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# TechnoSat - A Nanosatellite Mission for On-Orbit Technology Demonstration

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## ABSTRACT

In the last 25 years, TU Berlin developed, built, launched and operated a number of university class satellites. Throughout these missions, emphasis was placed on developing technologies for Earth remote sensing, communication and attitude determination and control. The nanosatellite mission TechnoSat has the primary objective to provide on-orbit demonstration capability for novel nanosatellite technologies and components. The satellite carries five main payloads: A separation system for nanosatellites, a hatch mechanism designed for protection and on-orbit calibration of infrared cameras, a fluid dynamic actuator for energy efficient attitude control, an extendable boom system that is employed for gravity gradient stabilisation and STELLA, a miniaturised star tracker. The secondary mission objective of TechnoSat is the on-orbit verification of the novel adaptive nanosatellite bus TUBiX20 (TU Berlin innovative neXt generation 20 kg nanosatellite bus). TechnoSat is scheduled to be launched in Q4 2014.


## INTRODUCTION

The numbers of launched pico- and nanosatellites continue to rise continuously [1]. At the same time the market of components and subsystems for this class of satellites grows at a fast pace. Due to the strict requirements in terms of reliability, such components usually undergo a comprehensive qualification campaign on ground. However, the mechanical stresses of the launch and the environmental conditions on-orbit cannot be thoroughly simulated. Therefore, on orbit verification (OOV) is required, in order to prove the reliability and performance of novel technologies, components or subsystems before they can be applied on advanced missions [2].

The German Aerospace Centre (DLR) identified a large demand by industry and research institutions for OOV flight opportunities in Germany. This resulted in an OOV program based on the TET (Technology Experiment Carrier) microsatellite [3]. The 120 kg satellite TET-1 was successfully launched in 2012 and provides a one-year mission duration for experimenttation.

The comparatively shorter development times and lower costs of a nanosatellite mission make this satellite class highly attractive for OOV missions [4]. The TechnoSat mission was developed to demonstrate the capabilities of the nanosatellite class for OOV applications.

## THE TUBIX SATELLITE BUS

TU Berlin is currently developing a nanosatellite bus, which is easily adoptable to a variety of missions, payloads and orbits. The development builds on 25 years experience in satellite development in which TU

Berlin launched 10 satellites [5, 6]. The TUBiX platform is developed in two versions, for a 10 kg and the 20 kg mission, namely TUBiX10 and TUBiX20. Currently, three missions based on TUBiX are being developed at TU Berlin, namely the S-Net, the TechnoSat and the TUBIN (TU Berlin Infrared Nanosatellite) mission [7].

TechnoSat is based on the TUBiX20 bus. The highly modular structure of the bus allows for adopting it to different payload sizes and power requirements by adjusting its height and adding customised solar panels. In order to increase the reliability of the bus, the design follows a consistent single-failure tolerant approach that builds on different cold and hot redundancies. Therefore, any one component may fail without jeopardising the mission. The attitude control system of the TUBiX20 platform can be easily adapted to any mission. It ranges from a coarse but highly energy efficient system, solely based on magnetic torquers as actuators to a high precision system with a pointing accuracy of approximately 10 arc minutes.

## THE TECHNOSAT MISSION

TechnoSat is a nanosatellite mission whose primary mission objective is the OOV of novel nanosatellite components. The secondary mission objective is the development and demonstration of the TUBiX20 nanosatellite bus. In this manner TechnoSat shall provide risk mitigation for the TUBIN mission, which will be launched one year after TechnoSat and is also based on TUBiX20. Due to the fact, that the payloads of the TechnoSat mission do not require high accuracy in pointing, the coarse attitude control system of TUBiX20 is included in the mission, providing a pointing knowledge of approximately 15 degrees and three-axis stabilisation with approximately 20 degree accuracy. Figure 1 shows a CAD model of the TechnoSat satellite.

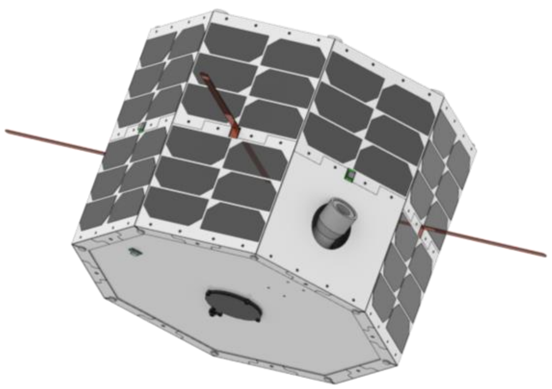

**Figure 1: CAD Model of the TechnoSat Satellite**

During the mission duration of one year, the capabilities of the different payloads and bus subsystems shall be demonstrated and their performance parameters shall be evaluated. Table 1 gives an overview over the basic parameters of the TechnoSat mission.

