Compatibility Assessment Between Amateur Radio Services and Galileo in the E6 Band

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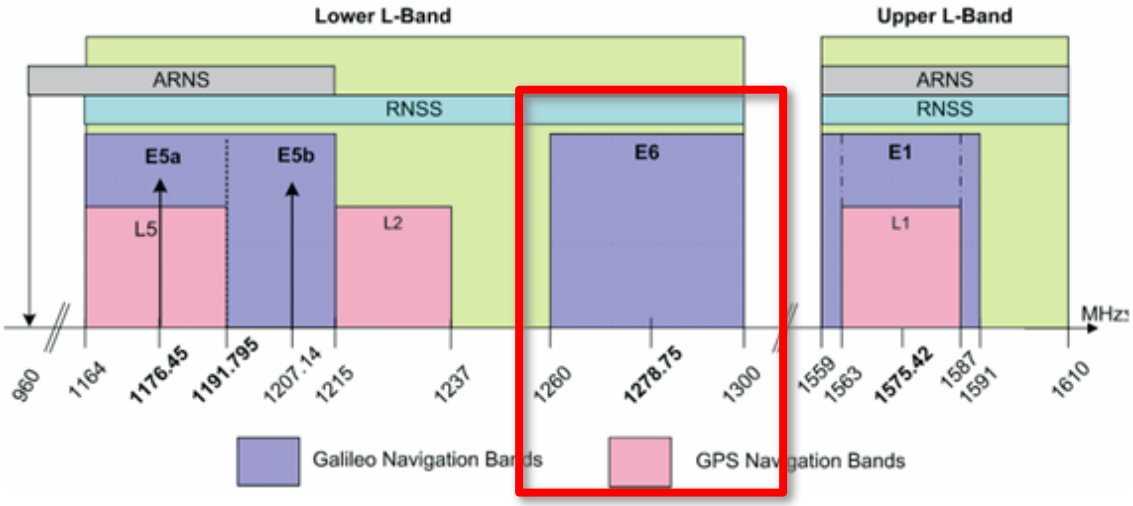
Joint Research Centre

The European Commission's in-house science service

Overview of radio services in E6 band



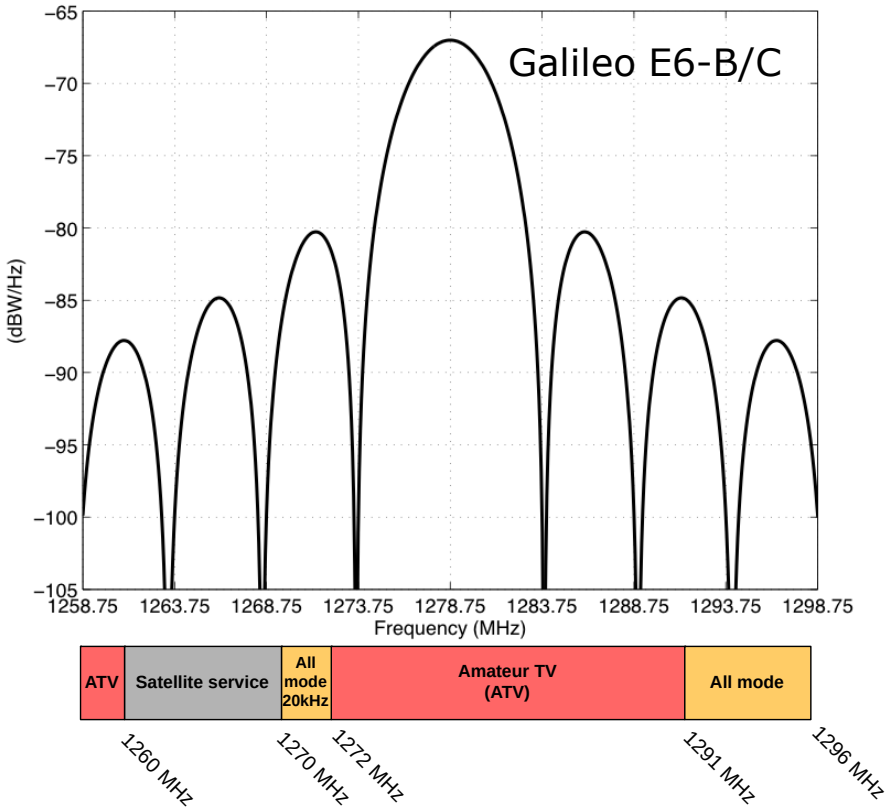
- The band **1260–1300 MHz** is allocated to **RNSS** on a **primary basis**.
  - ✓ The band is currently used by **Galileo**, **Beidou** and **QZSS**

- The band **1240–1300 MHz** (also known as 23cm band) is allocated to **Amateur Services (AS)** on a **secondary basis**
  - ✓ The AS allocation is used for many diversified services, the most relevant being Amateur TV (ATV)

23 cm Amateur Services

- Amateur radio within the 23 cm band is quite heterogeneous, supporting TV as well as voice/data systems:
  - ✓ FM voice repeaters
  - ✓ Digital voice repeaters
  - ✓ Digital data repeaters/links
  - ✓ **Amateur TV** repeaters (analog, DVB-S, DVB-T)

- The 23 cm band is probably the most popular band currently for ATV, however other bands are available and graduated migration may be feasible



