The Future of Secure Positioning and Timing: Insights from Jammertest 2025

25.11.2025

Shadman Razzaq Siddiqui, Product Strategy, u-blox AG
Samuli Pietilä, Product Strategy, u-blox AG

Speakers of today

Shadman Razzaq Siddiqui

Senior Technical Marketing
GNSS Automotive

Samuli Pietilä

Director Product Management
Timing and Infrastructure GNSS

Agenda

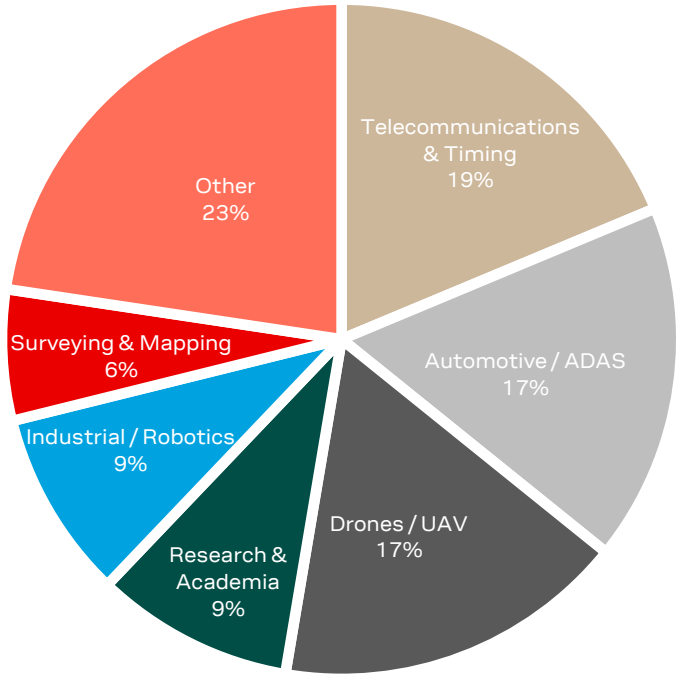
- Poll results: audience profile & their concerns
- Why field testing?
- System Setups: Automotive Positioning & Timing setup
- Test Area Overview
- Interference Scenarios
- Results: Jamming Resilience
- Results: Meaconing Resilience
- Results: Spoofing Resilience
- What's next
- Open Q&A

Audience poll results

Poll 1

Which industry are you from?

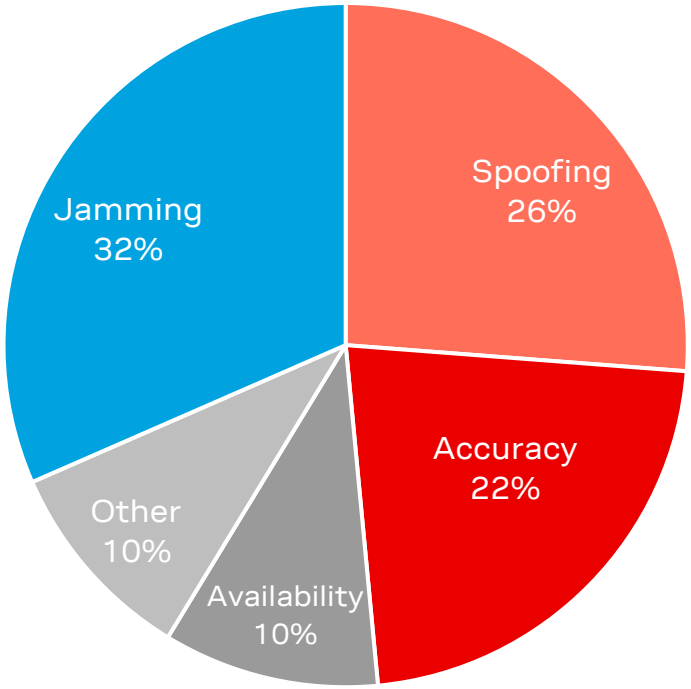
(Automotive / Industrial / Research / Other)



Poll 2

What is your top GNSS concern?

(Jamming / Spoofing / Availability / Accuracy)



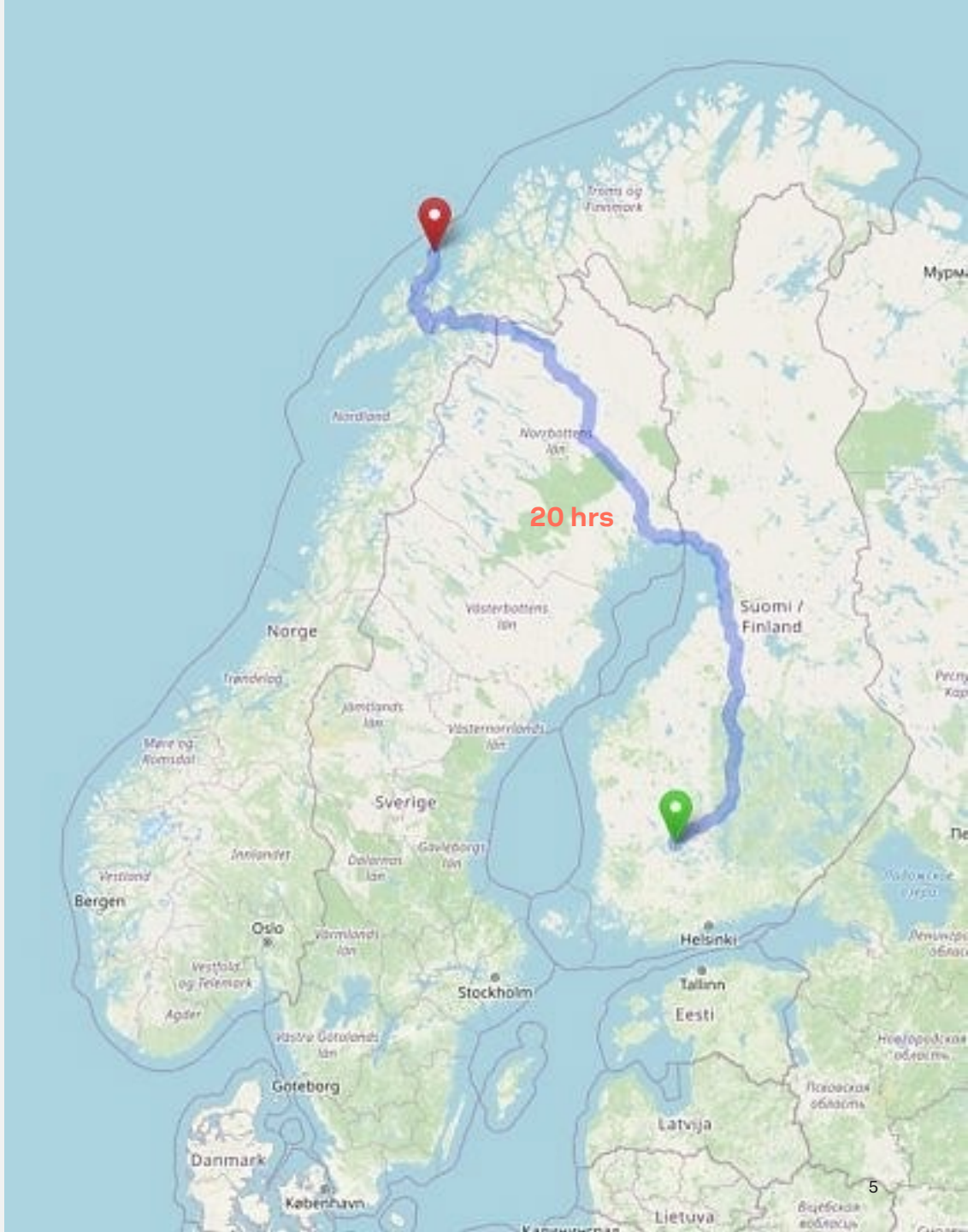
Why field testing?

Opportunity

- GNSS spoofing and jamming is illegal, in general
- Lab tests validate specifications; field tests validate performance under real interference

Objective

- Prove positioning continuity and integrity under live, open-sky jamming/spoofing



Positioning and stationary timing setups

Positioning Setup (Test car)

- Multiple DUTs in One Vehicle monitored and recorded
- Shared Antenna: ANN-MB2
- Reference System: Post-Processed Applanix

Stationary timing test setup

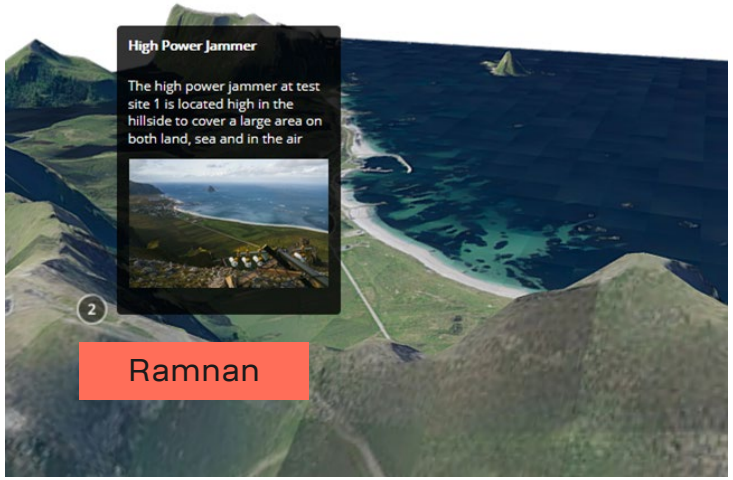
- Stable 1PPS reference provided by the organizers
- 8-channel time interval counter

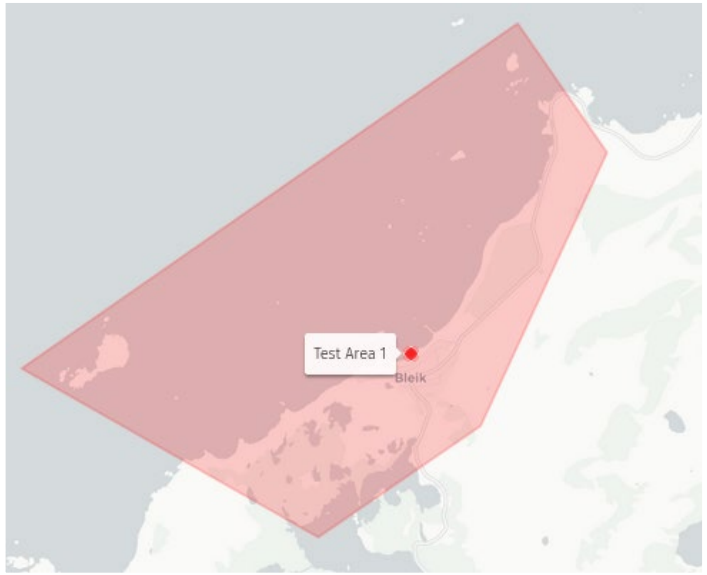
Test area overview

Test area 1: Bleik

Test activities include:

- High-power stationary jamming
- High-power unintentional Radio Frequency Interference (RFI)
- Stationary spoofing (focused on positioning and navigation)
- Stationary spoofing (focused on timing)
- Meaconing





Interference Scenarios Overview

Jamming

Core Waveforms:

- CW
- Swept CW
- PRN-like noise

Advanced Jamming:

- Drifting CW across bands
- PRN with Power Ramp

Meaconing

Single vs Multi-source

Compound Scenarios:

- Meaconing + Spoofing
- Meaconing + Jamming

Spoofing

Positioning Spoofing:

- Incoherent POS — synthetic ephemerides
- Incoherent POS — broadcast (true) ephemerides
- Coherent POS — broadcast ephemerides

Timing Spoofing:

- Incoherent TIM — synthetic ephemerides
- Coherent TIM — broadcast ephemerides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Results:
Jamming Resilience

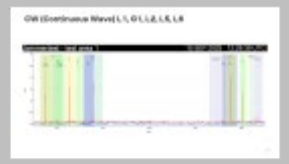
Jamming Types: CW · Swept CW · PRN

Jamming of L1 only and L1, G1, L2, L5, E6 signals - 47dBm Jamming at Ramnan

Test#1.2.1 and 1.2.5

CW (Continuous Wave)

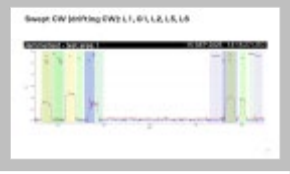
jamming signals use continuous wave (CW) modulation



Test#1.3.10 and 1.3.11

Swept CW (drifting CW)

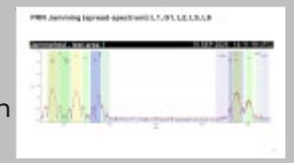
jamming signals jammer sweep across selected frequency bands



Test#1.4.5 and 1.4.6

PRN (spread-spectrum)

jammer transmit signals modulated with Pseudo Random Noise (PRN)



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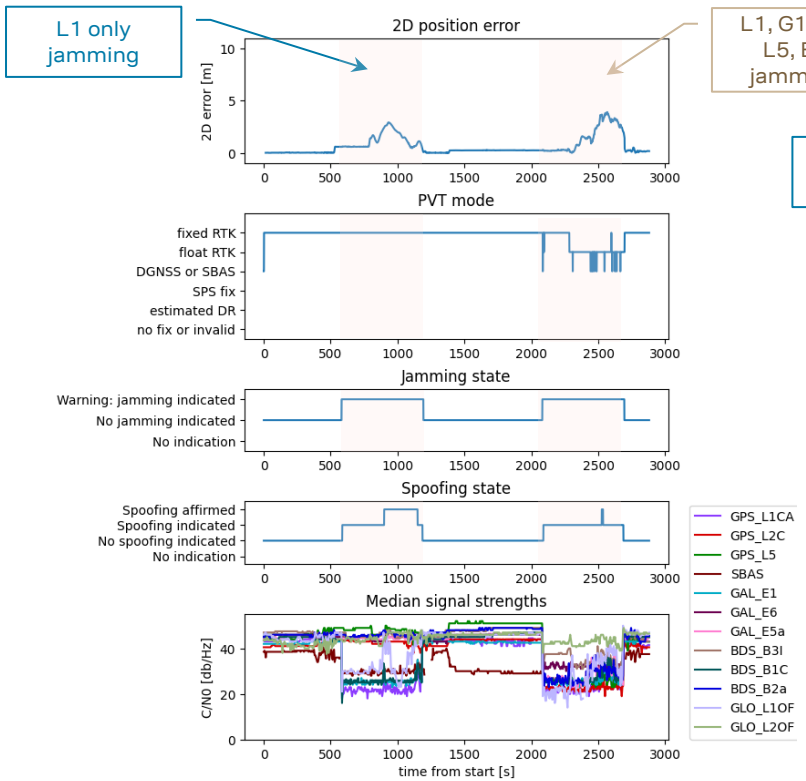

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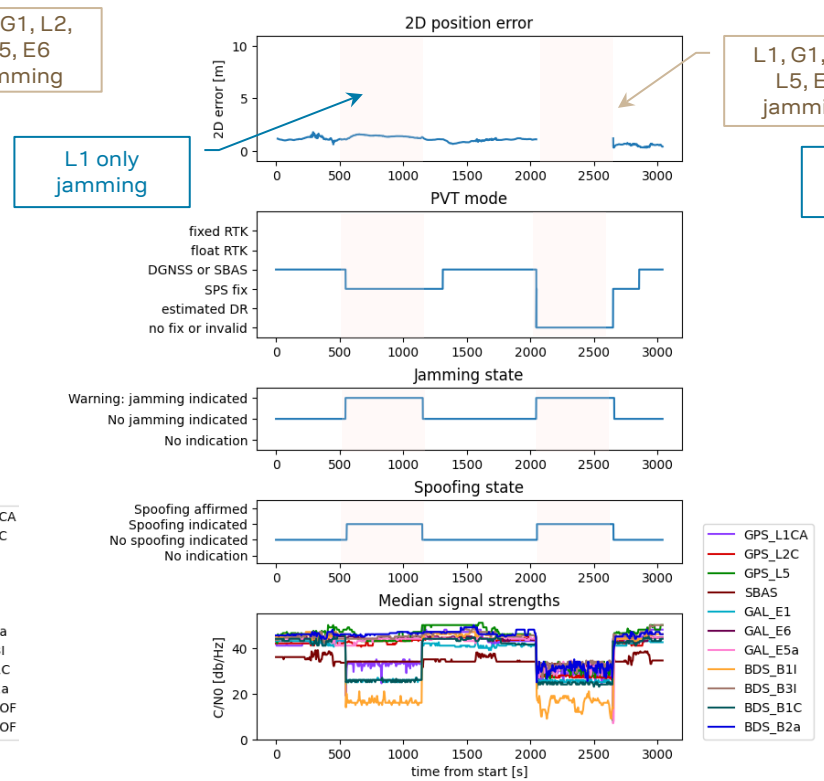

