Evaluation of NavIC L5/S-band signals, using high-end NTLab's GNSS receivers

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NavIC L5/S-band signals: overview

- There are four NavIC's signals (L5 SPS, L5 RS, S-band SPS, S-band RS) in two frequency bands:
  - L5: occupies the same frequency band as GPS L5 and Galileo E5a.
  - S-band: the only GNSS signal in S-band.

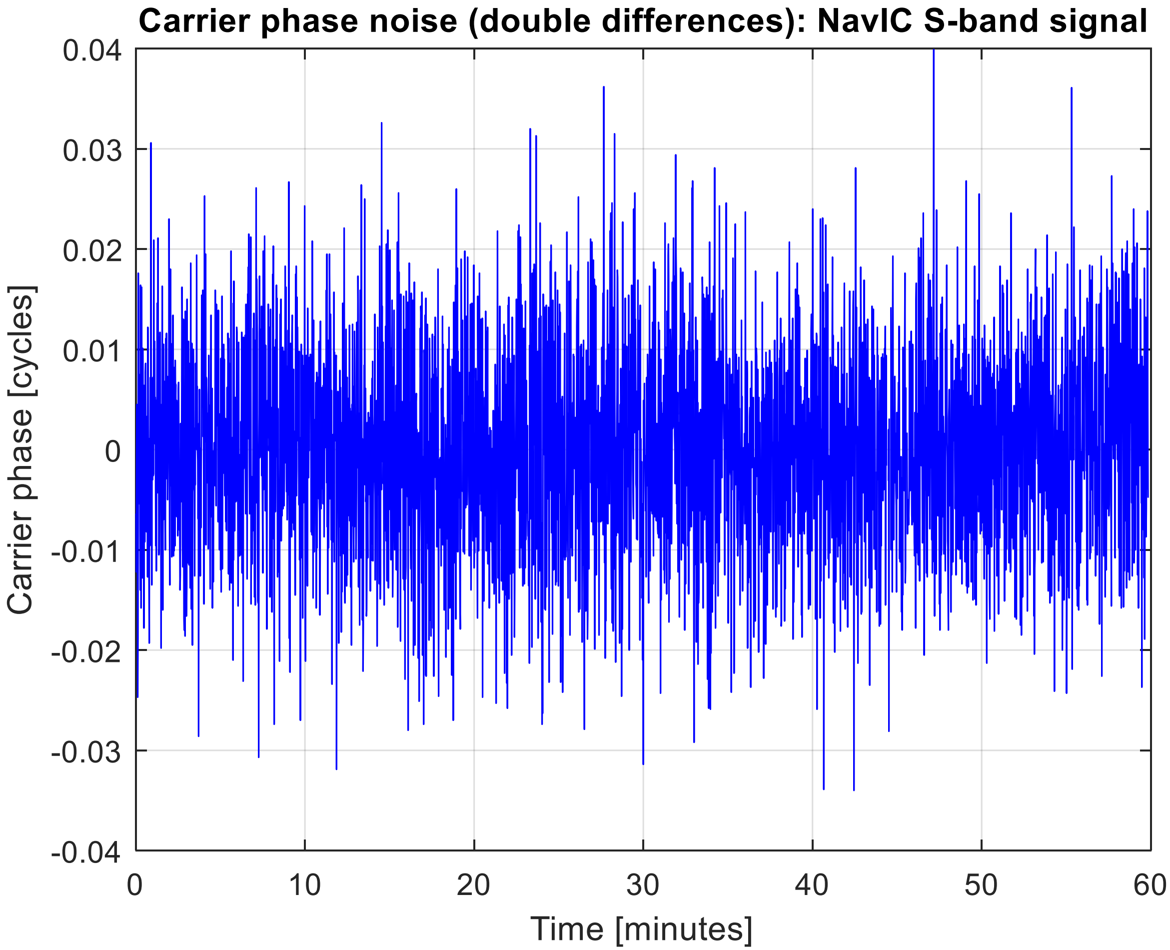
- SPS (Standard Positioning Service): a full set of information is available in IRNSS ICD (version 1.1, August 2017).

- RS (Restricted Service): information is available for authorized users only.

- Availability of S-band signal puts special requirements on GNSS antenna design and RF front-ends.

- To get a full usage of NavIC signals, these signals as well as NavIC itself have to be supported by international standards associated with GNSS positioning: RTCM SC-104, RINEX, NMEA-0183 and others.

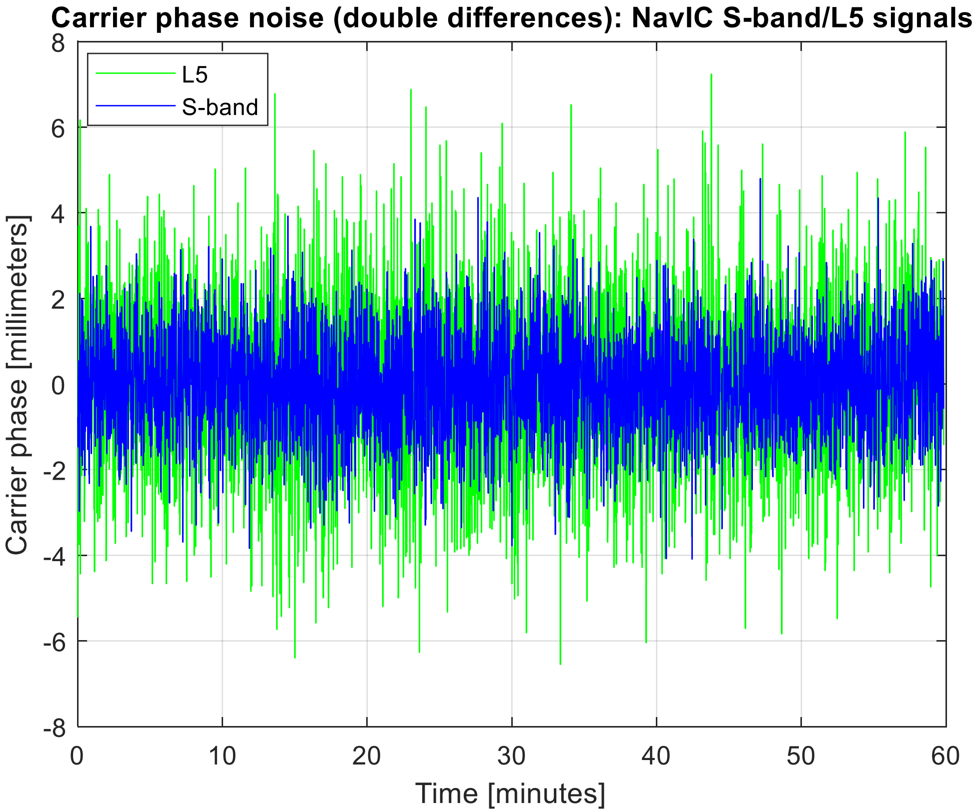
NavIC S-band signal (2492.028 MHz): evaluation of measurement precision



Zero baseline, NTL105
November 19th, 2019,
Minsk

Measurement precision:
0.6 мм (RMS)

NavIC L5 (1176.45 MHz) and S-band (2492.028 MHz) signals



Zero baseline, NTL105
November 19th, 2019, Minsk

Carrier phase noise:
0.6 мм (S-band) vs. 0.9 мм (L5)

NavIC signals:

- ✓ Measurement precision corresponds to high accurate positioning.
- ✓ Lower noise of S-band carrier phase observables compared with other GNSS signals.
- ✓ Possible interoperability of NavIC L5 signals with GPS L5 and Galileo E5a signals: to be investigated.
- ✓ Better estimation of ionospheric delay because of greater difference between L5 and S-band frequencies.

All such factors allow efficient usage of NavIC signals for high accurate positioning

Standardization of NavIC L5/S-band signals: RINEX and RTCM SC-104 3.X version.

- RINEX: supports scientific and research applications, de-facto standard in IGS network.

- RTCM SC-104 3.X version: can be used for scientific and research applications. Also, the important task of RTCM SC-104 standard is to provide interoperability between GNSS receivers of different manufacturers. RTCM SC-104 3.X version is the de-facto standard for high accurate real-time positioning.

Currently (December 2019), RINEX 3.04 version fully supports NavIC L5/S-band signals, including Restricted Service signals.

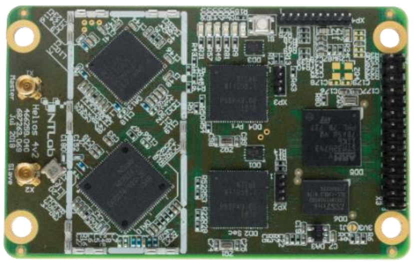
The mandatory requirement for inclusion NavIC signals into RTCM standard is the performing of Interoperability testing among receivers of different manufacturers. At the time being, NavIC L5 SPS Interoperability testing has been completed. However, S-band SPS Interoperability testing cannot be started because there is only one manufacturer of high-end receivers that declares the support of S-band SPS signal: NTLab.

