



Formation Flying using 2U-CubeSats within the NanoFF-mission

The Brijuni Conference, 29.08.22

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Adirim & The NanoFF Team**

Mission

Formation Flight Mission of two 2U-CubeSats

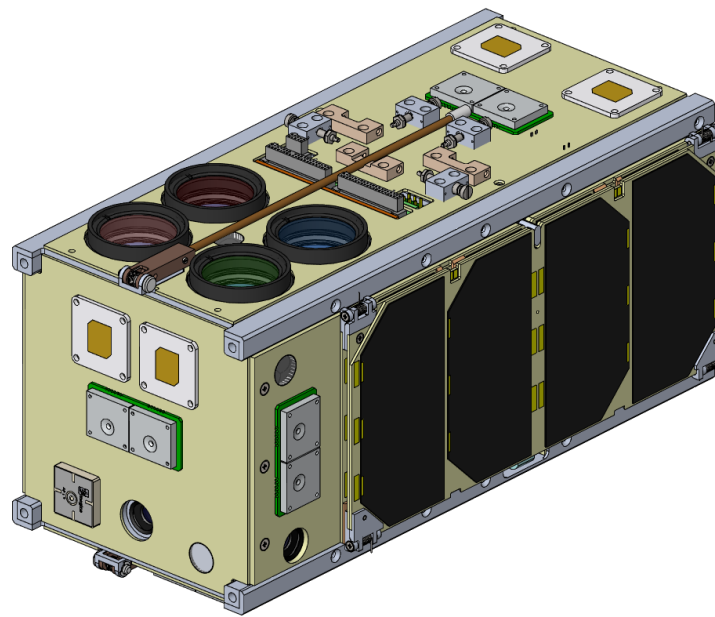
- Ground controlled Helix formation
- Autonomously controlled Helix, In-Track, Along-Track and PCO
- 50m closest approach

Technology Demonstration

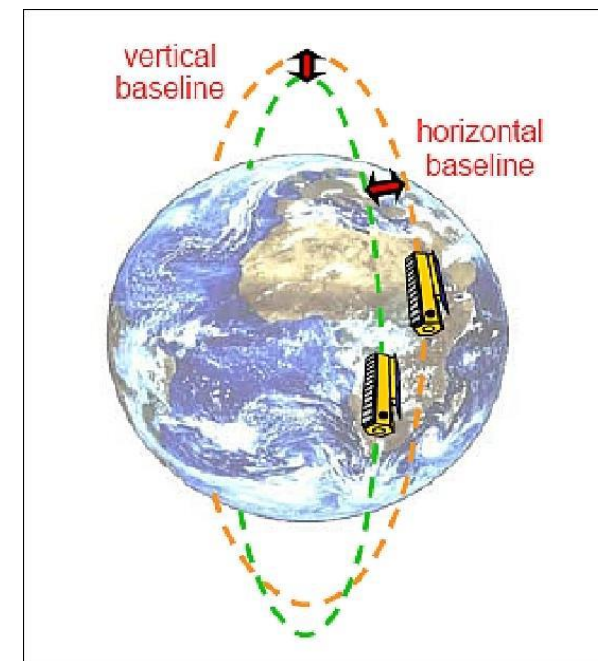
- Deployable solar panels
- Star Tracker
- S-Band Up/Downlink

Payload

- Camera system with four spectral channels



NanoFF CAD model

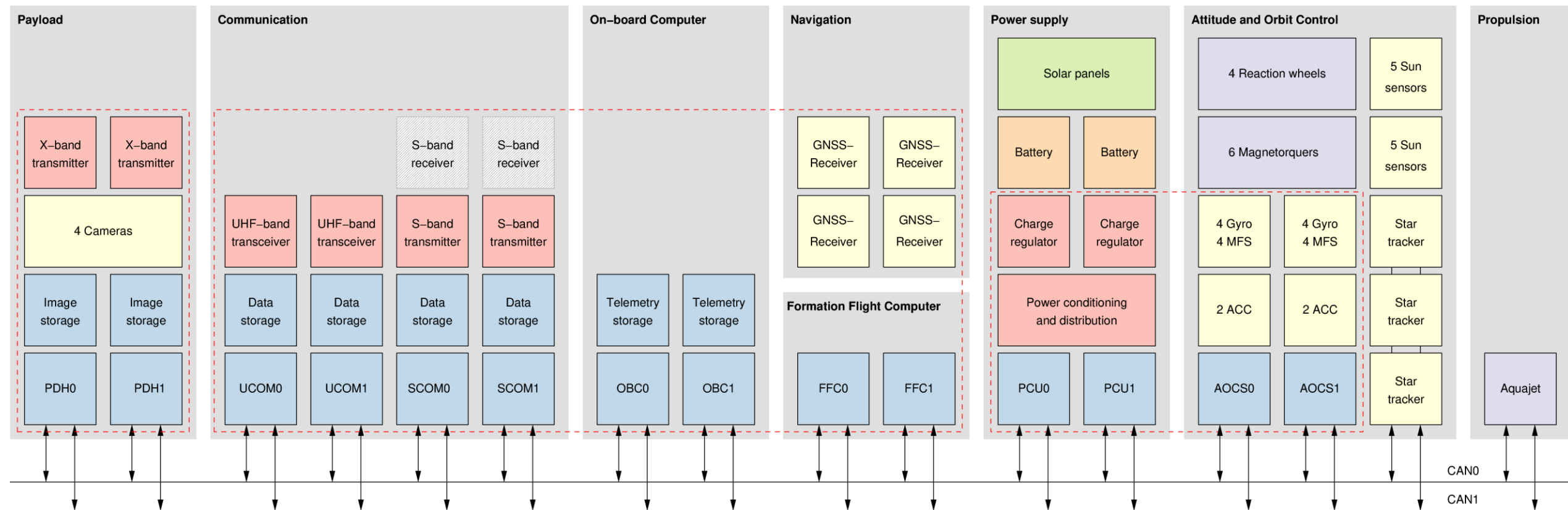


Helix Orbit [DLR]

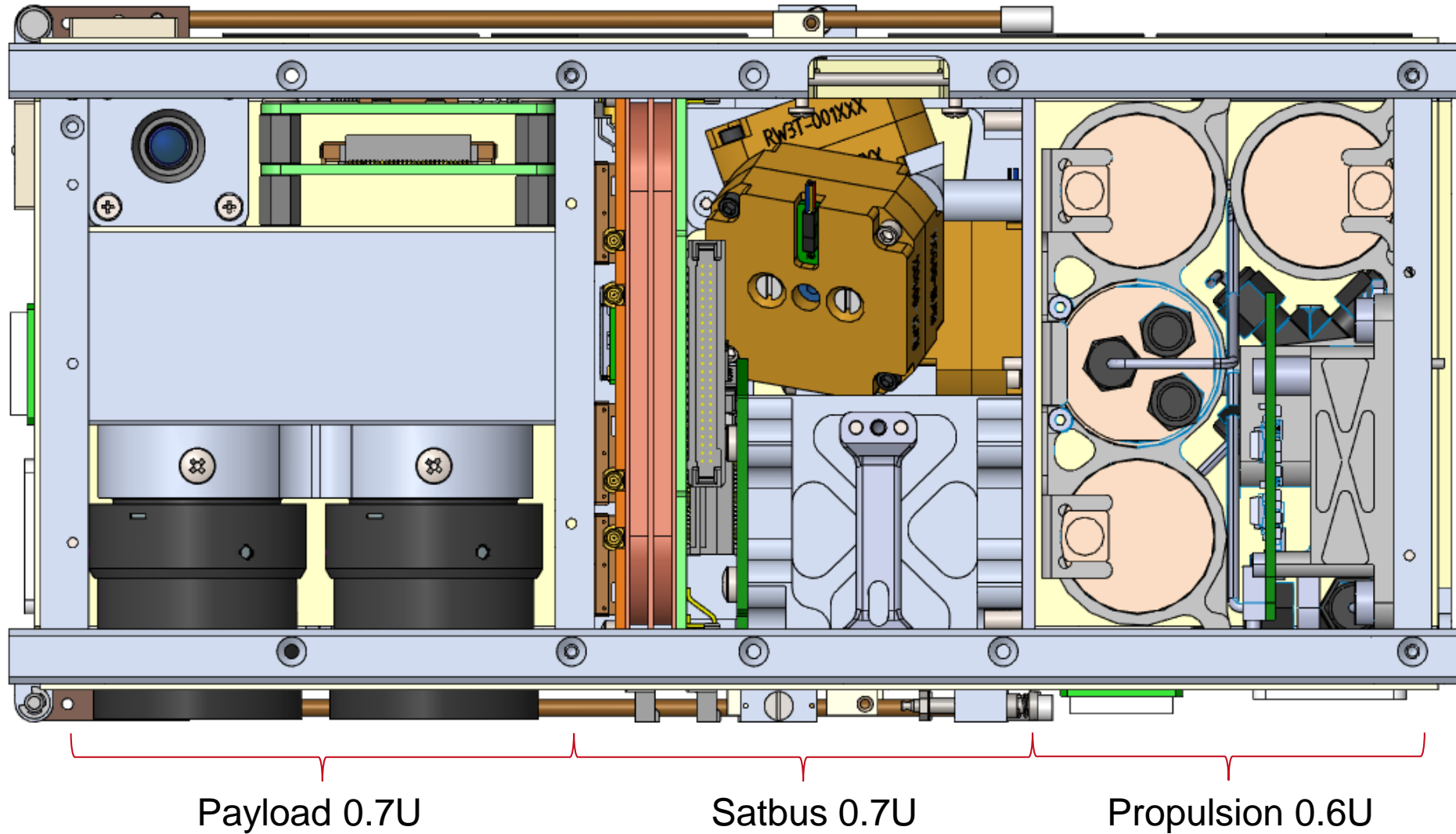
The NanoFF Team

Team Member	Responsibilities
Dr. -Ing. Sascha Weiß	Project Leader
M.Sc. Sascha Kapitola	Software, Camera System
Dipl. -Ing. Frank Baumann	Hardware, Electronics, Communication System
Dr. -Ing. Nikolas Korn	Hardware, Camera System, Star Tracker System
M.Sc. Felix Kübler	Software, Communication System
Phd Yeerang Lim	Autonomous Formation Flight
M.Sc Jose Diez	Software, Hardware, Electronics
M.Sc Debdeep Roychowdhury	Separation Strategy, Recovery Operations, Navigation, AOCS
B.Sc. Fynn Boyer	Software, AOCS
B.Sc. Julian Lindemeier	Software
B.Sc. Yagmur Denizler	Reaction Wheel System
PhD Ben Palmer	Software
Alan Lagenza	Software
B.Sc. Äantas Kesten	Software

