Protection of Clock Performance Against Jamming and Spoofing with Galileo Authenticated Service (OS-NMA): ITSF, 2021

GEARS
GalilEo Authenticated Robust timing System

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PLAN OF THE PRESENTATION

- Goals of the timing GNSS receiver technology development
- Signal and solutions filtering layered approach
- Multi-elements antenna spatial filtering
- RF signal Interference Detection and Mitigation (IDM)
- Authenticated navigation data (Galileo OS NMA)
- T-RAIM and multi-constellation
- Ionosphere correction model for single frequency solution
- Timing output from authenticated data vs standard open service
- Conclusion

WHY A NEW TIMING RECEIVER

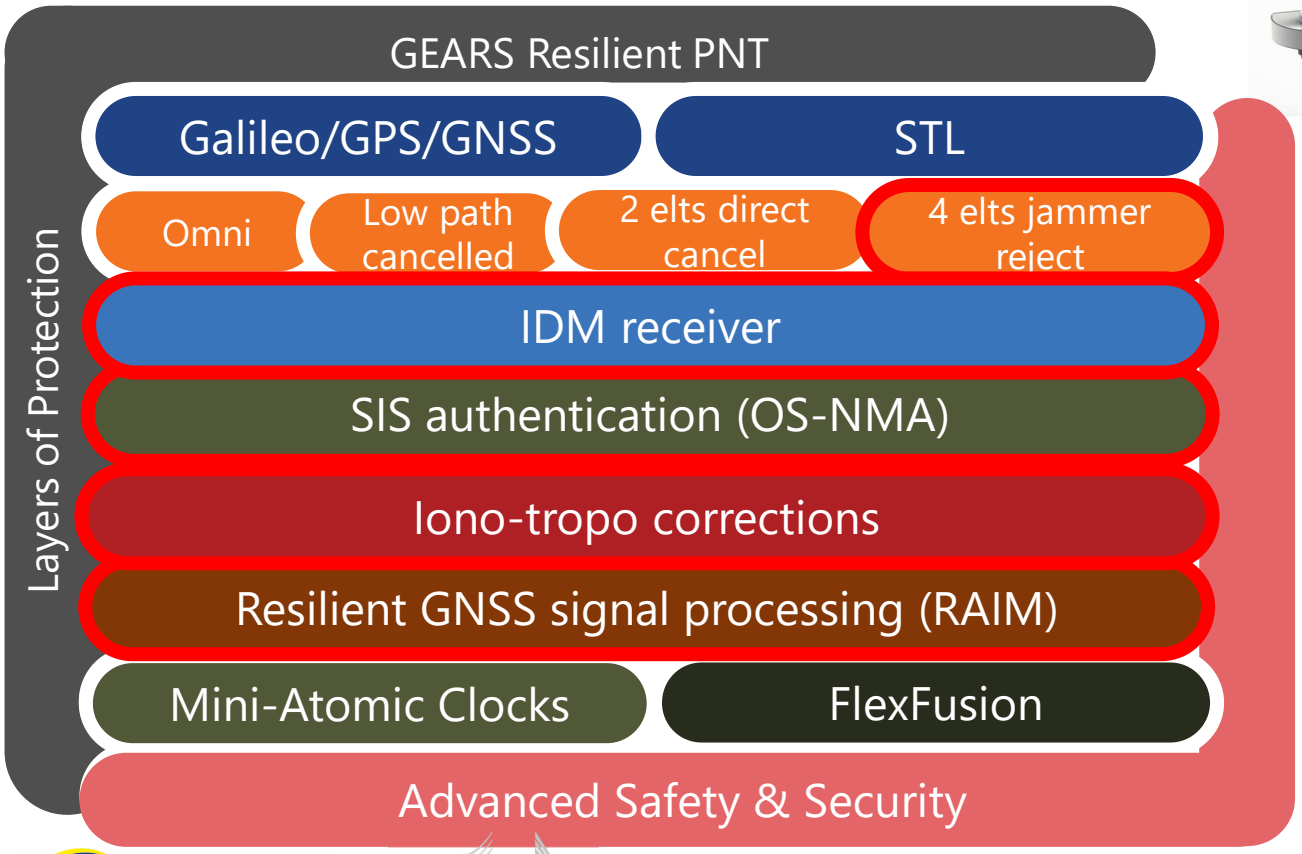
- Providing a Galileo-based timing receiver for Critical Infrastructures (CI) and targeted markets :
  - Telecom
  - Energy
  - Finance
- Granted by the European Union Agency for the Space Programme (Galileo Fundamental Elements Program) GSA/GRANT/05/2017-02
- Development and validation of new technologies with prototype by end 2021

