ENMAP SATELLITE BUS ON-BOARD OPERATIONS CONCEPT – FACILITATING DAILY OPERATIONAL TASKS BY APPLYING A ONE-TELECOMMAND PHILOSOPHY

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Abstract

The Environmental Mapping and Analysis Program (EnMAP) is a joint German initiative under the scientific leadership of the GeoForschungsZentrum (GFZ) Potsdam. In the EnMAP project OHB-System is responsible for the satellite bus, where the company Kayser-Threde, is the industrial prime contractor for the EnMAP space segment, and is responsible for the Hyper Spectral Imaging Payload. The EnMAP project is carried out under contract to the German Space Agency DLR with funds of the German Federal Ministry of Economic Affairs and Technology under grant No. 50 EP 0801. The EnMAP satellite will be operational in 2014 with a mission duration of 5 years.

EnMAP provides high quality hyperspectral Earth observation data on a frequent basis. The EnMAP information is based on about 230 spectral bands in the wavelength range from 420 nm to 2450 nm at a ground sampling distance of 30 m x 30 m and with an imaging capacity of 5000 km per day.

The design of the EnMAP satellite bus is now close to its finalization at the end of Phase C approaching a system CDR in the end of this year. This paper shortly summarizes the basics of the current design. Subsequently the advanced on-board operational concept of the EnMAP satellite bus is presented in detail. Hereby an emphasis is laid on the applied one-telecommand-philosophy for the most common daily operational tasks: Image acquisitions, payload data download and payload data deletion.

The EnMAP satellite bus' operational concept includes an autonomous on-board handling of these operational tasks. For an image acquisition several subsystems have to be activated, controlled and coordinated simultaneously. Using one telecommand for each subsystem, or even for each operation within the different subsystems, would lead to a great amount of telecommands. The EnMAP satellite bus requires only one telecommand per commanded sequence, including image acquisitions, payload data download and deletion. This is named the one-telecommand-philosophy. In Addition the payload data is autonomously compressed on-board, and, depending on the downlink duration, a matching amount of data is transmitted to the ground station, having sent only one telecommand.

This advanced on-board operational concept results in a very low effort for on ground modeling of on-board resources and mission planning for nominal operations. Especially for missions requiring only one individual satellite this is an advantage, and also for target and event observation scenarios, in which no permanent nadir pointing is performed. Due to this, the EnMAP satellite bus turns out to be a very suitable and cost effective platform for small earth observation satellites.

1. ENMAP MISSION OVERVIEW

The Environmental Mapping and Analysis Program (EnMAP) is based on a space borne hyperspectral imaging mission, which is capable of measuring the solar radiance reflected from the earth surface as a continuous spectrum. With its capabilities covering the visible, near- and short-wave infrared wavelengths, the EnMAP satellite mission will provide high quality Earth observation data on a frequent basis. The data will be applied for soil and land management, water monitoring, diagnostic mapping and analysis (research of raw materials, detection of brownfields) and disaster management.

The EnMAP Hyper Spectral Imager (HSI) provides information based on 230 spectral bands in the wavelength range from 420 nm to 2450 nm. The spectral sampling distance is about 6.5 nm in VNIR and 10 nm in the SWIR spectral region. The orbit parameters of the satellite are mainly the following:

- Altitude: ca. 643 km
- Inclination: ca. 98° (Sun Synchronous)
- Local time of descending node: 11:00

This orbital parameters enable a target revisit capability within 4 days, using the +/- 30° across-track pointing capability of the EnMAP satellite bus as seen in Figure 1.

The EnMAP payload will be operated as push-broom scanner, but with dedicated imaging tasks. It covers a swath width of 30 km, with a ground sampling distance of 30 m x 30 m.

The imaging performance of the EnMAP satellite is the following:

- Up to 50 images per day
- Up to 1000 km per orbit (corresponds to the maximum swath length of one image)
- Imaging capacity of 5000 km per day.

