FUTURE VERY HIGH RESOLUTION SAR & OPTICAL EARTH OBSERVATION MISSIONS

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ABSTRACT

Earth observation (EO) has become indispensable for monitoring of terrestrial geo-physical processes and security applications. To fulfil dedicated user needs in the future, sustainable related services will require more and more high-quality geo-information data at resolutions down to less than 1 m, which need also to be provided by satellite-based instruments. Beside military reconnaissance, typical civil applications and users of this kind of very high resolution (VHR) data are for instance urban mapping and emergency response (natural disasters monitoring & humanitarian aid).

Efficient environmental monitoring from space is therefore a fundamental necessity to provide reliable services on a global scale. Also the European initiative on Global Monitoring for Environment and Security (GMES) requires long-term contributions from independent co-operating missions providing frequent VHR data.

OHB-System and its partners have successfully developed and launched the SAR-Lupe satellite for VHR SAR imaging for military reconnaissance purposes. Based on this heritage the next generation platform for civil applications will be able to accommodate VHR payloads of both categories, optical as well as microwave (synthetic aperture radar - SAR).

This paper presents OHB's next generation platform core elements and will outline its performances to realize VHR missions supporting typical future EO applications. This platform provides a scaleable satellite approach, where special emphasis will be placed on the platform conformity to accommodate various VHR payloads, such as optical, as well as SAR systems.

The corresponding platform will provide exceptional capabilities to comply with corresponding payload requirements, such as high data rates and power demands, high agility and high-accuracy attitude control and pointing stabilities. Further, the platform's advantageous value-to-cost ratio and its modular approach enables it to fully adapt and comply with a wide range of mission objectives.

1. INTRODUCTION

Since the successful launch and operations of GeoEye's IKONOS II satellite (after an initial launch failure) in 1999, Very High Resolution (VHR) is available on a commercial basis. Projects to use VHR optical satellite sensor data started in the 60s with the use of spy satellites during the cold war.

The US Declassification of Cold War Reconnaissance Satellite Imagery provides access to the high resolution performance of American military spy satellites at that time.

FIG 1. Eiffel Tower, Paris, France, Acquired March 20, 1966 KH-7 Mission 4026 [1]

KeyHole-7 was operational from July 1663 to June 1967 at 1.2m resolution (FIG 1.); its imagery had a swath width of about 23.5km with a scene length anywhere from about 8km to 750km in length, the camera could be turned (tilted) in the cross-track direction to extend the field of regard.

The number of existing and announced high and VHR imaging satellite systems is growing permanently. 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.

1.1 Applications and Users

VHR Earth Observation are of interest for operational services like GMES (Global Monitoring for Environment and Security), military and commercial services.

More and more countries are entering the field of earth observation, so in near future 22 countries will have their own sensors in space. Already 10 of them are involved in VHR earth observation.

VHR imagery have uses in a number of different areas and various applications such as:

military:

- Object detection, recognition, identification (STANAG 3769, TAB 1.),

Type of target	Detection	Recognition	Identification
Bridges	6 m	4.5 m	1.5 m
Troop Units	6 m	2 m	≈ 0.5 m*
Airfield Facilities	6 m	4.5 m	3 m
Ports and Harbours	30 m	6 m	1.5 m
Coasts and Beaches	15 m	4.5 m	≈ 0.5 m*
RR-RR Yards Shops	15 m	4.5 m	1.5 m
Roads	6 m	4.5 m	1.5 m
Urban Areas	60 m	15 m	3 m
Terrain	N/A	91 m	3 m

TAB 1: Examples of the STANAG 3769 target types

- Theatre overview and
- Instructions on targets.

Governmental:

- Environmental monitoring: images took by VHR systems will contribute to the determination of polluter,
- Disasters Monitoring: constellation's observation capabilities in the optical and radar bands, combined with the short revisiting intervals will pay an important part for disaster monitoring and damage assessment such as earthquakes, floods and fires as well as man-caused disasters,
- Mapping: mapping of urban areas for monitoring the evolution of cities and for urban planning, making new maps and updating older ones,
- Security like emergency response, humanitarian aid (estimate intact routes, coordinate humanitarian aid measures), Traffic monitoring and identification (e.g. ships).

