Real-Time Demonstration of Integrated Communication and Navigation Services Using LDACS

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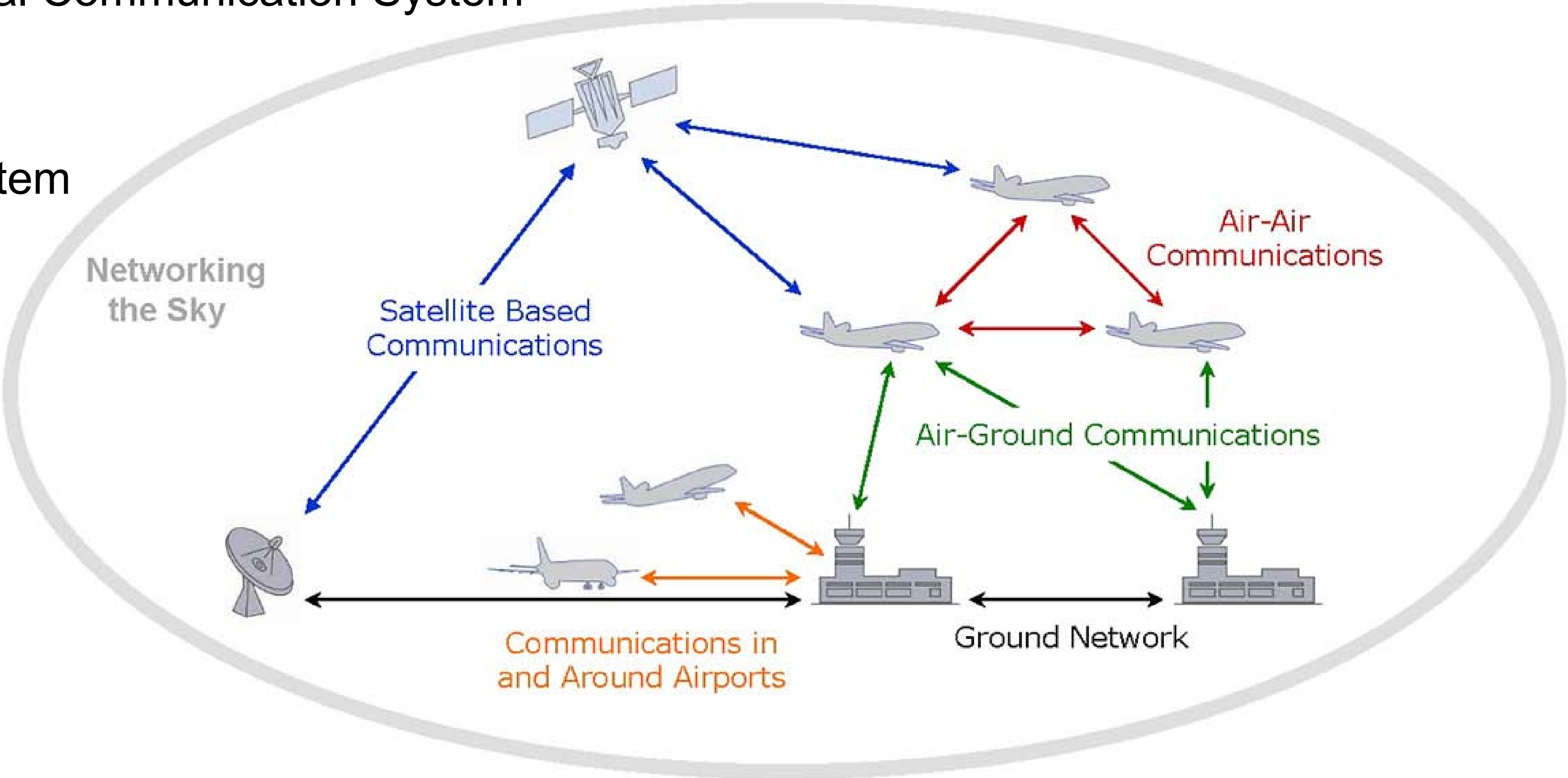
Integration of COM and NAV services for greater spectral efficiency: LDACS as a navigation system

