ENMAP SATELLITE BUS – A COST EFFICIENT PLATFORM FOR ADVANCED EARTH OBSERVATION MISSIONS

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ABSTRACT

The Environmental Mapping and Analysis Program (EnMAP) is a joint German initiative led by the GeoForschungsZentrum Potsdam, together with the industrial prime ship of Kayser-Threde and the satellite bus responsible OHB-System, under the super-vision of the German Space Agency DLR[1]. The launch of the satellite is planned for 2011 with a mission duration of at least 5 years.

With its hyperspectral capabilities covering the visible, near- and short-wave infrared wavelengths, EnMAP will provide high quality Earth observation data on a frequent basis. EnMAP provides information based on 218 contiguous spectral bands in the wavelength range from 420 nm to 2450 nm at a ground sampling distance of 30 m x 30 m. An imaging spectrometer, such as EnMAP, can resolve and detect biophysical, biochemical, and geochemical variables in distinct detail.

After a successful Kick-off the EnMAP project is currently in Phase B. This paper provides an overview of the on-going project results with a special focus on the satellite bus status. The paper highlights the bus core elements and their performances and capacities, which enable the fulfilment of the specific EnMAP mission requirements.

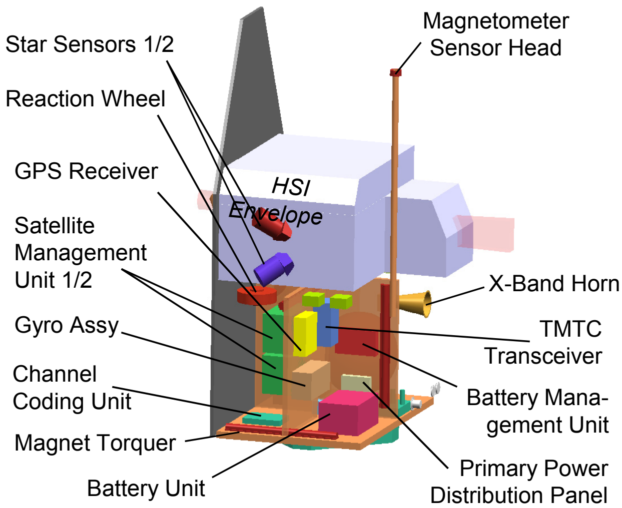
A special emphasis will be laid upon the modular approach of the satellite bus configuration, as well as on the accurate attitude control concept and the high rate on-board processing and downlink of the hyperspectral instrument data. Further, the paper addresses the high level of redundancy applied on the satellite bus, and it also outlines the overall cost-efficient approach that allows to realize the EnMAP project within its financial envelope of only 60 M€ including launch.

1. ENMAP SATELLITE BUS

Based on the heritage acquired from the SAR-Lupe project OHB-System provides a very suitable and cost effective satellite bus for the EnMAP mission. Its key advantages are a very modular and flexible configuration approach, a highly accurate attitude control concept and a high rate on-board processing and downlink of the payload (P/L) data.

1.1. Configuration

The preliminary configuration of the EnMAP spacecraft is shown in FIG 1 below.