GEARS TECHNICAL GOALS: SIGNAL PROCESSING BLOCKS

- OBJ# 1 High availability with jamming filtering:
  - Spatial filtering with multi-elements antenna (CRPA)
  - Frequency notch filtering with time adaptive scheme (IDM)
- OBJ# 2 High integrity and confidence level:
  - Navigation solution from authenticated data : Galileo OS-NMA signal in space
  - T-RAIM with multi-satellites and multi-GNSS solutions
- OBJ# 3 High accuracy to UTC:
  - Ionosphere single frequency NeQuick correction and dual-frequency correction
  - Timing accuracy < 50 ns to UTC

Development of 2 validation units : Antenna and Clock

SIGNAL AND SOLUTIONS FILTERING APPROACH WITH GEARS



Signal containing reference information
Strong **focus on Galileo signals**

Prevent jammer entering signal processing
Spatial filtering of RFI in up to 3 directions

Clean residual jammer in frequency vs time
Digital **filtering in frequency domain**

Authenticate navigation data
Galileo OS-NMA authenticated data

Improve single frequency iono-correction
NeQuick correction scheme

Detect (residual) anomalies/failures
Time Receiver Autonomous Integrity Monitoring

Local autonomy
high medium-term stability

Provide advanced safety and security
Dedicated test paterns

Clock

Threat Simulation

SMART ANTENNA

Resilience - Radio Frequency Interference (RFI) can seriously degrade time availability from GNSS constellations:

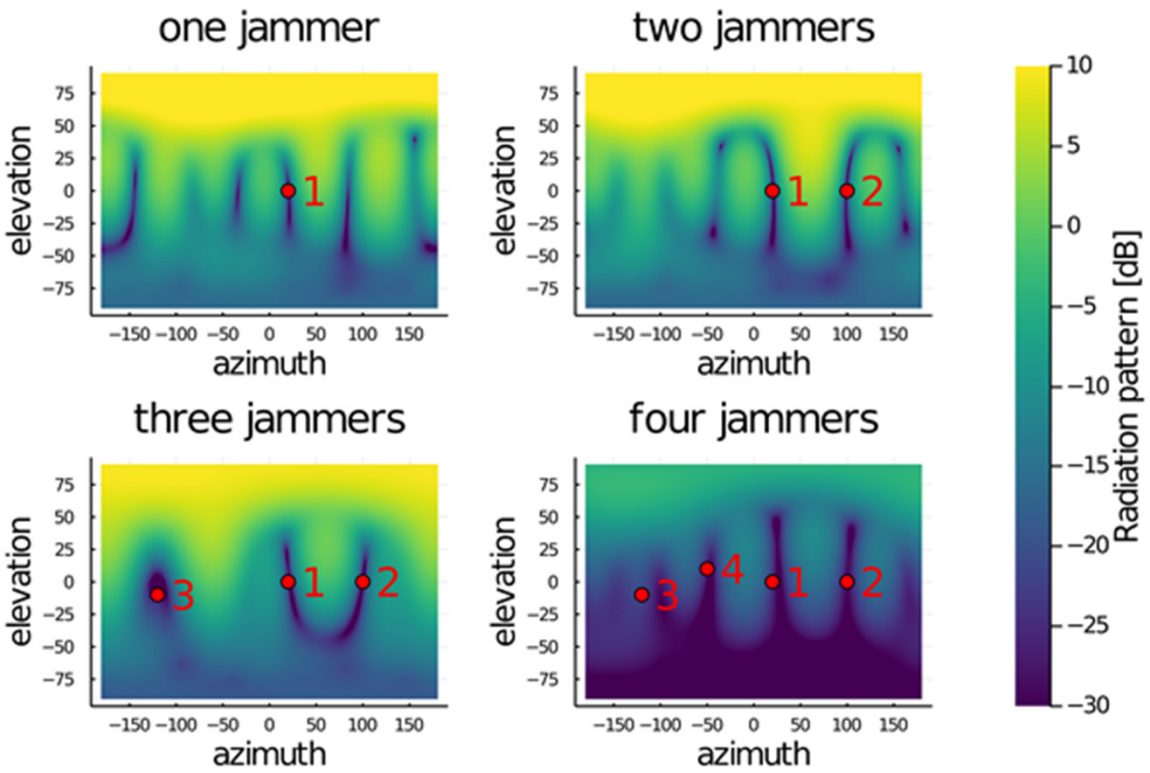
- 4-element Controlled Reception Pattern Antenna (CRPA) with null forming for spatial filtering of RFI.
- Protects Galileo and other constellations.
- Specially designed for use with the GEARS timing receiver.
- Receiver agnostic processing, will also work with other timing receivers.