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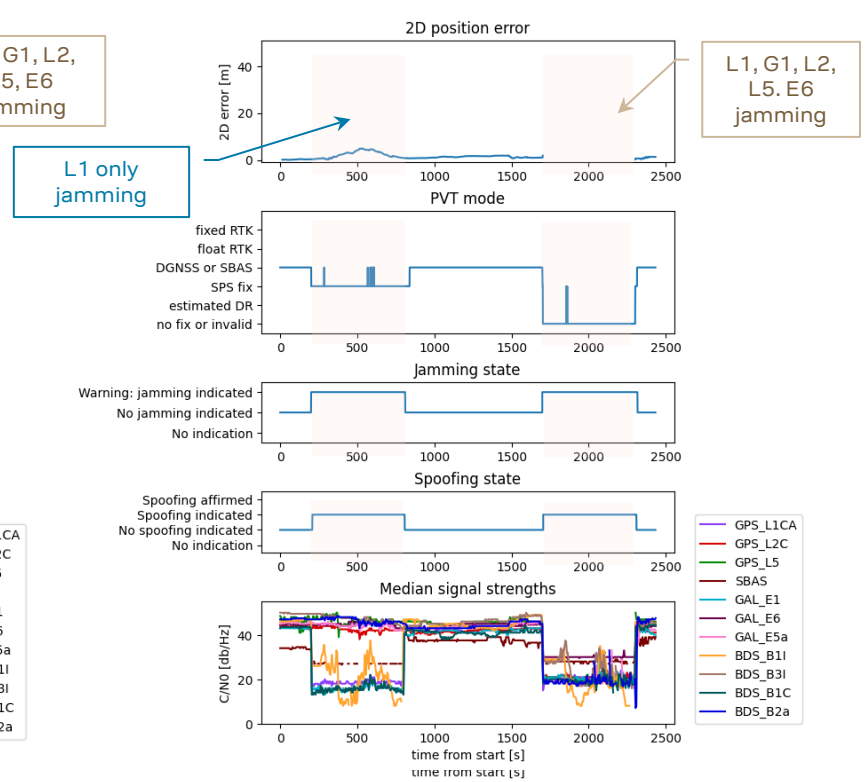

Advanced Jamming: Drifting Across Bands

1.8.1: 50 W PRN pyramid jamming, starting with only E6 and adding bands all the way up to E6, E5b, L5, G2, L2, B1I, G1, L1. The test then continues by removing bands one by one in reverse order, until ending up with only E6

1.18.5	CW signal drift: 1545 to 1620 MHz, 15 minutes sweep time
1.18.7	CW signal drift: 1620 to 1545 MHz, 15 minutes sweep time
1.18.13	50 W drift: 1150 to 1300 MHz, with CW and sweep time of 15 minutes
1.18.15	50 W drift: 1300 to 1150 MHz, with CW and sweep time of 15 minutes

E6
E6, E5b
E6, E5b, L5
E6, E5b, L5, G2
E6, E5b, L5, G2, L2
E6, E5b, L5, G2, L2, B1I
E6, E5b, L5, G2, L2, B1I, G1
E6, E5b, L5, G2, L2, B1I, G1, L1
E6, E5b, L5, G2, L2, B1I, G1
E6, E5b, L5, G2, L2, B1I
E6, E5b, L5, G2, L2
E6, E5b, L5, G2
E6, E5b, L5
E6, E5b
E6

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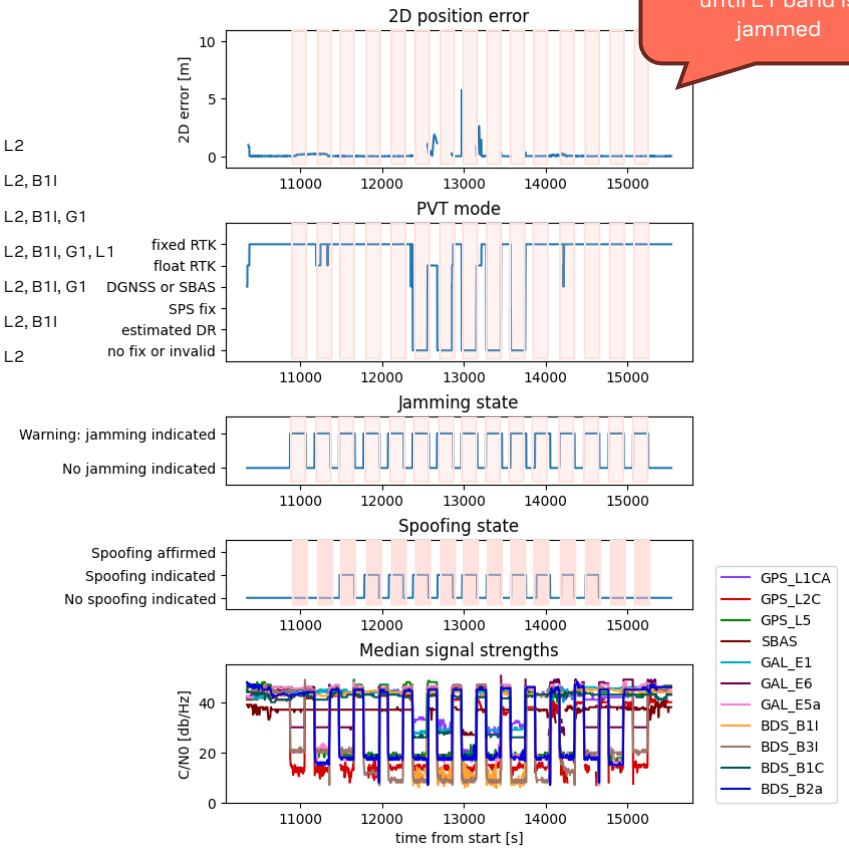
RTK FIXED Mode until L1 band is jammed



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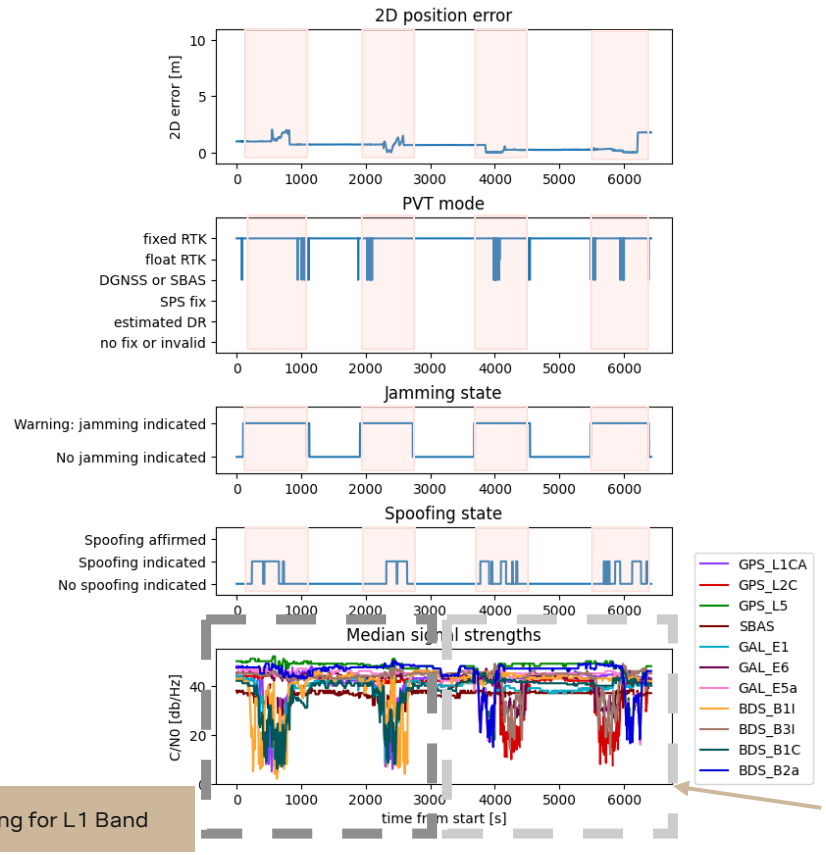

CW jamming for L1 Band

Sweep across E6, L2 and L5 bands

Advanced Jamming: Drifting Across Bands

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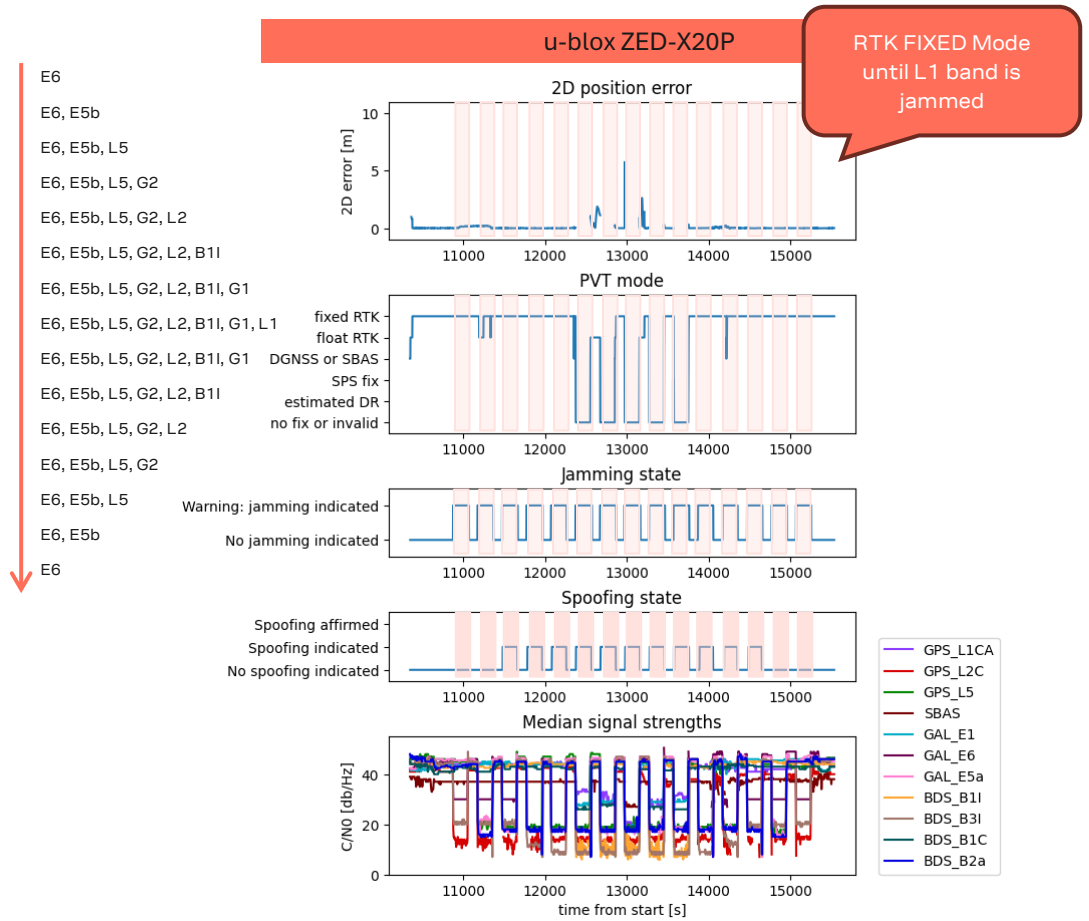
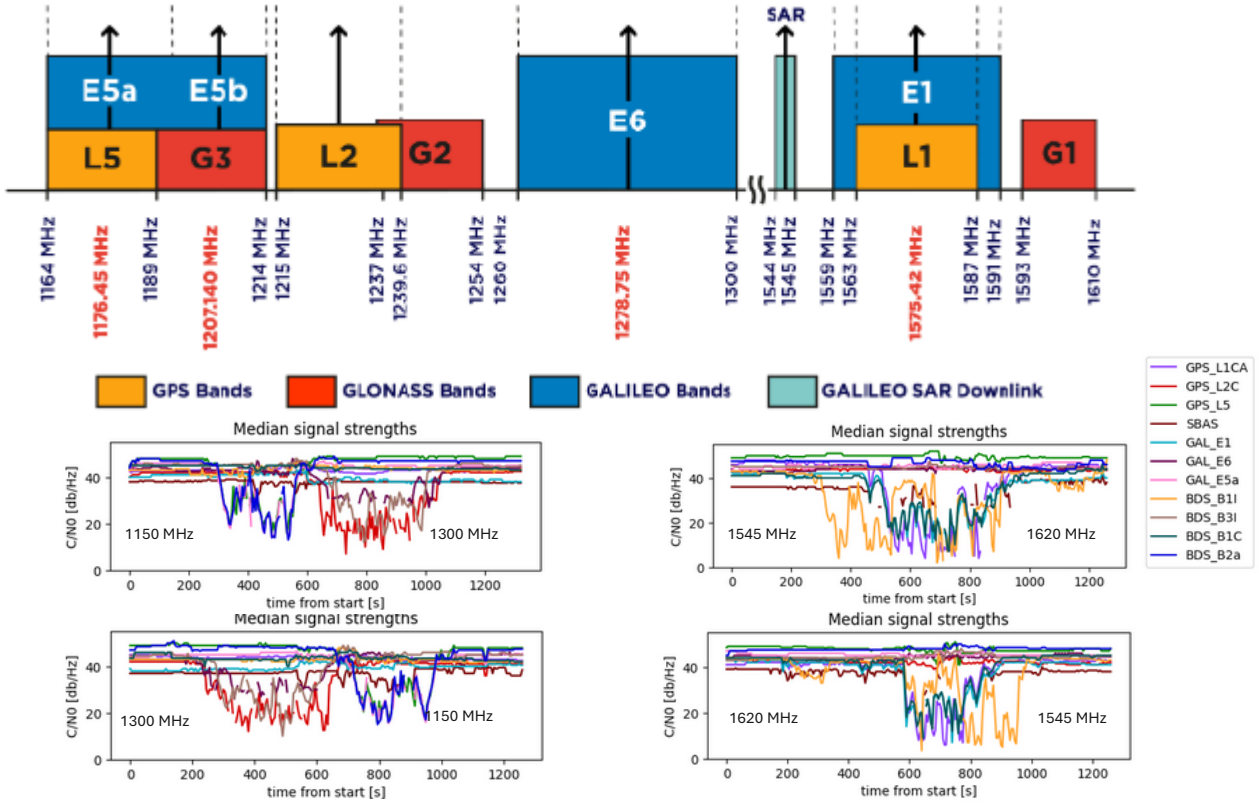
1.18.15	50 W drift: 1300 to 1150 MHz, with CW and sweep time of 15 minutes





Advanced Jamming:
PRN with power ramp L1, G1, L2, L5, E6

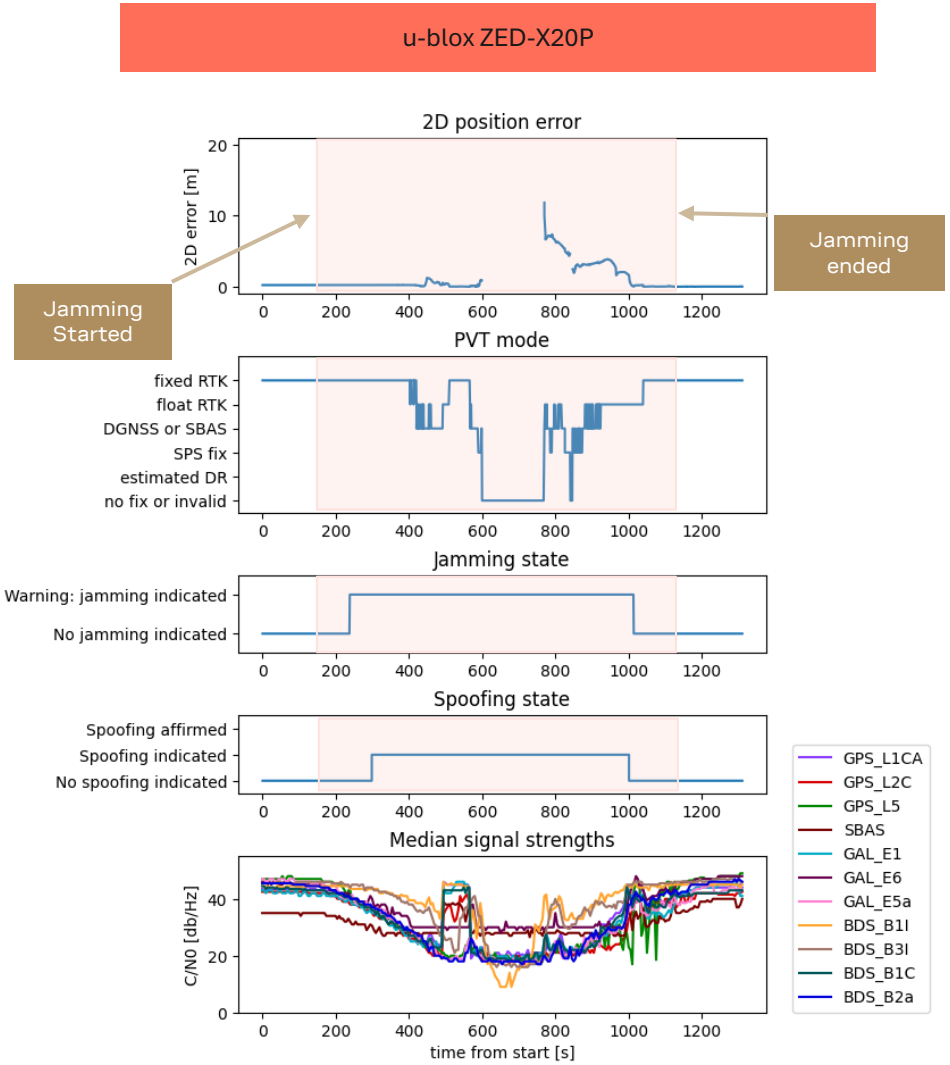
Test# 1.6.8

PRN jamming with a power ramp from 7.9 µW (-21dBm) to a maximum of 50 W (47dBm) at 2 dB increments, within the test bands. Power level step time 20 seconds

- The receiver starts detecting Jamming when the jamming power level is:

  In mW: ≈ 0.3145 mW.

