GNSSW-MLMSC

GNSS SW RECEIVER For Microlaunchers & Microsatellites

Final Presentation 06/12/2021

INNOVATING SOLUTIONS

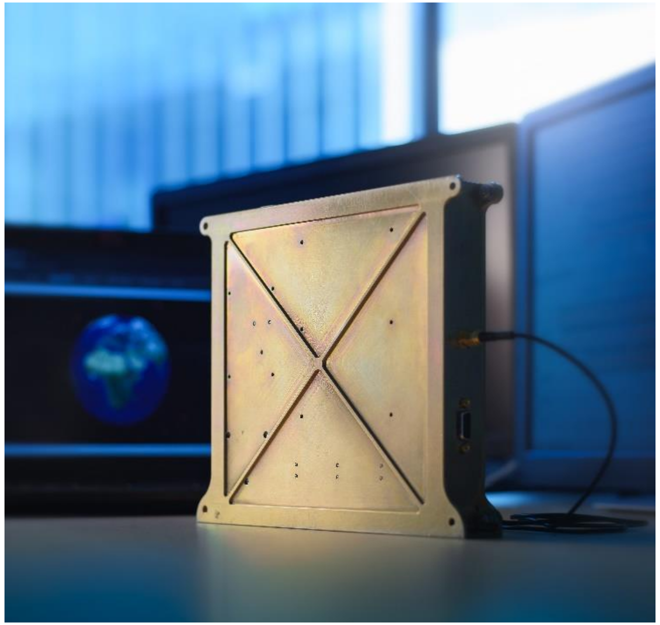
Agenda

- Management
- Requirements
- HW/SW Design
- Integration Activities
- Tests Activities
- Proof of Concept (Dual Frequency Receiver)
- Conclusions
- Discussion

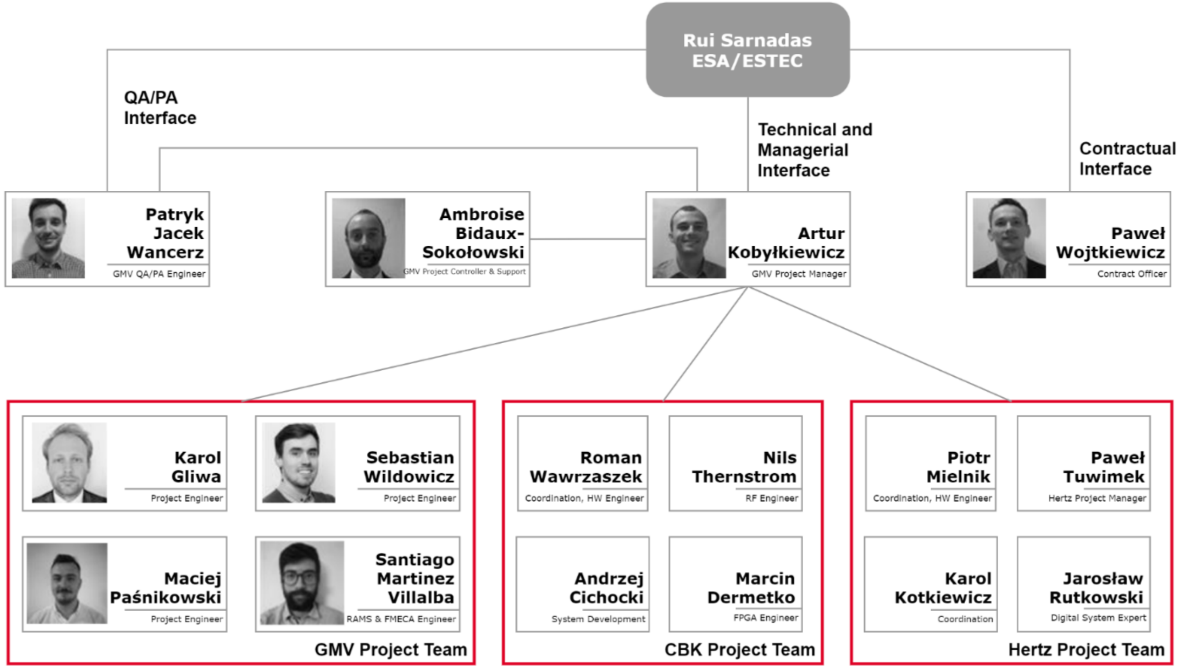
GNSSW-MLMSC
Management

General Info and Study Status

- The GNSSW-MLMSC project was focused on development and validation of the Single Frequency GNSS SW Receiver and evaluation of the project continuation by proof of concept for the Dual Frequency Receiver.
- The following Consortium was involved during the project:
  - **GMV Innovating Solutions** as prime and SW responsible
  - **CBK / PAN** as HW and Environmental Tests responsible
  - **Hertz Systems** as Performance and EMC tests Responsible
- The study was massively delayed (around 18m) due to HW development problems, issues found during first batch of Performance and Environmental tests and was followed by complications related to the global Covid-19 situation and availability of the tests facilities and personnel.
- The extensive Test Campaign has proven the product readiness and it will be flight proven on the MIURA1 microlauncher virgin flight in the 2022 (by the latest updates).
- The Dual Frequency Receiver has been also tested and the outputs proves solution reliability and its further development (under GNSSWLEO project) will be flight proven on the ESA GOMX-5 mission.



Project Team

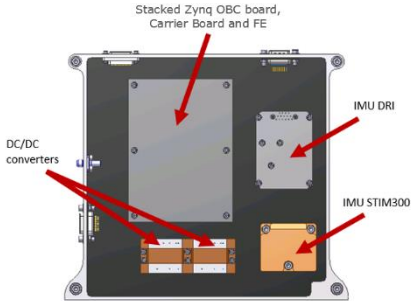


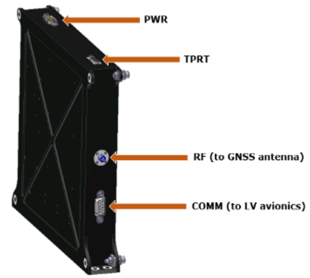
Schedule

Original Schedule		Effective Date	
KO	T0	10/2018	T0
SRR	TO + 2m	19/12/2018	T0 + 2m
PDR	TO + 5m	10/04/2019	T0 + 6m
DR	TO + 9m	27/11/2019 V2: 17/12/2019 CO: 09/06/2020	T0 + 20m
TRR	TO + 10m	27/11/2019 CO: 30/06/2020	T0 + 20m
AR	TO + 12m	15/12/2020 CO: 09/06/2021	T0 + 32m
DR L5/E5 PoC	TO + 16m	28/10/2021	T0 + 36m
Final Review	TO + 18m	28/10/2021 CO: 10/11/2021	T0 + 36m

Summary of Delivered Equipment/Software

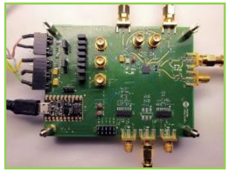
- Integrated GNSS Receiver (HW + SW)
  - fully functional dual band GPS+Galileo single frequencyL1/E1
  - Fully tested (in the scope of MLMSC activity)
  - delivered to Miura1 team as FLIGHT model
  - Activity continued in GNSSWLEO project



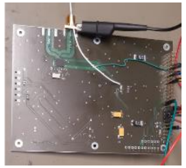


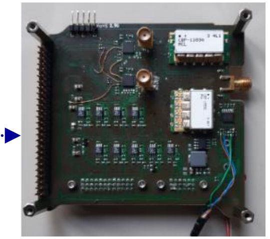
- Dual frequency RF Frontend design and manufacturing
  - Prototype dualband frontend
  - Partially tested with GSS9000 (and Spirent's SimGEN)
  - Activity carried on in GNSSWLEO project (already pre-validated)

Eval Board



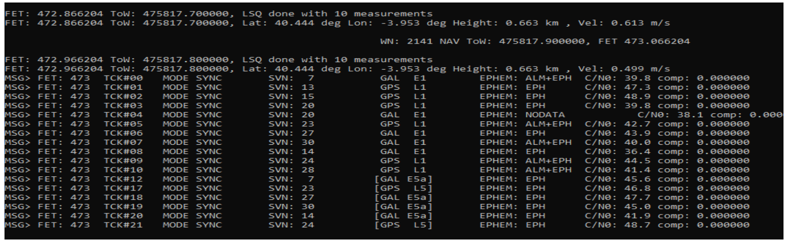
FE_V1





FE_V2

- Dual frequency receiver proof of concept
  - The software realization of dual frequency receiver
  - Supports L5, E5a signals
  - Acquisition and tracking implemented and tested with pre-recorded **REAL** signal
  - Activity continued in GNSSWLEO project



GNSSW-MLMSC

Requirements

Key SW Requirements

Req. ID	Requirement text	Rationale
[SW-LAUNCH-REQ-08]	The launcher receiver should provide navigation solution: PVT in real time.	For the needs of the SC control and external navigation if present.
[SW-LAUNCH-REQ-010]	The launcher receiver shall be able to acquire and track L1-C/A / E1-B/C and the corresponding civil signals from GPS and Galileo.	L1-C/A / E1-B/C frequency covers almost all the needs of the targeted missions.
[SW-LAUNCH-REQ-012]	The launcher receiver shall have the following starting modes: Cold start Warm start	To start in all the expected conditions independently of any other system.
[SW-LAUNCH-REQ-014]	The launcher receiver shall operate with the constellation configurations: Galileo-only, GPS-only and dual constellations.	These 2 constellations will cover most of the future space applications needs for civil use.
[SW-LAUNCH-REQ-016]	The minimum number of channels shall be: 12 channels for GPS-only 6 channels for Galileo-only 9 channels for GPS and Galileo	The number of channel and constellations should be in line with the processor performance.
[SW-LAUNCH-REQ-018]	The navigation accuracy (after dynamic filtering) will be dependent on the application, the following requirements for typical applications are provided here (position velocity & time): Launcher Navigation 50m, 5m.s-1	To fulfil the different mission requirements.
[SW-LAUNCH-REQ-020]	The TTFF in cold start shall be lower than 15min.	TTFF (Time to first fix) - a measure of the time required for a GNSS receiver to acquire satellite signals and navigation data (ephemerides), and calculate a PVT solution (position, velocity, time) based on the measurements.
[SW-LAUNCH-REQ-021]	The TTFF in warm start shall be lower than 5minutes.	TTFF (Time to first fix) - a measure of the time required for a GNSS receiver to acquire satellite signals and navigation data (ephemerides), and calculate a PVT solution (position, velocity, time) based on the measurements.

Key HW Requirements

Req. ID	Requirement text	Rationale
[HW-LAUNCH-REQ-09]	The L1-C/A / E1-B/C FE shall provide samples at 8MHz	
[HW-LAUNCH-REQ-010]	The L1-C/A / E1-B/C FE shall have a BW >=4MHz with 1 to 3bits (configurable) per sample at a frequency of 2MHz.	
[HW-LAUNCH-REQ-011]	The L1-C/A / E1-B/C FE shall provide 1bit I signal samples with 1 bit (sign) quantization.	For sampling the signal few possibilities are made available by Maxim FE. Baseline is to use the I component with an IF non zero.
[HW-LAUNCH-REQ-012]	The L1-C/A / E1-B/C FE shall have its intermediate frequency larger than half the bandwidth, IF >=BW/2.	

GNSSW-MLMSC
HW Design

PDR Baseline Architecture

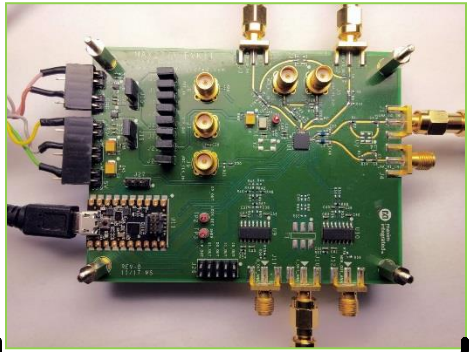
- Front-End architecture based on MAX2771 component, following cases will be proposed:
  - 3 identical channels, each have capability for providing either L1/E1 or L5/E5 (exclusively, both configurable)
  - 2 channels operational and 1 channel for redundancy purpose
  - Single channel version
- Digital part of the system is considered in following versions:
  - Utilization of SAMV71 microprocessor + FPGA architecture,
  - Zynq 7030 version for 2 bands receiver case,
  - New option on the horizon which could base on SAMA5D2

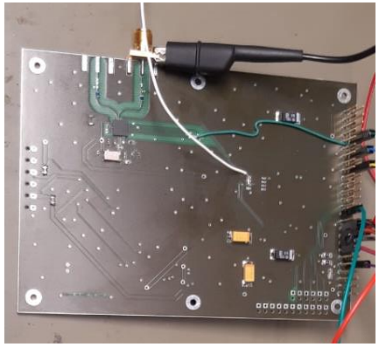
*) Baseline for single channel version to be tested on Miura1.

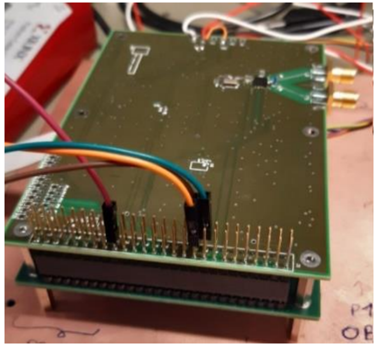
- Power system:
  - Two steps power conversion and distribution system based on DC/DC converter with galvanic separation as a first followed by LDOs.

