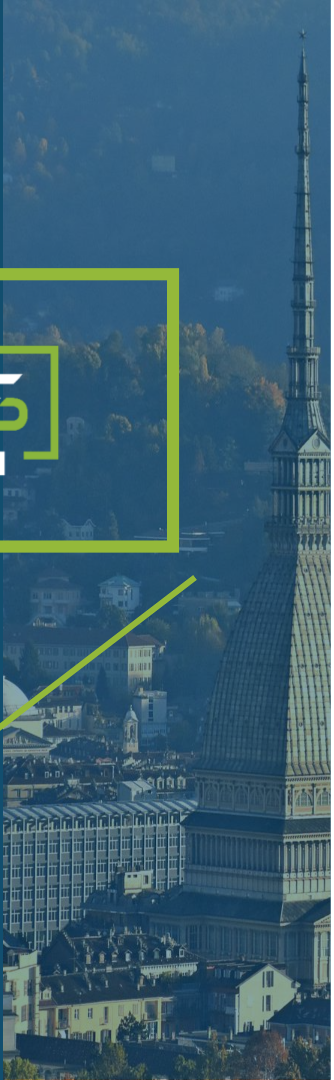


BASICS ON GNSS RECEIVERS

Gabriella Povero

Navigation Technologies

GNSS Training

AIT, Bangkok

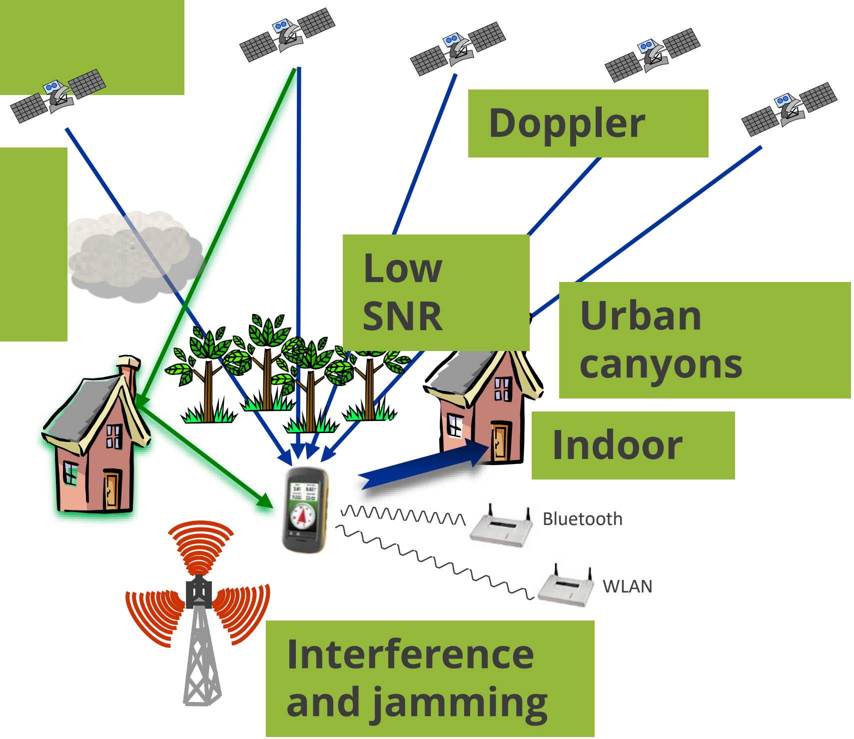
14 -18 January 2019

THE HARD WORK OF GNSS RECEIVERS

Control system errors:
- Clocks
- Ephemeris

Atmospheric errors:
- Ionosphere
- Troposphere

Multipath

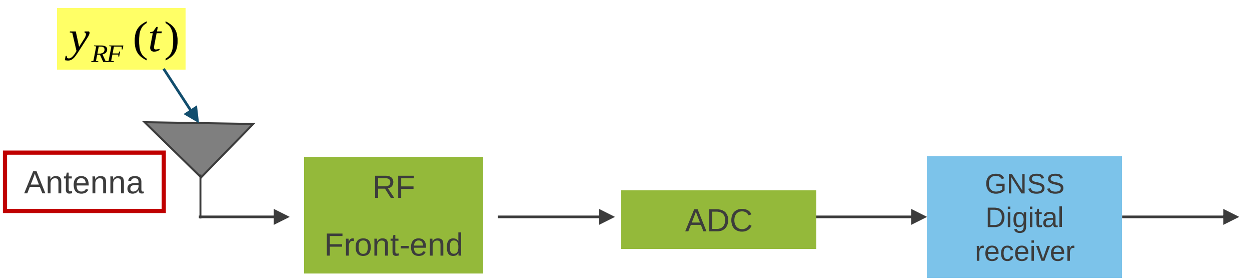


THE RECEIVER CHAIN

Let us consider the SIS of a single SV (space vehicle)

$$y_{TX}(t) = \sqrt{2P_R}\; c(t)\, d(t)\; \cos(2\pi f_{RF} t + \vartheta_{RF})$$

$$y_{RF}(t) = \sqrt{2P_R}\; c(t-\tau)\, d(t-\tau)\; \cos(2\pi (f_{RF} + f_d)t + \vartheta_{RF}) + w(t)$$



