CubeSat Operation Strategies and Lessons Learned

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ABSTRACT

The presentation addresses the key aspects of nano satellites mission operations, such as mission operations management structure, mission operations procedures, mission termination criteria and mission operations scheduling considerations.

Details will be revealed about the operation activities based on the ESA supported RadCube 3U CubeSat launched in August 2021 using in-house developed ground station and Mission Operation Control Centre in Hungary.

The main focus will be on the data downloading and operation strategies applied in the in-orbit demonstration mission, highlighting the importance of the batch files running on board and the scripts, which enable the autonomous operation independent form the link stability. In terms of the data management optimalization, the lessons learned from the encryption and compression techniques will be described. Besides the advantages of the redundant platform subsystems from operation side will be shown, as well as the in-orbit firmware update feature. The used method of the half-duplex communication will be summarized. Furthermore, the special coding with beacons will be explained including its impact to the predictable and cyclical data acquisition, since the beacon frames contain the most critical on-board telemetry data which makes it possible for the operators to see the status of the satellite during a pass, and they also support signal detection below the noise floor that can be used to check the status of the satellite even in case of a deployment failure.

The other focus will be the presentation of our FlatSat which is used as a development environment in general as part of the test process, and it is also extremely useful during the operation activities of the mission in several aspects from risk mitigation until bug fixing and failure assessment.

We also collect the overall experiences about the ground station and the challenges of the component selection and the reason why we chose to design own rotator.

Keywords: CubeSat, Satellite Operation, Mission Operation, Ground Station, FlatSat

1. INTRODUCTION

RadCube is an 3U CubeSat in-orbit technology demonstration mission funded by the Hungarian contribution to the ESA GSTP 6.3 program, launched in 2021 August 16.

The main mission objective is to demonstrate RadMag, a compact and adaptable cosmic radiation and magnetic field measurement payload instrument, capable of performing science-quality measurements applicable in space weather forecast and providing exact radiation environment data measured on-board on those spacecrafts where monitoring the radiation effects on electronics is of key importance.

RADCUBE is developed by two major Hungarian Space entities: the Centre for Energy Research (EK), responsible for the payload, and C3S LLC., the prime contractor and system integrator, responsible for the development of the 3U satellite bus, the ground segment, and the integration, verification, and operation of the satellite. Three major contributors of the project outside Hungary are Imperial College London (UK), providing MAGIC, a precision magnetometer to be deployed on-board, and Astronika (PL), providing an 80 cm boom and its deployment mechanism for the magnetometer. ESA ESTEC will provide CHIMERA, a radiation hardness assurance experiment demonstrating the synergistic design aspects between monitoring the effects of radiation on EEE components and simultaneous local radiation measurements. These three developments are physically part of the RadMag payload.

The present mission covers the development of all payloads and the platform, the integration, verification and launch of the satellite, the development of tracking station, the mission operations and science operations centers, the launch, and the operations for 8 months.

