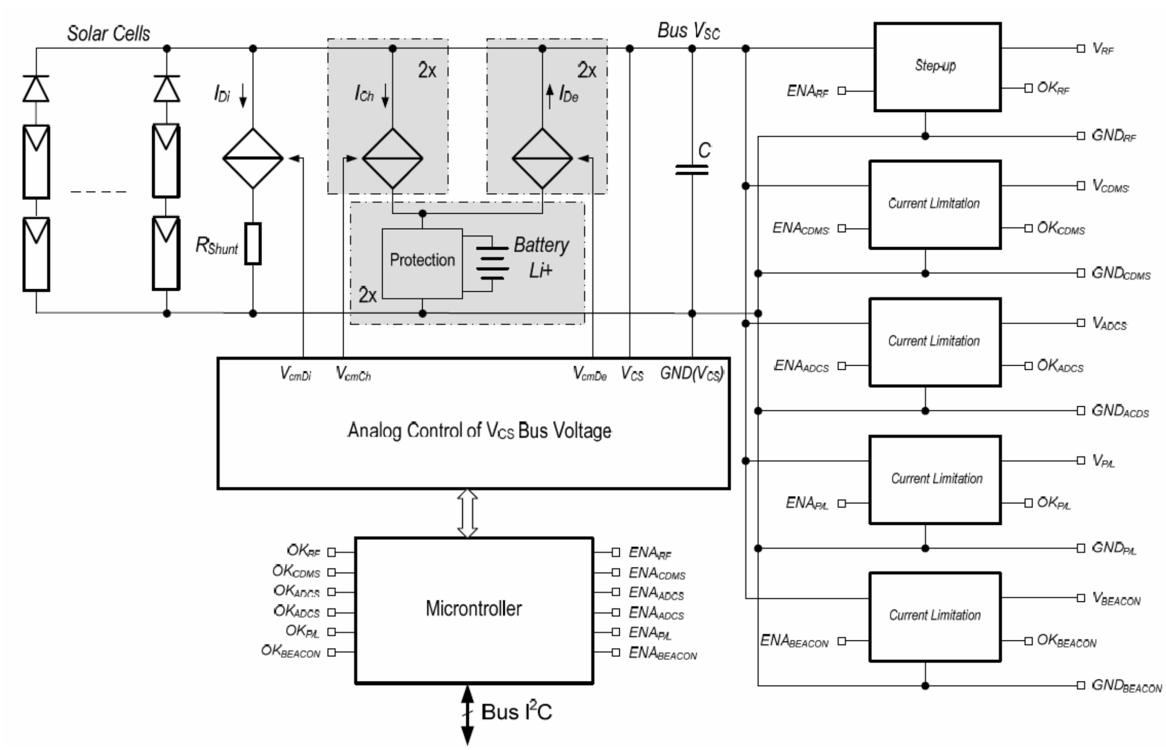



**Figure IV-24 : Electrical block diagram**

For the following topics please refer to the corresponding report:

- Satellite Electrical Architecture and Power System: [28]
- Latch up mitigation circuitry: [29]

## 6.6 On-board Command & Data Processing Hardware Architecture

### 6.6.1 Design Drivers

The CDMS board realizes the processing and scheduling functions of the SwissCube satellite. The main activities are:

- to perform scheduling, execution and verification of telecommands;
- to perform data storage of housekeeping data and telemetry;
- to execute the ADCS algorithms;
- to provide a time reference aboard the satellite
- to provide the interface for the payload detector
- to perform TC scripts.

A summary of the controller needs of the various subsystems is given in Table IV-14.

| Subsystem | Controller architecture | Memory | Remarks |
|---|---|---|---|
| EPS/Beacon/Receiver | 8 bit | | Read EPS vital parameters, such as battery voltage, temperature etc. Generate the beacon signal and manage the AX.25 protcol for data reception |
| RF Transmitter | 8 bit | | Manage the AX.25 protocol for data transmission |
| CDMS | 32 bit | 4MB | TM/TC scheduling, storage, verification & execution, ADCS algorithms, on-board timebase. I/F with payload sensor |
| ADCS | 8 bit | | Read data from the ADCS sensors. |
| Payload | 8 bit | | Control parameters of the payload sensor. |

**Table IV-14: Subsystem controller needs**

A study has identified two the following microcontrollers as best candidates for our application. This choice has to be confirmed by radiation testing.

- 16-bit Microcontroller: MSP460F169
- 32-bit Microcontroller: ATMEL AT91M558800A

The subsystem controllers will be treated in their respective paragraphs and shall not be detailed here any further

### 6.6.2 CDMS functional architecture

The functional architecture as shown in Figure IV-25 features latch-up protection and a watchdog timer for system resets. The system has been built to provide radiation robustness. The most common situations are listed in Table IV-15. Depending on the criticality of the subsystem and the complexity of the needed microprocessor/microcontroller, parts or all functional elements will be adopted. . Three types of memory have been selected ROM program storage, RAM as temporary memory and flash memory that will be used as non-volatile memory space.

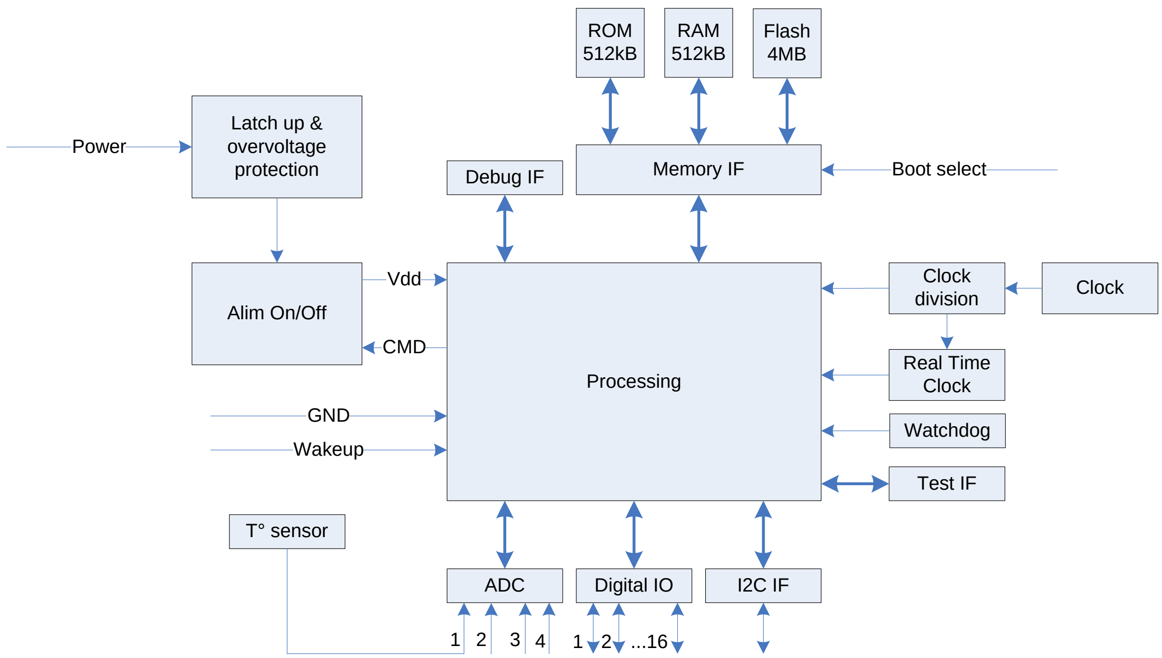



**Figure IV-25: CDMS functional architecture.**

| Failure | Consequence | Mitigation method |
|---|---|---|
| Software lock-up | Wrong operations are executed, no controller not controllable. | Hardware watch-dog timer |
| Single event latch-up (radiation) | Short-circuit within semiconductor chip. Burn-out of component | Latch-up protection circuit |
| Single event upset (radiation) | Bitflips in memory | • ROM for program code<br>• Error detection and correction for RAM/FLASH |

**Table IV-15: Failure scenarios for on-board microcontrollers/microprocessors**

### 6.6.3 Bus topology overview

The bus topology follows the logic of a distributed architecture, where all subsystems have their own controller. Figure IV-26 shows the two on-board busses. $I^2C$ has been chosen for the main bus due to its low power consumption and availability on most small microcontrollers. The payload will be connected to CDMS via a dedicated $I^2C$ [TBC] and the External Bus Interface for data exchange.

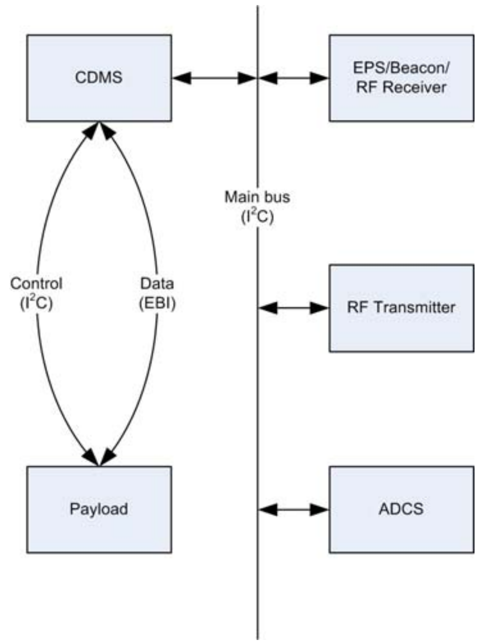



**Figure IV-26: Bus topology overview**

### 6.6.4 Baseline design

All subsystems will rely on Commercial off-the-shelf components (COTS). Table IV-16 resumes the various subsystem needs.

| Subsystem | Controller architecture | Memory | Remarks |
|---|---|---|---|
| EPS | 8 bit | n.a. | Step-up converter frequency > 100kHz |
| RF Transceiver | 8 bit | n.a. | |
| CDMS | 8 bit [TBC] | 750kBit | 150 compressed pictures stored |
| ACDS | 32 bit | n.a. | 10-20 MIPS |
| Payload | 8 bit | 16 kBit | Intermediate picture storage |

**Table IV-16: Subsystem controller needs**

At present no final choice has been made with respect to the different microcontrollers. Nevertheless a trade-off study has been conducted identifying the following chips as preferential:

- 8-bit Microcontroller: PIC18LF8680 and PIC18LF4680
- 32-bit Microcontroller: ATMEL AT91SAM7A1 (ARM7TDMI Core)

For further information on topics concerning the on-board command & data processing hardware please refer to the corresponding report:

- CDMS Hardware [30]

## 6.7 Telecommunication Subsystem

### 6.7.1 Design drivers

The main design drivers for the communication system are the low available power on-board the satellite. A second driver is the capability of satellite debugging and commanding at any rate or attitude.

### 6.7.2 Baseline design

The block diagram of the telecommunication system is shown in Figure IV-27. The design foresees to operate the beacon constantly and switch to the data transceiver once above a partner ground station.

The data transmitter sends the scientific and engineering telemetry at 1200 Bits/sec and the beacon sends only simple housekeeping data at very low speed in Morse code.

The two RF systems use different modulation for the emission. The main RF transmitter uses frequency modulation (FSK) and his power consumption is on the order of 2-3 W. The beacon uses amplitude modulation (OOK) and his power has to be as low as possible (in the order of 150 mW). The main RF transmitter and the beacon are using the same antenna; it is why there is a switch to select the source of the antenna. The chosen frequencies are both in the amateur band.

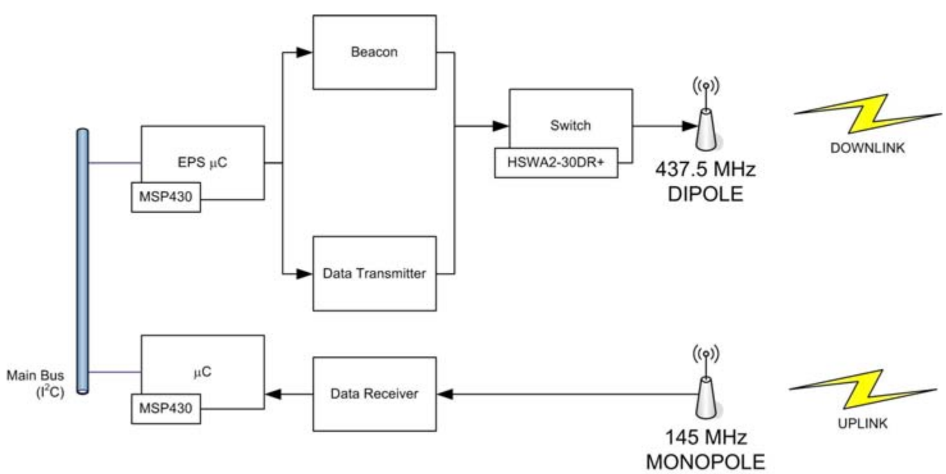



**Figure IV-27: Block diagram of the RF system**

<u>Data Transmitter</u>

The architecture used for transmission is shown in Figure IV-28. The micro-controller sends data to the modem. The modem which can be used is MX614 depending on the data rate. MX614 is a FSK modem capable of transmitting data rate up to 2400 bps. The modem communicates with the micro-controller and converts the data from digital to analog. This can be thought of as an analog to digital converter but it has extra functionalities like synchronization with the micro controller etc. This converted FSK signal is then passed through the FM modulator.

The carrier frequency 437.5 MHz is generated by the local oscillator and is modulated by the signal received from the modem. The generated FM signal is then passed through a power amplifier. The power amplifier is capable of transmitting 28dBm (>0.5 W). This is required to satisfy the link budget requirements for BER<$10^{-4}$. The power amplifier used is RF5110G manufactured by RF micro devices.