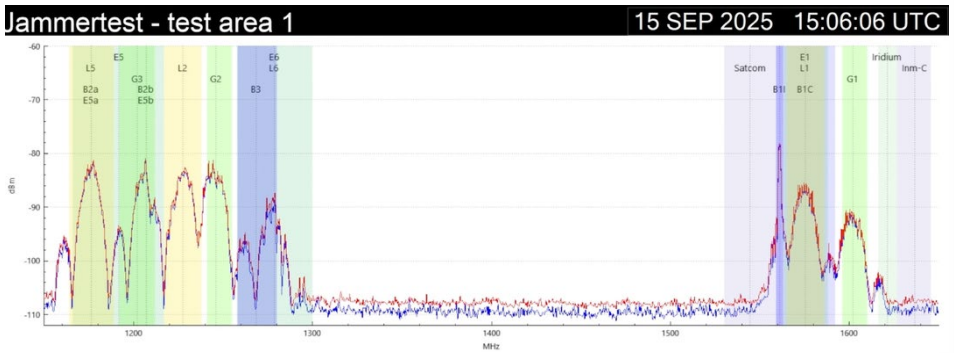
  In dBm: = −5.0 dBm.



Jamming in timing setup

Pyramid jammer, PRN noise at 50W

E6
E6, E5b
E6, E5b, L5
E6, E5b, L5, G2
E6, E5b, L5, G2, L2
E6, E5b, L5, G2, L2, B1I
E6, E5b, L5, G2, L2, B1I, G1
E6, E5b, L5, G2, L2, B1I, G1, L1
E6, E5b, L5, G2, L2, B1I, G1
E6, E5b, L5, G2, L2, B1I
E6, E5b, L5, G2, L2
E6, E5b, L5, G2
E6, E5b, L5
E6, E5b
E6



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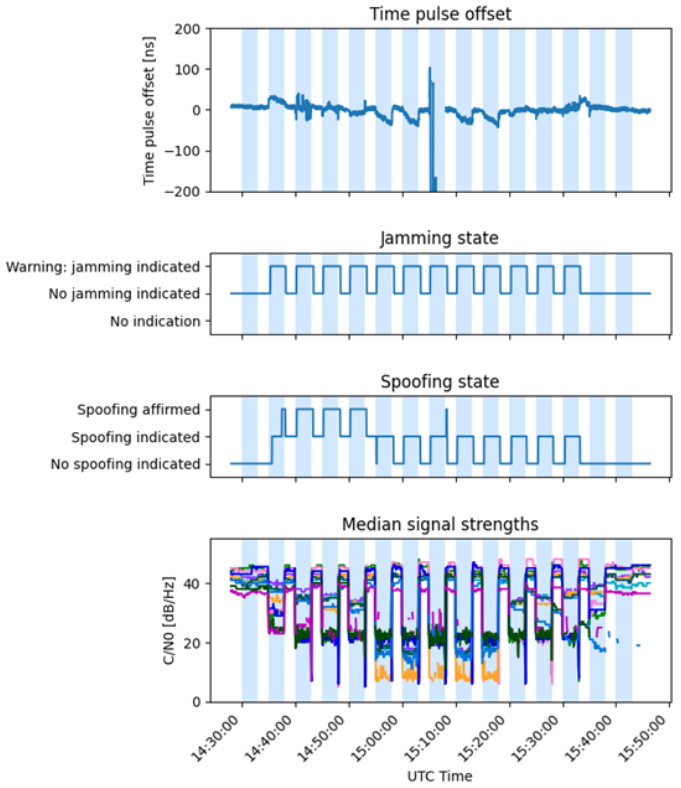
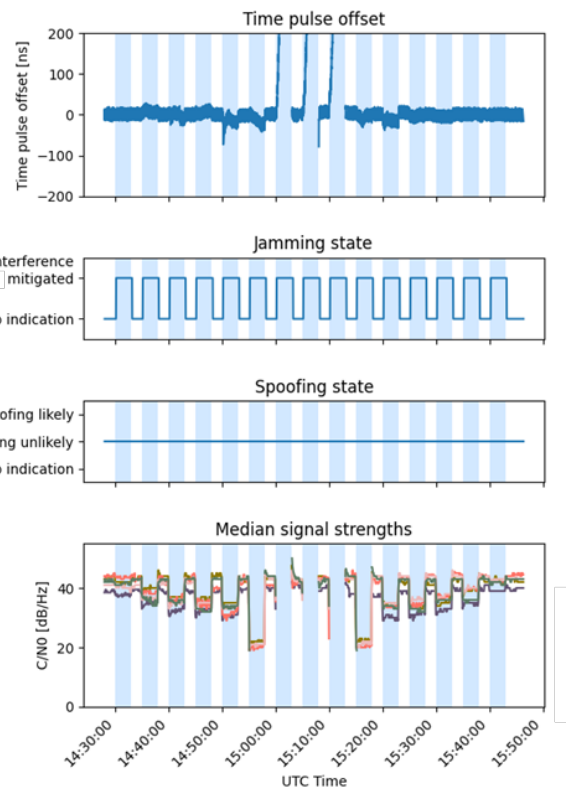
Test case 1.8.1 EVK_F9T_TIM225_OSNMA_LOOSE



Competitor A

Test case 1.8.1

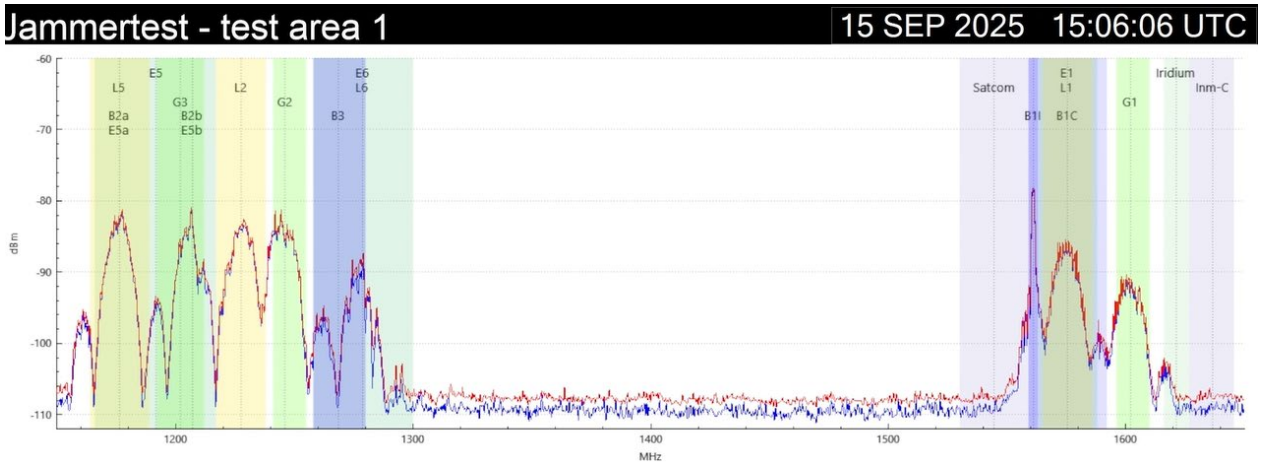


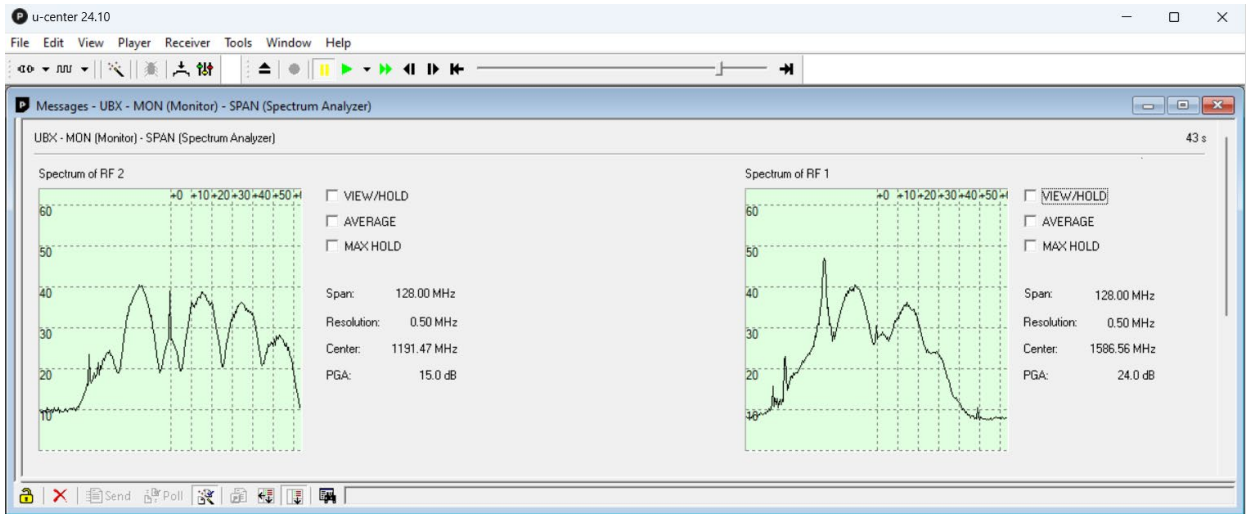
Built-in spectrum analyzer

- For those users who want to dig deeper… u-blox GNSS receivers provide built-in spectrum analyzer

- Useful during R&D to detect clock harmonics etc interference leaking into GNSS bands

- But also gives deeper insight into RF environment during jamming and spoofing events





Key takeaway: Jamming Resilience

1 **Early and Reliable Jamming Detection**	Jamming is detected consistently across CW, Swept CW, and PRN. • Detection threshold is low (~–5 dBm input): early warning before PVT fails.
2 **Stable Performance Under Single-Band Jamming**	RTK FIX maintained with single band jamming. • Multi-band redundancy (L2/L5/E5/E6) keeps position stable.
3 **Smooth Degradation Under Multi-Band Jamming**	No sudden jumps; position and time remains bounded and reliable.
4 **Spoofing Warnings May Trigger Under Heavy Jamming**	Strong jamming distorts correlation peaks → spoofing alert triggered. Jamming can distort signals enough to activate spoofing indicators • PVT integrity is preserved.
5 **Fast Recovery When Jamming Ends**	Instant satellite reacquisition. • Immediate return to RTK FIX when signals reappear.

Results: Meaconing Resilience

Stationary meaconing from single receiver

3.1.3: Meaconing RX1 at 10 W | 3.1.4 Meaconing RX1 at 10 W with initial jamming (PRN L1, L2, L5, G1, E6 and E5b at 50 W)

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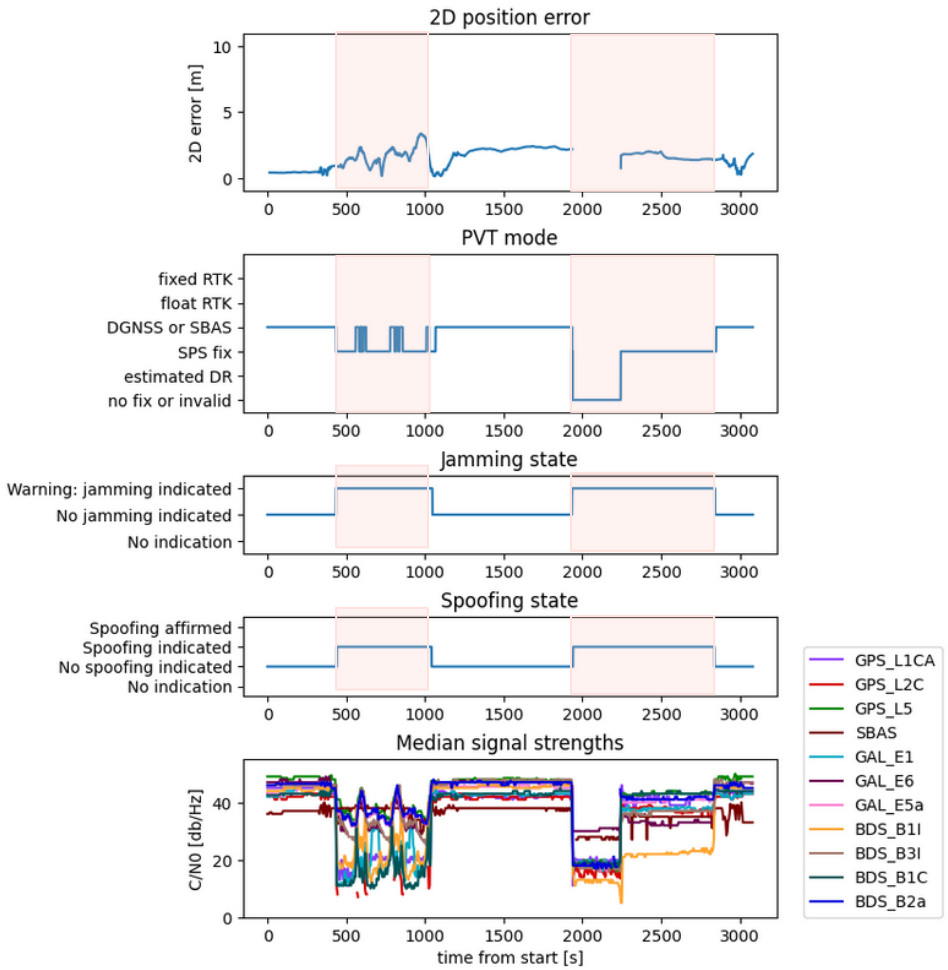
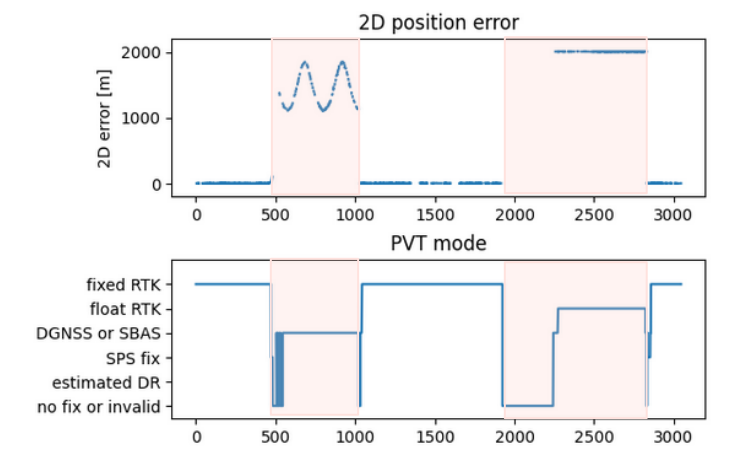
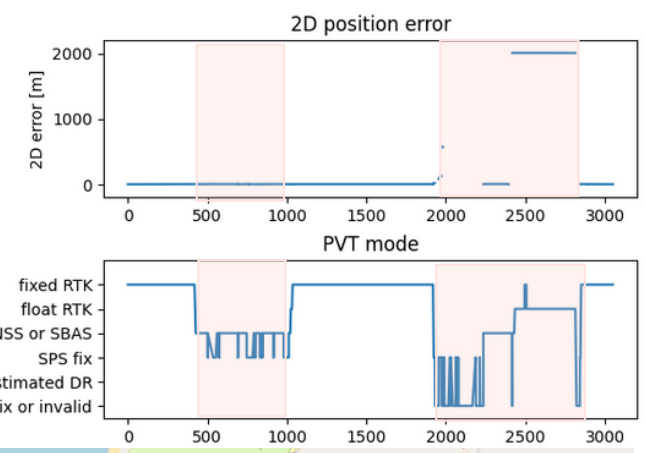


Competitor B



Competitor A



Stationary meaconing from two receivers

3.2.7: Meaconing: RX1 and RX2 at 10 W alternating with different switching frequencies

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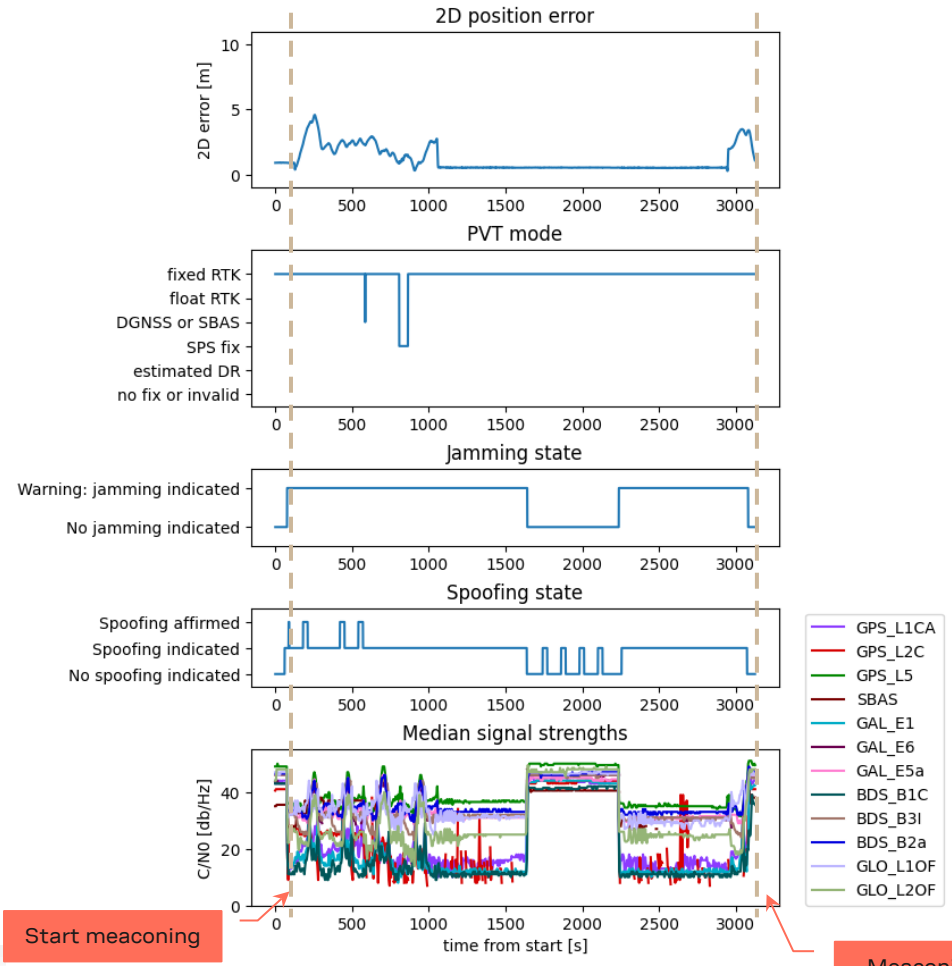
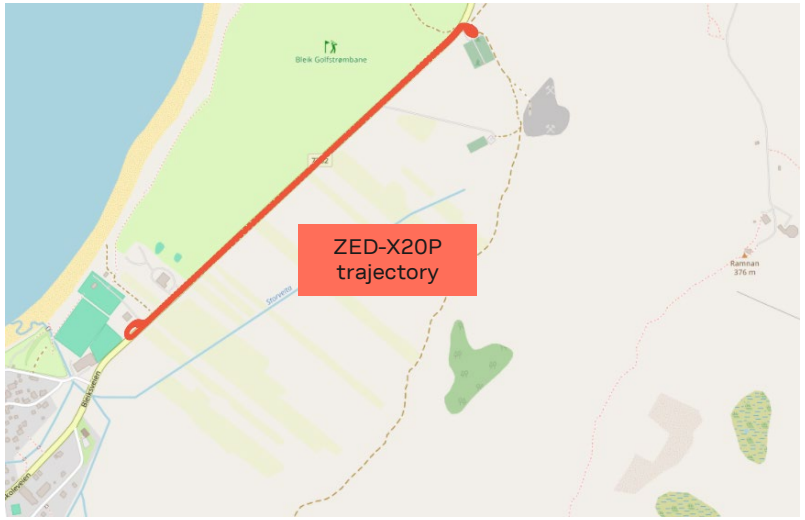


