THE RUBIN TESTBED FOR IN-ORBIT VERIFICATION OF MICRO- AND NANOTECHNOLOGIES

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ABSTRACT

Micro- and Nanotechnologies (MNT) find an increasing number of potential application areas in space technology but are halted by the current lack of flight heritage. This bottleneck must be removed before the MNT can fulfil their true potential for future space utilisation. OHB-System, together with the University of Applied Sciences in Bremen, has experience from the development, launch and operation of a series of small spacecraft for in-orbit verification of new technologies – the so-called Rubin spacecraft. The Rubins are small spacecraft launched as piggy-back passengers into typical low Earth orbits. Communication with ground is provided via intersatellite link through the Orbcomm system. The available envelope for a Rubin depends on the primary passenger(s) and range from about 20 kg down to a few kilos. The experience from these missions suggests that the Rubin could be an excellent platform for the in-orbit verification of MNT by providing cost-effective frequent launch opportunities with a short implementation schedule and adequate lifetime and performance. In order to provide a flexible platform for testing MNT different architectures are being considered which allow tailoring the Rubin concept to different payloads with different needs in terms of power, data handling and mission profile. This paper gives an overview of the Rubin background as well as provides an outline of the possible architectures for different ambition levels for a Rubin mission. The objective for the architectures remains to provide a cost-efficient, fast and frequent flight opportunity of MNT.

1. INTRODUCTION

The utilisation of Micro- and Nanotechnologies (MNT) for space is still slowed by the lack of opportunities to gain the important flight heritage - and thus acceptance - of these technologies. Only few technology demonstrator opportunities exist and the frequency with which they are offered cannot meet the demand for MNT flight qualification. This stands in contrast to the low requirements in terms of mass, power and dimensions of MNT, which suggests that finding flight opportunities should be an easy task. As long as this bottleneck is not removed the benefits of MNT in the space segment will remain marginal.

OHB-System, together with the University of Applied Sciences in Bremen, has experience in developing and launching a series of small and low cost spacecraft known as Rubins. So far six of these Rubins have been launched of which four have been attached to upper stages, one has been free orbiting, and one has been included on the AGILE spacecraft. The small spacecraft are launched into typical LEO orbits and communication for all Rubins is performed via the Orbcomm system providing global coverage for message-based services. The frequent flight opportunities, short development schedule and low overall cost means that the Rubin could become the European workhorse for the in-orbit verification of MNT by providing frequent and affordable verification flights. It has therefore been decided to investigate how to optimise the current Rubin platform to the needs for in-orbit verification of MNT.

2. RUBIN HERITAGE

In 2000 the BIRD-Rubin was the first payload to utilise the Orbcomm system for communicating between space and ground. This Rubin was launched together with the satellites Champ and MITA and managed to transmit a total of 1600 messages during its 5-day lifetime. The second Rubin was the first Rubin free-flyer satellite and was launched in 2002 on a Dnepr launch vehicle. Rubin 2 was fully controlled by messages transmitted via the Orbcomm system and proved thereby the capability of Orbcomm not only as a means for receiving satellite data but also for controlling the status of the satellite itself.

FIG 1 Rubin 2 (left) integrated on the Dnepr adapter ring

Rubin 3 and 4, launched in 2002 and 2003, were both launched as attached payloads on COSMOS launch vehicles. The purpose of these payloads were to test the launch vehicle tracing possibilities outside the range of the tracking stations and to measure and transmit data on acceleration, vibrations, position and payload separation status via the Orbcomm system.

Rubin-5 was launched in October 2005 as an attached payload on a COSMOS. The main payloads on this Rubin are a small detector for meteoroids and space debris as well as the Advanced Solar Antenna (ASOLANT) experiment, developed by Lausanne Polytechnic University in conjunction with OHB for ESA. This experiment consists of combined solar arrays and antennas, meant to unite two of the most volume-demanding elements on a spacecraft. The experiment provides power to the Rubin spacecraft and acts as antennas for a DLR GPS receiver and an S-band beacon transmitter. Additional payloads consist of a 3D magnetometer and a small camera. All payloads are managed by two Orbcomm modems also acting as onboard computers. Except for the external debris detector, the Rubin-5 is enclosed in a container of close to 1 bar pressure. Rubin 5 is still operational today (July 2007) [1], [2], [3].

