NAVISP-EL1-010 - LOCOMOTIVE

FINAL PRESENTATION

26/01/2021 - VISIOCONFERENCE

AGENDA

1. LoCoMotive project introduction
2. Market and user: drivers for LoCoMotive requirements
3. LoCoMotive development activities and tests
4. Roadmap toward end product
5. LoCoMotive project conclusion

Date:
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LoCoMotive project introduction

///LoCoMotive : "Low Cost GNSS for autoMotive" key concerns

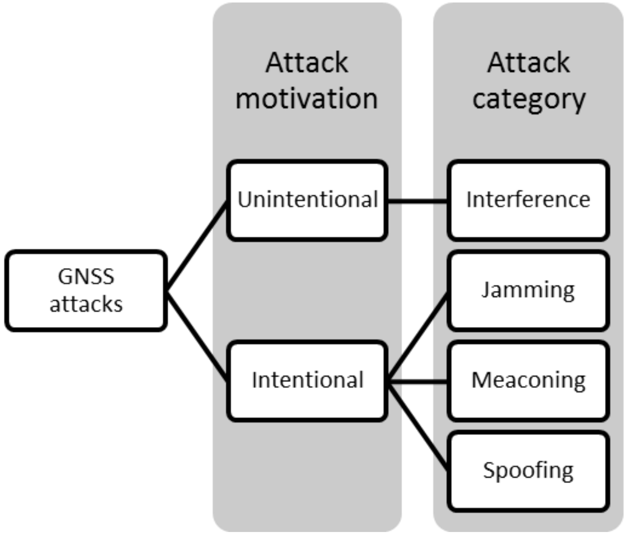
- Accurate Positioning for autonomous vehicle
- Reliable GNSS sensor for ADAS
- Automotive constraints: price and size
- Robustness to GNSS signal impairments
- Multi-antenna technologies and related signal processing algorithms
- Representative use cases for verification
- Feasibility of end product industrialization

SAE Autonomous Driving levels:

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

LoCoMotive project introduction

///GNSS signal threats:

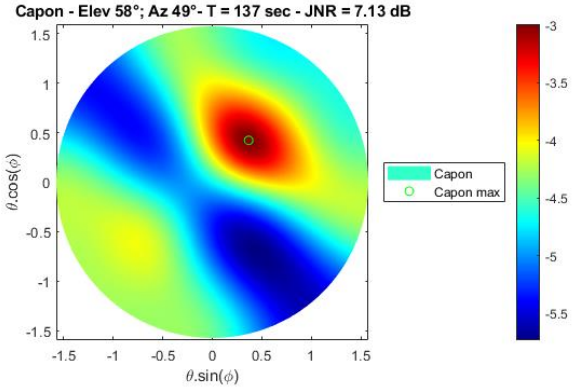


Classification by the CEN-CENELEC

- Most of threats are coming from a single RF source

///Multi-antenna mitigation principle

- The antenna is composed by several patches (4 in the case of LoCoMotive)
- Recombination of the phases of each patches
  ➔ measurement of the strength of the received signal on any Direction of Arrival (DoA), in azimuth and elevation
- Detection of DoA of the threat source
- Mitigation of the threat

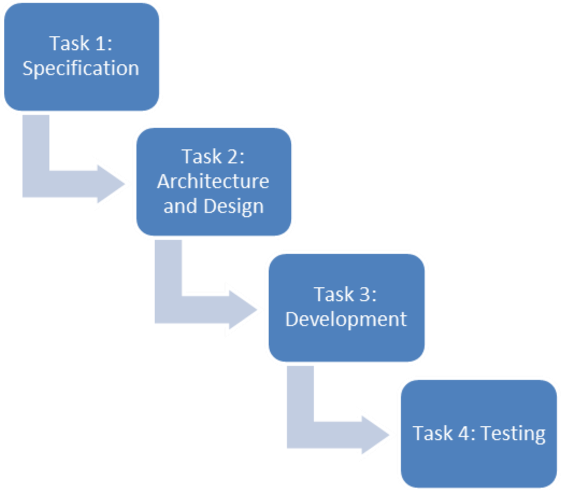


LoCoMotive project introduction

///Objectives of the project

- Make a status of the user and market, and a critical analysis of the technical needs
- Consolidate the system requirements
- Develop a prototype of the LoCoMotive receiver
- Identify the use cases for checking the multi-antenna algorithms
- Perform de test campaign
- Provide the findings, limitations and recommendations for a way forward
- Provide insights about the roadmap for end product

Work logic :



LoCoMotive project introduction

///Consortium

AGENDA

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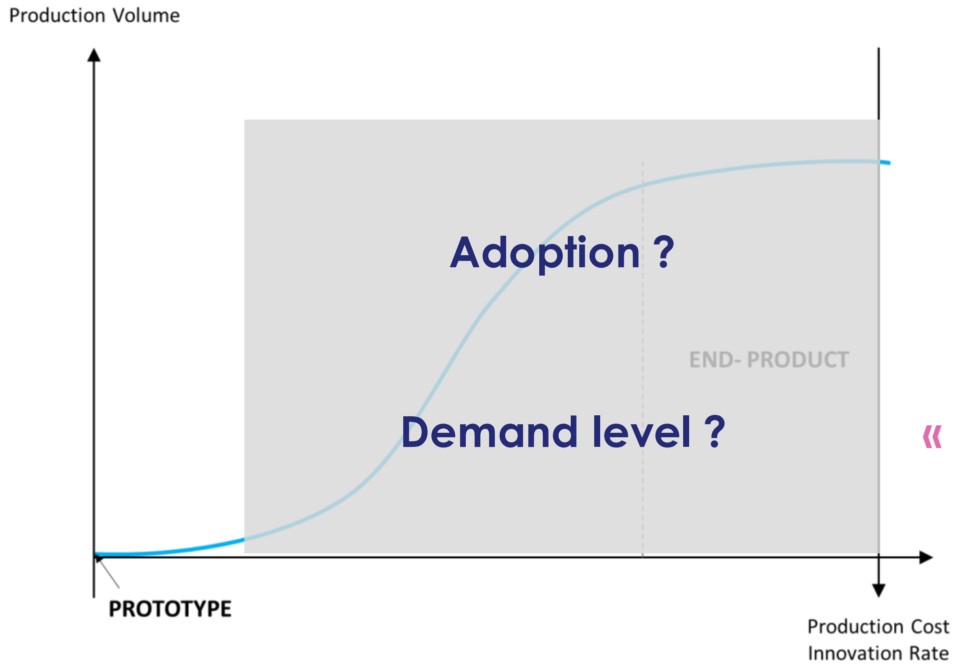
Market and user: drivers for LoCoMotive requirements

