

AsteroidFinder: A Small Satellite to Characterize the IEO Population

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ABSTRACT

The AsteroidFinder mission, the first mission in the DLR-Kompaktsatellit program, will help characterize the unknown Inner Earth Object population in terms of mass, size and distribution. The satellite shall operate for a period of one year, aiming to detect faint objects down to an apparent magnitude of 18.5 V_{mag} (under a sky background of 20.3 V_{mag}). The space segment of the AsteroidFinder mission consists of a small satellite with a mass between 150-200kg. The design of the AsteroidFinder satellite bus and instrument has been driven by a trade-off between conflicting performance parameters and shows that it is feasible to design a small satellite with high performance in terms of agility, stability and data volume to support a mission with a substantial scientific return. In order to achieve the required performance of the satellite, the satellite has been designed using a mixture between COTS hardware and own developments. The design method has implemented state-of-the-art engineering methods and has been based on tailoring of already existing standards. The AsteroidFinder project conducted the PDR in May 2011, and phase C/D is expected to be initiated before the end of 2011.

INTRODUCTION

The small satellites class represents a good trade-off between properties of larger satellites and the class of nano/pico satellites. The small satellite class enables missions with a significant scientific return at a lower cost than larger satellites. The small satellites achieve their high performance relative to their size by using state-of-the-art COTS technology and engineering methods in the design. Often large cost reductions are obtained using hardware which is less reliable than fully space qualified and radiation hardened hardware, with a lower mission lifetime as a consequence. Often mission lifetimes of 5+ years are not required by the scientific community, and therefore this aspect represents no significant impact on the scientific return.

The DLR-Kompaktsatellit Program

In 2007 DLR decided to initiate the DLR-Kompaktsatellit (DLR Compact Satellite) program. The DLR-Kompaktsatellit program has as an objective to provide a satellite platform for DLR payloads and their related research. The goal of the DLR-Kompaktsatellit program is to build on the experience gained inside DLR with the launch of BIRD (launched in 2001) and TET-1 (to be launched in 2011) satellites.

Three candidate missions for the first DLR-Kompaktsatellit mission were selected in 2007. During 2007 a study was conducted, at the then newly founded Institute of Space Systems, analyzing and evaluating the three candidate missions. At the end of 2007, the AsteroidFinder proposal was selected to be the first DLR-Kompaktsatellit mission. The mission is managed by the Institute of Space Systems, which is also responsible for developing the satellite bus. The payload is developed by the Institute of Planetary Research, DLR and the ground segment is handled by the German Space Operations Center (GSOC).

Apart from the scientific return, one of the objectives of the first DLR-Kompaktsatellit mission is to gain experience and knowhow to a newly founded institute and engineering team. The team assigned to the bus development of AsteroidFinder consists of a group of highly motivated engineers of which many have less than 5 years of experience in the field of satellite development, not counting experience gained by university projects such as CubeSats. The design team is supported by consultants from the German space industry throughout all phases of the project. The many trade-offs performed has ensured that the possibilities for enhancing and tailoring the performance achievable

with the platform is well known within the relevant areas.

THE ASTEROIDFINDER MISSION

Inner Earth Objects (IEO's) are objects whose orbit resides completely inside the Earth's orbit around the sun. IEO's represent a potential risk of collision with the Earth, due to the disturbance of the orbit due to other celestial objects (e.g. Venus or Mercury). IEO's are generally not visible from earth based telescopes due to the brightness of the sky at the required solar elongation angles for observation. Traditional asteroid surveys conducted from ground based telescopes therefore focuses primarily on near earth objects that have an aphelion outside the orbit of the earth, which allows to perform the surveys during the night. The difficulties of detecting IEO's from ground drives the need for a space telescope in order to detect and characterize the IEO population.

Mission Definition

The AsteroidFinder mission shall characterize the population of NEOs (Near Earth Objects) and in particular IEOs and Atens in terms of:

- Number of objects
- Orbital distribution and orbital parameters
- Size distribution

Asteroids shall be recognizable through their apparent motion against the fixed star background on subsequent images taken by the AsteroidFinder Instrument flying onboard the satellite bus platform. The observations shall enable the determination of short-arc orbits, whose accuracy shall be adequate to recover the detected objects within one month from ground-based follow-up observations, or from AsteroidFinder itself.