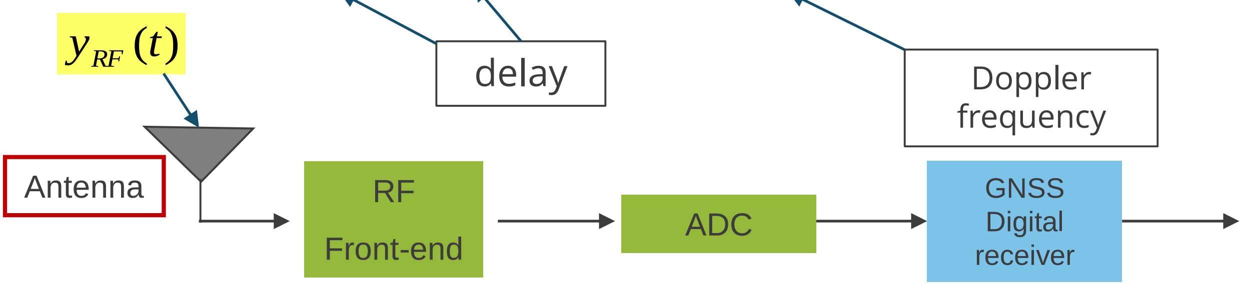
THE RECEIVER CHAIN

Let us consider the SIS of a single SV (space vehicle)

$$y_{TX}(t) = \sqrt{2P_R}\ \mathrm{c}(t)\ \mathrm{d}(t)\ \cos(2\pi\, f_{RF}\, t + \vartheta_{RF})$$

noise

$$y_{RF}(t) = \sqrt{2P_R}\ \mathrm{c}(t-\tau)\ \mathrm{d}(t-\tau)\ \cos(2\pi\,(f_{RF} + f_d)t + \vartheta_{RF}) + w(t)$$



GNSS ANTENNAS

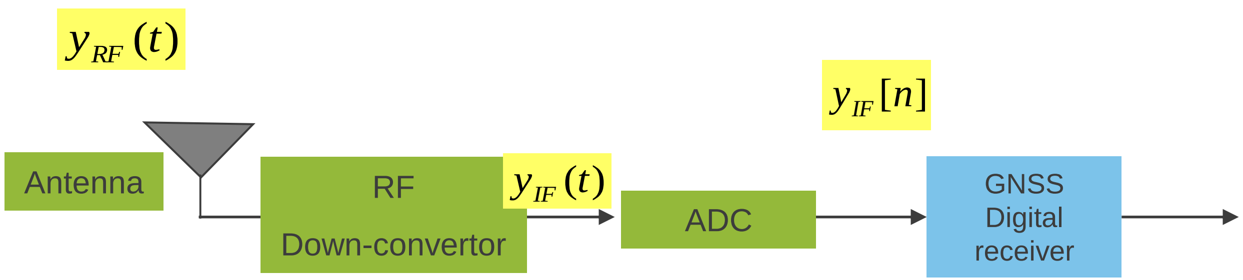
- Antennas receive, amplify and band-pass filters GNSS signals
- GNSS antennas are Right Hand Circularized Polarized (RHCP)
- Important parameters used to characterize GPS antennas are:
  - Central frequency (e.g.: GPS L1 = 1575.42 MHz) and bandwidth
  - Single or multi-frequency
  - Radiation pattern (directivity). Antenna GPS antennas are usually hemispherical
  - Impedance (typically 50 ohm)
  - Voltage Standing Wave Ratio (VSWR)
  - Noise factor
  - Gain
  - Multipath rejection capability
  - Jamming mitigation capability

THE RECEIVER CHAIN

Let us consider the SIS of a single SV (space vehicle)

$$y_{TX}(t) = \sqrt{2P_R}\ \mathrm{c}(t)\,\mathrm{d}(t)\ \cos(2\pi f_{RF} t + \vartheta_{RF})$$

$$y_{RF}(t) = \sqrt{2P_R}\ \mathrm{c}(t-\tau)\,\mathrm{d}(t-\tau)\ \cos(2\pi (f_{RF} + f_d)t + \vartheta_{RF}) + w(t)$$



$$y_{IF}(t) = \sqrt{2P_R}\ \mathrm{c}(t-\tau)\,\mathrm{d}(t-\tau)\ \cos(2\pi (f_{IF} + f_d)t + \vartheta_{IF}) + w(t)$$

