The Flexible Microwave Payload -2: A SDR-based GNSS-R instrument for CubeSats

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→ Introduction:
  ▪ FSSCat science case
  ▪ FSSCat mission overview

→ The FMPL-2:
  ▪ Instrument overview
  ▪ Detailed design:
    • Block diagram
    • Acquisition strategy
    • Software design
  ▪ Implementation overview
  ▪ Testing campaign

→ Conclusions
Introduction: FSSCat Mission, Science case – Needs & antecedents (i)

- **Soil moisture**: No SMOS or SMAP follow-on mission. CIMR L-band channel?
- **Polar and Snow monitoring**: Ice cover and thickness (≤ 60 cm) can be inferred from GNSS-R and L-band microwave radiometry ⇒ Floating ice, caps and ice sheets

**UK TDS-1 experience GNSS-R over ice and water**

**SMOS Artic ice thickness up to ~60 cm**

**SMOS downscaled soil moisture**

Spatial resolution (nadir reflection): Diameter 1st Fresnel zone ~600 m from h= 500 km

SMOS SIT products by BEC 3/11/2014
Spatial resolution (antenna footprint) Also produced by U. Hamburg

Spatial resolution from ~50 km to 1 km
An innovative mission consisting of two federated 6U CubeSats (3Cat-5/A and 3Cat-5/B).

- **3Cat-5/A payloads:**
  - FMPL-2: Dual microwave payload (Microwave radiometer + GNSS reflectometer) in a single instrument using a Software Defined Radio,
  - FSSEx and OISL: Radio and optical inter-satellite link technology demonstrators.
- **Science:** Soil moisture, ice thickness and extent, and water ponds on ice maps.

- **3Cat-5/B payloads:**
  - Hyperscout-2: Hyperspectral instrument combining for first time VNIR/TIR channels,
  - FSSEx and OISL: Radio and optical inter-satellite link technology demonstrators.
- **Science:** Terrain classification and pixel de-composition, cross-calibration with Sentinel-2, and on-board cloud detection using artificial intelligence.

Both 3Cat-5/A and 3Cat-5/B will test radio and optical communication technologies for future satellite federations.

- FMPL-2 and FSSEx developed by **UPC**
- O-ISL developed by **Golbriak Space**
- Hyperscout-2 developed by **Cosine**
- **Platform** design and integration from **Tyvak International**
- Data Processing Ground System (**DPGS**) implemented by **Deimos Portugal**
- Technical, financial, and management support from **ESA**
Introduction: FSSCat Mission Overview – Experiments/Observations (iii)

FMPL-2 Sea Ice Experiment:
- GNSS-R: sea ice & water pond mapping
- Microwave radiometer: ice thickness

Hyperscout Observations:
- Terrain classification
- Change detection
- On-board cloud detection with AI

FMPL-2 + Hyperscout Observations:
- Microwave radiometer: soil moisture
- Hyperscout: hyperspectral observation

Optical Inter-Satellite Link (O-ISL) experiment

Federated Satellite Systems experiment (FSSExp)
Flexible Microwave Payload -2:

Combined GNSS-R scatterometer and L-band Microwave Radiometer in a single instrument using Software Defined Radio.

Applications:
- Sea-ice detection (GNSS-R) and sea-ice thickness monitoring (MWR)
- Water ponds over ice (GNSS-R)
- Low resolution soil moisture (MWR)
- High resolution soil moisture after data fusion with Hyperscout-2 data
→ FMPL-2 is a dual microwave payload (cGNSS-R and L-band radiometer) implemented using an SDR.

→ SDR based on a GomSpace NanoSDR.

→ Novatel OEM719B GNSS receiver is used to geo-reference and time-tag all the observables and provide satellites in view to speed search.

→ RF-FE amplifies and conditions the signal before the SDR.