- LDACS: L-Band Digital Aeronautical Communication System



- Air-to-Ground Communication System
- Ranging demonstrated in 2012
- Positioning measurements in 2018
- Real-time positioning: 2019

https://www.ldacs.com/

Measurement campaign of March 2019

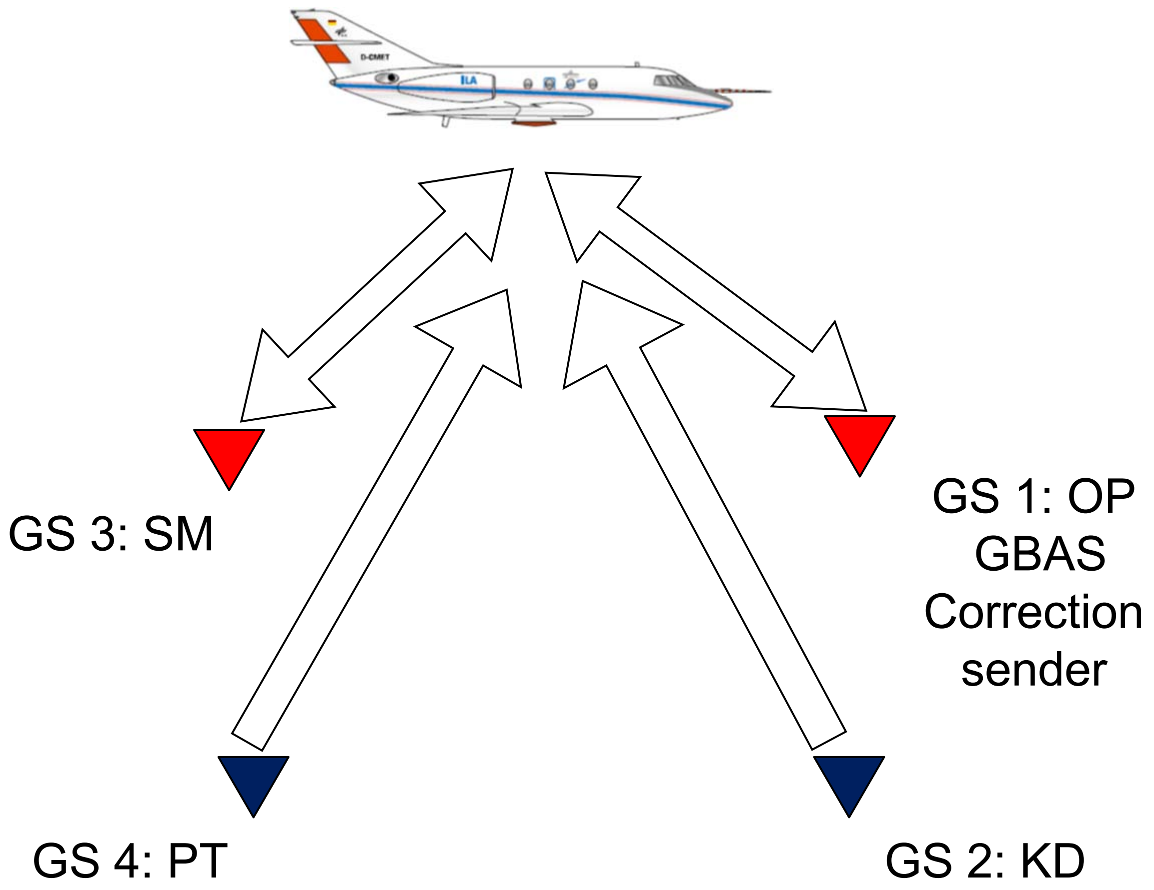
- Dual objective:
  - Characterization of LDACS as a communications system
  - Demonstration of real-time APNT

- This presentation focuses on the navigation perspective
  - Network of navigation ground stations
  - Design of ground stations
  - Airborne navigation receiver

