Photogrammetrie • Fernerkundung • Geoinformation 1/2002, S. 21–24, 2 figs.

CHAMP – the first FLEXBUS in Orbit

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Abstract: The launch of the German research satellite CHAMP was the successful premiere for a new ASTRIUM GmbH satellite concept.

The Flexbus satellite design and management concept was developed in view of shrinking budgets and great demand on reliable satellites enabling affordable missions in the area of science and earth observation. Compared to a conventional design and management approach the Flexbus concept applied on the CHAMP satellite development resulted in a cost reduction by factor 3.

The use of a mature basic architecture for the spacecraft bus and the combination of proven components with mission-specific payload elements make CHAMP a satellite which optimally adapts to individual mission and payload requirements.

Also the cooperation with the customer and principal investigator GeoForschungs-Zentrum Postdam (GFZ) and the satellite operator DLR was based on a new approach. Both partners were involved very early in the design and development phase.

Besides the proven technologies CHAMP features a first in orbit use of the in-house developed Coarse Earth and Sun Sensor CESS, foam isolated body fixed solar arrays and a low cost boom deployment mechanism. All three new developments performed very well.

Zusammenfassung: *CHAMP – Der erste Flexbus im All*. Der Start des deutschen Forschungssatelliten CHAMP war die erfolgreiche Premiere für ein neues Satellitenkonzept der ASTRIUM GmbH.

Das Satellitendesign- und -management-Konzept für den Flexbus wurde mit Blick auf die sinkenden Budgets und auf die große Nachfrage nach zuverlässigen Satelliten entwickelt, die Missionen für Wissenschaft und Erderkundung zu erschwinglichen Preisen ermöglichen. Verglichen mit einem konventionellen Design und Management wurde durch das beim CHAMP-Satelliten genutzte Flexbus-Konzept eine Kostensenkung um den Faktor 3 erreicht.

Dank der Nutzung einer ausgereiften Basisarchitektur für den Satellitenbus in Kombination mit bereits weltraumerprobten Komponenten und mit missionsspezifischen Nutzlastelementen konnte CHAMP optimal an individuelle Missions- und Nutzlastanforderungen angepasst werden.

Auch die Zusammenarbeit mit dem Nutzer und wissenschaftlichen Leiter, dem GeoForschungs-Zentrum Potsdam (GFZ), und mit dem Satellitenbetreiber DLR basierte auf einer neuen Herangehensweise. Beide Partner wurden frühzeitig in Entwicklung und Konstruktion einbezogen.

Neben den erprobten Technologien wurden bei CHAMP erstmals der im eigenen Unternehmen entwickelte Erde-Sonne-Sensor (Coarse Earth Sun Sensor CESS), fest montierte schaumisolierte Solararrays und ein kostengünstiger Ausklappmechanismus für einen Ausleger im Weltraum eingesetzt. Alle drei Neuentwicklungen haben sehr gut funktioniert.

1 Introduction

On 15th July 2000, the German geo-research satellite CHAMP was injected into its orbit by a COSMOS launch vehicle from Plesetsk, Russia. All satellite payload- and bus systems show excellent in-orbit performance and the nominal science mission activities are successfully under way. CHAMP is the first satellite which was built following the Flexbus approach, a concept specifically developed by ASTRIUM GmbH in the mid-90's to satisfy the world-wide demand for "faster, better, cheaper" access to space.

1432-8364/02/2002/0021 $ 1.00

The paper gives a general overview of the Flexbus concept and its influence on the individual steps of the satellite design and verification process. Using CHAMP as example, a summary is given of the engineering, product assurance and management guidelines followed during satellite development, production and testing to achieve the desired high quality product at minimum cost.

2 Technical Capabilities and Electrical Architecture

The Flexbus concept is tailored to serve a class of satellites with the following technical capabilities:

- Typical S/C mass between 150 kg and 1000 kg
- Typical S/C power up to 4 kW peak (battery supported) and 150 W to 1000 W orbit average (no real upper limit)
- 32 kbps / 1 Mbps S-Band downlink for HK and small payloads up to 300 Mbps X-Band downlink
- Up to 30 arcsec pointing performance via GPS / Star Tracker
- Lifetime typically 5 years
- Typically compatible with small satellite launchers like Athena, Taurus, Cosmo, ROCKOT etc.