System Overview

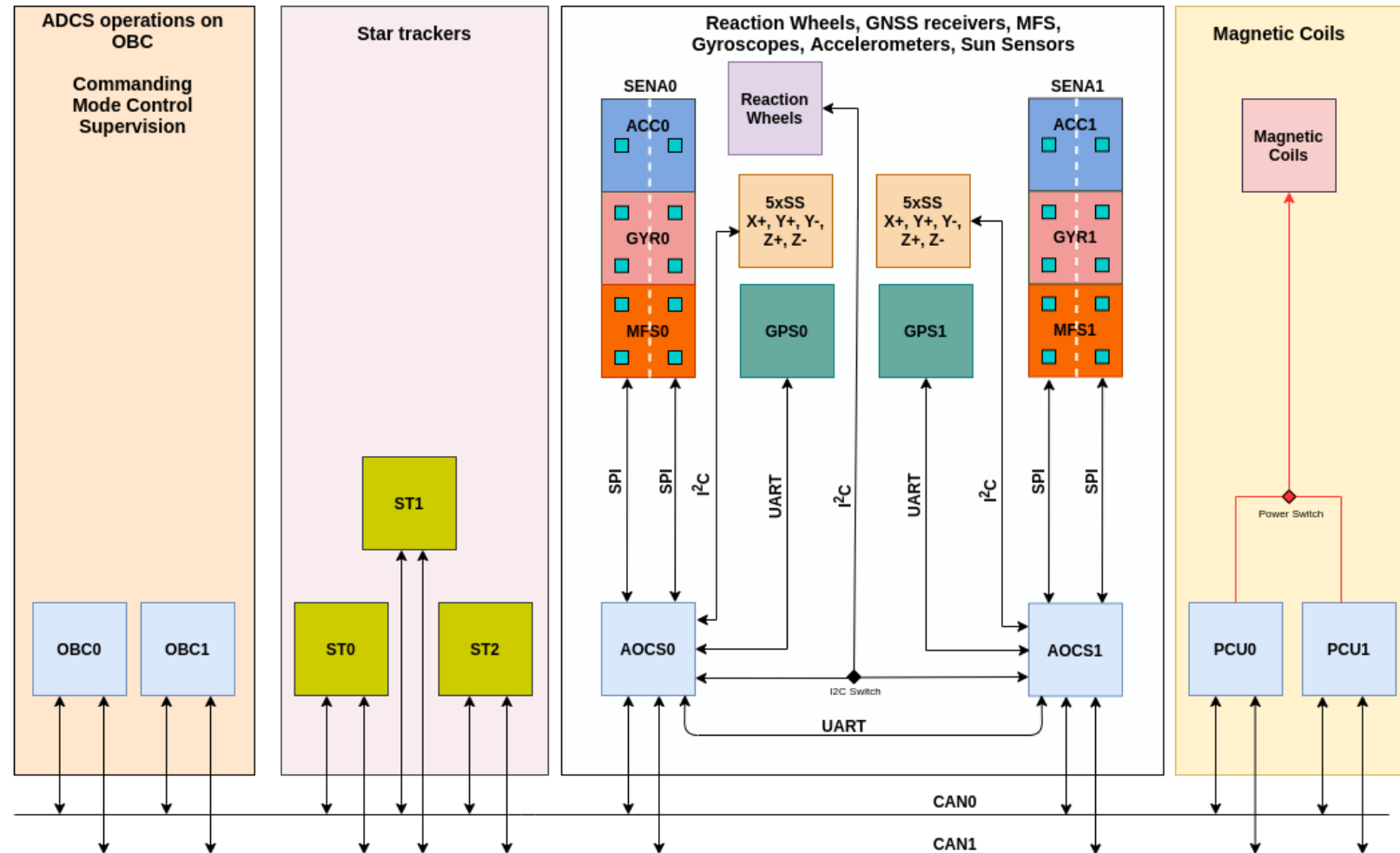


Component Segmentation



Attitude and Orbit Control System Overview

- 2 x 4 Gyroscopes
- 2 x 4 Magnetometers
- 2 x 2 Accelerometers
- 2 x 5 Sun Sensors
(Side Panels)
- 4 Reaction wheels
- 3 Star Trackers



Propulsion System Aquajet



Dimensions	94x94x59mm ³ (without connectors and cables)
Mass	ca. 580g (incl. electronics, without connectors and cables)
Propellant mass	ca. 80g
Working fluid	Water and antifreeze
Pressure (MEOP)	ca. 5.8 bar
Vcc (nominal)	12V / 5V / 3.3V
Electric power	Max. 7W
Isp	up to 700m/s
Thrust	up to 4mN (average 1mN)
Delta v	~ 15m/s

NanoFF EQM, FM1, FM2, FSM [Aerospace Innovation GmbH]

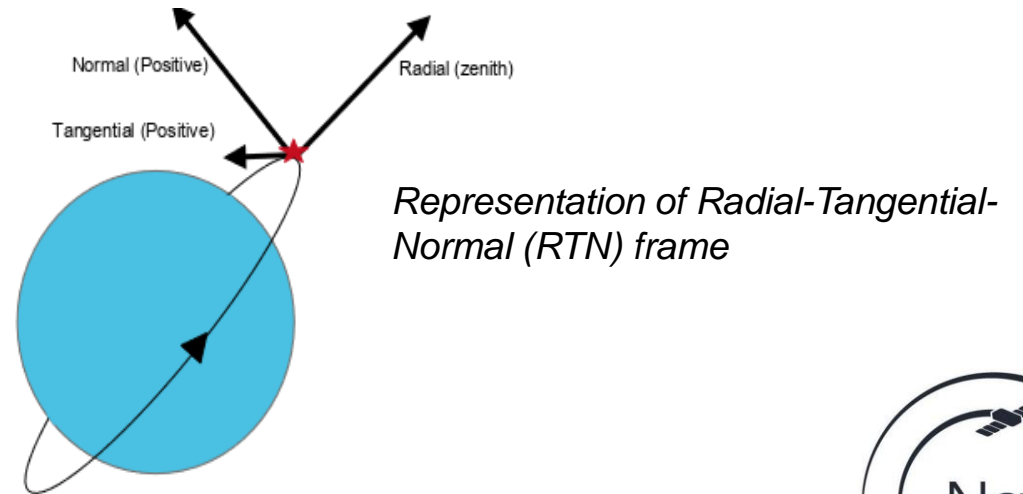


Formation Flight in NanoFF

- Use of Relative Orbital Elements

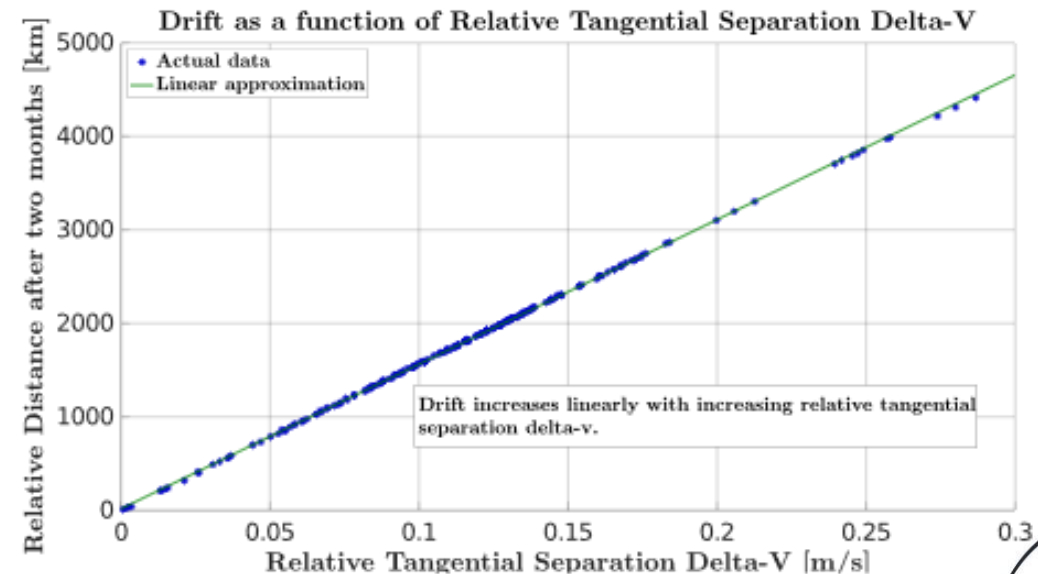
$$\delta\alpha = \begin{bmatrix} \delta a \\ \delta\lambda \\ \delta e_x \\ \delta e_y \\ \delta i_x \\ \delta i_y \end{bmatrix} = \begin{bmatrix} (a_2 - a_1)/a_1 \\ u_2 - u_1 + (\Omega_2 - \Omega_1) \cos i_1 \\ e_2 \cos w_2 - e_1 \cos w_1 \\ e_2 \sin w_2 - e_1 \sin w_1 \\ i_2 - i_1 \\ (\Omega_2 - \Omega_1)/\sin i_1 \end{bmatrix}$$

- For collision safety, $\delta e \uparrow \uparrow \delta i$ or $\delta e \uparrow \downarrow \delta i$
- Chaser satellite (the one with active control) is considered as the reference satellite.
- Based on the work and experience gained in DLR's AVANTI mission.

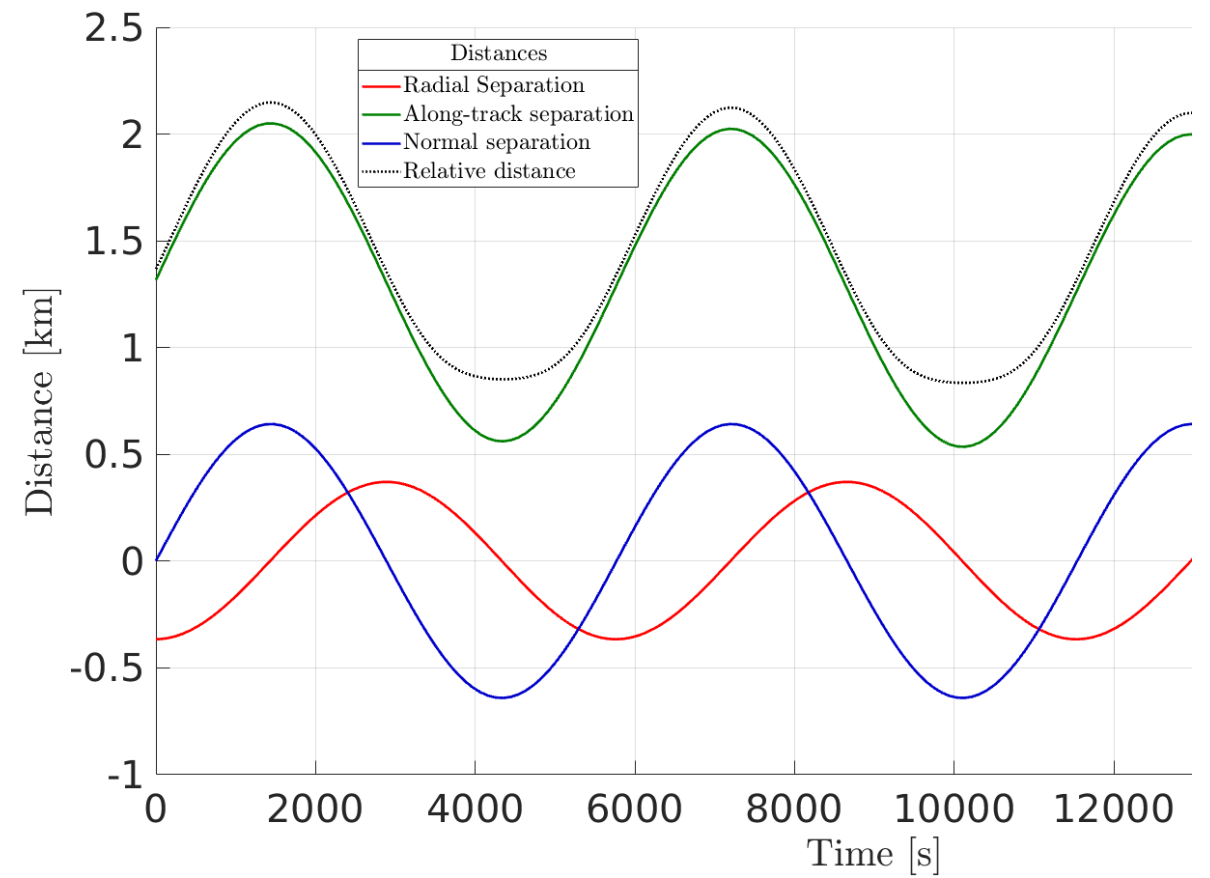
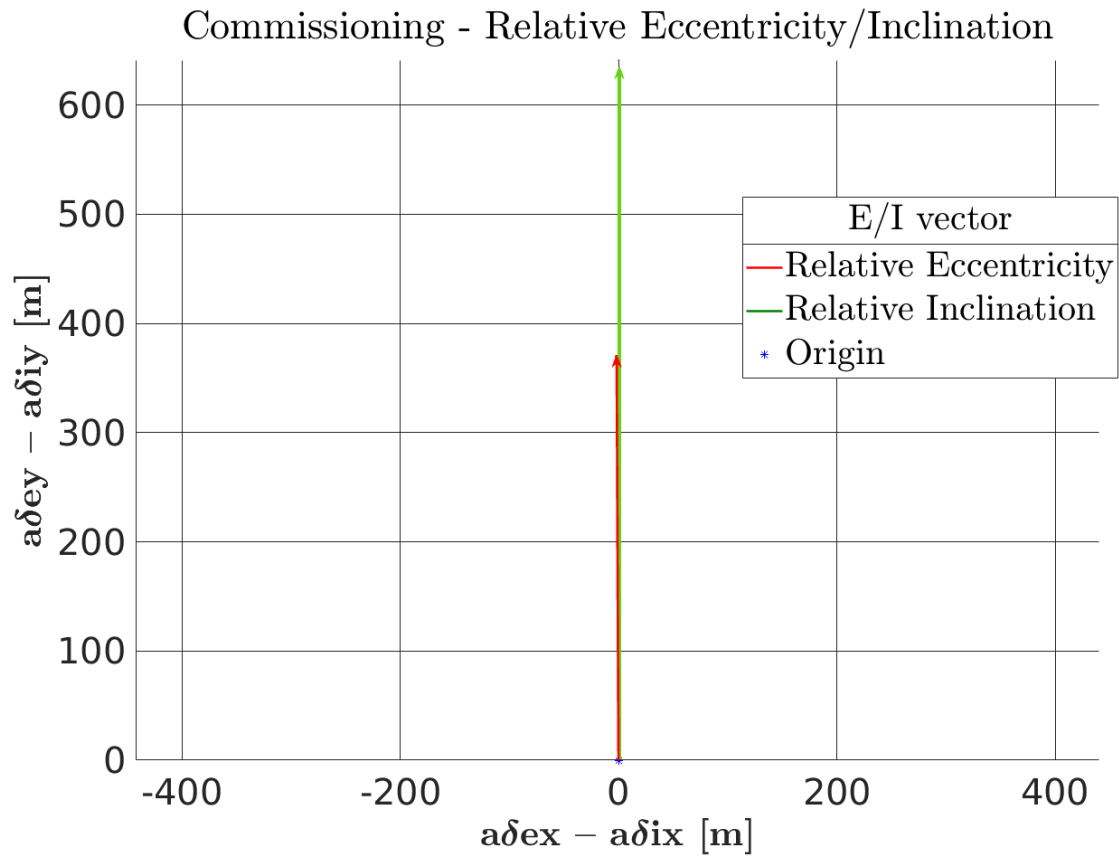


