# THE FLEXIBLE LEO PLATFORM FOR SMALL SATELLITE MISSIONS

J. Eickhoff[1], Friedrichshafen, DE; B. Chintalapati[1], Friedrichshafen, DE; P. Stoecker[1], Friedrichshafen, DE; W. von Kader[1], Friedrichshafen, DE; R. Traussnig[1], Friedrichshafen, DE; C. Sayer[2], Göteborg, SE; R. Peel[3], Milton Keynes, GB
[1]Airbus Defence and Space GmbH; [2]Cobham Gaisler AB; [3]4Links Ltd.

## Abstract

Spacecraft industry is heavily investing in constellation and new business missions, both requiring cost-efficient satellites. While satellites for large constellations are extremely tailored to a particular mission, like the Airbus Arrow platform used for OneWeb, complementary platforms e.g. for in-orbit verification applications need to be highly adaptable to varying customer requirements, instrumentation, orbits and operational concepts.

The “Flexible LEO Platform” - FLP2 for short - is a spin-off from the Airbus / University of Stuttgart cooperation during the FLP1 program. It targets towards affordable spacecraft offering a large flexibility in scale and platform/payload interfaces. The key advantage of this platform is its consequent modularity in hardware and software making it suitable for a variety of LEO (Low Earth Orbit) mission scenarios. Payload capacities reach from 25 – 100 kg and from 50 to 300 W average Pwr. The platform is multi-payload capable.

Keywords
Small Satellite Platform, Scalability in Size, Power, Number of Payloads, LEO Orbits, Modular Avionics Design

## 1 THE FLEXIBLE LEO PLATFORM

The University of Stuttgart, Germany, has developed a small satellite called “Flying Laptop” with support from Airbus Defence and Space GmbH, Friedrichshafen. The satellite was launched successfully on July 14, 2017 and at time of abstract submission is showing outstanding performance since then. Airbus responsibilities were the design of the “Combined Data and Power Management Infrastructure” (CDPI) [1] and coaching of the operations and flight software design. The resulting small satellite platform, on which the “Flying Laptop” was built, was called “Future Low-Cost Platform” (FLP Generation 1).

Airbus has functionally upgraded and industrialized this design to an even more modular, LEGO brick architecture for smaller LEO missions. This design is called "Flexible LEO Platform" (FLP2) and is available since begin of 2018. FLP2 can be adapted for missions with more demanding payloads and AOCS units. It is suited for satellites with a mass range btw. 50 and 200 kg and comes in customizable options like Cube, hut, multi-box and other designs.

The “Flexible LEO Platform” (FLP2) is designed for a lifetime > 5 years in 800 LEO orbit.

| Platform Budgets | Details |
|---|---|
| Wet Mass (PF + PL) | 50 - 200kg<br>incl. 20% Margin |
| Dry Mass (PF + PL) | 50 – 190<br>incl. 20% Margin for small version without and large version with el. propulsion |
| Propellant Mass (Xenon, EP) | 8 kg<br>incl. 20% Margin |
| Payload Mass | 25 - 100 kg<br>depending on satellite layout<br>incl. 20% Margin |

TABLE 1: Platform budgets

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## 1.1 Missions

FLP2 is also a fully three-axis stabilized platform. It is suited for a variety of mission scenarios performing either nadir-pointing Earth observation with e.g. scanner instruments, or target pointing Earth observation e.g. with camera instruments or inertial pointing e.g. for astronomical missions and telescope payloads – and obviously for combinations thereof.

The satellite platform meets international agency and industry standards, such as the CCSDS and ESA Packet Utilization Standard based communication protocols. A baseline Mission Information Base is available for the Mission Control System CCS5 (Terma B.V.).

