HARMONY GNSS-RELATED PHASE SYNCHRONISATION PRELIMINARY TEST RESULTS

MULTISTATIC RADAR 2025

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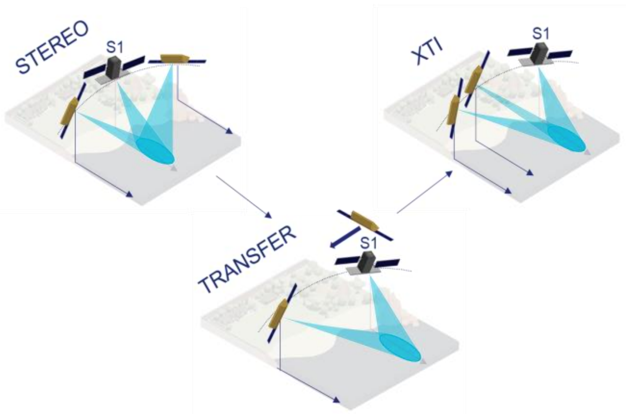
INTRODUCTION TO SAR INSTRUMENT FOR HARMONY MISSION

- Harmony is a unique mission concept, introduced by the European Space Agency (ESA) in the frame of the Earth Explorer 10 missions in order to expand the Sentinel-1 applications.
- The Harmony system employs a C-band passive SAR Instrument working in bi-static configuration with Sentinel-1 and an Optical payload allowing to obtain enhanced products for the observation of oceans, cryosphere and solid Earth.
- In the concept of bi/multi- static SAR mission based on non-cooperative instruments where the Master Satellite (Sentinel-1) performs monostatic acquisition, while the companion Satellite (Harmony) works as a Receiver only instrument (i.e. which receives the echo signals produced by the transmission of S1), the synchronisation among instruments is considered a key aspect in order to perform accurately a single pass interferometric Earth observation.

Harmony satellites concept of operations



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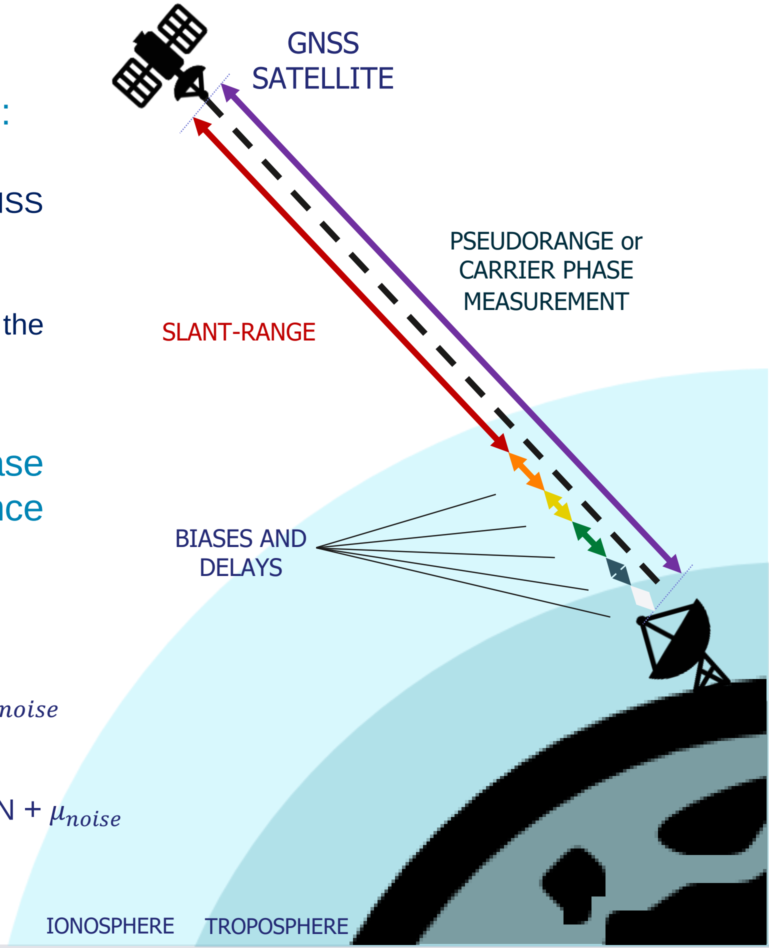
GNSS SYNCHRONISATION