Our colleagues will discuss communications aspects elsewhere

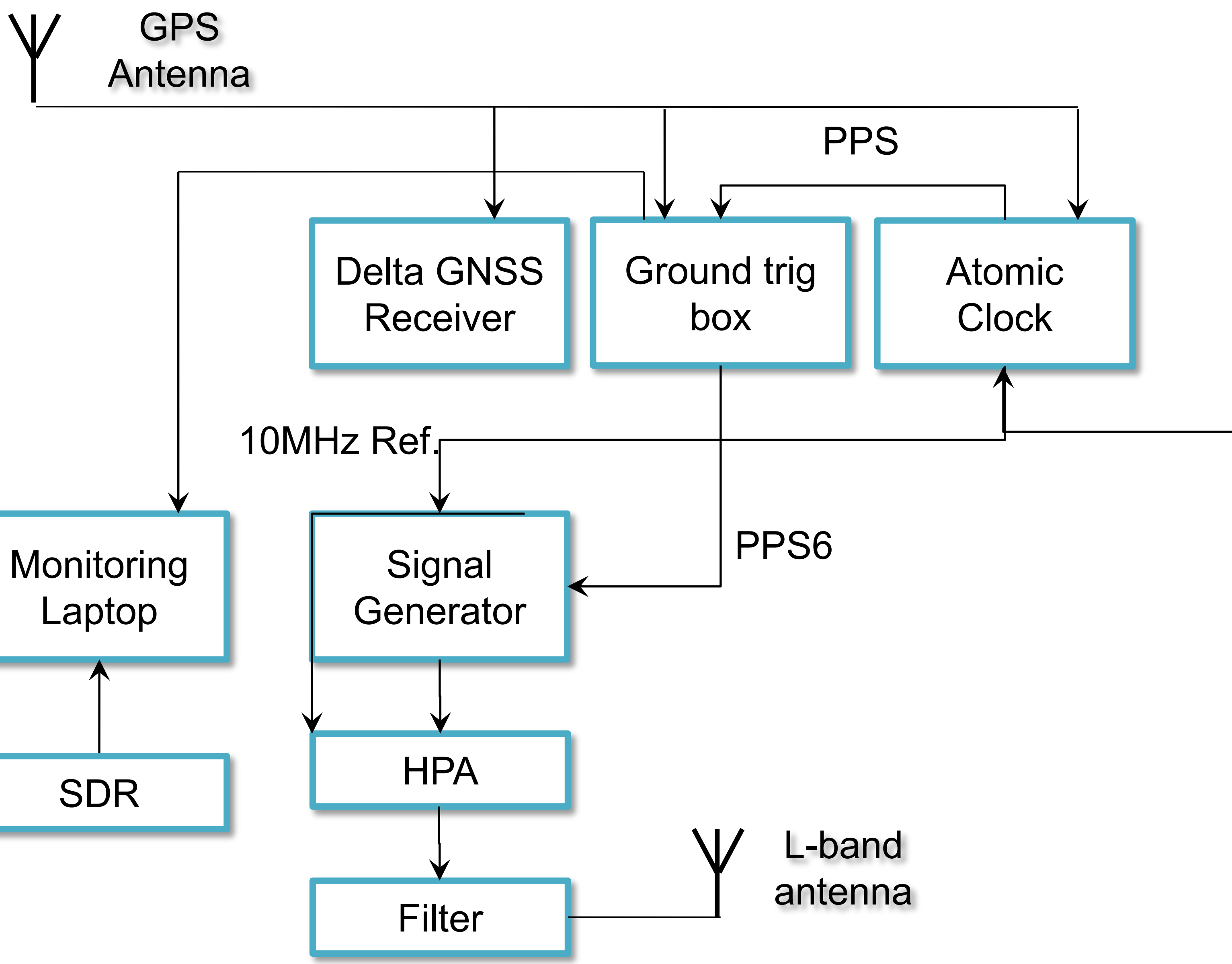
Campaign Setup: Four ground stations, one airborne station

- GS 1 and 3:
  - Full-fledged LDACS communication stations
- GS 2 and 4:
  - LDACS pseudoranging beacons
- GS 1 also operates single-station "mobile GBAS" reference station