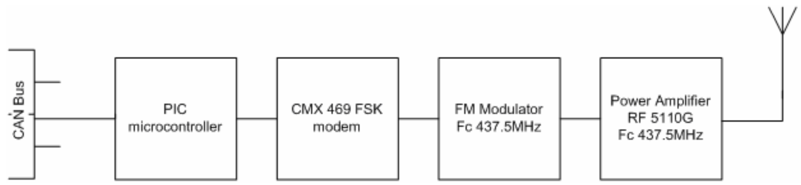



**Figure IV-28: Transmitter block diagram**

Data Receiver

The receiver design is based on the dual-conversion receiver architecture, which in a nutshell means the received frequency is down converted twice before demodulating the message signal from the carrier.

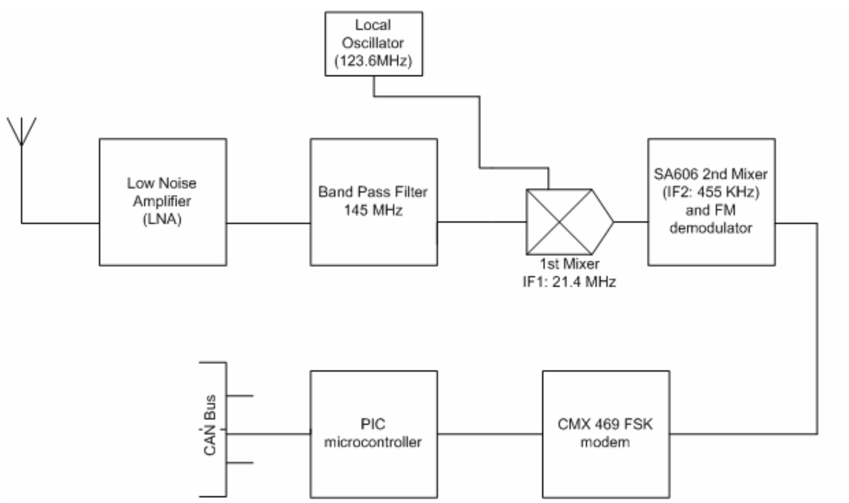



**Figure IV-29 Receiver Architecture**

Figure IV-29 shows the block diagram representation of the receiver. The major building blocks of receiver are a low noise amplifier, band pass filter, 1st mixer and final 2nd mixer /demodulator (SA606). The frequency plan of the receiver architecture is, the incoming carrier frequency is at 145 MHz, it is passed through a LNA to boost the signal power while removing noise from the incoming signal. The amplified signal is passed through a passive band pass filter. After which it is down converted to the 1st intermediate frequency (IF1) of 21.4MHz using 1st mixer and local oscillator. Finally, the message is passed through a SA606 chip, which is a single IC that includes the 2nd Mixer, IF amplifier and the quadrature FM demodulator. The mixer in SA606 converts the incoming signal to 455 KHz (IF2) before being demodulated by the quadrature detector.

Beacon

The architecture of the beacon subsystem is shown in Figure IV-30. When the beacon is turned on, the oscillator provides continuously the carrier frequency, in our case 437.5 MHz. Then the signal is modulated in amplitude (OOK) and finally amplified.

For the oscillator block the preferred solution is an overtone crystal oscillator.

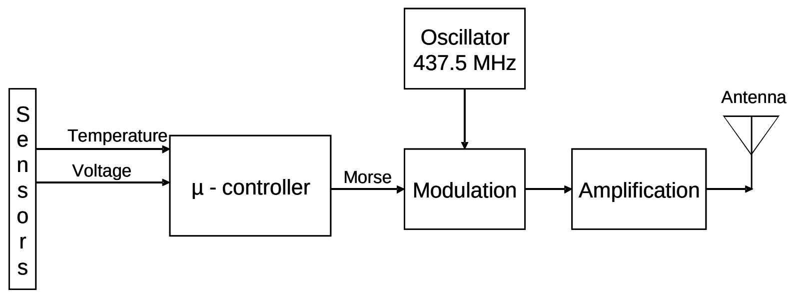



**Figure IV-30: Block diagram of the beacon**

<u>Antennas</u>

The chosen antenna configuration includes a quarter-wavelength monopole antenna for 145.8 MHz and a half wavelength dipole antenna for 437.5 MHz. Figure IV-31 shows the antenna layout and radiation patterns for SwissCube.

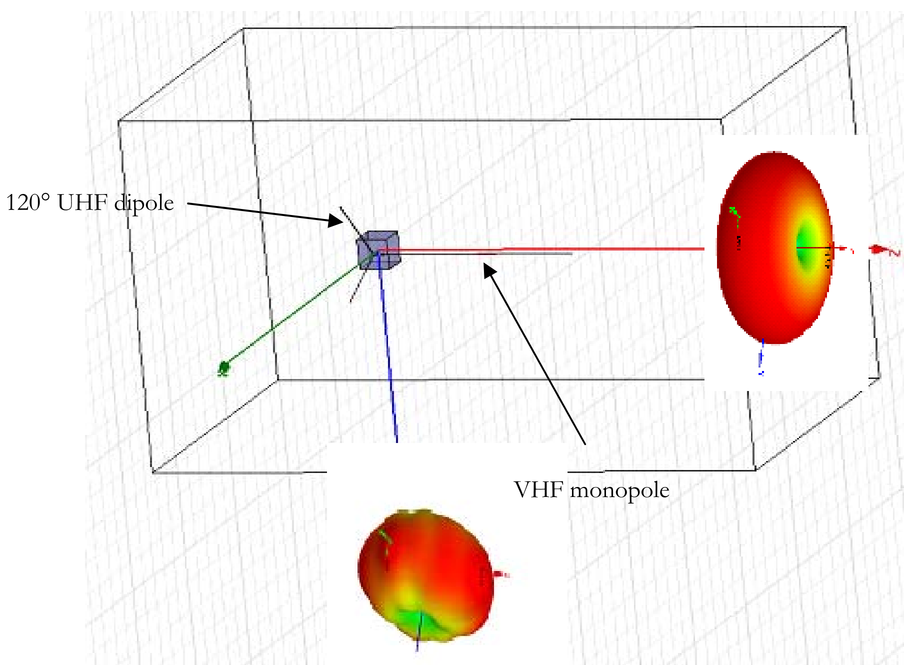
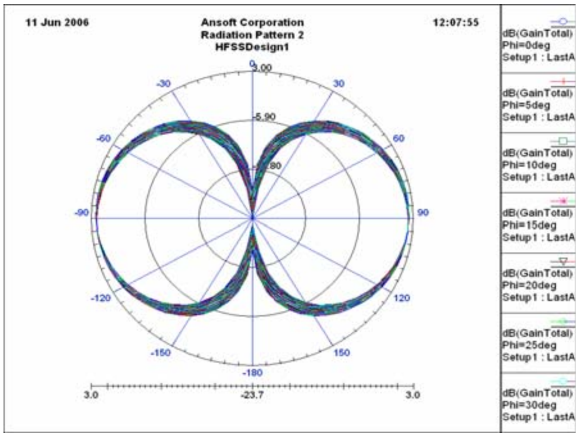
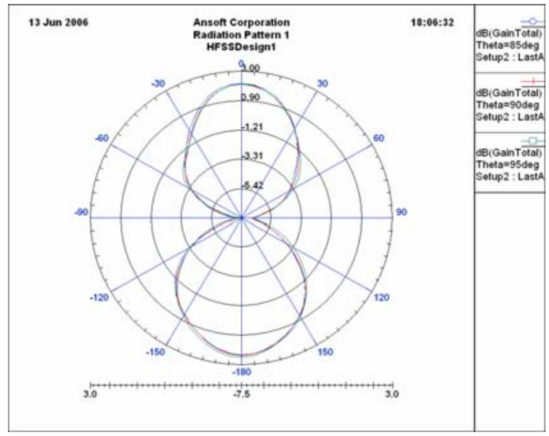



**Figure IV-31: Antenna layout and radiation pattern**

The UHF dipole has an angle of 120°. In this configuration the minimum gain when the antenna axis is pointing at the ground station is -7.5 dBi instead of -14.4 dBi for a 180° angle.




A.




B.

**Figure IV-32: Radiation pattern for antenna baseline design. A. VHF monopole, B. UHF dipole 120°**

For further information please refer to:

- Beacon [31]
- RF Transceiver [32]
- Antenna Design [33]

## 6.8 Software

### 6.8.1 Design drivers

TM/TC standardization concepts have been elaborated by the *Consultative Committee for Space Data Systems*, CCSDS, and are being applied to a certain extent by many space agencies including ESA and NASA. Although the EPFL satellite is not required to follow these specifications they might serve as starting point for the satellites software layout. The concept used is based on the *Open Systems Interconnection*, OSI, model, a 7 layer structure that has been defined by the International Standardization Organization, ISO, as network architecture. This concept allows a standardized data exchange between the different layers and simplifies therefore the development of communication systems.

Flight software will be included in the following subsystems:

- EPS/Beacon/RF Transmitter
- ADCS
- CDMS
- Payload
- RF Receiver

The overall software architecture should therefore consider this distributed topology.

### 6.8.2 Baseline design

The chosen baseline features a Command and Data Management system that will provide certain services on-board the satellite, namely:

- Housekeeping
- Scheduler
- Data Storage
- Time synchronization

These services will be accessible from ground or by the various subsystems. This will allow keeping the necessary hardware resources of the subsystems as small as possible.

**For further information please refer to:**

- SwissCube Flight software [34]

# V GROUND SYSTEM DESIGN

# 1 System Overview

The proposed ground system architecture for SwissCube combines the ground station topology used by the AMSAT community with additional tools required for satellite operations. The chosen architecture tries to maximize the amount of hard- and software jointly used during satellite testing and operations. Figure V-1 shows the hardware lay-out of the ground segment. Distinction will be made between the following three segments:

1. Ground Station System
2. Mission Control System
3. Satellite Check-out System

The three segments will be capable to operate in distributed manner. The OPSLAN could therefore be formed by a WAN connection using secured channels. This topology has the major advantage to allow remote control of the satellite from mission control during testing. It further allows database population during subsystem development.

The Swisscube Ground Stations (GS) will be located at the EPFL campus and at the HES-Fribourg campus. The antennas will be installed on a roof, and one room, next to the roof, will be dedicated to the electronic devices. The Mission Control will be located at EPFL and at HES-ARC St Imier.

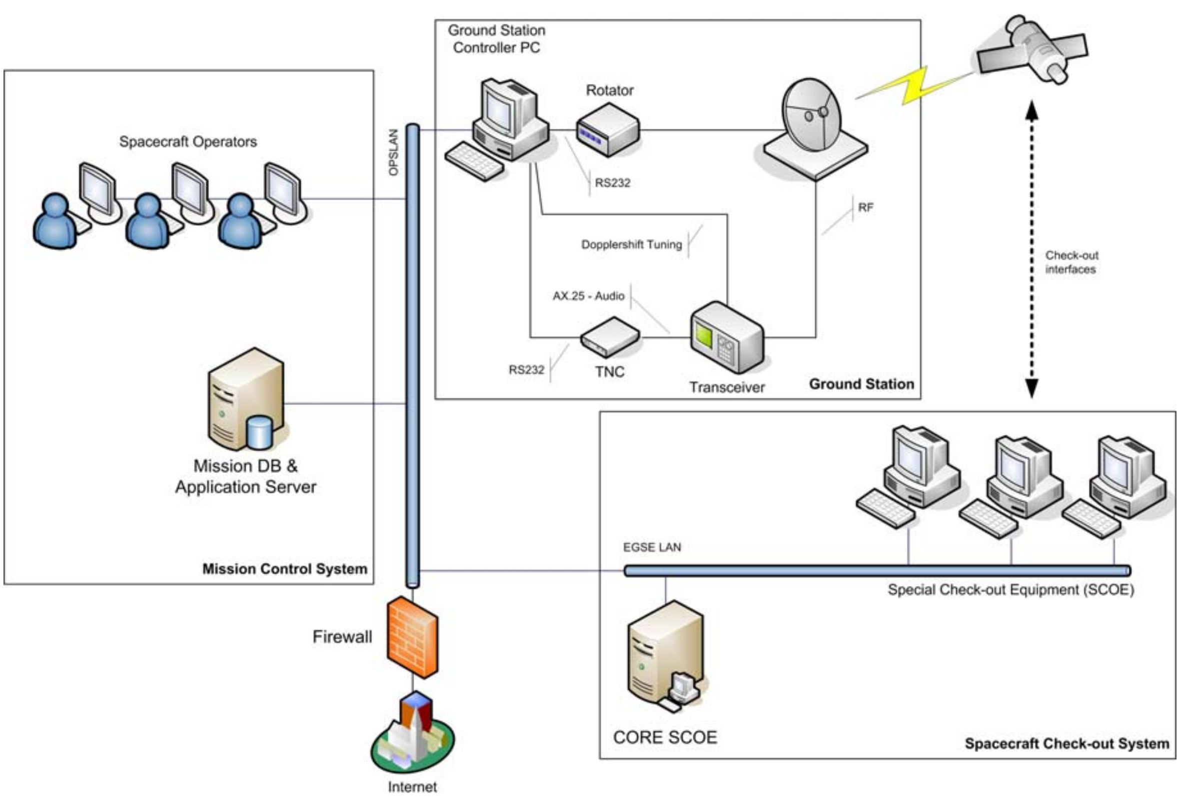



**Figure V-1: Ground segment architecture**

The main drivers for the development of the ground systems are summarized here:

2_PR_11_03 **Space to ground frequencies and protocols**

The ground to space communication link shall comply with the Amateur Radio Satellites services.