[1] Funded by the Federal Ministry of Economics and Technology, Ref. 50 EP 0601

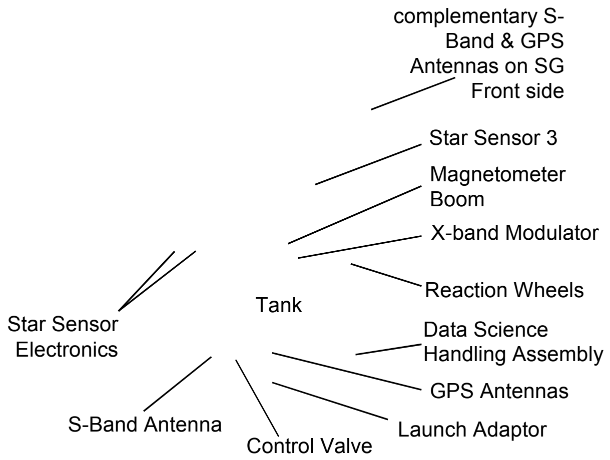


FIG 1. Preliminary EnMAP Bus Configuration

The EnMAP P/L is accommodated separately at the upper part of the spacecraft (see light blue envelope in Figure 1) to comply with high stability and thermal requirements of the optical elements. Further this accommodation provides maximum independency and most easy assembly of both the P/L compartment and the bus subsystems. The P/L can be thermally decoupled from other subsystems to minimize heat fluxes.

The overall dimensions of the S/C bus are (WxDxH) 1,8 x 1,2 x 2,0 m³, from which an envelope of approx. 1,7 m³ can be provided for the P/L.

Benefitting from its attractive stiffness to weight ratio, the bus core structure is manufactured in aluminum sandwich panels.

1.2. Spacecraft Budgets

The preliminary mass and power budgets are depicted in TAB 1 and TAB 2 respectively.

Including 50 kg of propellant the overall spacecraft mass sums up to 786 kg, which is fully compliant to the capability of numerous launchers into the EnMAP orbit, such as COSMOS.

EnMAP Mass Budget	
EnMAP Bus	532,0 kg
Payload	204,0 kg
EnMAP Dry Mass	**736,0 kg**
Fuel Mass	50,0 kg
EnMAP Wet Mass	**786,0 kg**

TAB 1. Preliminary EnMAP Mass Budget

The power consumption of the S/C bus as well as the payload in the corresponding operational mode is summarized in the power budget below. Together with an established EnMAP reference scenario these figures are the main drivers for the design of the solar generator power and the battery, which characteristics are presented in the following section 1.3.

EnMAP Power Budget						
	Preliminary EnMAP Power Modes					
All figures in Watts	Normal	Transition	Downlink	Calibration	Imaging	Orbit Manouver
EnMAP Bus	271	304	360	291	292	353
Payload	166	166	166	272	202	166
Subtotal Power	**437**	**470**	**526**	**562**	**493**	**519**
Losses	**13**	**14**	**16**	**17**	**15**	**16**
Total Power	**450**	**484**	**542**	**579**	**508**	**534**

TAB 2. Preliminary EnMAP Power Budget

1.3. Power Subsystem

The power subsystem constitutes of following functional components:

- Solar Generator (SG)
- Battery
- Battery Management Unit (BMU)

1.3.1. Solar Generator

The panel of the body-mounted SG is made of lightweight aluminium honeycomb structures selectively supported by dedicated CFRP elements. In this configuration the panel provides an area of approx. 4.6 m² that is available for solar cell assemblies, where the overall SG mass sums up to around 22 kg.

To satisfy typical high power demands of Earth observation payloads the SG is equipped with state-of-the-art GaAs triple junction solar cells. The relatively low degradation of these types of cells enables the SG to provide approx. 800 W end-of-life (EOL) to the spacecraft, assuming a preliminary cell layout as depicted in FIG 2.

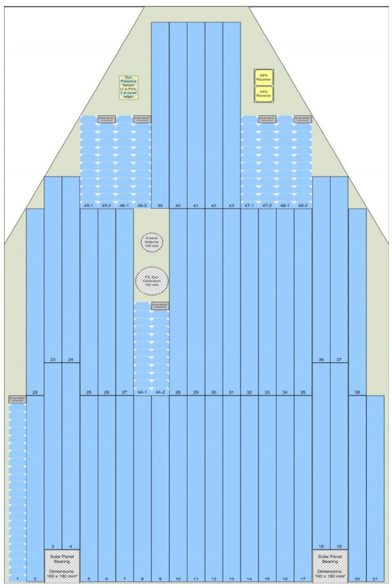


FIG 2. Preliminary Solar Generator Layout

Further, the SG accommodates dedicated sun presence sensors, GPS and S-band antennas, and P/L sun calibration can be performed through dedicated panel cut-outs.