3D model
of the CRPA prototype

SMART ANTENNA

Key Features

- Adaptive nulling continuously adapts the radiation pattern to adjust to changes in the RF environment for best RFI suppression.
- Works in 3 simultaneous frequency bands.
- Protects against up to 3 simultaneous sources of RFI.
- Works independently of RFI waveform, both for jamming and spoofing.

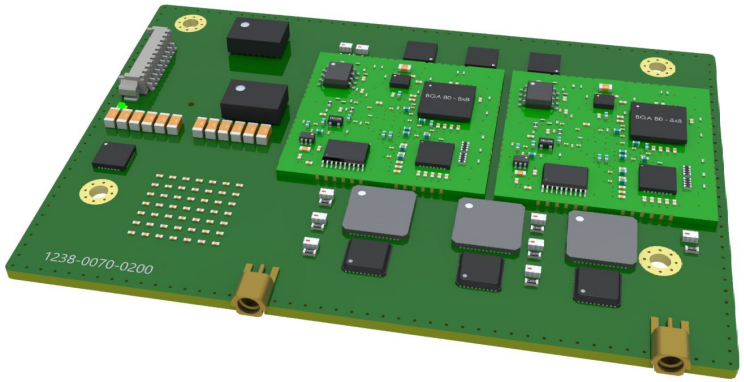


Simulated signals in Matlab®

RF SIGNAL INTERFERENCE DETECTION AND MITIGATION (IDM)

Resilience – Dedicated techniques to fight against Radio Frequency Interference (RFI):

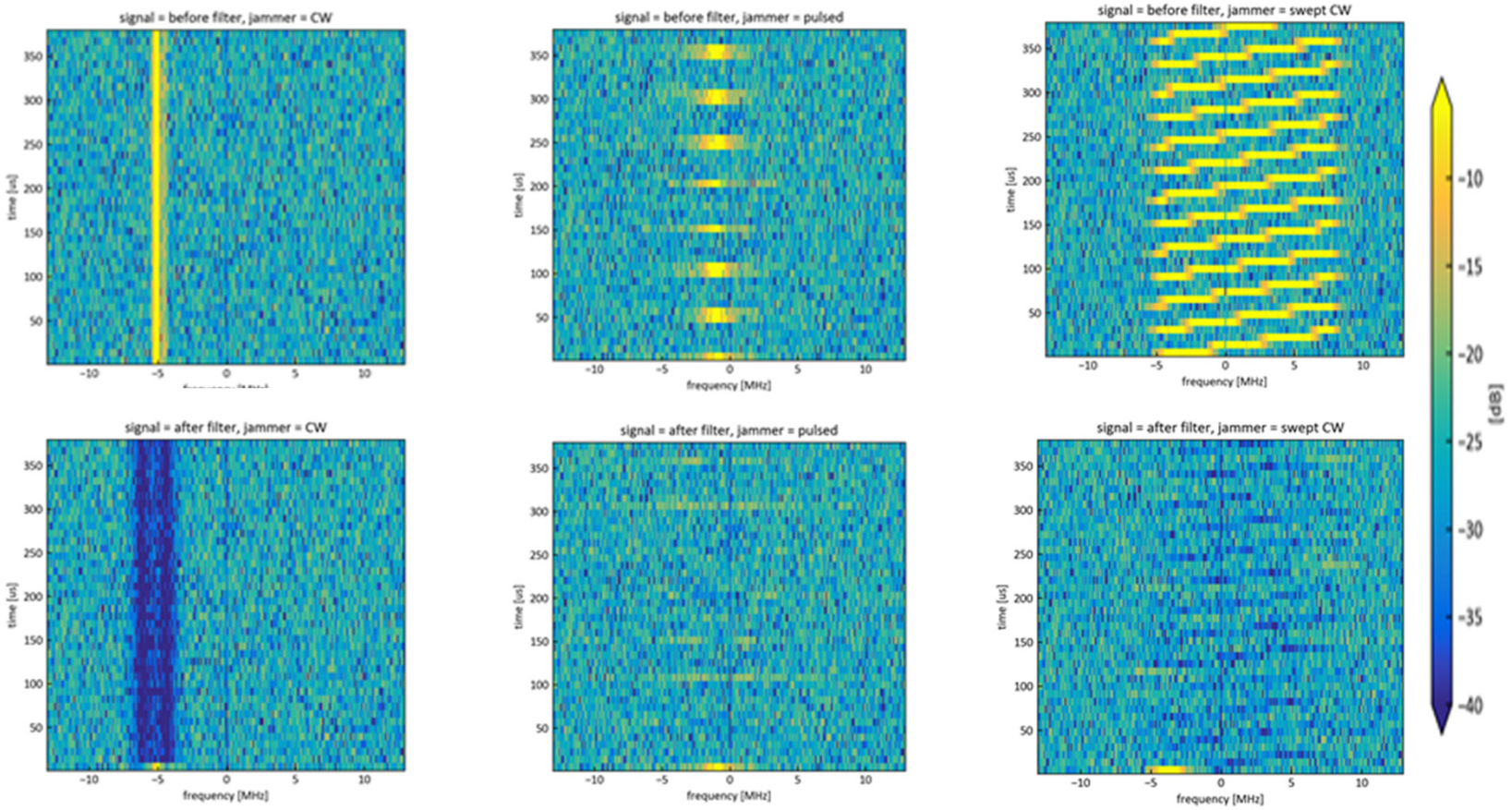
- Detects interference based on received power.
- Adaptive digital filtering in frequency domain.
- Filters the RFI signal before correlation.
- Filters the top 5 main types of jamming:
  - Wide Sweep (fast repeat rate),
  - Multiple Narrow band,
  - Triangular,
  - Tick type
  - CW
- Supports Galileo and other constellations.
- Filters 3 frequency bands in parallel.
- Designed to increase the GNSS signal carrier-to-noise ratio (C/N0) without introducing biases.