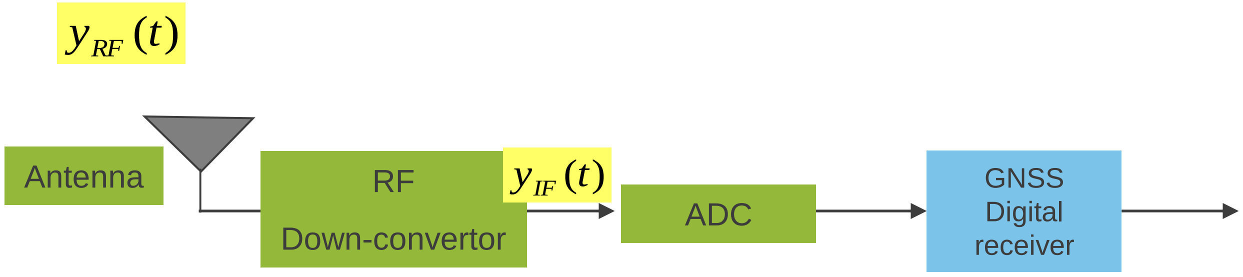
GNSS FRONT-END

RF down convertor

It down-converts and filters RF signals to an intermediate frequency (IF) compatible with analogue-to-digital converter (ADC) acceptable input.

Key parameters:

- Input frequency/ies
- Noise
- Linearity
- Automatic Gain Control (AGC)
- Isolation

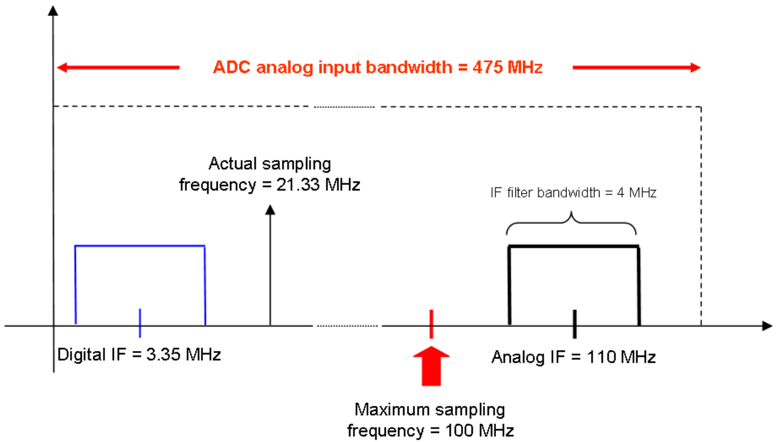


$$y_{IF}(t) = \sqrt{2P_R}\ c(t-\tau)\ d(t-\tau)\ \cos(2\pi\,(f_{IF}+f_d)t+\ \vartheta_{IF}) + w(t)$$

ANALOG TO DIGITAL CONVERTER (ADC)

Important parameters used to characterize the **ADC** are:

- **# of bits**: GNSS receivers works well with a low number of bits per samples (1,2, 1.5, 4 bits). Higher number of bits (8 bits) used for specific applications (e.g.: interference detection)
- **Analog input range**: defines the voltage range in input. Used in the design of the front end gain
- **Maximum sampling frequency**: depends on the device (e.g.: 60, 80, 100 Msps)
- **Analog input bandwidth**: Determine the maximum frequency of the signal that can be processed by the device



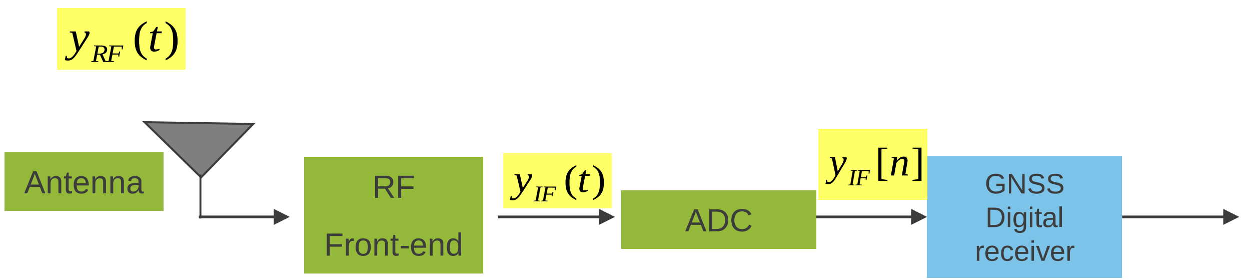
From Analog Device AD9288

THE RECEIVER CHAIN

Let us consider the SIS of a single SV (space vehicle)