Separation Strategy

- Launch from D-Orbit's ION
- Minimise collision risk (collision = relative distance < 0.5 m)
- Prevent formation evaporation (< 2000 km)
- Limit recovery operation duration (< 2 months)
- Limit delta-v usage for recovery operations (3 m/s)
- Two approaches:
 - Using conventional approach: Launching the two satellites in the same direction at a random location in orbit with an interval of 10 to 20 seconds (as done in the SNET mission).
 - **Using $\delta e/\delta i$ vector configuration (adapted from the AVANTI mission)**

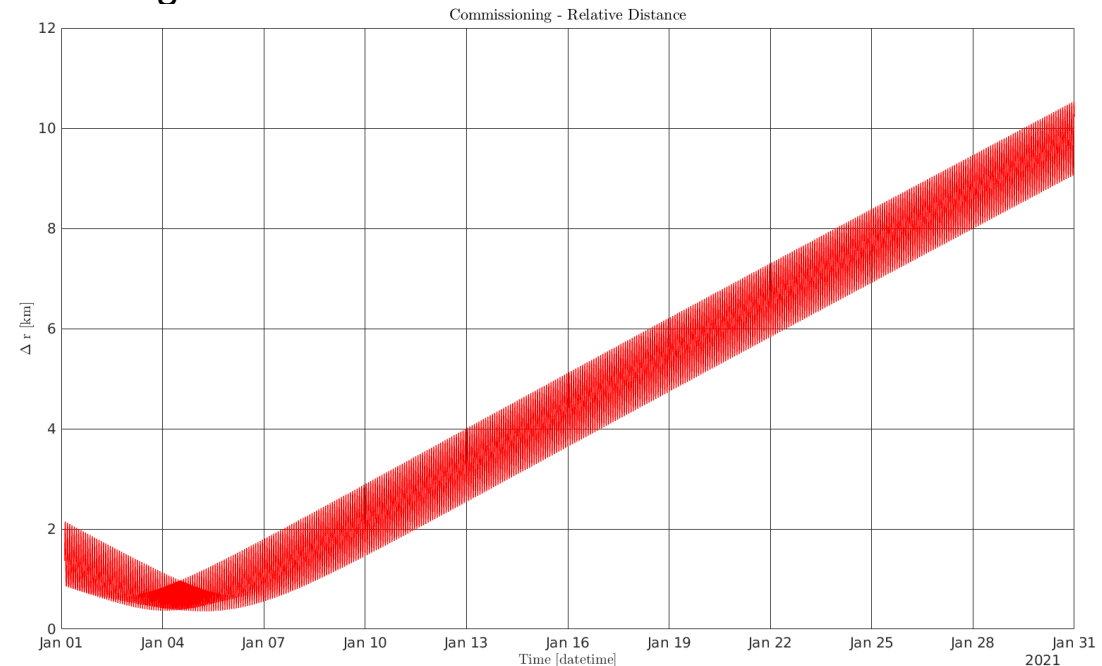
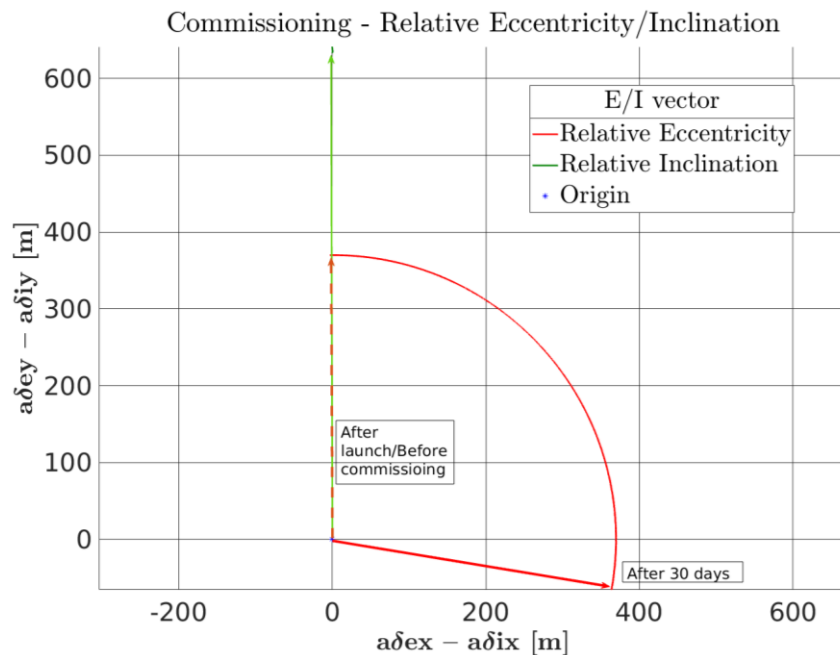


Post Deployment Relative Orbital State



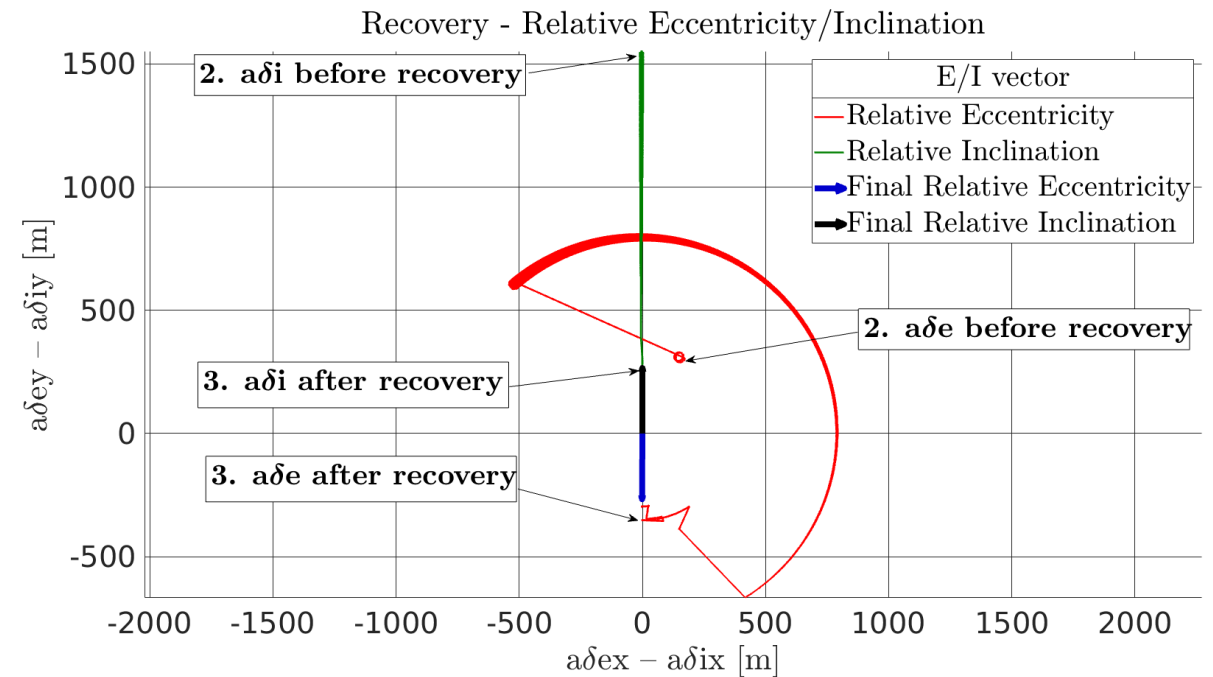
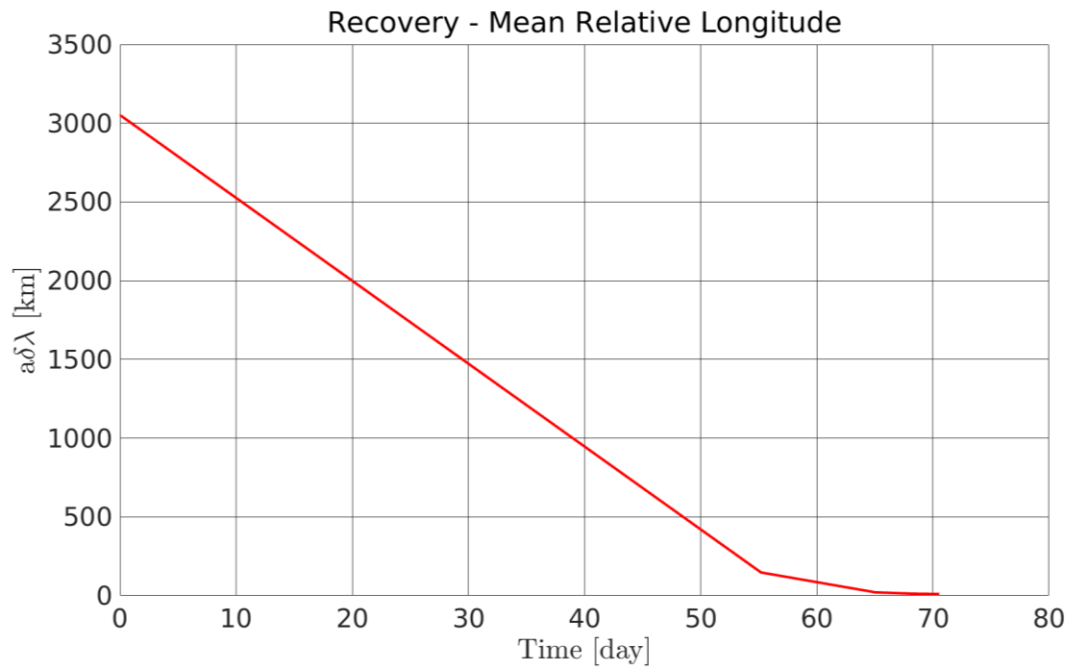
Deployment Sequence

1. Near North/South pole: NanoFF 1 = [-0.35; 0.1; 0.35;]; m/s delta-v (0.5 m/s absolute) in ION's RTN frame.
2. Wait for 0.5, 1.5, 2.5,....orbital periods of ION.
3. Near South/North pole: NanoFF 2 = [0.35; 0.1; 0.35;]; m/s delta- v (0.5 m/s absolute) in ION's RTN frame.
4. Recovery operations will start after successful commissioning.