3D model of the new receiver prototype with IDM integrated

RF SIGNAL INTERFERENCE DETECTION AND MITIGATION (IDM)

Jammer: CW Time Pulsed Swept CW



Spectrograms of simulations

Three types of Interference before …

and

after Filtering.

AUTHENTICATED NAVIGATION DATA: GALILEO OS NMA SIS

Main specifications:

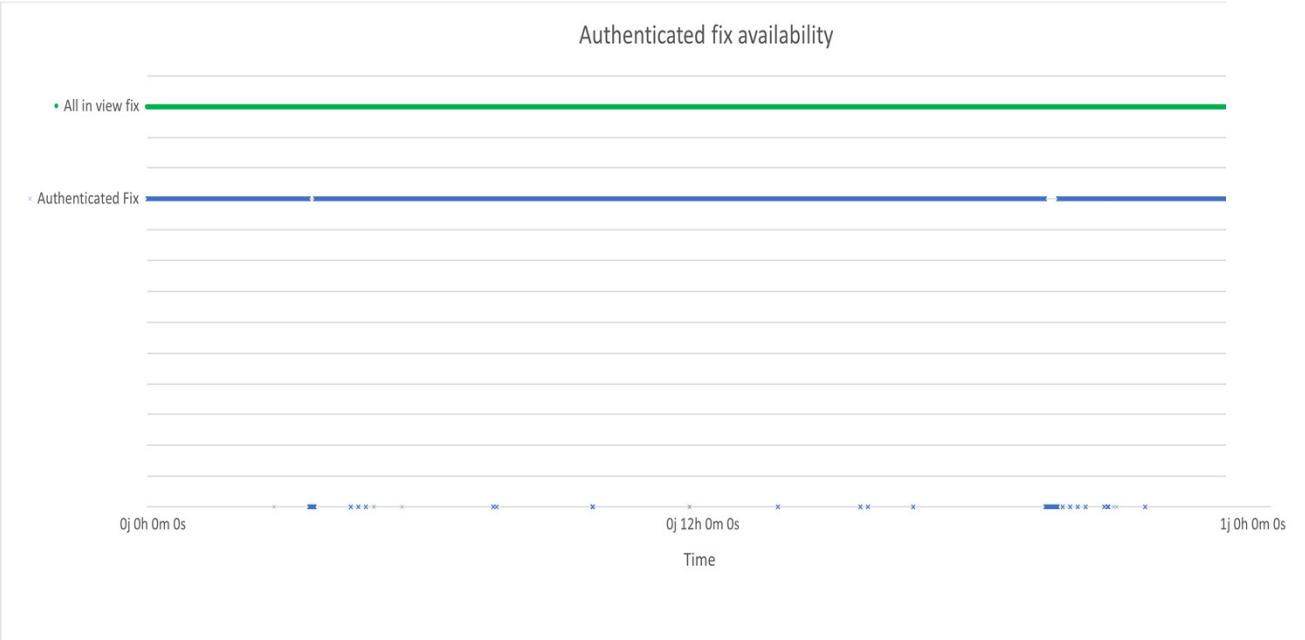
- Multi-bands & multi-constellations
- OS NMA implementation according to OS NMA SIS ICD v2.3
- Additional spoofing and jamming detection algorithms
- Provides both all satellites in view PVT solution and authenticated satellites only PVT solution
- Advanced security features
  (secure keys storage, firmware integrity, …)