$$y_{TX}(t) = \sqrt{2P_R}\ \mathrm{c}(t)\,\mathrm{d}(t)\ \cos(2\pi f_{RF} t + \vartheta_{RF})$$

$$y_{RF}(t) = \sqrt{2P_R}\ \mathrm{c}(t-\tau)\,\mathrm{d}(t-\tau)\ \cos(2\pi (f_{RF} + f_d)t + \vartheta_{RF}) + w(t)$$



$$y_{IF}[n] = \sqrt{2P_R}c^{(b)}(nT_s - \tau)d(nT_s - \tau)\cos(2\pi(f_{IF} + f_d)nT_s + \vartheta_{IF}) + w_{IF}[n]$$

delay

Doppler frequency

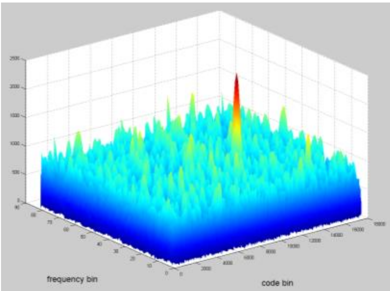
GNSS RECEIVER OPERATIONS

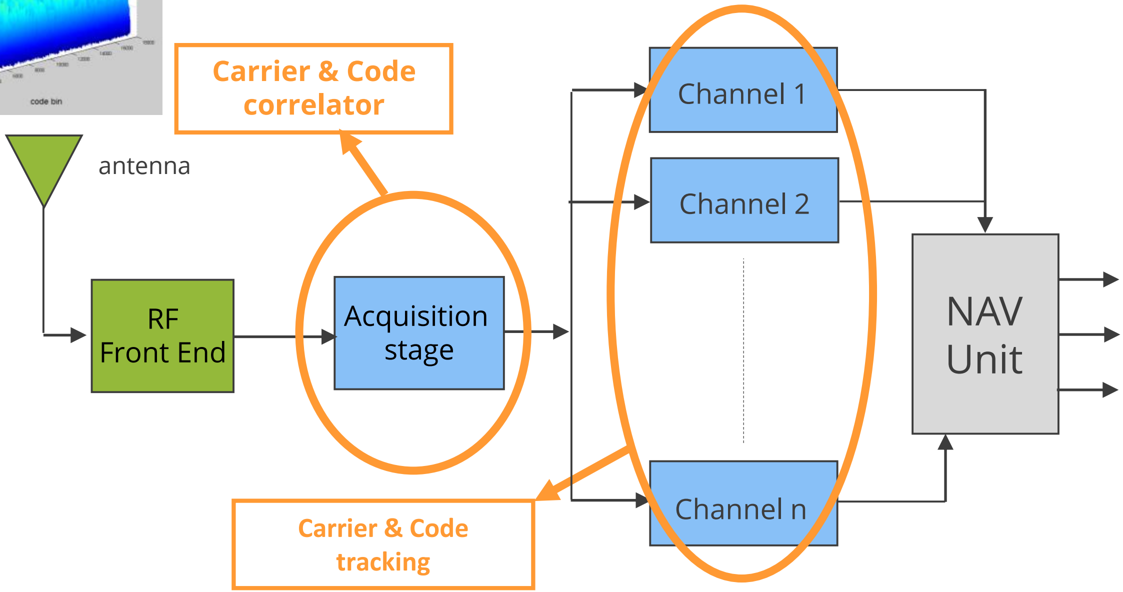
$$y_{IF}[n] = \sqrt{2P_R}c^{(b)}(nT_s - \tau)d(nT_s - \tau)\cos(2\pi(f_{IF} + f_d)nT_s + \vartheta_{IF}) + w_{IF}[n]$$

1. **Sky search** — Search for IDs of visible satellites
2. **Acquisition** — Code delay and Doppler estimates, rough alignment of code and carrier
3. **Tracking** — Refines code and carrier alignment

GNSS RECEIVER FUNCTIONALITIES

Baseband processing: Acquires and tracks incoming signals, demodulates signals.