Amateur services within the 23 cm band according to IARU guidelines

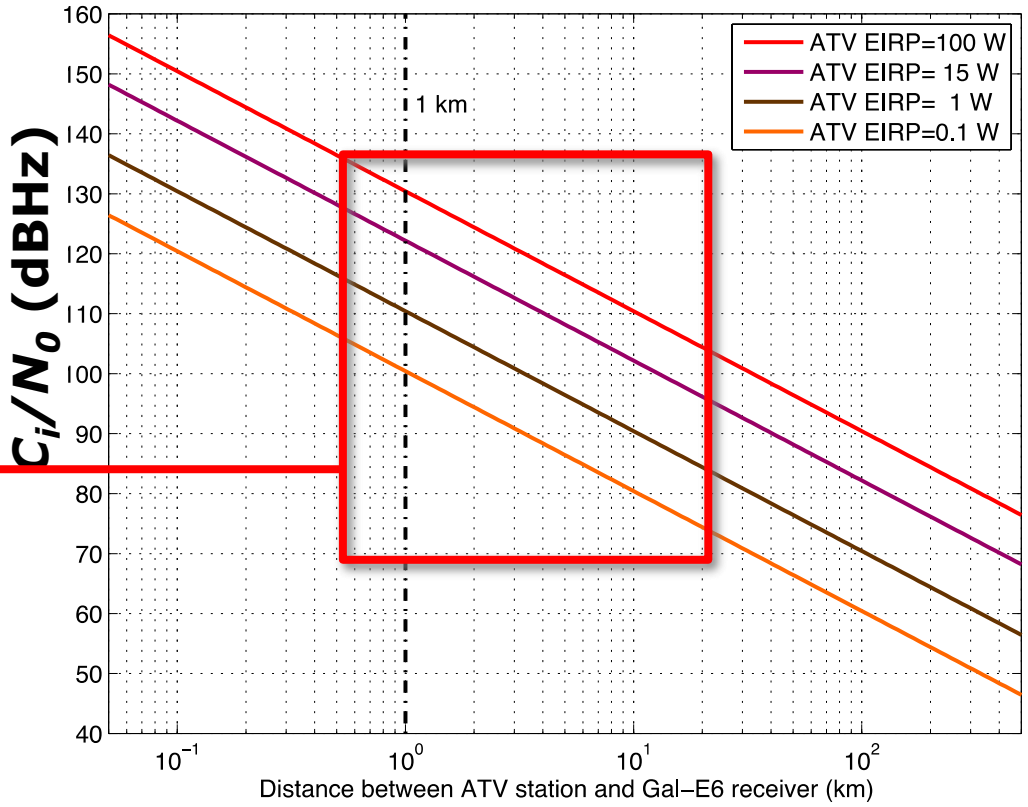
Amateur TV emission power levers

- Most ATV stations operate with EIRP around 0.1W to 15 W (some even with >100 W depending on national regulations)

C_i/N_0 > 100 dBHz can easily be experienced in practice. Examples:

- ATV with EIRP 1W @ 3 km
- ATV with EIRP 15W @ 10 km

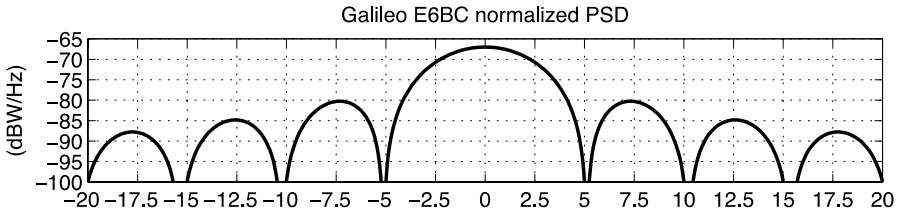
Interference power (C_i) to noise spectral density (N_0) due to an ATV station

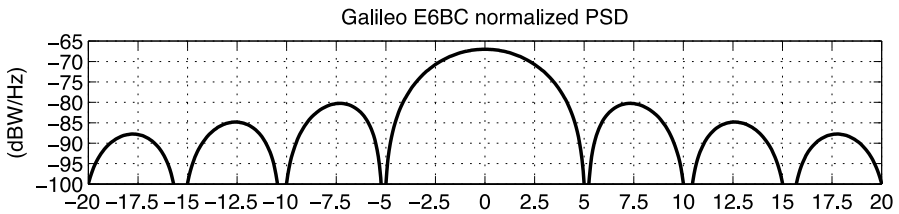


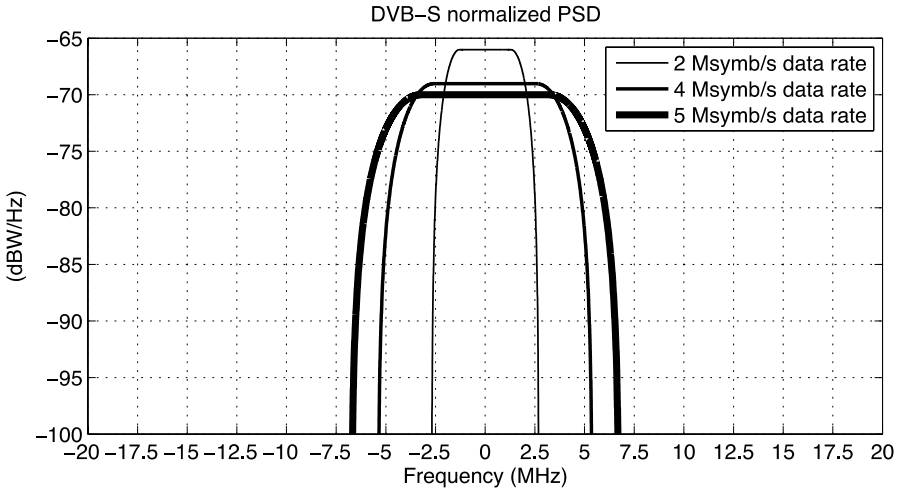
(distance in kilometers)

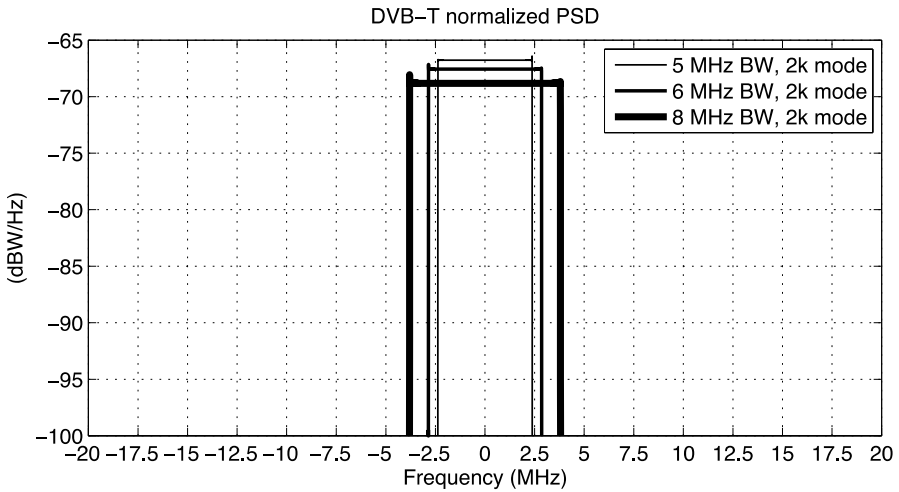
ATV Spectral Characteristics

- How do ATV signals look like compared to the Galileo E6 spectrum?
  - ✓ Digital ATV signals are modulated using either DVB-S (more common) or DVB-T standards with various bandwidths