/// Using GNSS signals as time-transfer has several advantages:

- GNSS is based on a stable Atomic Time Scale;
- Everywhere on the Earth's surface and at Low Orbits, at least four GNSS satellites are visible;
- Position of GNSS satellites is accurately known;
- Using a simple GNSS receiver and a good clock it is possible to obtain all the information to get synchronized to GNSST.

/// A GNSS receiver collects Pseudorange and Carrier-Phase measurements that provide a measurement of the distance between transmitter and receiver.

- The measurement is affected by various delays and error contributions:



$$\rho = \rho_{slantrange} + c\,(\Delta t_{rx} - \Delta t_{sv}) + c\,\Delta t_{iono} + c\,\Delta t_{tropo} + c\,\Delta t_{M} + c\,\Delta t_{calibr} + \sigma_{noise}$$

$$\phi = \frac{\rho_{slantrange}}{\lambda} + c\,\frac{(\Delta t_{rx} - \Delta t_{sv})}{\lambda} + c\,\frac{\Delta t_{iono}}{\lambda} - c\,\frac{\Delta t_{tropo}}{\lambda} + c\,\frac{\Delta t_{M}}{\lambda} + c\,\frac{\Delta t_{calibr}}{\lambda} + N + \mu_{noise}$$

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CARRIER PHASE COMMON VIEW

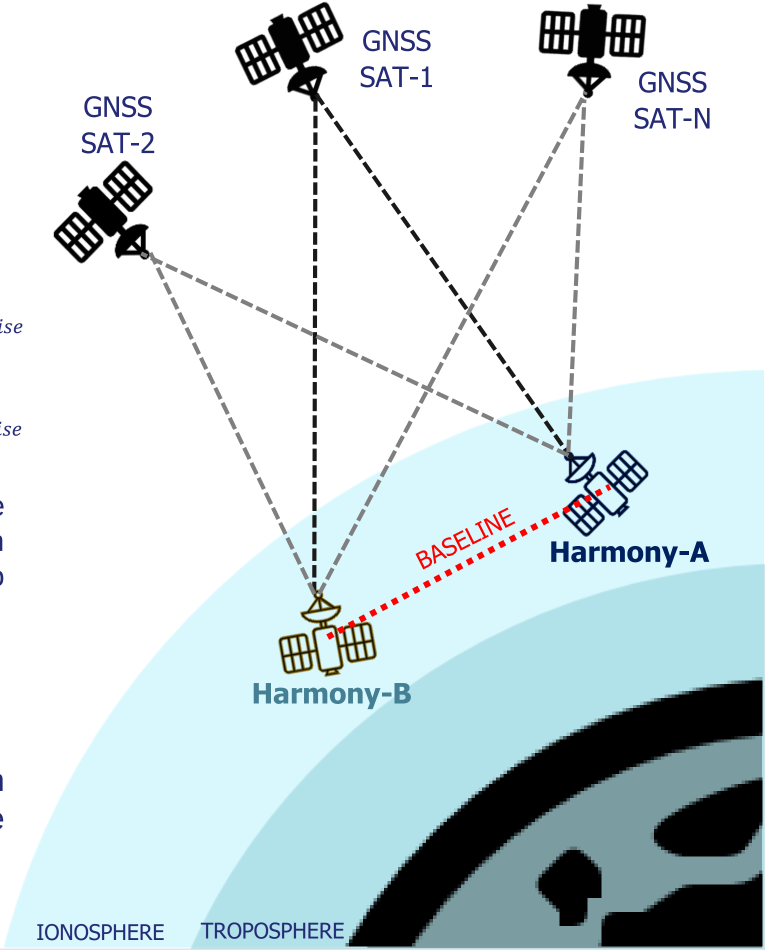
- From these measurements, by modelling the various error contributions, it is possible to obtain the Receiver Clock Bias Δt_{rx}, which is the desynchronisation value between a receiver and a GNSS satellite. Writing it for two different satellites:

$$\begin{cases} \Delta t_{rx,A} = \dfrac{\phi\lambda - \rho_{slantrange}}{c} + \Delta t_{sv} - \Delta t_{iono} + \Delta t_{tropo} - \Delta t_{M} - \Delta t_{calibr} - \dfrac{\lambda}{c}N - \dfrac{\lambda}{c}\mu_{noise} \\ \Delta t_{rx,B} = \dfrac{\phi\lambda - \rho_{slantrange}}{c} + \Delta t_{sv} - \Delta t_{iono} + \Delta t_{tropo} - \Delta t_{M} - \Delta t_{calibr} - \dfrac{\lambda}{c}N - \dfrac{\lambda}{c}\mu_{noise} \end{cases}$$

- Since clock bias is the difference between the clock of the receiver and the GNSS satellite, by subtracting the clock biases of two different receivers in visibility with the same satellite, the desynchronisation value between the two receivers A and B can be obtained.

$$\Delta t_{rx,A} - \Delta t_{rx,B}$$

- The desynchronisation value can be calculated using all satellites in common visibility between the two receivers; in this way, a more accurate result can be obtained.



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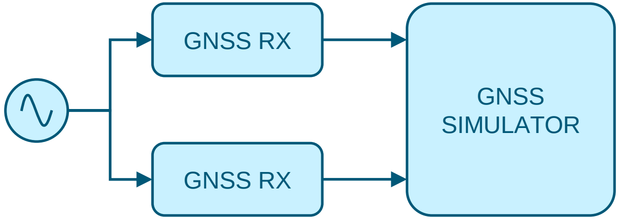
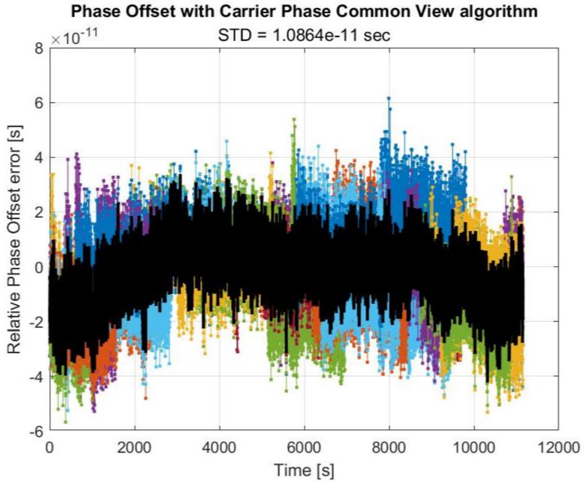
CARRIER PHASE COMMON VIEW

- The Carrier Phase Common View technique allows then to obtain the desynchronisation value between two receivers. Its application, however, is as accurate as the different error modelings that contribute to the calculation. In fact:
  - the term due to **geometric distance** is the most critical as it is important to know as accurately as possible the position of the GNSS satellite at the time of transmission and the receiving satellites at the time of reception;
  - the error due to the common **GNSS satellite clock** is cancelled out by the technique;
  - the **ionospheric error** can be reduced by using dual-frequency GNSS receivers;
  - the error due to the **troposphere** in the case of the Harmony application can be excluded from the computation by using an elevation mask;
  - in general, the technique reduces the modelling error and the smaller the **baseline** distance between the two receiving satellites, the better the estimate;
  - the use of **Carrier Phase** measurements compared to Pseudorange measurements allows greater accuracy and less noise in the measurement once the ambiguity unknown is resolved.
- During phase B2 a test campaign using EM Space Hardware was used in order to evaluate the impact of the different errors in the synchronisation budget.

