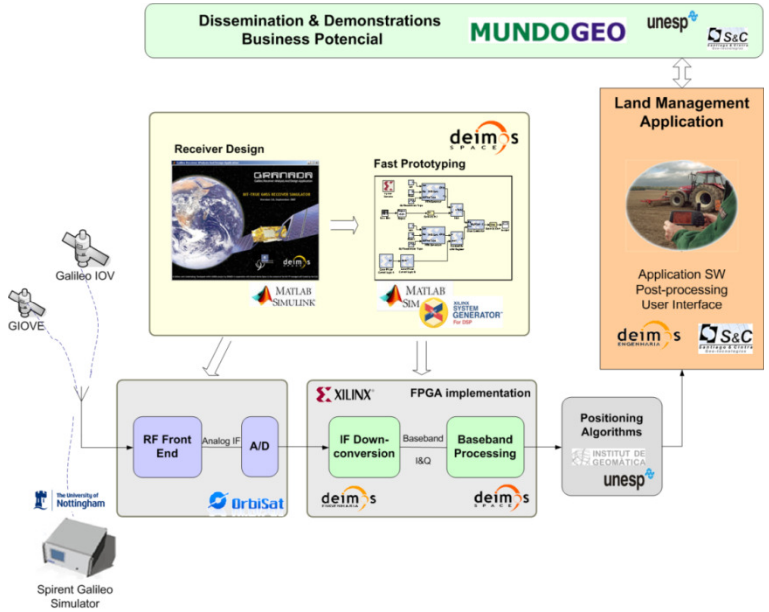

Galileo Signals for Surveying and Mapping

Pedro Freire da Silva

DEIMOS Engenharia

EuroCOW – Session 2: GNSS

Castelldefels

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SCOPE:

- Taking benefit of the new Galileo ranging signals, ENCORE project is building a low-cost Land Management Application to cover Brazilian needs in terms of geo-referencing and cadastre planning.

ACKNOWLEDGMENTS

SEVENTH FRAMEWORK PROGRAMME

- The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under the GNSS Supervisory Authority grant agreement FP7-GALILEO-2008-GSA-1 Proj. 247939.

- The ENCORE project is lead by **DEIMOS Engenharia** (Portugal) in partnership with: **Institute of Geomatics**, **DEIMOS Space** (Spain)**, University of Nottingham** (UK), **Universidade Estadual Paulista** (Brazil), **Orbisat da Amazônia Indústria e Aerolevantamento** (Brazil), **Santiago & Cintra Importação e Exportaçao Ltda** (Brazil) and **Editora Mundo GEO ltda** (Brazil).

- Introduction
- Regional Context
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- Algorithms
  - Base-band Processing
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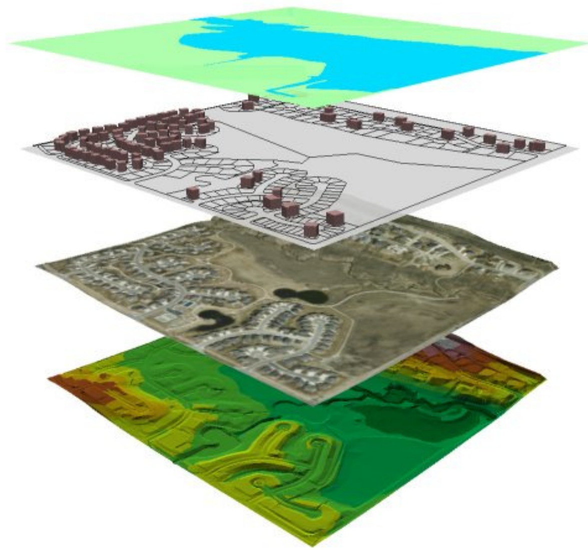
- ENCORE Project objectives:
  - Introduction of **Galileo terminals** in the Brazilian market for land management applications with possible future expansion to other South America countries and related applications;
  - Stimulating the participation of **international entities** from Brazil;
  - Development of a **high-precision** and **low-cost land management application** based on Galileo signals.

- Some facts:
  - Started in February 2010
  - Duration of 26 months
  - Ongoing validation and testing phase

- Land Management in Brazil
  - The Brazilian market still lacks information mainly in terms of geo-referencing of rural real estates (10.267/2001 Federal Law);
  - There is an increasing demand for topographical surveys of rural areas;
  - Commercially available professional GPS receivers are limited and expensive. The development of solutions tailored to the Brazilian needs is required and the technology involving Galileo receivers is shown to be extremely adequate to this purpose.

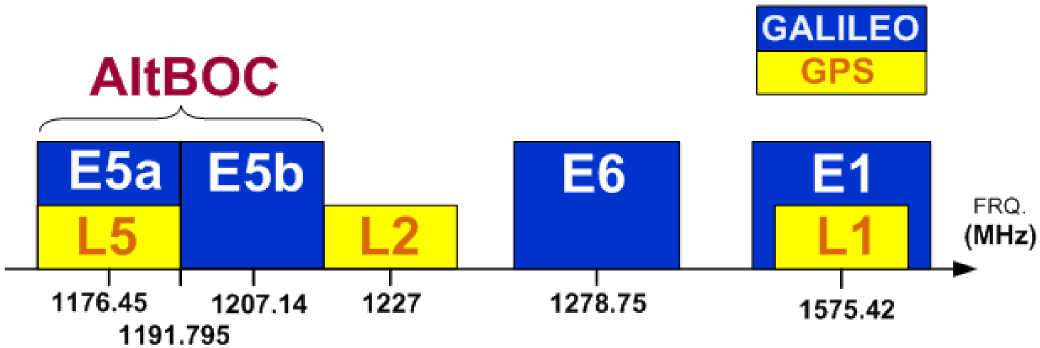
- Other potential applications
  - Urban property registration;
  - Mapping of urban infrastructure (e.g. basic sanitation, telephone, transport companies) for Geographic Information Systems (GIS);
  - Important to support the planning and decision-making in the urban environment.



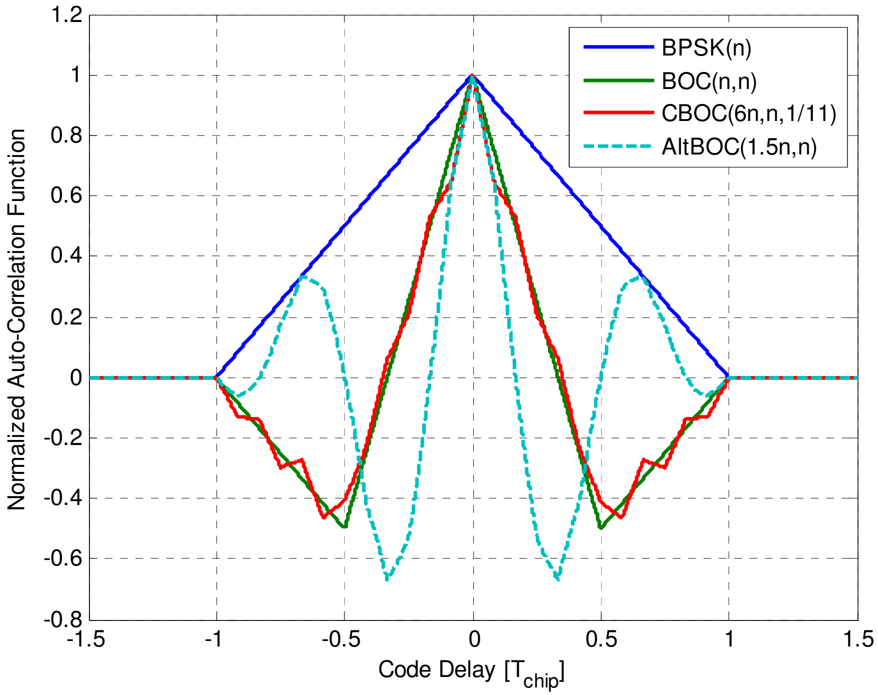
- Innovation in the project
  - Use Galileo Pseudorange Observables from Galileo
    - E5 AltBOC and E1 CBOC for **low tracking** & **multipath errors**;
  - Fill the gap for land management applications using Galileo
    - Intermediate **accuracies** between **Professional** (cm) and **Mass market** (meter) receivers, with lower **complexity** & **cost.**