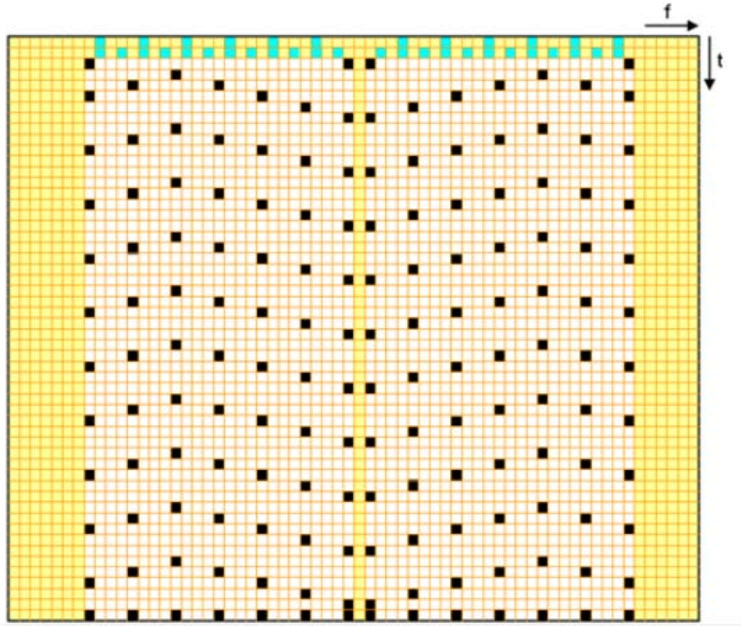


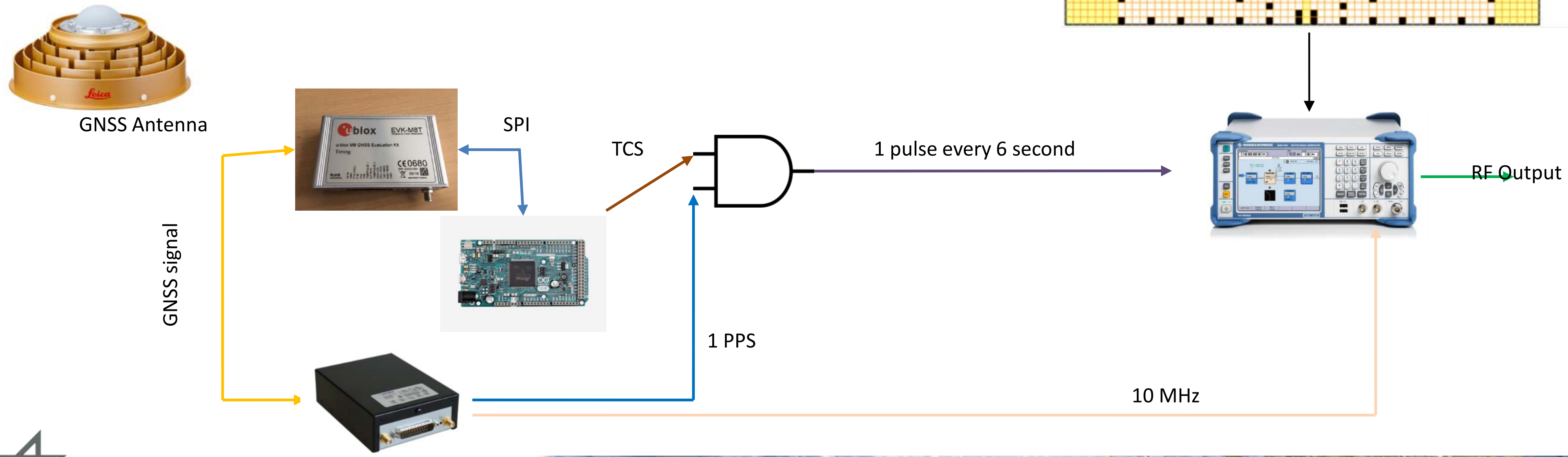
Ground station setup

- GPS-Disciplined Atomic Clock
- R&S Signal Generator SMBV 100A
- Javad Delta GNSS receiver
- Ground triggering box
- High Power Amplifier
- L-Band filter
- L-Band antenna
- Geodetic GPS antenna



