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RadCube IOD CubeSat Mission & System Definition Study

Executive Summary Report

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Table of Contents

1 Introduction

The RADCUBE project is an in-orbit demonstration mission of a compact, advanced radiation monitor instrument on a high reliability 3U CubeSat platform.

In the frame of the project a compact and adaptable cosmic radiation and magnetic field measurement instrument as primary payload will be designed, developed and operated in the form of a full-fledged scientific 3U CubeSat demonstration mission.

The two major technologies to be developed and demonstrated in orbit are the 3U CubeSat platform and the radiation and magnetic field instrument (RadMag) as primary payload, both novel and advanced technologies.

The purpose of this activity was to perform a technical and programmatic definition of the RADCUBE mission and the RADCUBE system (space and ground segment) including selection/accommodation of third party technology payload(s), concluding with a System Requirements Review.

The follow-on implementation and launch/operations phases of the RADCUBE IOD CubeSat mission are planned to be kicked-off under a separate contract, following successful completion of this activity, and the separate contract with MTA EK for the RADMAG instrument definition study. These follow-on phases were therefore not part of the current activity.

2 Mission requirements

Mission requirements and constraints, and high level payload user requirements, including the mission objectives, the mission constraints (launcher, orbit, target launch date, duration, communications coverage), the science observation requirements, the payload requirements (incl. operational & data), the mission phases and operational modes requirements, the autonomy requirements, the ground segment requirements, the mission data acquisition, storage and dissemination requirements have been specified in the Mission Requirements Document.

3 Mission Design

The operating modes are the central piece of the OBC software's operation. The operating modes influence the sequence by which the OBC gathers telemetry data, controls the radio, transmits telemetry data, and receives and acknowledges commands. Operating modes include:

- Initial operating mode,
- Safe operating mode,
- Normal operating mode
- Silent operating mode
- Deactivated passive operating mode

Based on most typical launch provider orbits, the RadCube is planned to be inserted into a sun-synchronous circular orbit between approximately 500-600 km initial altitudes, with a Local Time of Descending Node between 6:00 and 12:00 am.

The science operations will be done in two modes: either normal space activity mode or in high space weather activity mode. During normal mode, one telescope axis will be oriented to the local Zenith and the satellite will be constrained to rotate around this axis in order to either minimize drag or maximize solar power. During high space weather activity mode one telescope axis will be oriented to the Sun (TBC) and the satellite will be constrained to rotate around this axis in order to either minimize drag or maximize solar power.

The ground segment consists of three main parts: one or more Ground Station(s), Mission Operations Center and Science Operations Center. For the satellite-ground communications, a UHF radio link is planned. The ground stations and the MOC-SOC will be connected by internet.

4 Mission Analysis

For the RadCube mission, the launch window between 2018 Q4 - 2019 Q1 is foreseen currently. At this phase of the project, no actual orbit or launcher selection has been done. Based on 2016 Q3 and Q4 it is expected that 2018 Q4 – 2019 Q1 will have similar or better availability considering the increasing demand and emerging small satellite launchers. The conclusion is that launch availability will not be a problem but the actual orbit or launcher selection should be done in a later stage of the project.

Preliminary simulations were conducted using AGI STK for different initial conditions for 500-700 km sun-synchronous orbits to provide input to radio link and data download analysis. Lifetime analyses for maximum 25 years' lifetime verification and minimum 3 years' lifetime system requirement have been performed in DRAMA 2.0 and resulted in a initial orbit altitude of minimum 500 km and maximum of 623.8 km.

The estimated amount of data produced by the primary payload, the RadMag instrument is 2605 kByte (2,54 MByte) scientific data per day. The secondary payload, RHA, produces 4824 Byte/day data under nominal conditions, and maximum 11 kByte/day. An ECSS compatible protocol with RS(255,223) channel coding was used for the calculations of the amount of downlinked science data, which determined the RF overhead. Compression ratios were chosen based on previous experience. According to the mission requirements the on-board housekeeping data shall be on-board archived and transferred to the ground station. (The amount of archived raw data is 2,93 MByte/day.) The scientific data and the archived housekeeping data transmissions use the same RF link so the data traffic adds up (Table 1)

Table 1: Total amount of scientific and HK data transferred on the RF link

Total data on RF link [MByte/Day]				
RF Overhead	Compression ratio (Compressed/raw)			
	100% HK, 100% Sci	33% HK, 100% Sci	33% HK, 50% Sci	33% HK, 40% Sci
30%	7.1	4.6	2.9	2.6
35%	7.4	4.8	3.0	2.7
40%	7.8	5.1	3.2	2.8

All scientific and HK data is transmitted on the same M-LVDS buses between the payloads and the OBC and between the OBC and the COM-TCTM, so the duration of the M-LVDS transmissions adds up (Table 2).