At the present development stage the shape, size and – thus – achievable power of the SG has been optimized for the COSMOS launcher. Benefitting from its modular configuration, the platform can be easily adapted to other launchers, which would allow to achieve different power performances.

1.3.2. Battery

The EnMAP battery delivers the energy for the satellite in the eclipse as well as in sun phases where the power consumption exceeds the available SG power. It consist of Li-Ion cells that provide an energy density of 113 Wh/kg, where voltage ranges from 20 to 34 volts can be achieved. The charging process has been optimized in that way that the capacity fade during lifetime can be kept to a minimum, providing the best possible battery performance.

Fehler! Verweisquelle konnte nicht gefunden werden. below show the simulated battery state-of-charge during a typical one-day EnMAP scenario covering 15 orbits.

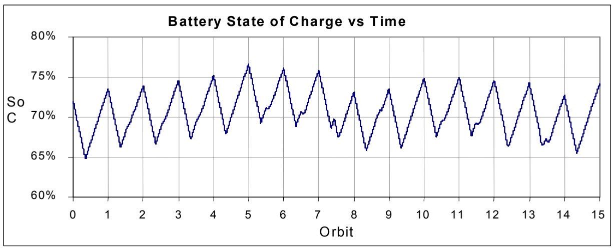


FIG 3. EnMAP Power Subsystem Characteristic

1.3.3. Battery Management Unit

The BMU supervises all battery relevant parameters and autonomously protect the battery in case of fatal software malfunction. The unit acquires the housekeeping data necessary for the S/W in order to manage the satellite energy sources. In addition, the BMU will switch-on the satellite after separation from the launcher.

The BMU implements the following functions:

- Under-Voltage Protection
- Over-Voltage Protection
- Battery Current Monitor
- Battery Voltage Monitor

1.4. Attitude Control Subsystem (ACS)

The EnMAP bus provides high accurate and reliable attitude control capabilities as required for highly sensitive optical and microwave instruments performing Earth observing applications. To achieve the requirements for various operational tasks, different ACS modes can be defined, such as:

- INIT MODE: Check out of basic functionality of the ACS elements according to a defined sequence of activities.
- NORMAL MODE: Sun pointing of the SG, 3-axis autonomous control, S/C standard operational mode.
- PRECISE MODE: Attitude of the satellite is manoeuvred according to dedicated attitude profiles in order to carry out specific tasks (data take, calibration, X-Band downlink, orbit manoeuvre).
- EMERGENCY MODE: Spin-stabilised coarse sun pointing in case of critical anomalies.

The spacecraft and its P/L is operated by means of so-called order files, which contain the essential information of the previously elaborated guidance profiles and are uploaded via S-band accordingly. The ACS on-board software will process the information contained in the uploaded files and will reconstruct (by means of interpolation) the complete original guidance profile computed on ground. With this concept the satellite is able to perform complex attitude manoeuvres. An extraction of an exemplary guidance profile is depicted in FIG 4 showing a fictive sequence of different ACS modes to allow dedicated spacecraft and P/L operations, such as image acquisition or S-band communications.

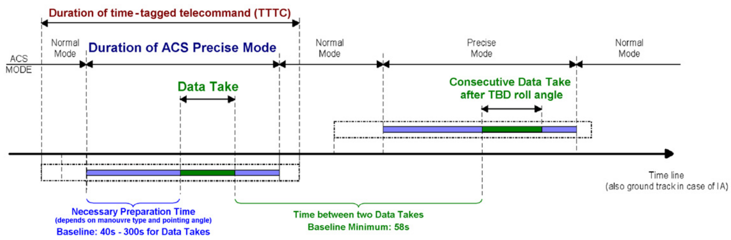


FIG 4. Exemplary Satellite Guidance Profile

In general, the hardware elements of the EnMAP ACS comprise sensors, controllers and actuators (see block diagram in FIG 5), where following essential functional components are explained in more detail in the following table.