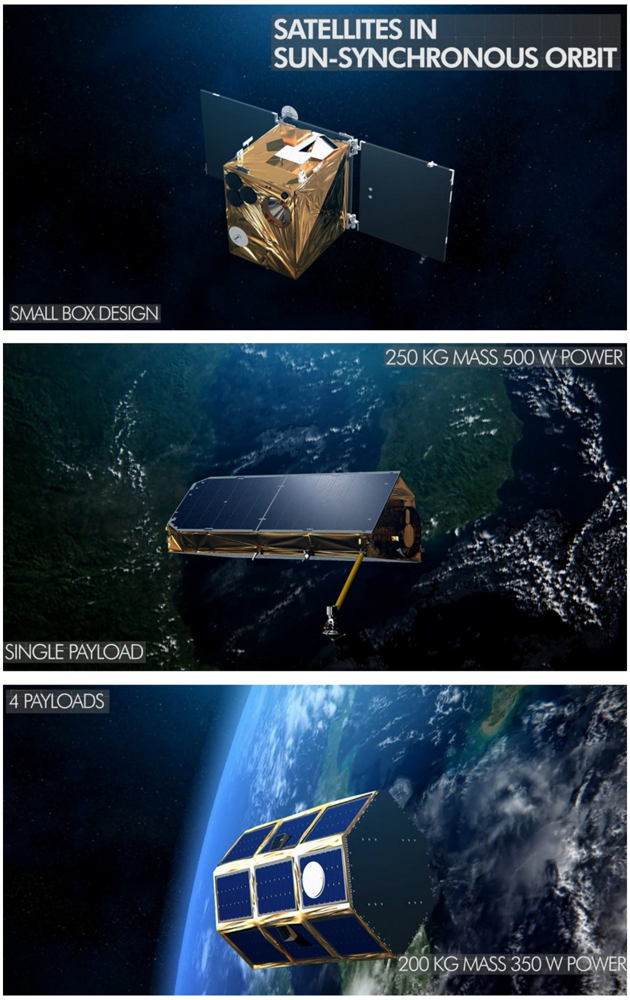

FIGURE 1: Example designs for flying and proposed missions

The target of the FLP2 service is to make the launch of customer's payload as simple and comfortable as possible. To this aim, Airbus works together with payload providers to opt for key payload interfaces while maintaining a highly-modular design of the platform.

Airbus has full-package AIT&V offers, taking care of all aspects of the assembly, integration, test, verification and launch, or it provides customized support tailored to the project needs at the customer's integration site.

## 1.2 Orbits

FLP2 is designed for a Low-Earth Orbit (LEO) with altitudes between 500 and 850 km, in sun-synchronous orbits as well as with inclinations in the broad range between 0 and 110°. This allows FLP2 to fly payloads above planet poles on each revolution or to fly lower inclined or even equatorial orbits.

## 1.3 Retirement strategy and debris mitigation

In 2002 the "Inter-Agency Space Debris Coordination Committee" of the United Nations adopted a code of conduct on the prevention of space debris. In order to adhere to the UN regulation, the FLP2 platform provides the following deorbiting functionalities:

On satellites with box design and overall S/C mass <= 120kg the device for adequate deorbiting will be a Capton Sail which increases the aerodynamic drag of the satellite in the residual atmosphere. It is a flat square sail and is deployed using a non-explosive bi-metal switch. The De-Orbiting-Mechanism is stowed within the launch adapter ring until its deployment at the end of the satellite mission.

A risk assessment has been carried out for two FLP1/2 platform designs in this box design and within the 120 kg mass perimeter. A probability of < $10^{-4}$ has been obtained, which relaxes the constraint of active deorbiting.

For satellite configurations with higher mass and/or higher orbit altitudes than 650 km the deorbiting can be further stimulated using the FLP2 propulsion system since here the total casualty risk is larger than $10^{-4}$. Here a controlled re-entry must be performed such that the impact foot-print can be ensured over an ocean area, with sufficient clearance of landmasses and traffic routes. FLP2 offers classic satellite deorbiting approaches for this kind of larger configurations.

