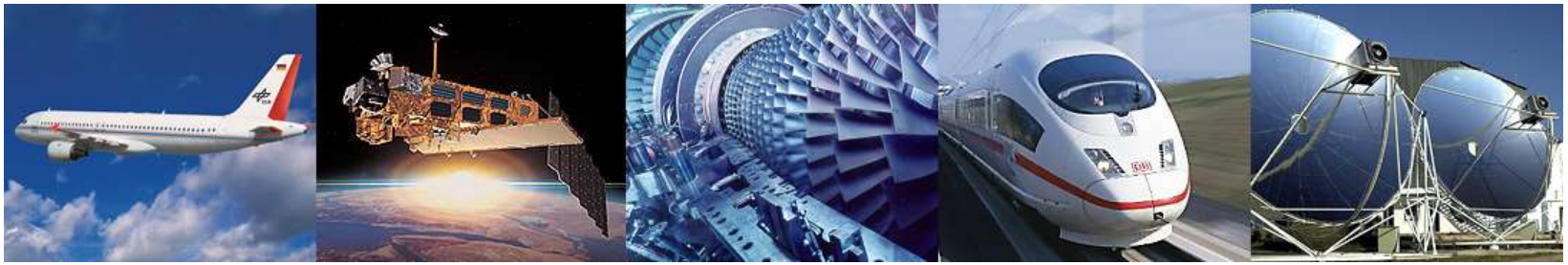
Current Challenges (and Solutions) in Satellite Navigation

Omar García Crespillo

Institute of Communication and Navigation



DLR

Satellite Navigation – Application Fields

- **Navigation:** automotive, aircrafts, shipping, space

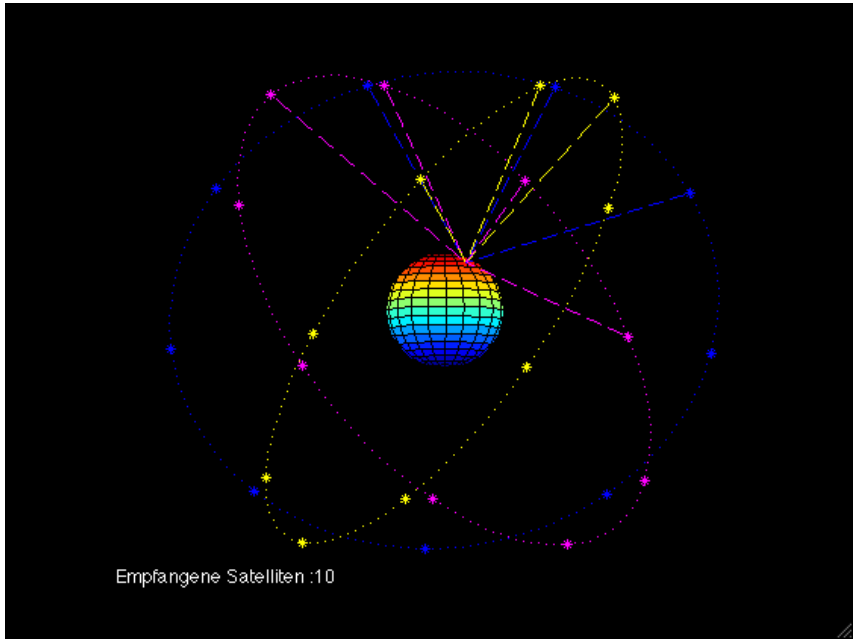
- **Geodesy:** surveying, mapping, geology, archaeology, civil engineering, topography

- **Time keeping:** mobile communication
- systems, internet traffic

- **Search and Rescue (SAR)**
- **Fleet management**
- **Traffic control**
- **Geolocation based games**
- **Marketing**
- **Social Networks**

Satellite Navigation – General Principles

- **Satellite broadcasts :**
  - orbital data and ephemeris
  - precise time stamp (atomic clocks)
- **Receiver measurements:**
  - compares transmission and reception time (flight time)
  - distance between satellite and receiver.
- Receiver placed in a spherical shell:
  - **trilateration**
  - **Position + time**

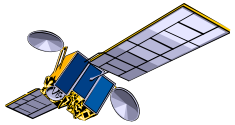


Safety of life applications (e.g. Civil aviation)

Safety of life applications

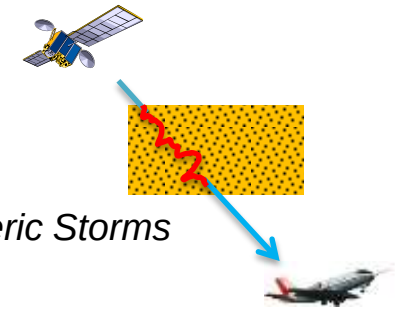
- Rely more on GNSS in the future (SESAR and NextGen)
- Allow for new type of approaches (e.g. curve)
- Increment of air traffic density → Reduce distance between aircrafts
- Not only accuracy is therefore important → **Integrity** and availability

GNSS Vulnerabilities



System Errors:

- *Satellite clock*
- *Orbital parameters*

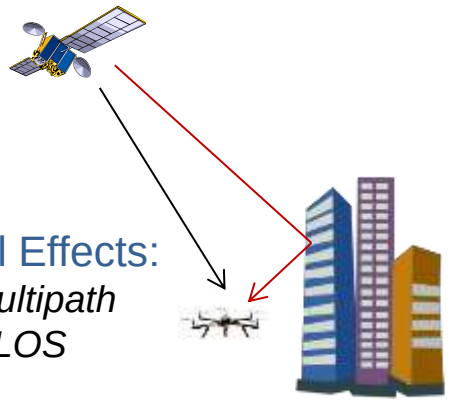


Atmospheric:

- *Tropo/Ionospheric Storms*
- *Scintillation*

Fake GNSS signal

(Spoofing)



Local Effects:

- *Multipath*
- *NLOS*

Interferences:

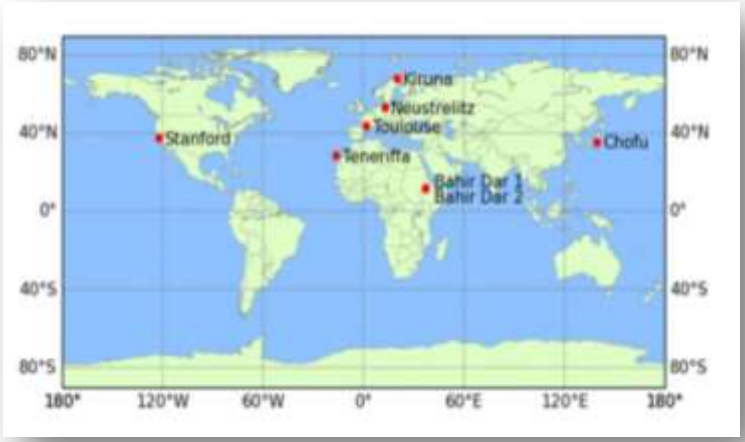
- *Unintentional*
- *Intentional (Jamming)*

System Error Monitoring

- Characterization of Satellite Orbit and Clock Errors

SIS Verification with
High Gain Antenna

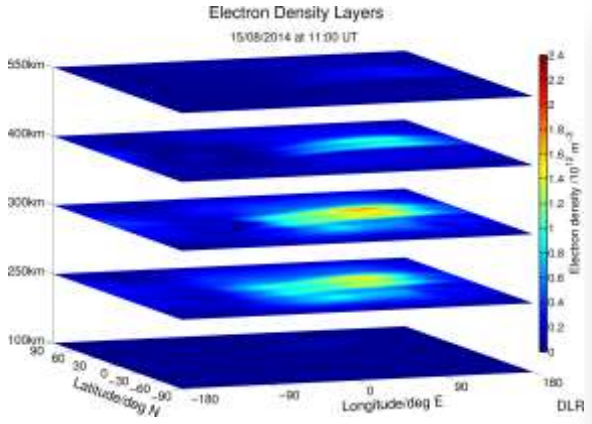
Experimentation and Verification
Network (EV-NET)

