The inside story of OPS-SAT

David Evans, OPS-SAT Space Lab Manager, ESA

ESOC Lunchtime Lecture

23/01/2024

Contents

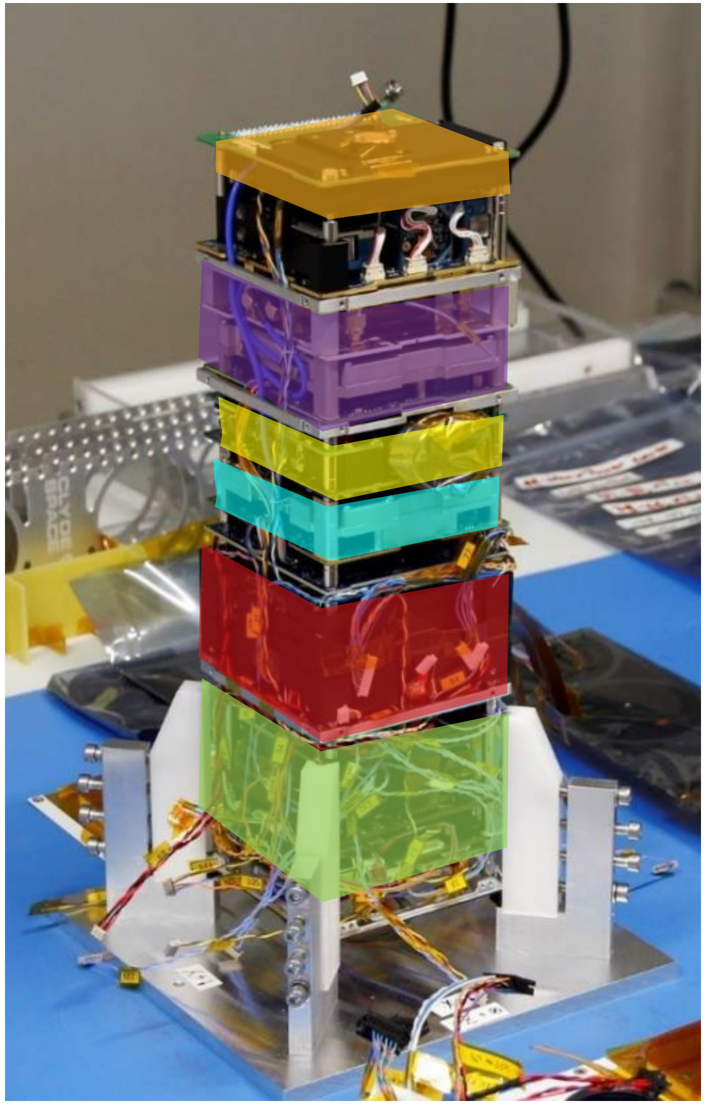
OPS-SAT-1

Satellite bus:

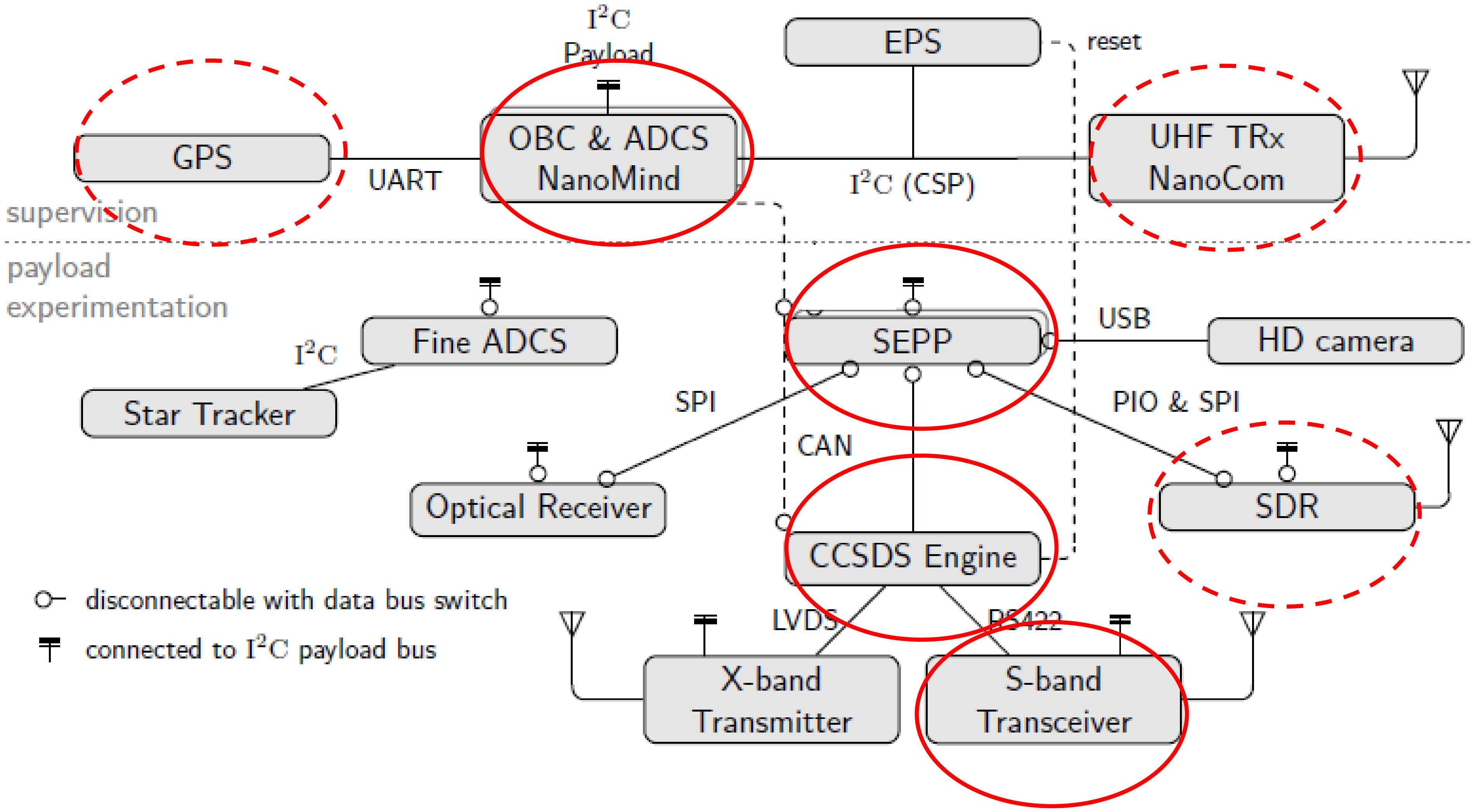
- Gomspace UHF AX100 radio + EPS/ACU
- Nanomind A3200 OBC (On-board computer, AVR32)
- S-band (2.2 GHz) TRX TMTC encoder/decoder (256kbps↑ 1Mbps↓)
- GNSS receiver

Satellite payloads available to experimenters:

- Software Defined Radio (LMS6002D)
- HD-camera (Nadir-facing)
- Optical receiver (data uplink via laser)
- Advanced iADCS (Attitude Determination & Control Sys.)
- X-band transmitter (3-50MBit/s)
- 2x Cyclone V SoC (800MHz Dual Core ARM Cortex-A9 + FPGA fabric) (called the SEPP)