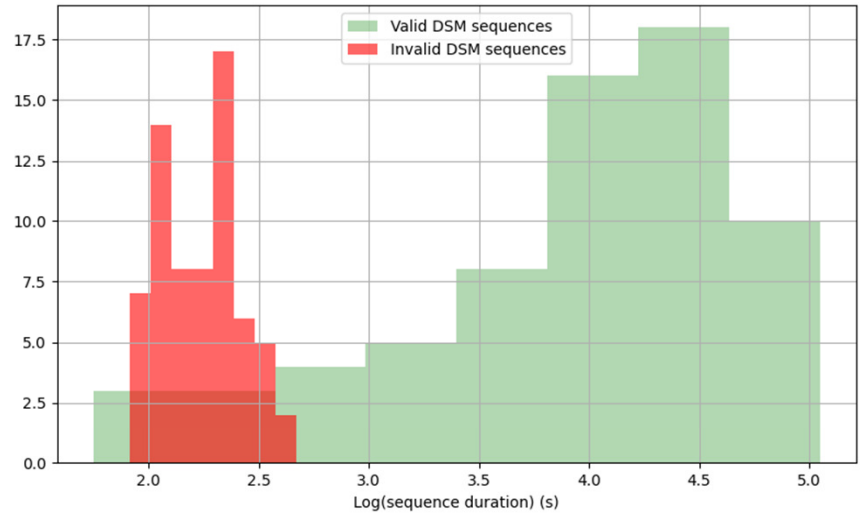
T5 based GNSS receiver

AUTHENTICATED NAVIGATION DATA: GALILEO OS NMA SIS

Authenticated data satellites PVT fix availability (at least 4 authenticated Galileo satellites) within SIS testing phase:

- Availability ~97,38% over 24 hours





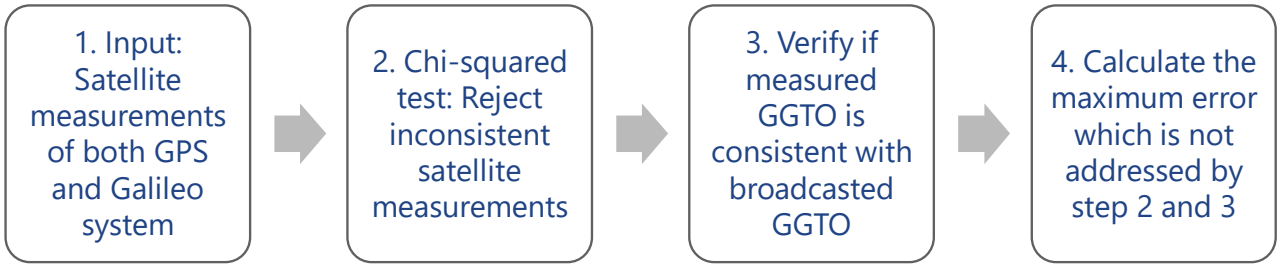
Digital Signature Message availability sequences over 15 days

- Availability improvement in progress with cross-correlation optimisation.
- Availability > 99 % for single satellite in view authenticated data, to be confirmed with timing only 0D computation solution

T-RAIM & MULTI-CONSTELLATION CAPABILITY

Utilize both Galileo and GPS satellites

- Standardize measurements (calculate z-scores) and use Chi-squared test to identify individual outlying satellites and exclude them for final solution
- Use broadcasted GGTO (Galileo to GPS Time Offset) to detect constellation-wide faults
- If constellation-wide fault is detected, receiver goes to hold-over mode
- Calculate the maximum error which is not addressed by step 2 and 3