	Accuracy	Complexity	Price
MASS-MARKET RECEIVERS *Pseudorange based*	Low (m)	Low	Low
PROFESSIONAL RECEIVERS *Carrier phase based*	Very High (cm)	High	High
ENCORE	**High** (few dm)	**Low - Medium**	**Medium**

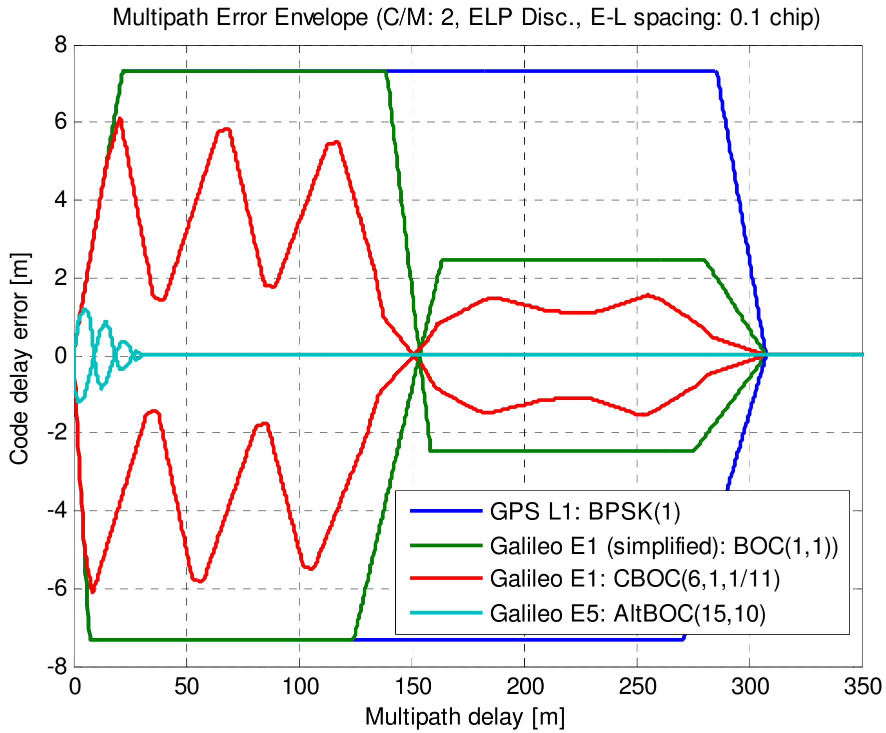
- Innovation in the project (cont'd)
  - Target Galileo Signals
    - E1 CBOC, E5 AltBOC signal characteristics result in:
      - Steeper Auto-Correlation Function peaks & higher spectrum occupancy
        - » Low **tracking noise**
        - » Excellent **multipath** robustness
  - Positioning Algorithms
    - Use **code observables** for instead of carrier phase
    - Aim for high accuracy **point positioning**



- Galileo signals in ENCORE

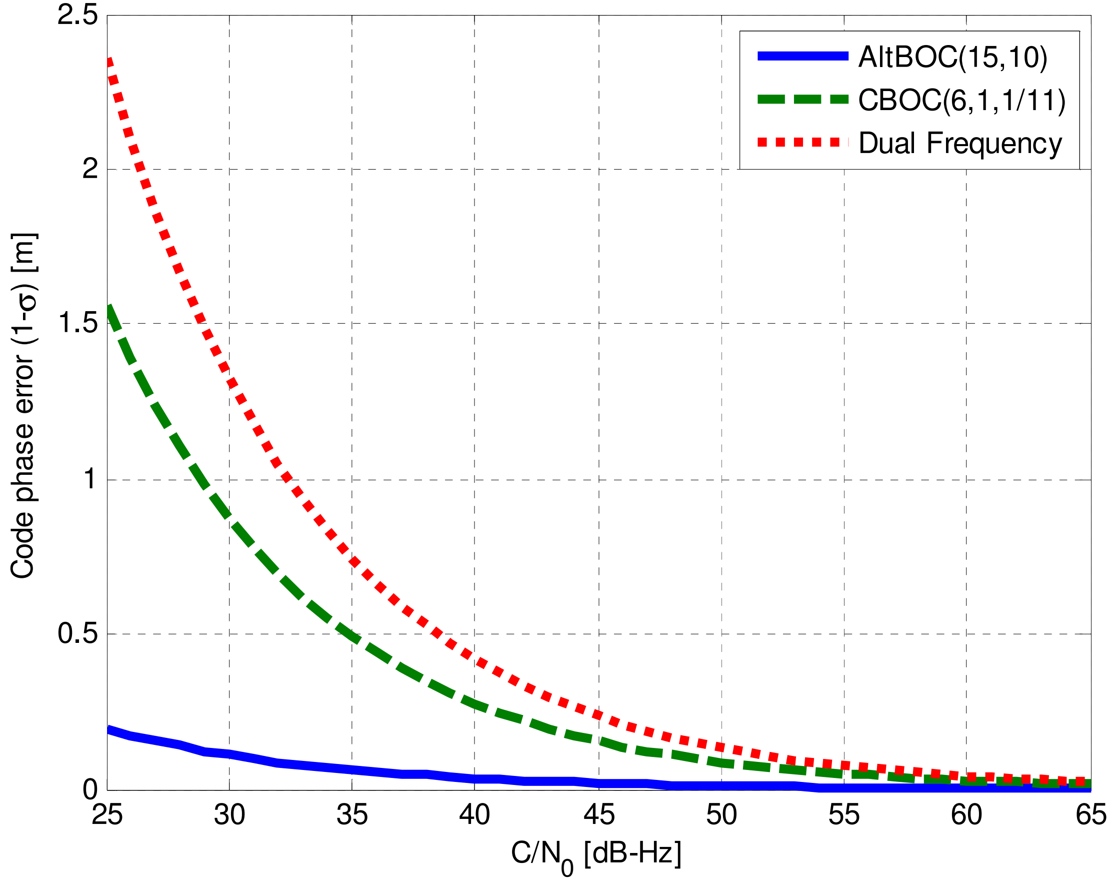


Auto Correlation Function



Multipath error envelope

- Galileo signals in ENCORE(cont'd)