The latest Rubin was included on the AGILE spacecraft, which was launched on April 23rd 2007. The objective of this Rubin is to act as the back-up solution for scientific data transmission from the satellite.

3. ORBCOMM

The Orbcomm system, used for communicating with the Rubins, is a satellite based, wide area, packet switched, two-way data communication system with global coverage. It provides alphanumeric message transmission similar to short emails. The system comprises the following three segments:

- Space segment: A constellation of currently 29 operational satellites arranged in seven orbital planes with inclinations between 45° and 108° and orbiting at altitudes from 710 km to 820 km. A new generation of the Orbcomm satellites is presently being integrated and tested. The socalled „Quick Launch“ with 6 satellites is the first step for increasing the system performance and from 2008 to 2010 further 23 next generation Orbcomm satellites are to be launched to replace existing space segment.
- Ground Segment: This is composed of 13 geographically distributed Gateway Earth Stations (GES) that communicate with the satellites, 5 Gateway Control Centres (GCC) that process message traffic and forward it through the GES to the satellites or to appropriate terrestrial communications networks for transmission to the back-office application or end-user and a single main Network Control Centre (NCC) which monitors and manages the flow of information through the system and provides the command, control and telemetry functions to optimize satellite availability.
- The subscriber (or user) segment, consisting of subscriber communicators, which are mobile or stationary user terminals used for e.g. personal messaging or to transmit and receive messages between assets and satellites[4].

Communication between subscriber communicators and the Orbcomm gateways is performed via the space segment, where satellites serve as data relay stations. While the GES establish the VHF communication link between the Orbcomm satellites and the ground segment as the satellites pass overhead the GCC provide the capability to complete the communication link with the end user. For the final data transmission Internet and standard email services are used.

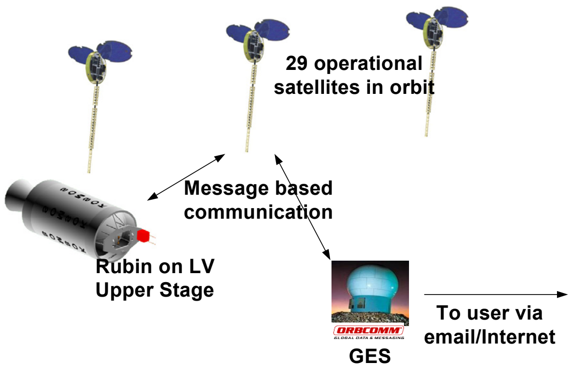

FIG 2 Communication Concept of Rubin via the Orbcomm Network

Two transmission modes are supported by the Orbcomm system:

– Direct Mode: In case the Orbcomm satellite can establish a link to user and gateway simultaneously direct transmission can be performed between the two.
– Store-and-Forward Mode: If the Orbcomm satellite cannot link to both simultaneously it will transmit the message in store-and-forward mode. In this mode, the satellite stores the received message (so-called GlobalGrams) in its onboard memory and dumps the message during the next pass over a Gateway Earth Station. For terrestrial applications typical average delay for this sort of transmission of less than 15 minutes have been observed.

The Orbcomm system is designed for small packet transmission only. In the direct transmission mode no maximum length has been specified but the largest message should for practical reasons not exceed 1000 characters. For the store-and-forward mode the maximum message length is limited to 182 characters, which should then be used as maximum for a robust system able to transmit through both the direct and the store-and-forward mode.

4. RUBIN FOR MNT

4.1. Concept

Rubin is a series of small spacecraft developed for in-orbit verification of new technologies. The main features of the Rubin spacecraft are:

– Low cost
– Fast schedule
– Frequent flight opportunities

The low cost and fast schedule is accomplished by the extended use of COTS components and a simple and reliable design. The frequent flight opportunities are achieved by the minimum impact of the Rubin on the main launch passengers facilitating the option of piggy back flights as well as the long collaboration between OHB-System and relevant launch service providers. The experience from the latest Rubin flights indicates that mission lifetimes of longer than 1 year can be accomplished with this simple and low-cost approach.

The Rubins are fully independent spacecraft providing their own power supply and storage, onboard computer as well as its own means of communication. Command and telemetry are transmitted via the Orbcomm network meaning that all interaction with the spacecraft and its payloads can be performed via email communication from a simple PC.