Commercial:

- Global information systems (e.g. google earth).

1.2 VHR Satellites Overview

Several VHR optical satellites systems are announced for the next years. In general the number of VHR observation systems will be enlarged very soon (TAB 2.). The tendency goes to higher resolution and lower weight; that means also in most cases to a lower price. In addition the tendency of international cooperation for system development is growing.

However, VHR is a very sensitive area due to its military usage. Components or even systems for VHR can only be sold between allied nations and is subject of stringent export license issues.

System	Country	Launch	Type	GSD [m]
GeoEye-1	US	fall of 2007	optical	0.41 PAN / 1.64 MS
WorldView-1	US	mid of 2007	optical	0.45 PAN
WorldView-2	US	01.07.08	optical	0.5 PAN/ 1.8 MS
Quickbird-2	US	18.10.01	optical	0.61 PAN/ 2.5 MS
EROS-B	Israel	25.04.06	optical	0.7 PAN
EROS-C	Israel	21.03.08	optical	0.7 PAN/ 2.5 MS
Pleiades-1	France	01.03.09	optical	0.7 PAN/ 2.8 MS
SARLupe 1-5	Germany	2006-2008	SAR	<1.0
COSMO-SkyMed-1	Italy	08.06. 07	SAR	<1.0
IKONOS-2	US	24.09.99	optical	1.0 PAN/ 4.0 MS
OrbView-3	US	26.06.03	optical	1.0 PAN/ 4.0 MS
Resurs-DK1	Russia	15.06.06	optical	1.0 PAN/ 3.0 MS
Kompsat-2	Korea	28.07.06	optical	1.0 PAN/ 4.0 MS
IRS Cartosat-2	India	10.01.07	optical	1.0 PAN
TerraSar-X	Germany	15.06.07	SAR	1.0

TAB 2. Overview of Very High Resolution Satellites [2]

Currently three commercially used VHR satellites are active. Ikonos-2, Quickbird and Orbview-3 have ground sampling distances (GSD) of 1m and better.

Even if these systems are commercial, most of the data is sold to US military customer and is not available on the free market.

The number of VHR satellites will grow very soon with the systems IRS Cartosat-2 from India, Kompsat-2 from South Korea, EROS-C from Israel, Cosmo-SkyMed from Italy and Pleiades from France having a GSD between 0.7m and 1m. In addition the resolution will be improved by WorldView-1, WorldView-2 and GeoEye-1 (OrbView-5) from USA down to 0.5m.

Germany is entering the field with TerraSar-X and SAR-Lupe. TerraSar-X was launched on 15.06.07 with a wide spectrum of scientific applications in fields like: hydrology, geology, climatology, oceanography, environmental and disaster monitoring, and cartography. The project is supported by BMBF (German Ministry of Education and Science) and managed by DLR (German Aerospace Center). SAR-Lupe is a SAR (Synthetic Aperture Radar) reconnaissance satellite imaging project, with OHB-System AG of Bremen as prime contractor. The first of five satellites is successful operational since December 2006.

Most of the VHR observation satellites are based on dual use e.g. WorldView, GeoEye-1, Pleiades and Cosmo-SkyMed. The highest percentage of the required funds is coming from military and the remaining free capacity is available for commercial applications.

1.3 System Requirements for VHR

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 (<<24h)
- High geo-localisation accuracy (<<100m)
- High ground resolution (<<1m)
- 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 archive that, the satellite has to provide very fast attitude manoeuvres. The satellite needs very high agility for multi target capacity.

2. VHR EXAMPLE: SAR-LUPE

SAR-Lupe (FIG 2.) is a highly innovative satellite system for global surveillance that OHB has developed for the German Ministry of Defense (BMVg) and the Federal Office of Defense Technology and Procurement referred to as BWB (Bundesamt für Wehrtechnik und Beschaffung).

