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AN INNOVATIVE TECHINQUE FOR DETECTING SOLAR AND GALACTIC RADIATIONS WITH AN ISOTROPIC SENSOR BY THE RAMSESS CUBESAT MISSION

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Abstract

Space missions, in Low Earth Orbit (LEO), outside of the Earth's magnetosphere are critical because of space radiation, including the high-energy particles of the Sun i.e., trapped protons and electrons of the inner and outer Van Allen Belts which are dangerous for the electronics of the spacecraft and/or a manned crew.

This paper deals with the ongoing development of RAMSESS (RAdiation Measurement Sensor with Enhanced Sensibility for Space exploration), a 6U-CubeSat project funded by the Italian Space Agency (ASI) in the framework of the national program Space 19/ALCOR. The main aim of the Cubesat mission is the validation in a relevant radiative environment of the payload, an innovative semiconductor-based (i.e., CdZnTe, hereinafter CZT) dosimeter through the characterization of the radiation environment in low-Earth polar orbit, near the outer Van Allen Belts.

The following sections report framework and mission motivations (Introduction), RAMSESS mission CONOPS (sec. 2), the payload (sec. 3), the platform (sec. 4), RAMSESS validation strategy (sec. 5) and conclusions (sec. 6).

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1. Introduction

Main sources of space radiation in Low Earth Orbit (LEO) are the high-energy particles of the Sun i.e., trapped protons and electrons of the inner and outer Van Allen Belts together with other causes such as the Galactic and extra-Galactic Cosmic Rays, anomalous Cosmic Rays. Outside of the Earth's magnetosphere (magnetopause) space radiation reaches critical high level dangerous for the electronics of the spacecraft and/or a manned crew.

In the framework of the emerging IoT domains, current standings and open research challenges [1], Low Earth Orbit (LEO) missions have become crucial for a variety of applications, from scientific research to commercial purposes.

One of the challenges in designing and operating LEO missions is estimating the total radiation dose that the spacecraft and its components will receive.

Models like CREME (Cosmic Ray Effects on Micro-Electronics) [1] and SHIELDOSE [2], are properly used by tools like SPENVIS to estimate the radiation dose a spacecraft will receive in a given orbit. On the other side the accurate estimation through space measurements of the radiation dose is crucial in ensuring the reliability and longevity of electronic components and system, as well as estimating the maximum radiation that astronauts will receive aboard the spacecraft. To this aim, in recent years Cubesat mission with radiation detector for collecting the data of the radiation environment in LEO have been growing up, to compare measurements obtained by radiation sensors versus data calculated by different prediction models used in space engineering.

In this framework, the ongoing development of RAMSESS (RAdiation Measurement Sensor with Enhanced Sensibility for Space exploration), a 6U-CubeSat project funded by the Italian Space Agency (ASI) is framed. The project is proposed by a consortium of universities and enterprise, led by the Italian Aerospace Research Centre (CIRA). The main aim is the characterization of the radiation environment in low-Earth polar orbit, near the outer Van Allen Belts, through an innovative radiation detector able to perform a selective dosimetry of the radiative environment and the collect measurements. Therefore, the main goal of the mission is the validation in a relevant radiative environment of this innovative semiconductor-based (i.e., CdZnTe, hereinafter CZT) dosimeter, designed by the enterprise Due2Lab, partner of the project. The isotropic sensor measures the total absorbed dose, the energy and nature of each single interaction event, without imposing any pointing specifications of the satellite.

3D CZT detectors can simultaneously measure total dose, individual event energy, and particle types, making them exceptionally versatile tools in space-based radiation environments. Their intrinsic position-sensitivity helps distinguish potential scattered gamma rays from the primary signal, thereby reducing the need for anticoincidence shielding. This capability also simplifies the identification of charged particles, such as electrons, protons, and ions, enhancing background suppression and improving the overall quality of the acquired data. These comprehensive measurements support precise monitoring of crew exposure, facilitate a deeper understanding of cosmic radiation composition, and increase the reliability of scientific investigations in extraterrestrial conditions.

CZT technology offers several advantages. Compared to scintillators, CZT provides superior energy and spatial resolution, making it ideal for high-precision spectroscopy. Unlike Germanium detectors, it is less sensitive to temperature fluctuations and operates without cryogenic cooling, eliminating bulky and complex systems. Its larger active volume compared to silicon-based detectors further enhances radiation detection and analysis performance. Additionally, CZT outperforms CdTe (Cadmium Telluride) in applications involving high-energy radiation and high fluxes, as it effectively mitigates the issue of polarization. These features make CZT detectors especially suitable for space missions, where precise radiation monitoring and particle identification are critical. They can simultaneously measure individual event energy and particle types, from which the total dose can be derived. Furthermore, A CZT detector has the advantage of reduced mass and volume (can be hosted in a 1U module), compared to semiconductor detectors based on Silicon (Si) and Cadmium Tellurium (CdTe).

