A last-minute upgrade: Rapid integration of an opportunity payload into the TUBIN mission

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ABSTRACT

Small satellites have established themselves as pathfinders for a broad range of applications. The ever-increasing capabilities of both platforms and payloads enable a variety of scientific and commercial applications in fields like communications, remote sensing or even interplanetary exploration based on this satellite class.

TUBIN is a microsatellite mission in the 20 kg class aiming at the detection of high-temperature events in the thermal infrared using microbolometer technology. To this end, the satellite carries a payload consisting of two infrared sensors in conjunction with a medium-resolution CMOS imager for the visible spectrum. The TUBIN mission implements the flight proven modular TUBiX20 microsatellite platform of Technische Universität Berlin that was first demonstrated on orbit in 2017.

XLink is an X-band transceiver developed by IQ wireless GmbH from Berlin, Germany in cooperation with Technische Universität Berlin. It bases on a modular software-defined radio platform providing two uplink and two downlink channels that can be configured to different frequency bands and provide downlink data rates of up to 100 Mbps. The transceiver was qualified for LEO applications in 2019, at which time TUBIN was already in production phase. However, given the significant advantages a that faster downlink channel would provide for the TUBIN mission, a study was conducted to assess the expenditure of a late integration of XLink into TUBIN. The changes in hardware could be limited to minor additions to two electronic boards and an update to an outer structure element to include the transceiver itself and necessary additional antennas.

This paper presents the integration of the XLink transceiver into the TUBIN satellite, while highlighting how the modular systems architecture of the TUBiX20 platform minimised the changes to the spacecraft required for this task. Furthermore, operational scenarios for the demonstration of XLink are presented, highlighting the potential advantages the transceiver may bring for the TUBIN mission. The ground segment of Technische Universität Berlin with the already existing three-meter dish has been extended to support X-band downlink and will be used for TM/TC as well as for broadband payload data reception.

INTRODUCTION

In the course of the last decades, small satellites have arisen as platforms for a broad range of commercial as well as scientific applications, pushing into those areas formerly reserved for larger spacecraft. In conjunction with demanding payload options, small satellite systems are required to use high-performance components to cater to the mission’s requirements.

Exemplifying a small satellite mission for scientific applications, the TUBIN mission carries an infrared payload with the objective to detect high-temperature events [1]. The satellite is based on the modular TUBiX20 microsatellite platform that was first demonstrated within the TechnoSat mission launched in July 2017. As an Earth Observation mission employing a total of three individual sensor systems, the TUBIN mission produces large amounts of data and, thus, requires adequate means of payload data downlink.

For nominal payload data downlink, two S-band transmitters are used offering moderate data rates. With the addition of the X-band transceiver XLink to the TUBIN spacecraft, the available data downlink capacities would be raised by a factor of more than 25 depending on the transmission modes. Here, XLink is integrated into the TUBIN mission as an in-orbit demonstration (IOD) payload, aiming at the verification of various different operating modes provided by the transmitter. Upon successful verification, the transceiver shall support the TUBIN mission as a nominal element of the platform.

XLink is an X-band transceiver offering high-speed data downlink capabilities in X band as well the option for S-band and X-band uplink for TM/TC and, thus, represents a stand-alone solution for small satellites. Due to its low SWaP budgets and its CCSDS compatibility, it can be integrated into a number of different application scenarios.

The necessary steps for the integration of this opportunity payload into the TUBIN spacecraft in hardware and software are highlighted in this paper focusing on the accommodation itself, the synergies with the architecture of the TUBIN spacecraft and the implications on mission operations.

THE TUBIX20 MICROSATELLITE PLATFORM

TUBiX20 is a microsatellite platform developed by Technische Universität Berlin to host challenging scientific and technological missions. It was first implemented within the TechnoSat mission launched in 2017 and its second instalment, TUBIN, is scheduled for launch in early 2021. As a third mission, TUBiX20 is designated to host the QUEEN payload. The QUEEN mission has recently passed its preliminary design phase [5,6].

