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VERY HIGH RESOLUTION EARTH OBSERVATION MISSIONS: FUTURE PERSPECTIVES

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ABSTRACT

Earth observation (EO) has become an indispensable tool in the fields of geophysics and security. Successful fulfilment of all relevant user needs can only be accomplished by future imaging technologies, if they are capable of providing high-quality geo-information data at increasingly better resolutions (< 1 m). Obviously, progress in space-based EO services has to keep up with these increasingly stringent user demands as well.

Originally an exclusive military field, very high resolution (VHR) imaging technology is becoming increasingly more popular in typical civil applications, e.g. urban mapping and emergency response (natural disaster monitoring, humanitarian aid, etc.). A driving force behind these developments is the European initiative on Global Monitoring for Environment and Security (GMES), which will frequently require VHR imaging data on a long-term basis. Therefore, foundation of an efficient monitoring system is an absolute necessity to provide reliable EO services on a worldwide scale in the future.

OHB-System and its partners have successfully developed and launched the SAR-Lupe spacecraft dedicated to VHR SAR (synthetic aperture radar) imaging for military reconnaissance purposes. Using the experience gained in this project, OHB-System has developed a next generation platform for civil VHR applications, which will be able to accommodate both optical and SAR payloads.

In this paper, an overview of typical VHR applications in the area of Earth observation is given. Typical user requirements regarding ground resolution, system response time and required technology are analysed. As end-to-end performance is an extremely significant factor, consequences for the complete VHR system are presented.

In addition, an outline of OHB's next generation platform's capability to realize VHR missions supporting typical future EO applications is shown. Its ability to accommodate different types of VHR payloads is emphasized. Furthermore, it will display an exceptional capability to comply with relevant payload requirements. Complemented by its attractive performance-to-cost ratio and modular approach, it is concluded that OHB's next generation platform will be a strong competitor for a wide range of VHR mission scenarios.

1. INTRODUCTION

VHR imagery have uses in a number of different areas. VHR earth observation isn't further on only of interest for military services but also for operational services like GMES (Global Monitoring for Environment and Security) and commercial services.

Military applications in the field of reconnaissance and surveillance are for example theatre overview, object detection, recognition and identification. Environmental or disasters monitoring are governmental applications, mapping and security like emergency response, too. Google Earth, as one example for global information systems, is a commercial application.

The number of existing and announced high and VHR imaging satellite systems is growing permanently. More and more countries are entering the field of earth observation. In near future 22 countries will have their own sensors in space. Already 10 of them are involved in VHR earth observation. In addition to new optical systems, VHR Synthetic Aperture Radars (SAR) will become in the next few years an important component in the imaging satellite fleet.

2. SYSTEM REQUIREMENTS FOR VHR

VHR system requirements are becoming more and more challenging. This chapter describes the user demands and the consequences for a complete HR system. Subsequently the derived platform design is explained.

2.1 REQUIREMENTS

The main reason for the higher geometrical resolution is based on military requirements, but it is also useful for civilian application.

A VHR system should fulfil the following requirements:

- large instrument Field of View (FoV)
- very short system response times on a global scale (<< 24 h)
- high geo-localisation accuracy (<< 100 m)
- high ground resolution (<< 1 m)
- cost effectiveness
- scalability on system level (satellite constellations)
- interoperability for information exchange for partner nations

Secondary requirements can be derived out of this requirement set because technical limitations exists.

It is for example not possible to increase the instrument FoV and the ground resolution at the same time. Therefore it is desired to have an increased number of images from specific hot spots or crises regions anywhere in the world and a short revisit time. To achieve that, the satellite has to provide very fast attitude manoeuvres. The satellite needs very high agility for multi target capacity. Very short system response time are required, too. The last feature is now described in detail.

2.2 SYSTEM RESPONSE TIME

The response time of a satellite system is typically understood as the time between the image orders and the delivery of the processed images. This end-to-end response time can be divided into certain individual time slots, which can be identified as:

1. time to uplink the image orders to the satellite,
2. time to reach the targets and to perform the imaging,
3. time to downlink the image data to the receiving station on ground,
4. time to process and deliver the requested image.