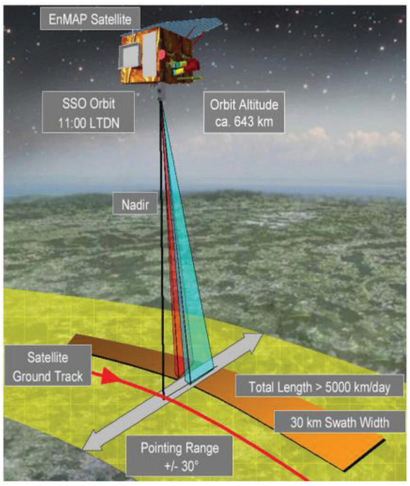

Figure 1. EnMAP imaging concept

The EnMAP satellite will have a mission duration of 5 years. After this period of nominal operation the satellite will perform dedicated re-orbiting maneuvers, in order to limit the remaining in-orbit lifetime and by this to be compliant with space debris mitigation measures.

The EnMAP satellite project is the first phase C/D project, which makes use of the proven SAR-Lupe satellite platform for an earth observation mission, which is quite different regarding the type of payload to be implemented.

Nevertheless, during EnMAP project it has been proven that the satellite platform is very well suited for the specific requirements of the EnMAP mission and its sophisticated hyperspectral imaging payload. This is especially due to its advantages of a very modular and flexible configuration, a highly accurate and agile attitude control concept and a high rate on-board processing and downlink of the payload data.

Because of these features the EnMAP platform provides a very suitable and cost effective solution, which can form the baseline also for other Earth observation missions in the medium to very high resolution area for optical or microwave applications.

The EnMAP project has proven the adaptation of the basic platform design to the demanding requirements of a specific Earth observation mission. This platform concept is currently developed towards a generic small satellite platform for Earth Observation projects: the LEOBUS-1000 platform.

The EnMAP current platform and different configurations in the future evolution for more demanding earth observation mission are shown in figure 2. LEO-BUS-1000 platform is currently proposed or under study for several missions like ESA's Earth explorer missions and next generation GMES missions, e.g. Sentinel-5 Precursor.

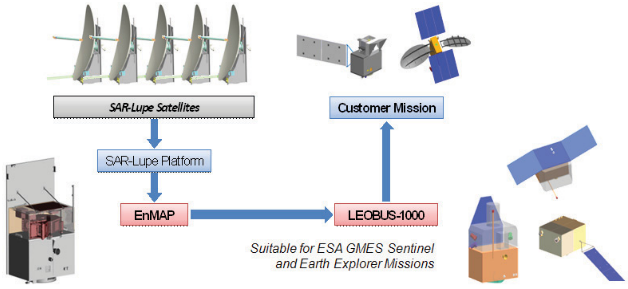

Figure 2. Future evolution of the EnMAP satellite platform

2. ENMAP SATELLITE CONFIGURATION

The EnMAP satellite consists of the payload, Hyper Spectral Imager (HSI) and the satellite bus which provide an adequate platform for the HSI. The satellite bus is based on the heritage of the successful SAR-Lupe project of OHB-System.

Table 1 provides an overview of the highlight features of the EnMAP satellite bus, including the capacity for the operation of the EnMAP payload.

EnMAP Satellite Bus Design Features	
Bus Dry Mass Payload Mass	496 kg (w/o margin) 265 kg (w/o margin)
Bus Compartment Payload Compartment	1.8 x 1.2 x 1.1 m³ 1.8 x 1.2 x 0.7 m³
Lifetime	5 years nominal
Bus Power Payload Power Solar Panel Capacity	320 W peak / 238 W std-by 285 W peak / 206 W std-by 945 W EOL (sun pointing)
Attitude Control	High accuracy, 3-axis stabilized
Orbit Control	Hydrazine blow-down system, up to 70 l fuel capacity
P/L Data Storage Data Processing Rate	512 Gbit (EOL) 1.3 Gbit/s, incl. off-line lossless CCSDS data compression
P/L Data Downlink	X-Band, 320Mbit/s
TM/TC	S-Band, full duplex up to 4/64 kbit/s (up/down)
Launcher compatibility	Baseline Launcher PSLV Basic compatibility to most common launchers

Table 1. EnMAP bus key features

The EnMAP spacecraft consists of payload compartment and the satellite bus compartment. This accommodation provides maximum independency and most easy assembly of both the payload and the bus subsystems. The Hyper Spectral Imager is accommodated in the payload compartment at the upper part of the spacecraft to account for the demanding stability and thermal requirements of the optical system. To minimize heat fluxes the payload is thermally decoupled from other subsystems to the maximum intent.

The lower part of the spacecraft is the satellite bus compartment, which houses all the subsystems of the satellite bus. Figure 3 shows the accommodation of the bus subsystems within the bus compartment.