Systems Architecture

The TUBiX20 platform utilises a modular systems architecture. It is based on a network of cold redundant computational nodes that communicate on a central data bus system while being supplied by a central power bus system. Via these nodes, components, sensors and actuators may interface to the spacecraft. This way, relevant performance parameters of the subsystems may be adapted with minimum effort in accordance with the mission requirements [2,3].

The TechnoSat Mission

The TechnoSat mission is the first instalment of the TUBiX20 platform tasked with the demonstration of novel technology payloads in orbit [4]. Additionally, it served as means of testing and validating the TUBiX20 platform for the first time to enable future missions. After the nominal end of the mission operations in July 2018, the spacecraft is currently in the phase of extended mission operations. TechnoSat carries a total of seven different technology payloads that were developed by German research institutions and industry. Select payloads have since been integrated into the nominal satellite operations and are used on a daily basis.

The TUBIN Mission

The TUBIN mission constitutes the second instalment of the TUBiX20 satellite platform. It is tasked with the detection of high-temperature events using microbolometer technology. Additionally, it shall demonstrate the capabilities of a small satellite platform to perform challenging tasks in Earth observation [1]. A detailed description of the TUBIN satellite is given in the section *TUBIN Systems Design*.

QUEEN Mission

QUEEN is a microsatellite mission with 35 kg launch mass carrying quantum technology components for in-orbit demonstration of high-precision optical frequency references based on rubidium two photon vapour cells [5,6]. Additionally, state-of-the-art small satellite components will be demonstrated within the QUEEN mission.

TUBIN SYSTEMS DESIGN

TUBIN is a 23 kg microsatellite that is tasked with detecting and monitoring high-temperature events from space using microbolometer technology. To this end, it features a payload suite comprised of two microbolometer focal plane arrays (FPA) sensitive in the thermal infrared (TIR) as well as a CMOS colour picture sensor sensitive in the visible range of the electromagnetic spectrum (VIS). The TUBIN configuration of the TUBiX20 platform constitutes an upgraded version of the implementation used for TechnoSat. The attitude determination and control system is extended by high-precision attitude sensors and a GPS receiver, while the communications system is extended by two S-band transmitter for payload data downlink. The passive thermal control system is tuned by applying specialized coatings on the primary structure of the spacecraft. A representation of the TUBIN spacecraft in flight configuration is shown in Figure 1.

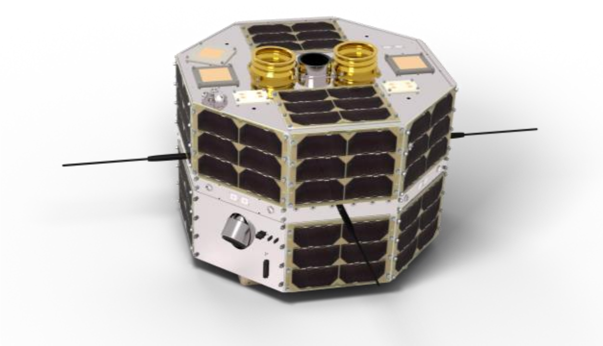

Figure 1: Rendering of the TUBIN spacecraft in flight configuration

The designated nadir side of TUBIN features three baffles for the payload suite as well as all patch antennas for payload data and telemetry downlink. The four UHF antennas enable omnidirectional low-speed radio communications for TM/TC when tumbling for instance after ejection or in safe mode. The main parameters of the TUBIN mission are summarised in Table 1.

Due to the modular design of the TUBiX20 platform, the TUBIN system design shows many similarities to TechnoSat and differences are mainly constituted by additional nodes and components present for TUBIN. However, this results in added complexity to facilitate higher overall performance.