In the following sections details about mission and platform will be provided. In particular, the definition of mission CONOPS and scenario has been carried out by Polytechnic of Milan and complying with the new ESA Space Debris Mitigation Requirements, focused on ensuring that the mission would encounter and detect the most significant radiative species, primarily electrons and protons (sec. 2). The 6U CubeSat platform is being developed by IMT, one of the Italian leaders in space-system engineering for nanosatellites. The design is flight proven being based on past projects also developed in the ESA framework, and the platform features high-TRL components (sec. 4). The high-performance (pointing, control) Attitude Determination and Control System design is provided by the University of Naples, Federico II (sec. 4). The payload is designed by Kayser Italia and Due2Lab and radiation data, divided into engineering classes and processed at raw high data rate, will be managed by a dedicated processor designed ad hoc for RAMSESS and transmitted to ground through a 3Mbps data link to the Mission and Payload Control Centre located in Livorno and managed by Kayser Italia (sec. 3).

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2. RAMSESS mission CONOPS and operative scenario

RAMSESS is a cubesat mission aiming to perform the in-orbit validation of a radiation sensor developed by Due2Lab, the Cadmium Zinc Telluride (CZT) detector which has the advantage of reduced mass and volume (can be hosted in a 1U module) and its suitable for high-energy particles, compared to semiconductor detectors based on Silicon (Si) and Cadmium Tellurium (CdTe). To this aim the design, the qualification and the launch of a 6U Cubesat in polar orbit (out of the magnetosphere, in the magnetopause) is planned with possible altitudes range 400-1000 km.

Starting from the needs of the scientific mission and the recently updated ECSS on Debris Mitigation [3], [4] and [5], the mission CONOPS and operative scenario will be defined.

Once launched the mission will go through the following phases:

- **LEOP:** after release from the launcher provider, the spacecraft will switch on and start beaconing through its TMTC subsystem, until acquisition of signal. The ADCS will detumble the spacecraft and solar panels will be deployed. If the telemetry received on ground does not underline any major issues, the commissioning phase can begin.
- **COMMISSIONING:** all the subsystems and the payload will be switched on and their functionality and performance will be assessed. After the successful completion of this phase, the nominal operations will start.
- **NOMINAL OPERATIONS:** the payload will be used to acquire radiation data, that are then downlinked communicating with the ground stations. The duration of the mission up to the end of this phase will be of 2 years. Further details on the use of the payload and on the downlink will be provided in the following sections.
- **DISPOSAL:** the subsystems will be passivated, and the natural decay of the orbit will be exploited for an uncontrolled re-entry, burning the satellite in the atmosphere. The duration of the mission up to the end of this phase will be <5 years, in compliance with debris mitigation guidelines.

Based on the CONOPS and the scientific objective of the mission, the mission analysis has been carried out, considering several possible alternatives to support the design of the mission and of the platform for RAMSESS.

Being RAMSESS a CubeSat with no recurrent propulsive capability, the most stringent requirement is that the spacecraft must re-enter in the atmosphere within 5 years from the launch date, as explained in the new ESA guidelines for the Debris mitigation [3], [4] and [5].

The most significant scenarios for trade-off based on mission and radiation environment analyses have been reported, in order of increasing complexity for the platform and for the operations:

- Circular orbit at the maximum possible altitude, with no disposal support devices;
- Circular orbit at a higher altitude, using disposal support devices after the nominal mission;
- Elliptic orbit covering a wide range of altitudes of interest, using disposal support devices from the beginning.

As a disposal support device, a drag sail has been preliminary considered for the analyses. The ADEO-P(ICO) drag sail system by HPS GmbH has been taken as reference [6]. The sail has an area of 1.7 m2 and an unmargined mass of 0.45 kg. The sail has already undergone technology demonstration in orbit. A possible short stopper is the fact that embarking a drag sail device has a strong impact on the configuration and on the interfaces of the platform. A propulsion unit can be considered as an alternative for disposal support. However, it would impact a lot on platform design and on all system budgets. Its use will be further investigated in the following phases if deemed necessary.

From the mission analysis, assumed the platform characteristic (Cubesat of specific dimension and weight) the maximum altitude for a circular orbit to ensure a disposal within 5 years has been determined using DRAMA/OSCAR software. The orbit is a circular SSO with an altitude of 470km, whose orbital decay analyses is reported in Figure 1. A SSO with the set characteristics has an inclination of 97.26°.

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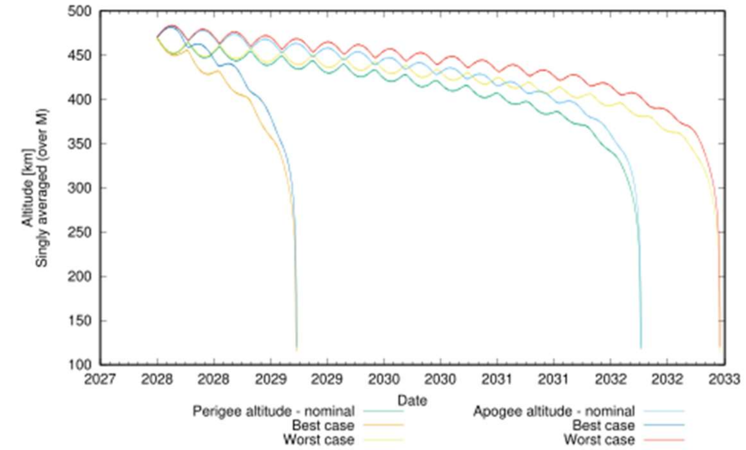

Figure 1: Orbital decay of a 470km circular orbit, DRAMA analysis.

