Phase A

System Engineering

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1 INTRODUCTION

The SwissCube project is multidisciplinary project involving the EPFL (Swiss Federal Institute of Technology), the University of Neuchâtel and three Engineer schools (Sion, Yverdon and St-Imier). The SwissCube is based on the CubeSat specifications. CubeSat is a type of picosatellite with the dimensions of 10x10x10 cm3 and weighting no more than 1 kilogram. But it's also possible to build double (20x10x10 cm3 and 2 kg) or triple (30x10x10 cm3 and 3 kg) CubeSat. The CubeSat standard offers many advantages. Due to its low weight and dimensions, the launch costs are reduced. Because many others universities around the world built or are building CubeSat, it is possible to exchange information among ourselves.

CubeSats also offer the possibility to many students to work in a very interesting but complicated domain, the space. In spite of its unique specifications, this kind of satellite has the same constraints due to the special environment as other satellites. The SwissCube will essentially need the same subsystems. The subsystems that we will find on our satellite are the EPS (Electrical Power System), the COM (Communication with Earth), the beacon, the CDMS (Control and Data Management), the payload and finally the ADCS (Attitude Control and Determination System).

I realized this semester project during the 8^{th} semester of my microengineering studies at EPFL. A semester project gives 12 ECTS credits, which represent a work of 12 hours per week. The goal of the project is to perform system engineering. The SwissCube System Engineer is the person that coordinates and verifies the design at the system level. This task ensures that all subsystem or elements of the SwissCube are compatible with each other and that they function under the environmental constraints. The student will maintain mass, power and other efficiency budget. The student will also establish the system level specifications, verification process and participate in the elaboration of the system level test plan

The report will first present the objectives of the project, the driving requirements and the global functions. The next part will describe the different options (trade-offs) at system level. Then the mass budget, the operational modes and the power consumption are described. Just before the conclusion the system level requirements are presented.

2 REFERENCES

2.1 Normative references

[N1] SwissCube Project Specifications, Noca Muriel

[N2] Vega user's manual, Perez Edouard

2.2 Informative references

[R1] Space Mission Analysis and Design, 3rd edition, W.J. Larson, J.R. Wertz

3 ABBREVIATED TERMS

ADCS	Attitude Control and Determination System
CDMS	Control and Data Management System
COM	Communication System
DOD	Depth of Discharge
EPS	Electrical Power System
HK	House keeping data
LDO	Low-Dropout Regulator
PCB	Printed Circuit Board
PL, P/L	Payload
TM/TC	Telemetry / Telecommand
DTS	Daylight WITH transmission and WITH science
DTnS	Daylight WITH transmission but WITHOUT science
DnTS	Daylight WITHOUT transmission but WITH science
DnTnS	Daylight WITHOUT transmission and WITHOUT science
ETS	Eclipse WITH transmission and WITH science
ETnS	Eclipse WITH transmission but WITHOUT science
EnTS	Eclipse WITHOUT transmission but WITH science
EnTnS	Eclipse WITHOUT transmission and WITHOUT science

4 SEMESTER PROJECT OBJECTIVES

The main objectives of this system engineering project were to make sure that all subsystems are compatible with each other and that the baseline design of the overall system has converged to satisfy the specifications. To fulfill these objectives, the following tasks were performed.

- Establishment of a Functional Block Diagram of the overall system
- Coordination with all subsystems to define and catalogue interface parameters
- Elaboration and coordination of system level trade-offs
- Establishment of a Mass Equipment List
- Definition of operational modes and power budget
- Definition of the system level requirements
- Establishment of hardware, data flow and cabling block diagram
- Documentation, preparation of end-of-phase review

5 DRIVING REQUIREMENTS

The driving requirements are those that have a particular influence on the design at the system level, or in other words, those that influence all the subsystem or most of them. First of all, the CubeSat standard gives a weight and volume limitation. The weight is limited to 1 kilogram, which implies that the structure has to be as light as possible but also has to respect the launch constraints. It also means, for example, that the magnetotorquers can not be bigger than a certain size although the control is not optimal. For every subsystem this factor is constraint.

The volume or size is a second driving requirement. In fact they are only six faces available to have solar array on. One of the faces has to have a solar free zone for the payload. The CubeSat size limits also the size of the components that must be put in. For example, the ADCS could require a lot of space to provide a sufficient attitude control or the PL has a limited focal length for its optic.

The kind of science mission defines driving requirements because depending on the observation that is to be performed, the size, the placement of the device, the pointing accuracy and stability, the power consumption, the amount of stored data have many influences on all subsystems. The size and the placement influences directly the S&C and the ADCS, the power consumption the EPS, the data amount the CDMS and the COM and the pointing accuracy and stability the ADCS and the EPS.

The orbit altitude range is a multiple constraint on the system. The altitude defines the eclipse and duration time, which influences the capacity of reloading the batteries and the duration they are used. The lowest altitude (400 km) gives the longest eclipse (36 minutes) and the shortest daylight. It is identified as the worst case for energy production and consumption. The altitude of 1000 km is the worst case for the ADCS because the magnetic field strength decreases with the altitude. That means that bigger magnetotorquers or more electrical power is needed to fulfill pointing requirements.

6 SYSTEM FUNCTIONAL DESCRIPTION

The following diagram (Figure 1) gives a general idea of the functionality of each subsystem and of the interactions between the subsystems. The power supply is represented in a blue dotted line and the data flow in dark gray. These two points will be discussed more in detail in the following sections. The EPS gives the electrical power to all the other subsystem, manages the batteries reloading and sends a message directly to the RF Beacon. It groups the batteries, the solar arrays, a control unit and diverse measurements devices (temperature, current, voltage). The COM, which is the main communication unit with the ground station, is composed of a RF receiver, a RF transmitter and a controller to communicate with the bus and to start or stop the transmissions. The CDMS gives the subsystem a reference time and stores all the data that have to be sent to the ground station between the communication sequences. It is composed of a controller, memories and a clock. The PL is the science module composed of a controller for the data processing and detector which depends on the exact wavelength that will be observed. The ADCS determines and controls the attitude of the satellite. It has different kind of sensors and actuators and a powerful calculator. The thermal subsystem is a passive system that regulates the temperature over the satellite with thermal links. And finally the S&C has to maintain the subsystem together and provide the structure to fix the loads.

