HOW HIGH PRECISION GNSS ENABLES NEW AUTOMOTIVE APPLICATIONS

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gmv INNOVATING SOLUTIONS

ROHDE&SCHWARZ
Make ideas real

AGENDA

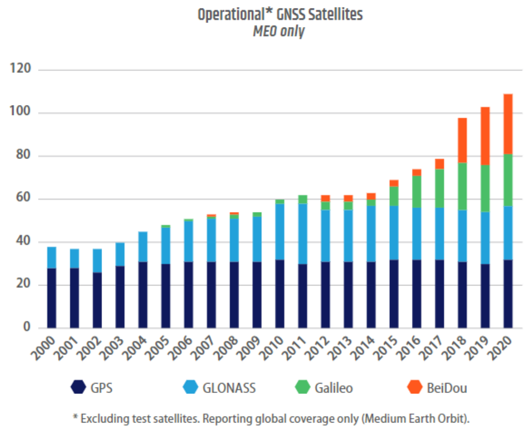
- **High precision enables emerging applications**
- Basic principles of high precision GNSS
- How a high precision GNSS network works
- Testing high precision GNSS
- Summary and Conclusions

GNSS TECHNOLOGY INTRODUCTION

GNSS = **G**lobal **N**avigation **S**atellite **S**ystem

Region	System Name
	GPS
	BEIDOU
	GALILEO
	GLONASS
	IRNSS/ NAVIC
	QZSS

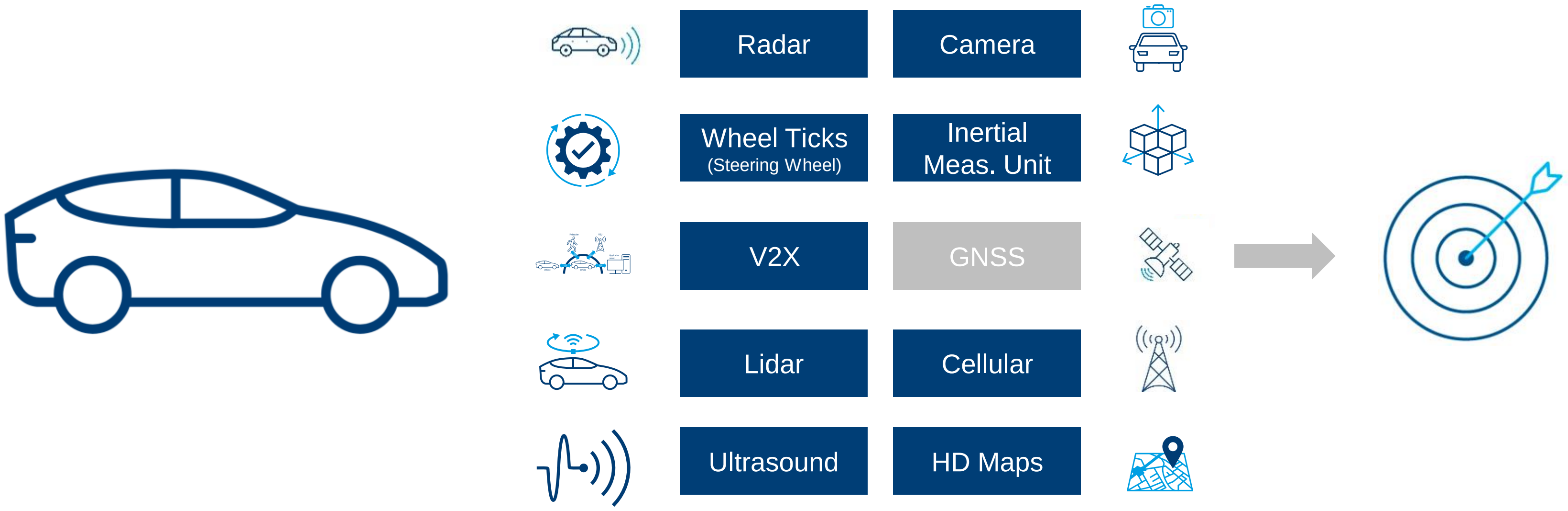
GNSS comprises of 6 major constellations, 4 with global coverage.



GNSS User Technology Report | Issue 3, 2020

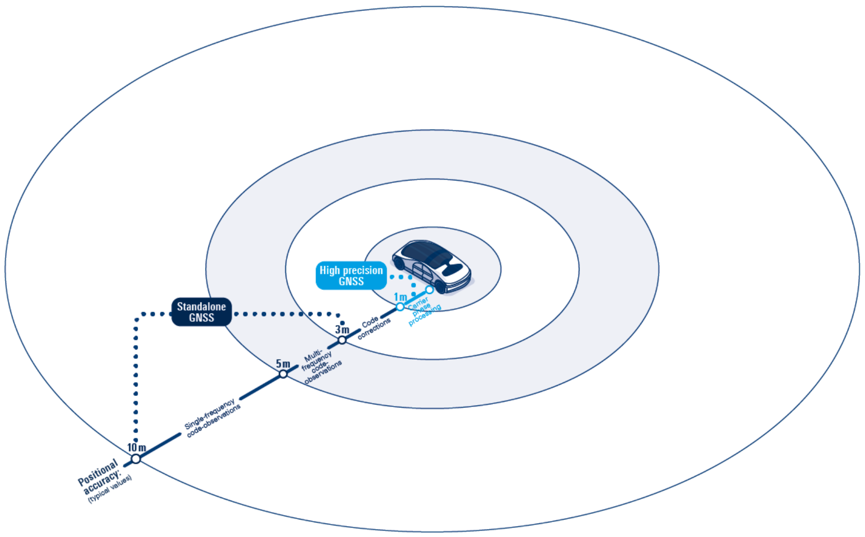
Positional accuracy from Standalone GNSS varies greatly on conditions. High Precision GNSS helps to improve this.

A VEHICLE HAS MANY SENSORS...



However only **GNSS** provides an **absolute position** today!