Component	Description
Star Sensors	Up to 3 identical units provide autonomously accurate 3-axis information.
Gyro Units	Supply a very direct, accurate and smooth angular velocity signal.
Magnetometers	3-axis measurement of the Earth magnetic field for rough attitude information and for the selective operation of the magnet torquers.
Sun Presence Sensors	Rough assessment of the sun direction.
Reaction Wheels	Main attitude actuators. Up to four wheels arranged in a tetraedric configuration for internal redundancy.
Magnet Torquers	Used as attitude actuators and for momentum management.

TAB 3. Essential EnMAP ACS Components

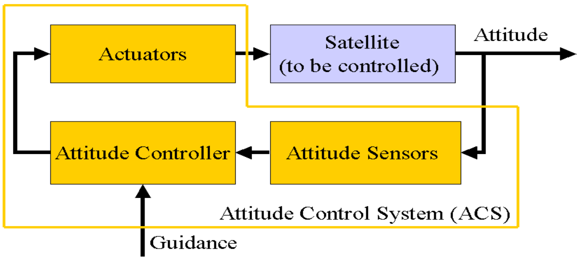


FIG 5. ACS Block Diagram

The optimized control of above described components allows to realize the required pointing knowledge of 100 m with an accuracy of less than 500 m at sea level.

1.5. Orbit Control Subsystem

The EnMAP bus is equipped with an Orbital Control System (OCS) comprising the following functional components:

- Hydrazine blow-down system
- Propellant tank with at least 50 kg capacity
- 2 thrusters with 1 N each
- Pressure and electrical components (such as valves, filters, transducers, etc.)

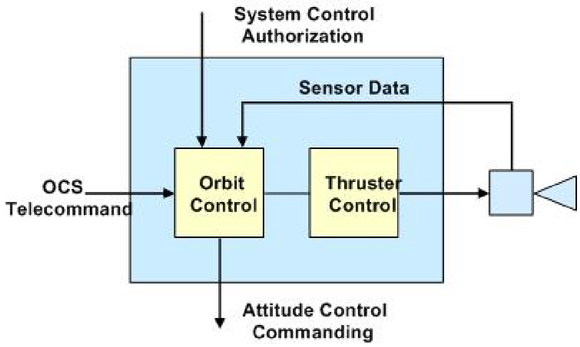


FIG 6. OCS Block Diagram

The OCS is required for the satellite commissioning and first acquisition of the nominal orbit after separation from the launcher, as well as to provide controlled thrust and thrust momentum for maintaining the nominal orbit during the operational lifetime. Also the execution of EOL-manoeuvres require the OCS in order to fully comply with the corresponding code of conduct for space debris mitigation.

In order to realize the maximum possible reliability of this subsystem the OCS for the EnMAP bus is designed to the criteria of minimum complexity.

1.6. High Rate On-board Data Processing

The EnMAP data handling subsystem comprises highly-efficient and reliable components that are capable to process optical Earth observation payload data with its typical high rates and volumes requiring minimum resources. Following units ensure the best mission-specific data handling performance:

- High-speed mass memory;
- Telemetry channel coding unit, conforming with CCSDS;
- X-band transmitter, performing data modulation and providing the RF signal to the
- High gain antenna.

Optionally the mass memory can be technically upgraded to allow high-speed data compression to minimize the data volume to be processed on-board and to be downlinked to the ground station.

The X-band transmitter provides the antenna with an RF signal at around 8200 MHz that allows the downlink of payload data with data rates up to 320 Mbit/s.

The modular approach enables the data handling subsystem to realize highly-flexible mission operations, and enables the S/C to comply with the requirements of various ground segments.

1.7. Thermal Control Subsystem

The Thermal Control System (TCS) is responsible for the regulation of the thermal environment within the EnMAP bus. This is primarily achieved by means of passive thermal control measures, such as multi-layer insulation (MLI) and heat pipe assemblies.