Table 2: Total transfer duration of scientific and HK data on M-LVDS buses

Total transfer duration on M-LVDS buses [s/Day]				
RF Overhead	Compression ratio (Compressed/raw)			
	100% HK, 100% Sci	33% HK, 100% Sci	33% HK, 50% Sci	33% HK, 40% Sci
0%	34.5	22.1	14.1	12.5
30%	44.8	28.8	18.3	16.3
35%	46.5	29.9	19.0	16.9
40%	48.3	31.0	19.8	17.5

Based on our calculations presented above the data rate of the internal data buses will be suitable for the mission. The amount of data that needs to be downloaded via the RF link adds up; required RF data rate depends on the visibility ratio of the satellite, and is detailed below.

Ground station visibility simulations were conducted using AGI STK for a ground station located in Budapest and 500km and 600km orbit altitude. Uninterrupted data download with a fixed data rate during the whole access window was assumed. Commanding, packet repeating, link direction changes, and system outage are not considered. Based on the obtained results the necessary link speed is of the order of several 10 kbps, up to 80 kbps for realistic minimum link start and end elevation. Minimum elevation as well as science data compression can significantly reduce required data link speed.

We investigated the incoming solar power histories for one typical orbit as a function of orbit altitude, LTDN and attitude mode. We used AGI simulations to determine illumination direction histories and used a geometry model and a baseline configuration to determine incoming input power histories including direct solar radiation, shadowing of solar panels by wings, and complex power characteristics of solar cell chains. In case of orbits with identical LTDN, incoming energy is only weakly influenced by orbit altitude. The influence of LTDN is orientation dependent, but significant in most cases. Orientation has a strong influence on incoming energy in all cases. Comparing the two nominal orientation candidates, X+ aligned with Zenith is significantly worse than Z+ aligned with Zenith. From all orientations, currently Z+ Zenith aligned and X- Sun constrained orientation is considered the best nominal orientation which also fulfils payload requirements. Also important is that the optimum input power orientation is a maximum drag orientation, with minimal lifetime.

The RadCube satellite's on-board autonomy shall provide measures to recover from critical failures. When such failures occur, the system shall try to transit to a state where vital components of the system remain operational and functional. The satellite shall automatically take action when such failures are detected. All non-mission critical subsystems (e.g payloads) shall be powered down in order to recover from a critical failure. Latch-up events shall be also detected by the system and in such case a power cycle is required in the corresponding module. Each subsystem shall be equipped with hardware watchdog timers that are reset periodically upon normal operation. The timeout signal of a watchdog timer shall initiate a recovery procedure where the originating subsystem is automatically restarted. The ADCS subsystem shall detect when the satellite is spun up extremely in any direction that would cause RF communication to be impossible. The ADCS subsystem shall intervene automatically in such situation by slowing down the extreme spinning. In case of critical microcontroller code bug, the microcontrollers shall be reprogrammable in orbit, from ground. The satellite shall be able to operate autonomously, and have a default (safe or nominal) behaviour if there is an unplanned long term ground segment outage. During a recovery procedure, the system transits to the *Safe operating mode* where frequency downscaling and powering off payloads shall occur. The system exits the Safe operating mode only when system self-checks pass and a positive energy balance is reached.

5 System Requirements

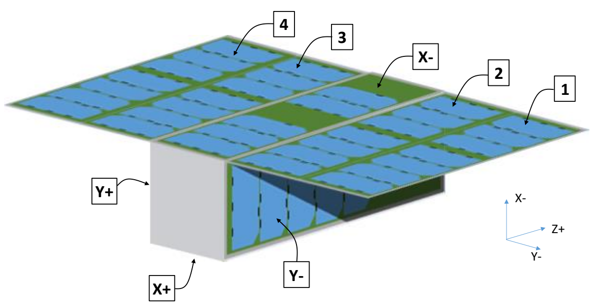
System level requirements relating to the spacecraft, payload and ground segment including at least system functional, performance and interface requirements, requirements for environment, cleanliness and ground handling, AIV, EMC, interfaces, modes and on-board autonomy/FDIR, ground segment requirements for ground stations, flight dynamics and simulation support, ground systems automation, and programmatic requirements (project cost and schedule) have been specified in the System Requirements Document.

6 System Design

The satellite will include the following subsystems: STRU, EPS (PDU, MPPT, BAT), OBC, COM-TCTM, AUX, ADCS, IPC (TBC), RADMAG, and RHA (TBC).

6.1 Spacecraft design concepts & trade-offs

Figure 1: Solar Array configuration



Due to the physical positions and dimensions of the solar arrays maximum input power has been calculated to be 48.5 W. (Albedo of the Earth's surface has been assumed to be 60%.) The candidate configurations were compared considering required number of MPPT channels, built-in over engineering (the sum of the maximum power of all channels versus the maximum input power from the solar arrays), and the amount of power lost in case of failure of MMPT channel with the highest power versus the maximum input power from the solar arrays (48.5 W).

