Performance and Interoperability of GPS/Galileo Receivers and Observables

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Septentrio satellite navigation

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Overview

- Review of the new GNSS signals and observable types (RINEX v3.0)

- Comparison of the observable types in terms of instrumental errors and biases

- Current Galileo activities and experimentations with GIOVE-A

New GNSS Signals

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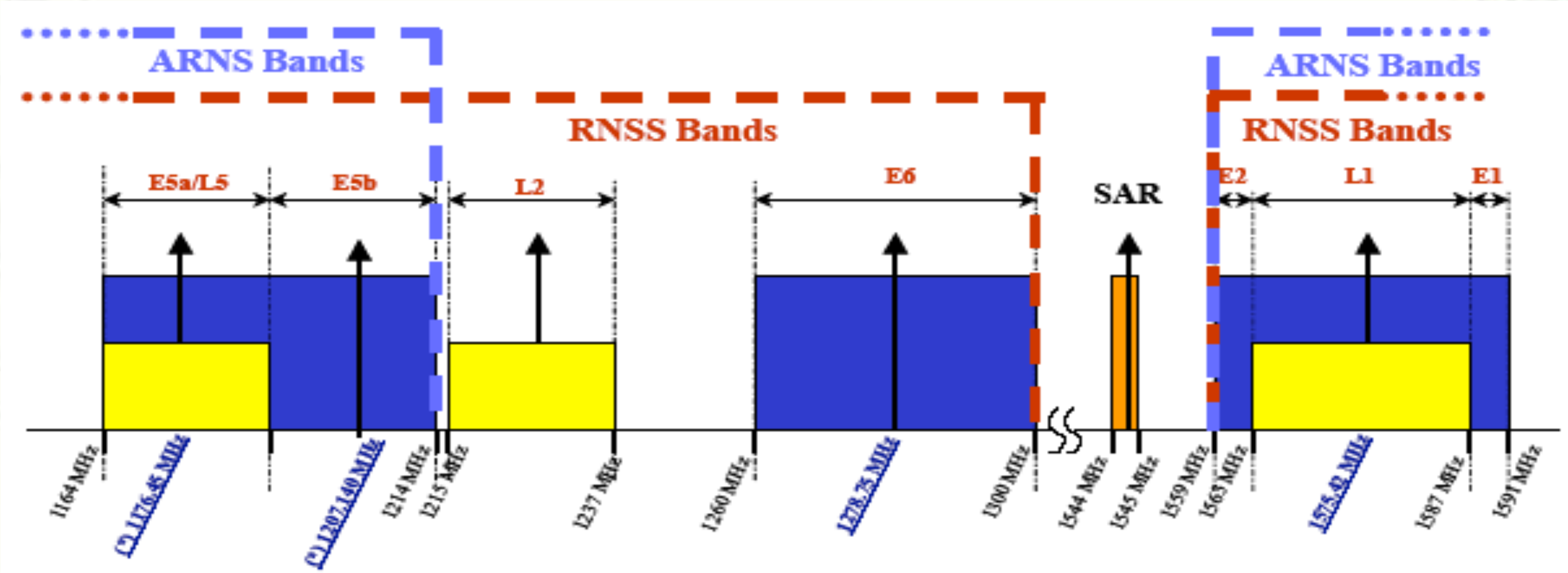

- Four new carriers (E5a, E5b, E5(AltBOC), E6);
- Presence of a Pilot (data-less) component on all new signals;
- Better modulation, with largely reduced tracking noise and multipath errors;
- Better navigation bits encoding (3 levels of error checking).