To minimize complexity and costs dedicated structural panels not covered with MLI serve as thermal radiators for waste heat removal from the bus subsystems themselves. As the P/L compartment is thermally decoupled from the platform, the manufacturer of the P/L will design and accommodate its own radiating elements according relevant P/L requirements, without any functional dependence from the bus subsystems.

Active thermal control of the satellite bus is only required for OCS components. Therefore the propellant tank, valves and filters are equipped with heating foils in order to avoid propellant freezing in orbit during critical mission phases.

In summary, the TCS of the EnMAP comprises following elements:

- Multi Layer Insulation (MLI)
- Heat Pipes
- Radiator
- Thermal Paint
- Thermal Fillers, Coatings and Washers
- Temperature Sensors
- Trace Heaters

1.8. TM/TC Link Subsystem

The Telemetry and Telecommand (TM/TC) subsystem is in charge of the communication between the satellite and the operational ground station. Therefore it provides both

- a command function according Packet Command Standard, in charge of reception and demodulation of telecommands sent from the ground, as well as
- a telemetry function according Packet Telemetry and Telemetry Channel Coding Standard, in charge of modulation and transmission to the ground of housekeeping data .

The TM/TC subsystem works in S-band (2250 MHz) and can be operated in full duplex mode. Hence, it is possible to transmit data with up to 64 kbit/s and receive telecommands from ground at the same time.

The simplified hardware concept is illustrated in FIG 7 and comprises following elements:

- Single TM/TC unit comprising 2 S-Band transmitters and receivers operated in hot redundancy each;
- 2 Antennas (+/- X direction) to guarantee TM/TC link in any case;
- Splitter, diplexer and harness.

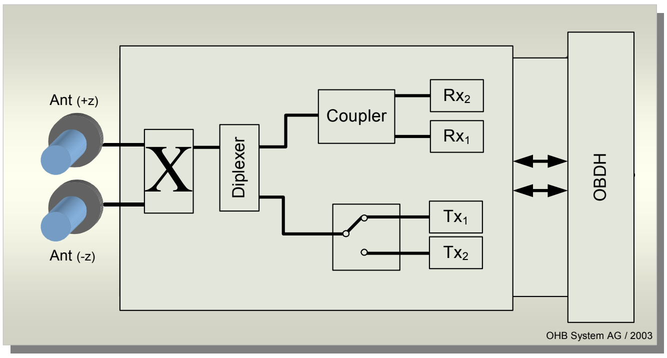


FIG 7. TM/TC Subsystem Block Diagram

The purpose of the S-band TM/TC antenna system is to provide a nearly omnidirectional antenna pattern in order to ensure the availability of the telemetry and telecommand link to the satellite independent from the actual attitude of the satellite.

This nearly omnidirectional pattern is achieved by the parallel operation of the two identical, hemispherical S-band antennas, which are mounted on opposite sides of the satellite. The boresight of the antennas are aligned in +XSat and –XSat direction respectively.

FIG 8. S-Band Antenna

A single S-band antenna unit is depicted in FIG 8.

2. CONCLUSION

Based on the SAR-Lupe heritage OHB-System offers a highly reliable and flexible satellite platform, which therefore allows the client to realize Earth observation missions in a cost-efficient manner. Further, its modular configuration supports the accommodation of optical as well as microwave payloads, which enables the platform to comply with various mission objectives. In summary:

- This platform was selected from the customer to realize the next German Earth Observation mission EnMAP according its challenging technical requirements and within its tight programmatic framework (60 M€ total costs incl. launch).
- The EnMAP project is currently in Phase B.
- In March 2007 the System Requirements Review has been successfully passed showing the compliance of the platform with the EnMAP mission and system requirements.
- Next steps are:
    - To establish bus specifications;
    - To derive equipment requirements;
    - To initiate procurement processes of dedicated components;
- The Phase B of the EnMAP project will conclude in September 2007 with the Preliminary Design Review.