GAMMA-A

Galileo Receiver for Mass Market Applications in the Automotive Area

Project Outcomes

31.08.2011

Outline

- **Project Overview**
- **Motivation**
- **Applications and Requirements**
- **System Overview**
- **Core Technologies (excerpt)**
  - Acquisition and tracking
  - Assisted and differential GNSS
  - Signal authentication
  - Multipath mitigation
  - Real-time kinematic technology
- **Receiver Development**
- **Conclusion and Outlook**

Objectives of the Project

- Contributes to the future market introduction of Galileo services and products in automotive applications
- Designed, developed, and tested a new 3-frequency Galileo/EGNOS/GPS satellite navigation receiver prototype
- Analysed potential solutions featuring future automotive applications
- Addressed new challenging applications in secondary domains e.g. rail, maritime, emergency services, and demanding location based services (LBS)

GAMMA-A Project Team

Fraunhofer IIS • Project Coordination • Receiver Hardware Development • Receiver Integration		TeleConsult AUSTRIA • Development of PVT software • Development of fusion and mitigation algorithms • Dissemination, webpage	OECON • Definition of Application Scenarios & User Requirements • Communication Link
TPI GmbH / S.r.l. • Dissemination • Quality Management	inPosition • Research on RTK solution for automotive environment	EPFL •Tracking Algorithms Analysis for CBOC/TMBOC/AltBOC Signals	IMST • Development of Highly Integrated RF Front End ASIC
Alma Mater Studiorum Università di Bologna A.D. 1088 • Development of Fast and Sensitive Acquisition Algorithms	The 4 2 5 Company Ltd • Market and Business Study	BOSCH • Antenna Design • Development of Antenna Prototype	ThalesAlenia Space (A Thales / Finmeccanica Company) • Assisted and Differential GNSS • Communication & Broadcasting Strategies • Analysing Position Authentication • Counter Signal Spoofing Technique

Work Breakdown Structure

GAMMA-A
(L1/L5/E5 GPS/EGNOS/GALILEO Receiver)

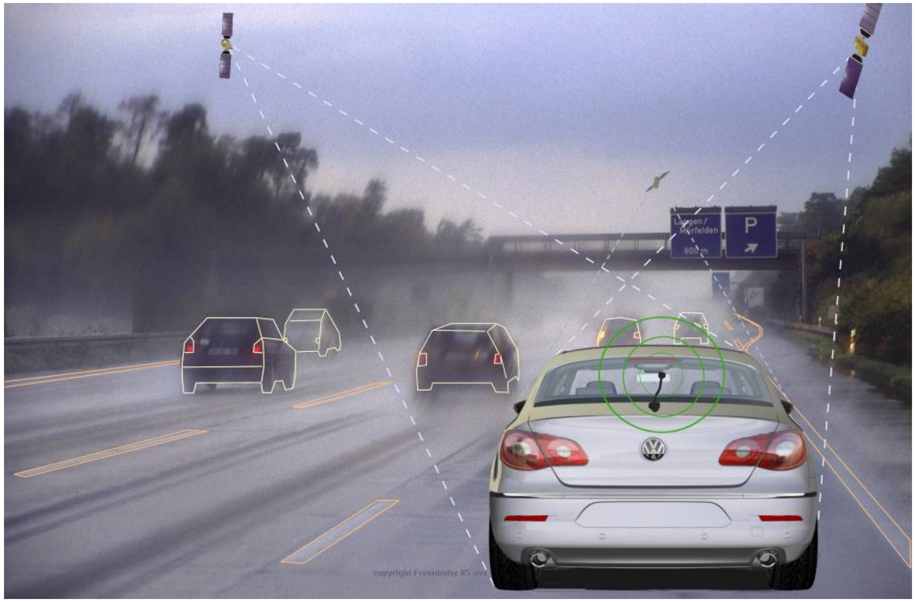
- **WPG 1000** Project Management – FhG-IIS
  - **WPG 1100** Project Management – FhG-IIS
  - **WPG 1200** Quality & IP Management – TPI
- **WPG 2000** Identification of Market Segment – OCN
  - **WP 2100** Application Scenarios – OCN
  - **WP 2200** User Requirements – OCN
  - **WP 2300** Study of relevant Mass Market Segments – 425Co
  - **WP 2400** Development of adaquate Business Models – 425Co
- **WPG 3000** Core Technology Development – IMST
  - **WP 3100** Correlation & Tracking of CBOC & TMBOC – EPFL
  - **WP 3200** Low Cost Receiver Integration – FhG-IIS
  - **WP 3300** Highly Integrated Dual Frequency Frontend – IMST
  - **WP 3400** Fast & Sensitive Acquisition and Reacquisition – UniBO
  - **WP 3500** Dual Frequency Based Ionospheric Corrections – TCA
  - **WP 3510** INS Coupling – TCA
  - **WP 3600** Fast & Robust RTK Solution – inP
  - **WP 3710** Assisted & Diff. GNSS – TAS-F
  - **WP 3720** Communication & Broadcasting Strategies – TAS-F
  - **WP 3810** Signal Authentication & Integrity (GNSS) – TAS-F
  - **WP 3820** Assessment of the position authentication – TAS-F
  - **WP 3900** Multipath & Interfer-ence Cancellation – TCA/UniBO
- **WPG 4000** Development of Receiver Prototype – FhG-IIS
  - **WP 4100** Definition of System Architecture – FhG-IIS
  - **WP 4200** Integrated Dual Frequency Antenna Design – Bosch
  - **WP 4300** ASIC Design of L1 & L5/E5a & E5b Low Noise RF-Frontends – IMST
  - **WP 4400** RF Frontend Module – IMST
  - **WP 4500** Digital Baseband Processing (Low Implementation Losses) – FhG-IIS
  - **WP 4510** Fast & Sensitive Acquisition Module – FhG-IIS
  - **WP 4520** Robust Tracking Module – FhG-IIS
  - **WP 4600** Processor Module (SoC) – FhG-IIS
  - **WP 4700** RTOS & System Software – FhG-IIS
  - **WP 4800** Robust PVT Solution (Dual Frequency, Multi-Standard) – TCA
- **WPG 5000** Integration and Validation of GNSS Prototype Receiver – FhG-IIS
  - **WP 5100** Receiver Integration Planning – FhG-IIS
  - **WP 5200** Integration of Functional Receiver on a FPGA Platform – FhG-IIS
  - **WP 5300** Specification of Verification and Test – OCN
  - **WP 5400** Receiver Integration & Test – FhG-IIS
- **WPG 6000** System Integration & Test – OCN
  - **WP 6100** Test & Validation Planning – VW/OCN
  - **WP 6200** Terminal Integration – FhG-IIS
  - **WP 6300** Appl. Development – OCN
  - **WP 6400** Integration in Car Platform – OCN
  - **WP 6500** Test & Validation Campaign – OCN
  - **WP 6600** Assisted & Diff. Data Server – TAS-F
  - **WP 6700** Dissimination – TPI

Motivation

- **Automotive industry demands:**
  - High accuracy, reliability, integrity and continuity
  - Low cost
- **Only high priced receivers available**
  - Costs as much as a middle class car
- **But automotive market is mass market**
  - Chance to start ASIC-development

Applications

- Automatic driving
- Lane departure warning
- Automatic lane keeping
- Green driving
- Service- / E-Call
- Ghost driver emergency stop
- Along track guidance