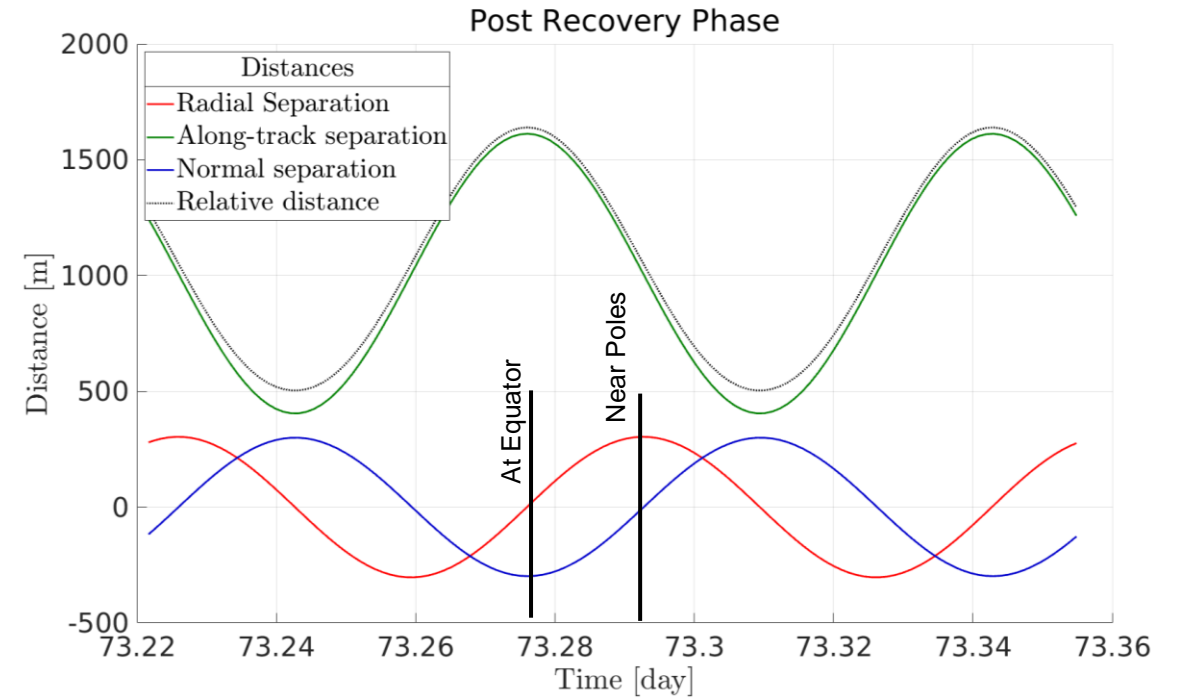
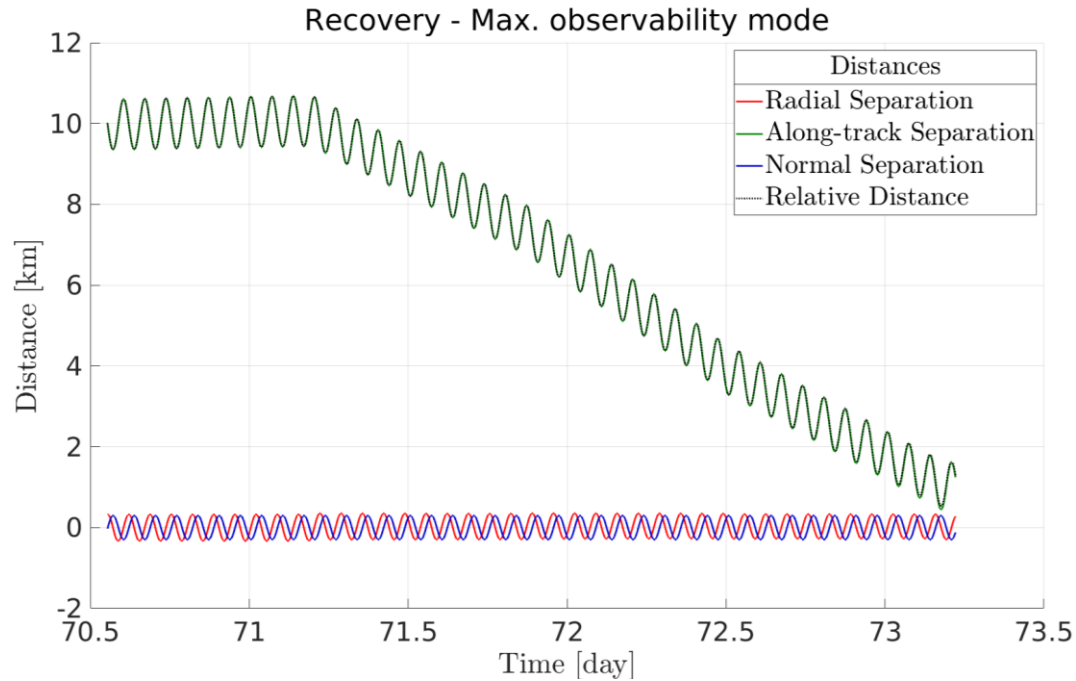


Recovery Operations

1. Formation control using the 4 Impulse maneuver group – 3 Tangential burns, 1 Normal burn
2. Example: Delta-V consumption 1.03 m/s in 1100 orbits



Recovery Operations: Passively Safe Helix Orbit



ROEs	$a_r \delta a$ [m]	$a_r \delta \lambda$ [m]	$a_r \delta e_x$ [m]	$a_r \delta e_y$ [m]	$a_r \delta i_x$ [m]	$a_r \delta i_y$ [m]
ROEs after commissioning	-350.4275	3046157.8753	137.6294	312.6268	-10.3324	1471.1643
Desired ROEs after recovery	0	1000	0	-300	0	300

Relative Navigation using GNSS Raw measurements

Objective: On-board relative position accuracy of less than 1 meter.

- Currently in on-board software implementation stage for two GNSS receivers: Ublox Neo M8T and SkyTraq Orion B16-C1.
- Estimate the relative position, estimate the relative velocity, propagate them during error scenarios.
- Planned order of experiments: GPS only, GPS + Galileo, GPS + Beidou, etc.

Challenges:

- UHF based Intersatellite Link (ISL) has limited bandwidth.
- The Chaser satellite has to deal with infrequent and old ISL data
- Limited on-board processing power

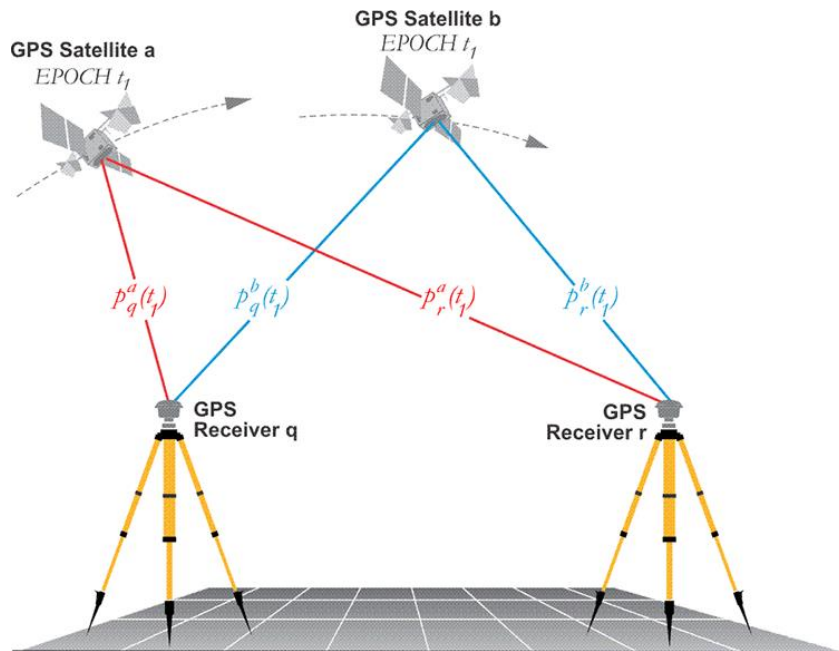


[u-Blox]



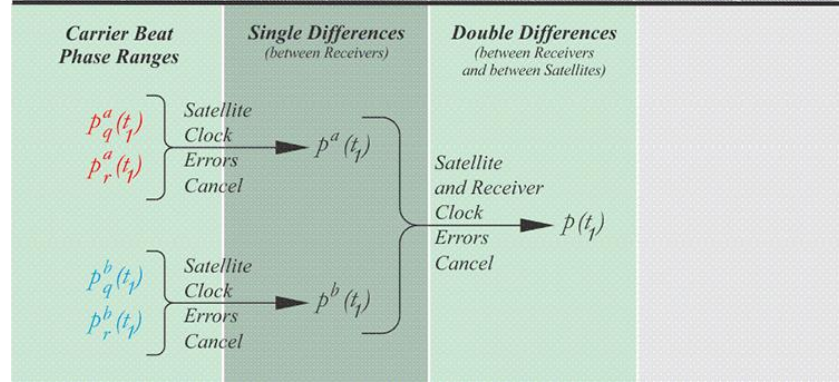
[Skytraq]

Double Differencing of Raw Measurements



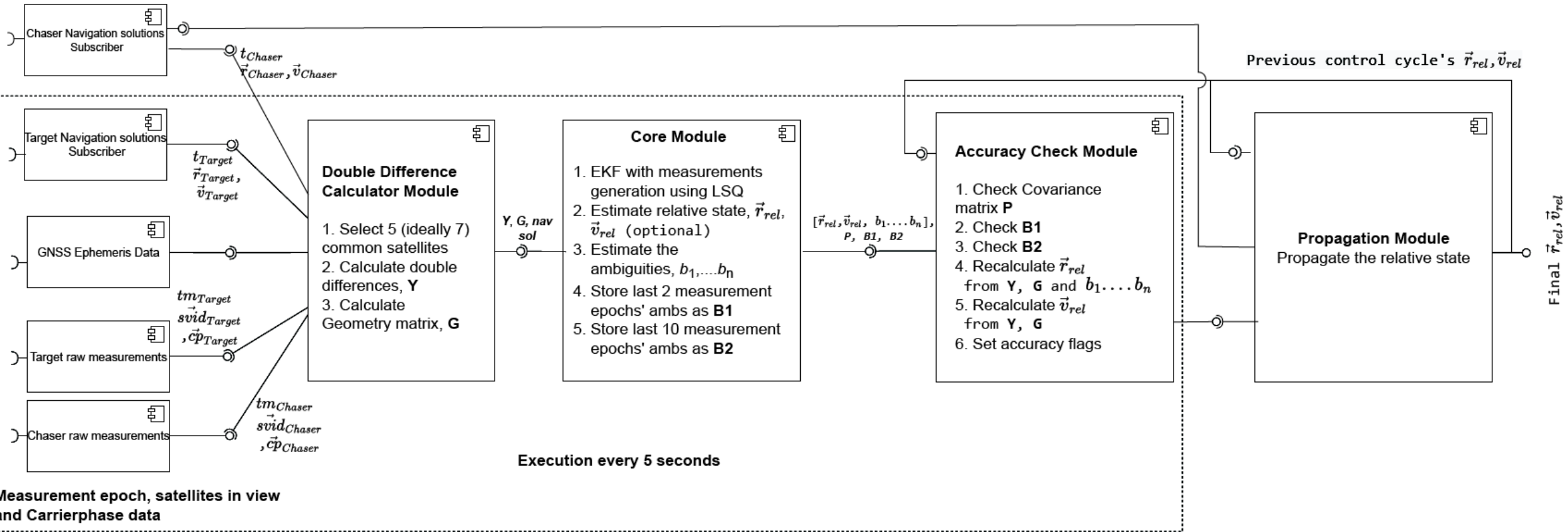
Error source	Single-Difference	Double-Difference
Ionosphere	Reduced, depending on the baseline length	Reduced, depending on the baseline length
Troposphere	Reduced, depending on the baseline length	Reduced, depending on the baseline length
Satellite clock	Eliminated	Eliminated
Receiver clock	Present	Eliminated
Broadcast ephemeris	Reduced, depending on the baseline length	Reduced, depending on the baseline length
Ambiguity term	Present	Present
Noise level with respect to one-way measurement	Increased by $\sqrt{2}$	Increased by 2

[D. Gebre-Egziabher and S. Gleason, GNSS applications and methods. Artech House, 2009]



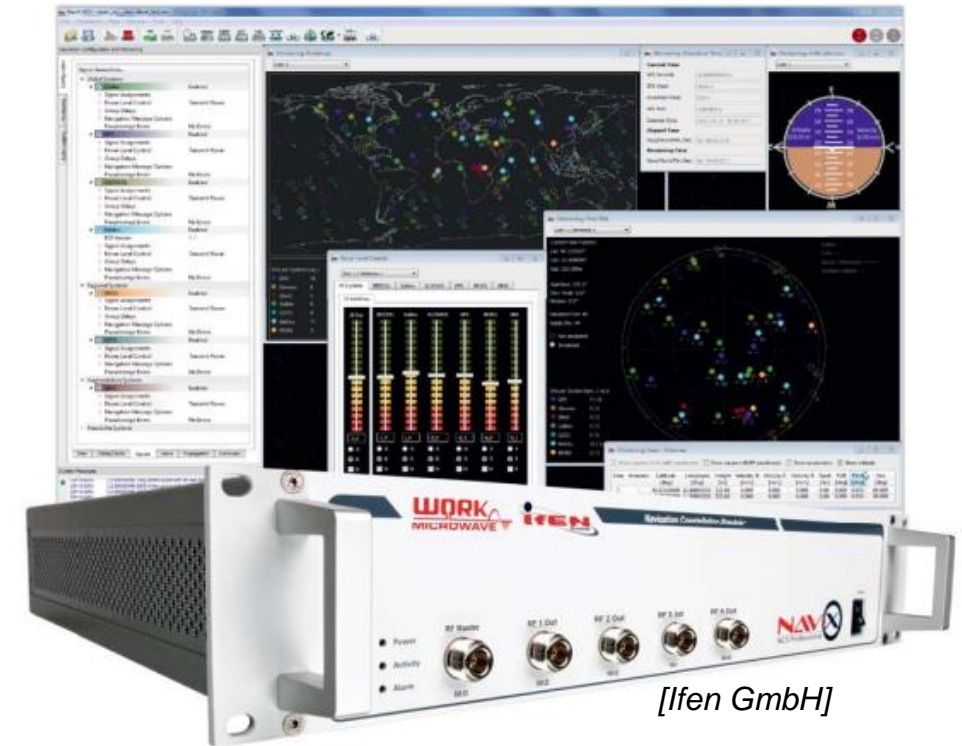
[J. Van Sickle, GPS for land surveyors. CRC press, 2008]