HIGH PRECISION GNSS CHARACTERISTICS



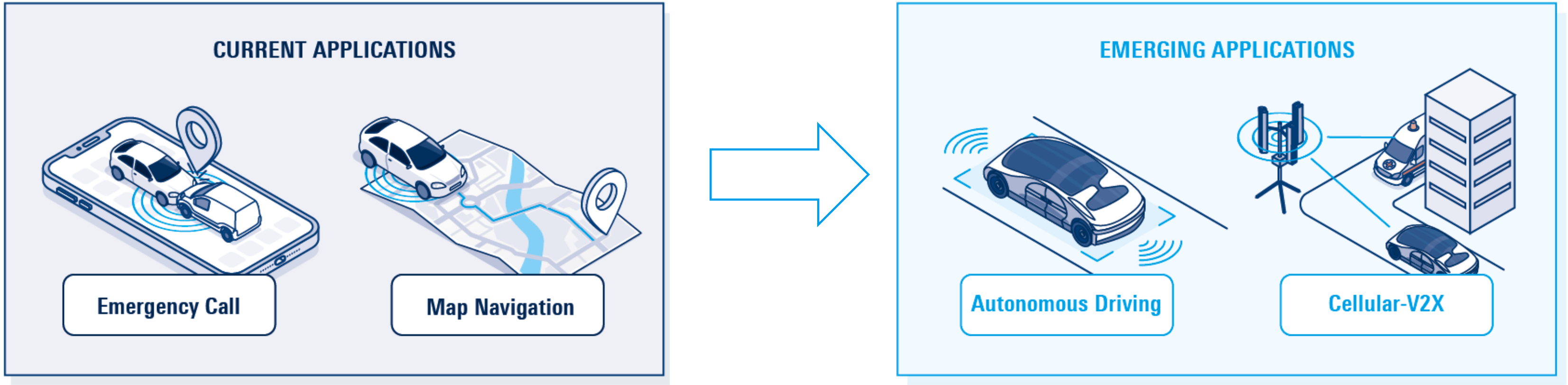
Highly precise position, with accuracy of <1m (typically 10cm)

Global footprint. Automotive industry does not want country specific solutions.

Integrity. High degree of confidence in the positional accuracy.

Continuity of Service. 24 hours per day, 7 days a week.

KEY GNSS AUTOMOTIVE APPLICATIONS



Emerging Applications require **High Precision GNSS**

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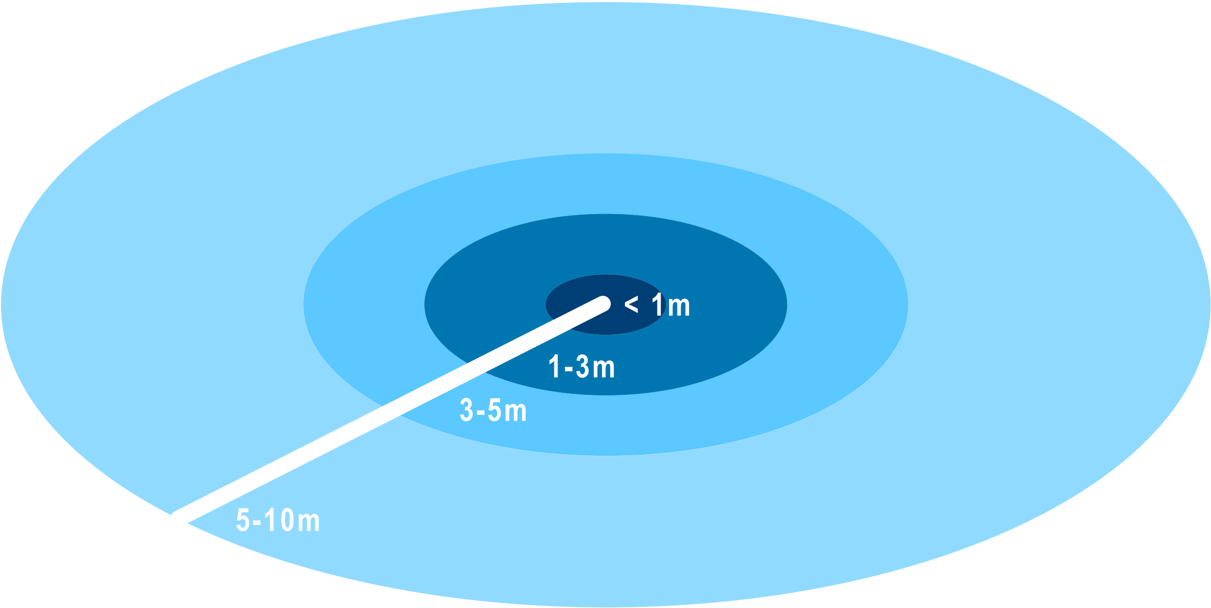
GNSS-BASED POSITIONING METHODS
FROM STANDALONE TO HIGH PRECISION GNSS



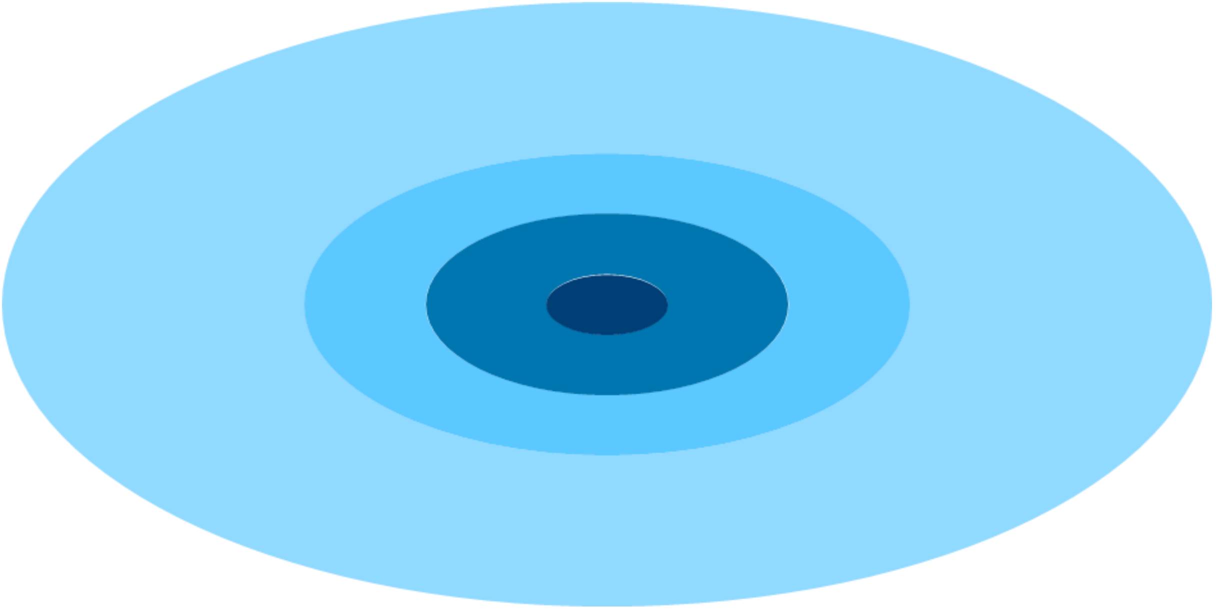
Standalone GNSS
Single-frequency code observations

