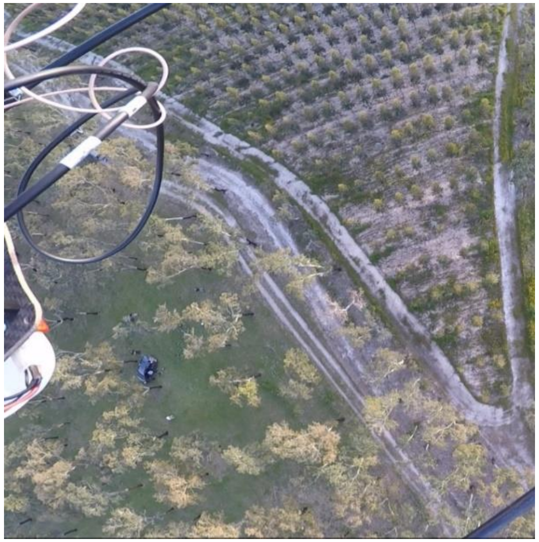
COREGAL: Exploring Galileo E5 Reflected Signals for Biomass Applications



September 2016

Project Technical Presentation - First GNSS-R Results

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Introduction

Context and Motivation

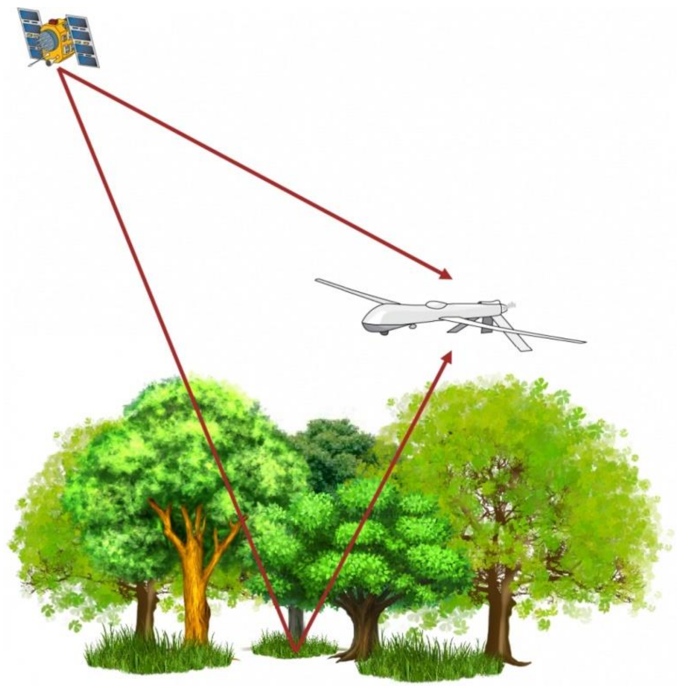
- **Why measuring biomass is important?**
  - Forests cover 30% of land surface and are a key socio-economic element
  - It is important to understand ecological and biogeochemical processes, such as Carbon Modeling
    - *Enabling Climate Research, Sustainable Forest Management and Enhancement of Forest Carbon Stocks*
- **How is biomass measured today?**
  - Spaceborne remote sensing and in-situ measurements are the most common sources of observables
  - Aboveground Biomass (AGB) is a key indicator, but monitoring AGB is difficult and expensive to maintain
    - *In-situ measures are very accurate but cover small areas*
    - *Spaceborne remote sensing covers very large areas, but lacks spatial precision required for large AGB estimates*

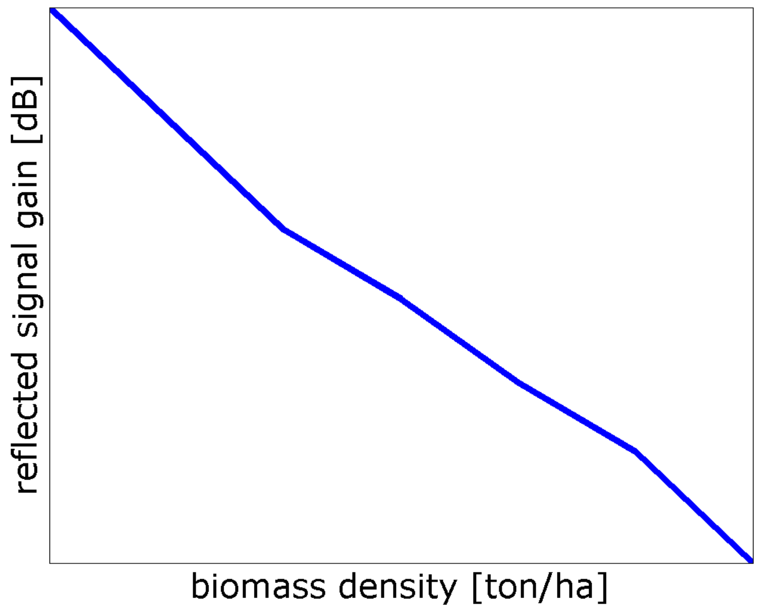
Context and Motivation [cont'd]

