INCREASING THE POWER DENSITY OF CUBESATS -
a Demonstration Scenario for deployable Solar Arrays

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Abstract: Recent developments in deployment systems and solar cells enable the generation of more than 100 W of electrical power for Nano Satellites. A first mission concept named PLUTO (PayLoad Under Test Orbiter) is developed in DLR Bremen. PLUTO is used as in-orbit demonstration for components and subsystems to identify problems on the way to application.
A central part is the Integrated Core Avionics (ICA) and its Unified Module Framework (UMF) used to support system design by combining avionic components and simplifying interfaces. The ICA UMF is compatible with the CPCI Serial Space Standard but tailored to enable applications between 3U CubeSats and stand-alone boxed systems. On PLUTO, ICA includes power handling, a software-defined radio and on-board computer, as well as advanced flight software.
While low-cost rideshares become, in theory, more and more abundant, every avionic demonstration still requires a flight mission willing to use experimental components for critical functionality. Because ICA offers compatibility down to 3U CubeSat size, a dedicated CubeSat mission for in-orbit demonstration is a cost-effective solution. The aforementioned solar array is the enabling factor for this concept while the ICA UMF provides an advanced electronics environment.

1. INTRODRUCTION

The DLR Institute of Space Systems is developing innovative satellite components for nano and small satellites. The institute's research ranges from avionics, over GNC components, mechanisms and structures to software and wireless technology. With component development being a critical part of the research effort, new hardware is continuously available. For the further maturation of this hardware, two options are of special interest: testing in a relevant environment and integration into a system. Both of these can be achieved with a flight mission, but this is difficult for components serving critical functions on the satellite bus. To mitigate the risks and challenges connected to this approach, the concept of the PLUTO was introduced as a test case to integrate all internal developments into a single system. Supported by the Core Avionics Testbed (CAT), a test environment which has been in development for many years now, this led to a nearly complete satellite system and provided valuable input for the component development and the shared interfaces. From a pure design concept to helping subsystem and component designers with input from a possible application case, PLUTO has recently evolved into a 6U CubeSat to fly in 2024. Stemming from a laboratory background, this mission will be a high-risk technology demonstration aiming at on-orbit testing of several components.
This paper describes the overall system design of PLUTO, with a focus on the accommodation of avionics designed for larger satellites on CubeSats, enabled through a large deployable solar array. The associated challenges and mitigation methods are briefly described and an outlook for further development is given.

2. SYSTEM OVERVIEW

The goal of PLUTO is to provide a flight opportunity for as many new components and subsystems as possible. Thus, the overall system was not designed top down but rather from the components perspective upwards, leading to a 6U CubeSat configuration to accommodate all needs in terms of power, data, thermal and mechanics. The key aspect for the overall design of the system was to accommodate components with high power demand and operate them for in-orbit demonstration. Figure 1 : System Overview of PLUTO. DLR developments are shown in grey. Dark grey indicates components included in the ICA UMF.Figure *1* shows a system level overview of the components on PLUTO and indicates all DLR developments in grey. These include a software-defined radio (SDR) for S-Band downlink and ADS-B signal monitoring [1], a multi-node computer system (designated Payload Data Handling, PDH in the diagram), ultra-wideband (UWB) wireless communications, retroreflectors for identification and orbit determination as well as the electrical power system (EPS). Due to its experimental character, the custom SDR's S-band communication is backed up through an off-the-shelf UHF transceiver for reliable TMTC communication, as will be detailed later on. The Attitude Control system is designed to provide three-axis stabilization with magnetorquers and reaction wheels. Gyroscopes, an accelerometer, a magnetometer and photo diodes on all sides provide coarse pointing information for initial operations, while a sun sensor improves the accuracy for sun pointing.