Standalone GNSS
Multi-frequency code observations

Augmented GNSS
Code corrections / error modelling

High-Precision GNSS
Carrier processing / error modelling

GNSS-BASED POSITIONING METHODS
FROM STANDALONE TO HIGH PRECISION GNSS



Standalone GNSS
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GNSS-BASED POSITIONING METHODS
FROM STANDALONE TO HIGH PRECISION GNSS

Standalone GNSS
Single-frequency code observations

Standalone GNSS
Multi-frequency code observations

Augmented GNSS
Code corrections / error modelling

- **Satellite-based augmentation systems (SBAS)**
- **Ground-based augmentation systems (GBAS)**

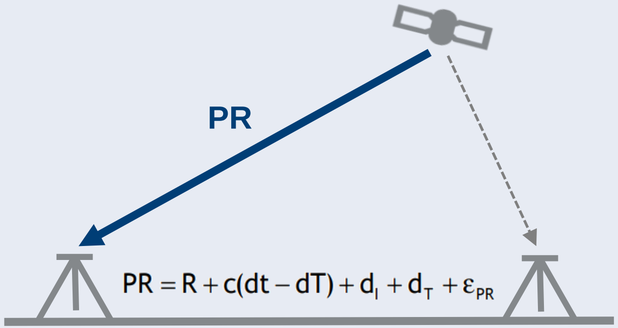
High Precision GNSS
Carrier processing / error modelling

- **Real-Time Kinematic (RTK)**
- **Precise Point Positioning (PPP)**
- **PPP-RTK**

1. STANDALONE GNSS POSITIONING
GNSS ERRORS

Measured distance PR between satellite and receiver contains errors

- Ionospheric errors
- Satellite clock errors
- Tropospheric errors
- Receiver clock errors
- Satellite orbit errors
- RX noise and multipath

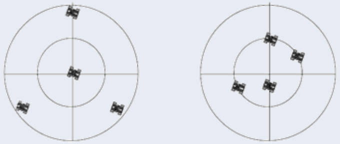


1. STANDALONE GNSS POSITIONING
GNSS ERRORS

UERE…user equivalent ranging error
HDOP…horizontal dilution of precision

GNSS Error budget (1σ)

Ionospheric errors	5.0 m	2.5 m	w/ iono model
Tropospheric errors	4.0 m	0.5 m	w/ tropo model
Satellite orbit errors	1.0 m	1.0 m	
Satellite clock errors	1.0 m	1.0 m	
RX noise and multipath	1.5 m	1.5 m	
UERE	6.7 m	3.3 m	



HDOP = 1.2 HDOP = 2.5

Horizontal positioning error

σ_P = HDOP x UERE [m]

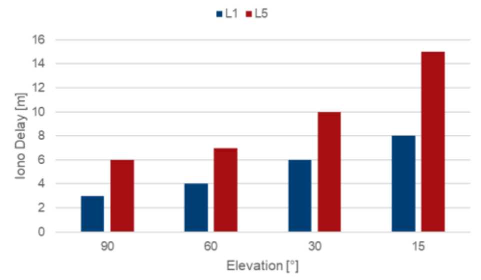
$\boldsymbol{\sigma_P}$ = 2.5 x 3.3 m **= 8.3 m**

High precision GNSS requires reduction or elimination of as many errors as possible

2. MULTI-FREQUENCY GNSS
ERROR MITIGATION

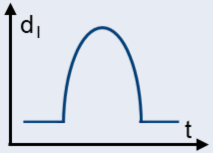
$$d_I(E) = f_M(E) \cdot \frac{40.31}{f^2} \cdot \mathrm{TEC}$$

„Normal" ionospheric conditions



Broadcast Iono Model (for SF users)

- 8 iono parameters
- Part of NavMsg



- Error reduction by 50%

Ionosphere-free pseudo-range

$$PR^* = \frac{f_1^2}{f_1^2 - f_2^2} PR_1 - \frac{f_2^2}{f_1^2 - f_2^2} PR_2$$

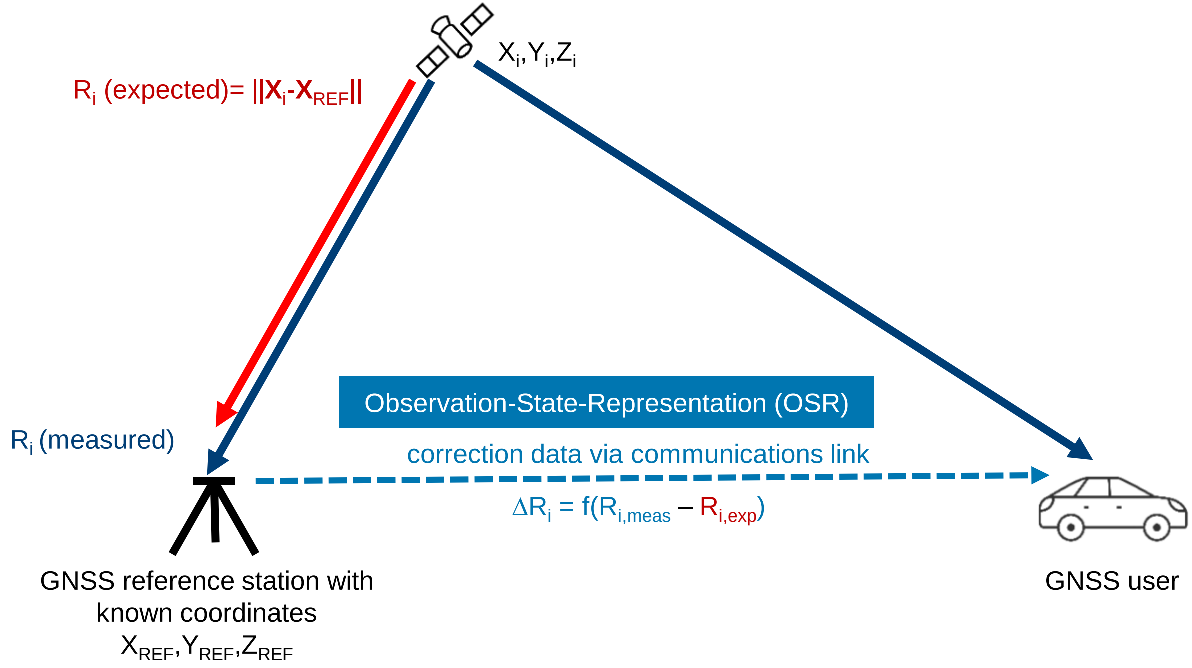
- Removes almost all iono delays
- Measurement errors are increased