T-RAIM & MULTI-CONSTELLATION CAPABILITY

Identifies individual faulty satellites…

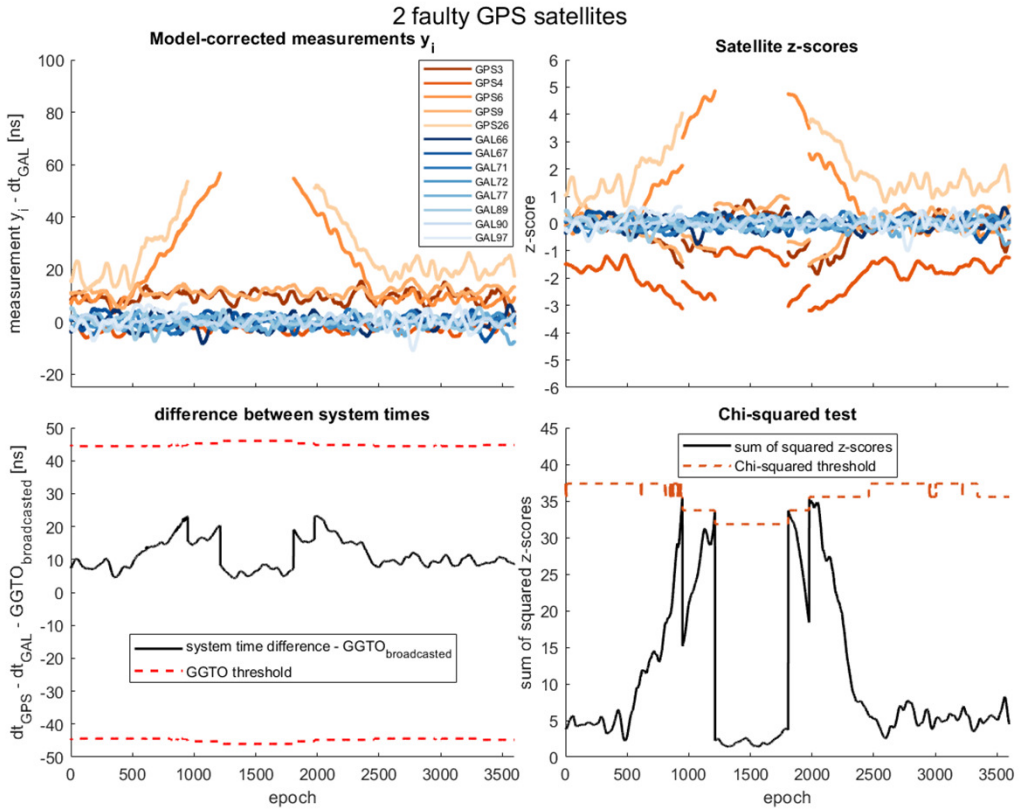
- Use model-based variances as weights to calculate the system time estimate, for Galileo

$$dt_{GAL} = \sum_{i=GAL} \frac{y_i}{\sigma_i^2} \Big/ \sum_{i=GAL} \frac{1}{\sigma_i^2}$$

- Use the system time estimate and model-based standard deviation to calculate satellite z-scores

$$z_i = \frac{y_i - dt_{GAL}}{\sigma_i}$$

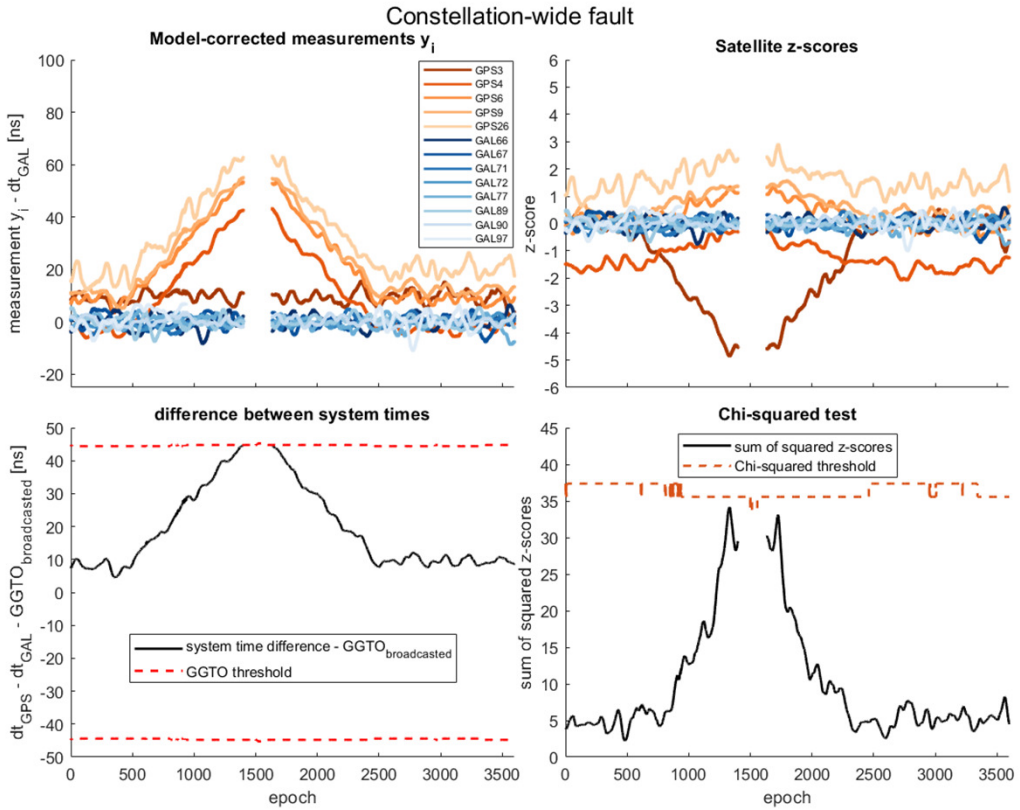
- Calculate the Chi-squared threshold based on probability of false alarm and number of satellites
- If the sum of squared z-scores exceeds Chi-squared threshold, exclude the satellite with highest absolute z-score
- After the exclusion, loop repeats for next satellite