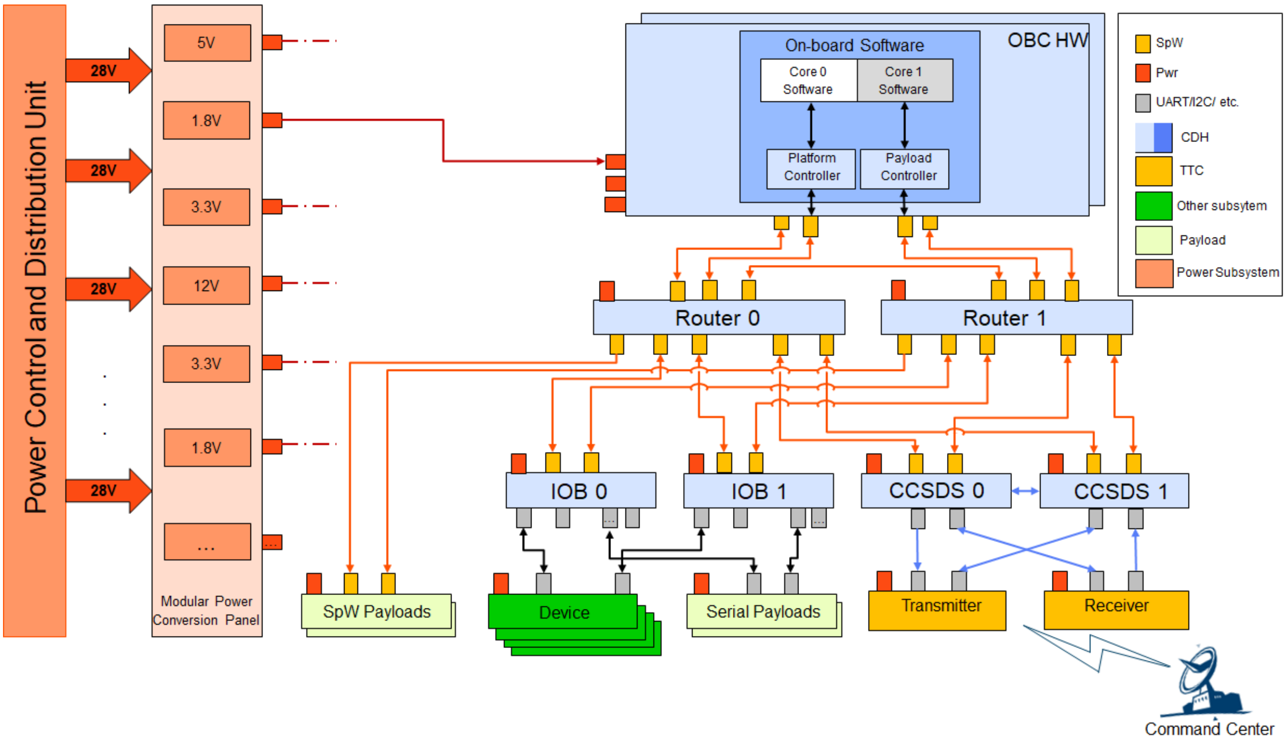

FIGURE 2: FLP2 System architecture overview.

## 2 THE MODULAR CORE AVIONICS CONCEPT

The key to the FLP2 system flexibility concerning payload hosting is its strictly modular Core Data Handling and Power subsystem modularity. FIGURE 2 provides an impression, however does not depict all redundancies nor cross couplings.

### 2.1 Core DHS Architecture

The primary connection of the CPU-Board to the S/C network is exclusively via SpaceWire (SpW). For each CPU board 2 cross-strapped SpW lines connect to 2 SpW routing switches (typically 8 port switches from 4Links Ltd.).

From there the further (also cross coupled) connections follow to the

- *hot redundant CCSDS Decoder/Encoder boards (incl. CLCW cross connection and HPC feedout to PCDU)*
- *the I/O-Boards (**digital RIU** for connection of all non SpW AOCS equipment)*
- *and to the payloads.*
- *The payload module may contain an additional SpW routing switch in case of large number of required devices or a SpW <-> Ethernet bridge.*

The CPU-board connects cmd/ctrl to the PCDU directly via serial link in FLP2.