- **How can COREGAL System help?**
  - Aims to provides an attractive biomass measurement solution using GNSS-R technique and small unmanned aircraft system (sUAS)
  - A first of its kind combined Position+Reflectometry (P+R) Galileo E1 and E5a+b receiver is developed as the main sensor for positioning and biomass estimation
  - Combines local precise measurements (retrieved with GNSS-R using a sUAS) with spaceborne measurements, to provide high-accuracy biomass maps
  - sUAS mission cost is an order of magnitude lower than manned mission

Context and Motivation

- **GNSS-R for Biomass measurement**
  - GNSS signals propagate through tree canopies, branches and leafs and acquire biomass which is later retrieved
  - GNSS L-band signals are sensitive to the above ground biomass

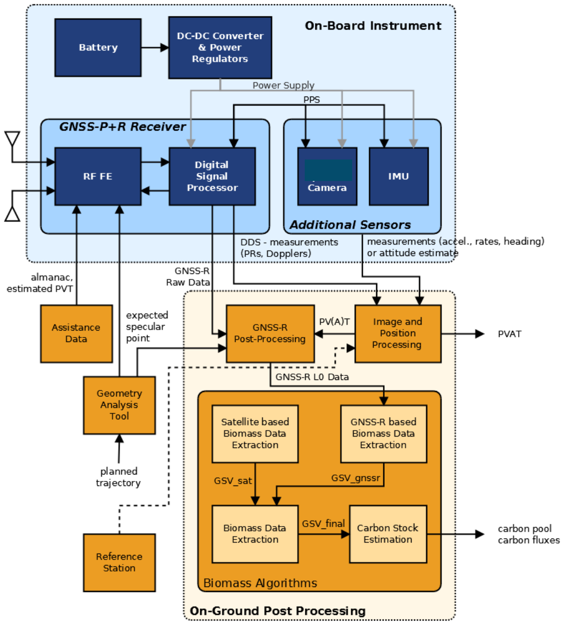




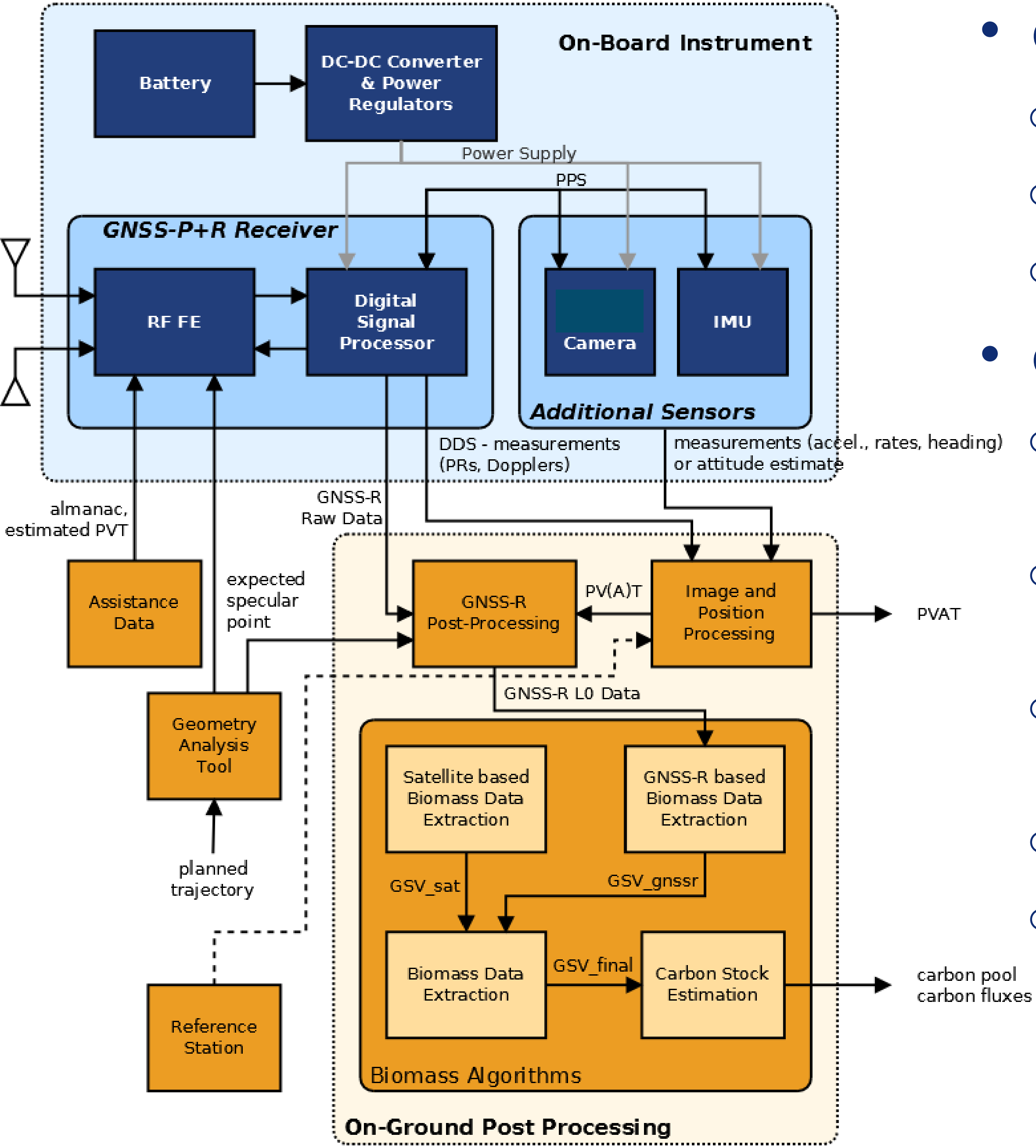
Context and Motivation [cont'd]

- **What are COREGAL Objectives?**
  - Study of Mediterranean ecosystems forests (Portuguese case study) and Brazil forests
  - Combine Galileo AltBOC E5 signals with Galileo E1 to enable high positioning accuracy
  - Use sUAS with a GNSS-R receiver and a passive optical multispectral imager for AGB mapping and estimation
  - GNSS-R signal properties with lower saturation in signal backscattering when compared to RADAR
  - Demonstrate the concept as part of a commercial service, with cost reductions and high-accuracy biomass mapping, accelerating Galileo adoption in Brazil
- **This presentation presents the COREGAL system and first results of the COREGAL project.**