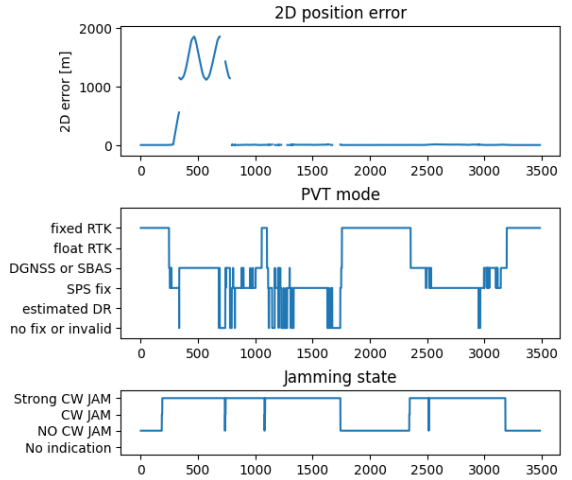
Start meaconing

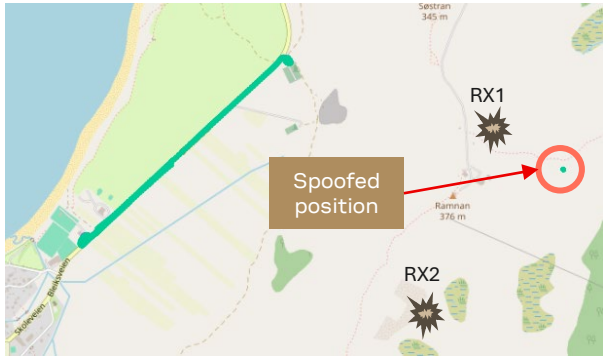
Meaconing ended



40dBm Meaconing from Porcellus at Ramnan. Two-minute intervals with increasingly rapid switching between receiving antennas RX1 and RX2.

Competitor C

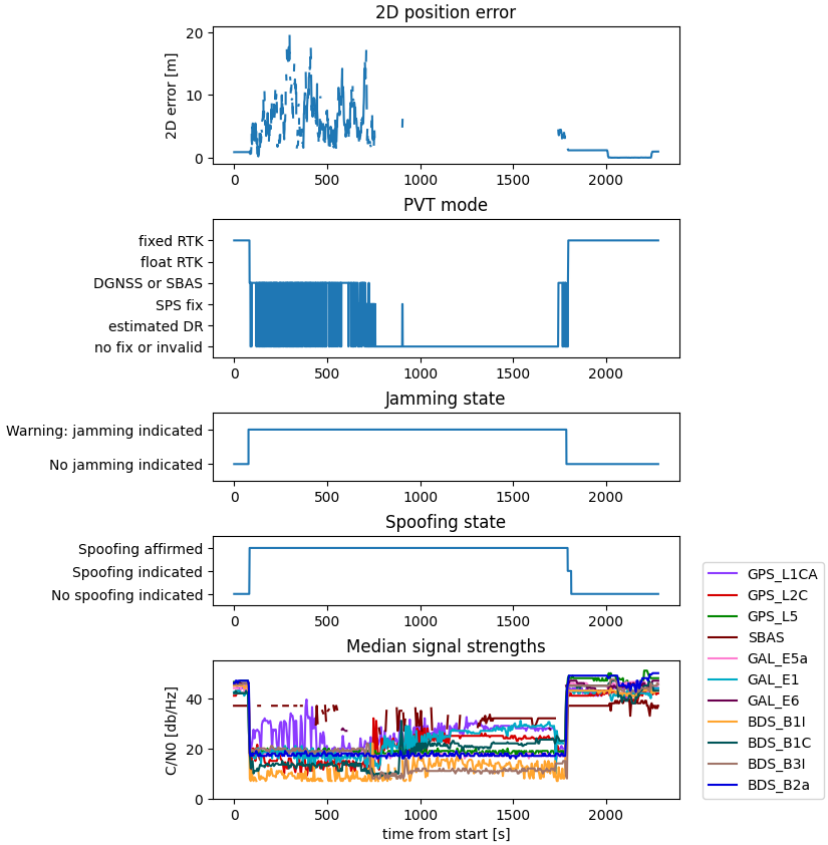




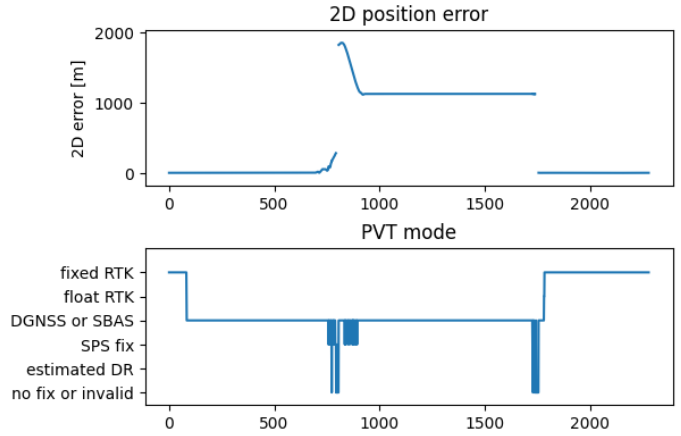
Stationary meaconing from two receivers

3.2.10 Meaconing: RX1 and RX2 at 10 W alternating with different switching frequencies and with jamming

u-blox ZED-X20P

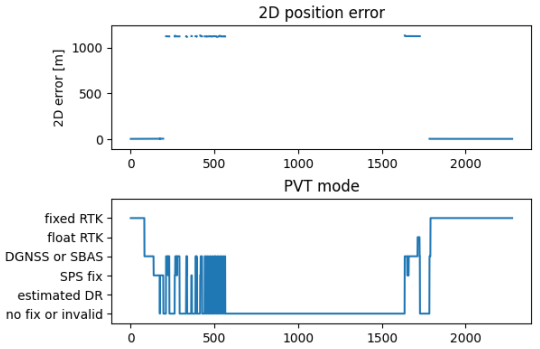


Competitor B

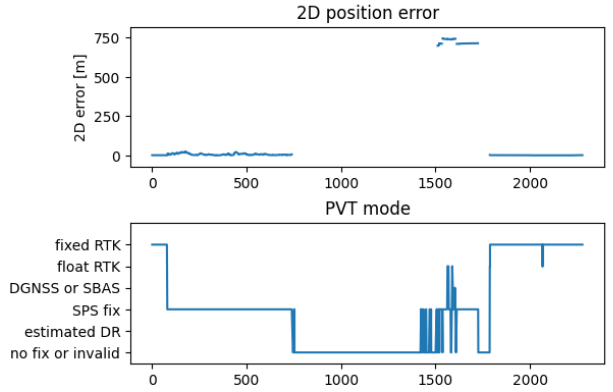


40dBm Meaconing from Porcellus at Ramnan with increasing switching frequency between receiving antennas RX1 and RX2. Accompanied by PRN jamming on L5, G1, G2, B1I, E5b and E6 from Porcus Maior.

Competitor C



Competitor A



Stationary meaconing from two receivers

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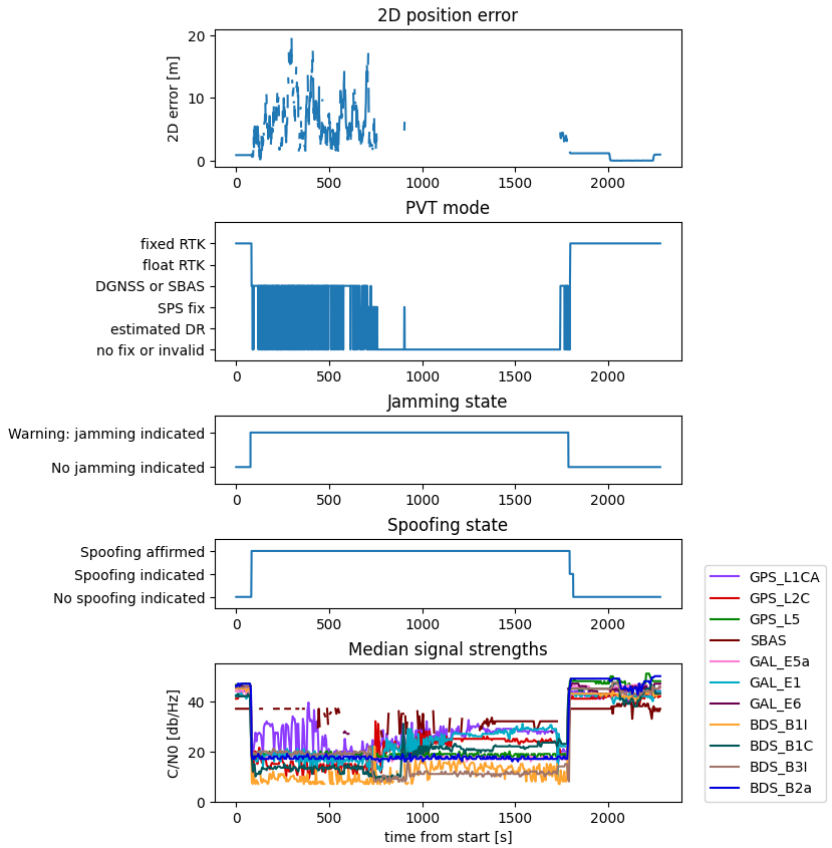
u-blox ZED-X20P



Competitor B

Competitor C

40dBm Meaconing from Porcellus at Ramnan with increasing switching frequency between receiving antennas RX1 and RX2. Accompanied by PRN jamming on L5, G1, G2, B1I, E5b and E6 from Porcus Maior.

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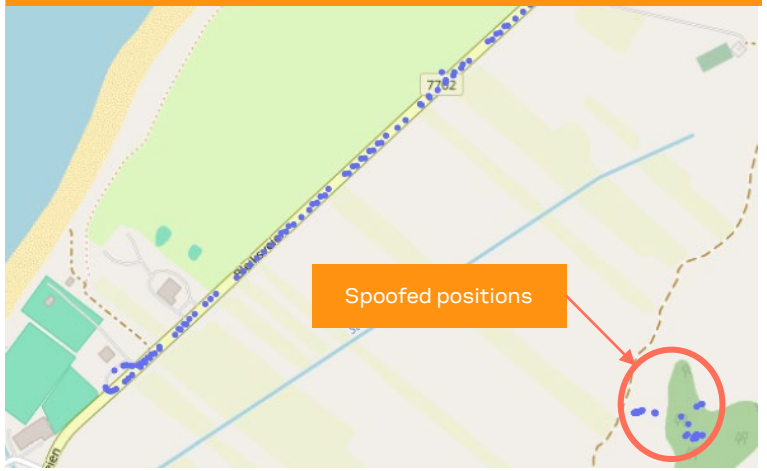
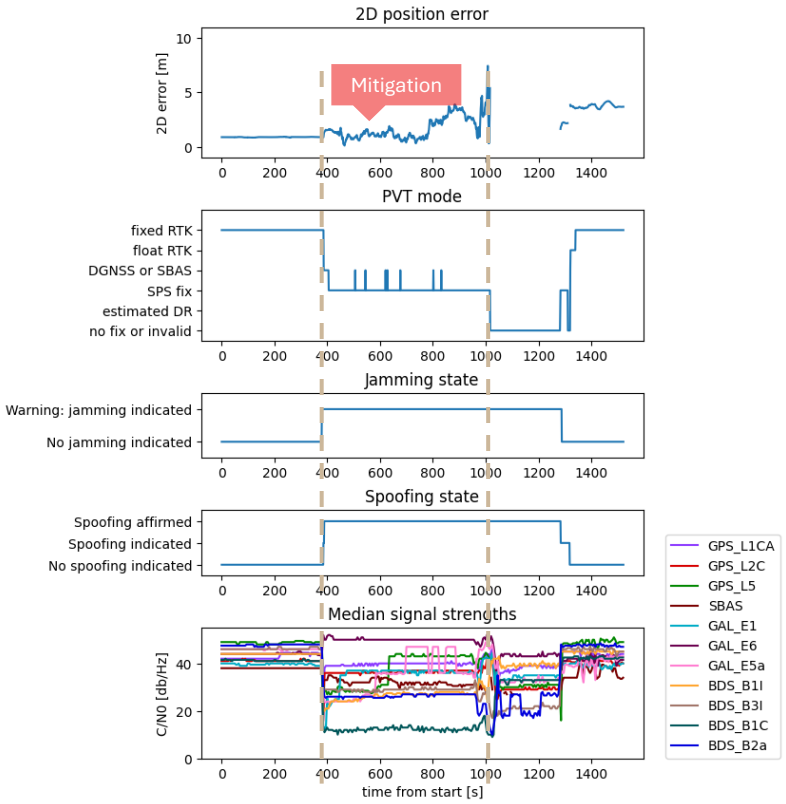


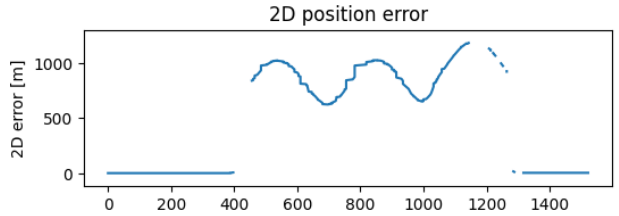
Meaconing and spoofing at the same time from different locations

3.4.1: Meaconing contain both L1 and L2 bands while spoofing is only L1 band

u-blox ZED-X20P



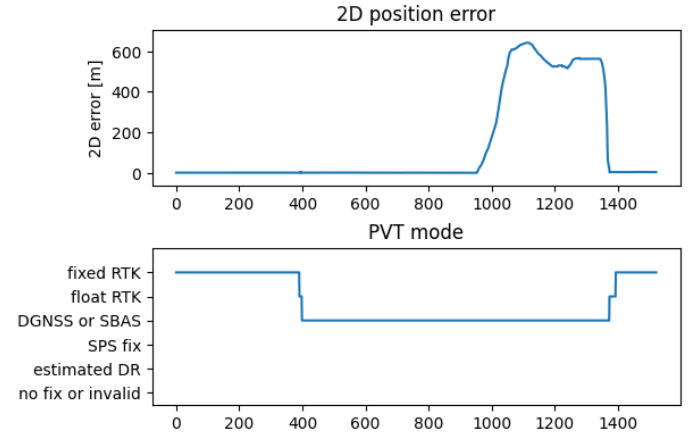
Competitor A



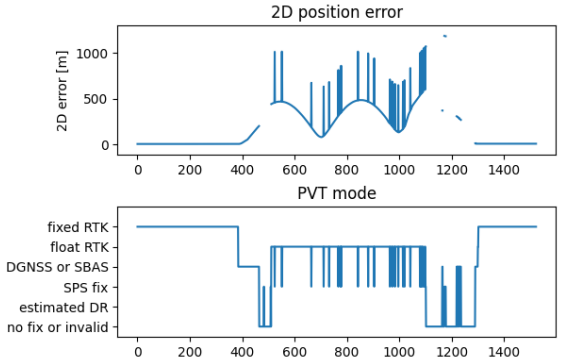
Meaconing from RX1, combined with spoofing signal from other location. Meaconing from Ramnan (mountain top) and cemetery. Spoofing from cemetery and Bleik. Spoofing route will be route 6

Route 6 (Bleik valley tour)