E1 & E5 AltBOC Code tracking error

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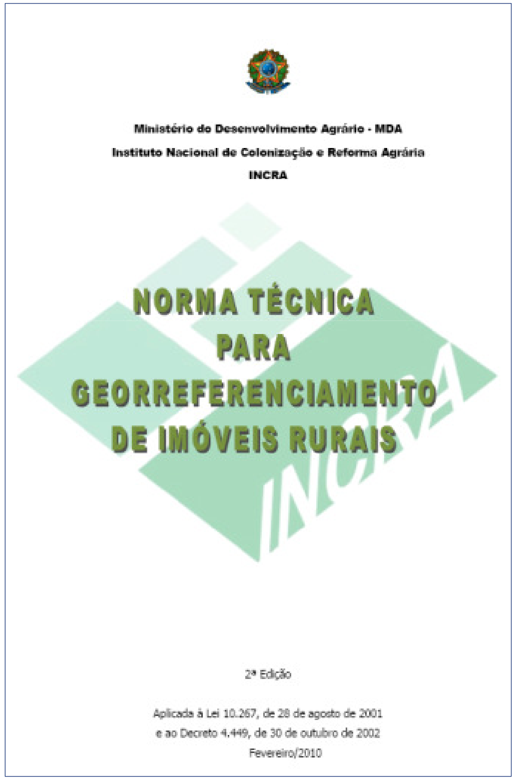
Regional Context

- Brazilian Law for land property registration (10.267/01)
  - Register includes a technical record, which includes coordinate of the vertices defining the property;
  - Fights against illegal land-grabbing operations in Brazil;
  - Generates a geo-referenced territorial database, a tool of key importance for the country's territorial management, planning and development.
- Main players
  - INCRA (Institute of Colonization and Agrarian Reform) responsible for establishment of technical criteria for the implementation, management and input of the **technical record**;
  - Landowners;
  - Professionals acting in the geo-referencing.

Regional Context

- INCRA Technical Norm Position accuracy, second edition
  - Rural properties require horizontal position error **< 0,5m** and **vertical < 1,5m**

Positioning Solution	Horizontal Accuracy (1σ)
C1 – Basic Support / Geo-referencing	≤ 0,10 m
C2 - Immediate Support/ Geo-referencing	≤ 0,20 m
C4 - Geo-referencing	**≤ 0,50 m**
C5 - Geo-referencing for natural limits (e.g. river)	≤ 2,00 m
C7 - Geo-referencing for restricted points (e.g. dense vegetation)	Method dependent



- Current status
  - A timeline for property registration according to its area has been defined, starting on the 20th of November of 2003;
  - In 2011, less than **1 %** of the total number of Brazilian properties have been geo-referenced and certified by INCRA;
  - The period of time established for geo-referencing is unlikely to be met. Important causes:
    - Cost of equipment
    - Reduced number of professionals
    - Delays in INCRA process
  - New deadlines have recently been set:
    - Law nº 7.620, 21st Nov 2011

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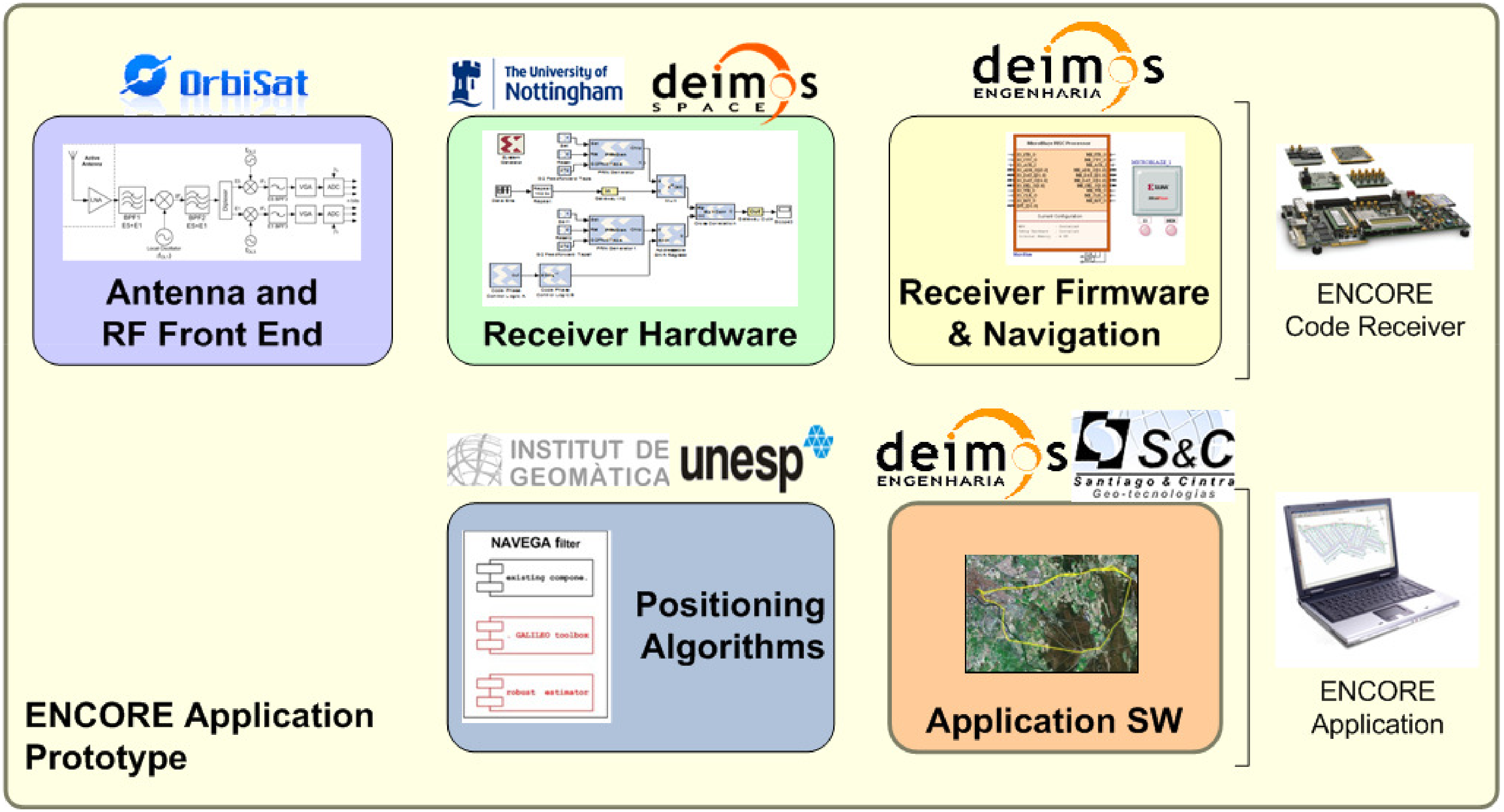
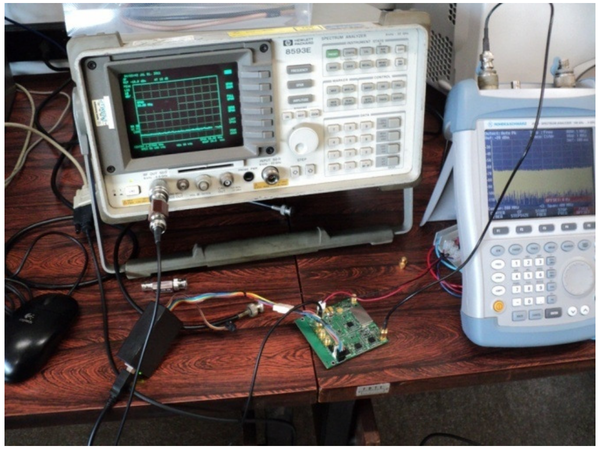
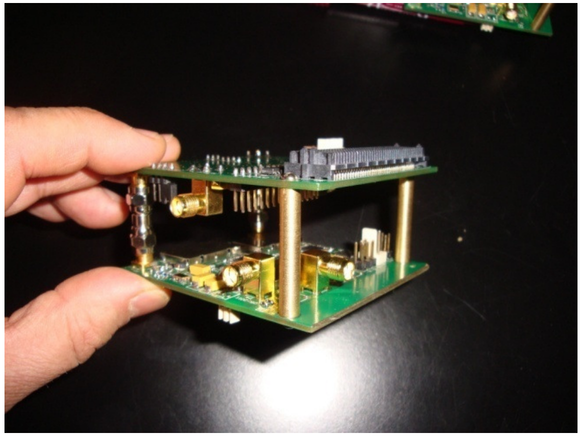
- Architecture overview