FE Development – Assumptions vs Implementation

MAX2771 eval board utilization → Custom made board development → Updated FE board development → Double bands FE board development







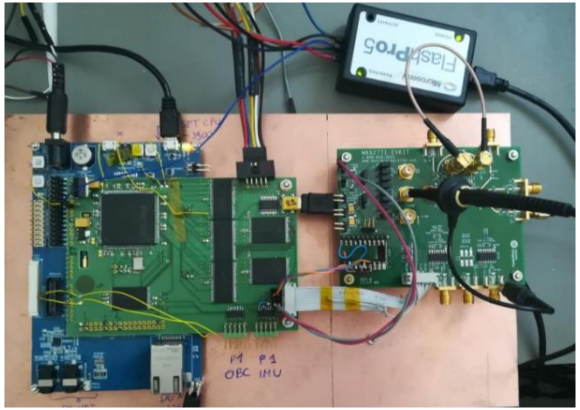
Utilized for preliminary tests and for reference.

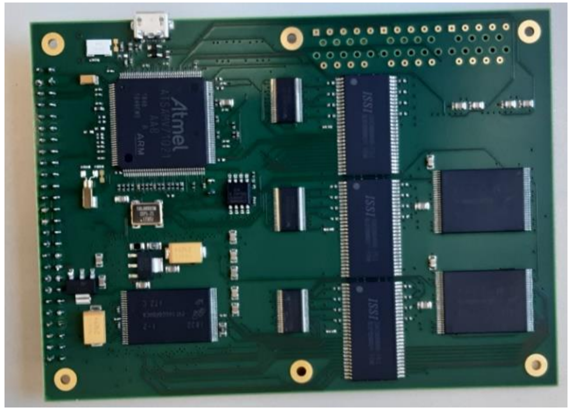
In fact there were 3 iterations between the first and final FM board of RF FE.

Double band receiver with integrated splitter and filters.

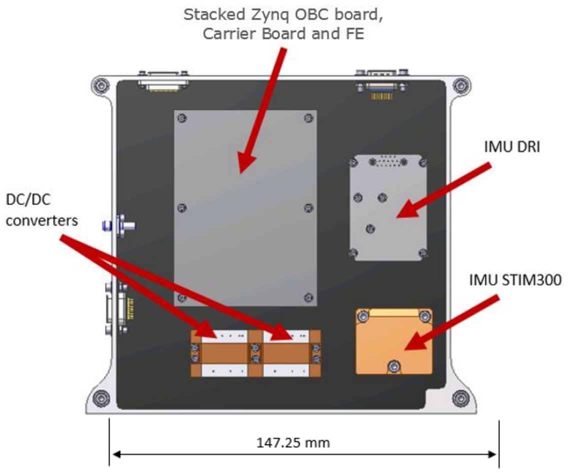
OBC Development – Assumptions vs Implementation

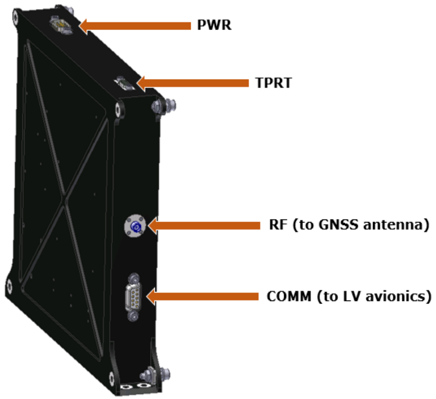
SAMV71 eval board utilization → Custom made board development → Zynq board utilization

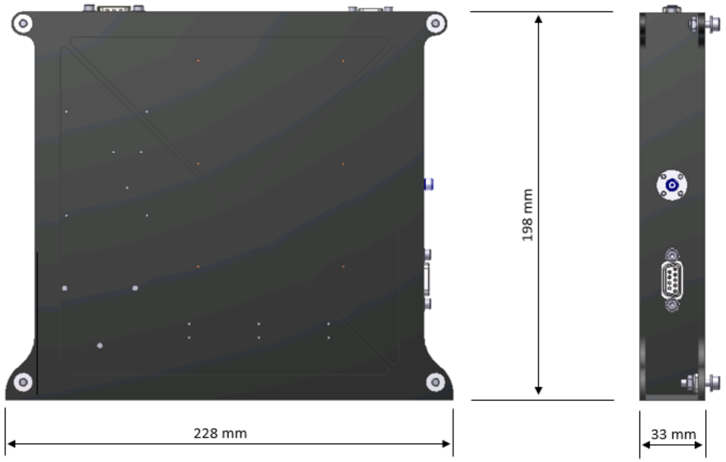


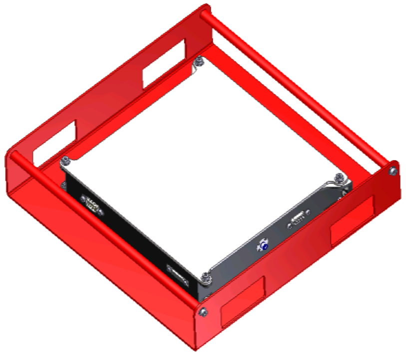


LV Single Band GNSS Receiver Design and Integration









Real Assembly

33mm of thick does not includes cover designed for protection and support during tests.

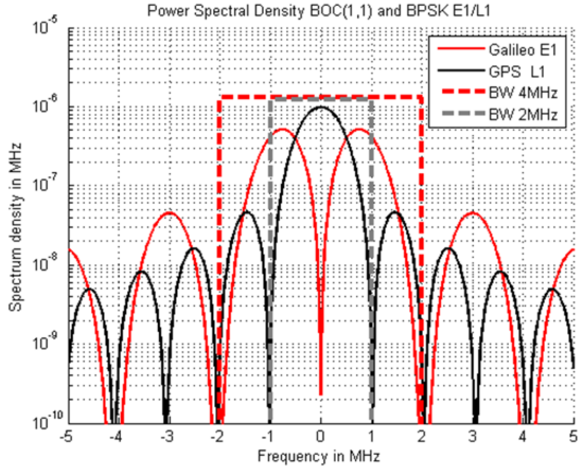
GNSSW-MLMSC
SW Design

Key GNSSW-MLMSC SW Features

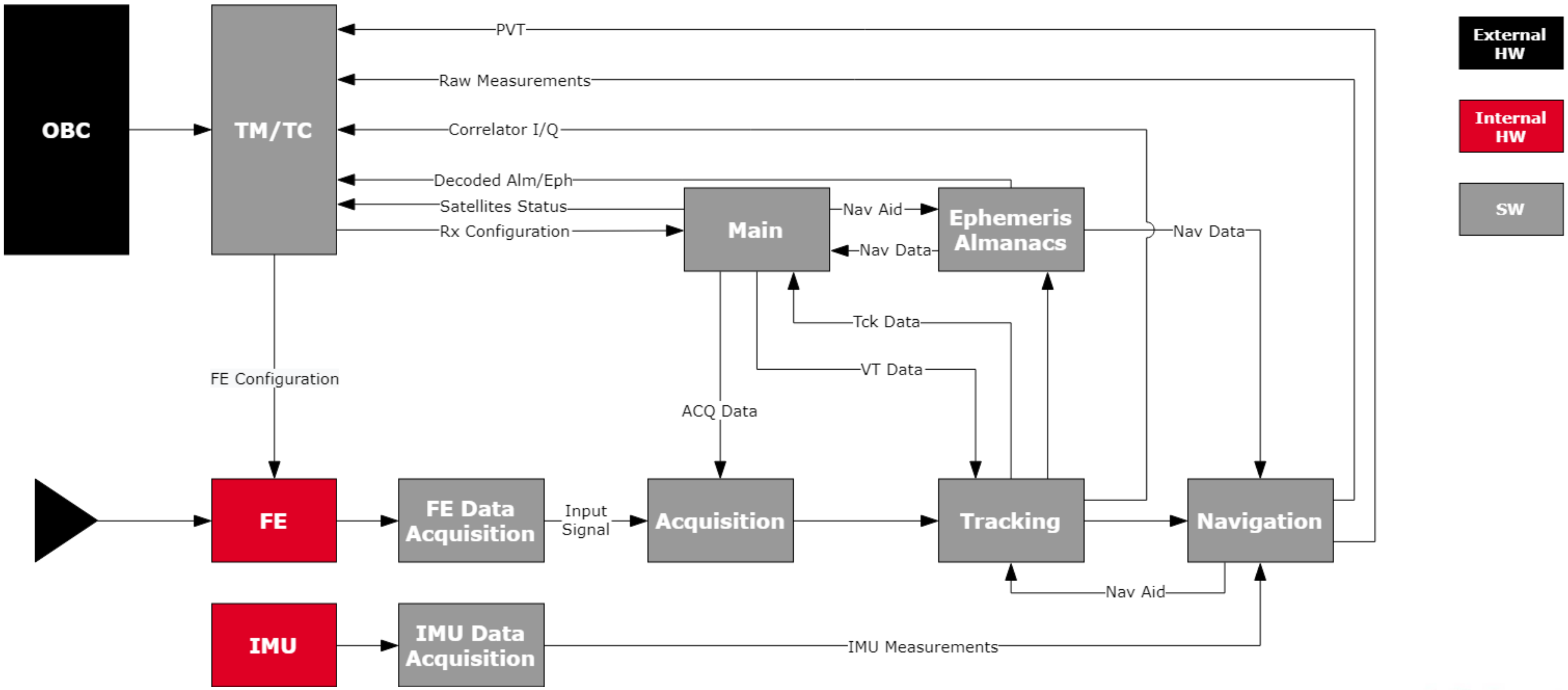
Focusing on Zynq implementation:

- The application runs on **RTEMS OS**
- Dual constellation (GPS+Galileo) using single frequency (L1-CA + E1-OS B+C)
- All **Signal Processing** done by **CPU**
  - pushes to the limits the computing capabilities of the platform
  - Utilizes processing „trick" in order to ensure real time operation
- 1-bit real (intermediate frequency) signal sampling
- **FFT acquisition**
- VT acquisition (narrow, time domain, fast) – used in Warm-start, and after stable PVT achieved
- Flexible SW architecture that allows for future improvement:
  - Porting the code for different CPU platforms with reduced effort (already multiple platforms tested, Zynq, Pynq, Leon-4, standalone windows application)
  - Moving blocks certain blocks of the receiver to FPGA module (e.g. Tracking module on Zynq)
- Code phase based navigation

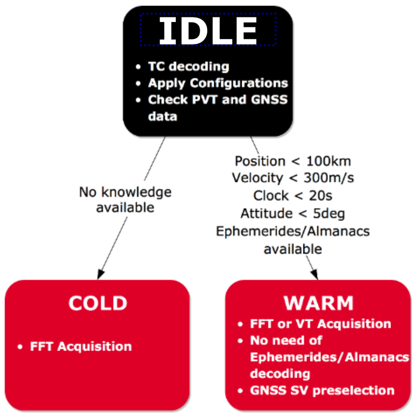
Parameter	Value
FE oscillator frequency	16 MHz
FE center frequency	1575.42 MHz
FE sampling frequency	**8 MHz**
FE bandwidth	4.2 MHz
FE intermediate frequency	**2046 kHz**
Quantization	1 bit (1 only)
GPS FFT Acquisition	1ms, 8 ksamples data, 0 padding to 2^14 samples, **resolution 488 Hz**
GAL FFT Acquisition	4ms, 32 ksamples data, 0 padding to 2^15 samples, **resolution 244 Hz**



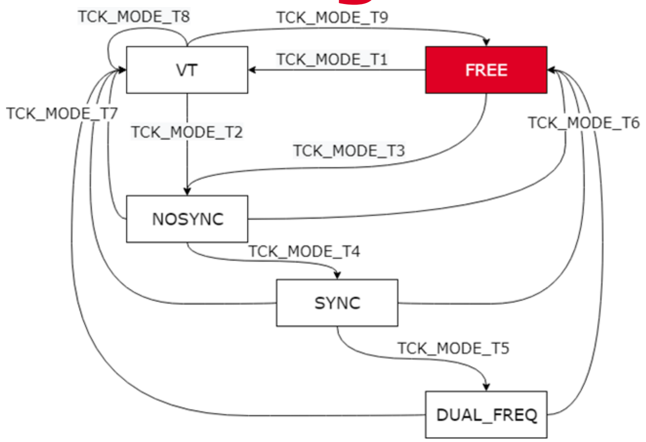
High Level Architecture



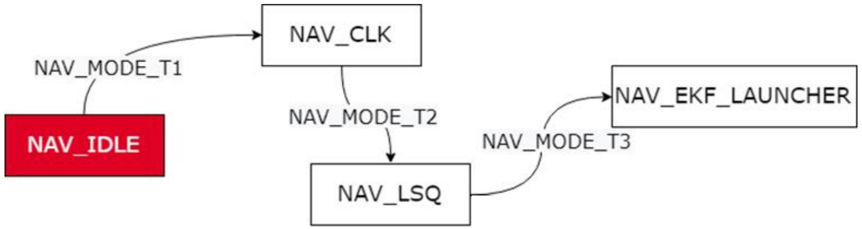
Receiver Modes



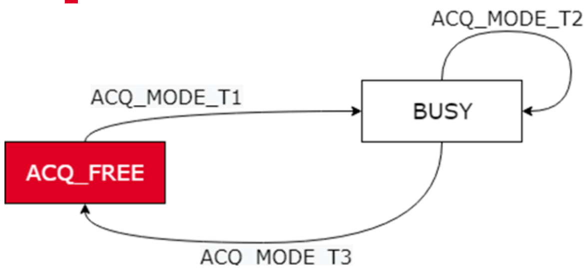
Tracking Modes



Navigation Modes



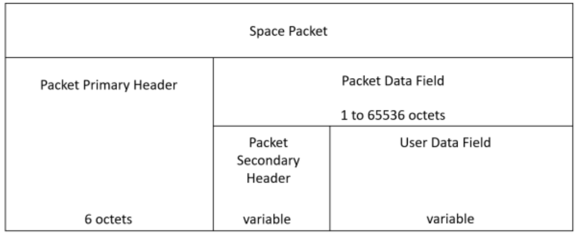
FFT Acquisition Modes



TC / TM

- The communication with the GNSS receiver realized via telecommands (TC) and telemetry (TM).
- It has been implemented using the CCSDS Space Packet protocol, to transport the PUS service messages.