**Table 1: Basic Data of the TechnoSat Mission**

| Parameter | Value |
|---|---|
| Launch Date | Q4 2014 |
| Design Lifetime | 1 year |
| Mass | 15 kg (TBC) |
| Volume | 406 × 406 × 311 mm (TBC) |
| Communication | UHF |
| ADC Sensors | Fibre-Optic Gyros, Sun Sensors, MEMS Magnetic Field Sensors, MEMS Gyros |
| ADC Actuators | Magnetic Torquers |

## THE TECHNOSAT PAYLOADS

TechnoSat carries a number of novel nanosatellite components for on-orbit verification as payload:

- AI Electromechanical Separation System (AIESS)
- Extendable Boom System (EBS)
- Fluid-Dynamic Actuator (FDA)
- Black-Body Hatch Mechanism (BBH)
- Star Tracker STELLA

### *The AI Electromechanical Separation System*

An essential feature of separation systems is the release method used for the separation of the satellite from the launch vehicle. Two distinct release mechanisms, pyrotechnical or electromechanical, may be employed. The advantages of electromechanical over pyrotechnical systems are the prevention of high shock loads and contamination by pyrotechnical substances or combustion products, as well as a higher safety and therefore higher acceptance by launch service providers. Moreover, electromechanical systems feature a higher reproducibility of the seperation and allow for a better handling with minor corresponding safety requirements during the test phase.

The AIESS (AI Electromechanical Separation System) is a separation system for the separation of satellites with a mass of up to 50 kg, which is currently under development at AI: Aerospace Institute, Berlin, Germany [8].

The following high-level requirements for AIESS have significantly determined its general configuration and functionality:

- AIESS shall feature a modular design
- AIESS shall feature a redundant separation mechanism
- AIESS shall avoid the usage of pyrotechnical components
- AIESS shall allow for numerous successive separations for ground testing

AIESS mainly consists of three rings, the satellite ring, the launch vehicle ring and the locking ring, as well as two hot redundant motor units (see Figure 2). Satellite and launcher ring are held together by a dynamic locking system and are pre-loaded radially by the locking ring, which also provides the required joint stiffness.

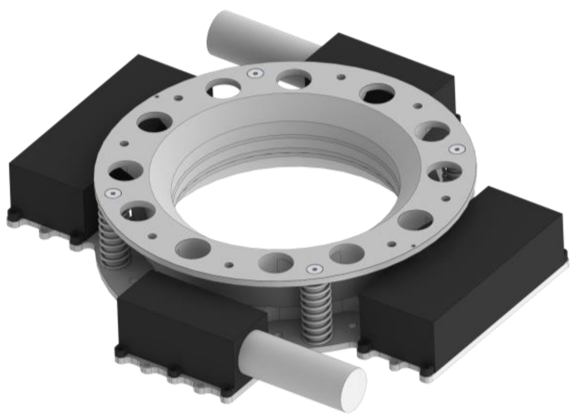

**Figure 2: CAD Modell of the AIESS Assembly**

The two motors units are mounted on the base plate of the launcher ring. They each rotate a self-locking jackscrew tangentially to the locking ring. A locking ring hook on the jackscrew causes a rotational movement of the locking ring. The self-locking characteristic of the employed jackscrew design provides an inherent safeguard against premature release.

The system is released by rotating the locking ring. It is equipped with cavities, which exactly align with the locking elements in the launcher ring while the system is unlocked. Once the locking elements shift into the cavities, the system is unlocked and a set of four compressed springs provide the required jettisoning energy to separate the spacecraft from the launch vehicle.

AIESS is equipped with two electronic compartments (EC), each of which contains a micro-controller for the processing of sensor data, such as the temperature, the status of the separation switches and the position of each jackscrew. Moreover, the ECs are equipped with DC/DC converters for the purpose of galvanic isolation of the system.

The technical specifications of AIESS are shown in Table 2.