TEST-100 ZERO-BASELINE SCENARIO

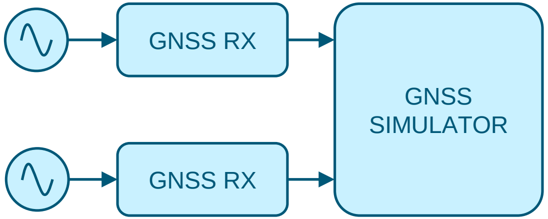
- In order to evaluate the behavior of two different GNSS Rx a first test simulating a zero-baseline scenario was conducted.
  - 2x GNSS Rx
  - 1x Spirent GNSS Simulator (with 2 antenna output)
  - 1x OCXO
  - 1x Phase Comparator
- Using one OCXO and a single orbital scenario for both satellites (GNSS RXs), the offset obtained from the Carrier Phase Common View technique is related to the behavior of the GNSS RXs.



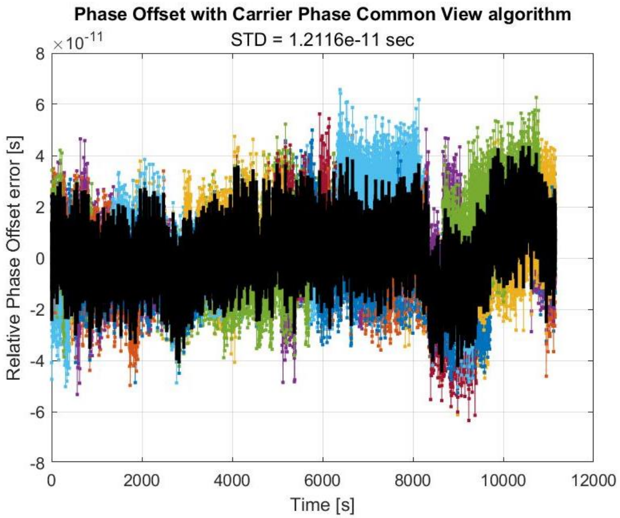


TEST-200 XTI AND STEREO FORMATION

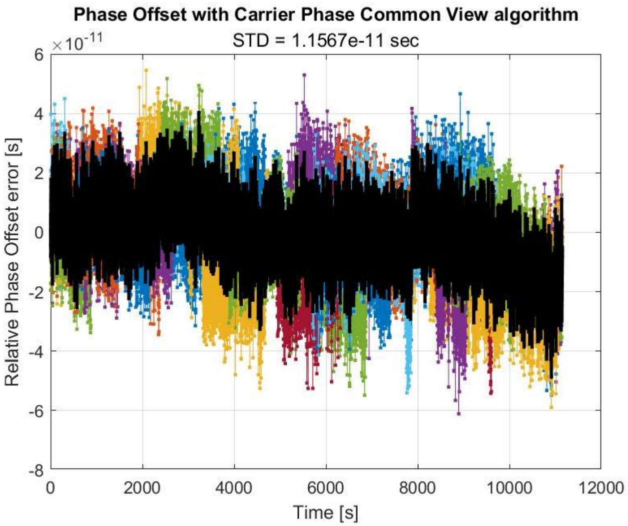
- Using the zero-baseline as a reference, it is possible to determine what values to expect in the case of baseline in the two configurations XTI and Stereo
  - 2x GNSS Rx
  - 1x Spirent GNSS Simulator (with 2 antenna output)
  - 2x OCXO
  - 2x Phase Comparator