COREGAL
System Architecture



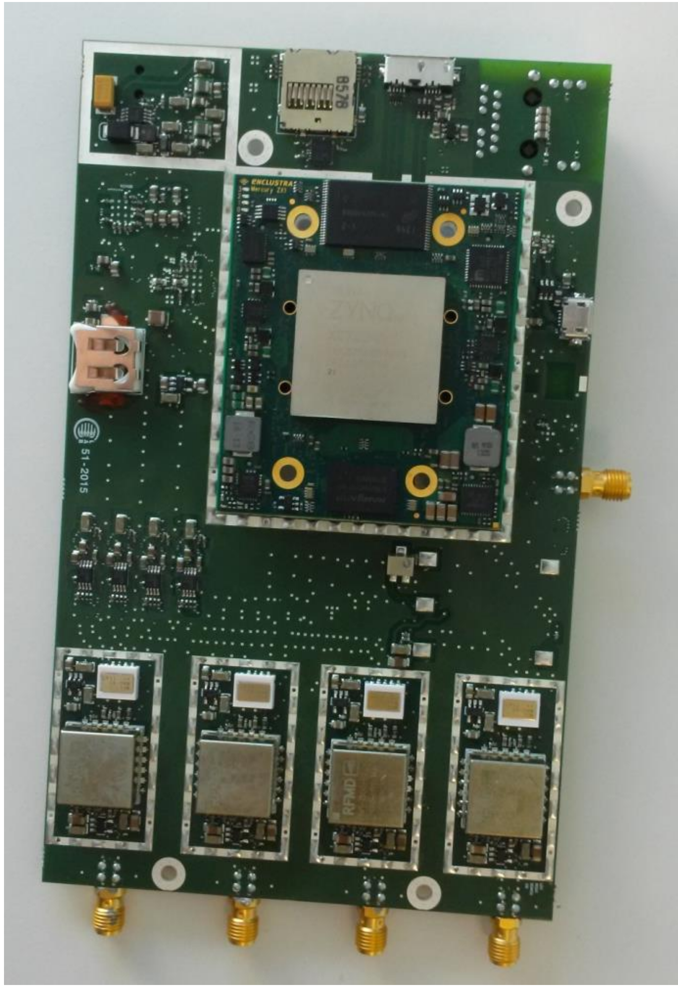
System Architecture



- **On-Board Instrument**
  - Antennas
  - GNSS-P+R Receiver
  - Optical Camera and IMU
- **On-Ground Post Processing**
  - Image and Positioning Processing;
  - GNSS-R Post-Post Processing
  - GNSS-R Based Biomass Data Extraction
  - Biomass Data Extraction
  - Carbon Stock Estimation

GNSS-P+R Receiver and Antennas

- **2 Multi-Frequency GNSS Antennas**
  - *RHCP antenna for direct signal*
  - *LHCP antenna for reflected signal*
- **Radio Frequency Front End**
  - *RF signal processing, down-conversion, ADC, supporting all GNSS bands*
  - *4 RF FE channels*
- **Digital Signal Processing**
  - *Xilinx Zynq-7000 (ARM+FPGA) based*
  - *Carrier and code de-spreading, tracking loop closure, PVT estimation and GNSS-R observables generation*
  - *44 GNSS hardware channels*
  - *BPSK, BOC, MBOC and AltBOC*



On-Ground Post Processing

- **GNSS-R post-processing, responsible for the post processing of raw GNSS data output by the onboard instrumentation.**
- **Image and position processing, responsible for precise PVAT estimation**
- **Biomass processing, comprised of the following:**
  - Biomass data extraction, responsible for the retrieval of AGB estimation from satellite and sUAS data; the two sources shall be combined to generate more precise biomass estimates
  - Carbon stock estimation, responsible for the estimation of carbon pools and fluxes, based on AGB estimation techniques

Tests

Test Trials Setup

- GNSS-R tests using USR RF FE
- Static and dynamic tests conducted over the past months
- Dynamic tests onboard UAVision quadcopter near Coruche, Portugal
  - *Where ground control biomass references are available*

Test Trials Setup [cont'd]

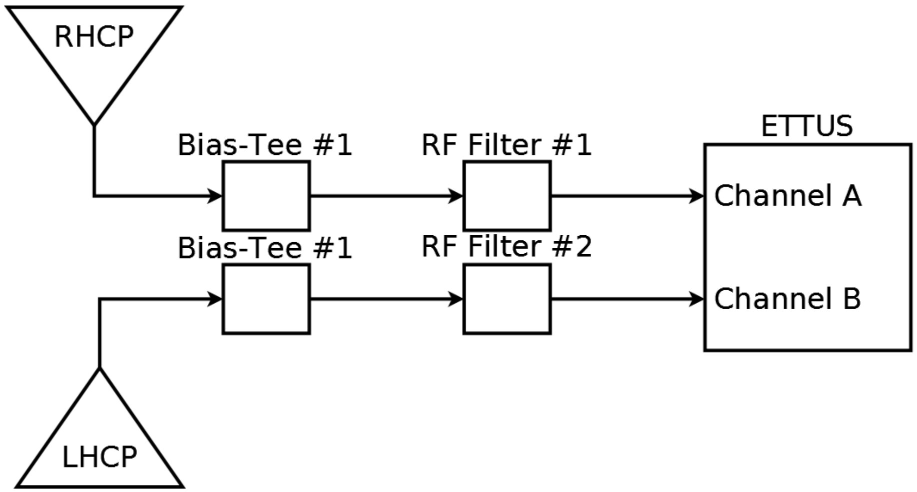
- **Test Procedure**
  - Data Acquisition
    - *Uplooking RHCP antenna pointed towards the sky*
    - *Downlooking LHCP antenna pointed towards the expected specular reflection point*
    - *Digital outputs (samples for direct and reflected signals) are recorded*
  - Data Processing
    - *Digital recorded samples post-processed to detect presence of direct and reflected signals*
    - *Carrier-to-noise ratio, C/N_0, and the reflected signal attenuation is estimated*