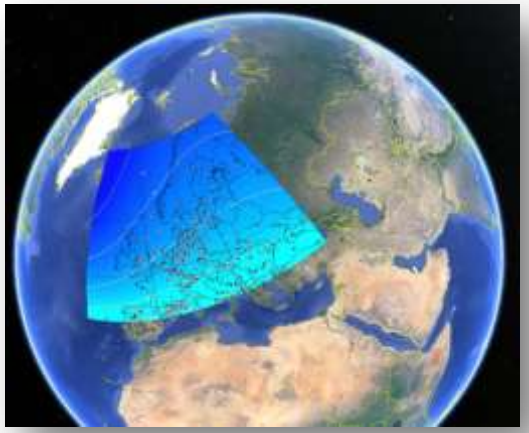


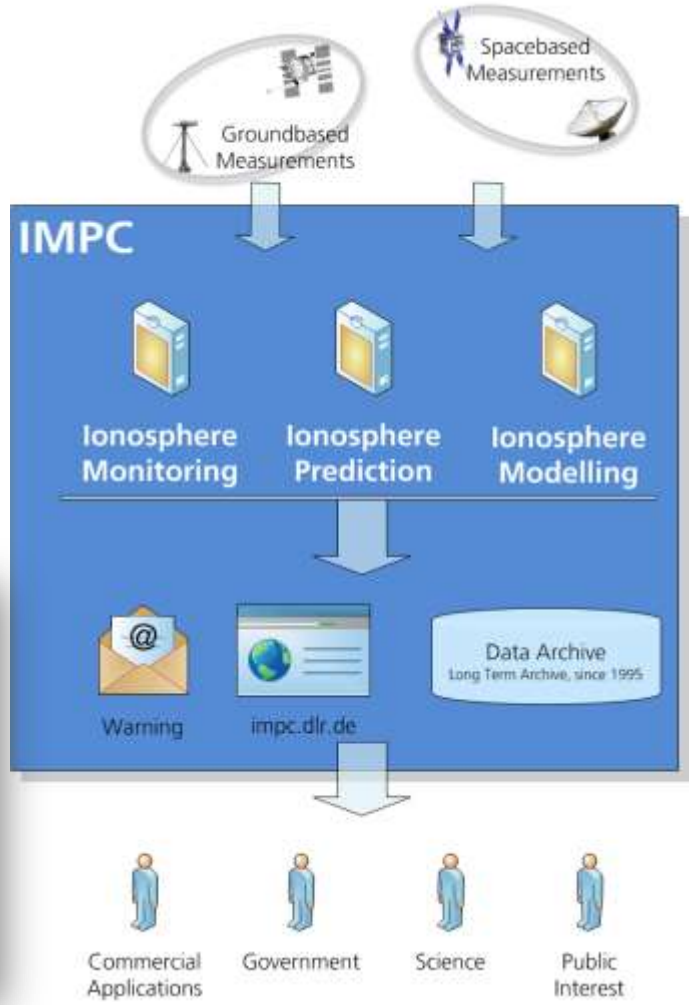
Ionosphere Monitoring Prediction Center (IMPC)

Detection, Analysis and alert of Ionospheric Events

- Modeling of the Ionosphere through the determination of the TEC (Total Electron Content)
- Detection of the amplitude and phase of scintillation for multifrequency GNSS measurements

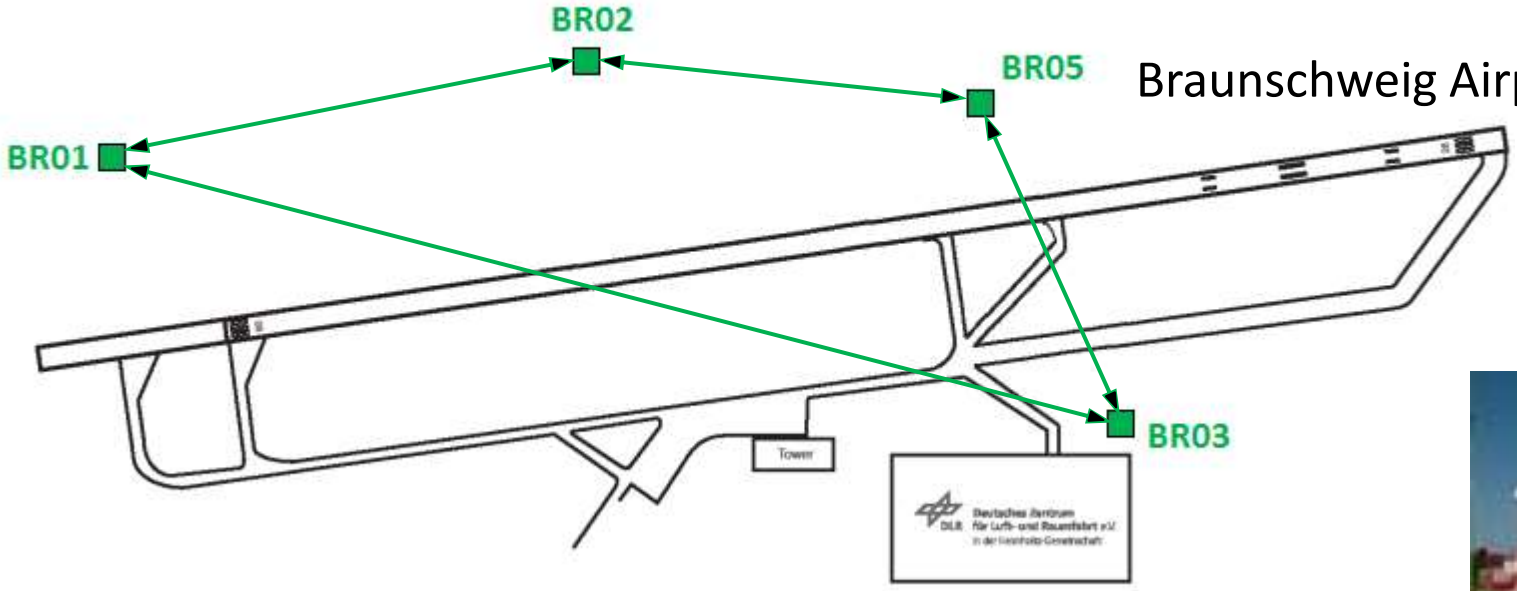






DLR

DLR GBAS Ground Facility



Braunschweig Airport

	L1	L2	L5
BR01	✓	✓	✓
BR02	✓	✓	✓
BR03	✓	✓	✓
BR05	✓	✓	✓

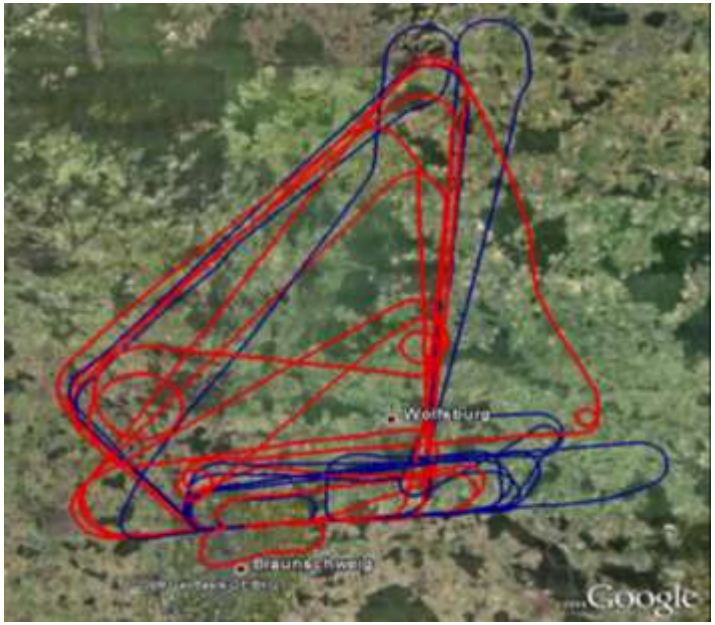
Since 6th May 2014:

Javad Delta Receivers with
GPS (L1 / L2 / L5) + Galileo (E1 / E5a) + Glonass
Connected to Leica AR25 choke ring antennas

DLR

DLR Research Aircraft

Evaluation of measurements and system performance through flight trials



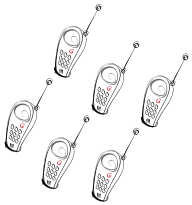
D-CODE (Dornier 228)
ATTAS (VFW 614)
ATRA (Airbus 320)

RF Interferences

- GNSS signals are deeply buried in the noise and can be easily disturbed by interference from other signals

- Received power at Earth surface:
  ~ -160 dBW =
  0.000 000 000 000 000 1 Watt

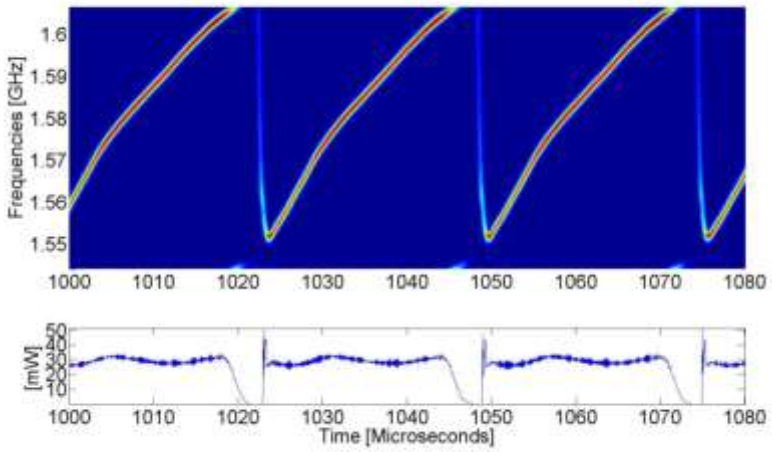
- Can be disturbed by:
  - Accumulated noise (e.g. UWB)
  - High power pulses (DME, TACAN)



