GNSS Training for ITS Developers

2 – European GNSS

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EGNSS

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EGNSS

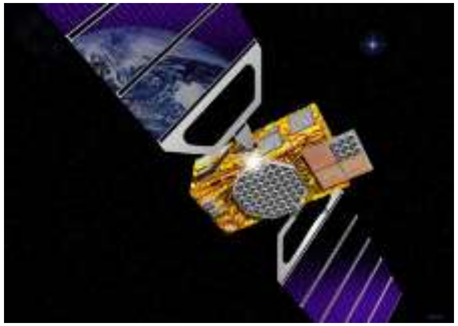
Galileo

- Initiative of the European Union (EU) and the European Space Agency (ESA), in collaboration with European Industries
- Galileo is a **civil system under civil control**
- Galileo offers more and new **services**
- Galileo is **independent** from GPS
- Galileo is **compatible** and **interoperable** with GPS

Galileo and GPS

US and EU Agreement in June 2004

- Adoption of a common signal for Galileo E1 and GPS III L1 open signals - BOC(1,1).
- Adoption of interoperable timing and geodesy standards to facilitate the joint use of Galileo and GPS
- Broadcast of GPS/Galileo time offset.
- Commitment to preserve National Security capabilities
- Non-restrictions of access to open service end-users



- **Interoperability**
- **Compatibility**

Compatibility and Interoperability

- **Compatibility** = ability of space-based PNT services to be used separately or together without interfering with each individual service or signal, and without adversely affecting national security

First: Do not Harm

- **Interoperability** = Combined use of two systems
  - Common center frequencies
  - Same Time Reference System
  - Same Coordinate Reference Frame

Interoperability

Interoperability is the result of an **optimization process** and derives from weighted consideration of:

- Compatibility (without performance degradation)
- Simple user receiver design
- Market considerations
- Vulnerability (common failures)
- Independence
- Security

COMPATIBILITY IS MANDATORY TO HAVE INTEROPERABILITY

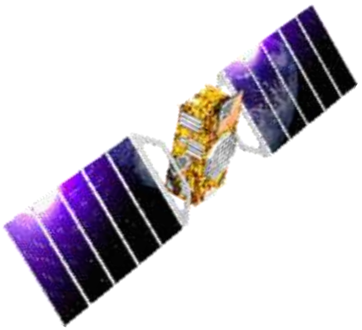
Galileo Adds-on

Precision	• Improved by new modulation schemes
Availability	• Improved by specific orbit design *
Coverage	• Improved by specific orbit design *
Reliability	• Improved by Authentication service (CS◊)
Accuracy	• Improved by High Accuracy service (CS◊)

* advantage also by multi constellation

◊ Commercial Service

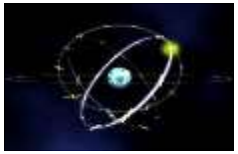
Galileo Implementation Plan



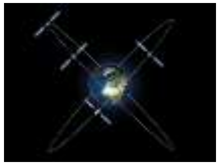
Full Operational Capability
Full services, 30 satellites
2020

Initial Operational Capability
Early services for OS, SAR, PRS
2015/2016

In-Orbit Validation
4 fully operational satellites and ground segment
2013



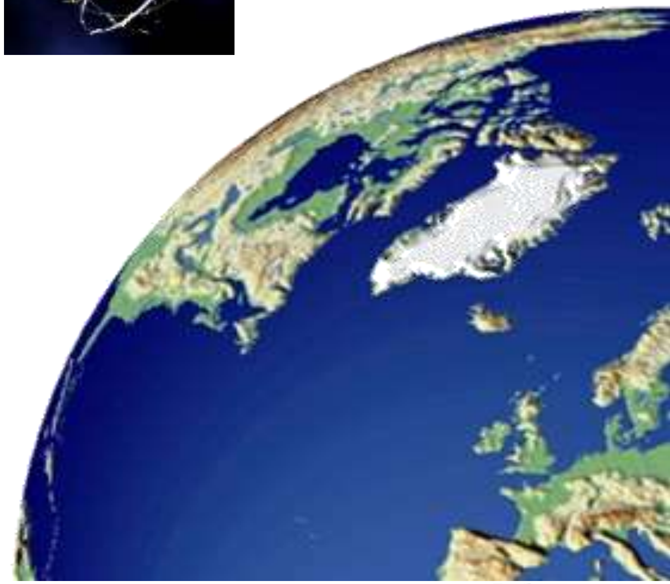
GIOVE A/B
2 test satellites
2005/2008



GALILEO GIOVE

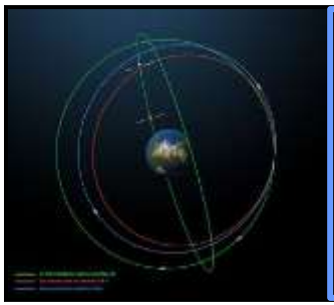
Galileo System Testbed v1
Validation of critical algorithms
2003

GALILEO GSTB-V1



Galileo is Taking Off

- First two **IOV operational satellites** launched on 21st October 2011
- Third and fourth Galileo satellites, completing the IOV **quartet**, launched on 12th October 2012
- On 12th March 2013, the first ever **position fix using only Galileo satellites and ground segment** was achieved.



- First two **FOC satellites** launched on 22nd August 2014
- Injection anomaly – lower and elliptical orbits
- By 13th March 2015, both sat moved to **corrected orbits** with repeat pattern of 20 days

- Four FOC satellites launched on 27th April / **11th September 2015**
- Galileo satellites 7 & 8 and 9 & 10 reached their orbit
- Current Galileo constellation: 4 IOV + 4 FOC + 2 FOC in corrected orbits
- **Next launch scheduled on December the 17th**

List of Galileo Satellites Tracked with NGene2

NGene2 Navigation Software Receiver

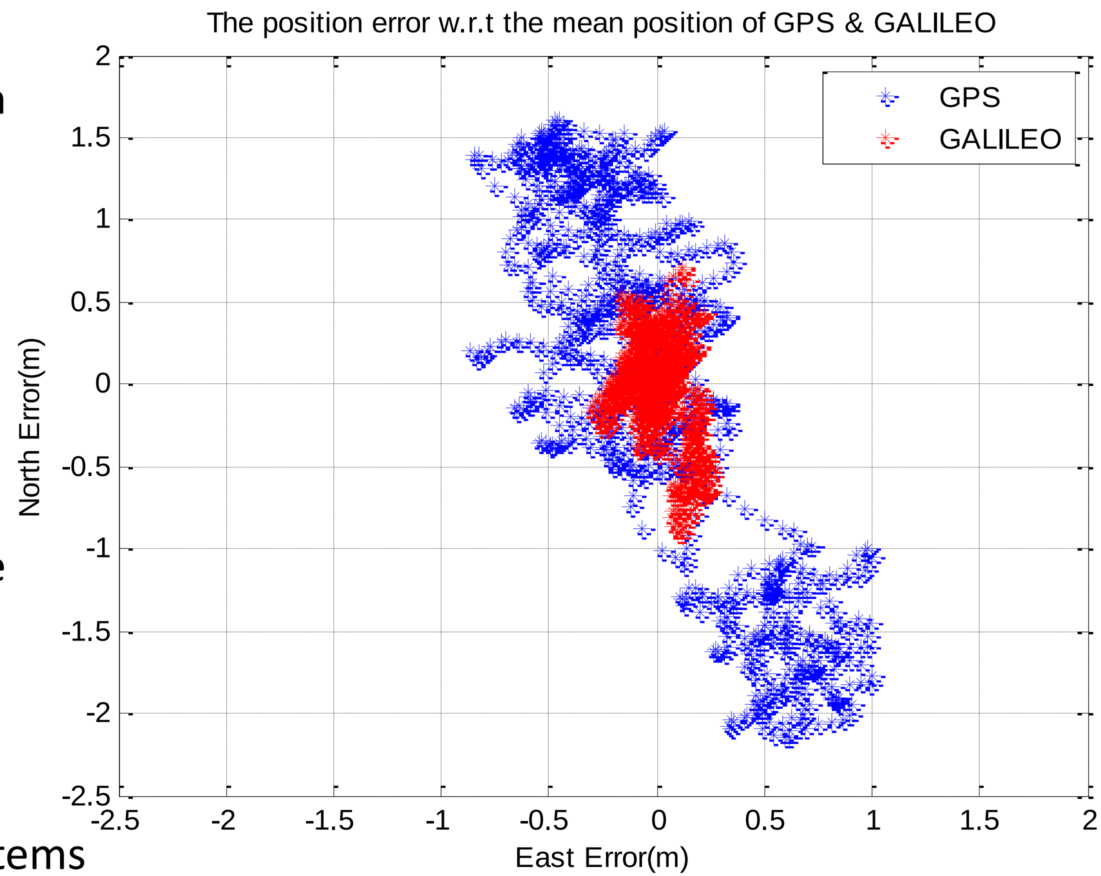
- **NGene2** is a navigation fully software receiver developed by **NavSAS**: a ISMB – Politecnico di Torino joint research group.

SV_{ID}	Name	Launch date	Acquisition and Tracking	Used in PVT
11	Galileo-IOV PFM (*Thijs*)	21/10/2011	✓	✓
12	Galileo-IOV FM2 (*Natalia*)	21/10/2011	✓	✓
19	Galileo-IOV FM3 (*David*)	12/10/2012	✓	✓
20	Galileo-IOV FM4 (*Sif*)	12/10/2012	✓	✓
18	Galileo-FOC FM1 (*Doresa*)	22/08/2014	✓	*
14	Galileo-FOC FM2 (*Milena*)	22/08/2014	✓	*
26	Galileo-FOC FM3 (*Adam*)	27/03/2015	✓	*
22	Galileo-FOC FM4 (*Anastasia*)	27/03/2015	✓	*

* Dummy navigation message

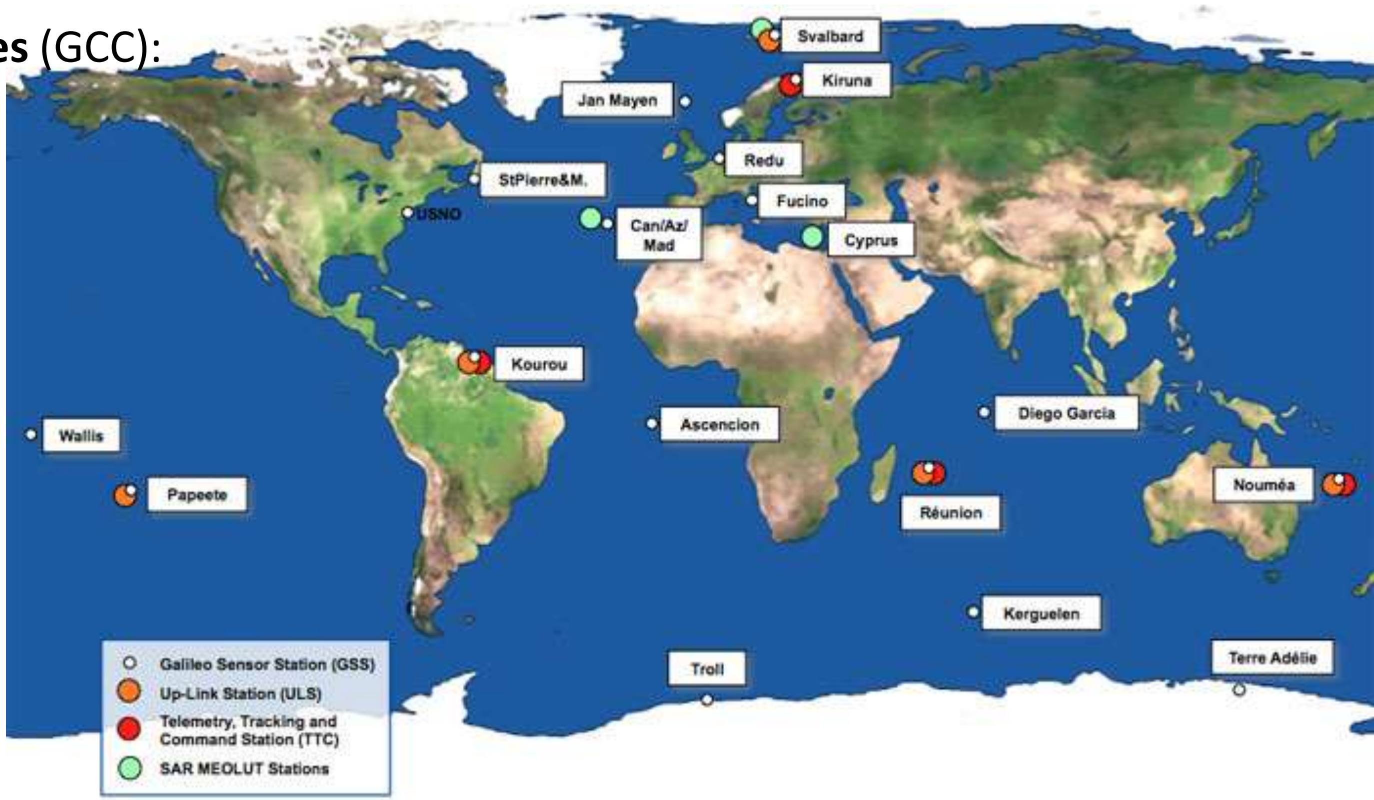
Galileo Real Early Performance (2014)