The **analog RIU** functions (e.g. reading of thermistors or sun sensors) are provided by the PCDU in this architecture.

The architecture features a single **reconfiguration unit** for both power failures as well as OBC board failures which is embedded in the internally redundant PCDU. This “Combined Data and Power Management Infrastructure” (CDPI) is patented by Airbus and is described in detail in [1].

### 2.2 CPU Boards

FIGURE 3: Cobham Gaisler CPU-board

FLP1 was based on a LEON3FT Cobham Aeroflex UT699 SBC with 4 MiB FRAM and 8 MiB SRAM and 33 MHz clock frequency. This board is TRL9 and is still available. However, it is limited to NVRAM bank size and thus overall OBSW size.

The new baseline is a Cobham Gaisler CPU-board (TRL7) based on the GR712RC dual-core LEON3FT SPARC V8 processor, with 8 MiB MRAM and 256 MiB SDRAM, running at 60 MHz clock frequency. The flight SW runs all Platform control tasks plus PUS stack on CPU core 0 and all Payload control functions are run on Core 1.

The CPU-board is designed to be fully radiation tolerant through the choice of components, as well as additional system-level mitigation strategies. The SDRAM is protected through a Reed-Solomon EDAC, and the boot MRAM by BCH EDAC, both handled appropriately by the flight software in case of upset events. The MRAM is additionally protected against latch-up events by a protector circuit combined with full I/O isolation [3]. Four banks of non-volatile memory are available: Two banks are reserved for an invariable, ground-installed "golden image", one bank of software associated per each CPU core. The two remaining banks are available for in-flight updates of the boot software. In case of a boot failure of the uploaded patch, a reset will cause an automatic fall-back to the golden image.

The CPU-board offers GPIO PPS out for e.g. STR strobing and PPS-in e.g. for remote clocking from GPS. It also offers a serial service IF and a debug IF for connection to S/C skin connector bracket.

### 2.3 SpaceWire Infrastructure

The SpaceWire network on FLP2 is constructed around two SpaceWire routers. These routers will normally operate in a cold-redundant configuration. Each CPU-Board is connected to both routers using SpaceWire links, and the two routers are joined to each other by a SpaceWire cross-link.

The SpaceWire routers are FPGA-based, and run the 4Links SRS router IP. This IP implements a standard ECSS-E-ST-50-12C-compliant SpaceWire router. In addition, it implements a packet header-modification scheme that allows instruments that do not support SpaceWire network addressing headers to operate within the FLP2. The routers support SpaceWire links at up to 50 Mbit/s for command and control purposes, and up to 200 Mbit/s for payload science data transmissions. Native SpaceWire-connected instruments may be connected directly to these routers.

The FLP2's SpaceWire network also supports nominal and redundant I/O boards that are based upon those flying on the University of Stuttgart's Flying Laptop (FLP1). Each I/O board is connected to each of the SpaceWire routers via a SpaceWire link, and implements a SpaceWire Remote Memory Access Protocol (RMAP) interface to all of the serial-connected instruments on the spacecraft.