Figure 2: RADCUBE Platform Digital Bus Systems

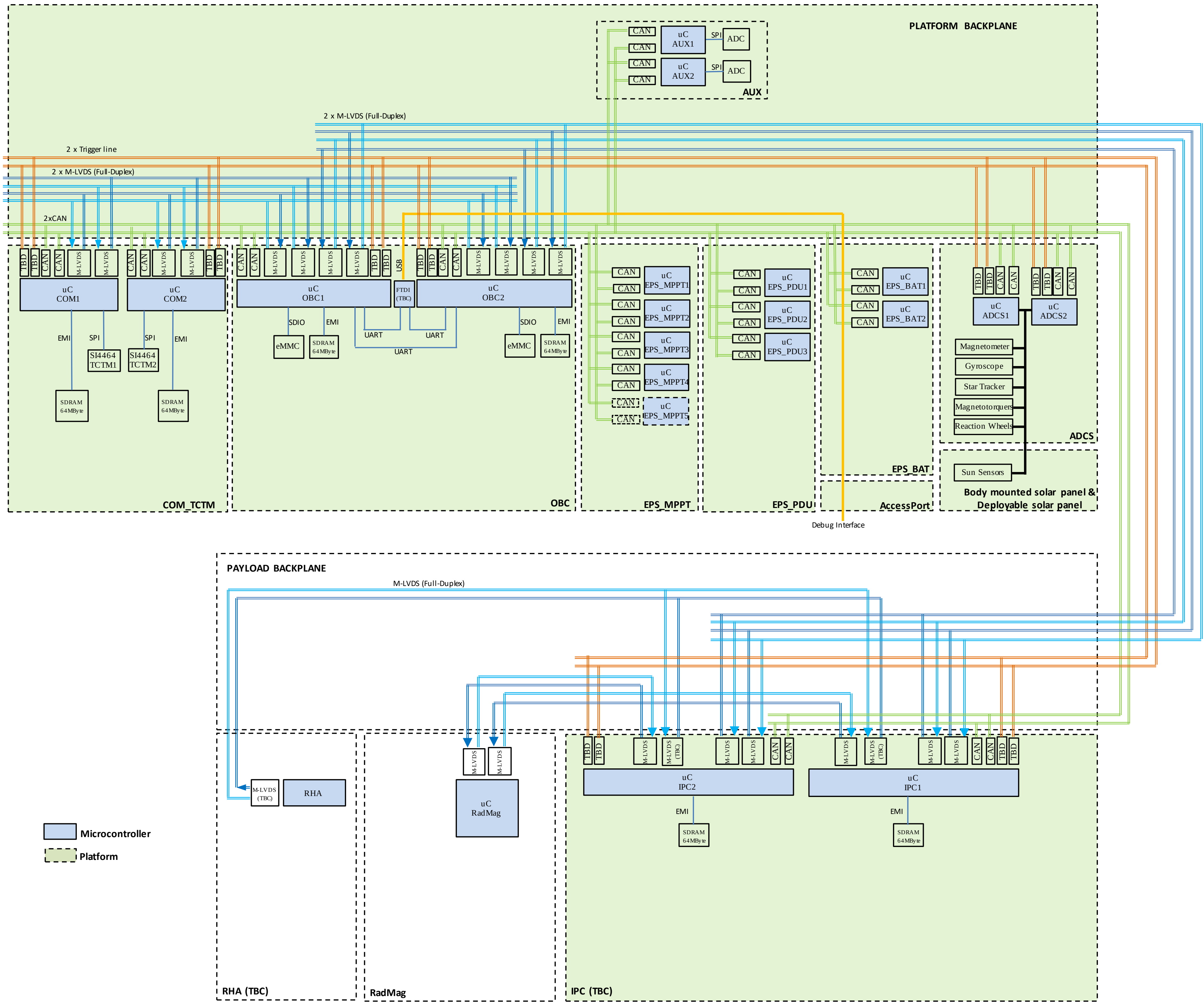
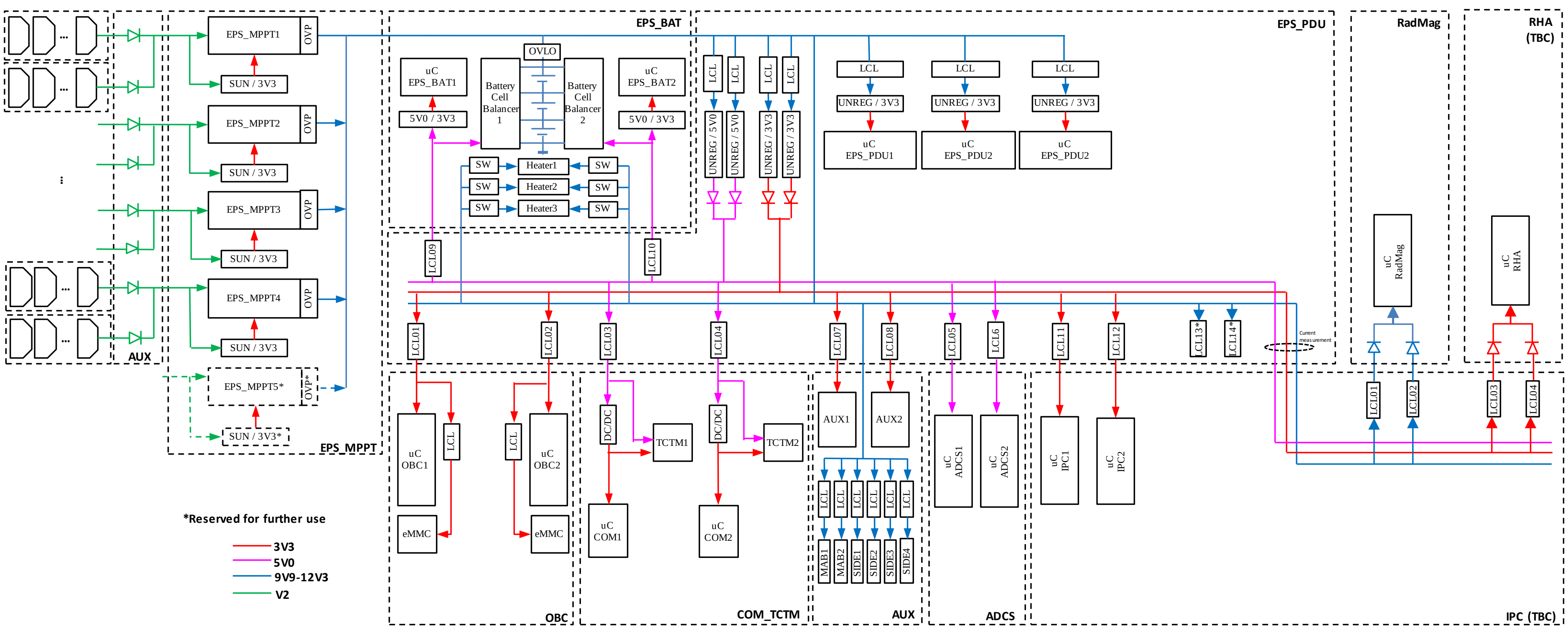