While the off-the-shelf radio, onboard computer and reaction wheels follow the typical PC104 form factor, and are accommodated in a single stack, the other components are designed to a new

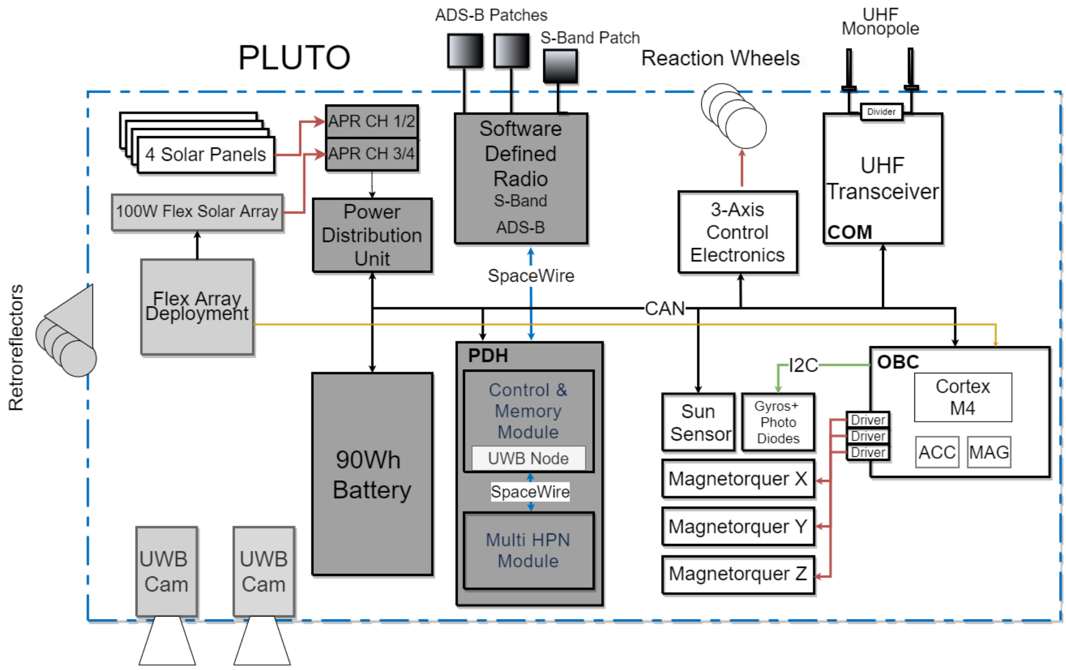

Figure 1 : *System Overview of PLUTO. DLR developments are shown in grey. Dark grey indicates components included in the ICA UMF.*

form factor called ICA UMF to overcome some of the limitations of PC104.

2.1 Integrated Core Avionics – Unified Module Framework

Under the name of ICA, research on the combination of multiple avionic subsystems (e.g. EPS, PDH, COM) into a single unit is carried out. The goal is to simplify interfaces, reduce size and mass and to reduce recurrent engineering efforts for subsystem integration. As the design is based on previous subsystem developments, a shared form factor had to be found to allow interoperability of the components. Furthermore, the compatibility with at least some CubeSat structures was envisioned for technology demonstration and a wider application range. This led