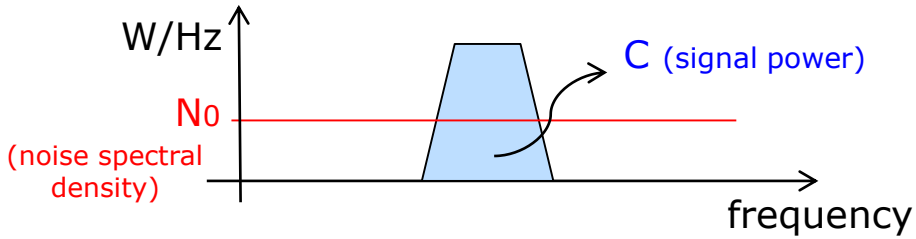
Regulatory Initiatives

- In the recent years there has been an increasing attention on the topic of the **compatibility between AS and RNSS** in the E6 band:
  - ✓ In 2013 interference was reported at the Galileo Control Center (GCC) in Oberpfaffenhofen coming from an ATV station at 18 km distance
  - ✓ The **German regulator** (BNetzA) very promptly instructed the ATV operator to shutdown the station for both the repeaters at 1278 MHz (analog ATV) and 1291 MHz (digital ATV)
  - ✓ TV repeater operations nearby are now terminated
- In 2014 very positive discussions started between Galileo the AS (**IARU and amateur societies**) involving **frequency regulators** as well, with the goal of finding a **long term solution**
- At the same time **a compatibility study** was initiated at the **JRC** in order to have a clear **assessment** of the impact of ATV into Galileo E6

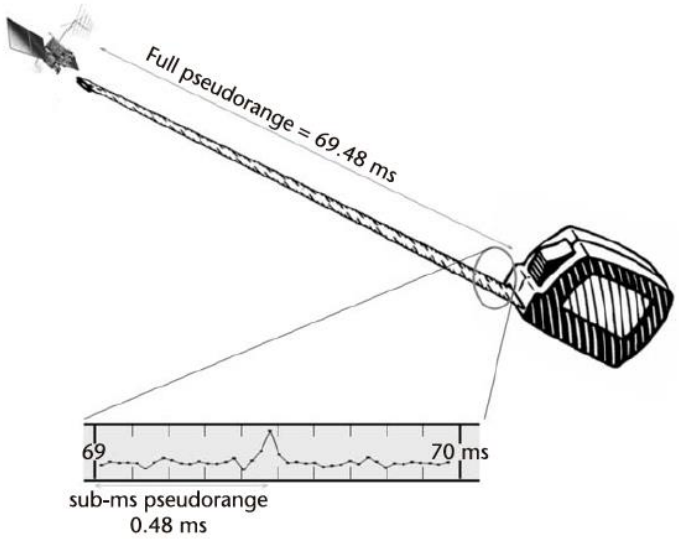
Analytical analysis

- From a theoretical point of view, three different metrics have been derived and analyzed for assessing/predicting the Galileo E6 performance degradation in the presence of interference sources:

C/N_0 degradation



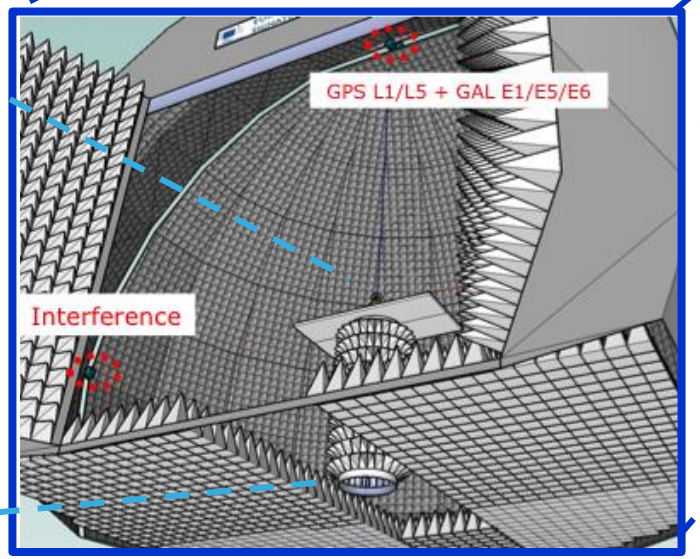
Pseudorange variance

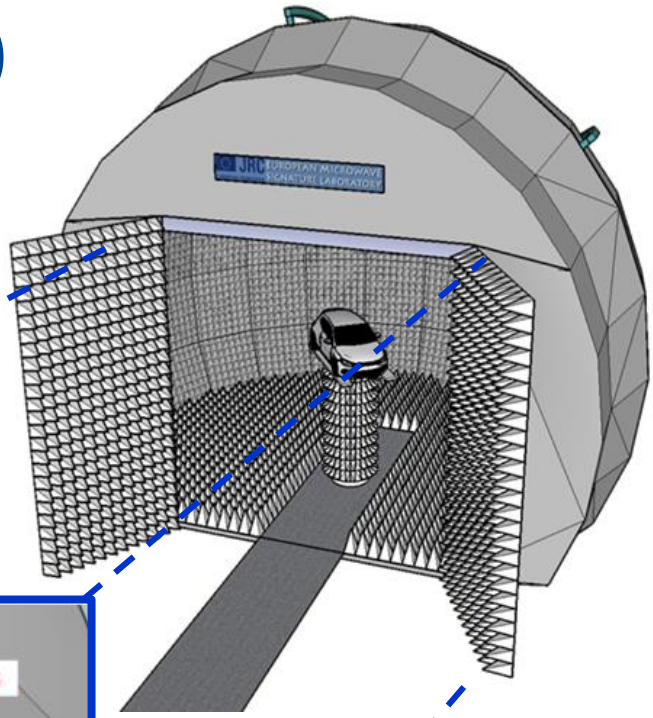


Bit error rate

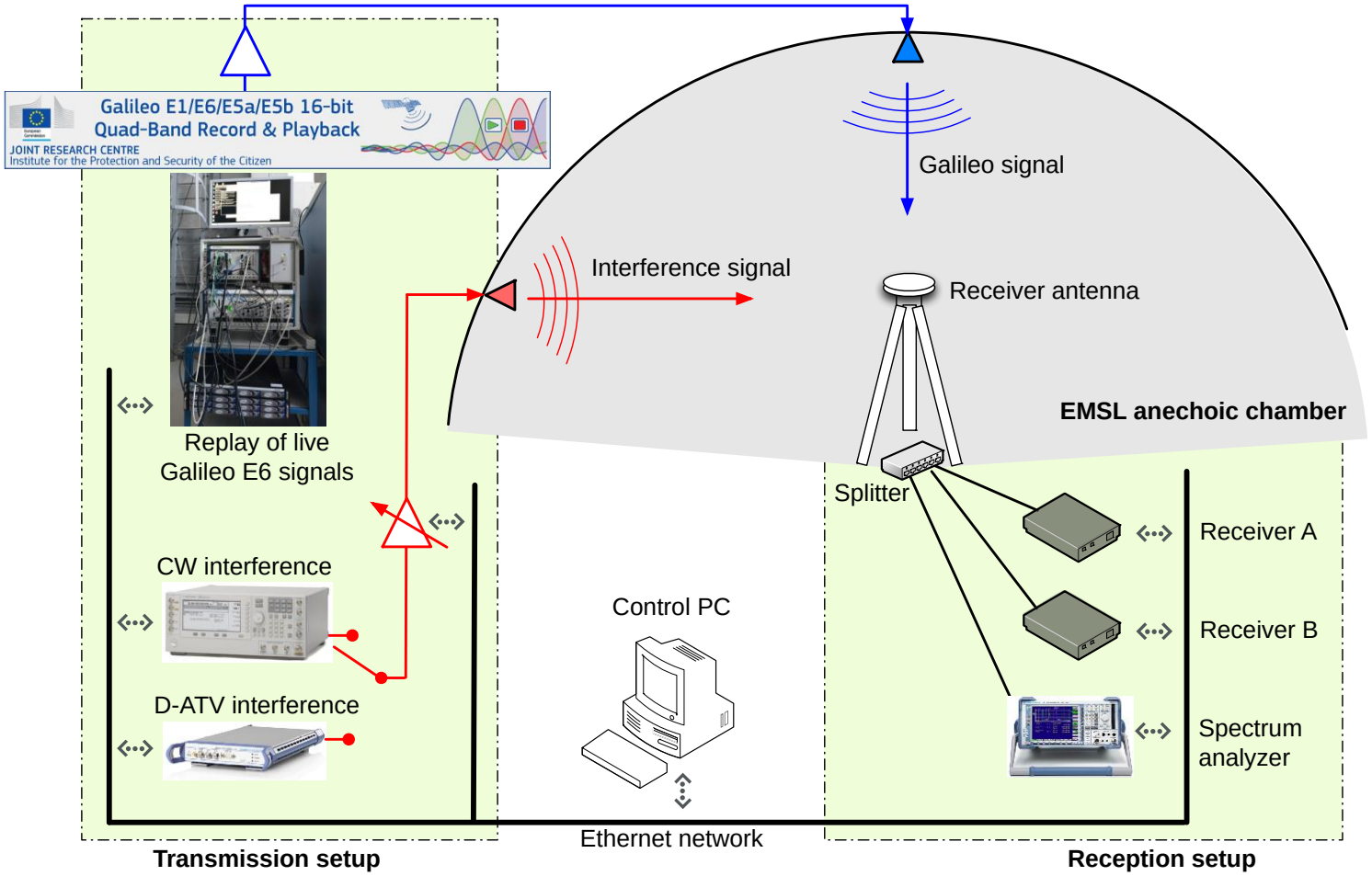
Experimental Setup (1/2)

- Experimental tests carried out within the **European Microwave Signature Laboratory** (EMSL) at the **JRC** (Ispra, Italy)



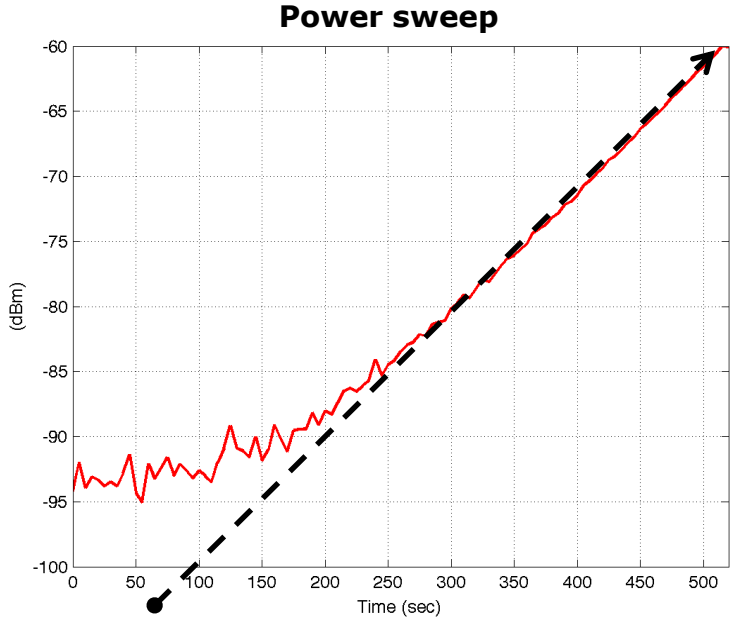


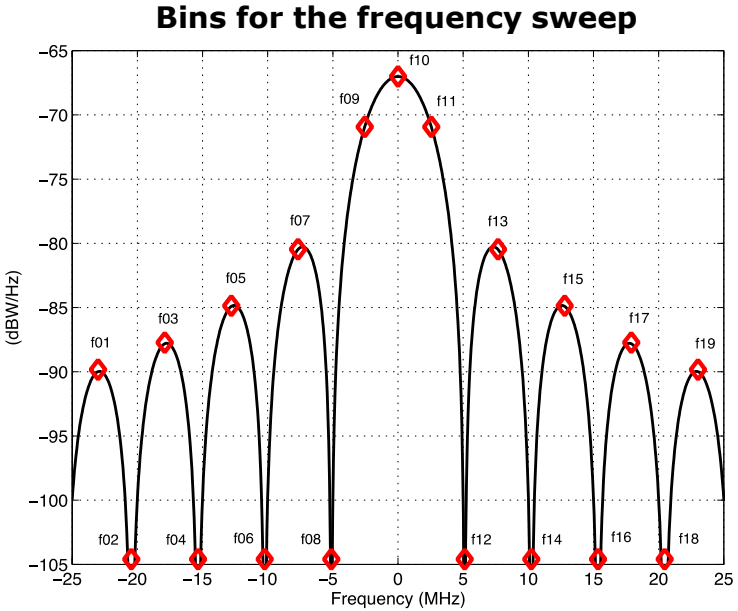
Experimental Setup (2/2)



Testplan

- **Coordinated** with IARU and amateur society members
- **Power sweep** up to a maximum C_i/N_0 of 100 dBHz
- Frequency sweep along a discrete set of **frequency bins** (maxima and minima of the Galileo E6 spectrum)
- **ATV signals**: narrowband (CW), DVB-S and DVB-T