Pilot vs. Data Component

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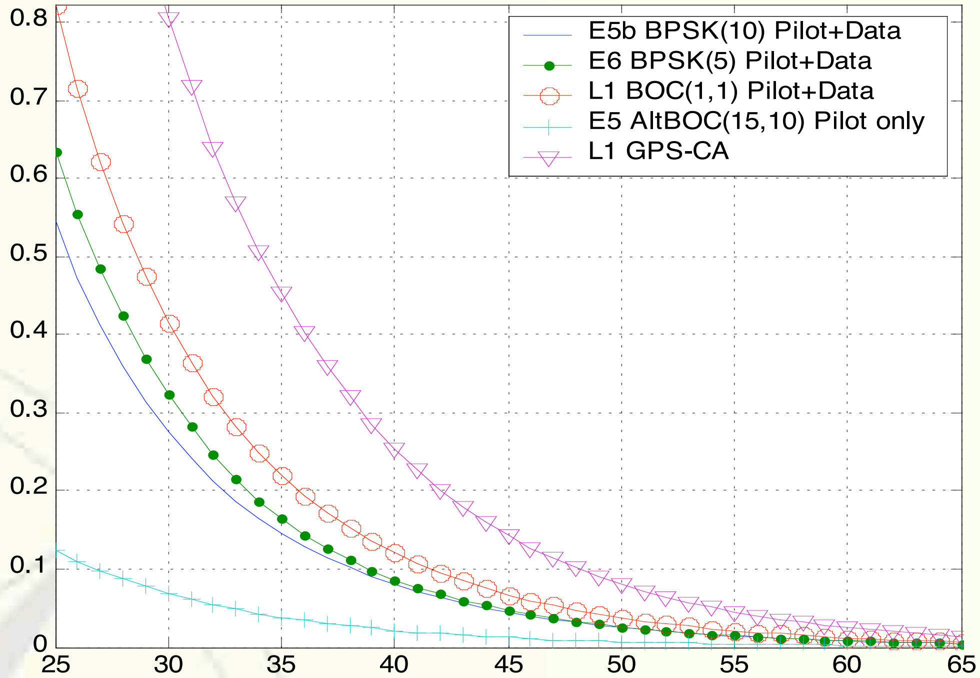
- All new signals are split in a data-bearing component and a data-less component (Pilot).
- Current GPS signals (except L2C) have no Pilot component. Receivers track the Data channel.
- Receiver tracking Pilot will benefit from:
  - More robust tracking, no ½ cycle slip, lower noise, faster carrier phase reacquisition.
- Receivers will have the choice to track the data or the Pilot component, or both → many new observable types, defined in RINEX v3.0.

New GNSS Observables (RINEX v3.0)

System	Freq. Band	Frequency	Channel or Code		Observation Codes			
					Pseudo Range	Carrier Phase	Doppler	Signal Strength
Galileo	E2-L1-E1	1575.42	A	PRS	C1A	L1A	D1A	S1A
			B	OS/CS/SoL	C1B	L1B	D1B	S1B
			C	no data	C1C	L1C	D1C	S1C
			B+C		C1X	L1X	D1X	S1X
			A+B+C		C1Z	L1Z	D1Z	S1Z
	E5a	1176.45	I	OS	C5I	L5I	D5I	S5I
			Q	no data	C5Q	L5Q	D5Q	S5Q
			I+Q		C5X	L5X	D5X	S5X
	E5b	1207.140	I	OS/CS/SoL	C7I	L7I	D7I	S7I
			Q	no data	C7Q	L7Q	D7Q	S7Q
			I+Q		C7X	L7X	D7X	S7X
	E5a+b (AltBOC)	1191.795	I		C8I	L8I	D8I	S8I
			Q		C8Q	L8Q	D8Q	S8Q
			I+Q		C8X	L8X	D8X	S8X
	E6	1278.75	A	PRS	C6A	L6A	D6A	S6A
			B	CS	C6B	L6B	D6B	S6B
			C	no data	C6C	L6C	D6C	S6C
			B+C		C6X	L6X	D6X	S6X
			A+B+C		C6Z	L6Z	D6Z	S6Z