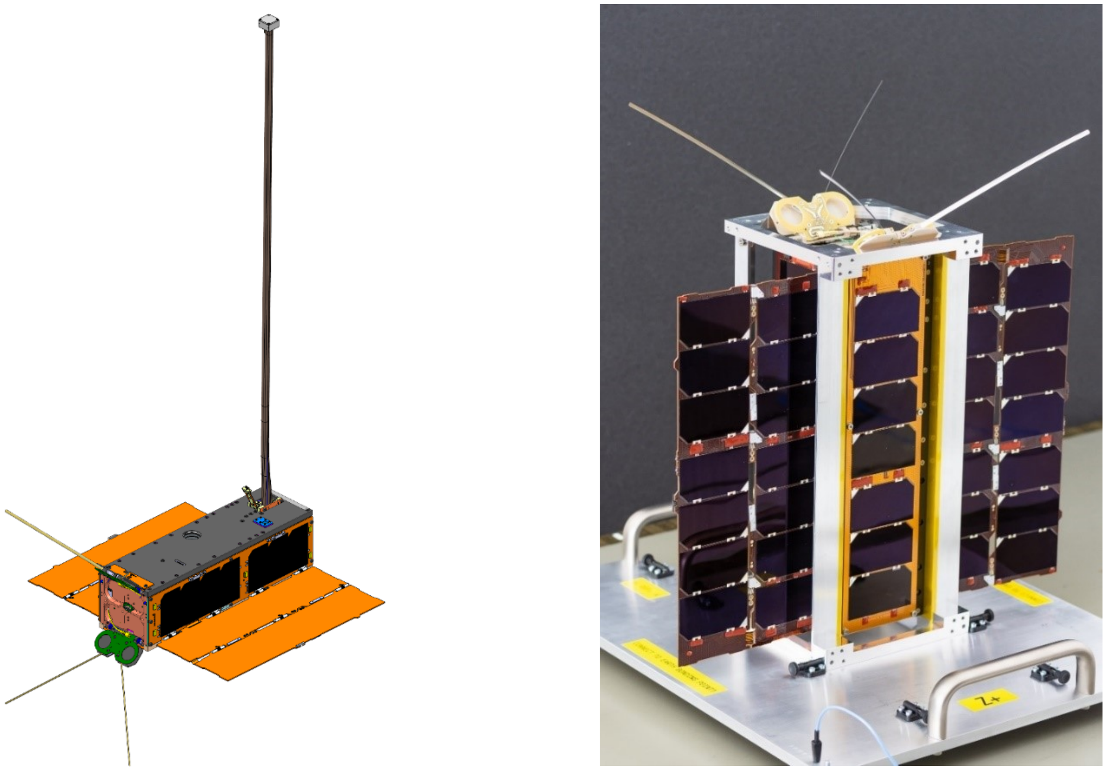

Figure 1: RadCube CAD Drawing with opened boom (left) and photo of the PFM satellite (right)

2. SYSTEM

2.1. Ground Station

The tracking station located in Budapest, Hungary (47°28'13.9"N 19°05'07.4"E) is intended to communicate with small satellites in Low Earth Orbit with modest data rate requirements. It operates in a section of the UHF band which is allocated to space services on a primary basis and is capable of half-duplex operation.

The simplified diagram on Figure 2 shows the physical arrangement of the tracking station elements. The equipment cabinet is located right at the bottom of the antenna mast to minimize the length of RF cabling. The exact location of the auxiliary mast has been determined to be able to observe the antenna system as well as the cabinet and the environment. The number and placement of the primary lightning protection rods has been determined during the design process of the lightning protection system.

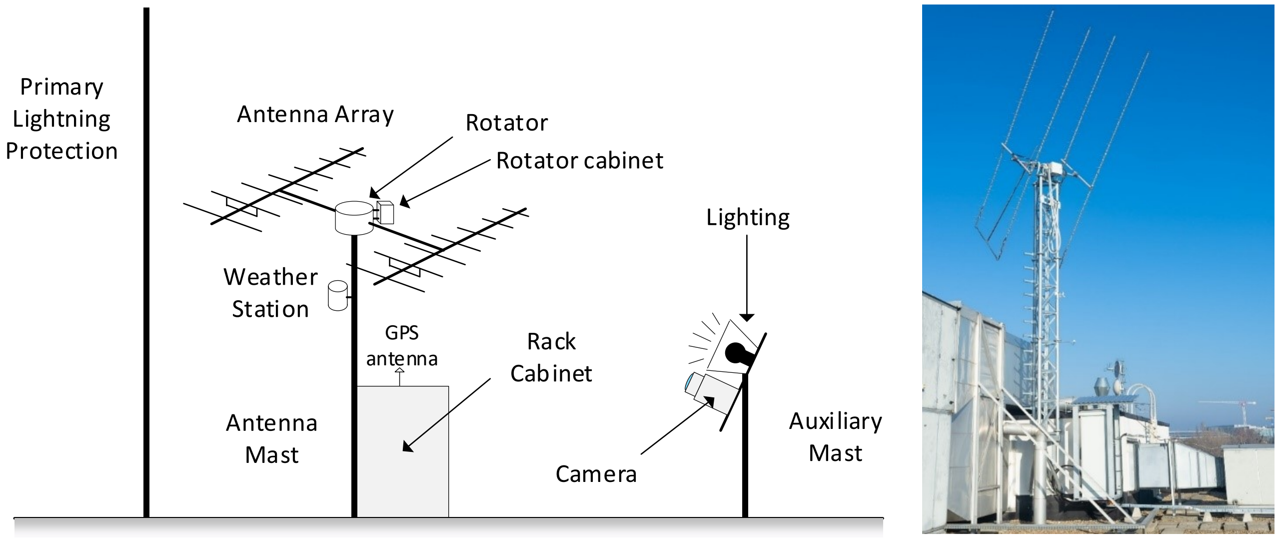

Figure 2: Grund Station layout (left) and photo of the Tracking Station (right)