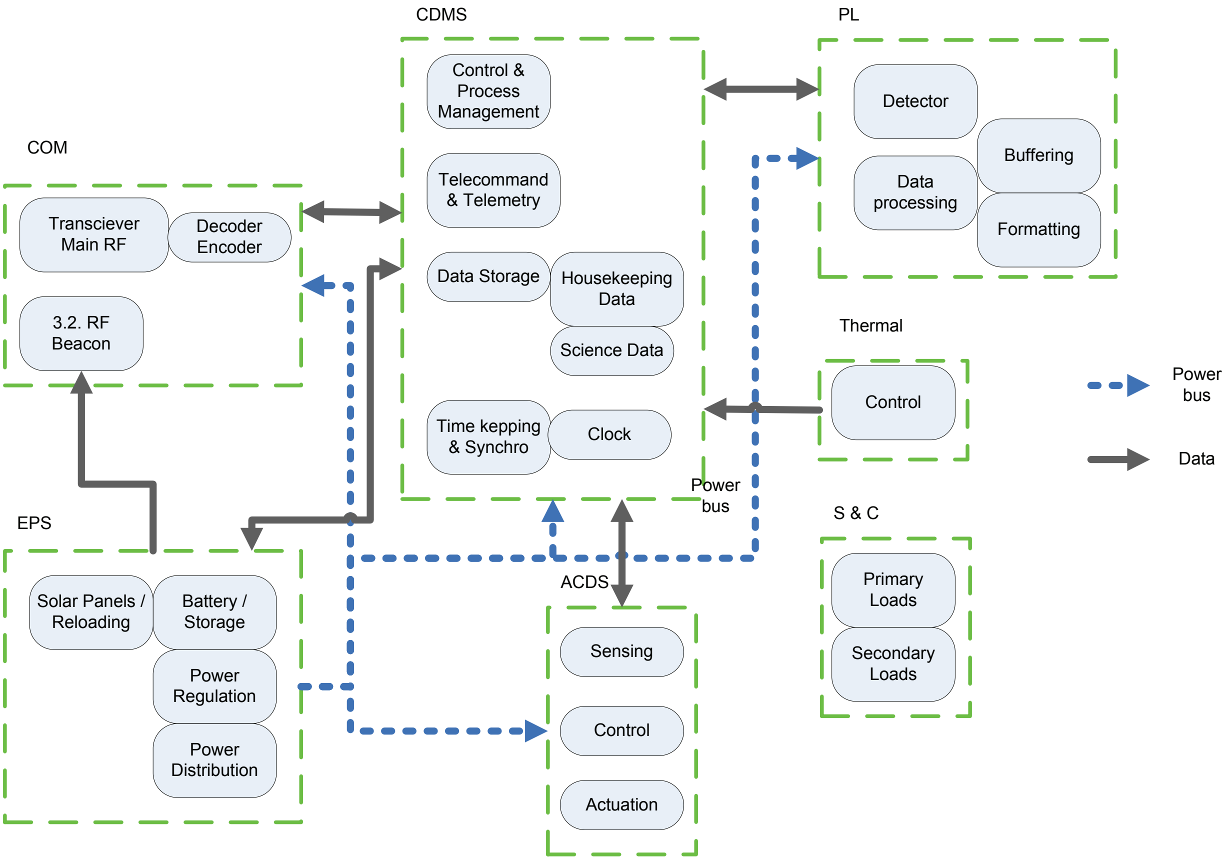

Figure 1 System Functional Block Diagram

7 SYSTEM LEVEL TRADE-OFFS

Each subsystem has its own problematic and solutions to resolve it. But some of the problems do not only concern the subsystem itself but the overall system. The trade-offs performed at the system level are summarized below and presented in a general point of view. The trade-offs are detailed in the corresponding reports.

7.1 Computing architectures

After the phase defining the functionalities of the future satellite, a concurrent design phase was realized in order to keep our ideas as open as possible and not to focus too early on a special variant without a sufficient justification

In Figure 2, 4 of the very first imagined subsystem's configurations are drawn. Two main options are available for the controller architecture distributed and centralized. Version 1 represents a distributed architecture. The advantages of this structure are the modularity and independence of each subsystem. They can be tested independently and assembled at the end. Another advantage is the possibility to replace one subsystem by a new one in case of failure or improvement. In these 4 versions, the RF Beacon is always represented with the EPS, but it isn't fixed yet. The consideration was that the beacon should be always enabled and that it will be easier and less power consuming to command it from the EPS, which will always be on to feed the other subsystems with electrical power. Problems could appear if the RF Beacon is commanded by the COM and the message sent from EPS. It is more robust that one element has interaction only with one subsystem. A disadvantage of this solution is the multiplication of the board and interfaces

In the second version the EPS, the CDMS and the beacon are grouped together. The CDMS is supposed to be the "brain" of the satellite and in this way it will be enabled most of the time. Again the EPS will anyway be on all the time and this trade-off save a controller in regrouping EPS with CDMS. The other subsystems are kept separate for the same reason than before. One of the disadvantages of this version is the loss of independence and modularity.

In the next version, the CDMS is now grouped with the ADCS. The reason to group them is the intense need of calculation power of the ADCS. The idea is to take a powerful and reliable processor and to use it as the central intelligence of the satellite.

In the last version the CDMS and the ADCS are still together on the same processor. The telecom functionality was added to EPS and beacon. This option has the advantage of reducing the number of boards and in that way it reduces the complexity of the connection between the subsystems. One big disadvantage is the increased risk of failure due to the grouping of several subsystems on the same board.

In the 4 different versions, the payload is always drawn as an independent component. This option offers the possibility to change very easily this part and to reorient the scientific goals of an observation project.