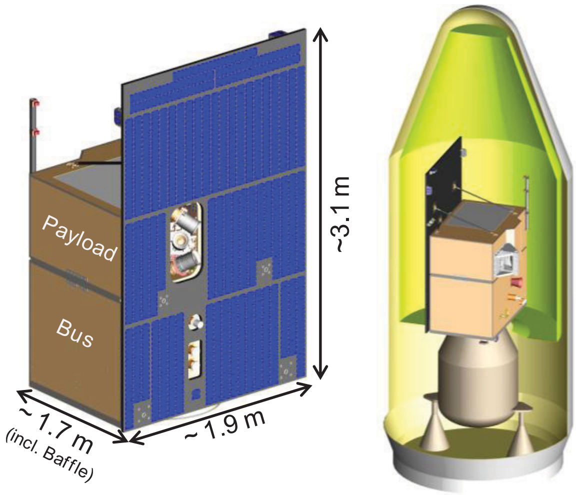

Figure 3. EnMAP bus and payload compartments (single and in the launcher compartment)

In Figure 3 one can see the assembly of the star sensors, which are accommodated directly on the payload optical bench in such way, that thermal and mechanical distortions, which contribute to the pointing error budget, are minimized. With this star sensor orientation and accommodation, the optimum pointing performance on satellite level is achieved.

The satellite bus provides an adequate platform for the HSI payload. Satellite bus consists of the following subsystems:

- Power Subsystem
- Satellite Management Subsystem
- Attitude Control Subsystem (ACS)
- Orbit Control Subsystem (OCS)
- TM/TC Link Subsystem
- Thermal Control Subsystem
- Payload Data Handling

The EnMAP payload data handling 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.

The following subsystems are part of the EnMAP payload data handling:

- Data Science Handling Assembly (DSHA), which includes high rate input multiplexer, mass memory and channel coding unit, conform with CCSDS
- X-band transmitter, performing data modulation and providing the RF signal high gain antenna.

The DSHA interfaces to the HSI payload via two redundant channel links, each of which is operating at 840 Mbit/s data rate, i.e. the complete input data rate of the DSHA is 1680 Mbit/s. One highlight feature of the EnMAP DSHA is the thematically sorting of the hyper spectral data into files, where one file includes the data of one channel per image only. This unique file handling concept significantly eases the downlink preparation and the further processing of the payload data on ground. The channel files are stored within the mass memory of the DSHA, which has the End of Life capacity of 512 Gbit.

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

For data transmission a high gain antenna is used, which ensures the high transmission rate with sufficient link margin. This concept has a drawback that the downlink requires a dedicated ACS pointing maneuver, during which no imaging can be performed. Therefore only the contacts during the night are used for downlink, because these cannot be used for image acquisitions. These contacts with the X-Band ground station in Neustrelitz are sufficient to dump the complete EnMAP payload data, which is sampled during one day (ca. 600 Gbit).

Additionally a lossless data compression (CCSDS) is implemented within the DSHA, which enables a compression ratio for the EnMAP hyper spectral data of an average of 1.6. Due to this, the data storage capacity on-board is increased.

For the EnMAP mission no payload data encryption is implemented, but this functionality can be included for other Earth observation missions, as well.

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

The complete configuration of the EnMAP spacecraft bus can be seen in Figure 4 below.

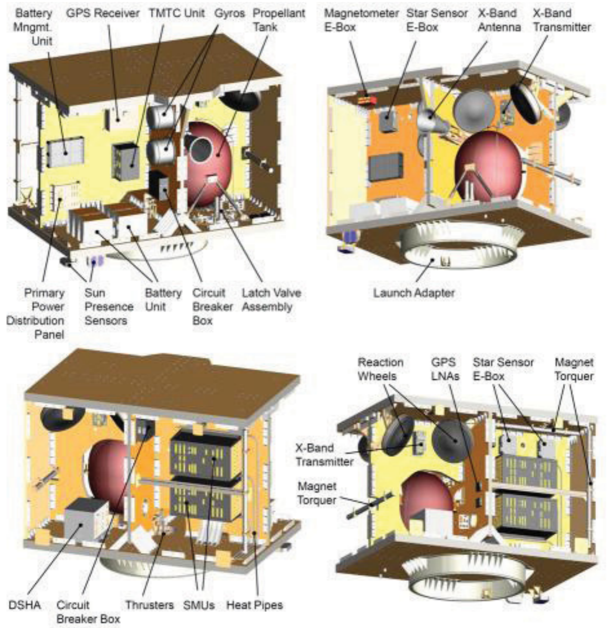

Figure 4. Bus subsystems internal configurations

3. MISSION OPERATION CONCEPT

Mission operation concept is divided into two categories:

- nominal operation
- contingency operation

Nominal operation covers the whole mission duration, from LEOP and Commissioning Phase, Nominal Phase to De-orbiting phase.