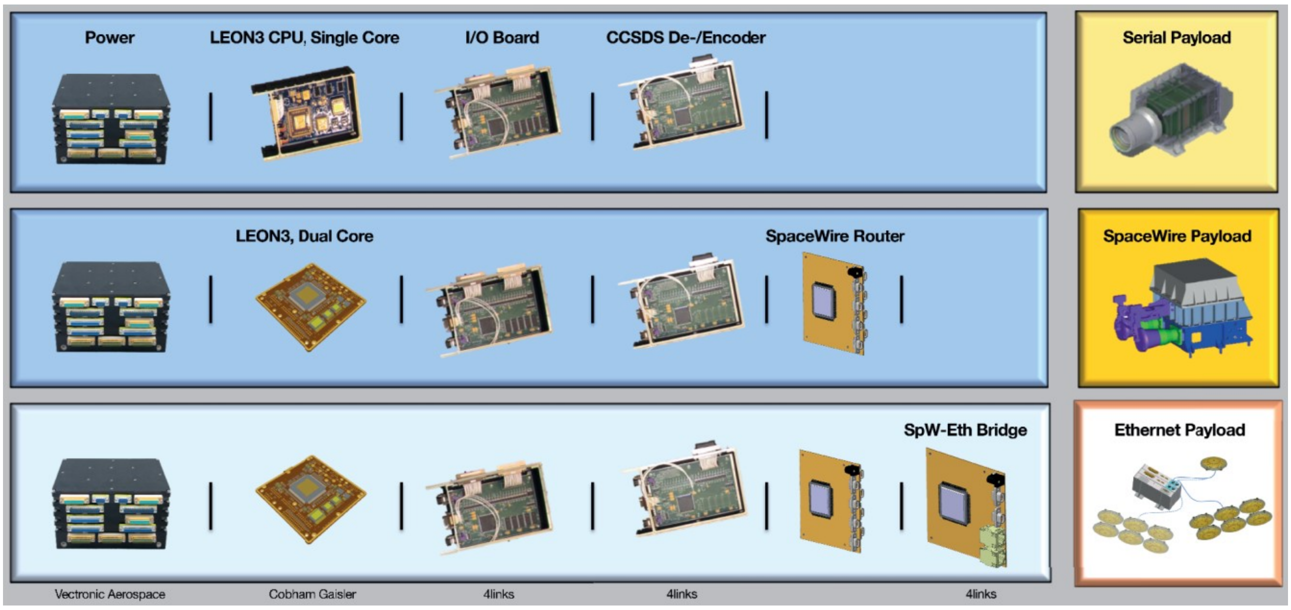

FIGURE 4: The FLP1/2 board sets (FLP1 in upper row).

The I/O-Boards furthermore feature dedicated memory banks for HK-Telemetry buffering btw. ground visibilities and for S/C state vector and S/C configuration vector.

| | |
|---|---|
| Processor | LEON3FT:<br>Cobham Gaisler GR712RC SBC dual-core 60 MHz |
| Memory | 8 MiB MRAM, 256 MiB SDRAM |
| Bus | 2x SpaceWire, 2x UART, Service IF, JTAG IF<br>CAN optional |
| Routing Switches | 2x 8 Port 4Links Rad. tolerant, 4x 8Port for large configuration with more than two SpW PLs |
| TTR Board | Rad. tolerant CCSDS De-/Encoder (new version from Q4 2018 onward) |
| I/O Board | Rad. tolerant digital I/O Unit, 4+16MB non volatile MRAM |
| PL Networks | Extendable with SpW PL routers by Nx8Ports, additional RS422 / 232 / 485, I2C, Ethernet |

TABLE 2: Core Data Handling subsystem elements

Finally, a redundant pair of SpaceWire-to-Ethernet bridges (also based on the same I/O board hardware) can be added to enable Ethernet-connected instruments to be attached to the FLP2. These bridges allow the CPU-Boards to generate TCP and UDP packets that are encapsulated in SpaceWire RMAP packets and transmitted onto the SpaceWire network. The SpaceWire-to-Ethernet bridges extract the Ethernet protocol packets from the SpaceWire packets, add the MAC address headers and drive them onto the Ethernet network. In the return direction, the bridges receive incoming Ethernet packets, remove the Ethernet framing, and encapsulate the remainder into SpaceWire RMAP packets for transmission to the CPU-Boards.

Copies of the I/O board hardware architecture are also re-used (by incorporating alternative IP) to drive the spacecraft's encrypted CCSDS uplinks and downlinks. These CCSDS boards are connected to each router using a separate SpaceWire link, for redundancy.