FIG 4 Horizon snapshot from the onboard camera on Rubin 5 [2]

Although the message size for a single message for utilising the store-and-forward transmission is limited to 182 characters larger files can be transmitted by distributing the files over several messages. This has for instance been used to transmit the image on FIG 4 from Rubin 5, which has a size of 4392 bytes [2]. For communication via the Orbcomm network a normal COTS Orbcomm modem as described in Section 4.3 is used. For the simpler Rubin missions this modem can also be used as the onboard computer.

The Rubins are either developed as attached payloads or as free orbiting platforms. So far only one has been free orbiting The advantages of staying attached to the upper stage include that no release or deployment mechanisms are needed, a benign thermal environment is provided by the large thermal capacity of the upper stage and only a slow motion is induced from the slow tumbling of the upper stage. For many applications the attached version has seen to be suitable and has therefore been chosen due to its higher simplicity compared to the free orbiting platform.

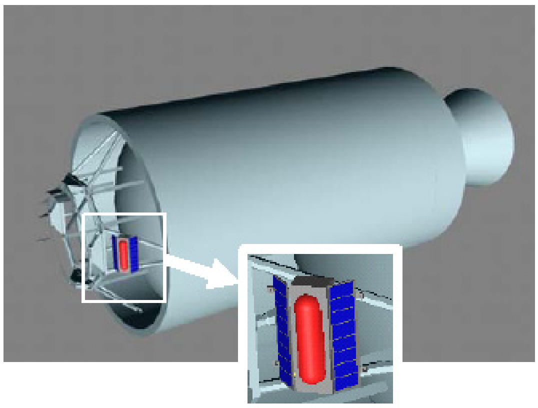

FIG 3 Rubin attached to a Cosmos upper stage

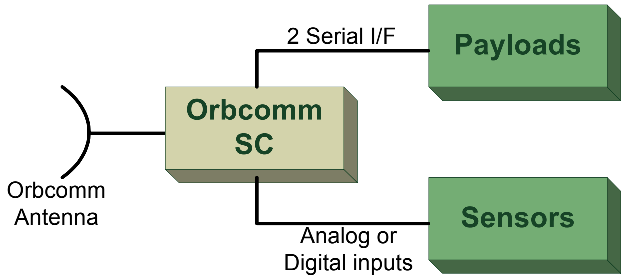

FIG 5 Simple Rubin configuration with Orbcomm SC acting as onboard computer with serial connections to payloads and sensors

4.2. Architectures

Based on the concept described above a variety of Rubin missions can be developed depending on the number and complexity of payloads and mission requirements. In the following the data communication architecture for different payload and mission concepts will be outlined.

The simplest architecture is based on the sole use of the Orbcomm SC (See 4.3) for communication via the Orbcomm network and for all onboard data handling tasks. This configuration has been used on the later Rubin missions and in a dual configuration with two communicators on Rubin 5 [3]. This simple configuration is shown on FIG 5. The two serial data interfaces can be used for two payloads while external sensors are sampled via the analog or digital inputs.

For communicating with more than two payloads or with payloads not equipped with one of the supported serial interfaces a dedicated bus interface can be inserted between the Orbcomm SC and the payloads. This configuration is shown on FIG 6 where a RS232/CAN interface has been implemented for communicating with the payloads via the CAN bus. This unit has been developed and tested for the Rubin but has not yet been flown on a mission.

Adding additional flexibility can be performed by the inclusion of small miniaturised remote terminal units (RTUs), which provide a variety of bus interfaces, analog and digital I/O as well as user programmable functionality. These could for instance be included where a payload does not have a suitable CAN interface or where management of the payload is necessary beyond the capability of the Orbcomm SC. The development process of the Rubin can also benefit from this approach if the payload supplier organises the entire payload management within the RTU so the only data interface with the Rubin is via the CAN bus. The candidate RTUs from Angstrom Aerospace Corporation are described in Section 4.4.