**Table 2: AIESS Specifications**

| Characteristic | Value |
|---|---|
| Actuation | Electromechanical |
| Electronic Connectors | 2 × D-Sub, 15 pins, double row (TBC) |
| Dimensions | 366 × 366 × 60.25 mm (TBC) |
| Mass | < 5 kg (TBC) |
| Supply Voltage | 28 V (TBC) |
| Electric Power | 87 W (incl. 10% margin) (TBC) |
| Separation Velocity | 1 m/s ± 15% (TBC) |
| Remarks | No pyrotechnics, ITAR free |
| Development Status | Functional test models successfully tested under microgravity conditions<br>Ground qualification under preparation<br>On-orbit verification planned for 2014/15 |

During the development phase of AIESS, four different functional test models were used to demonstrate the key technologies of the system under microgravity conditions. The various configurations of the functional test models differ from each other in the chosen motors and compression spring forces. All four configurations were successfully tested repeatedly under microgravity conditions during the 22nd DLR/Novespace parabolic flight campaign in April 2013 in Bordeaux, France (see Figure 4 and Figure 3).

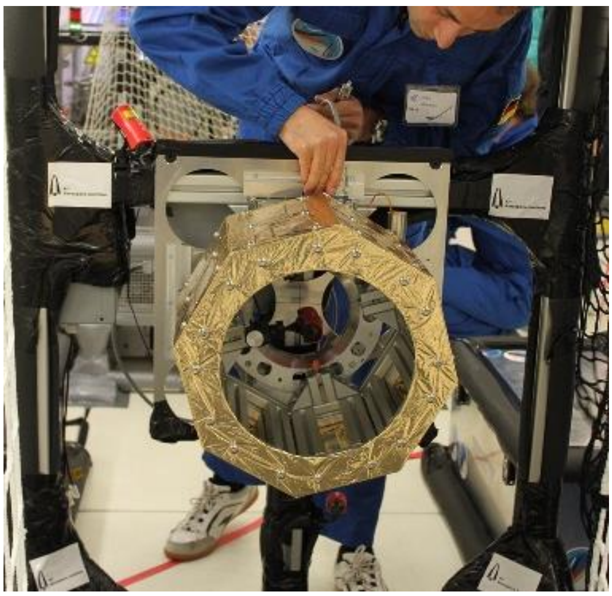

**Figure 3: AIESS Functional Test Model during Preparation for Parabolic Flight Experiment**

During the campaign, the following tests could successfully be completed:

- **Verification:** Successful demonstration of the separation of a dummy satellite with a mass of 20 kg.
- **Validation:** Successful demonstration of the reproducibility by repeating tests with the same functional test model.
- **Modification:** Successful demonstration of the system redundancy by successful separation despite simulated loss of one motor unit.


**Figure 4: Separation of Dummy Satellite during Parabolic Flight Campaign**

The next development step involves the design, manufacturing and integration of an AIESS qualification model, which will undergo ground qualification by mechanical and environmental tests.

### *Black Body Hatch System*

TUBIN, the follow-up mission of TechnoSat will carry a thermal infrared imager based on a microbolometer array [9, 10]. To maintain the data quality of such an imager, regular calibration procedures are mandatory. While radiometric calibration on ground can be performed by means of laboratory blackbodies, in-flight calibration is a much more demanding task. The Black Body Hatch system (BBH) was designed for in-flight calibration of the TUBIN infrared cameras. In order to reduce the risks associated with the use of such a novel system, it will be verified on orbit within the TechnoSat mission.

There are three common types of blackbodies, which were used for in-flight calibration of satellite payloads so far: cavity blackbodies, flat heaters with v-grooved surfaces and honeycomb-type blackbodies. Due to their complexity, size, mass and costs, none of these concepts is applicable within a nanosatellite mission. Therefore, a novel approach was chosen for the on-orbit calibration system for the TUBIN infrared payload.

Figure 5 shows a CAD Model of the BBH assembly. The assembly can be divided into two main parts, the opening mechanism and the calibration assembly.

**Figure 5: CAD Model of the BBH Assembly**

The opening mechanism is driven by two piezoelectric motors. A plain bearing mounted wheel transforms the motor forces into a momentum. Mechanical stops define the open and closed position of the hatch. Velocity and direction of the hatch movement can be changed by adjusting the frequency of the pulse-width modulated input. To allow for compensation of the temperature dependence of the resonance frequency of the motors, their temperatures are measured twice a second. A hall sensor measures the opening angle with a sampling rate of 10 Hz.