This orbit would grant an average daily contact time of 17 min 59 s with the Ground station, with an average passage duration of 5 min 26s. For a 470km circular SSO with 11h LTAN the beta angle is -15°, corresponding to an eclipse duration of 35min 23s over a period of 94min.

Recalling the scientific objective of the mission and therefore to assess the scientific relevance of the radiative environment encountered by the spacecraft during the mission, it is essential to evaluate the particle fluences in space for the three mission scenarios. The analysis of the radiation environment studied the space radiation fluences for the 3 principal LEOs: two Nominal Circular Orbit (470KM and 550KM) and an Elliptic Orbit (450-830 KM).
The goal is to calculate the Total Ionizing Dose (TID) for these orbits, leading to the derivation of the so-called Dose Depth Curves due to the major contributors to the radiation dosage, during both maximum and minimum solar activity.
The TID is calculated by considering trapped particles and solar flare particles as the primary contributors to ionizing radiation, while the contribution from galactic cosmic rays is considered negligible in the presence of these dominant sources.
The AP-8 and AE-8 models are used to estimate the fluences of trapped protons and electrons, respectively. These models are recognized as standards and are characterized by their comprehensive coverage of the entire energy range of trapped particles (100 keV to 400 MeV) within the Trapped Radiation Belts (or Van Allen Belts).
The SAPPHIRE model (Solar Accumulated and Peak Proton and Heavy Ion Radiation Environment) is employed to estimate the long-term solar particle fluences. This model provides detailed environmental specifications for the Solar Energetic Particle (SEP) environment under both solar minimum and maximum conditions.
In this study, the SAPPHIRE model is configured to calculate SEP fluences for the specific temporal period of the mission.
The analysis includes dose-depth curves for trapped protons and electrons derived from the AP8/AE8 models, as well as solar particles from the SAPPHIRE model. A secondary component is also accounted for: Bremsstrahlung emissions, which represent a continuous X-ray spectrum created by primary particles interacting with spacecraft materials, predominantly induced by electrons, and contributing to the total dose.
The ionizing doses are calculated at the centre of a solid sphere as a function of sphere radius using the SHIELDOSE code, which determines the absorbed dose as a function of depth in the aluminium shielding material of the satellite. “Aluminium” is selected as the shielding material, while “Silicon” (Si) is used as the target material for these calculations. These radiation environment models are implemented using ESA’s SPace ENVironment Information System (SPENVIS).
Figure 2 illustrates the variation in total dose caused by the different altitudes of the missions under the worst-case scenario of the maximum solar activity. Notably, a slight increase in aluminium shielding thickness from 1 mm to 1.5 mm results in a rapid reduction of the total radiation dose by approximately a factor of 2 over the 2-year mission duration. This effect is further depicted in Figure 3.

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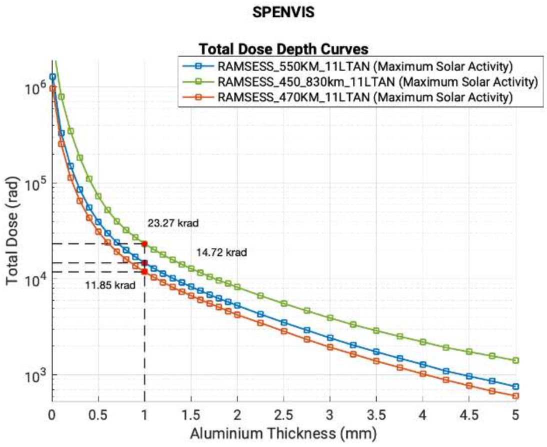

Figure 2: Comparison of Total Dose depth curves for circulars and elliptical orbits at maximum solar activity, highlighting the effect of 1 mm shielding thickness.

Calculations demonstrate that, despite the notable differences between the orbits, the radiation environment encountered remains largely consistent. If Figure 3 highlights a comparison of total doses for the orbits, Figure 4 delves into the contributions of various radiation sources. It is evident that the dose from trapped electrons, being the dominant component, correlates directly with the total dose. Similarly, the photon contribution—strongly influenced by trapped electrons—follows the same trend. In contrast, the impact of solar protons is virtually unaffected by the orbit.