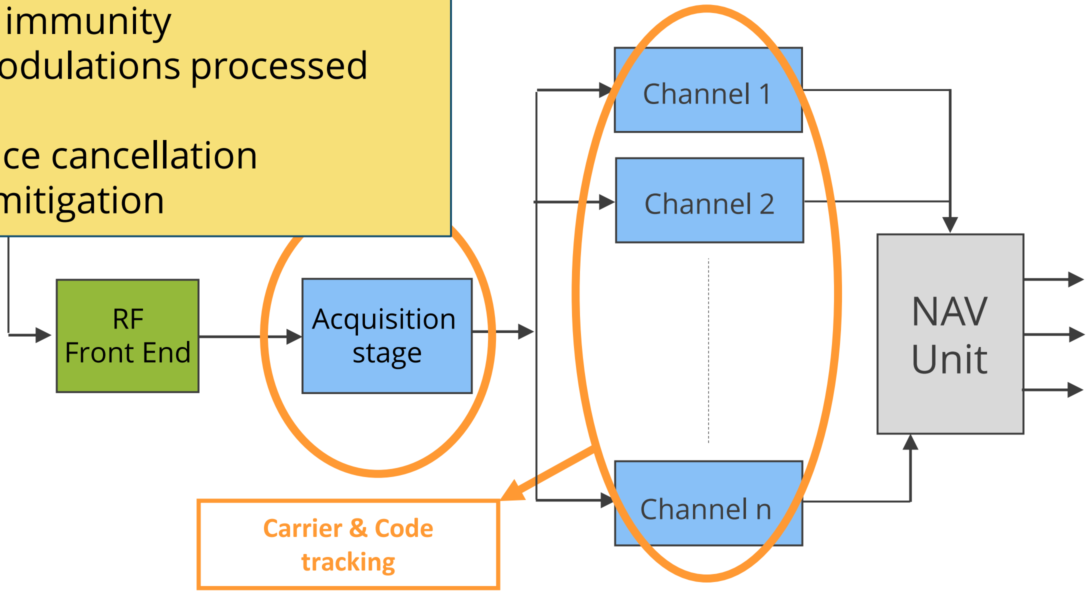


GNSS RECEIVER FUNCTIONALITIES

Baseband processing: Acquires and tracks incoming signals, demodulates signals.

Key parameters:

- Number of channels
- Measurement rate
- Carrier-to-Noise ratio (C/N0)
- Multipath immunity
- Signals/modulations processed
- Dynamics
- Interference cancellation
- Jamming mitigation



GNSS RECEIVER OPERATIONS

4 **Measurements** Pseudorange and data demodulation

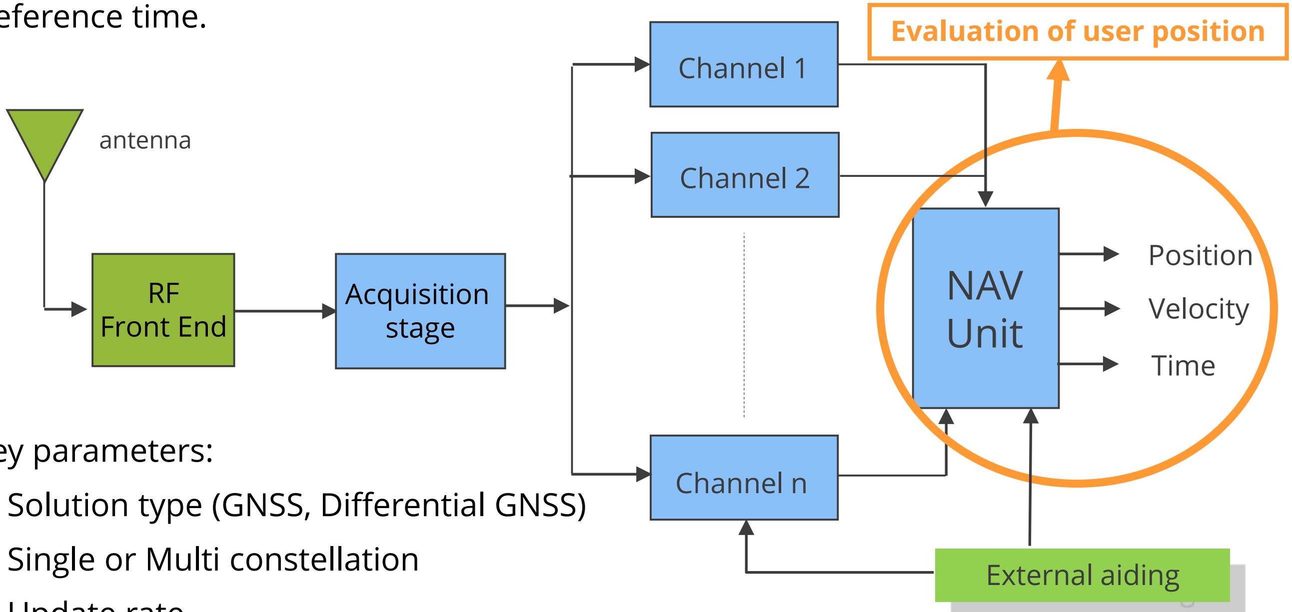
5 **Computation** Usually the PVT

6 **Integration with external info** Not present in all receivers

7 **HMI** Not present in all receivers

GNSS RECEIVER FUNCTIONALITIES

PVT (& Application) processing:
Computes the estimated position and receiver time offset relative to the constellation's reference time.