Range correction computation

$$d_I(f_1) = \left(\frac{f_2^2}{f_2^2 - f_1^2}\right)(PR_1 - PR_2)$$

- Removes almost all iono delays

3. CODE-BASED AUGMENTED GNSS
ERROR MITIGATION

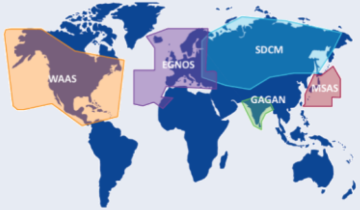


Satellite clock error	Eliminated
Satellite orbit error	Reduced
Ionospheric delay	Reduced
Tropospheric delay	Reduced
Receiver clock error	Still present
Noise and multipath	Still present

3. CODE-BASED AUGMENTED GNSS
SYSTEM CHARACTERISTICS

Small service area		Large service area
	Ground infrastructure	Reference station network + Central Processing Facility (CPF)
Observation-State-Representation (OSR) ▪ Range corrections ▪ Range rate corrections	Correction type	Space-State-Representation (SSR) ▪ Split total pseudo-range error into components ▪ Estimate error variations over entire region
GBAS	Examples	SBAS

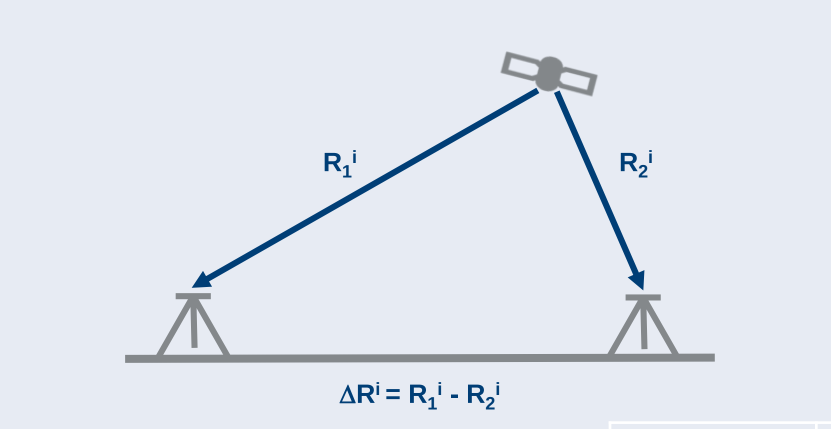
GBAS



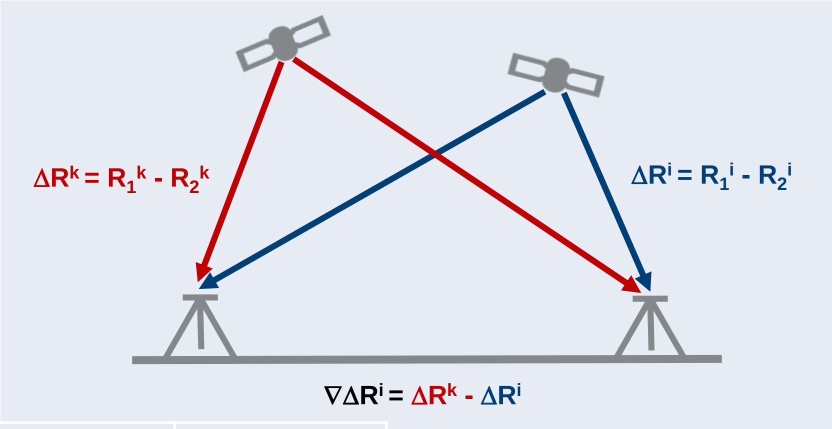
SBAS

4. CARRIER-BASED HIGH PRECISION GNSS
ERROR MITIGATION

Single Differences

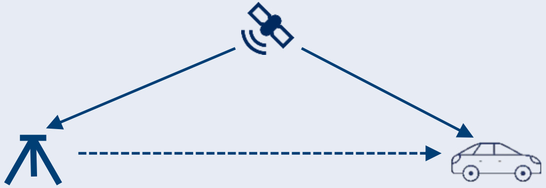
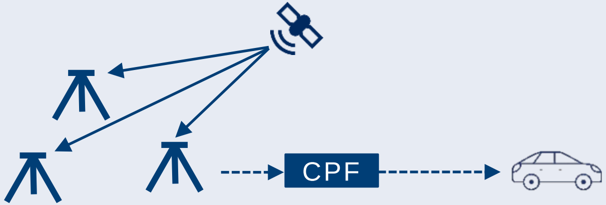


Double Differences



Eliminated	Satellite clock error	Eliminated
Reduced	Satellite orbit error	Reduced
Reduced	Ionospheric delay	Reduced
Reduced	Tropospheric delay	Reduced
Still present	Receiver clock error	Eliminated
Still present	Noise and multipath	Still present

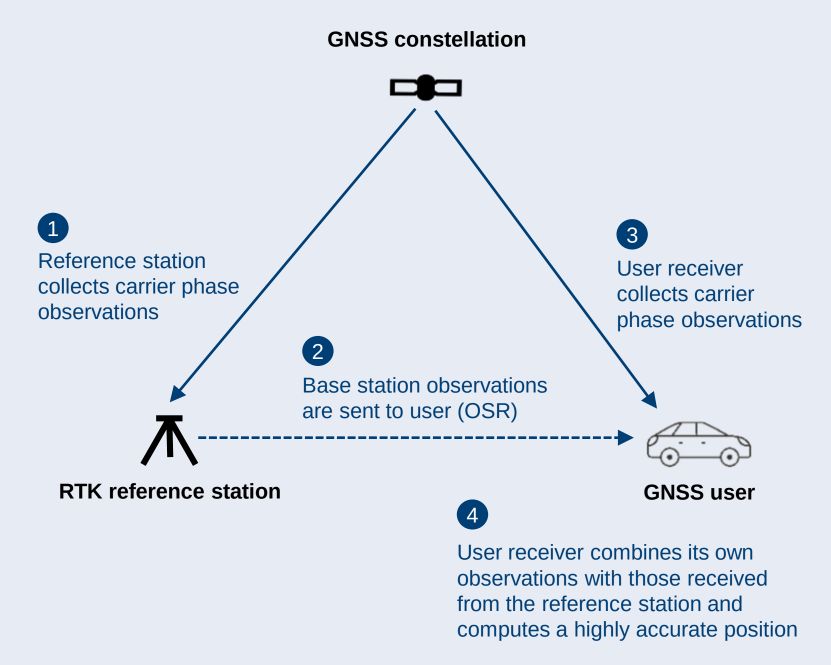
4. CARRIER-BASED HIGH PRECISION GNSS
SYSTEM CHARACTERISTICS

Small service area		Large service area
	Ground infrastructure	
Observation State Representation (OSR) ▪ Carrier phase observations	Correction type	Space State Representation (SSR) ▪ Provision of precise orbit parameters ▪ Provision of precise satellite clock parameters
 Real Time Kinematic (RTK)	Examples	 Precise Point Positioning (PPP)