### 2.4 The upgraded Authentication Concept

In upgrade to FLP1 the Flexible LEO Platform will offer a full featured authentication functionality from end of 2018 through the next generation of CCSDS boards and IP core:

Authentication is performed in both hardware and software depending on the destination of the telecommand. The hardware authentication is applied to the hardware commands only, while the telecommands handled by software are authenticated in software. The envisaged authentication mechanism is based on the description in ESA PSS-04-151 - Telecommand Decoder Specification. Authentication is performed on segments and is placed between the segmentation sublayer and the transfer sublayer, referred to as "option B" in CCSDS 350.0-G-2.

The authentication algorithm is based on a one-way function called “hard knapsack”, which relies on a 40-bit digital signature generated by applying a secret key on the segment. The same algorithm is used for generating the signature in the transmitting end as in the receiving end, using the same key. The authentication function is configured by sending command packets with a specific routing address in the segment header, allowing for configuration over the telecommand link.

The hardware authentication and the software authentication are configured independently.

Two keys are provided: a fixed key and a programmable key. The programmable key can be modified during the mission through command packets. To further increase security and to ensure that the complete segment, including authentication tail, is unique over large periods of time, a counter is included in the authenticated segment. The on-board authentication unit keeps a copy of the expected counter values and compares these to the received values. The inclusion of a counter value, will ensure that consecutive segments with the same content will have different 40-bit signatures.

## 3 THE ONBOARD SOFTWARE

The second reason for FLP2 flexibility is the object-oriented implementation of its Onboard Software (OBSW). The FLP2 flight SW is implemented in C++ hosted on the RTEMS operating system. The OBSW includes a PUS stack with standard and private modes – see [2].

Device handlers for the individual controlled equipment units are realized as plug-in classes. Thus, in brief the software architecture reflects the satellite sensor/actuator/payload/RF-equipment tree.

Similarly, the subsystem controller algorithms (AOCS controller) are integrated in dedicated mode specific mode control handlers. This allows for an efficient tailoring of the SW to new AOCS control modes for new missions.

Instead of Onboard-Control Procedures mode transfers for subsystem and the entire satellite are realized via sequential mode tables defining equipment mode switching, transition times and fallback modes. For more details refer to [2].

As already mentioned the OBSW was adapted to support the dual-core processor with fixed task allocation – Platform control on Core 0 and Payload control on Core 1.

The detailed hardware and software FDIR concept is similar to FLP1 (see [2] chapter 10) but is simplified and more robust thanks to the now available direct CPU-board <-> PCDU connection and is adapted to the SpW routing network.

## 4 POWER SUBSYSTEM

The electrical power supply of the flown and all studied FLP2 mission opportunities so far is based on fixed solar arrays or simple deployable panels. No Solar-Array drive is part of the platform equipment set yet.

The power subsystem is based on an unregulated ≈28 V bus.

For the box designs one solar panel is body mounted, two are deployed once the satellite is launched and separated from the launcher. Deployment can be initiated automatically via time by PCDU and in addition via TC to OBSW.

### 4.1 The PCDU

The Power Control and Distribution Unit (PCDU) detects the launcher separation, controls the power distribution to the components and adjusts the charging of the battery. And the PCDU monitors currents and voltages and reports corresponding onboard TM to the OBC.

Beyond these default operations in this “Combined Data and Power Management Infrastructure” (CDPI) [1] the PCDU executes further tasks. The PCDU hosts the **analog RIU** functionality for all AD/DA converters to e.g. read out thermistors or analog sensors.

Furthermore, the PCDU hosts the common Reconfiguration controller for the entire CDPI [1].

The PCDU also host the processing of for High Priority Commands (HPCs). The HPCs are decoded and sent to the PCDU without involving the OBC Processor Board. In this CPDI architecture they are directly processed in PUS TC format coming from the Core DHS TTR board. This patented architecture therefore does not require any Command Pulse Decoding Unit (CPDU).

| Criterion | Values |
|---|---|
| Bus Voltage | 27-34 V unregulated (operational)<br>22-36 V (Safe Mode) |
| Power (EOL) Orbit Average | 120 W – 300 W depending on selected Vectronic Aerospace PCDU model |
| PCDU peak power | 200W – 500W depending on selected Vectronic PCDU model |
| Platform bus | < 40W |
| Leaving payload power | 80W – 260 W average |
| Solar Panels | Depending on satellite design.<br>For Box design two flexible and one body mounted array.<br>For hexagon or roof design body mounted SA |
| Battery | Custom Li-Ion or LiFeP3 |
| Batt. Capacity | >=30 Ah To be tailored to mission power budget |

TABLE 3: Power subsystem characteristics.