CCSDS Packet Layout

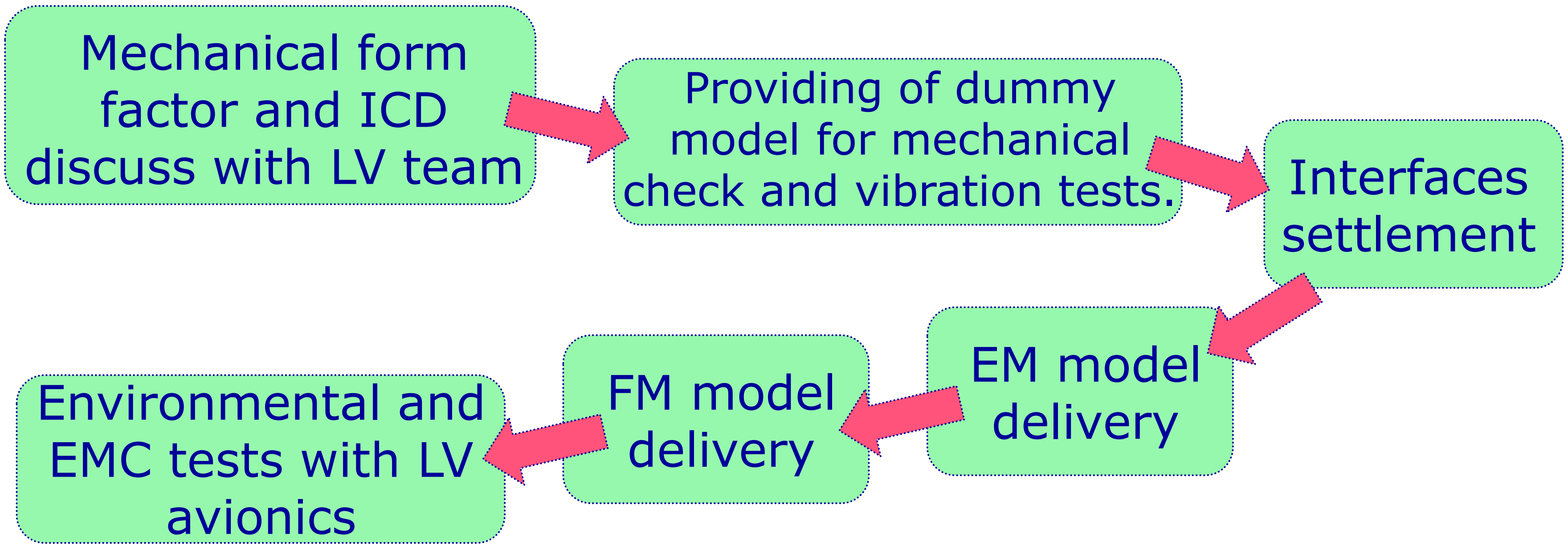


Example of Hausekeeping Service

SID	Content of HK	Message Type	HK size [bytes]	Packet size [bytes]	output rate [Hz]	data throughput [B/s]
01	FE Configuration	Front End (FE) configuration	48	65	-	-
02	RX Configuration	Message composed of five parameter sets: 1. GNSSW Configuration Parameters, 2. Acquisition (ACQ) Configuration Parameters, 3. Navigation (NAV) Configuration Parameters, 4. Tracking Lock (LCK) Configuration Parameters, 5. Tracking (TCK) Configuration Parameters	406	423	-	-
03	PVT	Position, Velocity and Timing (PVT)	164	181	10	1640
04	TCK CHn status	Tracking Channel (TCK_CHXX) Status Parameters	97	114	10	970
22	ACQ status	Acquisition Channel (ACQ_CHXX) Status Parameters	92	109	at acquisition event (satellite acquired or not acquired)	-
23	ALM/EPH SYSTEM SVNn	Almanac and Ephemerides (ALM/EPH) Parameters	236	253	at parameters update	-
91	SAT_STATUS	Satellite Status	80	97	10	800
92	RX_STATUS_MODE	Current GNSS receiver processing mode	5	22	at parameters update	-
93	MCU_LOAD	Current MCU load during GNSS signal processing	12	29	on demand by TC	-

GNSSW-MLMSC Integration Activities

Technical Actions Related to Flight Configuration



Summary:

- During development process several models has been exchanged with LV team
- Finally provided FM model is compatible mechanically and electrically with LV avionics
- EMC properties has been accepted by LV team and approved in common EMC testing

GNSSW-MLMSC

Tests Activities

Tests Schedule

Mono Frequency Receiver Performance Tests by Hertz:

- Anomalies and faults detected, further development was needed → **Secondary test campaign needed**
- The identification of fault points by **Hertz contributed with great software improvement and debug**

EMC tests by Hertz:

- Conducted on 18-21 August 2020

Hertz

Environmental tests by CBK:

- Thermal tests defined on 30 November 2020
- Vibration tests conducted on 21-22 October 2020
- Functional tests performed 01-03 December 2020 and during other Environmental tests activities

EMC tests by CBK:

- EMC tests to clarify Hertz results and to prove validity of CBK facilities:
  - First batch of EMC tests conducted on 01-09 October 2020
  - Second batch of EMC tests conducted on 26-30 October 2020

CBK

Secondary Mono Frequency Receiver Performance Tests by GMV:

- Conducted from 08 to 22 February 2021 to finalize the performance tests. The test covers most of the tests from Performance tests by Hertz. It was performed on PW.

GMV

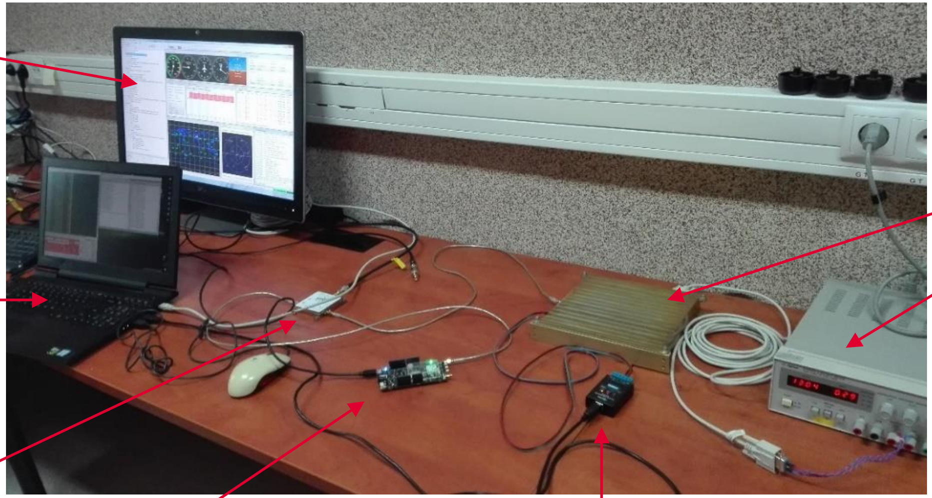
Hertz Systems Performance Test

- Test stand

In the MUT the GSS Spirent simulator was placed in separated Servers Room, in 19" rack cabinet

RF signals from simulator were distributed from the front RF output. GSS9000 for this output has possibility to transmit GNSS signals with maximum 20dB gain regarding nominal GNSS signals. **This 20dB gain was enough for GNSSW**.

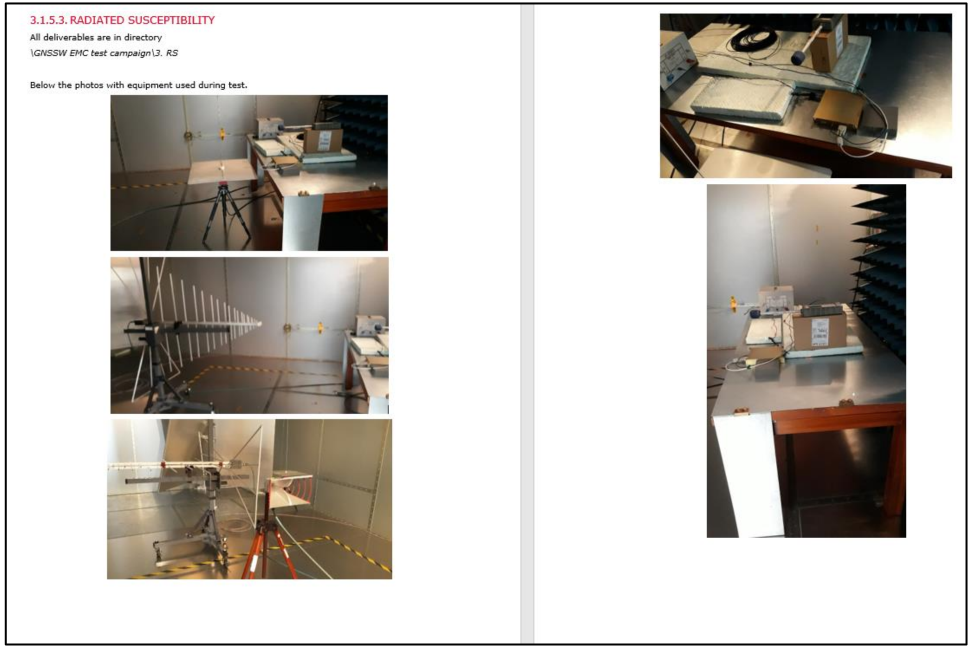
The GNSSW receiver with power supply and host computer were placed in the room adjacent to the Service Room. On the screen below GNSSW test stand is presented.



Hertz Systems EMC Test

- Results - Receiver Test Report for both Performance and EMC Tests (document consists 135 sheets) and all data files were delivered to GMV at 25/09/2020

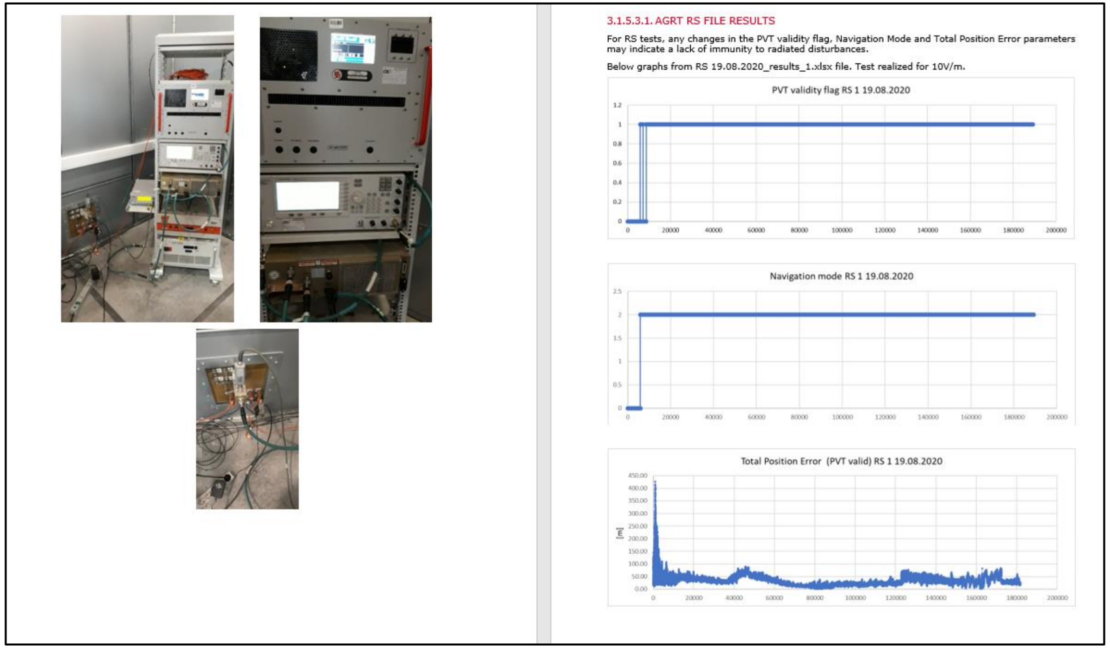
Below as example only part of results from RS


3.1.5.3. RADIATED SUSCEPTIBILITY

All deliverables are in directory

\GNSSW EMC test campaign\3. RS

Below the photos with equipment used during test.


3.1.5.3.1. AGRT RS FILE RESULTS

For RS tests, any changes in the PVT validity flag, Navigation Mode and Total Position Error parameters may indicate a lack of immunity to radiated disturbances.

Below graphs from RS 19.08.2020_results_1.xlsx file. Test realized for 10V/m.

Hertz Systems EMC Test

- Results Tables (*final document excerpt*)

Table 3-1: Radiated Emission Tests Results

Test ID	Parameter	Pass/Fail Criteria	Result
T01	2MHz do 30MHz (5 measurements): - standard measurement - receiver tracks SV signals, communication cable disconnected - as above plus communication interface covered with a copper tape - as above plus disconnected antenna (after acquiring of PVT solution) - only first 90 seconds after switch on	Measured values shall not exceed the required levels as reference in [HW-LAUNCH-REQ-024].	FAIL Note
	30MHz – 200MHz for V polarization		PASS
	30MHz – 200MHz for H polarization		PASS
	200MHz – 1GHz for V polarization		PASS
	200MHz – 1GHz for H polarization		PASS
	1GHz – 6.6GHz for H polarization		PASS
	1GHz – 6.6GHz for V polarization		PASS

Note:
To exclude of influence cables delivered in set on results, the measurement without communication cable is the most representative. For this test there are overflows only between 25-30MHz with maximum delta value 7dB. The receiver manufacturer should pay the attention on any electronics components that work in this frequency.