The second time slot is more or less represented by the global coverage performance of the satellite(s) and the imaging sensors on-board. For single Earth observation satellites this global coverage can only be achieved in the range of days, where the other time slots are in the range of hours. In order to reduce the overall response time it is therefore the reasonable first step to improve the coverage performance by implementing a constellation of multiple satellites. The following FIG 1 shows exemplary the improvement of the maximum and mean system response time, which can be achieve by adding additional satellites to a satellite constellation.

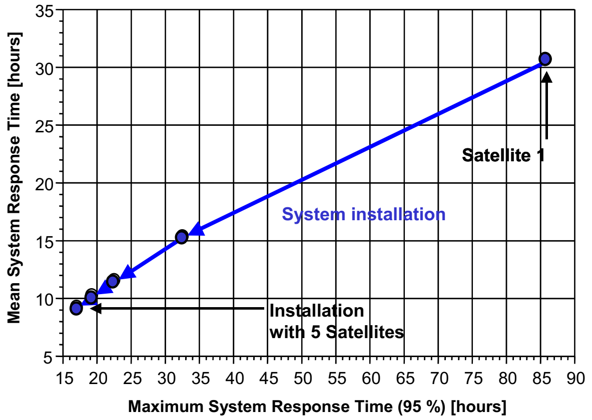

FIG 1: improvement of the system response time by the implementation of multiple satellites

Outgoing from a single satellite system one can see that there is a significant reduction of the response time by the implementation of a second and third satellite. But the performance gain, which can be achieved by each additional satellite, becomes lower and lower and there is a reasonable upper limit for the number of satellites, until which the performance gain is justified by the effort and cost for the installment and operation of a further satellite in orbit.

Such reduced system response times, as indicated in FIG 1 above, can be achieved for dedicated (prioritized) targets. But especially for security application in praxis there will be a higher number of image orders being concentrated within a typically country sized hot spot. If the satellites have a limited agility only one or two image orders can be fulfilled during each satellite pass. Simulations with concentrated multi-targets show that even with a satellite constellation the total response time for a set of concentrated image orders is significantly worse, if the agility of each satellite is limited. Here, it is the adequate solution to improve the satellite agility by the implementation of high performance attitude control actuators (and sensors).

Future satellite surveillance systems will ask for a system response time in the range of hours. To fulfill such a requirement it is not only necessary to implement a constellation of multiple and agile satellites, but one also has to optimize all the mentioned time slots of the end-to-end response time.

The first and the third time slot are more or less determined by the communication gaps between the space segment and the ground segment. On one side the order of magnitude of these communication gaps is depending on the number and the location of the utilized ground stations. But due to constrains wrt. cost and national sovereignty aspects, it is obvious that ground stations cannot be placed anywhere in the world. Here, an adequate mean to minimize the communication gaps is the utilization of inter-satellite communication links.

At OHB-System we already have implemented inter-satellite links (ISL) for low to medium data rate communication. In the Rubin satellite series we do use the ORBCOMM system as a LEO data relay to distribute data files between the satellites and the central ground station. In SAR-Lupe an S-Band ISL is implemented, by which the image orders are rapidly distributed within the complete satellite constellation (reduction of the first time slot of the end-to-end response time).

A further reduction of the response time can be achieved by the rapid downlink and handling of the image data. In future the amount of gathered image data will significantly increase. This is not only due to the higher resolution (without reducing the swath width), but also additional spectral frequencies or a combination of sensors on one platform is often desired, and finally the improved satellite agility enables the imaging of a higher number of images over a crisis region within one pass. In the end it is the handling (downlink and processing) of the extensive image data which can become the crucial bottleneck for the response time of future high resolution systems.

With today’s mission scenarios, which typically utilize an X-Band downlink to a limited number of ground stations, the data amount of future high resolution missions cannot be handled adequately to fulfill the required short response time. This is due to the bandwidth limitations of X-Band and especially because of the short contact durations between the satellite and the ground station, which proves to be the true bottleneck in LEO EO missions. A high data rate ISL in-between the LEO satellites provides no solution here.

To solve this bottleneck the following alternative solutions are currently investigated at OHB-System for future EO missions:

- usage of alternative frequencies in Ku- or Ka-Band or the usage of optical Laser Terminals for very high data transmission rates,
- additional implementation of data relay satellite(s) in the geostationary orbit (GEO).