Key parameters:

- Solution type (GNSS, Differential GNSS)
- Single or Multi constellation
- Update rate
- Latency

RECEIVERS CLASSES

	Description	Device Price [€]
	Handheld receivers for hikers and sailors. Small size with latitude-longitude displays and maps.	100 - 600
	Integrated GPS in mobile phones. Low cost and mostly single frequency.	50-600
	Maritime navigators. Fixed mount, large screens with electronics chart	100-3000
	In-car navigation systems. Detailed street maps and turn-by-turn directions. These systems can be also handheld (e.g. PDA)	100-2000

Price differences are due to reason independent from the embedded GNSS chip

RECEIVERS CLASSES

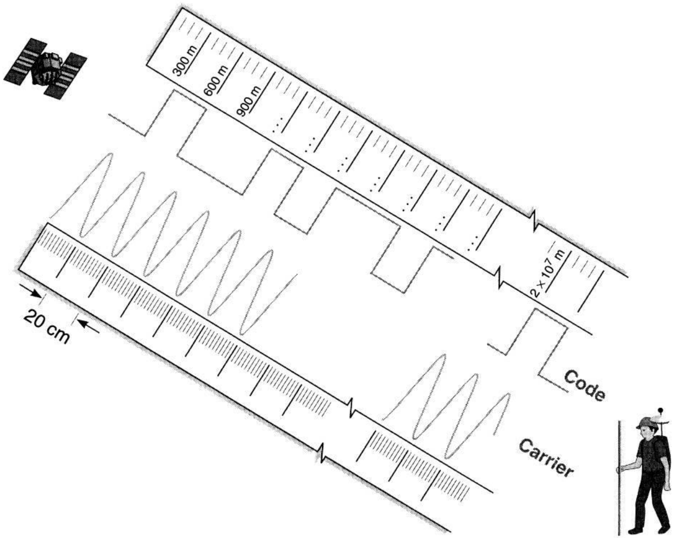
	Description	Approx. Price [€]
	Aviation receivers. FAA in US and EASA in Europe certified, panel mounted with maps. **INTEGRITY REQUIRED !**	>3000
	Survey and mapping professional receivers. Multi-frequency and differential GPS, centimeter accuracy	1500 – 30000

Price differences are due to reason independent from the embedded GNSS chip

GNSS MODULES

	Description	Approx. Price [€]
	Plug-in modules. Integrated receivers and antenna. Employed in tracking systems	30 – 700
	Original Equipment Manufacture boards. Employed for integration in other complex systems.	100 – 5000
	Chip sets. Employed for integration, but all the circuitry is needed	1 – 30

PROFESSIONAL VS MASS-MARKET RECEIVERS



Carrier Phase
vs
Code Phase?

Raw measurements availability and configurability

Configurability

DGNSS … RTK

RECEIVERS CLASSIFICATION: MARKET SEGMENT

Category	Receiver Characteristics
Consumer	Single frequency (few also double frequency), **cost driven**, high volume, moderate performance, also multi constellation
Light Professional	Single frequency, multi constellation, cost driven, low volume, good performance, integration with external devices, professional features
Professional	Multi frequency, multi constellation, cost/requirements driven, low volume, high performance, advanced processing algorithms
Safety of Life	Double/ Multi frequency, multi constellation, requirements driven, low volume, high performance, high reliability, **integrity, certification**
P R S	Double frequency, low volume, high performance, high reliability, requirements driven, integrity, advanced processing algorithms

GNSS RX FEATURES

- Constellation(s) exploited
- Military or civil receiver
- PVT update rate
- Indoor operations or high multipath environment
- Interference mitigation
- Dynamic conditions (from static to high dynamics)
- DGPS or WAAS/EGNOS capability (RTK input/output)
- Storage of log data
- Shock and vibration tolerance
- Cartographic support
- INS integration or dead-reckoning systems
- Integration with COM systems
- Portability
- Usability
- Power consumption
- Cost

EXAMPLE OF TECHNICAL SPECIFICATION (1)

Septentrio PolaRx4 PRO

- 264 hardware channels
- TRACK+: Septentrio's low-noise tracking algorithms
- GPS L1/L2/L2C/L5,
- GLONASS L1/L2
- Galileo E1, E5a, E5b, E5 AltBOC and GLONASS CDMA L3, Beidou signals (initially experimental)
- AIM+: Advanced Interference Monitoring and Mitigation
- APME+: extends Septentrio's patented A Posteriori Multipath Estimator to GLONASS, Galileo and Beidou signals
- ATrack+: is Septentrio's patented Galileo AltBOC tracking.

