GNSS SIGNALS INTRODUCTION

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GNSS Training

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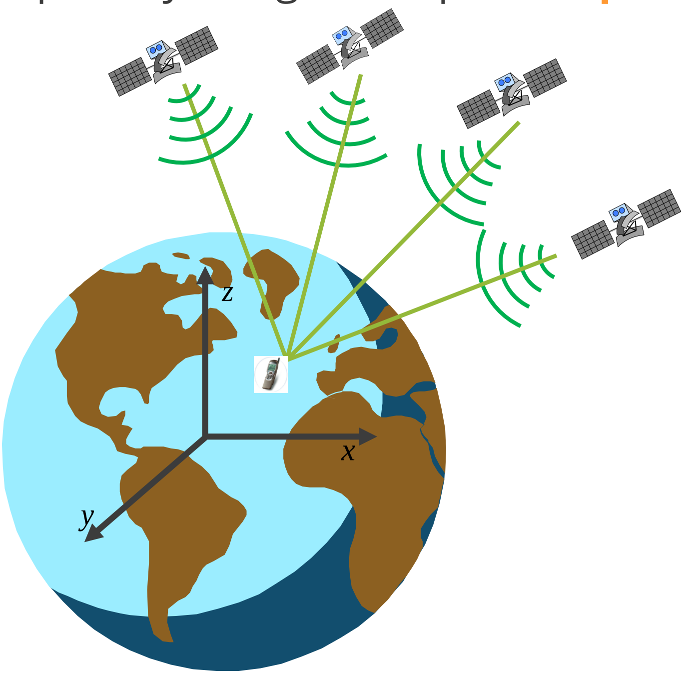
GNSS IN ONE SLIDE

A **Global Navigation Satellite System** (GNSS) consists of a constellation of satellites with global coverage, whose payloads are especially designed to provide **positioning of objects**



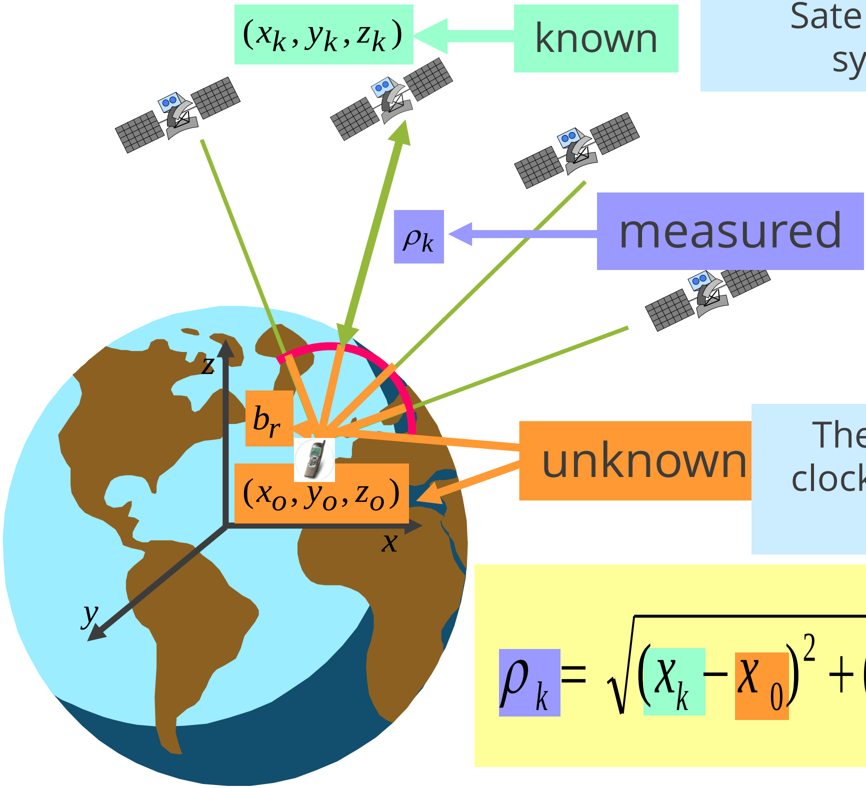
GNSSs implement the trilateration method (spherical positioning systems)

The satellites are at known positions, as we know satellite **orbits** and **time**.