Figure 3: RADCUBE Platform Power Distribution Network



The configuration with 4 MPPT channels (2x 17.4 W, 2x 9.9 W) featuring 54.6 W built-in power, 113% overengineering, and 40% worst case SOF loss of power was selected.

Based on the results of a market survey the main needs of the mission can only be met and the risks associated with the planned lifetime be mitigated with a newly developed C3S battery module. Minimum required battery capacity is determined by the (maximum) time spent in the eclipsed section of the orbit and the effective system level power consumption during this time. Average power consumption of on-board systems in “normal” operating mode is 15.7 W (incl. maturity margins and 20% system margin) for one orbit. Li-ion batteries do not feature a drastic drop in capacity near their EOL, as opposed to e.g. lead-acid batteries. Loss of capacity is gradual and continuous, so EOL is usually set at 20-30% lost capacity. The datasheets of SAFT Li-ion batteries include cell data for 600, and 1500 cycles respectively. During the planned mission duration, the number of charge cycles is estimated to be more than ten times larger, so these indicated capacity values cannot be used. Thus, the lifetime has been estimated. Based on these estimations, assuming 50% depth of discharge to increase battery lifetime, beginning-of-life battery capacity is min. 26.6 W. Due to past positive experience in Masat-1 only SAFT batteries were investigated. From battery cells fulfilling the requirements SAFT MP 174565 was selected with VL 34570 as a backup option; selection criteria were to minimize mass and volume.

Candidate topologies to be used in the MPPT channels were investigated, buck-boost converters were found to be suitable. Due to prevention of failure propagation, the lower number of switching devices in the circuit, and the less complex control circuit the ZETA converter is the most advantageous of the investigated buck-boost converter topologies. As dissipation in case of synchronous zeta converter is approx. one order of magnitude less than the non-synchronous case, synchronous rectification shall be used in the converters.

STM32F4 microcontrollers with Cortex-M4 core have been utilized in the precursor project and passed all tests (radiation tests were not included in the test campaign). Since then new information regarding the radiation tolerance of STM32F4 microcontrollers has come to light, proving them to be highly susceptible to radiation. Thus, alternative microcontrollers from different vendors have been investigated. Concrete type will be selected at the beginning of the next phase, from types with proven (radiation tests already performed, or flight heritage, or manufacturer certificate) radiation tolerance.

6.2 Thermal design concept

The RADCUBE satellite is based on a novel CubeSat satellite bus which was developed to TRL7 in a precursor ESA contract of the present mission. This novel cubesat bus features a new rigid electronics backplane, new type of electronic connectors, and a different mechanical and thermal interface concept from the usual CubeSats.