Test Trials Setup [cont'd]

- **RF FE configuration**

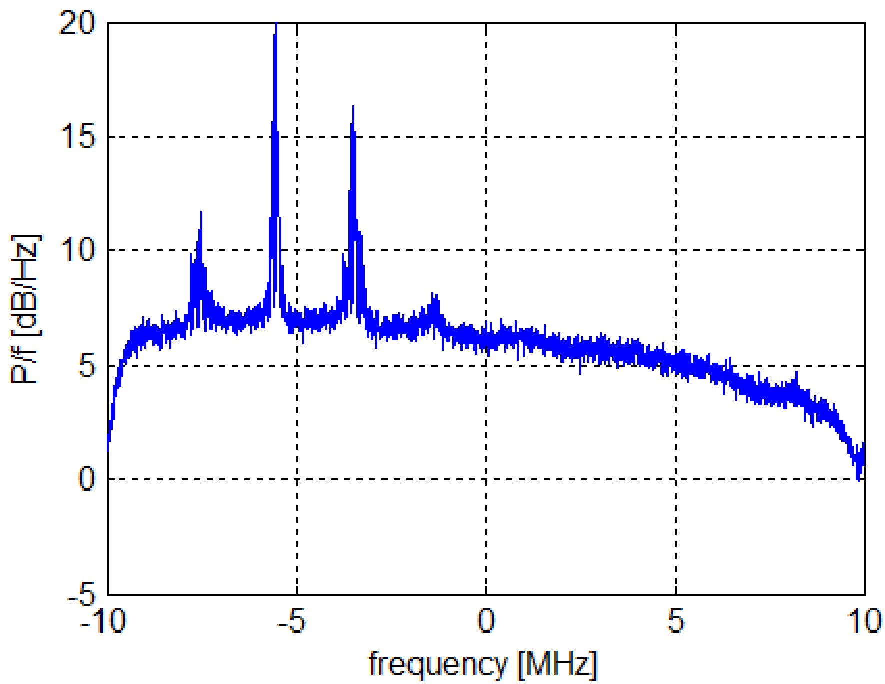
Sampling frequency	20 MHz
Digital bandwidth	20 MHz
Local carrier	1176.45 MHz
Acquisition length	60 s
Quantization level	16 bits
Coherent integration time	1 ms
Number of non-coherent combinations	200

- **RF Setup**



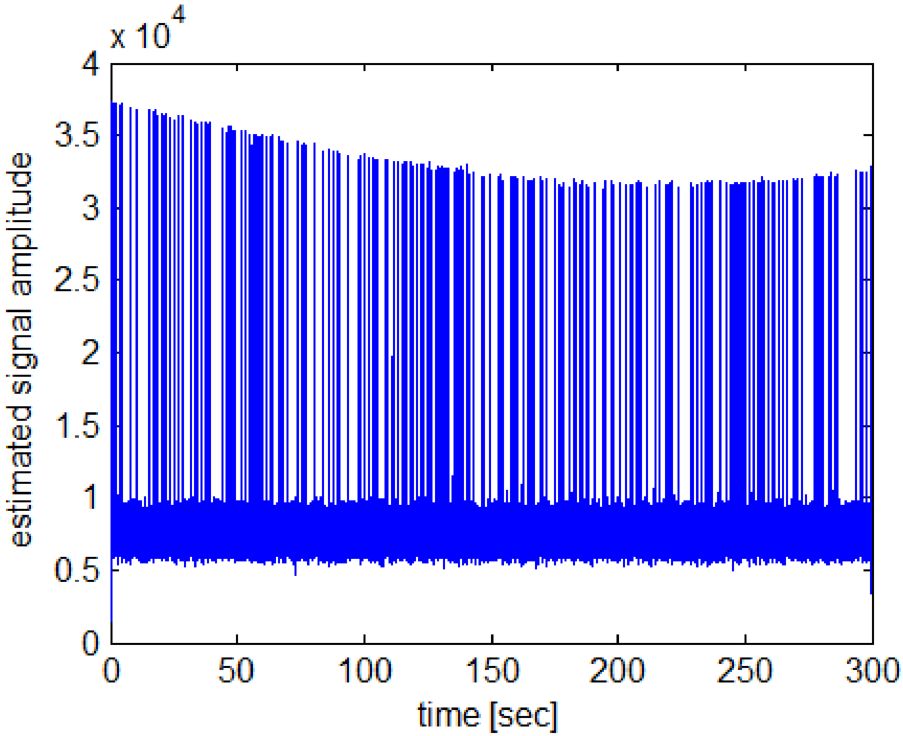
Test Trials Setup Tuning

- **E5 RF spectrum polluted with unwanted RF signals**
  - DME signal was also received
    - *Test trials conducted near Lisbon International Airport*
  - Potential weaker SNR