Table 3-2: Conducted Emission Tests Results

Test ID	Parameter	Pass/Fail Criteria	Result
T02	Conducted emission	Measured values shall not exceed the required levels as reference in [HW-LAUNCH-REQ-024].	FAIL Note

Note:
The original cable delivered for the test was reworked by Hertz (see description in the chapter 3.3.2). Nevertheless, the limits were exceeded.
During the analysis of the data from AGRT file (in post-processing), problems with the stability of PVT solutions were also observed. The nature of the disorder, that occurred short time after switch on are different as that observed in RS test and which were signalized during Performance (mono frequencies) tests.

Table 3-3: Radiated Susceptibility Tests Results

Test ID	Parameter	Pass/Fail Criteria	Result
T03	10V/m (8 measurements): 2kHz - 5MHz 5MHz – 30MHz 30MHz – 1GHz for H polarization 30MHz – 1GHz for V polarization 1GHz – 4,2GHz for H polarization* 1GHz – 4,2GHz for V polarization* 4,2GHz – 18GHz for H polarization 4,2GHz – 18GHz for V polarization	Measured values shall not exceed the required levels as reference in [HW-LAUNCH-REQ-024].	PASS Note
	50V/m (8 measurements): 2kHz - 5MHz 5MHz – 30MHz 30MHz – 1GHz for H polarization 30MHz – 1GHz for V polarization 1GHz – 4,2GHz for H polarization* 1GHz – 4,2GHz for V polarization* 4,2GHz – 18GHz for H polarization 4,2GHz – 18GHz for V polarization		PASS Note

* without the bandwidths 1090 – 1291 MHz and 1475 – 1675MHz

Note:
During the analysis of the data from AGRT file (in post-processing), problems with the stability of PVT solutions were also observed. The nature of the disorder, that occurred long time after switch on are very similar for that observed during Mono Frequencies Test.

Environmental tests performed in a context of GNSS-FM01 module

- **Monofrequency pre- assembly tests**
- **DRI IMU test**
- **Vibration Tests**
- **Active vs Passive antenna + LNA test**
- **Thermal Cycling Test**
- **TF verifications**

- Data completeness
- NAND data storage
- CLK frequency
- other

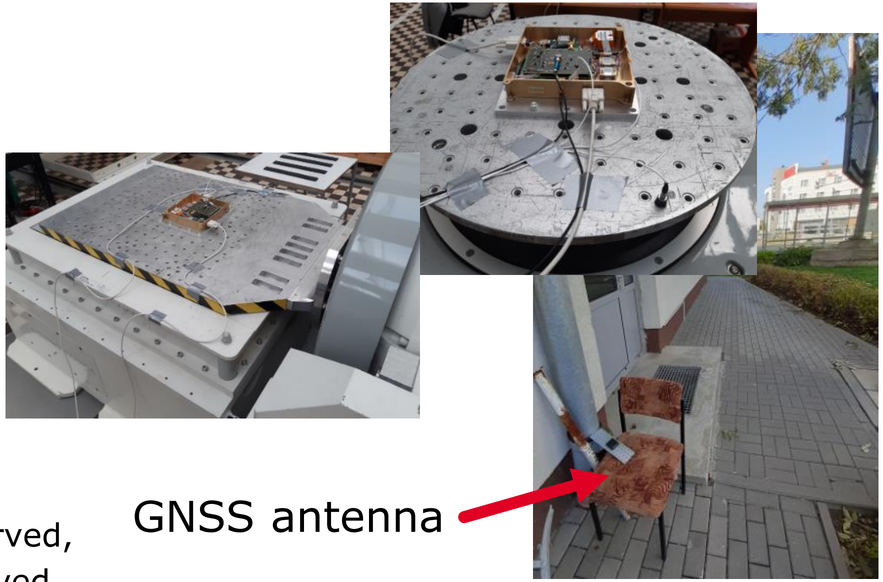
Performed in Institute of Aviation (Warsaw) premises

Additional EMC tests performed in CBK's Faraday's cages to verify HERTZ tests findings.

Environmental tests remarks

Vibration tests results proves that:

- no resonances in frequencies below 100Hz were observed,
- no malfunctions, resets or other problems were observed,
- no changes in structural integrity of the module were observed,



Thermal tests:

- no malfunctions in a form of resets, data drops or other has been observed.
- All parameters were nominal and in accordance with predictions.
- No significant impact of temperature on electrical properties was observed,
- minor (less than 10%) modulation of current consumptions was observed.

- EMC tests:
- tests performed by Hertz the receiver exceeds the emissions limits in RE and CE .
- Hertz findings were confirmed by CBK
- The emission issues source was identified as communication lines.
- Additional EMC filtering modules from VPT was bought and space in the mechanical frame for utilization of it has been selected. However due to acceptance of the levels by customer (LV team) this mitigation was not implemented finally.

Secondary Performance Test Campaign

- The Primary test campaign proven the most of required operational requirements but incompatibility and anomalies were detected to (and had to be fixed)
- It has been discussed and **agreed with ESA that test campaign must be repeated**
- Key incompatibilities and anomalies (**Hertz's input**):

Issue	Subject	description	status	Comment to the status/solution
During long duration stationary tests the position total error increased	***Receiver***	[...] increasing of position error was detected the tests with real SV signals were conducted. [...] The phenomenon also appeared for tests with real signals [...]	CLOSED	The source of rising position error has been detected and eliminated (clock bias has been erroneously taken into account twice in calculation of next measurements time, which resulted in inconsistency in synchronization beteen the measurements time and GNSS time)
During long duration stationary tests receiver has restarted itself	***Receiver***	This occurred for GAL static test and with Real SV signals test. For this second test the receiver during 14 hours restarted itself 2 times. The problem has been reported to GMV.	CLOSED	Problem detected and Fixed (watchdog triggering)
Long time required to requisition process (TTSF) after disconnecting antenna cable	***Receiver***	Disconnecting the antenna cable for a few seconds should work position reacquisition in time shorter than that for Warm Start. During that kind of test the receiver had a problem to reacquire SV signals. [...]	CLOSED	Disconnecting antenna cable is not nominal case. During test the signal shut down at GNSS signal simulator level has been tested and complete reacquisition has been observed.
The PVT solutions have time stamp of current time	***Receiver***	[...] After comparing data from simulator GSS moved on 100ms forward with PVT data from receiver [...]	CLOSED	Fixed,the timestamp (PVT ToW) is aligned correctly, confirmed in test campaign 2 - no adjustments on ToW has been done ever since then.
The receiver has worked only in System Mode Both	***Receiver***	After changing System Mode from "Both" to "GPS only" or "Galileo only" the receiver doesn't gave the PVT solution.[...] This problem was solved on Test Day 10 by changing firmware in receiver.	CLOSED	Solved, no problems observed when changing navigation system(s) since fix
Value of WN in PVT data for GPS only signals is wrong ad lack of WN for GALILEO – only signals	***Receiver***	WN reported in PVT message is distributed only for GPS SV signals and its value is >1023 but < 2046.Currently after 2 rollovers WN should be either < 1023 or > 2046.[...]	CLOSED	Solved,the Galileo to GPS ToW fixed (2 rollovers included in Galileo ToW)
The ToW from receiver exceeds 604800	***Receiver***	During analyzing of static tests results the value of ToW bigger than 604800 was detected.	CLOSED	Detected and fixed. Verified with ToW rollover on Saturday/Sunday (in Spiernt scenario)
The receiver has not worked with EKF	***Receiver***	The issue has been confirmed by GMV.	CLOSED	It is confirmed that EKF is not implemented in MLMSC
The receiver needs additional gain	***Receiver***	The minimum additional gain for default settings to work of the receiver properly is 20dB.	CLOSED	25dB external LNA has been used in second test campaign, nominal power in Spirent scenario.
Receiver data on the output only with 10Hz frequency	***General***	[...]" Because there wasn't possibility to change default value of the frequency of PVT data from receiver to 1Hz, during stationary long duration tests (4 hours) the size of files was so big for 10Hz [...]	CLOSED	The feature of sending PVT HK with 1Hz has been successfully retested. In nominal conditions the output rate of PVT HK is 10Hz. This configuration has bee used in second test campaign.
Resign during analysis from Matlab scrips	***General***	[...]Data processing in the Matlab environment was abandoned in favor of the data synchronization application and data presentation in the Excel environment [...]. Therefore, each measurement session consists of the subdirectori	CLOSED	N/A, In new test campaign all data has been post processed with a set of Matlab Scripts (modified or newly created)
Original Launcher scenario has to short standing part	***General***	[...]Because the standing part in Launcher scenario lasts 5 minutes this scenario can be tested only with Warm start [..]	CLOSED	Launcher scenario has 10min of static position at the begging.

Scope of Tests

- The scope of performance tests has been (slightly) reduced to minimize time of another campaign preserving all performance tests
- The reduction of (certain) tests' time and repetition number is considered not impacting the overall accuracy of tests

Table 3-21: Test Definition Scope

Test	Scope
T001	Performing two measurement sessions, each 4h to estimate the position error for real L1 GPS and E1 Galileo signals. Performing two measurement sessions, each 4h to estimate the position error for real L1 GPS and E1 Galileo signals.
T002	Verification of the correctness of decoding by the AGRT application of TM messages from the receiver and AGRT performance tests for the following assumptions: a) PVT and TCK data output frequency from the receiver - 10 Hz b) frequency of data output from GSS9000 - up to 50Hz
T004	To determine position error for single system (GPS) in static position
T005	To determine position error for single system (GALILEO)
T003	To determine position error for dual system (GPS and GALILEO) in static position
T007	To determine position error for single system (GPS) in dynamic position
T008	To determine position error for single system (GALILEO) in dynamic position
T006	To determine position error for dual system (GPS an GALILEO) in dynamic position
T010	To determine Time To First Fix (cold start) for single system (GPS) in static position
T011	To determine Time To First Fix (cold start) for single system (GALILEO) in static position
T009	To determine Time To First Fix (cold start) for dual system (GPS and GALILEO) in static position
T010W	To determine Time To First Fix (warm start) for single system (GPS) in static position
T011W	To determine Time To First Fix (warm start) for single system (GALILEO) in static position

Table 3-22: Reduced Test Plan with comparison to Nominal.

Nominal Test Plan					Reduced Test Plan			
Test	Single Test Duration [min]	Single Test Duration [h]	Nuber of repertitions	Cumulated Duration Time [h]	Reduced duration [min]	Reduced duration [h]	Reduced repetition number	Cumulated Reduced Time [h]
~~T001~~	~~240.00~~	~~4.00~~	~~2.00~~	~~8.00~~	240.00	4.00	0.00	0.00
~~T002~~	~~480.00~~	~~8.00~~	~~2.00~~	~~16.00~~	480.00	8.00	0.00	0.00
T004	240.00	4.00	1.00	4.00	120.00	2.00	1.00	2.00
T005	240.00	4.00	1.00	4.00	120.00	2.00	1.00	2.00
T003	240.00	4.00	1.00	4.00	240.00	4.00	1.00	4.00
T007	60.00	1.00	5.00	5.00	60.00	1.00	1.00	1.00
T008	60.00	1.00	5.00	5.00	60.00	1.00	1.00	1.00
T006	60.00	1.00	5.00	5.00	60.00	1.00	1.00	1.00
T010	30.00	0.50	5.00	2.50	30.00	0.50	5.00	2.50
T011	30.00	0.50	5.00	2.50	30.00	0.50	5.00	2.50
T009	30.00	0.50	5.00	2.50	30.00	0.50	5.00	2.50
T010W	10.00	0.17	5.00	0.83	10.00	0.17	5.00	0.83
T011W	10.00	0.17	5.00	0.83	10.00	0.17	5.00	0.83
T009W	10.00	0.17	5.00	0.83	10.00	0.17	5.00	0.83
T012	30.00	0.50	10.00	5.00	30.00	0.50	2.00	1.00

Tests Facility

- Test facility at Warsaw University of Technology at the Faculty of Geodesy and Cartography
- Campaign date: 08-22/02/2021
- The test setup has been modified wit **LNA** used
- Same scenario set is the same as for former test campaing