→ Up- and down-looking passive-patch antenna for both GNSS-R and L-band radiometry.
→ Data acquisition:
  ▪ Sampling rate = 4 MHz,
  ▪ Central frequency = 1413 MHz for both channels (GNSS L1/E1 signals down-converted from 1575.42 MHz)

→ GNSS signal sent upon request to the GNSS-R processor.

→ Calibration performed in both GNSS-R chains and L-band Radiometer chains as a Total Power Radiometer with Active Cold Load & matched load.
FMPL-2 Software Design: GNSS-R processor flowgraph

→ Data Processing Unit performs 3 different steps:
  ▪ Direct signal acquisition
  ▪ Reflected signal acquisition
  ▪ Reflected signal tracking

→ Signal processing block is always the same but with different Earth-configurable parameters:
  ▪ Amount of averaging (coherent/incoherent)
  ▪ Number of bins
  ▪ Number of satellites to be tracked
  ▪ Step repetition
→ Data Processing Unit takes continuous blocks of 40 ms raw data and performs the cross-correlation with pre-computed FFTs of a GNSS sequence in blocks of 1 ms for GPS and 4 ms for Galileo.

→ 40 ms sequence length to limit waveform/DDM blurring if retracking is not correct (retracking performed on ground)

→ 161-bin 500 Hz spaced matrix containing all PRNs (already FFT’ed) stored in the processor persistent memory.

→ Each averaged DDM stored as 16-bit PGM image in the processor memory for download.
FMPL-2: Implementation overview

→ Design to fit on a 1-Unit CubeSat:
  - Based on CubeSat PC104 standard, adapted for FSSCat mission (custom CubeSat backplane),
  - Weight: 1.4 kg,
  - Peak power consumption: 5 V @ 1.7 A (8.5 W).

Dual-band six-element patch antenna prototype
FMPL-2: Ambient test campaign

→ Functional verification with direct GNSS signals,

→ Test at ESA-ESTEC premises with Spirent simulator to check the GPS/DDM calculator in high-dynamics (LEO orbit).

→ Antenna pattern measurements measured in representative 6U CubeSat model
→ Reflected signal simulated with a **direct** High-dynamics signal

FMPL-2 sample DDMs:
- Direct signal: 80 bins, 10 ms of averaging
- Reflected signal: 21 bins, 40 ms of averaging
- Reflected tracked signal: 5 bins, 40 ms of averaging

Waveform of a simulated GPS L1 reflected signal:
5-bin DDM at 40 ms of averaging
Check that the instrument is able to withstand the launch (vibrations) and to perform in a wide range of temperatures:

- **Thermal-vacuum chamber test:**
  - 4 cycles, each cycle from -10 °C to 40 °C

- **Shake table test:**
  - Sine and random vibrations for each axis (X, Y, Z) at 12.5 g$_{rms}$

(a) TVAC test (-10 °C / +40 °C)  (b) Shake table test (12.5 g$_{rms}$)
Conclusions

→ **Smallsats and CubeSats** in particular are creating a revolution in the space business:
  - New market and business models for Nano-satellites,
  - New instruments and techniques for Remote Sensing fit into CubeSat philosophy:
    - Decrease Earth Observation revisit time and overall mission cost,

→ **FMPL-2** is a CubeSat-based cGNSS-R remote sensing instrument
  - Block diagram design and software design/implemention details presented,
  - FMPL-2 full functional tests performed at both ambient and environmental levels,
  - Already integrated in 3Cat-5/A and ready to launch!

→ Lack of Functional testing for GNSS-Reflections:
  - Test-bench needed to test GNSS-R payloads,
  - **GNSS-R simulator** conceived, implemented and tested by UPC together with a RFI detection/mitigation system
  - See demo at **GNSS+R 2019 In-Lab sessions “Implementation of a testbed for GNSS-R payload performance evaluation”**
Winner of the 2017 Copernicus Master
“ESA Small Satellite Challenge $S^3$” and overall Winner

$^{3}\text{Cat-5/A}$

$^{3}\text{Cat-5/B}$