### 4.2 The Avionics Power Supply Modules

During design and development of FLP2, first mainly data handling functionality and mechanical structure was modularized. When focusing on Power Subsystem on-board most spacecrafts, it becomes distinct, that power electronics are significantly customized even though their electrical requirements are similar. A large majority of small satellites are equipped with a Power Control and Distribution Unit (PCDU), which supplies a 28 Volts Power Bus

(PB) through the satellite. Subsystems within the satellite, e.g. data handling or sensor, actuator or payload electronics, however require low supply voltages like 5V, 3.3V or 1.8V. Therefore, the power interface of satellite subsystems requires Step Down Converters.

Now with the consequent FLP2 flexibility the problem came up that not in all platform configurations all sensor power interfaces or all OBC board interfaces are necessary. A design-to-the-max would have been an overshoot for the small and extremely cost sensitive variants.

Therefore, the application of dedicated Power Supply Modules was initiated, modules which are powered by the PCDU with bus voltage and supply the required operational voltage to the devices. For the Core DHS units this is sketched out in FIGURE 2 on the left.

A reduced set of both power and voltage level classes could be identified to provide electrical energy to a variety of subsystems in the satellite platform without changing power electronic hardware for each class. Down converters, linear regulators and filters for Electro Magnetic Interference (EMI) mitigation are integrated on the Modular Power Boards (MPB), which execute the power conversion.

A typical block diagram of such an MPB is depicted in FIGURE 5.

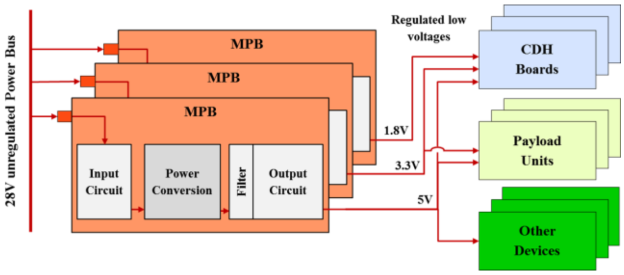

FIGURE 5: Functional block diagram of MPB

Depending on the electrical requirements of each panel, various supply or protection (e.g. LCL) boards can be equipped as well as additional filters. Overall, the Modular Power Boxes (MPBx) dimensions are approx. 80x70x70mm.

## 5 PAYLOAD ACCOMMODATION & INTERFACES

FLP2 is a flexible platform concerning the integration of one or more customer payloads to exploit their R&D and/or commercial targets. The applications can cover the areas of

- In-Orbit-Demonstration/Validation (IOD/IOV) missions
- Earth Observation & Science (EOS) also for small constellations or formations.

Furthermore, it is suited for special applications, such as

- Space debris detection (ESA brochure [8])
- Space debris removal (CleanSpace One from EPFL Lausanne is being built on the FLP2 core platform)

FLP2 can serve as multi payload carrier, purely limited by the payload's mass and power requirements.