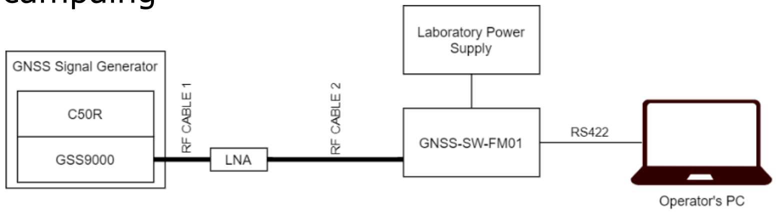
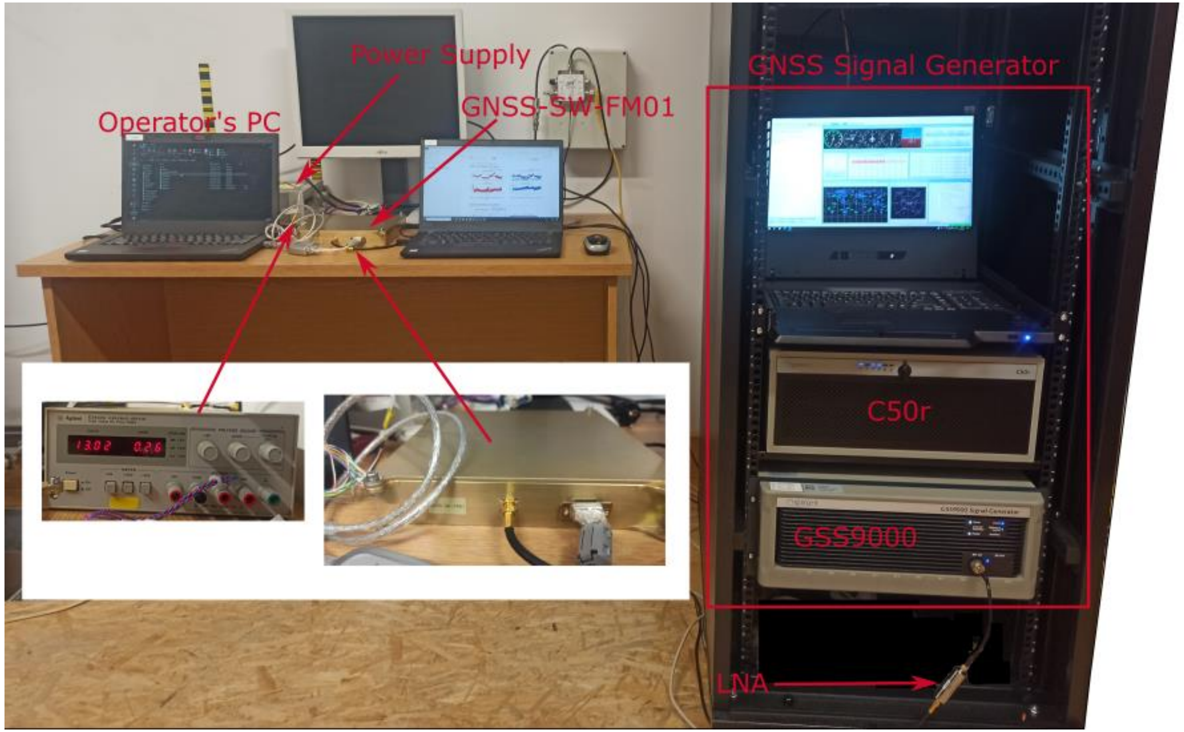
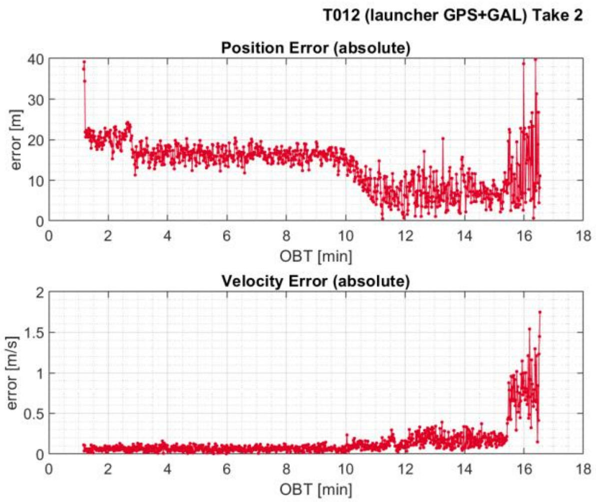


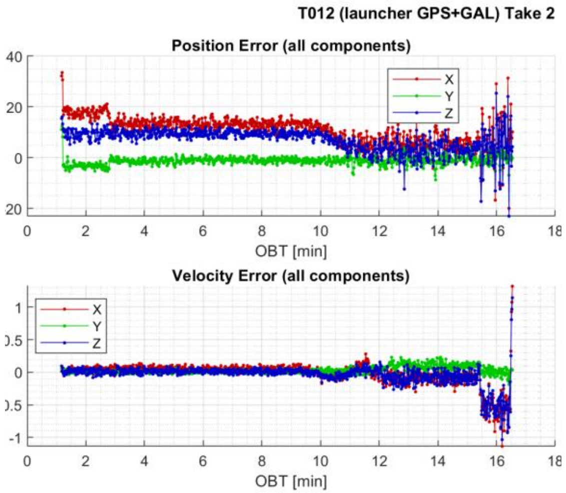
Table 3-23: Summary of test configuration

No	Device	Model andSerial Number	Addidtional Information
1	GNSS-SW-FM01 (DUT)	GNSS-SW-FM01	DUT, SW version 2.5.0
2	GSS9000/C50r	90002044	GNSS Signal Generator
3	LNA	Tallysman TW 120, 20200117	G = 25dB
4	Power Supply	Agilent E3630A	
5	RF Cable 1	n/a	L ~= 20 cm
6	RF Cable 2	n/a	L ~= 2.5 m
5	Operators PC	n/a	commanding GNSS-SW and logging data with AGRT
6	AGRT	V1.0.0.33	Application for GMV Receiver Testing (HERTZ)

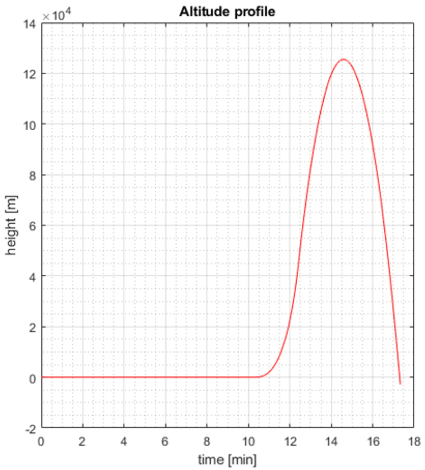


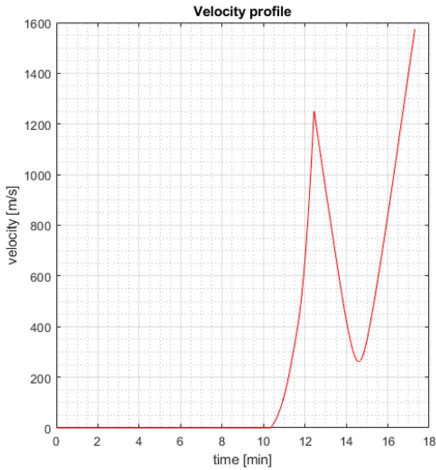
Results (Launcher)

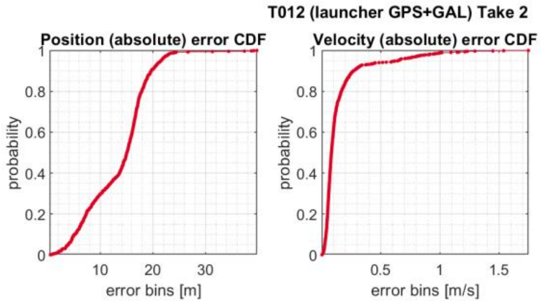




Motion profile





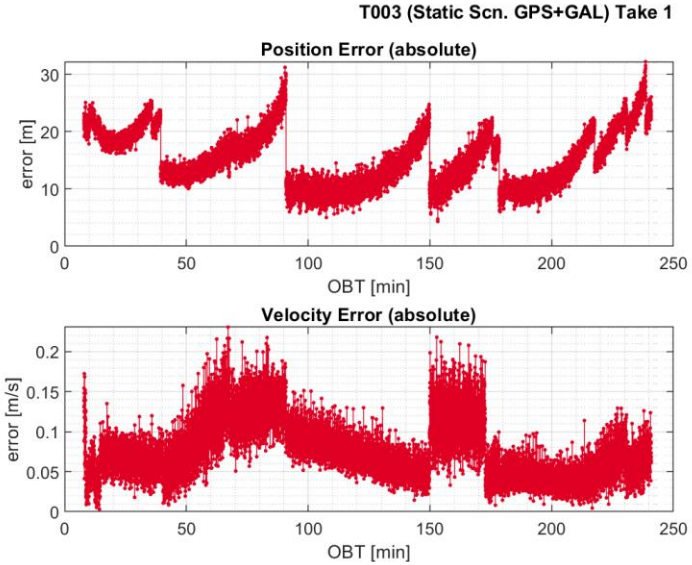


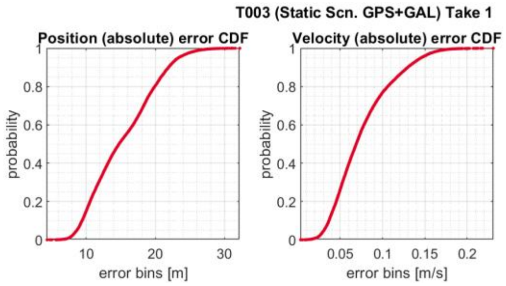
error	mean	μ+3σ	unit
pos.	13.5	30.9	[m]
vel.	0.147	0.760	[m/s]

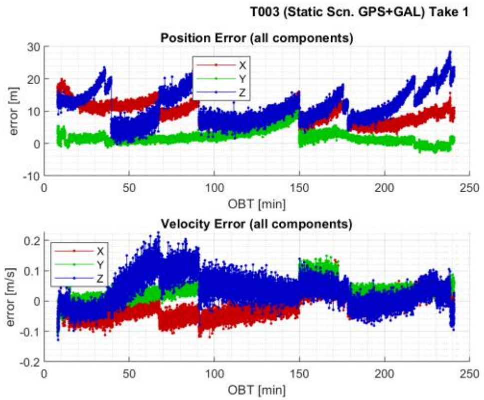
- Navigation during whole flight
- Reduced atmospheric delay and position error at high altitudes

Secondary Performance Test Campaign

Results (Static)

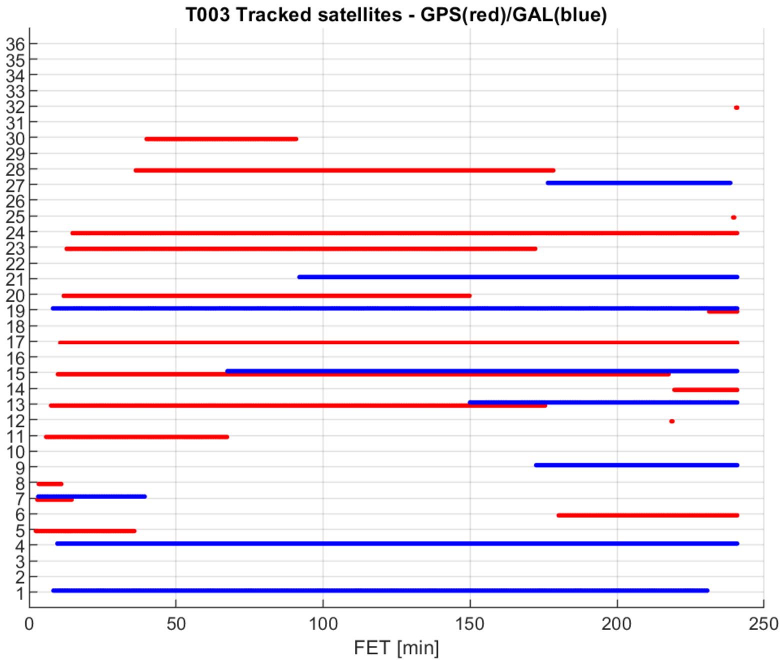




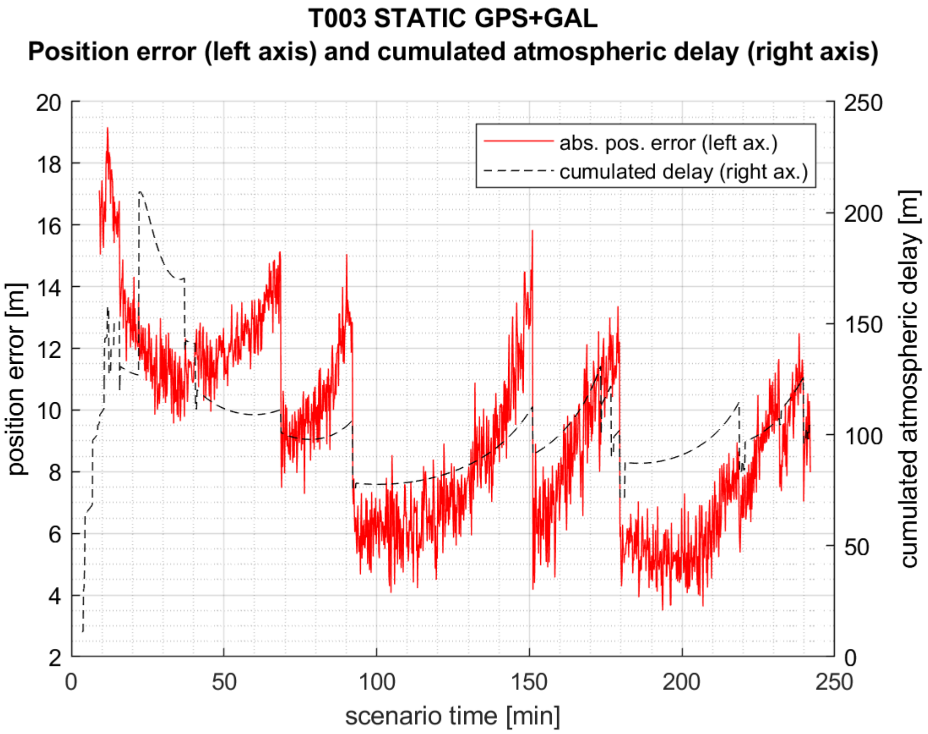


error	mean	μ+3σ	unit
pos.	15.3	29.8	[m]
vel.	0.076	0.183	[m/s]