Table 1: Parameters of the TUBIN mission

Parameter	Value
Orbit	550 km SSO (tbd)
Launch date	2021
Design lifetime	1 year
Spacecraft mass	23 kg
Spacecraft volume	465 x 465 x 305 mm³
Communications	UHF: TM/TC S band: downlink S band: uplink (payload) X band: up / downlink (payload)
Attitude sensors	IC magnetometers, fluxgate magnetometers, MEMS gyroscopes, fiber optic rate sensors, star trackers
Attitude actuators	Magnetorquers, reaction wheels
Orbit determination	Laser ranging, GPS

Figure 4 illustrates the system's overview of the TUBIN spacecraft. It is separated into functional units or subsystems denoted by grey boxes. These functional units may consist of one or several computational nodes that are interfacing to components or other periphery. The computational nodes that interface are coloured dark blue. They interface to the common data bus depicted in blue and the common power bus depicted in red. Additionally, these nodes may interface to sensors, actuators or other components that do not allow for direct interfacing to the platform. Data is distributed across the platform through the redundant data bus system applying a publish-subscribe communication scheme.

In the following section, the TUBIN payload suite is highlighted in greater detail.

The TUBIN Payload Suite

In accordance with the design premises of modularity and interchangeability that are the formative principles of the TUBiX20 platform, the payload design is also build of several interchangeable units that are independent of the sensor type and the satellite platform's favoured data link associated to it. These so-called *modular camera electronics* (MCE) consist of an interface board, a processing unit as well as a power unit and the corresponding sensor unit. While the TIR sensor is a commercial-off-the-shelf component, all other electronic boards have been developed by Technische Universität Berlin. Together with the sensor assemblies for VIS and TIR, the stacks constitute to a total of four and six PCBs per camera type, respectively. A representation of the TUBIN payload suite in conjunction with optics and baffles is depicted in Figure 2. Here, the MCE stacks are attached to the bottom of the optical deck.

Every PCB in the camera stack is dedicated to specific tasks, namely interfacing to the satellite platform, powering the camera stack, processing the image data and acquiring said data. The modular camera electronics for the TIR and VIS cameras are adapted to meet the sensors requirements. While the TIR camera head consists of three electronic boards, the VIS camera developed in-house consists of a single sensor board. The power boards are also tailored to the sensor's specific power needs while the processing and interface boards are the same for every camera.

Figure 2: Digital representation of the TUBIN payload suite

Interfacing to the satellite is done via 100 Mbit/s Ethernet connections with a central switch in TUBIN's avionics department. The satellite's PDH computer is part of the network together with the cameras. As every camera has its own processing capabilities and mass data storage, the PDH's tasks are reduced to forward telemetry and commands between the satellite platform and the cameras and transmit the cameras' pictures via TUBIN's flight proven S-Band transmitters to the ground.

The processing layer of each camera features a powerful processor that runs an embedded Linux. It can boot from two different non-volatile memories for added robustness against data loss due to the space environment. The boot selection and a synchronization signal are transmitted parallel to the Ethernet connection via I/O lines from the PDH computer. Exploiting the Ethernet network, every camera can access the images of other cameras. Paired with the processing power, an ample data storage and the possibility to run highly developed image processing libraries, the cameras can easily produce higher level data already on board of the satellite. Figure 3 gives an overview over the MCE and the respective power and data interconnections between its elements.

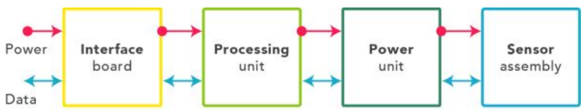

Figure 3: Schematic of the modular camera electronics (MCE)

