GNSS Interference Mitigation: a Measurement and Position Domain Assessment

D. Borio and C. Gioia

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Introduction

Growing number of interference and jamming events reported all around the world (e.g./ www.gnss-strike3.eu)

Re-think receiver design
including **interference mitigation capabilities**

visited on
Apr 14/21

Greetuny Posizionamento Scudo Mini GPS Plus Beidou Scudo di Posizionamento Doppia modalit?Accendisigari Accendisigari Alimentazione 12-24V (Colore:Nero)

Marca: Greetuny

20 voti

Prezzo: 14,99 €

Tutti i prezzi includono l'IVA.

Nuovo (2) da 14,99 € + 4,99 € di spedizione

- Prevenire efficacemente il posizionamento satellitare GPS, il posizionamento satellitare Beidou interferisce in modo efficace con i segnali satellitari GPS
- non influisce sulla normale ricezione dei telefoni cellulari
- alta potenza, piccola leggerezza, copertura Grande, facile da trasportare, impedisce efficacemente il posizionamento del sistema di posizionamento satellitare GPS auto / mobile!
- Quando lo scudo è utile, conservarlo in un luogo asciutto e ben ventilato per evitare un'esposizione prolungata a nebbia salina e gas nocivi
- Quando si pulisce la superficie, si prega di interrompere l'uso di solventi chimici per evitare l'accumulo di acqua nella macchina

› Visualizza altri dettagli prodotto

Jammers still easily available even on popular **e-commerce platforms**

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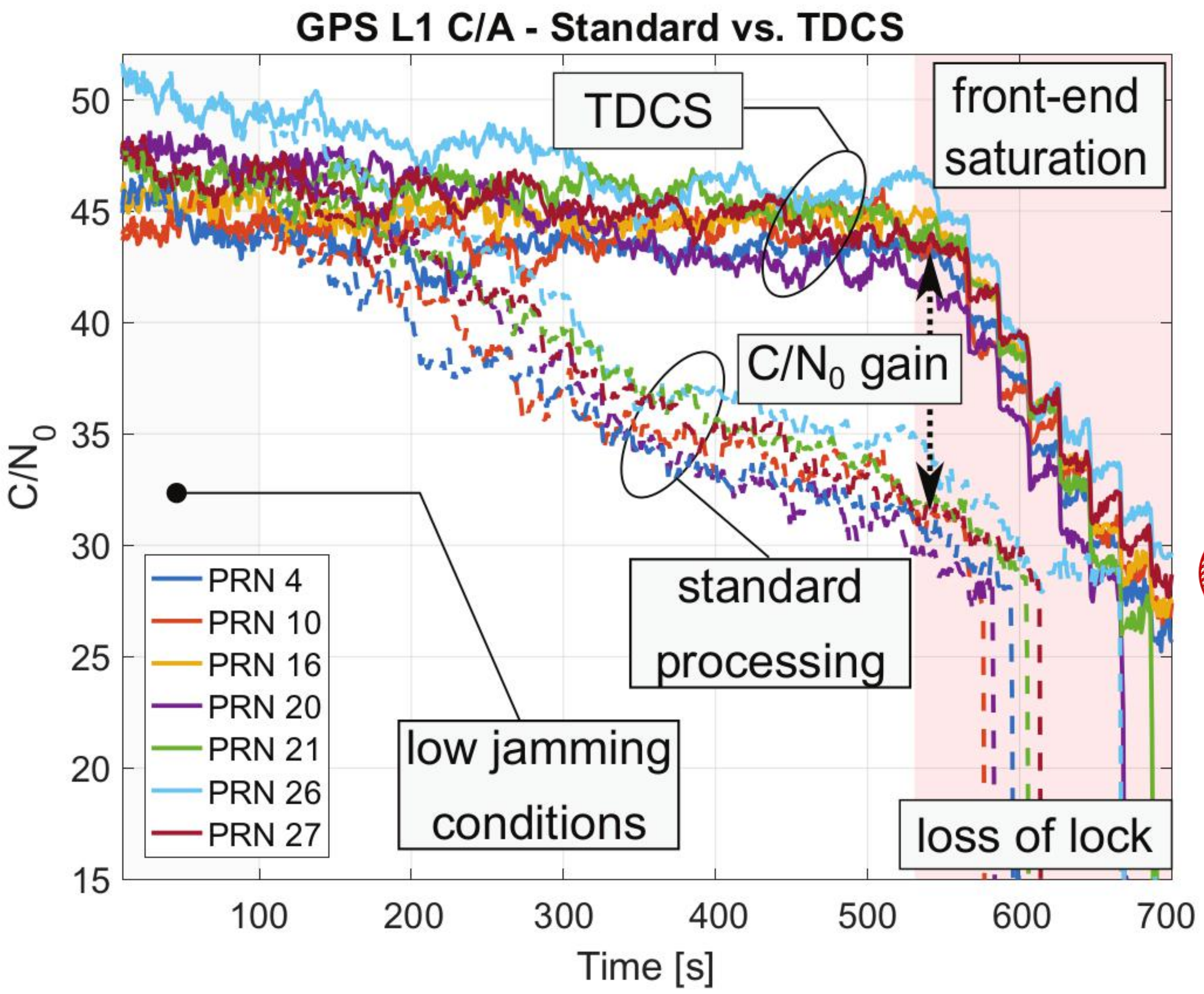
Beyond the Effective C/N_0



Interference mitigation (IM)
often evaluated in terms of **effective C/N_0**

how many dB IM provides?

Effective C/N_0: does not tell the full story!
Biases, distortions, loss of efficiency not accounted for

Goals

Experimentally evaluate the effect of interference mitigation techniques on **pseudoranges** and **position solution**

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Agenda

Introduction

Interference Mitigation: Review and Demo

Experimental Setup

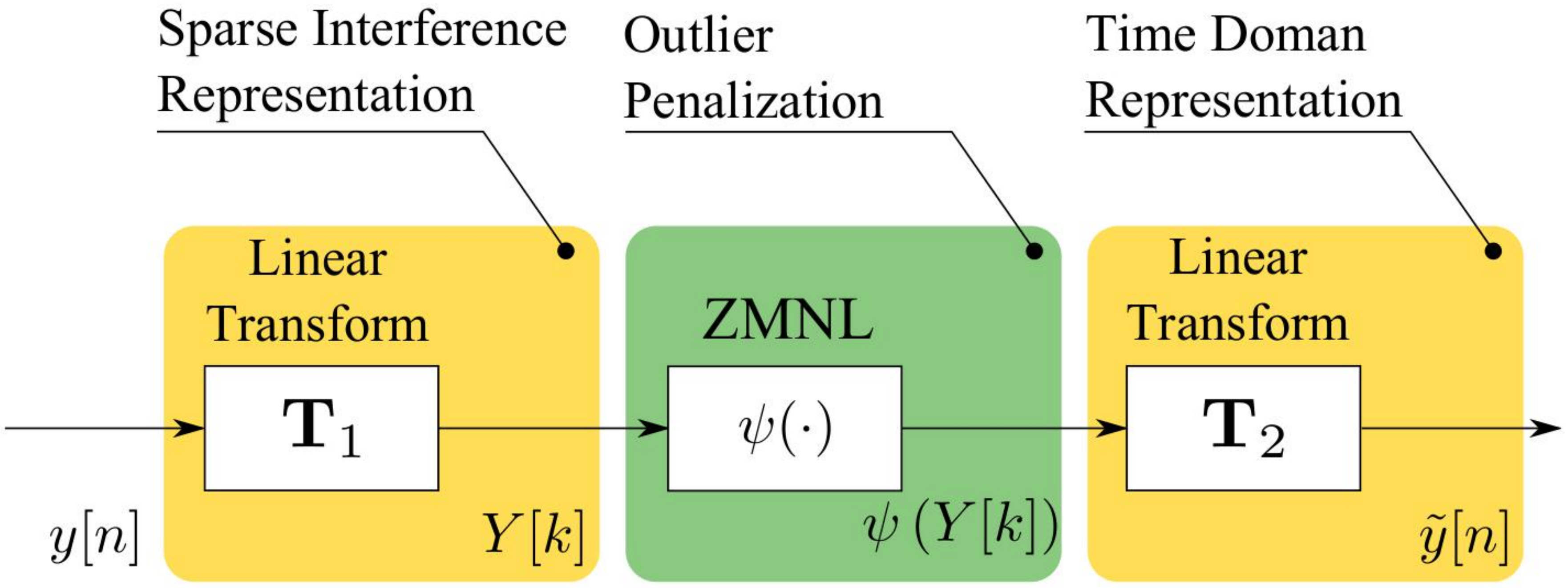
Experimental Results

Conclusions

Code and data samples available at:

https://github.com/borioda/gnss_jamming_demo

Robust Interference Mitigation



Four techniques:

- Time Domain Pulse Blanking (**TDPB**)
- Time Domain Complex Signum (**TDCS**)
- Frequency Domain Pulse Blanking (**FDPB**)
- Frequency Domain Complex Signum (**FDCS**)

Three Steps:

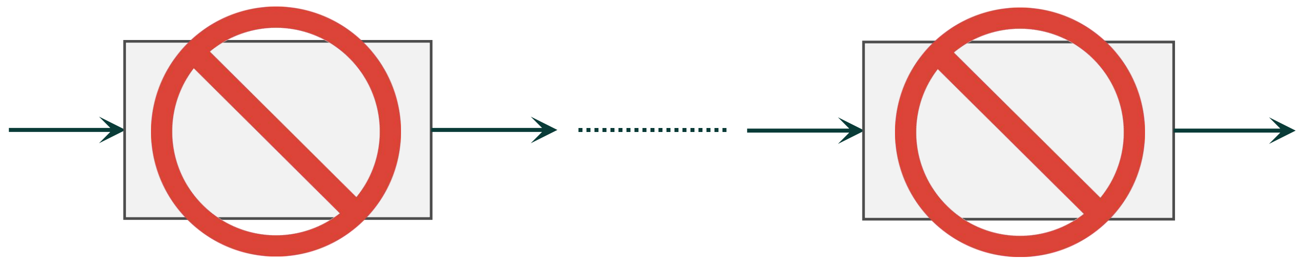
1) **Linear Transform,** $\mathbf{T}_1(\cdot)$: bring the samples in a domain where **interference is sparse**

2) **Zero-Memory Non-Linearity,** $\psi(\cdot)$: **penalize** the impact of **outliers**

3) **Second Linear Transform,** $\mathbf{T}_2(\cdot)$: samples back in the **time domain**

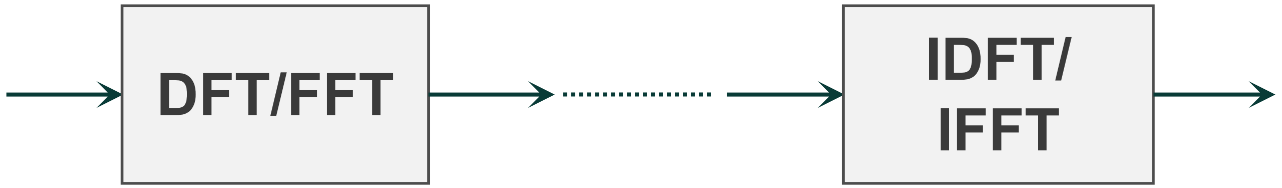
Transforms and Non-Linearities

Time Domain



No Transform needed (**filtering could be used**)

Frequency Domain



Periodic interference signals (**CW, swept**)
have a **line** (**sparse**) spectrum

Frequency excision techniques

Complex Signum

$$\psi\left(Y[k]\right) = \begin{cases} \dfrac{Y[k]}{|Y[k]|} & \text{if } Y[k] \neq 0 \\ 0 & \text{if } Y[k] = 0 \end{cases}$$

Use phase information only

Pulse Blanking

$$\psi\left(Y[k]\right) = \begin{cases} Y[k] & \text{if } \left|Y[k]\right| < T_h \\ 0 & \text{otherwise} \end{cases}$$

T_h: decision threshold

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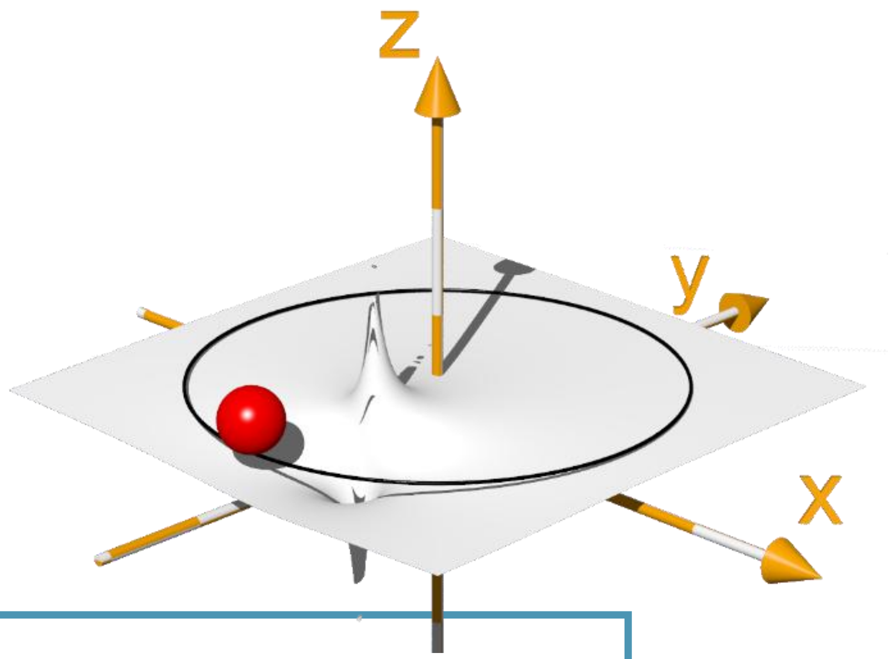
Adaptive Notch Filter



Remove **instantaneously narrowband interference** by applying a notch in the frequency domain

Filter transfer function

$$H_{ANF}(z) = \frac{\boxed{1 - z_0 z^{-1}}}{1 - k_\alpha z_0 z^{-1}}$$

Pole contraction factor

$$0 \leq k_\alpha < 1$$

k_α close to 1: **narrow** frequency notch
slower **adaptation**, closer to **instability**

Notch frequency

$$z_0 = A_0 \exp\left\{ j 2\pi \frac{\boxed{f_0}}{f_s} \right\}$$

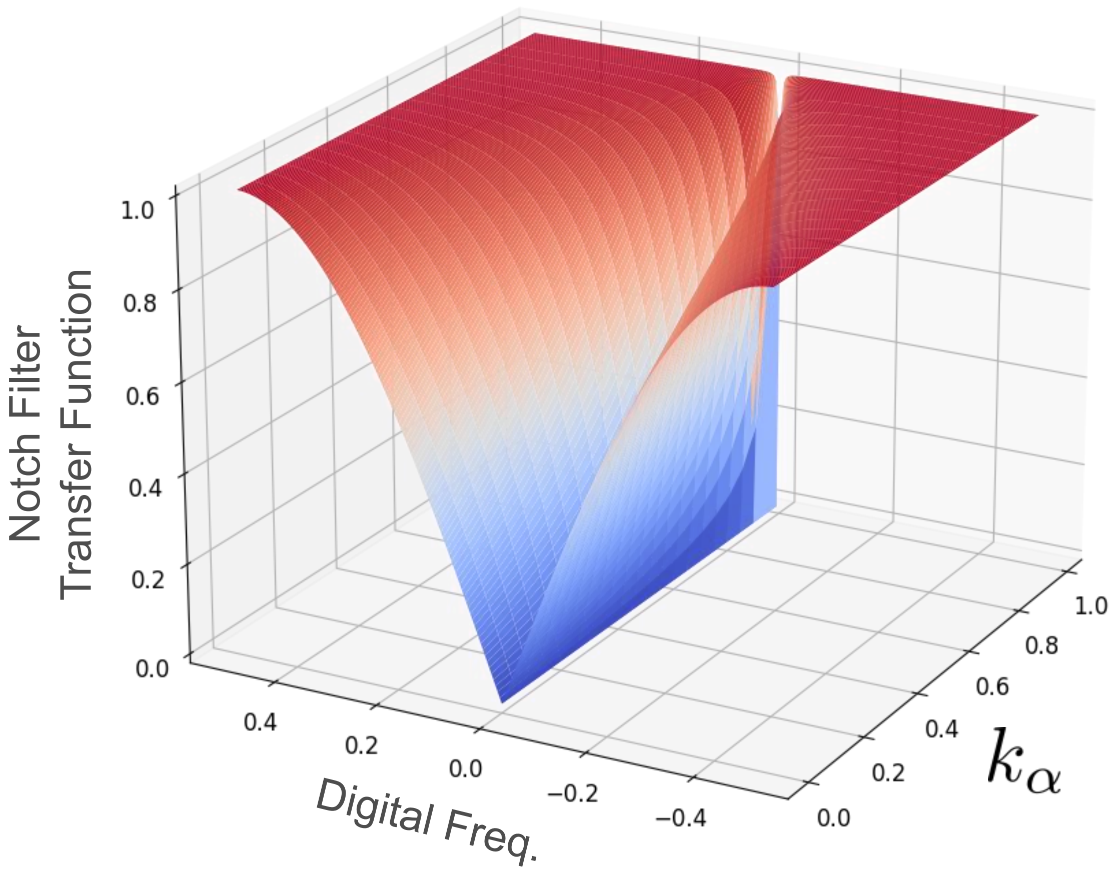
track interference frequency

Effective for signals of the type:

$$i[n] \approx z_0 i[n-1]$$

Adaptation Process

z_0 estimated epoch by epoch:
minimization of the **energy of the output signal**



gradient descent algorithm:

adaptation step

$$z_0[n+1] = z_0[n] + \frac{\boxed{\delta}}{E_y}\tilde{y}[n]y^*_{AR}[n]$$

input signal energy

output signal

$$y_{AR}[n] = y[n] + k_\alpha z_0[n] y_{AR}[n-1]$$

$$H_{ANF}(z) = \frac{1 - z_0 z^{-1}}{\boxed{1 - k_\alpha z_0 z^{-1}}}$$

output of the Auto-Regressive
(AR) part

Two parameters: **pole contraction factor**, k_α, and **adaptation step**, δ

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Parameter Settings

TABLE 1 Interference mitigation parameters and typical values

Technique	Parameter	Value	Comments and references
ANF	Pole contraction factor, k_α	[0.7,0.9]	For swept interference (Borio , O'Driscoll, and Fortuny, 2012; Qin, Dovis, et al., 2019; Qin, Troglia Gamba, et al., 2019; Troglia Gamba et al., 2012; Wendel et al., 2016)
		[0.9,0.98]	For CWI (Calmettes et al., 2001; Raasakka & Orejas, 2014; Troglia Gamba et al., 2012)
	Adaptation step, δ	$\delta < \sqrt{\frac{1-k_\alpha}{4}}$, [0.001,0.1]	(Calmettes et al., 2001; Qin et al., 2019; Wendel et al., 2016)
PB	Decision Threshold, T_h	$\alpha_T\sigma$	Require noise floor estimation (Bastide, Chatre et al., 2004; Raimondi et al., 2008; Rugamer et al., 2017; Wang et al., 2010)
		quantization level	Noise floor estimated by the AGC (Bastide, Macabiau et al., 2003; Borio & Cano, 2013; Hegarty et al., 2000)
complex signum	Parameter free		(Borio & Closas, 2018)