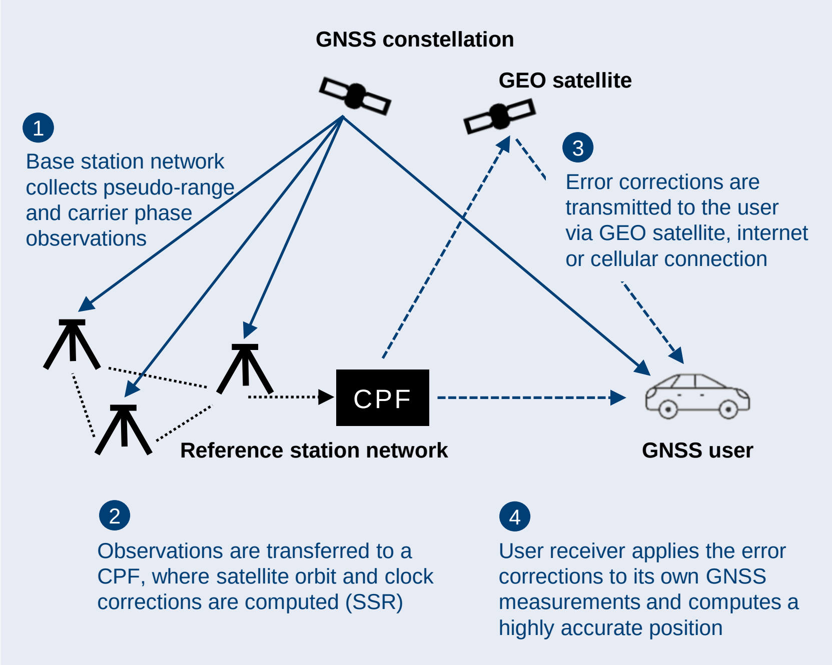
4. CARRIER-BASED HIGH-PRECISION GNSS

RTK VS. PPP: BASIC PRINCIPLE

Real Time Kinematic (RTK)



Precise Point Positioning (PPP)



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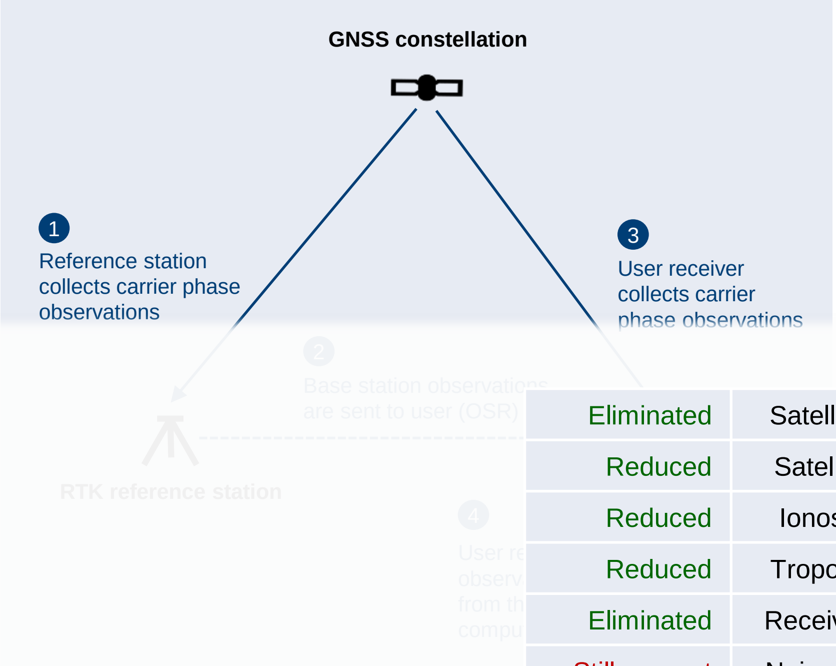
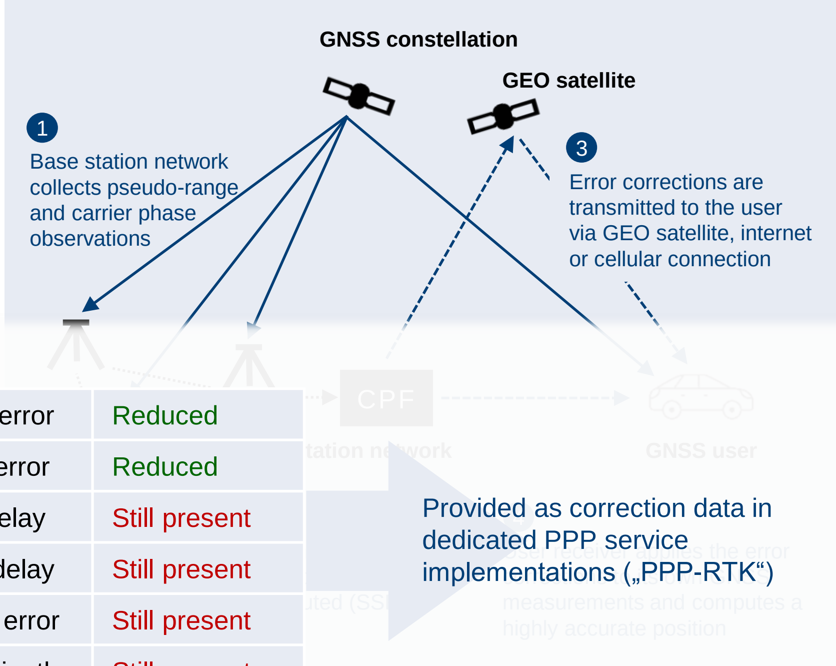
RTK VS. PPP: BASIC PRINCIPLE