- Galileo is benchmarked to GPS in terms of precision in the estimation of the position
- In mid 2014 only 3 Galileo satellites were transmitting a valid navigation message
- The position computation was performed using L1 data From:
  - 5 GPS satellites
  - 3 Galileo + 2 GPS satellites
- Chosen GPS and Galileo satellites were those in view during the same time period and which elevation and azimuth angles were similar in pairs. The aim of this scenario is to have common ionospheric and troposheric effects for both the systems



Galileo Ground Segment

- **>20 sensors stations**
- **1 In Orbit Testing** (IOT) centre (Redu, BE)
- **2 Galileo Control Centres** (GCC):
  - Oberpfaffenhofen, DE
  - Fucino, IT
- **2 Launch and Early Operations Phase** (LEOP) centres
  - Toulouse, FR
  - Darmstadt, DE
- 9 **UpLink Stations** (ULS)
- 5 **Telemetry Tracking & Command** (TTC) stations
- 3 Search & Rescue Medium-Earth Orbit Local User Terminal (SAR MEOLUT) Stations



Galileo Services

- **Open Service (OS):**
  - **Freely available service** for Mass-Market applications requiring simple positioning and no guarantee of service

- **Commercial Service (CS):**
  - It is for professional use requiring higher accuracy and it may offers a guaranteed service in return of a fee
    - broadcasting of supplementary data to foster *commercial applications*
    - signal *encryption/authentication*

Galileo Services

- **Safety-of-Life (SoL) Service:**
  - Integrity service for transportation application
  - Recent official decision of re-profiling (descoping) as Integrity Monitoring Service

- **Search-And-Rescue (SAR) Service:**
  - Real-time detection of distress alarm
  - It is compatible with COSPAS-SARSAT
  - It needs a return link

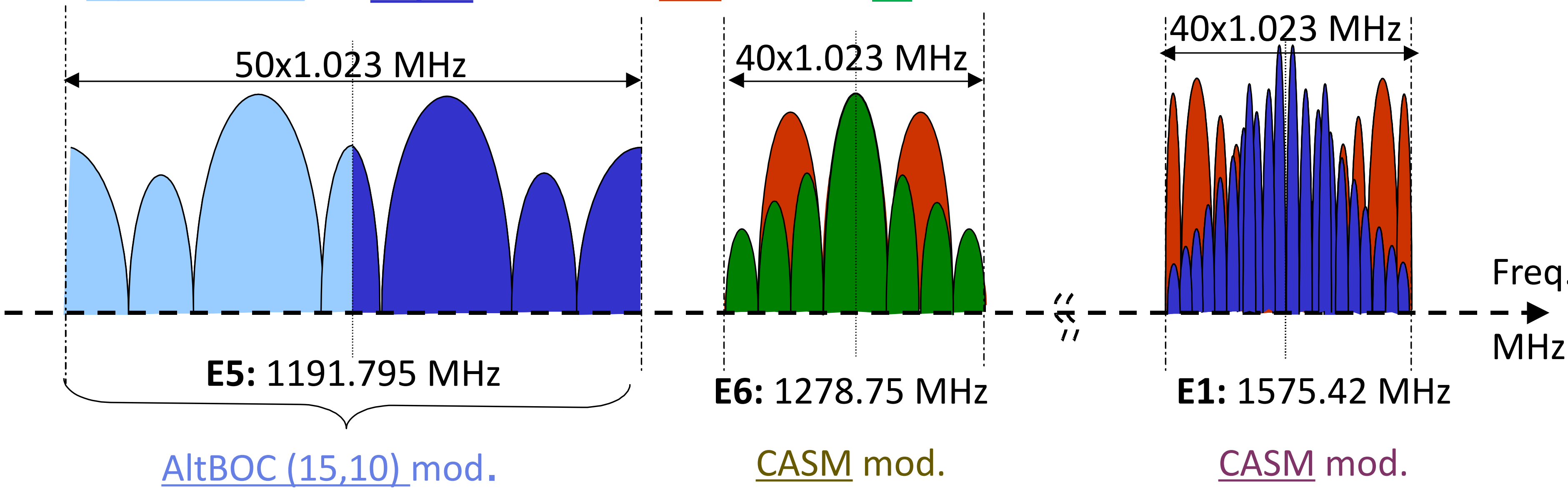
- **Public Regulated Service (PRS):**
  - Reserved to government authorized-users only

Galileo Services: Current Status

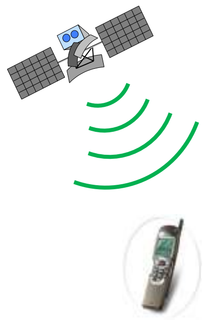
- Open Service: → available public documentation (ICD)
- Commercial Service: → under design
- Safety-of-Life Service: → being re-profiled
- Search-And-Rescue: → payload activated in Jan 2013
  (ground stations ready on October 2013)
- Public Regulated: → restricted ICD

Galileo Signals and Mapping to Services

E5A Data+Pilot	E5B Data+Pilot	E6A	E6B-C	E1A	E1B-C
QPSK-like mod.	QPSK-like mod.	$BOC_{cos}(10,5)$	BPSK(5)	$BOC_{cos}(15,2.5)$	CBOC(6,1,1/11)
Rc = 10.23Mcps	Rc = 10.23Mcps	Rc = 5.115	Rc = 5.115	Rc = 2.5575	Rc = 1.023
Rs = 50 Mcps	Rs = 250 Mcps	Rs = -	Rs = 1000	Rs = -	Rs = 250
Open Service	OS/CS	PRS	CS	PRS	OS/CS



Navigation Signal in Space



The signal broadcast by the navigation satellites must:

- Allow the user to **estimate the pseudorange** user-satellite
- Carry some **useful data**
- Be **robust** to the transmission through the atmosphere
- Identify in a **unique way** the satellites

The SIS is characterised by:

- Frequency Band
- Carrier Frequency
- Modulation Scheme
- Multiplexing Format
- Ranging Code
- Navigation Data Format
- Transmitted Power