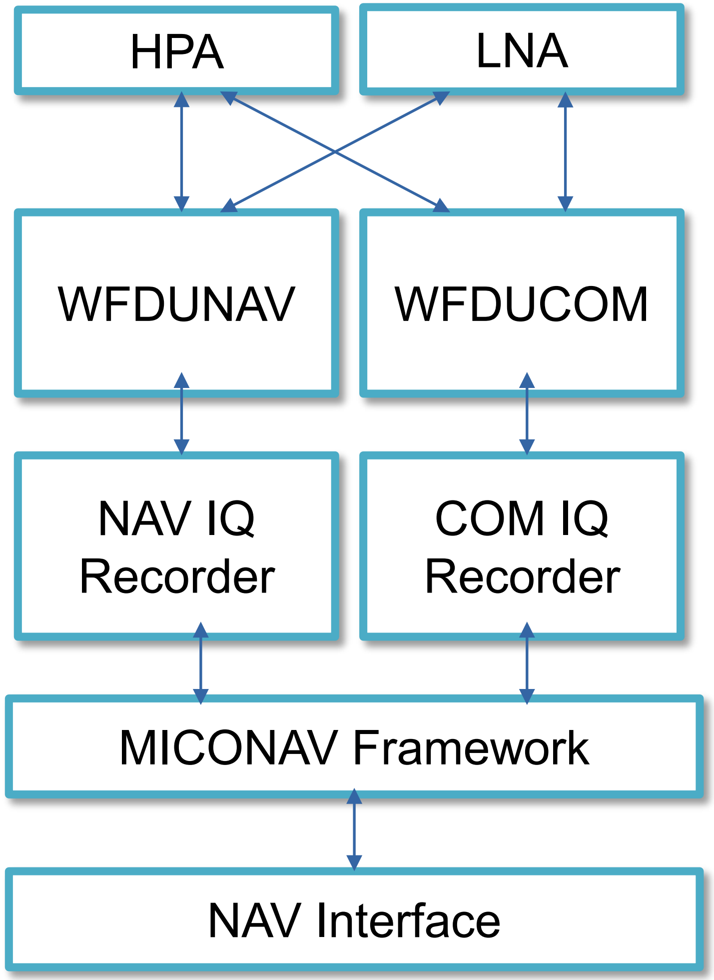
Time synchronization of ground stations



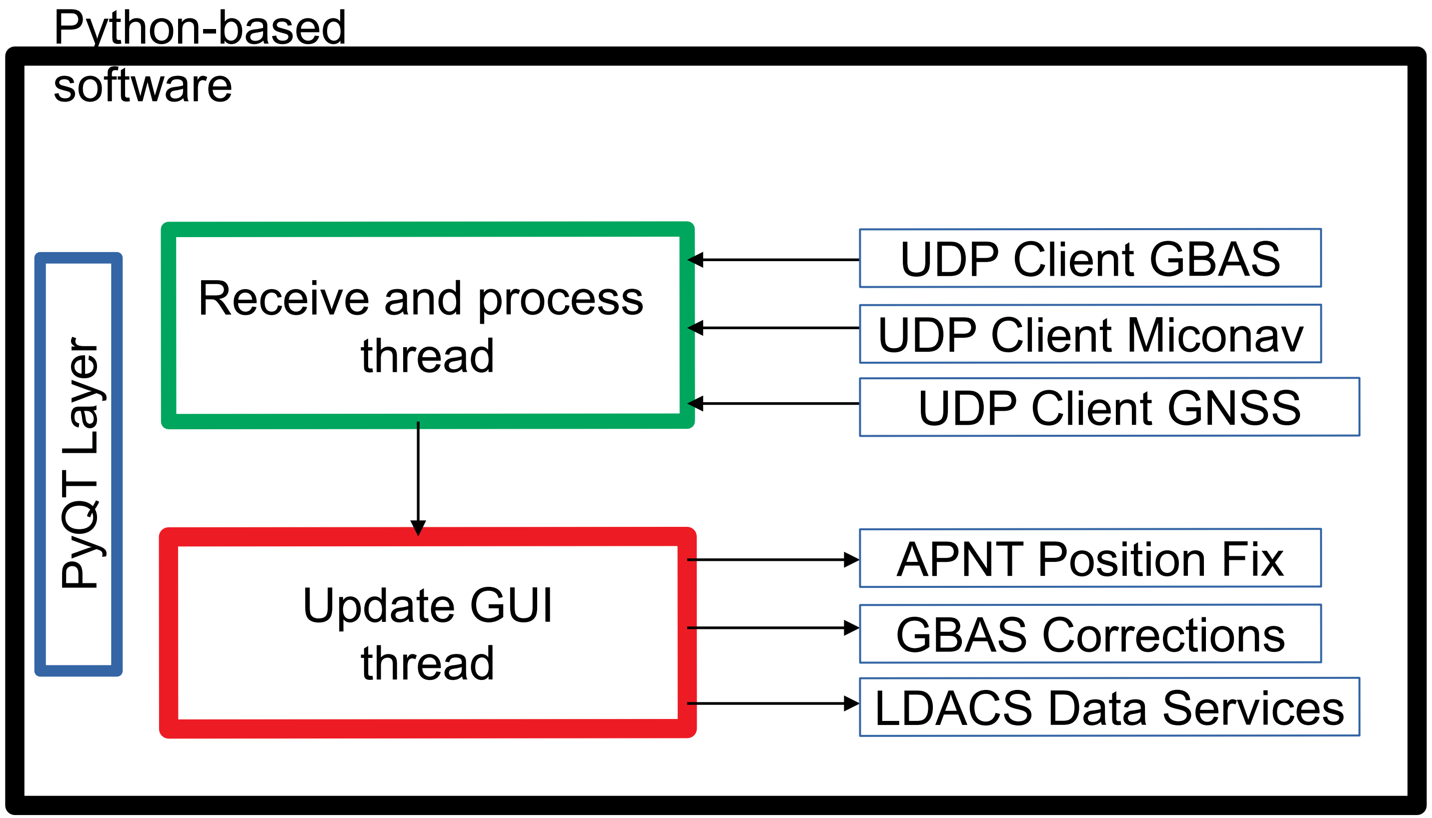


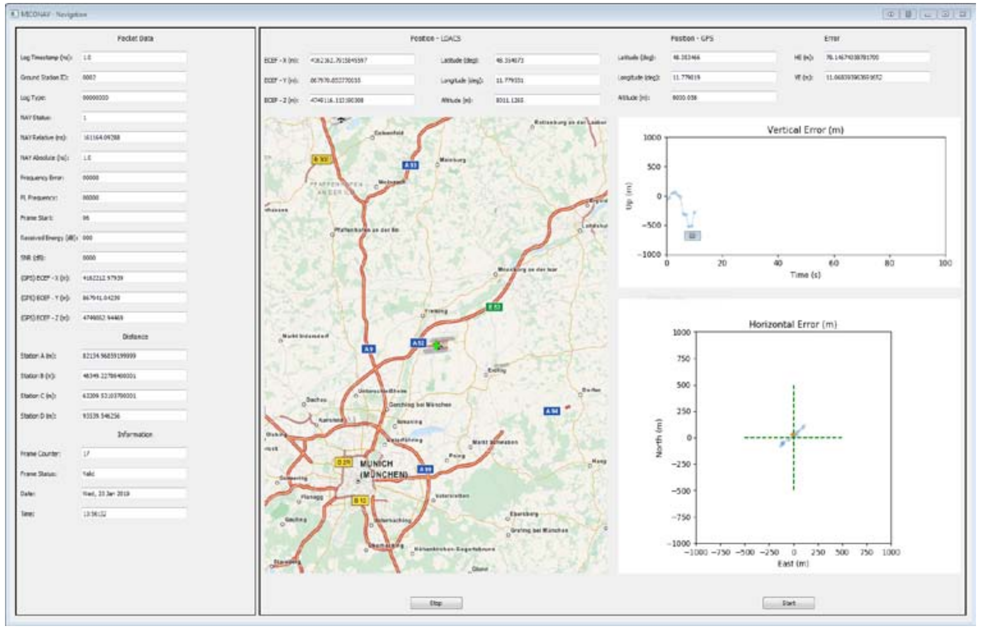
Hardware Architecture on Airborne Station

- Pseudorange measurements computed on LDACS receiver
- GPS measurements from on-board receiver
- GBAS data received through LDACS



Navigation Software Architecture





Computations - APNT LDACS positioning

- Combine pseudorange
- At least two pseudorange stations for bias clock.
- The weighting matrix diagonal elements are inverse of range error variance

$$\boldsymbol{F}(\boldsymbol{x}, b) = \begin{pmatrix} \rho_1 - \|\boldsymbol{s}_1 - \boldsymbol{x}\| \\ \vdots \\ \rho_k - \|\boldsymbol{s}_k - \boldsymbol{x}\| \\ \rho_{k+1} - \|\boldsymbol{s}_{k+1} - \boldsymbol{x}\| \\ \vdots \\ \rho_N - \|\boldsymbol{s}_N - \boldsymbol{x}\| \end{pmatrix} \Rightarrow$$