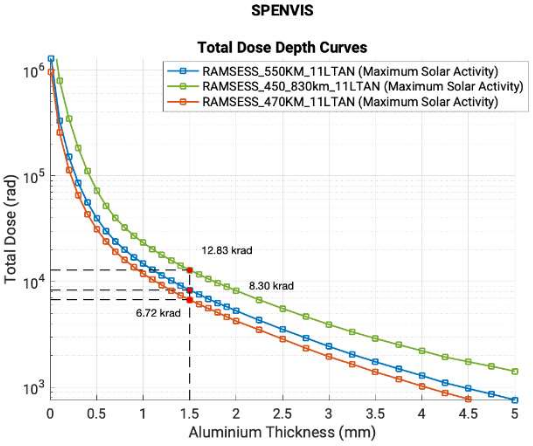

Figure 3: Comparison of Total Dose depth curves for circulars and elliptical orbits at maximum solar activity, highlighting the effect of 1.5 mm shielding thickness.

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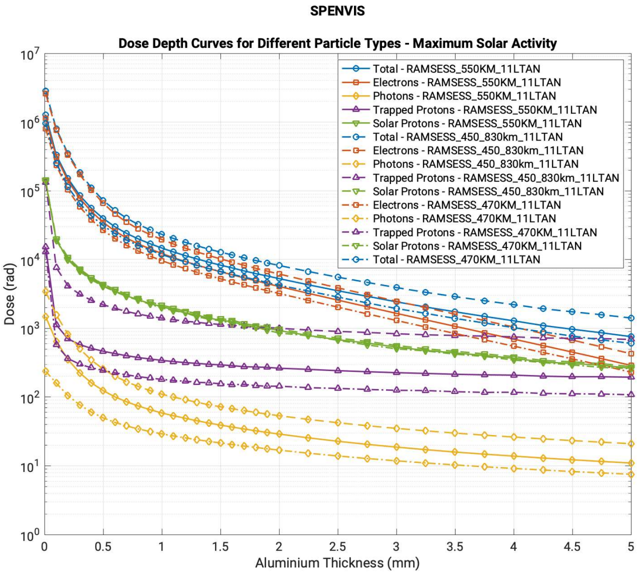

Figure 4: Comparison of Total Dose depth curves for circulars and elliptical orbits at maximum solar activity.

Although a marked increase in trapped protons is observed at the higher-altitude orbit, with contributions rising by approximately an order of magnitude, it is important to note that the proposed detectors are selective to particle type rather than their origin. Given that solar protons remain the dominant contributor, no significant differences in the overall proton dose between the two orbits have been noted. In conclusion, the proposed missions can be considered essentially equivalent, as the minimal differences in the radiation environment do not have a significant impact on overall mission outcomes.

Due these results, a trade-off between the previous mission scenarios has been carried out, considering the foreseen radiation environment in all cases, and the impacts of the possible orbits on the possible launch opportunities and on the platform design. Regarding this last aspect, the elliptic orbit would strongly impact on the development process of the platform, with the subsystems that will have to be qualified for a wide range of altitudes. In addition, as already stated the elliptic orbit would require the deployment of the solar sail at the beginning of life, adding complexity to the ADCS. Moreover, an ad hoc orbital transfer will be needed by the launcher or orbital transfer vehicle that will have to deliver RAMSESS to its operational orbit.

On the other side, as shown, the radiative environment does not exhibit major changes in the range 400-1000km for the relevant aspects to the RAMSESS mission. Consequently, no major advantages are foreseen at this stage in the selection of elliptical orbits or even circular orbits that need drag support devices.

In conclusion, the 470 km circular orbit has been selected as the current preferred baseline.

3. The payload

The payload of the RAMSESS mission has been designed ad hoc for the mission and it will be based on hardware and components with past space heritage and radiation hardened features. The heart of the payload of RAMSESS is an innovative and isotropic radiation detector produced by Due2Lab along with the analog electronic for the signal conditioning of the species and a local high voltage power supplying system. The analog part with the detector interfaces the satellite bus by means of a still designed ad hoc electronic for digitalization and data handling; the latter digital part of the payload is designed by Kayser IT.

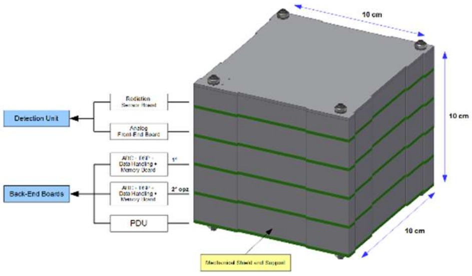

Figure 5: Preliminary CAD model of the 1U Payload

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3.1 CZT Detector

The core of the payload of RAMSESS is the 3D CZT detector. This detector represents a step forward for space radiation monitoring and spectroscopic applications. It is a combination of dosimetry, particle discrimination, and background suppression in a compact, cryogen-free design makes it an ideal candidate for next-generation space missions.

In the RAMSESS mission, the capabilities of the CZT detector will be rigorously tested and validated in a real operational environment, aiming to demonstrate the sensor's potential as a reliable and advanced solution for future space exploration missions. In the LEO environment, where particles and radiation originate from all directions, the proposed geometry of the CZT detector has been specifically designed to be isotropic and enable 3D localization of interactions. This ensures accurate detection and analysis regardless of the incident angle of the radiation.