Bands & Frequencies

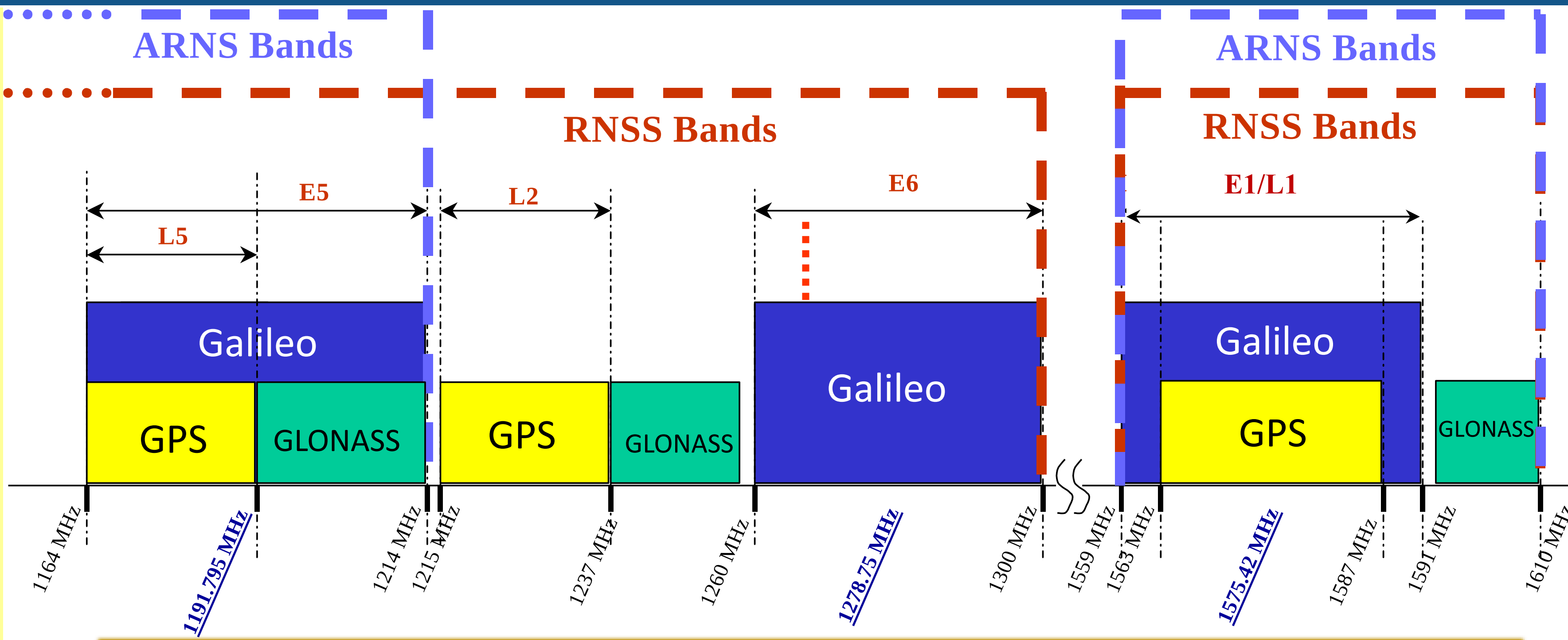
Modulation schemes

Multiplexing

Codes

Navigation Data

Bands Allocation



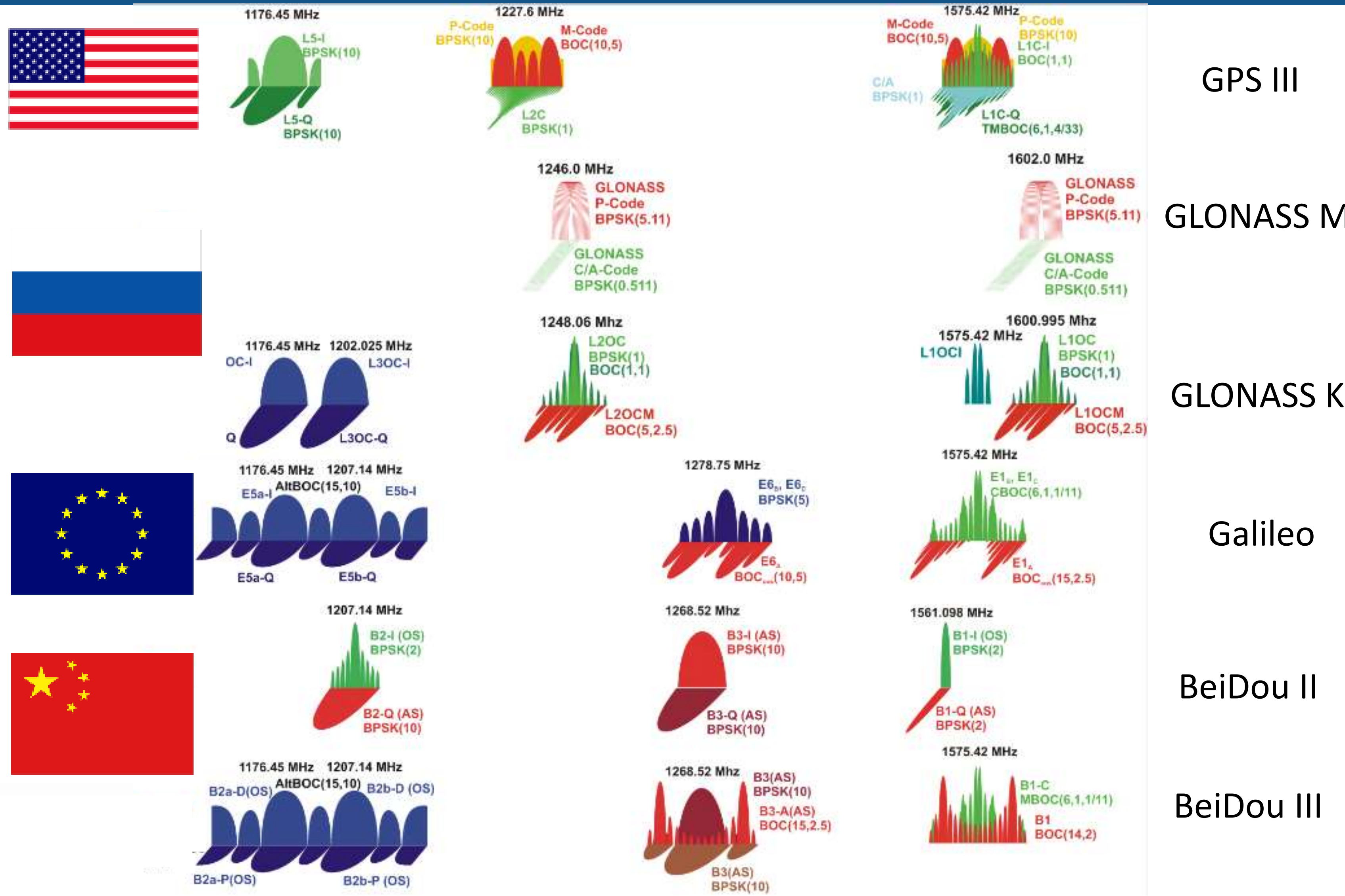
- At European level, **L1** band has been **renamed to E1 for Galileo**
- **E1/L1** and **E5a/L5** are common to GPS bands for **interoperability**

ARNS: Aeronautical Radio Navigation Service

RNSS: Radio Navigation Satellite Services

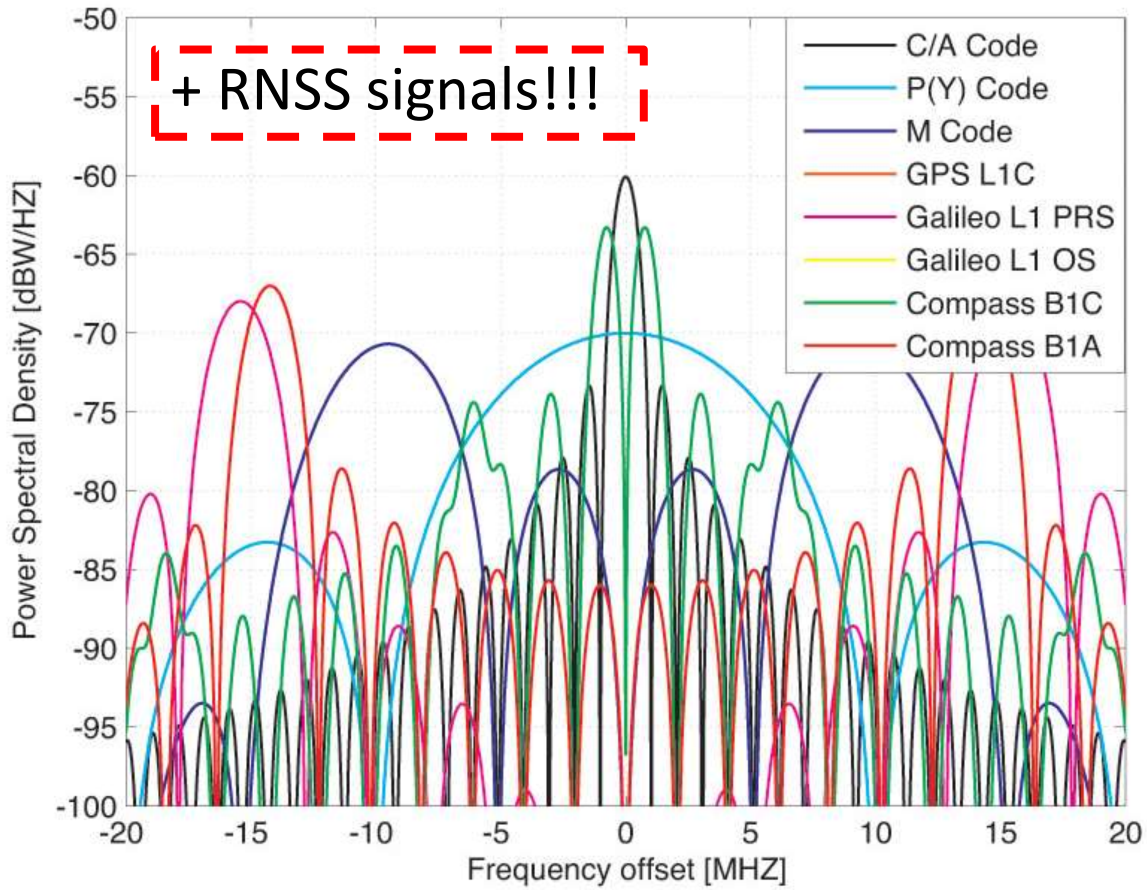
GNSS Signals

Bands & Frequencies



GNSS Signals in L1 (E1)

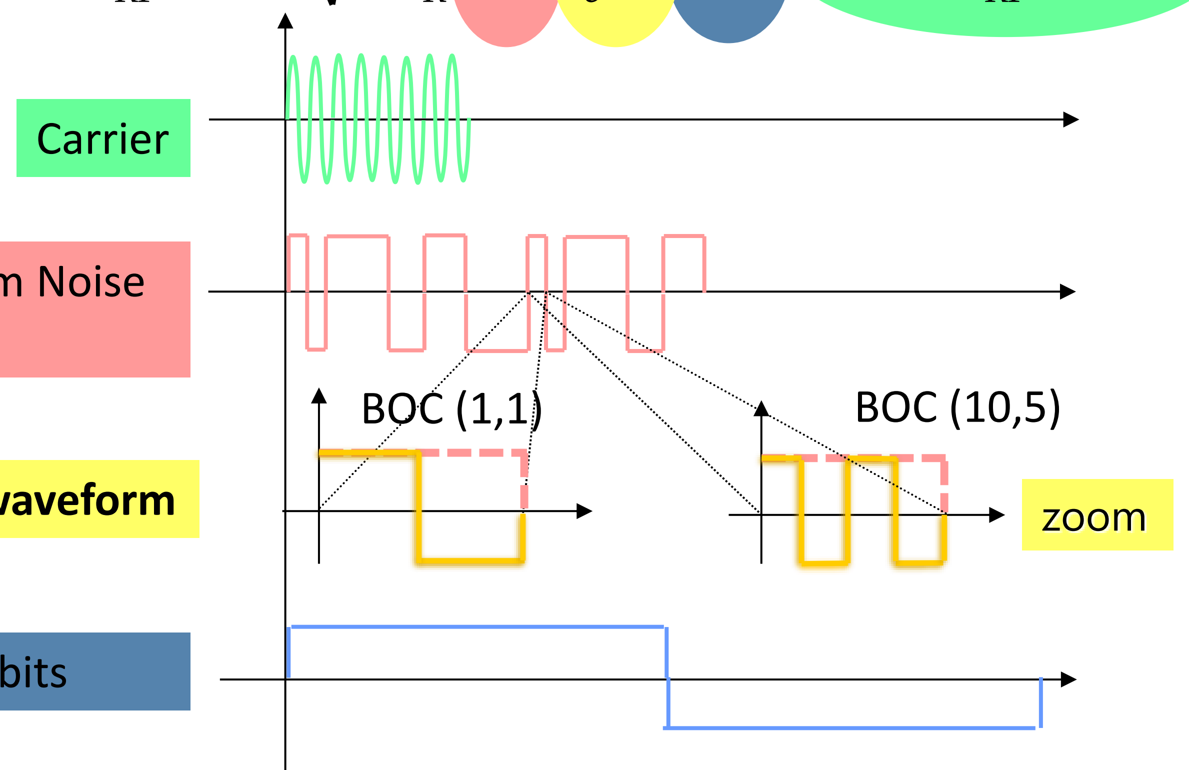
L1 happens to be the most crowded band



Galileo BOC modulation

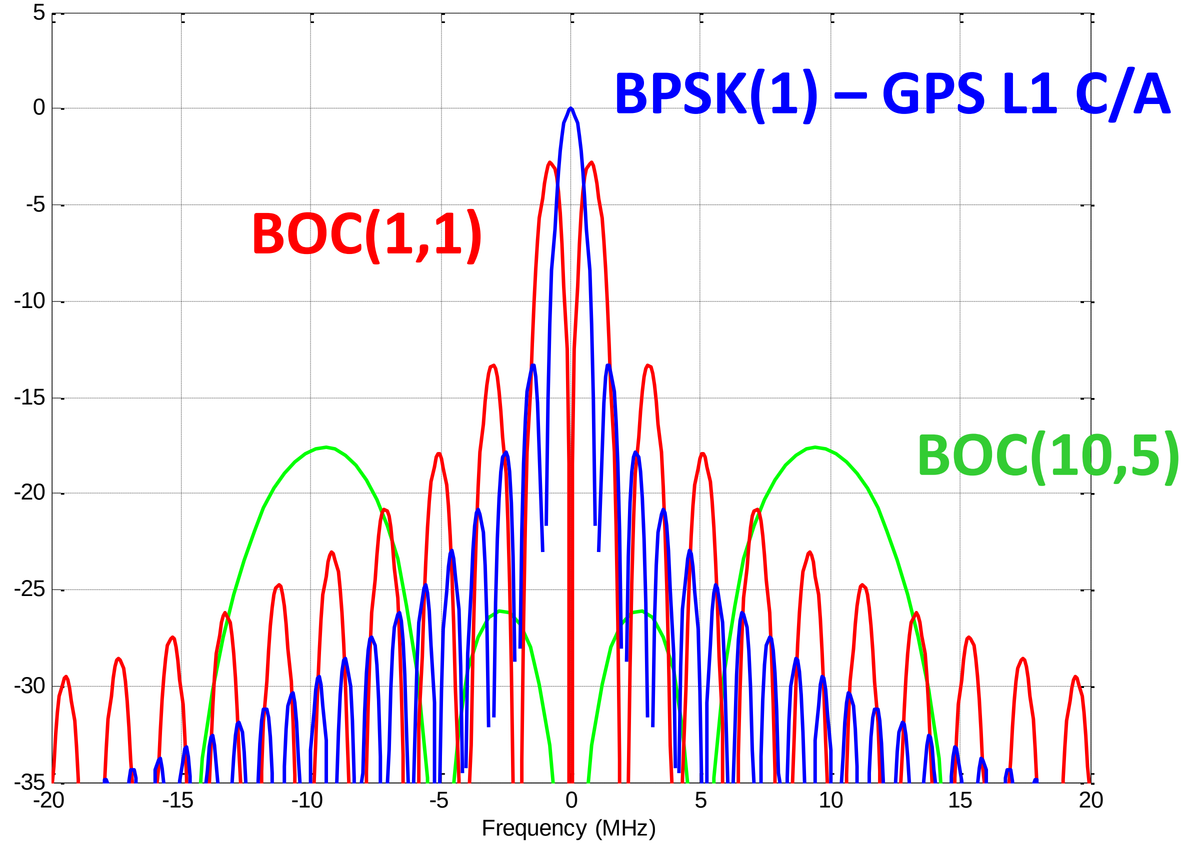
BOC modulation (in new and modernized SISs, innovative modulation schemes have been proposed (BOC, MBOC, AltBOC…)