*For student satellite this is the easiest solution to implement.*

2_PR_15_06 **Compatibility of ground system with other satellites**

The ground system shall be capable of operating with other external amateur radio satellites than the Project's and possible networks of amateur radio ground stations.

*This requirement allows an independent way to test the ground station and train personnel before launch of the Cubesat. The same ground system might be used for future tracking network, which implies that the design shall have the possibility to conform/adapt to a standard network.*

3_GS_11_xx: **Ground system operating lifetime**

The project shall design the ground system to have an operating lifetime greater or equal to [48] months.

The two last requirements ensure continuity with follow-up satellites. It also allows an independent way to test the ground station and train personnel before launch of the Cubesat. The same ground system shall be used for future tracking network, which implies that the design shall have the possibility to conform/adapt to a standard network.

# 2 Ground Station System

## 2.1 Design Requirements

The ground station system establishes the physical RF link between the space and ground segment. It controls the antenna rotors, the terminal node controller (TNC) and the transceiver. The ground station will be based on commercial off-the-shelf components.

The ground station design has to guarantee compatibility with the Radio Amateur systems and to reduce the development time by using COTS elements. To increase the downlink/uplink time the design should allow the compatibility and collaboration with other ground station systems.

To accommodate the requirements described above, it was determined that the SwissCube Ground Station should have the following features:

- Cross beam or circularly polarized Yagi
- Computer tracking system
- Computer controlled AZ-EL rotators
- Full-duplex dual band radio computer controlled tuning
- TNC and Soundcard interface for TLM and packet
- Transceiver control software
- Mast mounted receiver preampifiers

## 2.2 Design Overview

### 2.2.1 EPFL Ground Station

The ground-station will be built on the roof of the EL building of the EPFL. One part, the antenna system, will be installed outside on a mast. It will reuse parts of the existing infrastructure. The other part, the control electronics, will be located in a storage room about two floors below the roof.

Figure V-2 shows the system Block Diagram for the Ground Station. It shows all connections and devices. Table V-1 also shows the planned manufacturer and model of the devices.

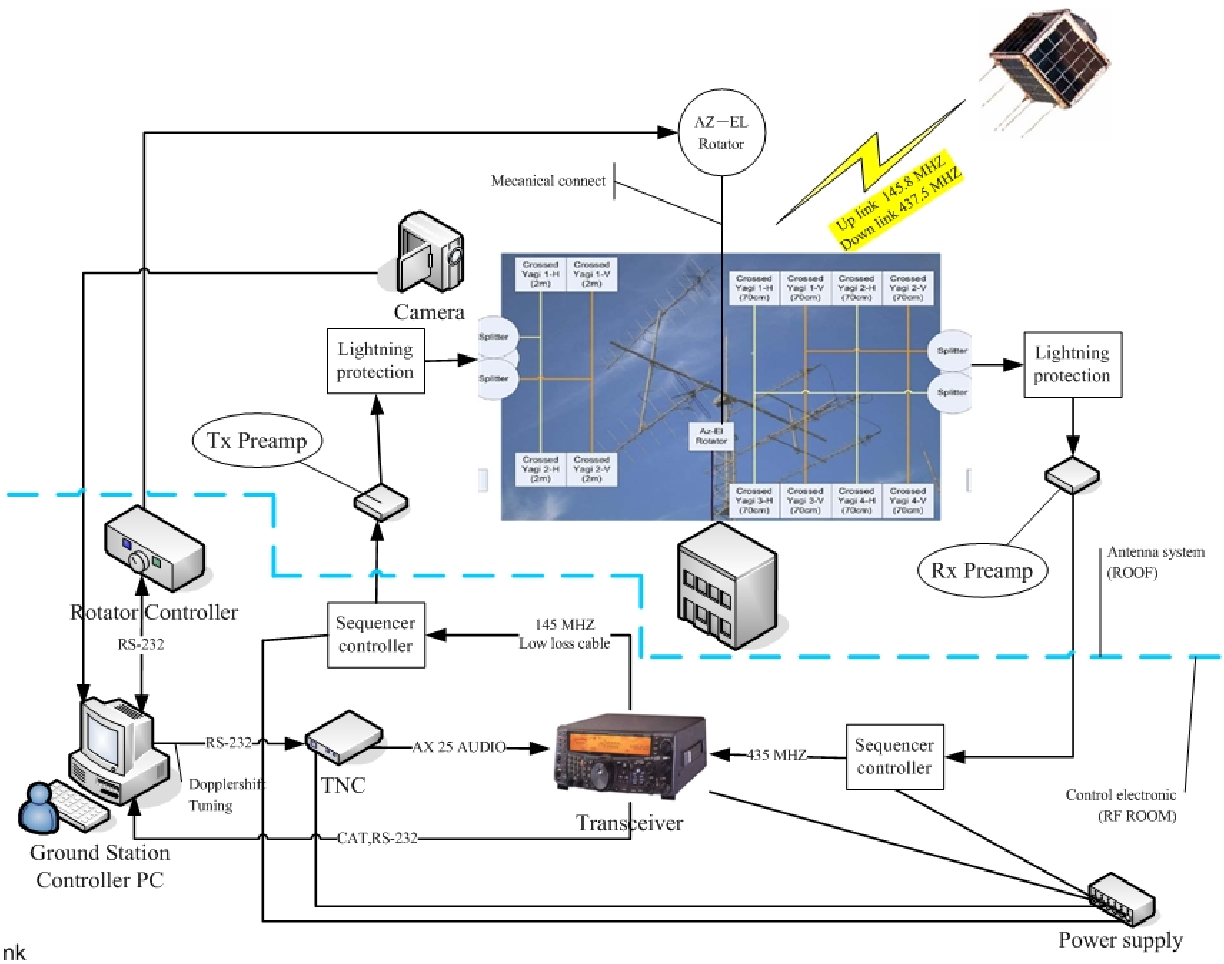



**Figure V-2: EPFL Ground Station block diagram.**

The telecom data protocol between the ground and the space systems is the AX.25 and was chosen for its wide-spread use in the Amateur Radio community.

| Element | Model | Function | Choice Rationale | Purchased |
|---|---|---|---|---|
| **Control electronics** | | | | |
| Transceiver | Kenwood TS-2000 | combination transmitter /receiver | See Note 1. | Yes |
| TNC | TNC2H-DK9SJ SYMEK | AX.25 packet modem | 1) capable to decode the Pacsat protocol.<br>2) adapted to the speed of transmission going from 1200 to 38400 Bauds | Yes |
| Controller PC | 486 IBM PC | 1) control the antenna positioning motors for tracking of the satellite<br>2) control the transceiver, including Doppler correction | Available and free | Yes |
| Rotator controller | RC2800 PX-EL Controller | Command the rotator's position | | Yes |
| SWR meter | CN-103LN or CN-801VN | Check the quality of the match between the antenna and the transmission line | | No |
| Sequence controller | DCW-2004 for SP-2000 and SP-7000 | Ensures the proper sequencing of both power amplifier and preamplifier switching | | No |
| Amplifier (Optional) | HLV 300 | Amplifies uplink signal | | No |
| Power supply | GSV-3000 | | | Yes |
| **Antenna System** | | | | |
| Tx Preamp | SSB-Elektronik SP-7000 | Low noise amplifier | Recommended by radio amateurs | Not needed |
| Rx Preamp | SSB-Elektronik SP-2000 | Low noise amplifier | Recommended by radio amateurs | No |
| Lightning protection | Lynics 20310-3 | Protect from lightning damage | | No |
| Power Splitter | | | | No |
| AZ-EL rotator | EL: M2 MT1000<br>AZ: M2 OR2800 | antenna rotators | | No |
| Uplink Antennas 2-m | 2 CP: 2MXP20 Yagis | | Good G/T<br>Optimized for stacking | No |
| Downlink Ant. 70-cm | 4 CP: 436CP42 Yagis | | Gain and F/B are excellent | No |
| Mast | Check if needed | | | |
| Additional clamping, beams and mounting HW | See detailed documentation | | | No |

**Table V-1: EPFL Ground Station hardware.**

Note 1: The criteria for the choice of the transceiver were:

- Band of frequencies adapted to the frequencies of the CUBESAT radio amateurs (145.8MHz for upload and 437.5 MHz for download).

- The transceiver must be able to recognize all the modes used for satellite radio amateur operations: FM, USB, LSB, CW, AM, AFSK, 9600 bauds packet, 1200 bauds packet.
- Possibility of controlling the transceiver by PC.
- Good compensation of the Doppler effect: the step of the synthesizer must be to the maximum of 1 kHz.
- Full Duplex: broadcast on a band and reception on the other one (VHF > UHF or UHF> VHF). The full duplex mode is currently not a requirement for the SwissCube but it is or might be for other satellites.
- Software support.

**Figure V-3** shows the existing Antenna mast on the EL Building. The whole RF part will be replaced and new rotators will be installed.

**Figure V-3: Current installation on the roof of the EL building.**

Figure V-4 shows the baseline layout of the ground-station with two circularly polarized 2m Crossed-Yagi antennas for the uplink and four 70cm antennas for the downlink. The Yagi-Uda antenna is the standard antenna for television. It's a directive antenna that has one active dipole, reflectors and directors. They offer a good choice in terms weight/gain ratio. Figure V-5 shows the radiation patterns of available Yagi antennas for 2m and 70 cm.

**For further details please consult:**

- Ground Station Telecom Infrastructure Description and Specifications [35]

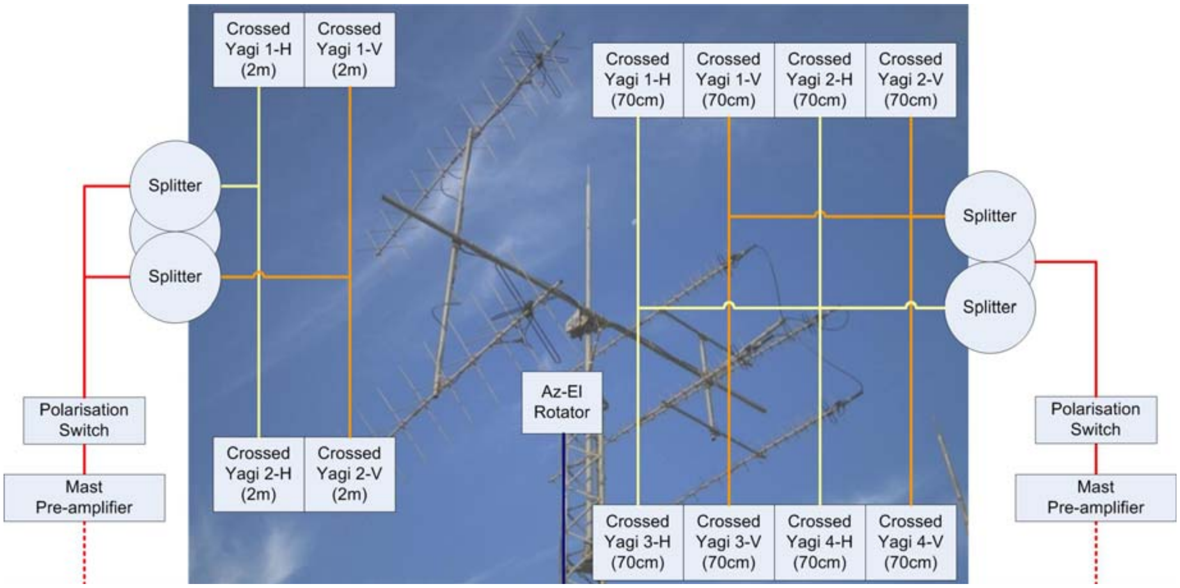



**Figure V-4: Antennas layout.**

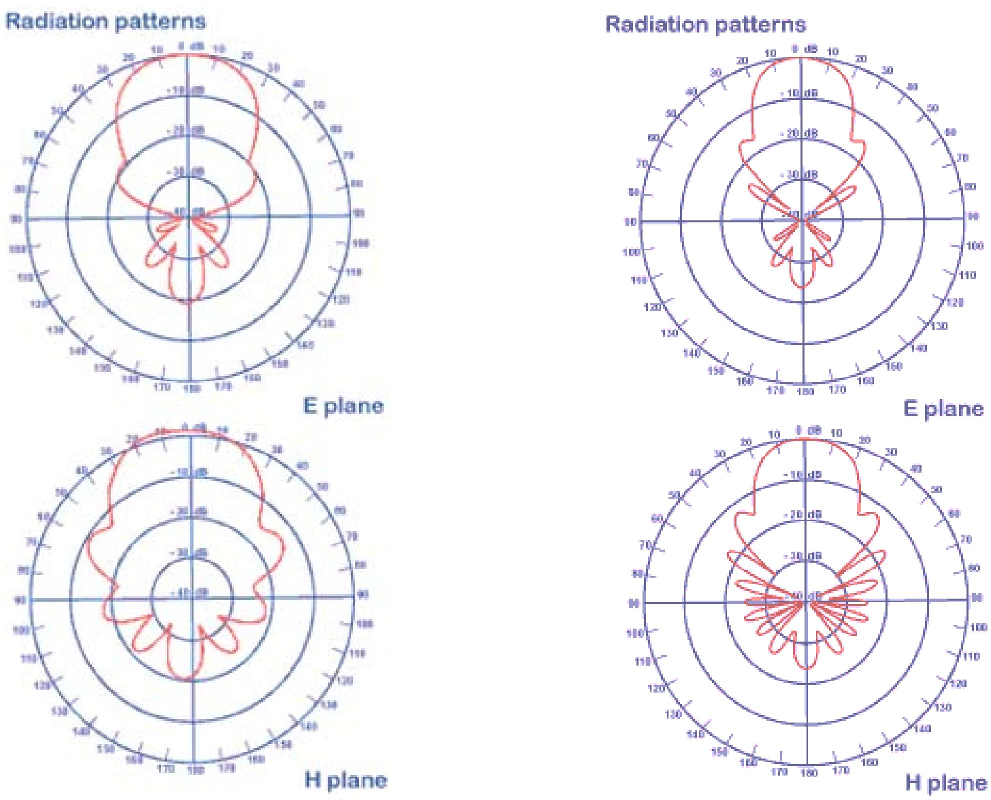



**Figure V-5: Radiation pattern of a 2m and 70cm Yagi Antenna**

### 2.2.2 HES-Fribourg Ground Station

The ground station in Fribourg was used a few years ago for Radio Amateur and educational purposes. The data collected from reports of past semester and diploma projects written by students and from spec-sheets is summarized below. These specifications will have to be confirmed and completed (G/T, EIRP etc.) during an upcoming semester project.