Competitor B



Competitor C



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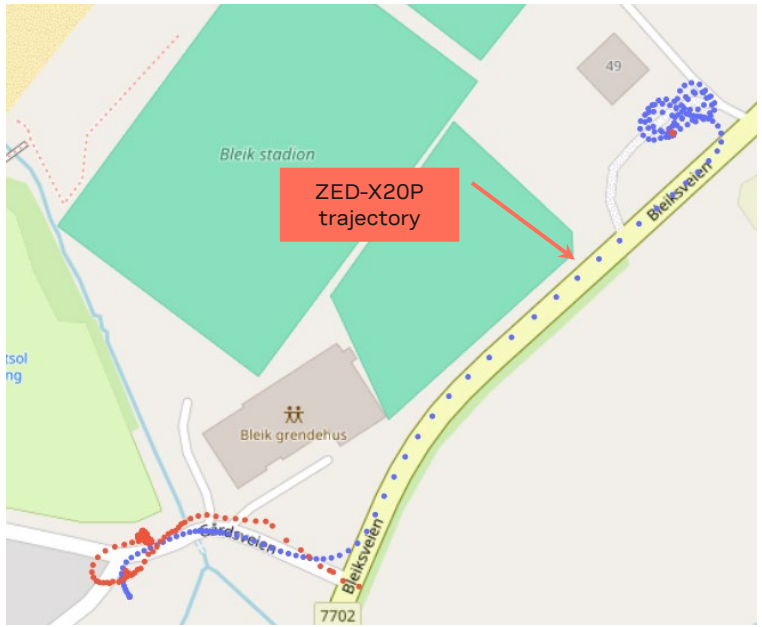

Competitor A

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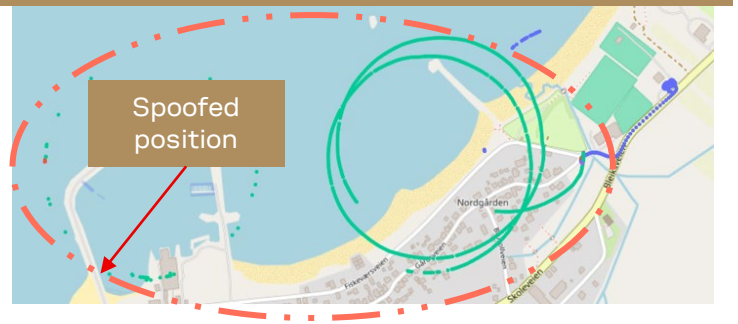
Route 6 (Bleik valley tour)

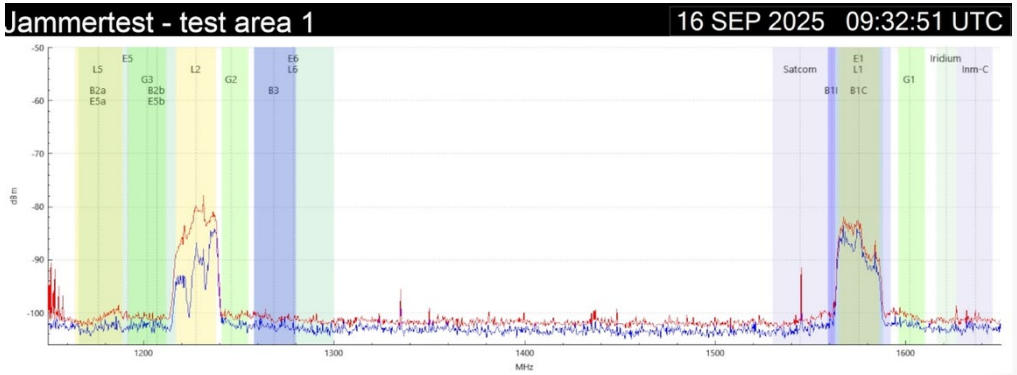
Competitor B

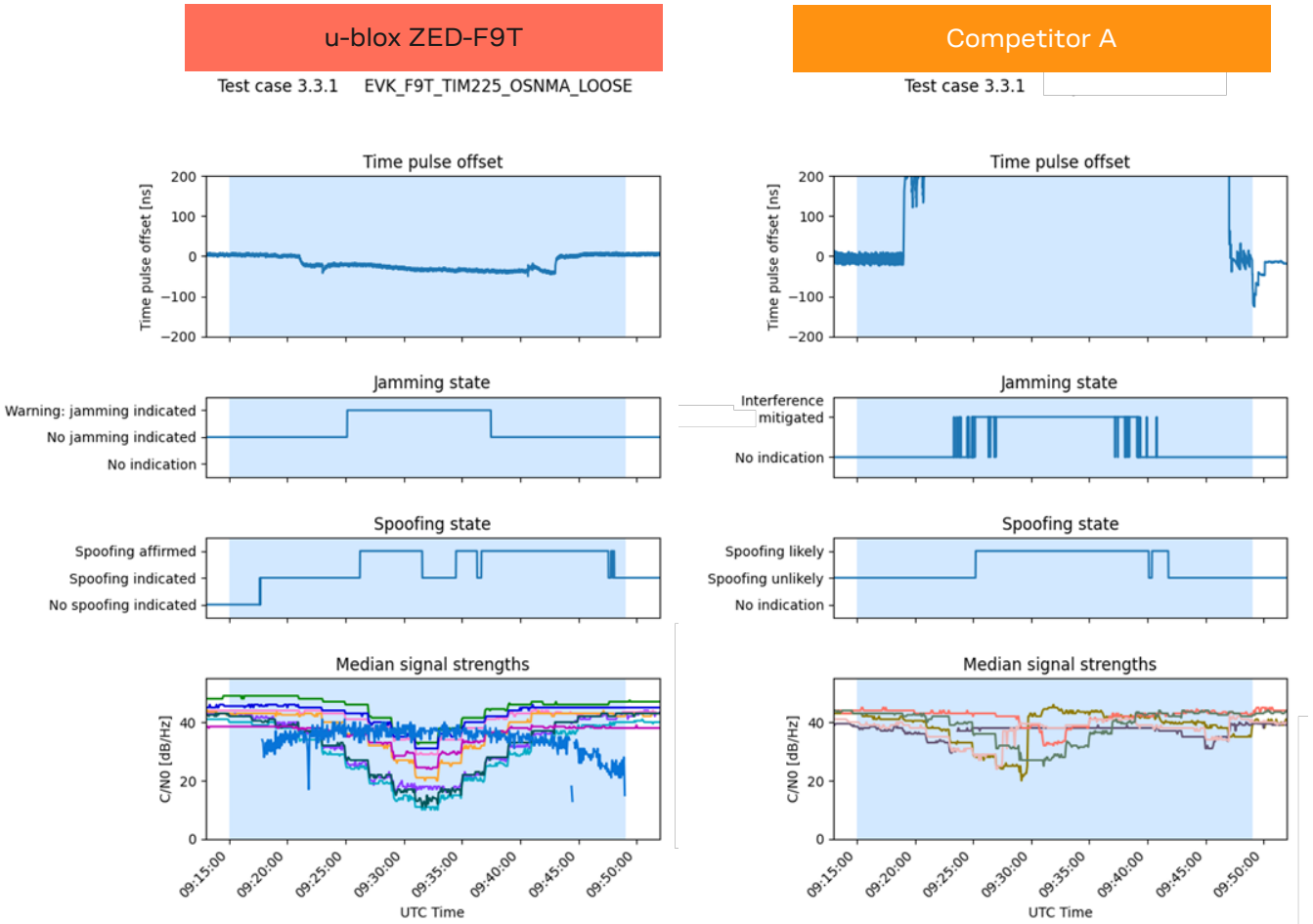
Competitor C



Meaconing in timing setup

- Rebroadcasting real GNSS signals with a small time delay
- Target is to fool the receiver to output:
  - ✓ The position of the meaconing system, and
  - ✓ Delayed time
- TX power is ramped up from 1mW to 10W and back in 5dB steps





Key takeaway: Meaconing Resilience

1 **u-blox Rejects False Positions**	Across all meaconing scenarios — single source, dual source, alternating, stationary, mobile — u-blox did not follow any false/meaconed trajectory.
2 **Spoofing/Meaconing Alerts Trigger Correctly**	Spoofing alerts rise whenever correlation or consistency checks fail No “false spoofing”
3 **Multi-Band and Time Consistency Checks Are Extremely Strong**	u-blox consistently detects when signals disagree Rejects unstable or contradictory meaconed ranges
4 **Combined Meaconing + Jamming Still Does Not Break Integrity**	Even with simultaneous PRN jamming + alternating meaconing, u-blox: • Does not drift into spoofed zones • Position snaps back to ground truth without instability
5 **u-blox Stays Grounded in Reality**	• No km-level deviations • No latch onto spoofing routes • No collapse into fake coordinates
6 **Fast and Clean Recovery**	As soon as interference stops: • Signals return • PVT re-enters RTK quickly

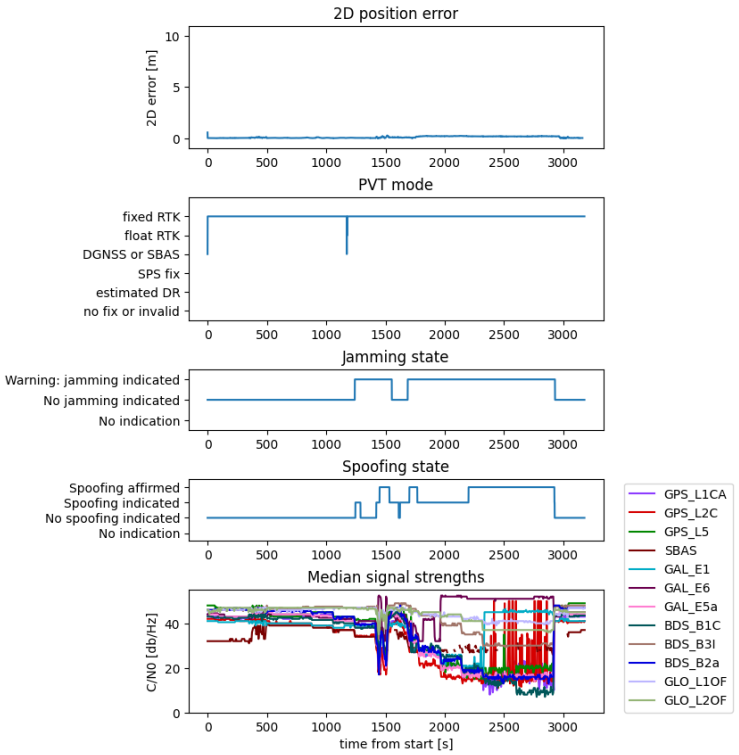
Results: Spoofing Resilience

Incoherent position spoofing from stationary spoofer using synthetic ephemerides

2.1.1 Large position and time jump, with power ramp, L1 C/A L2C L5 E1 E5 E6

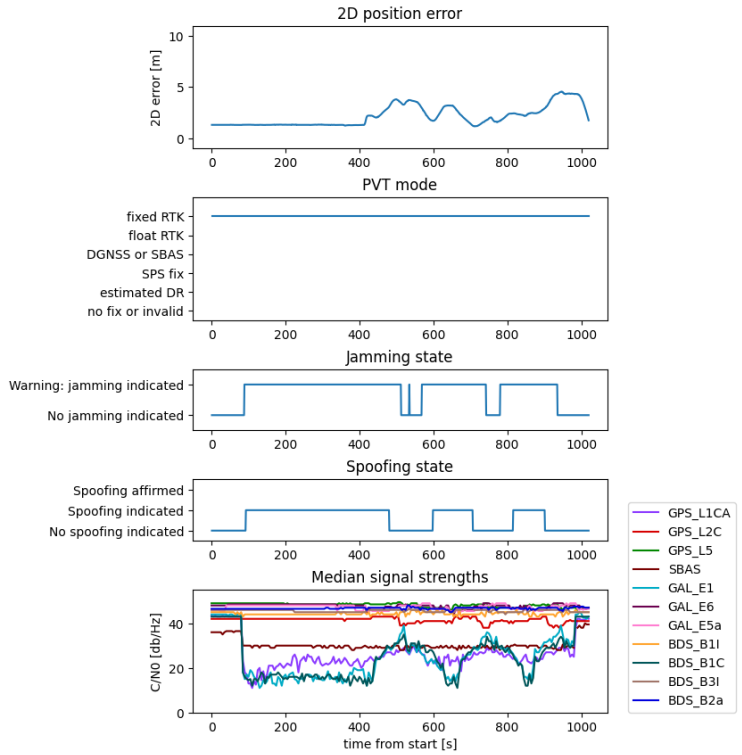
5 dB steps, with each step lasting 3 minutes.

u-blox ZED-X20P



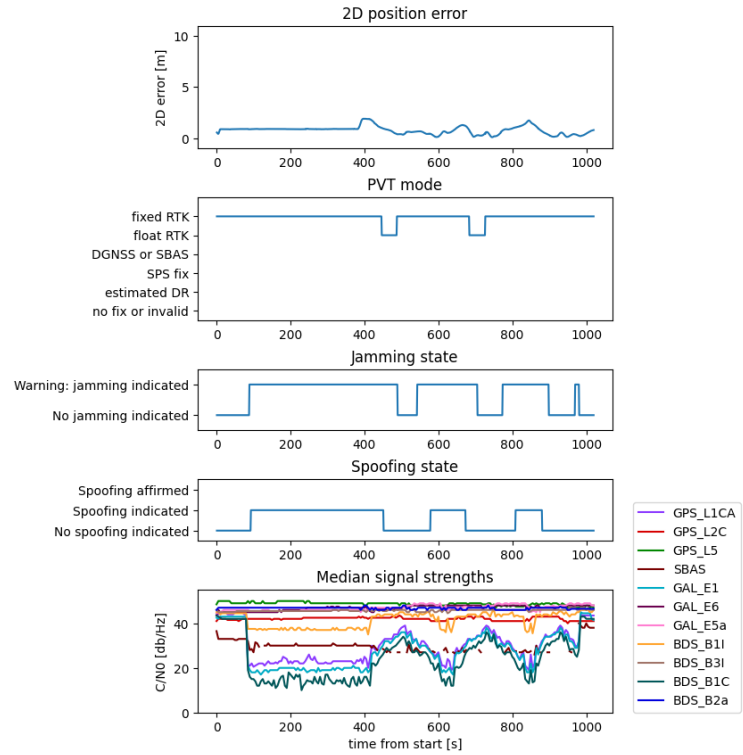
2.1.2 Large position and time jump. GPS L1 C/A only

u-blox ZED-X20P



2.1.3 Large position and time jump. Galileo E1 only

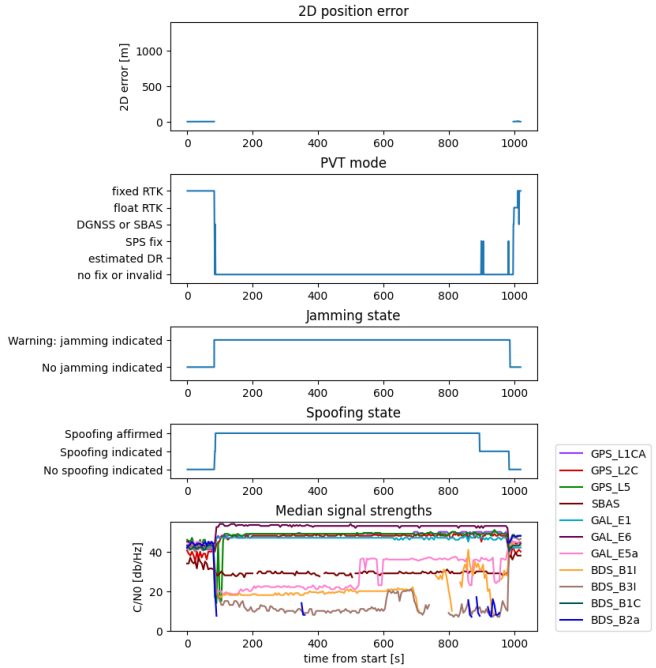
u-blox ZED-X20P

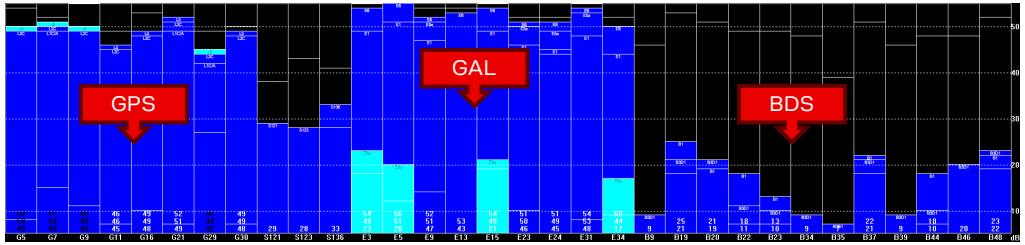


Incoherent position spoofing using broadcast(true) ephemerides

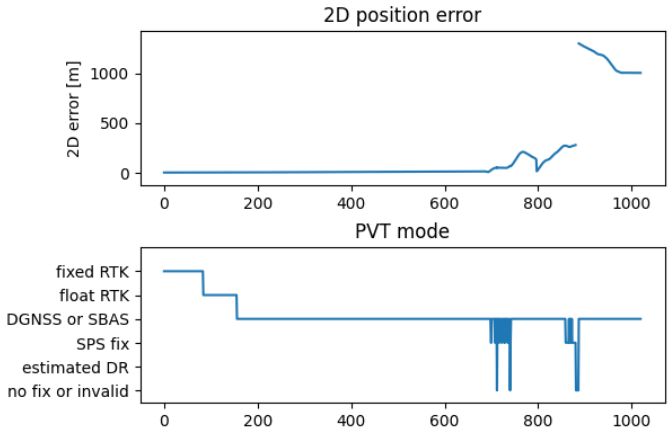
2.2.3 Position jump L1 C/A L2C L5 E1 E5 E6 – Simulated position: Cemetery