  - High Power Continuous Wave (Harmonics from TV stations etc.)
  - Personal Privacy Devices Jammers

Interference by GPS Jammers (PPD) at Newark Airport

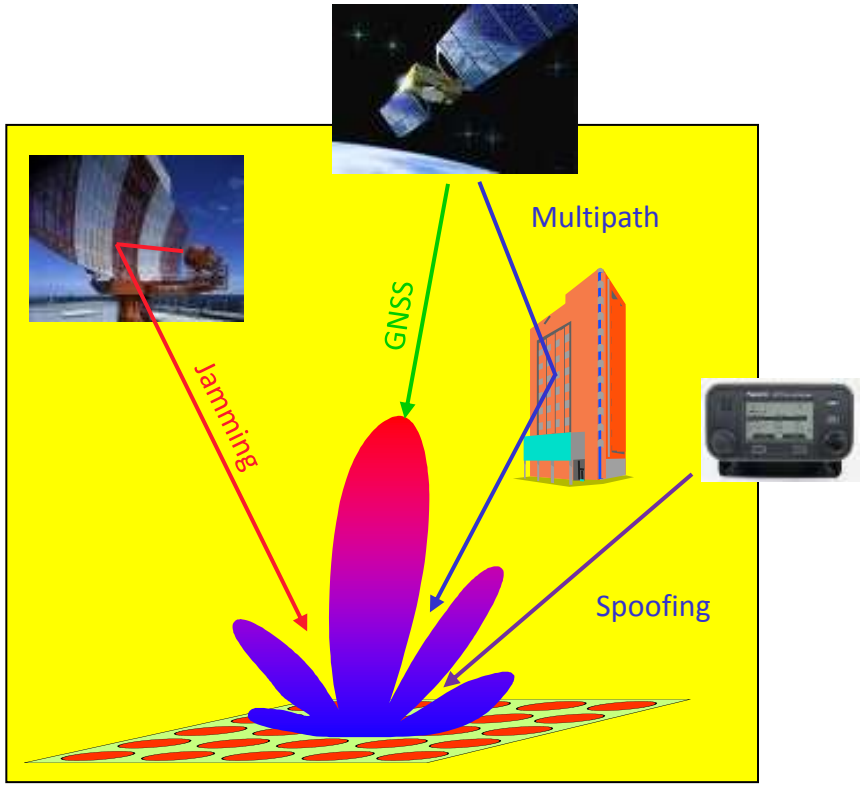
- Intentional jamming is reality!
- Personal Privacy Devices (jammers) disturb GPS and GBAS reference stations
- Operation illegal
- Price: $ 30 - $ 200 in Internet
- Interference mitigation required



Source: R.H. Mitch et al., Signal Characteristics of Civil GPS Jammers, ION GNSS 2011

Airport Newark Liberty International, Motorway close to airport

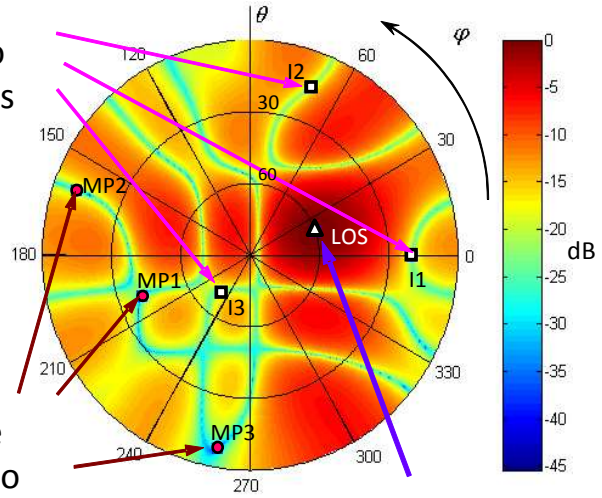
Adaptive Antennas
Interference and multipath mitigation



Antenna size approx. 95 x 95 cm²

Antenna pattern of 5 x 5 array after beamforming

Nulls at the directions to interferences



Nulls at the directions to multipath

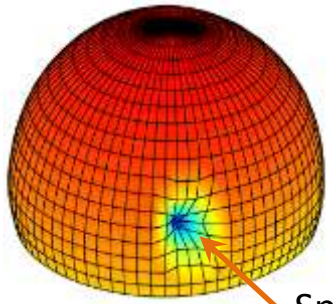
Maximum at LOS

DLR

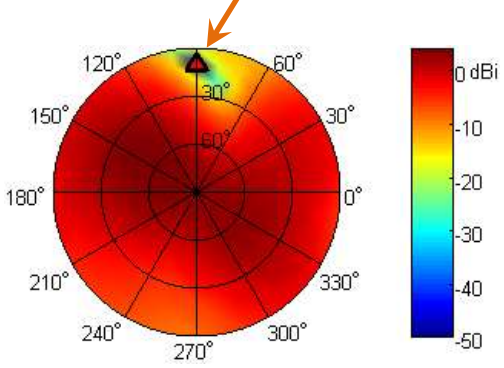
Pre and post correlation techniques: Beamforming

- Pre-correlation

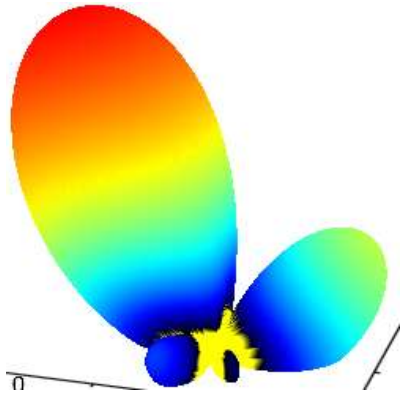
Desired reception pattern:

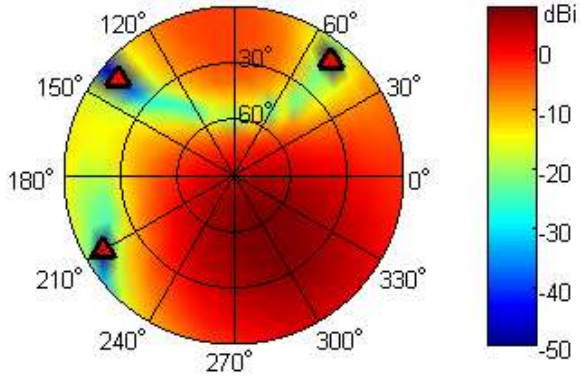


Spatial zero to mitigate jammer

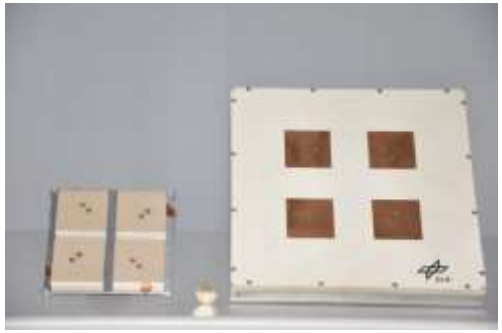


- Post-correlation

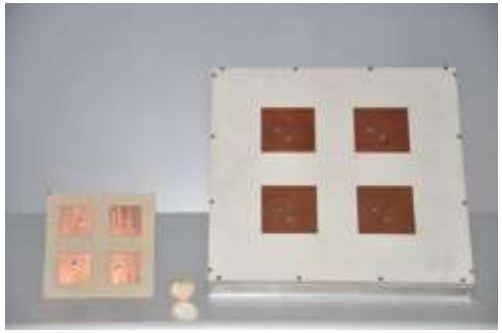




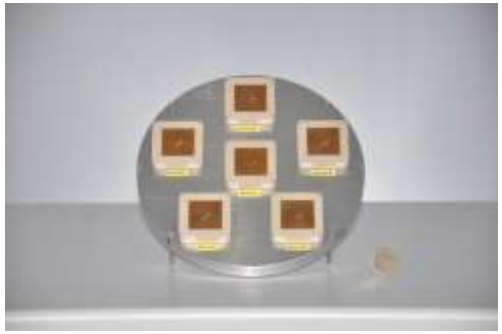
Some DLR GNSS Antenna Arrays



Galileo E1/E6 standard and miniaturized



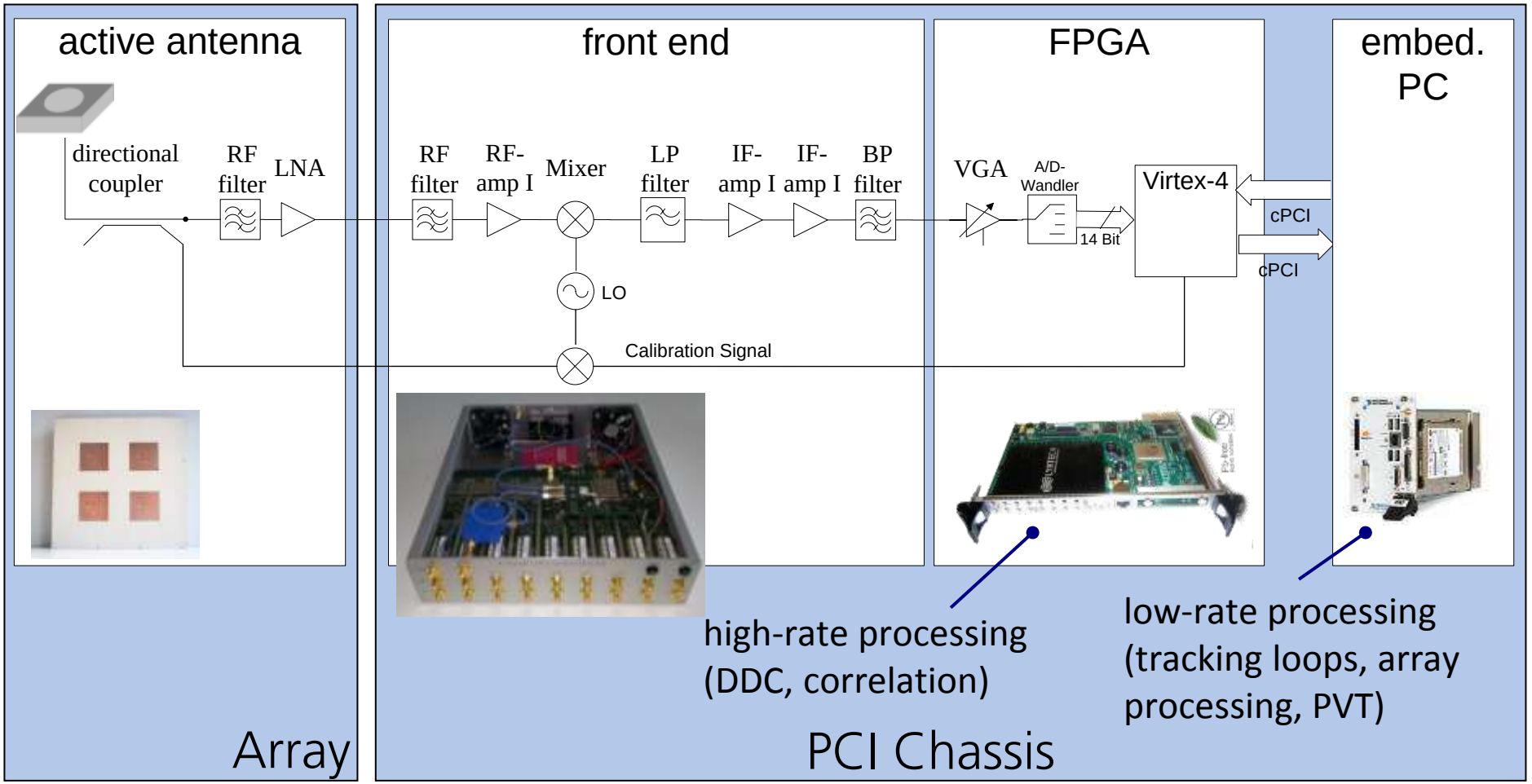
Galileo E1/E5 standard and miniaturized



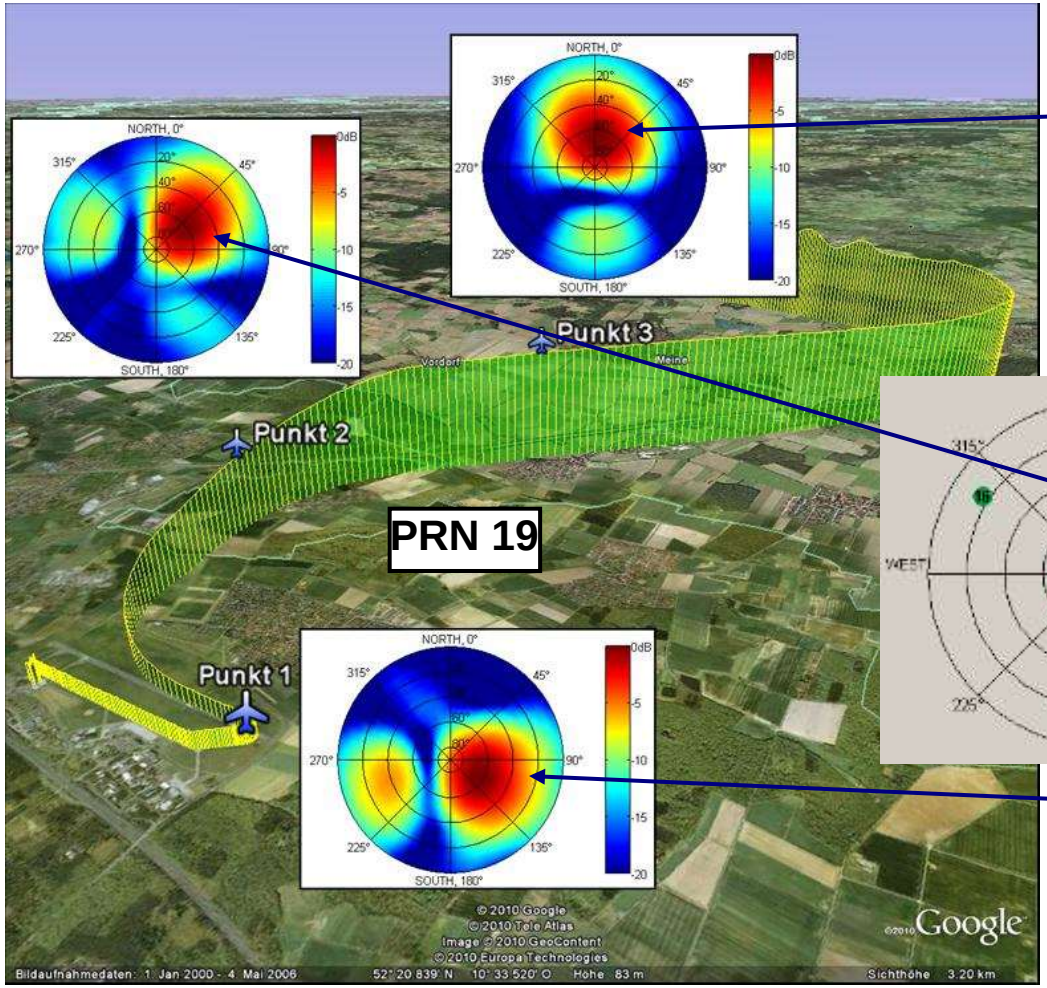
GPS miniaturized