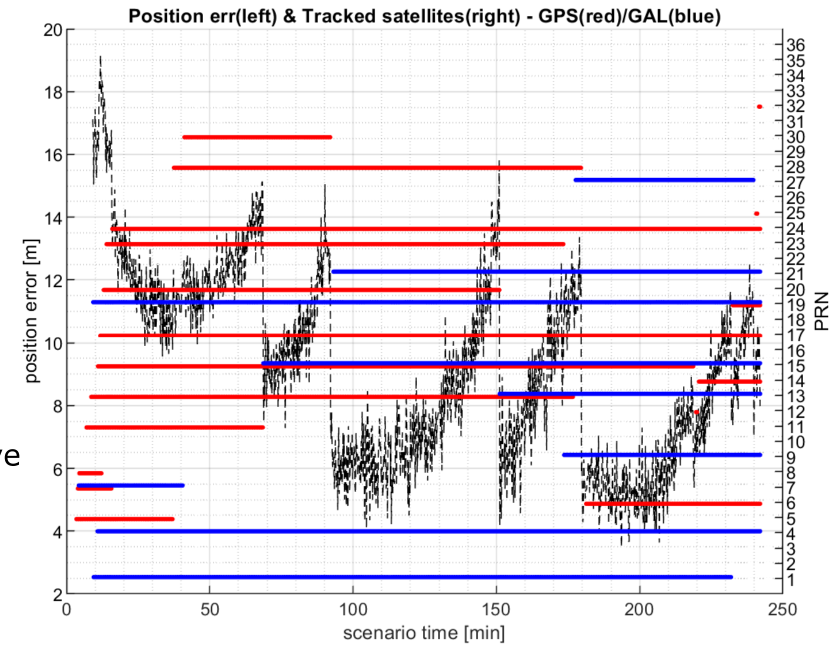
- Performance within required ranges
- Sudden jumps in position observed



Analysis of Anomalies



- **No Atmospheric corrections implemented**
- Simple hemispherical Antenna pattern used in STATIC and DYNAMIC cases
- Real antenna pattern used in Launcher case
- Atmospheric delay impacts the error
- Satellites low above horizon have good C/N0 contribute with high atmospheric delay



- The „jump's" position correlates ideally with cumulated atmospheric delay change (of tracked satellites)
- The error rises as SVN approad end of its visiblity (low above horizon)
- A „jump" occures when the satellite disappears

Tests Summary, Performance, TTFF

Performance (PVT)

GPS+GAL

Static Scenario

error	mean	μ+3σ	unit
pos.	15.3	29.8	[m]
vel.	0.076	0.183	[m/s]

Dynamic Scenario

error	mean	μ+3σ	unit
pos.	17.4	28.8	[m]
vel.	0.070	0.200	[m/s]

GPS

Static Scenario

error	mean	μ+3σ	unit
pos.	19.3	30.3	[m]
vel.	0.056	0.132	[m/s]

Dynamic Scenario

error	mean	μ+3σ	unit
pos.	17.2	27.0	[m]
vel.	0.056	0.160	[m/s]

GAL

Static Scenario

error	mean	μ+3σ	unit
pos.	16.0	29.3	[m]
vel.	0.089	0.256	[m/s]

Dynamic Scenario

error	mean	μ+3σ	unit
pos.	14.5	27.2	[m]
vel.	0.122	0.369	[m/s]

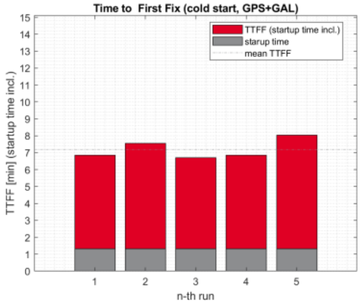
Launcher Scenario

GPS+GAL

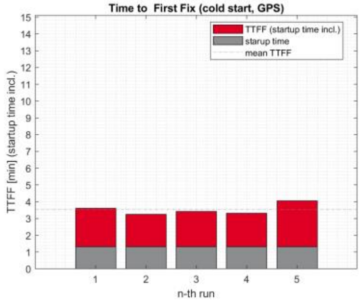
error	mean	μ+3σ	unit
pos.	13.2	28.3	[m]
vel.	0.111	0.801	[m/s]

error	mean	μ+3σ	unit
pos.	13.5	30.9	[m]
vel.	0.147	0.760	[m/s]

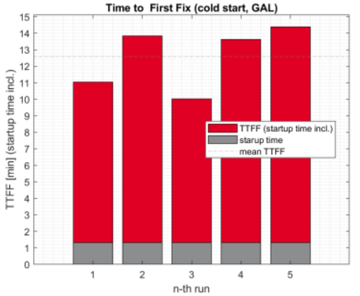
Time To Fix (cold start)



mean	7.2
max	8.0

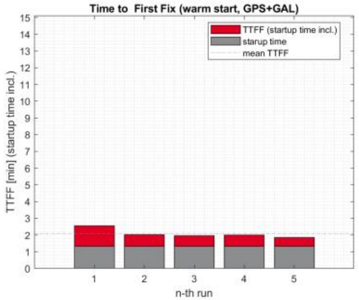


mean	3.5
max	4.0

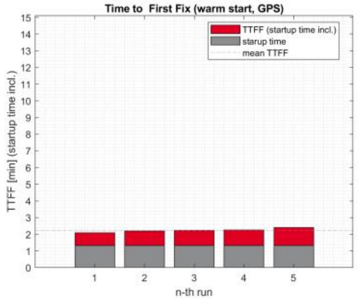


mean	12.6
max	14.4

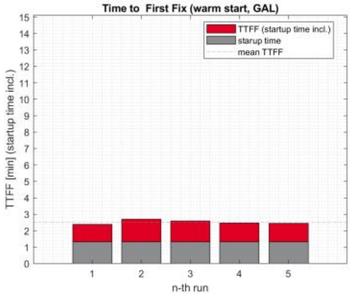
Time To Fix (warm start)



mean	2.1
max	2.6



mean	2.2
max	2.4



mean	2.5
max	2.7

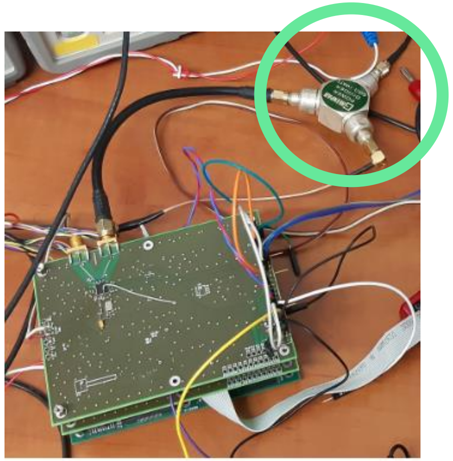
Conclusions

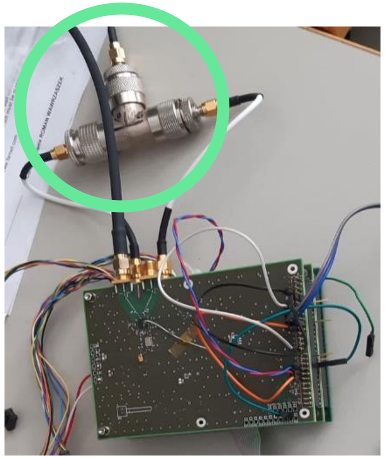
- Secondary test campaign succesfully verified required performance
- The 3sigma position error is at the edge of the required perfomance – the impact of the atmosphere. Furher development needed towards limiting of the impact:
  - Implementation of **atmosphere modeling** and compensation
  - Implementing dual-frequency ionospheric free combination
- Mean postion error less than 20m (usually ~15m as expected) satisfies the requiremtns
- TTFF (COLD START) within required ranges:
  - Visible time differences of GPS and GALILEO (4x longer code for GAL E1)
  - Potentiall optimization for speed of FFT module (further development) is advised
- WARM START TTF considered very satisfying
  - less than 3min in all configurations (**that includes 1.5min SW boot time** as well!)

GNSSW-MLMSC

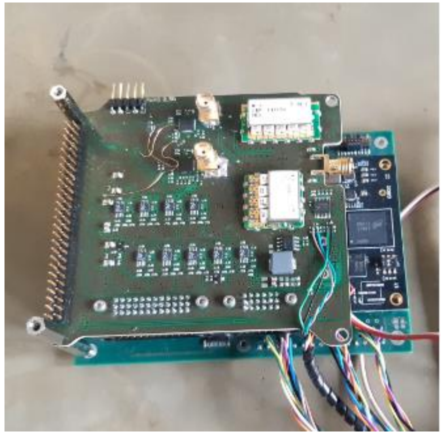
Dual Frequency Receiver Proof Of Concept

L1/L5 Receiver – HW Implementation





L1L5_v1 receiver hardware built in form of stacked of 2 FE modules identical with those manufactured for LV.



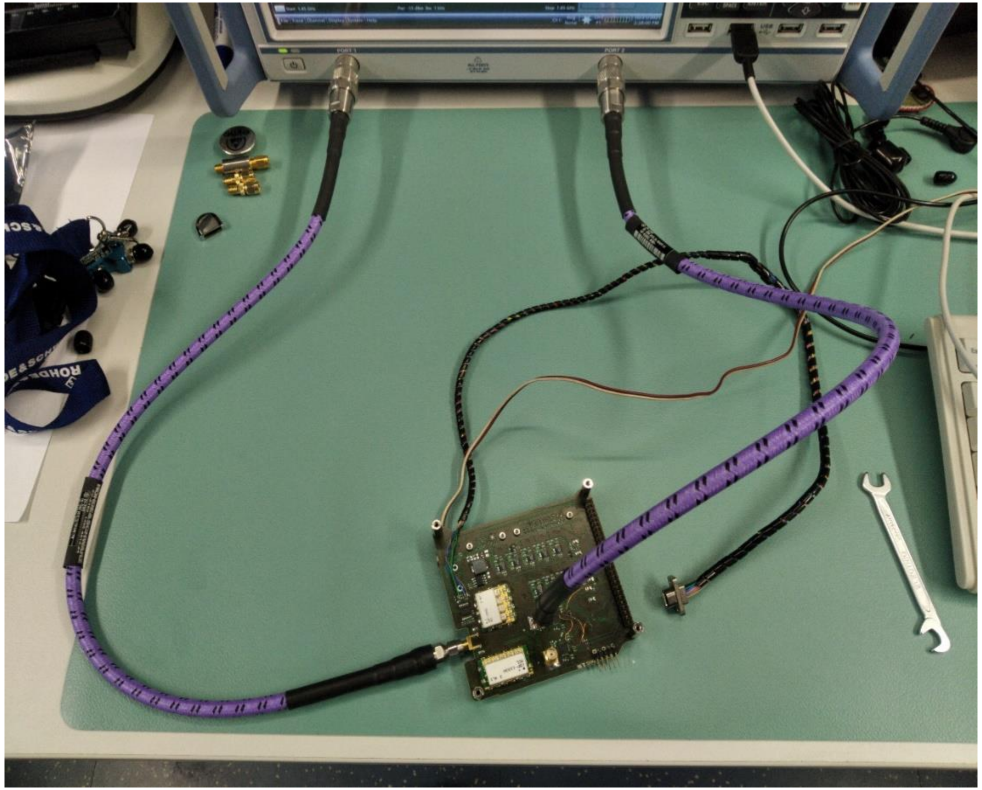
L1L5_v2 receiver hardware built in form of single FE board with incorporated RF combiner, similar to GOMX5 design combined with GNSSW-MLMSC.

Both configurations has been tested with respect to basic functionalities i.e. acquisition of L1 signal and L5 signals and data completness. Satellites were wisible in signals in both cases.

L1/L5 receiver – RF tests results

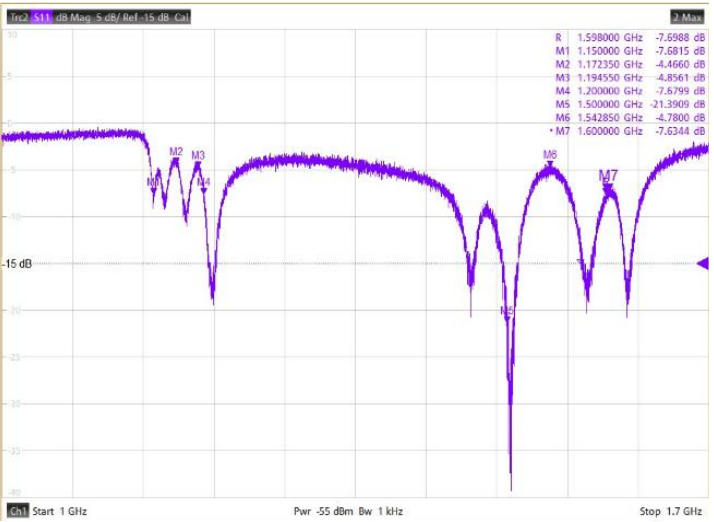
Following equipment has been used:

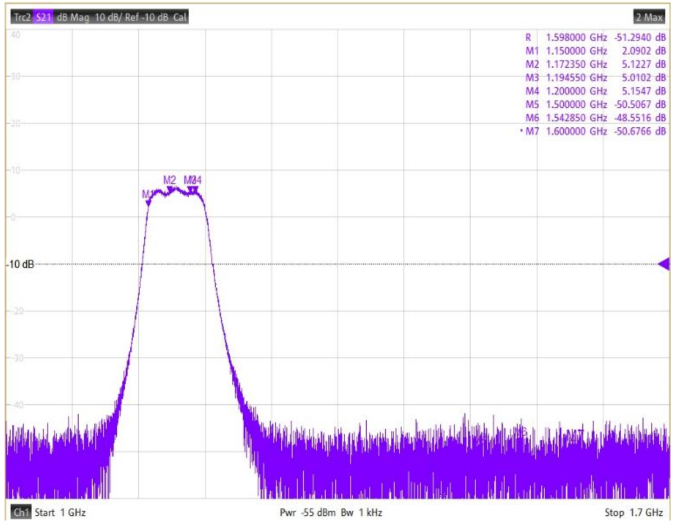
- Analyzer ZNB8 Rohde&Schwarz,
- two wires ZV-Z192,
- Power supply M10-DP-305E MCP Lab Electronics.