The tracking station subsystem layout shown on **Hiba! A hivatkozási forrás nem található.** for reference. This shows the units within the subsystem and their main connections. Supply voltage connections from the power supply unit to the rest of the units are omitted for clarity. Most of the units each correspond to one single physical block and these blocks are integrated into an equipment cabinet. One exception is lightning protection where primary protection is distributed outside of the cabinet and secondary protection is located at the various galvanic connection terminals of the cabinet. The other exception is housekeeping which has sensors and actuators located at various points both inside and outside.

Table 1: Technical specification of the ground segment

Transceiver type and manufacturer:	**Self-developed SDR, C3S LLC.**
Power Amplifier type and manufacturer:	**HD31347, HD Communications Corp.**
Transmit mode:	**CW, GMSK**
Rated max. output power:	**100 W**
Transmission bandwidth:	**3.8 … 225 kHz**
Transmission line length:	**20m (coaxial)**
Transmission line attenuation:	**0.7 dB**
Receiving sensitivity:	**-117 … -105 dBm**
Signal to Noise Ratio:	**>11 dB**
Antenna type and manufacturer:	**4 x M2 402CP42 (YAGI), M2 Antenna Systems Inc.**
Antenna main beam gain:	**24,1 dBi**
Antenna polarization:	**Circular**
Antenna main beamwidth:	**10 °**
Rated max. EIRP:	**44.1 dBW**
Used max. EIRP:	**7 dBW**
Antenna front to back ratio:	**23 dB**
Transmit frequency:	**401.75 MHz**
Receive frequency:	**401.75 MHz**
Harmonic levels:	**<70 dBc**

2.2. Space segment description

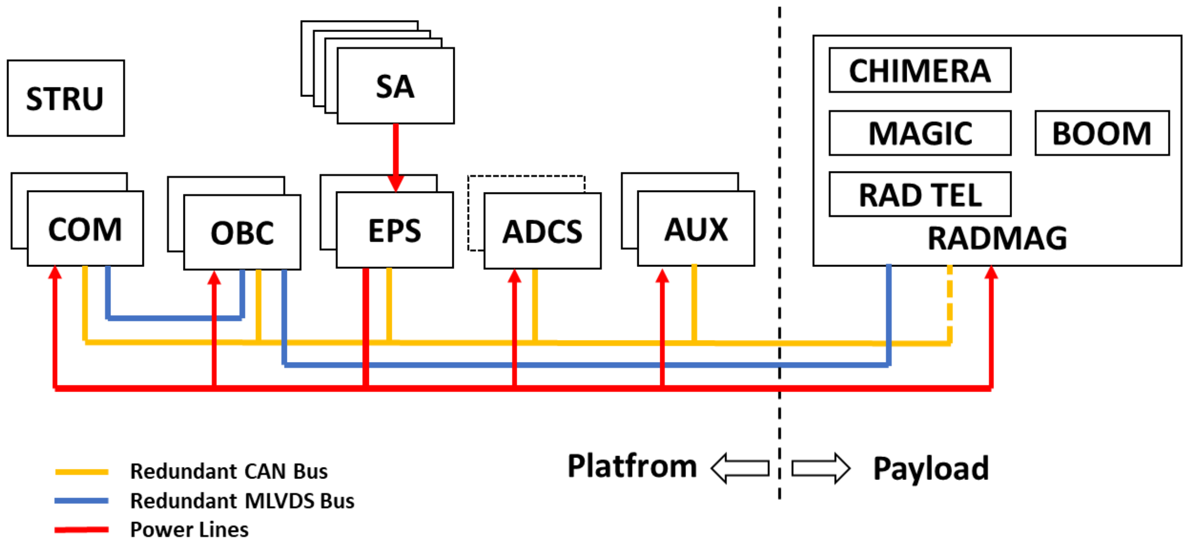

Figure 3: RadCube Space Segment block diagram

The main parameters of the basic system are shown in the table below.