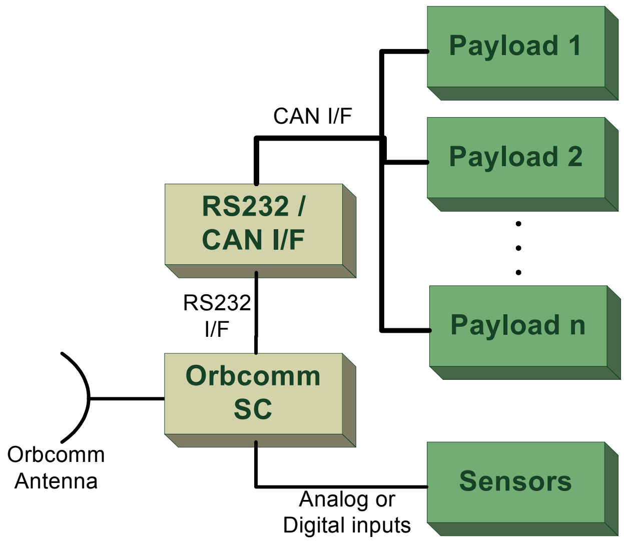

FIG 6 Rubin configuration with CAN I/F for communicating with several payloads

For later and even more advanced versions of the Rubin the computing and interface capability of the Orbcomm SC will not be sufficient and the step towards a dedicated onboard computer must be performed. This is for instance expected to be necessary for the Rubin as a 3-axis controlled free-orbiting spacecraft where the attitude control system will require frequent sensor updates and actuators, such as wheels and magnet torquers, shall be commanded. A dedicated onboard computer can also be necessary for payloads that require a higher level of management and payload data handling than what can be achieved with the Orbcomm SC in combination with the RTUs. This configuration has not yet been implemented on a Rubin mission.

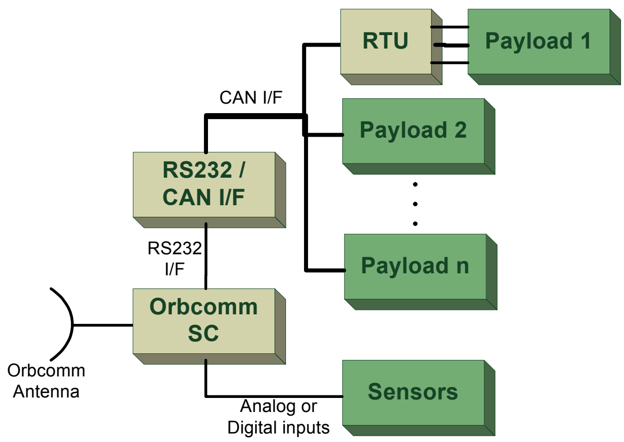

FIG 7 Adding a Remote Terminal Unit can perform distributed payload management while maintaining simple communication with the Orbcomm SC

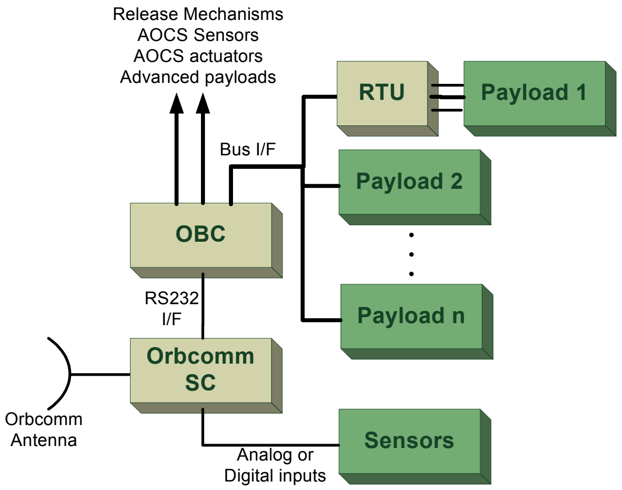

FIG 8 Complex version of the Rubin utilising a dedicated onboard computer (OBC) for avionics and advanced payload management and data handling

4.3. Orbcomm Subscriber Communnicator

A number of different Orbcomm subscriber communicators (SC) are available on the market at different performance levels and with different features. The most basic models provide simply a serial port, power input, and VHF connection, while more advanced SC feature multiple analog and digital I/O ports, integrated GPS receiver, battery charging circuitry and the capability to load and execute customer developed software. Common for all models is the core software ensuring a reliable transfer of data compliant with the Orbcomm VHF communication interface specification.