The autonomous on-board operations concept is most advantageous for the nominal daily operations. For LEOP and commissioning, de-orbiting and contingency operations the advantages are rather small.

Within the LEOP and Commissioning Phase several tasks have to be performed in a certain order to guarantee the correct start-up and testing of the satellite. These tasks include: initial activation, commissioning of the satellites subsystems and general performance tests. During LEOP and Commissioning an intensive supervision of the satellite's health is ensured. The tasks during this phase are specific and must be supervised continuously. The same conditions must be applied for de-orbiting and contingency operations. Individual operational tasks are necessary and a full time observation of the satellite's health is needed. Therefore the autonomous on-board concept does not facilitate these activities.

During the nominal phase, routine operations are performed on a daily basis. The EnMAP satellite's ground stations are Weilheim and Neustrelitz, where Weilheim is used for the S-Band contact (TMTC) and Neustrelitz for the X-Band contact (payload data download). As mentioned before, for payload data download only the night time X-Band contacts are sufficient to dump the complete EnMAP payload data. For the S-band contacts an average of 30 min per day are reached with the given orbit characteristics. During this time all commanding and receiving of telemetry must be completed. During daily operations the most common tasks are image acquisitions, payload data download and subsequent deletion of the data.

For these tasks, especially for an image acquisition, several subsystems have to be activated, controlled and coordinated simultaneously. Using one telecommand for each subsystem, or even for each operation within the different subsystems, would lead to a great amount of telecommands. In Addition, the ground station would need to have a detailed knowledge of the on-board timings. The EnMAP satellite bus requires only one telecommand per commanded sequence, including image acquisitions, payload data download and deletion. This is named the one-telecommand-philosophy.

The EnMAP payload (HSI) is controlled via scripts, so that changes on the payload timings and sequences do not change the concept of image acquisitions.

In Addition the payload data is autonomously compressed on-board if required by imaging command.

For the payload data download, depending on the downlink duration, a matching amount of data is transmitted to the ground station autonomously, having sent only one telecommand.

In Figure 5 a block diagram showing all EnMAP Bus subsystems is given. The needed subsystems for the different operational tasks described above are controlled by the satellite management unit (SMU).

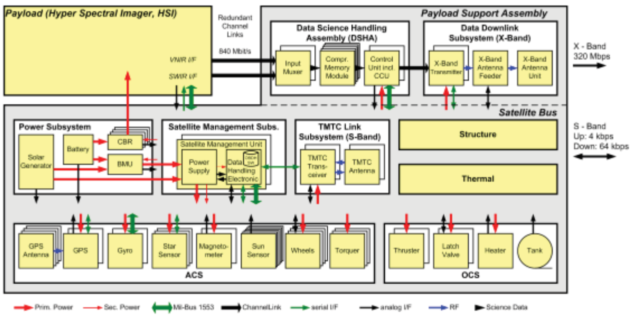

Figure 5. Bus subsystems, block diagram

The applied one-telecommand philosophy (see section 3.2) results in a very low effort for on ground modeling of on-board resources and mission planning for nominal operations. It is not necessary to have knowledge of the exact on-board timings. The generation of telecommands for image acquisitions and other operational tasks can be done according to simple rules provided in the satellite's operations manual.

3.1. S/C to Groundsegment Interface

Satellite and ground station communicates using two interfaces; S-Band link for telemetry and telecommand and X-Band link for payload data. Figure 6 gives an overview of the EnMAP satellite to ground interface.

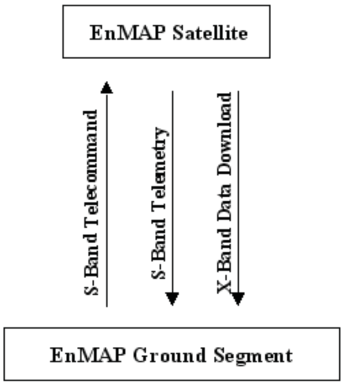

Figure 6. Satellite to ground segment interface

For telecommanding two types of telecommands:

- immediate telecommands (TC)
- time-tagged telecommands (TTTC)

The telecommand structure of both, the TC and the TTTC, is identical. The only difference is that the time tagged information is appended to the packet header of the telecommand packet. The time-tag information determines when to start the telecommand execution.