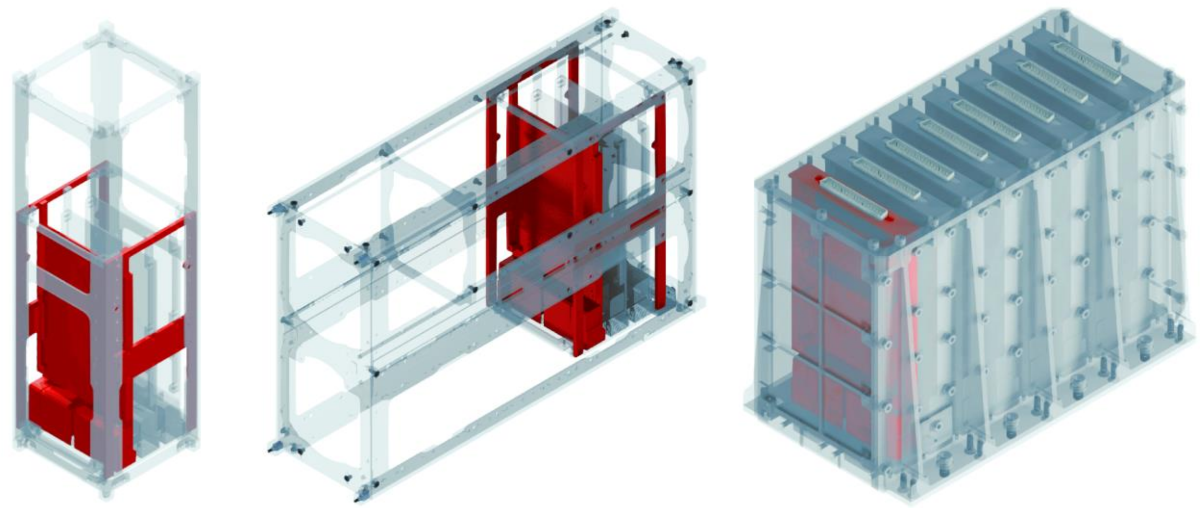

Figure 2 *: ICA UMF scalability from 3U CubeSat to stand-alone subsystem. Same component can be used in all configurations*

to the creation of the ICA Unified Module Framework (UMF), a backplane based configuration mechanically compatible with CPCI Serial Space but tailored to fit into a 3U CubeSat. As shown in Figure *2* the same component can be used across a wide variety of applications.

Compared to PC104, this configuration has several advantages, especially on CubeSats. Firstly, the backplane enables more connections and makes higher data rates feasible. Secondly, the use of dedicated mounting frames for the boards improves the thermal connection of the board to the primary structure. And lastly the usable area per board is about 125cm². Compared to the overall board area of 85 cm² for PC104 this enables the use of larger components, more complex designs and reduces the overhead needed for connectors. Although mainly intended to demonstrate the ICA for later application in larger systems, the application in a CubeSat environment may be of interest for science missions with challenging requirements.

To highlight the difference in power consumption between the ICA and the other satellite components, Table *1* shows the mean and peak consumptions for all larger consumers. All systems on PLUTO can in total consume up to 25 W, while the combined PC104 Stack made of UHF radio and OBC can operate continuously with less then 10% of that. This large range of possible consumption is needed to provide a load for the deployable solar array and to gather data on the thermal behavior of the system on one hand while also allowing low energy survival for potential troubleshooting and debugging.

Table 1 *: Power Consumption of PLUTO Components*

Unit	*Power Consumption Mean / Peak*
PDH Control	*3 W*
PDH Performance	*10 W*
GSDR	*4.5 W / 9.5 W*
PCDU	*1 W*
UWB Cameras	*<0.1 W / 3 W*
Reaction Wheels	*2 W / 5 W*
PC104 Stack	*1.2 W / 3.3 W*

2.2 Power Generation

On the power supply side, the 100 W solar panel is the enabling technology for this mission. It deploys from a single 1U volume on the top of PLUTO and unfolds to nearly 1 m² covered with 100 triple junction solar cells connected in a 10s10p configuration. [2] Figure 3 shows PLUTO with the deployed solar panel. Five strings each are connected to two array power regulators (APRs) taking care of the maximum power point tracking (MPPT) and converting the input

voltage down to the battery voltage. The battery is made of commercial 18650 Li-Ion Cells connected in a 4s2p configuration to keep the charge current at a tolerable level but to still provide high efficiency step-down conversion to 12V bus rails.
Additionally, four body-mounted solar panels are mounted on the satellite sides to generate power before deployment of the large array or while tumbling. These are connected to two additional APRs supplying the same battery. Two of these panels are mounted on one large side leading to about 16 W of power generation even without the large panel deployed.
To minimize the conversion losses in the PCDU, the APRs for the deployable solar array are based on GaN Transistors.