Simplified system data architecture diagram



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Problems before the launch

The GPS open field test fails

SEPP-1 fails during TVAC testing

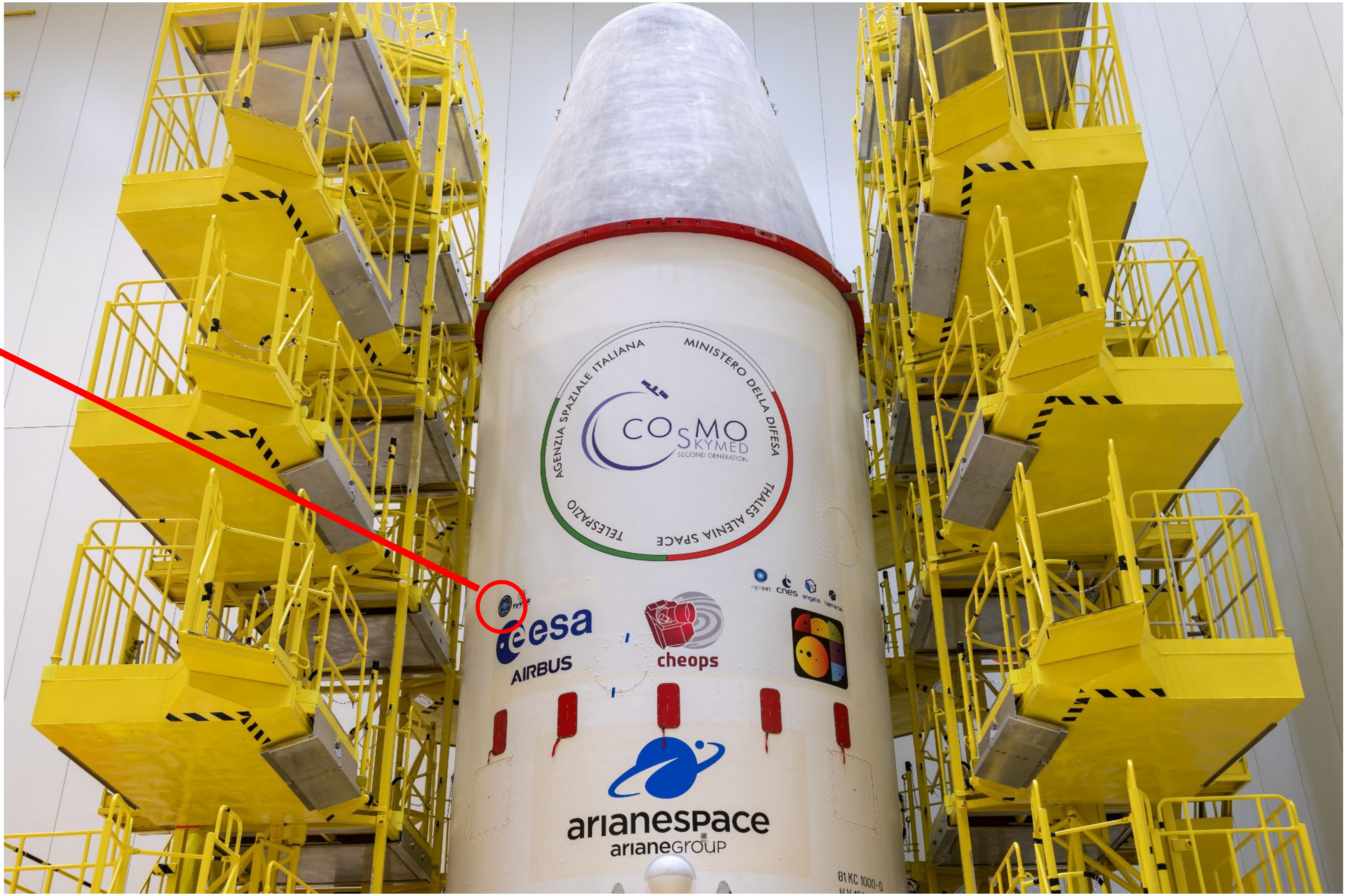
ESOC-2 (UHF) does not work

The agreed manpower budget is cut from three to two engineers

Asked to pay 250K to use the MCR for the LEOP

December 18th 2019: Launch day

Logo



1st Pass

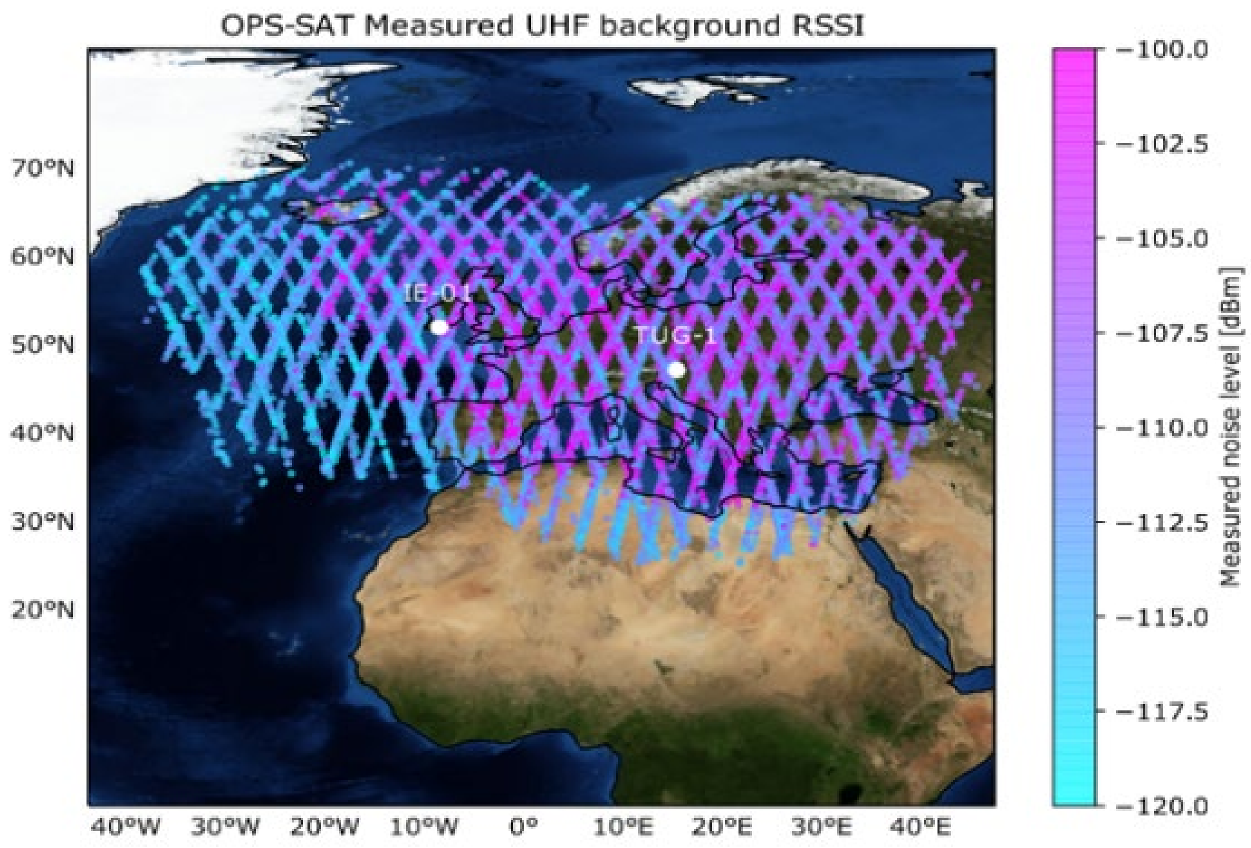
No packet received

2nd Pass

No packet received

Thankfully, we had the support of hundreds of radio amateurs

Communication Problems



UHF:

- Communication noise floor unexpectedly high

S band:

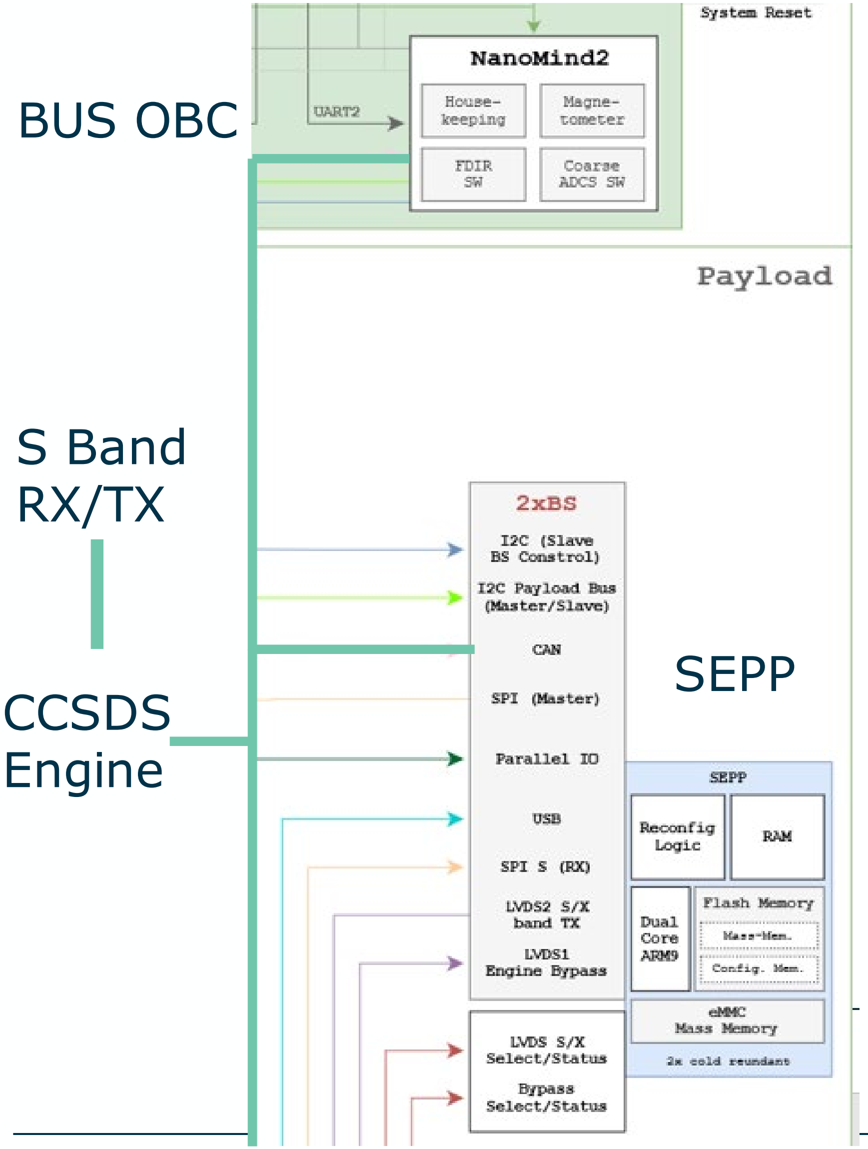
- We see a 10 dB increase in the on-board S band RX noise level whenever we power on the TX
- Then three weeks into the mission, ESOC-1 SSPA fails. We lose 6 dB of uplink power
- COVID arrives, and we are told that it will take nine months to repair ESOC-1

OBSW:

- We discover a bug that means it is too dangerous to turn on the S band TX

We desperately need an OBSW update!

Updating the OBSW



Updating the OBSW required 5000 commands each of which has to arrive otherwise you must start again

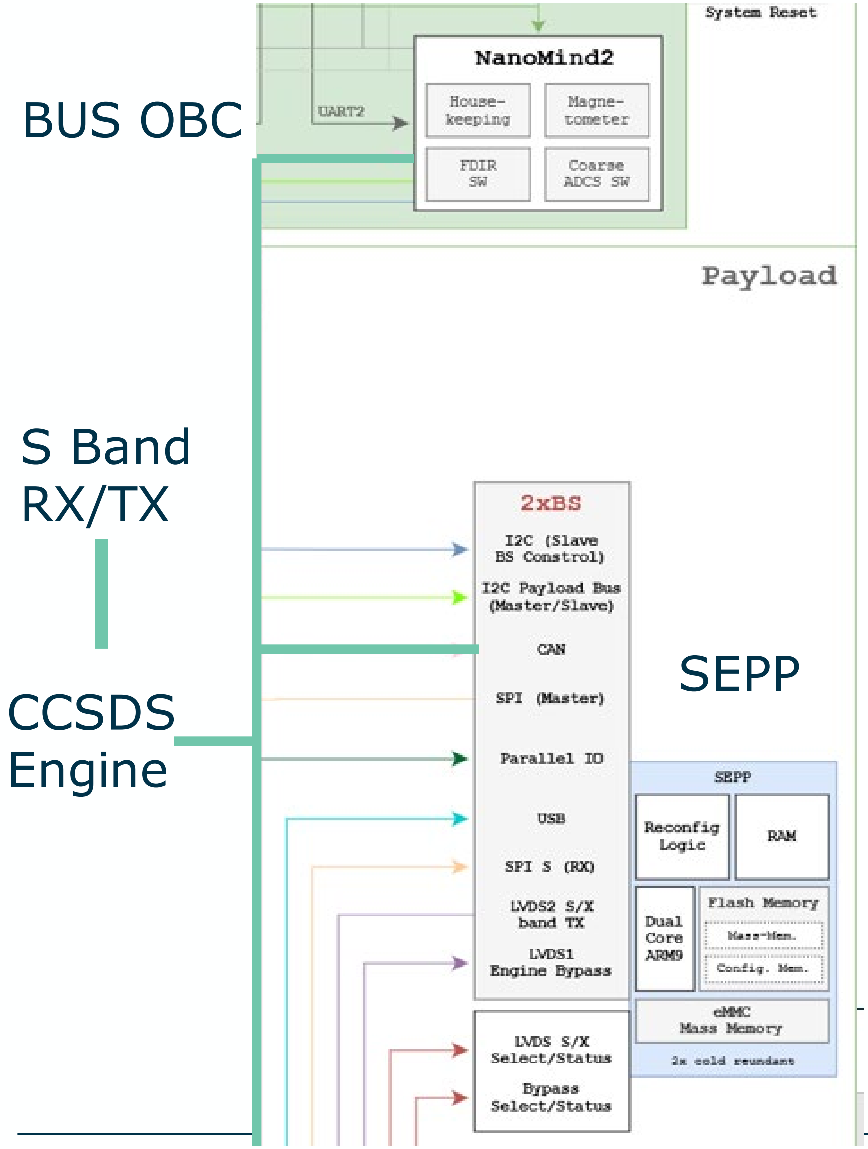
How could we do this with two minutes of commanding per day and it was completely unpredictable when it might occur?