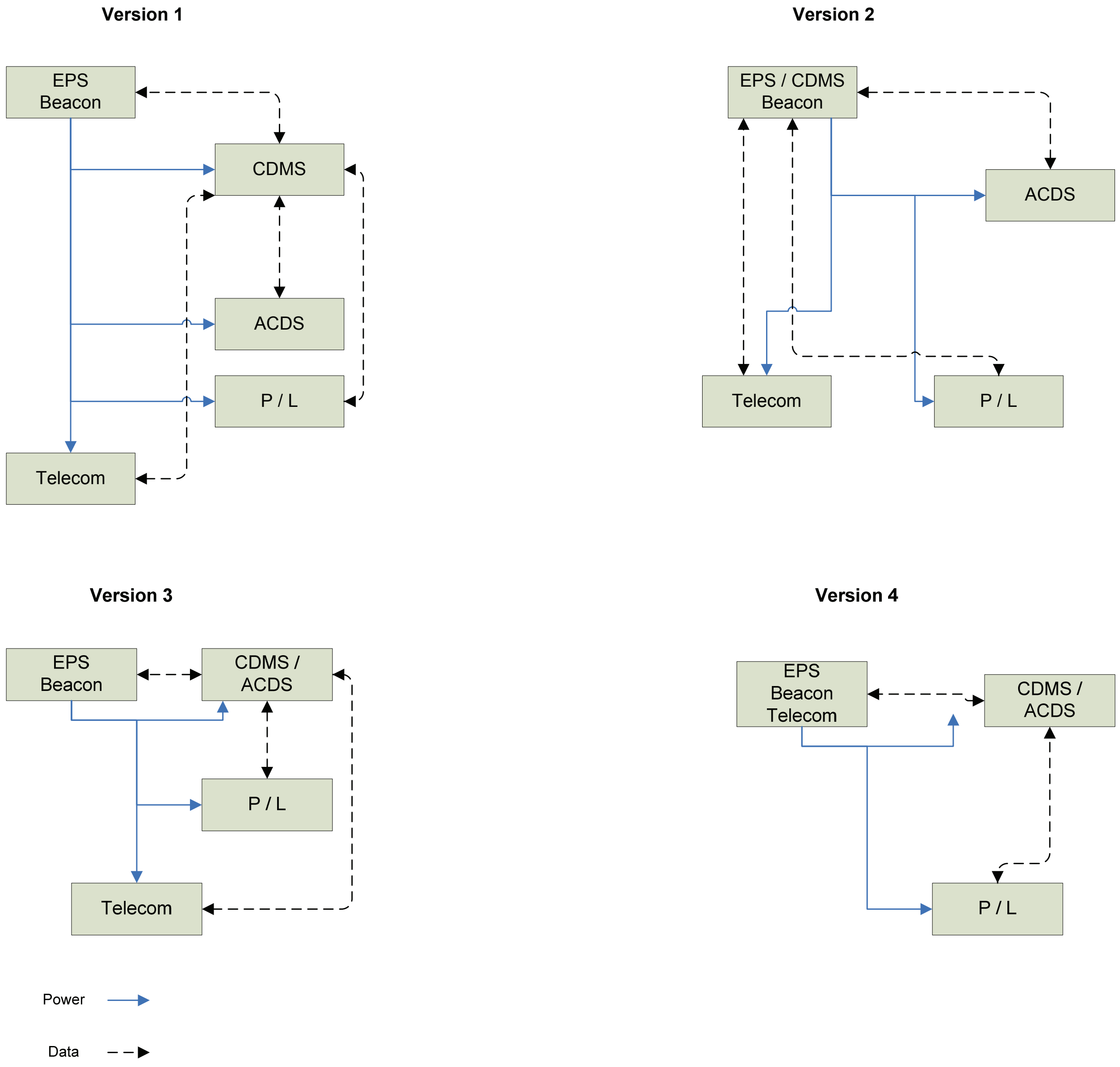

Figure 2 System trade-offs

7.2 Structure and configuration

The CubeSat standards offer the possibility to build double or triple CubeSats. A double satellite is just twice longer 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 monobloc structure (one piece) to "IKEA kit" structure with a large number of pieces. The monobloc 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 PL placement and how to arrange the boards around it.

7.3 Data bus trade-offs

A lot of different kind of busses exists like RS family, I2C, CAN. They can be sorted in 2 categories, the differential busses and the not differential. Differential busses, like the CAN, offer the advantage to be more robust to perturbations but their consumption is bigger.

One trade-off is to choose one robust differential bus for the all the system, on which all the subsystem are connected. It offers the advantage that all the controller use the same protocol. The disadvantages are that the bus can be overcharged if all the subsystems communicate at the same time and that there is a risk to have a failure and to lose the unique bus. An other trade-off is to add a redundant "survival" bus or dedicated busses for less life-crucial subsystems like the PL.

8 SYSTEM DESCRIPTION

This chapter describes the system operational modes system baseline. The system baseline is a compilation of the subsystem baseline.

8.1 Operational modes

This section details the principal operational modes in which the satellite will be during his in-orbit lifetime.

8.1.1 Start

After the satellite will be ejected from the P-POD, it is required to wait 15 minutes before doing anything. First of all the EPS will start and check the battery voltage. If this voltage is sufficient, it will start the initialization sequence. If the battery voltage is not sufficient, it will wait TBD minutes before it tries again to start. If the satellite loses all its electrical power or in case of reset, it will start again from here.

8.1.2 Initialization mode

When the battery voltage is sufficient, the initialization sequence will start checking each subsystem after each other. As it is shown in the schema, the battery voltage will checked after every initialization step. If the voltage is not sufficient, the satellite will wait before it checks another subsystem. After all the subsystems are controlled, the system will change to Safe mode.

8.1.3 Safe mode

In this mode only the EPS and the beacon are on. EPS switches off all other subsystems if the battery capacity is under a predetermined threshold. Before switching off it should send a command to the CDMS to shut down softly the subsystems. The EPS allows the system to go back in nominal mode when the battery capacity is high enough

8.1.4 Nominal mode

The nominal mode is a general purpose mode. When the system is in this mode, it is possible to control the attitude, to start a science phases (taking pictures) and to communicate with the ground. In nominal mode, the satellite can always receive TC's from the ground. 8 different cases have been identified in this mode. They will be described in the in the power budget.

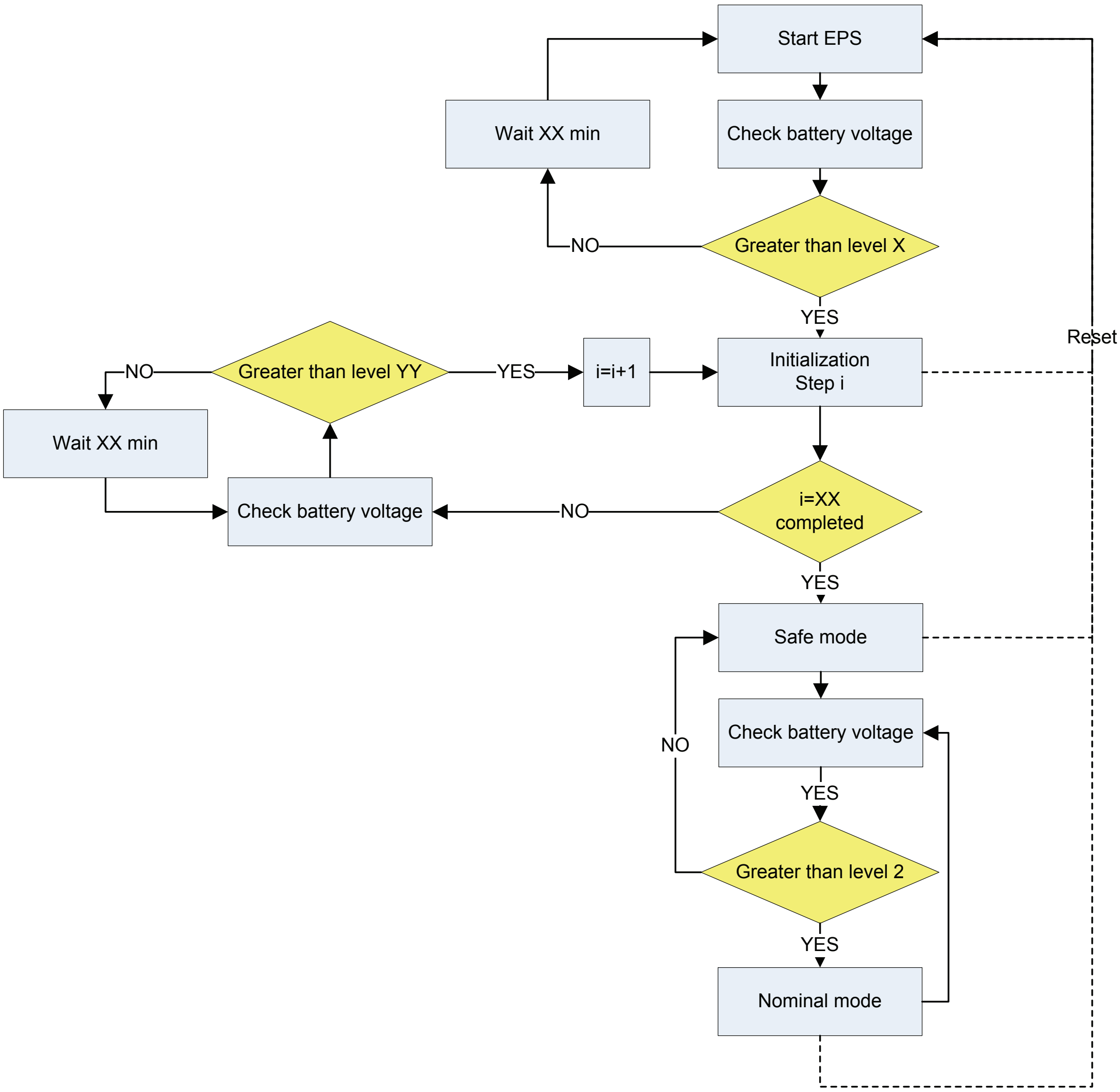

Figure 3 Flow diagram

	Beacon	EPS	CDMS	ADCS	PL	COM receiver	COM transmitter
Start		x					
Initialization	1		2	3	4	5	6
Safe	x	x					
Nominal	x	x	x	x	x	x	