Real Time Kinematic (RTK)	Precise Point Positioning (PPP)





Eliminated	Satellite clock error	Reduced
Reduced	Satellite orbit error	Reduced
Reduced	Ionospheric delay	Still present
Reduced	Tropospheric delay	Still present
Eliminated	Receiver clock error	Still present
Still present	Noise and multipath	Still present

Provided as correction data in dedicated PPP service implementations („PPP-RTK“)

GNSS-BASED POSITIONING METHODS
SUMMARY

	Standalone GNSS		Augmented GNSS		High-precision GNSS		
	SF	MF	DGNSS	SBAS	PPP	PPP-RTK	RTK
Correction type	---	---	OSR	SSR	SSR	SSR	OSR
Observable	Code	Code	Code	Code	Carrier	Carrier	Carrier
Service area	Global	Global	Local/Regional	Regional	Global	Global	Local/Regional
Error mitigation/modelling/correction							
Satellite clock error	x	x	✓	✓	✓	✓	✓
Satellite orbit error	x	x	✓	✓	✓	✓	✓
Ionospheric delay	x	✓	✓	✓	x	✓	✓
Tropospheric delay	x	x	✓	x	x	✓	✓
Accuracy	5 - 10 m	3 - 5 m	1 - 3 m	1 - 3 m	dm	< 10 cm	1 cm + 1 ppm

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GNSS TECHNOLOGY FOR ADAS

High Accuracy Positioning
Sub-decimeter Level

Absolute Positioning
Other technologies only provide differential positioning

Robust Safety Case
High maturity (SOTIF-like) reached and demonstrated in applications for civil aviation. Key for ISO26262 safety argumentation

Global Coverage
GNSS Availability EVERYWHERE

Independency
This technology is independent from other sensors in the car

Velocity
GNSS provides absolute velocity of the vehicle

Orientation
GNSS provides orientation values when integrated with IMU

Enhanced setup usability
Antenna and **Receiver** are used in several application

- E-CALL
- TOLLING
- TACOGRAPH
- NAVIGATION
- ...

Built-In Anti-Spoofing & Anti-Jamming

GNSS trajectory
GNSS is currently a booming technology, with years of maturity, acting as the technological solution for a wide variety of sectors. Many countries are investing in developing their own Navigation Systems, proving its worth