SOLUTION:

- Try to load a compressed file to the SEPP that contains all the space packets needed for the OBSW load, then expand it
- Load a SEPP application to spoof the OBC into thinking the SEPP is the ground and send them slowly out of ground coverage
- Apply an ACK/NAK protocol on-board so that the SEPP application is sure that a command arrives before it sends the next one

The OBSW update went from one week to 90 minutes

Getting frequent, high quality HKTM

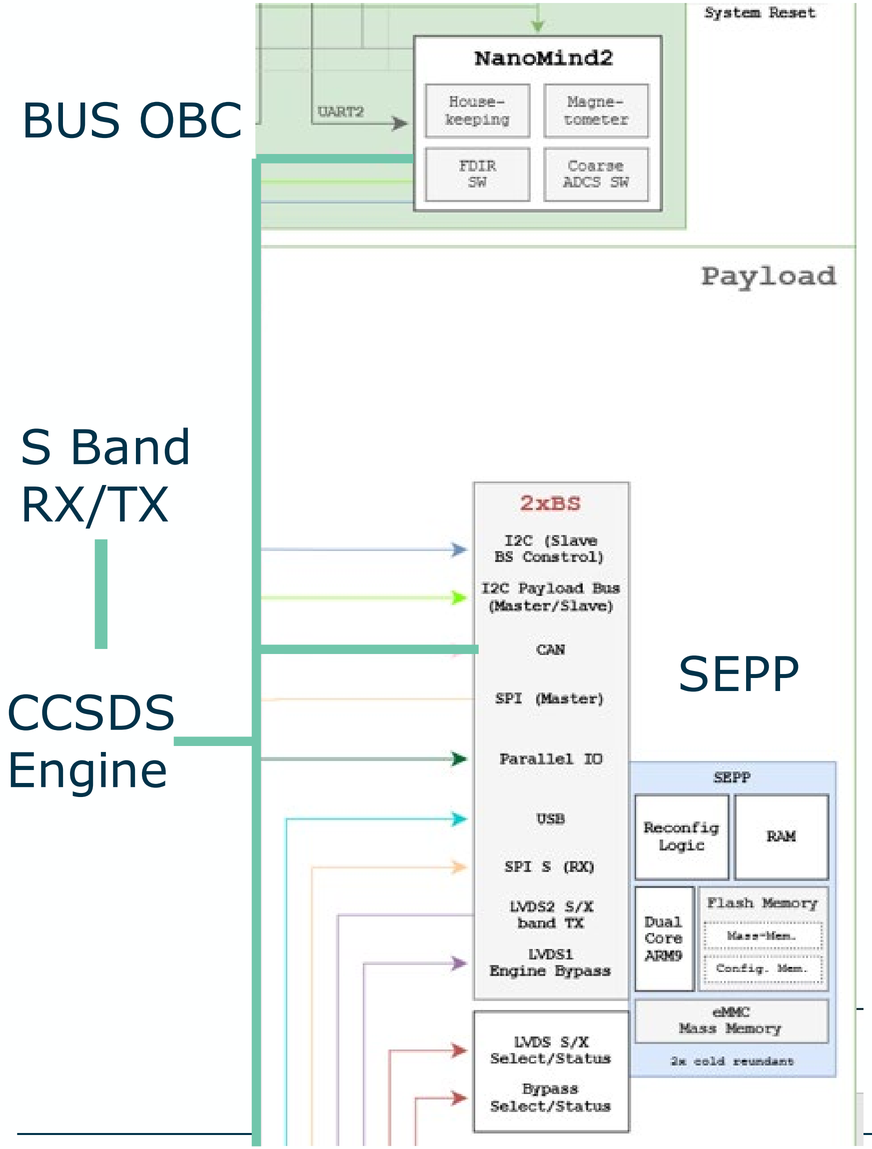


SOLUTION:

- Send TM to the CCSDS engine (TM encoder) even when the TX is off
- Load a SEPP application to sniff the CAN bus and collect the traffic
- Filter for the HKTM packets, collect in files and compress
- Whenever commanding becomes available downlink the compressed files using CFDP
- Expand on the ground and playback into SCOS

10x increase in TM volume compared to ideal nominal case

Performing the commissioning



What about running all the commissioning procedures under these communication conditions?

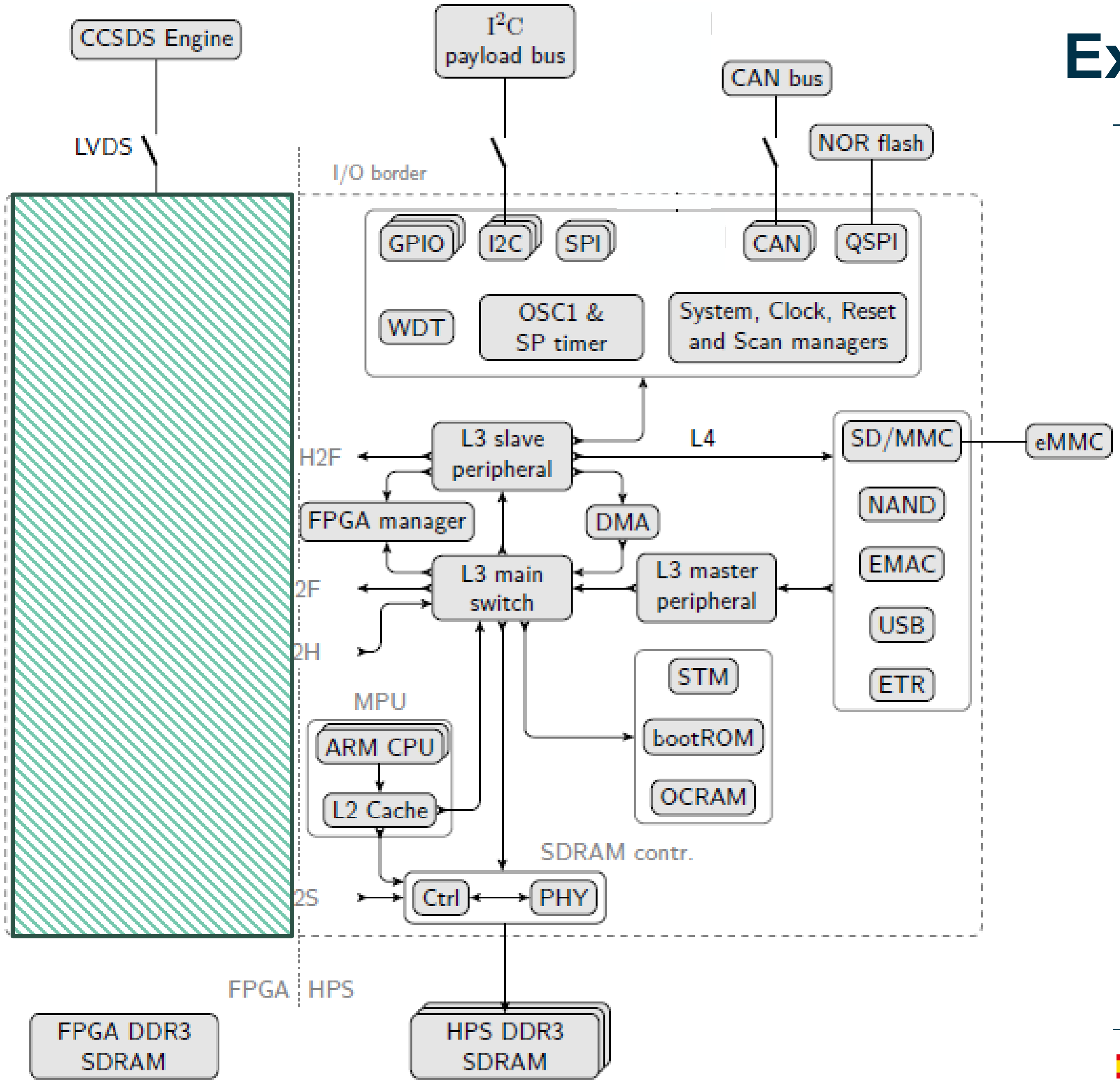
SOLUTION:

- All the commissioning procedures were converted to scripts with associated logs
- These scripts could be triggered by the TTQ
- The logs would be compressed and downloaded by CFDP, analysed and the scripts adjusted if necessary