Card-based electronics units are directly connected to the primary structure with two CardLok wedge lock devices. Boxed units are connected to the primary structure by screws. Our thermal solution is different in many aspects from a usual CubeSat thermal architecture, which is based on a stack of PC-104 format cards. The CardLok solution provides a direct thermal as well as mechanical interface between the electronics and the primary structure. This results in a predominantly parallel thermal achitecture as opposed to a usual PC-104 stack, which has a predominantly serial thermal architecture.

Conductive transfer dominates the intra-unit heath paths. The primary structure is the thermal path between the different units and the spacecraft surface. The primary structure is built from minimal number of components reducing the number of thermal contact resistances. Multiple dedicated heaters will be used for active temperature control of the battery pack. Currently three batteries are foreseen, and each battery will have at least one heater monitored by one (dedicated) temperature sensor.

6.3 Data processing hierarchy and software architecture

On-board housekeeping data is generated in the system modules. All system modules distribute their housekeeping data periodically via the CAN bus. The OBC processes housekeeping data and archives it. The OBC stores two versions of housekeeping data, the original (uncompressed) version, and a (lossless) compressed version, which allows faster download to the Ground station. When requested by the Ground Station, the OBC creates transfer frames from housekeeping data, and sends it to COM-TCTM via M-LVDS bus. COM-TCTM processes the transfer frames and transmits them to the Ground Segment via the RF link.

System modules can be commanded via CAN bus. Commands can be generated three ways: inside the satellite (according to on-board autonomy), by the Ground Segment (in this case the Ground Segment creates a telecommand and transfers it via the RF link, the COM-TCTM module receives the radio message and decodes the transfer frames, then sends it to the OBC via the M-LVDS bus. The OBC processes the decoded transfer frames and generates the original telecommand from it, then executes the command. Firmware update is controlled by the OBC via CAN bus, and the OBC can be commanded to perform firmware update via the RF link or the Access port. Thus, firmware update is a subset of commanding.

The RadMag instrument produces primary scientific data and temporarily stores it in its internal memory, so there is no need for continuous data transfer between RadMag and the Platform. The data is transmitted to the OBC via M-LVDS bus (through the IPC, or directly if no IPC is included). The OBC may compress the scientific data to increase RF link efficiency.

The OBC plays a central role in the system as it controls operation of other modules and collects housekeeping data from each subsystem. Control commands and housekeeping data travel on the CAN bus which connects all system modules. A real-time operating system is used as an intervening software layer to provide pre-emptive task switching and transparent scheduling for the user applications.

The RadCube system architecture is designed in a way that allows reconfiguration of microcontroller firmwares on-the-fly. Every microcontroller in the platform backplane contains a bootloader. When requesting a firmware update, the bootloader switches to firmware update mode, and loads the firmware content to the microcontroller's memory overwriting the previous software. The bootloader code itself and the '*calibration values and digital identifiers storage'* is protected against override. Firmware reconfiguration is requested from the ground segment and is controlled on-board by the OBC for each submodule. Each firmware contains the type ID of its target module. If an attempt is made to update a module with a firmware of incompatible type the OBC rejects the request.

For each subsystem, the software modules are divided into four layers according to their usage of hardware components. Each subsystem includes a real-time operating system (RTOS), which can efficiently manage the complex duties of the subsystem's microcontroller. *Reprogramming*, *Autonomy Control*, *Operation Mode Control* and *Access Control* modules are separated for each subsystem and marked as high level software modules. Each subsystem includes an *Engine* module, which is responsible for command interpretation, command distribution among the tasks of the subsystem's microcontroller. The next layer includes modules like a *Time Synchronization Unit*, which synchronizes the subsystem's time with the time of the OBC, a *CAN Control Unit*, a *Housekeeping Data Measurement Unit, etc.* The lowest level is responsible for direct HW management, i.e. reading temperature via ADC, or Memory access, Communication management, Watchdog timer, etc.

6.4 EMC mitigation, bus voltage regulation, and grounding scheme

Surface coating of primary structure elements and RF shielding boxes will be designed so that the elements are joined electrically on an area as large as possible. The radio transceiver unit will be placed into an electrically conductive shielding box to decrease emitted noise and to increase its immunity to ambient noise. The RadMag experiment will be placed into an electrically conductive shielding box to decrease emitted noise and to increase its immunity to ambient noise. To decrease interference with the scientific measurement "silent mode" has been included into the satellite's operating modes. In this mode, the satellite will emit as little electric and magnetic noise as possible as is compatible with limited operation. Due to the RadMag experiment's magnetic measurements the satellite will be designed to minimize magnetic noise in the 5-50 Hz (TBC) range.

On board the satellite energy is distributed on regulated and unregulated busses (3V3, 5V0); all busses have a maximum load capacity of 4.0 A (TBC).