Thermal Noise Error

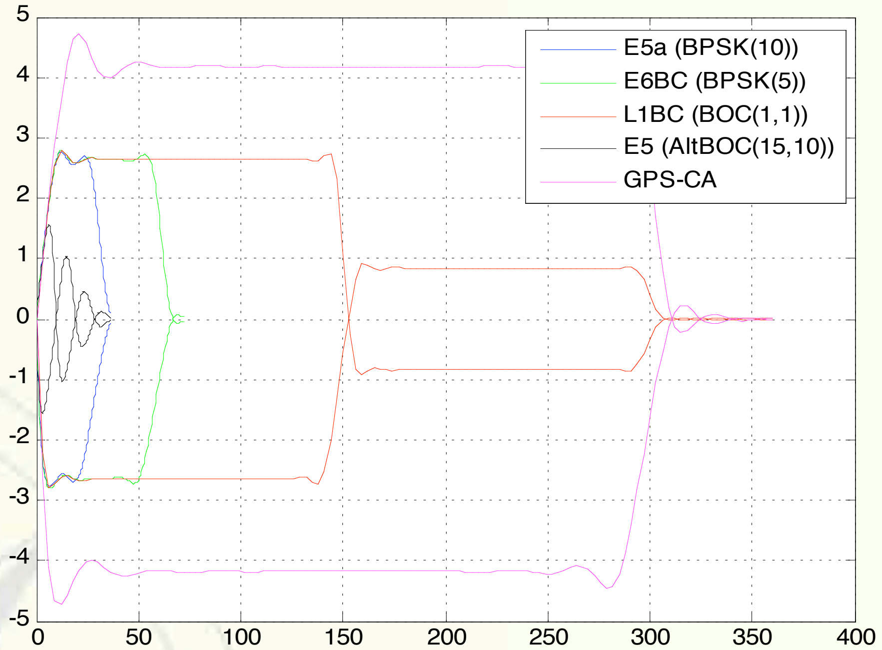
- Pseudorange thermal noise largely improved compared to current GPS.



- Carrier thermal noise not improved.
- Pilot and Data noise samples are independent. Pilot noise lower at low C/N_0

Multipath Error

- Code MP error largely improved compared to current GPS.



- Phase MP error slightly improved.
- Pilot and Data have exactly the same multipath error.

Satellite Pilot/Data Biases

Signal type	Multiplexing scheme	P/D phase bias (degrees)	P/D code bias (ns, 2σ)
GPS L5	QPSK	90+/-5.7 (*)	<10 (*)
GAL E5a,b,AltBOC	AltBOC	90+/-TBD	0 (TBC)
GAL L1	CASM	180	0 (TBC)
GAL E6	CASM	180	0 (TBC)

(*) ICD-GPS-705

- GPS:
  - Nav frame contains Inter-Signal Correction (ISC)

201	207	215	223	231	239	247	263	268	273	277
Δt_{LSF} 6 LSBs	T_{GD} 8 BITS	$ISC_{L1C/A}$ 8 BITS	ISC_{L2C} 8 BITS	ISC_{L5I5} 8 BITS	ISC_{L5Q5} 8 BITS	Reserved for L5 16 BITS	5 BITS	5 BITS	4 BITS	CRC 24 BITS

$$ISC_{L5I5} = t_{L1P} - t_{L5I5}$$

$$ISC_{L5Q5} = t_{L1P} - t_{L5Q5}$$

- Galileo:
  - Expected no P/D code bias, and no phase bias in L1 and E6;
  - Expected similar phase quadrature error as GPS L5 in the E5 band.

Receiver Pilot/Data Biases

- Pilot and Data have exactly the same satellite-independent hardware delay and phase shift in receiver;
- Galileo E5a and GPS L5 have exactly the same hardware delay and phase shift.
- L1 Galileo and L1-CA GPS have very small differential delay (<1ns) (will disappear with new GPS L1C);
- All measurements sampled at the same time!

Pilot/Data Comparison: Summary

- Thermal noise independent on Pilot and Data
  - → Combined tracking helps reducing the noise term
- Multipath identical on Pilot and Data
  - → No multipath reduction by using Pilot
- Optimal tracking scheme:
  - For Code tracking,
    - Pilot-only, or combined Pilot/Data (assuming no P/D biases)
  - For Carrier tracking:
    - Pilot-only. Combined tracking is not recommended because of the ½ cycle slips.
- Data observables may have different code/phase biases than Pilot observables.

Noise and Pilot/Data Bias Estimation

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- Difference between Pilot and Data observables only contains thermal noise and inter-signal biases:

$$PR_P - PR_D = Bias_{PR} + \Delta n_{PR}$$
$$\Phi_P - \Phi_D = Bias_{\Phi} + \Delta n_{\Phi} + (N + MultiplexingAngle)$$

- Direct way of measuring sub-millimeter Pilot-Data biases, and of assessing the noise statistics.