Satellite broadcast signals toward users on Earth

All the information data necessary to perform the trilateration are contained in the **Signal in Space** (SIS) transmitted by the satellites

THE NAVIGATION EQUATION



Satellite clocks are synchronised

The receiver has a clock bias vs satellite clocks

$$\rho_k = \sqrt{(x_k - x_0)^2 + (y_k - y_0)^2 + (z_k - z_0)^2} + b_r$$

THE NAVIGATION SOLUTION

If we consider 4 satellites:

$$\begin{cases}
\rho_1 = \sqrt{(x_{s1} - x_0)^2 + (y_{s1} - y_0)^2 + (z_{s1} - z_0)^2} + b_r \\
\rho_2 = \sqrt{(x_{s2} - x_0)^2 + (y_{s2} - y_0)^2 + (z_{s2} - z_0)^2} + b_r \\
\rho_3 = \sqrt{(x_{s3} - x_0)^2 + (y_{s3} - y_0)^2 + (z_{s3} - z_0)^2} + b_r \\
\rho_4 = \sqrt{(x_{s4} - x_0)^2 + (y_{s4} - y_0)^2 + (z_{s4} - z_0)^2} + b_r
\end{cases}$$

measured

Known (written in the navigation message)

x_0, y_0, z_0, b_u

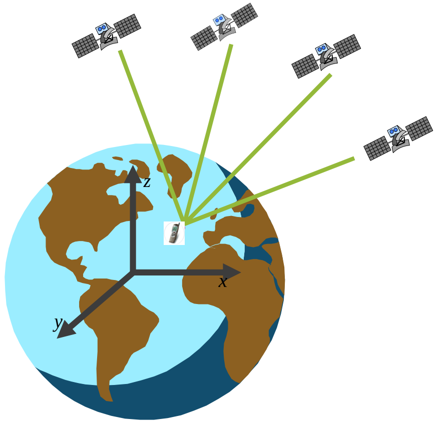
4 unknowns

$b_r = c \cdot b_u$

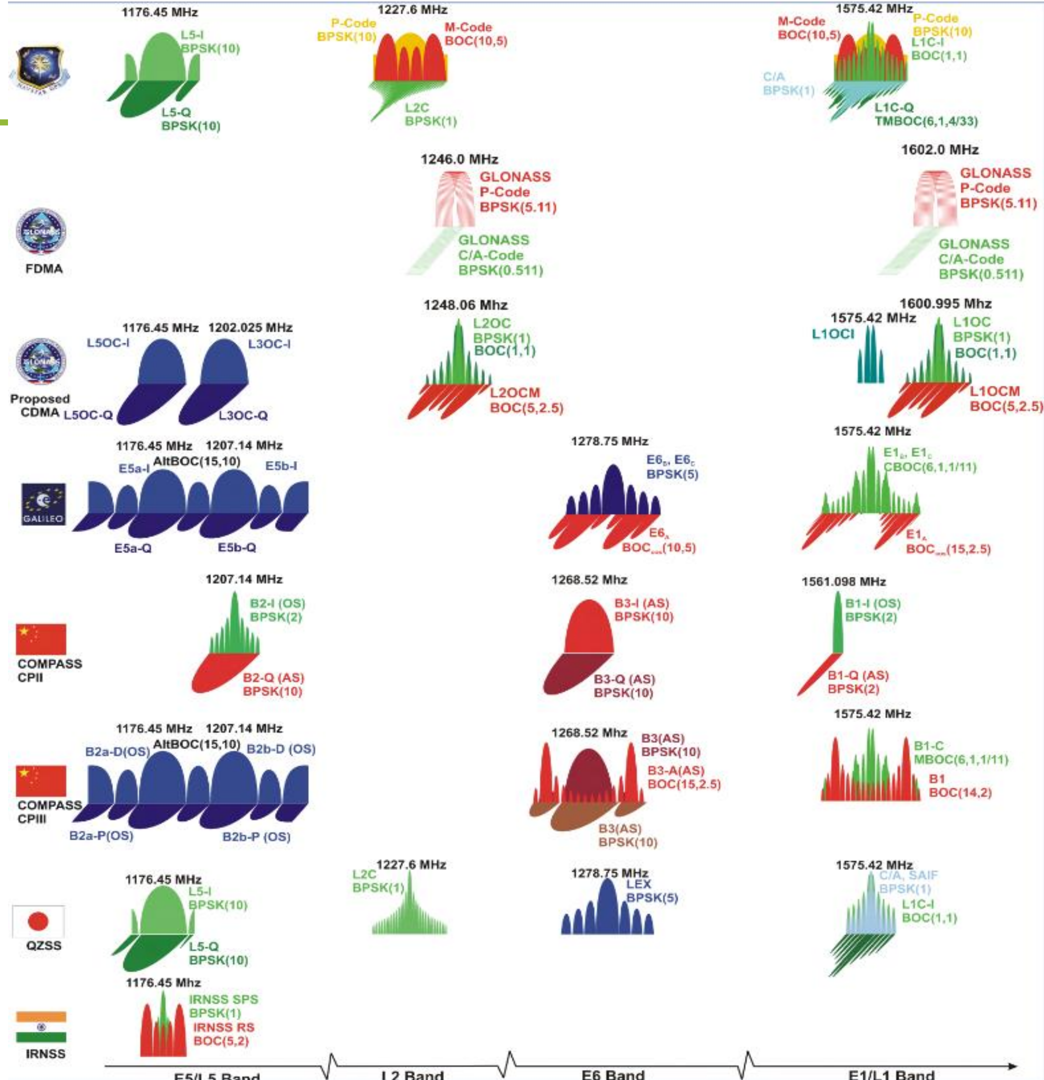
THE NAVIGATION EQUATION

REMARKS

- In order to estimate its position a receiver must have **at least four satellites** in view
- The satellites must be in **Line-of-Sight**
- If a larger number of satellites is in view a better estimation is possible. In the past the combination of four satellites giving the best performance was chosen
- Modern receivers use **several channels** in order to perform the position estimation