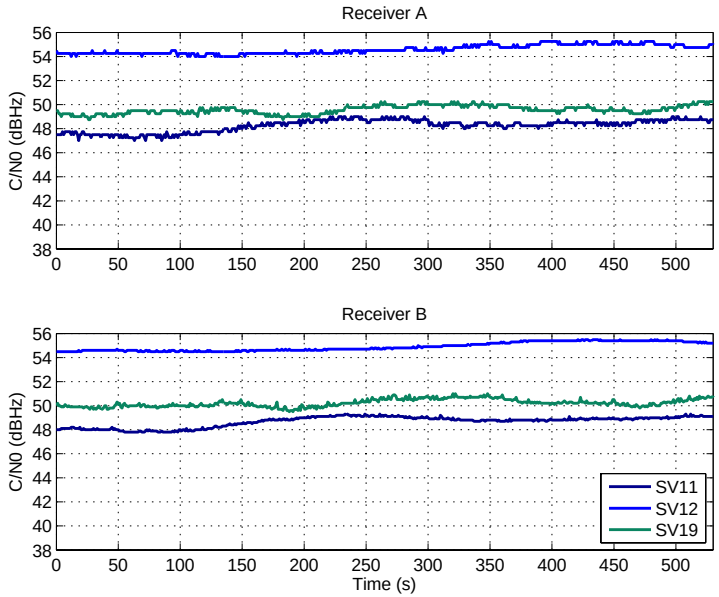




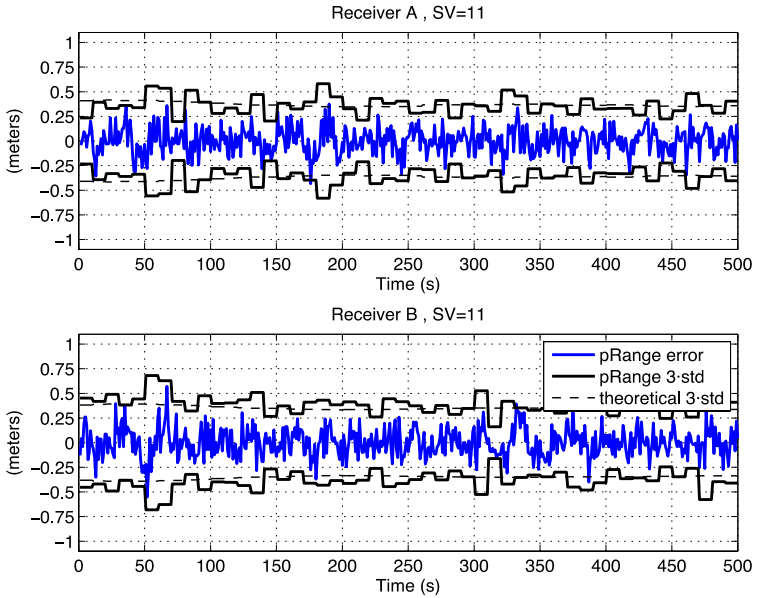
Experimental Results (1/5)

- Galileo E6C baseline performance **(no interference)**

Baseline C/N_0

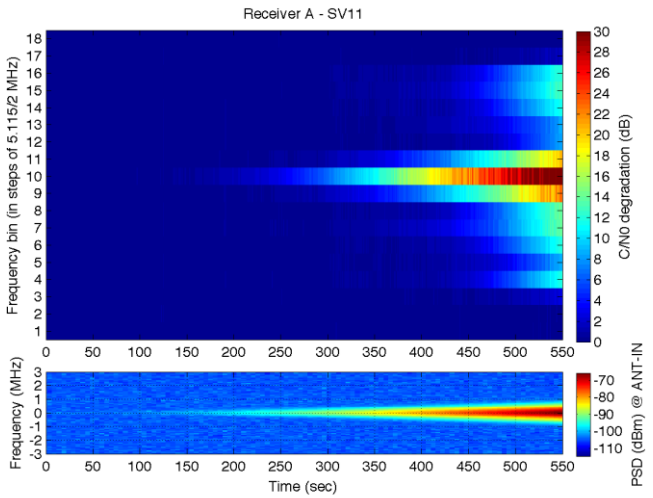


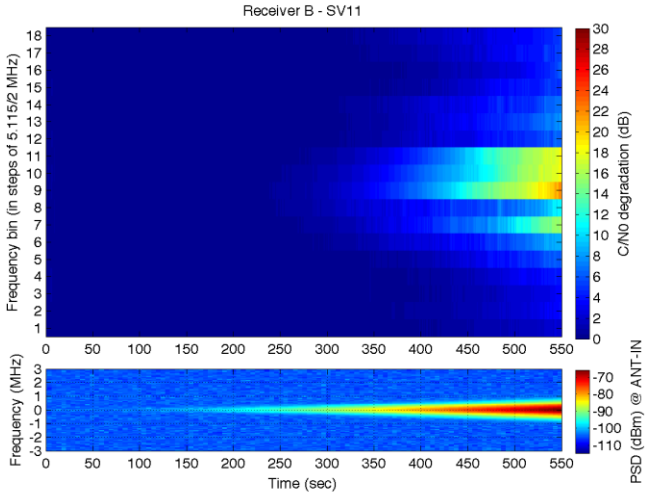
Baseline pseudorange residuals

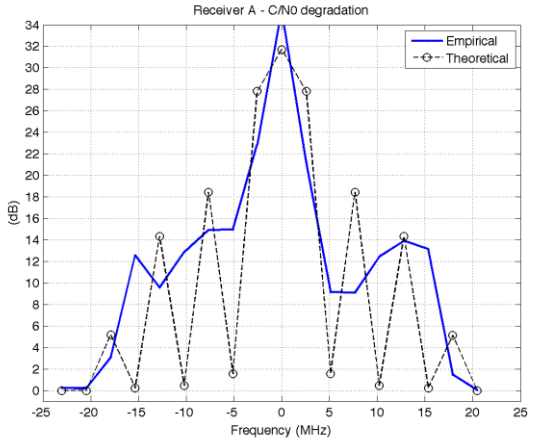


Experimental Results (2/5)

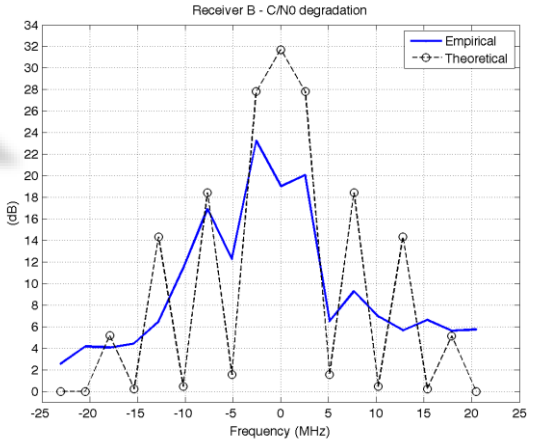
- Galileo E6C performance under **narrowband AS**