Table 1 System powered for modes

8.2 General block diagrams

8.2.1 Electrical BD

The following diagram shows the electrical power distribution in the whole satellite. The grounding is not represented here. To see it in detail, the EPS report should be consulted. The green dashed line represents the different boards

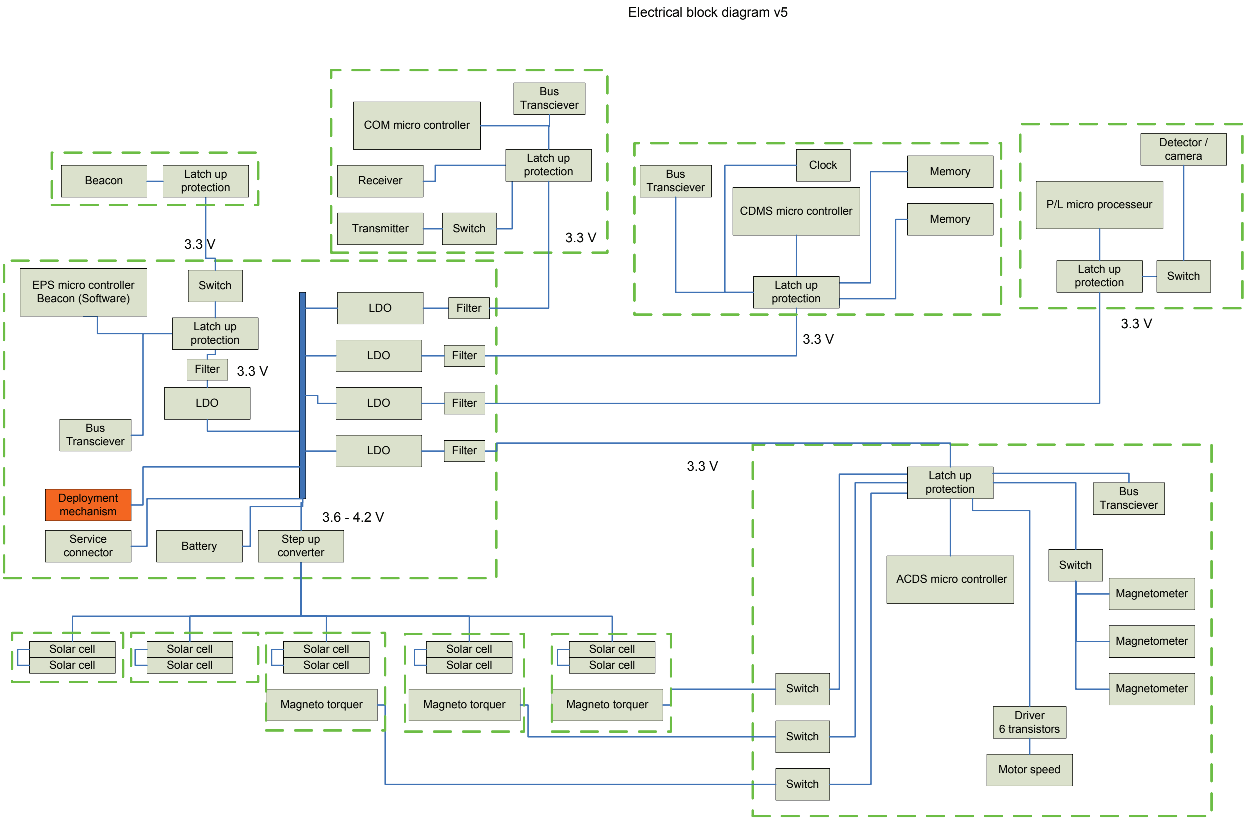

Figure 4 Electrical block diagram

8.2.2 Data flow BD

The data flow block diagram represents all the connections for the information transfer between the different subsystems. Several possibilities had to be discussed to choose the data bus type, the number of busses and how to connect the subsystems together. Two important criteria to decide how to group the subsystem on the bus are the importance of loosing the subsystem for the general functionality and the amount of data generated by each subsystem. The EPS and ADCS will acquire a lot of information through their sensors but most of them will just serve an internal use. They will not be sent to CDMS over the bus. Both subsystems will only send a few HK and TM data to CDMS, who will store them until the next transmission opportunity. The COM subsystem will also send a couple of HK and TM

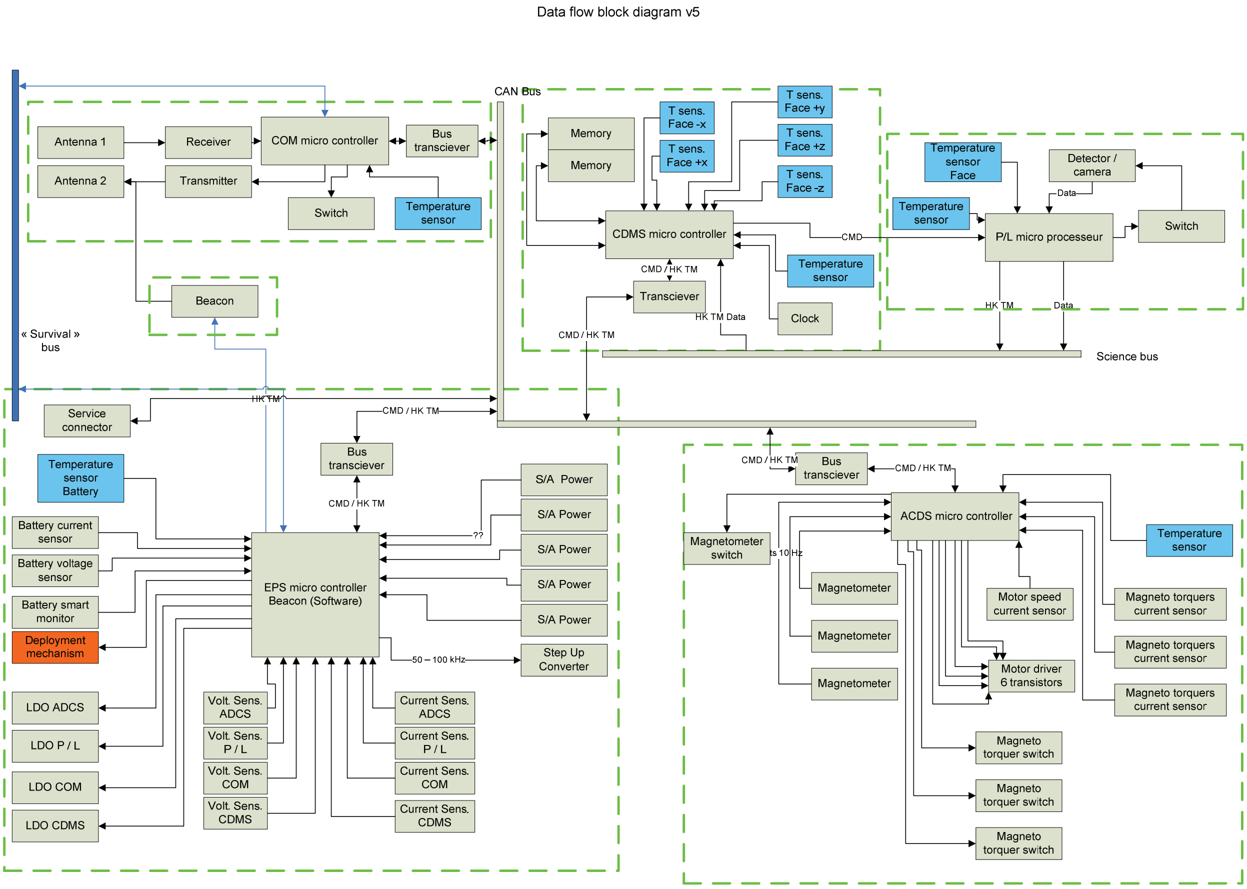

Figure 5 Data flow block diagram

8.2.3 Hardware BD

The following diagram is a compilation of the electrical and data flow block diagram. The green dashed frames represent the different boards and faces according to the above presented mass budget. The connections between the elements are not drawn. The boards will be slotted in the connectors on the mother board (CDMS board). In order to minimize the cabling the magnetotorquers will be placed adjacent to the ADCS boards. The detailed placement of the boards is described in the Structure & and configuration report. The referential is defined with a +x vector toward the velocity vector, the +z direction is toward the Earth center and the +y is pointed like in a right hand referential.