/// Market driver: Innovation lifecycle

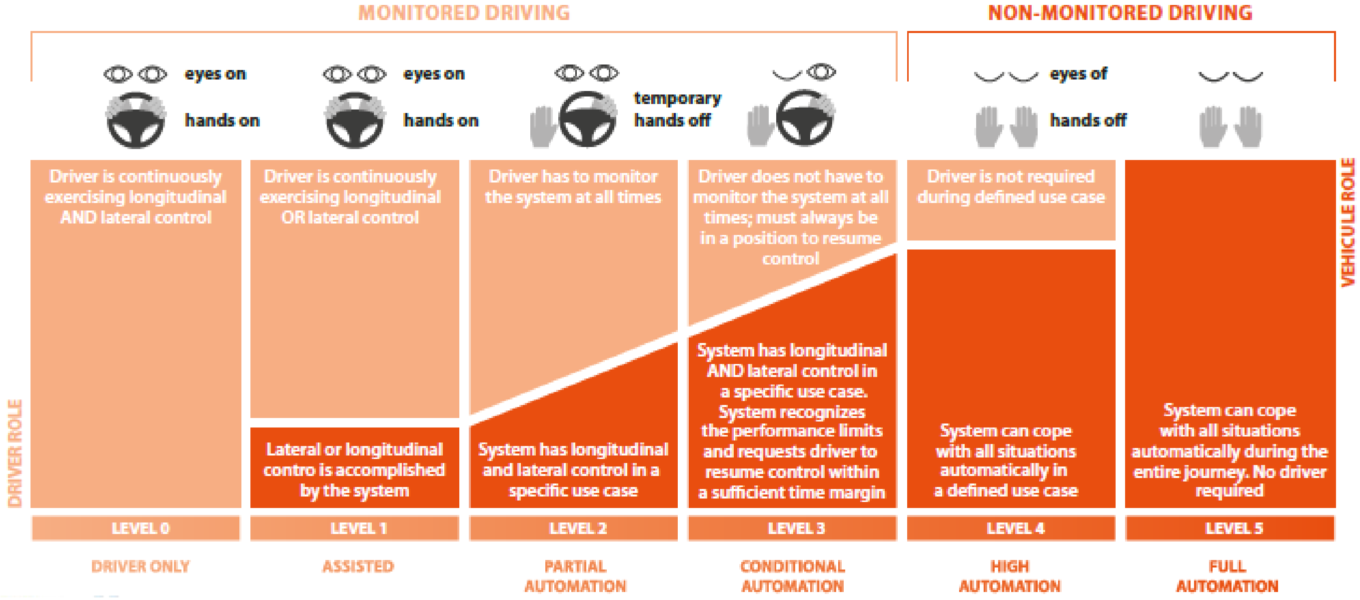


LoCoMotive is a Technology Push

« Low-Cost » comes with high market demand

Market and user: drivers for LoCoMotive requirements

/// Market driver: GNSS in ADAS



AD level 2/3:

Core PNT

AD level 4/5:

Complementing PNT

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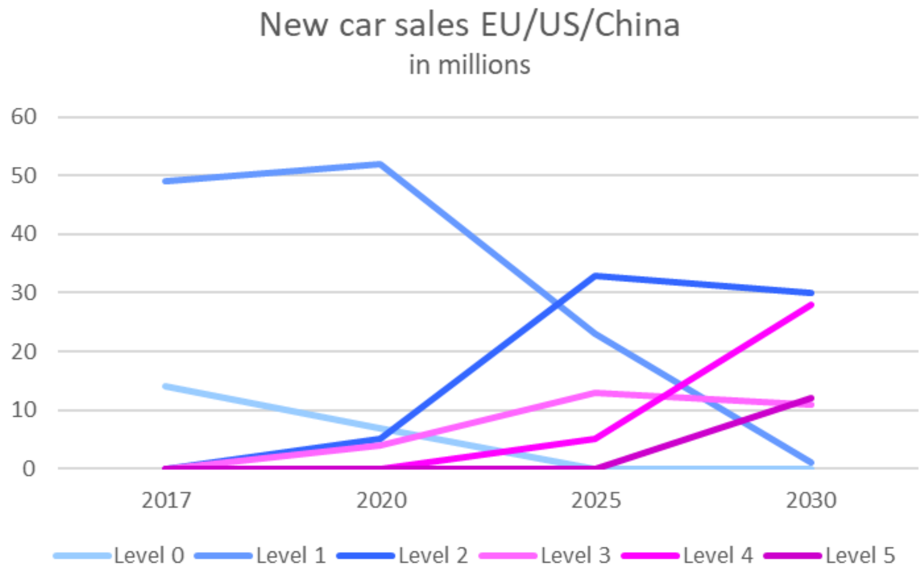
Market and user: drivers for LoCoMotive requirements

/// Market driver: ADAS market forecast in 2017

EU market ~1/3 of Total

Pivot in 2025: AD2/3 ➔ AD4/5



Extracted from « PWC 2017 Digital Auto Report »

Update 2020: ~5Y delay for AD4/5 take-off *(PWC Digital Auto Report 2020)*

Market and user: drivers for LoCoMotive requirements

/// User driver: User Consultation Platform 2017

AD 1/2/3

User requirement	Value
Horizontal accuracy	Between 50cm and 100cm
Vertical accuracy	Better than 2m
Availability	Better than 99.9%
Time to First Fix (TTFF)	Less than 30 seconds
Integrity	Yes
Authentication	Yes

AD 4/5

User requirement	Value
Horizontal accuracy	Better than 20 cm
Vertical accuracy	Better than 2m
Availability	Better than 99.9%
Time to First Fix (TTFF)	A few seconds
Integrity	Yes
Authentication	Yes

Market and user: drivers for LoCoMotive requirements

/// User driver: Standardization bodies ETSI / CEN-CENELEC

- Probability of False Alarm (PFA)
- Probability of Detection (PD)
- Time To Alert (TTA)
- Attack scenarios, multipath model

/// User driver: Vehicle dynamics – EU recommendations/best practices

- Maximal speed: 130km/h
- Lateral acceleration: 0.5g

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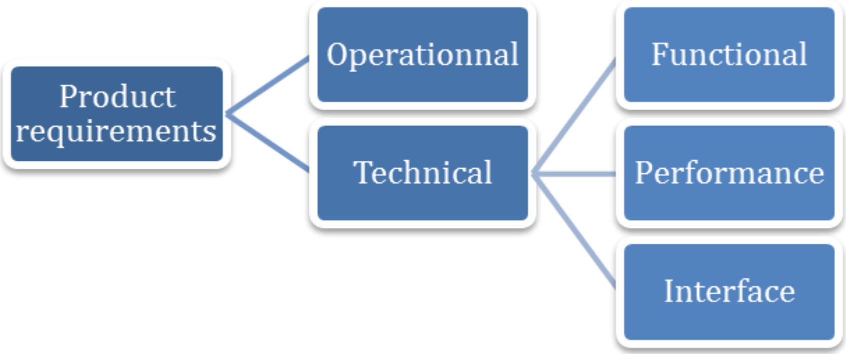
Market and user: drivers for LoCoMotive requirements

/// User requirements: Prototype and End-product



/// Target performances

- Robustness to attacks by comparing with low-end and high-end receivers
- PFA <10%, PD>80%, TTA<5s

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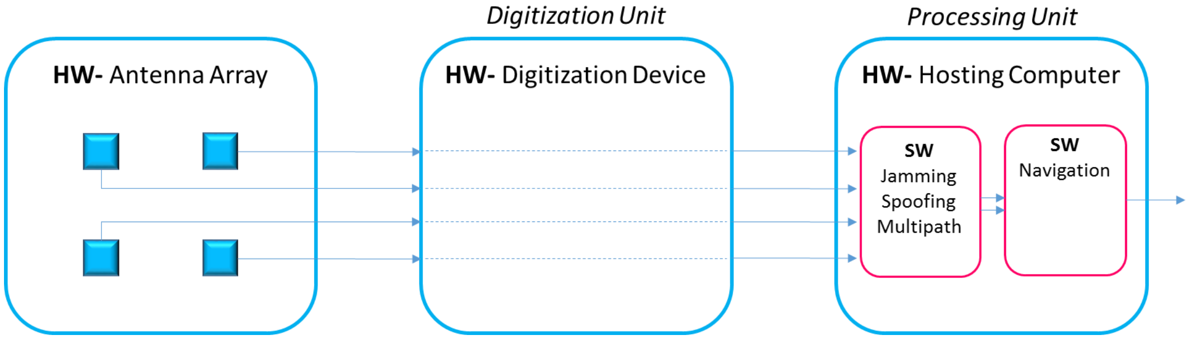
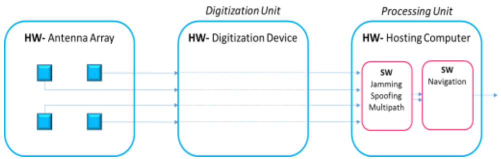
LoCoMotive development activities