u-blox ZED-X20P

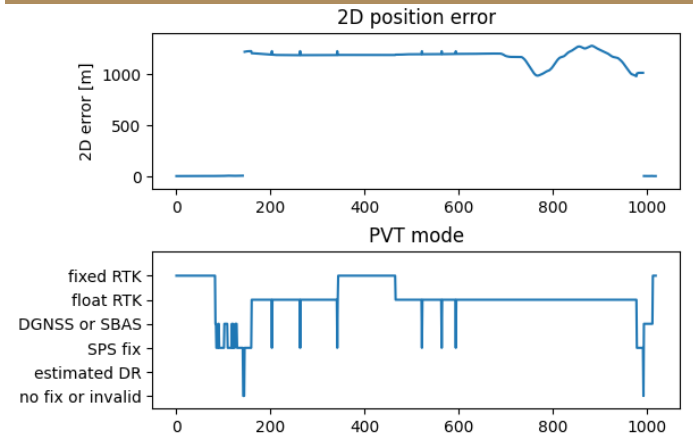




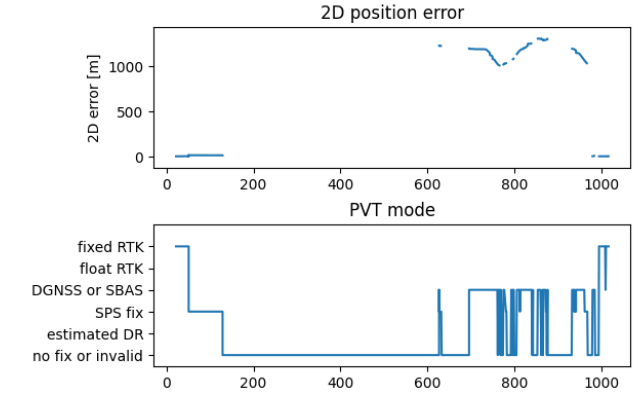
Competitor B



Competitor C



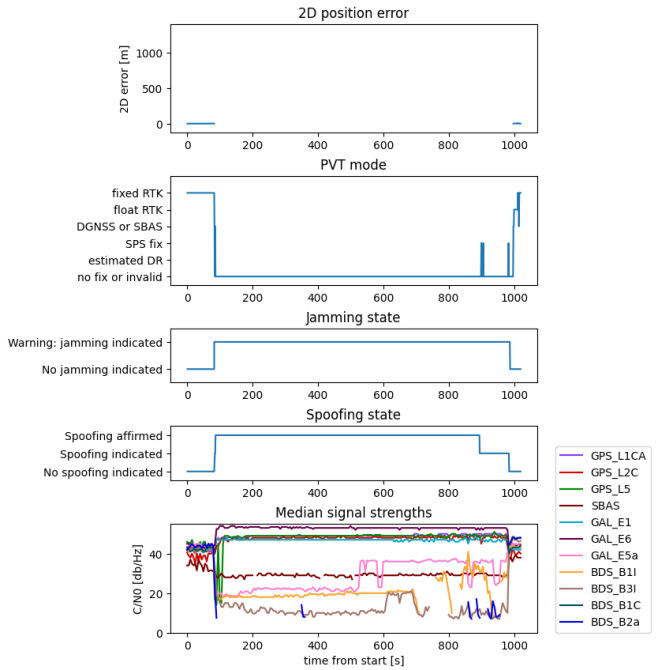
Competitor A

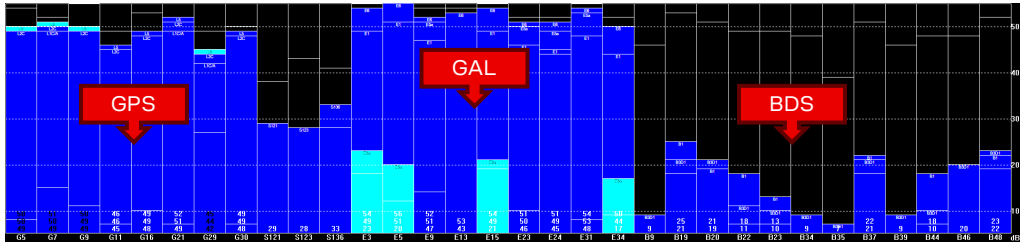


Incoherent position spoofing using broadcast(true) ephemerides

2.2.3 Position jump L1 C/A L2C L5 E1 E5 E6 – Simulated position: Cemetery

u-blox ZED-X20P

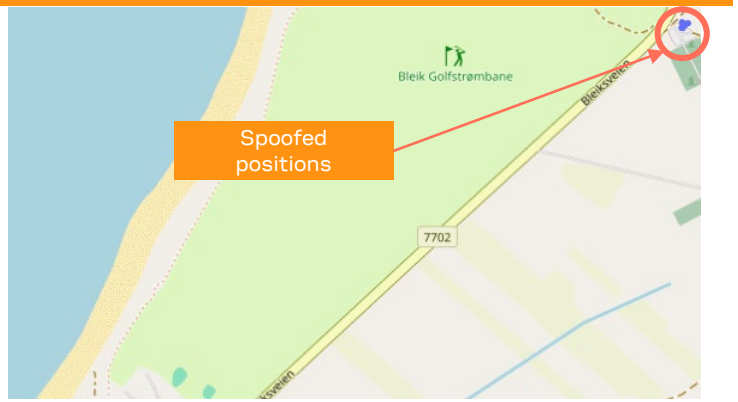




Competitor B

Competitor C

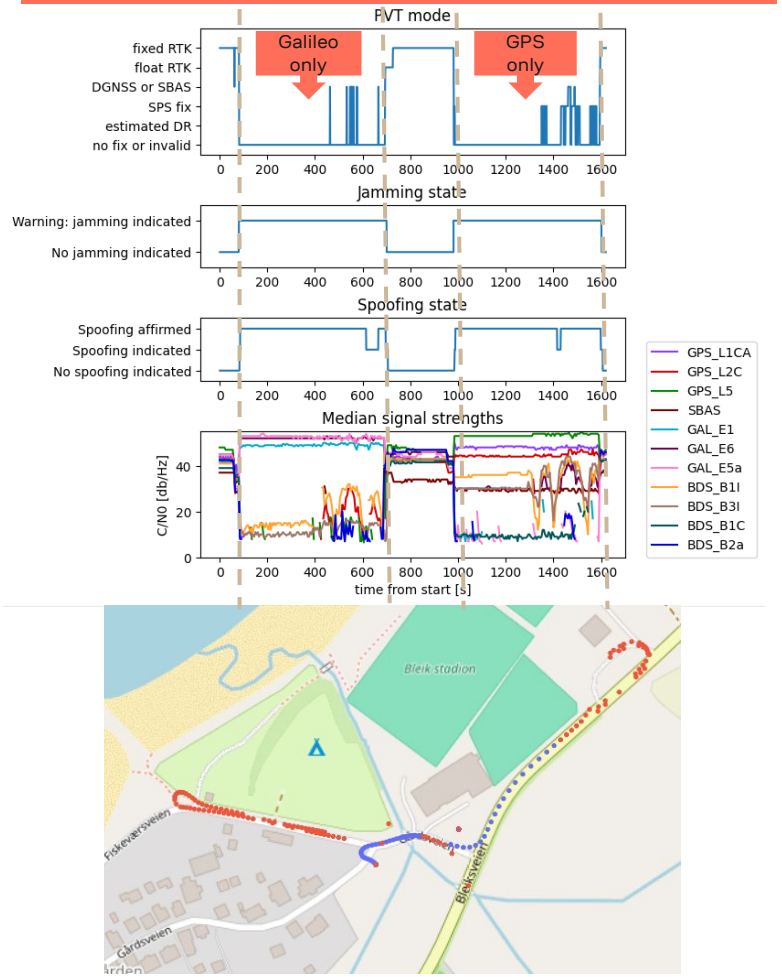
Competitor A



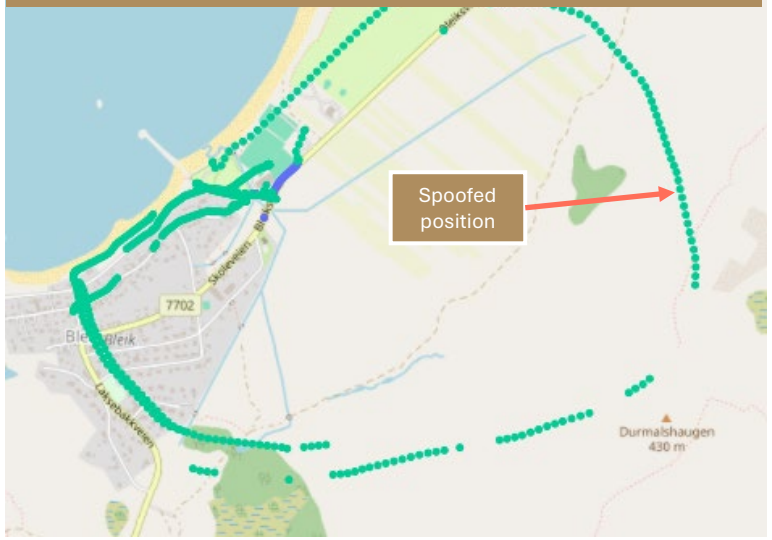
Incoherent position spoofing using broadcast(true) ephemerides

2.3.8: Simulated driving (route 1). Galileo only. E1 E5 E6.
2.3.5: Simulated driving (route 1). GPS only. L1 C/A L2C L5.

u-blox ZED-X20P



Competitor C



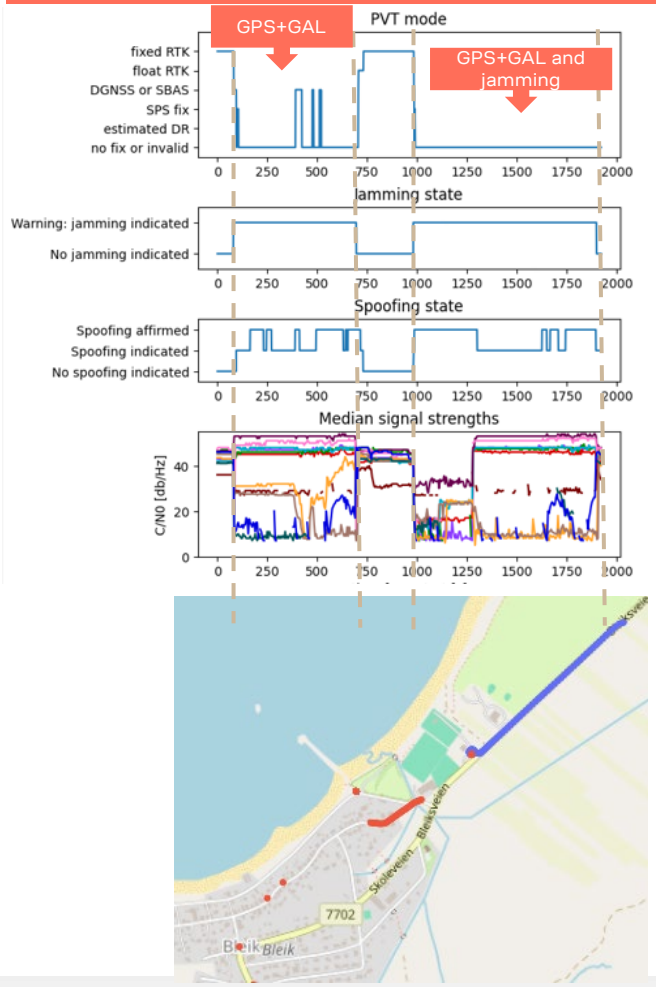
Route 1

Competitor B

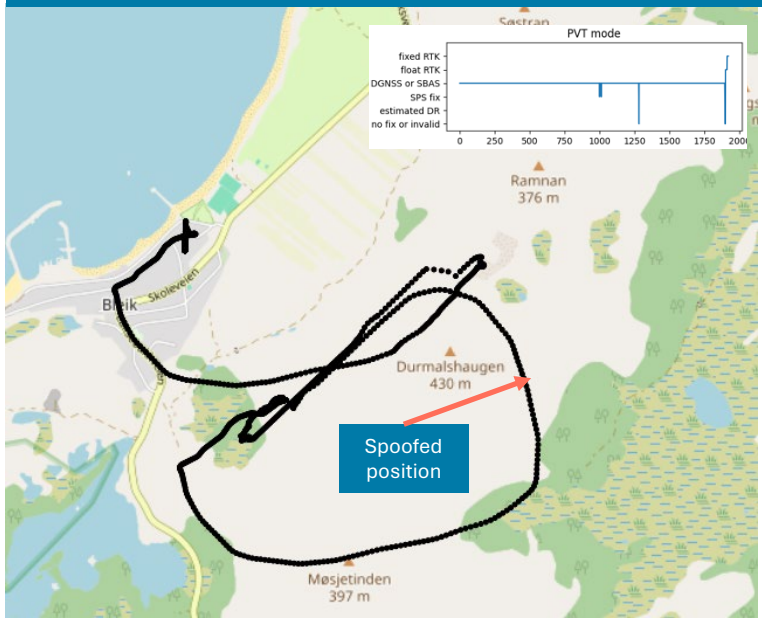
Coherent position spoofing using broadcast(true) ephemerides

2.3.10: Simulated driving (route 1). L1 C/A L2C L5 E1 E5 E6.
2.3.11: Simulated driving (route 1) with initial and continuous jamming. L1 C/A L2C L5 E1 E5 E6.

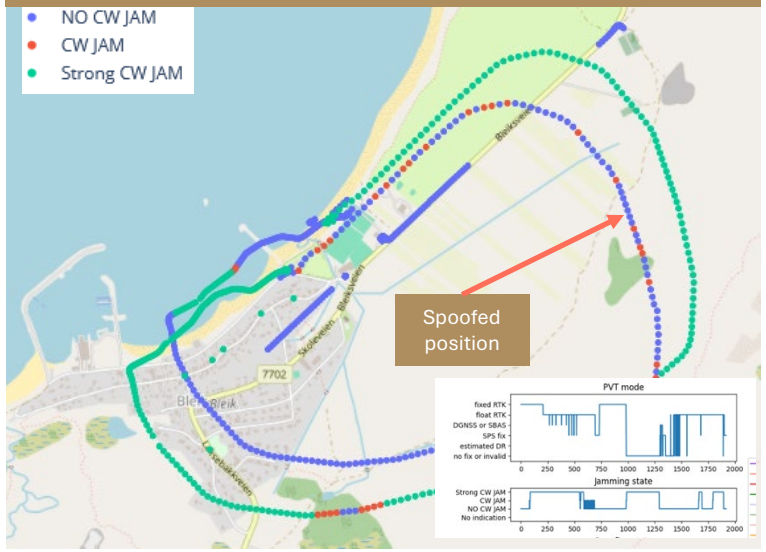
u-blox ZED-X20P



Competitor B



Competitor C

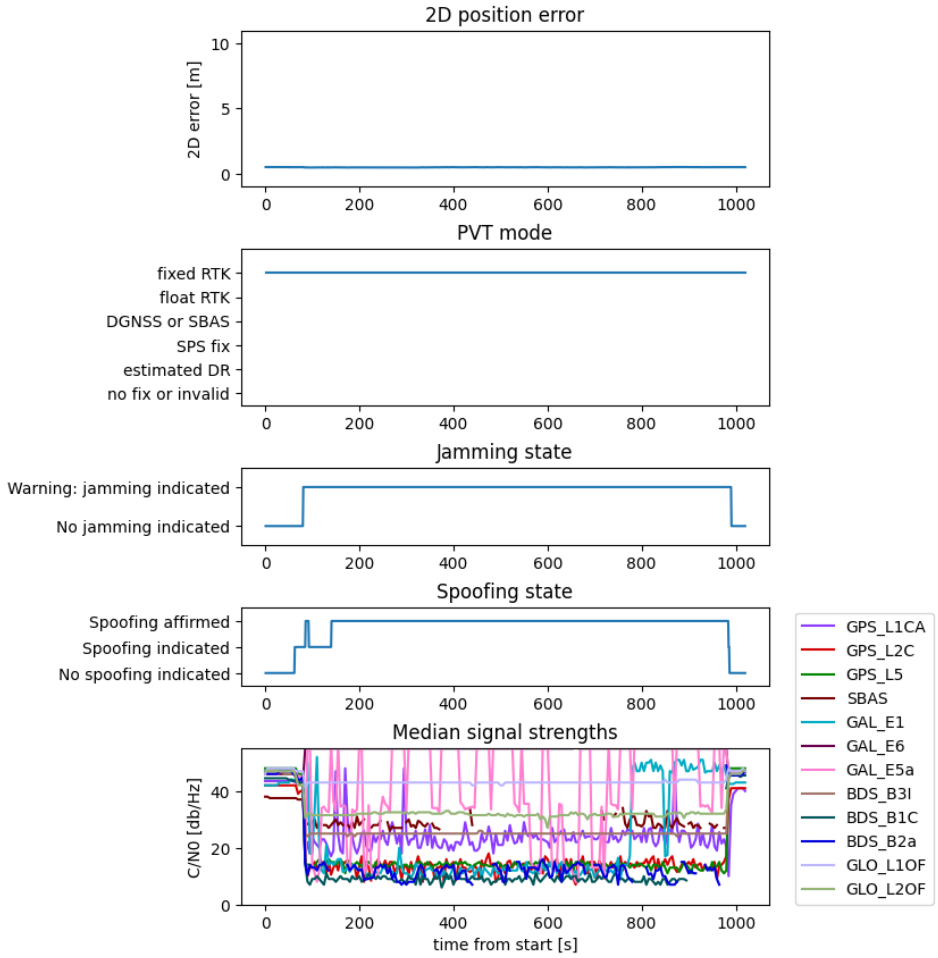


Route 1

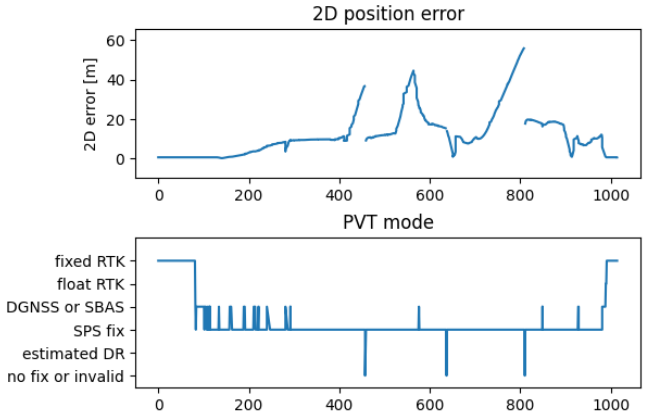
Incoherent time spoofing using synthetic ephemerides