General	• 3U CubeSat structure, modular design • Compatibility with CubeSat Standard • Dimensions 100 x 100 x 340.5 mm • Satellite mass: 4.629kg • At least 1U volume for payloads • Subsystems: STRU, EPS, OBC, COM, AUX, ADCS, RADMAG (payload) • Redundant OBC, COM, AUX, EPS • Designed for high reliability • Solutions for preventing single point of failure in main subsystems
OBC	• Cortex-M7 core up to 300 MHz CPU speed • 16 GB eMMC and 16 MB MRAM memory • Redundant 1 x CAN bus (up to 1MBit/s) • Redundant 2 x MLVDS (up to 11.25 Mbit/s) • High-Accuracy RTC
COM	• Half-duplex RF communication with up to 150 kbit/s data rate (both for uplink and downlink) • RF communication, encryption (AES) and authentication • 9.65 Mbyte/day average data download with 1 ground station
EPS	• Battery cells are protected from under-voltage, overvoltage, overcharge, over-discharge and under-temperature • Total incoming solar energy decreased by MPPT efficiency (per orbit) is up to 48.8 Wh • Power Distribution Unit with 12 system Latch-up Current Limiters

ADCS	• 3-axis gyroscopes, magnetometer, magnetorquers, sun sensors and reaction wheels • 3-axis high-precision stabilization

Figure 4: RadCube Space Segment key features

4. NOMINAL OPERATION AND LESSONS LEARNED

During nominal operations, the telecommunication link is controlled by the tracking station with very limited autonomy on board the satellite. The tracking station calculates the position and speed of the satellite, extrapolated from the latest publicly available orbital parameters. From these data, it is possible to predict (with some errors) the satellite elevation, communication range i.e. achievable bit rates and Doppler shift as a function of time.

By default, the tracking station is in RX mode and the satellite is in Out of Range mode: it transmits a single telemetry packet and a beacon signal, with 5 kbps data rate in every tOR interval. When the satellite is in RX mode, it is expecting to receive commands with 2.5 kbps data rate. To limit power consumption an Idle phase is also included in the beacon mode.

As soon as the tracking station detects a beacon signal it transmits the first TC packet(s). This first command set shall include commands to configure the data rate and the RX bandwidth of the satellite transceiver. At the end of the transmission the tracking station commands the satellite to switch into transmitter mode and gives the time of the TX period. Still using the default data rate, the satellite first transmits an acknowledgment of the successfully decoded and executed commands, see more information about the acknowledge in Chapter 13.2 (at least the data rate setting command shall be acknowledged at this data rate) then switches to the new data rate and starts the transmission of the other TM packets.

When the satellite is within communication range, it normally downlinks TM packets. The transmission is stopped after tTX_N or according to a previously sent command for an RX time slot to wait for further commands. These tell the satellite what operations to perform next.

The graphical user interface of the Mission Operations Center offers a fine-grained, manual method of TC assembly and TM display used extensively in the earliest stages. The service which handles the File Transfer protocol also has a GUI for manual functions operated by the user.

As the mission progressed and operation procedures and requests matured, we shifted from the manual, graphical user interface-based workflow to scripted operation. This enabled a certain degree of automation and led to faster, more robust actions and therefore confident operation.

Scripting the operation also made possible a higher level of control based on feedback. The operator is able to query actions on a very high level of abstraction and would be made sure that the procedure goes as planned, with programmed testing of the satellite’s responses and internal state. To provide an example, the script would wait for the first pass of each day, wait for the first beacon message, and start a data acquisition procedure. This requires issuing multiple telecommands in order, and should only proceed to the next command, if the previous succeeded. After the data acquisition started and finished, in order to efficiently download the data, the operator would need to compress the resulting file to save precious downlink time. With the compressing done, the file needs to be downloaded, decompressed and distributed to our Partners. Scripting makes these kinds of procedures easy to implement, reuse and adapt to new requests/requirements.

As mentioned, the downloaded scientific result files and platform data would need to be supplied to the consortium members. An FTP server is used for this purpose. C3S LLC. places the new files on the server, and an automated e-mail message notifies the necessary personnel about the availability of fresh data. The valuable scientific data product is planned to used by ESA Space Situational Awareness Program.

Even with the continuing link imperfections and interferences, robust automated operation and fault-tolerant ground segment functions made possible the facilitation of the production and download of the required amount of scientific data. Continuous logging of the link statistics -along with telemetry, housekeeping and weather data- enabled us to easily reflect and evaluate performance over extended periods of time.

6. SUMMARY AND CONCLUSIONS

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