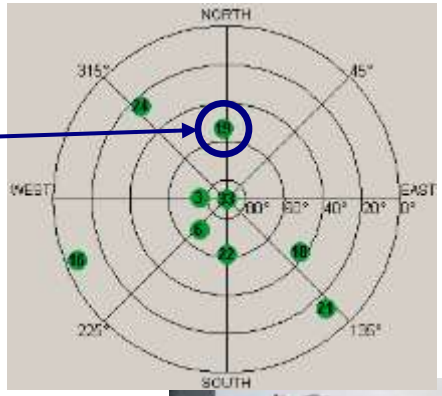
GPS conformal

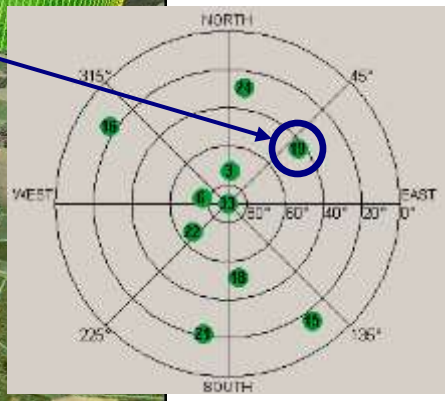
Practical Realization: Complete System

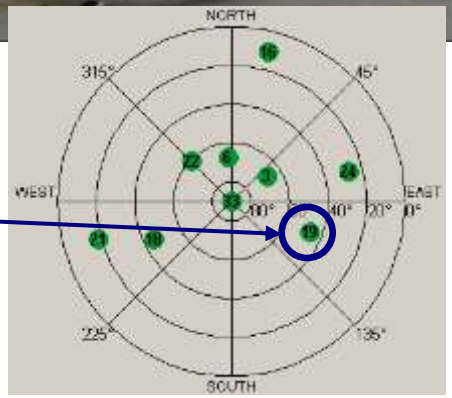


Beamforming and DOA-estimation in Flight Tests



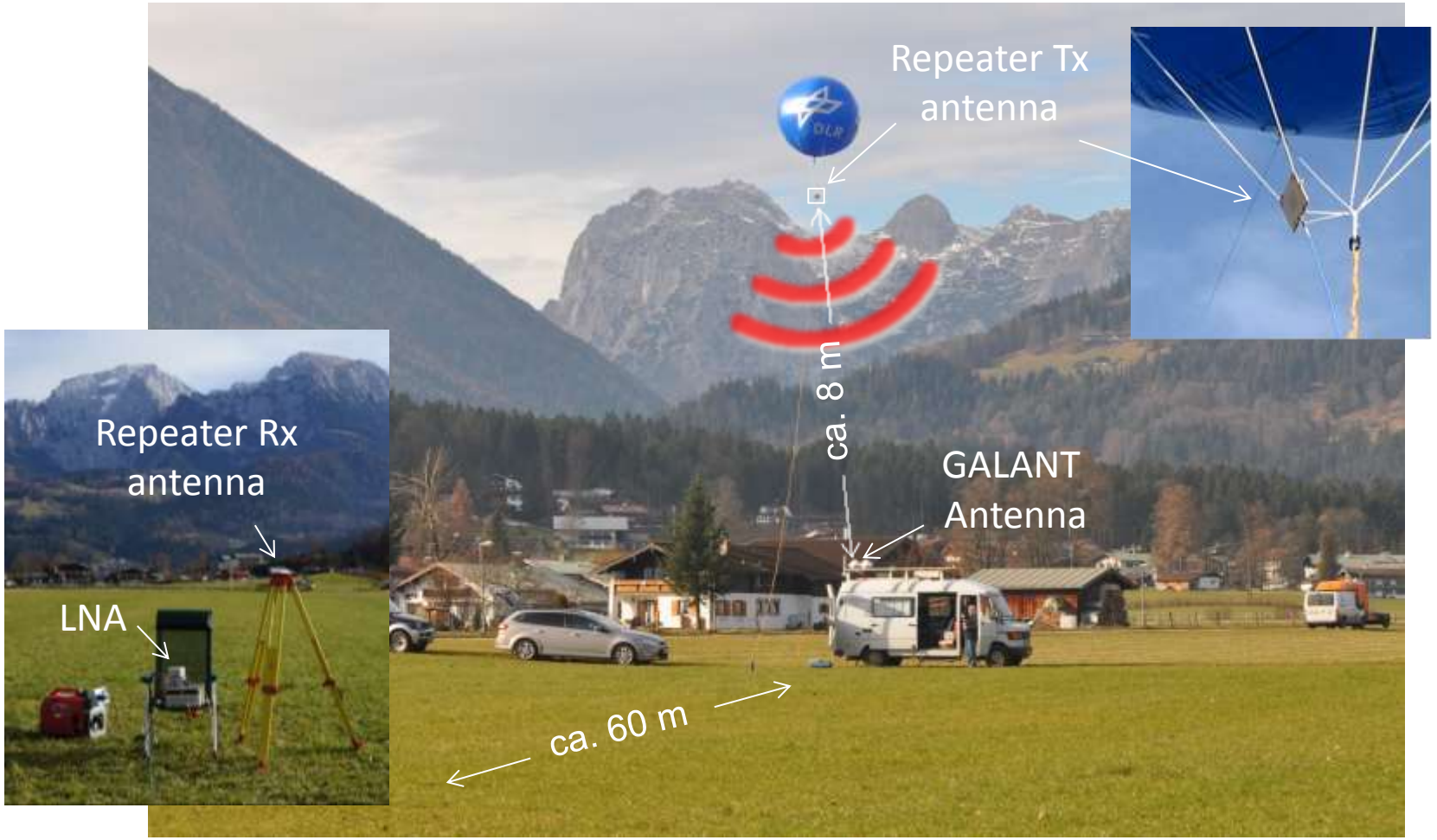




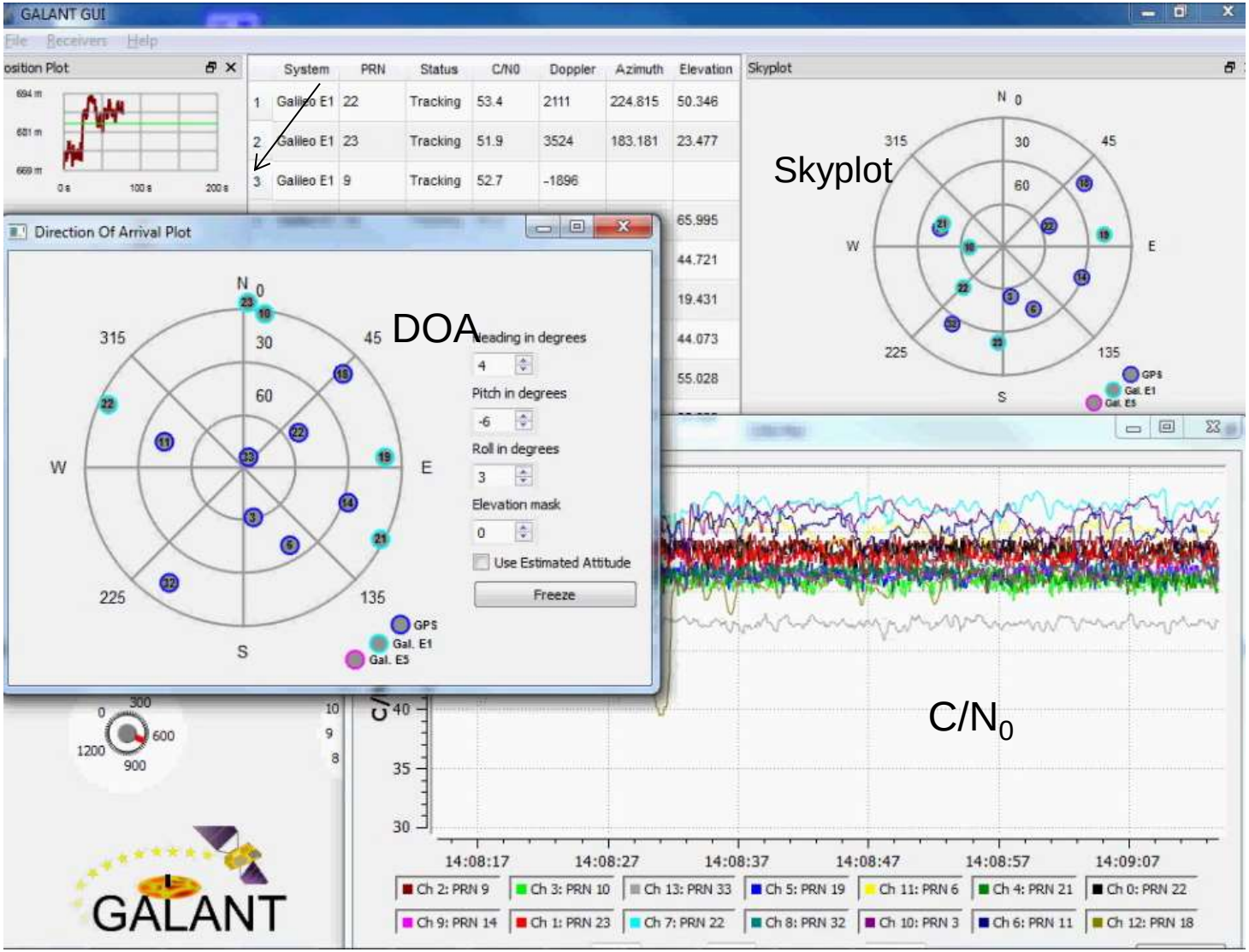


DLR

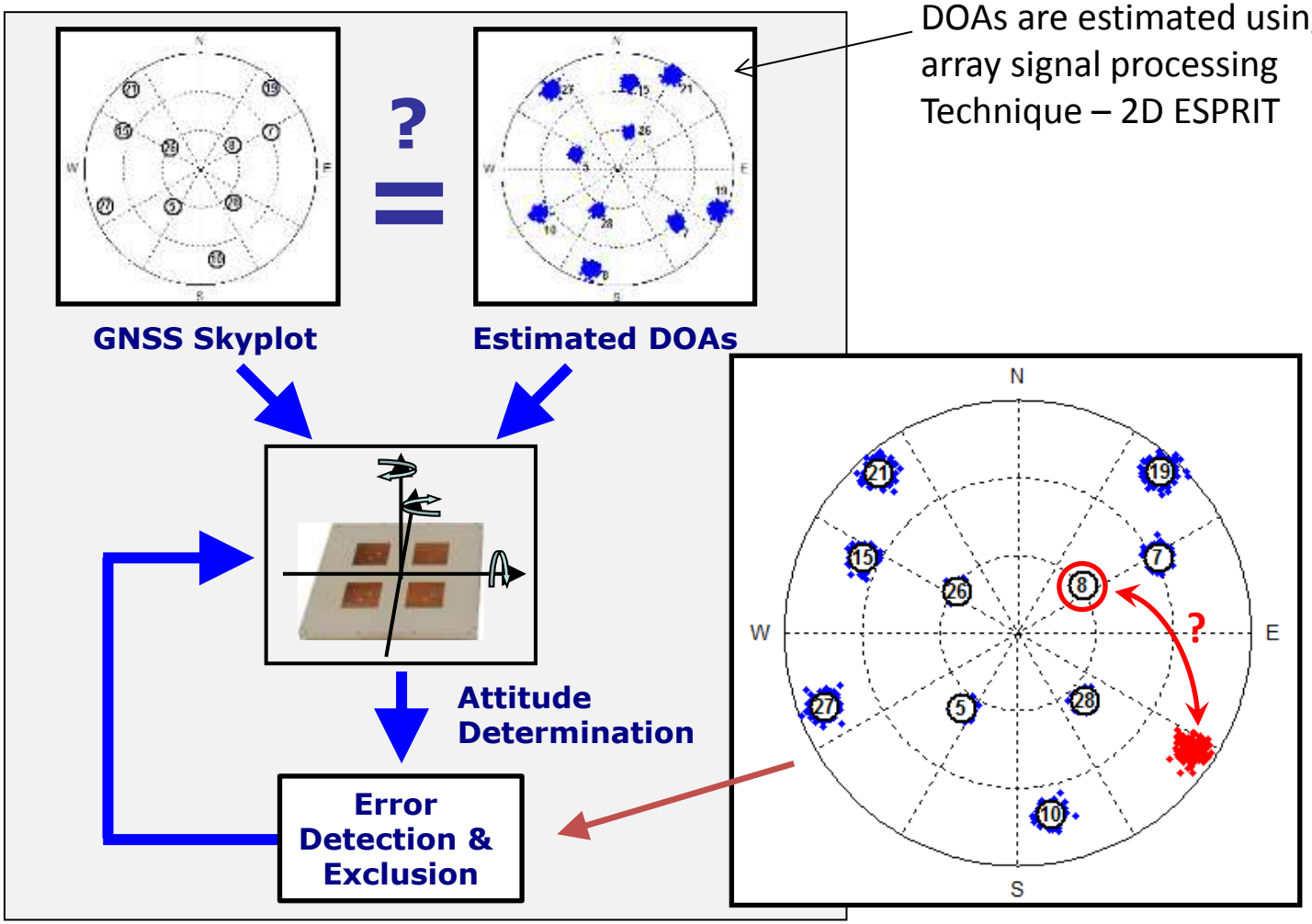
Repeater Test Set-Up



Direction of Arrival (DOA) Estimation in Repeater Scenario