EXAMPLE OF TECHNICAL SPECIFICATION (2)

Septentrio PolaRx4 PRO

Pseudorange noise (not smoothed)		Carrier Phase	
GPS L1 C/A	16 cm	L1/E1	<1 mm
GLONASS L1 open	25 cm	L2	1 mm
Galileo E1 B/C	8 cm	L5/E5	1.3 mm
Galileo E5 A/B	6 cm	Doppler	
Galileo E5 AltBOC	1.5 cm	L1/L2/L5	0.1 Hz
GPS L2 P(Y)	10 cm		
GLONASS L2 (mil)	10 cm		

EXAMPLE OF TECHNICAL SPECIFICATION (3)

NovAtel 628

- 120 hardware channels
- GPS L1 L2 L2C L5
- GLONASS L1 L2
- Galileo E5a E5b E5 AltBOC
- Beidou B1 B2
- QZSS
- L-Band
- RT-2 (RTK algorithm)
- Pulse Aperture Correlator (PAC) multipath mitigation technology
- SPAN INS integration technology
- …

EXAMPLE OF TECHNICAL SPECIFICATION (4)

NovAtel 628

Pseudorange noise (not smoothed)		Carrier Phase	
GPS L1 C/A	4 cm	L1 GPS	0.5 mm
GLONASS L1 open	8 cm	L1 GLONASS	1 mm
GPS L2 P(Y)	8 cm	L2	1 mm
GPS L2C	8 cm	L2C	0.5 mm
GPS L5	3 cm	L5	0.5 mm
GLONASS L2 open	8cm		
GLONASS L2 mil	8 cm		

EXAMPLE OF TECHNICAL SPECIFICATION (5)

NovAtel 628

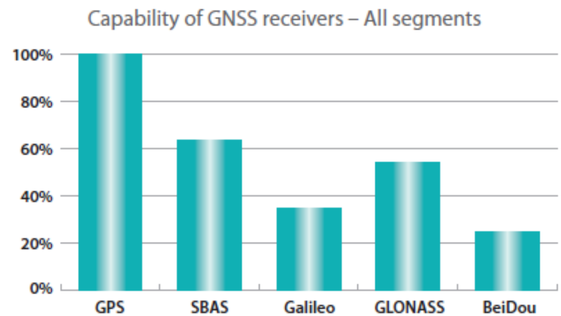
Position Accuracy (RMS)	
Single point L1	1.5 m
Single point L1/L2	1.2 m
SBAS (GPS)	0.6 m
DGPS	0.4 m
L-band VBS	0.6 m
L-band XS	15 cm
L-band HP	10 cm
RT-2	1 cm + 1ppm (BL)

Signal Reacquisition	
L1	<0.5 s (typical)
L2	<1.0 s (typical)

Maximum Data Rate	
Measurements	100 Hz (20 SV)
Positions	100 Hz (20 SV)

Vibration	
Random vibe	MIL-STD 810G (Cat 24, 7.7 g RMS)
Sine vibe	IEC 60068-2-6

GNSS RECEIVERS CAPABILITY

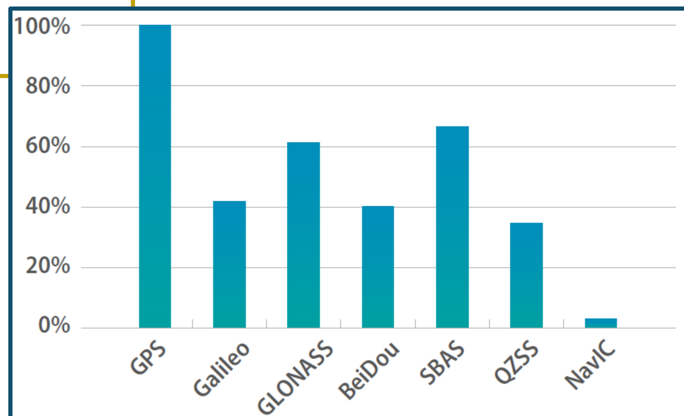


* Analysed manufacturers: CSR, Furuno, Hemisphere GNSS, Japan Radio Co., Leica Geosystems AG, Mediatek, NavCom Technology, Nottingham Scientific Ltd, NovAtel, Orolia, Septentrio, STMicroelectronics, Topcon, Trimble, U-blox, Avidyne, Broadcom, Esterline, Garmin, Honeywell, Infineon, Intel, John Deere, Kongsberg, Omnicom, Qualcomm, Rockwell Collins, SkyTraq Technology, Texas Instruments, THALES Avionics, Universal Aviation.