$$\boldsymbol{W} = \mathrm{diag}(\sigma_1^2, \sigma_2^2, \cdots, \sigma_N^2)$$

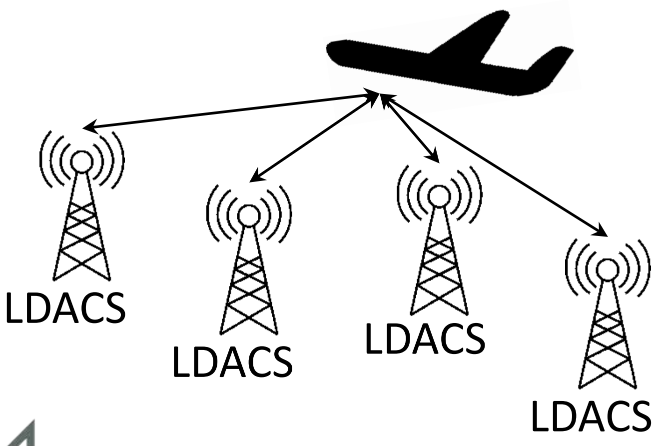
$$\boldsymbol{G}(\boldsymbol{x}, b) = \frac{d\boldsymbol{F}(\boldsymbol{x}, b)}{d(\boldsymbol{x}, b)}$$

$$\Rightarrow \begin{pmatrix} \Delta \boldsymbol{x} \\ b \end{pmatrix} = (\boldsymbol{G}^T \boldsymbol{W} \boldsymbol{G})^{-1} = \boldsymbol{H} = \begin{pmatrix} \sigma_E^2 & \cdot & \cdot & \cdot \\ \cdot & \sigma_N^2 & \cdot & \cdot \\ \cdot & \cdot & \sigma_D^2 & \cdot \\ \cdot & \cdot & \cdot & \sigma_T^2 \end{pmatrix}$$