$$x_{RF}(t)=\sqrt{2P_R}\,c(t)\,s_c(t)\,d(t)\sin(2\pi f_{RF}t+\varphi)$$



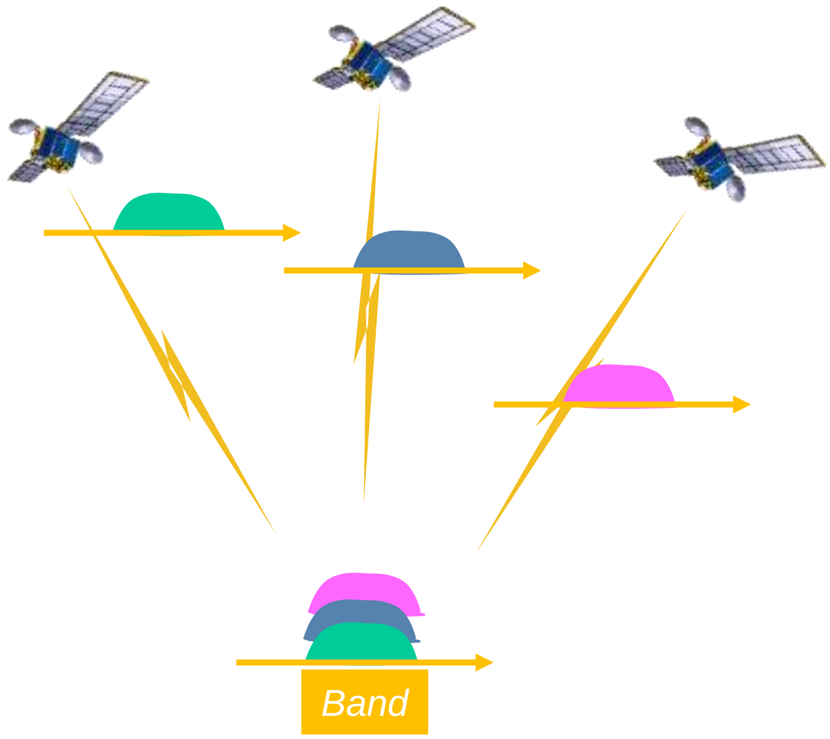
Note: in the graphs the signal periods are not realistic (only pictorial)

Power Spectral Density (normalized)



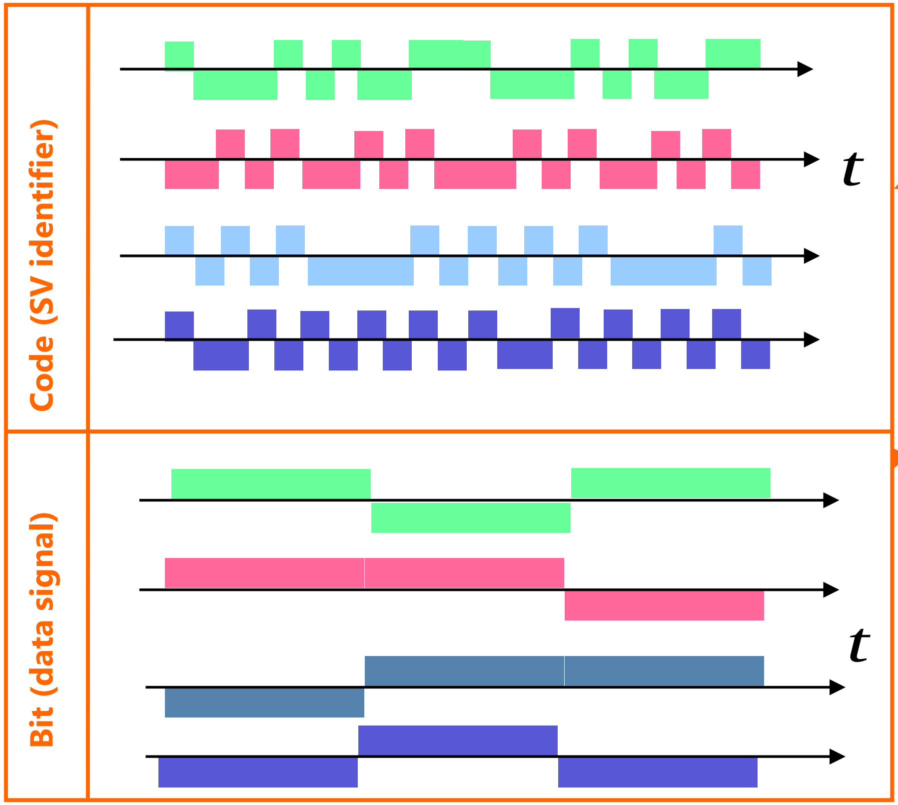
CDMA Technique

- **Code Division Multiple Access** (**CDMA**) is a multiple-access technique for transmitters sharing the same band
- The data-signal band is spread using a code, which is **unique for each transmitter**



Information Carried by Signal in Space

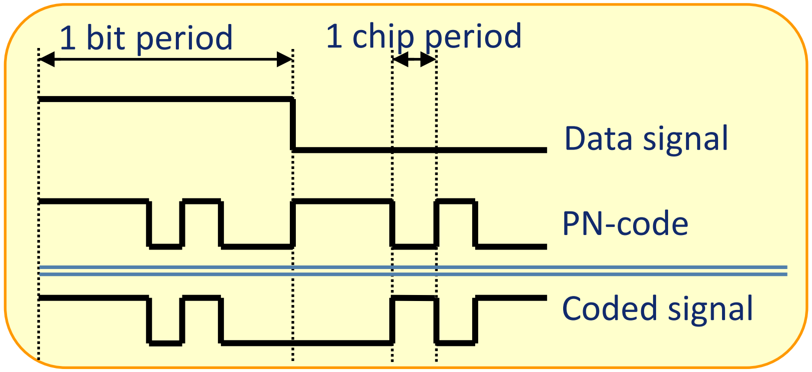
M u l t i p l e x i n g



Each SV has to transmit:

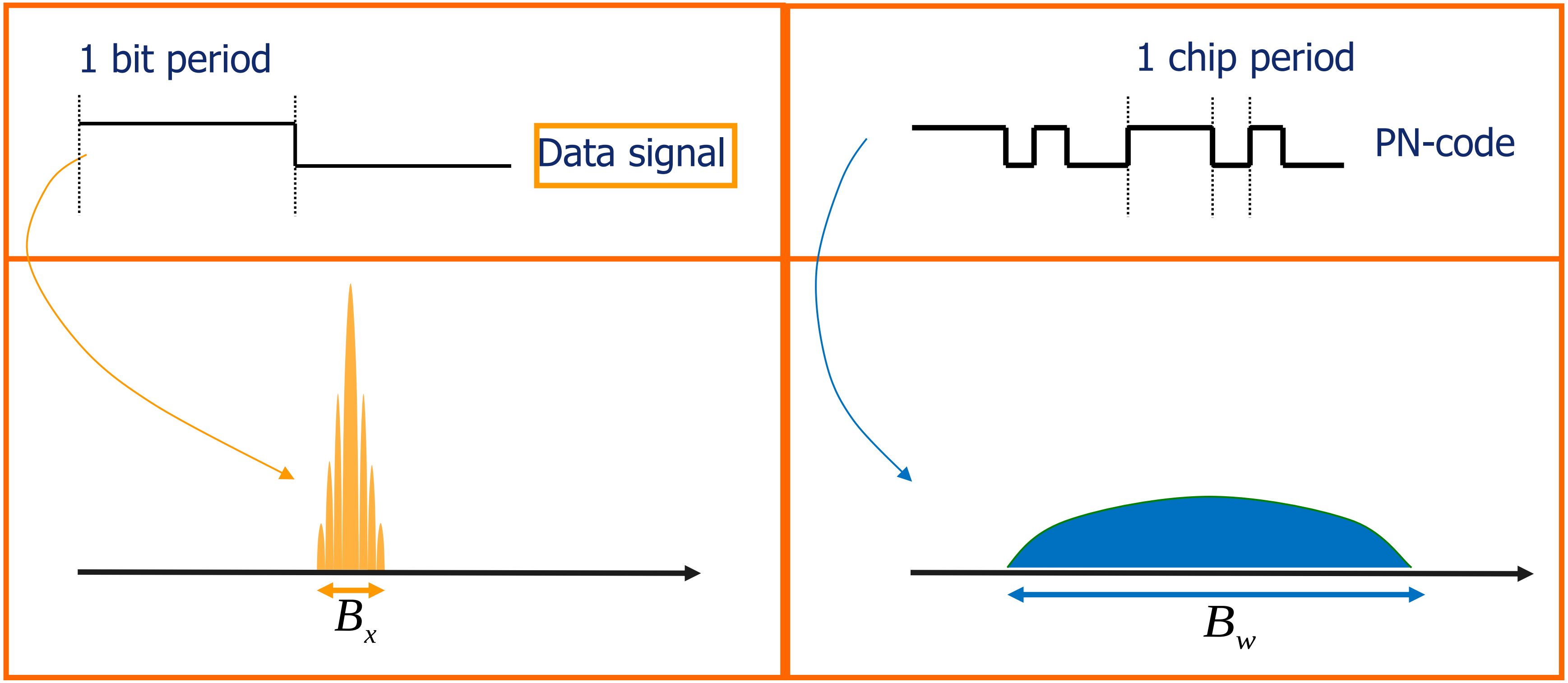
- its identifier
- its time and position

The data signal is multiplied by a pseudo random binary sequence (**PN-code**), generally referred to as pseudo noise (*PN*)



Spread Spectrum (I)

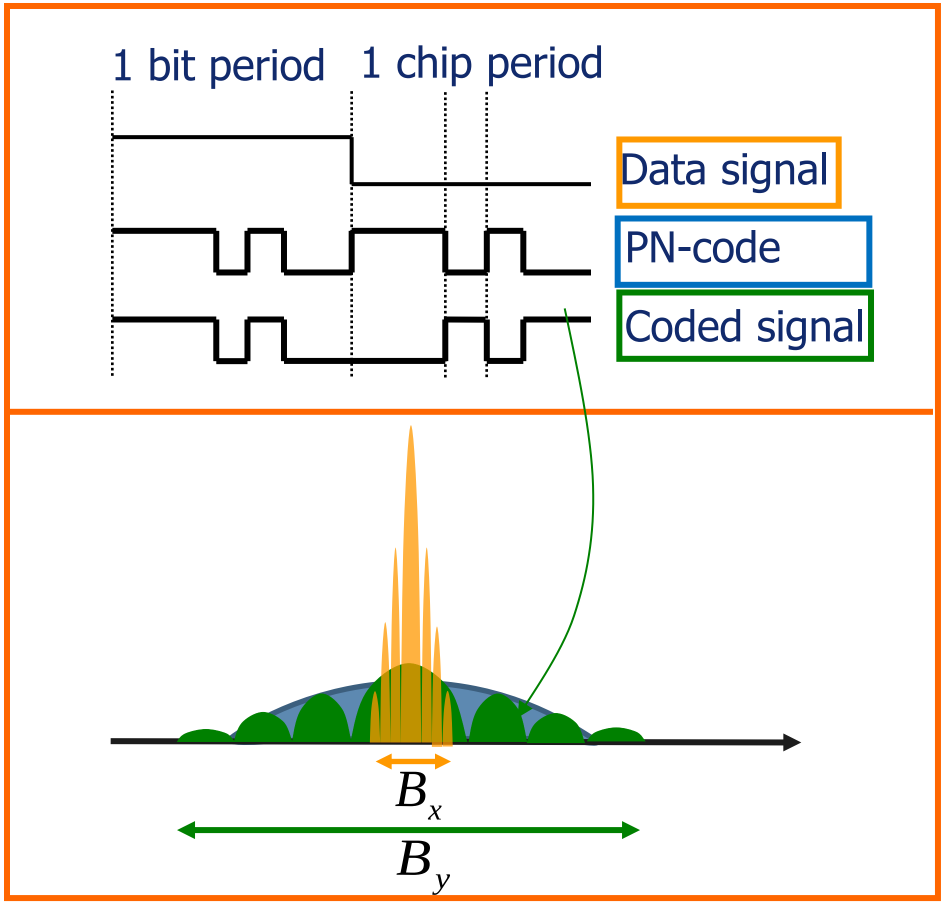
CDMA as a Spread Spectrum Technique



If a signal with a narrowband B_x is combined with a PN code: …

Spread Spectrum (II)