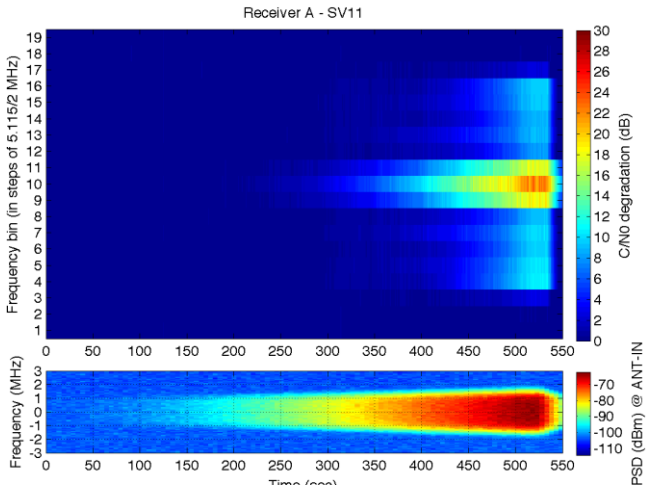


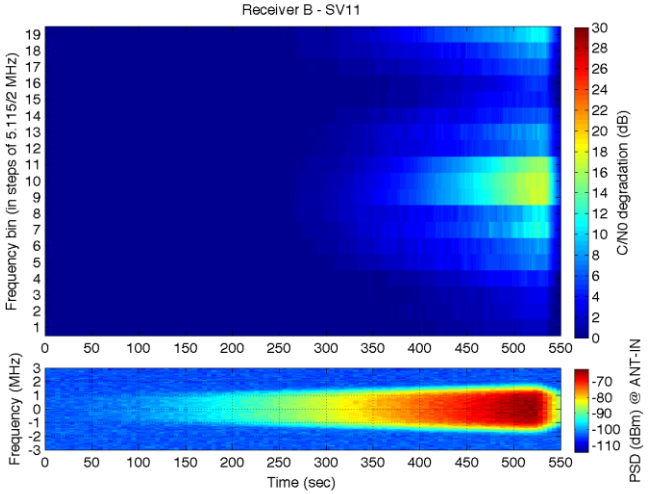
Max losses: > 35 dB
Avg losses: 14 dB

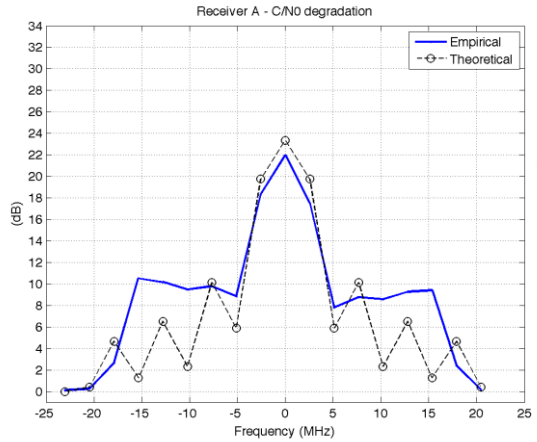


Experimental Results (3/5)

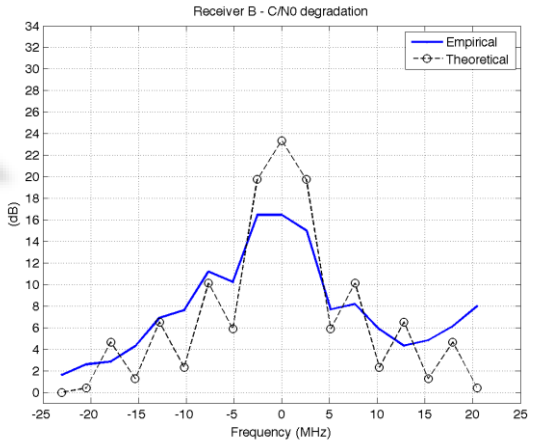
- Galileo E6C performance under **DVB-S @ 2Msps ATV**





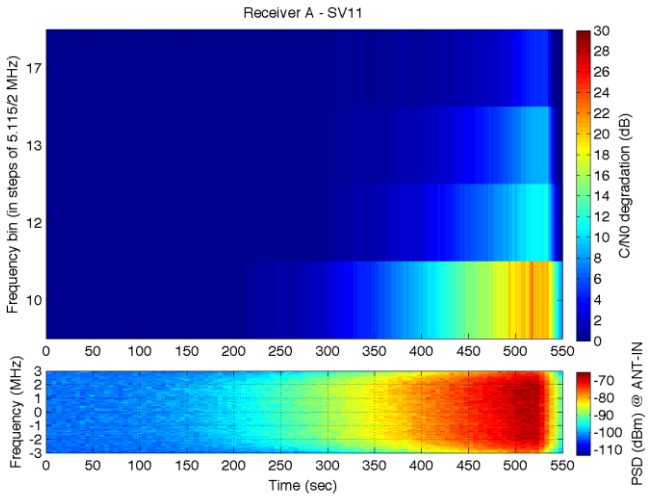


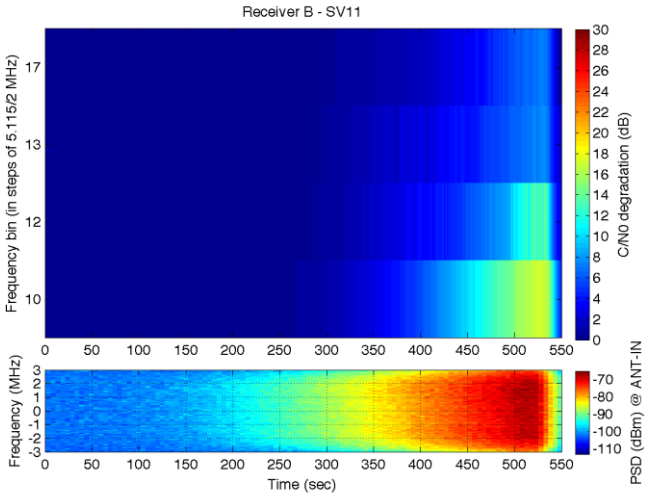
Max losses: > 20 dB
Avg losses: 10 dB

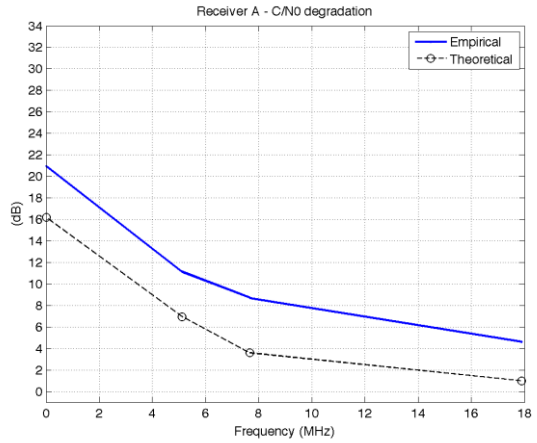


Experimental Results (4/5)

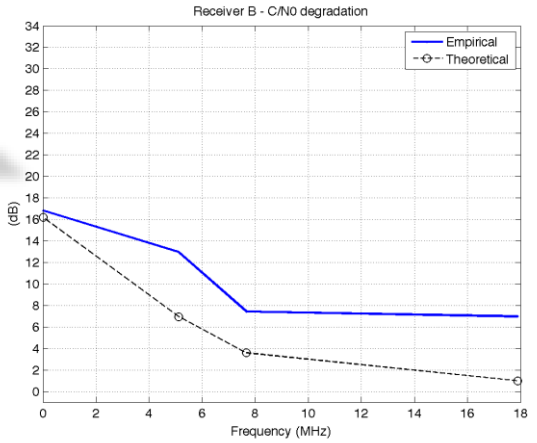
- Galileo E6C performance under **DVB-S @ 5Msps ATV**