- Requires flexible user-configurable tracking algorithm in receiver.

Ionospheric Dispersion in E5 band

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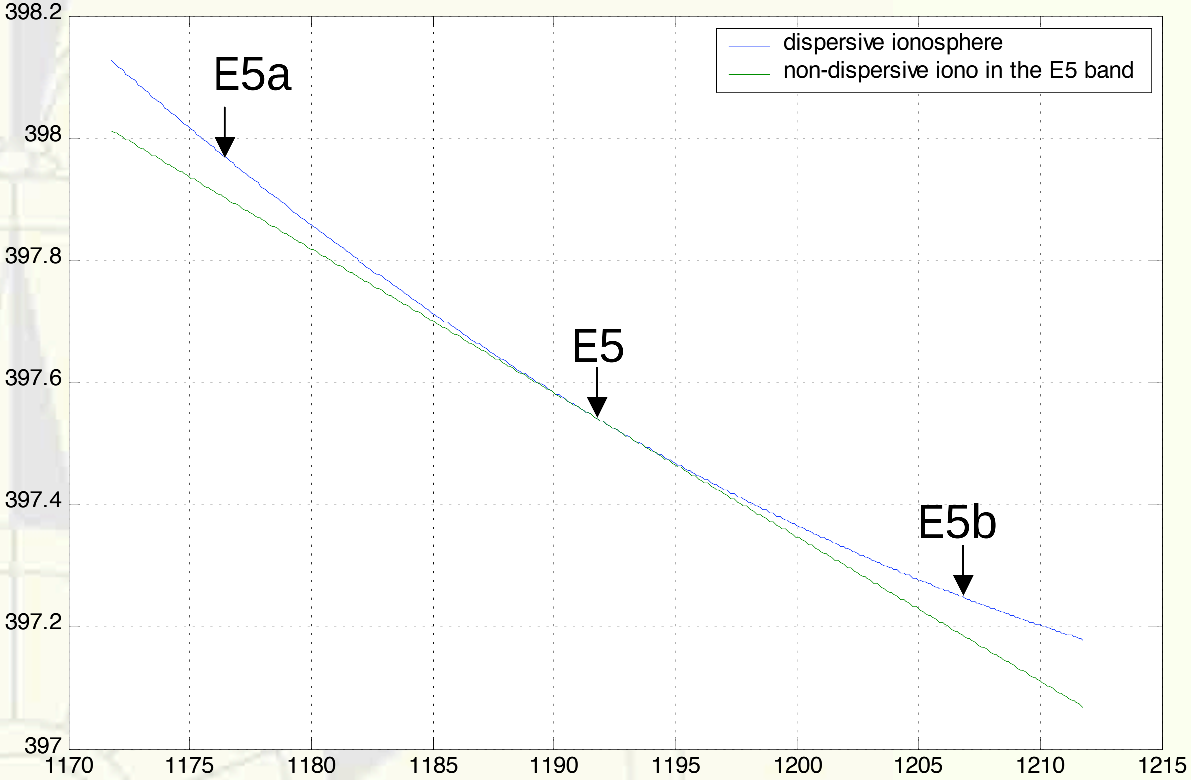
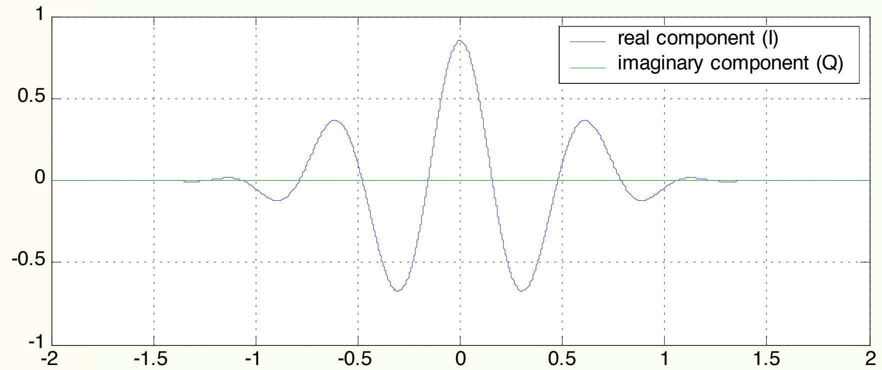
- Ionosphere delay different in E5a and E5b
  - → Signal distortion?