1) Uplink

11.4 dB of antenna-gain (crossed 9-element yagi)

17 dBW transmitter power-level (Yaesu FT-847, no external power-amplifier so far)

0.066 dB/m of attenuation for 30 m of coaxial-cable (Huber–Suhner S_07212BD)

2) Downlink

14.5 dB of antenna gain (crossed 17-element yagi)

0.125 μV of receiver sensitivity for 10 dB S/N at SSB/CW (2.2 kHz of bandwidth) (Yaesu FT-847, no preamplifier so far)

0.098 dB/m of attenuation for 30 m of coaxial-cable (Huber–Suhner S_07212BD)

### 2.2.3 Ground Stations Performance Summary

Table V-2 summarizes the estimated ground station performances.

| | ***2m Antenna 144-146 MHz Uplink*** | | ***70cm Antenna 430-438 MHz Downlink*** | |
|---|---|---|---|---|
| | *EPFL* | *HES-FB* | *EPFL* | *HES-FB* |
| Transmitter power | 17 dBW | 17 dBW | | |
| Antenna type | Stack of 2 2MXP20 Yagis | 2 CP Yagis | Stack of 4 CP: 436CP42 Yagis | 2 CP Yagis |
| Antenna Gain | 15.4 dBi | 15.1 dBi | 19-25 dBi | 14.5 dBi |
| Beamwith | | | 21° | 21° |
| Elements | 2*18 | 2*9 | 4*19 | 2*17 |
| Feed impedance/Conn | 50 Ohm / N | | 50 Ohm / N | |
| Transmission line losses | 6 dB | 2 dB | 1.85 dB | 2.9 dB |
| Ground station EIRP | 26.4 dBW | TBC | | |

**Table V-2: EPFL and HES-Fribourg performance estimates.**

### 2.2.4 Ground Station Network (GSN)

It is possible that the SwissCube project will benefit from parallel developments in ground station networking (GENSO) or from the established radio-amateur community of AMSAT. Table V-3 shows the various options for SwissCube using radio amateur frequencies.

The Global Educational Network for Satellite Operations (GENSO) is a project carried out under the auspices of the International Space Education Board and coordinated by the Education Department of the European Space Agency (LEX-E).

The project aims to provide a mutually beneficial service to all educational satellite projects by combining their ground stations into a collaborative, internet-based network, vastly improving mission return by increasing the amount of available communication time.

Three different types of ground-stations might be considered:

- **Radio Amateur Shack:** This ground station is operated by a radio amateur somewhere on Earth. All types of hardware should be expected, including the manual pointing of an antenna. The data integrity for this ground station types is typically low since its material is not known a priori. Nevertheless this could be interesting choice for beacon data recovery.
- **GENSO:** Allows the user to remotely operate a Ground Station, the big difference compared to the radio amateurs is that the ground station can be operated by SwissCube staff or integrated into an automated operations scheme. In order to operate within GENSO the SwissCube stations have to use GENSO software and operation time has to be given to other satellite operators.
- **SwissCube:** Major drawback of a single ground station is its small coverage.

| | Radio Amateurs | GENSO | SwissCube |
|---|---|---|---|
| **Number of stations** | > 100 | 3-10 | 2 |
| **Coverage** | Global (++) | Global (+) | Local (--) |
| **Operator** | Radio amateur | SwissCube staff (Remote operation) | SwissCube staff |
| **Beacon data integrity** | + | + | ++ |
| **TC integrity** | -- | + | ++ |
| **TM integrity** | - | + | ++ |
| **Constraints** | Need to create a web-interface to recover/send data<br>AMSAT requires to provide some radio amateur I/F when using their frequencies | Need to make GS compatible with GSN | No constraints |

**Table V-3: Comparison of potential SwissCube Ground Stations**

Concluding might be said that it would be very advantageous to participate in the GENSO for satellite operation which would significantly increase coverage time. Further Radio Amateurs should be included to obtain extra housekeeping data. This is particularly true during LEOP where the satellite will should be monitored as often as possible to determine possible errors.

# 3 Mission Control System

## 3.1 Design requirements

The mission control system design shall provide the following basic functions:

- Telemetry reception & processing
- Telecommanding (manual, automatic)
- Data displays and prints
- Real time updates
- Data storage (archiving) & retrieval

The system shall have a client – server topology where the various subsystems/flight operators shall monitor and command the satellite from terminals connected to the operations server. More advanced features such as the display of the subsystem state in graphical form (synoptic pictures) can be added once the core elements have been designed and implemented.

For mission control the approach shall be consistent with the various operational phases of the mission. Two principal modes have been identified, namely;

- In-orbit check-out of the satellite (LEOP & Safe-Mode) during which only basic commands are sent one-by-one and the results monitored in real-time.
- Autonomous operation. In this mode the ground segment is "pre-programmed" by satellite operators in advance of a pass. During the pass the ground segment performs autonomous operations by downloading telemetry data and uploading new telecommands into the satellite's scheduling system.

## 3.2 Design overview

The architecture of the space ground segment used is similar to the ESA ground segment. It uses a modular architecture because all components are connected to a software router (EGSE Router) developed by ESA.

The Mission Control Software (MCS), also called **GSS** for **Ground System Software**, is a monitoring and control system. Its role is to send telecommands to the spacecraft (or SCOE), and to manage the telemetries received. For this task, ESA uses the system SCOS 2000 developed by ESOC/ESA and industrial partners. SCOS 2000 is a generic system and is functionally complete, but this makes it complex to configure and not quite adapted for a small spacecraft. The next section describes the GSS developed for the SwissCube project.

The user interface is vital to the GSS. SCOS 2000 has an interface to view the housekeeping, to send telecommands, etc. and a programmable one used to develop the mission specific parts. In the SwissCube GSS, we have a core and three system interfaces used to create clients around it. Four clients have been developed so far (see [36]). Figure V-6 shows the interfaces to the router.

The ground station has an antenna and uses a small software application to communicate with the spacecraft. The SCOE is a test system used to test a subsystem. The simulator is used to simulate the behavior of the spacecraft when testing the GSS or the user interfaces.

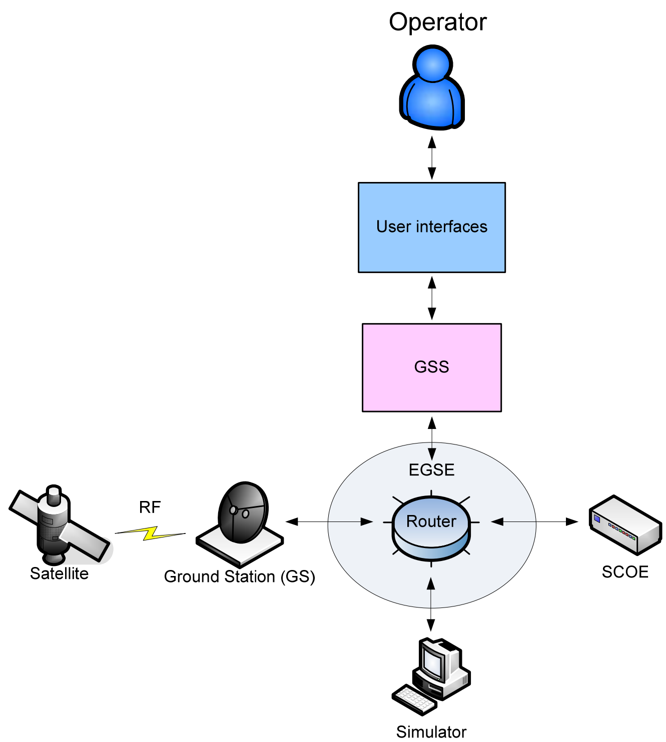



**Figure V-6: Ground System router interfaces.**

### 3.2.1 Ground System / Mission Control Software Architecture

This is the architecture that we designed and implemented. All the components are detailed in the subsequent chapters.

The architecture of the GSS contains three layers. The first one at the bottom is composed of the Core and the TC/TM Catalog Access where all the logic and processing are done. Above it are the system interfaces that expose the system to the outside with the use of Web Services and provide things like security, data validation, etc. The system is interoperable so that clients or other project developers, the third layer, could develop their interfaces with various technologies via the use of Web Services.

The main part of this architecture is the Core. This is the central part where of all the processing of the data, to sent or received, is done. The core is designed so that there is no mission specific processing done in it (except the monitoring modules) and thus can be kept the smallest possible to maximize its reliability and scalability.

At the client level, the monitoring (rich monitoring client) and the control (TC manager client) are well separated. This was done after much discussion and with the input from experts from ESA. With the separation, the decisions are more thoroughly thought of or are even taken by two people;

one that monitors and the other that controls. This avoids controlling errors when it's too easy to interact with the spacecraft.

At the other side of the system, all the communication is done via the EGSE Router, which is a routing software developed by ESA. It was chosen as it makes the system independent of the actual communication with the spacecraft (not well defined at this point). Furthermore it allows the use of tools developed by ESA such as a "Spy" that capture all the traffic for debugging purpose.

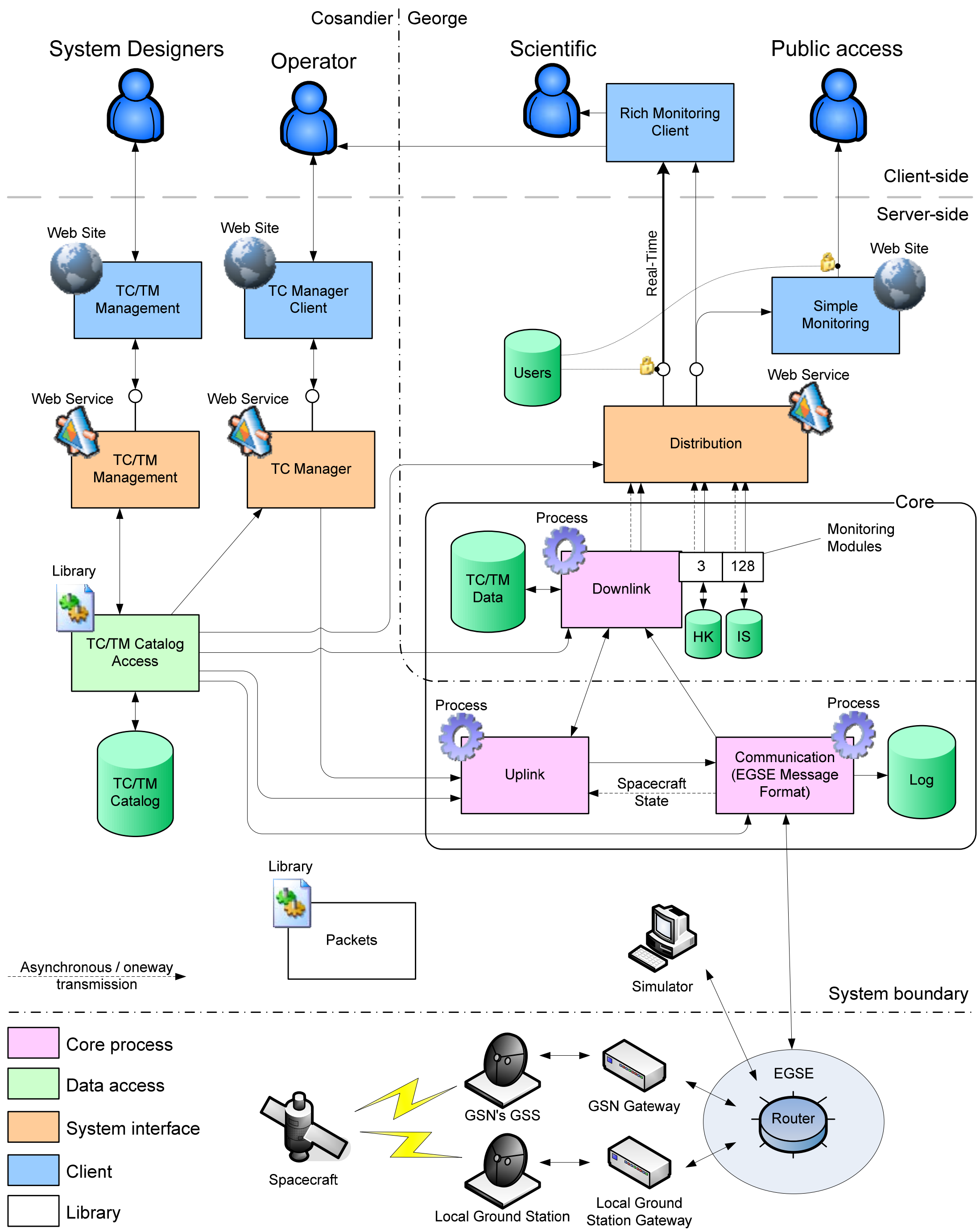



**Figure V-7: GSS and user interface architecture.**

### 3.2.2 Programming environment

Based on experience and knowledge, the OS chosen to develop the software was Microsoft Windows.