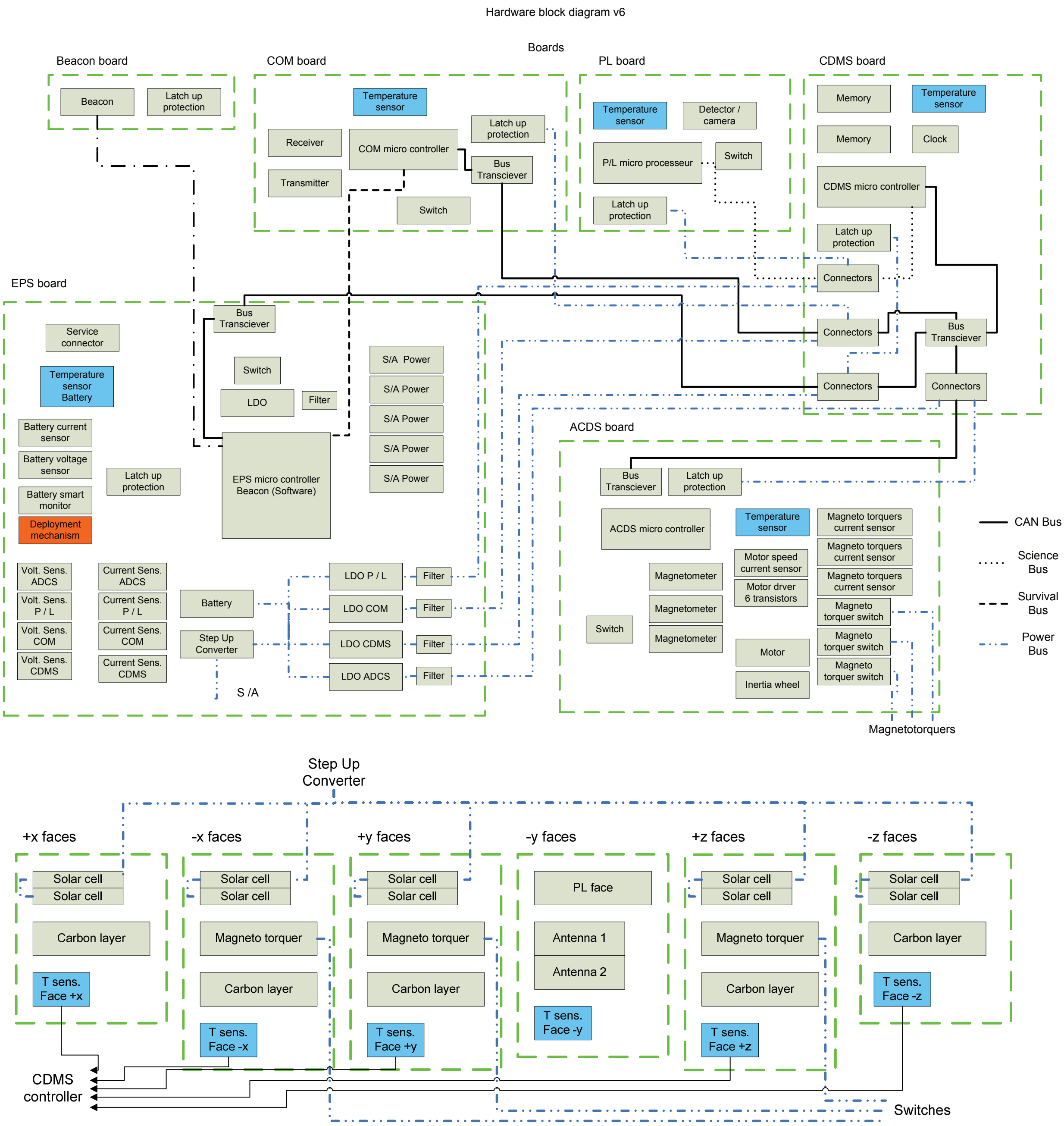

Figure 6 Hardware block diagram

9 SYSTEM BUDGET

9.1 Mass budget

Due to the CubeSat specifications, the satellite has to weight less than 1 kilogram. At this stage of the project, a margin of 10 % at least is necessary. In the following table, the mass of each subsystem is listed. The detailed mass budget can be found in the appendix A.1.

Subsystem	Mass [g]
Structure & Configuration	223.3
EPS	172
ADCS	150.4
CDMS	94
Payload	90
COM	155
Mechanism & antenna	20.35
Thermal	8
Total	913.05

Table 2 Subsystems mass budget

Te see the weight repartition in terms of hardware, I group the subsystem on boards and faces. The faces don't have the same weight because there is only three magnetotorquers and only five faces are covered with solar panels. In spite of its little number of elements, the CDMS board is relatively heavy because we will use it as a connection and mother board. The other boards will be slotted on it. Again the detailed repartition on the boards can be found in the appendix A.2.

Boards / Faces	Mass [g]
EPS board	146
ADCS board	60
CDMS board	94
Payload module	92
COM board	105
Beacon board	50
General structure	195.45
face +x	21.8
face -x	40.1
face +y	37.8
face -y	13.6
face +z	37.8
face -z	19.5
Total	913.05

Table 3 Board and faces mass budget

9.2 Power budget

Since solar array are body mounted on 5 faces of the cube, the power (energy) consumption is a very crucial point in the design of our satellite. The establishment of the power budget is done with many assumptions. The worst case in term of orbit duration is considered and an important 30 % margin is book kept.

9.2.1 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 100 mW each on average
- ADCS inertia wheel is always in use and need 100 mW on average
- ADCS controller and magnetometers are always on
- EPS is on all the time (eclipse and daylight)
- RF Data transmission sends 7.5 minutes long data message (5 min Science data and 2..5 min HK and TM data)

9.2.2 Power modes

Once the satellite is in function which is corresponding to the nominal mode of the operational modes, there are 8 different state cases fro the satellite to be in, 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 cases or modes pf use are listed in Table 4.

DTS	Daylight WITH transmission and WITH science
DTnS	Daylight WITH transmission but WITHOUT science
DnTS	Daylight WITHOUT transmission but WITH science
DnTnS	Daylight WITHOUT transmission and WITHOUT science
ETS	Eclipse WITH transmission and WITH science
ETnS	Eclipse WITH transmission but WITHOUT science
EnTS	Eclipse WITHOUT transmission but WITH science
EnTnS	Eclipse WITHOUT transmission and WITHOUT science

Table 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 modes.

9.2.3 Power consumption

The power consumption is calculated in terms of energy for each part of the orbit, in daylight and in eclipse. All the values come from approximations of the subsystems. A margin of 30 % is added to the total consumption.