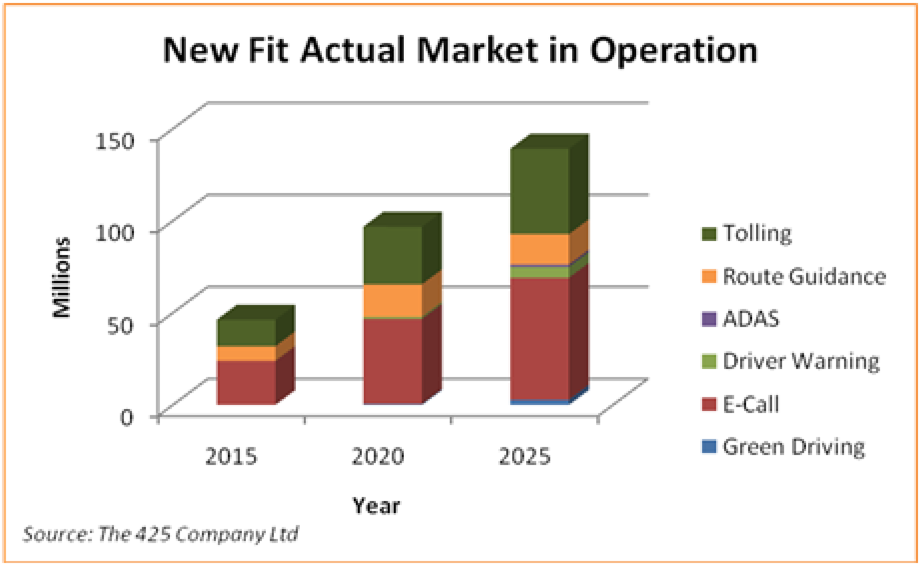


Requirements

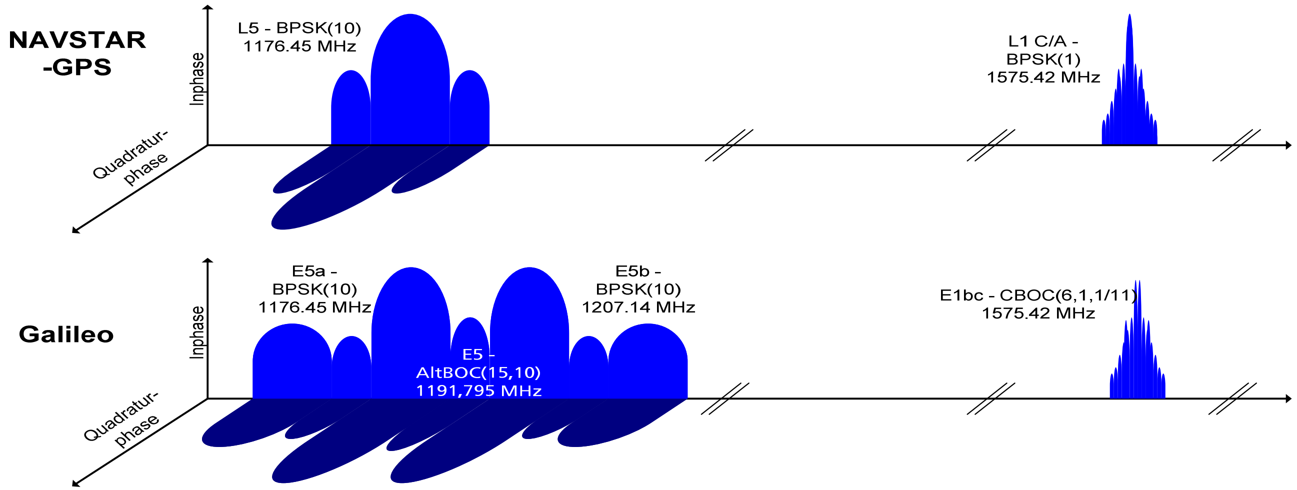
	E-Call	Ghost driver Emergency stop	Automatic driving	Green driving
Accuracy	20 m	1 m	0,2 m	2 m
Authentication		X	X	
Integrity		X	X	X
Continuity	$3 \cdot 10^{-5}$	$5 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	$3 \cdot 10^{-5}$
Update rate	1 Hz	1 Hz	10 Hz	1 Hz
Acquisition Cold	15 s	15 s	10 s	10 s
Hot	5 s	1 s	5 s	5 s

Business Models and Market Segments

- **Study of relevant mass market segments**
  - Prediction of market
  - Business drivers
- **Development of adequate business models**
  - Estimate costs and prices
  - Business viability
    - All applications viable
    - Total business very large
    - Significant competition in some applications
    - Transfer of technology planned
  - Sensitivity analysis