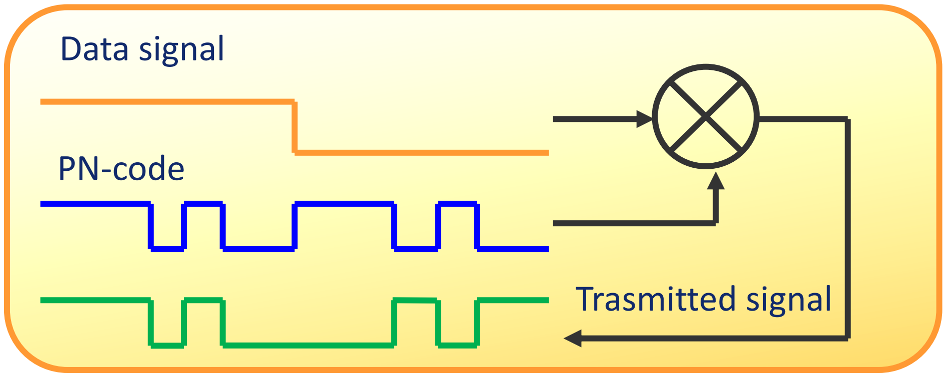
- The bandwidth B_y of the resulting signal is the sum of band B_x and the large band of the code B_w (Fourier transform property)
- The total **transmitted power** stays equal
- The bandwidth B_y of the resulting signal is **much greater** than B_x. The name “spread spectrum” indicates that the spectrum is spread
- The level of the power spectral density decreases

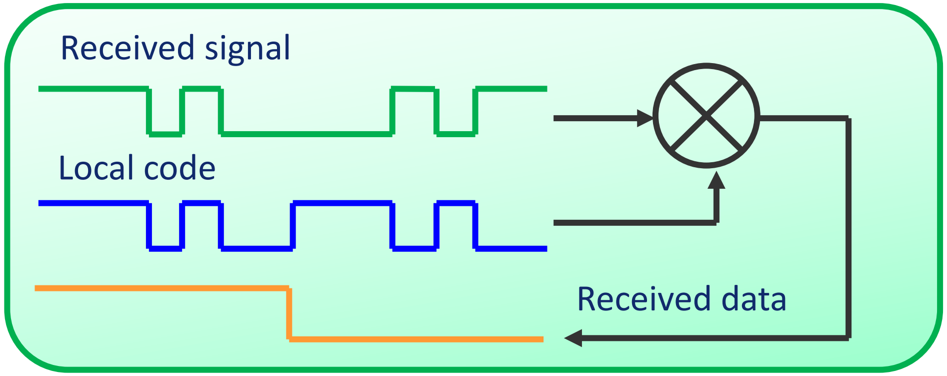


Spreading and despreading

Spreading and despreading can be represented in the time domain

TX

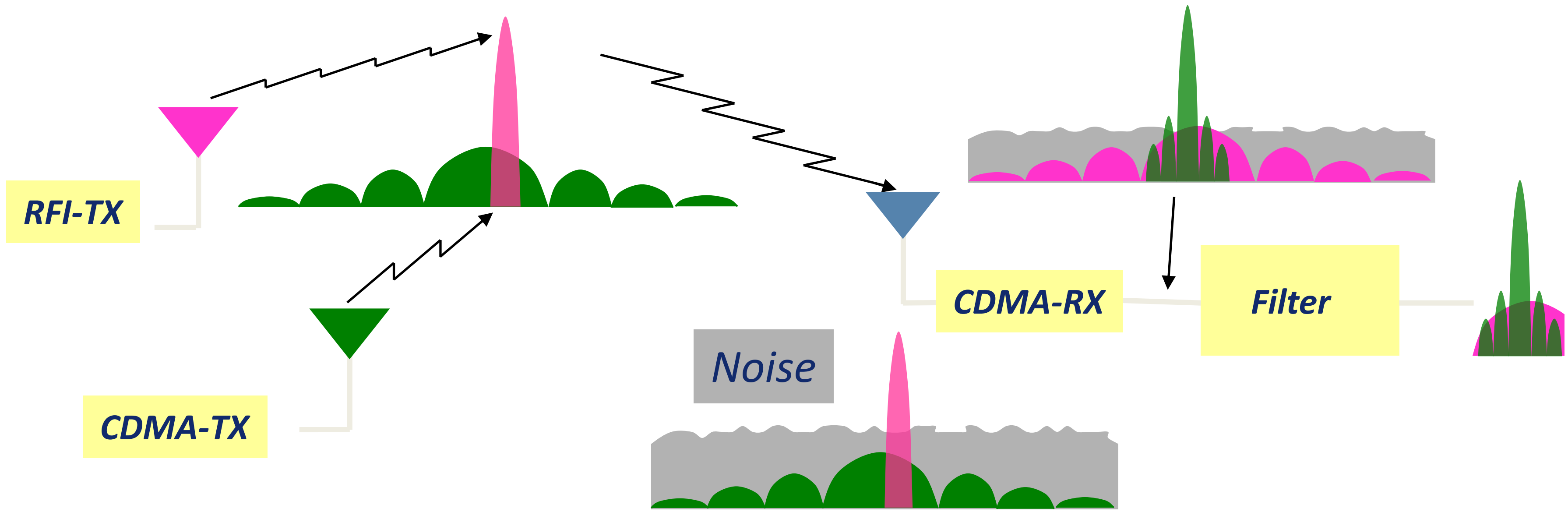




RX

Effects on Noise and Interference

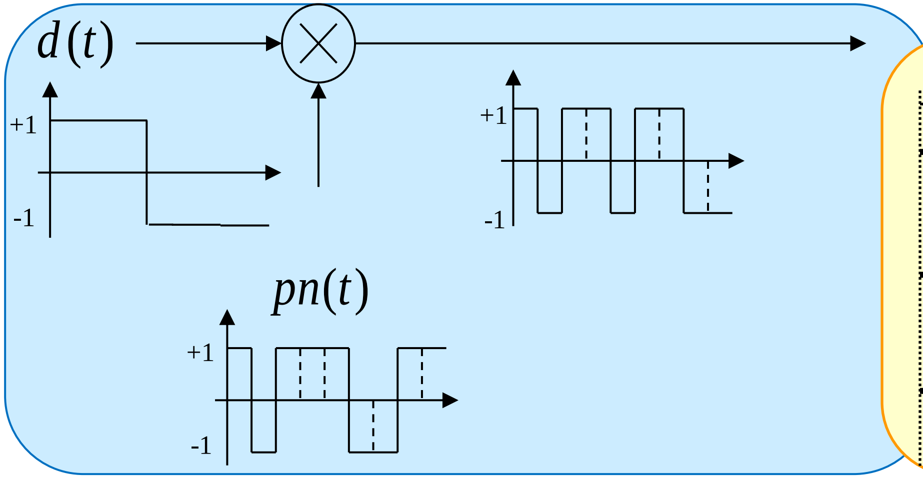
CDMA : Effects of Radio Frequency Interference (RFI)

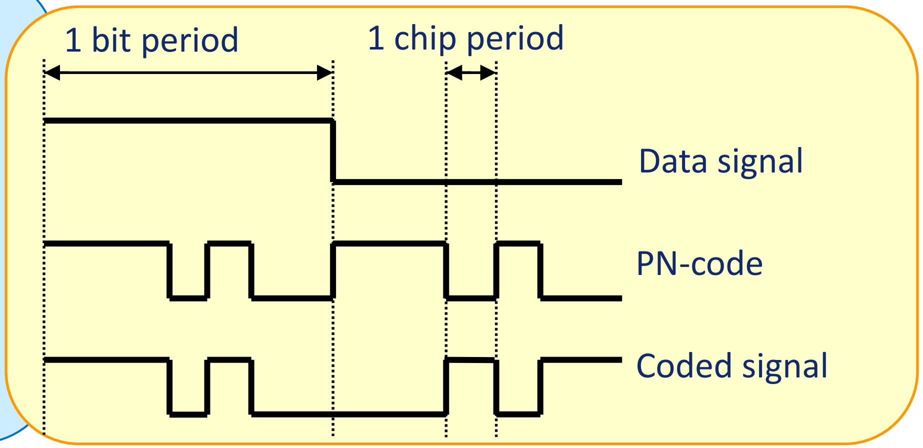


Pseudo Noise Codes

The PN-Code: a sequence of chips

- The data signal is multiplied by a pseudo random binary sequence (**PN-code**), generally referred to as pseudo noise (*PN*)
- Such sequences have **noise-like properties** (spectral flatness, low cross-correlation values)





Signals Correlation (I)

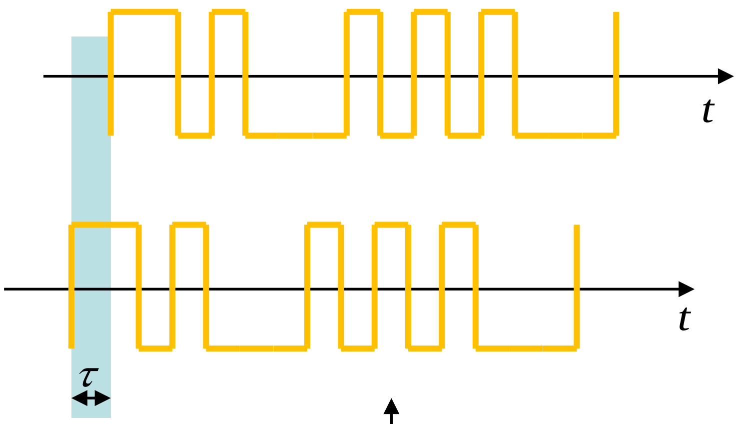
Code Correlation: Auto Correlation

- Code

$$c_i(t)$$

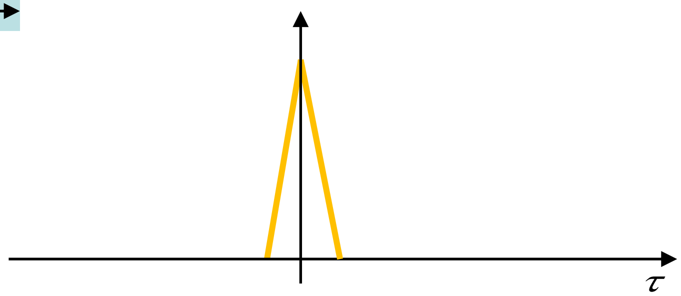
- Code translation

$$c_i(t+\tau)$$



- Auto Correlation

$$R_i(\tau) = \int_{-\infty}^{+\infty} c_i(t)c_i(t+\tau)dt$$



Signals Correlation (II)