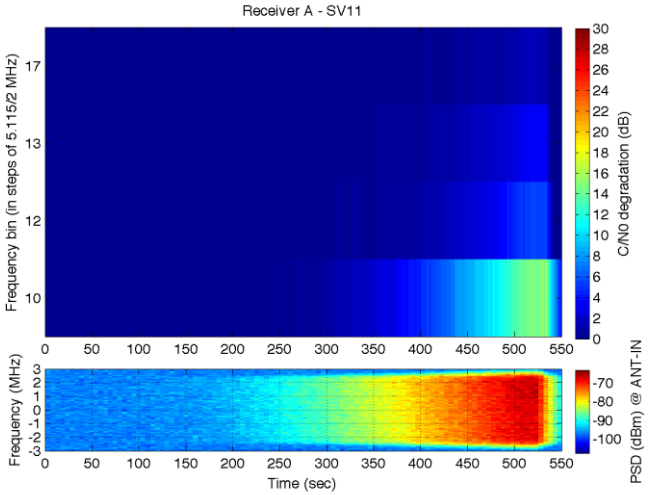


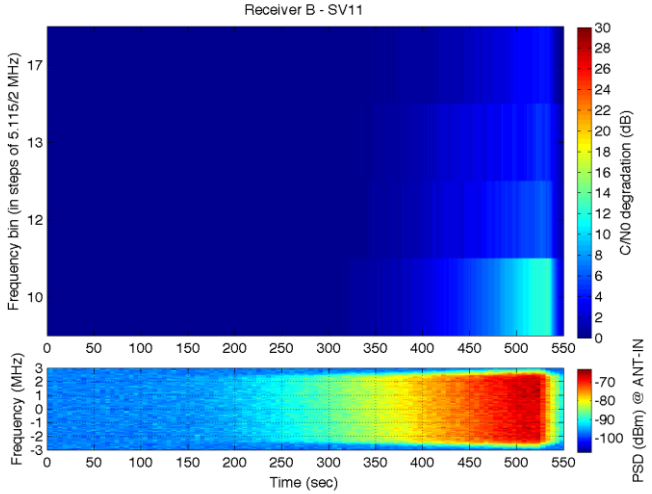
Max losses: > 20 dB
Avg losses: 9 dB

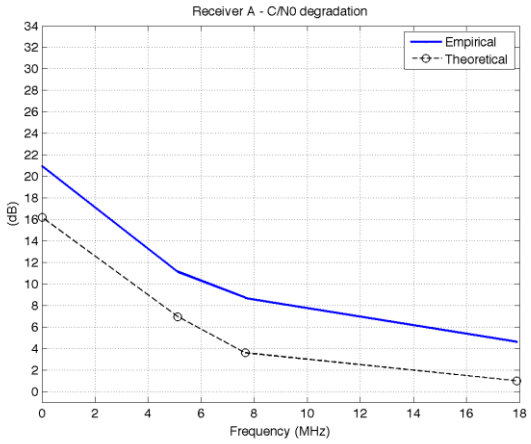


Experimental Results (5/5)

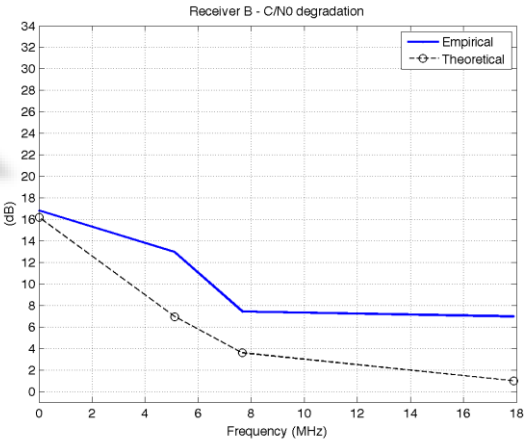
- Galileo E6C performance under **DVB-T @ 5MHz ATV**







Max losses: > 20 dB
Avg losses: 9 dB



Pseudorange performance (1/2)

- In general terms, the **variance of the pseudorange residuals** can fairly be predicted using the theoretical results derived in the report
- Maximum degradation: **x10** baseline pseudorange variance ($\frac{\sigma^2_{\text{interf}}}{\sigma^2_{\text{baseline}}} \approx 10$)

- Example: **CW signal at C_i/N_0 placed over the main lobe** of the Galileo E6 spectrum

Expected pseudorange degradation

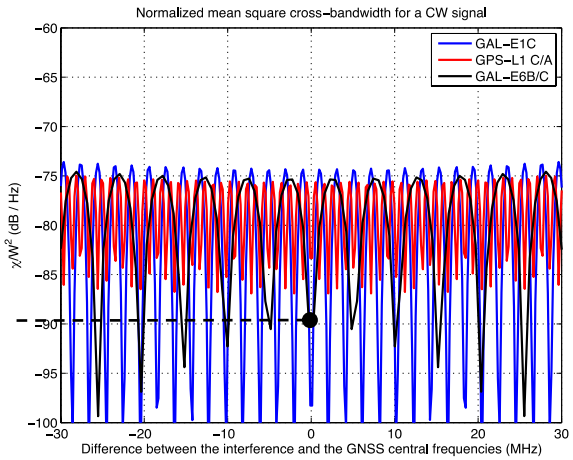
$$\frac{\sigma^2_{\text{interf}}}{\sigma^2_{\text{baseline}}} \approx$$

$$\approx \frac{C_i}{N_0}(\text{dBHz}) + \frac{\chi_{i,g}}{W^2}\left(\frac{\text{dB}}{\text{Hz}}\right)$$