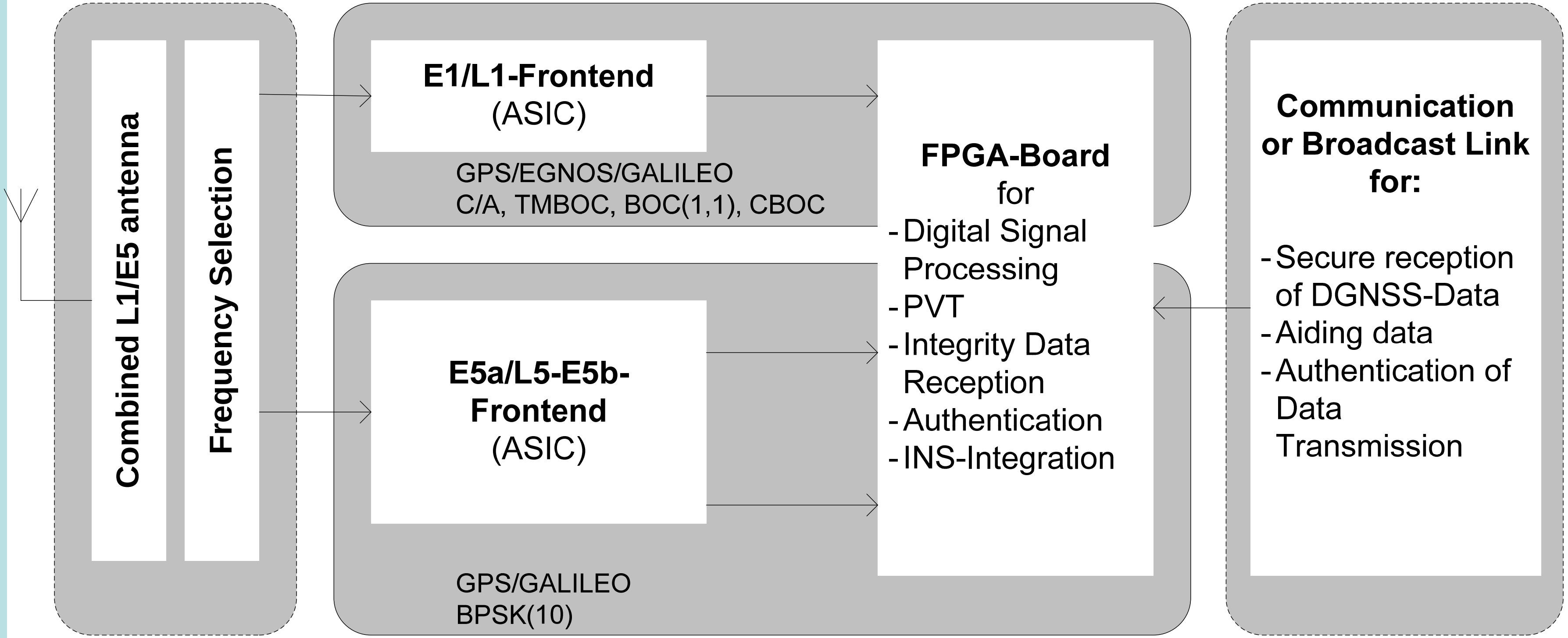


System Overview: Signals



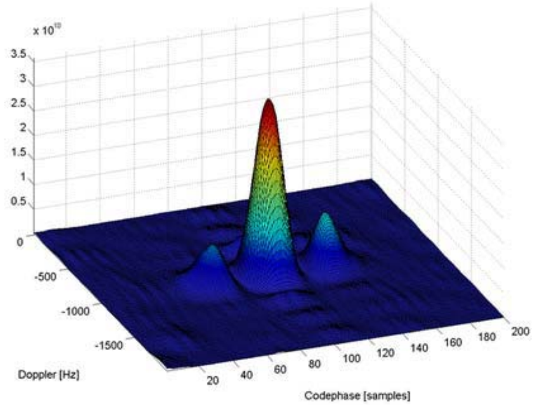
GNSS Signal	Carrier Frequency [MHz]	Modulation	Required Bandwidth [MHz]
GPS L1 C/A	**1575.42**	**BPSK(1)**	**2**
EGNOS	**1575.42**	**BPSK(1)**	**2**
Galileo E1 bc	**1575.42**	**CBOC(6,1,1/11)**	**14**
Galileo E5a	**1176.45**	**BPSK(10)**	**24**
GPS L5	**1176.45**	**BPSK(10)**	**24**
Galileo E5b	**1207.14**	**BPSK(10)**	**24**

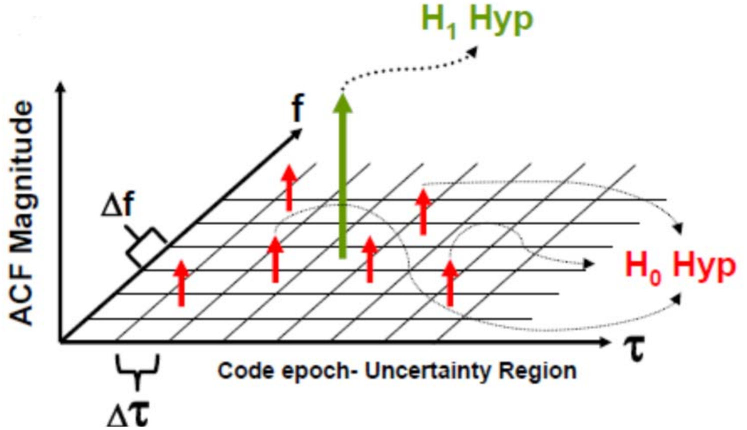
System Overview: Schematic



Acquisition

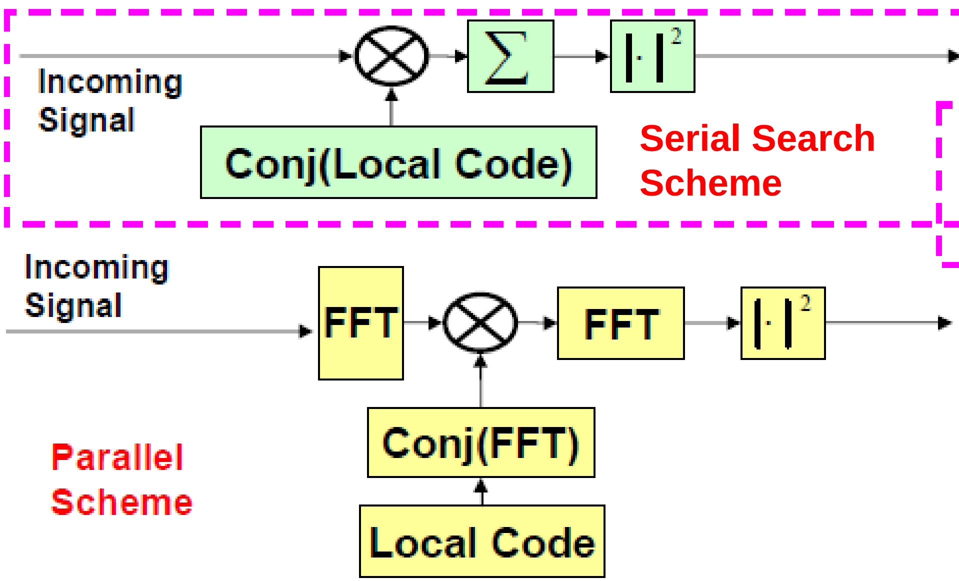
- **Code Acquisition** is notoriously the basic operation in all GNSS applications
- Directly **impacts** on the **Time To Fix** and on the system **QoS**
- Goal**:** Identify the **Code Epoch** (τ) and the **Frequency Offsets** (fe) of a specific satellite signal
- **Uncertainty Region (**UR**)** is discretized into **Time Slots** Δτ **,** and the frequency domain is discretized into **Frequency Bins** Δf**:**
  - Two-dimensional matrix must be scanned to find Correct Hypothesis (H1)
  - A large number of Incorrect Hypotheses (H0)





Acquisition

- **Two different search strategies can be defined:**
  - **Serial search** (i.e. schemes based on one or more correlators)
    - Consecutive time/frequency tests
  - **Parallel acquisition** strategies (i.e. FFT/IFFT schemes)
    - Simultaneously tests all the possible code phases (frequency tests are required)



Selection of the correct hypothesis through different **Decision Criteria**

Threshold Crossing (TC)
- Compares each decision variable in turn with an optimized threshold

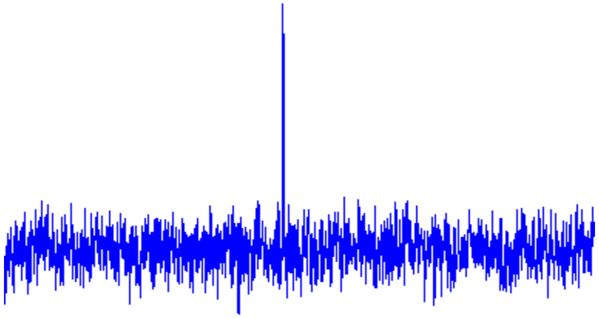
MAX
- Decides in favor of the cell with the largest correlation value
- Requires to scan the entire UR

MAX/TC
- Hybrid solution

Acquisition Hardware: FFT-based

Coarse Search:

FFT → High sensitivity algorithm →



Fine Search GPS:

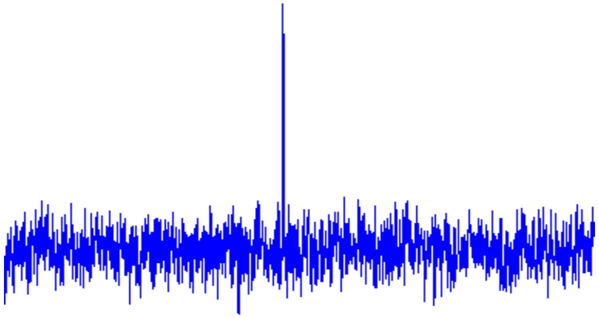
GPS/GALILEO Time correlator → High sensitivity algorithm →

SEVENTH FRAMEWORK PROGRAMME

Acquisition Hardware: FFT-based

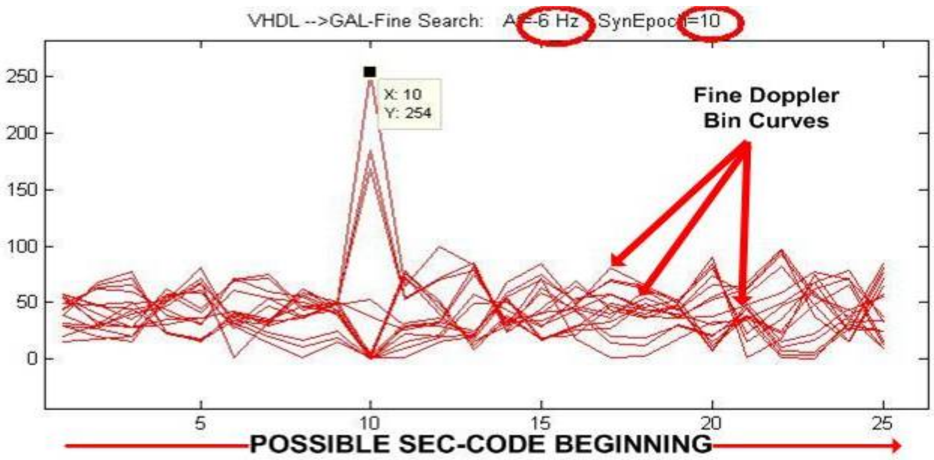
Coarse Search:

FFT → High sensitivity algorithm →



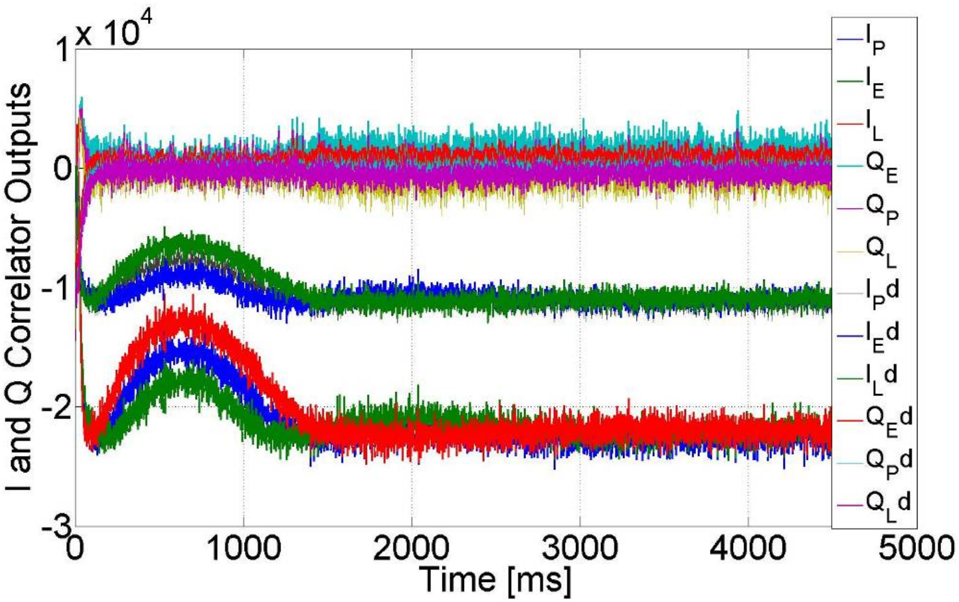
Fine Search Galileo:

GPS/GALILEO Time correlator → High sensitivity algorithm →



Tracking

- **Secondary codes on E5a/E1 CBOC overview**
- **Secondary code acquisition strategies**
- **Secondary code wipe-off influence on tracking**
- **Collaborative data/pilot code tracking:**
  - Non-coherent channel combining
  - Coherent channel combining
- **For E5a tracking**
- **For E1 CBOC**



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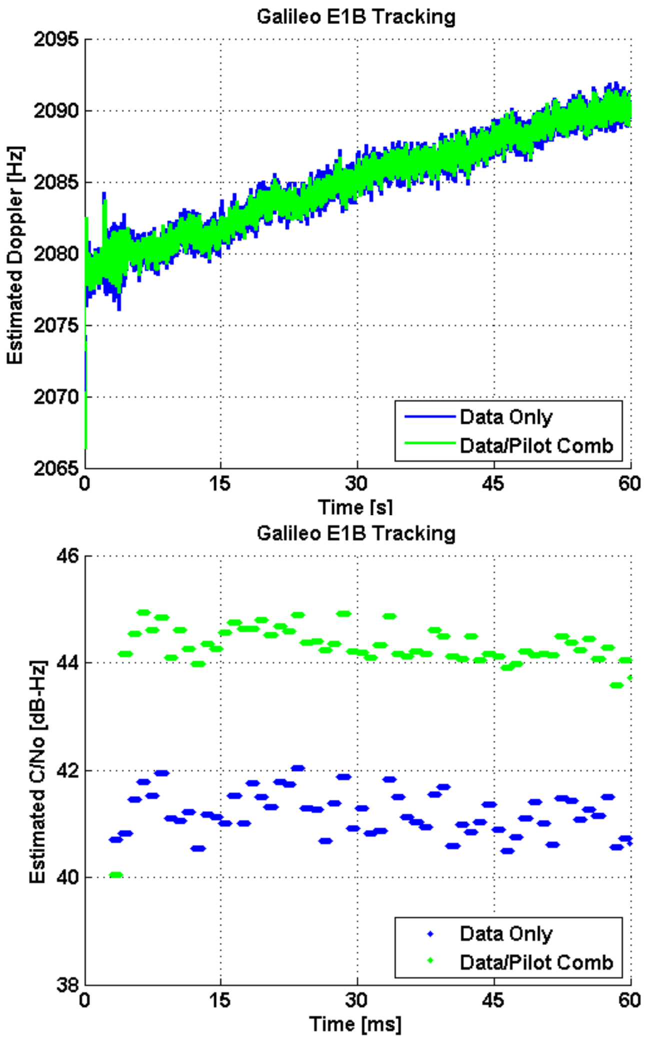
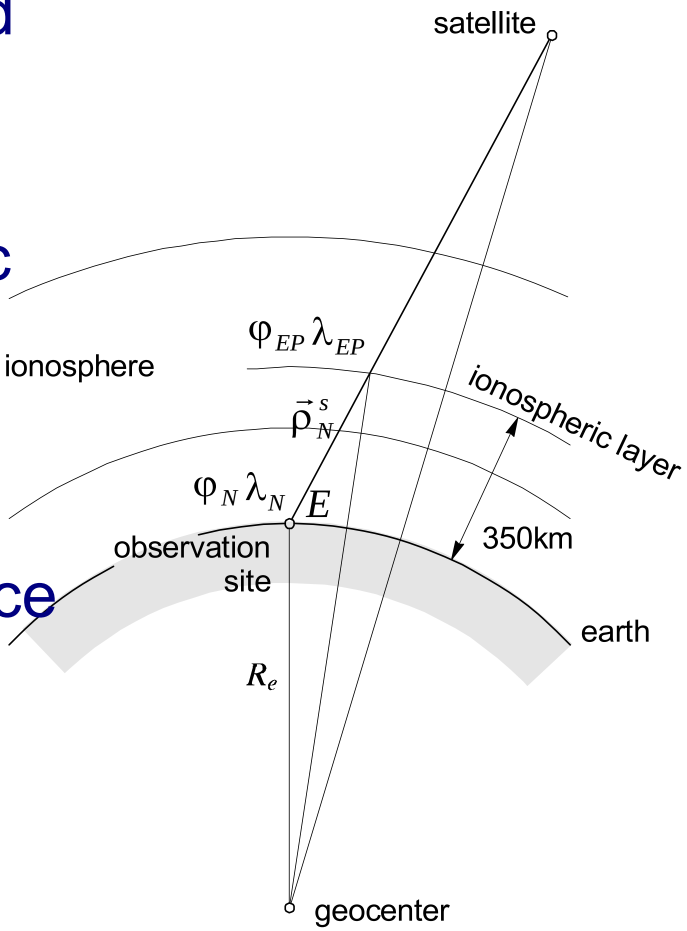
Tracking

- **Test results E1B**
  - Data channel only
  - Data/Pilot combining:
    - pilot-only carrier tracking
    - non-coherent code combining
- **Advantages**
  - Estimated Doppler and C/N0 are less noisy
  - Received power 3 dB higher