Code Correlation: Cross Correlation

- Code

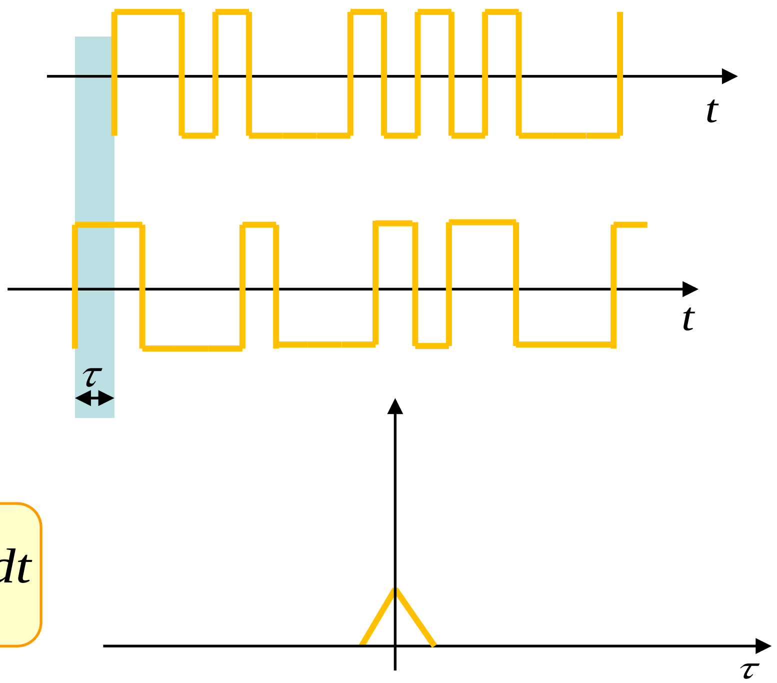
$$c_i(t)$$

- Code translation

$$c_k(t+\tau)$$

- Cross Correlation

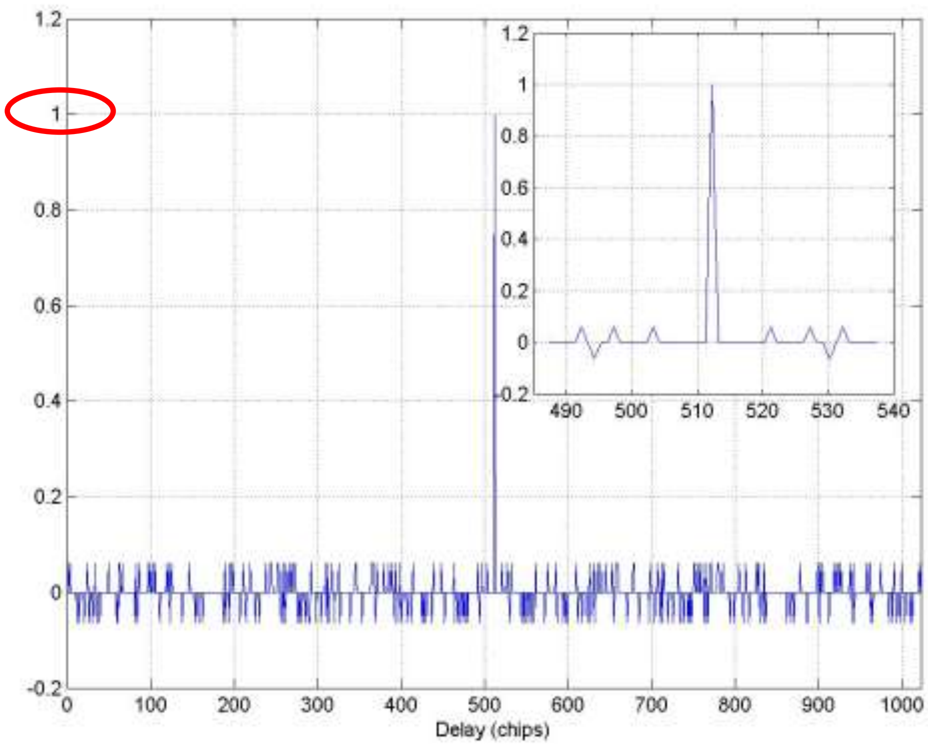
$$R_{ik}(\tau) = \int_{-\infty}^{+\infty} c_i(t)c_k(t+\tau)dt$$



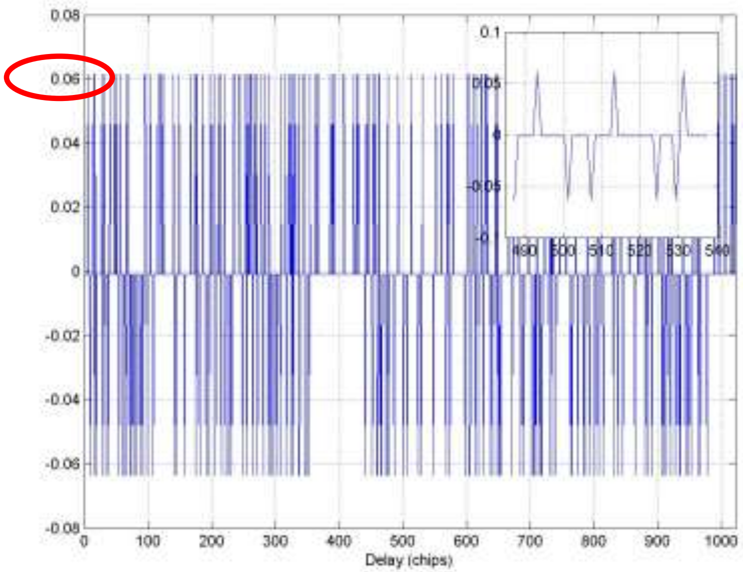
Codes

Signals Correlation Examples

GPS C/A code



Autocorrelation of satellite 16



Cross-correlation between satellites 16 and 27

Navigation Data Frame Structure

Galileo Message Data Stream: the navigation message is transmitted in the data stream as a **sequence of frames**

Each **frame** consists of **subframes**

Each **subframe** consists of **pages**

(their number depends on the signal band)

Message	Signal	Data rate	Page duration	# Pages in a sub-frame	# Sub-frames in a frame
F/Nav	*E5a*	50 sps	10 s	5	12
I/Nav	*E5b E1B*	250 sps	2 s	15	24
C/Nav	*E6C*	1000 sps	1 s	15	8
G/Nav	*E6P E1P*				

The I/NAV message is the same on E5b and E1-B. Page sequencing is swapped, halving message reception time by a dual frequency receiver.

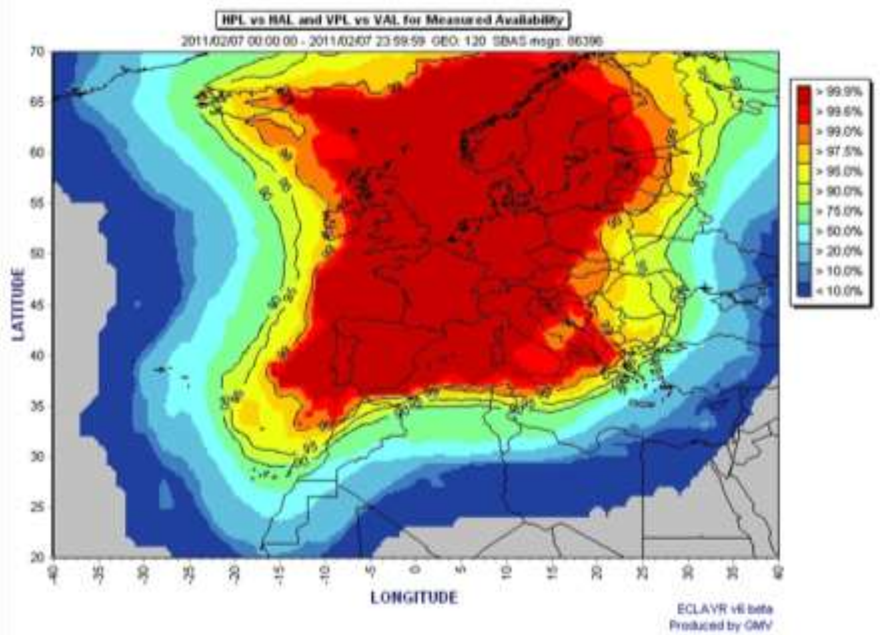
Table of Content

EGNSS

EGNOS

- EGNOS is an **AUGMENTATION** system

- Its purpose is to **enable aircrafts to use GPS for all phases of flight**, from *en route* down to *precision approaches* to any airport within its coverage area.



- EGNOS was promoted by European Tripartite Group formed by Eurocontol, the European Community and the European Space Agency.

- Its main features are the provision of:
  - Wide Area Differential corrections
  - Integrity information

Differential Systems

- EGNOS is based on the differential GPS (DGPS) concept (now DGNSS)

- Differential systems can be divide in two groups:
  - Local Area Augmentation Systems (or Ground Based Augmentation Systems)
  - Wide Area Augmentation Systems (or Space Based Augmentation Systems)

→ **EGNOS**

- Their aim is to **mitigate some errors** worsening GNSS receivers performance

- If a pseudorange measurement is considered, its error can be can be split in:
  - **Satellite clock error** (with respect to GNSS time system)
  - **Satellite ephemeris error**: due to uncertainty in the satellite position
  - **Ionospheric delay**: caused by the free electrons in the ionosphere
  - **Tropospheric delay**: due to varying humidity, temperature, pressure
  - **Multipath** and Receiver **noise**: local phenomena

Errors Spatial Correlation

Some among these error components are told to have a **high spatial correlation**: i.e. their effect varies slowly at location changes and two receivers not far apart experience similar errors

- **Satellite clock errors** have the identical impact on each user
- **Ephemeris error** impacts varies slightly depending on the user position
- **Ionospheric and Tropospheric effects** are spatially correlated: a distance of several kilometers produces just small changes in pseudorange measurements.
- **Residual errors** are due to spatially uncorrelated sources of errors like noise, multipath or interference.

A set of GNSS reference stations provides information about spatially correlated errors components for a specific area

Safety

EGNOS is a **Safety of Life** system.
For such systems, some parameters are used for the performance evaluation:

- **Availability**: ability of the system to perform its function at the initiation of the intended operation.
- **Continuity**: ability of the total system to perform its function without interruptions during the intended operation.
- **Accuracy**: degree of conformance between the computed user position and the true position.
- **Integrity**: ability of the system to provide timely warnings to users when it may not be used to navigate

Satellite Based Augmentation Systems (SBAS)

The first SBAS to be conceived was the **American WAAS** developed by the Federal Aviation Administration to augment the GPS.

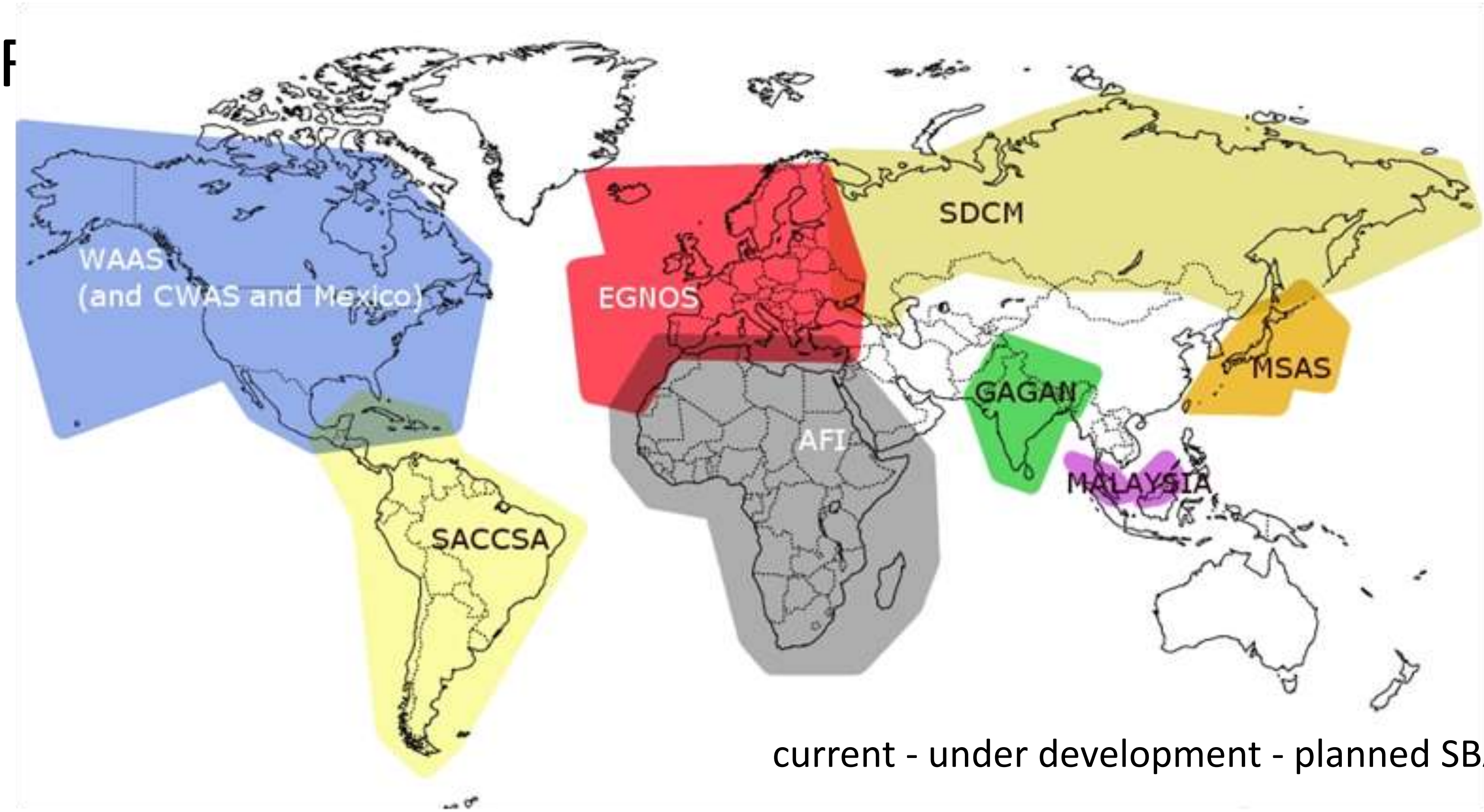
RTCA DO-229 standard defines minimum performance, functions and features for SBAS-based sensors that provide position information to a multi-sensor system or separate navigation system.