A major design driver for the opening mechanism is the demand for high reliability. In case of a malfunction in the regular opening system, an emergency opening should be possible at any time. Due to the code of conduct for space debris mitigation, and the risks associated to the use of pyrotechnics aboard the satellite, a solution as used in the BIRD (Bispectral Infrared Detection) mission, where the hatch would have been blasted off by a small explosive charge, is not applicable. Instead, a preloaded torsion spring is used for emergency opening. Its torque was calculated to be at least twice the sum of the holding torque of the motors and the friction torques of the bearing. During nominal operation the spring is secured by a fuse wire that can only be released by telecommand. The basic parameters of the opening mechanism are given in Table 3.

**Table 3: Specifications of the opening mechanism**

| Parameter | Value |
|---|---|
| Total Volume | 70 × 70 × 20 mm |
| Mass | approx. 50 g |
| Supply Voltage | 3 V |
| Power Consumption | 3.6 W |

To achieve good calibration results, three parameters of the calibrator assembly are of importance: the temperature uniformity, the precision of its measurement and the emissivity of the calibrator surface.

The centrepiece of the calibrator assembly is a space qualified foil heater. To minimize the heat conduction between the heater and the calibrator housing, it is isolated by PTFE isolation rings. The control circuit of the heater is designed in such a way, that the temperature can be stabilized at any point above ambient temperature and below 40° C.

In order to achieve a uniform, high emissivity a variety of different coatings were tested. As a result, a special metal velvet coating with self-adhesive metal backing was chosen. Its spectral characteristic is shown in Figure 6. Due to the metal backing, the heat is evenly distributed over the calibrator surface, which enhances the temperature uniformity.

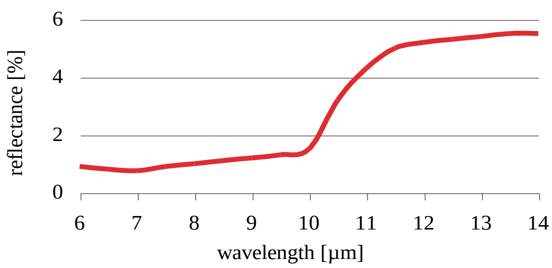


**Figure 6: Hemispherical Reflectance of the Metal Velvet Coating**

The temperature of the calibrator surface is the most important input parameter for calculating the calibration coefficients. Therefore, the precision of the temperature measurements directly affects the quality of the instrument data. In order to obtain a fine resolution of the temperature measurements, two 24-Bit temperature sensors are used. The measurement accuracy within a temperature range of -5° C to +50° C is 0.1 K. The temperature is measured with a sampling rate of 10 Hz and averaged over 10 measurements for both sensors. The heating process takes approximately 2 minutes, depending on the ambient temperature. The basic parameters of the calibration assembly are given in Table 4.

**Table 4: Specifications of the calibration assembly**

| Parameter | Value |
|---|---|
| Total Volume | 72 × 72 × 8 mm |
| Mass | approx. 30 g |
| Supply Voltage | 12 V |
| Power Consumption | 10 W |

Due to the fact, that the calibrator assembly consists only of space-qualified components, the qualification campaign onboard TechnoSat will focus on the opening mechanism.

During the mission duration of one year the infrared payload of TUBIN will be calibrated at least 5 times a day. Consequently, the opening mechanism should be capable of performing at least 1800 opening cycles. To verify this capability, the hatch will be opened and closed 20 times a day for 90 mission days as part of its verification on TechnoSat. After the verification of the regular opening mechanism, the emergency opening will be demonstrated.

***Extendable Boom System***

The Extendable Boom System (EBS) is a single-use extendable boom for gravity gradient attitude stabilization of small satellites. Furthermore, a payload can be placed at the tip of the boom to conduct measurements outside the satellite’s sphere of influence. Table 2 gives an overview over the basic parameters of the EBS.