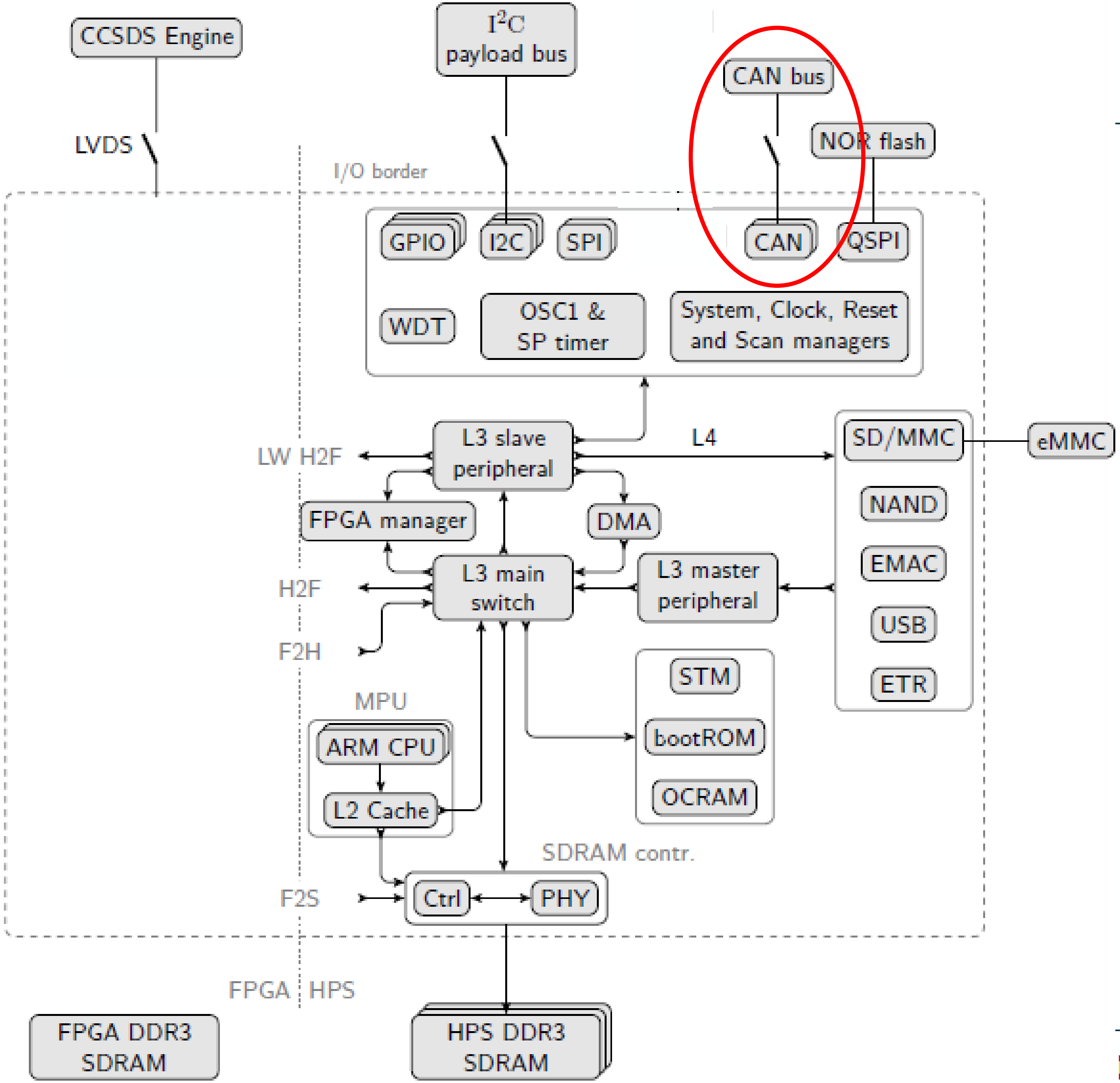
90% of the commissioning procedures were completed before we got the ground station repaired in Sept 2020

4 weeks later the OPS-SAT Space Lab service was open for business

Exploiting the in-orbit FPGA



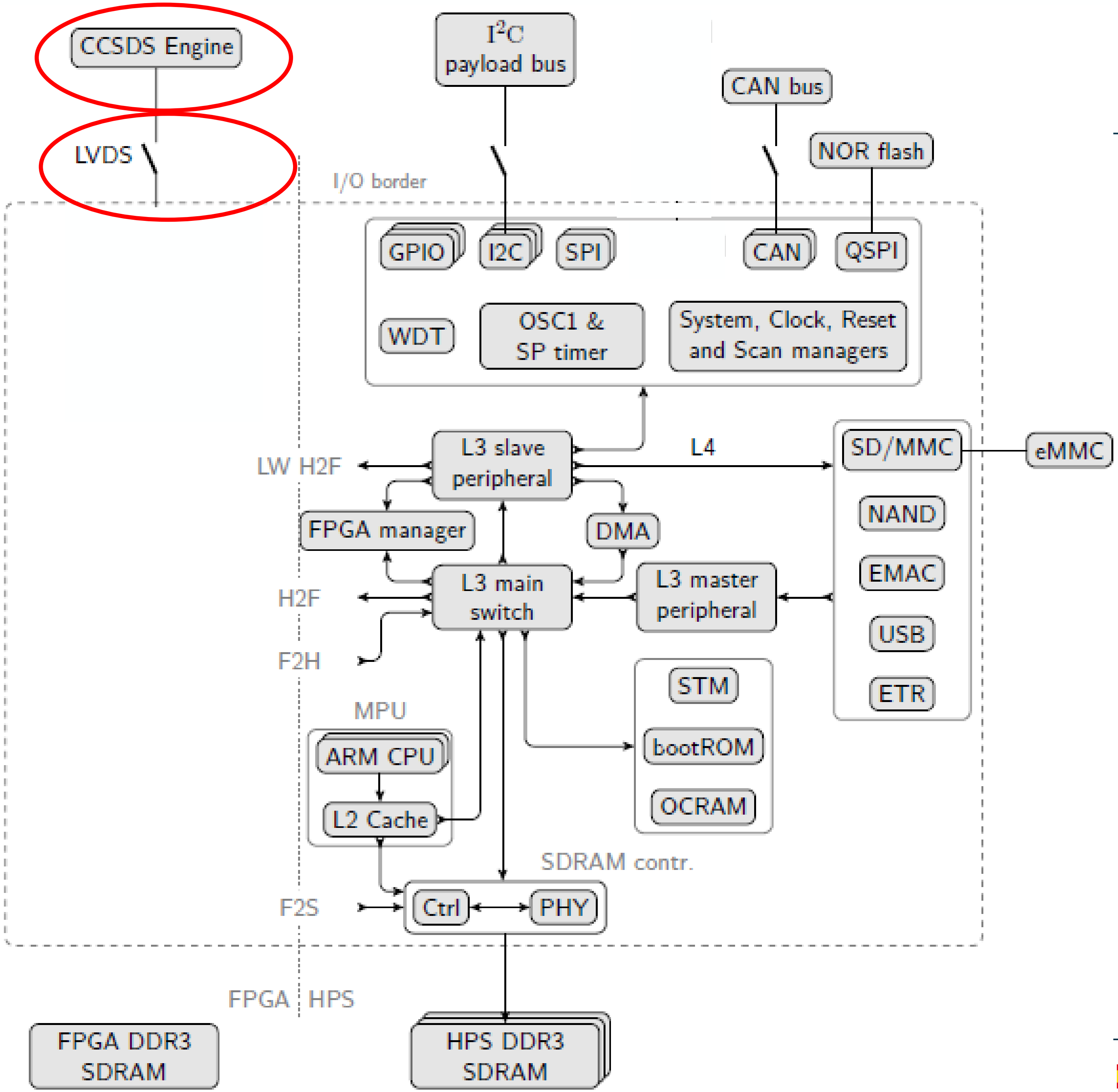
- Implement a new data handling bus in orbit
- Load state of the art hardware debugging tools to the spacecraft
- Load a completely new and improved TC decoder and TM encoder to the spacecraft