These solutions lead to a minimization of the data downlink time (third time slot of response time), which is also a driving part of the information age, which is definitely required to be minimized for security applications.

The implementation of a high data rate ISL between LEO and GEO introduces additional requirements to the attitude control concept of the EO satellite. An important requirement is here not do degrade the image taking performance of the satellite in terms of number of images and image accuracy.

The fourth time slot of the response time deals with the processing of the image data on ground. It is clear that the extensive data amount of high resolution missions will have impacts on the processing HW and SW, which will have to be used for such missions in the future. But furthermore an improved in-orbit attitude control performance of the satellite helps to reduce the effort and duration, which is necessary for the ground possessing of the data. The better the attitude accuracy, which can already be achieved on-board of the satellite, the lower the effort on-ground for the geo-correction of the image, which today is often made manually and time-consuming via ground control points.

2.3 CONSEQUENCES FOR PLATFORM DESIGN

VHR is one major characteristic of next generation imaging systems. Beside the high resolution such applications specifically ask for very short system response times, high geo-localisation accuracy, etc. as discussed in section 2.1. Derived from these user demands, the following secondary requirements were achieved:

- increased number of images from specific regions anywhere in the world
- short revisit time

To comply with these requirements, the satellite has to provide fast attitude manoeuvres. Next generation VHR systems have to be very agile for multi target capacity.

All these issues are important driving requirements for the design of future EO surveillance systems and satellites. OHB works on the next generation VHR systems. The following section provides system and platform design issues with respect to next generation systems.

2.4 PLATFORM DESIGN

For each requirement discussed in section 2.1 design solutions are discussed hereafter in detail:

For high geo-localisation accuracy:

- highly accurate star sensors and gyros,

FIG 2. SODERN Hydra [3]

- stiff structural elements and connections to minimise residual vibrations after attitude manoeuvres,
- implementation of the attitude sensors on a rigid optical bench (FIG 3) very close to the imaging payloads,
- multi-frequency navigation solution for precise position and timing information (dual frequency GPS or Galileo),
- very precise onboard time coordination between imaging and attitude control system sensor data sampling.

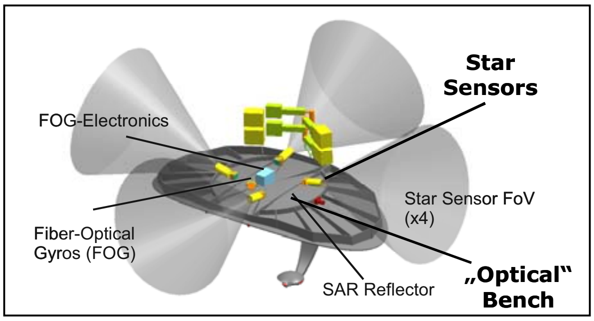

FIG 3: star sensors implemented on optical bench

For very high agility:

- symmetric and lean design of the satellite structure to achieve balanced and reduced moments of inertia with respect to the relevant slew axes,
- high performance reaction wheels (dual reaction wheels or magnetic wheels) to reduce the dead-time between to successive images.

FIG 4: TELDIX Magnetic Bearing Wheel l., CMG 15-45S r. [4]

For cost effectiveness and modularity:

- integrated and modular design of the satellite bus and camera (subsystem building blocks), making the system more reliable and cost efficient,
- camera optics and bus mounted as a separate module.

For scalability:

- scalability of the power subsystem in terms of the number of implemented panels,
- platform can accommodate payloads in the range of 200 up to 500 kg building a satellite in the range of 800 up to 1200 kg.

For system response time:

- optical laser terminal for high-data rate inter-satellite link with a GEO relay satellite or other satellites in constellation,
- simultaneous imaging and data transmission to a ground station (antennas with pointing mechanism, FIG 5).

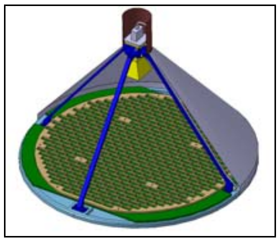

FIG 5: antenna with pointing mechanism

With these design features, OHB-System is able to provide a feasible satellite platform also for the demanding requirements of future VHR EO missions.