**Table 5: Specifications of the EBS**

| Parameter | Value |
|---|---|
| Tube Material | CuBe25 |
| Tube Length | 5000 mm |
| Tube Diameter | 17.5 mm |
| Tube Wall Thickness | 0.07 mm |
| Stowed Volume | 120 × 120 × 150 mm |
| Mass (Exclusive Tip Mass) | approx. 1.7 kg |
| Deployment Speed | approx. 0.4 m/s |
| Power Consumption During Expansion | approx. 9.2 W |
| Data Interface | 2 x CAN 2.0 |

The centrepiece of the system is a five-meter long slotted Copper-Beryllium-Tube. While the boom is retracted, the tube is wound onto a spool. Inside the spool a spring applied safety brake inhibits any motion, while not supplied with electrical power. The spring-loaded expansion process is activated by connecting the brake to the supply voltage, allowing the spool to rotate. The boom can be extended progressively up to 4500 mm. Deployment speed and boom length are measured by an inductive sensor.

A sensor-board with a MEMS gyro, a MEMS accelerometer and a MEMS magnetic field sensor is located at the tip of the boom. The cable for power supply and data transmission of both sensor board and payload is stowed in a cable magazine while the boom is retracted and runs inside the tube once the boom is extended. During launch the boom is secured by the failsafe brake and an additional nylon wire, which is cut by a heating element. Figure 7 shows a CAD model of the EBS assembly.

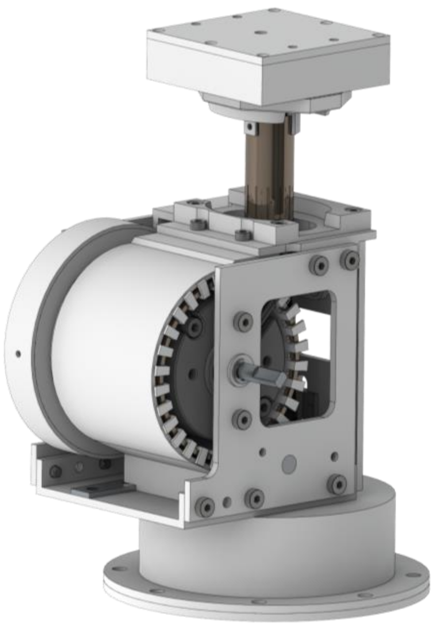

**Figure 7: CAD Model of the EBS assembly**

To test the dynamic behaviour of the tube during extension, as well as to determine the most suitable deployment velocity for the application within the TechnoSat mission, the EBS will be tested with different boundary conditions on a parabolic flight campaign in September 2013.

During the TechnoSat mission, the boom will be extended in sub-steps of one meter. This will allow for analysis of the dynamics of the satellite for different lengths of the boom. The results are then used to refine the simulation of the satellites gravity-gradient dynamics.

***Fluid-Dynamic Actuator***

The Fluid-Dynamic Actuator (FDA) is a novel attitude control actuator for small satellites, which is currently under development at TU Berlin, Germany. The system consists of a closed ring structure containing liquid metal, an electromagnetic pump and the respective control electronics. A direct-current conduction pump uses the Lorentz body force to accelerate the liquid metal in the ring and hence to store angular momentum. For the verification within the TechnoSat mission Galinstan, a eutectic alloy of Gallium, Indium and Tin is used as liquid metall. Due to its simple design, which does not include any moving parts the FDA offers strong shock resistance and low abrasion.

While hall sensors can be used to measure the angular velocity of reaction wheels they cannot be applied within the FDA. Consequently, there is no way to determine the current value of angular momentum directly. To overcome this obstacle, a MEMS gyroscope is used to measure the angular rate of the entire satellite. Furthermore, the reverse voltage of the direct-current conduction pump is measured, to determine the currently conserved angular momentum. As an additional advantage of the system, it is expected that the liquid metal provides nutation damping. For the TechnoSat mission FDA-A4 was developed. The specifications of the system, shown in Table 6, are tailored to the requirements of a nanosatellite mission.

**Table 6: Specifications of the FDA-A4**

| Parameter | Value |
|---|---|
| Angular Momentum Capacity | $25 \times 10^{-3}$ Nms |
| Maximum Torque | $20 \times 10^{-3}$ Nm |
| Working Fluid | Galinstan |
| Total Mass | 1100 g |
| Nominal Supply Voltage | 5 V |
| Nominal Power Consumption | 1 W |
| Supply Voltage for High Torque Mode | 12 V |
| Power Consumption for High Torque Mode | 6 W |
| Fluid Ring Diameter | 300 mm |
| Data Interface | 2 × CAN 2.0 |

For the verification within the TechnoSat mission a single axis system that provides actuation capabilities around the satellite's roll axis is applied. It will be the first application of a liquid metal-based attitude actuator on orbit and shall demonstrate the capabilities of this technology to be used as attitude control actuator for nanosatellites.