The 3D CZT designed for the LEO Environment results in a state-of-the-art CZT crystals surrounded by a guard-ring anode, with a single planar cathode on the opposite side. The 3D CZT detector's electrode configuration allows precise determination of the energy and spatial coordinates (x, y, z) of radiation interactions within its volume. As illustrated in Figure 6, the detector design incorporates a defined coordinate system. The depth (z) of the interaction is derived from the cathode-to-anode signal ratio, achieving submillimeter resolution. Moreover, by processing signals from adjacent non-collecting pixels, subpixel accuracy can also be achieved in the x–y plane.

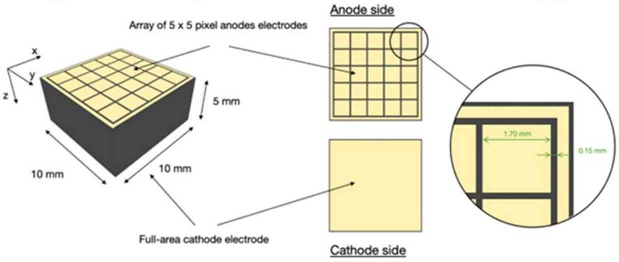

Figure 6: 3D CZT detector design.

The detector is biased with a negative voltage (typically 200 V/mm) applied to the cathode. When charged particles or photons interact within the detector volume, they generate electron-hole pairs that drift in opposite directions under the influence of the resulting electric field. This movement induces signals on the electrodes, directly generating an electrical current.

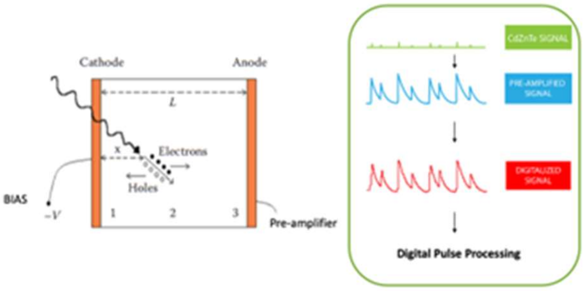

Figure 7: Operating Principle: Block Diagram.

A dedicated low-noise, high-gain pre-amplifier unit enables the conversion of current to voltage for ionizing events detected by the sensor. Each pixel and the cathode are connected to individual pre-amplification channels. The gain of the pre-amplified signal can be fine-tuned by selecting specific feedback capacitor values within the operational amplifier's feedback loop, allowing the dynamic range to be optimized for particles with varying energy levels.

3.2 Data Handling System (DHS) of the Payload

The amplified analogic signals are subsequently digitized by the digital part of the payload for the data handling, starting with a 18-bit ADC, and the resulting data is processed by an FPGA to identify the nature and energy of the detected ionization events.

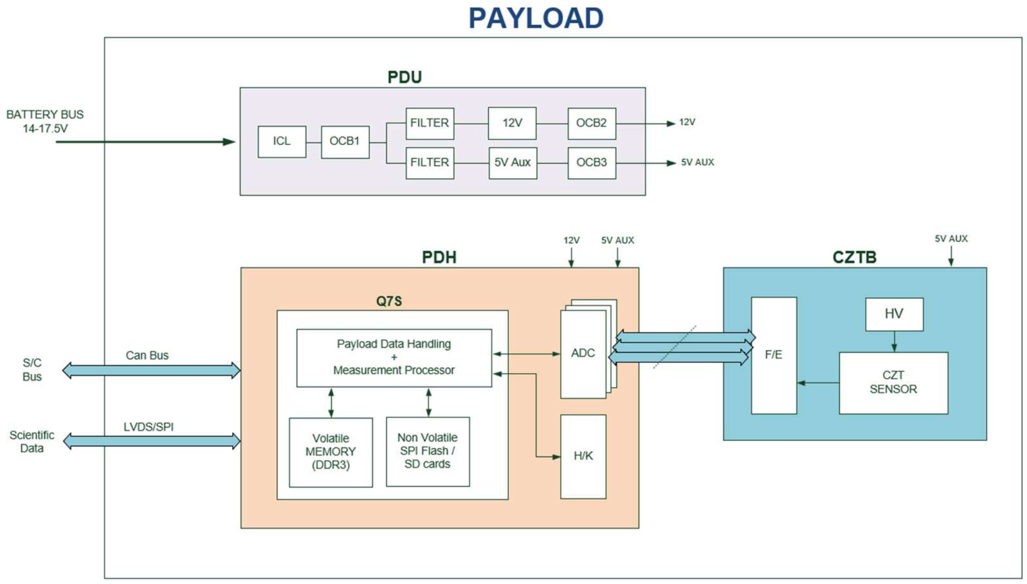

Figure 8: Schematic of the Power and Data Handling System of the Payload.

The Data Handling System of the Payload includes two main sections, one called Payload Data Handling (PDH) including the 18 bit ADC section and the real data management section, based and space qualified SoC FPGA controller. This data handling solution has been designed to support price-sensitive commercial missions that require reliable, qualified solutions. This solution is also small size, low mass and power consumption make it ideal for nano satellites applications. It also Incorporates a dual-core Cortex™-A9 MP Core processors and enhanced hardware/firmware recovery mechanisms which provides eventually advanced precision performance for the most demanding nanosatellite missions. It features an All-Programmable System-on- Chip (AP SoC), including a wide array of hardware interfaces. The electronic boards, finally combine a small form factor with broad networking, processing and I/O capabilities. At the core of the data handling system is a hybrid environment of powerful CPUs and reprogrammable logic, providing consistent, reliable performance. The library of logic and software functions is augmented by onboard analog and digital I/O.