... complete literature review in the paper

Live Demo

developed in python and provided as Jupyter Notebooks

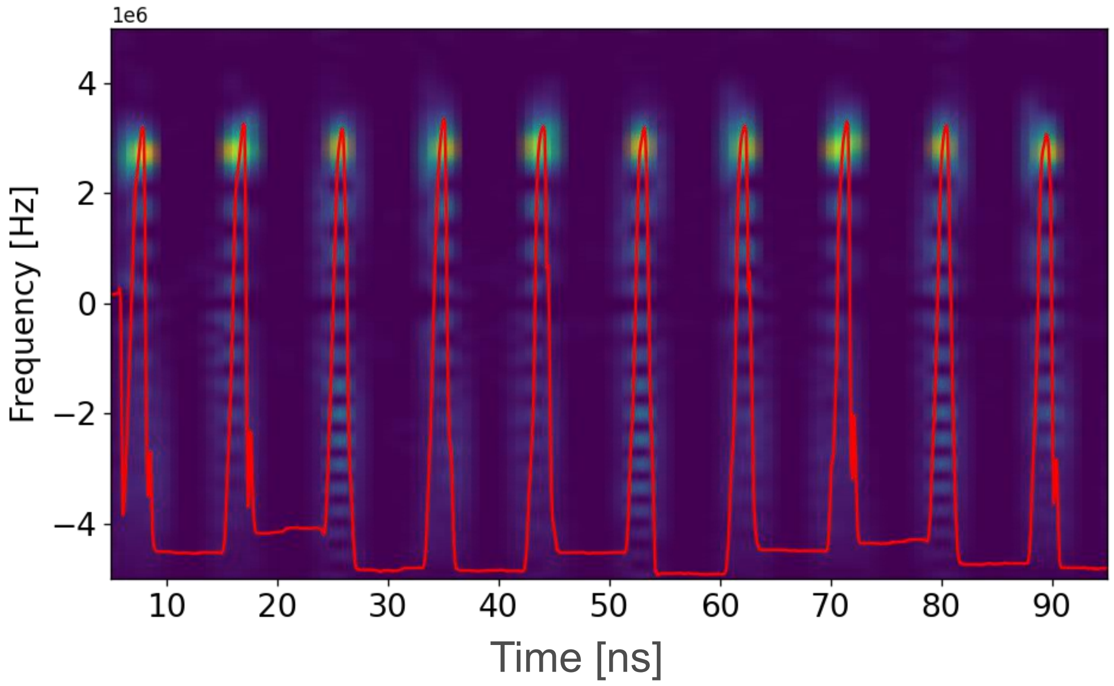
jupyter

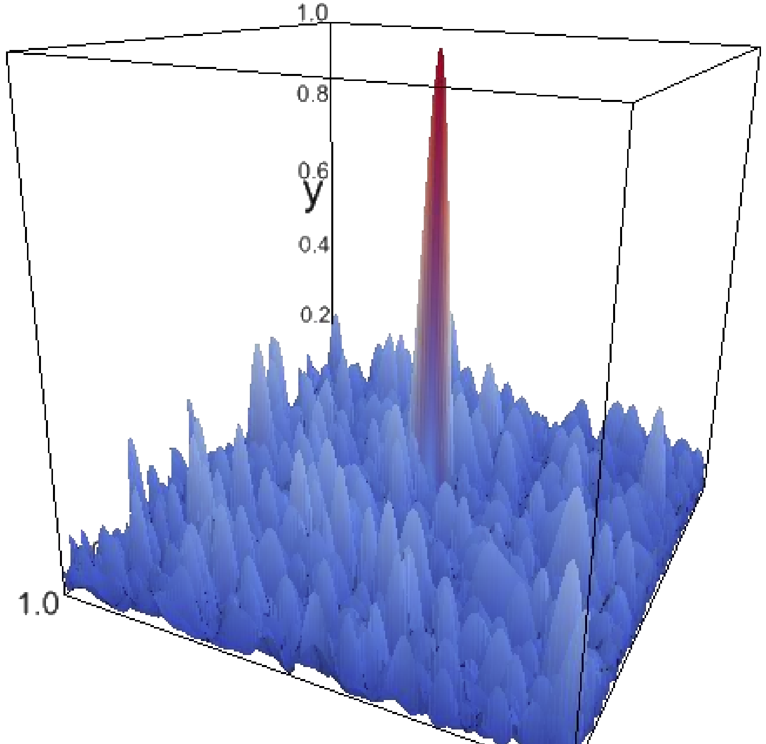
- Processing of jamming data with the ANF

- Impact of different IM techniques on the Cross-Ambiguity Function (CAF) - Acquisition stage

https://jupyter.org/

"The Jupyter Notebook is an open-source web application that allows you to create and share documents that contain live code, equations, visualizations and narrative text"





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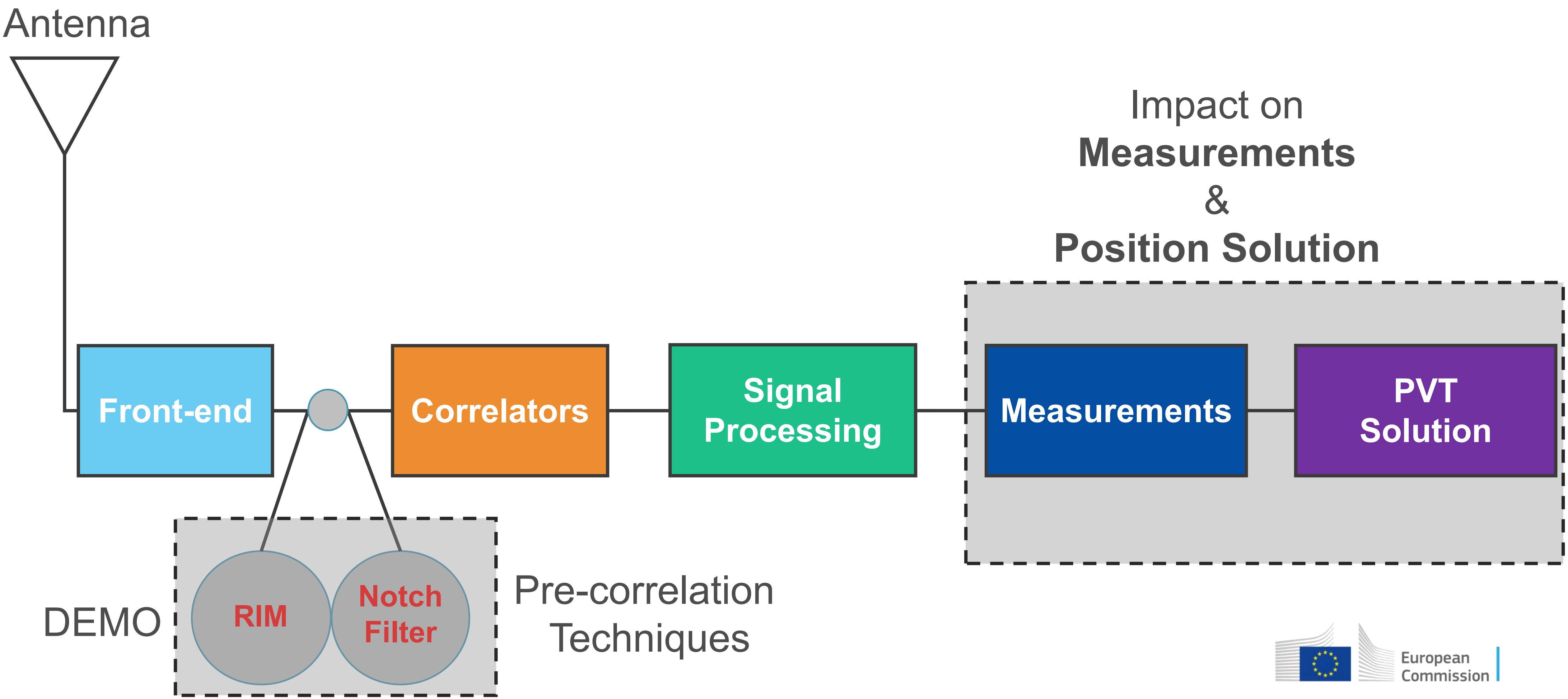
GNSS Processing Stages