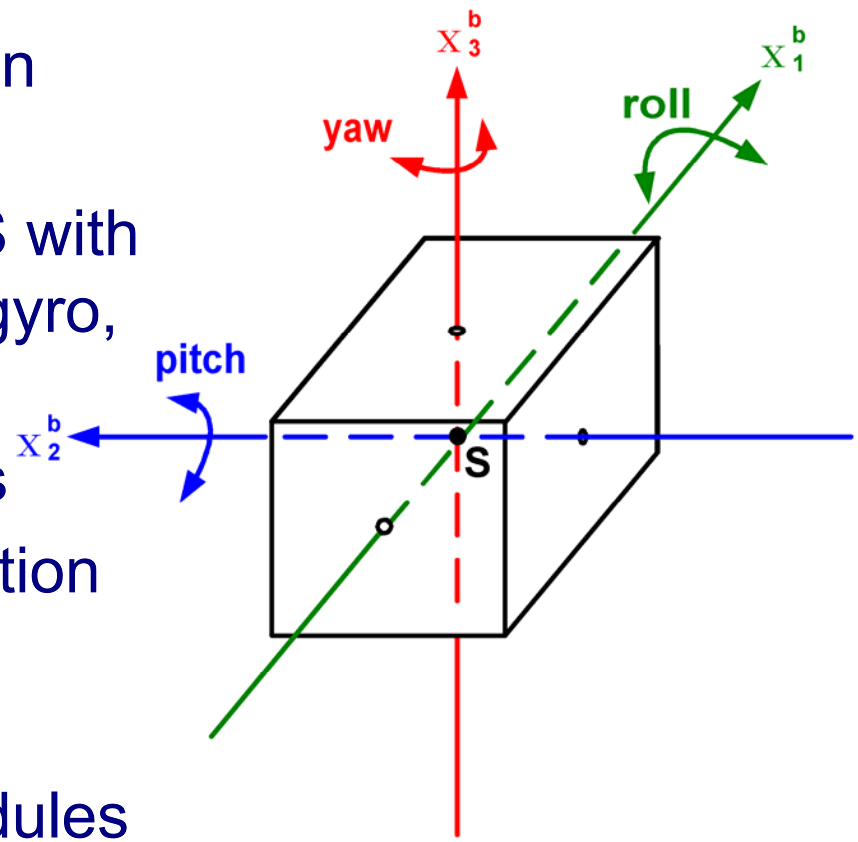
Dual Freq. Ionospheric Corrections

- Analysis of ionospheric models and algorithms
- Dual frequency approach for estimation/mitigation of ionospheric effects
- Comparison of methods and elaboration of weighting strategies
- **Advantages:** Improved performance
- **Outcome:**
  Reliable algorithms and software modules for ionospheric mitigation



INS Coupling

- Elaboration of mathematical fundamentals of sensor fusion (low- cost)
- Simulation of coupling GNSS with various sensors (odometer, gyro, accel.)
- Analysis of integrity concepts
- **Advantages**: Increased position availability with high integrity
- **Outcome**:
  Algorithms and software modules for implementation



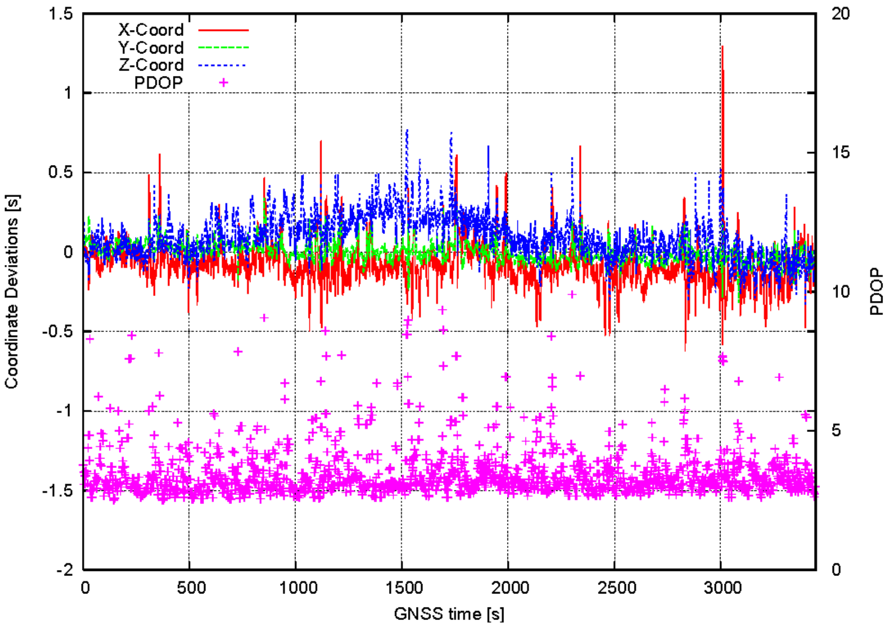
RTK for Automotive Applications

Challenges

- **Rapidly changing distances to „reference stations“**
- **Irregular availability of raw observations**
  - Due to direct car environment (obstructions, reflections)
  - Due to data link drop-outs (reference information)
- **Positioning with less than 5 satellites may be required**
- **Target initialisation time: 10 seconds**
- **Target position accuracy: ~0,10 m**
- **Standard professional RTK approaches are failing**
  – Different satellite visibility for different vehicle
  – Frequent interruptions of signals

RTK for Automotive Applications

- **RTK-type concept developed**
  - Very short RTK initialisation times within 10 seconds with rapidly changing scenarios achieved
  - A demonstrator has been developed



- **Automotive RTK with dm-accuracies possible for**
  - Detection of actual lane for vehicle
  - Detection of manoeuvres between lanes in early stage

Assisted and Differential GNSS

- Specification of GNSS Assistance (live and simulated) with SUPL client integrated on receiver

- Analysis of future SUPL 3.0, LPP include RTK and PPP
  - high accuracy assistance

Communication & Broadcasting Strategies

- Private Radio Networks (TETRA)
  - critical review of location standards LIP, and use of SDS signaling
- DSRC for Car2Car and Car2Infrastructure recommendations
- Anti-collision use case analysis with DPOS or NRTK

Signal Authentication

- Threats analysis to service SoL or liability-critical
  - Non-cooperative user a high threat to pay per use and regulatory infrastructure
- Proposals for Galileo Signal Authentication
  - Interleaved with unknown PRN or Watermark

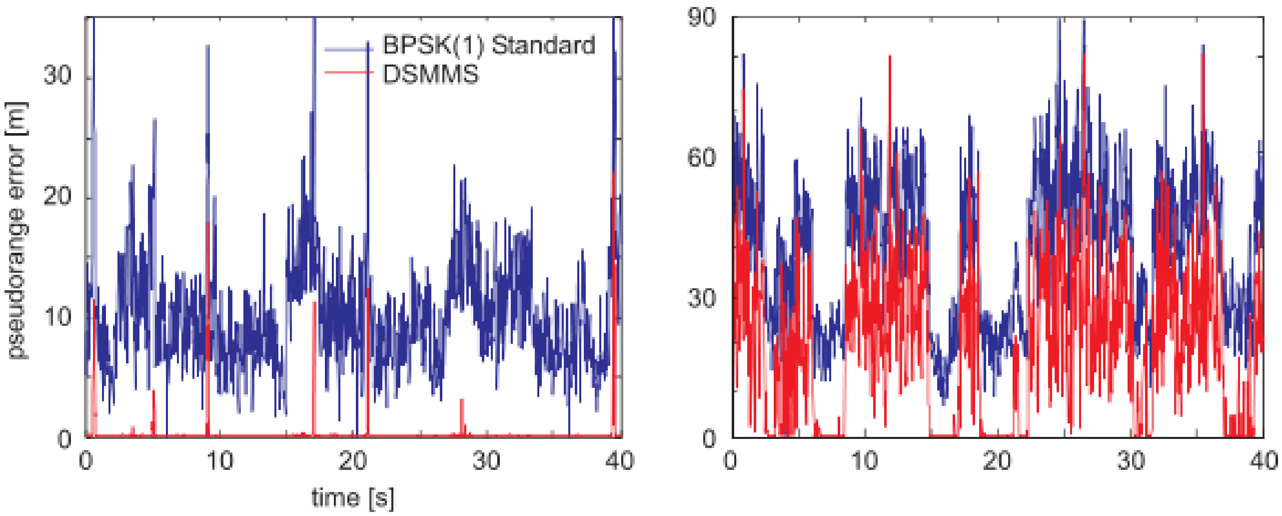
Simulation on Fraud & Signal Authentication