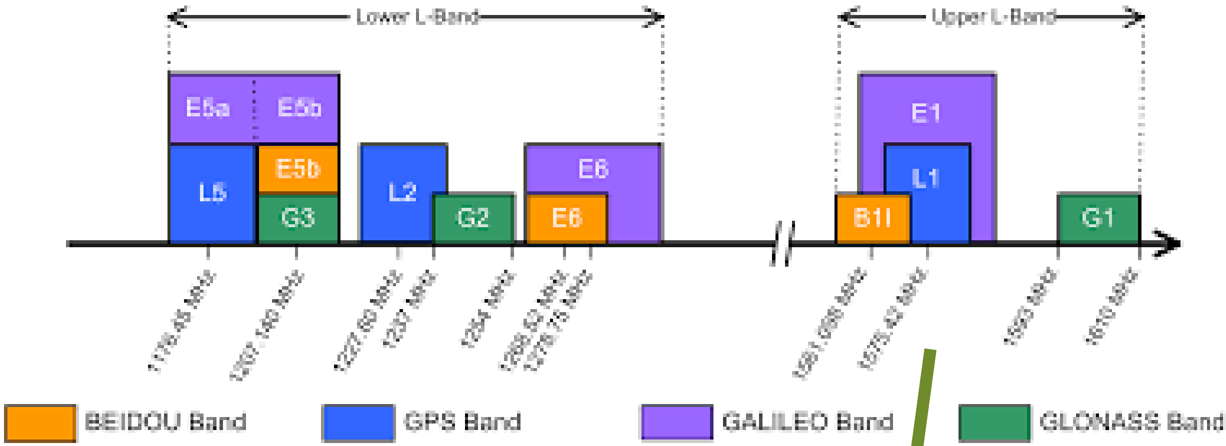


MULTI-GNSS

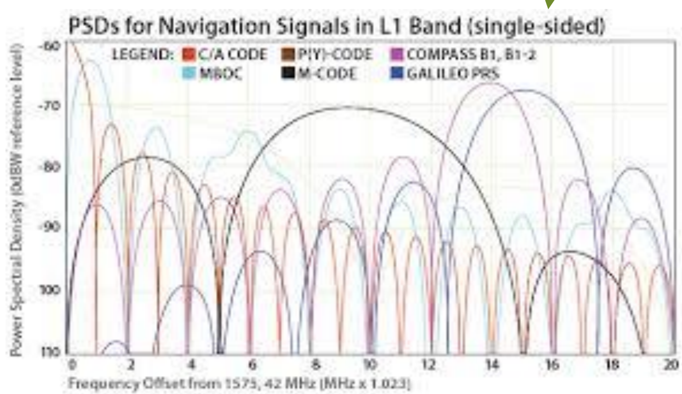


1176.45 MHz
L5-I
BPSK(10)
L5-Q
BPSK(10)
1227.6 MHz
P-Code
BPSK(10)
M-Code
BOC(10,5)
L2C
BPSK(1)
1575.42 MHz
M-Code
BOC(10,5)
P-Code
BPSK(10)
L1C-I
BOC(1,1)
C/A
BPSK(1)
L1C-Q
TMBOC(6,1,4/33)
FDMA
1246.0 MHz
GLONASS
P-Code
BPSK(5.11)
GLONASS
C/A-Code
BPSK(0.511)
1602.0 MHz
GLONASS
P-Code
BPSK(5.11)
GLONASS
C/A-Code
BPSK(0.511)
Proposed
CDMA
1176.45 MHz
1202.025 MHz
L5OC-I
L3OC-I
L5OC-Q
L3OC-Q
1248.06 Mhz
L2OC
BPSK(1)
BOC(1,1)
L2OCM
BOC(5,2.5)
1600.995 Mhz
1575.42 MHz
L1OCI
L1OC
BPSK(1)
BOC(1,1)
L1OCM
BOC(5,2.5)
GALILEO
1176.45 MHz
1207.14 MHz
AltBOC(15,10)
E5a-I
E5b-I
E5a-Q
E5b-Q
1278.75 MHz
BPSK(5)
BOC(10,5)
1575.42 MHz
CBOC(6,1,1/11)
BOC(15,2.5)
COMPASS
CPII
1207.14 MHz
B2-I (OS)
BPSK(2)
B2-Q (AS)
BPSK(10)
1268.52 Mhz
B3-I (AS)
BPSK(10)
B3-Q (AS)
BPSK(10)
1561.098 MHz
B1-I (OS)
BPSK(2)
B1-Q (AS)
BPSK(2)
COMPASS
CPIII
1176.45 MHz
1207.14 MHz
AltBOC(15,10)
B2a-D(OS)
B2b-D (OS)
B2a-P(OS)
B2b-P (OS)
1268.52 Mhz
B3(AS)
BPSK(10)
B3-A(AS)
BOC(15,2.5)
B3(AS)
BPSK(10)
1575.42 MHz
B1-C
MBOC(6,1,1/11)
B1
BOC(14,2)
QZSS
1176.45 MHz
L5-I
BPSK(10)
L5-Q
BPSK(10)
1227.6 MHz
L2C
BPSK(1)
1278.75 MHz
LEX
BPSK(5)
1575.42 MHz
C/A, SAIF
BPSK(1)
L1C-I
BOC(1,1)
IRNSS
1176.45 Mhz
IRNSS SPS
BPSK(1)