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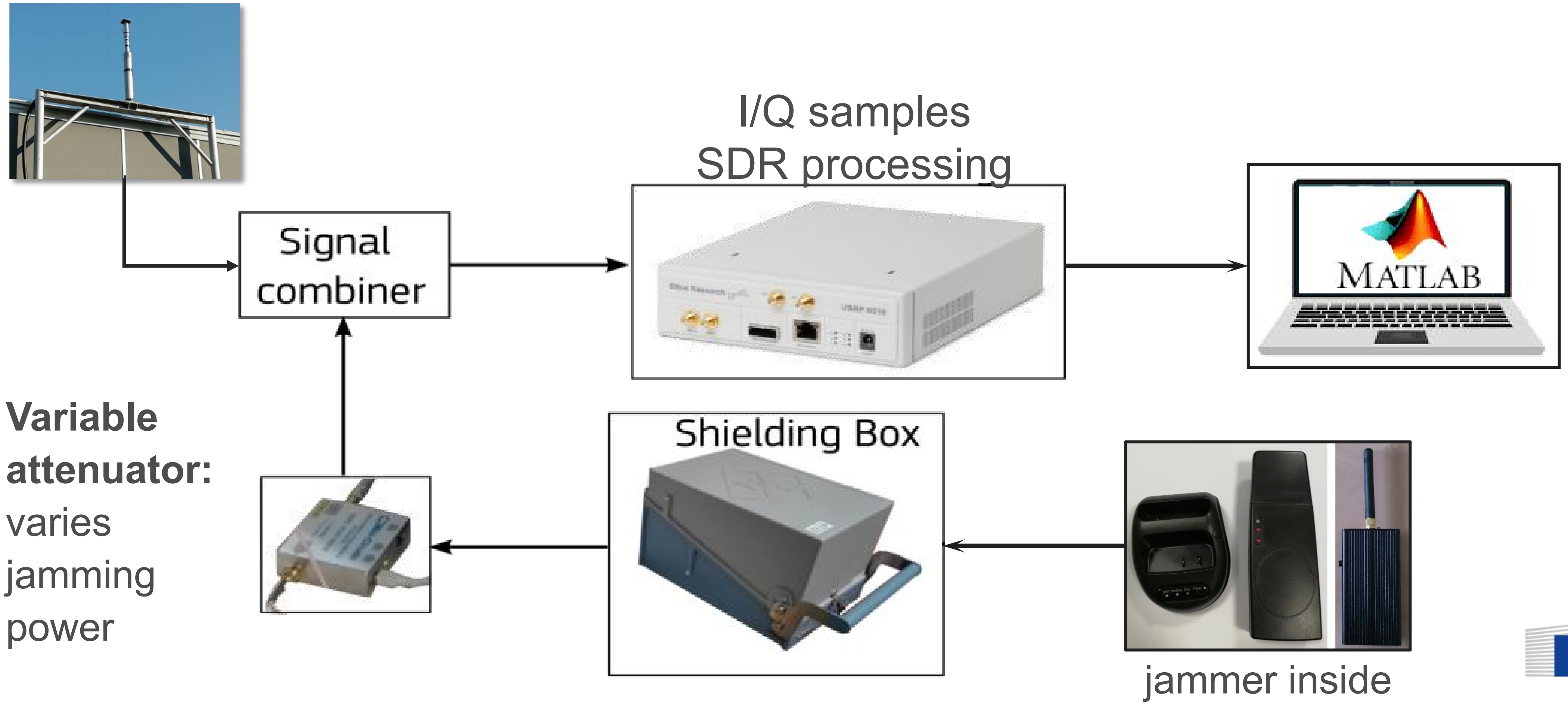
Experimental Setup (I/II)

SDR approach:
data stored to disk and re-processed several times

Live clean GNSS signals **3 modulations**:
BPSK(1), BOC(1, 1) and BPSK(10)



Variable attenuator: varies jamming power

Custom Matlab **software receiver**

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Experimental Setup (II/II)

Several tests: effect of **signal quantization** and **GNSS modulations**

In all tests: jammer power up to **front-end saturation**

GPS and Galileo analyzed **separately**

Parameter	Test 1	Test 2	Test E5B
Samp. Freq.	10 MHz	10 MHz	20 MHz
Cent. Freq.	1575.42 MHz	1575.42 MHz	1207.14 MHz
Bits	8	16	8
Attenuation step	1 dB	1 dB	0.25 dB
Attenuation step Interval	30s	20s	2s
Jammer Type	Swept	Swept	Swept

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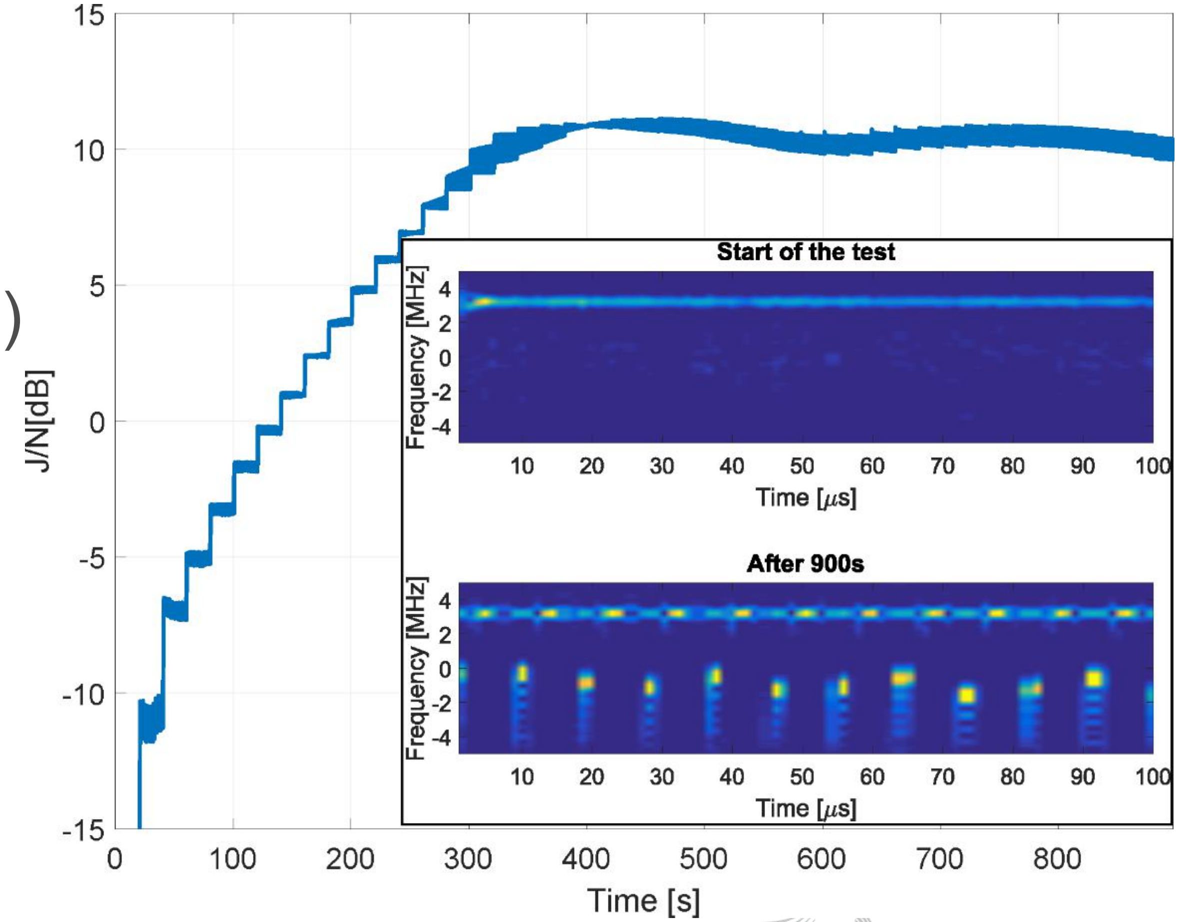
Test 1 on GPS L1 C/A and Galileo E1C

Total **length:** about **15 min**
First 100s: **negligible jamming**
front-end **saturation** after **400 s**