Relative Navigation using GNSS Raw measurements

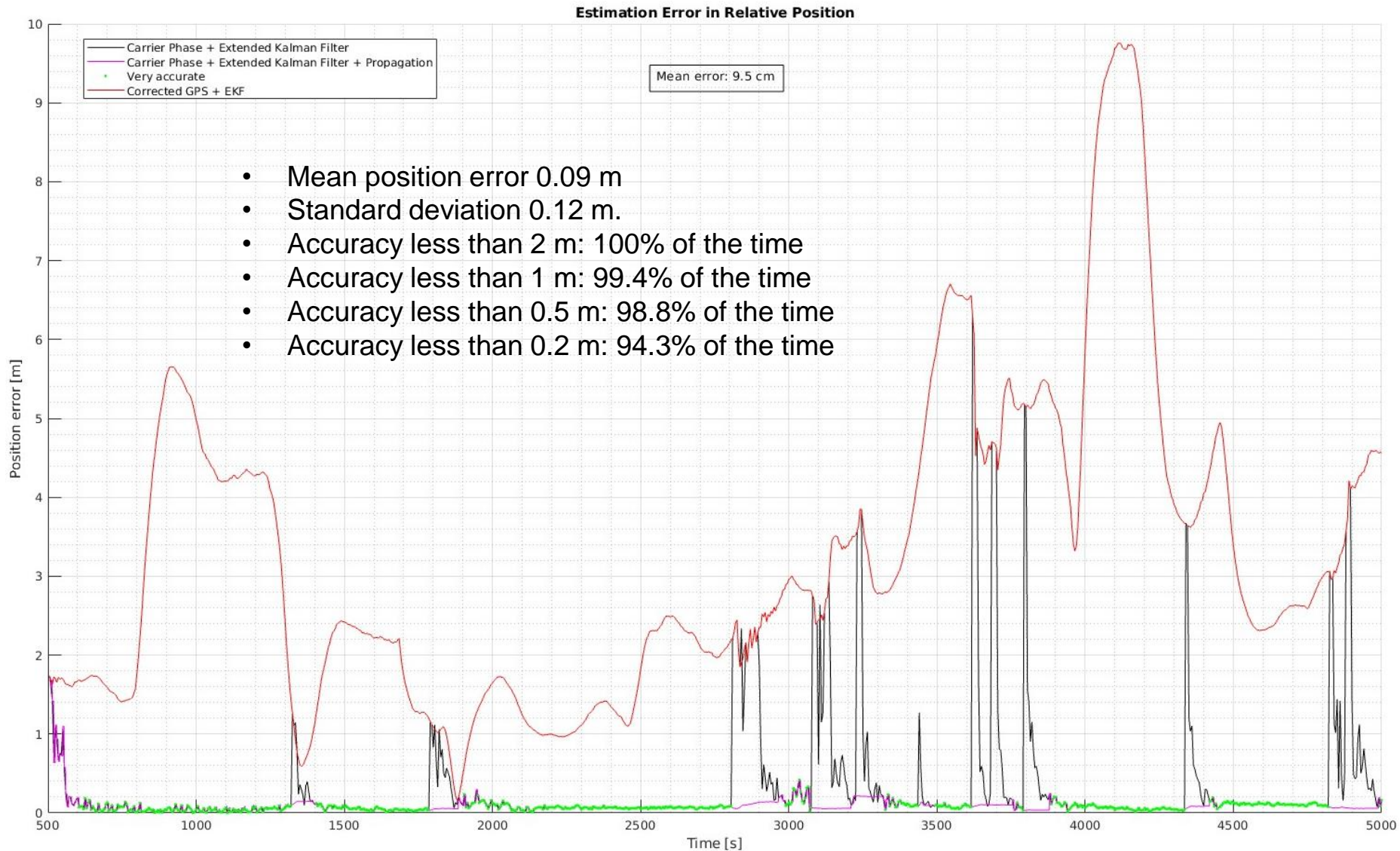


Precise Relative Navigation Test Setup and Results

- NavX-NCS GPS Simulator at L1 frequency → Ublox Neo M8T and Skytraq Orion B16-C1
- Sun synchronous orbit at 550 km with ROEs:
- Desired ROEs: $a_1 \delta a = 0 \text{ m}$, $a_1 \delta \lambda = 0 \text{ m}$, $a_1 \delta e_x = 0 \text{ m}$, $a_1 \delta e_y = -300 \text{ m}$, $a_1 \delta i_x = 0 \text{ m}$, $a_1 \delta i_y = 300 \text{ m}$
- Results
 - Mean position estimation error: 10 – 20 cm
 - Accuracy less than 1 m: 95% of the time

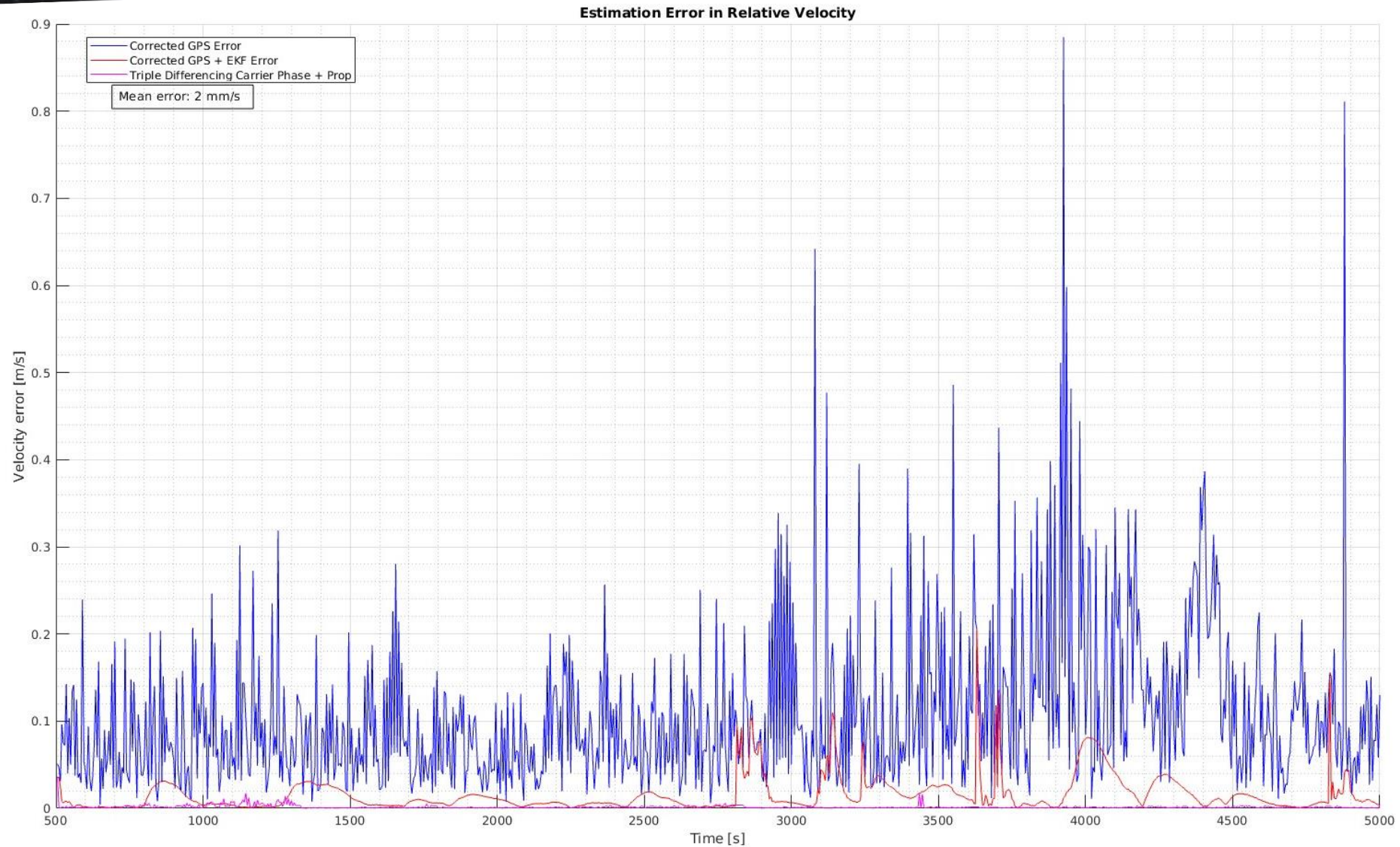


Relative Position Results

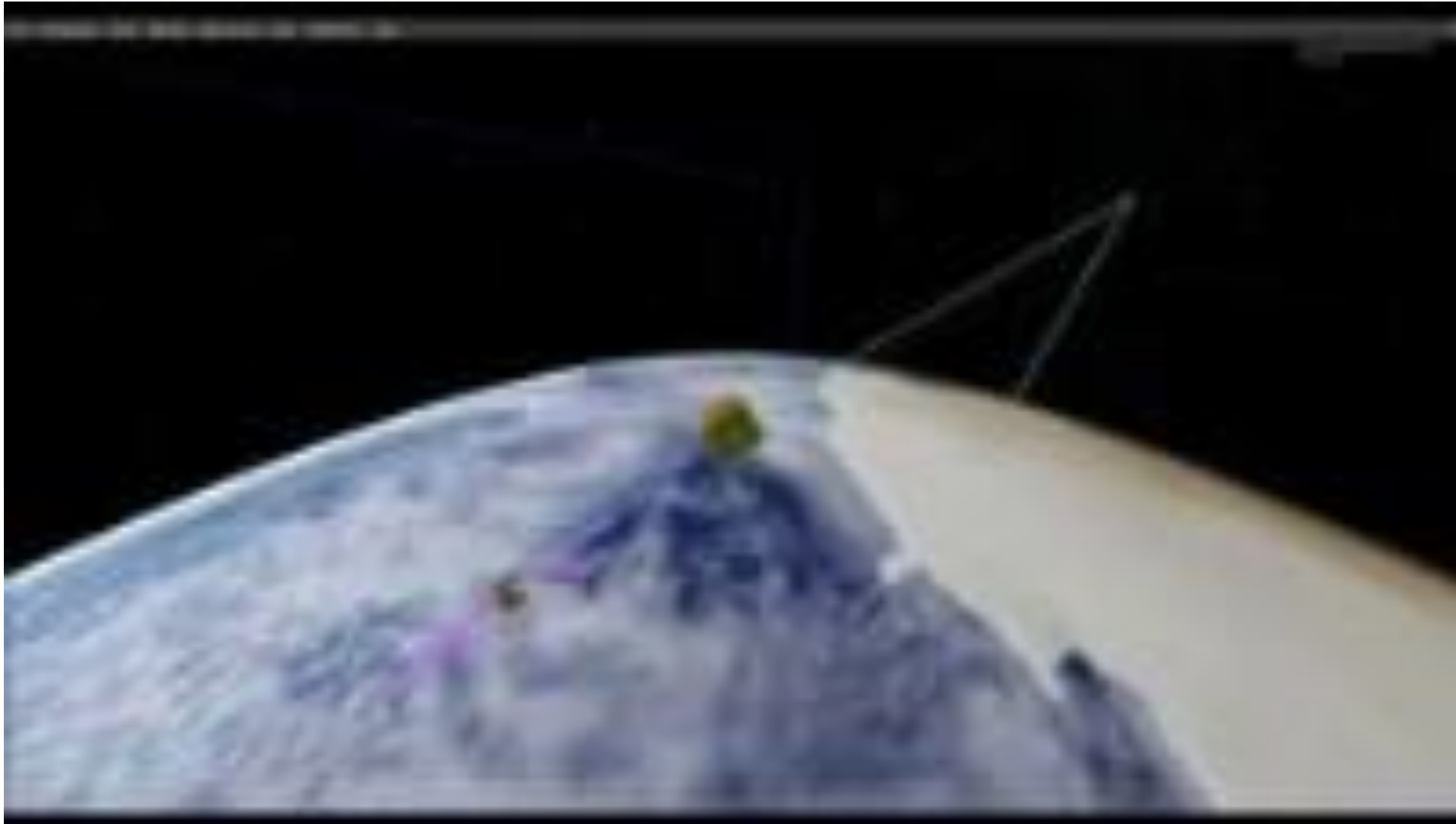


- Mean position error 0.09 m
- Standard deviation 0.12 m.
- Accuracy less than 2 m: 100% of the time
- Accuracy less than 1 m: 99.4% of the time
- Accuracy less than 0.5 m: 98.8% of the time
- Accuracy less than 0.2 m: 94.3% of the time