3. Operations

PLUTO is a high-risk mission, since most components have not previously been operated in orbit and there is only limited experience with deploying large array structures from CubeSats [3]. To minimize loss of data, the system design provides fallback solutions based on proven hardware (such as an off-the-shelf on-board computer (OBC) and UHF transceiver) to continuously collect telemetry data for debugging. Furthermore, the active life of PLUTO is roughly split into three phases with increasingly critical operations to increase the chances for providing meaningful operational data for all systems. Due to the current status of the mission, these plans are still preliminary.

Early Orbit Phase: The initial operations of PLUTO will be limited to the commercial components and body mounted solar array. A first analysis indicates a generation capability of around 3 W for the random tumble expected after deployment. With the limited power input, it is possible to operate these components continuously, detumble, orient towards the sun and bring the satellite into a spin along the axis perpendicular to the large side panel. Communications will be limited to UHF.

Sun-pointing limited Science: The spin axis of the satellite is facing towards the sun, around 16 W are generated by the dual panel during sun phase, allowing for around 10 W of continuous consumption.
Not all components can be operated simultaneously, but by scheduling the operations, all systems can be tested and verified. The battery is used to buffer the power consumption.

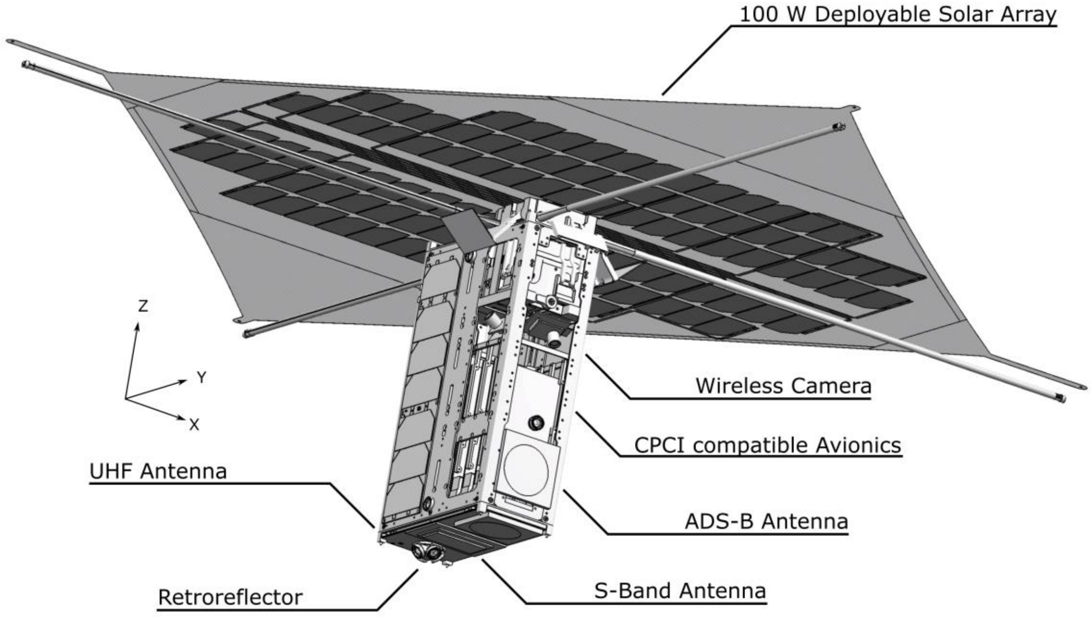

Figure 3 : *Overview of the PLUTO 6U CubeSat with the solar panel deployed. Side panels removed. Global reference axis in accordance with [4].*

This mode will be kept for about three months to generate a basic set of data for all components on PLUTO.

Solar Array Testing: The rotation of PLUTO is stopped and the Z+ side (see Figure 3) is roughly oriented towards the sun. All non-essential loads are disconnected to preserve power and allow prolonged telemetry downlink via UHF in case of problems. The deployment process of the solar array is started and should be completed within a few minutes. This can be monitored by a camera and deployment switches inside the unfolding mechanism. If the deployment is successful, the power generation telemetry indicates a rising charge current and the satellite can return to full operations. Due to the large solar panel acting like a drag sail, the remaining time in orbit would then be limited to around one year. During this time, attitude control will be limited but the collected data will provide useful input for follow-up missions. The power generation of the deployable panel will be measured and compared against the illumination through fixed photo diodes providing reference data.