In addition to detecting IEOs, AsteroidFinder should also discover a number of Near Earth Objects, and an even larger number of Main Belt Asteroids, thereby contributing to our understanding of those populations.

Mission Description

The main science objective of AsteroidFinder is to discover a significant number of IEOs, determine their orbits and estimate their sizes. As seen from 1 AU, these objects are located at small solar elongations, and therefore the main search area for AF is the region of interest (RoI) defined by -60° ; -30° and $+30^\circ$; $+60^\circ$ in sun-centered ecliptic longitude and from $+40^\circ$ to -40° in sun-centered ecliptic latitude. **Fehler! Verweisquelle konnte nicht gefunden werden.**Figure 1 shows the positions of all objects from the IEO model population

given by ¹ down to a size of about 100m and over a period of 5 years, with the RoI overplotted as red rectangles. The inner limit in sun-centered longitude (-30° and $+30^\circ$) is driven by practical design limitations (baffle design and in the telescope straylight rejection properties) and by the increased sky background brightness due to the Zodiacal Light. The outer limits in longitude and in latitude are chosen to maximize the search efficiency and not to interfere with the major NEO ground-based surveys.

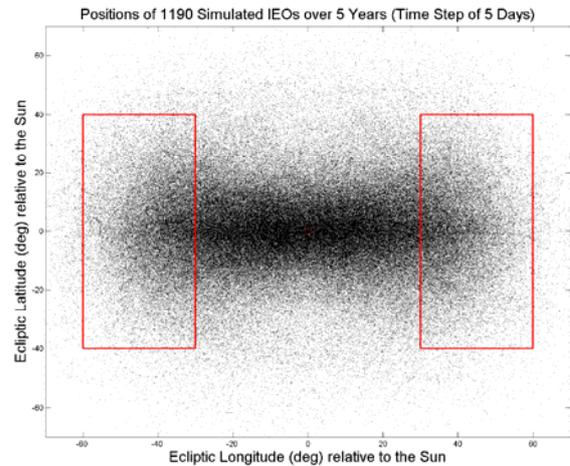


Figure 1: Region of Interest

Mission Phases

The nominal mission duration is 1.25 year, which includes approximately 1 week of LEOP, and ~3 months of commissioning and characterization of the performance of the satellite. The AsteroidFinder satellite will be launched into a sun synchronous orbit, designed for an LTA N between 0500 and 0700 throughout the mission lifetime, which will optimize the time available for observations in the region of interest. Due to the glow of the atmosphere, the payload requires minimum orbital altitude of 550km at the end of the mission. The disposal of the satellite will be done by passive means, i.e. natural decay.

Science Planning and Mission Operations

The mission operations will be performed by the German Space Operations Center (GSOC), based on the requests from the science team. Based on a model of the spacecraft performance, the science team will prepare an operational profile including an attitude profile, instrument data acquisition commands, and instrument calibration commands. The profile will be sent to GSOC which will perform a constraints check ensuring that the requested profile is compatible with the most recent telemetry and flight dynamics information. If the requested profile is approved, it will be converted into a

time tagged command queue, which will be uploaded to the spacecraft. The majority of the operational schedule will be prepared approximately 4 days prior to being uploaded to the spacecraft. In order to react to possible detections of IEO's, two orbits per day has been reserved for short-term planned observations. These profiles will be prepared a minimum of 12 hours prior to being uplinked to the spacecraft by the science team. If the constraints check fail for the proposed schedule, a backup schedule will be used, which is uploaded together with the nominal schedule.

SPACE SEGMENT OVERVIEW

The space segment of the AsteroidFinder mission consists of a single satellite.

The scientific return of the mission is primarily determined by three performance parameters which drive the design of the satellite. The parameters and the impact on the design of the satellite will be described in the following paragraphs and are summarized in Table 1.