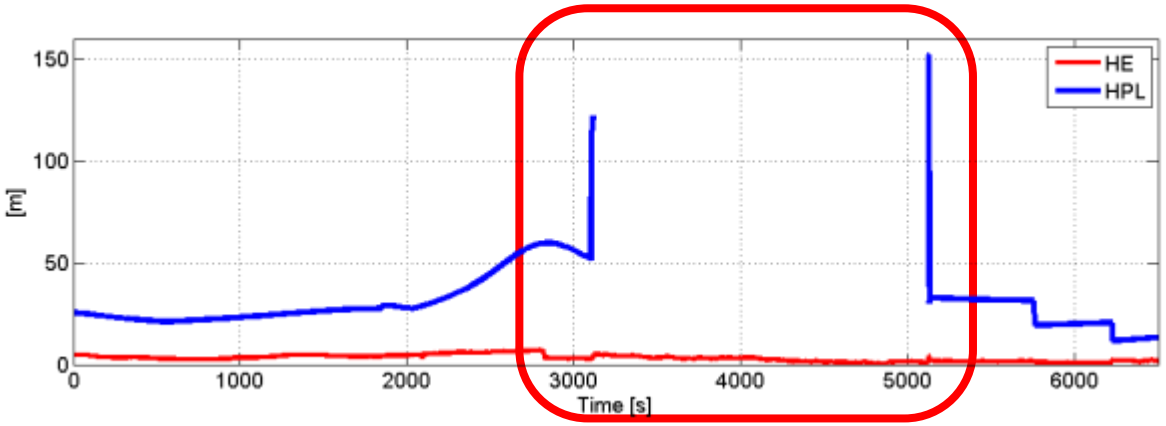
Concept of Joint Attitude Determination and Spoofing Detection Algorithm



M. Appel, A. Konovaltsev, and M. Meurer, " Robust Spoofing Detection and Mitigation based on Direction of Arrival Estimation," in Proc. ION GNSS+ 2015, Tampa, FL, USA, 2015.

Loss of satellites due to maneuvers: Inertial Coasting

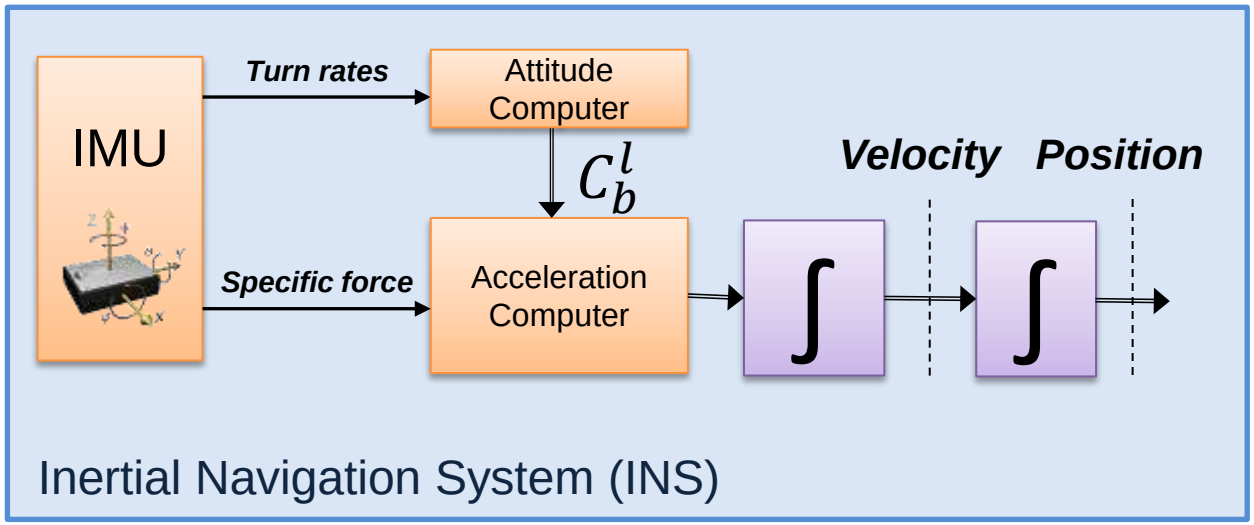
- Loss of satellites due to maneuvers
- Time gap due to restart of smoothing filters