4. Challenges & Outlook

With PLUTO introducing a set of components that have previously not been used on CubeSats, there are problems arising from the integration of these independent developments as well.
The attitude control for the deployed configuration of PLUTO is challenging for two reasons. Firstly, being designed as lightweight and as compact as possible, the deployable panel is not as rigid as a conventional foldable solar array made of stiff substrate, and will introduce additional oscillations into the system. Furthermore, the lack of a solid substrate makes the whole panel flexible to some degree even when fully deployed. The extent of the flexibility and the impact on the system level attitude control will be carefully monitored during the mission to improve models and enable accurate pointing for future missions. Secondly, the shape of the solar panel causes shading on all sensors mounted to the satellite body. This is especially critical when trying to achieve sun pointing with the deployed array and cannot be solved easily by simply mounting a sun sensor on the array, since this would impede folding for the stowed configuration. Currently, investigations to provide sun angle information through the partly transparent deployable solar array are underway. Alternatively, a star tracker could be used to provide attitude information even when shaded from the sun. However, this was discarded for PLUTO due to cost and space restrictions, but is a viable option for future missions.
Another critical aspect is the thermal behavior of the satellite. If stable sun pointing can be achieved, and solar panel deployment is successful, the satellite body is continuously in the shadow of the deployed array, leading to lower temperatures and enabling the use additional radiator surfaces for improved power dissipation.
A first simulation using four 80 x 200 mm² aluminum fins as deployable radiators on the edges of the satellite body suggest that a power dissipation of up to 50 W could be achieved with component temperatures around 40°C, enabling full use of the deployed panel for a future mission. Alternatively, a flexible radiator solution as described in [5] could provide similar performance while being easier to accommodate. During the PLUTO mission, data on the changing satellite body temperature is collected and analyzed as additional input for further development. Due to the risk of no stable attitude control after panel deployment, radiators have not been implemented on PLUTO.

5. Conclusion

A concept for a CubeSat with a large deployable solar panel and high power demand is presented. The concept is currently being implemented into a mission to fly on a launch provided through the DLR microlauncher competition in 2024. An overview about the power demand, component adaptation and system level implementation is given and potential problems specifically regarding thermal and attitude control are highlighted. The PLUTO mission will be a first test for the deployable solar array and pave the way for an advanced later mission making full use of the generated power.

6. References

[1] J. Budroweit and A. Koelpin, "Design challenges of a highly integrated SDR platform for multiband spacecraft applications in radiation enviroments," in 2018 IEEE Topical Workshop on Internet of Space (TWIOS), Jan. 2018, pp. 9–12. doi: 10.1109/TWIOS.2018.8311399.

[2] P. Seefeldt and T. Spröwitz Development of New Solar Array Concepts for Space Applications. Beyond solar cells: new approaches to radiation conversion, MAPEX Symposium 2021, 29-30 Sep. 2021, Bremen, Germany.

[3] P. Laube et. Al. ADEO-N – Deployable Passive De-Orbit Sail Subsystem Enabling Space Debris Mitigation for CubeSats, SmallSats and Constellations. (2021)Available online at: https://indico.esa.int/event/321/contributions/6321/attachments/4306/6425/ADEO-N%20The%20European%20Commercial%20Passive%20De-Orbit%20Subsystem%202021.pdf

[4] CubeSat Design Specification Rev. 14 CP-CDS-R14 Available online at: https://static1.squarespace.com/static/5418c831e4b0fa4ecac1bacd/t/5f24997b6deea10cc52bb016/1596234122437/CDS+REV14+2020-07-31+DRAFT.pdf

[5] C. van Lierop, Deployable radiator wig for high performance CubeSats. Available online at: https://repository.tudelft.nl/islandora/object/uuid%3A5bfd6486-bf23-42d1-89f4-e0fe41ebc286