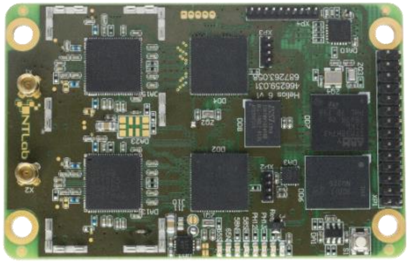
Concepts of Open Architecture and Open Platform (in a few slides) can help in standardization of S-band signal along with the full use of RS signals. Before that, information about NTLab's GNSS receivers and obtained results in measurement precision and RTK/PPP positioning domains is provided.

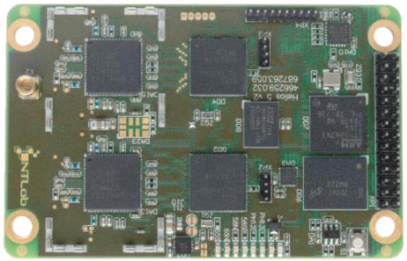
OEM GNSS receivers of Helios family: general information

- Multi-constellation: GPS, GLONASS, Galileo, BeiDou, NavIC, QZSS, SBAS (WAAS, EGNOS, GAGAN, MSAS, SDCM)
- Multi-frequency: GPS L1/L2C/L5, GLONASS G1/G2, Galileo E1/E5a/E5b, BeiDou B1/B2, NavIC L5/S-band, QZSS L1/L2C/L5, SBAS L1/L5.
- Positioning modes: stand-alone (absolute), code differential (DGNSS), code regional (SBAS), carrier phase differential (RTK), carrier phase global (PPP), carrier phase regional (PPP-AR: under development).
- *Measurement precision of carrier phase and pseudorange observables corresponds to geodetic level of positioning accuracy.*
- Dual-antenna GNSS modules (Heading, Pitch/Roll).
- MEMS-based IMU sensor on board for loosely-coupled GNSS/INS integration.
- *Raw measurements are available for user's secondary processing.* The user can develop his/her own algorithms (source code) for specific application running inside STM32H7 microcontroller (Open Architecture).
- Availability of powerful SMARC platform connected to GNSS receivers (Windows/Android/Linux OS, LoRa, NB-IoT, GSM, Wi-Fi, BlueTooth).
- Communication interfaces: UART, CAN, USB, Ethernet.
- Operating temperature is complaint with Industrial grade.

GNSS modules of Helios family: specification



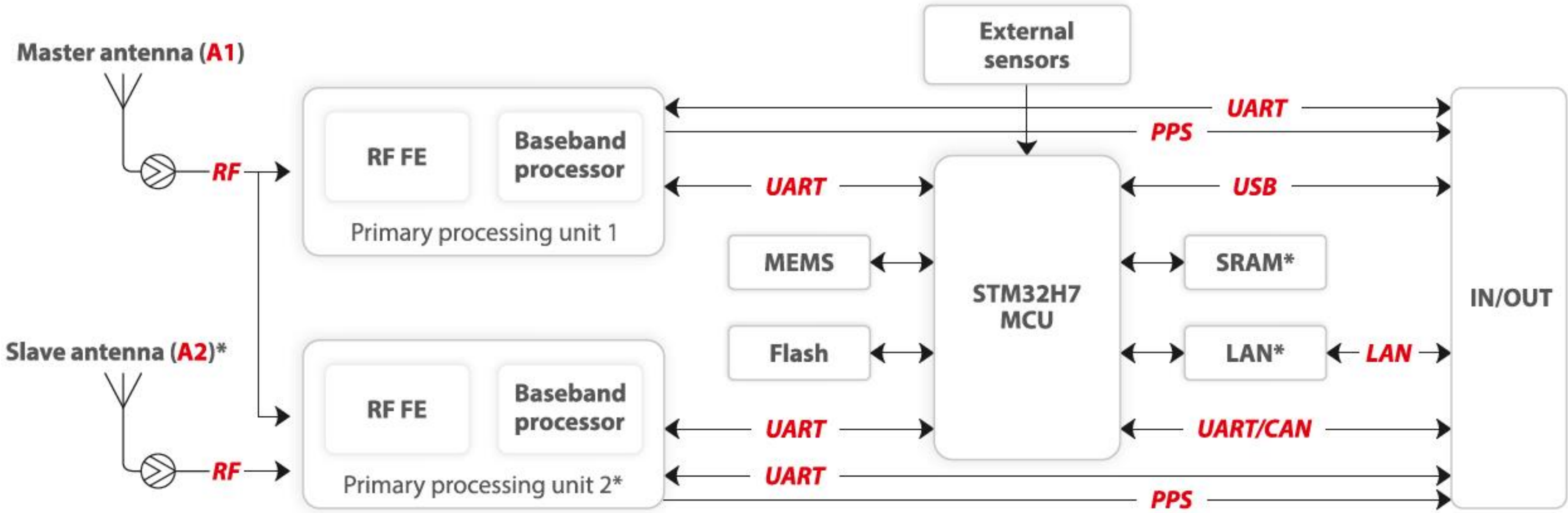




	NTL101	NTL104 Master antenna	NTL104 Slave antenna	NTL105 Master antenna	NTL105 Slave antenna	NTL106
GPS	L1, L2	L1, L2, L5	L1, L2	L1,L2,L5	L1, L2	L1, L2
GLONASS	L1, L2	L1, L2	L1, L2	L1, L2	L1, L2	L1, L2
Galileo	E1, E5b	E1, E5a	E1	E1, E5a, E5b	E1, E5b	E1, E5b
BeiDou	B1, B2	B1, B2	B1	B1, B2	B1, B2	B1, B2
NavIC	-	L5, S-band	-	L5	-	
SBAS	L1	L1, L5	-	L1, L5	-	
Heading determination (RMS),***						
Yaw	2°	0.1°		0.1°		2°
Pitch	2°	0.2°		0.2°		2°
Roll	2°	0.2°		0.2°		2°
RTK mode accuracy						
Horizontal	5 мм + 0.5 мм/км					
Vertical	8 мм + 1.0 мм/км					
Other parameters						
Interfaces	2 x UART, 1 x USB	3 x UART (or 2 x UART + 1 x CAN), 1 x Ethernet, 1 x USB				
Interface protocols	RTCM 3.X, Novatel OEM, NMEA-0183, NTL Binary					
Size	71 x 46 x 10 мм					
Power consumption	< 0.9 W	< 1.8 W		< 1.6 W		

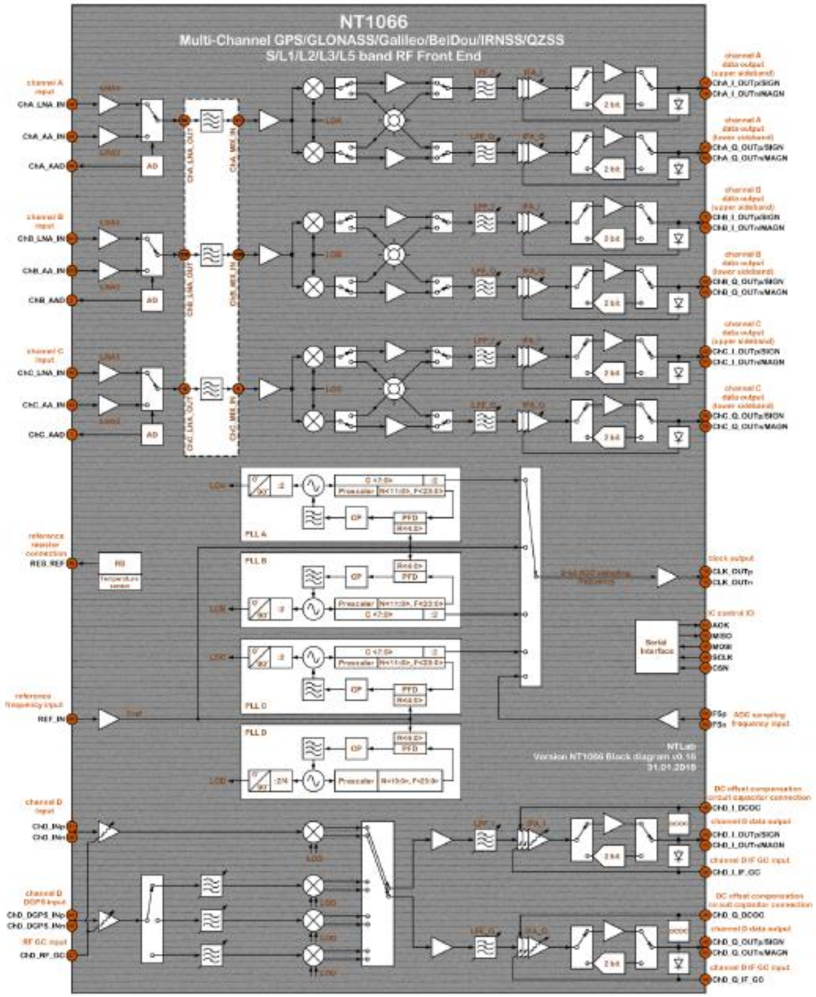
* List of signals depends of settings
** 2 meters baseline (NTL104 and NTL105)
*** NTL101 and NTL106 implement heading/pitch/roll determination, using loosely-coupled algorithms with MEMS-based IMU