///Design of the LoCoMotive prototype



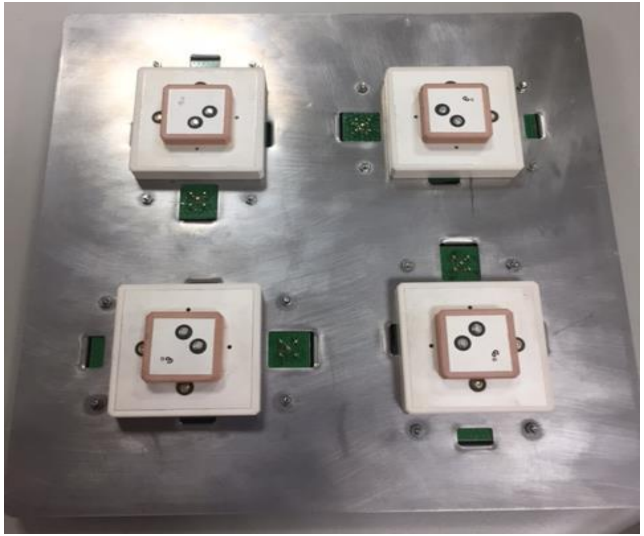
- Antenna designed with low-cost objectives
- Digitization / processing units based on TAS/Saphyrion collaboration and existing products
  - **GEMS** (GNSS Environment Monitoring Station): the SDR GNSS processing core multi-constellation, multi-frequency, real time receiver, embedding most of the state-of-the-art GNSS signal processing for sake of receiver robustness and integrity
  - **GDAS-2S** (GNSS Data Acquisition System)

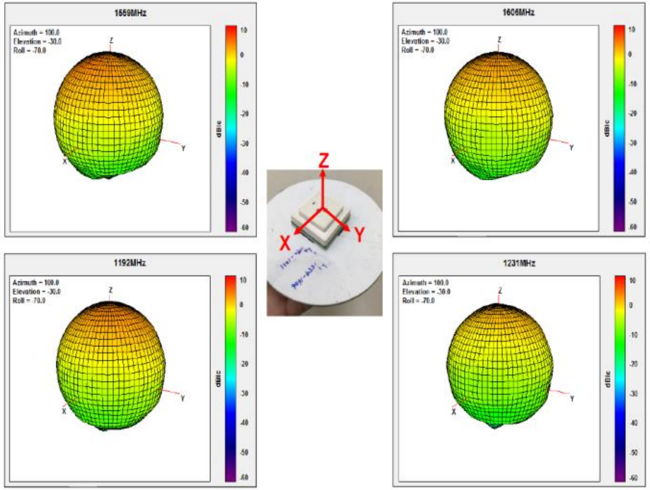
LoCoMotive development activities



///Design of the LoCoMotive prototype: the 4-patch antenna

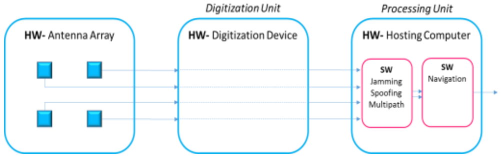
- Low grade antenna consistent with low cost solution (300€)
- 4 patches array (Automotive Grade L1/L2/L5 patch antenna)
- Frequency bands : L1, L2 and L5, compatible with GPS, Galileo, Glonass, BeiDou





- Radiation pattern: consistent circularity and axial ratio

LoCoMotive development activities



///Design of the LoCoMotive prototype: the 4-patch antenna

- Mechanical drawing drivers:
  - The distance between patch centers must be lower than half the smallest wavelength to process, i.e. approximately 9.5 cm
  - The metal plate constituting the ground plane must be as large as possible so as to reduce as much as possible mutual coupling between elements
  - The total size of the antenna must not exceed 30 cm

Antenna Characteristics	L1 band	L2/L5 band
Frequency	1560~1610 MHz	1160~1240 MHz
Bandwidth	50 MHz	80 MHz
Polarization	RHCP	
Axial Ratio	3 dB	
Peak Gain	4 dBic	
Circuit Characteristics		
Frequency	1560~1610 MHz	1160~1240 MHz
Voltage	5 V	
Current	70 mA	
Output VSWR	2	
Gain	28 dB	
Noise Figure	2 dB	

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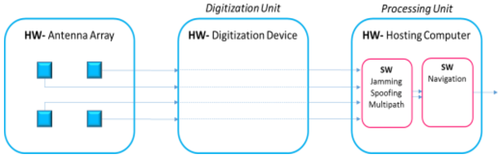
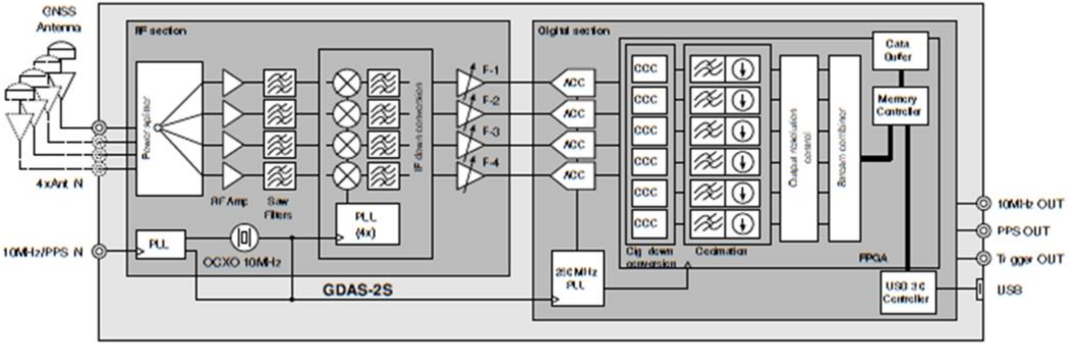
LoCoMotive development activities

///Design of the LoCoMotive prototype: the digitizer



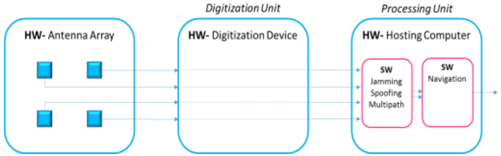
- Based on **GDAS-2S** product
  - High performance and flexible digitizer
  - Already supports 4 independent RF inputs
  - Max. capture transfer rate 250 MByte/s



- Frequency plan:

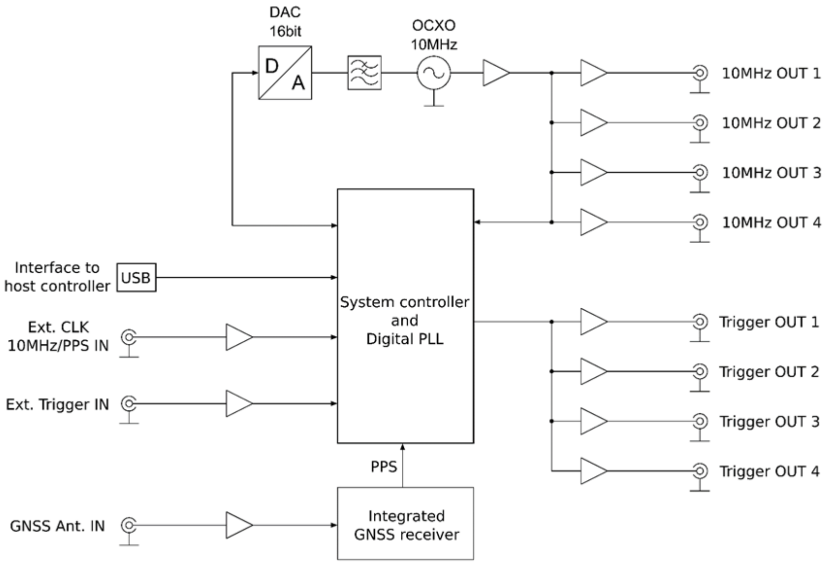
GNSS RF Bands [MHz]	GNSS Signal	Image type	BW [MHz]
L1 : 1560~1610 MHz	GPS/Galileo/Glonass/Beidou	USB	50
L2/L5 : 1160~1240 MHz	GPS/Galileo/Glonass/Beidou	LSB	80