The CAN protocol already available on the Nanomind OBC bus was also implemented on the payload CAN bus

This was fine for the OBC connections as they were limited by the Nanomind speed

But for the SEPP-CCSDS connection it resulted in useful data rates of 150 kps on a RF link that could theoretically support 1 Mbps in S Band and 50 Mbps in X band…



Before launch it was decided to connect the CCSDS engine and SEPP with a high speed LVDS line – but there was no time to implement a protocol on top

Spacewire Lite was fused into the CCSDS engine before launch

We reprogrammed the other side into the SEPP FPGA in orbit

After some problems, it worked! We increased the end-to-end data rate of the mission by a factor of six

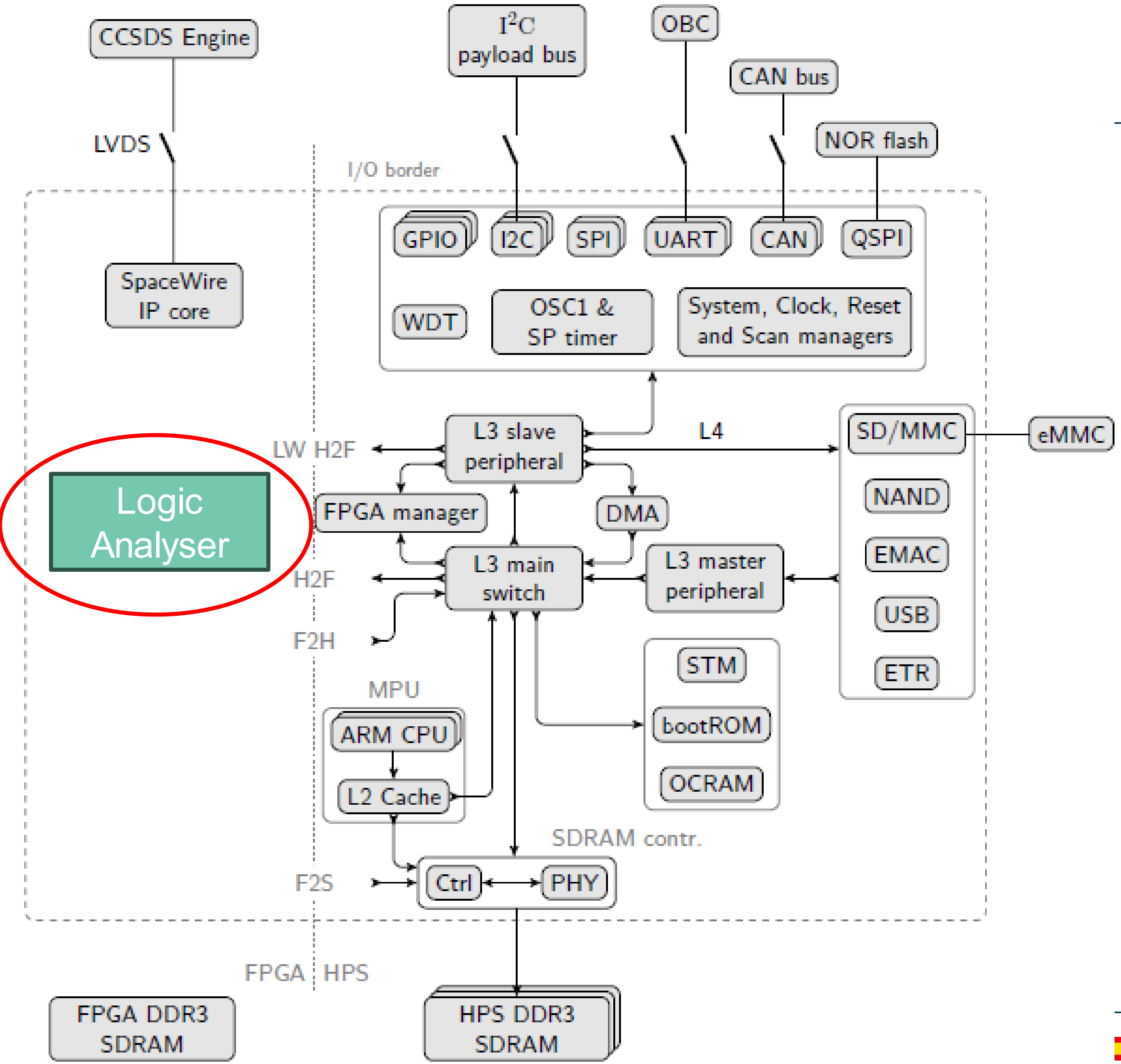
The impact of implementing the new bus in orbit

- With SpaceWire implemented, the bus transfer units became large enough that sending “IP packets inside the CCSDS space packets” made sense. So we implemented a thin IP layer on the link

- As the SEPP is running Linux, suddenly many native Linux services became available out of the box e.g. Rsync, SSH, remote kernel messages, demons, and everything in Busybox

- This allowed the mission control team to increase the productivity of the mission by an order of magnitude with very little effort. Functions that previously would have to written by us, tested and then loaded to the spacecraft became “one-liners”

- The experimenters also benefited from this “explosion” - allowing new types of concepts to be quickly and efficiently tried out in space



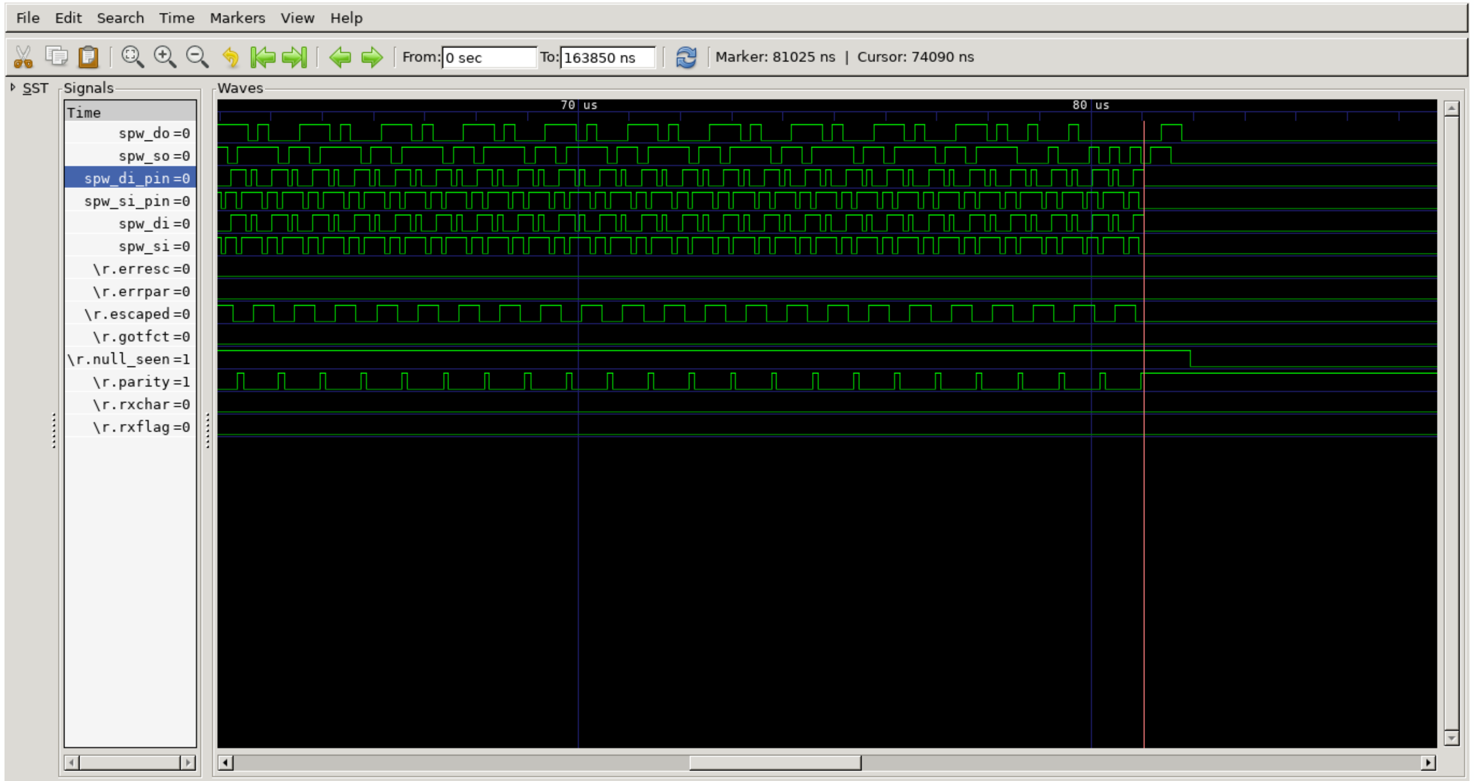
Sometimes the SpW interface did not work and we had to fall back to CAN (low telecommand and telemetry rates) and no TCP/IP available