GNSS receivers of Helios family: block diagram



* Optional. It depends on NTL10X modification

Key technology designed by NTLab



RFIC NT1066

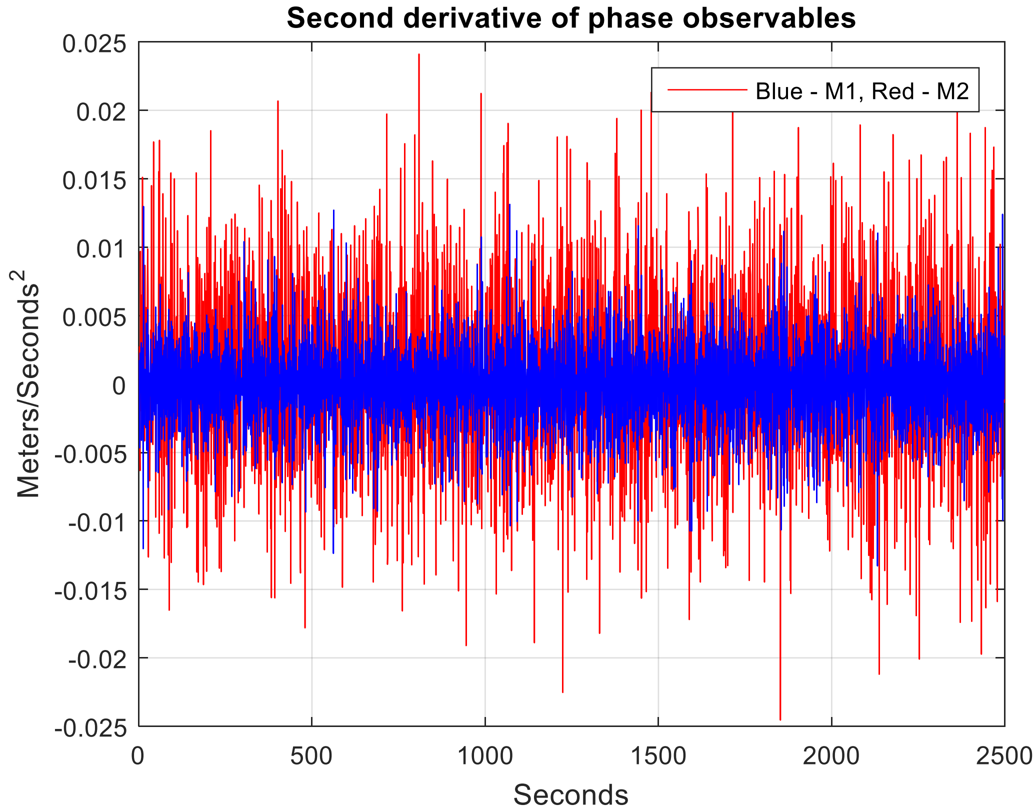
All key components are designed by NTLab

- RFICs: NT1065, NT1066, NT1068. These are four-channels RF front-ends for simultaneous reception of GPS/GLONASS/Galileo/BeiDou/ IRNSS/QZSS signals. The unique feature of NT1066/1068 is the support of NavIC S-band signal.
- ASIC: NT1058 includes correlators and a separate processor.
- PCB schematic.
- Firmware for GNSS signal tracking.
- Positioning algorithms.
- Software for supporting Open Architecture, Open Platform concepts.

Also:

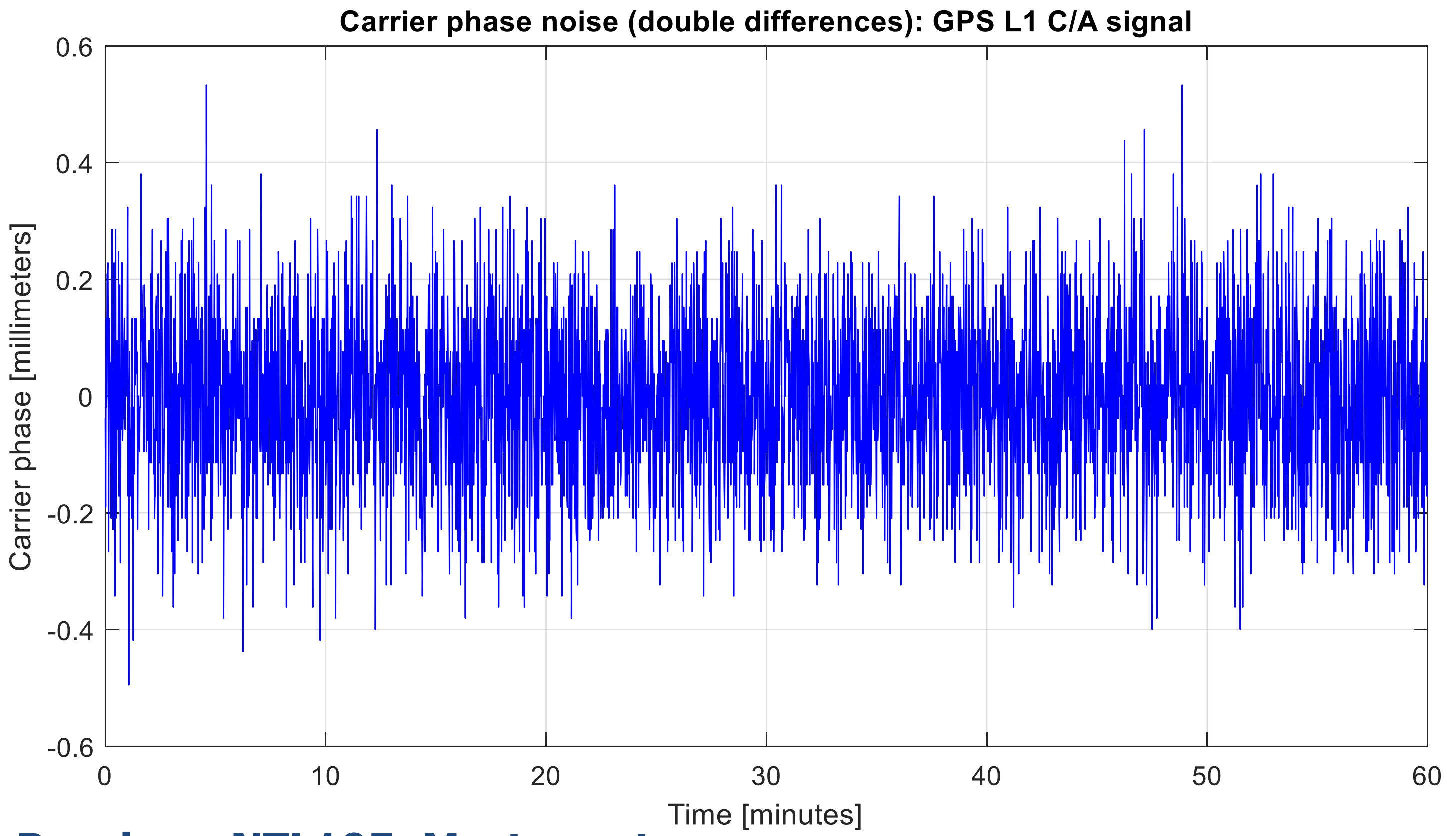
- Windows client for controlling GNSS modules' settings.
- RINEX converter.

Tests with Spirent GSS6700 simulator and temperature chamber (capable of -40 - +85 ºC temperature range)



- Evaluation of GNSS signals' measurement precision (noise) under pre-defined environment (multipath, ionospheric/tropospheric errors etc.).
- Evaluation of signal tracking stability under high dynamics or challenging environment.
- Evaluation of stability of different types of quartz oscillators, using second derivative of carrier phase observables as a function of temperature (example).
- Evaluation of GLONASS code biases for FDMA signals.