2.4.12 Static + Pseudorange error, L1 C/A L2C L5 E1 E5 E6

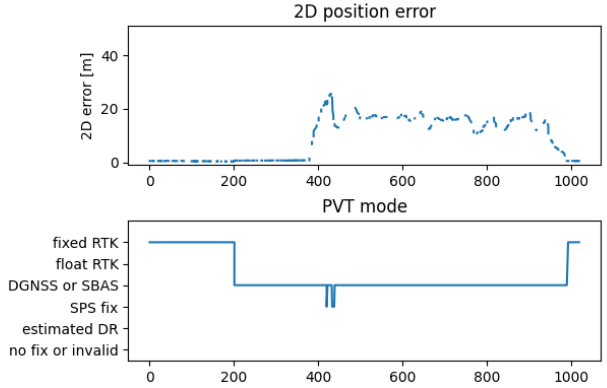
u-blox ZED-X20P



Competitor A



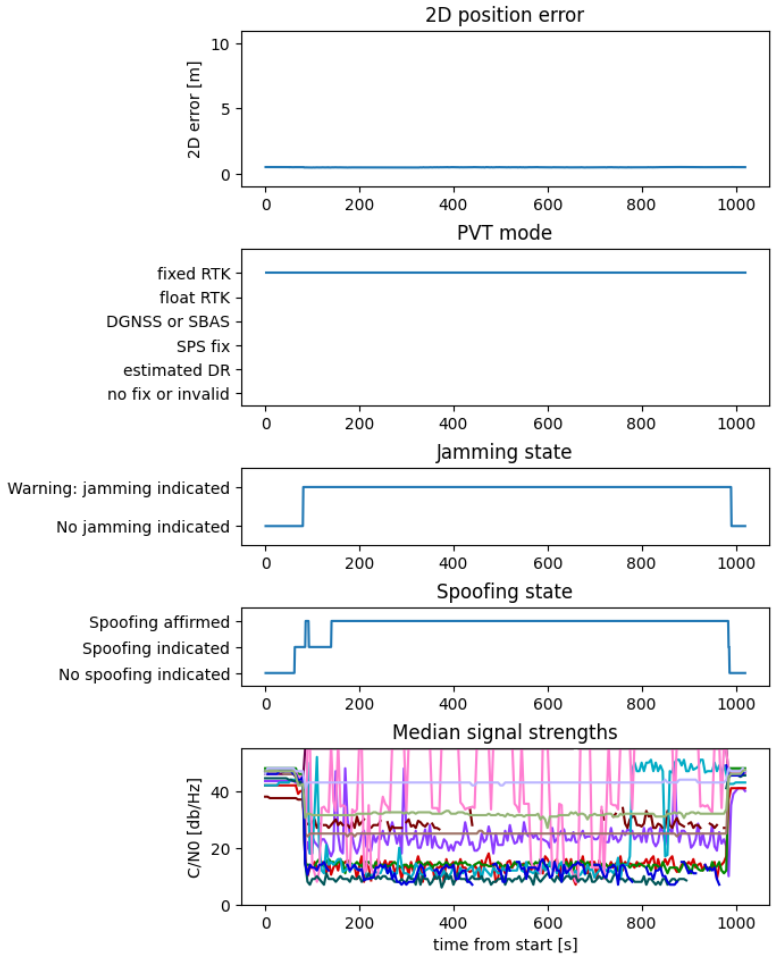
Competitor C



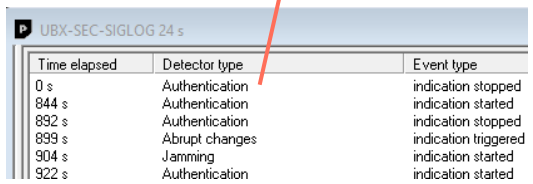
Incoherent time spoofing using synthetic ephemerides

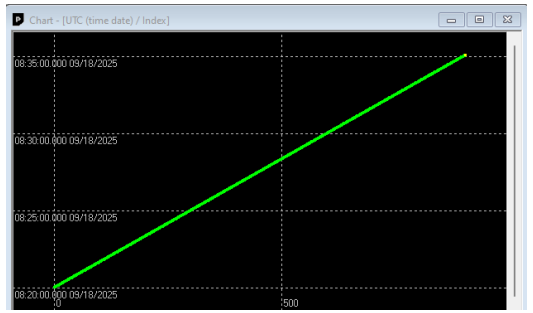
2.4.12 Static + Pseudorange error, L1 C/A L2C L5 E1 E5 E6

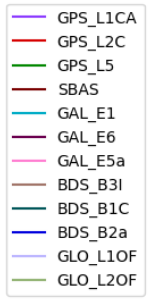
u-blox ZED-X20P

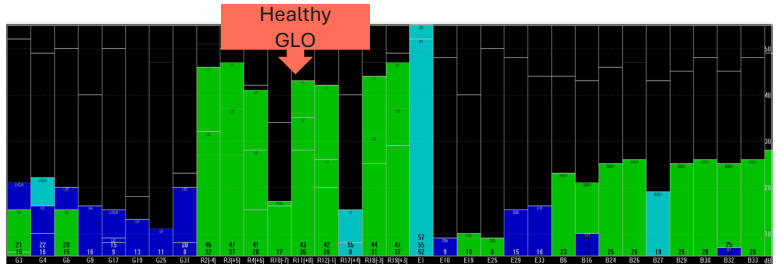


OSNMA based detector

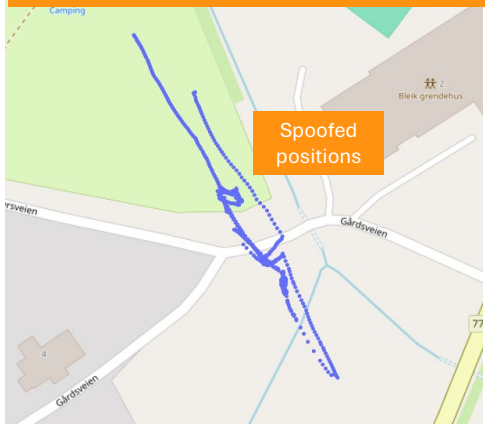




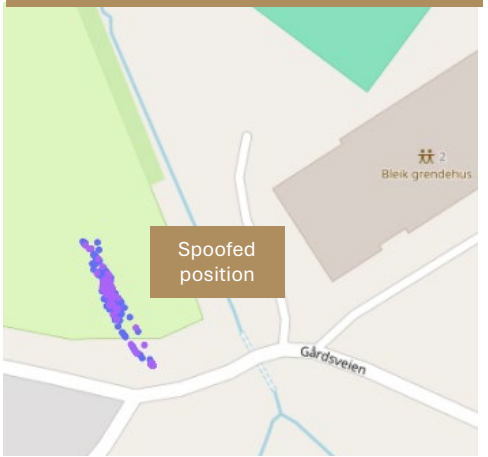




Competitor A

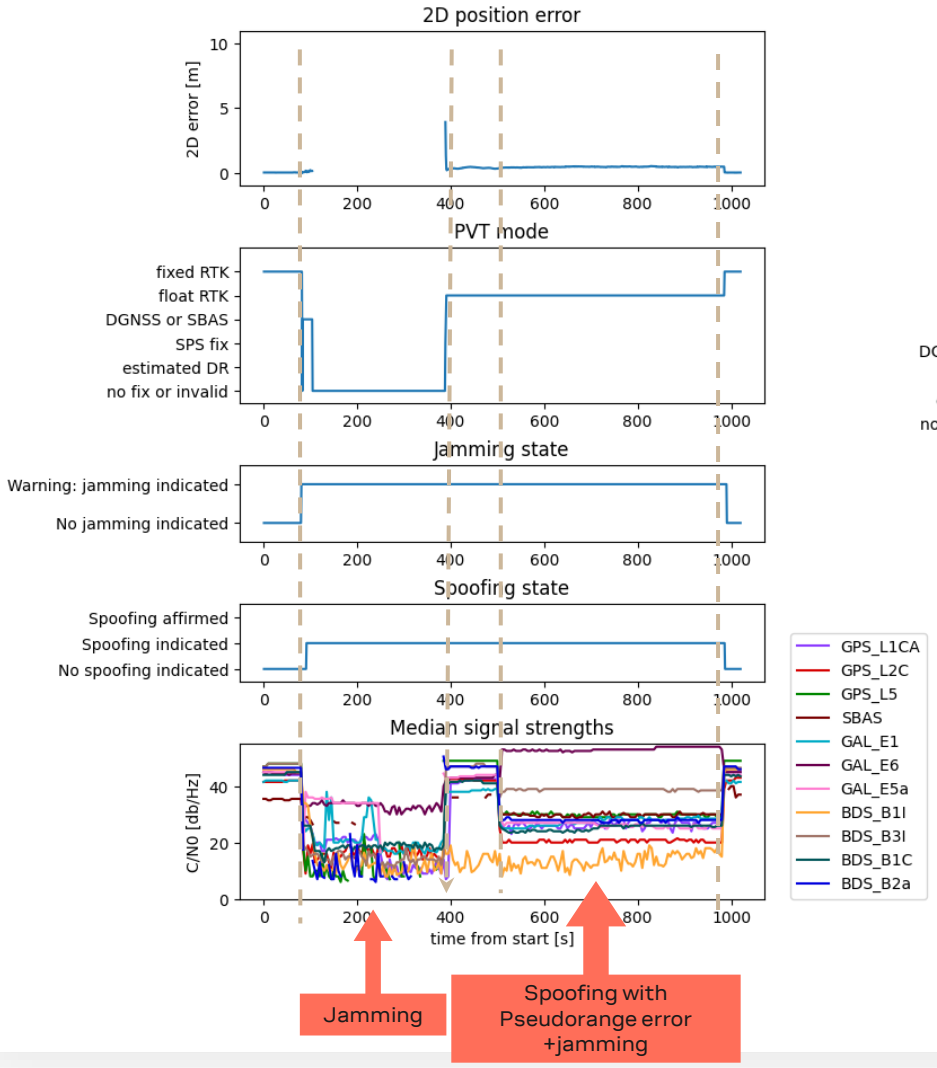


Competitor C

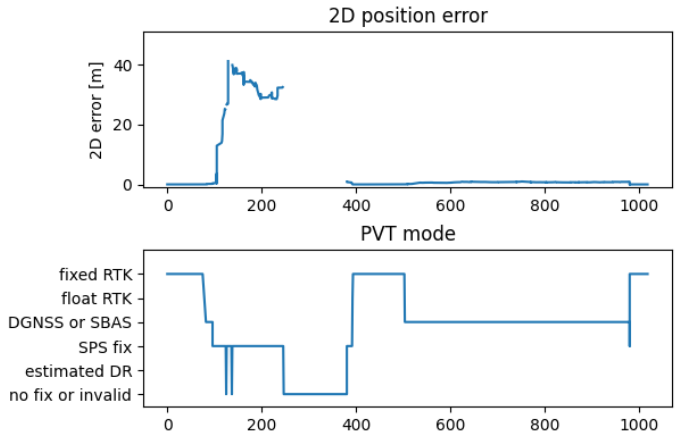


Incoherent time spoofing using synthetic ephemerides

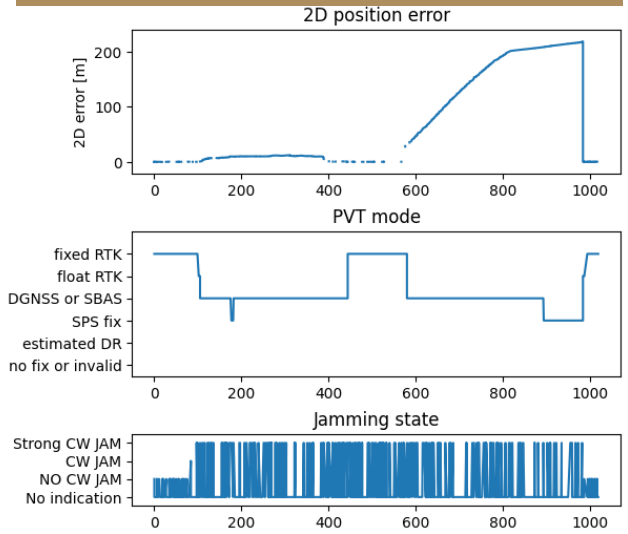
u-blox ZED-X20P



Competitor A



Competitor C



2.4.13: Static + Pseudorange error, with initial and continous jamming

Signals: GPS L1 C/A, L2C, L5. Galileo E1, E5, E6. 5 minutes of initial jamming (L1, G1, B1I, L2, E5b, L5 with 2 W) prior to spoofing transmission, then continuous on other bands than the ones spoofed.

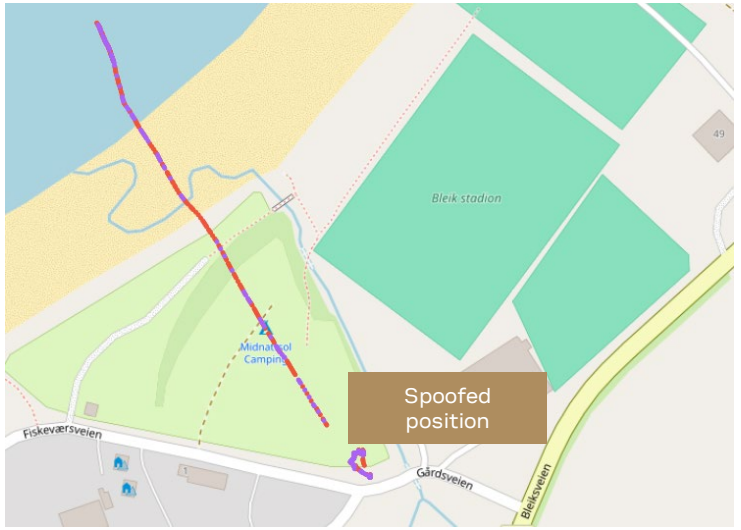
The pseudorange error is applied to all satellites, starting five minutes after the spoofing start

Incoherent time spoofing using synthetic ephemerides

u-blox ZED-X20P

Competitor A

Competitor C



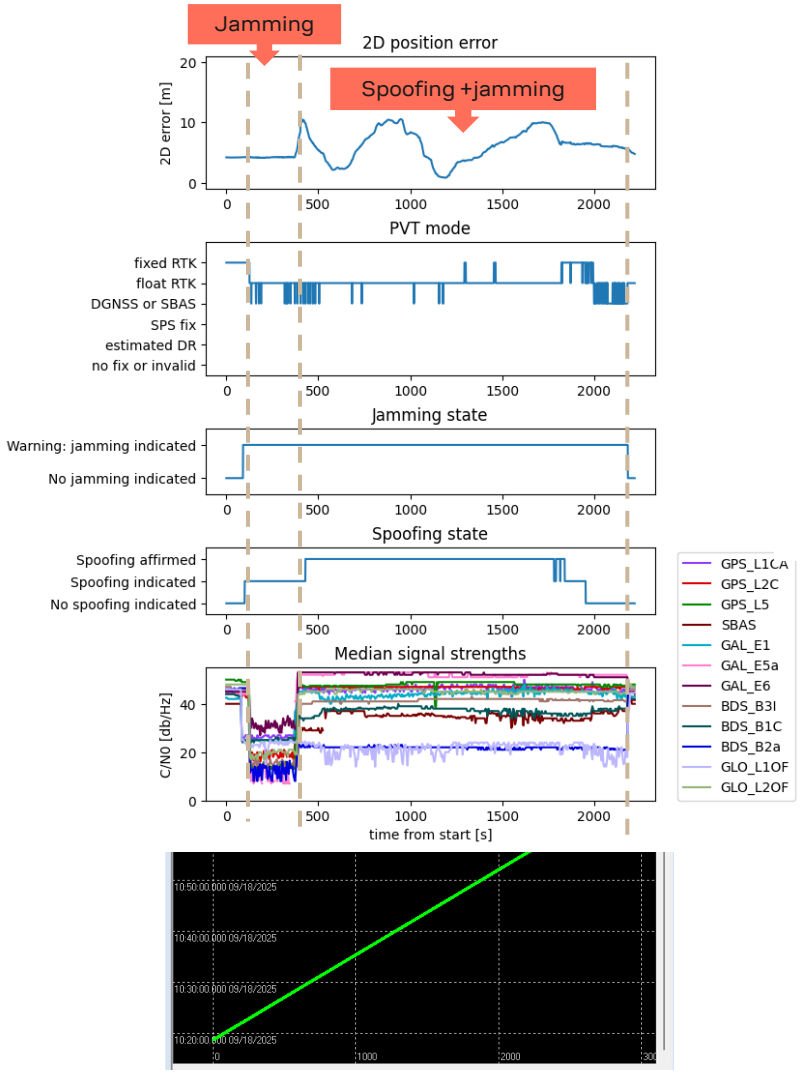
2.4.13: Static + Pseudorange error, with initial and continous jamming

Signals: GPS L1 C/A, L2C, L5. Galileo E1, E5, E6. 5 minutes of initial jamming (L1, G1, B1I, L2, E5b, L5 with 2 W) prior to spoofing transmission, then continuous on other bands than the ones spoofed.