LoCoMotive development activities



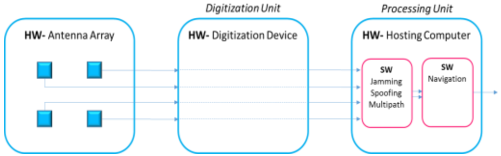
///Design of the LoCoMotive prototype: the digitizer

- Development of the **DUAL GDAS-2S**
  - For managing multi-antenna / bi-frequency ➔ 8 digital streams (8 channels)
  - Assembly of two GDAS-2S
  - Need of precise synchronization between both GDAS-2S



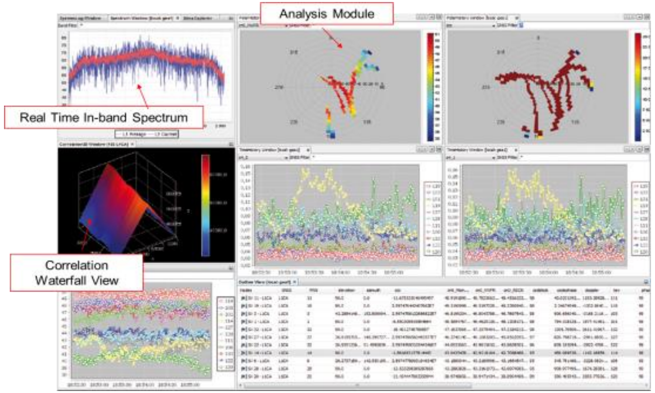
Synchronizer block diagram

LoCoMotive development activities



///Design of the LoCoMotive prototype: the processing unit

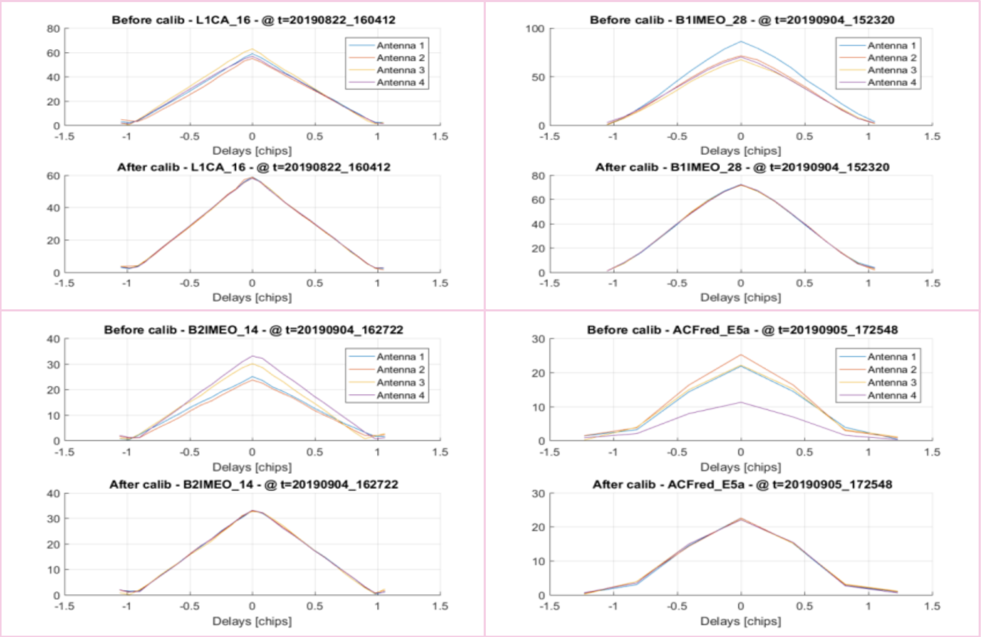
- Based on **GEMS** product (GNSS Environment Monitoring Station)
  - SDR GNSS processing engine used by TAS for any R&D, prototyping, demonstrators, monitoring
  - Multi-constellation, multi-frequency, real time receiver, embedding most of the state-of-the-art GNSS signal processing for sake of receiver robustness and integrity
  - Processing shared between CPU and GPU



LoCoMotive testing activities

///Unitary tests: check of the HW through the antenna calibration

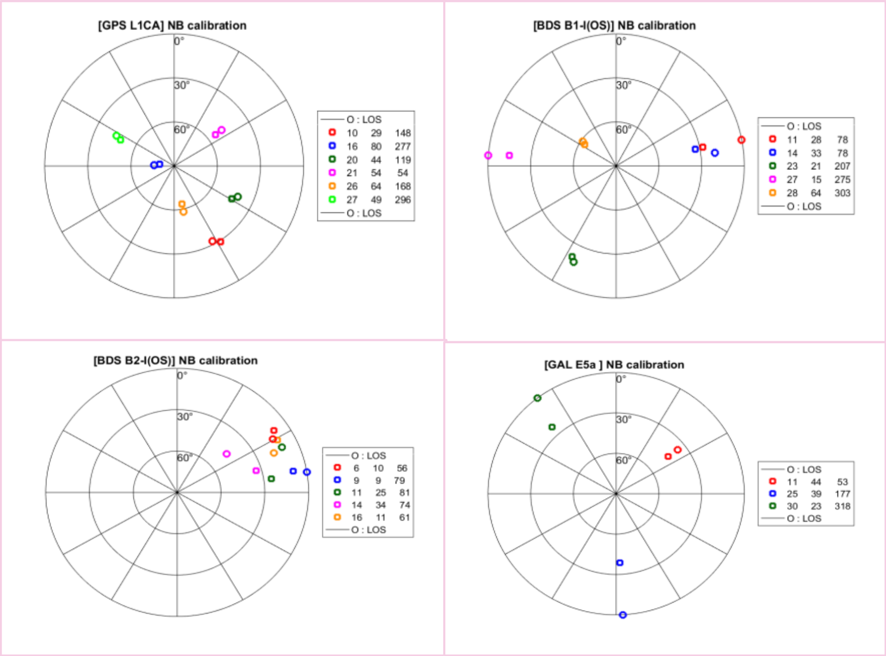
- Calibration: need to align the 4 patches in phase and power (patented: US10578744B2/EP3203267 – "Method of calibration a satellite radio navigation receiver")
  - Wide band calibration:
    - Estimation of coefficient of a FIR filter that align in amplitude, delay and shape the correlation functions
    - The estimated FIR is subsequently applied on the incoming signals from each antenna



LoCoMotive testing activities

///Unitary tests: check of the HW through the antenna calibration

- Calibration: need to align the 4 patches in phase and power
  - Narrow band calibration (estimated DoA after calibration vs reference DoA from ephemeris):
    - Estimation of 4 phase offsets (one for each antenna) and array orientation that align estimated DoA with actual ones (from ephemeris)
    - The 4 phase offset are added to the FIR filter by multiplying its coefficients by the corresponding complex number



LoCoMotive testing activities

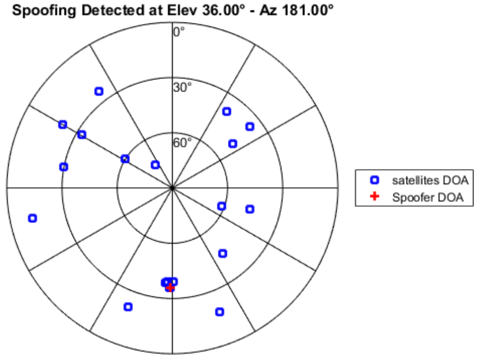
///Unitary tests: check of multi-antenna algorithms and DoA estimation