9.2.3.1 Day-light

The most consuming subsystem in the satellite is by far the ADCS. It is always used during daylight. Because the satellite has to be oriented in special direction during the eclipse and because it is more difficult to orient it after you shut down the ADCS for a long time, it was decided to control the attitude all the time. The EPS is another big consumer during daylight. The main reason is the 10 % losses of the Step up converter and the consumption of the LDO that regulate the bus voltage at 3.3V. The calculation is detailed in the EPS report. The third big consumer is the transmitter but only for a short duration. It is less likely that we will transmit every orbit, it depends on the agreements that we will have with other universities. The 4 consumption cases are presented here. The DTS case is the most consuming and the DnTnS the less. The values for the EPS consumption change because the losses of the LDO also change when different subsystems are enabled or not.

Subsystem	Power [mW]	Duration [hrs]	Total energy [mWh]
EPS	497.6	0.94	467.74
Payload	25	0.94	23.50
CDMS	40	0.94	37.60
Beacon	150	0.47	70.50
ADCS control	150	0.94	141.00
ADCS sensor	30	0.94	28.20
ADCS Magnetotorquers	300	0.94	282.00
ADCS wheel	100	0.94	94.00
Main RF control & receiver	20	0.94	18.80
Main RF transmitter	2000	0.13	250.00
Total			1'413.34
Total with 30 % margin			**2'019.06**

Table 5 DTS

Subsystem	Power [mW]	Duration [hrs]	Total energy [mWh]
EPS	492.6	0.94	463.04
CDMS	40	0.94	37.60
Beacon	150	0.47	70.50
ADCS control	150	0.94	141.00
ADCS sensor	30	0.94	28.20
ADCS Magnetotorquers	300	0.94	282.00
ADCS wheel	100	0.94	94.00
Main RF control & receiver	20	0.94	18.80
Main RF transmitter	2000	0.13	250.00
Total			1'385.14
Total with 30 % margin			**1'978.78**

Table 6 DTnS

Subsystem	Power [mW]	Duration [hrs]	Total energy [mWh]
EPS	444.6	0.94	417.92
Payload	25	0.94	23.50
CDMS	40	0.94	37.60
Beacon	150	0.47	70.50
ADCS control	150	0.94	141.00
ADCS sensor	30	0.94	28.20
ADCS Magnetotorquers	300	0.94	282.00
ADCS wheel	100	0.94	94.00
Main RF control & receiver	20	0.94	18.80
Total			1'113.52
Total with 30 % margin			**1'590.75**

Table 7 DnTS

Subsystem	Power [mW]	Duration [hrs]	Total energy [mWh]
EPS	439.6	0.94	413.22
CDMS	40	0.94	37.60
Beacon	150	0.47	70.50
ADCS control	150	0.94	141.00
ADCS sensor	30	0.94	28.20
ADCS Magnetotorquers	300	0.94	282.00
ADCS wheel	100	0.94	94.00
Main RF control & receiver	20	0.94	18.80
Total			1'085.32
Total with 30 % margin			**1'550.46**

Table 8 DnTnS

9.2.3.2 Eclipse

During the eclipse the EPS will consume less power during the eclipse because the step up converter losses don't exist because there no energy to be converted from the solar cells. The most consuming subsystem is the ADCS again. To take pictures of the Night Glow the satellite need to be oriented in a precise direction. There are also 4 different power consuming cases. They are presented below. Again the factor that differ the most is a communication with a ground station.

Subsystem	Power [mW]	Duration [hrs]	Total energy [mWh]
EPS	229	0.60	137.40
Payload	25	0.60	15.00
CDMS	40	0.60	24.00
Beacon	150	0.30	45.00
ADCS control	150	0.60	90.00
ADCS sensor	30	0.60	18.00
ADCS Magnetotorquers	300	0.60	180.00
ADCS wheel	100	0.60	60.00
Main RF control & receiver	20	0.60	12.00
Main RF transmitter	2000	0.13	250.00
Total			831.40
Total with 30 % margin			**1'187.71**

Table 9 ETS

Subsystem	Power [mW]	Duration [hrs]	Total energy [mWh]
EPS	224	0.60	134.40
CDMS	40	0.60	24.00
Beacon	150	0.30	45.00
ADCS control	150	0.60	90.00
ADCS sensor	30	0.60	18.00
ADCS Magnetotorquers	300	0.60	180.00
ADCS wheel	100	0.60	60.00
Main RF control & receiver	20	0.60	12.00
Main RF transmitter	2000	0.13	250.00
Total			813.40
Total with 30 % margin			**1'162.00**

Table 10 ETnS

Subsystem	Power [mW]	Duration [hrs]	Total energy [mWh]
EPS	176	0.60	105.60
Payload	25	0.60	15.00
CDMS	40	0.60	24.00
Beacon	150	0.30	45.00
ADCS control	150	0.60	90.00
ADCS sensor	30	0.60	18.00
ADCS Magnetotorquers	300	0.60	180.00
ADCS wheel	100	0.60	60.00
Main RF control	20	0.60	12.00
Total			549.60
Total with 30 % margin			**785.14**

Table 11 EnTS

Subsystem	Power [mW]	Duration [hrs]	Total energy [mWh]
EPS	171	0.60	102.60
CDMS	40	0.60	24.00
Beacon	150	0.30	45.00
ADCS control	150	0.60	90.00
ADCS sensor	30	0.60	18.00
ADCS Magnetotorquers	300	0.60	180.00
ADCS wheel	100	0.60	60.00
Main RF control & receiver	20	0.60	12.00
Total			531.60
Total with 30 % margin			**759.43**

Table 12 EnTnS

9.2.4 Solar array power production

Usually when a satellite is built, a power budget is established, and when the power consumption during eclipse and daylight is known the solar array can be sized. For a CubeSat, it will be proceeded in the other way. The solar array surface is dimensioned at its maximum and the satellite builder has to look that he will not need power that is not available. The minimal required power production can be easily calculated with the following formula,

$$P_{sa} = \frac{\left(\frac{P_e T_e}{X_e} + \frac{P_d T_d}{X_d}\right)}{T_d}$$

where P_e is the consumed power during eclipse, T_e the eclipse time, P_d the consumed power during daylight, T_d the daylight time. The two coefficients, X_e and X_d, represent respectively the efficiency of the paths from the solar arrays through the batteries to the individual loads and the efficiency directly from solar array to the loads. According to literature we should choose $X_e = 0.6$ and $X_d = 0.8$. These values are used with a peak power tracking device. Without the device they can be replaced by 0.65 and 0.85. Because the losses of the different voltage converter and of the solar cells have already been considered in the power budget, we assume that these coefficients are equal to 1. If this formula is used with energy, you just need to addition the energy required during the eclipse and the energy required during daylight to calculate the amount of energy that must be produced during daylight. The energy that must be produced is just the sum of the energy needed during the eclipse and during daylight.

According to the calculation of the EPS group, the satellite will produced in the worst case 2686 mWh. To calculate we also considered the Albedo. According to the datasheets the solar cell have an efficiency of 26.6 percent ideally. The efficiency can be multiplied by 0.75 when the losses are considered. The losses factors are the degradation over lifetime due to UV and radiations, the temperature, the mismatches and fabrications problems, the wiring and diodes. As the temperature increases, the efficiency decreases. Another important factor of degradation is the cosine. The maximum is reached when the sun direction vector is collinear to the perpendicular vector of the cell. The last factor that was considered is the limit angle. That means if the solar rays hit the surface with a too flat angle, the cells won't produce any energy. An angle of 20 degrees was chosen.