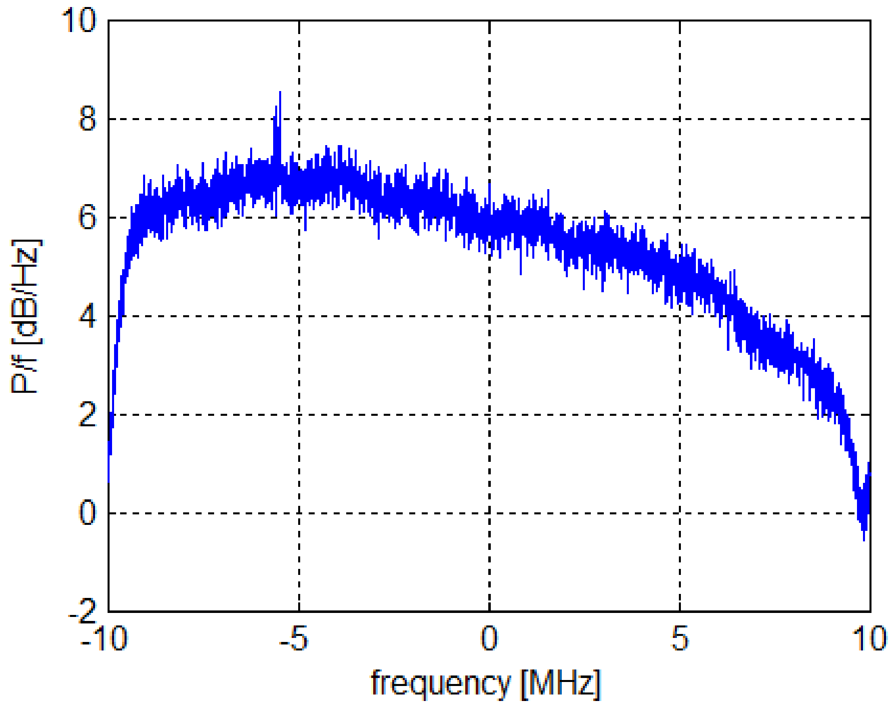
Test Trials Setup Tuning [cont'd]

- DME signal can be described as a train of paired pulses (amplitude spikes)
- DME interference mitigation was performed by removing the amplitude spikes in time-domain (applying pulse-blanking)



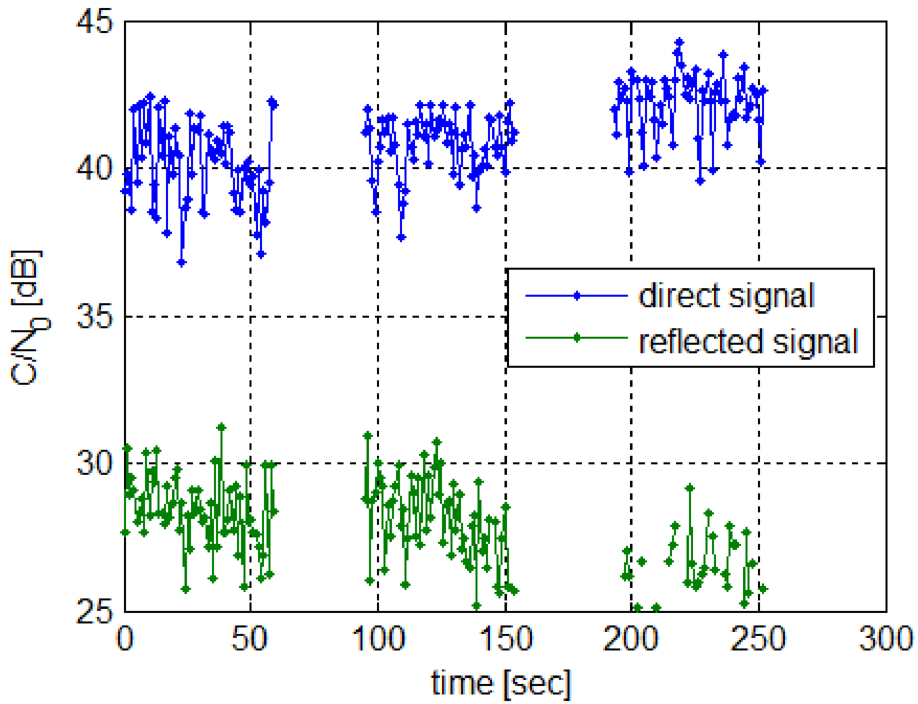
Test Trials Setup Tuning [cont'd]