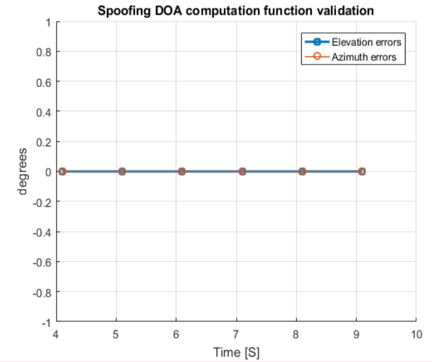
- Made by simulation, illustration with Spoofing detection algorithm
  - Scenario (spoofed satellites in red: transmitted by a single RF source):

Satellites (PRN)	Elevation (°)	Azimuth (°)
1	36,66	182,18
2	62,68	113,10
3	33,93	49,59
4	10,91	299,96
5	9,40	256,57
6	33,31	303,10
7	36,66	182,18
8	46,66	105,03
9	29,70	279,47
10	49,63	53,93
11	14,04	159,00

Satellites (PRN)	Elevation (°)	Azimuth (°)
12	36,66	182,18
13	16,97	201,10
14	59,12	303,60
15	36,66	182,18
16	21,88	323,58
17	76,96	329,88
18	44,43	140,92
19	36,66	182,18
20	40,61	35,68
21	36,66	182,18

  - DoA estimation:





➔Spoofer detected if a set of SV have the same DoA

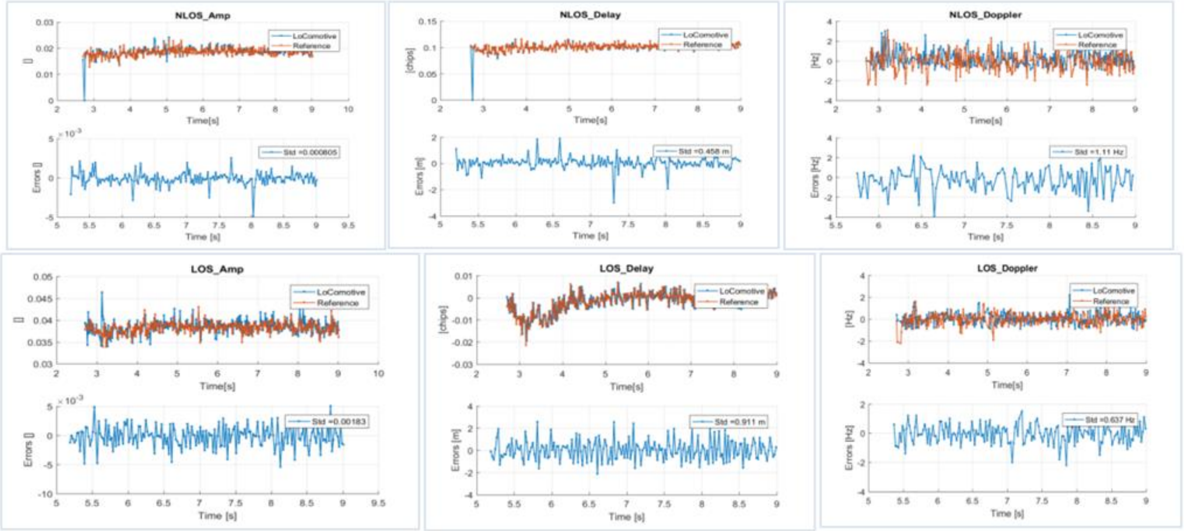
LoCoMotive testing activities

///Unitary tests: check of post-correlation SAGE algorithm

- SAGE is the algorithm used to decompose received signal from multi-correlators output into multiple paths while estimating the characteristics of each path (Amplitude, Phase, Doppler, Delay, DoA)
- Scenario:

Band	PRN	Path	Elevation (°)	Azimuth (°)	CN0(dB)	Duration(s)
GPS L1	17	LOS	35	55	45	9
		MP	15	135		

- Results:



LoCoMotive testing activities

///Extra tests: check of pre+post-correlation algorithms

- Run in the frame of study with CNES: optimization of SAGE algorithm in mono and multi-antenna

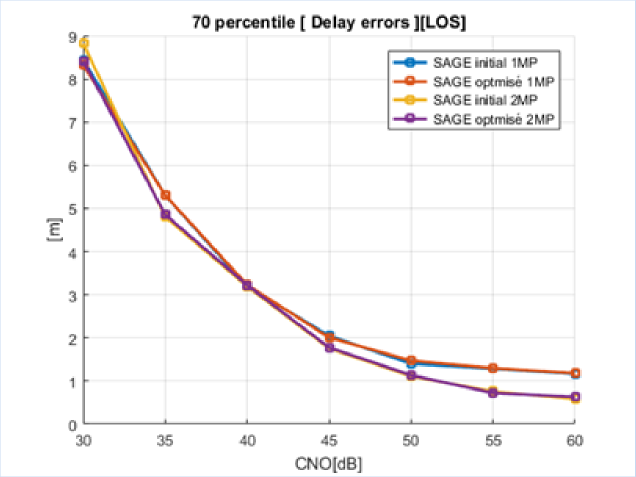


Figure 1 : MONO-ANTENNA

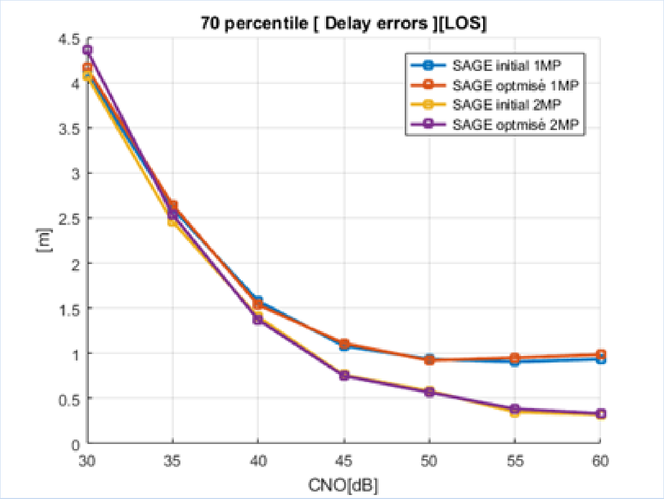


Figure 2: MULTI-ANTENNA

- Improvement of 3dB in multi-antenna

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LoCoMotive testing activities

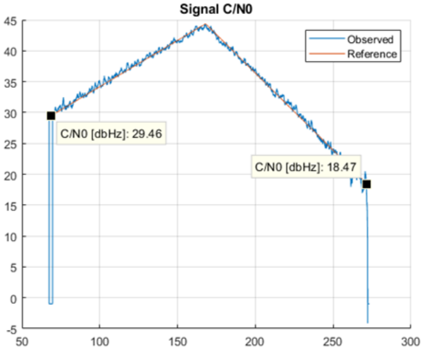
///Laboratory tests

Use of NAVYS RFCS

- Multi-constellation, multi-frequency
- 48-channel multi-band generation capability
- CRPA testing capability
- Spoofing simulation (authentic constellation in parallel with spoofed one)

Sensitivity tests (E1 CBOC)

	LoCoMotive receiver optimized parameters
Acquisition parameters:	
• accumulation time	200 ms
• coherent integration (1 full code period)	4 ms
Tracking parameters:	
• integration time	20 ms
• Delay lock loop bandwidth (aided)	0.1 Hz
• Phase lock loop bandwidth (aided)	5 Hz
• Frequency lock loop bandwidth (aided)	5 Hz