The Orbcomm SC used for the latest Rubin missions, and also foreseen for the near-future missions, is the QuakeGlobal Q2000 Compact Orbcomm GPS Modem with Electronic Bus Interface. The Q2000 is a versatile, feature-rich SC in a rugged housing and especially developed for operation in a hostile environment. Although the Q2000 is not designed for utilisation in space experience from the existing missions indicate that the SC is very suitable for lower duration missions in LEO.

Q2000 for a Rubin mission enables the features:

- VHF communication via Orbcomm
- 4 analogue input lines
- 8 digital input lines
- 4 output switches
- Real time clock
- 2 RS232 serial ports
- RS485 port
- CPU for execution of user written software
- 2 Mb memory available for storage of user equipment data
- Sampling rate of 100 Hz of user equipment [5]

4.4. AAC Miniaturised RTU

Angstrom Aerospace Corporation (AAC) are presently developing and testing a set of miniaturised Remote Terminal Unit (RTU) modules, which are of high interest for the function of Rubin as a testbed for a number of different small technologies. The first generation RTUs units are utilising FPGAs and external microcontrollers to provide a flexible and functional communication interface to a large variety of equipment. The second generation is being developed together with Saab Space and shift from FPGA/Microcontrollers to a fully qualified ESA Application Specific Integrated Circuit (ASIC) [6]. The first generation RTUs are based on Actel 1 MGate FPGAs, which together with an Atmel microcontroller provides the features:

- Redundant CAN 2.0b and Spacewire
- Optional Plug ‘n Play (PnP) over CAN
- 6x14 bit A/D
- 4x12 bit D/A converter
- General 8 bit I/O bus with interrupts
- Serial Peripheral Interface with 6 slave addresses
- UART
- Power control,
- 60 User I/O connected to FPGA (for integration of I^2C or other functions).
- 48 bit distributed spacecraft elapsed time
- latch-up protection

All is included in a silicon 3D-System-in-Package (3D-SiP) package with a mass of 4 g and dimensions 33x33x2.5 mm^3. The modules include a software core, which is common to all RTUs, and a user specified part (both for microcontroller and FPGA), which can be programmed to the individual user needs. The FPGA has approximately 900 kGates free for the user depending on the configuration [7]. The module is available with an integrated spacewire router if wanted for a point-to-point bus-like chain.

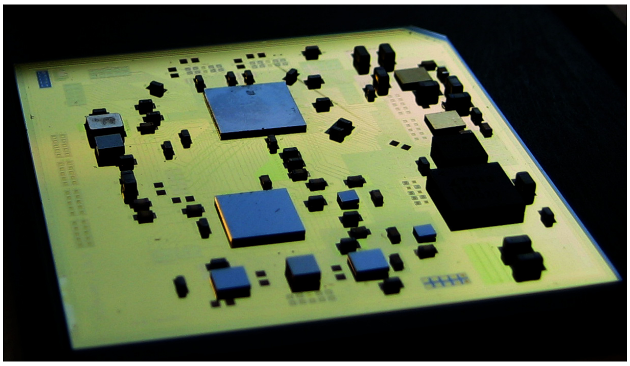

FIG 9 Photograph of a Angstrom Aerospace 3D-SiP RTU module, with only flip-chipped components on a 525 mm silicon substrate with hermitically sealed metallic Through Silicon Vias (TSV)

The RTUs' versatile functionality and low resource requirements make these components ideal for providing a flexible interface to MNT components for later Rubin flights and other smallsat missions.

5. CONCLUSION

The Rubin was presented as a means for in-orbit verification of space technologies. A number of missions have been successfully flown already and OHB-System is now investigating the potential for optimising the Rubin concept for the flight qualification of micro- and nanotechnologies for space applications. In order to utilise the Rubin for a variety of MNT payloads with different needs, different architectures for the Rubins are being investigated. The simplest architectures utilise the Orbcomm Modem for communication as well as the onboard computer with direct interfaces to sensors and payloads. Gradual increase of the Rubin performance foresee the utilisation of:

- serial/CAN interface (developed but not flown)
- Miniaturised RTUs (developed but not flown)
- Dedicated onboard computer

The flexibility provided by the different architectures enables the Rubin to accommodate a wide range of small payloads and facilitate the positioning of Rubin as the workhorse for in-orbit verification of space technologies in Europe.

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