Spirent GNSS simulator: carrier phase noise of GPS L1 C/A signal (PRN 14, 15)



Receiver: NTL105, Master antenna.
Carrier phase noise: 0.07 mm (RMS)
Similar performances are demonstrated for GLONASS G1SP and Galileo E1 signals

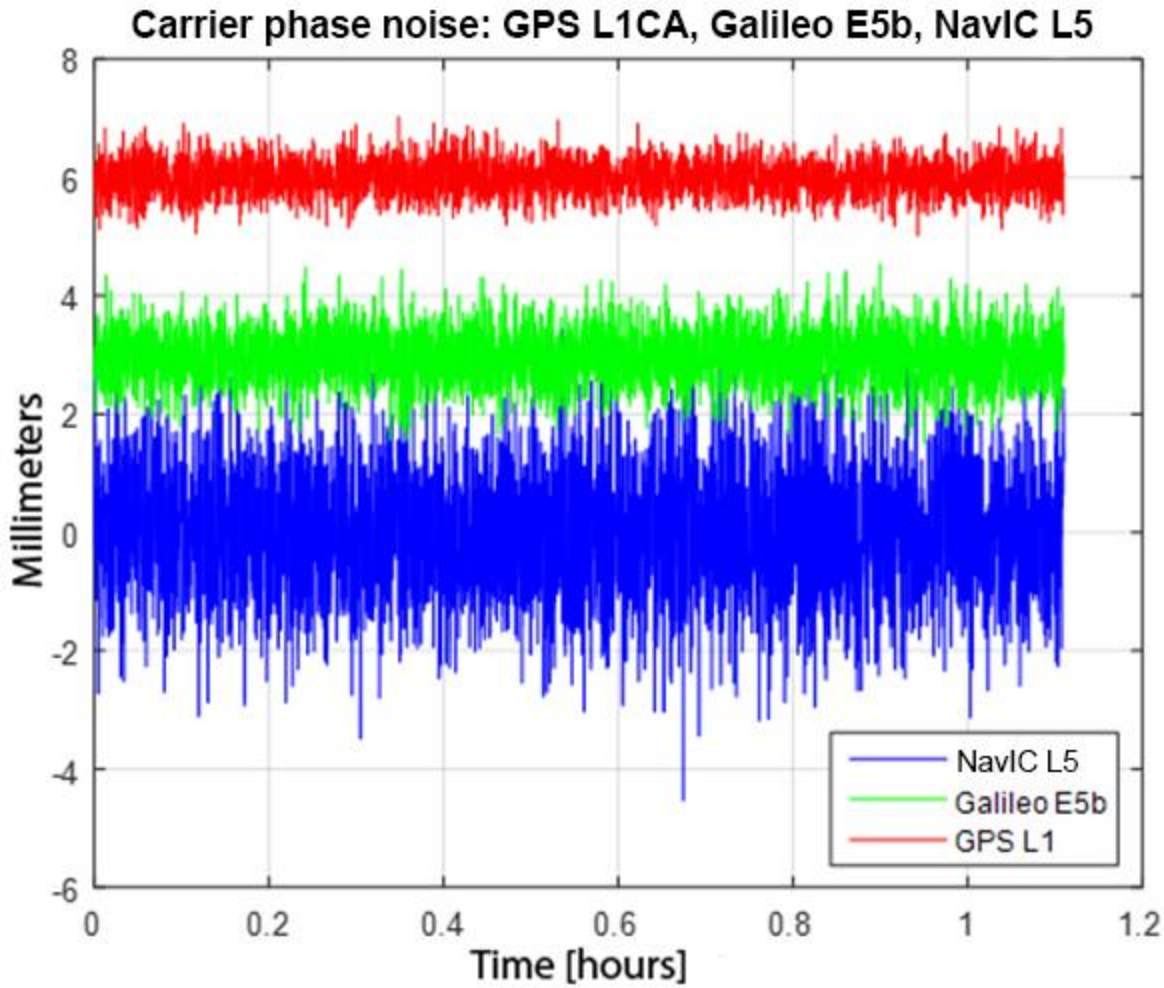
Antenna setups for GNSS researches and testing




- Two antennas Trimble Zephyr Base 3
- Two antennas Topcon PG-F1
- About 2 meters and 20 meters baselines for evaluation GNSS signals' measurement precision, RTK/PPP accuracy, accuracy of heading and pitch/roll determination

Permanently working antenna setups for researches in high accurate GNSS positioning

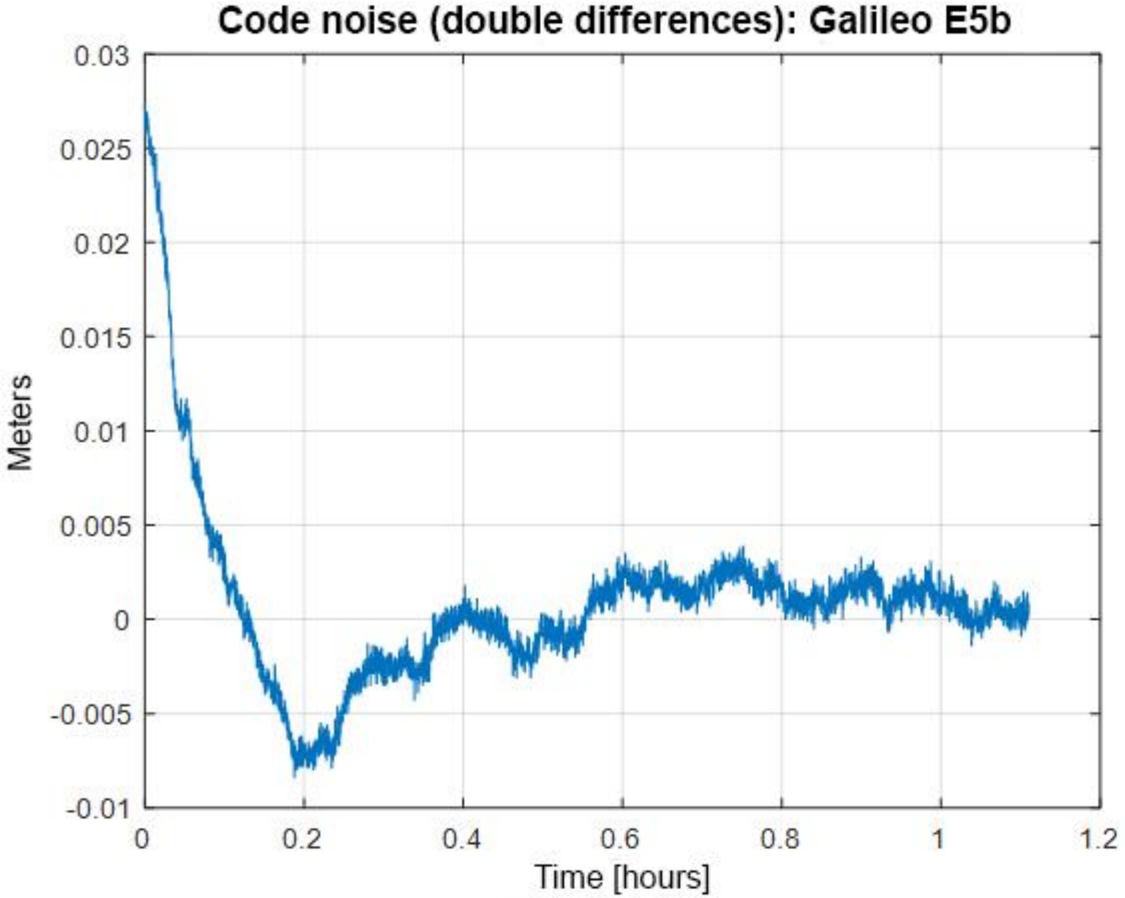
GPS L1 C/A, Galileo E5b, NavIC L5 signals: evaluation of measurement precision



Zero baseline, NTL105
April 2019, Skolkovo

Measurement precision for all signals **<0.8 мм (RMS)**

Noise of smoothed pseudoranges (Galileo E5b signal as an example)

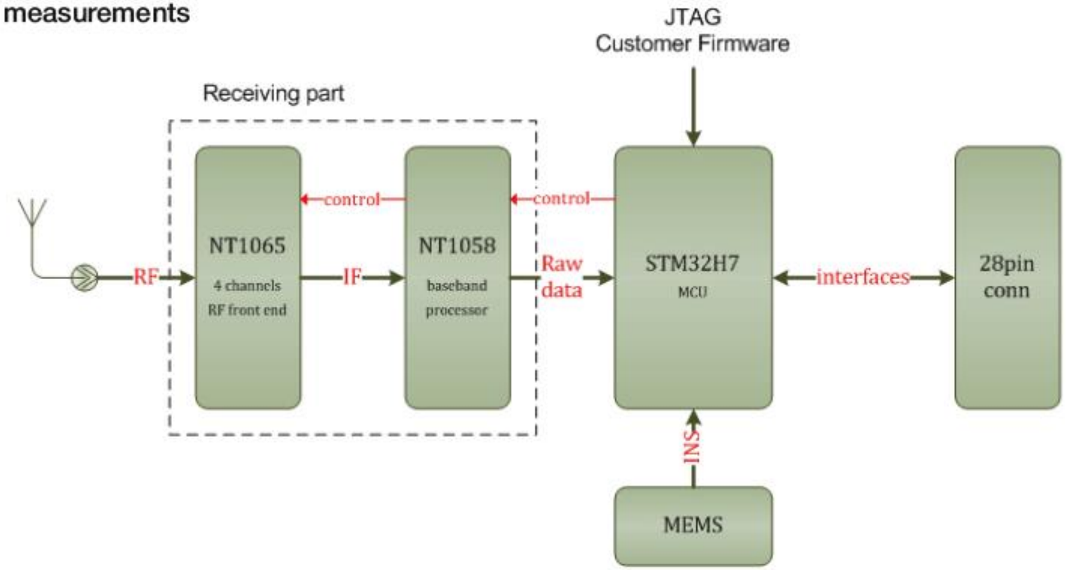


Zero baseline, NTL105
February 19th, 2019,
Skolkovo

Transition process can be seen. When the smoothing filters are settled, there is a very good correspondence between smoothed pseudoranges of two NTL105 modules