Limiting magnitude: The limiting magnitude of the telescope determines the required brightness of the object which can be detected. The brightness of the IEO's is determined by the size, albedo coefficient, phase angle and distance between AsteroidFinder and the object. The limiting magnitude therefore has a direct impact on the whether an IEO is detectable by AsteroidFinder, and as a consequence the number of IEO's which will be detected throughout the mission. The required limiting magnitude drives the telescope design, in particular the telescope aperture and the detector technology used. The limiting magnitude furthermore drives the requirements for the satellite platform in terms of stability of the satellite during observations and the thermal design which must ensure that the detectors are operating around their optimal temperature in order to reduce the signal to noise ratio.

Astrometric accuracy: The astrometric accuracy determines the accuracy of which the position of the IEO's can be determined. A high astrometric accuracy is required to ensure that follow up detections can be performed, and therefore directly impacts the number of IEO's for which a good orbit determination can be achieved. The requirement for astrometric accuracy drives the design of the telescope and in particular the detector array to be used. The astrometric accuracy can be increased by subsampling of the detector array with a larger data volume as a consequence. Finally due to smearing of the images to be taken, the stability of the instrument impacts the astrometric accuracy achievable by the mission.

Field Coverage: The field coverage parameter determines the coverage of the survey performed by AsteroidFinder. The coverage has a direct impact on the amount of IEO's which can be detected. The field coverage parameter drives the design of the telescope; where a larger field of view will increase the coverage percent, but however with a fixed aperture size will lower the limiting magnitude. Another significant performance parameter which directly impacts the field coverage of the mission is the agility of the satellite. A high spacecraft agility will increase the time available for observation throughout the mission. Finally the field coverage also drives the thermal design of the spacecraft due to the location of cold radiators and thermal constraints.

In general the three parameters are competing e.g. for a fixed telescope aperture size an increase in limiting magnitude and astrometric accuracy, by reducing the field of view will result in a decrease in field coverage. An extensive tradeoff between the three performance parameters has been performed in Phase A of the mission in order to derive the requirements for the satellite.

Parameter	Determines	Driver for	Affects
Limiting Magnitude	- Brightness of detectable IEO's	- Telescope Aperture Size - Telescope Design - Thermal Design - Instrument Stability - Telemetry System	- Number of IEO's discovered
Astrometric accuracy	- Orbital accuracy of detected IEO's - Follow-up capability	- Telescope Design - Detector selection - Instrument Stability - Telemetry	- Orbit determination of IEO's - Number of IEO's detected
Field Coverage	- Survey Coverage percentage	- Telescope design - Spacecraft Agility - Thermal Design - Telemetry System	- Number of IEO's discovered

Table 1: Summary of Satellite Design Drivers

Space Segment Configuration

The main elements of the AsteroidFinder satellite are depicted in Figure 2. The satellite consists of a satellite bus compartment, a payload compartment, deployable solar panels, a sunshield and finally the cold radiator and the MLI encapsulating the payload compartment.

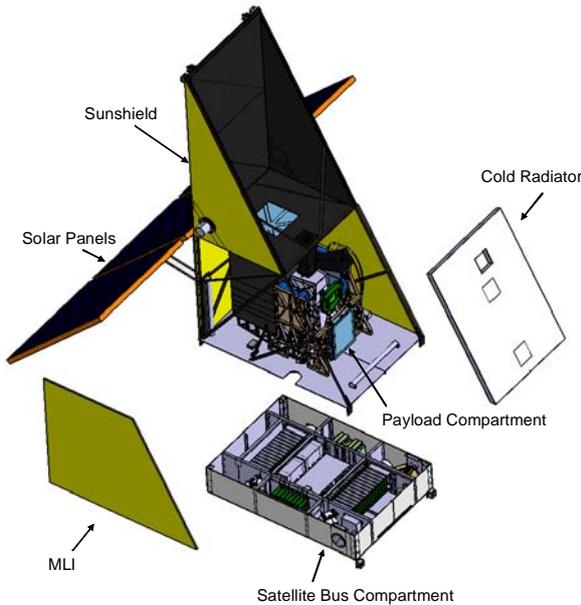


Figure 2: Main elements of the AsteroidFinder Space Segment

The majority of the satellite bus units are located in the ‘satellite bus compartment’, with the exception being units which functionality requires them to be located elsewhere (e.g. magnetorquers, magnetometers and sun-sensors).