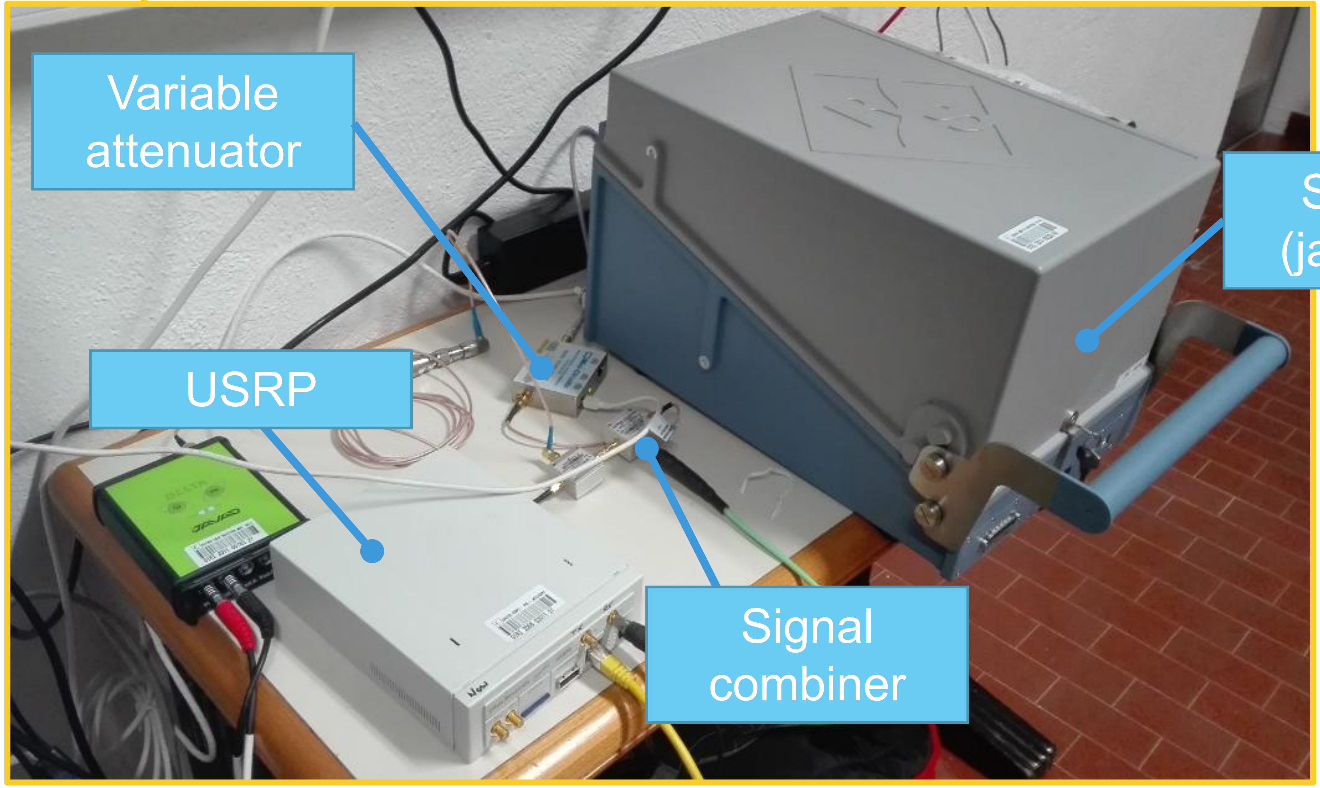
GPS L1 C/A and Galileo E1C (pilot processing) analyzed separately: **two independent solutions**

8 Bit quantization

Wideband interference

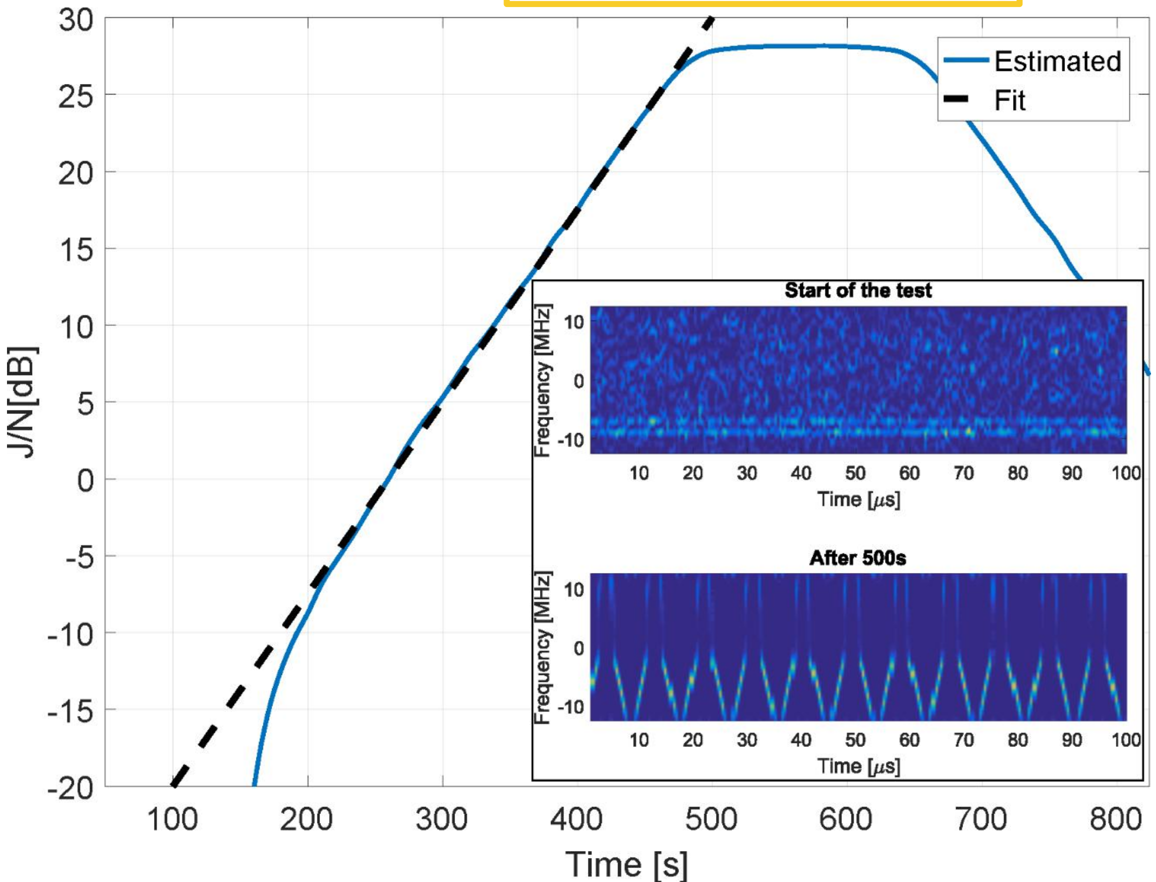


Test on E5B



NonSMA-Battery Jammer in the shape of a **DECT**

Total **length** about **15 min**, first **100 s negligible jamming**, front-end **saturation** after **500 s**



Wideband interference

Galileo E5B position solution

L1 Pseudorange Differences

$$\Delta Pr(t) = Pr_{NoMit}(t) - Pr_{Mit}(t)$$

Average Pseudorange Differences under low jamming (first 100 seconds of Test 1): **decimeter level** (processing noise level)

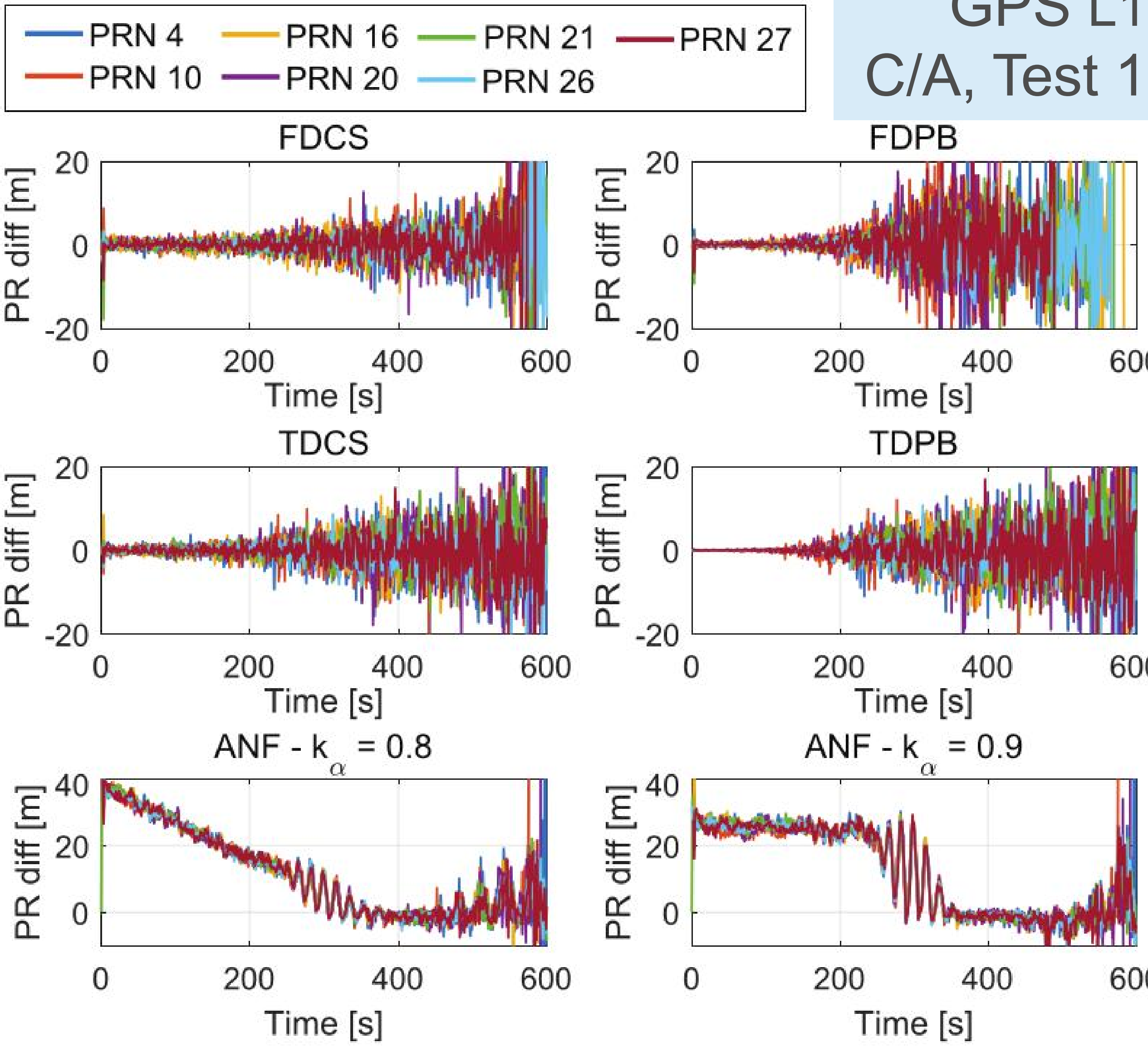
Increased variance due to the effect of the **increased jammer power**