Flight proven across multiple mission applications for a range of customer requirements this readily available solution has inherited advanced error detection and correction. RAM is protected via an EDAC mechanism to guard against radiation effects. This mechanism provides protection, not only against data modifications, but also against errors in the address decode logic.

The second section of the DHS includes the power distribution system which starting from an unregulated power bus from the Electric Power System (EPS) of the platform provides the rest of the payload with two (passively) regulated main and auxiliary power lines, along with the own embedded protection devices.

3.3. Radiation Measurements, on-Board Data Management

To maintain comprehensive control over the sensor’s performance once in orbit, a so-called “snapshot” (significant radiation event to be captured) operating mode has been designed for the detection unit. In this mode, each detector electrode can independently issue a trigger signal to the processor. Upon receiving such a trigger, the processor synchronously records the state of the entire system (i.e., all electrodes) immediately before and immediately after the event that generated the snapshot, regardless of which electrode produced the trigger. These snapshots are referred to as the “secondary data” of the mission.

The trigger condition is programmable and based on surpassing a predefined threshold in the pre-amplified, filtered, and conditioned signal. This filtering and conditioning are designed to mitigate spurious spikes and minimize false triggers, thereby optimizing the use of the limited available memory. With this approach, it becomes possible to identify unexpected particles or ionizing events and adjust the implemented digital signal processing algorithms accordingly.

To estimate background events and identify potential trigger issues, a dedicated scheduling for the acquisition of secondary data could be implemented at regular intervals and for predefined durations, with all trigger thresholds set to the minimum. This approach would help detect any malfunction in one or more preamplification-acquisition channels and allow for adjustments to the threshold levels of the problematic channels accordingly.

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By collecting a limited number of such snapshots each day, within the constraints imposed by the final payload architecture (i.e. memory size), it will also be possible to post-process these data to reconstruct the primary events described previously, albeit with reduced statistics.

3.4. Radiations Energy and Dose Phenomenology, Background Noise suppression

Using the partial histograms derived from the primary data, it is possible to determine the energy distribution of ionizing events detected by the sensor. Considering the CubeSat's inherent shielding conditions, these energy distributions can then be employed to calculate the Total Ionizing Dose (TID) absorbed by the detector. The response function of the device to the various particles depends on the radiation-matter interactions involved in the detection process and it can be obtained by means of proper simulations and experimental calibrations. This allows to estimate the fluence and, consequently, the corresponding dose of the external radiation.

During the mission, the payload will be exposed to various background radiation sources that must be carefully considered for data validation. Operating in a polar LEO orbit, the sensor faces a diverse radiation environment where various background sources can affect measurements. Primary cosmic rays—mainly high-energy protons and heavier ions—interact with the spacecraft and detector materials, generating secondary particles and increasing overall background. These primary cosmic rays, composed mainly of high-energy protons and electrons, interact with the Earth's atmosphere, generating a cascade of secondary particles, including neutrons, muons, and gamma photons, which can affect measurements. The Earth's albedo, including backscattered electrons and photons, further contributes to the background complexity, along with neutrons produced by cosmic ray interactions with the ground and the magnetosphere. Extragalactic background radiation in the X-ray and gamma-ray bands, though generally weaker, can accumulate over long integration times. Additional noise arises from self-scattering within the detector housing and potential activation of detector and spacecraft materials by high-energy particle fluxes. Finally, the spacecraft's shielding itself can generate scattering effects and secondary particle production, altering the detected energy spectrum.

Several strategies may be considered to enhance the signal-to-noise ratio and mitigate these contributions, such as selective shielding approaches, optimized detector geometry, and advanced data-processing algorithms that discriminate between genuine interactions and spurious events. While the 3D CZT architecture inherently aids in tracking and distinguishing different types of radiation, its effectiveness can be augmented by carefully planning calibration campaigns, leveraging simulation tools, and implementing tailored event selection criteria. A thorough understanding and accurate modelling of these background sources are essential to ensure the reliability of radiation dose measurements and to effectively discriminate between electrons, protons, and gamma photons.

4. The platform

The satellite of the RAMSESS mission is based on 6U CubeSAT standard of dimensions in Figure 9. The Satellite is composed by two deployable solar panels and another one fixed on the satellite body structure. In this configuration, the satellite is equipped with 7 body-mounted solar cells and 32 deployable solar cells with an efficiency of 29.5%, Figure 10.