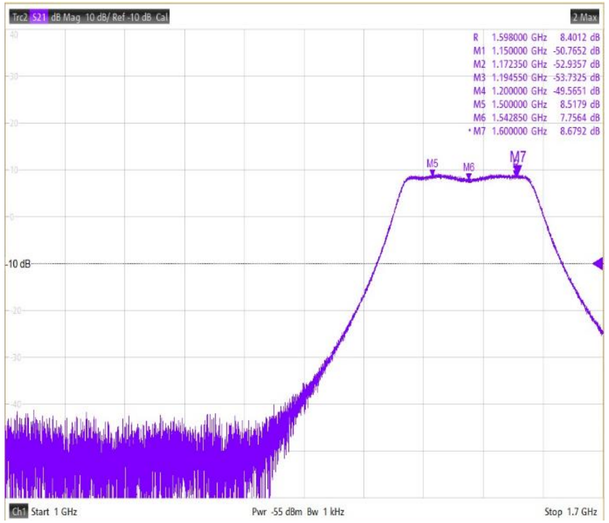


L5/E5 Proof of Concept

L1/L5 Receiver –VSWR, Gain







Matching in L5 band is at least -3.5 dB and -5.0 dB at L5 centre frequency: 1176.45 MHz

Matching in L1 band is at least -7.0 dB and -12.5 dB at L1 center frequency: 1575.42 MHz

Minimum gain is 4.0 dB and 5.5 dB at centre frequency – 1176.45 MHz

Centre frequency 1.181 GHz. FWHM is 92 MHz Flat gain area at top fully covers band from 1164 MHz to 1189 MHz

Minimum gain is 4.0 dB and 5.5 dB at centre frequency – 1176.45 MHz

Centre frequency 1.181 GHz. FWHM is 92 MHz Flat gain area at top fully covers band from 1164 MHz to 1189 MHz

L1/L5 Receiver – RF Tests Results Summary

- Obtained gain level in L5 band wing was around 5dB while for L1 it was around 8dB. Both channels contains LNA which theoretical gain is around 15dB.
- Obtained VSWR values are around 4.4 (S11 -4dB) and 2.1 (S11 – 9dB) and are quite far from expectations and simulations. Further analysis of the case is ongoing.
- Due to lack of equipment characterized by appropriate parameters, i.e. noise generator characterized by very low and reliable signal levels, it was impossible to obtain credible results of measurement of noise figure. Problem has been identified and confirmed during tests. The IR WTU is working to prepare equipment for tests in the next week (2nd-3rd of November).

SW Implementation

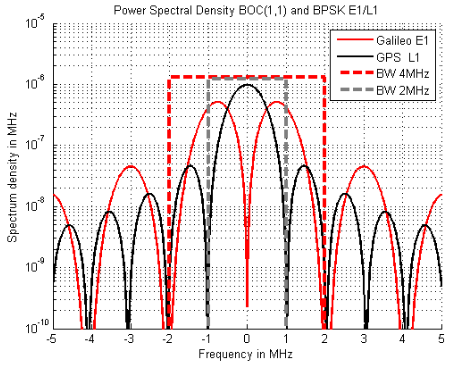
Primary Codes (PRN)

- 10.23 Mchip/s - chipping rate of the primary PRN code for both GPS L5 I/Q and Galileo E5a I/Q is

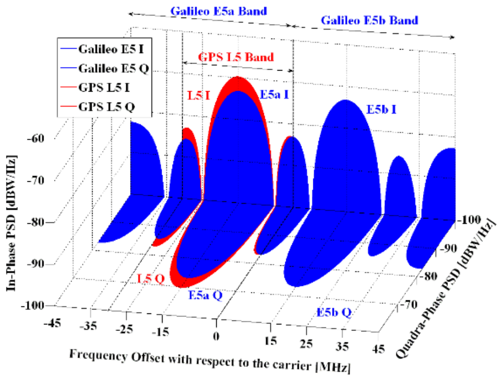
Secondary Cedes

- NH20 for GPS L5-Q – 20 chip long 1 chip/ms
- NH10 GPS L5-I – 10 chip long, 1 chip/ms (mixed with nav. data)
- Arbitrary 100 chip long code for GALILEO E5a-Q with the frequency of 1chip/ms
- Arbitrary 20chip long code for GALILEO E5a-I with the frequency of 1chip/ms (mixed wit nav. data)

L1 BW~=2MHz
E1 BW ~=4MHz



L5/E5a BW~=24MHz
(main lobe BW~= 16MHz)



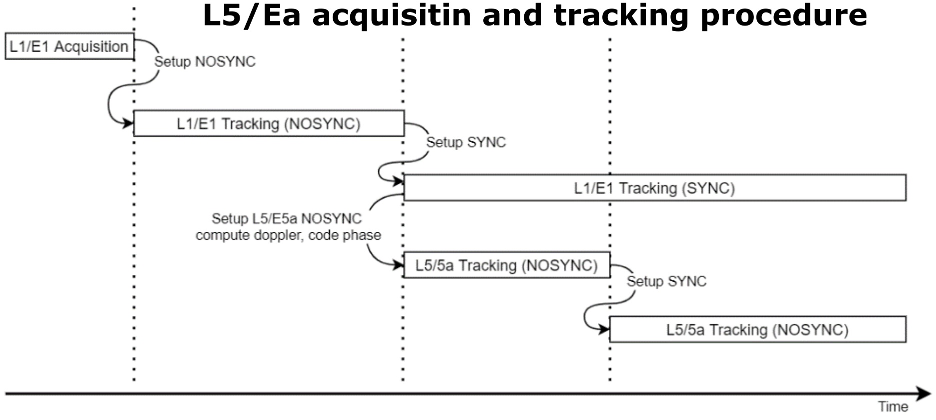
L1 to L5 Doppler frequency relation:

$$f_{d-L5} = f_{d-L1} \cdot \frac{L_5}{L_1}$$

L1 to L5 Code phase relation:

$$\varphi_{code-L1} \cong \varphi_{code-L5}$$

L5/Ea acquisitin and tracking procedure



L5/E5a frequency plan used

Parameter	Value
FE center frequency	1176.45 MHz
FE sampling frequency	32MHz
FE bandwidth	16MHz
FE intermediate frequency	8MHz

Tests of the SW Implementation (Real Signal)

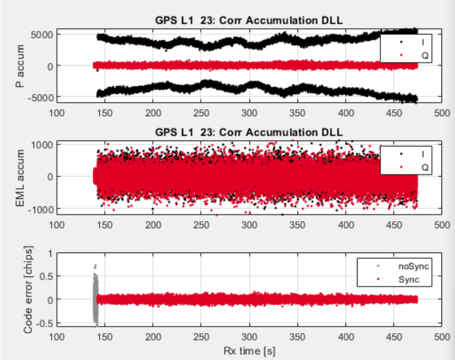
- Real antenna (at ESAC on 22/01/2021) signal captured with USRP X300 (10 min, IQ, Zero IF 16 bit @ 25Msps ~60GB)
- Converted/resampled to the format required by the MLMSC

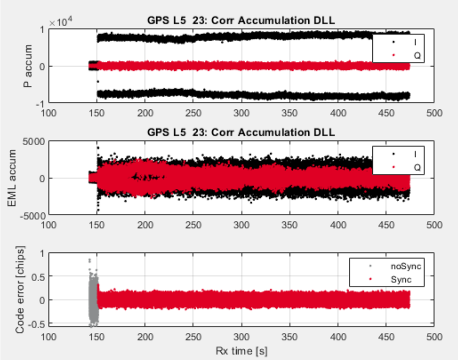
Acqisition and Tracking stsatsus

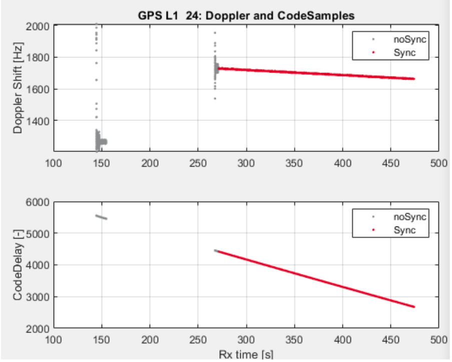
- GPS L5 capable SVN (blockk IIF, III): G23,G24
- Galileo 20 reported to be damaged (NO data transmitted, E5 lost)
- All valid Galileo sattelites tracked in Dual mode
- All valid GPS L5 capable satellites tracked in dual mode

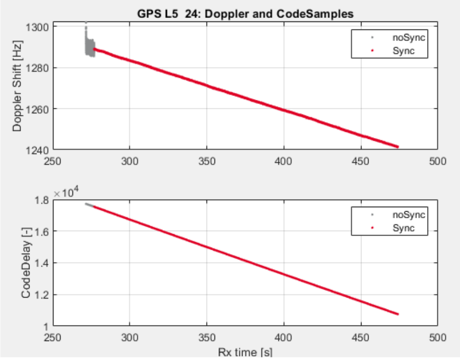
```
FET: 472.866204 ToW: 475817.700000, LSQ done with 10 measurements
FET: 472.866204 ToW: 475817.700000, Lat: 40.444 deg Lon: -3.953 deg Height: 0.663 km , Vel: 0.613 m/s

                                                      WN: 2141 NAV ToW: 475817.900000, FET 473.066204

FET: 472.966204 ToW: 475817.800000, LSQ done with 10 measurements
FET: 472.966204 ToW: 475817.800000, Lat: 40.444 deg Lon: -3.953 deg Height: 0.663 km , Vel: 0.499 m/s
MSG> FET: 473  TCK#00   MODE SYNC       SVN:  7         GAL  E1        EPHEM: ALM+EPH  C/N0: 39.8 comp: 0.000000
MSG> FET: 473  TCK#01   MODE SYNC       SVN: 13         GPS  L1        EPHEM: EPH      C/N0: 47.3 comp: 0.000000
MSG> FET: 473  TCK#02   MODE SYNC       SVN: 15         GPS  L1        EPHEM: EPH      C/N0: 48.9 comp: 0.000000
MSG> FET: 473  TCK#03   MODE SYNC       SVN: 20         GPS  L1        EPHEM: EPH      C/N0: 39.8 comp: 0.000000
MSG> FET: 473  TCK#04   MODE SYNC       SVN: 20         GAL  E1        EPHEM: NODATA           C/N0: 38.1 comp: 0.000
MSG> FET: 473  TCK#05   MODE SYNC       SVN: 23         GPS  L1        EPHEM: ALM+EPH  C/N0: 42.7 comp: 0.000000
MSG> FET: 473  TCK#06   MODE SYNC       SVN: 27         GAL  E1        EPHEM: EPH      C/N0: 43.9 comp: 0.000000
MSG> FET: 473  TCK#07   MODE SYNC       SVN: 30         GAL  E1        EPHEM: ALM+EPH  C/N0: 40.0 comp: 0.000000
MSG> FET: 473  TCK#08   MODE SYNC       SVN: 14         GAL  E1        EPHEM: EPH      C/N0: 36.4 comp: 0.000000
MSG> FET: 473  TCK#09   MODE SYNC       SVN: 24         GPS  L1        EPHEM: ALM+EPH  C/N0: 44.5 comp: 0.000000
MSG> FET: 473  TCK#10   MODE SYNC       SVN: 28         GPS  L1        EPHEM: ALM+EPH  C/N0: 41.4 comp: 0.000000
MSG> FET: 473  TCK#12   MODE SYNC       SVN:  7        [GAL E5a]       EPHEM: EPH      C/N0: 45.6 comp: 0.000000
MSG> FET: 473  TCK#17   MODE SYNC       SVN: 23        [GPS  L5]       EPHEM: EPH      C/N0: 46.8 comp: 0.000000
MSG> FET: 473  TCK#18   MODE SYNC       SVN: 27        [GAL E5a]       EPHEM: EPH      C/N0: 47.7 comp: 0.000000
MSG> FET: 473  TCK#19   MODE SYNC       SVN: 30        [GAL E5a]       EPHEM: EPH      C/N0: 45.0 comp: 0.000000
MSG> FET: 473  TCK#20   MODE SYNC       SVN: 14        [GAL E5a]       EPHEM: EPH      C/N0: 41.9 comp: 0.000000
MSG> FET: 473  TCK#21   MODE SYNC       SVN: 24        [GPS  L5]       EPHEM: EPH      C/N0: 48.7 comp: 0.000000
```

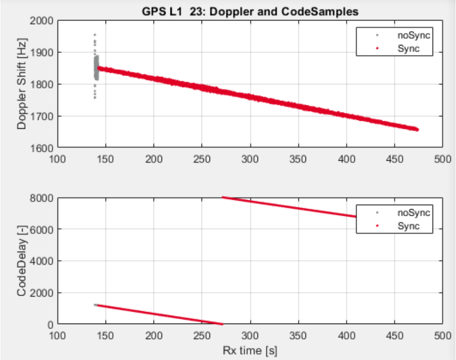
Tests of the SW Implementation (Real Signal)