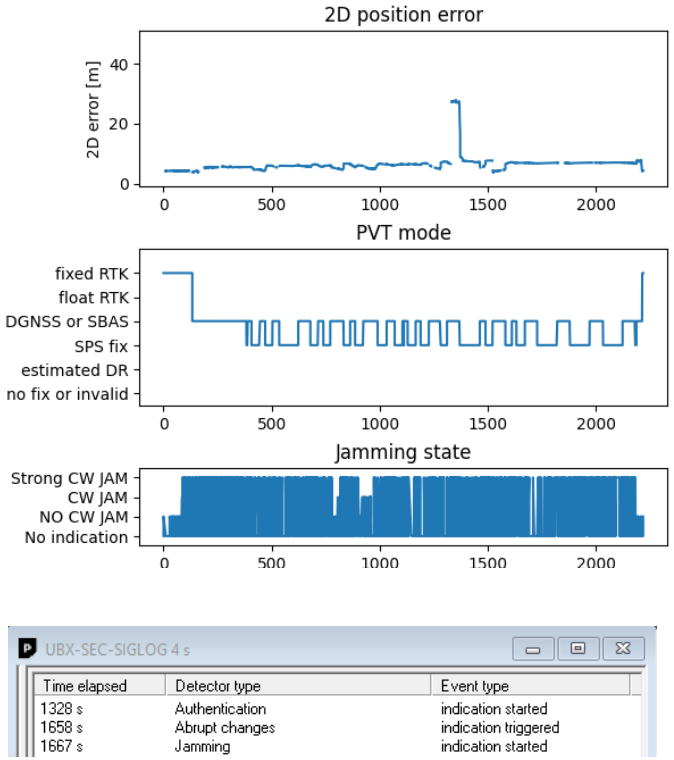
The pseudorange error is applied to all satellites, starting five minutes after the spoofing start

Coherent time spoofing using broadcast(true) ephemerides

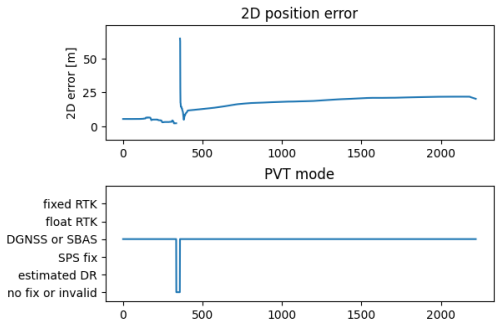
u-blox ZED-X20P



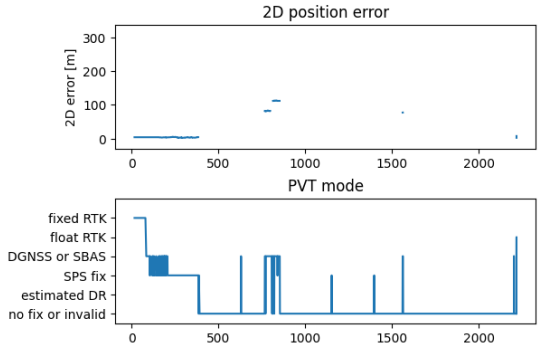
Competitor C



Competitor B



Competitor A



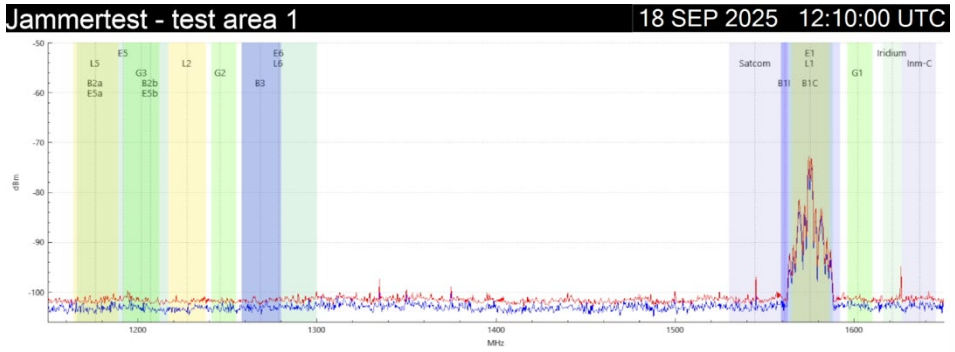
2.5.25 Static + UTC-parameter nav. data manipulation (adding leap seconds),

Signals: GPS L1 C/A, L2C, L5. Galileo E1, E5, E6.
5 minutes of initial jamming (L1, G1, B1I, L2, E5b, L5 with 2 W) prior to spoofing transmission, then continuous on other bands than the ones spoofed

Spoofing in timing setup

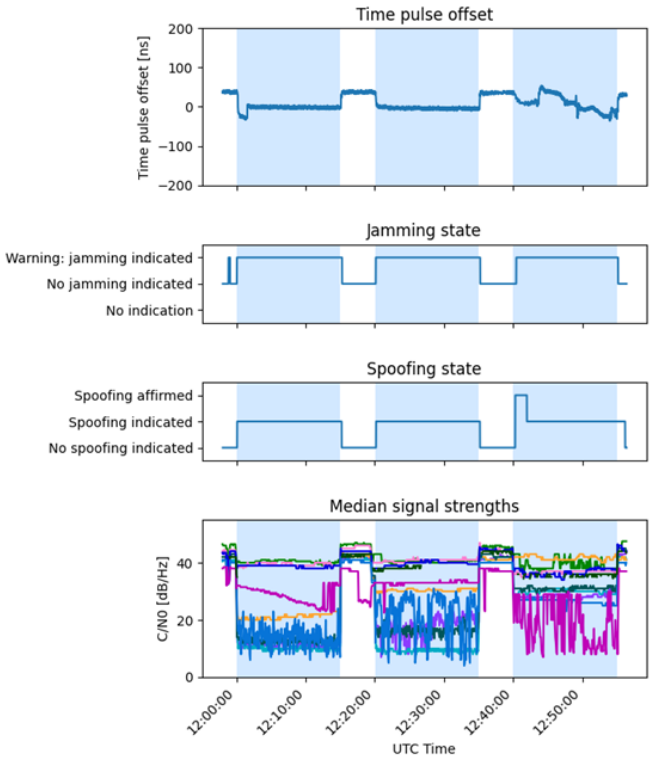
Time spoofing 15 mins into future

- Spoofer position is fixed to real antenna coordinates
- 2.5.5 Galileo E1, 0.0316W
- 2.5.4 GPS L1 C/A, 0.0316W
- 2.5.6 All signals, 1e-5W



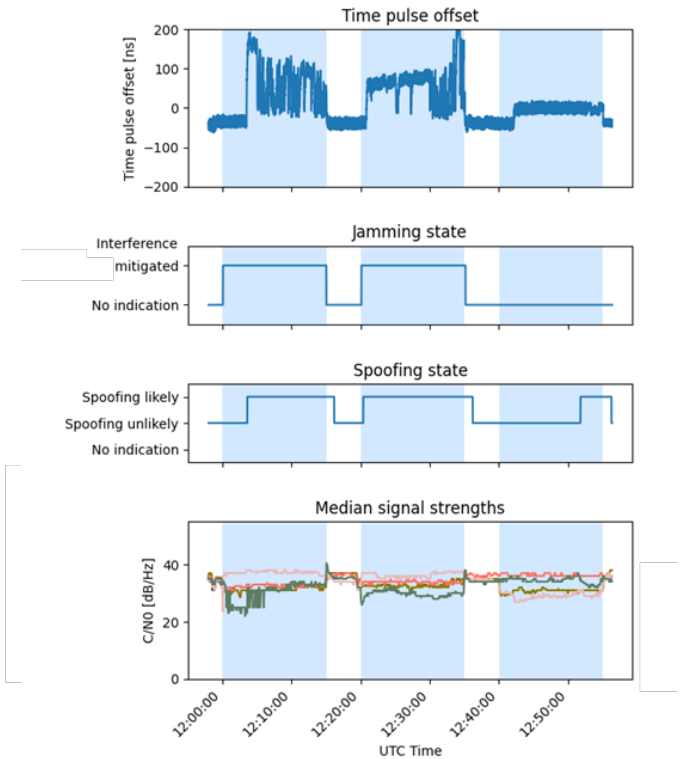
u-blox ZED-F9T

Test cases 2.5.5 2.5.4 2.5.6 EVK_F9T_TIM225_OSNMA_LOOSE



Competitor A

Test cases 2.5.5 2.5.4 2.5.6



Key takeaway: Spoofing Resilience

1	**u-blox detects spoofing across all attack types**	• Incoherent & coherent • Position & time spoofing • Synthetic & real ephemerides • Multi-band (L1/L2/L5/E1/E5/E6) • Combined spoofing + jamming
2	**u-blox consistently rejects false positions**	• No large jumps • No km-level deviations • No following spoofed paths
3	**Integrity remains intact even under strongest attacks**	• Abrupt changes → flagged • OSNMA Authentication → flagged • Jamming → flagged
4	**u-blox outperforms all competitors**	• Competitors follow spoofed trajectories (100s of meters)
5	**Time spoofing is also rejected**	• UTC manipulation detected • Pseudorange time shifts flagged • No “fake time” takeover

What's Next?

The next ZED-X20P firmware release: planned for early 2026 will bring the improvements demonstrated here into production

X20 automotive module!

Coming Soon

Integrity With Awareness:

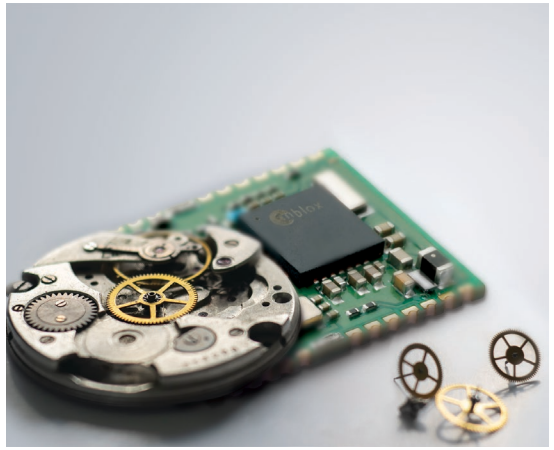
Navigation is available, but conditions are not nominal.

Open Q&A

More information on u-blox.com

Recording of this webinar

https://www.u-blox.com/en/webinars/jamming-spoofing-secure-positioning-jammertest



GNSS timing page

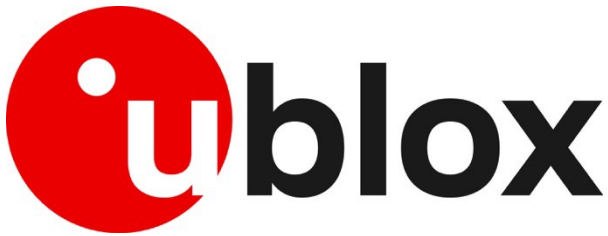
https://www.u-blox.com/en/time

Blog article

https://www.u-blox.com/en/blogs/tech/gnss-jamming-spoofing-detection-jammertest-2025-andoya

Technology page

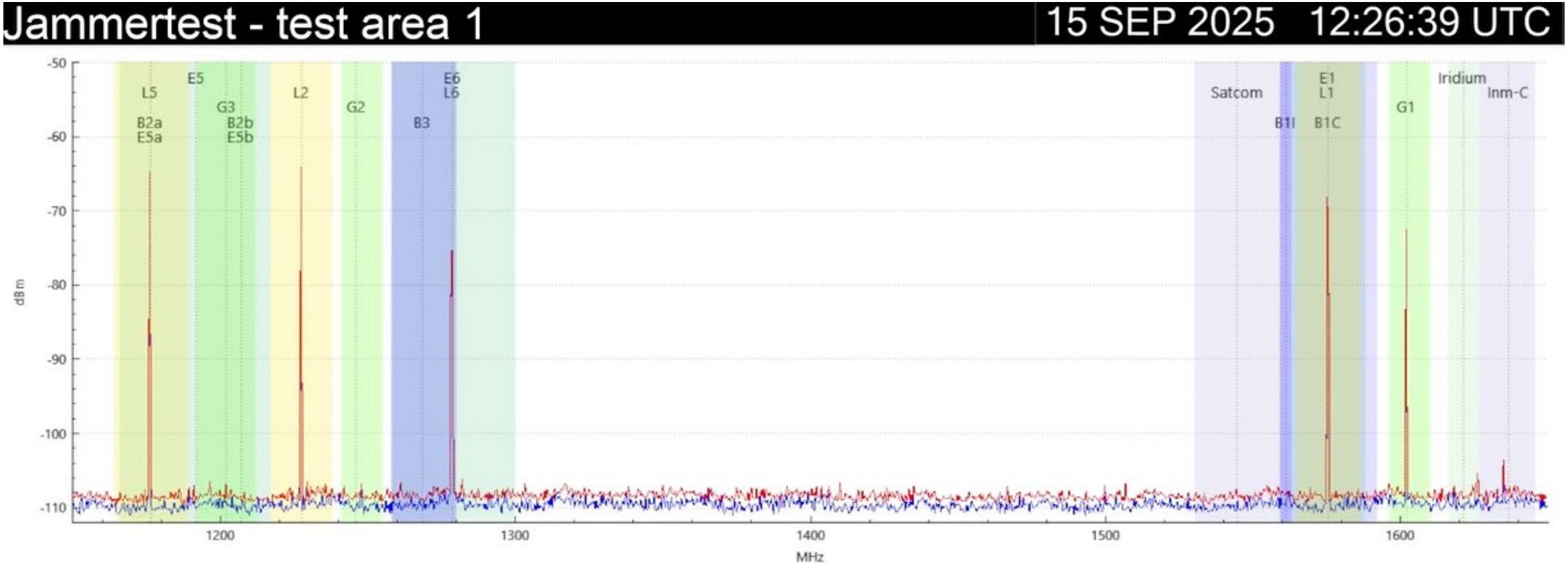
https://www.u-blox.com/en/technologies/osnma-galileo-spoofing



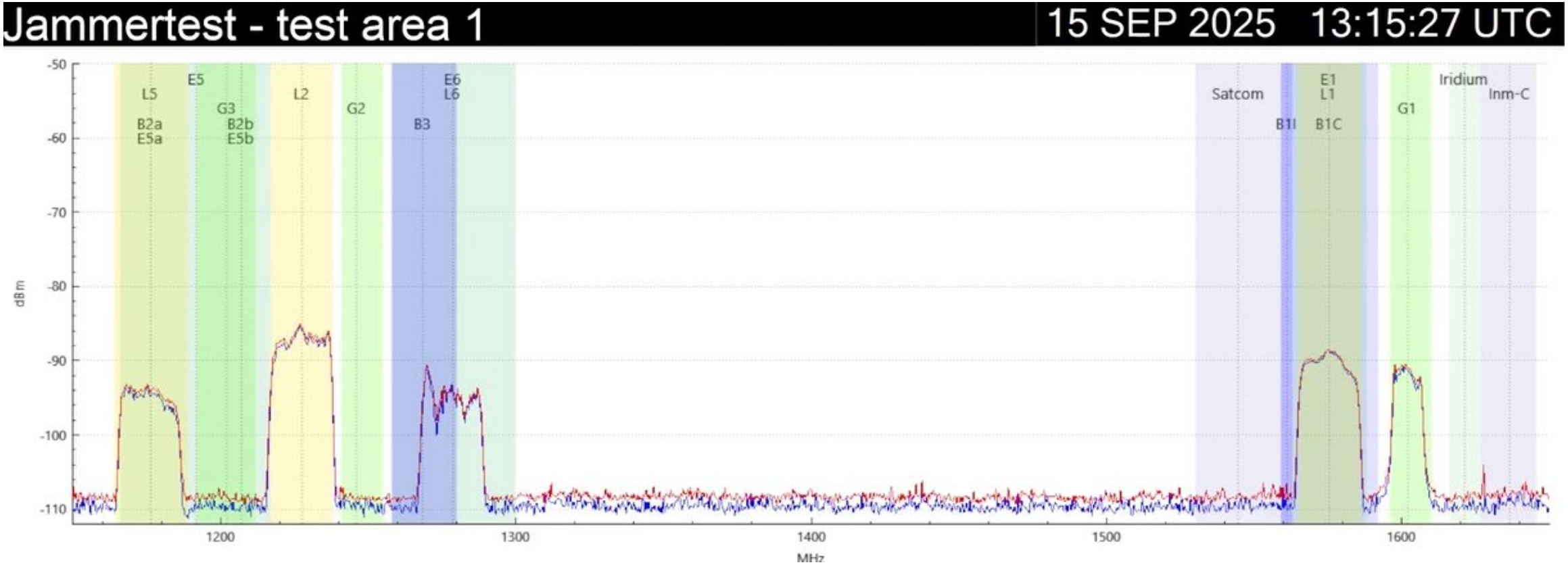
Locate and connect every thing.

Appendix

CW (Continuous Wave) L1, G1, L2, L5, L6



Swept CW (drifting CW): L1, G1, L2, L5, L6



PRN Jamming (spread-spectrum): L1, G1, L2, L5, L6