The payload data processing and power conversion units are located in the satellite bus compartment, and all remaining payload units are located inside the payload compartment.

The solar panels are stowed during launch, and deployed in a 45 degree angle after spacecraft separation. The stowed configuration of AsteroidFinder can be seen in Figure 3.

The sunshield is constructed using MLI, and the inner layer consists of a material which has a low reflectivity. The sun shield has an angle of 27 degrees with respect to the telescope boresight. The sunshield ensures that direct sunlight does not enter the telescope aperture during nominal operations.

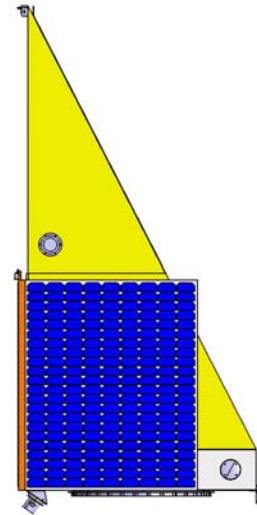


Figure 3: AsteroidFinder in stowed configuration

Bus-Payload Interface

The main electrical interfaces between the payload and the satellite bus consists of 4 cold redundant SpaceWire connections each operating at 10 Mbit/s and 14 separate power switches, providing a total of 150W during nominal operations. The mechanical interface between the instrument and the satellite bus consists of three iso-static mounts.

A functional diagram of the AsteroidFinder Space Segment can be seen in Figure 5. Fehler! Verweisquelle konnte nicht gefunden werden..

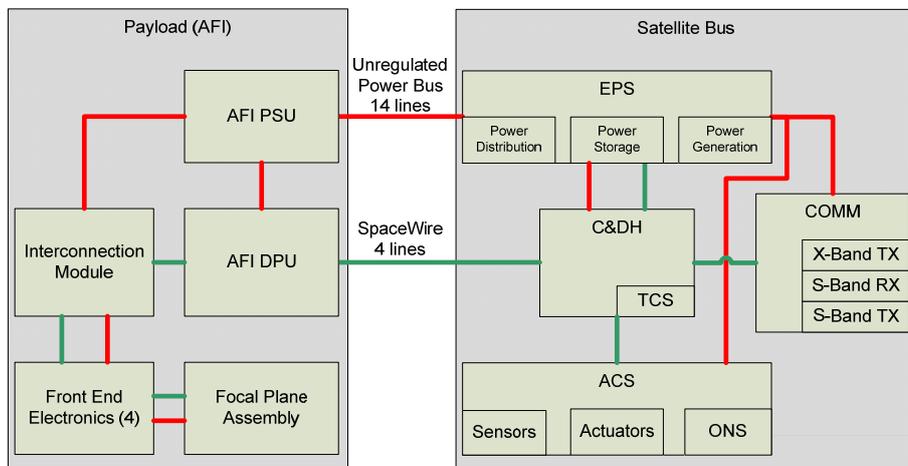


Figure 4: Space Segment Functional Diagram

ASTEROIDFINDER INSTRUMENT

To achieve its goals the mission has to detect small objects of various surface albedos, including extremely dark ones, near the direction of the Sun. This requires the instrument to be zodiacal background limited over the entire region of interest, which corresponds to a magnitude of $V = 18.5$ at 30 degree solar elongation and $V = 19.6$ at 60 degree solar elongation. Long exposure times (~ 1 min) and, therefore, a high pointing stability is needed. Since the stability requirement is beyond the capability of the satellite bus, image stabilization is implemented at instrument level. Furthermore straylight suppression is one of the main design drivers, which affects all aspects of the instrument and the spacecraft design.

The instrument consists of two main elements; the telescope assembly and the DP U/PSU assembly. The telescope assembly can be seen in Figure 4 and consists of the telescope itself, the focal-plane array (detectors), the front-end electronics (FEE), the interconnection module (IMU), baffle and a cover.

The thermal control and telemetry/telecommanding capabilities are provided by the spacecraft bus.

A novel and purely reflective off-axis optical telescope (Cook Schmidt), with an astigmatic four-mirror design, has been adopted as a result of extensive trade-off studies performed on different types of telescopes. This optical design can handle a large field-of-view, being simultaneously very compact and having optimum straylight rejection. The telescope is based on all-Cesic® design both for the structure and the mirrors. This solution results in a compact and stiff design which has favorable mechanical and thermal properties.