Open Architecture concept for Helios family of receivers

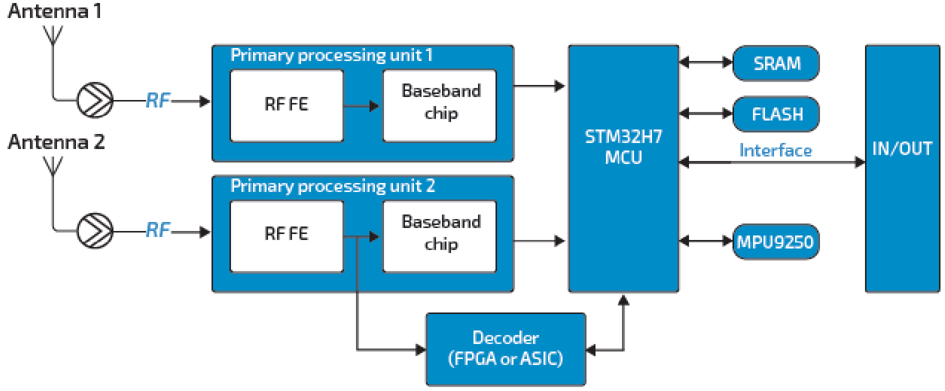
- Four-channel RF front-end NT1065 or NT1066 / NT1068 allows to cover the entire GNSS frequency plan
- Baseband NT1058 is used for raw measurements
- Processor STM32H7 allows to get RTK solutions



Helios family of receivers are GPS/GLONASS/Galileo/BeiDou/NavIC/QZSS/SBAS high-end GNSS OEM receivers with Open Architecture. Modules maintain the industrial standard form-factor (28 pins). GNSS raw measurements are available for developers as well as API functions to control the baseband chip. Customers could use NTLab firmware or develop their own proprietary firmware (or use third-party firmware) for on-board MCU (STM32H7) to implement positioning processing (RTK, PPP, etc.).

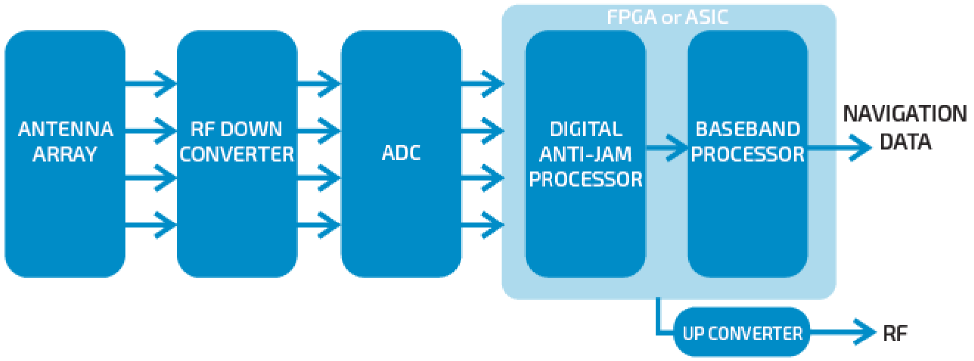
Open Architecture concept for NavIC RS (preliminary)

BLOCK DIAGRAM OF GNSS OEM MODULE FOR NAVIC RS (PRELIMINARY)



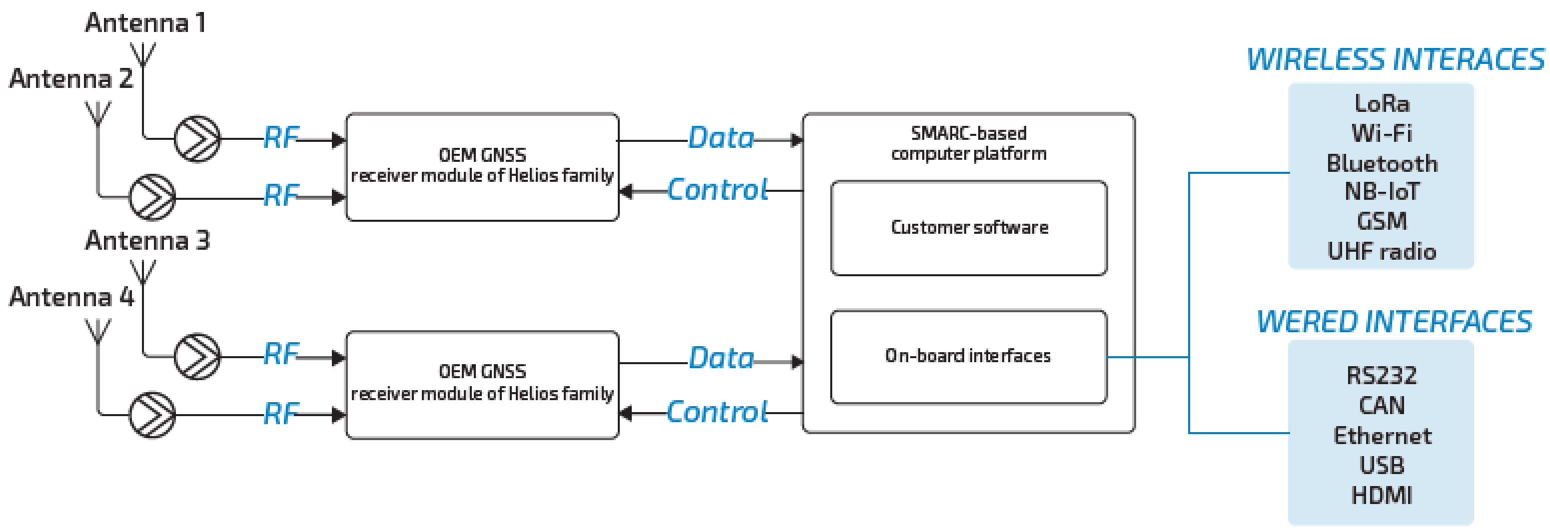
New feature - additional decoder based on FPGA (or ASIC) allows user to develop embedded software to support receiving of NavIC's Restricted Service signals along with Open Service ones.

BLOCK DIAGRAM OF ANTI-JAMMING OEM MODULE FOR NAVIC RS (PRELIMINARY)



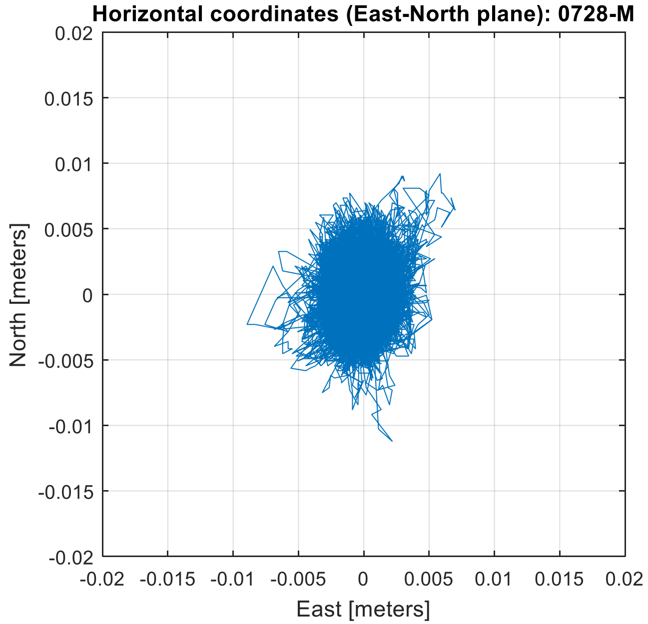
New NTLab anti-jamming OEM module with FPGA (ASIC) on board allows user to create solutions for anti-jamming and baseband processing, including Restricted Service signals supporting.