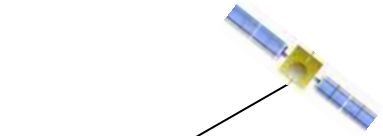


Continuity and availability requirements might not be fulfilled

DLR

Multisensor Fusion





GNSS

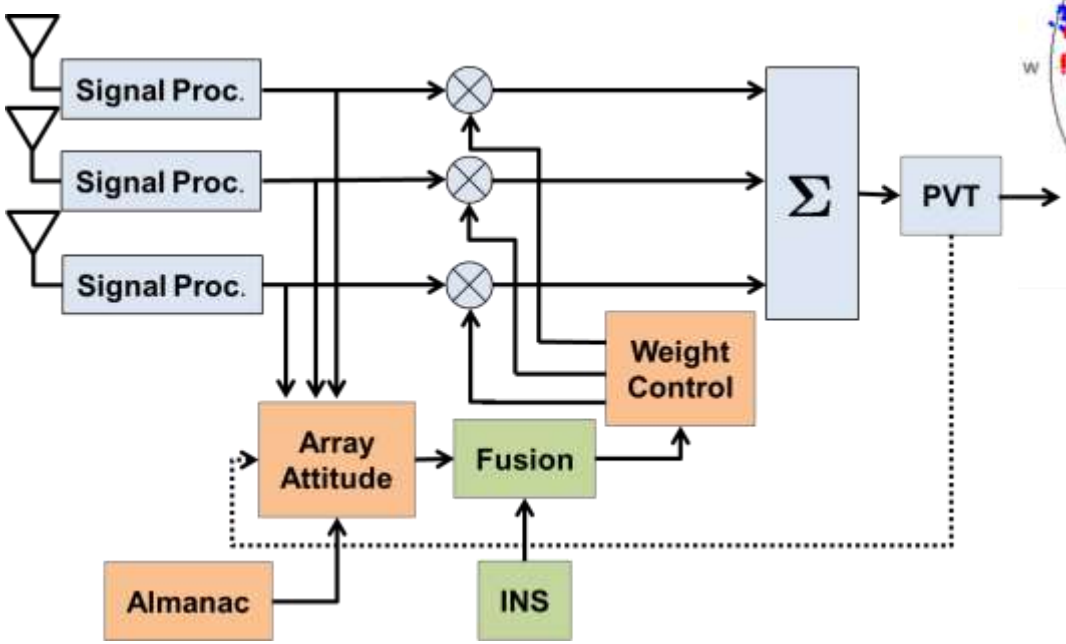
Compass

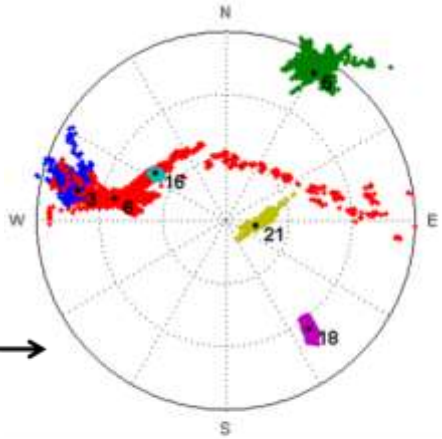
Barometer

Terrestrial

DLR

Highlight: Inertial aided array antenna attitude





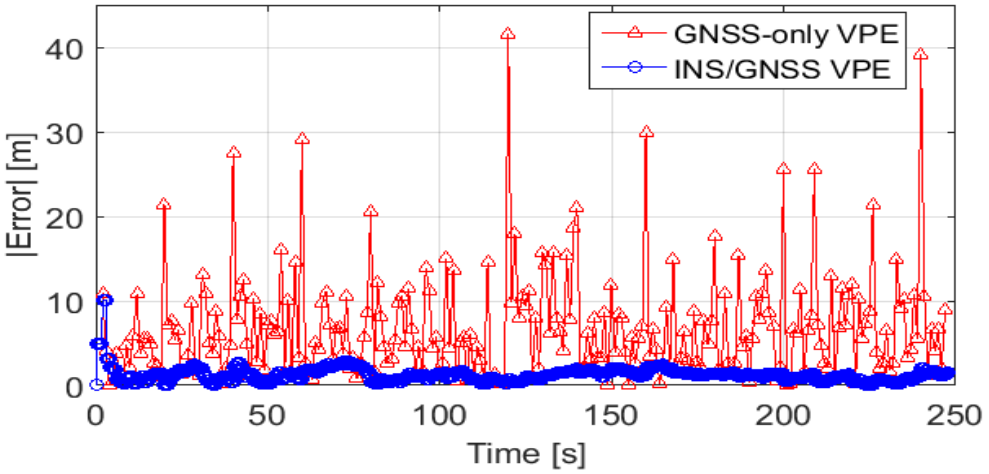
Stand-alone ML DoA estimation

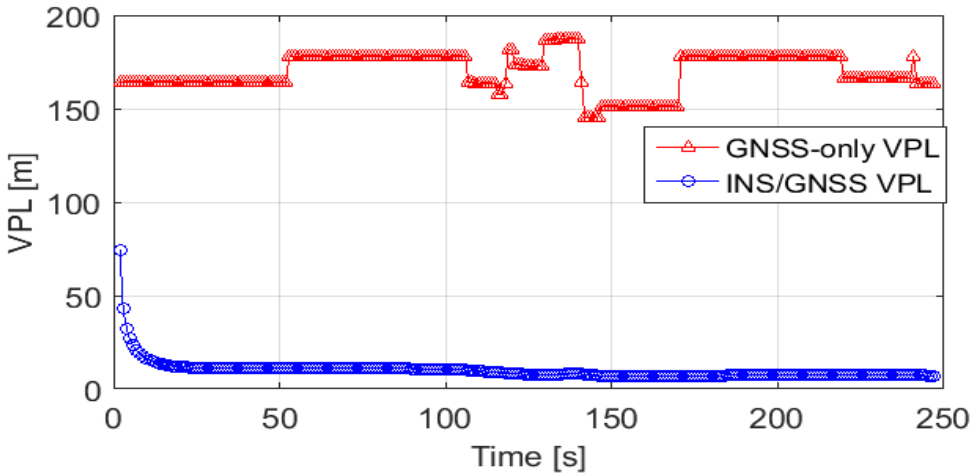
DoA estimation with inertial aided array attitude

- Improving the signal-to-noise ration (CN_0 improvements of 10 dB possible)
- Reliable tracking the Line of Sight (LoS) satellite signal

Multisensor Fusion

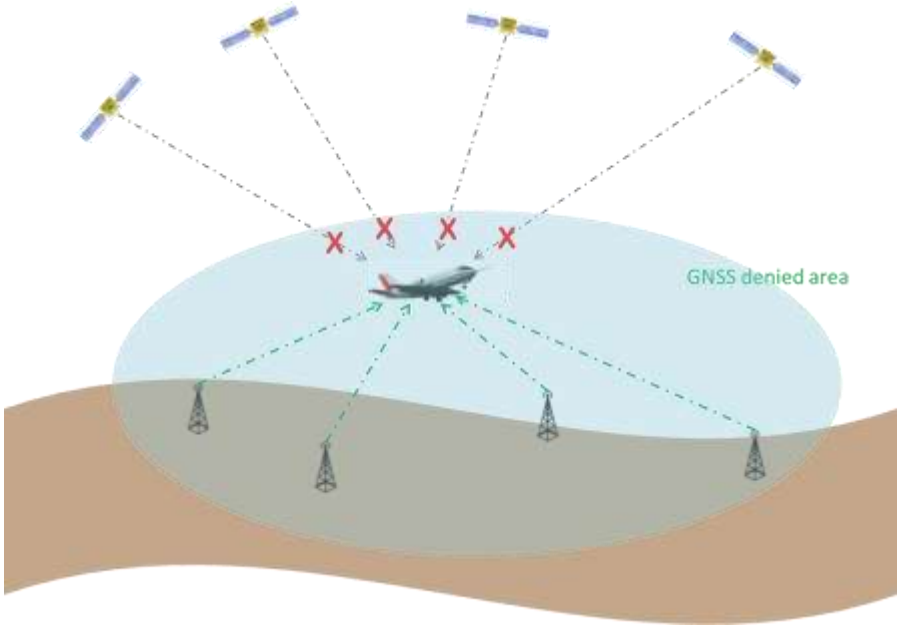
- Accuracy improvement
- Low sensitivity to faults/biases
- Local and global fault detectability improvement
- Availability improvement thanks to the reduction of Protection Levels

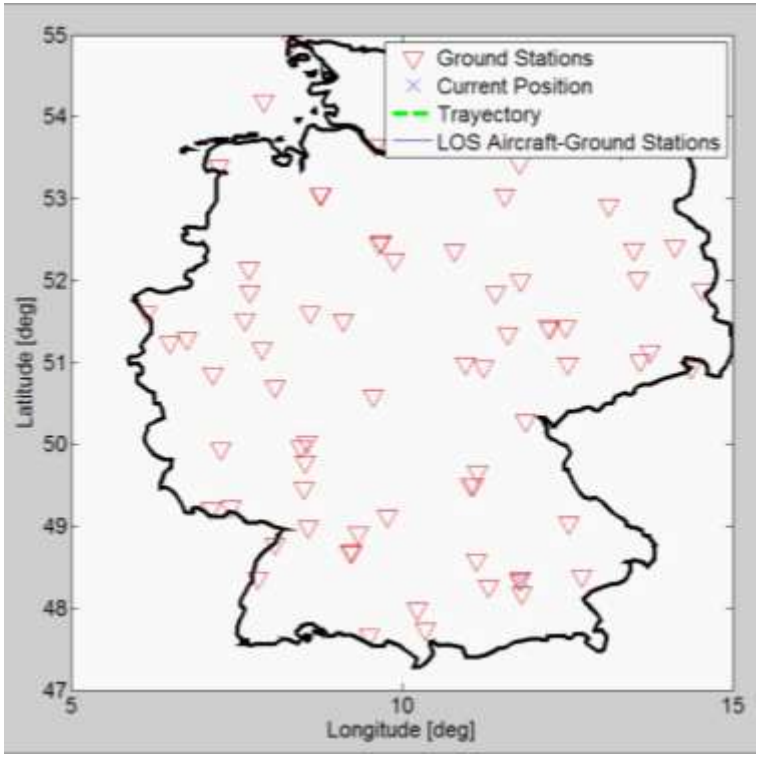




Alternative Position Navigation and Timing (APNT)