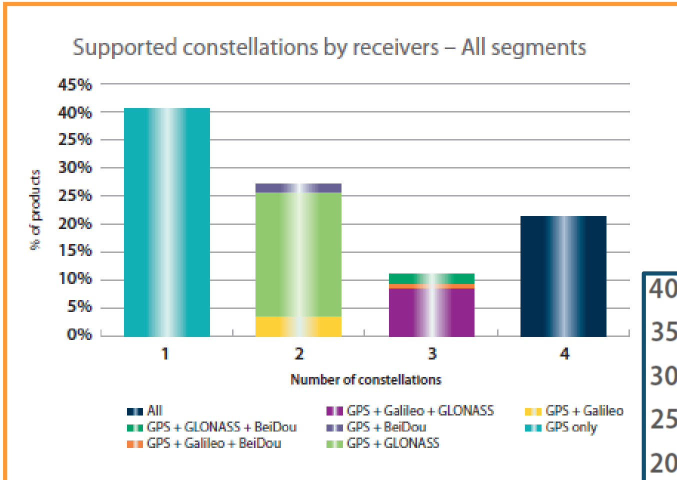
** Please note that the capability of GNSS devices presented in Market Report Issue 3 cannot be compared with the ones from the current edition due to different group of manufacturers used in the analysis.

GNSS Market Report 2015 (GSA)

GNSS Technology Report 2018 (GSA)



GNSS RECEIVERS CAPABILITY



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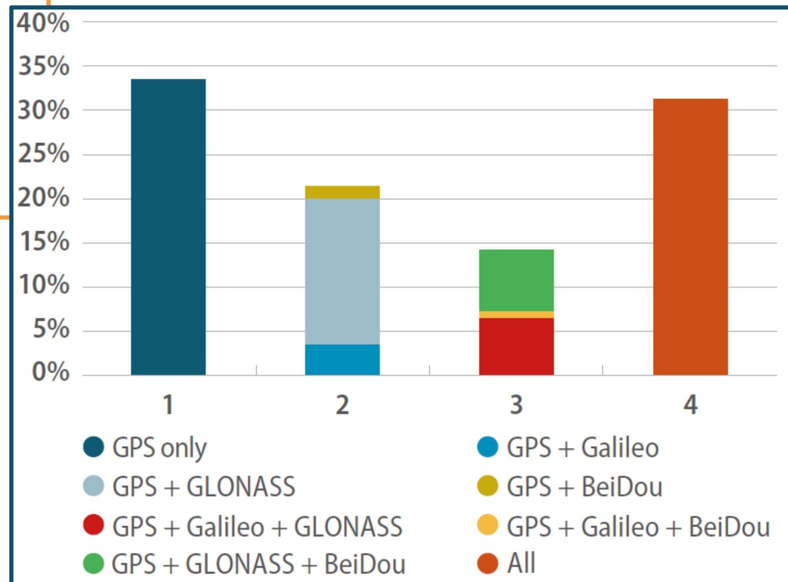

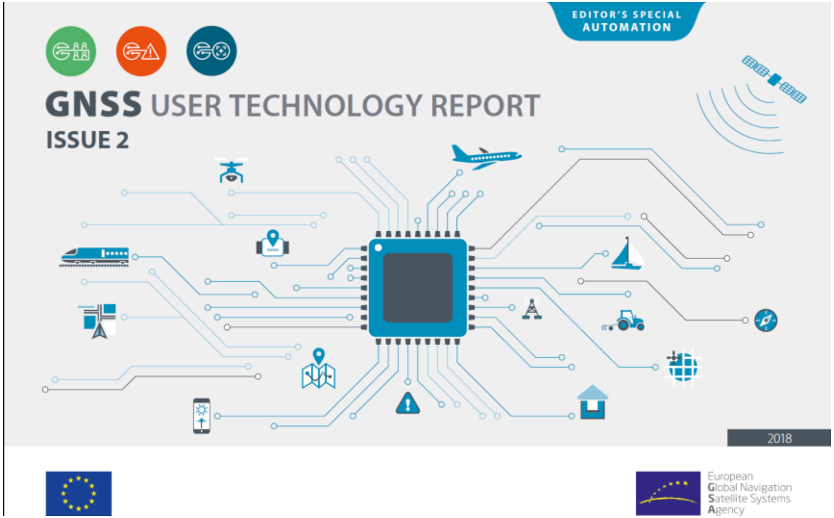

https://www.gsa.europa.eu/system/files/reports/gnss_user_tech_report_2018.pdf

CONTACT

GABRIELLA POVERO

gabriella.povero@linksfoundation.com
www.navsas.eu
www.ismb.it

LINKS FOUNDATION

Via Pier Carlo Boggio 61 | 10138 Torino

+(039) 011 2276 150

f @linksfoundation

in linksfoundation

t @linksfoundation

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