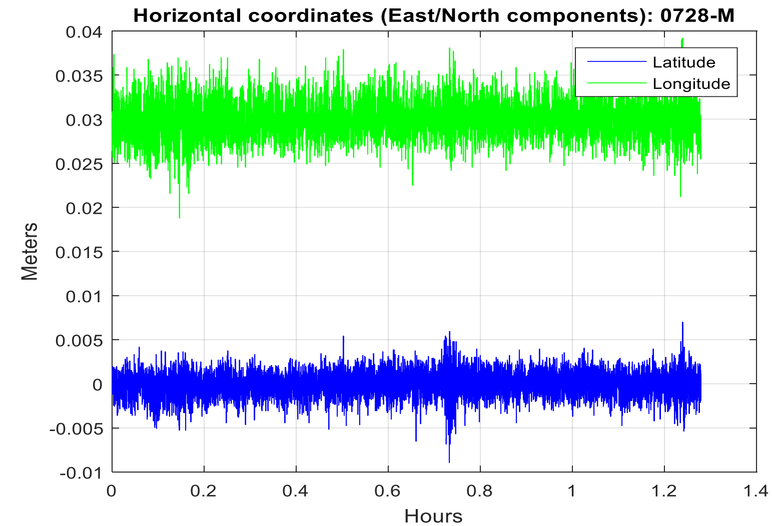
Open Platform concept for Helios family of receivers
(e.g., GNSS reference station capable of working in IGS network)

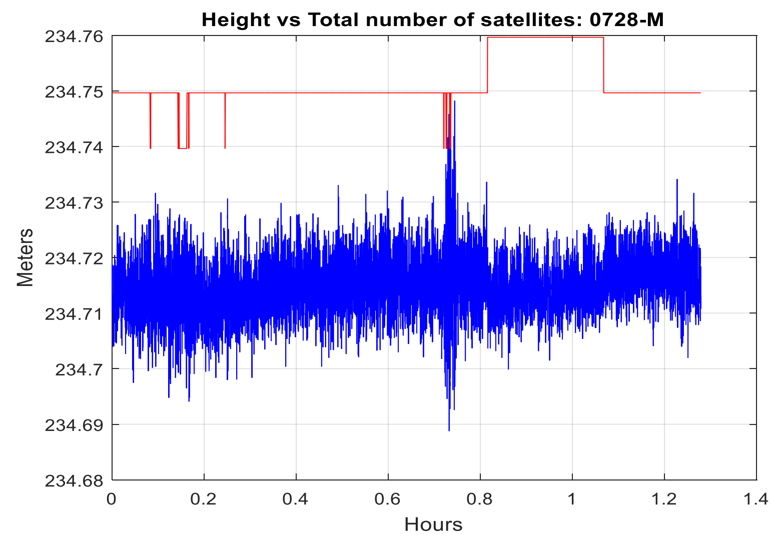


The open platform is based on the high precision OEM GNSS receiver modules of Helios family and SMARC-based computer platform. The addition of SMARC computer to OEM NTL10X modules allows using extended set of GNSS applications along with the use of additional communication protocols. Customers can use the platform for development their own proprietary SW or use a third-party SW to create an effective solution for each specific case, using on-board Computer-on-Module Platform with Windows/Android/Linux OS.

RTK accuracy at zero baseline (Trimble BD930 as a base)





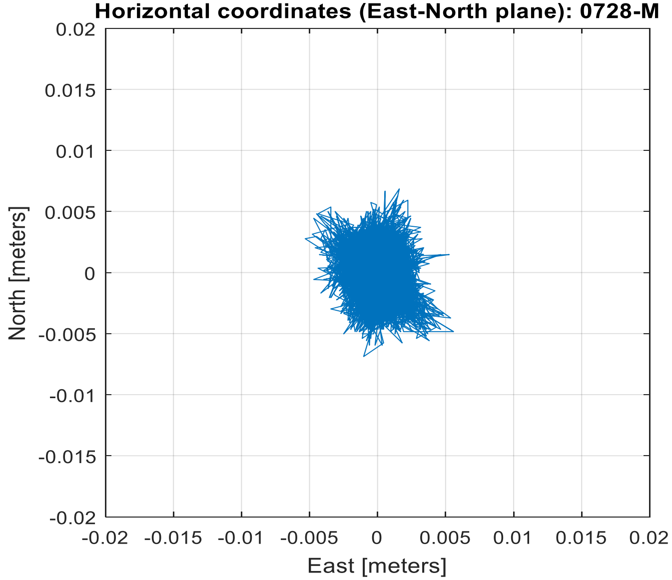


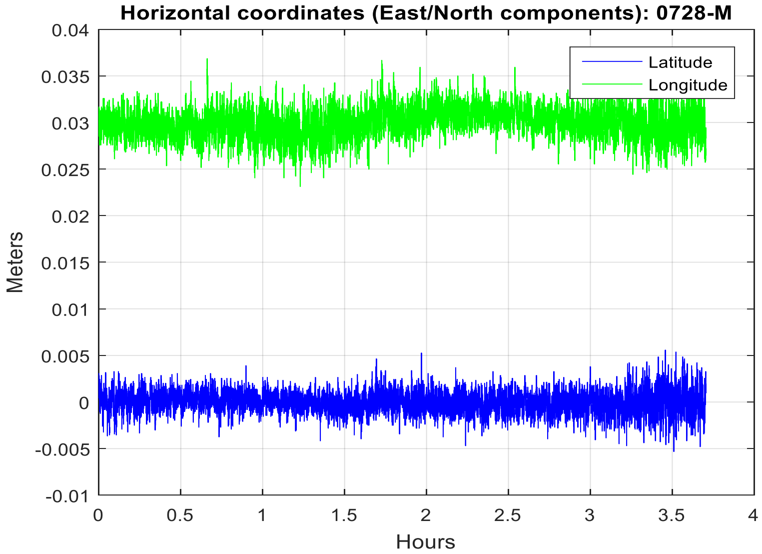
Setup:

- Zero baseline, GPS-only, April 9th, 2019
- BD930 (Trimble) as a reference station
- Two NTL105 modules as rover receivers
- Antenna Trimble Zephyr 3 Base
- RTCM 3.X messages

ID / Par.	Lat	Lon	Hor. (2D)	Alt (Ver.)	3D
0728-M	0.0012	0.0018	0.0022	0.0046	0.0051
0726-M	0.0012	0.0018	0.0022	0.0047	0.0051

RTK accuracy at zero baseline (NTL105 as a base)

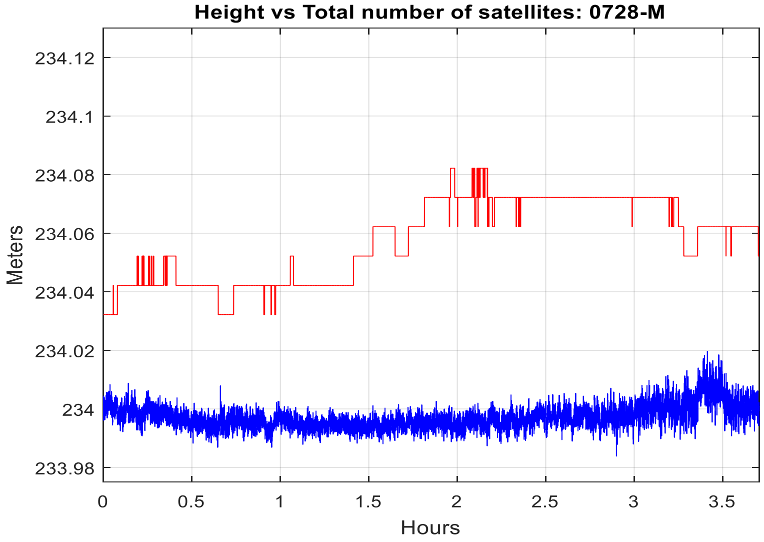




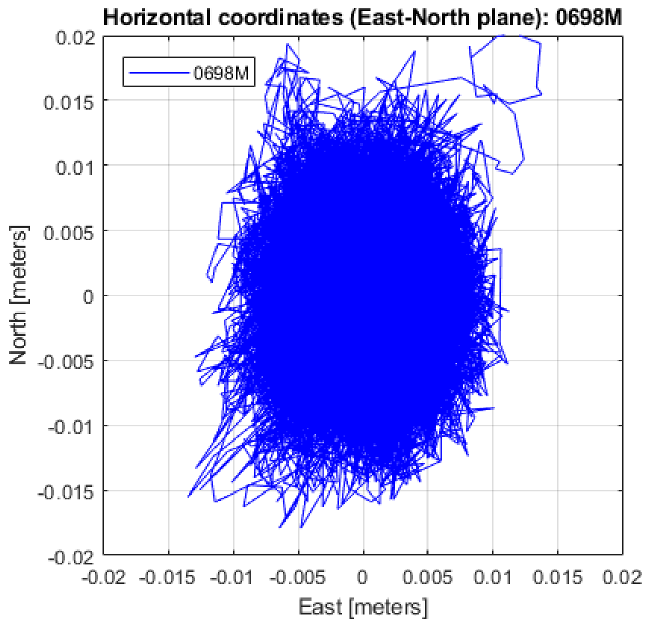
Setup:

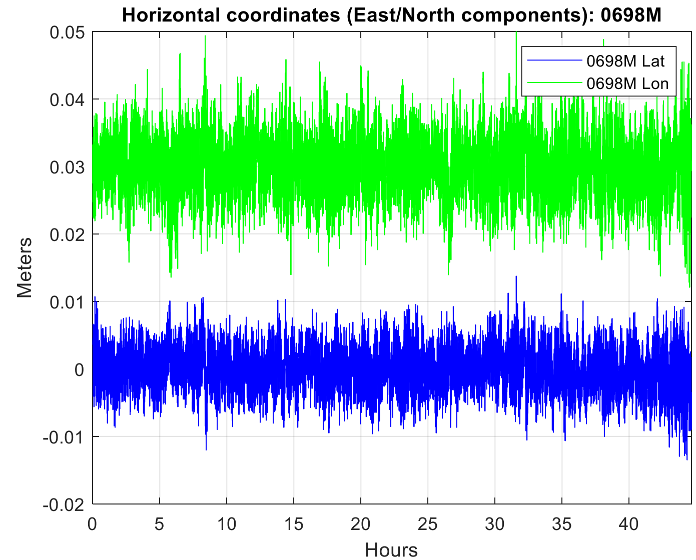
- Zero baseline, GPS-only, April 11th, 2019
- NTL105 as a reference station
- Two NTL105 modules as rover receivers
- Antenna Trimble Zephyr 3 Base
- RTCM 3.X messages