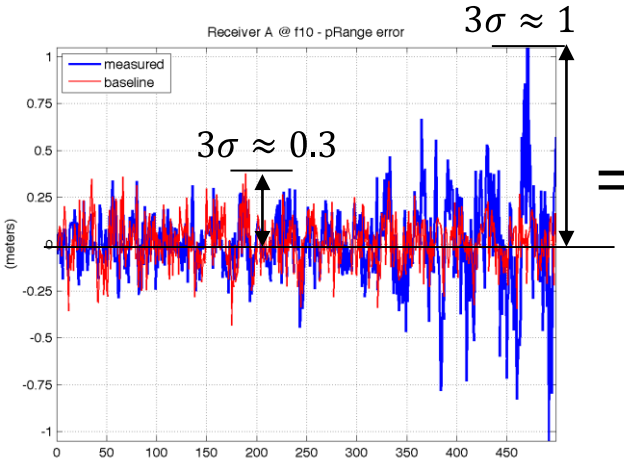
$$= 100\text{dBHz} - 90\frac{dB}{Hz}$$

$$= 10\text{dB}$$

$\Leftarrow$



Measured pseudorange degradation @ C_i/N_0=100dBHz

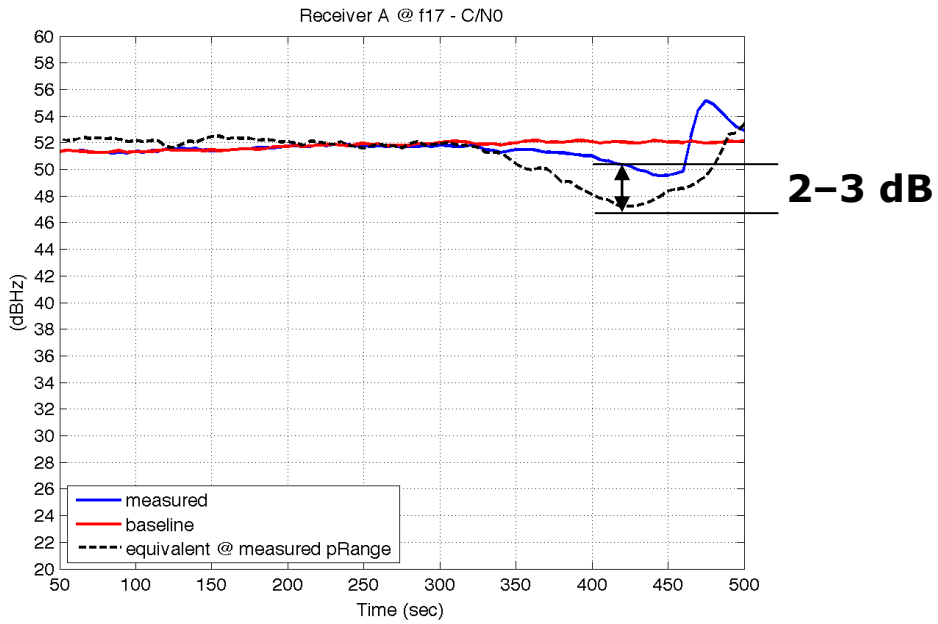


$\Rightarrow \frac{\sigma^2_{\text{interf}}}{\sigma^2_{\text{baseline}}} \approx 10$

Pseudorange performance (2/2)

- Care must be taken at the **edges of the band**, where the **pseudorange degradation** may be **larger** than the one that could be inferred just by looking at the C/N_0 reported by the receiver

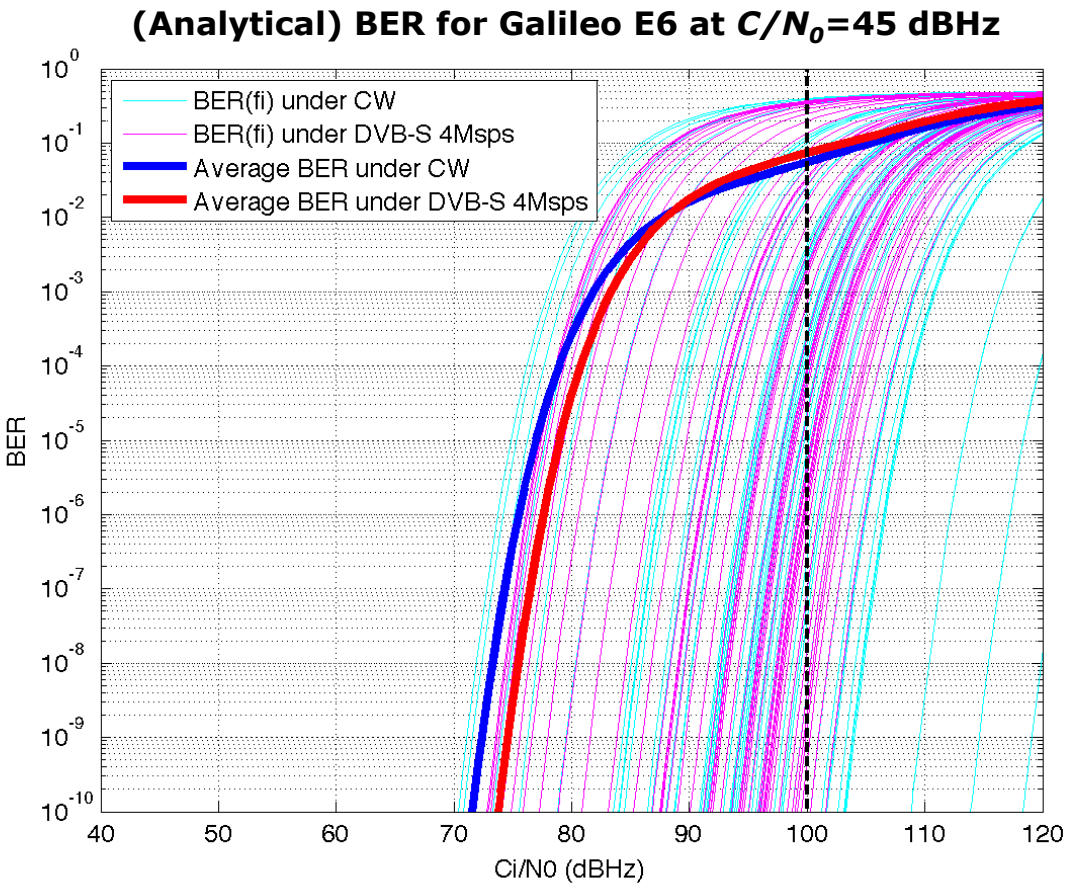
- Example: **CW signal at C_i/N_0 placed at the edge** of the Galileo E6 spectrum



The pseudoranges behave as driven by an equivalent C/N_0 that is below the one actually reported by the receiver.

Bit error rate performance

BER(fi): bit error rate when the ATV interference is placed at any central frequency "fi" within the E6 band.



Summary (1/2)

- Experimental tests with live signals were carried out using high-end E6-enabled receivers and a testplan coordinated with IARU members
- Experimental tests have been validated with analytical derivations
- A realistic scenario has been considered with maximum C_i/N_0=100dBHz (i.e. equivalent to **EIRP=1W@3km** distance, or **EIRP=15W@10km**)
- The maximum observed degradations are:

C/N_0 Degradation:	>30 dB losses (for CW) 20 dB losses (for DVB-S/T)
Pseudorange variance:	x10 increase.
Bit error rate:	
• for C/N_0 losses > 20–25 dB,	BER collapses (i.e. tends to 0.5)
• for average C/N_0 losses (10dB),	BER > 0.01 @ C/N_0 =40dBHz

Summary (2/2)

- Noting the ATV impacts on the Galileo E6 signals (and certainly **other RNSS systems** using the same frequencies):
  - ✓ AS already acknowledges its secondary status and has indicated **compliance** where necessary
    - but, **additional** radio regulatory **decisions** may be required
  - ✓ Galileo working with EU national authorities to determine **appropriate measures**
  - ✓ wider decisions at **CEPT** and **ITU** level could be expected in future

- Important to underline that **some AS applications** may be easily **compatible with GNSS**