T-RAIM & MULTI-CONSTELLATION CAPABILITY

… and constellation-wide faults

- Solution contains error because of satellite system time estimates (based on model) and broadcasted GGTO estimate (based on specifications)
- Errors of system time estimation are assumed to be Gaussian – likewise the GGTO estimate error is Gaussian. Then the total error is also Gaussian.
- Calculate GGTO threshold based on variances of those errors and probability of false alarm
- If the measured system time difference is too far from the broadcasted GGTO, set the receiver into hold-over mode



IONOSPHERE CORRECTION MODEL FOR SINGLE FREQUENCY

NAVIGATION SOLUTIONS POWERED BY EUROPE

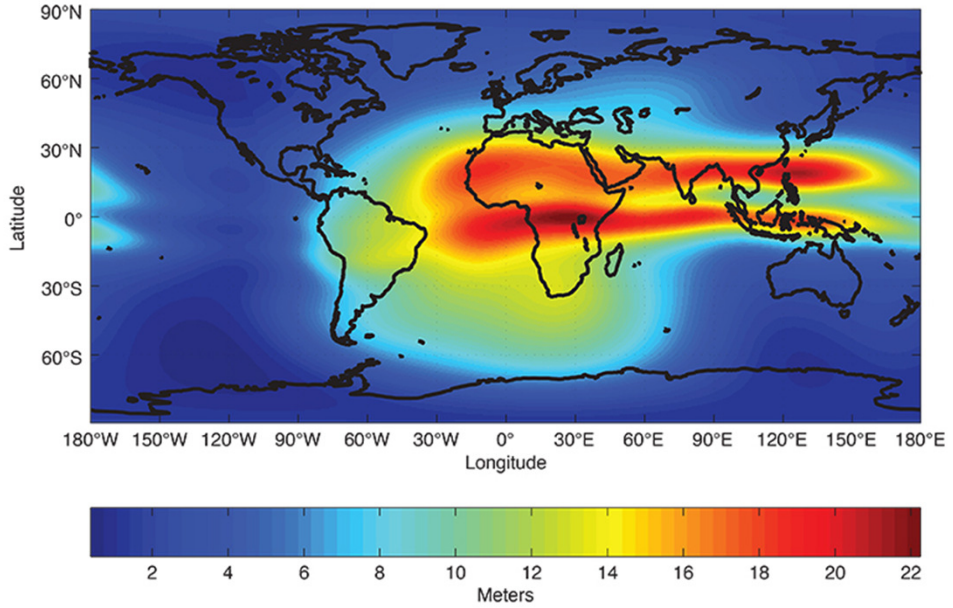
EUROPEAN GNSS (GALILEO) OPEN SERVICE

IONOSPHERIC CORRECTION ALGORITHM FOR GALILEO SINGLE FREQUENCY USERS

Resilience – Signal delays due to the ionosphere electron density can seriously degrade timing accuracy from GNSS constellations:

- Uses, by default, dual-frequency corrections to compensate for ionospheric errors.
- Employs NeQuick algorithm to correct single-frequency Galileo signals as fall-back.
- Fully compliant with the EC NeQuick algorithm description*.
- Smart implementation with error < 2% of reference model.
- Computation time about 30 ms