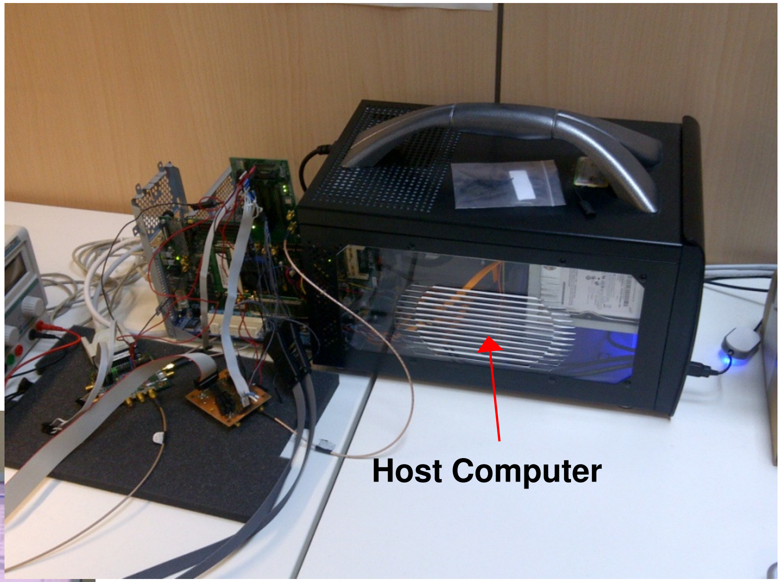


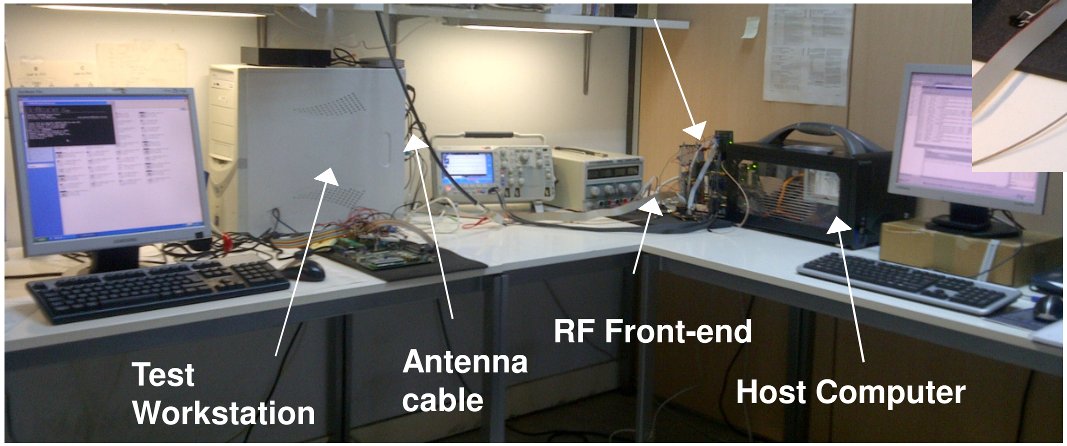
- Antenna and RF Front-end
  - Active Antenna :
    - Passive Element + Low Noise Amplifier
  - RF Converter :
    - Diplexer + RF Filters + Oscillators + Mixers + IF Filters + Amplifiers
  - Analog-to-Digital Converter :
    - IF -2 Filters, AGC Amplifiers, Oscillators, A/D Converters, FMC connector