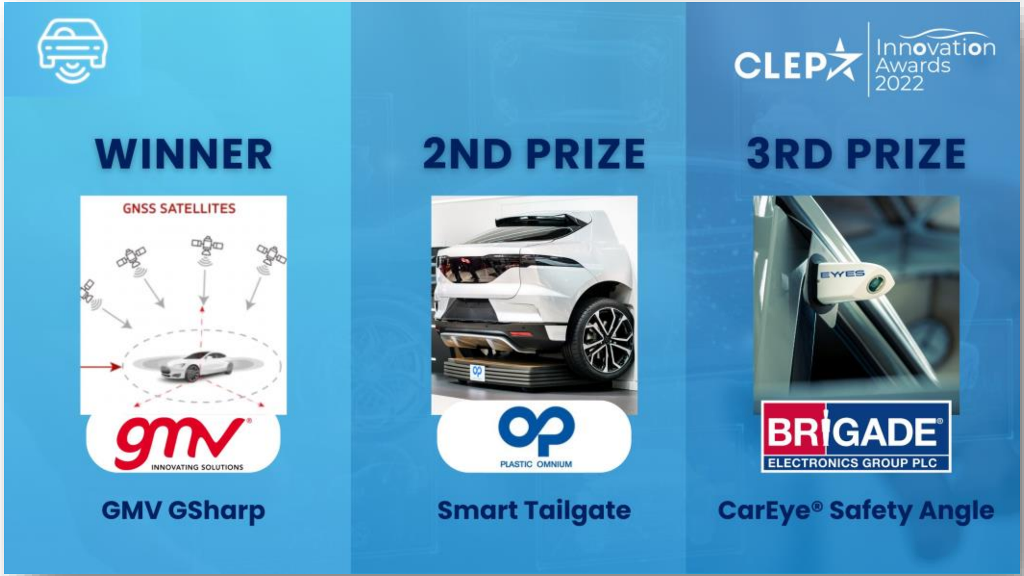
SAFE AND HIGH ACCURACY POSITIONING FOR AUTOMOTIVE

1 CORRECTION SERVICE

2 POSITIONING ENGINE

GMV GSharp

SAFE HIGH-ACCURACY RELIABLE POSITIONING FOR AUTOMOTIVE

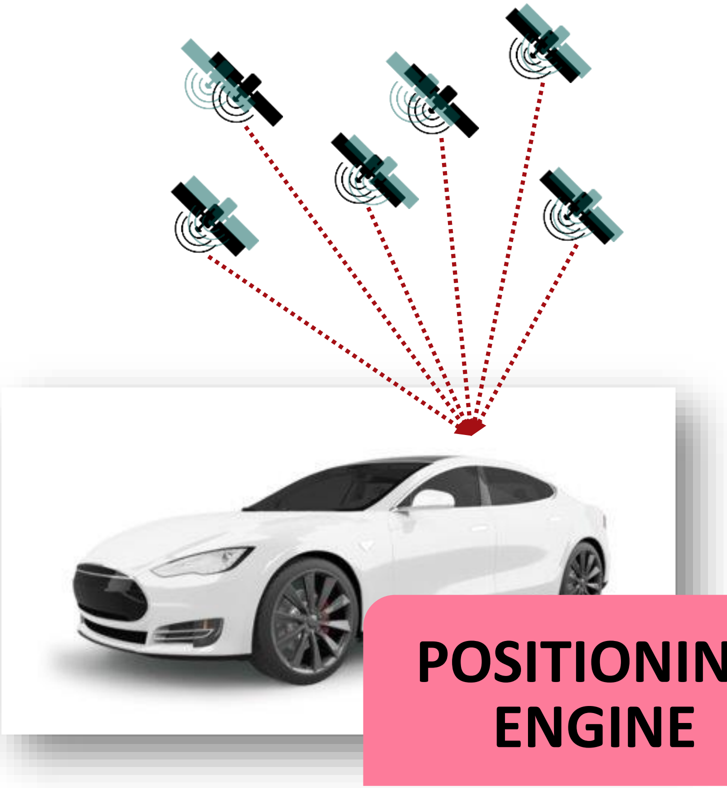


SAFE AND HIGH ACCURACY POSITIONING FOR AUTOMOTIVE

1

CORRECTION SERVICE

Delivery Chain



GMV GSharp

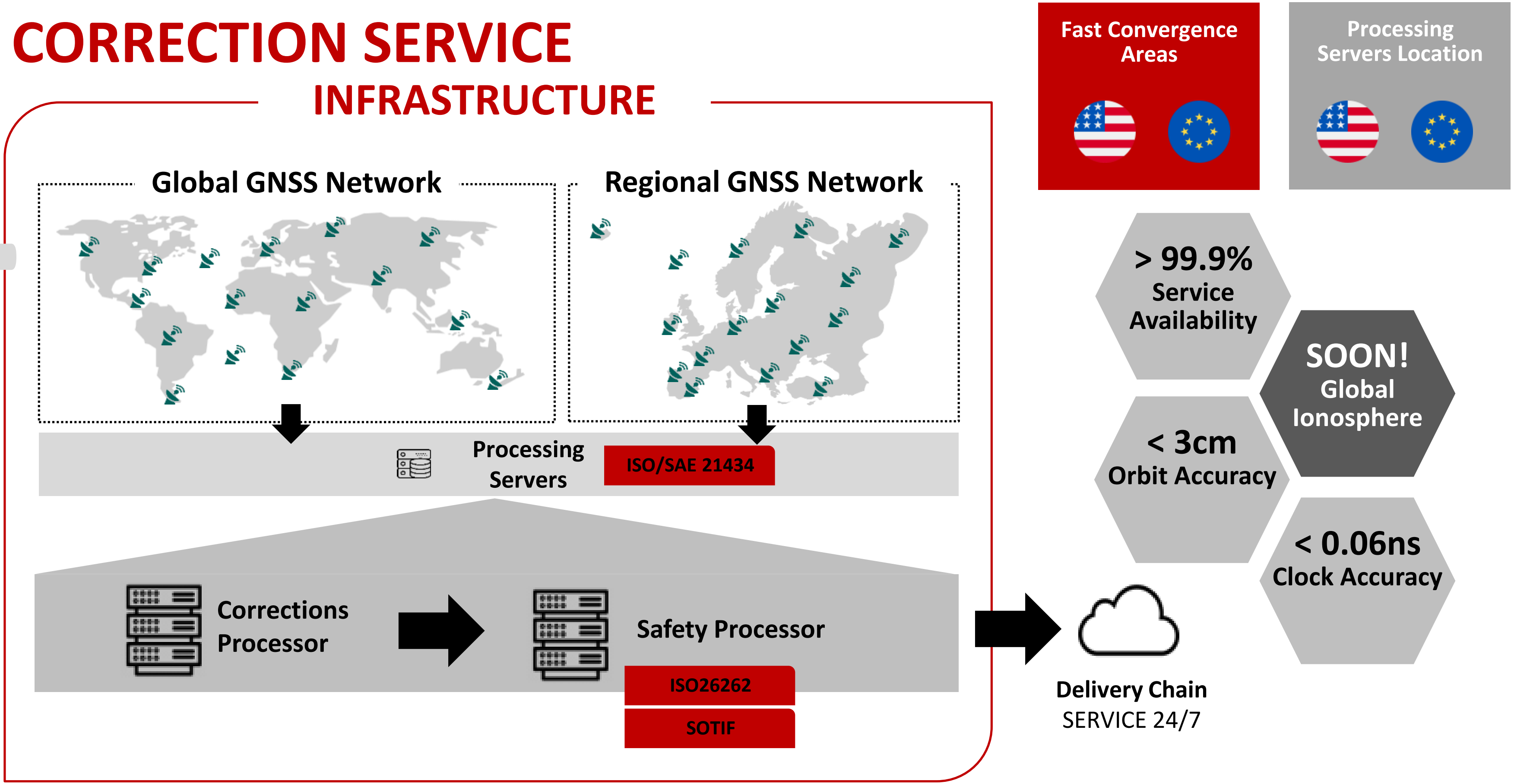
SAFE HIGH-ACCURACY RELIABLE POSITIONING FOR AUTOMOTIVE

POSITIONING ENGINE

2

ISO/SAE 21434 | ISO26262 | SOTIF | ASPICE

1. CORRECTION SERVICE



2. POSITIONING ENGINE

2 PE

ISO26262

SOTIF

ISO/SAE 21434

ASPICE

PPP+RTK

- < 10cm Horizontal Accuracy p95
- < 0.25º Heading Accuracy p95
- < 30sec Convergence Time
- 10^{-7} /h Integrity Risk
- < 0.1 m/s Horizontal Velocity Accuracy

With <u>mass-market</u> automotive GNSS receiver!

HOW?

<u>TEST & VALIDATION</u>

sys

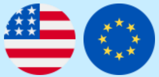
sw

safety

2. POSITIONING ENGINE

2 PE

GMV has thoroughly tested their PE solution across several driving campaigns accomplished in the last two years



Tens of thousands of km recorded

Influence Factors

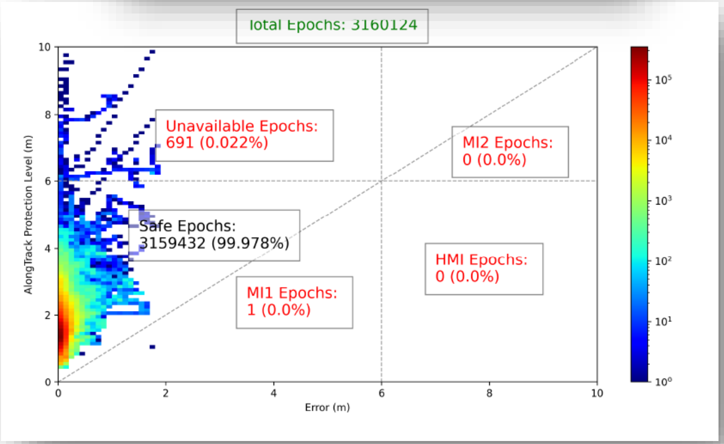
sys

sw

safety

Fault Free and Fault included Analysis

Include massive fault testing to insert errors in the GNSS measurements →
GNSS RF signals **Simulator needed!**