Pseudorange differences: **zero mean** for RIM

ANF: **delay common** to all pseudoranges

Impact of ANF parameters

GPS L1 C/A, Test 1



E1C Pseudorange Differences

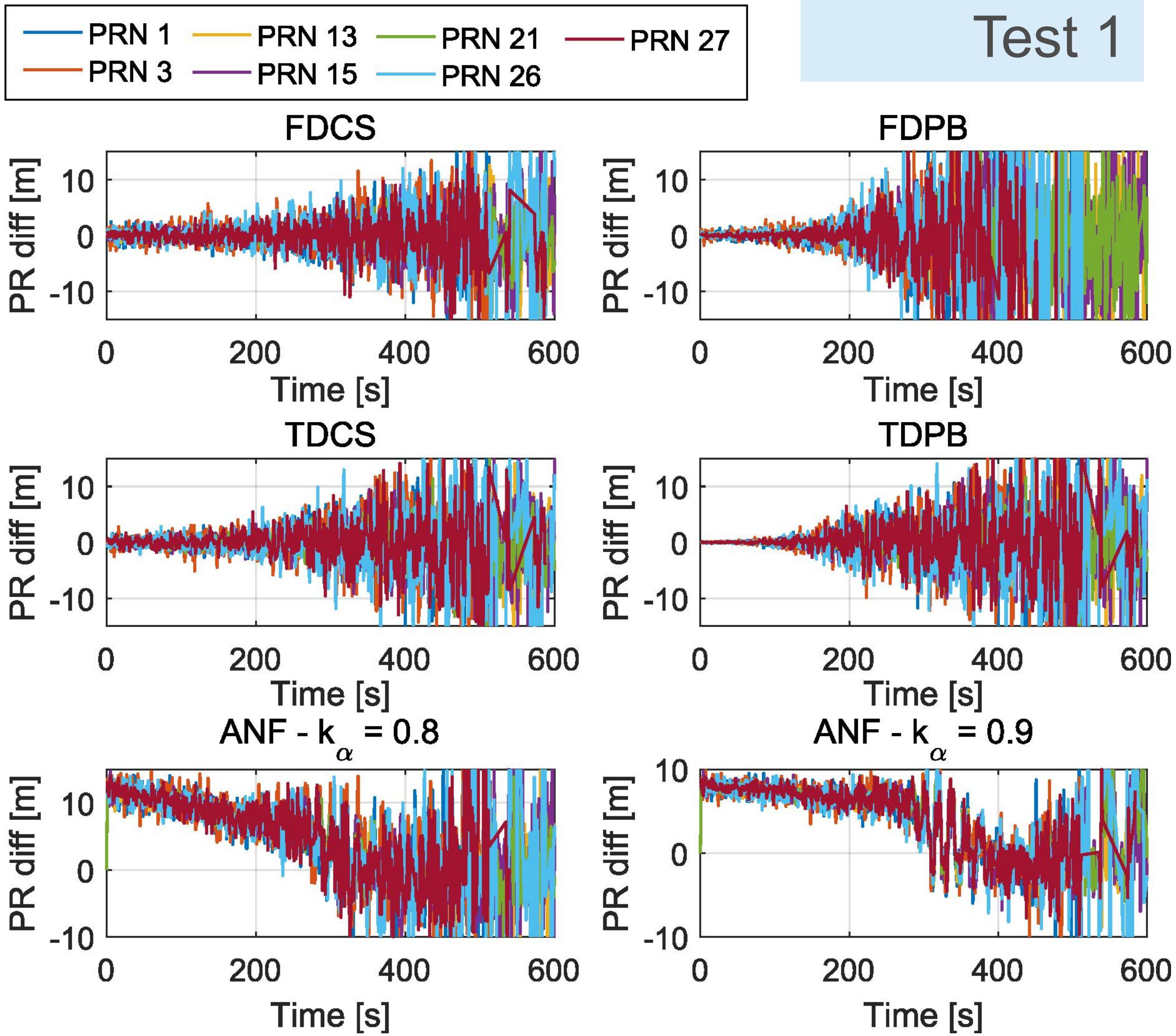
Galileo E1C, Test 1

RIM techniques **do not introduce biases** on pseudoranges for Galileo as well

ANF delay: **time-varying** due to the progressively increase of jamming power

Different delays on GPS and Galileo: **modulation dependent bias**

Delay difficult to predict



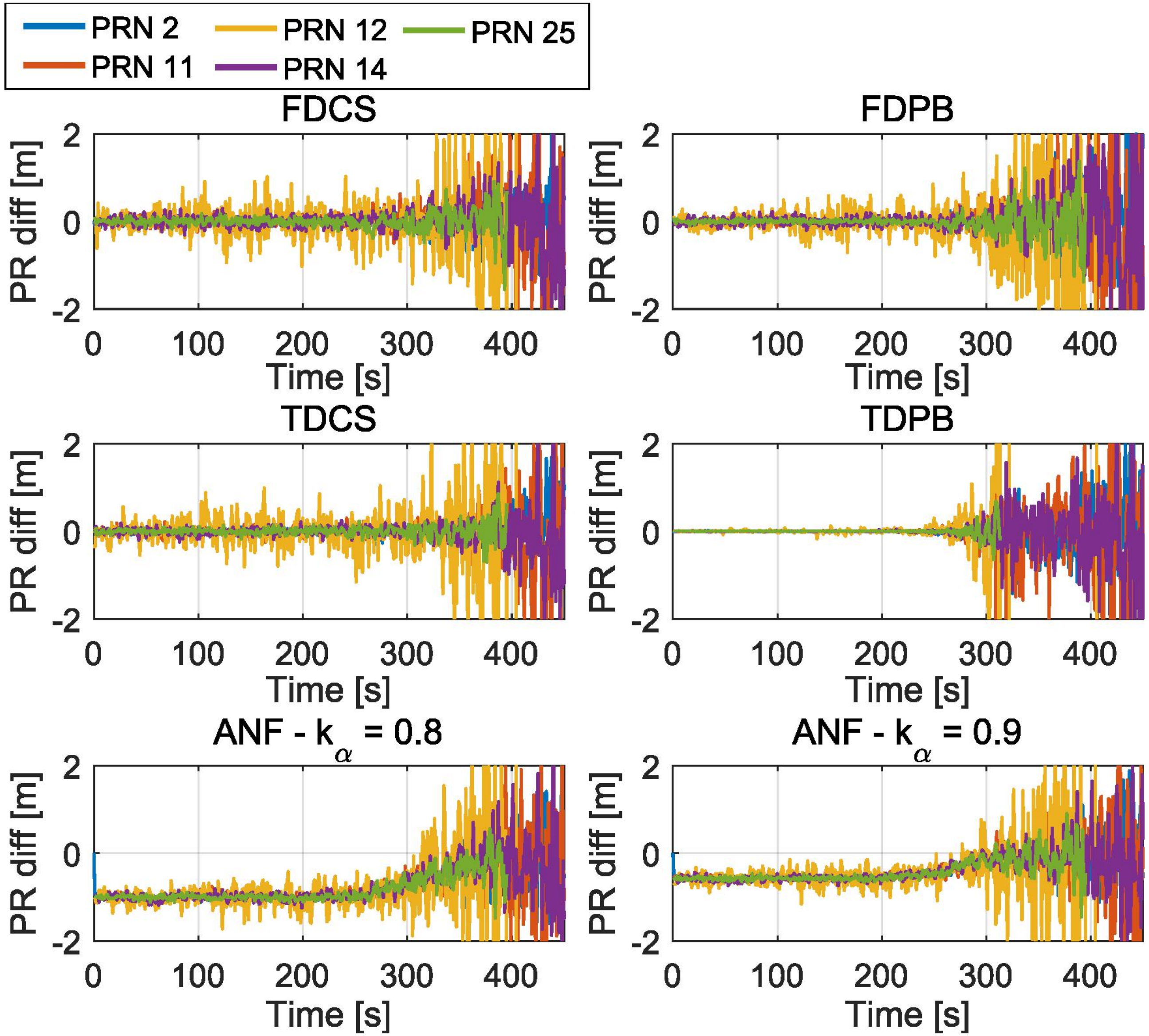
E5B Pseudorange Differences

Also in this case: **no biases** for RIM

Low jamming conditions**: difference in** the **cm** level

Time Domain processing**: most effective**

Clear bias observed for the ANF (1 m for k_α= 0.8, 0.6 m for k_α= 0.9) decreasing to zero after about 300 seconds



Position Domain Analysis

Antenna location carefully surveyed (known coordinates)
Position solution: **Weighted Least Squares (WLS)**, weights based on satellite elevation
For the different cases: **comparison of position error time series**

Position Domain Analysis (I/III)