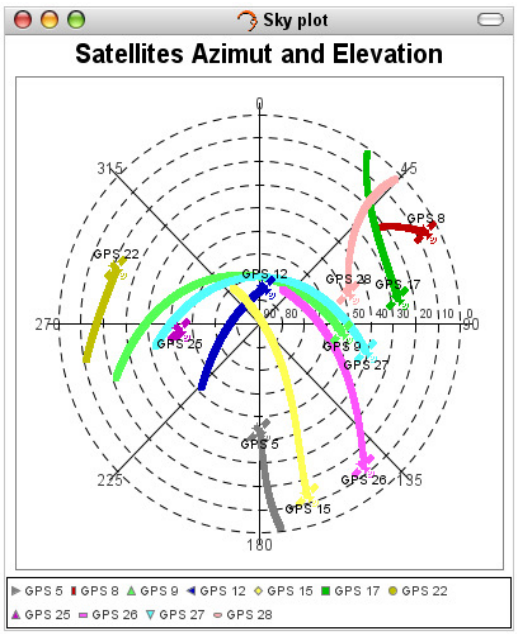


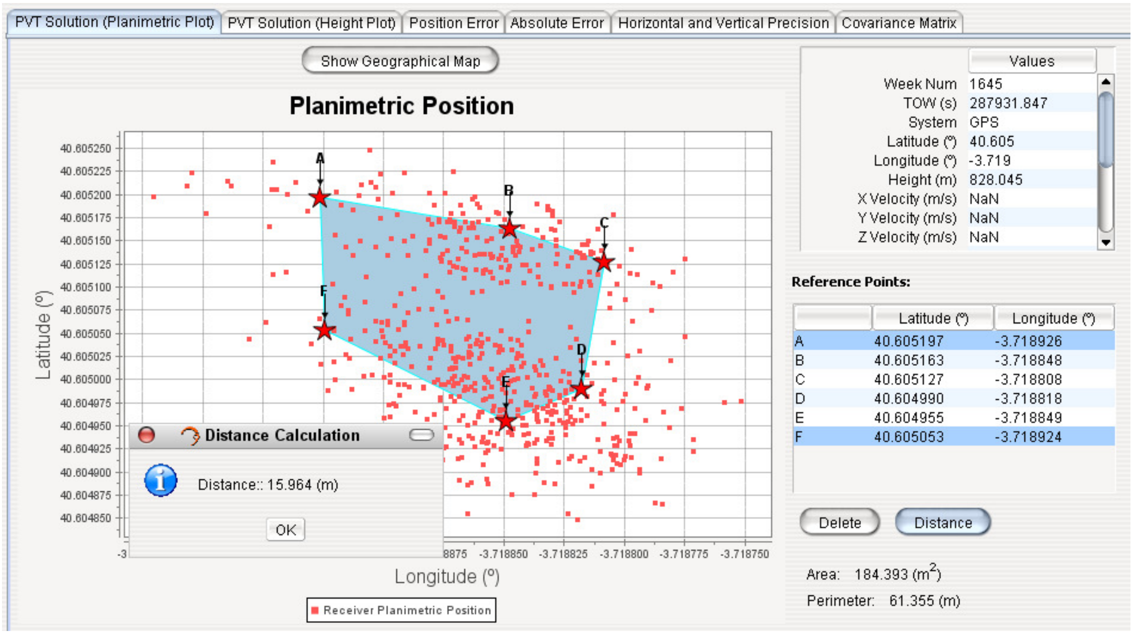
- Receiver Prototype





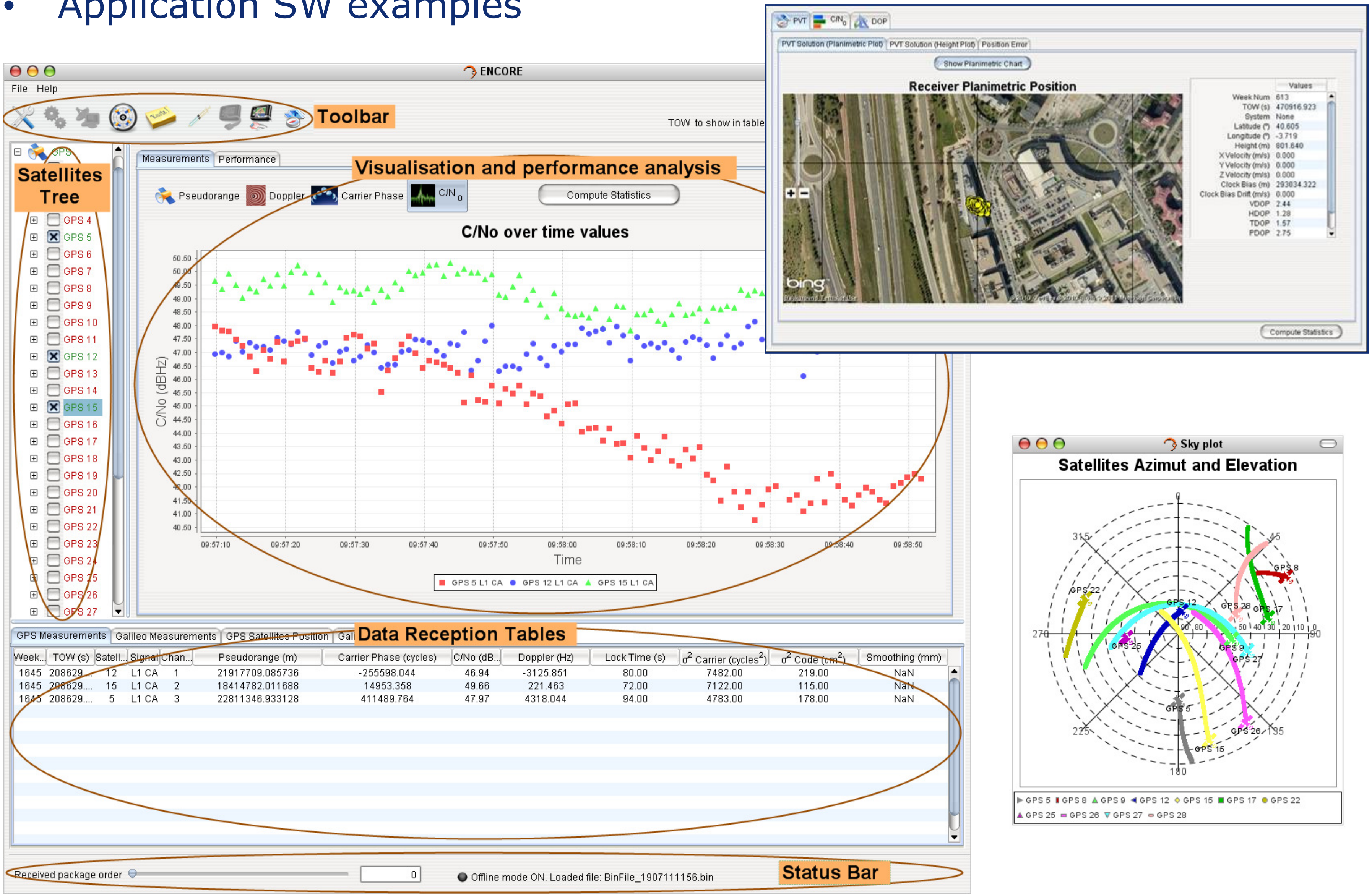
- Application Software
  - Visualization and processing of receiver data
    - Post-Processing or Real-time solution capability
    - Basic data visualization (C/N0, area, perimeter,…)
  - Interface the receiver (TCP/IP proprietary format)
  - Runs on a standard PC but portable to other platforms