An immediate telecommand is executed immediately after reception via S-Band Telemetry from ground. The immediate result is sent via S-Band Telemetry to ground by a Nominal Telemetry Packet in case of successful execution or as an Error Telemetry Packet if a failure occurs.

A time-tagged telecommand is executed not immediately after reception, but at the time defined in the time tag. After the reception of the TTTC an acceptation reply is sent to the ground station. This indicates to ground whether the time-tagged telecommand has been successfully received and inserted into the command schedule or not (e.g. command schedule full).

For the TTTC the execution reply (nominal or error telemetry packets) as generated at execution time will not be sent directly to the ground station. All these telemetry packets are written into the system report file, which can be downloaded to the ground station by file transfer.

3.2. One-Telecommand Philosophy

Performing tasks such as image acquisition, data download or orbit control maneuvers require activation, control and coordination of several subsystems simultaneously. The implemented advanced on-board operation concept with its one-telecommand philosophy facilitates the conduction of these tasks and reduces the complexity of ground operations and mission planning tasks (e.g. scheduling). The concept enables the on-board computer to execute and supervise these tasks and autonomously control the EnMAP subsystem equipments accordingly.

The one-telecommand philosophy will be applied for the following tasks:

- Image acquisition, standard ground observation
- HSI (hyper spectral imager) calibration
- Payload data download
- Payload data deletion
- Orbit control maneuver

For each of these tasks only one telecommand has to be sent from the ground station. These tasks are commanded via time-tagged telecommands (TTTCs). The TTTC include all necessary parameter for the according task and a time tag to define the start of execution. The on-board execution of the TTTC starts automatically at the specified time. The on-board computer controls all necessary subsystems and commands the required subsystem operations during the execution of the TTTC. Details on the different tasks are given in the following sections.

3.2.1. Image Acquisition and HSI Calibration

Image acquisition and calibration maneuvers are initiated via a time-tagged telecommand by the ground station. Subsystems involved are mainly the HSI, the mass memory and coding unit (DSHA) and the attitude control subsystem (ACS). For the on-board computer there is no difference in handling of the subsystems between the image acquisitions and the payload calibrations (in case an ACS precise maneuver is required). Both tasks, image acquisition and calibration, require the same management of the ACS and the DSHA. The only difference is that the instrument will be commanded to the image acquisition or calibration command sequence.

Depending on the imaging type (Standard ground observation or HSI Calibration) a different number of spectral channels will be recorded in the DSHA. The type of imaging and the spectral channel configuration used will be defined in the parameters of the TTTC. According to these parameters the DSHA and the HSI will be setup.

For an image acquisition a specific ACS pointing to the target is required. Therefore the ACS will be set to the so called precise mode, where the satellite will be moved according to a specific guidance profile. The TTTC includes a so-called ACS guidance list, which represents the required ACS pointing profile in form of attitude quaternions. The ACS on-board software will process the information contained in the uploaded list and will reconstruct (by means of interpolation) the complete guidance profile originally computed on ground.

In addition the DSHA will be configured so it is ready for the storage of payload data at the defined start time.

The instrument will be preheated a specific time before the data take starts. The according command and the imaging time tag will be sent to the instrument so that the data take can take place at the required time, controlled by the HSI. In case there are two image acquisitions with a short time offset (less than the time required to pre-heat the HSI camera), the camera will not enter a stand-by mode after the first image acquisition end and be kept on the preheating temperature. In the case that the second image acquisition is not performed (e.g. deleted) the HSI will autonomously switch the camera to standby mode after a defined time if no further imaging sequence is started.

An example of a simplified imaging profile is depicted in Figure 7, showing a fictive sequence of different ACS precise modes to perform a number of subsequent image acquisitions at different pointing angles.