3. SATELLITE BUS CONFIGURATIONS

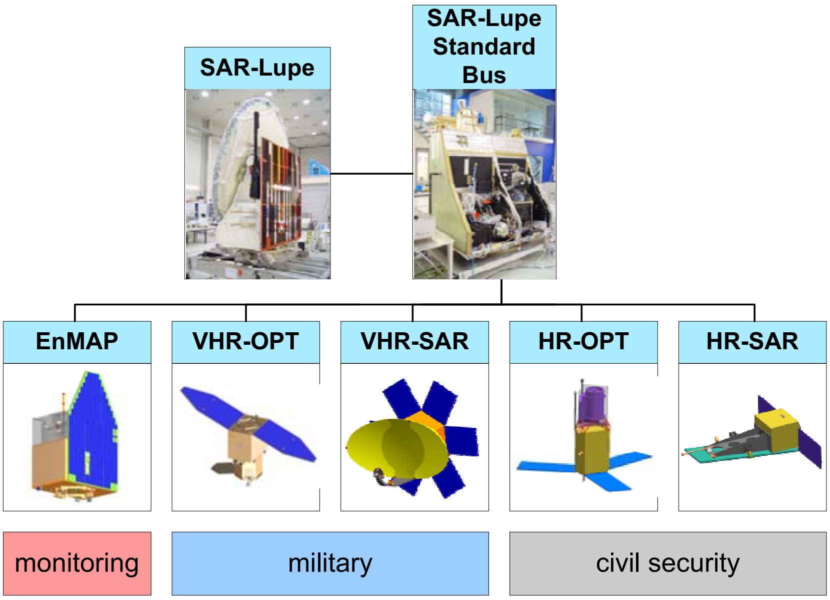

FIG 6: OHB satellite bus configurations

In FIG 6 the satellite bus configurations of the OHB-System AG are depicted. This bus configurations, which are under development at the moment benefits from the heritage of the SAR-Lupe project.

3.1 Detailed Satellite Bus description – exemplary from the ENMAP Mission

Based on this heritage 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.

CONFIGURATION

The preliminary configuration of the EnMAP spacecraft is shown in FIG 7 below.

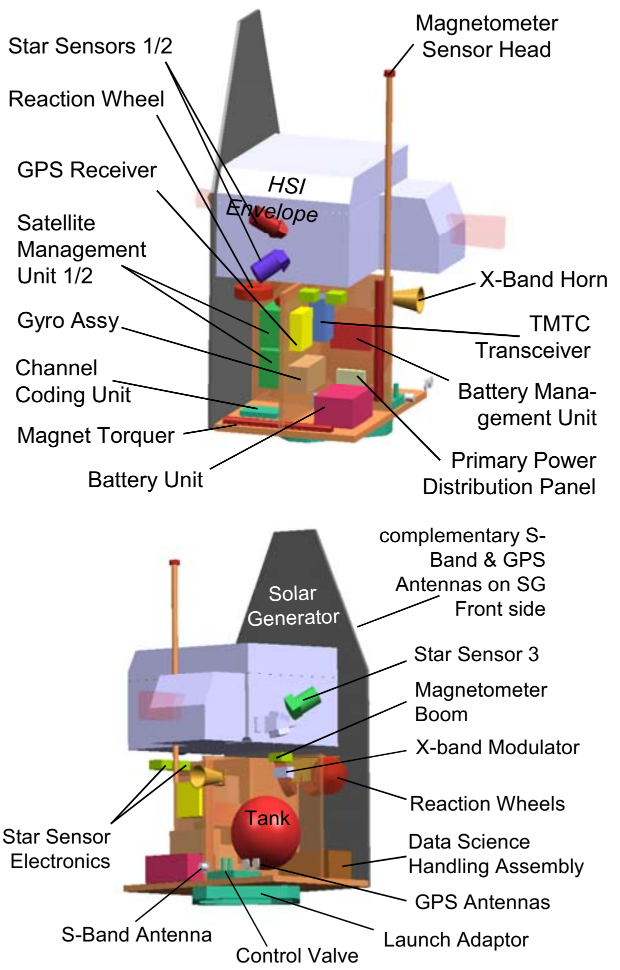

FIG 7: EnMAP bus configuration

The EnMAP P/L is accommodated separately at the upper part of the spacecraft (see light blue envelope in FIG 7) 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. Benefiting from its attractive stiffness to weight ratio, the bus core structure is manufactured in aluminium sandwich panels.