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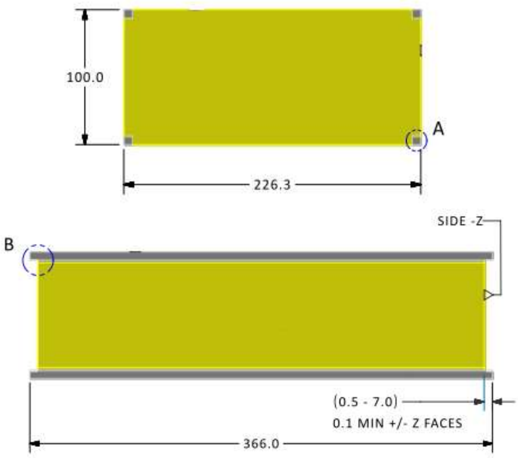

Figure 9: Satellite dimensions compliant with the CubeSAT Design Specification. Above - Top View, Below-Lateral View.

On the outer faces are located the S-Band antennas, UHF antenna, GNSS antenna, ADCS sensors (deployable magnetometer, sun sensor, etc…).

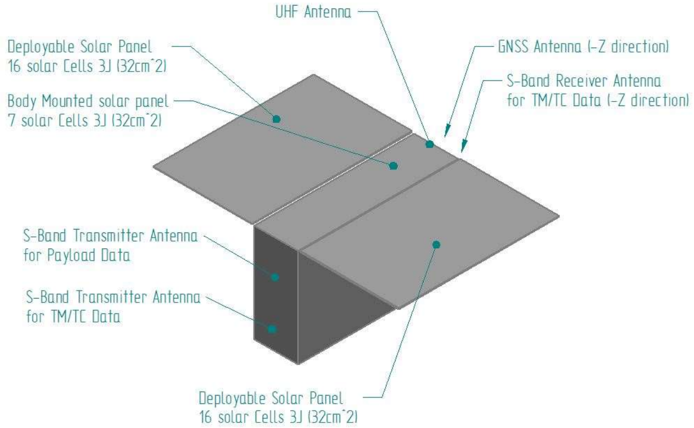

Figure 10: RAMSESS Satellite.

Internally, the satellite is composed by the following subsystems and Payload:

- OBC included GNSS receiver
- Power Distribution Module (PDM) and Battery Pack
- UHF Transceiver with deployable antennas
- S Band transceiver with two fixed patch antennas
- S Band transmitter with a dedicated S-Band antenna
- ADCS suite, composed by:
  - 4 Reaction Wheels in pyramid config
  - Star tracker (TBC)
  - 3 x Magnetorquers
  - Coarse Sun Sensors
  - 2 x Fine Sun Sensor
  - 1 x Deployable Magnetometer
  - 1 x Compact Redundant Magnetometer
- The Payload

All subsystems / modules described in the previous paragraph are connected through power, data and rf interconnections as in Figure 11.

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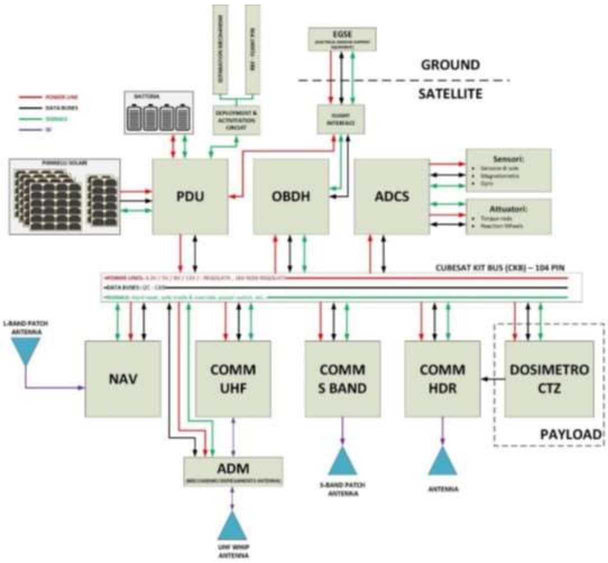

Figure 11: RAMSESS physical architecture.

5. RAMSESS Validation strategy

The mission of RAMSESS aims to bring the payload including the CZT Detector and eventually the overall satellite to a final Technology Readiness Level (TRL) to a ‘flight qualified’ status equal to 7. The accomplishment of this final target envisages an articulated stepwise approach mostly focused on the payload, being the rest of the platform subsystem based on higher TRL starting level; exception is made for the EPS where the recent ESA’s Debris Mitigation Guidelines has been issuing a significant redesign for taking in account energy passivation features after the operative lifetime of the satellite; also in this case IMT, in charge of the design of the platform, has been selecting a suitable EPS to also be space qualified and flight proven.

The Validation Strategy is split in two main phases, one foreseen to be completed before the B phase of the project and mostly involving the only CZT Detector (and its ancillary analog electronic) and less the payload and the platform; the other phase will be performed in the next C/D phases and will have as the main object the satellite also including the payload; last step is eventually the flight mission of RAMSESS and of the its innovative radiation Detector, envisaged in early 2029.

5.1. Validation of the CZT Detector

Validation of the standing alone detector includes two principal qualifications, one focused on the radiation species spectroscopic verification and discrimination capabilities evaluation: the other one aiming to a pre-qualification or preliminary evaluation of the Detector suitability for the launch loads environment (i.e. vibrations, shock and thermal vacuum) to be performed in suitable Space Qualification Laboratory.