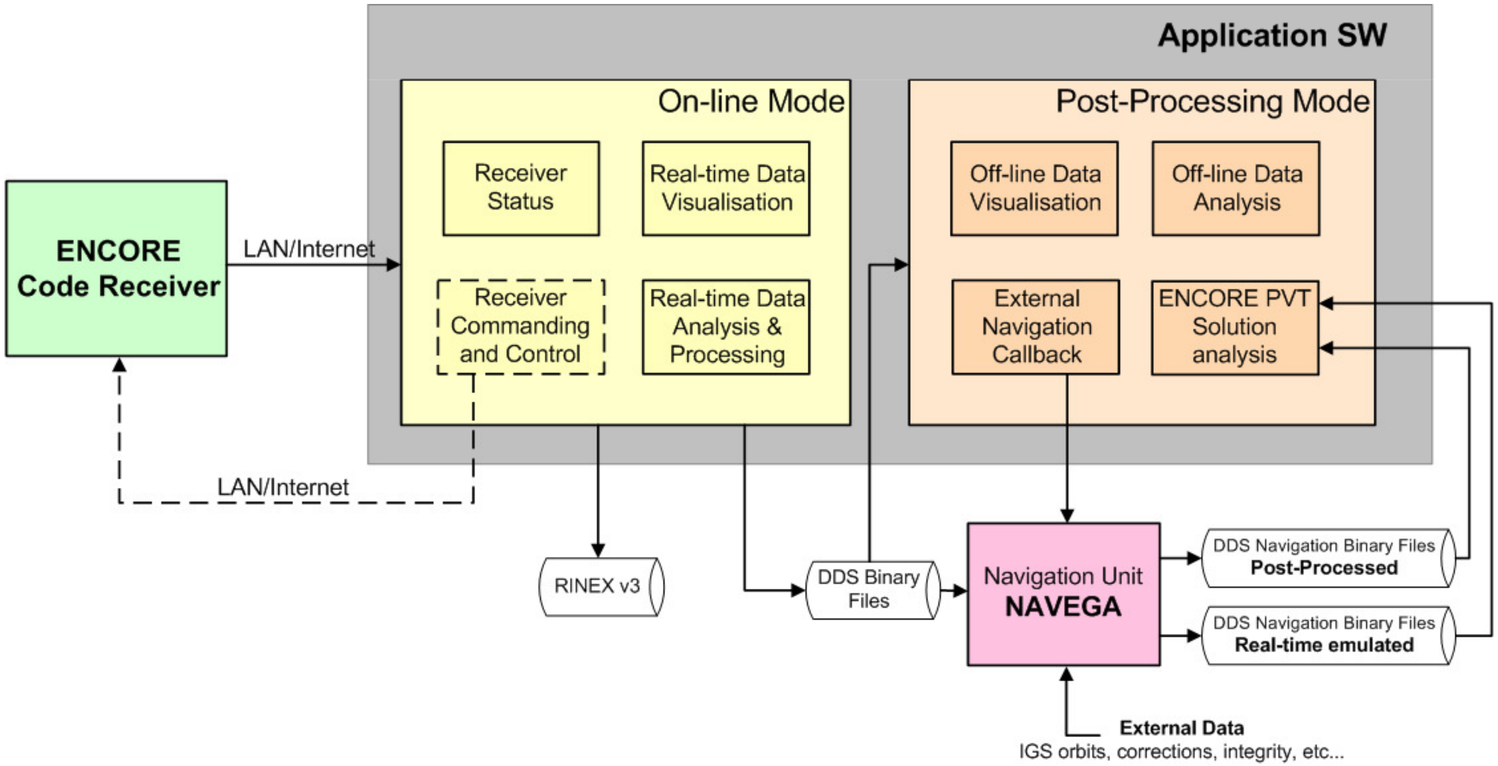
ENCORE System Architecture

- Application SW examples



ENCORE System Architecture

- Application SW is the receiver "companion" tool
  - **On-line mode**: for real-time visualisation and analysis of the received status and generated data
  - **Post-processing mode**: for off-line visualisation and processing of stored data
  - **Output Files generation**: including RINEX v3 and output binary files



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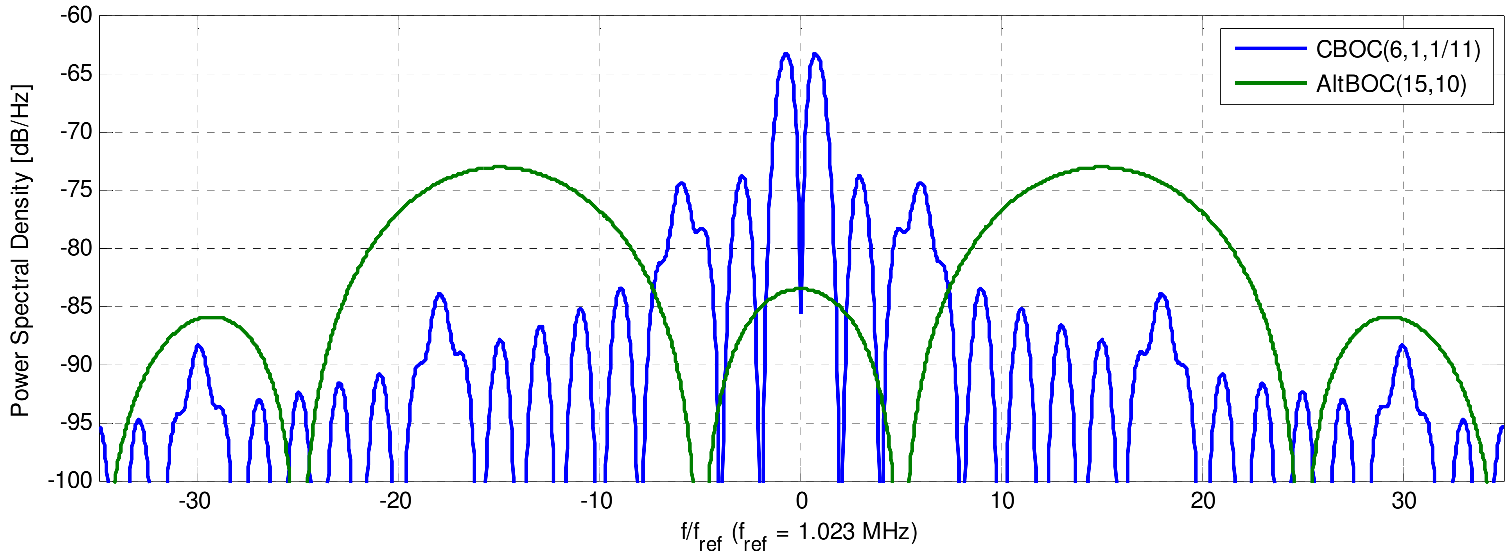
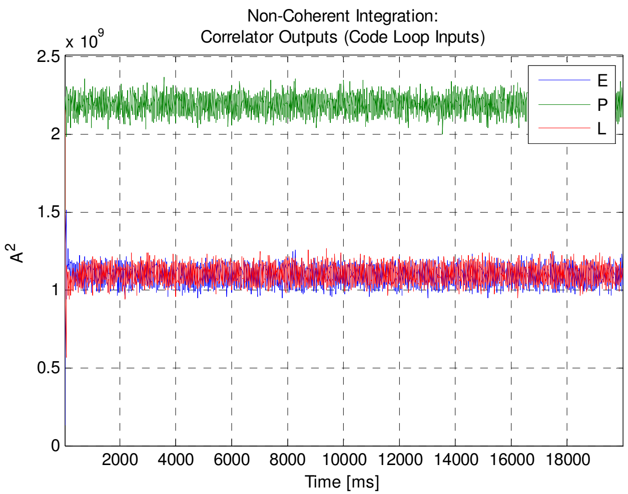
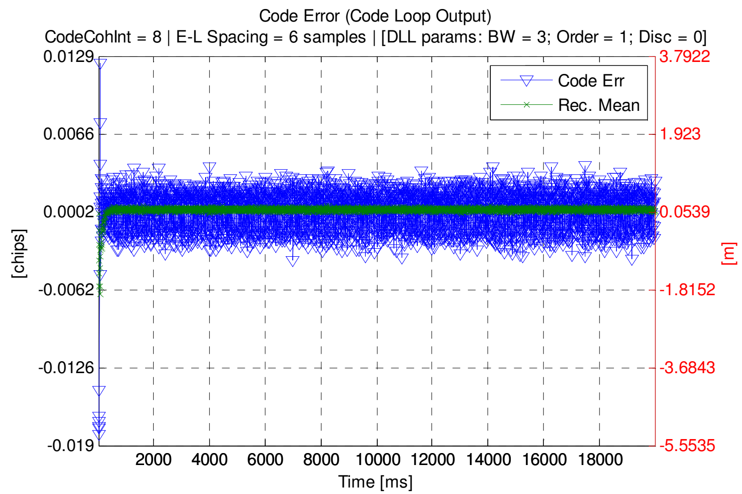
- Different receiver architectures have been studied
  - Main factors considered in the trade-off:
    - Support E1 CBOC and E5 AltBOC
    - Take advantage in terms of accuracy and multipath robustness
    - Minimise HW complexity and resource usage
    - Reuse existing in-house DSP cores
    - Flexibility for upgradeability with minimum HW impact