$$\Downarrow$$

$${\sigma_{NSE}}^2 = \sigma_E^2 + \sigma_N^2$$

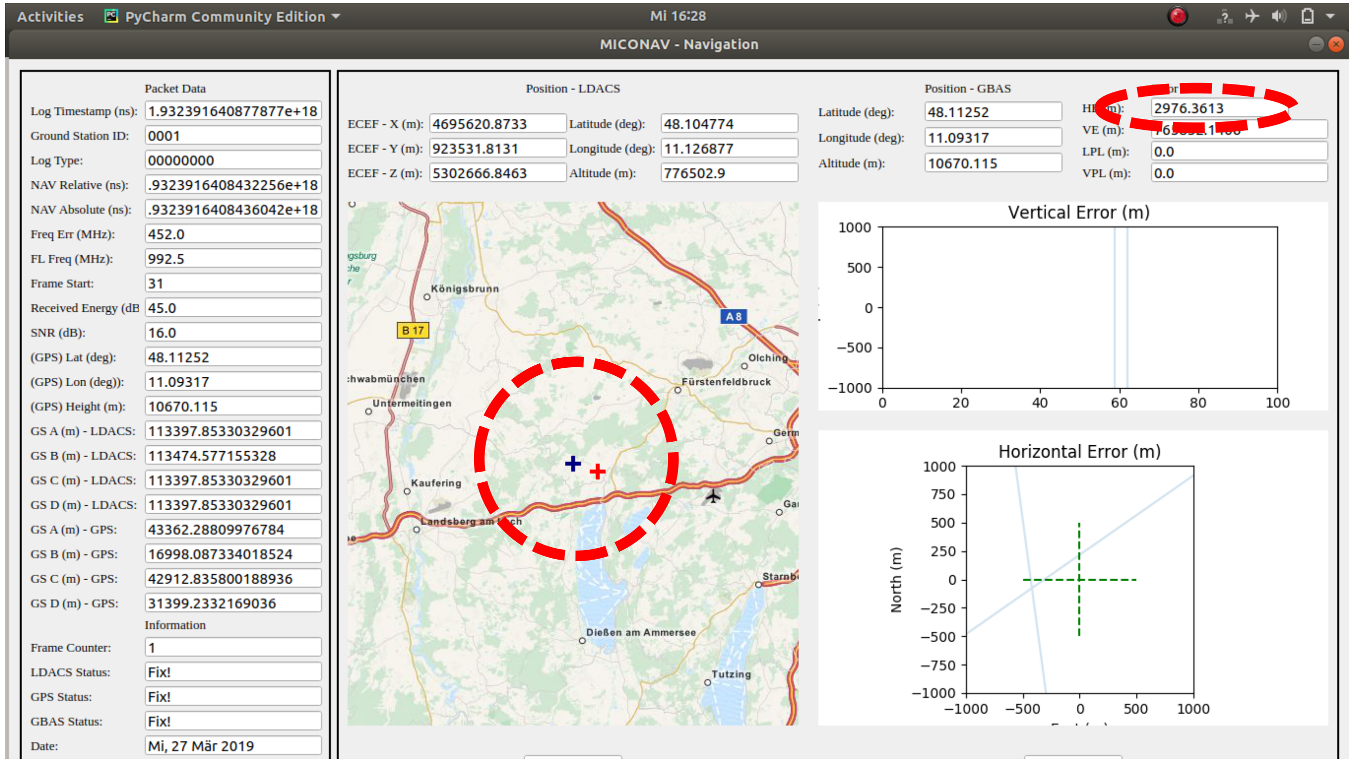
$${\sigma_{VERT}}^2 = \sigma_Z^2$$



Results: Feasibility demonstrated

- GBAS over LDACS position fixes and protection levels in real time

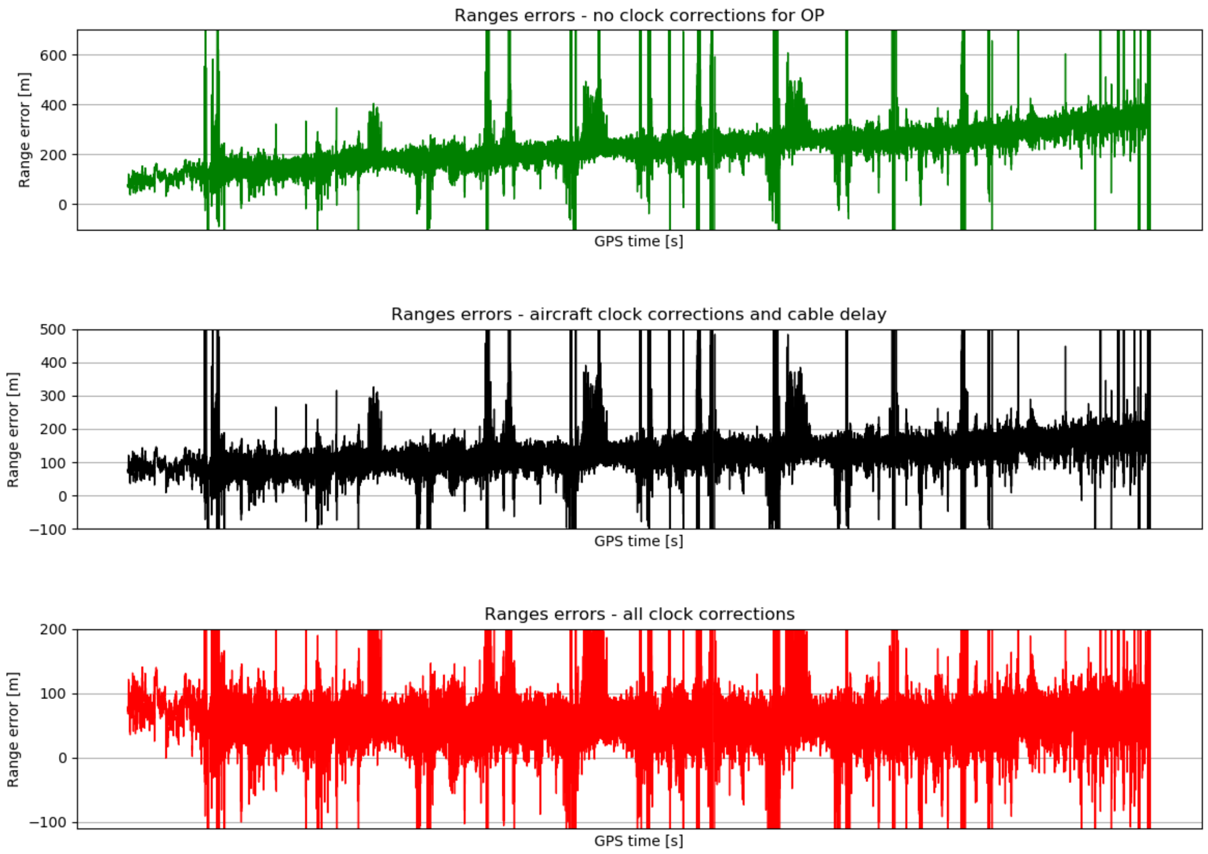
- LDACS-based APNT in real time:
  - Position fixes within 2.9 km of reference



Further work

- Post-processing of measurements
- Identify sources of bias in GS

- Next measurement campaign: fusion with iner
  and barometric sensors



DLR

Thank you for your attention!