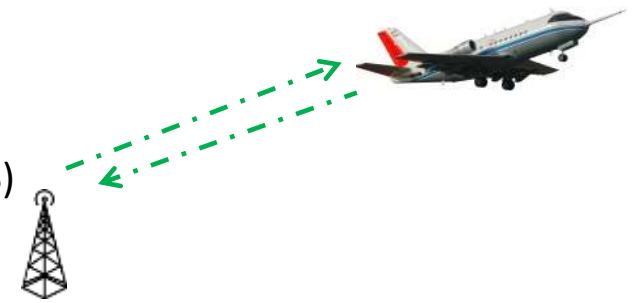
- It is meant to be a GNSS backup System





Signals under consideration:

- Distance Measurement Equipment (DME), eDME
- L-band Digital Aeronautical Communications System (LDACS)
- Universal Access Transceiver (UAT)
- Mode S transponder/1090 Mhz (ADS-B)



DLR Oberpfaffenhofen

Employees: 1.590

Area: 245.000 m²

Research institutes and facilities:

- Microwaves and Radar Institute
- **Institute of Communications and Navigation**
- Institute of Atmospheric Physics
- Remote Sensing Technology Institute
- Institute of Robotics and Mechatronics
- German Remote Sensing Data Centre
- Space Operations and Astronaut Training
- Galileo Control Centre
- Flight Experiments

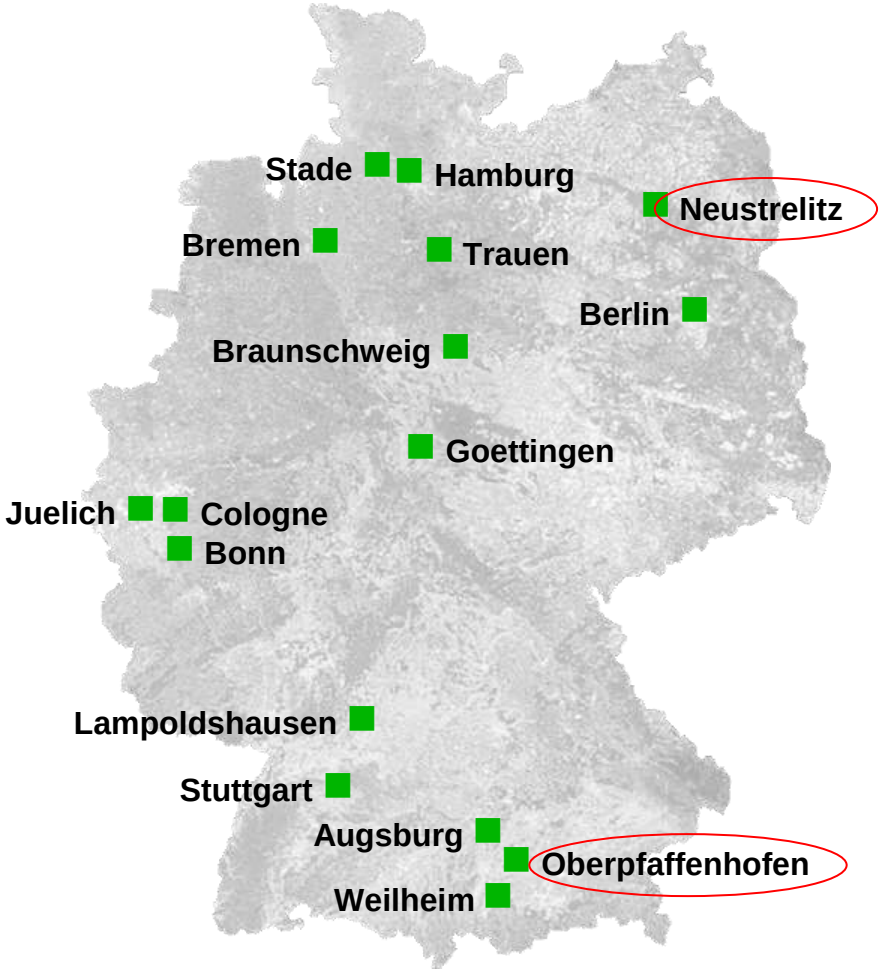
Institute of Communication and Navigation

Employees

- ~ 140 employees
- ~ 115 scientists/PhD candidates

Facilities

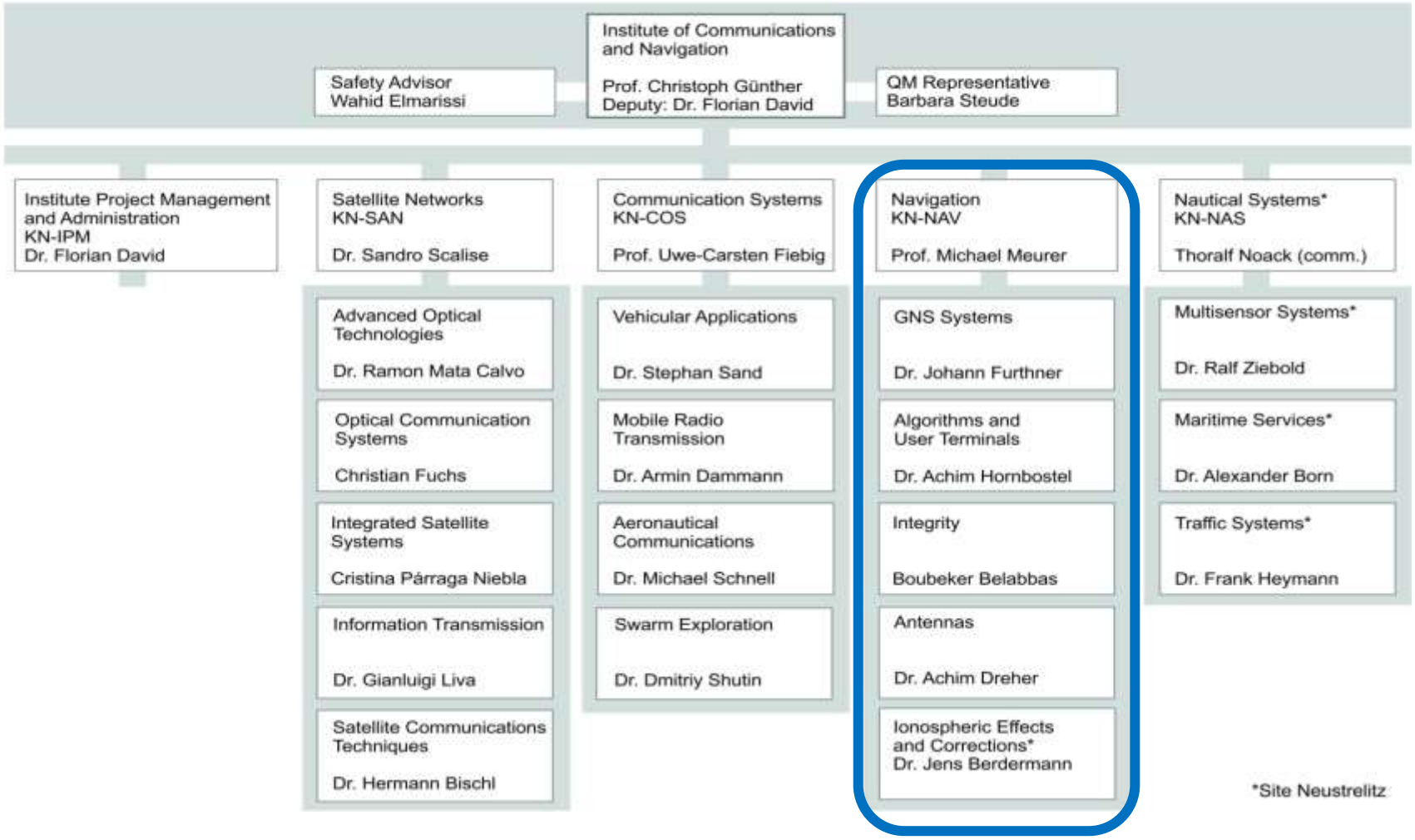
- Neustrelitz
- Oberpfaffenhofen



Organization Chart

Institute of Communications and Navigation

Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft



OHB-KN-Organigramm, Stand: 01.10.2014

Satellite Navigation

DLR