- Study of critical services requirement
- State of the art: spoofing attacks and detection methods
- Assessment of selected methods
  - 5 driving records GPS+MEMS
  - Simulation of 17 indicators on 5*5 cross-checks

Multipath Mitigation

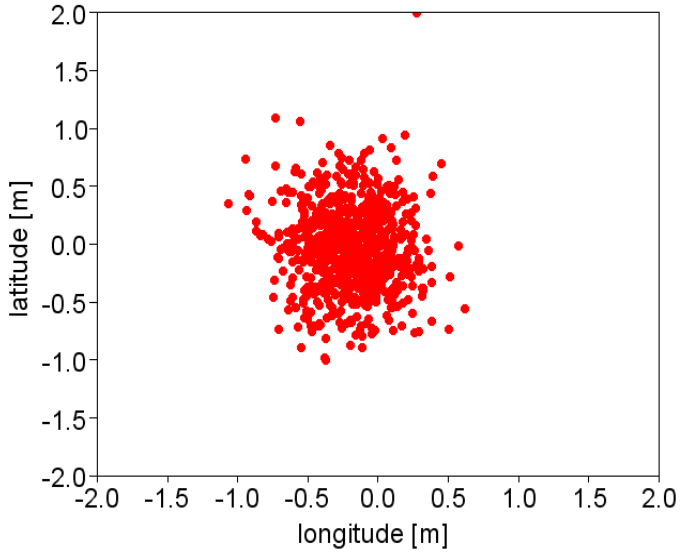
Dual-signal multipath mitigated solution (DSMMS)

- Assumption: same propagation path for different frequencies
- Difference between ranges to same satellite is multipath error



Position Velocity Time (PVT)

- Development of a robust dual frequency PVT solution tailored to the requirements of automotive applications
- Process combined Galileo/GPS/EGNOS L1/L5/E5 signals



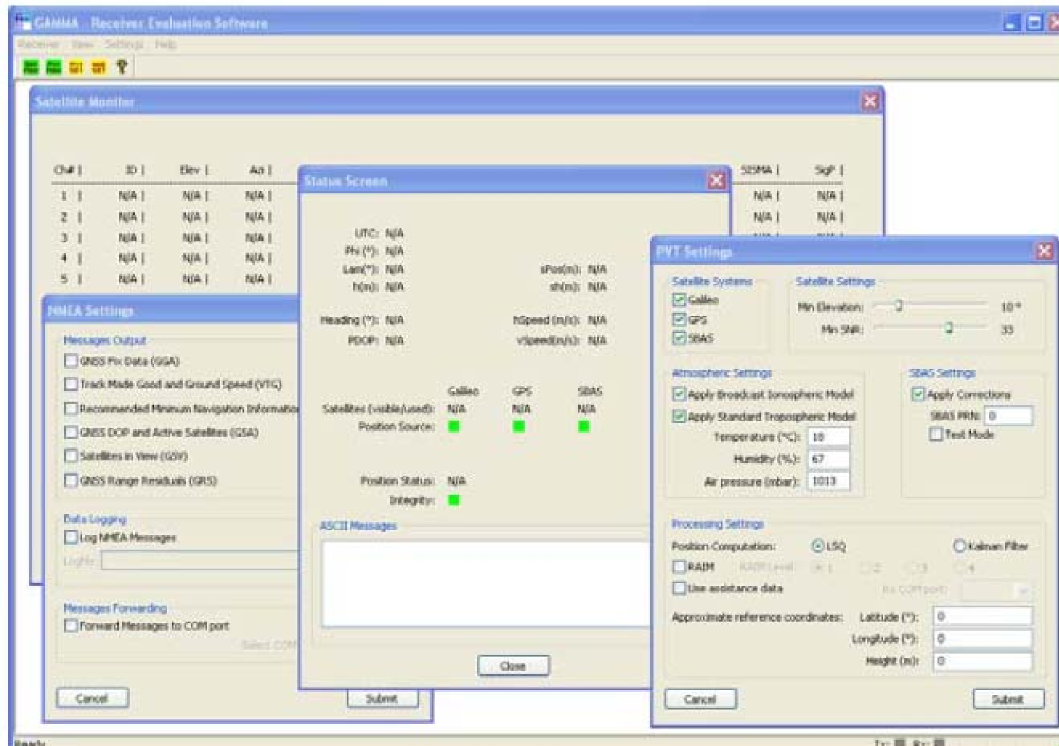
- Implementation dual-frequency based ionospheric corrections
- Mitigate multipath and interference
- Fuse automotive sensor measurements with GNSS-based results

GNSS Signal Generator

- **Software based constellation and signal simulator**

Used for:

- Core technology studies
- Test and validation



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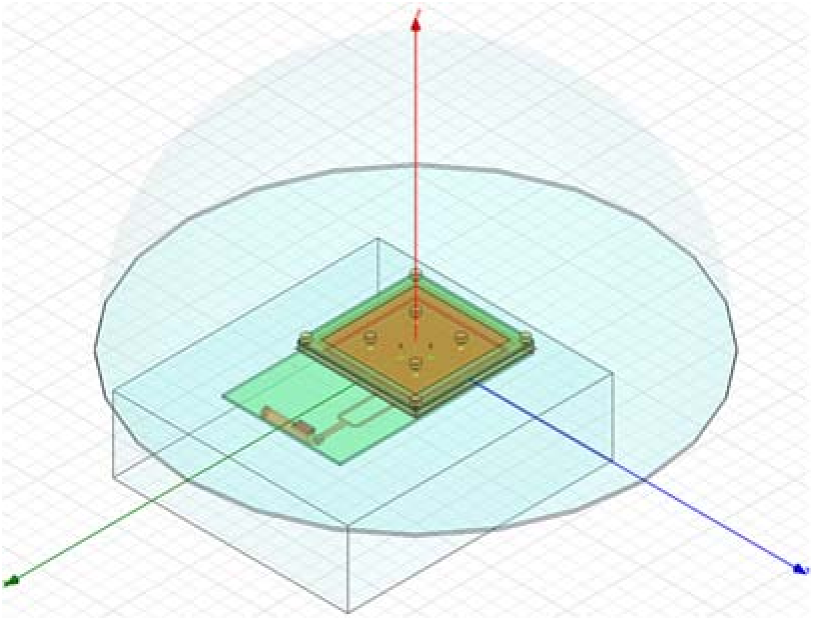
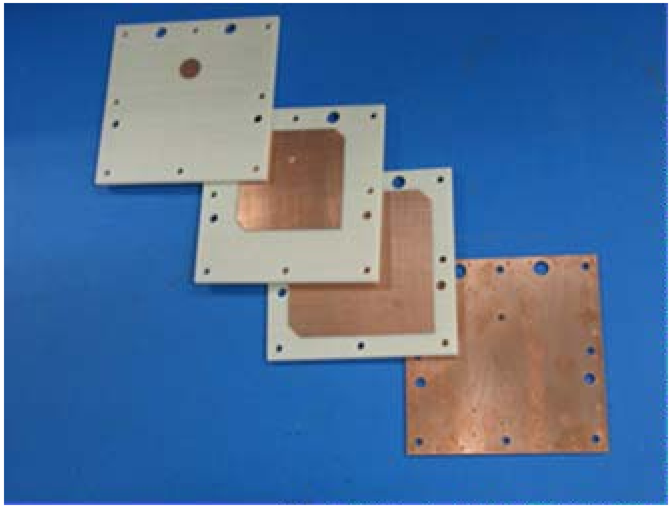
Antenna