$$\varphi(f) = I_0 \frac{f_{E5}^2}{f}$$

Effect on Correlation

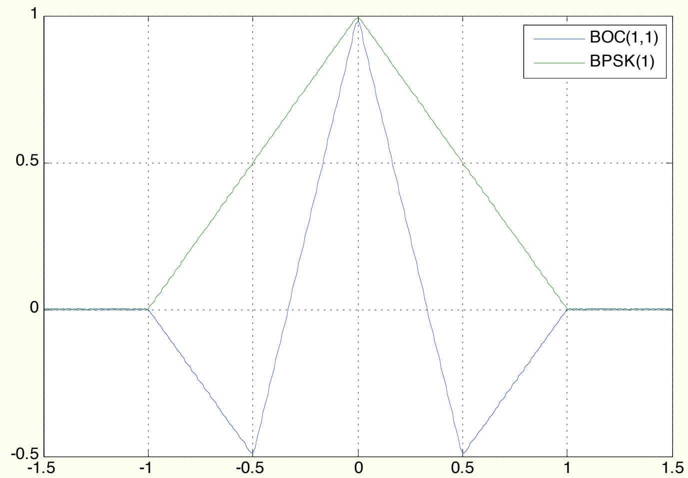
- Ionosphere causes an a slight distortion of the correlation peak. Worst case:
  - Rotation: <2cm
  - Shift: <5cm
  - Amplitude loss: <2%



- Likely negligible for all practical applications

Other Potential Issues

- Galileo uses BOC modulations
  - Multi-peak correlation
    - Wrong tracking possible, but with very low probability



Current Galileo Activities

GSTB-V2 / A

GSTB-V2 / B

- GSTB-V2 objectives:
  - Frequency filing
  - Evaluation of MEO environment
  - On board clock characterization
  - Analysis of signal performance
    - Thermal noise and multipath
    - Code/Code and Carrier/Carrier coherency
    - Correlation peak
    - Chip pulse shape
    - Interference

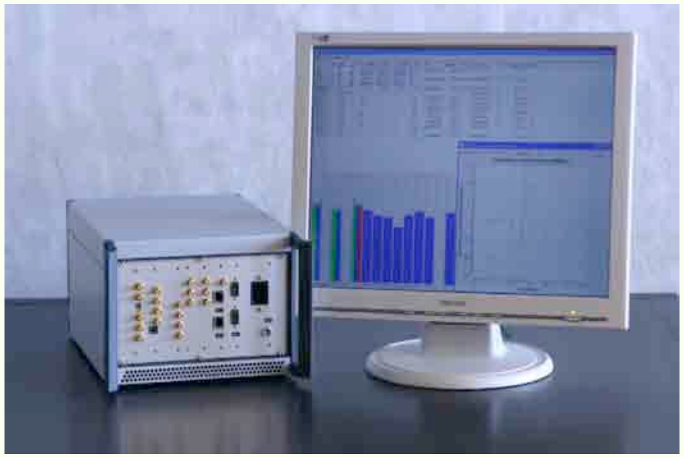
Receiver and Antenna

Galileo reference antenna (Space Engineering)

- All GPS/Galileo wide bands (E5, E6, L2, L1)

GeNeRx : dual-mode GPS/Galileo receiver (Septentrio)

- Receiving signals from GIOVE-A (since Jan '06)
- 6 fully flexible channels + 1 AltBOC
- All types of Galileo signals+GPS L5
- Incl. GPS all-in-view L1/L2 receiver
- Large flexibility of tracking parameters
- Upgradable to Galileo IOV constellation
- 1PPS in for time transfer



Preliminary Results

Signal type	Code tracking noise (cm) referred to 45dB -Hz
L1BC_x	8
E5a/E5b	6
E6BC	6
E5	1.5
E6A	2
L1A_x	2

Signal type	Carrier tracking noise (mm) referred to 45dB -Hz
L1_x	1.0
E6_x	1.1
E5_x	1.3