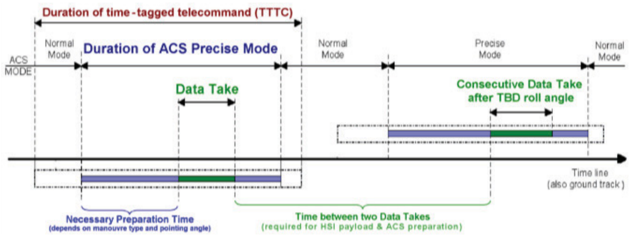

Figure 7. Simplified imaging profile

The TTTC also includes information whether the data shall be compressed or not. If compression is required, the process is started autonomously as soon as the acquisition of data is stopped.

The compression process can be interrupted by an execution of a new image acquisition TTTC. If there is a new image acquisition, the DSHA will automatically suspend the compression process if it is still running. Once the new files are recorded, the file compression process will be continued. The compression process works autonomously supervised by the DSHA.

On ground the different time parameters will be calculated, according to simple rules defined in the operations manual, to configure the Image Acquisition TTTC on the basis of the Image Acquisition start time. But once sent to the S/C all necessary tasks for the image acquisition are performed autonomously on-board by having sent only one telecommand. Combining all the times in one telecommand enables the on-board S/W to supervise the complete sequence belonging to one complex task. The execution reply represents the status of the complete task, and not only of one dedicated command to one element or subsystem. Due to this the operator is able to judge about a successful or erroneous sequence by means of one reply code.

3.2.2. Payload Data Download

A payload file download maneuver is also initiated via time-tagged telecommand by the ground station. In this telecommand all necessary information is given so that the downlink can be performed without any further ground contact via S-Band.

Within the DSHA the image data is sorted and for each channel of an image acquisition a separate file is generated. These files are marked with the according image ID and channel ID. The image ID is given by the ground operator. The channel identifier is given autonomously during the image acquisition. Each file is addressed via its image ID and its channel ID. This guarantees an explicit allocation of the image files to the commanded image acquisition.

The TTTC for the file download maneuver contains information of the start and end image IDs and channel IDs and the duration of the X-Band contact. The files within the DSHA are marked with a so called download flag. This flag indicates whether a file has already been downloaded or not. Using this information the DSHA autonomously detects the files to be downloaded and transmits them during the contact period.

All downloaded files are marked as downloaded after the completion of the download. In the case that not all of the commanded files can be downloaded, the remaining files will not be marked as downloaded. These files can be downloaded in a following contact.

It can be configured whether all files (already downloaded and not yet downloaded) or only not yet downloaded files should be transmitted. Thus, the ground operator does not need to specify exactly which files should be downloaded. He can just define a start and an end image ID and all files that have not been downloaded before will be transmitted. In case a download of a dedicated file should be repeated, the download flag can easily be set back to “not downloaded”.

Due to this the ground station can schedule a download maneuver with always the same set of parameters for the start image identifier, start channel and end image identifier and end channel. Only the start time for the X-Band contact, the duration of the data downlink and the ACS parameters must be adjusted for the specific maneuver. The size of the files must not be checked and no calculation which files can be downloaded during the X-Band contact must be made on ground.

In Figure 8 an example operational scenario including image acquisitions and file downloads is shown.

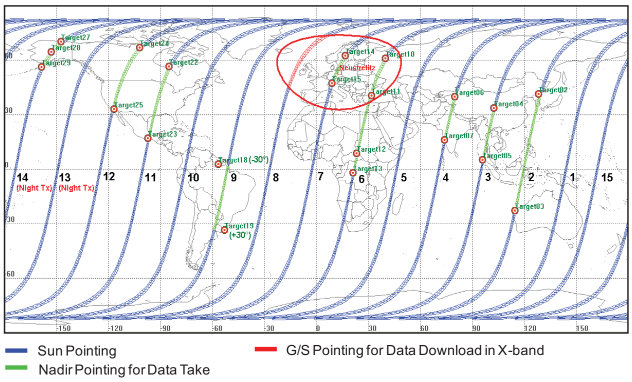

Figure 8. Operational scenario (example)

Within the mass memory no file will be autonomously deleted. To delete any files, a specific telecommand initiated by the ground station must be executed (see next section).

The execution of the payload data download maneuver is similar to the image acquisition maneuver. The ACS subsystem needs to perform a rotation of the S/C to point the X-band antenna towards the ground station. During the ACS preparation the DSHA will be configured and switched to its transmission mode to enable the file download. Other than for image acquisition the instrument is not involved for the file download process.