There were four possible styles of programming at our disposal:

- Native (C, C++): offers great performances, but for a program that must be able to run 24/7 for weeks (for example no memory leaks allowed), this was not a reasonable choice as we don't have the necessary experience and time to attains such quality with this kind of programming.
- LabView: Used by the ESA for the new version of their EGSE Router, the choice to use it was taken seriously. But due to an almost total lack knowledge of it and the completely different approach to programming, it would have required too much time to learn it.
- Scripting (Python, Perl, etc.): Dismissed directly due to the lack of type-safety, scalability and reliability when working with them.
- Managed (.NET, Java): These technologies bring great RAD (Rapid Application Development) and come with great framework and libraries for almost everything. The greater memory usage is outweighed by the automatic memory management especially needed for long running applications that must not suffer from memory leaks.

As a result, a managed programming environment was chosen. Based on internal experience, the selection of .NET was straightforward. Consequently, the programming language (the .NET platform support numerous programming languages) chosen is C# 2.0 as it is the most used and best supported on the .NET platform (it was developed in conjunction of it).

Having chosen the .NET Framework running on Microsoft Windows, the most natural choice of database software was Microsoft SQL Server for its great integration with the two. So no external library is needed to access the database and it adds performance counters to Windows that enable us enhanced debugging and scalability tests.

**For further details about each of the elements, please consult:**

- Ground System Software Description and User Manual [36, 37]

### 3.2.3 User Interfaces

This section briefly describes the user interfaces. More details can be found in [37].

To manage and configure the GSS, a "TC/TM Management" website was created (see Figure V-8). The telecommands can be sent by the "TC Manager Client". The monitoring can be performed via two clients, a website and rich client. The rich client is real-time and can display all the information relating to the monitoring to the spacecraft operator. Simple monitoring is a simpler web-based interface available to display the monitoring for all those interested without the need to install a client. It is also intended to provide access to the telemetry for the public.

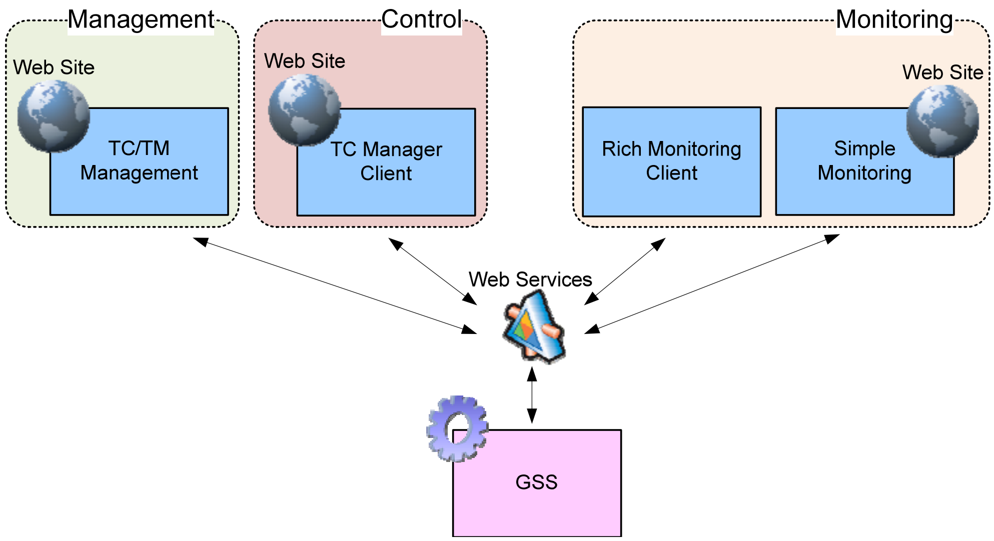



**Figure V-8: User Interface to the GSS.**

<u>TC/TM Management</u>

The TC/TM Management is a website to configure the GSS, and to parameterize the mission telecommands and spacecraft parameters (see Figure V-9). This website is used before the launch.

The GSS Configuration page is used to configure the "spacecraft ID" and mission description.

The Mission Configuration page is used to configure mission constants. In this version of GSS only the "Telecommand Checksum Type" and the "Telemetry Checksum Type" field is used by the system. The GSS supports the insertion and the modification for all parameters. It is only the interface which currently limits the configuration of certain configurations.

The APID (Application Process ID) uniquely corresponds to an on-board application process. This is used in the CCSDS packet header and the choice of APID values is mission-specific.

The service type indicates which service correspond the type in PUS. Service types 0 to 127 shall be reserved for the standard ECSS-E-70-41A, service types 128 to 255 are mission-specific.

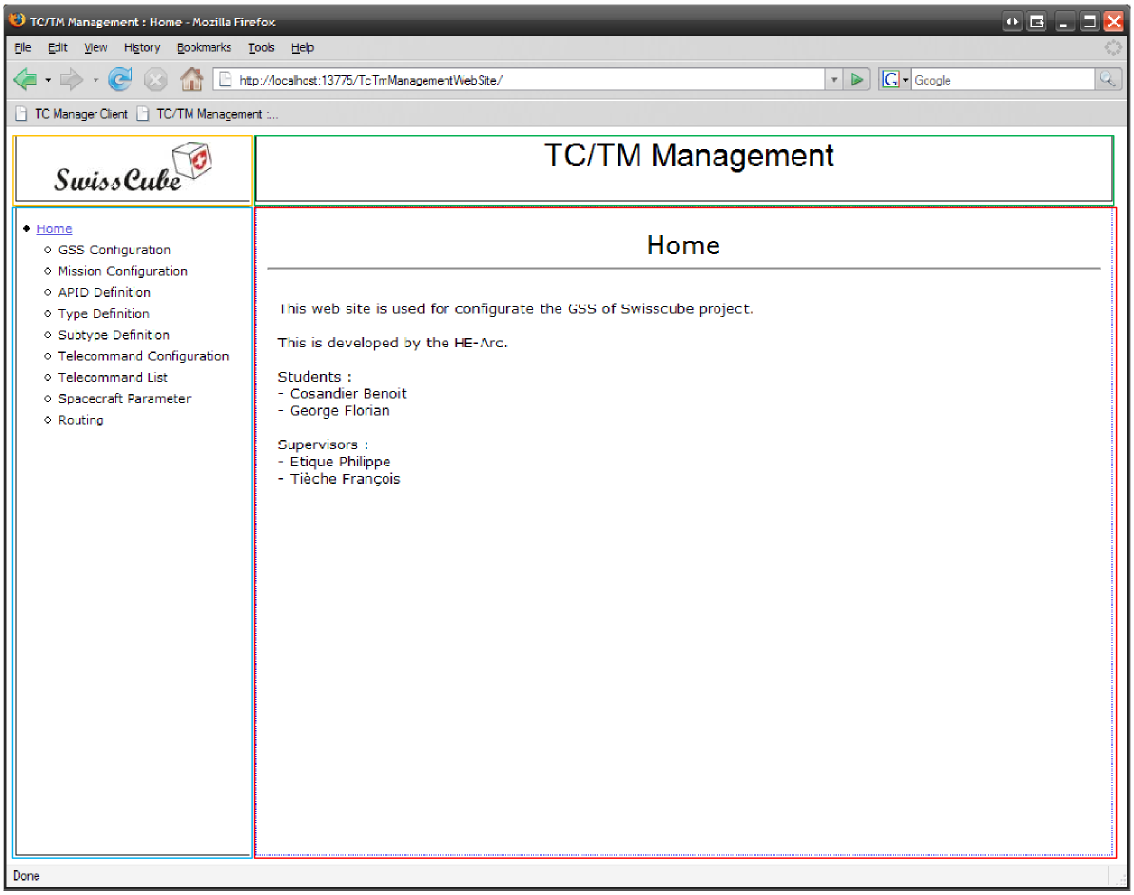
With a service type, the subtype uniquely identifies the nature of the service. Within standard services, subtypes 0 to 127 shall be reserved in the standard ECSS-E-70-41A, subtypes 128 to 255 are mission specific. Within mission-specific services, all subtypes (0 to 255) are available for mission-specific use.

The Telecommand Configuration page is used to define the telecommands and associated parameters.

The Telecommand List page lists the telecommands. This page it is used to modify and delete a telecommand. It is in relation with the page "Telecommand Configuration".

A spacecraft parameter is a housekeeping parameter which can be reported from the spacecraft to the ground station and and which specifies how the GSS should treat the parameter.

The GSS uses a system of routing, each APID correspond to a route (the ID in EGSE Router). When a telecommand is send by the GSS, this table is used to check where the telecommand must be sent. If the route for a APID is not defined, the GSS must use the route defined for the APID = 0, hence the APID = 0 is the default route.




Logo area

Title area

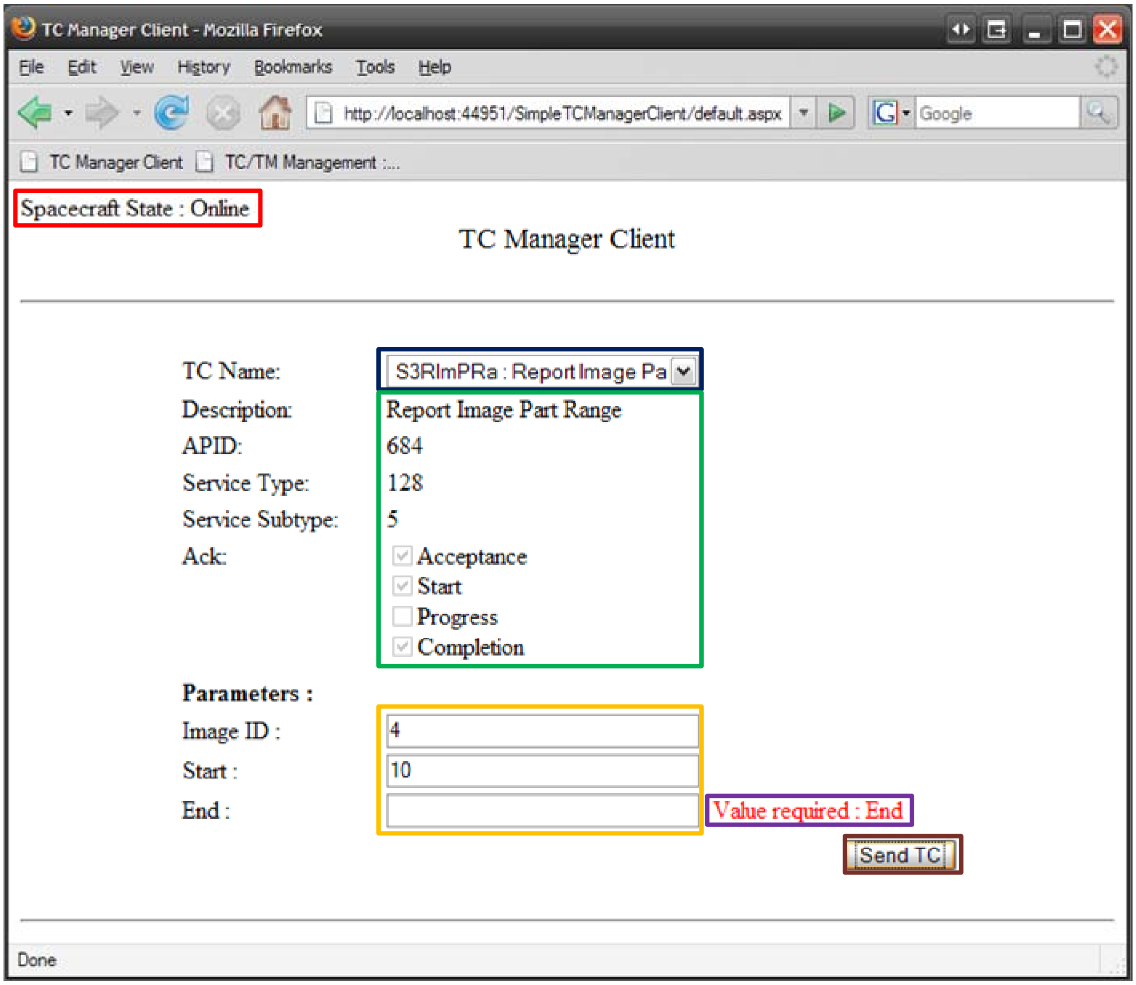
Menu area : Used the menu for selected which component you want to configure.

Content area : it's this area who display the configurations for TC/TM Management.

**Figure V-9: TC/TM Management Structure.**

TC Manager

The TC Manager is used to send a telecommand. This client permits sending the telecommands defined in the TC/TM Management site section. Figure V-10 shows the interface.




Display the satellite's state (Online or Offline).

Select the Telecommand by the name.

Display the description of the telecommand, who is selected in the Dropdown List.

Enter in these textboxes the parameters of the telecommand.

It's a validator, which is display only if the textbox on the left are empty.