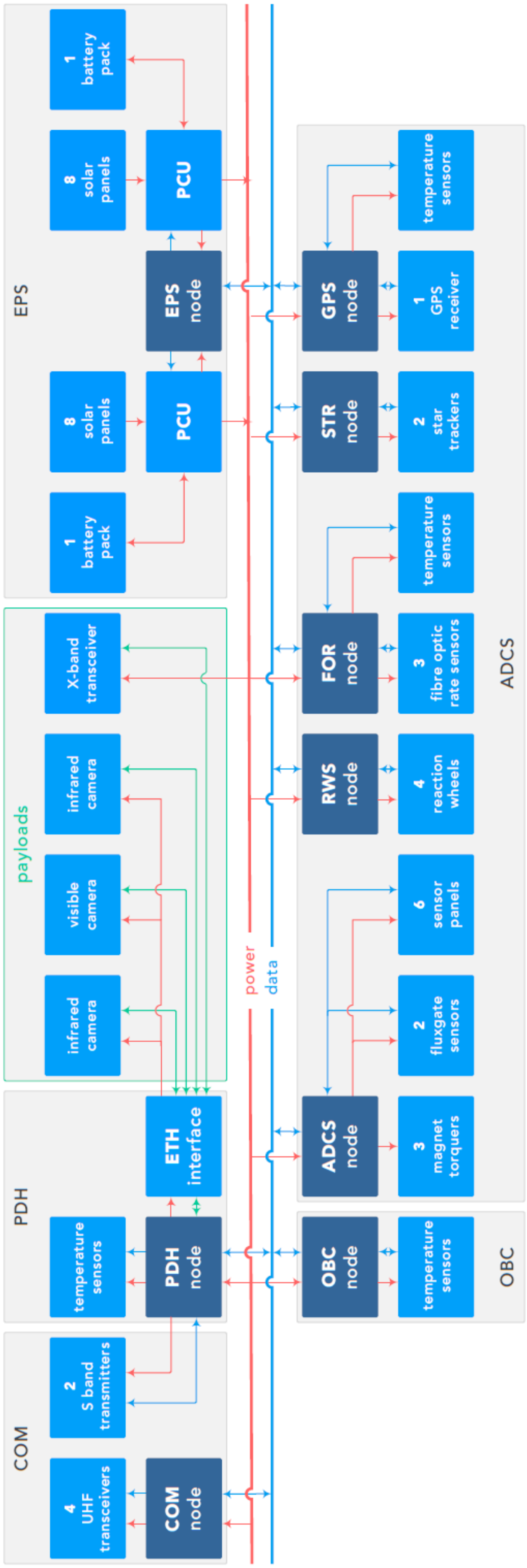

Figure 4: System design of the TUBIN spacecraft (figure modified from [1])

THE XLINK TRANSCEIVER

XLink is a software-defined-radio (SDR) based S-band and X-band transceiver making use of multiple input multiple output technology (MIMO) technology. It enables high data rates and transmission reliability using adaptive modulation and encoding and offers low size, weight and power (SWaP) budgets to allow for a wide variety of applications. XLink has been developed and qualified within a joint collaboration between IQ wireless GmbH and Technische Universität Berlin and will first be demonstrated in orbit within the TUBIN mission. Figure 5 shows the XLink transceiver module. One can see the power, data and EGSE interfaces of the transceiver as well as the four RF interfaces for realizing different uplink and downlink channels.

Figure 5: Model of the XLink transceiver

XLink features a total of four channels dedicated to X-band uplink, X-band downlink and S-band uplink, respectively. CCSDS compatible transmission modes enable the use of compatible ground stations for operations and payload data downlink.

The main parameters of XLink are summarised in Table 2.