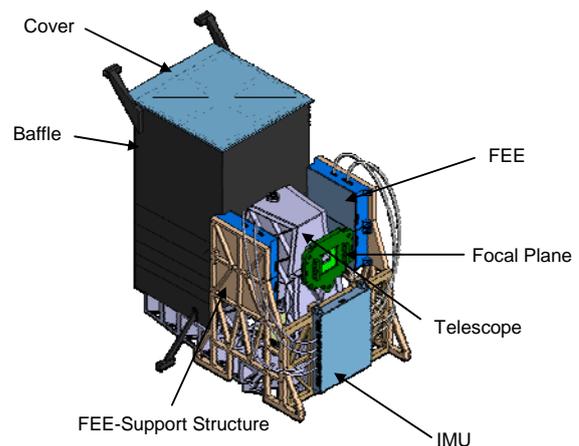


Figure 5: AsteroidFinder Instrument Telescope Assembly

The characteristics of the telescope are summarized in Table 2.

The telescope, for which the conceptual design has been performed in the frame of an industrial study, is equipped with a focal plane array composed of four independent detector arrays, which are based on the innovative Electron Multiplying CCD201-20 from e2v. Data from each detector will be processed in a separate processing chain, thereby providing system redundancy. The resulting instrument data is stored in the mass-memory system of the satellite bus until it is downlinked to ground.

Telescope Key Parameters	
Field of View	2.662° x 2.1° ¹
Focal Length	760 mm
Effective Aperture	200x200mm ²
Pixel Resolution	2048 x 2048
Pixel Size	13µm x 13µm
IFOV	0.001° x 0.001°

Table 2: Key parameters of the telescope

SATELLITE BUS OVERVIEW

One of the main drivers in the initial phases of the AsteroidFinder mission was to utilize the experience gained by the satellites BIRD and TET-1 satellite, and therefore the satellite bus uses heritage design similar to these missions where ever possible, either due to technical or programmatic reasons.

The satellite bus contains the standard elements of a small satellite without a propulsion subsystem. The satellite bus provides the following primary functions:

- Primary power generation, storage and distribution
- Attitude control
- Store and forward of payload data
- Telecommanding and telemetry handling and interface to ground.

The primary performance parameters and characteristics are summarized in Table 3.

In Figure 6 an overview of the satellite bus can be seen.

AsteroidFinder Satellite Bus Characteristics			
Bus compartment dimensions		0.7 x 1.0 x 0.18 m ³	
Payload envelope		0.82 x 0.67 x 0.50 m ³	
Platform Mass	149kg / 113kg ²	Payload mass	30kg
Deign lifetime	2 years	Thermal control	Passive, with emergency heaters
Bus power consumption	819W Peak 158W Average	Payload power consumption	204W Peak 115W Average
Solar panel capability, sunpointing, EOL	515 W	Power generation (design scenario)	312 W
TM/TC Uplink Downlink	8 Kbit/s 270 Kbit/s	Payload data	27GiB / day
ACS Agility	Slew Time [Deg] [sec] 5 60 10 90 15 100 30 130	ACS Stability	0.875 arcsec / 200ms

Table 3: Satellite bus main characteristics

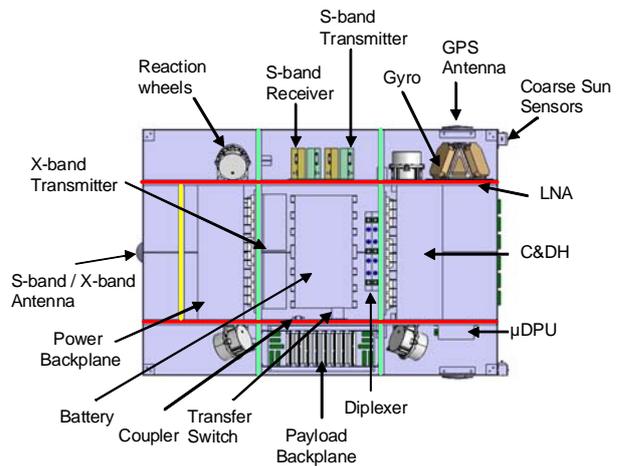


Figure 6: Satellite bus overview

¹ Effective FOV is 2°x2° due to the mechanical design of the focal plate

² No margins assumed.