Click on this button when you want send the telecommand.

**Figure V-10: TC Manager Client interface.**

Simple Monitoring

This web application provides a simply mean to visualize all the monitoring data. Only viewing the telemetry is publicly available, the other sections require to be authenticated.

The TC page shows all the telecommands sent or waiting to be sent. They are displayed in reverse chronological order (most recent first). See Figure V-11 for an example.

1 2 3 4 5 6 7 8 9 10 ...

| Token | Date | Time | APID | SF | SC | ST | SST | R | G | T | A | S | 0 | 1 | 2 | 3 | C | Data |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1362 | 23/12/2006 | 22:09:47 | 684 | 0 | 973 | 128 | 1 | O | O | O | O | O | O | | | | O | - |
| 1361 | 23/12/2006 | 22:02:24 | 684 | 0 | 972 | 128 | 1 | O | O | O | O | O | O | | | | O | - |
| 1360 | 23/12/2006 | 21:50:34 | 684 | 0 | 971 | 128 | 1 | O | O | O | O | O | O | | | | O | - |
| 1359 | 23/12/2006 | 21:33:16 | 684 | 0 | 970 | 128 | 4 | O | O | O | O | O | O | | | | O | 00-04-01 |

**Figure V-11: Example of TC queue.**

A similar page shows all the telemetries received. They are displayed in reverse chronological order (most recent first). See Figure V-12 for an example.

1 2 3 4 5 6 7 8 9 10 ...

| Id | Token | Date | Time | APID | SF | SC | ST | SST | Data |
|---|---|---|---|---|---|---|---|---|---|
| 3920 | 1362 | 23/12/2006 | 22:09:48 | 684 | 3 | 973 | 128 | 2 | 00-03-45-8D-90-17-00-04-... |
| 3919 | 1361 | 23/12/2006 | 22:02:25 | 684 | 3 | 972 | 128 | 2 | 00-03-45-8D-90-17-00-04-... |
| 3918 | 1360 | 23/12/2006 | 21:50:34 | 684 | 3 | 971 | 128 | 2 | 00-03-45-8D-90-17-00-04-... |
| 3917 | 1359 | 23/12/2006 | 21:33:16 | 684 | 3 | 970 | 128 | 6 | 00-04-01-08-19-29-21-49-... |
| 3916 | 1358 | 23/12/2006 | 21:28:57 | 684 | 3 | 969 | 128 | 2 | 00-03-45-8D-90-17-00-04-... |

**Figure V-12: Example of TM queue.**

Another page displays all received values (with their reception date and time) for the selected housekeeping parameter. See Figure V-13 for an example.

Parameter: EPSV0003

**EPSV0003**

| Date | Time | Value |
|---|---|---|
| 11/12/2006 | 14:07:39 | 90 |
| 11/12/2006 | 14:07:34 | 160 |
| 11/12/2006 | 14:07:30 | 105 |
| 11/12/2006 | 14:07:24 | 190 |
| 11/12/2006 | 14:07:14 | 190 |

**Figure V-13: Housekeeping parameter display.**

A fourth page provides the means to retrieve the payload images received. See Figure V-14.


**Figure V-14: Example image retrieval.**

Rich Monitoring Client

The Monitoring Client provides both a rich and interactive interfaces in order to visualize all available monitoring related information regarding the spacecraft. The main window of the application that is displayed when launching the client is shown in Figure V-15. It is from this window that the different modules can be launched.

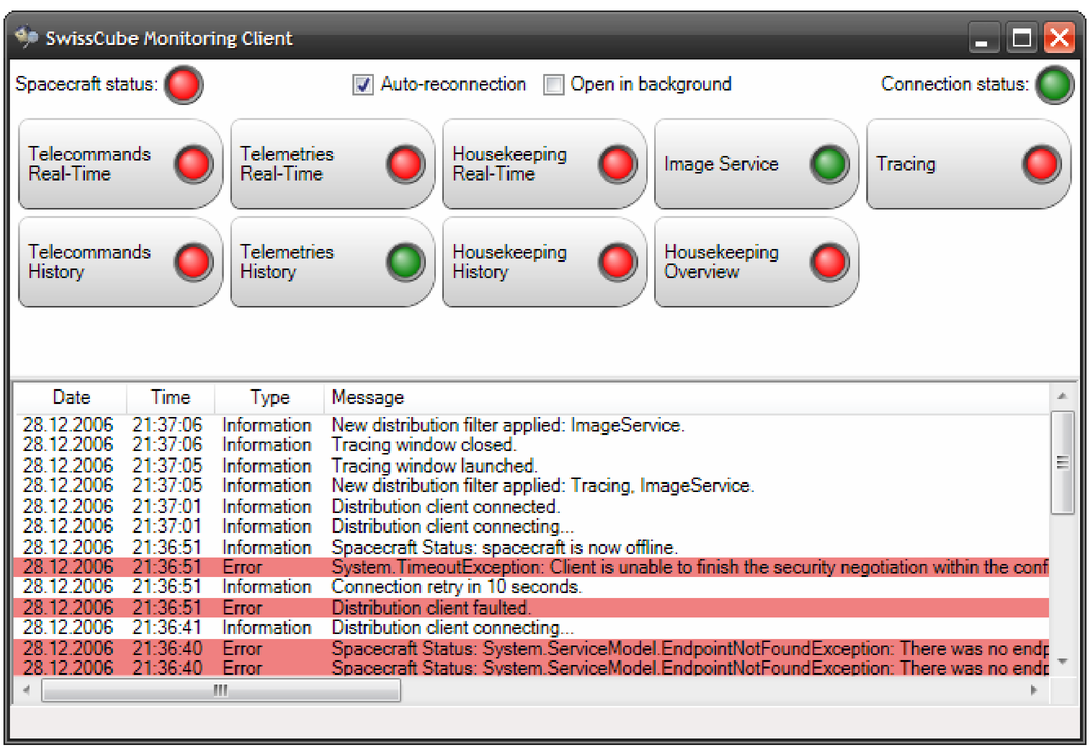



**Figure V-15: Rich monitoring client display.**

1. Spacecraft Status: indicates the current status of the spacecraft and is periodically updated (Green=online, Red=offline).

2. Auto-reconnection: if checked, the client will automatically try to reconnect to the distribution server if the connection is lost or can not be established.
3. Open in background: if checked, the modules windows will be opened behind the main window.
4. Connection Status: indicates the current status of the connection (Green=connected, Red=disconnected, Orange=fault)
5. This zone contains a list of all loaded modules. The application comes with bundled modules that are described in [37]. The light indicates whether the module is open (green) or closed (red). When a real-time module is closed, real-time data is not sent by the server and thus does not consume network bandwidth.
6. Message window: contains information about the client itself: such as important messages, warnings and error messages.

### 3.2.4 Further developments

Further developments include:

<u>Monitoring data export</u>

Add a functionality enabling the exportation of the monitoring data. For example the housekeeping values could be use in a program like Microsoft Office Excel to perform complex analysis.

<u>Housekeeping graphs</u>

Allow the user to visualise the housekeeping values as graphs. An early prototype has already been developed and is available in the source directory under the name "MC Prototype" (WPF Application).

<u>Definitions import</u>

Add the possibility to import mission definitions in the TC/TM Management. This would enable the transfer of a configuration from a test GSS to another one.

<u>Time correlation implementation</u>

Due to the lack of specification on information on time management aboard the spacecraft, this functionality is not yet implemented.

<u>Log replay</u>

Allow the replay of a communication log. This would provide better debugging support and equipment testing.

<u>Error handling and display</u>

Better handling of the malfunctions or occurring errors and improved quality of the messages displayed in theses case so they can be more easily corrected.

<u>Performances</u>

There are places in the software where the performance can be greatly improved like in the Packet library conversion algorithms or by regrouping the Core in only one process.

# 4 Ground Support Facilities and Test Benches

The SwissCube verification will be done using test benches as early as possible. Functional system test benches shall replace whenever possible software models with hardware in-the-loop.

The check-out system will allow AIT operations to be performed while operating as early as possible using the mission control software (MCS). It will be composed of all the necessary special check-out equipment (SCOE) to validate the satellite. The CORE SCOE will coordinate the work between the various SCOE's. For simplification purposes CORE SCOE could be integrated with MCS.

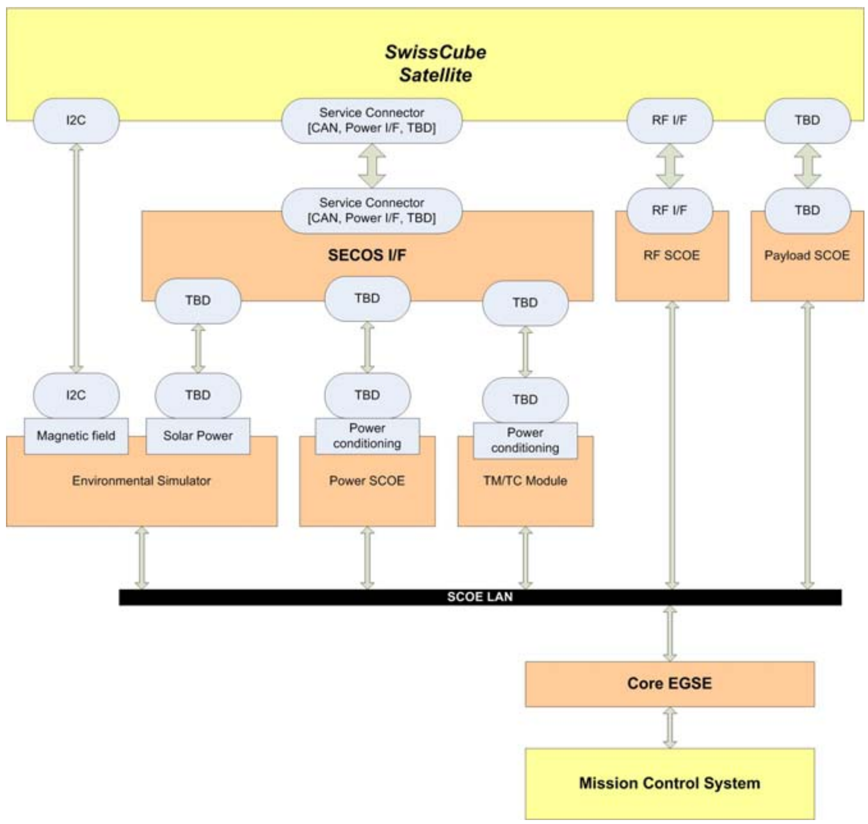



**Figure V-16: SwissCube real-time test bench environment**

### 4.1.1 Integration model test bench

The integration model will be functionally representative of the end items in electrical and software terms.

The testbench objectives are:

- to test the functional behaviour of the electrical and software parts
- to test electrical and data interfaces

- to investigate failure modes.

#### 4.1.2 Engineering qualification model test bench

The electronic equipment of the SwissCube subsystems and the SwissCube Payload will be installed on the EQM test bench.

It will be flight representative in electrical I/F and function, but as baseline only one functional branch will be realized.

The Test Bench configuration will be a 3-D representative and it will be flight representative w.r.t harness length and orientation as well as the unit position and orientation.

The build standard of the EQM Test Bench will not be identical to flight units: there may be deviations as regards internal redundancies, mechanical interfaces, parts quality, electrical characteristics (e.g. transient behavior).

The main objectives of the EQM Test Bench are:

- Check the electrical and functional interfaces between the units.
- Verify the functionality of the avionics subsystems and on-board software.
- S/C autonomy functional verification
- Validation of communication and power interfaces between the payload and the platform.
- EGSE validation including the EGSE software and verify the EGSE capability to perform the planned test.
- Validation of the test sequences to be re-used for PFM test campaign.

The Test Bench will be kept operational all along the AIT sequence to be usable for potential failure analysis or for validation of software modification.

After the integration of all units at platform level (e.g. ADCS, CDMS,…) the instrument will be integrated as PFM into the Test Bench for system level tests.

# VI CONCLUSION

# 1 Conclusion

This report summarizes the work performed by the students during their semester and master projects from September/October 2006 to February 2007. About 5 students remained from the 25 students in Phase A, and about 20 new students joined the project.

Phase B of the project was hardware oriented with the development and functional tests of major space subsystems. Besides the beacon development, payload and flight software, all other subsystems are on schedule and within expectations. System level work could start with the arrival of 2 new students at the end of Phase B. A lot remain to be done in this area, but the work should be well advanced by June 07.

Critical design questions remain in the areas of:

- Beacon and payload design;
- ADCS control algorithms;
- Software design and tests/validation planning;

The project understands that some elements will need to continue some developments before closing Phase B and the deadline has been set to the end of the next semester in June 07.

# VII REFERENCES, ABBREVIATIONS AND DEFINITIONS

# 1 References

[1] S3-B-SE-1-0-Level_1and2_specifications.doc.

[2] S3-B-SE-1-0-Level_3_SSR.doc.

[3] S3-B-SE-1-0-SUBSYSTEM_specifications.doc (6 documents).

[4] S3-B-SE-1-0-IWA_specifications.doc.

[5] S3-B-SE-1-1-Specifications_rules.doc.

[6] S3-B-SE-2-2-AIVplan.doc.

[7] *CubeSat Design Specification*. Revision 9, Cal Poly, May 2005.

[8] S3-B-STRU-1-3-Launch Environment.doc.

[9] *Dnepr User's Guide*. Iss. 2, ISC Kosmotras, Nov. 2001.