- Acquisition threshold about 29.5 dBHz
- Tracking threshold about 18.5 dBHz
- Nota: only one patch used for C/N0 estimation and tracking decision

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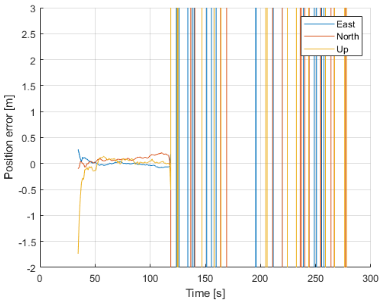
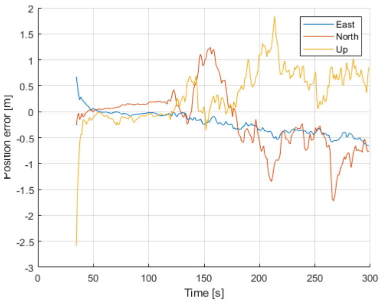
LoCoMotive testing activities

///Laboratory tests

Jamming tests in static

- Wide band jammer simulated by NAVYS from 120 sec
  - Multi-antenna mitigation algorithm makes robust the tracking process (left = without mitigation, right = with mitigation)





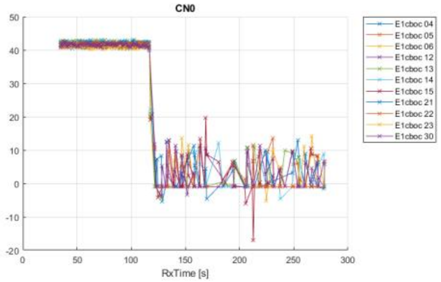
- Without mitigation: the tracking is lost for the most of the time
- With mitigation: tracking is robust, however it is degraded by the spatial blanking (cancels the jammer in the DoA, however cancels also the useful signal

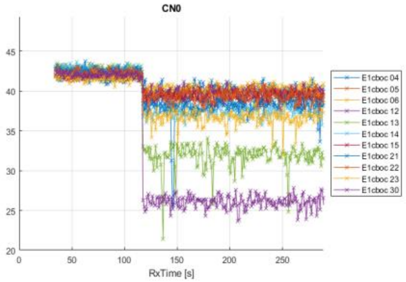
	HPE_50	VPE_50	HPE_95	VPE_95	HPL_50	VPL_50	HPL_95	VPL_95	HMI	VMI	Availability
With interference protection	0.56	0.79	1.19	2.23	33.07	47.31	37.20	49.63	0.00	0.00	100.00
With interference protection Before interference apparition	0.15	0.11	0.27	0.44	28.12	44.29	28.15	44.55	0.00	0.00	100.00
With interference protection After interference apparition	0.67	0.57	1.33	1.23	29.79	48.98	30.92	54.12	0.00	0.00	100.00
Without interference protection	0.19	0.13	1921090.0	3531909.5	28.13	44.38	322.84	330.47	0.00	0.00	61.07

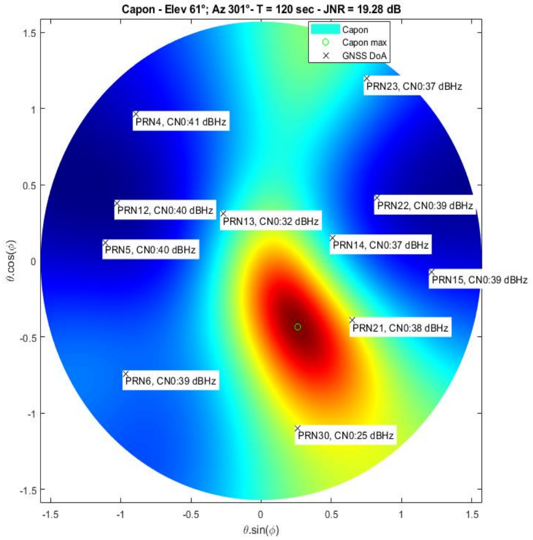
LoCoMotive testing activities

///Laboratory tests

- <u>Jamming tests in static</u>
  - Wide band jammer simulated by NAVYS from 120 sec
    - C/N0 estimation by the LoCoMotive receiver (left = without mitigation, right = with mitigation)







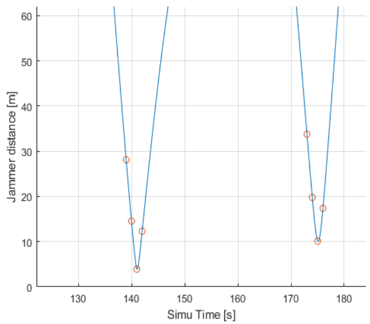
    - The satellites (PRN) located close to the detected source of jamming are roughly more impacted by the signal blanking
    - However all the satellites are impacted
- Nota: blanking function may induce a phase jump in the measurements that can disturb accurate positioning algorithms

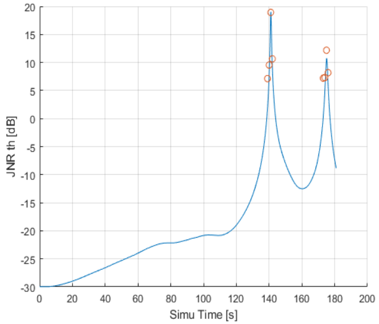
LoCoMotive testing activities

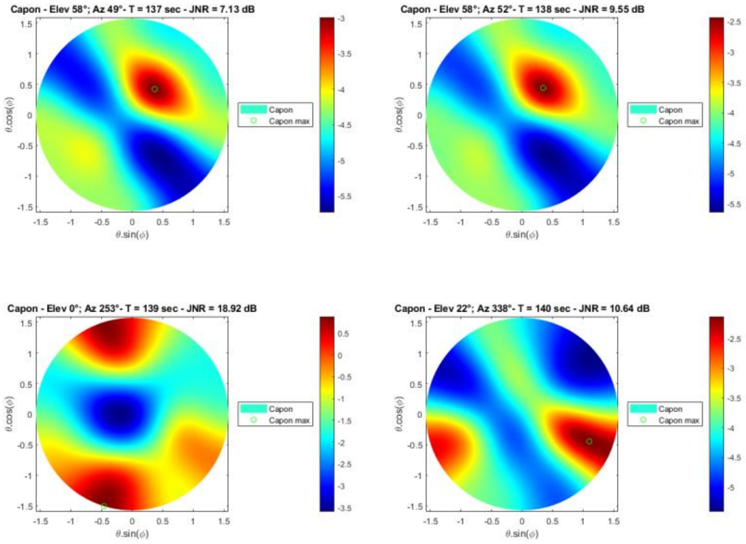
///Laboratory tests

Jamming tests in dynamic

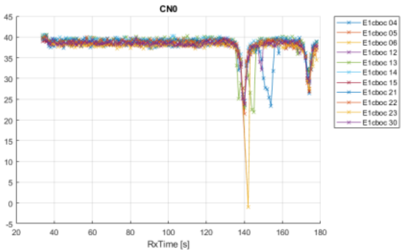
- Wide band jammer simulated by NAVYS with dynamic profile:
  - In red circle the time corresponding to plot below:



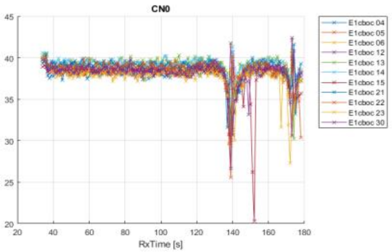




- The jammer have been followed by the algorithm (moving DoA)
- Robustness improved when JNR is high



Without mitigation



With mitigation

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LoCoMotive testing activities