These standards are intended to be applicable to other SBAS providers, such as European Geostationary Navigation Overlay Service (EGNOS), the Japan’s Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS)and the Indian GPS Aided Geo Augmented Navigation (GAGAN)

Other SBAS commercial providers offer non SoL services upon payment of a fee, these services first developed in the agricultural world.

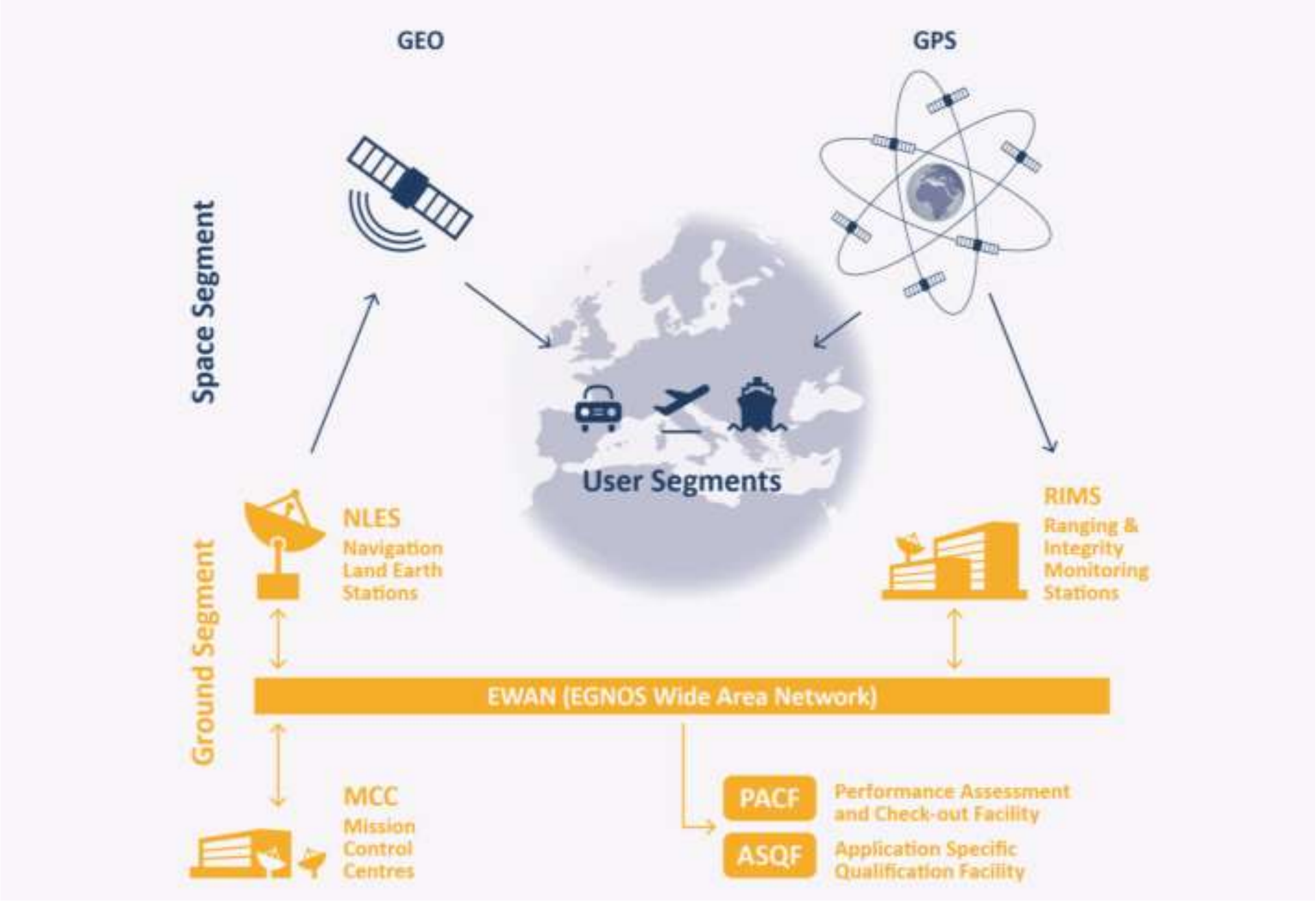
Satellite Based Augmentation Systems

- F



current - under development - planned SBAS

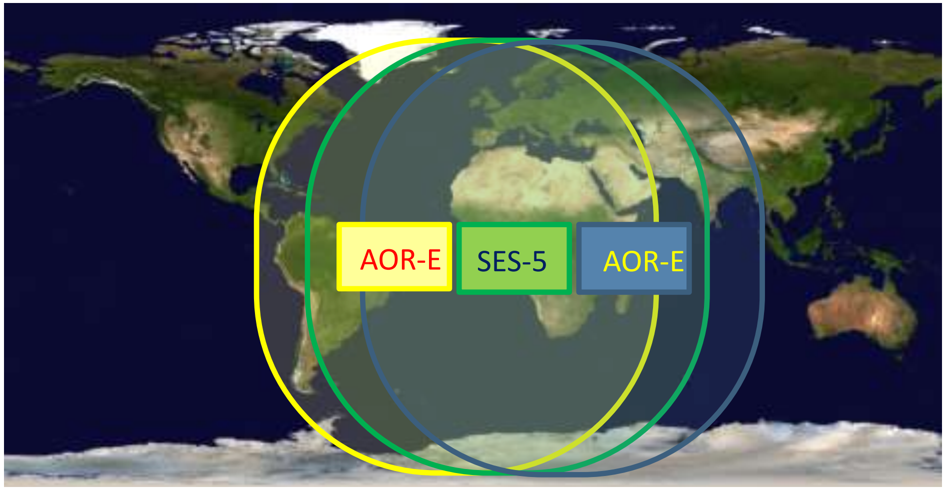
EGNOS System Architecture



EGNOS Space Segment

EGNOS data transmission primarily relies on three telecommunication geostationary satellites centred over Europe:

- Inmarsat-3 AOR-E (Atlantic Ocean Region East) stationed at 15.5° W. **PRN 120**
- Inmarsat-3 IOR-W (Indian Ocean Region West) stationed at 25.0°E. **PRN 126**
- SES-5 stationed at 5.2°E under commissioning **PRN 136**

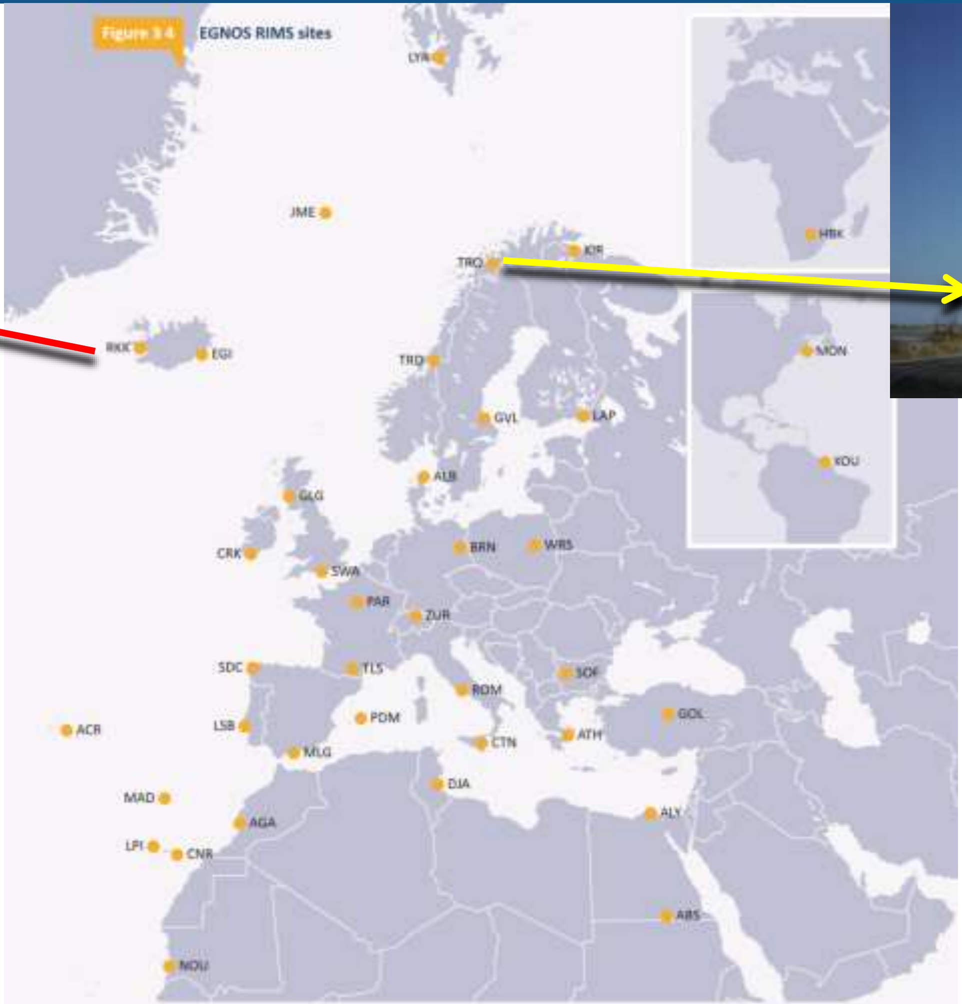


EGNOS System Release 2.4.1.M entered in operations the 30th of June

Real time info on the signal status for each GEO is provided at: http://egnos-user-support.essp-sas.eu/new_egnos_ops/

The Safety of Life Service Definition Document contains the public information on EGNOS) (http://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_sol_sdd_in_force.pdf).

EGNOS
Ranging and Integrity Monitoring Stations



> 34 RIMS

EGNOS Services

EGNOS provides three services:

- **Safety of Life**
  - http://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_sol_sdd_in_force.pdf
- **Open Service**
  - http://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_os_sdd_v2_2.pdf
- **EDAS (EGNOS Data Access Service)**
  - http://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/library/official_docs/egnos_edas_sdd_v2_1.pdf

EGNOS Signal and Messages

- EGNOS Signal Structure
- EGNOS Message Types
- Use of EGNOS information

All these topics are discussed in:

Minimum Operational Performance Standards (MOPS) for Global Positioning System/Wide Area Augmentation System Airborne Equipment, RTCA/DO-229 D

Issued by the Special Committee 159 of the

Radio Technical Commission for Aeronautics

Signal Structure

- The signal broadcast via the SBAS GEOs to the SBAS users is designed to minimize standard GPS receiver hardware modifications: it is a GPS signal with a higher data rate.
  - Gold code from 120 to 138 are reserved for SBAS
  - Data rate will be 250 bits per second. The data are rate ½ convolutional encoded with a Forward Error Correction (FEC) code. Symbol rate that the SBAS receiver must process is 500 symbols per second (sps).
- Each 250 bits data block lasts **one second** and contains a **single message**.
- **64 Message Types** are foreseen but currently just a dozen are relevant.