XTI Formation



Stereo Formation



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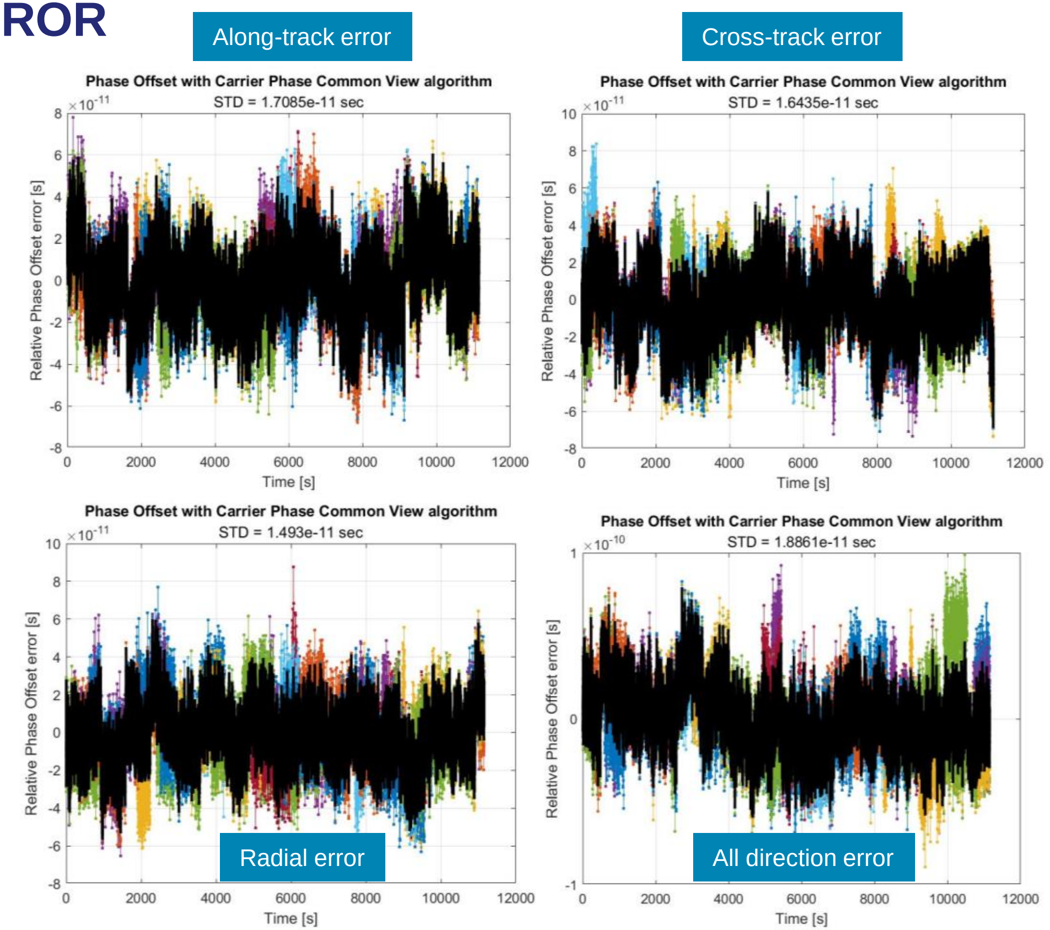
TEST-300 GNSS POSITION ERROR

- A possibility to reduce the position error of the GNSS satellites in post-processing is to use the Precise Orbits products from IGS. That products have an accuracy of 2.5cm.
- In the Spirent configuration is possible to add an error on the GNSS satellite position w.r.t. the “clean” measurements obtained with the test before.
- So with the same test setup as for the test before, an error of 2.5cm was added in the different directions.
- → it can be seen that the case with all directional errors has a higher STD than the cases with an error only along one direction. It can be seen also that the value has increased compared to the ideal case with no position error.



TEST-400 HARMONY SATELLITES POSITION ERROR

- In a similar way is possible to evaluate the impact of an error in the ODTS estimation of the Harmony satellites.
- Using the same test set-up and adding an error in the position of the receiver is possible to evaluate the difference between an ideal case

- Analysis on-going

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CONCLUSIONS AND WAY FORWARD

- /// Tests show that through the Carrier Phase Common View technique, a synchronisation value in the picosecond range can be achieved.
  - The receivers have their own behaviour that leads to a synchronisation error in the order of 10ps STD.
  - In the real case, the position of the GNSS satellites can be calculated using Precise Orbit (sp3). The accuracy of these products (2.5cm) leads to a synchronisation error in the order of 6-7ps.
  - The ODTS algorithm is very important as an accuracy of 5cm in estimating the position of satellites can lead to an error of TBC ps. (on-going)
- /// Experimentation shows that the Carrier Phase Common View technique's error residuals lead to a very good knowledge of the desynchronisation value in the case of satellites in Low Earth Orbit constellation.
- /// **Q&A**

THANK YOU FOR THE ATTENTION!

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