As it was said before the combination of the 8 cases gives 16 power modes. In Table 13 the power consumption for each mode is given. The boxes in white are corresponding to the modes whose consumption is below the threshold given by the produced energy.

	ETS	ETnS	EnTS	EnTnS
DTS	3'206.78	3'181.06	2'804.21	2'778.49
DTnS	3'166.49	3'140.78	2'763.92	2'738.21
DnTS	2'778.46	2'752.75	2'375.89	2'350.18
DnTnS	2'738.18	2'712.46	2'335.61	2'309.89

Table 13 Power consumption for each mode

Only 4 of the 16 modes consume less than the power that can be produced. They all do not offer the possibility to communicate, which is just not acceptable. This means that it is impossible to fulfill the mission every orbit. Among the other modes, several are also unacceptable. All the modes without science during the eclipse can be excluded. The modes with not transmission opportunities during day can also be excluded because, according to the mission planning, will pass over our ground station mostly during day time. The still available modes are in the boxes in white in Table 14.

	ETS	ETnS	EnTS	EnTnS
DTS	3'206.78	3'181.06	2'804.21	2'778.49
DTnS	3'166.49	3'140.78	2'763.92	2'738.21
DnTS	2'778.46	2'752.75	2'375.89	2'350.18
DnTnS	2'738.18	2'712.46	2'335.61	2'309.89

Table 14 Possible power modes

A solution is to perform several orbits without science and transmission to get enough energy and then to allow the PL to perform science and the main RF transmitter to communicate. If the highest consuming mode (worst case) is considered (DTS ETS), and that the CubeSat make one such orbit, it has to stay during 2 orbits without doing science and transmission in order to respect the allowed power.

	Nbr of orbits	Energy/orbit	Total energy
DTS ETS	1	3'206.78	3'206.78
DnTnS EnTnS	2	2'309.89	4'619.78
Total			7'826.56
Power production	3	2686	8'058.00

Table 15 Budget in the worst case

9.2.5 Battery capacity

To dimension the battery capacity, two things must be taken in account. First the battery capacity has to be greater than the amount of energy needed during an eclipse. Second the battery must be oversized by calculating the DOD. The DOD is the percentage of the full capacity of the battery that is used during each cycle. It depends on the satellite lifetime, in other words it on the number of charge/discharge cycles. As it is required, the mission will last at least 3 months, but we would like to be operational during one year. On a heliosynchronous orbit, the satellite will turn 15 times around the Earth in one day. For ones year, it will do 5475 revolutions. According to the literature, we should choose a DOD of 30 % for this number of cycles.

As seen before, the satellite needs about 1188 mWh during the eclipse (0.6 hr) in the worst case. But in the same worst case it consumes 2019 mWh of the 2868 mWh that are produced during daylight. That means that they are 667 mWh available to reload the battery. This energy corresponds to 30% of the total capacity of the battery. So we obtain a total capacity of 2223 mWh, which must be divided by the battery voltage (4.0V). The battery capacity has to be at least of 556 mAh. A Varta battery with a capacity of 800 mAh is chosen. This battery gives 960 mWh energy (4.0 V and 30% DOD). This energy is not sufficient for the worst eclipse case. A second battery with the same capacity is added on order to provide the rest of the energy that is needed during the worst eclipse. The batteries can be reloaded during the 2 next orbits (2 W available).

A second battery is also an advantage if one failed. Only scenario has to be changed.

9.2.6 Summary

To summarize, the satellite will have enough energy to transmit and to take pictures every 3 orbits. The only limitation is to have enough ground stations to download the amount of data.

The energy that the antenna deployment requires is not included in the budgets because in consume only 2000 mW during 1 second which correspond to 0.55 mWh only.

9.3 Data budget

The following budget is a rough estimate of the data that will be exchanged between the subsystems and between the SwissCube and the ground station.

Subsystems	Description	To sub.	Size	Freq.	Bus
P / L					
	Picture data	FS	large	Depend	Science bus
ACDS					
	TM temperature	FS / GS	small	Rep. HK	CAN Bus
	TM Magnetotorquers	FS / GS	small	Rep. HK	CAN Bus
	TM Magnetometers	FS / GS	small	Rep. HK	CAN Bus
	TM Motor	FS / GS	small	Rep. HK	CAN Bus
	TM Life status	FS / GS	means	Rep. HK	CAN Bus
	TM Attitude control application	FS / GS	means	Depend	CAN Bus
	Send Telecommand	EPS	small	often	CAN Bus
EPS					
	TM temperature	FS / GS	small	Rep. HK	CAN Bus
	TM voltage subsystem	FS / GS	small	Rep. HK	CAN Bus
	TM temperature battery	FS / GS	small	Rep. HK	CAN Bus
	TM battery current sensor	FS / GS	small	Rep. HK	CAN Bus
	TM battery voltage sensor	FS / GS	small	Rep. HK	CAN Bus
	TM battery smart monitor	FS / GS	small	Rep.	CAN Bus

				HK	
	TM mechanism status	FS / GS	small	Rep. HK	CAN Bus
	TM current sensor subsystems	FS / GS	small	Rep. HK	CAN Bus
	TM S/A Power solar panels	FS / GS	small	Rep. HK	CAN Bus
	TM step up converters	FS / GS	small	Rep. HK	CAN Bus
	TM subsystem status	FS / GS	small	Rep. HK	CAN Bus
	Power solar panels	ACDS / FS / GS	small	often	CAN Bus
	TM life status	FS / GS	means	Rep. HK	CAN Bus
	Send Telecommand	ACDS	small	often	CAN Bus
COM					
	TM temperature	FS / GS	small	Rep. HK	CAN Bus
	TM transmission status	FS / GS	means	Rep. HK	CAN Bus
	Connect to ground station	FS	means	Depend	CAN Bus
	Disconnection to ground station	FS / GS	small	Depend	CAN Bus
	Life status	FS / GS	means	Rep. HK	CAN Bus
	Send data to ground station	GS	large	Depend	CAN Bus
	Send Telecommand	ALL	small	Irregular	CAN Bus
CDMS					
	TM temperature	FS / GS	small	Rep. HK	CAN Bus
	Memory status	FS / GS	means	Rep. HK	CAN Bus
	Life status	FS / GS	means	Rep. HK	CAN Bus
Flight Software					
	TM synchronize timer with ground station	GS	means	Depend	CAN Bus
	TM send scientific data from memory to ground station	GS	large	ETVGS	CAN Bus
	Send housekeeping command from memory to ground station	GS	large	ETVGS	CAN Bus
	Life status	FS / GS	means	Rep. HK	CAN Bus

Ground station	Send Telecommand	ALL	small	often	CAN Bus / Science bus
	Send Telecommand	ALL	small	often	

10 SYSTEM LEVEL REQUIREMENTS

The establishment of the budgets and the baseline gives some more requirements. These concern only the space system and not other system for example the Ground segment. The new requirements are listed below.