- **E5a power spectral density after pulse blanking**
  - DME interference mitigation:
    - *Pulse-blanking technique – signal amplitude set to zero when a DME pulse is detected*
    - *Previous visible frequencies spurious are now either not visible or atenuated*



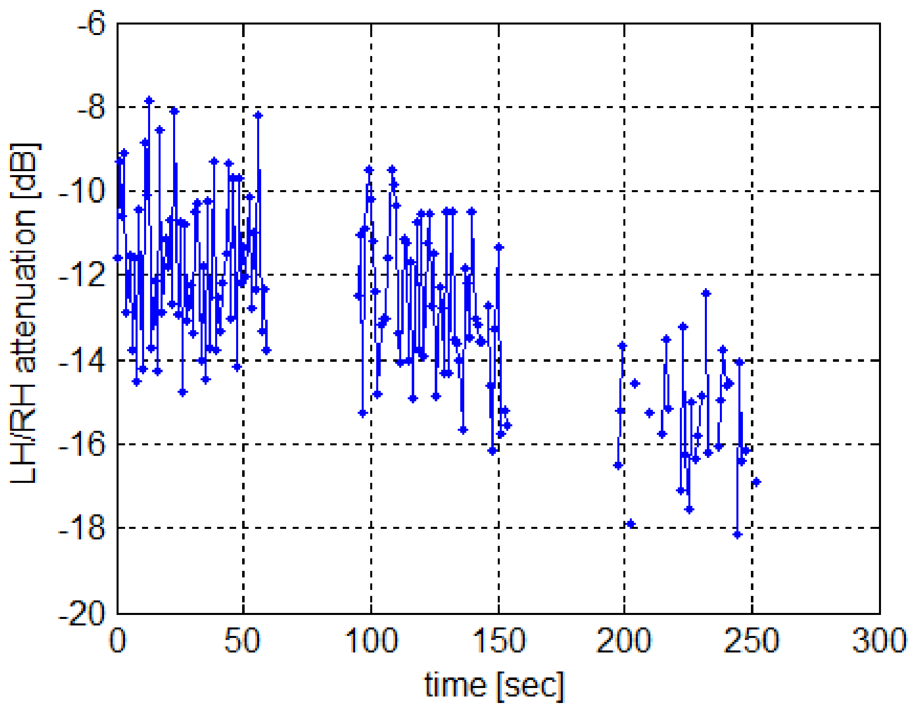
Test Results [cont'd]

- C/N_0 for the direct and reflected signals was estimated for three sequential acquisitions
- 60 sec length using Galileo E5a SVID 26
- Acquisitions start at 0, 95 and 195 sec
  - *Reflected signal not detected at certain time epochs in the third acquisition*



Test Results [cont'd]

- Estimated reflected signal reflectivity
  - *Average reflectivity of -14 dB, corresponding to dry and rough soil covered with low vegetation*
  - *A slight decreasing trend is visible, most likely due to elevation changes and specular pointing movement*



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Conclusions

Conclusions

- Presented a high-level view of the COREGAL system architecture
- Development of GNSS-P+R receiver targeting high accurate position estimates and GNSS-R
  - *New receiver motherboard compatible with all known civilian or open-service GNSS signal*
- First prototype is being tested
  - *First COREGAL test campaigns started in June 2016 and will continue to take place over the next few months*
  - *GNSS signals reflected over vegetation have been collected to generate GNSS-R raw data to early test the COREGAL concept*
- Presented GNSS-R raw data obtained
  - *Correlation outputs and reflected signal reflectivity*

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Questions?

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Thank you for your attention