Design Drivers for the Satellite Bus

The primary design drivers for the satellite bus are derived from the design drivers for the space segment, and are summarized below:

High agility between observations: In order to maximize the amount of mission time available for scientific observations the spacecraft has to be able to minimize the time spent for slewing between two inertial pointing attitudes. Furthermore a minimum spacecraft agility is required in order to avoid stray light originating from earth albedo to enter the telescope to maintain the thermal constraints of the cold radiator. Due to the requirements for high agility of the spacecraft, the satellite bus follows a highly integrated approach, and much effort in the accommodation of the bus units has been spent in order to reduce the MoI of the satellite.

High pointing stability during observations: The spacecraft shall have a high stability during observations with the telescope in order to prevent blurring of the images taken by the instrument. The pointing stability requirement affects the actuators which can be used for the attitude control system, and therefore is closely related to the high agility requirement.

Payload data generation volume: The payload will generate approximately 27GiB per day with a peak generation rate of 3GiB per hour during the nominal mission. With 4 ground station contacts per day, providing a total contact time per day of ~26 minutes, this requires a relative large amount of onboard storage, and a high speed data link.

Power demand: AsteroidFinder has a relative high power demand compared to its class. One of the primary contributors to the MoI of the spacecraft is the solar panels, and therefore an optimized panel design, and power consumption for the satellite is required.

Thermal requirements of the instrument: In order to achieve the required noise to signal ratio in the observations, an operating temperature of -85 degrees C is required at the focal plate where the CCD's are mounted. The surrounding electronics all have operating temperatures close to or above 0 degrees C, which results in large temperature differences over relative short distances.

The following sections will contain a brief description of the systems which constitute the satellite bus.

Structure and Configuration

The structure of AsteroidFinder is based on a hash(#) architecture, with two walls extending the full length of the satellite bus (illustrated in red in Figure 6), and the remaining walls being bolted together with the primary walls (illustrated in green). The payload is structurally connected to the bus structure using three iso-static mounts, of which two are mounting on the intersection between the walls. An additional wall is added to the bus compartment in order to support the last connection point of the payload (illustrated in yellow). The launch adapter is connected to the hash structure in eight points providing a strong and stiff load carrying path from the launcher to the payload. The payload compartment is constructed from carbon struts, which forms the basic structure upon which the MLI and cold radiator is mounted. The structure of the payload compartment and the sunshield can be seen in Figure 7.



Figure 7: Illustration of payload compartment and sunshield structure

Avionics System

The satellite bus is centered around the avionics system, which provides the interconnection of all the units onboard the satellite. The challenges in a typical avionics system development include the complexity of the system, the software-hardware interfaces and the difficulties to handle different interfaces in a single system. The avionics concept for the satellite bus for the DLR-Kompaktsatellit targets these problems and aims to provide a solution consisting of both software and hardware².

The core avionics consists of the middleware switch, which serves as a central node of information exchange and data interface for all units onboard the satellite, the onboard computer and the Analog/Digital units. The only exception to this concept is the X-band transmitters, which due to their high data rate (>100Mbit/s) is connected directly to the onboard computers, and the S-Band receivers and transmitters since a large part of the TM/TC encoding is implemented as part of the onboard computer. An

architectural overview of the MWS concept can be seen in Figure 8.