SPACEGRAFT 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.

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.

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

3.2 VERY HIGH RESOLUTION SATELLITES

For a complete VHR system, including space and ground segment, different trade-offs have to be performed. With respect to the design considerations mentioned in the sections above, the trade-offs include:

- camera performance,
- orbit options,
- downlink performance,
- satellite agility,
- ground processing time,
- reliability,
- number of satellites,
- number of ground stations,
- costs,
- etc.

All the requirement issues, discussed in section 2.1, are important driving requirements for the design of future EO surveillance systems and satellites.

The following figures provide an overview of current OHB-System design solutions for VHR Earth observation missions. FIG 8 shows the satellite design for a high resolution SAR mission and FIG 9 for a high resolution optical mission.

After evaluating the above trade-off elements, a potential system could consist of following elements:

- ground segment (for mission control, image reception and image exploitation), consisting of
  - one fixed ground station and
  - one transportable remote ground station,
- space segment, consisting of two satellites carrying an optical payload

As a result, a summary system description is given in TAB 3.

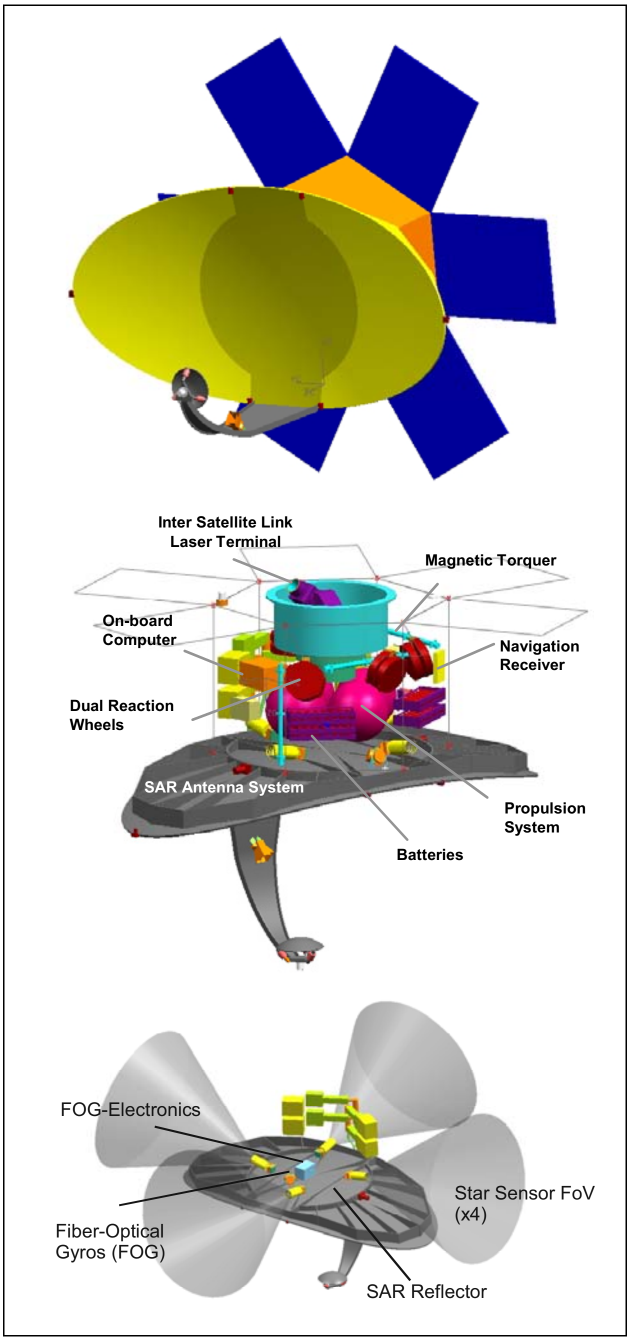

FIG 8: OHB-System satellite solution for a high resolution SAR mission

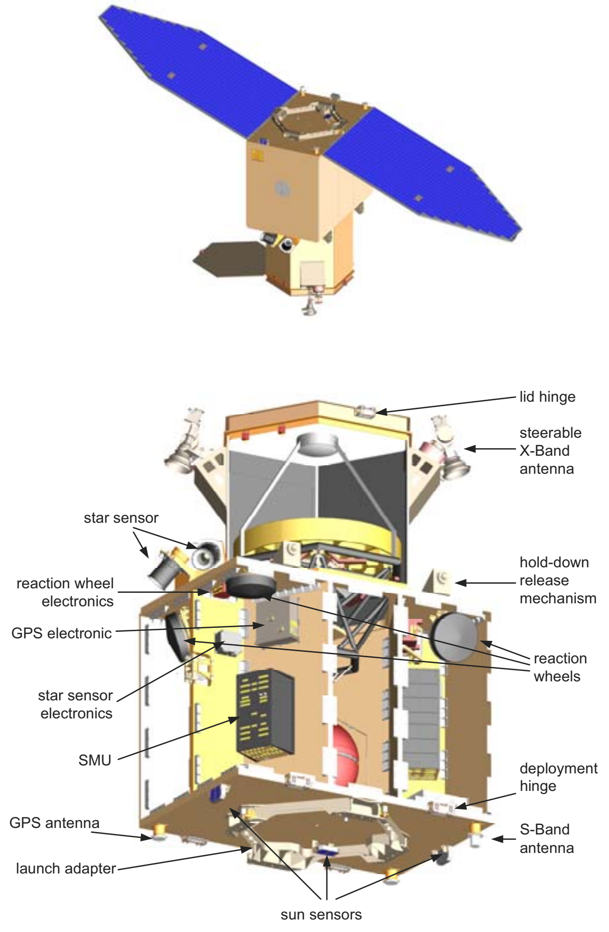

FIG 9: OHB-System satellite solution for a high resolution Optical mission

POTENTIAL NEXT GENERATION SYSTEM

The following TAB 3 gibes an overview of the features of a potential next generation VHR system.

System	
Constellation	2 satellites
System response time	Level 3 data: from 3 h up to maximum 32 h, mean 15 h
System capacity	100 spot images/day (1 shift, 40% clouds)
Survivability	resident against space environment, secured against hijacking, ECM can not harm the satellite.
Security	secured and encrypted data links: satellite <-> ground; ground <-> ground