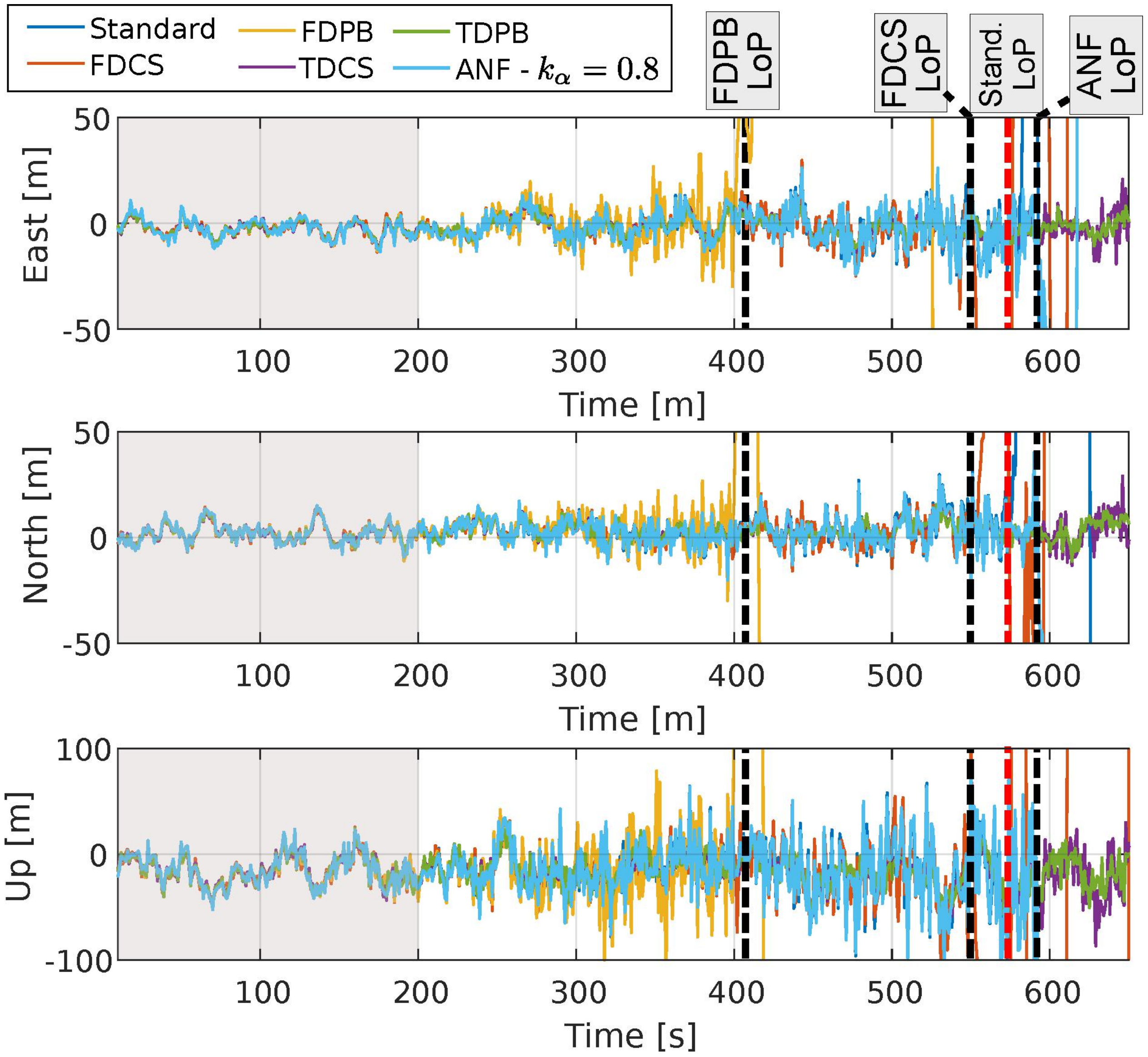
GPS L1 C/A, Test 1

Benefits of **RIM**: TD RIM quite effective

FDPB deteriorates performance: **increased variance** and **early solution unavailability**, … (see discussion during demo)

FDCS does not improve wrt standard processing

ANF no significant **improvements**



Position Domain Analysis (II/III)

Galileo E1C, Test 1

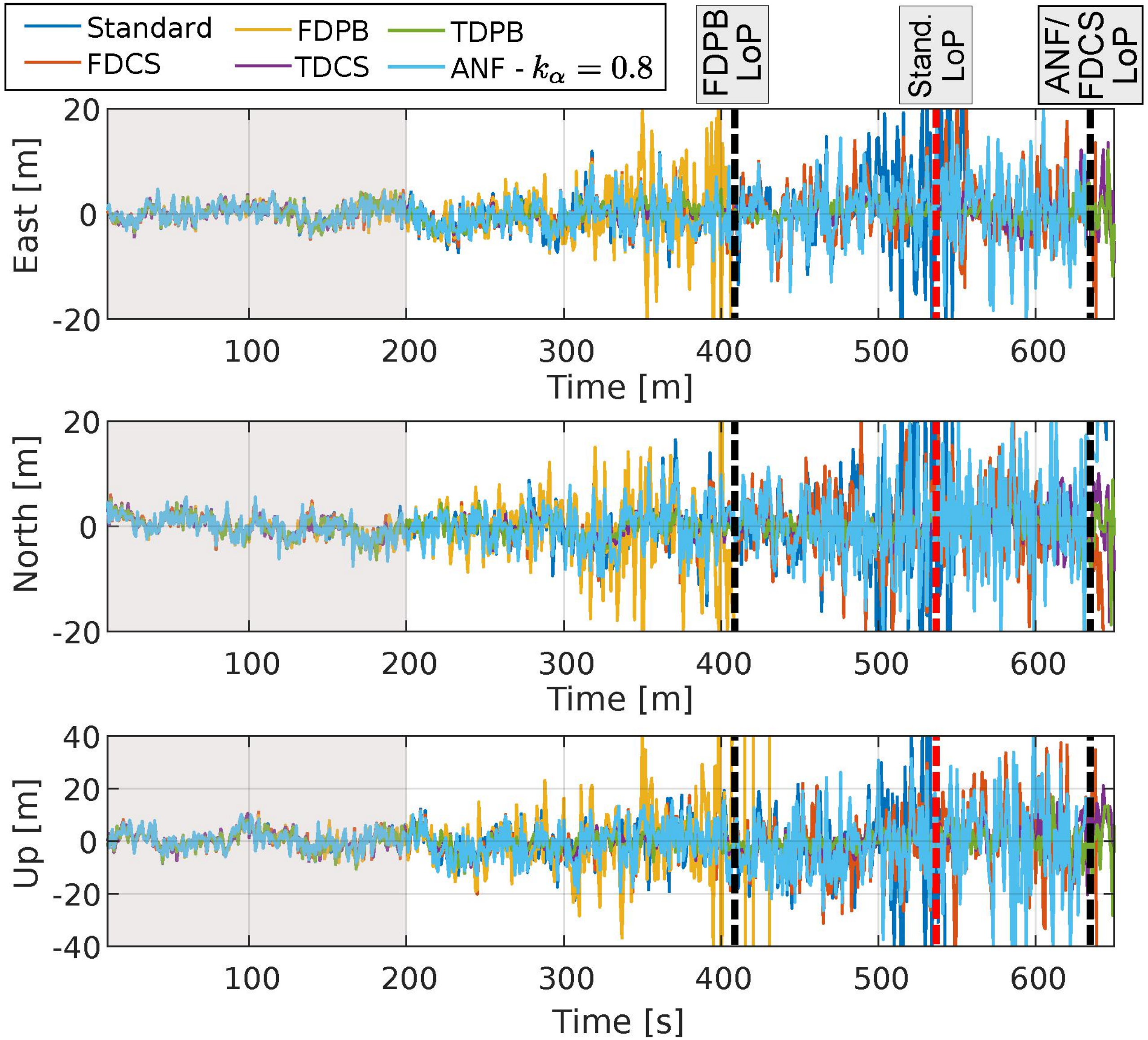
Findings **similar** to the **GPS L1** case

No degradations for low levels of jamming

Frequency domain **RIM ineffective** due to the jamming signal nature

TD techniques: the **most effective**

Improved solution **availability** with respect to GPS mainly due to **pilot processing**