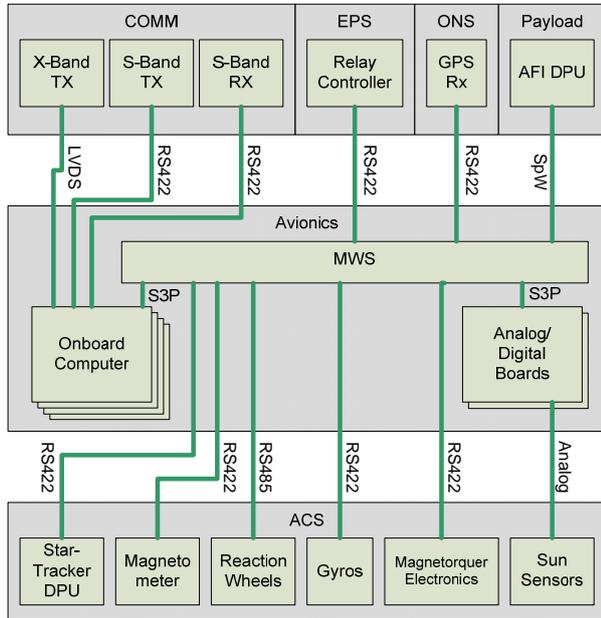


Figure 8: MWS Centered Data Interface Architecture

The MWS is a publish/subscribe multicast bus. Each interface port of the MWS provides a protocol translation layer to connect a device with its own interface and protocol to the Middleware Bus. The MWS is FPGA based (will possibly later be implemented in ASIC to increase robustness), and can be tailored to the specific mission and requirements ensuring a quick turn-around time for partial re-use of the satellite bus.

Electrical Power System

The power system for the AsteroidFinder mission shall deliver 273W on average during the operational phase of the mission to the operating units. The power distribution for AsteroidFinder is based on an unregulated power bus, which is connected directly to the battery. The electrical power system consists of the following elements:

- Solar generator
- Battery charge regulators
- Battery
- Power distribution units
- Power regulation units

The solar arrays consist of 28% efficiency triple junction solar cells, providing a EOL power output of 515W. The cells will be mounted on deployable solar arrays which will be deployed in a 45 degree angle with respect to the telescope boresight vector. This allows for the maximum power generation during the operational profile foreseen for AsteroidFinder.

In order to maximize the power output available from the solar panel and minimize the thermal impact, the battery charge regulation is based on MPPT units rather than a shut based approach. Multiple MPPT's are coupled in parallel in order to increase the failure tolerance.

The AsteroidFinder satellite bus is equipped with a 1.2 kWh battery (rated at the beginning of the LEOP phase). The battery design is primarily driven by the requirements for the LEOP phase, and the ability to provide sufficient power for detumbling of the satellite after separation from the upper stage and sun-acquisition.

The power distribution is handled by a controller board which accepts a serial interface, and operates solid-state switches allowing to power units on and off. Depending on the criticality of the unit, various switch combinations are utilized, e.g. for all the transmitters a quad-switch is utilized ensuring that a single point of failure does not cause a fail-on or fail off scenario.

Attitude Control

The attitude control system is designed based on the requirements for a high stability during imaging and high agility between imaging, while slewing. If the same actuator configuration is used to control the spacecraft attitude in both operational modes the resulting performance will be a compromise of the two given with the available technology. A tradeoff has been performed in order to assess the possibility of using a cold gas based actuator system for the slewing phase, and a set of small reaction wheels maintain the attitude during imaging. Due to the high number of slews which has to be performed during the mission (on average 500-700 per day) this actuator configuration proved unfeasible due to the high amount of propellant required. A propulsion based actuator configuration would require the use of fuels which are able to provide a high isp. A propulsion system represents a challenge during handling and integration, which was not deemed feasible for the first mission of the DLR-Kompaktsatellit. Therefore this option has not been investigated further.

The actuator configuration used is instead based on the heritage design from BIRD and TET-1 consisting of a

set of reaction wheels, and magnetorquers. The magnetorquers are used to de-saturate the wheels, as well as detumble the satellite in the initial phase after separation. With this actuator configuration it is possible to achieve an acceptable performance.

The attitude determination is performed using a combination of gyros, magnetometer, star trackers, and sunsensors. In order to achieve the high pointing accuracy the instrument will be utilized as an attitude sensor when fine pointing is required.

Communication

AsteroidFinder includes two communication systems; TM/TC downlink/uplink in S-Band, and the payload data downlink in X-Band. The two systems operate independently of each other, and will be used simultaneously in the nominal mission scenario. The TC uplink operates with a bitrate of 8Kbit/s. The TM downlink has a data rate of 270Kbit/s. In the nominal phase of the mission, one TM/TC ground contact is foreseen per day. All TM/TC contacts in the nominal mission scenario are scheduled to be performed by the GSOC station in Weilheim, Germany.