Due to its flexibility w.r.t the payload management, payloads with diverse interfaces can be connected, such as with serial connections, SpaceWire interfaces and - for the first time - payload units with Ethernet interface, using a 4Links SpW-Ethernet Bridge [5].

| Data Interfaces | Details |
|---|---|
| Serial | RS232, RS422, RS485, all standardized baud rates |
| SpaceWire | PL cmd/ctrl 50 mBit/s, PL science data routing up to 200 mBit/s |
| Ethernet | Up to Gigabit Ethernet (standard Eth, no TTE) |
| CAN Bus | According to CAN standards, no traffic shaping, no collision avoidance in case of multiple PLs |

TABLE 4: Payload command/control interfaces

| | Details |
|---|---|
| Onboard MMU | Options: 16 GB SpaceWire MMU,<br>256 GB Ethernet MMU |
| PL Communications | 60 Mbps X band downlink, 8PSK modulation, CCSDS<br>Alternatively Ethernet packets encapsulation DVB-R2/S2 protocols [6] |

TABLE 5: FLP2 Payload subsystem budgets

The FLP2 transceiver system provides a large payload data downlink capability that benefits of an antenna with hemispherical coverage that has been designed for use on board of small satellites. The pattern shape has been optimized particularly for LEO missions with nadir/target orientation and reaches rates up to 60Mbps over an X-band link.

Science data storage options vary from SpaceWire or Ethernet routing solutions depend on the payloads network. The OBDH architecture provides high performance coupled with optionally redundant modules for improved reliability with a storage capability up to 256GB for science data.

| Payload Hosting | Details |
|---|---|
| Nadir Bay | Default |
| Stellar Bay | Optional |
| Bow-side Bay | Optional |

TABLE 6: Payload hosting options

## 6 AOCS

The set of standard AOCS sensors and actuators of FLP2 are listed below. Not all missions may need all of them, e.g. some simple missions may waive reaction wheels and only base their ACS on magnetotorquers as actuators. Similarly, not all missions may need Gyroscopes.

| Sensor | Quantity | Manufacturer |
|---|---|---|
| GPS | 2 | DLR - Phoenix Successor |
| Star Tracker | 1 (with 2-3 heads. Electronics internally redundant) | Technical University of Denmark |
| Gyroscopes | 3+1 | NG-LITEF |
| Sun Sensors | 8+8 | Azurspace |
| Magnetometers | 1+1 | Zarm |

TABLE 7: AOCS sensors

| Actuator | Quantity | Manufacturer |
|---|---|---|
| Reaction Wheels | 4 | Rockwell Collins |
| Magnetotorquers | 3 int. red. | Zarm |

TABLE 8: AOCS actuators

The total pointing error during one pass is less than 150 arcsec and the pointing knowledge is better than 7 arcsec.

## 7 PROPULSION

FLP2 can be equipped with various propulsion subsystems like cold-gas, chemical and electric - HEMPT or Resistojet.

| Actuator | Quantity | Manufacturer |
|---|---|---|
| Cold Gas Propulsion | 4+4 | Airbus |
| HEMPT or Hall Effect electric Propulsion | 2x3 | Airbus / OneWeb |
| Resistojet Propulsion | 4 | SSTL |
| Chemical Propulsion | 4+4 | Airbus |

TABLE 9: Propulsion options

## 8 PLATFORM COMMUNICATION

The TT&C subsystem consists of two receivers and two transmitters, in combination referred to as the transceiver, one nominal and one redundant each. The nominal and redundant “paths” both use a separate diplexer for the connection to the antennas. A 3dB hybrid coupler is used to split the signal to the two antennas.

With the new CCSDS decoder/encoder available from Q4 2018, the downlink data rate will extend to at least 192 kbit/s. The platform communication provides TC uplink authentication on Segment level for TCs and HPCs.

| TT&C | Details |
|---|---|
| Transceiver & Antenna | S-Band |
| Uplink | 2025-2110 MHz (4-64 kbit/s) |
| Downlink | 2200-2290 MHz<br>128 kbit/s default, ≥192 kbit/s with new CCSDS board from Q4 2018 |

TABLE 10: Platform communication characteristics

## 9 SUMMARY

The design lifetime of the FLP2 platform is 5 years in 800 km LEO orbit with its default equipment. Optional variants e.g. for GEO or deep space are prepared by design, implementable through use of identified dedicated further ruggedized board chipsets. These upgrades are prepared by design and are not implemented by default for the LEO variant since being cost drivers.

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## 11 EXAMPLE APPLICATIONS