The grounding scheme of the satellite was defined along the following considerations: The scheme is star point grounding. The star point is a dedicated, expansive ground area on a dedicated layer in the backplane. Electrically conductive surfaces have been designed on the structure and the backplane that are pressed together by the screws fastening the backplane to the structure. The structure and the electrical ground are connected via the shielding box of the COM-TCTM subsystem.

6.5 Mass budget

Table 3: Summarized Mass budget

Description	Nominal Mass [g]	Mass incl. margin [g]
Mass of RADMAG	1090.9	1200.0
Mass of RHA	42.3	50.8
Mass of Platform	3021.0	3403.1
TOTAL MASS:	**4154.2**	**4653.9**
TOTAL MASS including system margin (10%):		**5119.3**

As a conclusion, if we take into account the 10% mass system margin on top of the equipment level margin, the overall mass of the satellite becomes 5119.3 grams, which is below the 6000-gram mass limit requirement of the orbital deployer.

6.6 Power budget

In the current phase of the project decrease of incoming energy due to single point failures or increase of power consumption due to the same has not been included in the study. In calculating the energy balance of the various operating modes for calculating incoming energy and converting average power into energy an orbit time typical for the particular orbit was used. MPPT efficiency was conservatively estimated to be 90%.

Orientations X- sun pointing and Z+ zenith pointing are the candidates closest to be selected as nominal orientations for the mission, with Z+ magnetic field lines pointing as an alternative for extended scientific operations. For these orientations, the power consumptions shall be decreased by approximately 1W to achieve a long term positive energy budget. This is foreseen to be solved in later development phases. However, for a random walk attitude – representing a critical tumbling situation – the long-term energy balance is negative. This needs further investigations. As a conclusion, we see that the above problems add manageable risks which can be retired by making the energy balance positive by the end of Phase B2, PDR.

6.7 Link budget

A target operating frequency band, within the capabilities of the available communication system elements, was selected according to the applicable ITU regulations and recommendations. It was verified that the width of this band is enough to handle the required channel capacity with a wide margin. Note: The usage of this band is still subject to regulatory approval.

The calculations show that the available channel capacity, using adaptive bit rates, is significantly higher than the required one. This allows for the usage of a simplified bit rate control scheme and still provides some growth in the amount of data if needed.

6.8 Data budget

The RF communication link will be half-duplex, therefore link time shall be divided into two parts, one for download and one for upload. The planned ratio is 90% to 10%, so neither downloaded data nor uploaded data shall exceed respectively 90% and 10% of the total amount of data. Estimated data amount on the RF link is 3.45 MB/day.

The satellite shall be capable of 1-week of autonomous operation, so it shall be able to archive scientific and HK data of 1 week (we assumed that both compressed and raw version shall be stored on-board). The satellite shall also store firmware updates. Based on our calculations this requires 212 Mbyte on-board storage capacity. As the

C3S OBC includes 4 GByte internal storage, the C3S OBC's storage capacity is (more than) sufficient for the current mission.

6.9 Data availability estimation

In Normal operating mode downlink of at least 50% of the data generated by RADMAG must be downlinked within 24 hours; within 12 hours in case of solar flares. Orbit and satellite visibility simulation performed with AGI STK were used to study transit times during the whole mission, using 12-hour and 24-hour sliding windows. Low-elevation passes with less than 30s transit times were discarded. Preliminary calculations indicate the RADMAG instrument and the satellite will generate approximately 4.5 MB data per day, so at most 2.25 MB must be downlinked within 12 hours.

As a conclusion of the data availability analysis, with 36 kbit per second average link speed, which results in a 94.73%-time ratio of availability with less than 12 hours' delay of science and HK data for a 600 km orbit and an 89.87%-time ratio of availability for a 500 km orbit. If the required data download is compressed further to 1.25 MB/12 hours, the above figures go up to 99.98% and 97.72%. Conclusion: data compression improvement of downloadable data, especially science payload data is an important task for detailed design phase.

6.10 Preliminary pointing budget

The main pointing requirements for RADCUBE can then be summarized as an APE of 10° (3σ). A comparison of the three commercial solutions for a complete ADCS suitable for RADCUBE mission has been performed. Despite bare numbers in terms of performance suggest that pointing specifications shall be met by all of the systems, some open points/concerns arises, among which:

- structural adaptation of the existing solutions to RADCUBE size/mass constraints;
- adaptation of pointing modes might be required in some cases;
- redundancy/reliability is not clearly addressed from available documentation. Hardware redundancy seems totally absent; fault detection and management may be difficult to implement.

These issues give rise to an increase uncertainty of actual performance with respect to rated ones, and may lead to cost increase during the development or integration processes. The joint development of a custom solution is therefore advisable to keep full control of RADCUBE ADCS subsystem. RADCUBE pointing requirements most likely can be met with a reduced set of sensors/actuators (compared to available COTS solutions). Our current baseline solution under evaluation (to be further consolidated by analyses) consists of a configuration featuring:

- Actuators: 3 magnetorquers (possible addition of 3 in cold/hot redundancy); 3 momentum wheels.
- Sensors: 2 triaxal magnetometers (in cold redundancy) + 6 coarse + 6 fine (TBC) sun sensors.