In order to downlink the payload data generated, a total of 27GiB must be downlinked per day, which will be performed using 4 downlink passes per day at the GSOC ground station in Neustrelitz, Germany, which is also the location of the payload data center. The required bitrate for the X-band downlink is 138 Mbps.

The communication system provides quasi-omnidirectional coverage in S-Band for both transmission and reception, with the possibility to increase the link margin when transmitting in a nadir pointing attitude by using a dedicated nadir antenna. For the X-band downlink isotropic antennas are used.

DESIGNING A SMALL SATELLITE MISSION

The development of the satellite bus is performed as a mix between procurement of off-the-shelf items and internal development. The use of commercial off-the-shelf items reduces effort and man-power required, and allows designing the satellite with a relative small team of engineers. The primary new development for the AsteroidFinder mission is the development of the avionics system, which includes the onboard computer, MiddleWare Switch and the Analog/Digital Units. The development of these systems is being performed by the department of Avionic Systems (RY-AY) which is part of the Institute of Space Systems. The development of the power system will be sub-contracted based on a bidding process which will be initiated with the kick-off of phase C. The structure and mechanisms will be developed and manufactured by the Department of

Composite Design at the Institute of Composite Structures and Adaptive Systems, DLR, with the only exception being the hold-down mechanisms which will be procured. All other units of the satellite bus will be procured as commercial items.

AsteroidFinder has been designed based on a tailored subset of the ECSS standards. The tailoring of these standards has been performed in order to greatly reduce the cost and man-power required. In order to further reduce the design overhead the lean engineering principle has been implemented according to methods described in the existing literature. For further details see ⁴.

The design of AsteroidFinder has been performed using state-of-the-art engineering methods including an extensive use of the concurrent engineering and concurrent design approach. For Phase 0/A a standard concurrent engineering approach was followed; due to the lack of documented applications of concurrent engineering in Phase B, an approach was developed and applied by the engineering team to continue applications through Phase B. The experiences and lessons learned from applying concurrent engineering in phase B is described further in ³.

The extensive use of the concurrent engineering approach has also enabled to perform the design of the satellite bus as a series of many small iterations, rather than applying relatively large margins and conservative assumptions for the units. In order to meet the performance requirements for the satellite bus, in particular with respect to the agility requirement, a highly compact and optimized design is required. While this approach has increased the number of design iterations, and therefore the development time, it has enabled to achieve a performance which meets the requirements.

CONCLUSION

The AsteroidFinder mission fulfils the objectives of the DLR-Kompaktsatellit program, by allowing a DLR developed payload access to space, and carry out a mission with a high scientific output. The AsteroidFinder mission will help to characterize the IEO population and will support the further development of the available models leading to a better understanding of the potential risk of a collision with the Earth in the future.

The AsteroidFinder platform demonstrates that a small satellite platform can be utilized for missions with a high scientific return. Furthermore the performance of the satellite bus developed for the AsteroidFinder mission has been well characterized during the Phase

0/A/B design and is well understood by the engineering team. The satellite bus can be re-used for future missions in the DLR-Kompaktsatellit program, either in its current configuration or tailored to meet specific needs (e.g. orbit control) with a significant lower turn-around time from mission definition to technical readiness.

1. Bottke, W.F. et al. "Debiased Orbital and Absolute Magnitude Distribution of the Near-Earth Objects." *Icarus* 156, 399–433, 2002
2. Montenegro, S and Haririan, E, "A Fault-Tolerant Middleware Switch for Space Applications" Proceedings of the Third IEEE International Conference on Space Mission Challenges for Information Technology, 2009
3. Findlay, R, Braukhane, A, Schubert, D, Pedersen, J.F , Müller H, Essmann, O "Implementation of Concurrent Engineering to Phase B Space System Design", Unpublished
4. Findlay, R, Eßmann, O, Hoffmann, H, Messina, G, Mottola, S, Müller, H, Pedersen, J.F "AsteroidFinder: Implementing A Small Satellite Mission To Detect IEO's", Unpublished