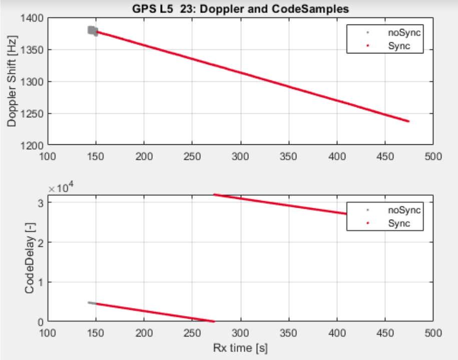


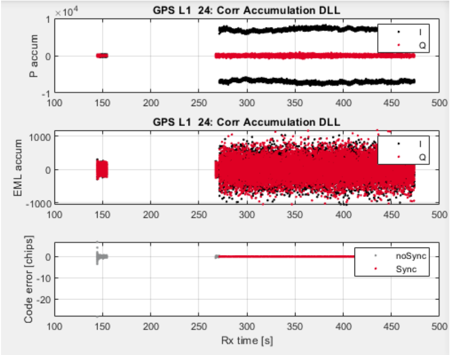


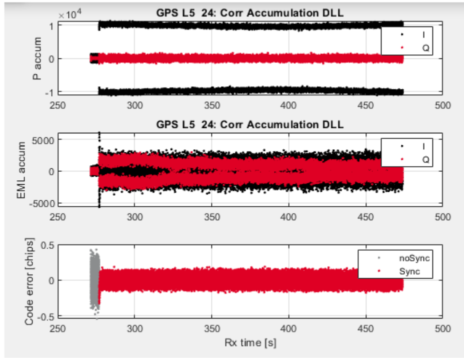




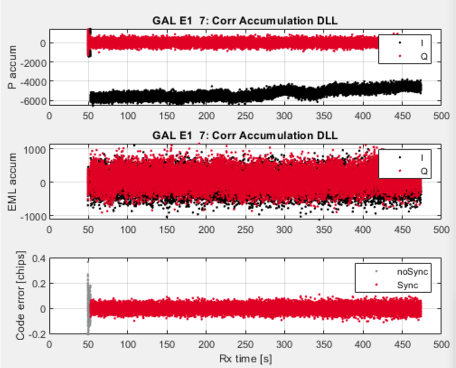


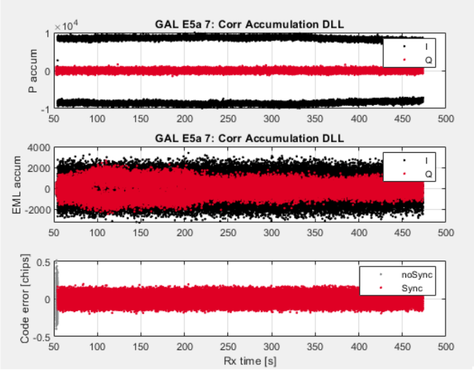


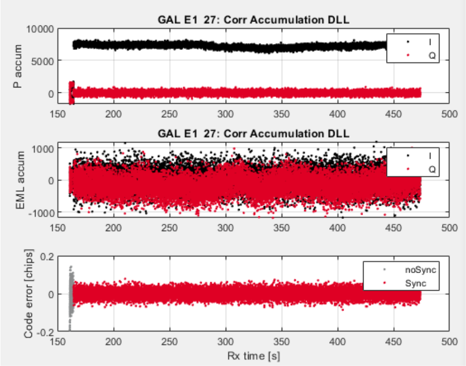


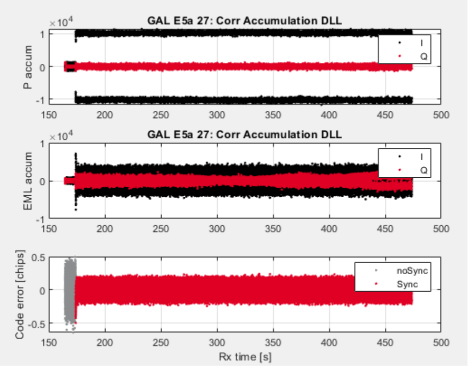


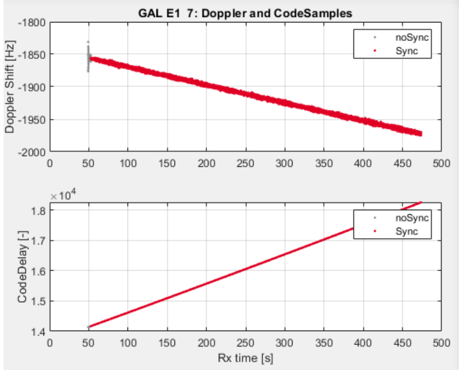
Tests of the SW Implementation (Real Signal)

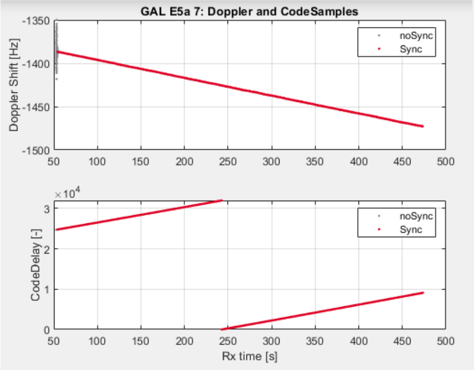


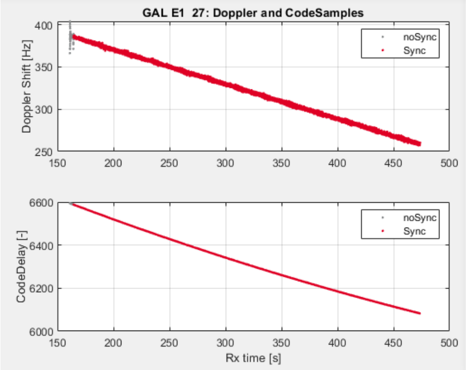


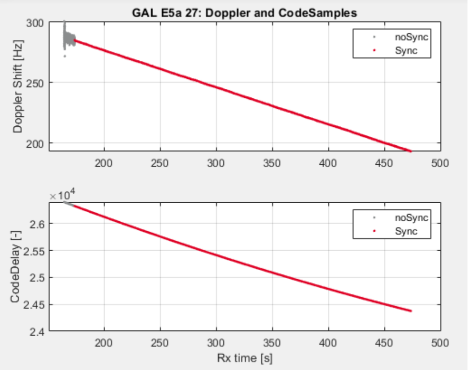






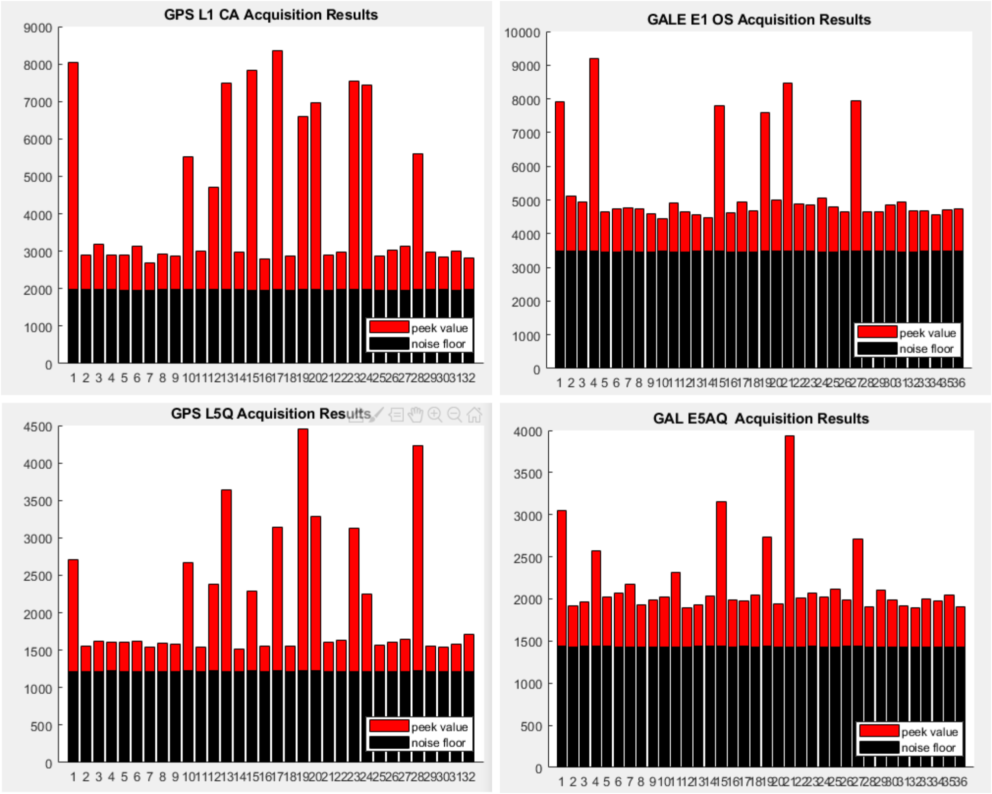






HW Implementation - Signal Acquisition Tests (L1L5_v1)

- tests with GNSS signal simulator (Spirent GSS9000 and SimGEN, WUT faculty of Geodesy).
- all the satellites transmitting both L1/E1 and L5/E5 frequency
- processed with dedicated Matlab script which performs FFT acquisition
- All the L1/E1 satellites acquired represented by tall bars are also find (most often) with distinctive power in the L5/E5a



GNSSW-MLMSC
Conclusions

Project Outcome

- In the scope of this activity the GMV's GNSS Software Defined Radio Receiver has been adapted for microlaunchers applications, dual core Zynq7030 processor and for the dual frequency signals tracking.
- Two Front-End's were developed and tested (single and dual frequency) with the real signals and Spirent simulator.
- The output of the project is a GNSSW-MLMSC software with technological maturity level of **TRL 7**.
- The flight of MIURA1 launcher (out of the project scope), which will carry on the GNSSW Receiver as a payload, will raise the maturity of the solution to **TRL 8-9**.
- The product, the **Flight Model** of the receiver, passed all the environmental tests, including EMC, Thermal and Vibration. It also successfully passed extensive Performance tests.
- The project outcome is a **baseline** for the ongoing activity: Dual Frequency GNSSW Receiver – GNSSWLEO.

Main Characteristics of the GNSSW SW Receiver for ZYNQ		
Channels	12	
Signal	GPS L1 C/A code GAL E1 OS code+pilot	
Processor used	Zynq 7030 Dual Core	
CPU load	Around 72% with 12 tracking channels (GPS+GAL)	
Cold Start (GPS+GAL)	Max time	8.0 min
	Mean time	7.2 min
Warm Start (GPS+GAL)	Max time	2.6 min
	Mean time	2.1 min
Navigation Accuracy (mean | 3σ)	Position: <20 m | <30 m Velocity: <0.15 m/s | <0.8 m/s	

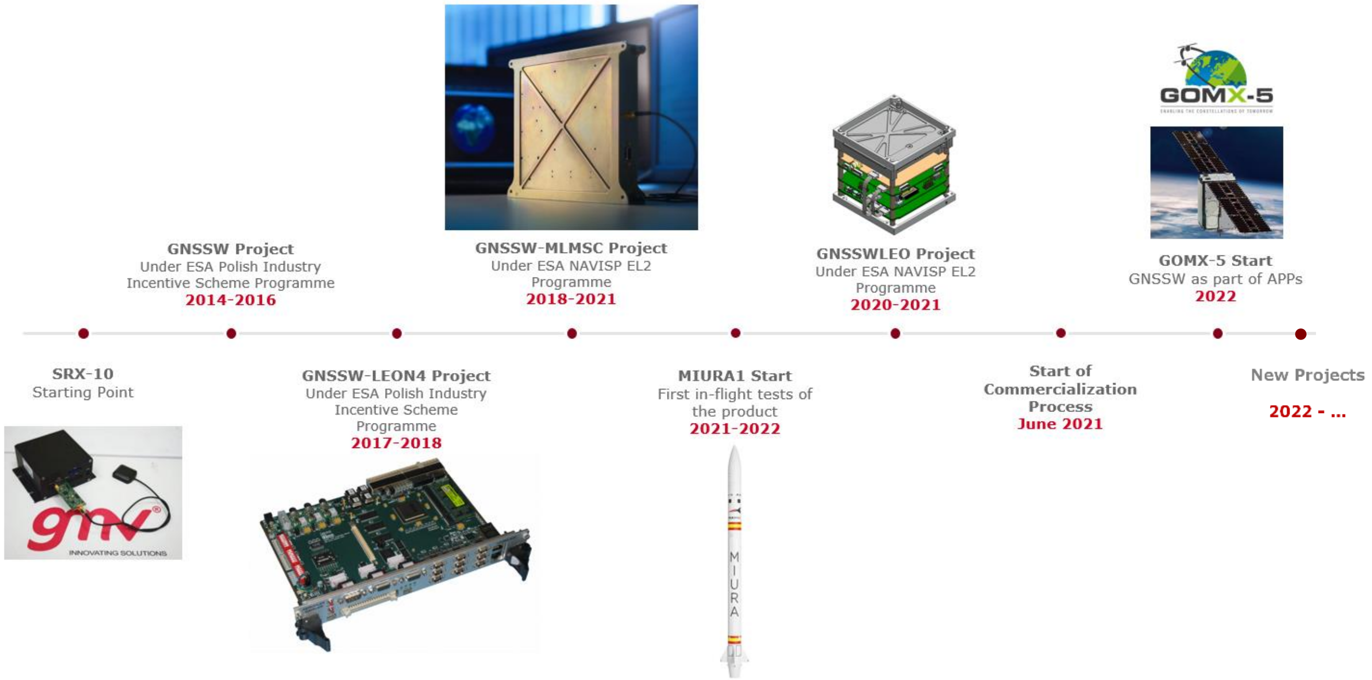
According to the information from avionics bay team **All tests performed** with GNSSW-MLMSC Receiver passed **succesfully**.

Several tests within the EMC campaign were **dedicated to the GNSS Receiver** and No abnormal behavior was reported.

EMC Test Campaign was performed in Tres Cantos, Spain (March-April 2021).

Roadmap to Commercialization

- Presented strategy that shaped product ready to be used by space industry
- Prediction of new projects that expected that will allow for further evolution of the product (AFTS, P2OD)
- The Receiver is already the subject of the commercial sale (not yet signed)
- Currently TRL 7 after the environmental tests
- TRL 8-9 after Miura experiment



GNSSW-MLMSC

Discussion

www.gmv.com

THANK YOU

Contact person: akobylkiewicz@gmv.com

Product e-mail: sextans@gmv.com

BLOG