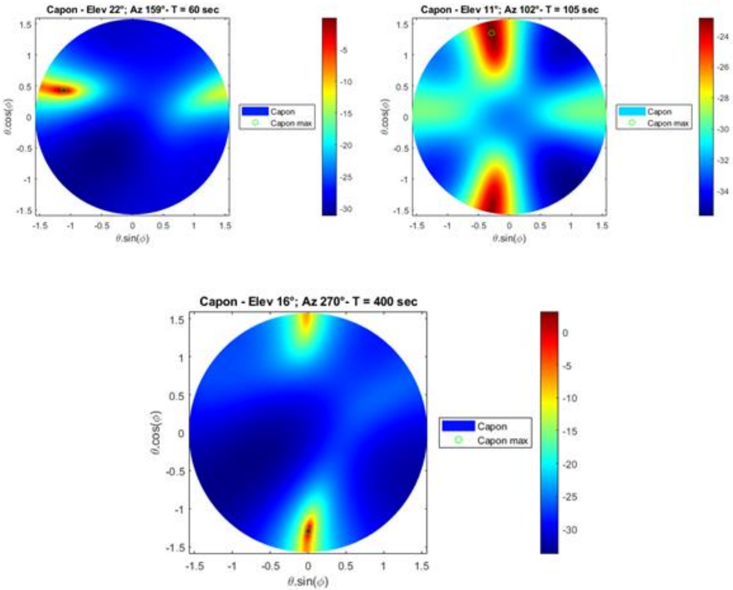
///Laboratory tests

Spoofing detection tests in dynamic

- Scenario:

<table>
<tr><td>Receiver position</td><td>static ; lat: 43.554139°, long: 1.482708, height: 216.01</td></tr>
<tr><td>Spoofer position</td><td>static ; lat: 43.554308°, long: 1.482708, height: 222.84
Az 180°, El : 20°, D=20m</td></tr>
<tr><td>Spoofed trajectory (virtual trajectory suggested by the spoofer)</td><td>
<table>
<tr><th>Start date of event</th><th>Event</th><th>Duration [sec]</th></tr>
<tr><td>T0</td><td>Receiver position, no spoofing</td><td>100</td></tr>
<tr><td>T0+100</td><td>Static spoofing</td><td>20</td></tr>
<tr><td>T0+120</td><td>Linear acceleration of the virtual trajectory of 0.1 m/s² towards North up to a speed of 12 m/s</td><td>120</td></tr>
<tr><td>T0+240</td><td>Constant speed of the virtual trajectory of 12 m/s towards north</td><td>120</td></tr>
<tr><td>T0+360</td><td>Linear acceleration of the virtual trajectory of -0.1 m/s² towards North up to a speed of 0 m/s</td><td>120</td></tr>
<tr><td>T0+480</td><td>Static spoofing</td><td>>120</td></tr>
</table>
</td></tr>
<tr><td>Spoofer power</td><td>3dB above the authentic signal</td></tr>
</table>

- T= 60 sec: DoA in accordance with authentic PRN#12 location
- T = 105 sec: spoofer active and predominant, authentic signal still present with weaker level
- T = 400 sec: only spoofer is followed (authentic signal lost)



Focus on PNR#12 at T=60 sec, T=105 sec, T=400 sec

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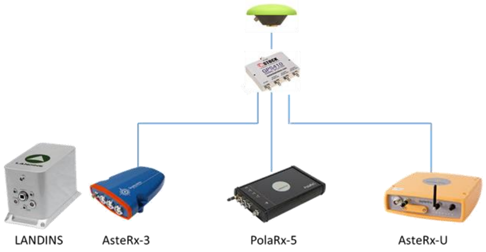
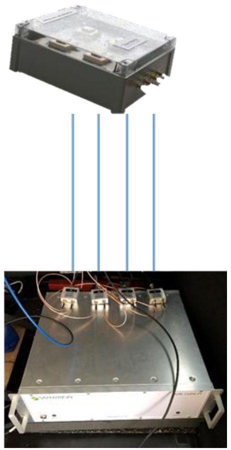
LoCoMotive testing activities

///Live experimentation tests

- Objective is to check the complete LoCoMotive prototype in actual urban GNSS environment
  - To check the performance of the antenna array and the multi-antenna algorithms
  - To check the post-correlation algorithm (multipath mitigation)
  - To check the interest of multi-frequency
  - Installation in GUIDE test vehicle (www.guide-gnss.com)





- Urban trajectory (in Toulouse):

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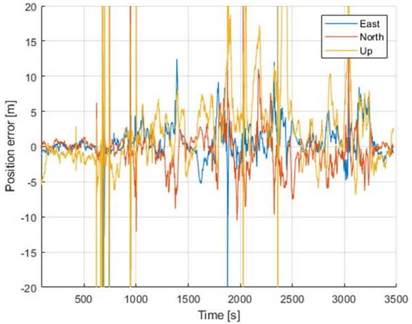
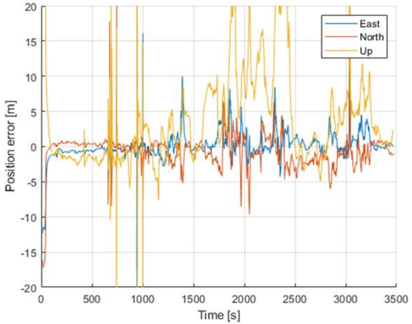
LoCoMotive testing activities

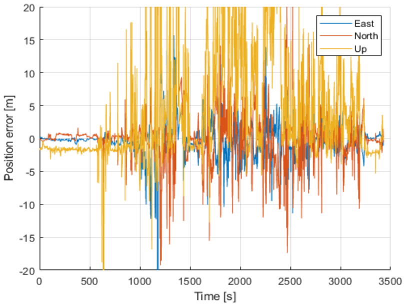
///Live experimentation tests

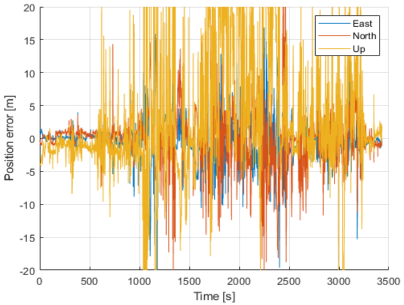
- PVT error of LoCoMotive receiver, embedding Multi-correlators (left = Multi-antenna, right = mono-antenna)

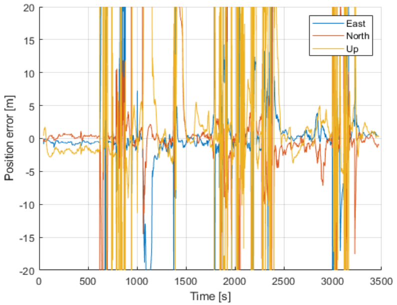




- PVT error in EmLP-corellator: left = Septentrio, middle = Ublox, right = LoCoMotive







LoCoMotive testing activities

///Live experimentation tests

PVT performances

		HPE_50	VPE_50	HPE_95	VPE_95	HPL_50	VPL_50	HPL_95	VPL_95	HMI	VMI	Availability
Bi-constellation (GPS/GAL) Mono-freq (L1)	Multi-antenna MC (KF PVT)	1.63	2.60	7.67	13.93	27.52	44.03	81.07	179.35	0.00	0.00	99.21
	Mono-antenna MC (KF PVT)	1.31	2.63	5.62	20.35	25.06	40.72	56.83	131.00	0.00	0.00	99.33
	Mono-antenna EmLP (KF PVT)	1.29	2.14	24.07	54.26	34.41	52.68	216.26	471.23	0.00	0.00	96.70
	RTKLib PVT (WLS) with Septentrio data	1.31	2.11	10.51	24.49	12.33	9.22	15.13	12.32	2.67	21.8	98.22
	RTKLib PVT (WLS) with Ublox data	2.02	2.57	12.51	28.04	14.30	10.28	17.44	13.07	2.74	20.74	98.95
	Septentrio PVT with PP-SDK	0.58	1.43	5.44	11.47	19.24	28.37	47.89	93.38	0.00	0.00	100.00
Bi-constellation (GPS/GAL) Multi-freq (L1/L5)	Septentrio PVT with PP-SDK	1.40	2.17	5.24	15.55	17.35	27.66	49.99	99.40	0.00	0.00	100.00
All possible const All possible freq	Septentrio (4 const, 3 freq) (Manufacturer PVT)	0.86	0.66	4.78	11.76	4.81	6.55	26.70	38.82	0.99	3.88	100.00
	Ublox (4 const, 1 freq) (Manufacturer PVT)	1.40	2.50	4.86	5.08	6.65	9.60	12.05	16.48	0.00	0.00	100.00