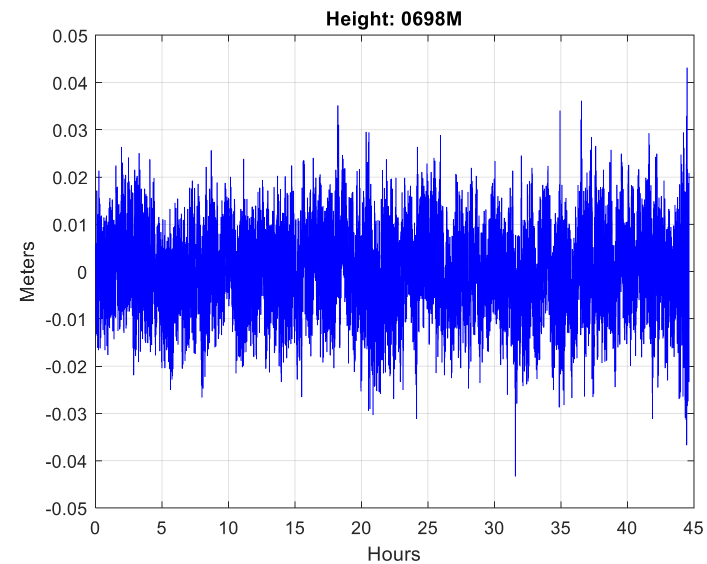
ID / Par.	Lat	Lon	Hor. (2D)	Alt (Ver.)	3D
0728-M	0.0011	0.0015	0.0019	0.0040	0.0044
0726-M	0.0011	0.0015	0.0019	0.0039	0.0043



RTK accuracy at 20-meters baseline (NTL105 as a base)





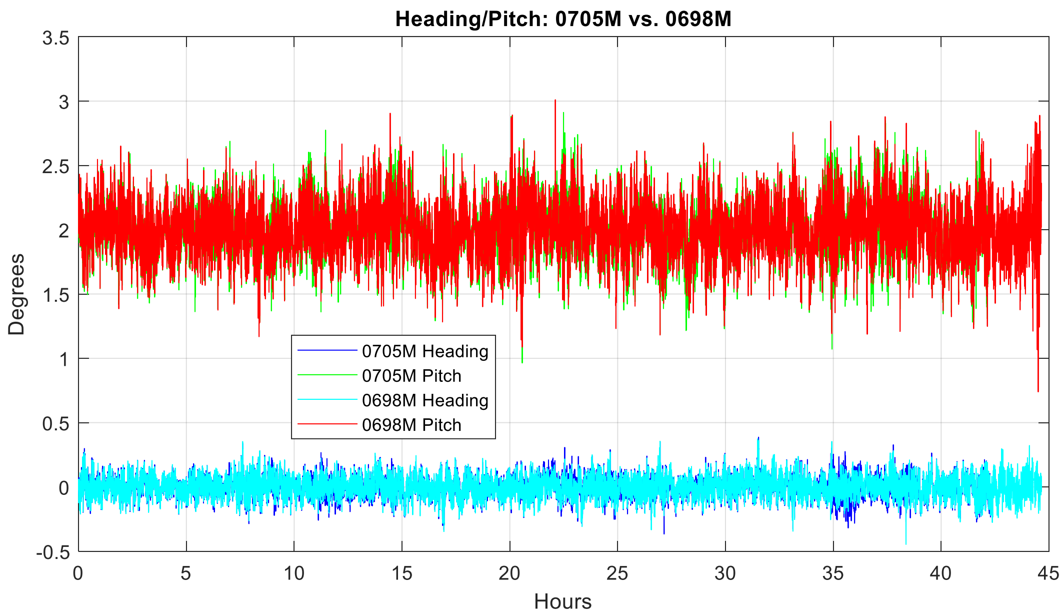


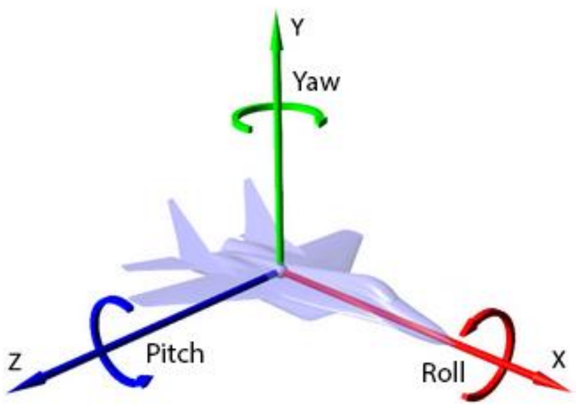
Setup:

- Baseline about 20 meters, GPS+GLONASS, November 19th, 2019
- NTL105 as a reference station
- Two NTL105 modules as rover receivers
- Antenna Trimble Zephyr 3 Base
- RTCM 3.X messages

ID / Par.	Lat	Lon	Hor. (2D)	Alt (Ver.)	3D
0698-M	0.0027	0.0036	0.0045	0.0072	0.0085

Heading and pitch at 2.20 meters baseline





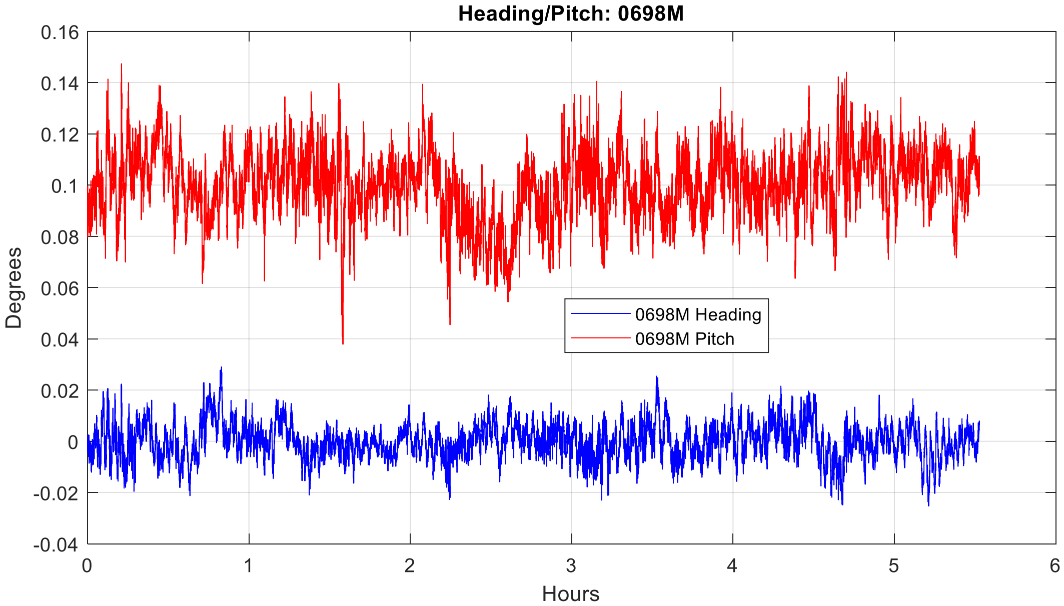
Setup:

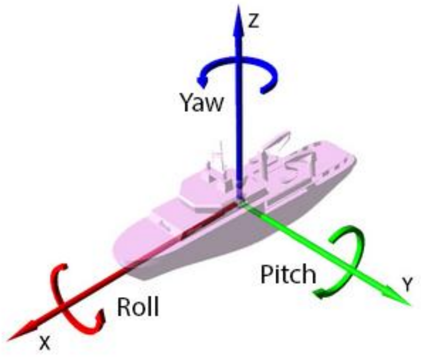
- Baseline 2.20 meters, GPS+GLONASS, November 19th, 2019
- Two NTL105 modules working 45 hours (about 2 days)
- Antenna Trimble Zephyr 3 Base (master) and Topcon PG-F1 (slave)