This would allow keeping a lower level of complexity, both from H/W and S/W points of view, and at the same time a higher degree of redundancy/reliability. Furthermore, to guarantee sufficient stability during science measurements, the use of momentum bias is foreseen at certain stages of the mission. This will also allow to avoid excess drift of attitude during eclipses, and/or whenever a full attitude determination solution is not available.

6.11 Subsystems

A preliminary design, or in case of subsystems from the precursor project redesign, has been performed for all subsystems. Please see RADCUBE-TN5 System Design Report for details.

6.12 External interfaces

The satellite shall be a 3U CubeSat whose mechanical parameters shall be in compliance with the CubeSat Design Specification (CDS) REV 13 (chapter 3.1. and Annex B). The satellite will use the C3S STRU which is compatible with the cited standard.

A “remove before flight” pin (RBF), a power interface, and a digital interface is available on the Access Port (AP) of the satellite (the power and digital interfaces may be accommodated in the same physical connector). The battery can be charged and monitored and the system modules can be powered on for testing purposes via the power connector. The digital interface can be used for advanced testing and updating the firmware of the system modules.

6.13 Ground Segment interface

There is a RF communication link between satellite and Ground Segment. The ground station antenna, the antenna rotator and the RF terminal will be specified in details during a later phase of the project. The available frequency bands to implement the Satellite – Earth, Earth – Satellite links are defined by ITU Radio Regulations.

The ground segment software has a graphical user interface where the operator can assemble telecommands and push them to the execution queue. The main user interface view in Mission Control shows a timing diagram of queued telecommands. The operator is able to issue any possible command defined in the system and place them in appropriate time slots when the satellite is in sight in terms of RF communication. The user interface provides a view where the operator can enqueue these commands for later execution. Automatic or manual transmission timing of the commands can be set up as well.

Mission Control personnel can visualize inbound telemetry data coming from the satellite, such as housekeeping, measurement and custom payload data in a user interface view. Timestamped downloaded data and system health check status indicators can be visualized in this view.

The system stores any data that is received from the satellite or transmitted as a telecommand in a database with a timestamp. Transmitted telecommands and their optional payloads are also saved to the database upon transmission. Telecommands assembled and enqueued for later transmission/execution are also saved in the database.

6.14 Ground segment architecture

There are three major parts of the system:

1. The ground stations implementing the RF interface between ground and space segment. Main components: antenna, antenna rotator, tracking support and RF terminal.
2. Second part is a coordinator application implementing: the connector to ground stations, to mission control and to science control; data distribution service via public connectors (push service); high level functionality such as schedulers (pass, telecommand), authentication and identity management; archiving of data flow, actions and events
3. The third component is a group of user interfaces (UI).

The RF terminal shall be able to connect to the coordinator application through Ethernet. The coordinator application shall be able to handle multiple ground stations as input/output data resource. The coordinator application shall be implemented as a role based application which ensures that the application can be deployed on a server, in a computation cloud or even on a developer notebook.

In case a ground station loses connection to the coordinator application, it shall be able to operate in standalone mode. In standalone mode, the ground station shall track RADCUBE, receive telemetry and save downloaded data into a local database. The local database will be synchronized when the connection restored.

In case of using multiple ground stations, one of them will be assigned the master ground station role. The master ground station is responsible for commanding the satellite and setting the communication data rate and synchronize the downlink parameters with slave stations. Synchronization of downlink parameters is necessary if downlink baud rate can be set from ground to optimize downlink bandwidth.

The coordinator application is responsible for authentication of clients, performing scheduling (pass information, telecommand) and synchronizing the operation of ground stations (in case is more than 1 ground station). The payload data and satellite health data will be stored in a separate database. The application shall provide push data service to subscribed services such as mobile client applications, public website (one-way data flow). The application shall provide a bi-directional data interface between payload operators (MTA EK and ESA) and the satellite.

The downlinked science data (or satellite health data) shall be transferred to the payload operators transparently, meanwhile the telecommands (or requests) shall be first placed into a queue, reviewed by a responsible operator and approved before putting the request into a telecommand queue. This process shall help to keep RADCUBE in a safe operational state and filter requests which might endanger the mission.

The mission operation interface consists of Operator Interface and Operator Display. Operator Display provides a view of all HK, Ground Station data and information of satellite passes for the operator. Operator interface is responsible for commanding and scheduling telecommand.

Implementation details such as programming language, workflows, use of technologies will be defined during a later phase of the project.