Relative Velocity Results

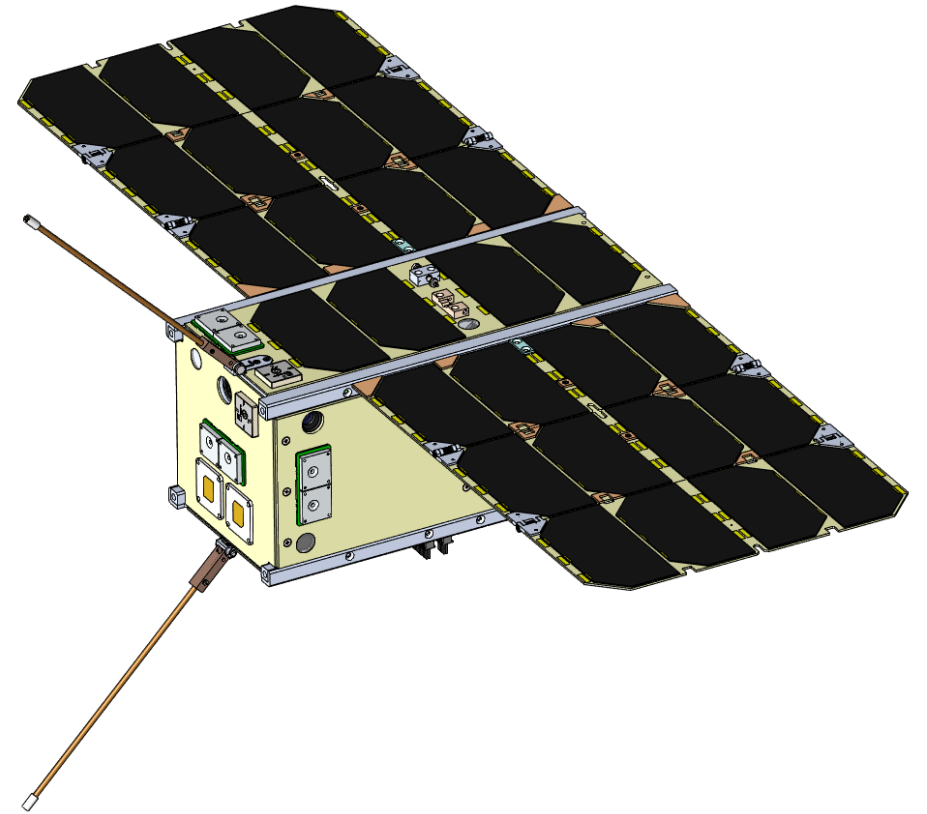


Planned NanoFF Helix Formation



Conclusion

- Fully redundant, highly miniaturized satellite bus
- Usable for 2U/3U-CubeSats
- Suited for formation flight missions
- Development of several technologies
 - S-Band Transmitter
 - Deployable Solar panels
 - Star Tracker
 - Camera System
- NanoFF Launch in Q2 2023
- NanoOOV (Nanosatellites for On-Orbit Verification)
 - Multi-band GNSS receivers for high-accuracy navigation
 - RADAR sensors for proximity operations
 - Deorbiting module
 - Fluid Dynamic actuator for attitude control
 - Visual relative navigation operations



Thank You!



Gefördert durch:



Bundesministerium
für Wirtschaft
und Technologie

aufgrund eines Beschlusses
des Deutschen Bundestages

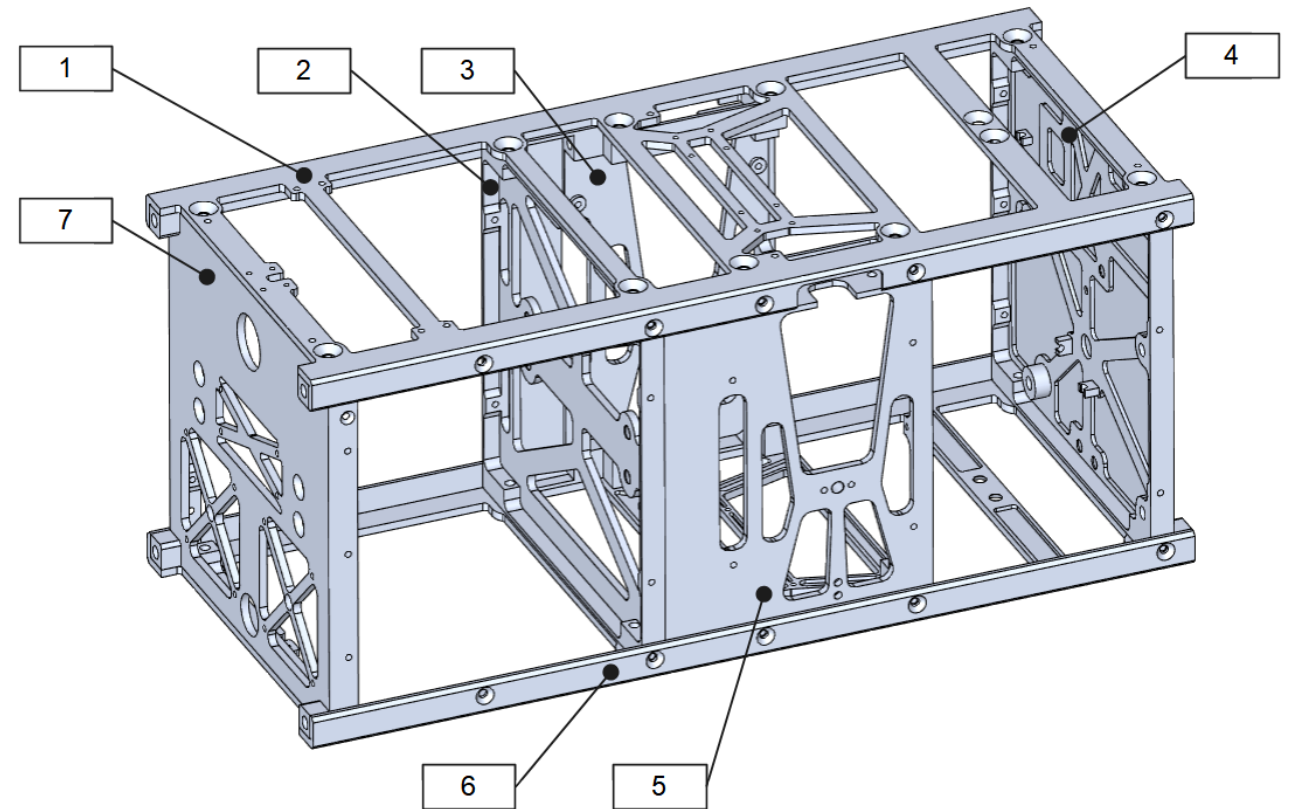


Deutsches Zentrum
DLR für Luft- und Raumfahrt e.V.

DLR Grant number NanoFF: 50 RU 1803

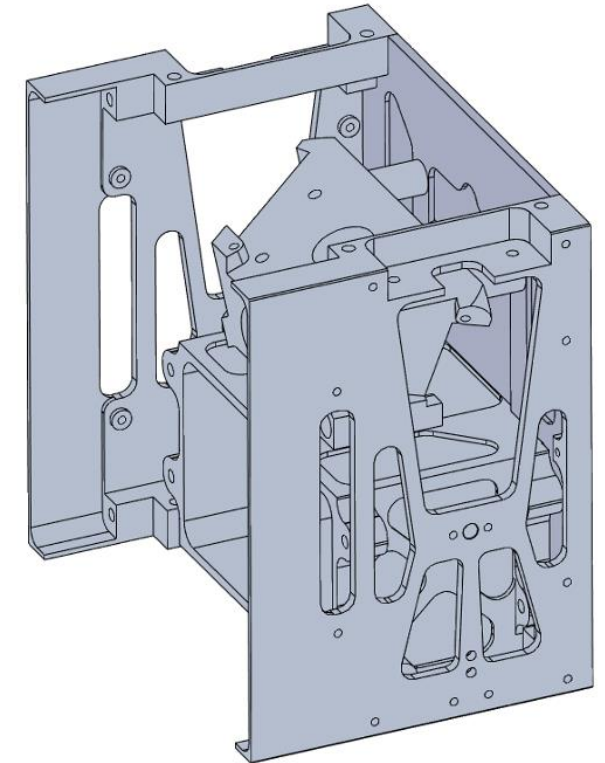
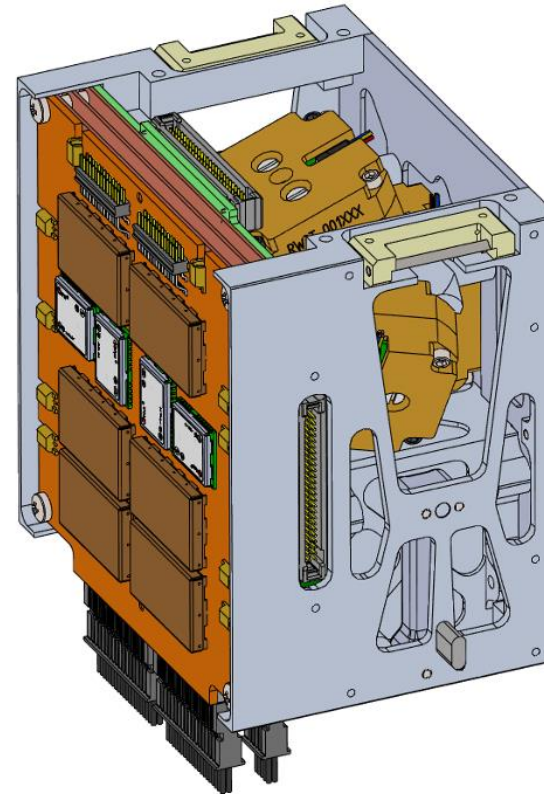
Primary structural parts

- There are seven primary structural parts
 - Two connecting structure including the rails in +Z and -Z (1 and 6)
 - The top and bottom plates (4 and 7)
 - Intermediate plate in X-Axis between the satellite bus and the payload (2)
 - Side elements of the satellite bus in +Y and -Y (3 und 5)
- The satellite bus itself has a bottom plate to be separated from the propulsion system



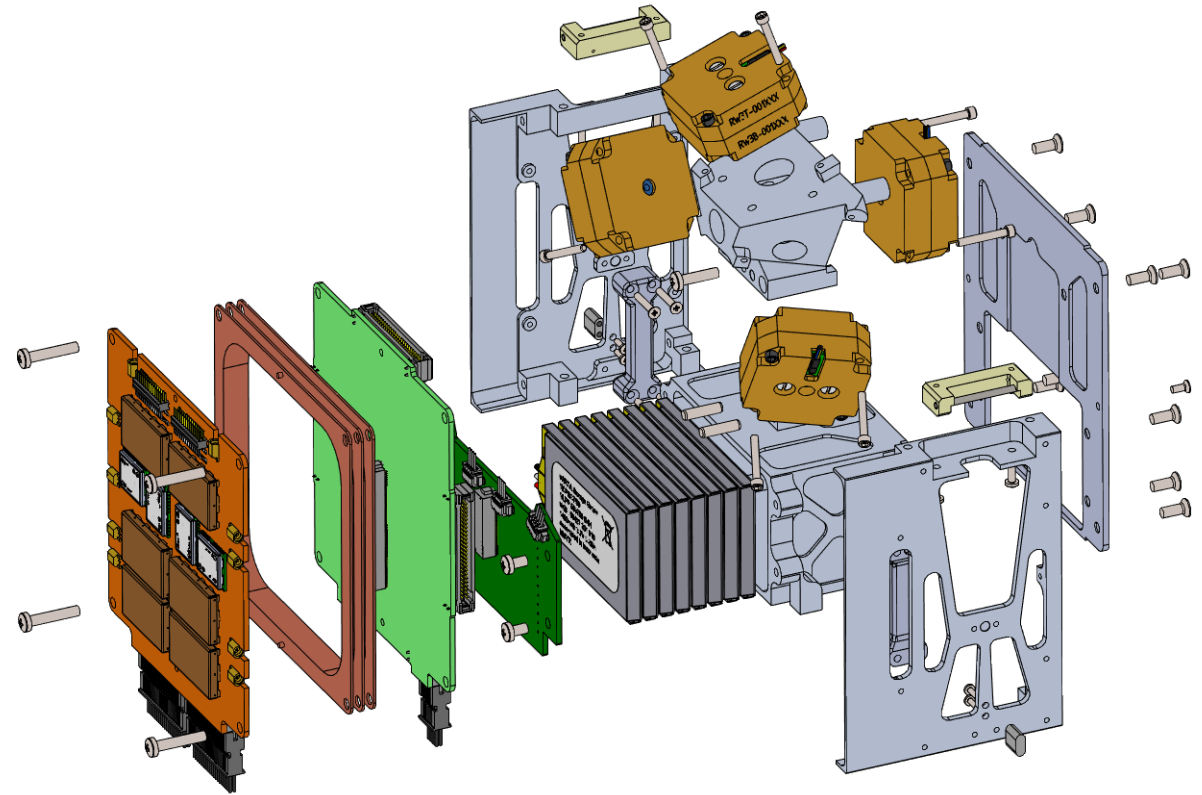
Satellite bus

- NanoFF's satellite bus was developed as a self-contained, self-supporting, structural unit
- The complete subsystem can be integrated and tested prior to integration into the satellite
- In addition to the two primary structural elements in +Y and -Y, the subsystem has:
 - An intermediate deck in X
 - The battery housing
 - The tetrahedron structure for the reaction wheels