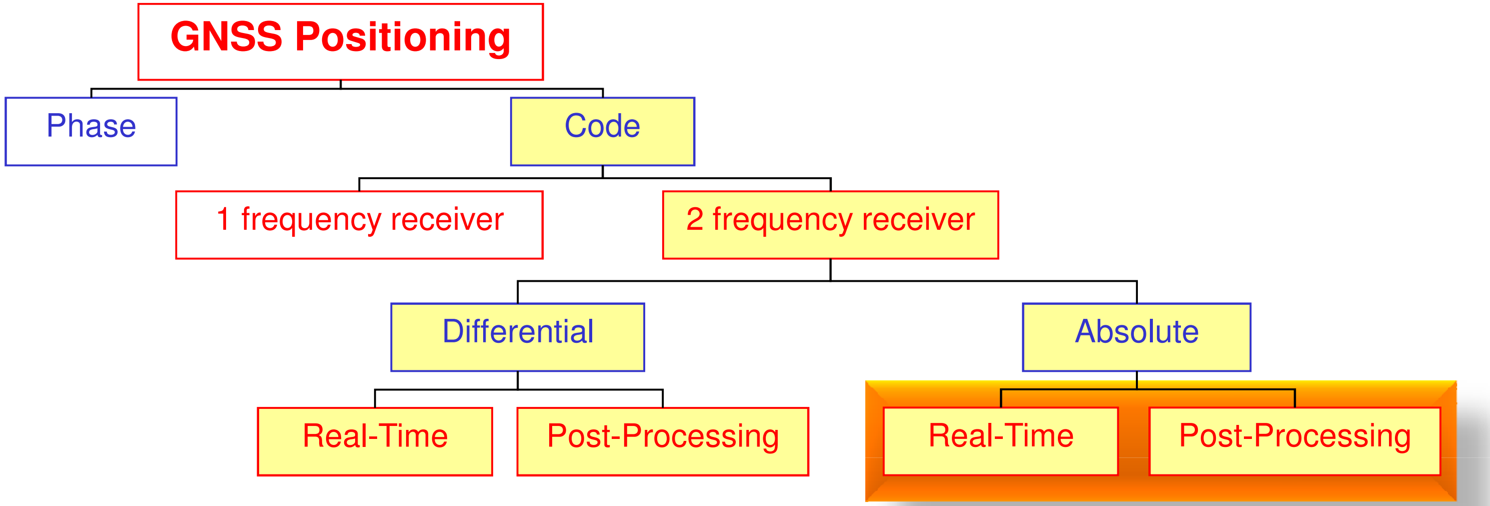
- **E5** Signal Processing strategy
  - Data demodulation and long integration support is required
    - Excluded data–only or pilot only approaches (i.e. use of pilot channels for tracking and data channels for data extraction)
  - Harvest multipath robustness potential of the AltBOC modulation
    - Excluded SSB processing approach (i.e. use coherent double side band processing = “full AltBOC”)
  - Avoid different DSP architectures for AltBOC and MBOC signals
    - Excluded AltLOC approach (i.e. use of AltBOC sub-carrier)
  - Minimize processing gain losses due to simplifications
    - Excluded simpler approaches such as:
      - Binary sub-carrier
      - Real sub-carrier

- **E1** Signal Processing strategy
  - Data demodulation and long integration support is required
    - Excluded data–only or pilot only approaches
  - Harvest accuracy and multipath robustness potential of the CBOC modulation
    - CBOC subcarrier requires higher complexity HW wrt to binary sub-carrier but enables the best performance
  - Avoid different DSP architectures for AltBOC and CBOC signals





- Positioning Algorithms Strategy is inspired on PPP



- Although the receiver is a dual frequency, the positioning algorithm won't be based on iono-free combination (E1 is too noisy);
- Use E5 AltBOC code observables (centimeter errors) with:
  - Specific models to consider ionospheric variaton, receiver biases
  - Satellite orbits & clocks from IGS and tropo from INPE
- Real Time (RT) and Post Process (PP) position determination allowed
- Differential processing is possible but main target is absolute

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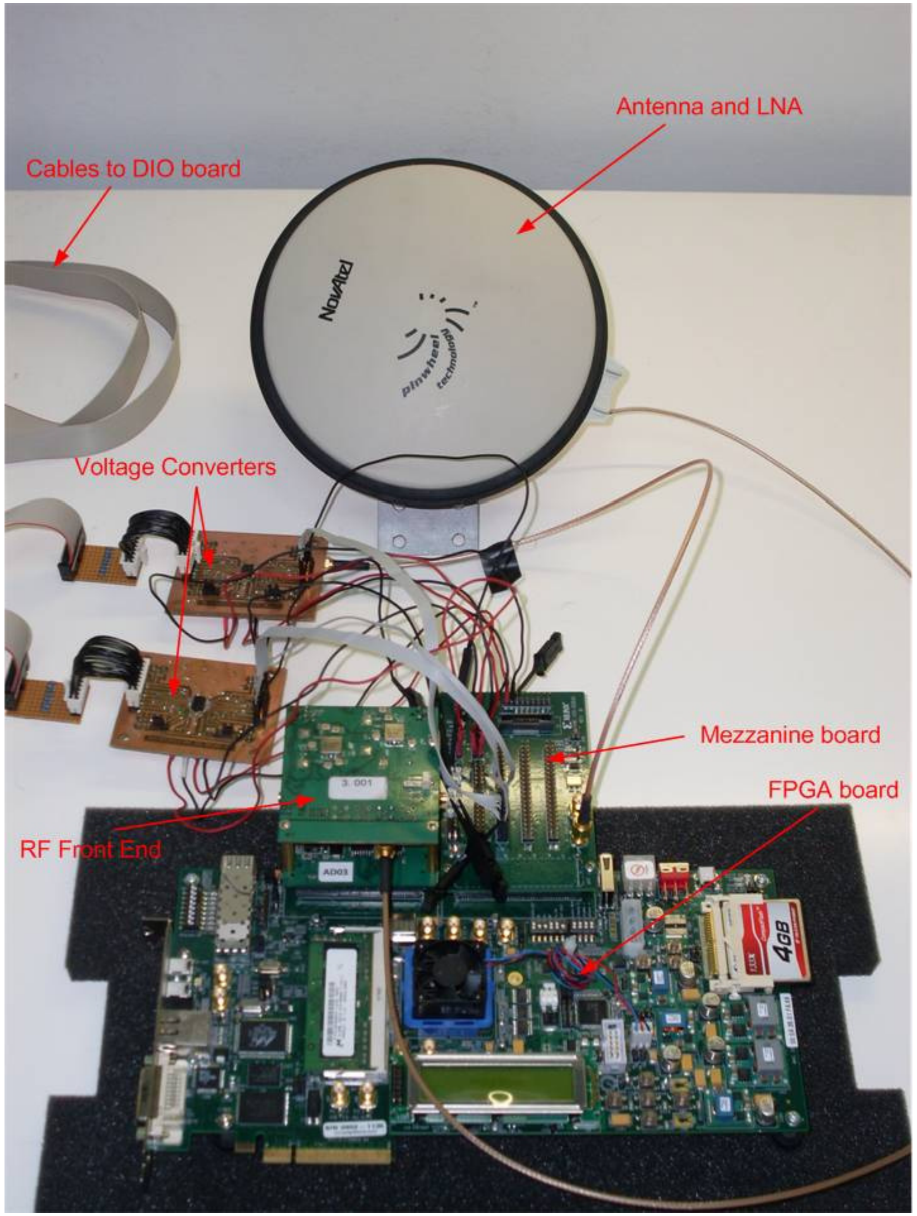
- Tracking Results (1/3)
  - FPGA input setup:
    - » DIO Board
      - Synthetic
      - Recorded