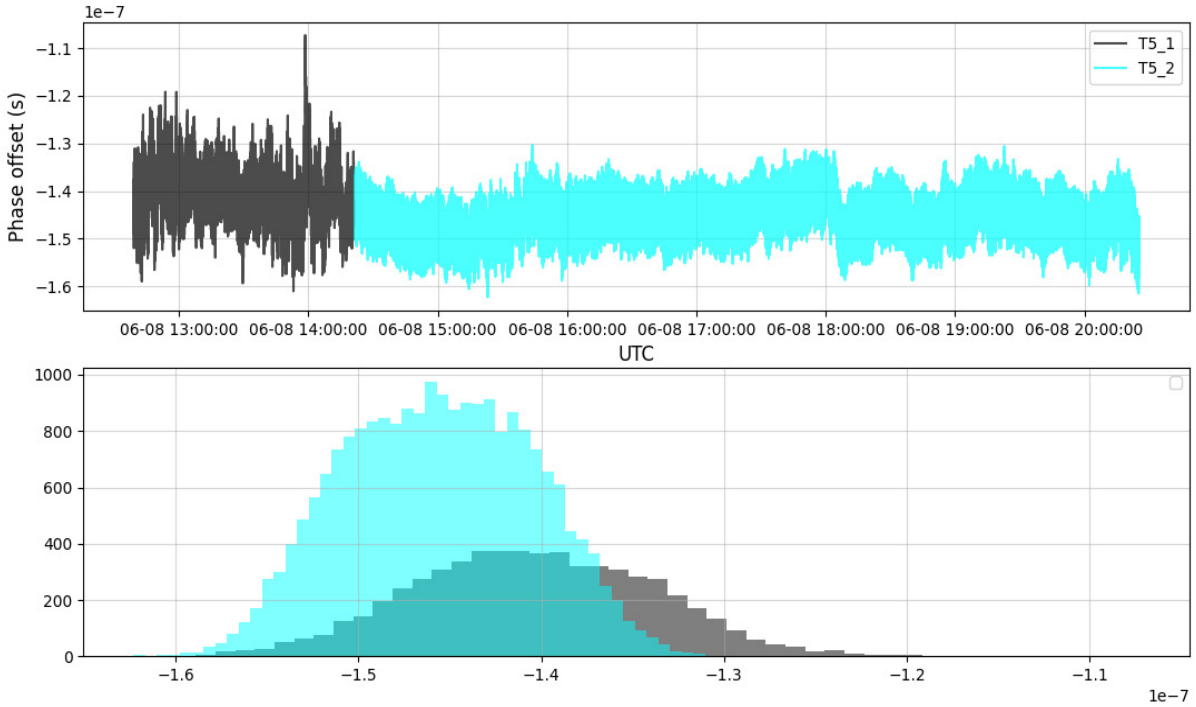
* Ionospheric Correction Algorithm for Galileo Single Frequency Users, Issue 1.2, September 2016

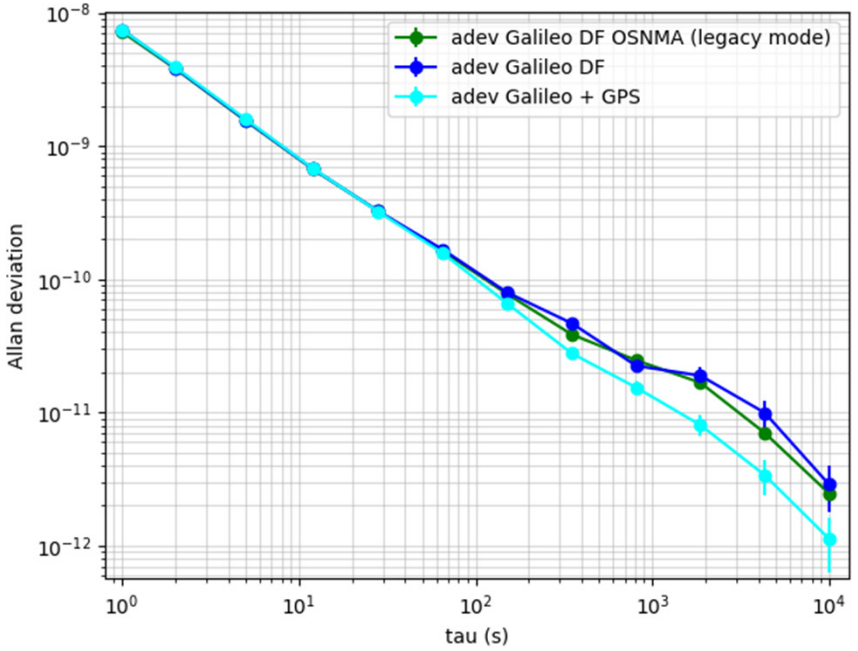


Impact of ionosphere on GNSS reception

TIMING OUTPUT OF AUTHENTICATED SIGNALS VS STANDARD OS

Comparison of time solution with live open sky SIS





Grey is authenticated Galileo only 3D fix solution

Blue is standard multi-GNSS 3D fix solution

Allan deviation at the output of internal receiver

Note: Offset is uncalibrated but consistent in both cases

CONCLUSION

⇒ Galileo will soon provide authenticated data that will increase protection of applications against intelligent spoofing threat

⇒ Combination with spatial, frequency and time domain filtering will provide a reliable and highly available source for master clock reference to international time scales

⇒ Performances of 3D fix derived from Galileo authenticated data with available receiver are very close to other GNSS sources

⇒ Pure timing 0D fix performances need to be explored further