7 Space to ground interface

The space to ground interface has been specified in the Space to ground interface control document. It shows the visibility and communication range parameters of the spacecraft as calculated from the orbital parameters. The required data downlink channel capacity is summarized based on the amount of scientific and housekeeping telemetry data. As the estimated uplink requirements are much less critical, those are not considered. The document specifies the utilized data coding, encryption and authentication procedures and the formatting of the communication packets (both for downlink and uplink directions).

It defines the frequency and modulation scheme used for communication between the spacecraft and the ground station and shows the results of the calculations which determine the available communication bandwidth. An adaptive bit rate control method is specified to fulfil the downlink data requirement. The target parameters of the ground station transceiver are included.

The second part of the document defines the ground station interfaces to the rest of the ground segment. It shows the purpose, architecture and connections of all interfaces.

The ranging interface connects, via the internet, to the publicly available orbital parameter database to compute the actual position of the spacecraft for accurate ground station antenna pointing. The database interface connects to the central relational database of the mission which stores all downlink data and the ground station operational logs.

The front-end human interface provides, via a web browser, either local or remote access to the collected and visualized housekeeping telemetry data and allows commanding of the spacecraft or the scientific payload. The other front-end interface connects to the hardware elements of the ground station for control and performance monitoring.

8 Payload-platform interface

The payload-platform interfaces have been specified in the Payload-platform interface control document.

8.1 RadMag

RadMag is supplied on one voltage level, which is the Platform battery voltage. Power is supplied to RadMag via two LCLs, i.e. RadMag has redundant power supply. The RadMag instrument is connected to the platform via a redundant CAN bus (TBC) or via a redundant M-LVDS bus (preferred). The two (cold-redundant, half-duplex) CAN bus' physical layer is compatible with the ISO 11898 standard. The two (cold-redundant, full-duplex) M-LVDS buses are compatible with TIA/EIA-899 standard.

RadMag will generate up to 5.5W power consumption (including 20% margin), which will be generated internally in the instrument electronics assembly. The Detector assembly will generate negligible heat dissipation compared to the electronics. The detector assembly itself will be separated from the main power consuming electrical cards in order to ensure that the temperature of the sensitive detectors is below +40°C. Properly designed thermal paths in the platform structure to the external satellite thermal interfaces with properly chosen thermal coating may be able to passively cool down the detectors (TBD); the direct external thermal interfaces of the instrument, the titanium detector windows, may also have a key role in this. The main instrument thermal design driver is to separate the thermally sensitive sensors from the electrical system of the instrument both internally and by the external payload-platform interface, and to find thermal paths to passively cool the detectors.

The interface temperature of the RadMag instrument shall be in the range of [-40; +40] °C in any operative conditions. The interface temperature of the RadMag instrument shall be in the range of [-40; +60] °C in any non-operative conditions (e.g. storage).

The interfaces capable of distributing the high internal dissipation of the electronics assembly shall have a high heat transfer coefficient (value TBD). The interfaces of the detector assembly shall have such heat transfer coefficients (TBD) which enables the lowest sensor temperatures in the above range. Thermal interfaces shall be elaborated further and defined in detail once the design of RadMag solidifies.

8.2 RHA

RHA is supplied at 3.3V (TBC) voltage level. Power is supplied to RHA via two (TBC) LCLs, i.e. RHA has redundant power supply (TBC).

RHA’s current design uses 0/3.3V single ended full-duplex UART bus. Our system bus uses differential signals, so RHA’s data bus needs to be modified. The first option is to use a full-duplex M-LVDS bus (compatible with TIA/EIA-899 standard). This modification only affects the physical layer and requires only the addition of a transceiver. The second option is the use of two (cold-redundant) CAN buses (compatible with the ISO 11898 standard). This modification affects higher communication layers, and requires a CAN controller and two CAN transceivers. The first option is preferred, as RadMag is connected to the platform via M-LVDS buses.

9 Product Assurance

The Product Assurance Plan describes how C3S is planning to implement Product Assurance Management (ECSS-Q-ST-10) and Quality Assurance Management (ECSS-Q-ST-20), how Safety (ECSS-Q-ST-40) will be considered, how EEE Components (ECSS-Q-ST-60) and Materials and Processes (ECSS-Q-ST-70) will be selected, how Software Product Assurance (ECSS-Q-ST-80) will be implemented, how Reliability and Maintainability will be achieved. It also includes a compliance matrix.

10 System development plan

The System Development Plan defines the product tree, list product tree items, and indicates their qualification status. It assesses currently known risks, identifying long lead items and critical items. It presents a modification plan for existing subsystems to tailor them to mission needs, including justifications for the modifications. It defines the model philosophy on the satellite level as well as on subsystem level. It summarizes the test plan and describes the development plan for HW and SW components, including the HW/SW co-development approach. It list tolls and facilities that shall be utilized in the project and gives an overview of the planned project management, including project organization, proposed work breakdown structure, work package descriptions, proposed project schedule, and proposed cost breakdown structure.