For operations this is like returning to the dark ages

However the power of having a powerful Linux based system in combination with a reconfigurable FPGA came to our rescue again

A logic analyser was programmed into the FPGA to help diagnose the problem in space, as if we were on the ground

Enabling in-orbit troubleshooting



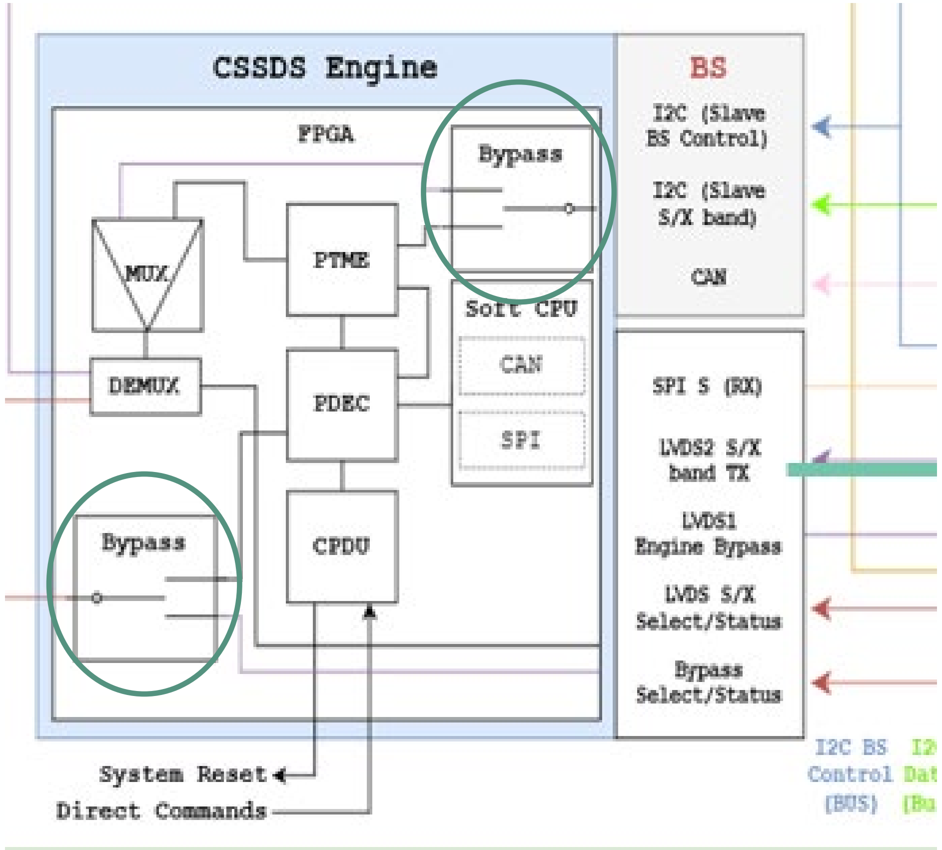
We have been able to perform tests on the link in-orbit that are unthinkable on a traditional space mission

- Recording the voltage level on the SEPP pins at nanosecond frequency
- Delaying the strobe and/or the data lines and sweeping +/- 300 nanoseconds to see what happens
- Inverting the lines
- Monitoring the statistics on the link up/down transitions, CRC errors, packets sent and received etc

The problem was identified as being on the CCSDS engine side (fused). However, we were able to adjust configuration to find a solution which is much more stable, if not solved

Completely bypassing the CCSDS engine

TX/RX



TX/RX

The Spacewire link still has a limitation of 10 Mbps. Can we remove it?

Yes, we can turn the engine into a simple router with no data processing. Effectively we connect the SEPP FPGA directly to the transponders of the spacecraft

The FPGA code to implement the entire TC decoder and TM encoder parts of the CCSDS engine entirely in the SEPP FPGA is under flight testing now

This will allow us to remove the speed constraints of the CCSDS engine, fully exploiting the full speed of the X band TX (i.e. 50 Mbps)

Using in-orbit AI operationally

(a) Earth

(b) Edge

(c) Bad

(a) Land

(b) Coast

(c) Sea

Georges Labrèche and SMART CAM

Pushing the Software Defined Radio limits

Feature Article:

DOI. No. 10.1109/MAES.2022.3143875

Implementation of a GNU Radio-Based Search and Rescue Receiver on ESA's OPS-SAT Space Lab

Tom Mladenov, David Evans, **European Space Operations Centre (ESOC), 64293 Darmstadt, Germany**
Vladimir Zelenevskiy, **Telespazio Germany GmbH, 64293 Darmstadt, Germany**

Then an experimenter found it worked at GPS L1….
Then another reconfigured the interface in the FPGA to produce a streaming interface…

Enabling in-orbit Cyber Security Demonstrations

Introducing new areas to the potential of space

ENABLING & SUPPORT

A successful first stock trade in space, celebrated by ESA's Rolf Densing and CEO of flatexDEGIRO, Frank Niehage

30/09/2021 457 VIEWS 2 LIKES 459452 ID

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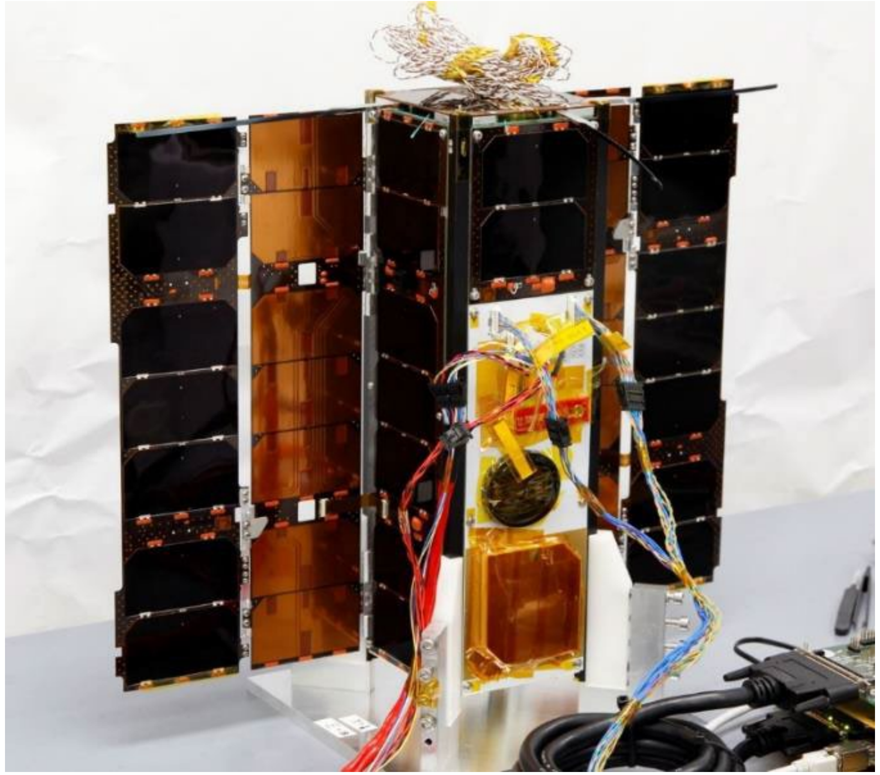
International Recognition