Integrity: with/without Corrections

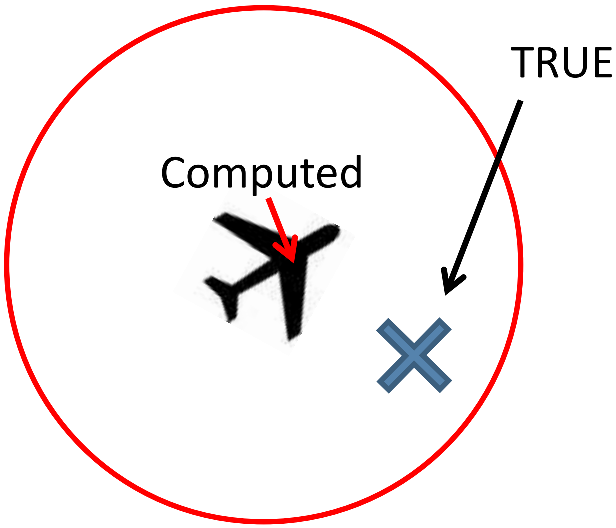
A given SBAS GEO can broadcast either **coarse integrity data** or both **coarse integrity data** and **wide area corrections**.

- The coarse integrity data include **use/don't-use information** on all satellites in view of the applicable region, including the GEOs.
- **Correction data include estimates of the error after application of the corrections:**
  - σ^2_{UDRE} is the variance of a Normal distribution associated with the **user differential range error** for a satellite after application of fast corrections and long term corrections, excluding atmospheric effects
  - σ^2_{GIVE} is the variance of a Normal distribution associated with the residual **ionospheric vertical error** at an IGP for an L1 signal.

The Integrity Concept

"I know I'm getting this accuracy, the system is not lying to me…"

- During a specific flight operation the pilot must be aware that the plane true position is within a circle having its centre in the computed position



- The circle radius is called **Horizontal Protection Level** (Vertical PL is also defined)

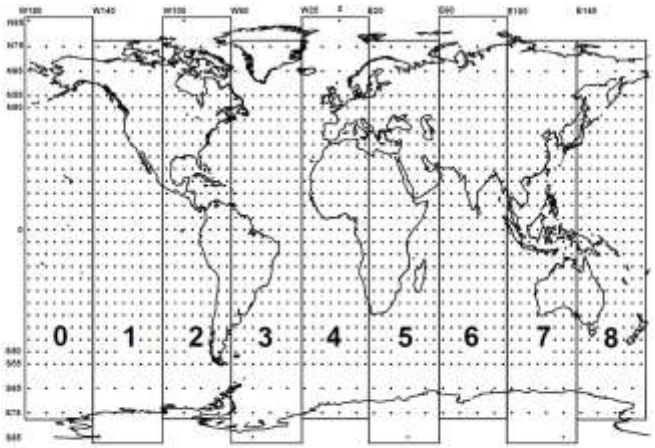
- Integrity is assured if an alarm is raised in case the circle becomes too big

- HPL bound the error with a determined probability.

Correction Types

There are three types of correction concerning errors originating from the satellite:

- Fast corrections:
  - for rapidly changing errors such as those due to Selective Availability
  - common to all users and broadcast as such (pseudorange difference)
- Long-term corrections:
  - for slower changing errors due to long term satellite clock parameters and ephemeris errors
  - the users are provided with satellite position and clockerror estimates for each satellite in view.
- Ionospheric corrections
  - separately, a wide-area ionospheric delay model is provided and sufficient real-time data to evaluate the ionospheric delays for each satellite using that model.



IONOSPHERIC GRID

Residual Error Variance Parameters

Four parameters have to be taken into account for the evaluation of **residual error** and hence **integrity:**

- $\boldsymbol{\sigma^2_{flt}}$ which takes into account $\boldsymbol{\sigma^2_{UDRE}}$ and its degradation in time
- $\boldsymbol{\sigma^2_{UIRE}}$ which takes in account $\boldsymbol{\sigma^2_{GIVE}}$ interpolated for the user position
- The data for the computation of these two terms are broadcast by EGNOS
- $\boldsymbol{\sigma^2_{i,tropo}}$ which takes into account the residual error following the application of the tropospheric correction provided by a specific model
- $\boldsymbol{\sigma^2_{air}}$ which takes into account the operational environment (*air* stands for aviation) and the GNSS receiver characteristics.

Residual Error Variance Computation

For satellite *i*

$$\sigma^2_i = \sigma^2_{i,flt} + \sigma^2_{i,UIRE} + \sigma^2_{i,air} + \sigma^2_{i,tropo}$$

provides the pseudorange measurement residual error variance after the application of EGNOS corrections

But how to use this obtain ***integrity*** information?

High Level Integrity Requirements

Integrity requirements involve:

- The limit maximum allowed circle radius: **Alarm Limit**
- The probability that a wrong information is provided (error>PL) without an alarm being raised: **Integrity Risk**
- The time within the above mentioned alarm must be raised: **Time to Alarm**

The three parameters vary depending on the different flight phases.

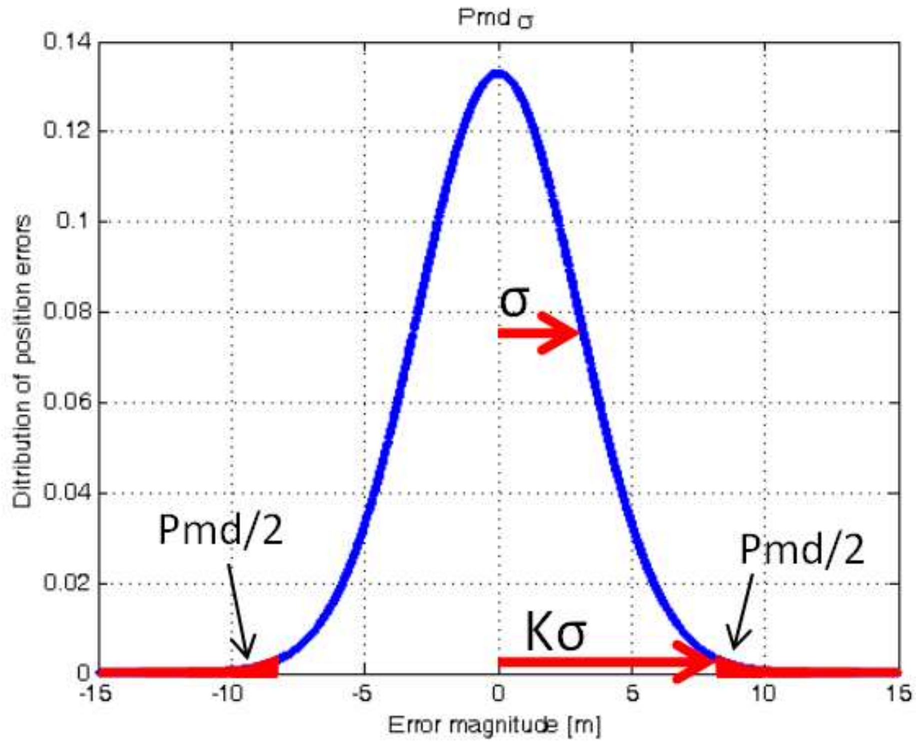
How to obtain integrity information from σ?

GEOMETRY

- Pseudoranges errors affects the positional error
- Residual error estimates (variances) on pseudorange can be translated in the position error variance.

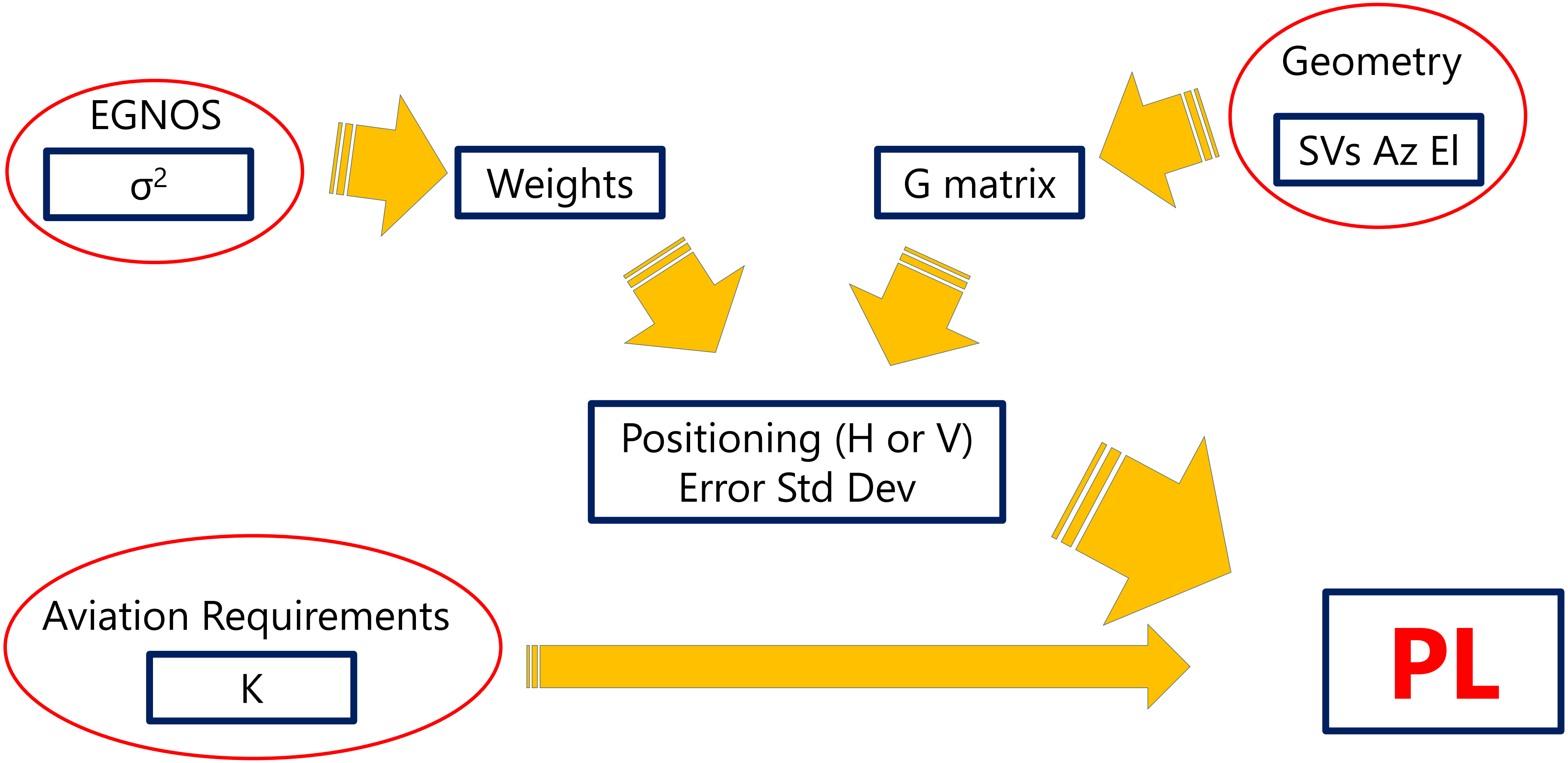
PROBABILITY

- Once the variance on the position is computed this is multiplied by a factor ***K*** to fit the **integrity risk** requirement
  In other words the probability of a missed detection of a dangerous situation must be lower than a threshold the (integrity risk)



Visualisation of the integrity risk, intended as probability of a missed detection, as the area of a Gaussian distribution tails

Protection Level Computation



Further Information about EGNOS

http://egnos-user-support.essp-sas.eu

where is available:

- Information on historical and real-time EGNOS performance
- EGNOS Signal in Space (SIS) status
- Forecast on SIS availability and EGNOS performance
- EDAS information and registration
- EGNOS adoption material and tools.

http://egnos-portal.gsa.europa.eu

where information can be found about:

- EGNOS applications
- Developers platform
- Business support

EGNOS helpdesk coordinates

For questions & information: +34 911 236 555 egnos-helpdesk@essp-sas.eu

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