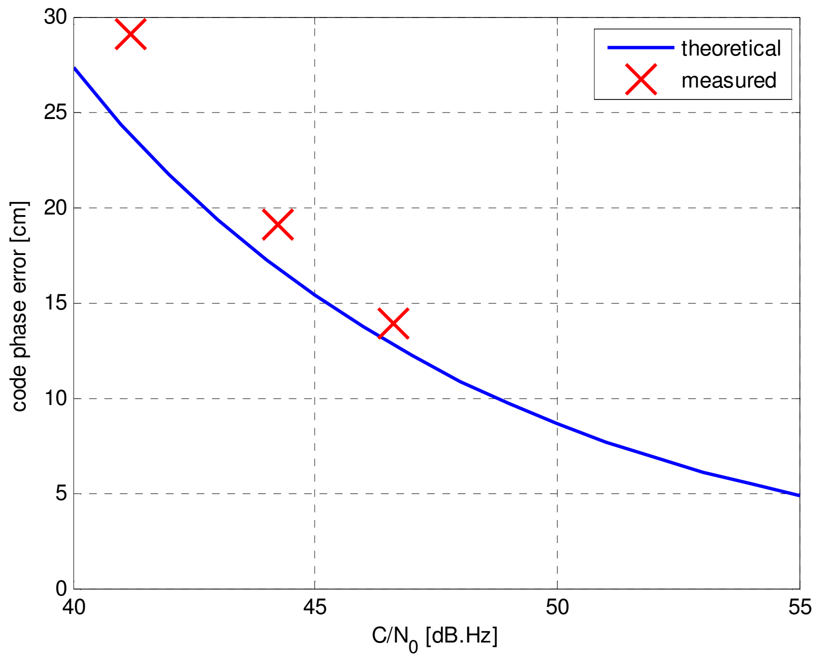
      OR
    - » Antenna + RF FE



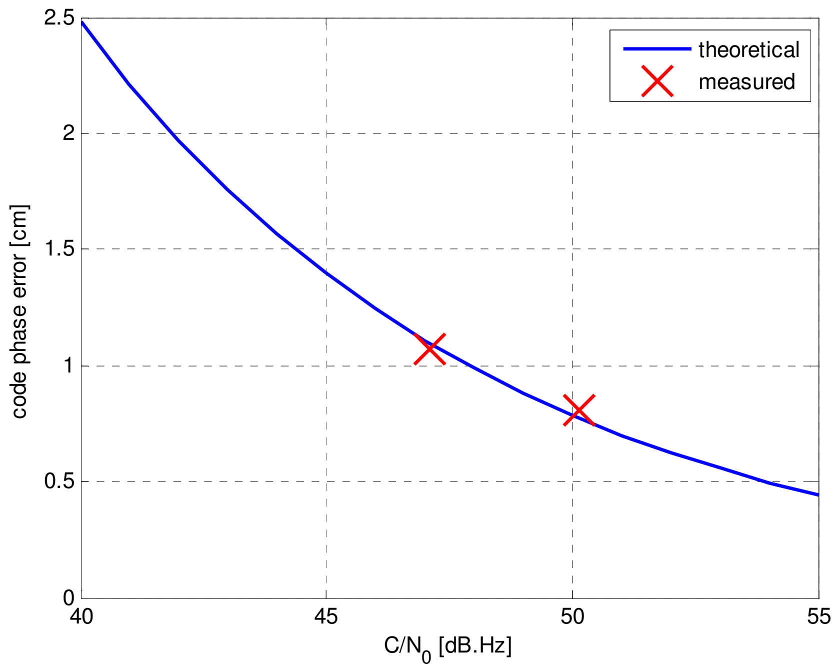
- Tracking Results (2/3)
  - GNSS receiver was fed with synthetic E1 CBOC(6,1,1/11) and E5 AltBOC (15,10) signals with different powers

Parameters	Values	
Signal	E1 CBOC	E5 AltBOC
Integration period [ms]	4	1
E-L spacing [chip]	0.0853	0.1705
Code discriminator	E-L Power	
Code loop bandwidth [Hz]	1	
Carrier discriminator	Q/I	
Carrier loop bandwidth [Hz]	4	
Pre-correlation sampling frequency [MHz]	120	

- Tracking Results (3/3)
  - Overall agreement of theoretical and measured data
    - E1 code tracking error typically below **20 cm** (>44dBHz)
    - E5 code tracking error typically below **1.5 cm** (>47dBHz)



E1 CBOC



E5 AltBOC

First Results

- Positioning Results for E1/E5 combination
  - First results based on a set of synthetic RINEX data

Station name	BRAZ
Station type	Static
Station position (λ, ϕ, h)	15º 56' 50.9112" S, 47º 52' 40.3283" W, 1106.02 m
Orbits	Galileo, 18 satellites
Dates and duration	2007-04-16, 12h and 2007-04-21, 12h
Ionosphere	TEC maps for the simulation dates (nominal ionosphere)
Troposphere	EGNOS troposphere model with 0.05m coloured noise applied
Receiver clock error	0.8 ns
BGD estimation error (1-σ)	0.5m for (E1 E5a) and 0.5m for (E1 E5b)
Epoch interval	300s
Elevation mask	10 º
Orbit errors (1-σ)	radial: 0.1, along-track: 0.52, cross-track: 0.14m, satellite clock: 0.3 ns
Front-End filter	52 MHz double-sided / all frequencies
DLL mode	Dot Product model, 1Hz loop bandwidth for all codes

- Point Positioning Results for E1/E5 combination (cont'd)
  - Kinematic (K) and static (S) processing for day 12/4 and 21/4
    - Horizontal precisions (σ) (estimated std deviation) at the cm-level, from **0.01 m to 0.03 m**
    - Horizontal accuracies (μ) (true v.s. estimate) at dm level, from **-0.16 m to 0.12 m**

	ENU position errors						clock (m)	
Test	μ_E	μ_N	μ_h	σ_E	σ_N	σ_h	μ	σ
S-16	-0.16	0.12	-0.36	0.02	0.03	0.06	0.52	0.06
K-16	-0.13	0.10	-0.36	0.02	0.03	0.25	0.54	0.18
S-21	-0.14	0.12	0.29	0.03	0.01	0.11	0.16	0.35
K-21	-0.12	0.12	0.18	0.02	0.03	0.14	0.20	0.36
average no. of satellites: 5.8 (S-16, K-16), 6.1 (S-21, K-21)								

  - Ongoing tests with different setups
    - With and without GPS L1/L5, static and kinematic receivers, RT and PP modes, precision and broadcast orbits.

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Conclusions

- ENCORE is exploring Galileo signals and…
  - is an on-going project which is undergoing testing and validation;
  - is developing an application in the Brazilian context, including:
    - Receiver prototype implemented on a FGPA based on the novel **Galileo** signal characteristics
    - Specific exploitation of **Galileo** AltBOC signal capabilities with great potential in the survey community
    - A dedicated RF Front-end and antenna for E5 and E1
    - Positioning algorithms for surveying and mapping applications
  - is specially suited when cost, multipath robustness and infrastructure requirements are critical, e.g. remote areas, mapping…

THANK YOU!

Project website: http://www.encoreproject.org