- Transmission and science cannot occur more than every three orbits according to the power budget
- The RF Beacon can transmit a 15 sec long message every 30 sec with a power of 150 mW
- The main RF controller and receiver are always enabled
- The main RF transmitter is on during 7.5 min and need 2000 mW
- The magnetometers always function and consume 10 mW each
- The magnetotorquers are always in use and need 100 mW each on average
- The inertial wheel is always in use and need 100 mW on average
- The mass allocations are defined by the mass budget

11 CONCLUSION AND FUTURE WORK

The phase A of the project defines the feasibility. The result of this phase is the establishment of a system baseline and budgets. Each subsystem was analyzed and trade-offs were elaborated in order to find the solutions that can fulfill the requirements. The most promising trade-off of each subsystem was taken with the others to make the system baseline. It also permits to establish the power and the mass budgets. Both are under the limits with a margin of 8.7 % for the mass and a 30 % margin for the power. It is clear that they are established on many assumptions and estimation, but precise enough to gives new requirements.

The future work would be to follow the development of each subsystem in order to keep the budgets up-to-date and recalculate them in an iterative process. As the project is at its beginning, lot of work is still to be performed like the definition of the interfaces and connections, the definition of the failures that can happen on the SwissCube, the advanced design of the boards, the definition of the test procedure, the tests themselves. This is a non exhaustive list.

Appendix A Mass budget

A.1 Detailed mass budget for each subsystem

Elements	Mass	Nbr	Total
Structures			**223.3**
frame	100	1	100
kill switch	3	2	6
lateral face	13.3	3	39.9
payload face	12.6	1	12.6
screw M2	0.3	12	3.6
spring	2	2	4
top face	15.6	2	31.2
Cabling	10	1	10
Spacer PCB stack	2	8	16
			0
EPS			**172**
Battery	14	2	28
Solar Cell	2.6	10	26
Step up converter	10	1	10
Common mode filter	5	5	25
LDO	2	5	10
Controller	10	1	10
PCB	30	1	30
Latch up protection	1	1	1
Bus transceiver	2	1	2
Beacon switch	1	1	1
Battery temperature sensor	1	1	1
Service connector	5	1	5
Battery current sensor	1	1	1
Battery voltage sensor	1	1	1
Battery smart monitor	4	1	4
Voltage sensors (ADCS, PL, COM, CDMS)	1	4	4
Current sensors (ADCS, PL, COM, CDMS)	1	4	4
S / A Power sensors	1	5	5
connector	4	1	4
			0
ADCS			**150.4**
Inertia wheel	13.5	1	13.5
Structure for wheel	7	1	7
motor	15	1	15
magnetometer	2	3	6
Magnetotorquers	18.3	3	54.9
Controller	10	1	10
Latch up protection	1	1	1
Bus transceiver	2	1	2

Temperature sensor	1	1	1
Motor driver 6 transistors	1	1	1
Motor current sensor	1	1	1
Magnetometer Switch	1	1	1
Magnetotorquers current sensor	1	3	3
PCB	30	1	30
connector	4	1	4
			0
CDMS			**94**
controller	10	1	10
Memory	10	2	20
Connection board	30	1	30
clock / oscillator	5	1	5
Temperature sensor	1	1	1
Bus transceiver	2	1	2
Latch up protection	1	1	1
connectors	25	1	25
			0
Payload			**90**
All	90	1	90
Optical device		1	
Photosensor module		1	0
Controller		1	0
Electronic		1	0
switch		1	0
Latch up protection		1	0
PCB		1	0
connector		1	0
			0
Telecom			**155**
Controller	10	1	10
Receiver	30	1	30
Transmitter	30	1	30
Beacon all	50	1	50
Switch	1	1	1
Temperature sensor	1	1	1
Latch up protection	1	1	1
Bus transceiver	2	1	2
PCB	30	1	30
connector		1	0
			0
Mechanism and Antenna			**20.35**
dipole 437 MHz + monopole	7.1	1	7.1
Connectors	1.5	2	3
POM fixations	0.6	2	1.2
Contact points ALU	0.35	3	1.05
Melting wire fixation	2	1	2
Cables	3	1	3
Screws	0.3	10	3
			0
Thermal			**8**

Solar Cell Thermocouples (6)	1	6	6
Payload Temperatures Measurements (2)	1	2	2
			0
			0
			0
		Total	913.05

A.2 Detailed mass budget for boards and faces

	Mass	Nbr	Total
EPS board			**146**
Battery	14	2	28
Step up converter	10	1	10
Common mode filter	5	5	25
LDO	2	5	10
Controller	10	1	10
PCB	30	1	30
Latch up protection	1	1	1
Bus transceiver	2	1	2
Beacon switch	1	1	1
Battery temperature sensor	1	1	1
Service connector	5	1	5
Battery current sensor	1	1	1
Battery voltage sensor	1	1	1
Battery smart monitor	4	1	4
Voltage sensors (ADCS, PL, COM, CDMS)	1	4	4
Current sensors (ADCS, PL, COM, CDMS)	1	4	4
S / A Power sensors	1	5	5
connector	4	1	4
ADCS board			**60**
magnetometer	2	3	6
Controller	10	1	10
Latch up protection	1	1	1
Bus transceiver	2	1	2
Temperature sensor	1	1	1
Motor driver 6 transistors	1	1	1
Motor current sensor	1	1	1
Magnetometer Switch	1	1	1
Magnetotorquers current sensor	1	3	3
PCB	30	1	30
connector	4	1	4
CDMS board			**94**
controller	10	1	10
Memory	10	2	20
Connection board	30	1	30

clock / oscillator	5	1	5
Temperature sensor	1	1	1
Bus transceiver	2	1	2
Latch up protection	1	1	1
connectors	25	1	25
Payload module			**92**
Optical device	90	1	90
Photo sensor module		1	0
Controller		1	0
Electronic		1	0
switch		1	0
Latch up protection		1	0
PCB		1	0
connector		1	0
Payload Temperatures Measurements (2)	1	2	2
COM board			**105**
Controller	10	1	10
Receiver	30	1	30
Transmitter	30	1	30
Switch	1	1	1
Temperature sensor	1	1	1
Latch up protection	1	1	1
Bus transceiver	2	1	2
PCB	30	1	30
connector		1	0
Beacon board			**50**
Beacon (all)	50	1	50
General structure			**195.45**
frame	100	1	100
kill switch	3	2	6
screw M2	0.3	12	3.6
spring	2	2	4
Cabling	10	1	10
Spacer PCB stack	2	8	16
Inertia wheel	13.5	1	13.5
Structure for wheel	7	1	7
motor	15	1	15
dipole 437 MHz + monopole	7.1	1	7.1
Connectors	1.5	2	3
POM fixations	0.6	2	1.2
Contact points ALU	0.35	3	1.05
Melting wire fixation	2	1	2
Cables	3	1	3
Screws	0.3	10	3
face +x			**21.8**
top face	15.6	1	15.6

Solar Cell	2.6	2	5.2
Solar Cell Thermocouples (6)	1	1	1
face -x			**40.1**
top face	15.6	1	15.6
Solar Cell	2.6	2	5.2
Magnetotorquers	18.3	1	18.3
Solar Cell Thermocouples (6)	1	1	1
face +y			**37.8**
lateral face	13.3	1	13.3
Solar Cell	2.6	2	5.2
Magnetotorquers	18.3	1	18.3
Solar Cell Thermocouples (6)	1	1	1
face -y			**13.6**
payload face	12.6	1	12.6
Solar Cell Thermocouples (6)	1	1	1
face +z			**37.8**
lateral face	13.3	1	13.3
Solar Cell	2.6	2	5.2
Magnetotorquers	18.3	1	18.3
Solar Cell Thermocouples (6)	1	1	1
face -z			**19.5**
lateral face	13.3	1	13.3
Solar Cell	2.6	2	5.2
Solar Cell Thermocouples (6)	1	1	1

Total	913.05