The Flexbus electrical reference architecture is based on the idea to build a mission tailored solution out of a set of existing and well proven modules and units.

Cold redundant chains and cross strapping capabilities are applied on unit and system level. This approach allows to match recurring costs with mission specific requirements without additional implementation of riscs.

The quality approach for EEE-parts requires as a minimum compliance with MIL 883 class B for integrated circuits, JAN TX for discrete parts and MIL ER with failure rate R for passive elements. Radiation tolerance is typically 10–20 krad and design measures to withstand single event upsets or latch ups are mandatory.

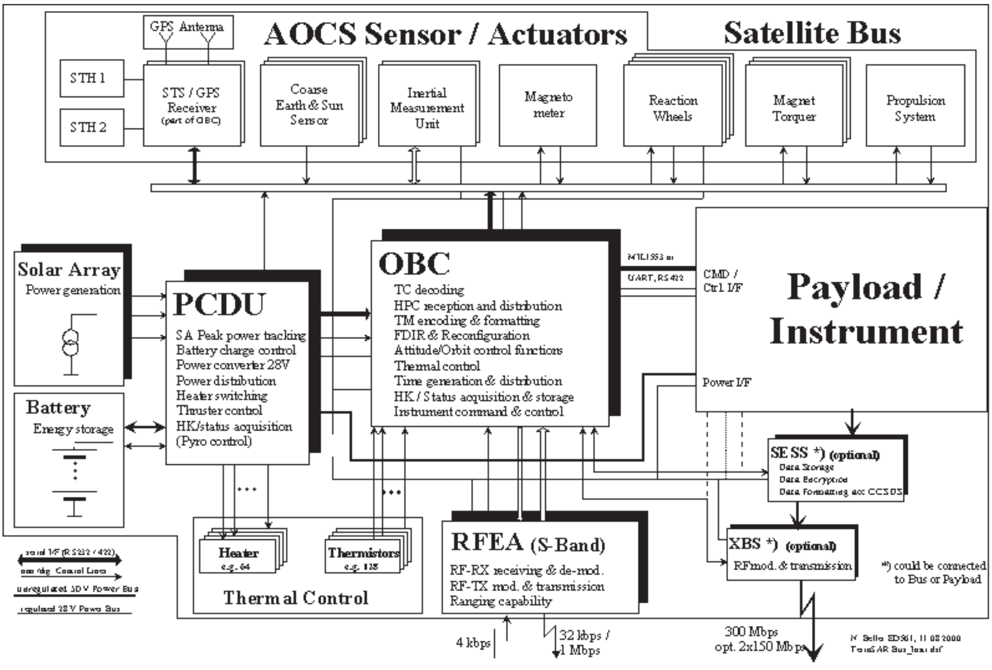

Fig. 1: Flexbus Electrical Reference Architecture.

3 Project Management, System Engineering and Verification

The Flexbus concept asks for a close cooperation with the customer starting with begin of the mission and requirements definition phase and ending with the in orbit commissioning. The engineering team should be staffed by both partners and co-location of the team is recommended. The selected satellite operating organization should be involved in the project team with definition of the check-out environment including the staffing of check-out operators.

The Flexbus concept does not foresee to subcontract system engineering tasks. Subcontracts are limited to component level tasks. Payload elements are utilized for bus functions where ever reasonable. The system design process is based on a thoroughly performed FMECA resulting in an adequate FDIR concept fulfilling the required single point failure tolerance.

The definition and verification process of requirements is usually described in one document which is commonly developed and serves as contractual basis. The design is verified by analytical models for structure, thermal, AOCS, CESS, boom deployment and mass properties. Results of analysis are compared with system test results where ever feasible. The bench mark to proof flight worthiness is a tough and complete functional and environmental test program. For CHAMP this program resulted in an accumulated satellite on ground operating time of more than 2000 hours. Test cases are defined on system level in order to identify interface problems and system design weaknesses. I.e. during the thermal vacuum test a complete loss of power situation was established in order to proof the satellites capability to recover autonomously once the solar array is sufficiently illuminated by the sun.