To implement the validation and verification strategy for the CZT detector some samples of a so-called “breadboard” have been designed by Due2Lab.

5.2. Breadboard Physical and Design specification

Each single Bread Board consists of two main subunits: the detector PCB and the associated pre-amplification boards. The detector PCB serves as the physical host for the CZT detector, onto which electrodes (pixels, cathode, and guard) are bonded. This board also integrates a DC-DC converter capable of generating the high-voltage (HV) bias required to establish the internal electric field within the CZT crystal, ensuring proper charge carrier drift. In addition to the DC-DC converter, the detector PCB accommodates the necessary passive components - primarily resistors and a few capacitors - used for stabilizing and filtering potential disturbances from the HV supply, as well as the decoupling capacitors required for proper pre-amplification of the cathode signal. Furthermore, the detector PCB features high-

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density connectors, enabling seamless integration with the two dedicated pre-amplification boards. The testing of the breadboard allows a preliminary verification and validation strategy in the A and B phases of the project.

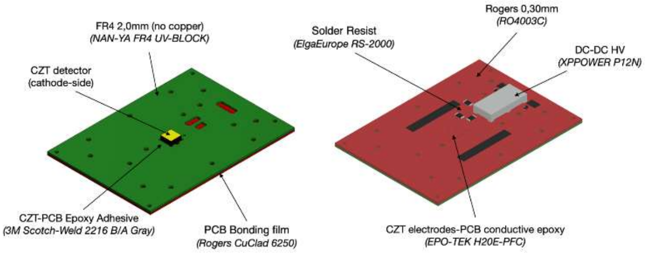

Figure 12: PCB-detector, materials & main components.

5.3. Validation Plan of the CZT Detector

5.3.1. Ionizing radiation testing

The ionization radiation testing phase is designed to thoroughly characterize the detector’s spectroscopic performance and assess its resilience to radiation-induced damage. Following several steps of the testing.

Prior to the qualifications, a calibration of the detector versus the radiating species, i.e. electrons, protons,.. also supported by the assessment with the numerical results of a model of the CZT, is also foreseen.

I. **Baseline Gamma Spectroscopy**

Initially, the system will be exposed to well-defined gamma-ray sources such as Na-22 and Cs-137 arranged in a Photon Parallel Field (PPF) configuration. These sources are chosen because their known and distinct gamma energies allow for a clear assessment of the detector’s intrinsic energy resolution, calibration, and linearity prior to any radiation damage.

II. **Alpha Particle Response**

After establishing the baseline gamma performance, the detector will be tested with alpha particles emitted by an Am-241 source. Alpha particles from Am-241 provide a high-energy (approximately 5.5 MeV) reference point, enabling the evaluation of the detector’s charge collection efficiency, energy calibration, and spectroscopic resolution under different interaction conditions than those encountered with gamma rays.

III. **High-Dose Irradiation**

To simulate the effects of long-term exposure to harsh space radiation environments, the detector and its associated electronics will be subjected to a controlled high-dose X-ray irradiation using a 160 keV, 600 W X-ray tube. This process will deliver an accumulated dose on the order of 20–30 kRad. Such a dose level is chosen to represent a worst-case scenario for radiation damage, allowing the team to observe potential degradation in detector performance, component stability, and signal integrity.

IV. **Post-Irradiation Assessment**

Following the irradiation, the entire sequence of gamma spectroscopic measurements will be repeated with Na-22 and Cs-137. By comparing pre- and post-irradiation results, any shifts in energy resolution, sensitivity, or noise levels can be identified. This comparison will help determine whether the device and its electronics maintain their expected performance range, confirming the suitability of the chosen.

materials, design strategies, and protective measures for the intended mission environment.
Through these tests, the team will gain insights into the detector’s robustness, validate its resistance to radiation damage, and establish confidence in its ability to deliver reliable data over the lifetime of the mission.

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5.3.2 Launch Load Qualification

The objective of the testing campaign is to perform a preliminary evaluation (even if the launcher of RAMSESS is unknown to date) of the suitability of the CZT detector, accommodated in a bread board fashion, to the typical launch and the space environment. With more detail, one of the bread board with the CZT Detector will be subjected to some tests to be performed in the CIRA's Space Qualification Laboratory aimed at verifying the suitability of the assy to the condition deemed the most critical during the future complete mission: at least Random/Sine Vibration Tests as representative of the launch (Vega C envelope will be taken as reference), Thermal Vacuum cycles to be representative of the current orbital RAMSESS mission.
The full qualification of the payload and the CubeSat will be dealt after phase B.

6. Conclusions

The paper presents the 6 U Cubesat mission, RAMSESS, for the characterization of space radiation in LEO (out the magnetosphere) with an innovative CZT detector.
After the description of the mission CONOPS and radiation environment for the mission scenario, details about the detector CZT and the validation strategy before the flight have been provided.
The RAMSESS project is currently at the middle of B phase, which will be concluded within September 2025.

7. Acknowlegment

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