Table 2: Specifications of the XLink transceiver

Parameter	Value
Downlink frequency	8025 to 8500 MHz
X-band uplink frequency	7145 to 7250 MHz
S-band uplink frequency	2025 to 2110 MHz
Maximum RF output	Up to +30 dBm
Downlink data rate	Up to 100 Mbit/s
Modulation	BPSK, QPSK, 8PSK
Uplink data rate	64 kbit/s
Data interface	Ethernet, SPI
Power consumption (transmit)	< 15 W
Power consumption (receive)	< 4.5 W
Operating temperature	-20 to 50°C
Dimensions	90 mm x 65 mm x 25 mm
Mass	< 200g

XLINK IN ORBIT DEMONSTRATION

The XLink transceiver has been developed within the XLink project. Here, the XLink transceiver has been built and qualified for use in low-Earth orbit [7]. As a next step, the in-orbit demonstration of the XLink transceiver is planned within the TUBIN mission. While the opportunity to include XLink into the TUBIN mission occurred late into the production phase of the spacecraft, the modular platform architecture allowed for the integration with minimal adaptations. As the largest constraint in payload operations for TUBIN is the limited data rate provided by the S-band transmitters, this technology demonstration payload greatly synergises with the mission.

The integration of XLink into the TUBIN architecture is illustrated in Figure 4. Generally, the accommodation of XLink can be divided into four different aspects, namely mechanical accommodation, electrical accommodation, software accommodation and accommodation into the ground station infrastructure.

Mechanical Accommodation

The XLink transceiver is a small device of 90 x 65 x 25 mm with a mass of less than 200 grams. Consequently, it could still be fitted into the satellite on the nadir deck between the baffles and the front solar panel as depicted in Figure 1.

The configuration of XLink used in the TUBIN mission offers dual-channel X-band downlink, X-band uplink, as well as S-band uplink. The two X-band downlink channels are combined by means of a combiner that is directly attached to the housing of the XLink transceiver. Thus, XLink requires the addition of three antennas. Here, the X-band uplink antenna and the X-band downlink antenna are located in close proximity to the transceiver left and right of the solar panel on the nadir deck as can be seen in Figure 1.

Electrical Accommodation

The XLink transceiver may be supplied voltages between 8 V and 18 V with the option of raising the voltage limit to 50 V on demand. The power interface is constituted by a 15-pin Nano-D connector. Due to the wide supply range, the transceiver can be supplied by the unregulated power bus of the platform. Here, an unused power interface provided by the central avionics compartment could be used for supplying the transceiver and only the hardware protection limits needed to be adjusted to the needs of the device. The unregulated power bus may range from 12V to 18V.

The XLink transceiver features both SPI and 100 Mbit Ethernet as data interfaces. Since the TUBIN payload suite already communicate via an Ethernet switch provided by the platform, XLink could be added to the existing Ethernet network by interfacing to a surplus Ethernet port of the interface board at the central avionics compartment.

An excerpt of the system architecture of TUBIN highlighting payloads, Ethernet switch and XLink transceiver is shown in Figure 6.

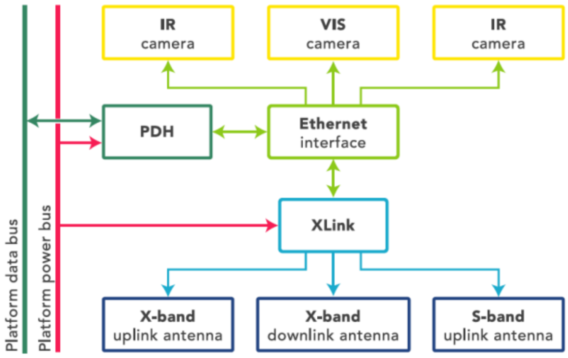

Figure 6: Excerpt of the TUBIN system design illustrating the interfaces between the TUBIN platform, the camera payloads and the XLink transceiver

Software Accommodation

XLink provides an Ethernet interface used both for providing the transceiver with data for downlink as well as for commanding the device and receiving its telemetry. As described, XLink is connected to the spacecraft's Ethernet switch that interconnects to the PDH node and the three cameras of the payload suite. Upon being cleared for nominal operations, XLink shall primarily be used to downlink data produced by the cameras.

Since payload data storage is directly realised on the cameras, imagery will be transferred from the cameras to the XLink module. Forwarding and receiving data using XLink is handled via its internal TCP/IP service server. As the PDH does not have the capability to manage TCP/IP connections, all communication with XLink is managed by the cameras. To enable bidirectional communication for telemetry and commands between bus and XLink, the cameras translate the proprietary protocol used between PDH and cameras to TCP/IP and vice versa.