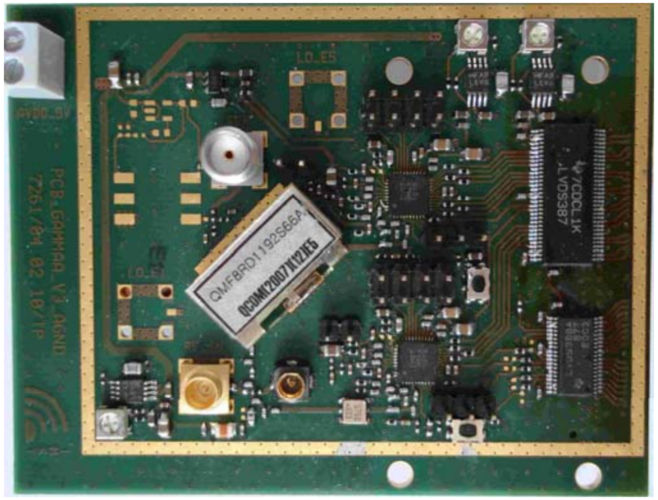
- Stacked patch structure
- E1/E5a/b combined output
- Simulation with HFSS
- Prototype development



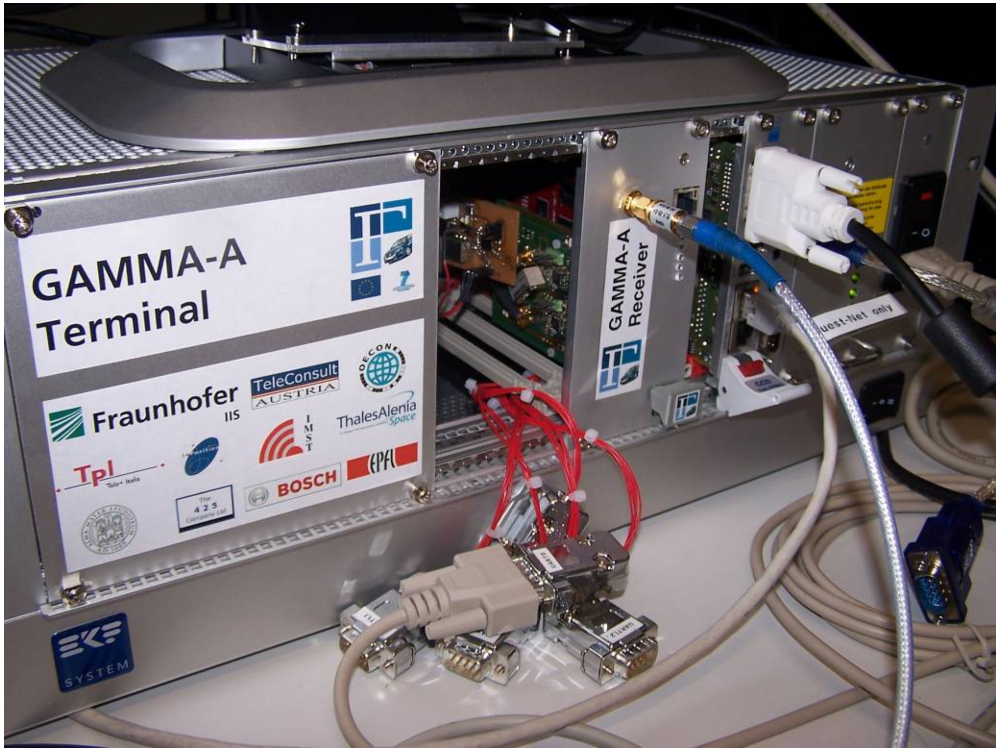


RF Frontend Module

- **Highly Integrated Dual Frequency Frontend**
  - Development of a concept for a highly integrated three frequency band (E1/E5a/E5b) low power frontend:
    - Development of specification for the frontend
    - Development of block level specification for the frontend IC
- **ASIC Design of L1&L5 E5a & E5b RF frontends**
  - Development of frontend IC
    - Simulation, layout and checks of integrated circuit blocks and IC
- **Design of frontend module**
- **Test and validation of frontend IC and frontend module**



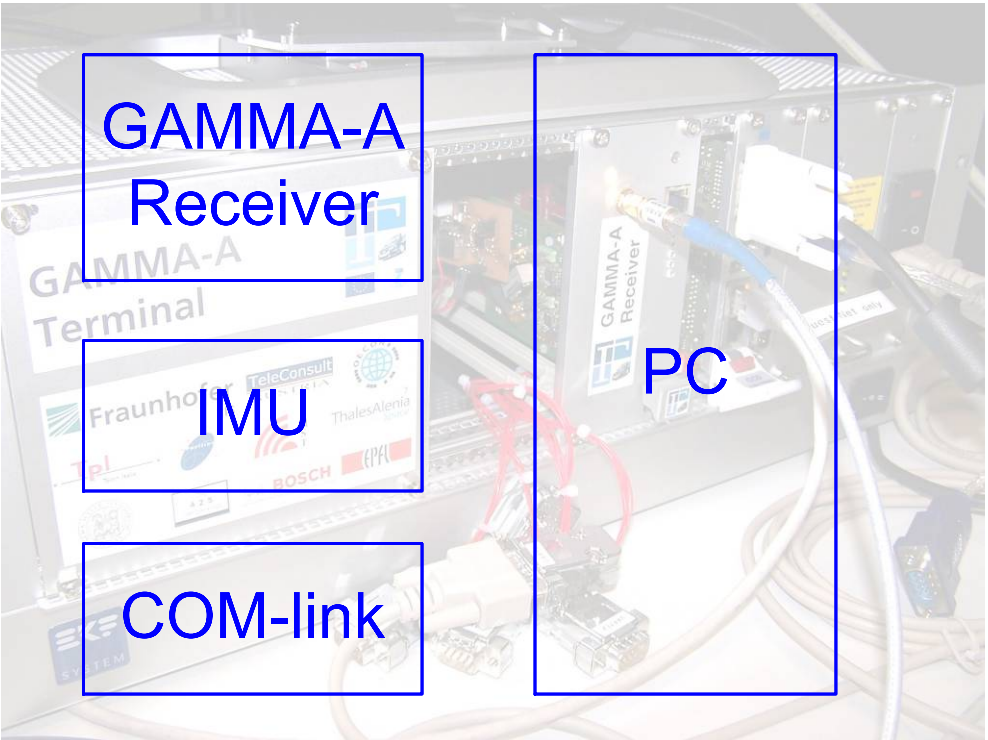
Prototype Receiver



Envisaged performance:

- 0.1 m RTK
- 1 m (95%) stand alone
- 2 GNSS+SBAS
- 3 Frequencies
- 7 Signals
- 10 Hz update rate
- 20 Satellites in view