Becoming a start-up "factory"

Name	Function	Present Position
Alexander Lange	OPS-SAT YGT July 15 – July 16	Co-Founder and Head of Software Engineering Xelera Technologies, Germany
Claudiu Cherciu	OPS-SAT YGT Sep 16 – Aug 18	Employee Number One Romanian InSpace Engineering (RISE), Romania
Benjamin Fischer	OPS-SAT YGT Sept 18 – Aug 18	CEO and Co-Founder at Arctic Space Technologies, Sweden
Felix Hessinger	OPS-SAT Intern Jan 19 - Aug 19	CTO and Co-Founder at Arctic Space Technologies, Sweden
Georges LaBreche	OPS-SAT Intern Sept 20 – Jan 21	CEO and Founder at Tanagra Space, Estonia
In addition to the many experimenters that have founded successful companies….		

Becoming a Space Lab

- 100+ companies from 20 countries have registered 276 experiments
- JPL, JAXA, CNES, DLR, EU commission now on-board
- Many start-ups, research institutes and New Space
- ESA Academy, Fly your satellite, ESA HR, University courses..



GPS jamming experiments with Austrian Air Traffic Control, Army

1st ever Search and Rescue messages decoded in space for the first time

1st ever successful in-flight reprogramming of a Neural Network

D3TN ring road (interplanetary internet) successfully tested for 1st time

1st ever successful stock market trade in space with FlatexDEGIRO and Tradegate

On-board AI in daily use to classify camera pictures (SMART CAM)

Direct commanding of satellite over the internet by experimenters now routine

TCP/IP direct connection to satellite, allowing standard IT tool use e.g. SSH, Rsync..

Space Wire successfully implemented in-orbit increasing data downloads by 10

1st ever in-flight control of a satellite using EGS-CC

1st ever offensive Cyber Security demo on a live operational spacecraft (Thales)

Fastest turnaround from experimenter registration to results from space is 72 hours

Contents

But what is OPS-SAT Space Lab?

A service enabling in-orbit experimentation open to European/Canadian industry, research institutes, academia and international space agencies.

Principle	How?
Independent	ESA can as laboratory provider can assure confidentiality and exclude breaching of industry IPRs
Safe	Special design of space and ground assets, ESA expertise available in the design and testing phases
Fast	ESA handles the risk and execution, allows experimenters to concentrate on rapid value creation, fail fast to succeed quickly approach
Open	Experiments are not predefined, the ground and space assets carry powerful reconfigurable hardware and software, an unprecedented level of access is granted to the experimenters
No charge for users	No contracts, simple processes, best effort service

Presently this is not domain restricted (e.g. EO, telecoms, security etc) and it is not in-orbit demonstration

How is OPS-SAT Space Lab structured?

OPS-SAT Space Lab Experiment Service	OPS-SAT Space Segment Procurement	OPS-SAT Ground Segment Procurement
On-boarding	Liaise with delegates/programmes	IT equipment, ground stations, network provided by SMILE
Consultancy	Project Management	Application-level ground software
Test	Launch procurement	
Execution	OBSW maintenance	
Experiment infrastructure (ground and on-board) development and maintenance		

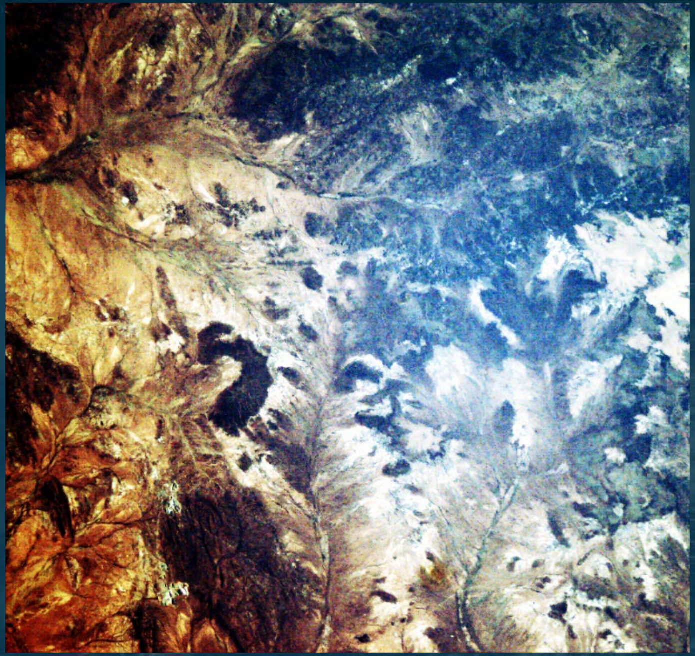
Future OS Space Lab missions

Space Element	Programme	Theme	Lifetime	Notes
OS-1	GSTP	PROTOCOLS	2019-2024	Deorbits in 2024
OS VOLT	SCYLIGHT	OPTICAL/QUANTUM	2025-2028	50% use agreed
OS POLSKA	GSTP	FORMATION FLYING	2027-2030	KO in this CMIN cycle
OS “EST/H”	SCYLIGHT	OPTICAL	2025-2027	Initial proposal imminent
CyberCube	ESO	CYBER	2025-2027	Handover to OS after 6 mths

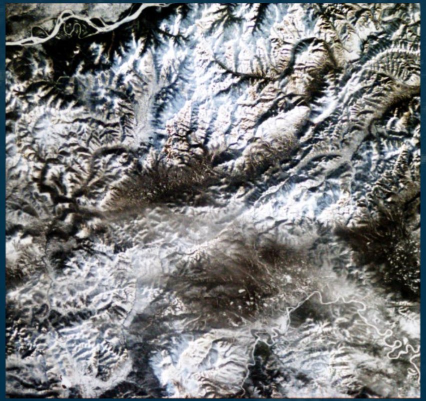
Present OPS-SAT Mission Control Team

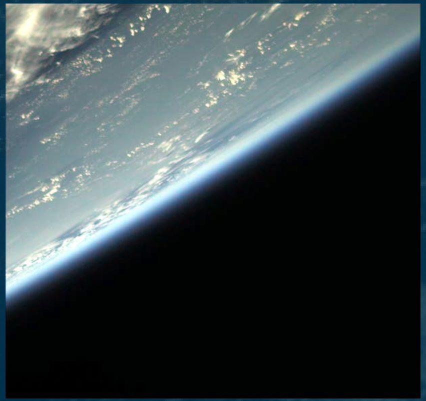
Present OPS-SAT MCT

Vladimir Zelenevskiy
Tim Oerther
Rodrigo Laurinovics
Marcin Kovalevskij
Marcin Jasiukowicz
Dominik Marsk
Maximilian Henkel
Georges Labrèche
David Evans



Thank you!





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