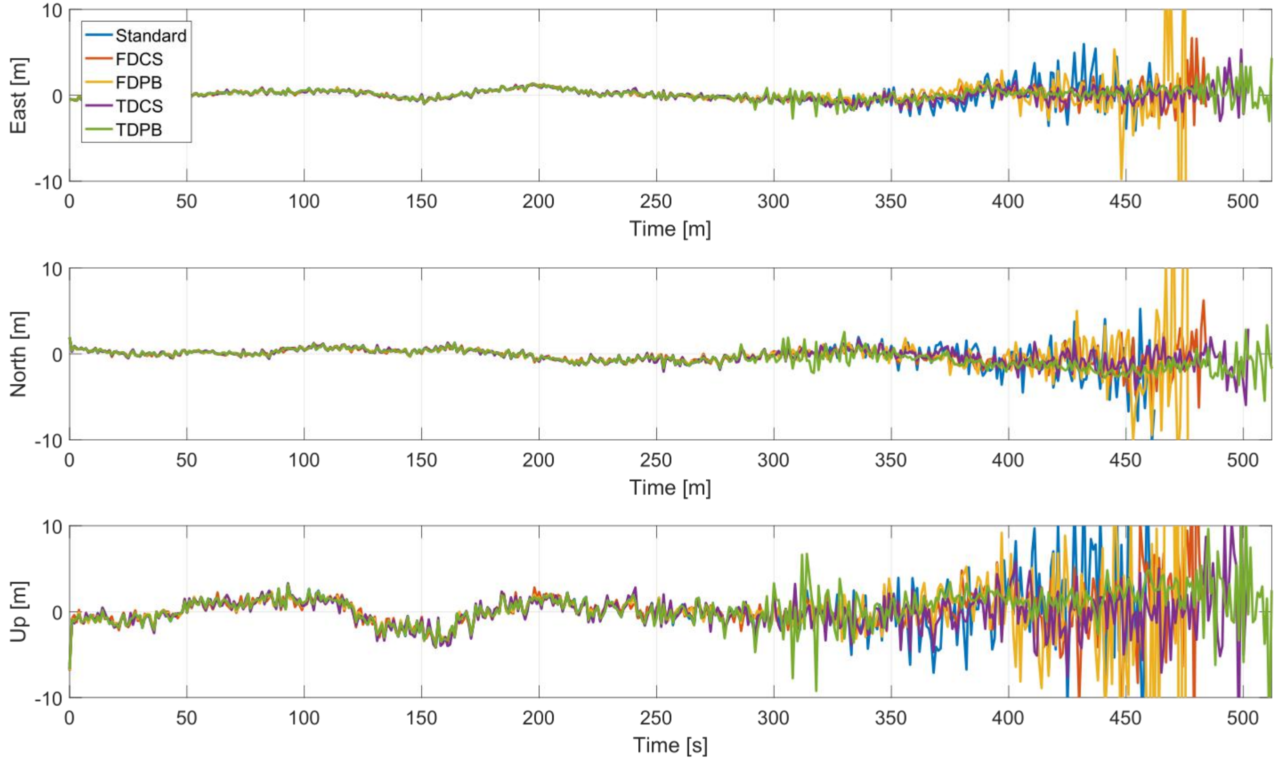


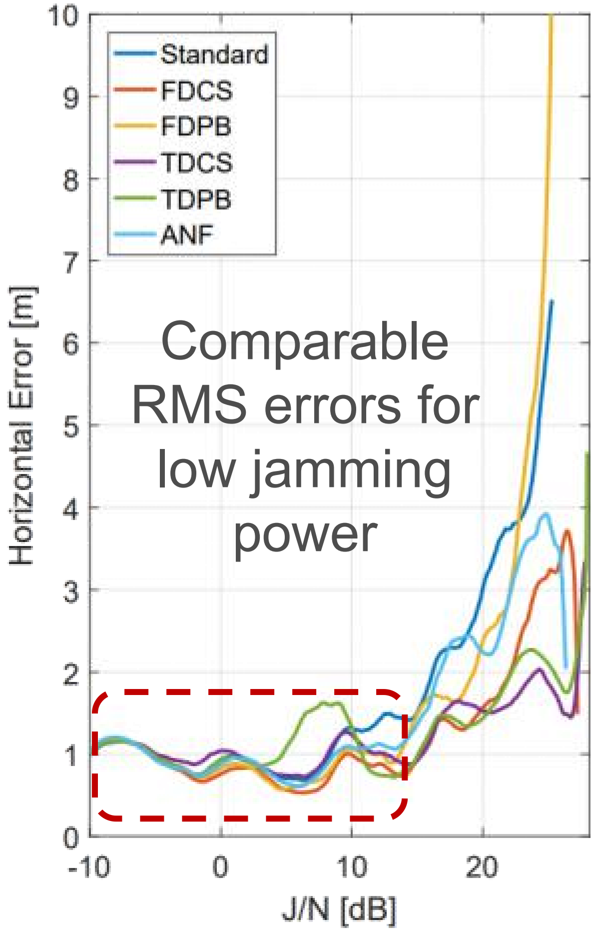
Position Domain Analysis (III/III)

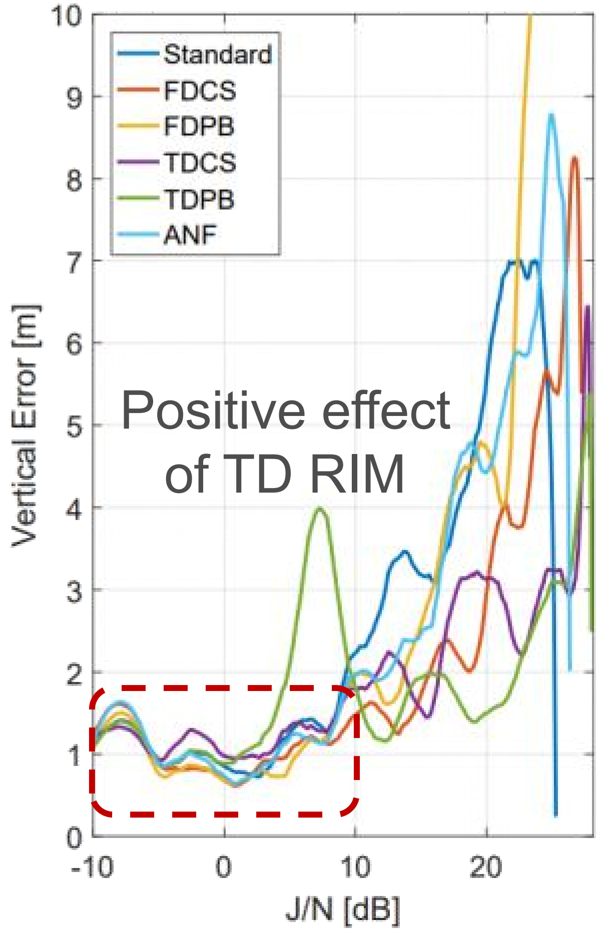
Galileo E5B

No bias introduced in the position time series

Benefits of RIM







Also in this case, **FDPB not effective** (performance degradation)

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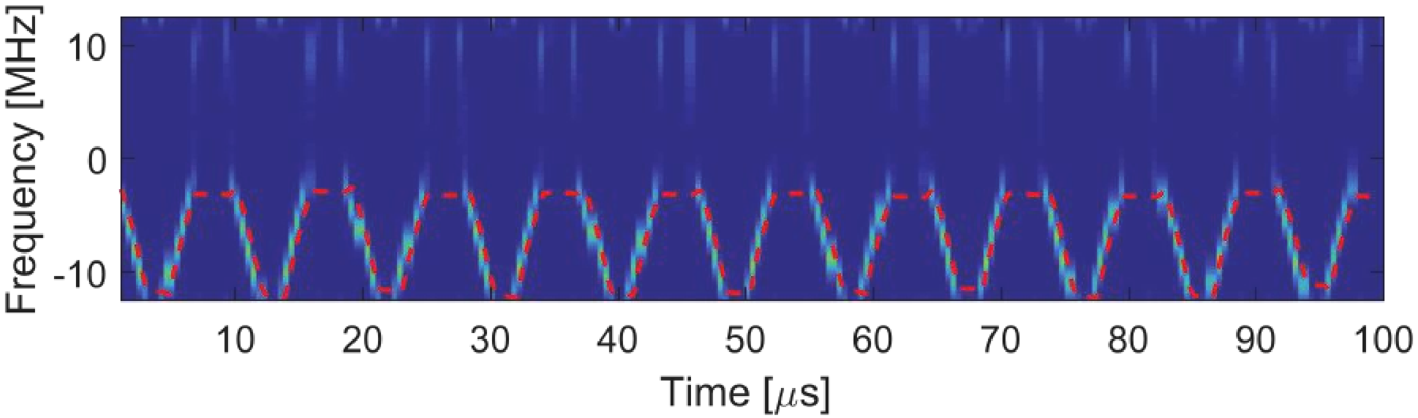
Conclusions

RIM techniques: **no biases** in both measurement and position domains

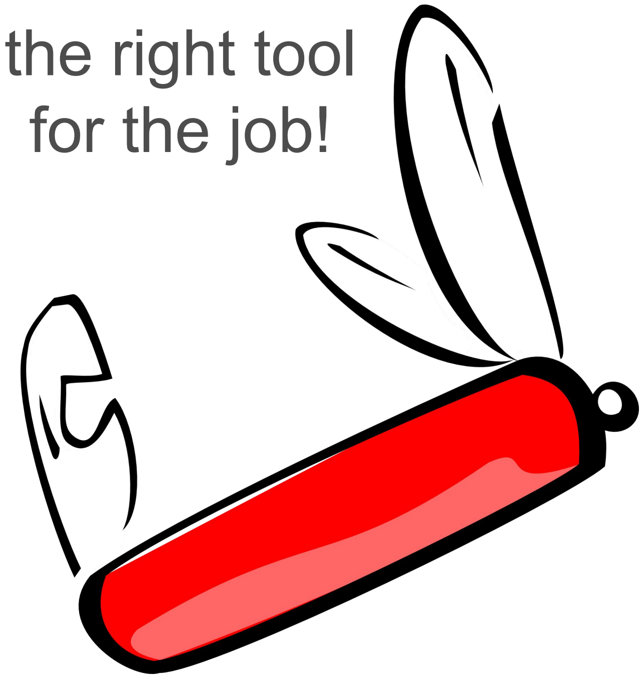
ANF: significant **biases** on the pseudoranges but **no effect** on final **SPP position** solution

Negligible effects under low jamming conditions

Significant **improvements** in terms of solution **availability** and **RMS error**



the right tool for the job!



Selection of the most appropriate **technique** and of its **parameters**: **space for research**

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Daniele Borio, Ciro Gioia

... or contact the authors:

daniele.borio@ec.europa.eu
ciro.gioia@ec.europa.eu

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