Prototype Receiver



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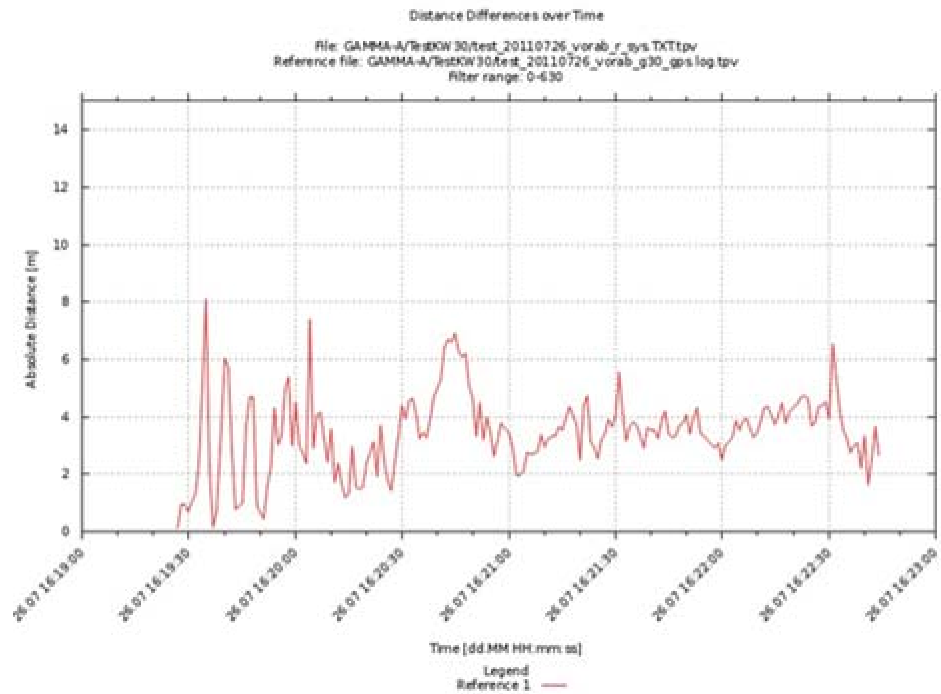
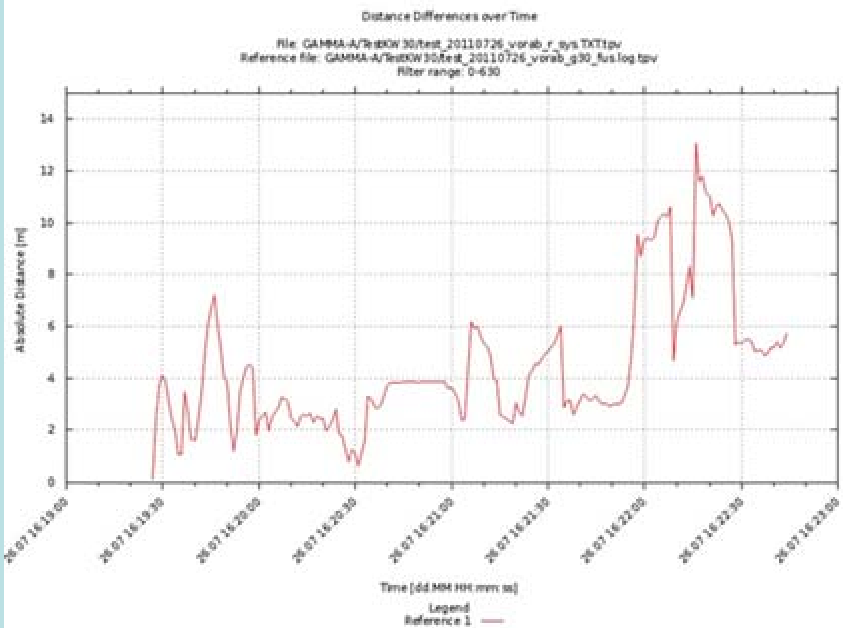
Test and Validation Campaign

Differences in meter between GAMMA-A GPS solution and reference solution →





← Differences in meter between GAMMA-A fusion solution and reference solution

- **Laboratory Tests**
  - Testing the performance of the GAMMA-A receiver using a GNSS Simulator

- **Field Tests**
  - Installation of the GAMMA-A receiver in a vehicle
  - Testing the performance of the GAMMA-A receiver for automotive applications under automotive conditions

Outlook

GENEVA

- Addresses two collision avoidance use cases
  - Stop line assistance
  - Left turn assistance
- Takes advantage of satellite navigation, environment perception, and extended digital maps

http://www.geneva-fp7.eu/

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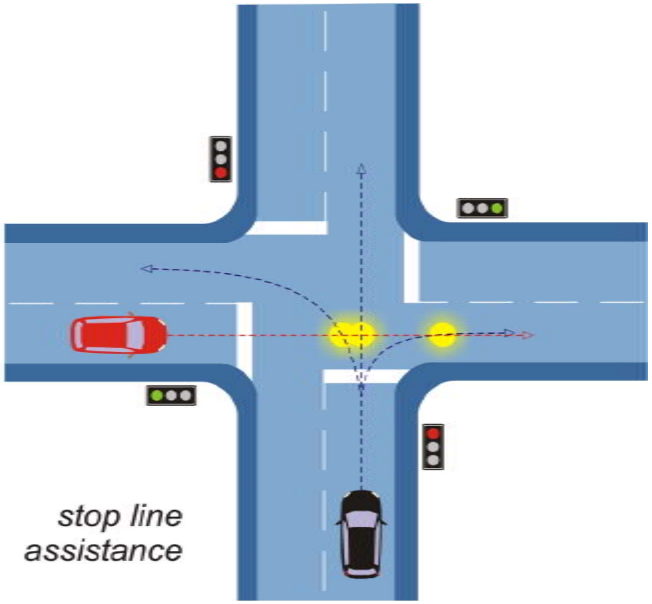
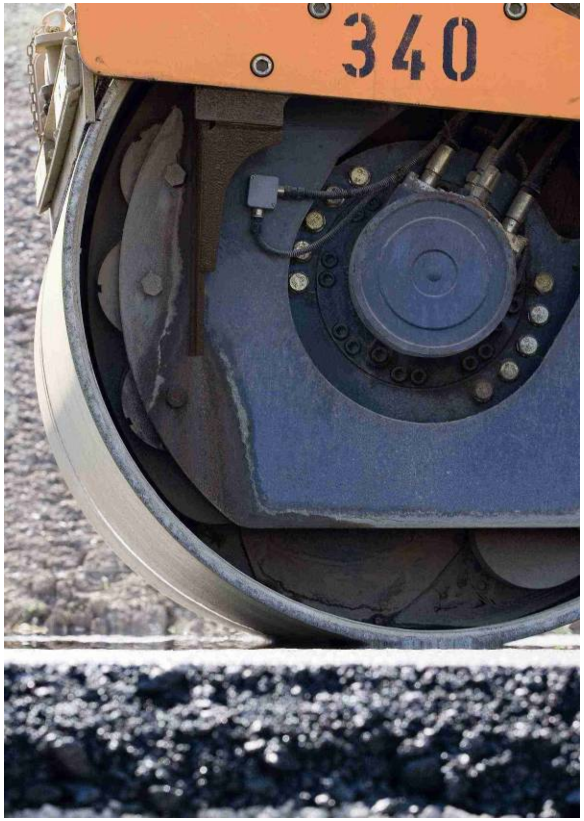


Outlook

ASPHALT

– High precision applications in:
  - Road construction
  - Fleet management and logistics in the construction just-in-time process chain

http://www.asphalt-fp7.eu



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