FIG 2. SAR-Lupe Satellites

The system consists of:

- five satellites, as depicted in FIG 4.,
- a ground segment for satellite control (semi-automated operation by OHB) providing:
  - Control of the space segment,
  - Reception and processing of raw SAR-data,
- and a ground segment for image exploitation (Information Management, operation by the military user),
  - User interface
  - Evaluation, analysis and archiving

The first satellite FM1 (FIG 3.) has been launched on 19th December 2007 with a Russian COSMOS3M from Plesezsk and is operational since then. FM2 integration is completed. The launch is planned for July 2007. The integration of FM3 and FM4 is nearly completed. The ground stations are operational.

The main system features, are listed below:

- All-weather, day and night capability by X-Band SAR,
- Two standard scene sizes:

  > 8 x 60 km² at high resolution,

  > 5.5 x 5.5 km² at highest resolution,
- Geometrical resolution: < 1 m,
- System response time: < 19 h,
- Images per day: > 30,
- Lifetime: >10 years,
- Reliability: ~ 98% per year.

FIG 3. SAR-Lupe Flight Model

The SAR-Lupe system satellites operate in 3 approximately polar orbit planes (FIG 4.) at an approximate altitude of 500 km and use the same antenna for image acquisition and X-band data downlink. They are equipped with an S-band link for commanded telemetry via ground station and via inter-satellite link.

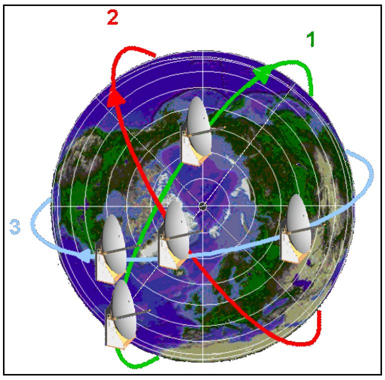

FIG 4. SAR-Lupe Constellation Architecture

The main characteristics of the SAR-Lupe satellite bus are:

- Size: approx. 4 x 3 x 2 m3,
- Mass: approx. 770 kg,
- Average Power: approx. 250W,
- Orbit Control: Hydrazine system.

The satellites feature two image acquisition modes, the STRIP-SAR operating in Nadir direction and the SLIP-SAR, which rotates the entire satellite in order to increase the integration time and therefore the in-track resolution. However, the system is based on technology, which is readily available. To secure and guarantee the operation for more then 10 years, high redundancy concepts are employed. System and satellite operation is managed by OHB.

3 OHB – NEXT GENERATION SYSTEMS

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 1.3.

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 sections provide system and platform design issues with respect to next generation systems.

3.1 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 Figure 5 shows exemplary the improvement of the maximum and mean system response time, which can be achieve by adding additional satellites to a satellite constellation.

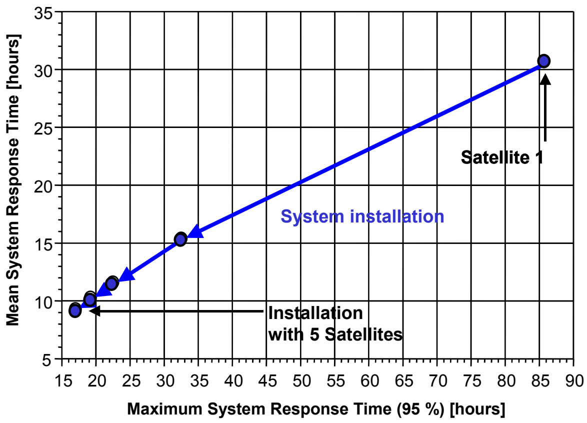

FIG 5: Improvement of the System Response Time by the Implementation of Multiple Satellites

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 Figure 5 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.

3.2 Next Generation Platform

The following figures provide an overview of current OHB-System design solutions for VHR Earth observation missions. Figure 6 shows the satellite design for a high resolution SAR mission and Figure 7 for a high resolution optical mission.