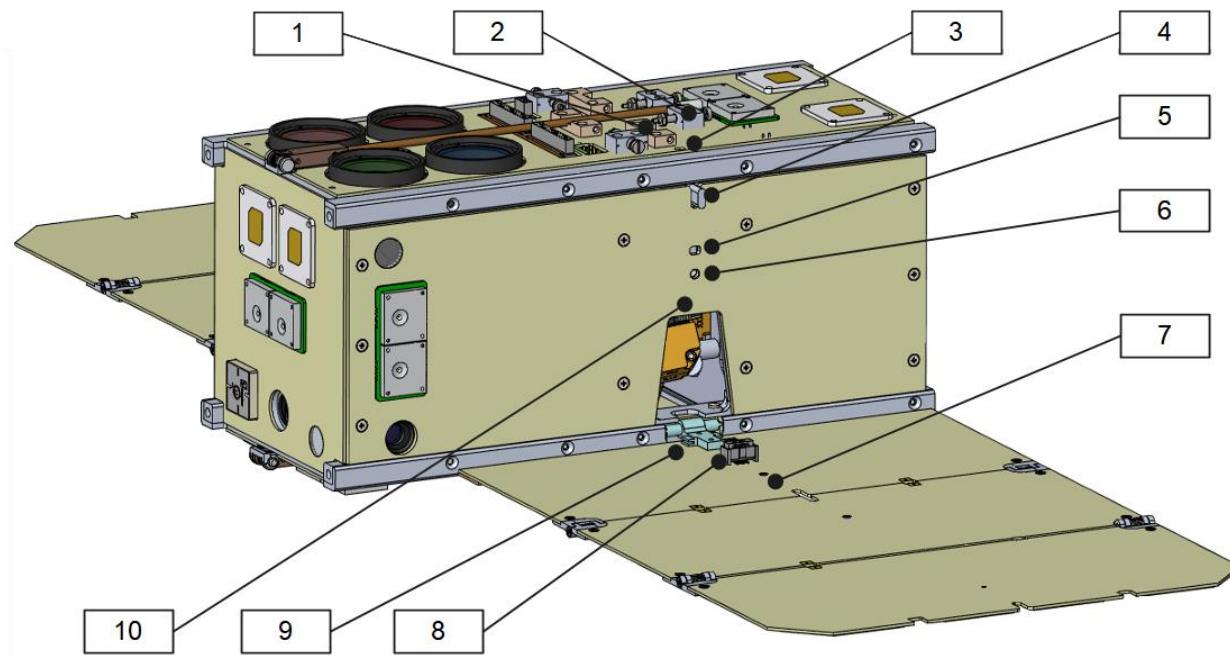
Satellite bus

- The structural elements are both screwed and secured by locating pins (between RW structure and battery compartment).
- The reaction wheels are electrically connected to the BMS via a pluggable cable connection
- The BMS, the OBC-COM-NAV board and the PCU are connected via board-to-board connectors.
- The air coil is soldered to the PCU
- The satellite bus also houses the central joint of the solar panels



Release mechanisms

- NanoFF has a total of four release mechanisms, two each for the UHF antennas and two for the solar panels
- For the UHF antennas, the release mechanism is based on the system developed during the S-NET mission
- The individual mechanisms are secured by a taut nylon thread (2)
- A redundant fusible link (1) guarantees safe triggering
- The nylon thread for the panel deployment is guided to the -Z side by means of a 3D printed guide (6) (3)



Satellite bus electronics: OBC/COM/NAV

Combined PCB with several subsystems

Communication

- 2 Transceiver in UHF-Band (UCOM)
- 2 Transmitter and 2 Receiver in S-Band (SCOM)

Data Handling

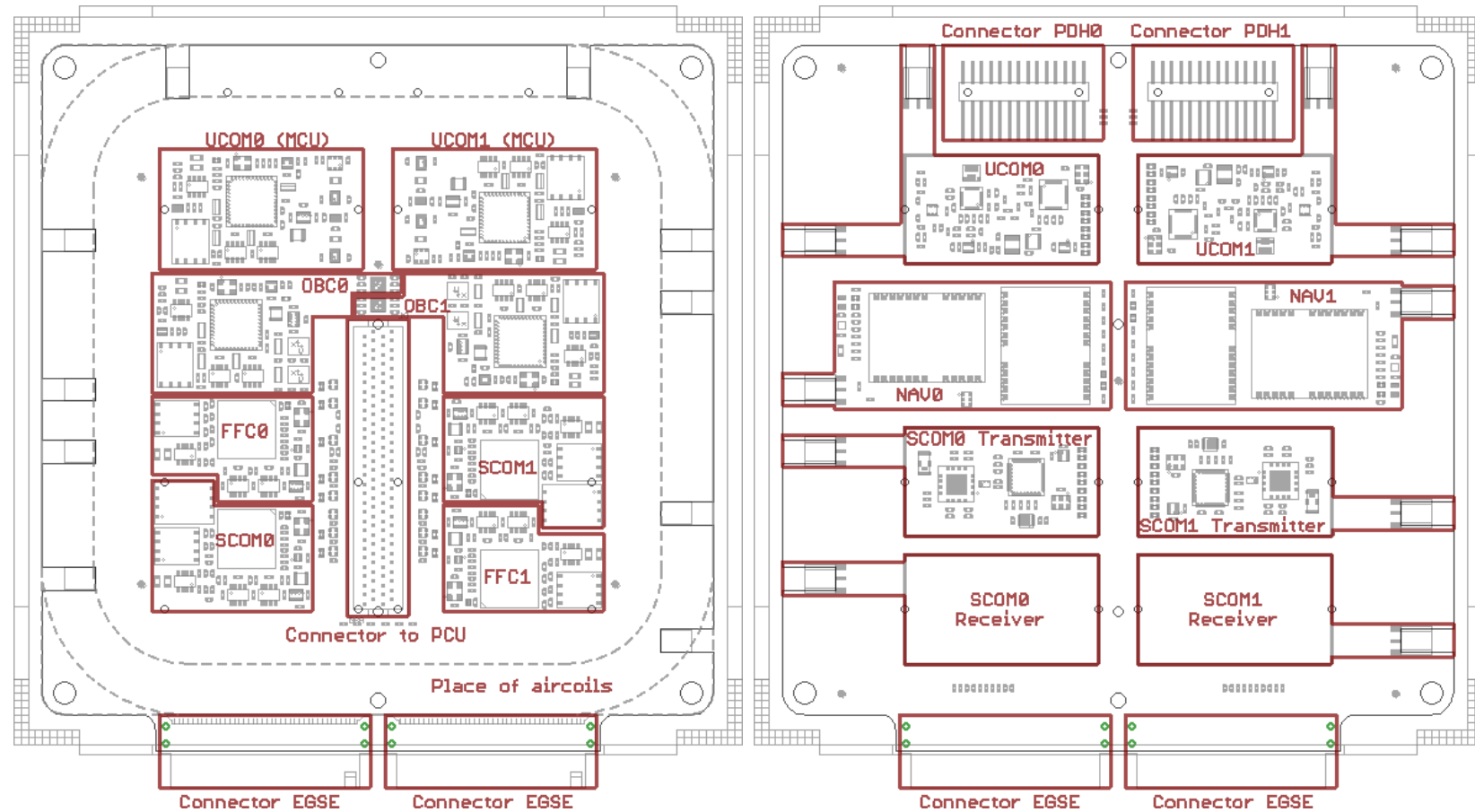
- 2 On-Board Computer (OBC)
- 2 Formation Flight Computer (FFC)

Navigation

- 4 GNSS Receiver (NAV)

EGSE

- Access to all μ Cs of the satellite



Satellite bus electronics: PCU/AOCS

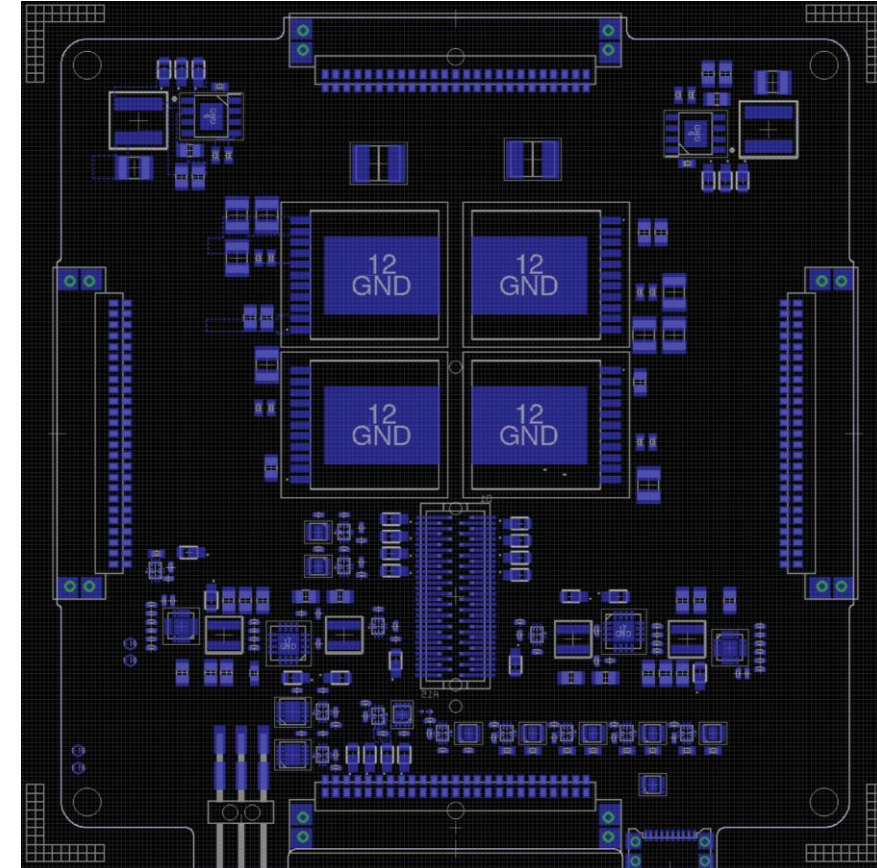
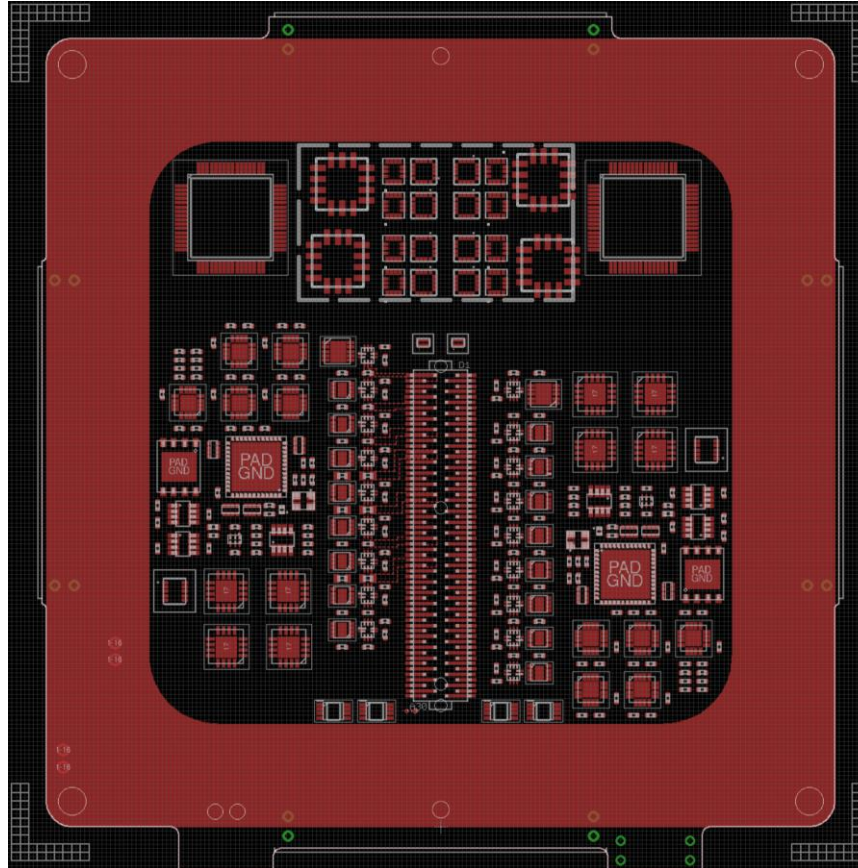
Combined PCB for PCU/AOCS