The primary objective of the experiment is the successful commissioning of the FDA. Secondary objectives include the demonstration of attitude manoeuvres using the FDA as actuator and the demonstration of the nutation damping capabilities of the system.

Figure 6 illustrates the FDA-A4; as a safety measure, the metal-filled ring structure is located inside an enclosing frame structure.

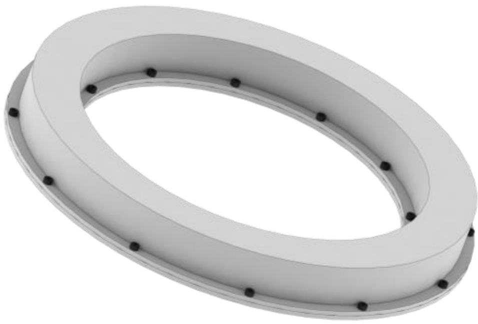

**Figure 8: CAD Model of the FDA Assembly**

***Star Tracker STELLA***

The star tracker STELLA, shown in Figure 9, is designed for pico- and nanosatellite applications and it therefore obeys all dimensional constrains commonly encountered in these satellite classes. STELLA distinguishes itself from other star trackers through its small size, its low mass and its low power consumption. It uses innovative algorithms and modern hardware. The functionality and capability of STELLA is shown in more detail in [11].

**Figure 9: STELLA Star Tracker**

The project phases design, implementation, construction and qualification have been completed. The next step is the on-orbit verification of STELLA within the TechnoSat mission. The most important physical parameters and specifications of STELLA are listed in Table 7.

STELLA was developed in two years, beginning with the requirement and concept phase. During the following design phase hardware and software were developed and finally qualified through a full qualification program according to ECSS, which includes thermal-vacuum, shock, vibration and radiation testing [12].

**Table 7: STELLA Specifications**

| Parameter | Value |
|---|---|
| Accuracy | 0.01° pitch/yaw, 0.04° roll 3σ |
| Field of View | 14,3° diagonal |
| Power Supply | 3.3 V |
| Power consumption | 275 mW (average) |
| Dimensions incl. Baffle | 91 × 46 × 58 mm |
| Mass incl. Baffle | 167 g |
| Operation Temperature | -25° … +55°C |
| Life time in LEO | 2 years (ref. 500 km) |
| Data output | Quaternion in ICRF |
| Output data rate | 4 Hz |
| Main interface | 2 × CAN 2.0B, 2 × UART |
| Connector | OMNETICS |

A flight model (FM) of STELLA has been prepared for verification within the TechnoSat mission. The objectives of the verification are to run several functional and performance tests procedures on orbit. First, the FM will be operated without providing attitude information to the satellite bus. After successful verification the star tracker can optionally integrated into the attitude control loop of the satellite.

During verification, STELLA will be tested in all is operational modes, which are listed in Table 8.

**Table 8: Test Modes of STELLA**

| Mode | Duration in Minutes | |
|---|---|---|
| | Min. | Max. |
| Base Mode (BM) | 10 | 100 |
| Attitude Determination Mode (ADT) | 10 | 100 |
| Image Download Mode (IDL) | 10 | 10 |
| Software Update DSP (SWUD) | 5 | 5 |
| Software Update FPGA (SWUF) | 10 | 10 |
| Star Catalogue Update Mode (SCU) | 30 | 30 |
| Star Catalogue Check Mode (SCC) | 5 | 5 |

After the initialization sequence STELLA will switch to the base mode (BM). In this mode the star tracker is idle and collects and distributes housekeeping data such as temperature, current and voltage from internal software modules and sensors. From base mode STELLA can be commanded into attitude determination mode (ADT). In this mode the star tracker computes the attitude and provides quaternions to the satellite bus. Furthermore, STELLA has the capability to transmit any recorded image via its main interface. This requires a transition to image download mode (IDL). Using the additional modes software update DSP (SWUD) and software update FPGA (SWUF) the main logic ICs of STELLA can be reprogrammed. Additionally, a star catalogue update mode (SCU) and star catalogue check mode (SCC) are implemented to provide update capabilities for the internal star catalogue to repair memory content compromised by radiation effects.

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