- LoCoMotive receiver in multi-correlator configurations outperforms other configuration. However Septentrio receiver, however on a different antenna (Javad Grant 5T) presents better results.
- In urban environment the multi-antenna algo does not bring apparent improvement, contrarily to simulation prediction
  ➔ quality of antenna questioned
- Multi-correlator shows superiority in the most demanding situations, and offers reduction of Protection Level
- Reference receivers with multi-constellation are better in accuracy and availability

AGENDA

1 LoCoMotive project introduction

2 Market and user: drivers for LoCoMotive requirements

3 LoCoMotive development activities and tests

4 Roadmap toward end product

5 LoCoMotive project conclusion

Roadmap toward end product

/// Background

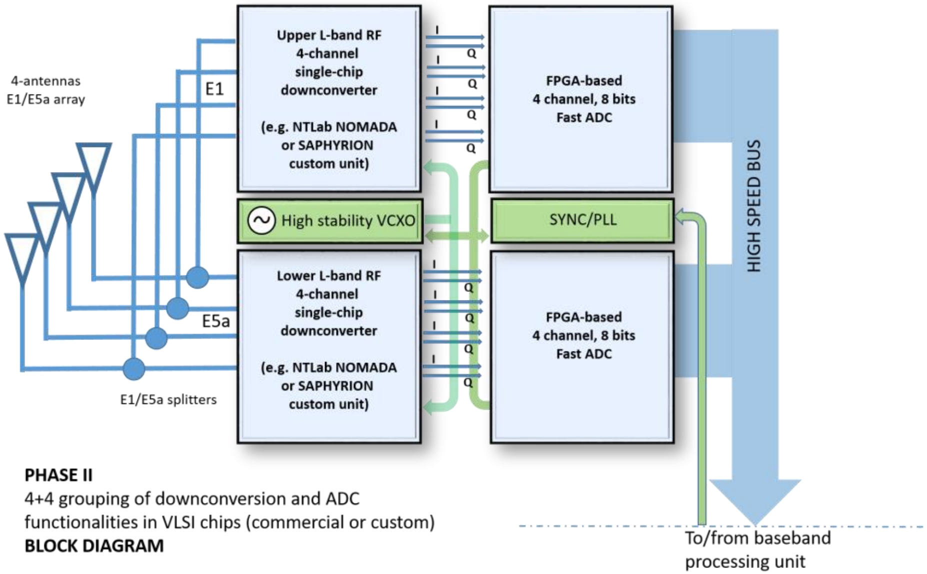
/// The use of GDAS-2S was suggested in the project in order to asses, by a highly sophisticate instrument containing and optimized 4-channels, coherent down-conversion unit, modified for the purposes of the project, a reference scenario enabling to attain the maximum possible performance of the intended architecture.

The modified GDAS-2S unit

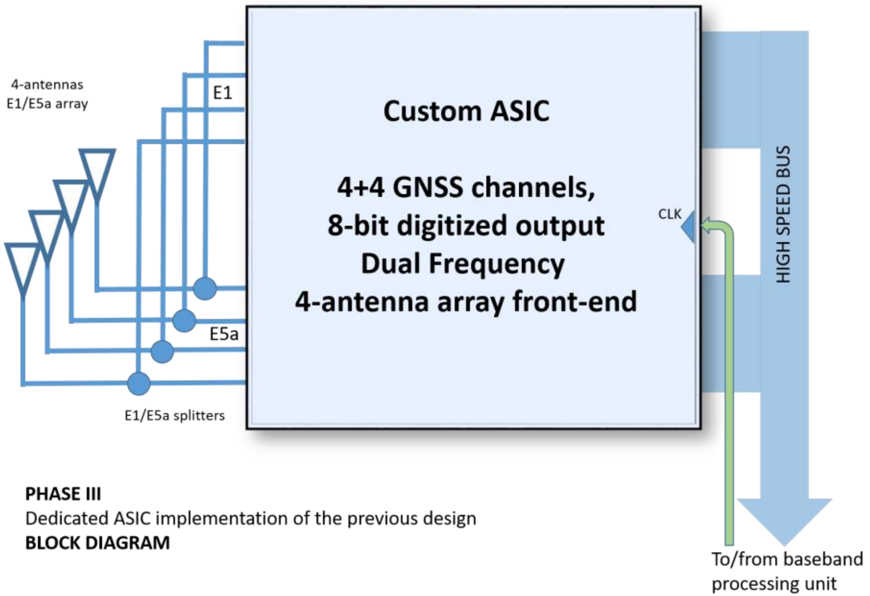
The modified/enhanced GDAS-2S, custom built for the project, has been successfully exploited in the planned experiments. Obviously, owing to its nature of standalone system, it is not a candidate for the industrialized embodiment but has allowed “setting the standard” against which other, low-cost implementations could be compared.

Roadmap toward end product

/// Process to industrialization



PHASE II
4+4 grouping of downconversion and ADC functionalities in VLSI chips (commercial or custom)
BLOCK DIAGRAM



PHASE III
Dedicated ASIC implementation of the previous design
BLOCK DIAGRAM

Saphyrion envisages a two-step industrialization roadmap after the conclusion of the Project (Phase I). In Phase II, a simplified frontend made by several Ics will be rather easily assembled. In Phase III, a complete RF ASIC will gather in a single die all the functionalities needed.

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Roadmap toward end product

/// Commercial and customer opportunities

Phase II product could reach levels of cost already affordable for medium-volume specialized applications in aerospace and Defence. In specialized contexts the importance of discriminating against or detecting spoofing is viewed as an immediate advantage, The concept has been outlined by Saphyrion to few selected aerospace counterparts (ELBIT SYSTEMS (IL), RAFAEL (IL) LEONARDO (IT) and expression of interest for more detailed evaluation have been received.

Phase III product is definitively aimed for mass-market application. Its natural ecosystem would be that of “resilient” GNSS receivers for automatic drive cars. In this context, the growth of interest for such a solution is strictly linked to the overall progress of automatic drive cars, where the enthusiasm has been somewhat moderated by several deadly accident events and by the COVID crisis. Saphyrion has established some preliminary contacts with MAGNETI MARELLI, a renowned Tier 1 supplier of automotive electronics, in view of further discussions.

A market closer to maturity is that of drones which have to be operated in urban areas. Saphyrion interacts with the relevant Italian regulatory body (ENAV) and plans to give a presentation of LoCoMotive technology at the end of the epidemic emergency.

AGENDA

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LoCoMotive project conclusion

///Overall outcomes and lessons learnt

- A consolidated set of requirements suitable for mass market automotive applications.
- A relevant prototype developed: HW and SW.
- A low grade antenna array tested, highlighting some limitations.
- Some innovative algorithms (multi-correlator, multi-antenna) tested in representative environments, confirming the added value of such technology for:
  - RF threats mitigation (jamming, spoofing, multipath), and robustness of the positioning solution;
  - Improvement of the accuracy, in particular in demanding situation;
  - Identification of possible phase jump while activating the blanking.
- A roadmap for industrialization toward the end product, based on implementation in a SoC (System of Chip).

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Thank you for your attention!