The duration of downlink phase is equivalent to the X-Band contact time. At the start of the downlink phase, a set of commands are sent by the on-board computer to start the transmission and the file download process. The DSHA will be set to its transmission mode, so that the transmission process can be initiated and prepared within the DSHA. After contact establishment the DSHA will be commanded to start the download of the payload data. The DSHA transmits autonomously a matching amount of data based on the information (downlink duration, files to be downloaded…) from the TTTC. If no image data is available the DSHA autonomously generates idle frames.

In addition to the DSHA the X-Band transmitter is controlled by the on-board computer. It will be switched on and off according to the X-Band contact time given in the TTTC.

The control of the ACS subsystem is identical to the other maneuver.

As for the image acquisition the file download process is performed completely autonomously on board the S/C having sent only one telecommand.

3.2.3. Payload Data Deletion

Files in the mass memory of the DSHA will be deleted only by a telecommand from ground and not autonomously.

The deletion telecommand, similar to the file download command, can be executed for all files or only for already downloaded files in a specific range.

This concept foresees that a general delete command can be executed which does not consider the specific file number for the actual deletion process. Instead of adjusting the file number for every single file deletion, it is recommended to setup the telecommand that a range of files can be deleted.

With the parameter of the telecommand which defines that only already downloaded files will be deleted, the not downloaded files are still available for the next download manoeuvre.

With this concept of the deletion process the ground station does not necessarily have to know which files are already downloaded when scheduling this command. But it is recommended to check which of the files are successfully downloaded to avoid the deletion of the files that are not successfully downloaded. As explained in section 3.2.2 each file is marked with a download flag. This flag can be easily configured, and hence set back from “downloaded” to “not downloaded”. Thus the designated file will not be deleted and the downloaded of the file can be repeated in the next contact.

Thus, only one telecommand is needed to delete all files or all already downloaded files within the mass memory.

3.2.4. Orbit Control Maneuver

Orbit control maneuver are not a part of daily operations. Nevertheless the one-telecommand philosophy is applied here as well.

For an orbit maneuver mainly the attitude control subsystem and the orbit control subsystem are involved. Again all necessary tasks are controlled by the on-board computer when the telecommand has been sent to the S/C.

The ACS needs to perform a precise maneuver similar to the maneuvers for image acquisition and payload data download. The S/C’s attitude has to be changed so that the thrusters will be fired in the correct direction.

For the OCS, there are three main tasks that have to be controlled during the maneuver: thruster catalyst preheating, thruster activation and deactivation.

The TTTC for orbit maneuver includes the time to start the telecommand, time tags for activation/deactivation of thrusters, and the necessary ACS guidance information.

In the case two orbit maneuvers should be performed a minimum time offset is necessary. A determination of the changed orbit should be performed by the ground segment to ensure the orbit maneuver has been performed correctly and the changes are as expected. In addition the ACS subsystem requires a specific time to autonomously de-saturate the reaction wheels after the maneuver. Compared to the time needed for the orbit determination the time needed for reaction wheel de-saturation is really small.

The attitude accuracy of the satellite during thruster firing is autonomously supervised onboard the satellite. The ground station can configure a limit value for the attitude deviation by a configuration command. If the satellite attitude deviation exceeds the configured limit value at any time during thruster firing, a current orbit maneuver is autonomously aborted. Otherwise deviations of the satellite attitude during thruster firing would lead to deviations of all orbit parameters from the calculated target values.

As for the other maneuvers the orbit maneuver is performed completely autonomously on board the S/C having sent only one telecommand.

4. CONCLUSION

The EnMAP satellite bus’ operational concept with its one-telecommand philosophy has been outlined in detail within this paper. It includes an autonomous on-board handling of the most common operational tasks such as image acquisitions, payload data downloads, payload data deletions and orbit maneuvers. For all of these tasks several subsystems have to be activated, controlled and coordinated simultaneously. The EnMAP satellite bus requires only one telecommand per each of the above mentioned tasks. This is named the one-telecommand-philosophy. In addition other on-board autonomies, such as autonomous compression and sorting of payload data, are implemented.

This advanced on-board operational concept results in a very low effort for on ground modeling of on-board resources and mission planning for nominal operations. Especially for missions requiring only one individual satellite this is an advantage, and also for target and event observation scenarios, in which no permanent nadir pointing is performed. Due to this, the EnMAP satellite bus turns out to be a very suitable and cost effective platform for small earth observation satellites.