AOCS

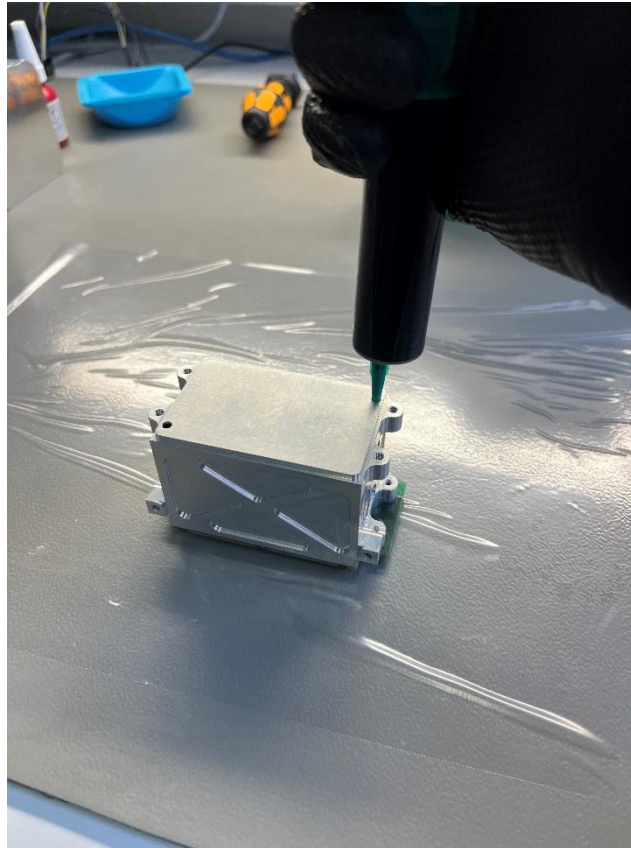
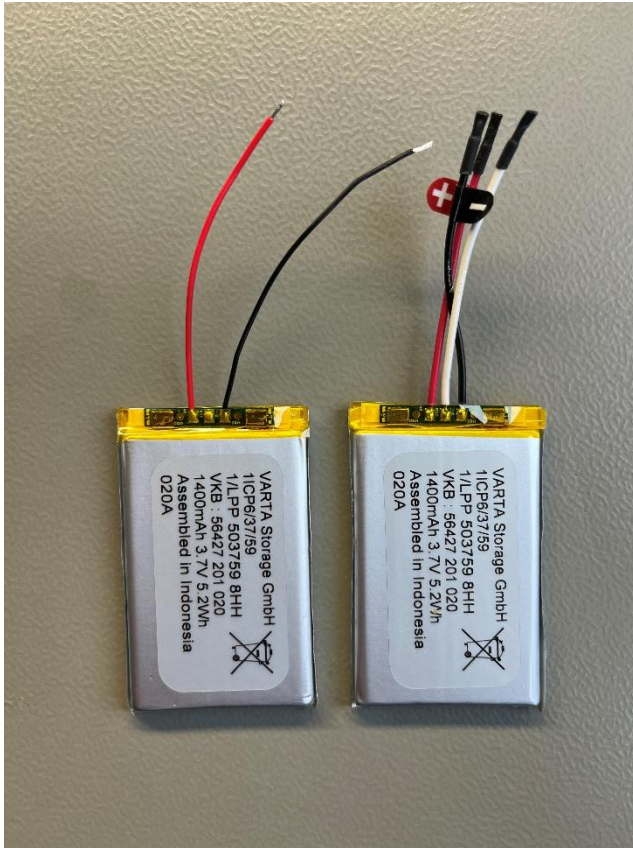
- 2x4 Gyroscopes
- 2x4 Magnetometers
- 2x2 Accelerometers
- 2x5 Sun Sensors (Side Panels)
- 4 Reaction wheels
- 3 Star Trackers

PCU

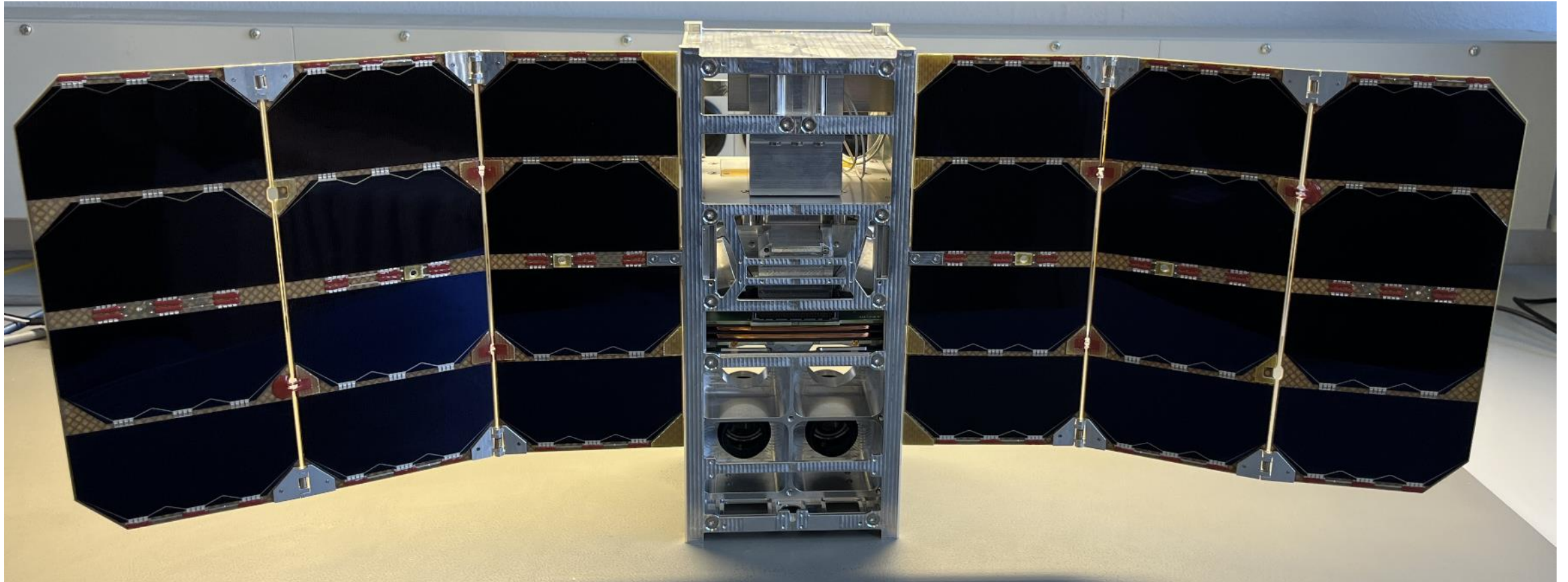
- Redundant System
- 12V, 5V, 3.3V



Satellite bus: EPS

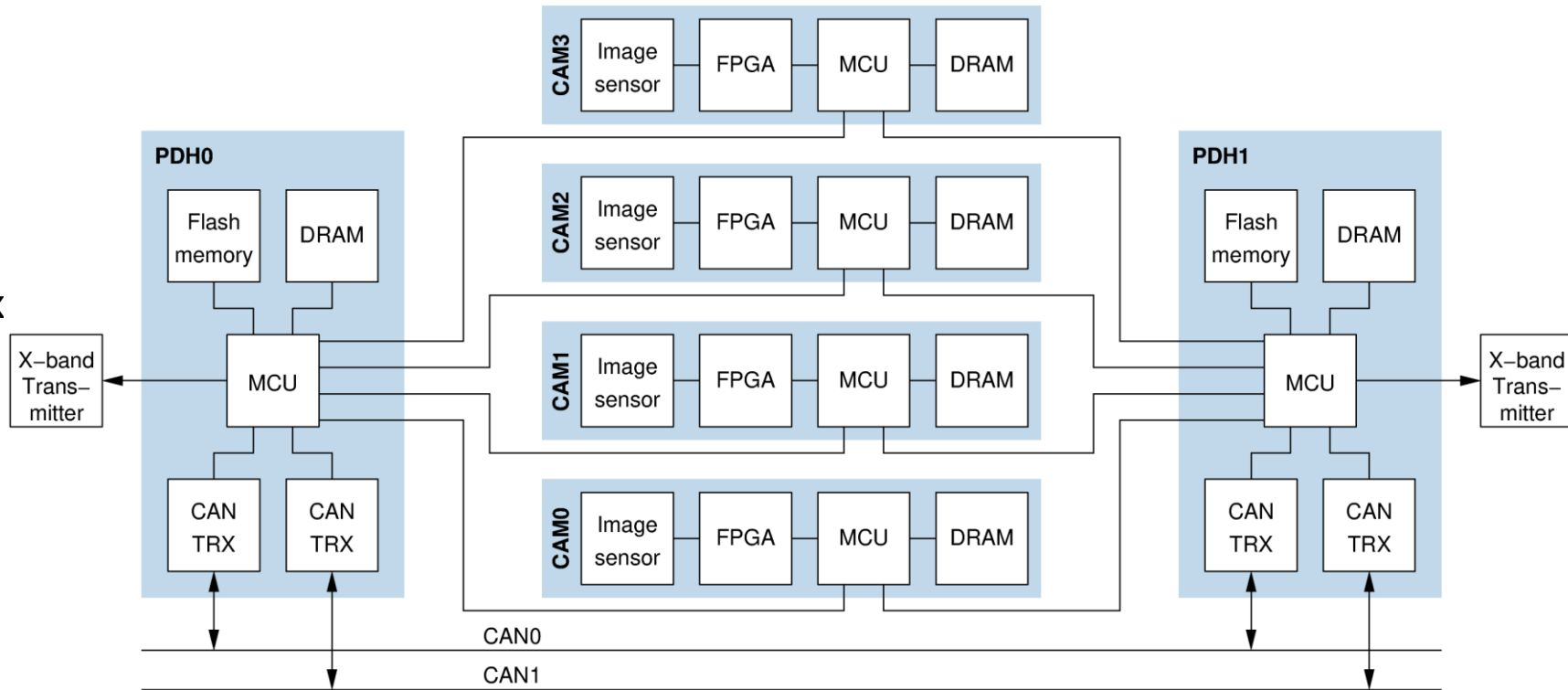


Satellite bus: EPS



Camera system

- Multispectral camera system
- Ground resolution of 30m @525km SSO
- MTF of 0.4
- Global Shutter sensor with a pixel size of $2.74\mu\text{m}$ and 12Mpx
- Swath width of 131km
Height 96km
- Stripes of consecutive pictures
- Filters chosen with another department of TU Berlin for forest surveillance (4 red channels), other satellite RGB and near IR



Key Parameters

	2U NanoFF	3U NanoOOV
Communication		
Downlink UHF	Up to 9.6 kbit/s	Up to 9.6 kbit/s
Downlink S/X-band	Up to 4 Mbit/s	Up to 4 Mbit/s
Uplink UHF	Up to 9.6 kbit/s	Up to 9.6 kbit/s
Uplink S-Band	Up to 1 Mbit/s	Up to 1 Mbit/s
Electrical Power System		
Solarpower	36 W	55 W
Storage	47 Wh	47 Wh
AOCS		
Determination	30 arcsec	30 arcsec
Pointing	0.5°	0.5°
Position	5 m	1 m
Velocity	0.1 m/s	0.01 m/s
Propulsion	~ 15 m/s	~ 11 m/s
Payload Volume	0.7U (1.3U w/o propulsion)	1.6U (2.2U w/o propulsion)
Camera System	30m GSD	tbd