gmv

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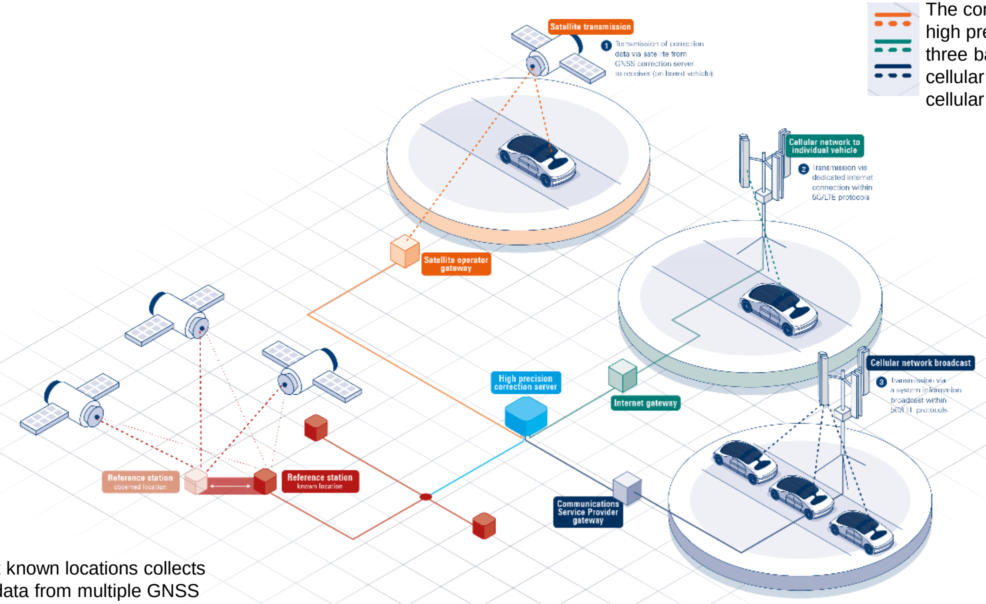
SUMMARIZING THE SYSTEM

The correction data is transmitted from the high precision correction server to the user via three basic methods: Satellite transmission (1), cellular network to individual vehicle (2) and cellular network broadcast (3)..



A network of reference stations at known locations collects pseudo-range and carrier phase data from multiple GNSS satellites and compares this to the known location of each reference station. The difference between the known and indicated location allows error correction data to be calculated.

A central high precision correction server processes the collected data and generates measurement corrections (RTK) and/or computes satellite orbit, and clock corrections (PPP)..

HIGH PRECISION GNSS TESTING CONSIDERATIONS

Testing GNSS receiver in a reproducible and controllable environment

Ability to inject specific “errors” and corresponding correction data

Ability to test the system as a “Black Box” on component or Full Vehicle level

Ability to test with correction data from a live network with live GNSS

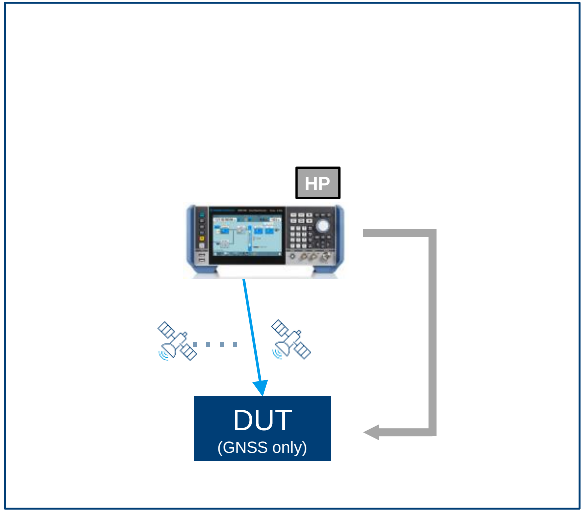
Reduce the amount of time and resources required by more efficient testing

Legend

- HP — High Precision Corrections
- DUT — Device Under Test
- High Precision Correction Data
- Correction Provider Server
- CMX500 5G Radio Comms Tester
- SMBV100B GNSS Simulator

HIGH PRECISION GNSS TEST APPLICATIONS

1



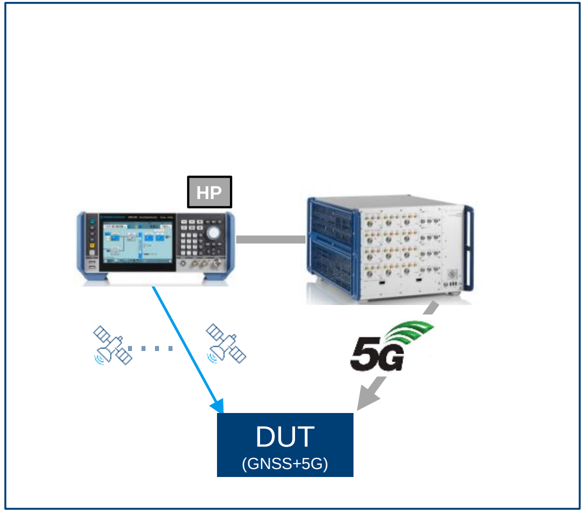
GNSS receiver/modules in Lab

Typically receiver development & verification at Tier1, Tier2 or silicon provider

Source: ST website

Source: ublox website

2

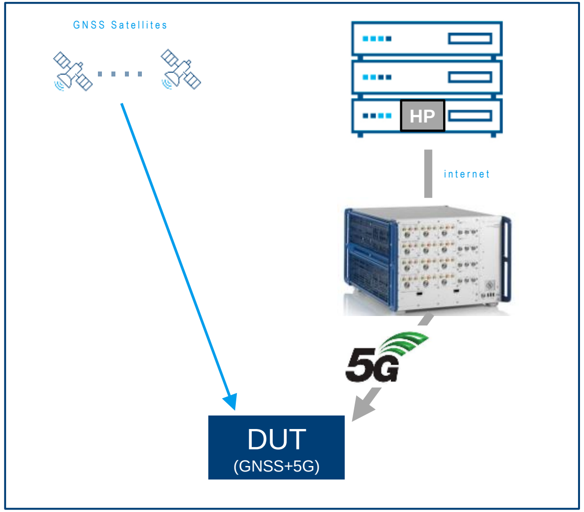


ECU/TCU and Full Vehicle

Typically ECU/TCU Tier1, Car OEM or cellular operator lab testing

Continental Automotive - Telematics Control Units

3



ECU/TCU and Full Vehicle

Typically ECU/TCU Tier1, Car OEM want to make a functional test

Continental Automotive - Telematics Control Units

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SUMMARY AND CONCLUSIONS

High Precision GNSS positions based on RTK/PPP can achieve the requirements for emerging automotive applications.

4 key pillars of the technology are
High Precision, **Global availability, Integrity** and **Continuity** of service

Testing in a controlled and reproducible environment is important to accelerate high precision GNSS time to market and minimize your investments.

TEST IT TRUST IT

www.rohde-schwarz.com/automotive