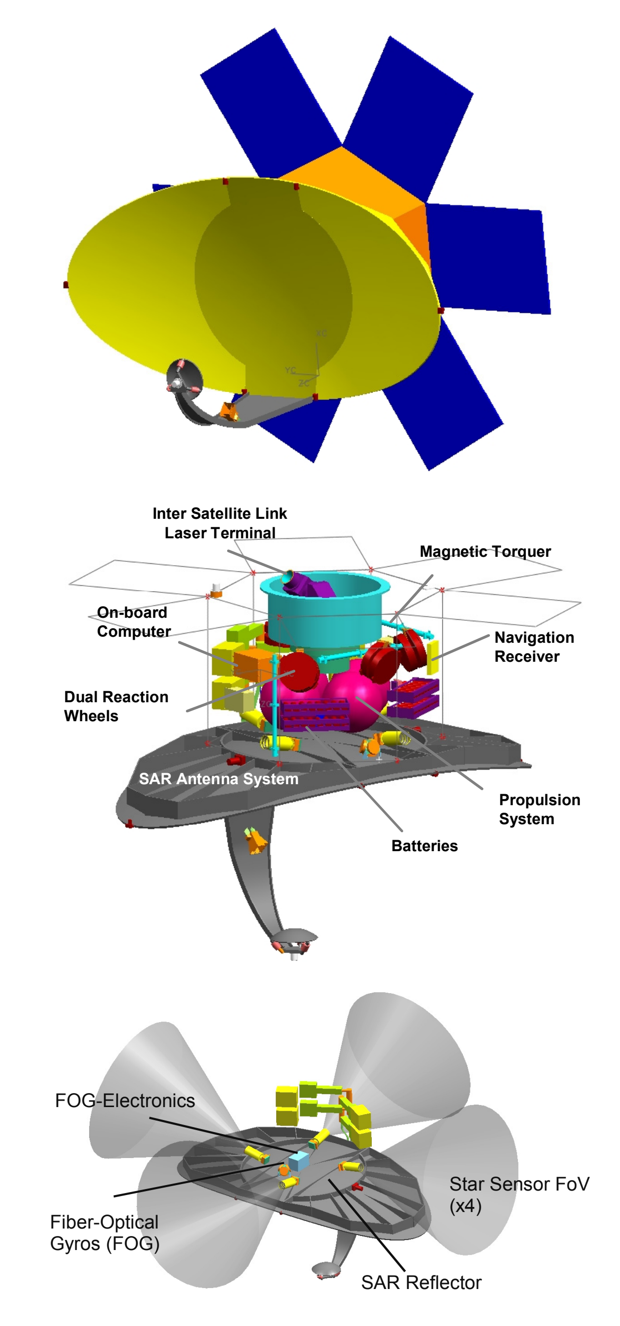

FIG 6: OHB-System Satellite Solution for a Future High Resolution SAR Mission

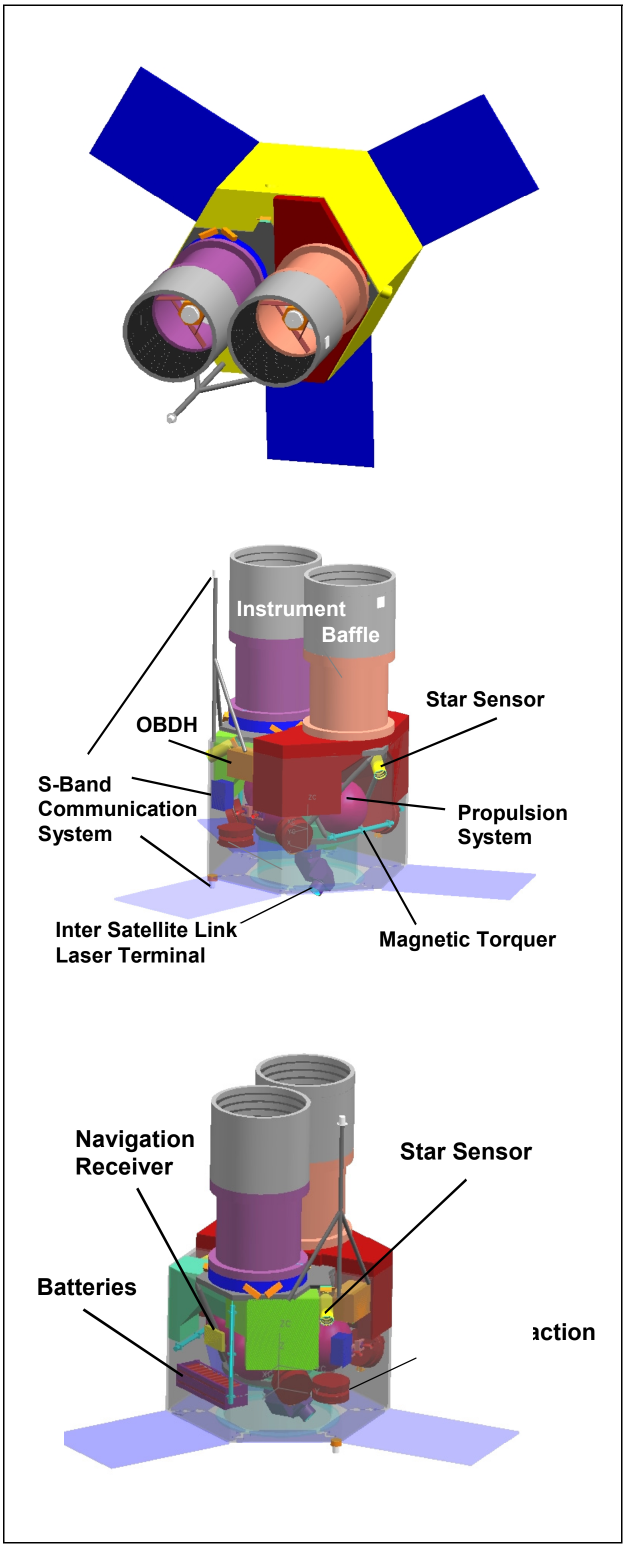

FIG 7: OHB-System Satellite Solution for a Future High Resolution Optical Mission

For each requirement discussed in section1.3 both of these design solutions feature the following specific highlights in detail:

For high geo-localisation accuracy:

- highly accurate star sensors and gyros,

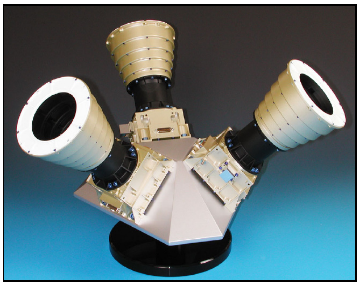

FIG 8. SODERN Hydra [3]

- stiff structural elements and connections to minimise residual vibrations after attitude manoeuvres,
- implementation of the attitude sensors on a rigid optical bench (as shown in FIG 7.) 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.

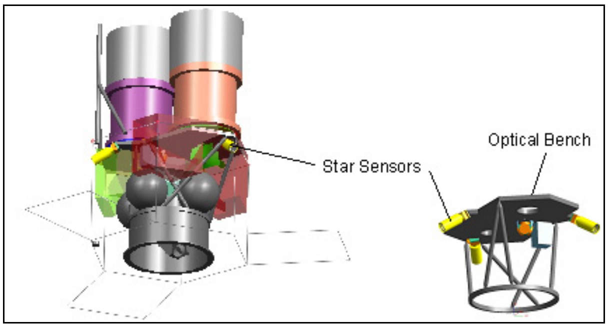

FIG 9: Star Sensors implemented on Optical Bench

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 10: 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 500kg building a satellite in the range of 800 up to 1200kg.

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 11.).

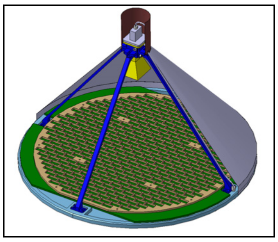

FIG 11: Antenna with Pointing Mechanism

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

3.3 Potential Next Generation System

For a complete next generation 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.

After evaluating these trade-offs 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 electro-optical payload,

and provide the following specific features:

System	
Constellation	2 satellites
System response time	Level 3 data: from 3h up to maximum 32h, mean 15h
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	17km x 17km (14Gbit)
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	30min
Images per day	80 (CR = 1,5) or 320 (CR = 6)
Ground Segment	
Processing time	< 2h 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 Conclusion

OHB-System AG is working on the design of near future Earth observation systems for very high ground resolution. Out of the user demands for VHR imaging, global Earth coverage at very fast system response time, demanding requirements for the agility for the satellite (constellation) result, which drive also the satellite design as a whole.

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.

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