Heading (RMS) : **<0.07°**
Pitch (RMS): **<0.19°**

ID / Par.	Heading	Pitch
0705-M	0.0693°	0.1868°
0698-M	0.0680°	0.1845°

Heading and pitch at 25 meters baseline



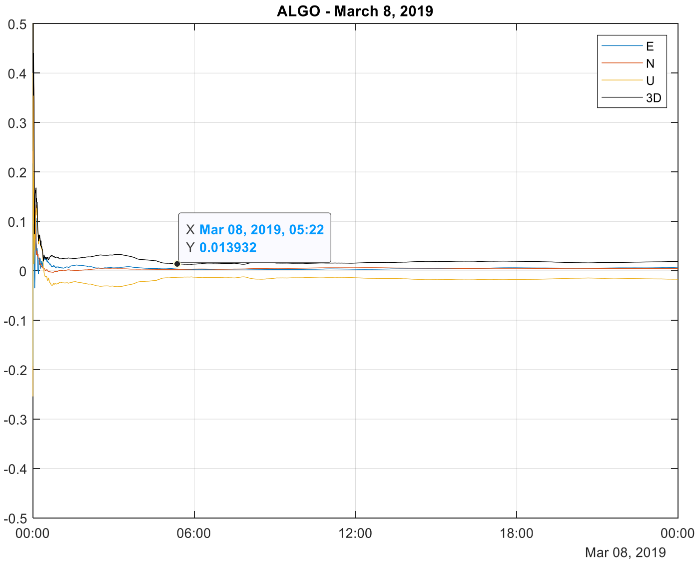


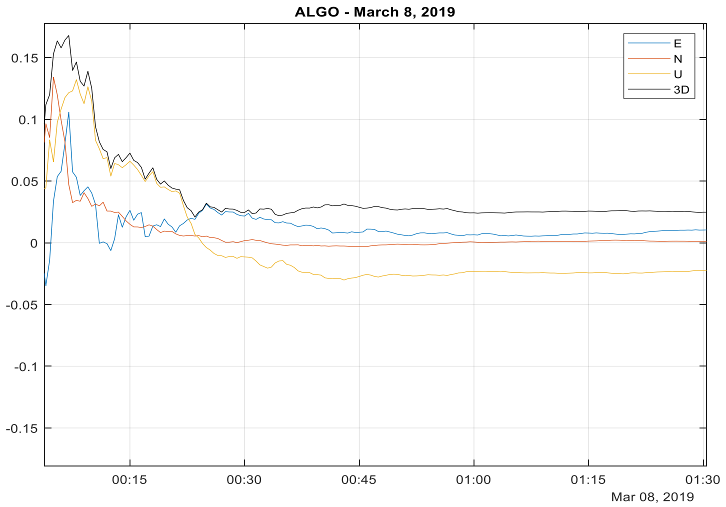
Setup:
- Baseline 25 meters, GPS+GLONASS, December 5th, 2019
- NTL105 module working 5.5 hours
- Antenna Trimble Zephyr 3 Base (master) and Trimble Zephyr 3 Base (slave)

Heading (RMS) : **<0.007°**
Pitch (RMS): **<0.014°**

ID / Par.	Heading	Pitch
0698-M	0.0069°	0.0132°

PPP accuracy (IGS ALGO station, Final IGS orbits/clocks)





Current implementation of NTLab's PPP algorithms allows reaching 10 cm (RMS, 3D) accuracy within about 10 minutes and 5 cm accuracy within 20 minutes (no tropospheric or ionospheric corrections used) with respect to exact ITRF2014 coordinates. Verified, using IGS data with Final orbits.

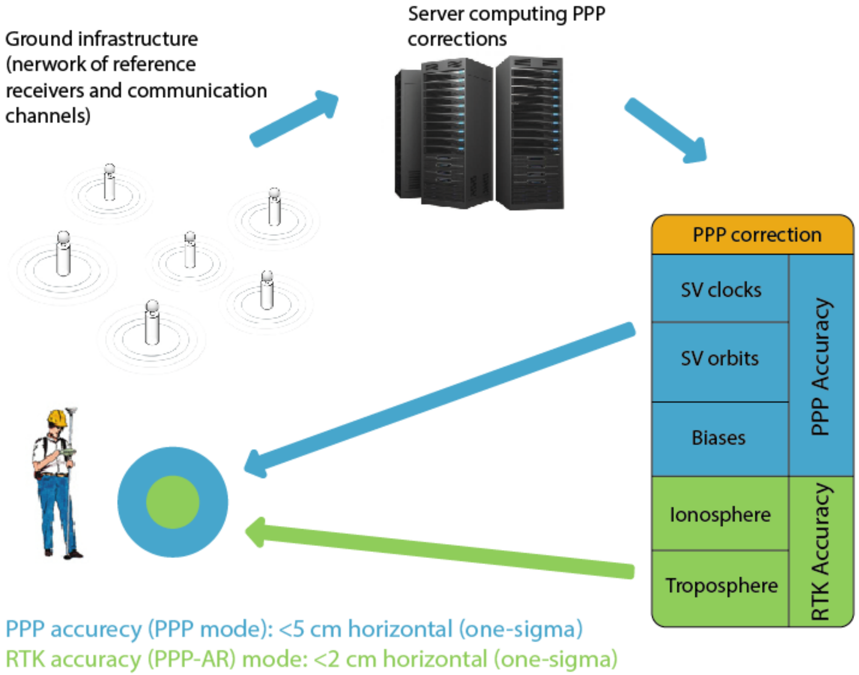
Accuracy on the order of 2 cm is reached in a few hours.

PPP algorithms for NTLab modules are under development:

- experiments with IGS data and SP3 files.
- evaluation of public and proprietary sources of PPP real-time corrections.
- "fine tuning" of PPP algorithms.

Expected to be released in spring 2020.

General scheme of PPP/PPP-AR processing



RTK level of positioning accuracy can be reached within typical for RTK positioning time frames (from seconds to up to a few minutes, depending on environment, total number of satellites and signals etc.) if, in addition to orbit/clock corrections, tropospheric and ionospheric corrections are available. Otherwise, convergence time can be on the order of a few tens of minutes to reach 5 cm horizontal accuracy.

Ground infrastructure:

- **Network of the reference receivers.**
- **More dense network for computing tropospheric/ionospheric corrections.**
- **Communication channels for connection to the server in real-time mode.**

Processing center:

- **PPP software, running in the server (computation of corrections to broadcast orbits and clocks, tropospheric/ionospheric corrections).**
- **Organizing data stream for sending PPP corrections to the rover receivers (e.g., RTCM SSR messages) via available communication channels (L-band, Ethernet, GSM etc.).**

Rover receivers:

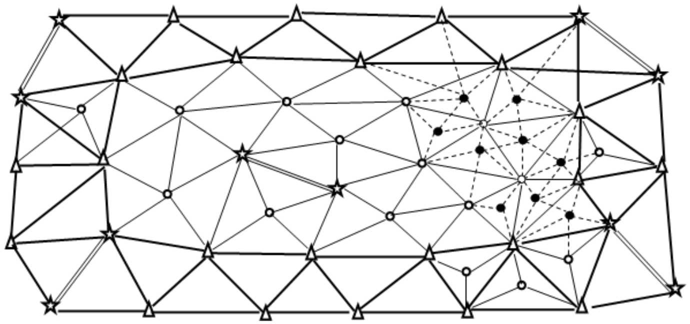
- **State-of-the-art PPP/PPP-AR algorithms for computing precise positions.**

Proposal on PPP Regional Service using NavIC L5/S-band signals

As it was noted, NavIC L5/S-band signals have got a big potential for high accurate positioning. This potential should be investigated and exploited “in full”. As its implementation, Regional PPP Service using NavIC L5/S-band signals can be considered with the following components:

- Network of reference stations capable of tracking NavIC L5/S-band signals with sufficient precision.
- More dense network will be required for generating tropospheric and ionospheric PPP corrections.
- Communication channels for connection to the server.
- Algorithms capable of computing orbit/clock corrections at the server. The next step would include the support of PPP-AR mode.
- Generating of appropriate data stream in pre-defined format (e.g., RTCM SSR messages). (Standardization of RTCM SSR for unified PPP-AR mode is not finished yet).
- Rover receivers capable of NavIC L5/S-band signals with PPP engine inside.

NTLab can contribute to development of all components of PPP Regional Service based on NaviC L5/S-band signals and is open for cooperation.



Outputs

- NTLab's high-end GNSS receivers working at geodetic (highest) level of positioning accuracy can be used for evaluation and usage **NavIC L5/S-band** signals for wide spectrum of applications.

- There is a possibility for evaluation **both SPS and RS** NavIC signals.

- Performances of NTLab's modules are verified, using Spirent simulator and "live" signals. Measurement precision of carrier phase observables is **equal or less than 0.8 mm**.

- NavIC L5/S-band observables have got **a high potential for using in RTK/PPP positioning.**

- Full flexibility (from scientific researches to up to commercial usage) in using the full set of NavIC signals, including RS signals, has been provided by **Open Architecture / Open Platform concepts.**

- There are no black boxes in NTLab's technology: **signal processing is under full control of the researchers.**

- Real-time results in positioning domain confirm high quality of GNSS observables generated by NTLab's modules. RTK accuracy at zero baseline is: **<2 mm.** For non-zero baselines, RTK accuracy is **5 mm + 0.5 mm/km and 8 mm + 1.0 mm/km** (horizontal and vertical components, respectively).

- **Regional PPP Service** would be perfect implementation of big potential of **NavIC L5/S-band signals** for high accurate positioning.

Thank you for your attention

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