4 New developed Hardware Elements

4.1 *CESS – Course Earth Sun Sensor*

The patented CESS hardware consists of six single sensor heads arranged on the satellite in such way that an omnidirectional and unobstructed view to space is given. Each head is equipped with two equally sized optical surfaces of different properties. The IR absorptance is the same but the visible light absorptance is different. Behind each reflector three PT 1000 thermistors are placed.

This hardware configuration allows to take temperature measurements driven by earth and sun illumination. The readings are weighted by majority voting and averaging and then extrapolated to steady state equilibrium temperatures.

Based on this input temperatures an algorithm derives overall heat flux input and corrects for earth albedo. The output is a computed earth vector and a computed sun vector transferred into the satellite body fixed coordinate system.

The expected in orbit performance is 6° for the sun vector knowledge and 15° for the earth vector knowledge. The full performance as designed could not be completely verified on CHAMP because two of the six sensor heads were degraded by ex-

● Integrated System Test (2 times) ● Mission Simulation Test (2 times) ● Abbreviated Functional Tests (20 times) ● RF – Compatibility Test at Ground Station ● End to End tests with Mission Operations System (3 times) ● Full functional system test in TV ● End to End tests of AOCS sensors & actuators ● Boom deployment tests ● Cold Gas System proof pressure and leak tests	● Thermal Balance / Thermal Vacuum Test ● Random and Sine Vibration Test ● EMC Test ● DC Magnetic Test ● Acoustic Test ● Physical Properties ● Static & Dynamic Balancing Pyro shock test

Fig. 2: Summary of CHAMP satellite functional and environmental test program.

cessive heat load during ascent. The early mission experience shows that the CESS even with its degraded hardware configuration allows a safe attitude control of the satellite in case of fine attitude loss. The design will be used on GRACE satellites without change.

The basic advantages of the design are low mass, negligible power demand and minimum on board processor resources and low recurring costs for future applications.

4.2 *Foam isolated solar panels*

The CHAMP mission specifics asked for body mounted solar panels. The generic advantages of body mounted solar panels are high µg – quality; high agility of spacecraft, quick re-establishment of fine pointing requirements and high aerodynamic design capability. The generic drawback is that high thermal isolation between spacecraft body and surface of the solar panels is needed. Traditional designs cover this need by the implementation of spacers and Multi-Layer-Insulation between the basic satellite structure and the solar generator. This is costly.

For the CHAMP mission ASTRIUM introduced a new isolation concept. The MLI was replaced by 40 mm thick foam made of Kapton open pore material. This is a commercially available product fulfilling all basic material requirements for the use in space. The foam is directly glued to the face sheet of the honey-comb structure and covered by a CFRP face sheet. The solar cells are glued to the face sheet according existing standards.

The thermal insulating capability proved to be very efficient. This is verified by extensive vacuum tests on ground as well as by the excellent in orbit performance on CHAMP. Temperatures on the cells surface range from $+120°$ to $-120°C$ pending on orbit conditions while the temperature of the inner panels surface is damped to $20°C$ typically. Initial problems with the gluing process are completely solved. The design will be used on GRACE satellites without change.

4.3 *Boom deployment mechanism*

The magnetic sensors of the CHAMP payload need to be placed as far as possible off the satellite's body. This configuration is established in orbit by the deployment of 4 m long boom. In order to match the launch configuration requirements under the fairing an 180 deployment angle is required. ASTRIUM adapted a design already flown on 64 Globalstar missions. The mechanism consists of four springs bent by 180 degrees and such carrying the energy necessary for successful boom deployment once the launch hold down is released. The springs also serve to pull the boom in a stiff and predefined configuration to the satellite body once the deployment motion is damped out by friction. CHAMP in orbit data show both, as designed deployment behaviour and as designed stiff fixation to the satellite body.

5 Summary

With the successful start of the mission CHAMP it is demonstrated that the Flexbus concept is a good solution to realize robust and reliable satellites on a commercial basis which is affordable in terms of costs and schedule for scientific institutions.

The CHAMP satellite was designed, built, tested and launched within 42 months. The costs are roughly one third compared with traditional programs. The in orbit results of the initial mission phase are very promising and confirm the accomplishment of all system requirements.

ASTRIUM appreciates very much the open attitude of GFZ and DLR approaching the Flexbus management and design concept and thus paving the way for more affordable and successful missions.

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