Satellite	
Image resolution	PAN: 50cm / MS: 2m at Nadir
Localization accuracy	<10 m for Level 3 processed image data (depending on the Digital Elevation Model accuracy)
Spot image size	17 km x 17 km (14 Gbit)
Data storage and download	data storage capacity 768 Gbit (EOL), write speed up to 6 Gbit/s, data rate for transmission up to 522 Mbit/s
Transmission per satellite	
Transmission	X-Band (8 GHz), 600 Mbit/s using polarization multiplex
Avg. contact time per day	30 min
Images per day	80 (CR = 1,5) or 320 (CR = 6)
Ground Segment	
Processing time	< 2 h from Level 0 to Level 3 for one spot image
Archive size	1000 TBytes for 500.000 spot images for 7 years operation
Workstations (WS) / Operators	25 WS for 25 operators assuming 100 spot images per day at nominal working hours. Transportable GS: 8 WS for 8 operators with 30 spot images per day
Interoperability	prepared for multi-user capability and for Transportable Remote Ground Station

TAB 3: overview of specific features provided by the potential next generation system

4. CONCLUSIONS

OHB-System AG is working on the design of near future Earth observation systems for very high ground resolution. The user demands for VHR imaging are becoming more and more challenging: Very high ground resolution, very high agility and very short system response times are required. Primary this leads to high agile satellites or satellite constellations but it drives the satellite design as a whole, too.

The philosophy of the next generation platform is not to provide a standard platform as a whole but to reuse as far as possible proven subsystems like the avionics or propulsion subsystem and to adapt (or scale) the performance by exchanging components like star sensors or adapting the structure elements.

Due to security aspects, the very high ground resolution together with a fast system response will play a dominant role in the near future. Such systems can be realized on national level but also a co-use with the GMES initiative could be an approach for the benefit of Europe.

5. REFERENCES

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