[10] EHB-0003. *Rockot User's Guide*. Iss 3. Rev. 1, Eurockot, Apr. 2001.

[11] CCSDS 100.0-G-1. *Telemetry – Summary of Concept and Rationale – Green Book*. Consultative Committee for Space Data Systems (CCSDS). Green Book Iss. 1., Dec. 1987.

[12] CCSDS 200.0-G-6. *Telecommand – Summary of Concept and Rationale – Green Book*. Consultative Committee for Space Data Systems (CCSDS). Green Book Iss. 6., Dec. 1987.

[13] ECSS-E-70-41A. *Space Engineering – Ground Systems and Operations – Telemetry and Telecommand Packet Utilization*. European Cooperation for Space Standardization – ECSS, Jan. 2003.

[14] *AX.25 Link Access Proctol for Amateur Packet Radio*. Tucson Amateur Packet Radio Corporation (TAPR). Ver. 2.2, Jul. 1998.

[15] S3-A-COMM-1-1-LinkBudget: *AMSAT / IARU Annotated Link Model System – SwissCube Project*. Iss. 1, Rev. 1., June 2006.

[16] S3-B-CDMS-1-0-CDMS.

[17] S3-B-SET-19-0-Electrical_Block_Diagram.

[18] S3-B-SET-1-2-Data Budget].

[19] S3-B-PL-1-0-Science_Mission_Definition_and_Payload_System_Engineering.

[20] S3-B-STRU-1-4-StructureConfiguration.

[21] S3-B-TCS-1-1-Thermal Management.

[22] S3-B-MECH-1-0-Mechanisms.

[23] S3-B-ADCS-1-1-Control_Algorithm.

[24] S3-B-ADCS-1-3-Magnetic_sensor.

[25] S3-B-ADCS-1-4-ADCS HW.

[26] S3-A-ADCS-1-5-ADCS.

[27] Lithium Polymer Battery Evaluation Final, Report, Craig Clark, SPFF-67268.

[28] S3-B-EPS-1-1-Electrical_Power_System.

[29] S3_B_EPS_1_0_RBF_LUP_FMS_HBG.

[30] S3-B-CDMS-1-0-CDMS.

[31] S3-A-COMM-1-0-Beacon.

[32] S3_B_COM_1_1_TELECOM.

[33] S3-B-MECH-1-0-Mechanisms.

[34] S3-B-SOFT-1-1-FlightSoftwareEPSCOM.

[35] S3-A-GS-1-0-GS Telecom Infrastructure Description.

[36] S3-B-GS-1-0-GS_MC_software.

[37] S3-B-GS-1-0-GS_MC_SW_User_Manual.

# 2 Abbreviated terms

| | |
|---|---|
| ADCS | Attitude Control and Determination System |
| BOL | Beginning Of Life |
| CCD | Charged Coupled Device |
| CDMS | Control and Data Management System |
| COM | Communication System |
| DOD | Depth of Discharge |
| EOL | End Of Life |
| EPS | Electrical Power System |
| GaAs | Gallium Arsenide |
| HK | House keeping data |
| LDO | Low-Dropout Regulator |
| Li-Ion | Lithium-Ion |
| Li-Po | Lithium-Polymer |
| LV | Launch Vehicle |
| MPPT | Maximum Power Point Tracking |
| $I^2C$ | Inter-Integrated Circuit |
| PCB | Printed Circuit Board |
| P/L | Payload |
| PV | Photovoltaic |
| SEL | Single Event Latch-up |
| SPAD | Single Photon Avalanche Diode |
| TBD | To be defined |
| TC | Telecommand |
| TM | Telemetry |

# 3 Definitions

| | |
|---|---|
| Albedo | Albedo is a measure of reflectivity of a surface or body. It is the ratio of total electromagnetic radiation reflected to the total amount incident upon it. The average albedo of Earth is about 30%. |
| Dropout voltage | The dropout voltage is the minimum difference between input and output voltage that a LDO needs to do the output voltage regulation. |

# VIII APPENDICES

# 1 Appendix A: Phase A Review Comments and Action Items

| Topic or Subsytem | From | Comment / Recommendation | AI Status |
|---|---|---|---|
| ADCS | L. Alminde | 3° pointing, determination should be 10x better. 10° would be realistic. | Implmtnd |
| ADCS | L. Alminde | Simpler concept for gathering data | Implmtnd |
| ADCS | K. Laursen | Solar Panels will induce a lot of error | Implmtnd |
| ADCS | K. Laursen | Use sun sensors and gyros | Implmtnd |
| ADCS | K. Laursen | Algorithm ok! | Implmtnd |
| ADCS | K. Laursen | Same coordinate system for determination and control | Implmtnd |
| ADCS | K. Laursen | Do not use an idealized system for the magnetic field | Open |
| ADCS | R. Krpoun | PWM interference with magnetometer | Open |
| ADCS | R. Krpoun | Gravity gradient could be sufficient for 10° precision | Looked at |
| ADCS | L. Alminde | Use momentum bias mode in Y axis | Looked at |
| ADCS | K. Laursen | Model more precisely disturbances | Implmtnd |
| ADCS | K. Laursen | Momentum wheel axis should be major axis | Implmtnd |
| ADCS | M. Noca | Drag equivalent to manetotorquers torque | Implmtnd |
| ADCS | M. Noca | Take into account measurement errors | Open |
| Antenna Mechanism | R. Krpoun | Adherence of the wire to the nylon | Open |
| Antenna Mechanism | A. Bonneman | Nylon wire above optics, contamination issues. Dynema good replacement | Open |
| Antenna Mechanism | W. Hanselmann | Electrical isolation of the antenna | Open |
| Antenna Mechanism | W. Hanselmann | Matching in UHF if very close to metal might change | Open |
| Antenna Mechanism | L. Alminde | Eigenfrequencies | Open |
| Antenna Mechanism | A. Bonneman | Backup wire to be included | Open |
| Antenna Mechanism | M. Noca | Test provoked smoke, not tolerable, find other material | Open |
| CDMS | K. Laursen | Simpler concept for gathering data | Implmtnd |
| CDMS | K. Laursen | 8 bit microcontroller - ADCS? | Looked at |
| CDMS | K. Laursen | EDAC integration into chip? | Looked at |
| CDMS | K. Laursen | CAN-bus why 1Mbit? | Looked at |
| CDMS | K. Laursen | EEPROM for data storage, why not Flash | Looked at |
| CDMS | A. Bonneman | Why different busses, CAN, I2C, RS232...? | Looked at |
| CDMS | L. Alminde | Avoid I2C complicated implementation | Looked at |
| CDMS | A. Bonneman | Make a frequency list of every component and look at EMC | Open |
| CDMS | A. Crausaz | Maybe remove transceiver | Looked at |
| CDMS | M. Noca | Look at goal of the bus, make it simple, one bus! | Implmtnd |

| Topic or Subsytem | From | Comment / Recommendation | AI Status |
|---|---|---|---|
| End to end info | A. Bonneman | Page 5: acknowledgement of TC received | Implmtnd |
| End to end info | K. Laursen | List all the parameters in the system and put in software | In progress |
| End-End Info System | L. Alminde | Simulator good idea | Open |
| End-End Info System | L. Alminde | AX.25 run in What mode? Datagram or connection oriented. Recommand using AX.25 in the data mode. | Implmtnd |
| End-End Info System | L. Alminde | AX.25 recommended because used by radio amateurs | Implmtnd |
| End-End Info System | L. Alminde | Simulator should allow to inject comm errors | Open |
| End-End Info System | A. Bonneman | Simulator "flag" should be added to avoid confusing FM with test models (flag indicates simulator mode). | Open |
| End-End Info System | A. Bonneman | Command EPS off should not be implemented | Open |
| End-End Info System | K. Laursen | Erroneous TC requirement should be revised | Open |
| End-End Info System | A. Bonneman | TC encryption: should be considered and acknowledgement if code is correct or not. | In progress |
| End-End Info System | K. Laursen | Flight software update | Looked at |
| End-End Info System | K. Laursen | Peek and poke Algorithm could be implemented | In progress |
| End-End Info System | A. Bonneman | Frequency of uplink should not be published | Implmtnd |
| End-End Info System | K. Laursen | Why only 0 to 23 bytes of data? Can make it bigger if we need to. | Looked at |
| End-End Info System | A. Bonneman | Review time synchronisation concepts and requirements. Also be aware that amateur 1 and 2 will have diff time synchronization. | Open |
| End-End Info System | R. Krpoun | First TC will arrive w/o time synchronisation. | In progress |
| EPS | A. Crausaz | Use only discrete parts for EPS | Implmtnd |
| EPS | A. Crausaz | Combine latch-up protection with current limiter protection (or LDO) | Looked at |
| EPS | A. Crausaz | Do not use micro-processor in EPS and in all essential functions | Implmtnd |
| EPS | A. Crausaz | Battery charger: match for radiation tolerance of the Ics, think of making a DC/DC converter to have a regulated bus | Implmtnd |
| EPS | A. Crausaz | EPS Schemes looks very strange: did you take into account that you have 4 power components, blocking diodes in solar array, 1 diode in step up, 1 transistor in LDO, 1 transistor in latch-up protection? Regulated bus implies no LDOs and OK if battery fails. | Looked at |
| EPS | A. Crausaz | Maximum peak power point tracker: be careful with failure mode. | Looked at |
| EPS | R. Krpoun | Latch-up before or after LDO? | Looked at |
| EPS | L. Alminde | Temperatrue range to low, other cubes 20-36° op temp | Looked at |
| EPS | A. Crausaz | A lot of losses through the selected design, two diodes | Looked at |

| Topic or Subsytem | From | Comment / Recommendation | AI Status |
|---|---|---|---|
| EPS | A. Crausaz | Bus concept might not be best solution, maybe 1 stabilised bus | Implmtnd |
| EPS | L. Alminde | LiPo not A good choice needs to be tested in vacuum | Looked at |
| EPS | A. Crausaz | Reliability issues | Looked at |
| EPS | H. Shea | Measurement of the current | Implmtnd |
| EPS | K. Laursen | MPPT (Max. peak power tracker) all the time | Open |
| EPS | A. Bonneman | 30% albedo to optimistic | Looked at |
| EPS | A. Bonneman | Penumbra effects | Looked at |
| EPS | A. Bonneman | What happens after deployment where does the power go? | Implmtnd |
| EPS | A. Crausaz | Check radiation sensitivity of battery charger | Open |
| EPS | A. Crausaz | Operational environments needs to be taken into account | Looked at |
| EPS | L. Alminde | What happens whten the charge current varies | Looked at |
| EPS | L. Alminde | Charging might be possible below 0°C, screening needs to be done | Implmtnd |
| EPS | A. Crausaz | Battery charge/discharge regulator might be integrated | Implmtnd |
| EPS | K. Laursen | FMECA of all electronic subsystem | Looked at |
| EPS | K. Laursen | Ramp-up controller might be better choice for Latch-up protection | Looked at |
| EPS | A. Crausaz | Latch-up EPS | Implmtnd |
| EPS | K. Laursen | Telemetry about Latch-up | Looked at |
| EPS | M. Noca | LDOs imply too much losses | Looked at |
| EPS | M. Noca | LiPo batteries: poly structure in vacuum swells, deforms and loses capacity | Looked at |
| EPS | M. Noca | Max power tracking: algorithm? | Looked at |
| EPS | M. Noca | Albedo: 30% too optimitic | Looked at |
| EPS | M. Noca | Eclipses: take into account penumbra for alalbedo calculations | Looked at |
| EPS | M. Noca | What happens if cells are illuminated and there is no consumption? | Implmtnd |
| EPS | M. Noca | Do FMECA analysis | Looked at |
| EPS | M. Noca | Try to test batteries for real operations | Looked at |
| EPS | M. Noca | NEVER TRUST DATASHEETS, take margins, make tests | Looked at |
| EPS | M. Noca | Latch-up: write down requirements on the load | Looked at |
| EPS | M. Noca | Why not a ramp up controller? | Looked at |
| EPS | M. Noca | Do a proper grounding scheme | Implmtnd |