Accommodation into the Ground Station Setup

To accommodate the XLink transceiver and X band capabilities in general into the ground segment, several upgrades were carried out. First, a new antenna feed was mounted on the 3-meter dish antenna at Technische Universität Berlin, which necessitated an upgrade of its structure. This new feed supports S-band and X-band up- and downlink in both LHCP and RHCP polarisations at the same time. The performance of the new S-band and X-band system was validated by establishing a link between the dish and another reference antenna located several hundreds of meters away.

Thanks to the modularity of XLink's software-defined radio architecture, it enables the usage of both proprietary modulation and coding which provides the best performance but also several CCSDS compatible modes that ensure the compatibility with most ground stations. By using a suitable system on ground, the three-meter dish at Technische Universität Berlin can be used to send data to TUBIN and receive data of the payload suite.

CONCLUSIONS

The modular TUBiX20 platform facilitates the addition or removal of components late into the design process. This is exploited by the addition of XLink to the TUBIN mission amidst the satellites production phase. The mechanical and electrical integration of the transceiver have been completed, the software integration is on-going.

Upon launch, the performance parameters of the XLink transceiver will be analysed using several ground stations including the COTS X-band ground station at Technische Universität Berlin. In a later stage of the mission, the XLink transceiver may be integrated into the nominal operations of the spacecraft to drastically enhance the payload data downlink capabilities.

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References

1. Merlin F. Barschke, Julian Bartholomäus, Karsten Gordon, Marc Lehmann and Klaus Brieß, 'The TUBIN mission for wildfire detection using nanosatellites', CEAS Space Journal, vol 9, iss. 2, pp. 183-194, 2017.
2. Merlin F. Barschke and Karsten Gordon, 'TUBiX20 – A Generic Systems Architecture for a Single Failure Tolerant Nanosatellite Platform', presented at the 65th International Astronautical Congress, Toronto, Canada, 2014.
3. Merlin F. Barschke, Karsten Gordon, Philip von Keiser and Mario Starke, 'FDIR Approach of a Modular Satellite Platform Architecture', presented at the 67th International Astronautical Congress, Guadalajara, Mexico, 2016.
4. Merlin F. Barschke, Karsten Gordon, Marc Lehmann and Klaus Brieß, 'The TechnoSat mission

for on-orbit technology demonstration', presented at the 65th German Aerospace Congress, Braunschweig, Germany, 2016.

5. Aline Dinkelaker, Akash Kaparthy, Sven Reher, Ahmad Bawamia, Christian Kürbis, Robert Smol, Heike Christopher, Andreas Wicht, Philipp Werner, Julian Bartholomäus and Merlin Barschke, 'Optical quantum technologies for compact rubidium vapor-cell frequency standards in space using small satellites' Journal of the British Interplanetary Society, vol. 72, pp.74-82, 2019.
6. Merlin F. Barschke, Aline N- Dinkelaker, Ahmad Bawamia, Julian Bartholomäus, Akash Kaparthy, Sven Rotter, Philipp Werner, Elizabeth Klioner, Clement Jonglez, Juan M.H. Crespo, Markus Krutzik, Christopher Schmidt, Christian Guchs, Klaus Jäckel and Mathias Reibe, 'The QUEEN Mission to Demonstrate an Optical Rb Frequency Reference Payload and Advanced Small Satellite Platform Technology', presented at the 70th International Astronautical Congress, Washington D.C., United States of America, 2019.
7. Mathias Reibe, Klaus Jäckel, Merlin F. Barschke and Clément Jonglez, 'A Modular Family of High Data Rate SDR Transceivers', presented at the 33rd Annual AIAA/USU Conference on Small Satellites, Logan, United States of America, 2019.