| Topic or Subsytem | From | Comment / Recommendation | AI Status |
|---|---|---|---|
| Flight software | K. Laursen | An OS consumes in general less power. Less power when idle. But OS implies overhead scheduling. | Looked at |
| Flight software | K. Laursen | Not having an OS does not simplify the code | Looked at |
| Flight software | K. Laursen | Scheduling overhead is a disadvantage in OS | Looked at |
| Flight software | A. Bonneman | Rewrite boot sequence of the system, critical | Open |
| Flight software | L. Alminde | Critical failure requirements | Open |
| Flight software | K. Laursen | Data exchange format between systems must be looked at | In progress |
| Flight software | A. Bonneman | Data budget missing | In progress |
| Flight software | A. Bonneman | Implementing deployment mode is critical cause of possible SW loop | Open |
| Flight software | A. Bonneman | R 28.3, R 28.4: dansgerous statements, check applicability | Looked at |
| Flight software | A. Bonneman | Careful about times. Need watchdog back-up. | Open |
| Flight software | K. Laursen | Correct process diagram (slide 6) | Implmtnd |
| Flight software | K. Laursen | Check scenario of memory clean up before reset. Current configuration shows that memeory clean-up is not possible before reset. | Open |
| Ground System | R. Krpoun | Full duplex mode constraint (?) | Open |
| Ground System | R. Krpoun | Spectrum analyser to analyse incoming signal needed | Implmtnd |
| Ground System | K. Laursen | LNA to be added | Implmtnd |
| Ground System | K. Laursen | SWR feed to match the antennas to the radio. | Implmtnd |
| Ground System | A. Bonneman | Need a back-up GS, Netherlands OK | Implmtnd |
| Ground System | A. Bonneman | Get a radio amateur license | In progress |
| Ground System | A. Bonneman | Start process to register for frequency license (plan 1 yr in advance) | Open |
| Ground System | A. Bonneman | Get help from radio amateur to set up ground station, as soon as possible | In progress |
| Ground System | K. Laursen | Ground station working with space simulator | Open |
| Ground System | A. Bonneman | Plan for flight plans | Open |
| Mission Design | R. Krpoun | Specify software LU mitigation | Open |
| Mission Design | E. Kopp | No need for shielding at this altitude, but LU might occur etc. | Looked at |
| Mission Design | L. Alminde | Shielding very important even at this altitude | Looked at |
| Payload Instrument | L. Alminde | Compression, should maybe be done on the CDMS not on payload processor | Implmtnd |
| Payload Instrument | A. Bonneman | Perform operations on-ground whenever possible | Implmtnd |
| Payload Instrument | K. Laursen | 1° Pointing accuracy very stringen | Implmtnd |
| Payload Instrument | A. Bonneman | Weight factors on trade-off | Implmtnd |
| Payload Instrument | M. Borgeaud | "Depth" of image at 400km/1000km altitude | Implmtnd |
| Payload Instrument | A. Crausaz | Spinning vs. 3-axis stabilized, justification | Open |
| Payload Instrument | K. Laursen | Why choose SPAD over CCD, analyis for CCD? Why not CMOS? | Implmtnd |
| Payload Instrument | K. Laursen | Test SPADS for radiation | Started |

| Topic or Subsytem | From | Comment / Recommendation | AI Status |
|---|---|---|---|
| Payload SE | M. Borgeaud | Why not more lines? Document answer. | Implmtnd |
| Payload SE | E. Kopp | Filter Resolution 4nm? | Implmtnd |
| Payload SE | L. Alminde | Error in specification 6nm filter | Implmtnd |
| Payload SE | K. Laursen | Compression algorithm needs to be specified | Looked at |
| Payload SE | L. Alminde | There may be more opportunities than 10 min downlink per day, look at what happens | Looked at |
| Payload SE | L. Alminde | Move/transfer data to the CDMS. Payload should be as simple as possible | Implmtnd |
| Project Management | L. Alminde | Plan for training of other interested universities in communicating with our sat | In progress |
| Project Management | A. Bonneman | Review structure of requirement (functional, performance, operational) | Implmtnd |
| Project Management | A. Bonneman | Set-up the mapping of requirements and derived requirement as soon as now! | In progress |
| Project Management | | Involvment of lab staff increased with visits to companies | In progress |
| Project Management | | Convince EPFL board of directors to support project | Open |
| Project Management | | Involve media and personality to increase project visibility | In progress |
| Project Management | M. Noca | Change to 4 nm in the requirement document | Implmtnd |
| Project management | A. Bonneman | Create different schedules for different subsystems | In progress |
| Project management | A. Bonneman | To fill the gaps: internshipd with other universities | Implmtnd |
| Project management | A. Bonneman | Cost: do extensive breakdown, show hidden cost. | Implmtnd |
| Project management | A. Bonneman | Cost: get students to call for components | Implmtnd |
| Project management | L. Alminde | Students cannot spend half of their semester doing tests. Their school requirements would not be fulfilled. | Looked at |
| Project management | A. Bonneman | Do Phasing with phasing overlapping each other. | In progress |
| Project management | A. Bonneman | Diagrams have to be reassessed every semester depending on the number of students and the quality. | In progress |
| Project management | A. Bonneman | Involvement of employees not knowing about space: with your sponsors you should organize a workshop to show theses people what you expect from them. | In progress |
| Project management | A. Bonneman | Convince the university board of the importance of the project. You need from top down the enthusiasm. Then it is easier to find people, profs and students | Open |
| Project management | A. Bonneman | Get the MEDIA talk about your projet. Important people at a national level to support the project. It should be a NATIONAL PRIDE. | Implmtnd |
| Project management | A. Bonneman | Reject the students that are not wiling to work. | Implmtnd |

| Topic or Subsytem | From | Comment / Recommendation | AI Status |
|---|---|---|---|
| Project management | A. Bonneman | Check also internships from other universities at EPFL to fill the gaps | Implmtnd |
| Project management | A. Bonneman | Costs will be higher than expected. Do not forget people salaries. | Implmtnd |
| Project management | A. Bonneman | Ask the students call companies to get components. Companies are more likely to give to students then to project managers. Sponsorships are deducted from taxes | Implmtnd |
| Project management | A. Bonneman | For each student get a documentation package ready so they do not loose time getting into the project. | In progress |
| RF Antenna | L. Alminde | Link budget update on information generated | Implmtnd |
| RF Antenna | A. Bonneman | Mass Requirement design driver? Better efficiencies with larger Mass budget? | Open |
| RF Antenna | A. Bonneman | Other configurations suggested, see report Delft | Open |
| RF Antenna | K. Laursen | Aluminum block is worst case. What if sides are simulated as composite? Design for realistic worst case. | Open |
| RF antenna | K. Laursen | Design antenna connectors | Open |
| RF antenna | A. Bonneman | Trade antenna mass for efficiency | Open |
| RF antenna | M. Noca | Detail the deployment system and make sure we have redundancy | Open |
| RF Beacon | W. Hanselmann | Need spectrum analysis, avoid pollution of other frequencies | Open |
| RF Beacon | W. Hanselmann | Purity of the oscillator vs. start-up | Open |
| RF Beacon | K. Laursen | Requirement for frequency stability | Open |
| RF Beacon | W. Hanselmann | Thermal drift compensation | Open |
| RF Beacon | A. Crausaz | Thermal - -23 to 10°C thermal range | Open |
| RF Beacon | W. Hanselmann | RF switch single point failure | Open |
| RF Beacon | W. Hanselmann | 75 Ohm and 50 Ohm matching between beacon and data transmitter | Open |
| RF Beacon | L. Alminde | Which system has responsibility over RF switch | Implmtnd |
| RF beacon | L. Alminde | Take beacon functionality and put it in main RF | Looked at |
| RF beacon | K. Laursen | Power switch is a danger, might be better not to have a switch at all | Looked at |
| RF data transmitter | W. Hanselmann | Harmonics generated by local oscillator, "SPUR" analysis | Open |
| RF data transmitter | L. Alminde | Option to have higher data rate | Looked at |
| RF data transmitter | A. Bonneman | Heat generated by the PA calculated? | Looked at |
| RF data transmitter | A. Bonneman | Corrections in the document to be handed to prakash | Open |
| RF data transmitter | W. Hanselmann | PA COTS what about radiation | Looked at |
| RF data transmitter | A. Crausaz | Voltage increase might lead to more efficiency, analysis | Looked at |

| Topic or Subsytem | From | Comment / Recommendation | AI Status |
|---|---|---|---|
| RF data transmitter | A. Bonneman | Turn-off receiver software function should not be implemented | In progress |
| RF data transmitter | R. Krpoun | Add references to the work of Holger Eckhardt | Open |
| RF data transmitter | W. Hanselmann | Maybe use RF transmitter for beacon | Looked at |
| RF data transmitter | W. Hanselmann | Discrete PA | Implmtnd |
| RF data transmitter | A. Bonneman | What happens when switch on the beacon and data transmitter? Should have a SW switch | In progress |
| RF data transmitter | A. Bonneman | Calpoly requirement to be able to turn off the transmitter. Be careful not to be able to turn off the receiver! | In progress |
| RF data transmitter | W. Hanselmann | Commercial amplifiers will need radiation specs | In progress |
| RF data transmitter | A. Bonneman | Be careful about power amplifiers heat removal/thermal design | Open |
| RF data transmitter | W. Hanselmann | Spur analysis done? | Open |
| RF data transmitter | W. Hanselmann | Do a list of all frequencies in the satellite to start EMC analysis | Open |
| RF telecom | W. Hanselmann | Merge data transmitter and beacon into one single subsystem | In progress |
| RF telecom | A. Crausaz | Trade off efficiency and overall energy consumption vs. Dedicated power line at higher voltage for RF power amplifier + RF beacon | In progress |
| Structure and Configura | M. Noca | M1 bolts are really tiny, check what is available on the market | Looked at |
| Structure and Configura | M. Noca | Thermal stress for PCBs | In progress |
| Structure and Configura | M. Noca | Define soldering joints | In progress |
| Structure and Configura | M. Noca | Accessibility: build | In progress |
| Structure and Configura | M. Noca | Do a proper grounding scheme | In progress |
| Structure and Configura | M. Noca | Don't forget about venting | Implmtnd |
| Structure and Configura | A. Bonneman | Build a cable harness model ASAP | In progress |
| Structure and Configura | A. Bonneman | Spacers are good, but after vibration may get a problem, especially thermal path | In progress |
| Structures/Configuratio | K. Laursen | Solder joints + pin connections, vibrations | In progress |
| Structures/Configuratio | K. Laursen | Thermal stress on connectors | In progress |
| Structures/Configuratio | A. Bonneman | Easy to machine requirement? | Implmtnd |
| Structures/Configuratio | A. Bonneman | Cable Model | In progress |
| Structures/Configuratio | A. Bonneman | Use "real" bolts and screws | Implmtnd |
| Structures/Configuratio | A. Bonneman | Location of the kill switch and remove before flight takes space | Implmtnd |
| Structures/Configuratio | A. Bonneman | Spacers that screw have to be revised | Implmtnd |
| Structures/Configuratio | K. Laursen | Use lead-free components | In progress |
| Structures/Configuratio | K. Laursen | PCB's, do not use FR4, GPD Printca. | In progress |
| Structures/Configuratio | A. Bonneman | Venting | Implmtnd |
| Structures/Configuratio | A. Bonneman | Battery and comm position | Implmtnd |

| Topic or Subsytem | From | Comment / Recommendation | AI Status |
|---|---|---|---|
| System Engineering | W. Hanselmann | The circuits have been designed with a commencial approach. No IC's or components will be available in space quality nor will appear on COTS list | Open |
| System Engineering | L. Alminde | EPS - How was the power input calculated | Implmtnd |
| System Engineering | A. Bonneman | Start considering single point failures | In progress |
| System Engineering | L. Alminde | EPS - Is latch-up protection implemented in the system | Implmtnd |
| System Engineering | L. Alminde | Functional modes of EPS, Start-up and reset procedures | In progress |
| System Engineering | L. Alminde | Solar panels bad choice for solar sensors | Implmtnd |
| System Engineering | A. Bonneman | Mass budget margins needed | Implmtnd |
| System Engineering | L. Alminde | EPS - Do the step-up converters need to be turned on/off during night? Power might be generated | In progress |
| System Engineering | A. Bonneman | Derived requirements should be called "constraints" | Implmtnd |
| System Engineering | E. Kopp | Cabling and harness in Structure Mass budget? | Implmtnd |
| System Engineering | A. Bonneman | Set-up requirements traceability matrix | In progress |
| System Engineering | A. Bonneman | Need to think about how to start the system on its own | In progress |
| System Engineering | K. Laursen | Turning things on and off all the time can be a problem | Open |
| System Engineering | A. Bonneman | Add weighting factors to tradeoffs | Implmtnd |
| System Engineering | M. Noca | Latch-up protection block diagrams to make consistent | Implmtnd |
| System Requirements | A. Crausaz | Ask for FMECA and contigency (e.g. antenna not deployed) | Open |
| System Requirements | A. Crausaz | Force the interface design (unique) for busses and thermal (board design) | In progress |
| System Requirements | A. Crausaz | Add specification on the over-voltage, over-temperature protection (separation of regulation from protection circuitry) | Open |
| Thermal | A. Bonneman | Adjust to 400-1000 km | Implmtnd |
| Thermal | L. Alminde | Infrared effects are taken into account | In progress |
| Thermal | A. Bonneman | Solar cell efficiency only 18% | Implmtnd |
| Thermal | A. Bonneman | Look int ESATAN, NEVADA | Open |
| Thermal | A. Crausaz | No active regulation | Implmtnd |
| Thermal | ? | Recommendation, Thermal conduction layers | In progress |
| Thermal | ? | Conformal coating | In progress |
| Thermal | M. Noca | Work thermal interfaces | In progress |

| Topic or Subsytem | From | Comment / Recommendation | AI Status |
|---|---|---|---|
| Verification and Test | A. Bonneman | You will want to shake your satellite on your own pod | Open |
| Verification and Test | A. Bonneman | Clarify all requirements, make traceability matrix. Tricky part is the transition between the phases. | In progress |
| Verification and Test | A. Bonneman | Development testing on subsystems | In progress |
| Verification and test | A. Bonneman | Work on SW interfaces | In progress |
| Verification and test | A. Bonneman | Make log for all changes during tests | Open |
| Verification and test | A. Bonneman | GSE: do it now, design for GSE interfaces (check pins, extra connections for GSE) | In progress |
| Verification and test | A. Bonneman | Think about protective covering, mounting provisions, for instance cover for the camera (can do both bake-out and thermal at the same time) | In progress |
| Verification and test | A. Bonneman | Tradeoff pin savers vs. testing | In progress |
| Verification and test | A. Bonneman | Thermal balance test is needed | In progress |
| Verification and test | A. Bonneman | Critical ACDS testing is needed (build a Helmolz Cage, or use facility in Delpht) | Open |
| Verification and test | A. Bonneman | Start simple with ACDS tests, and build up | Open |