IRNSS RS
BOC(5,2)
E5/L5 Band
L2 Band
E6 Band
E1/L1 Band

MULTI-GNSS



Lower L-Band
Upper L-Band
E5a
E5b
L5
E5b
G3
L2
G2
E6
E6
E1
L1
B1I
G1
1176.45 MHz
1207.140 MHz
1227.60 MHz
1237 MHz
1254 MHz
1268.52 MHz
1278.75 MHz
1561.098 MHz
1575.42 MHz
1593 MHz
1610 MHz
BEIDOU Band
GPS Band
GALILEO Band
GLONASS Band



PSDs for Navigation Signals in L1 Band (single-sided)
LEGEND: C/A CODE
P(Y)-CODE
COMPASS B1, B1-2
MBOC
M-CODE
GALILEO PRS
Power Spectral Density (dBW reference level)
-60
-70
-80
-90
-100
-110
0
2
4
6
8
10
12
14
16
18
20
Frequency Offset from 1575.42 MHz (MHz x 1.023)

GNSS SIGNAL IN SPACE

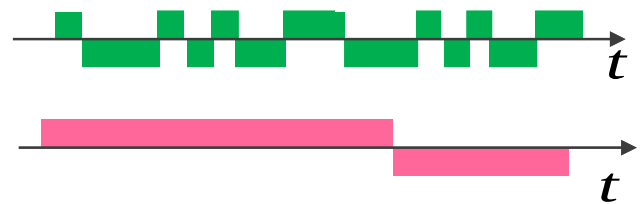
The signals broadcast by the navigation satellites:

- Allow the user to estimate the distance (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

$$x_{RF}(t) = \sqrt{2P_c}\, c(t)\, d(t) \cos(2\pi f_L t + \theta_{L1})$$



GNSS SIGNAL IN SPACE

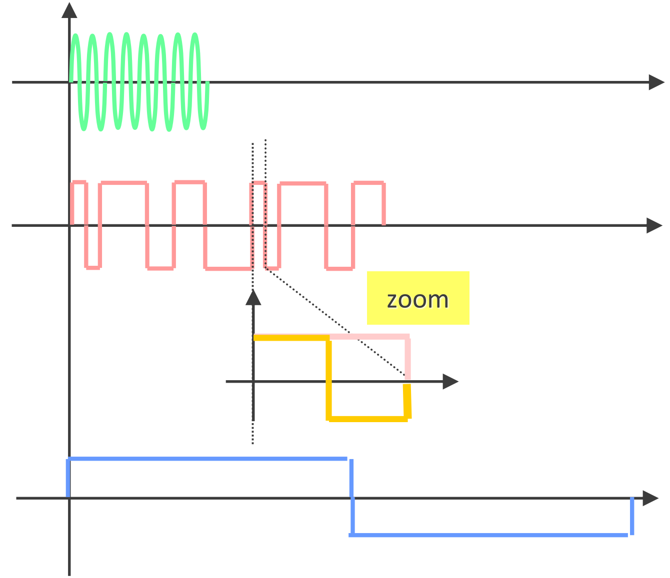
$$x_{RF}(t) = \sqrt{2P_R}\, c(t)\, s_c(t)\, d(t) \sin(2\pi f_{RF} t + \varphi)$$

Carrier

Ranging code: Pseudo-random noise (PRN) sequence of chips (typ. 1023 chips per ms)

Subcarrier (not always present)

Navigation data: sequence of bits



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

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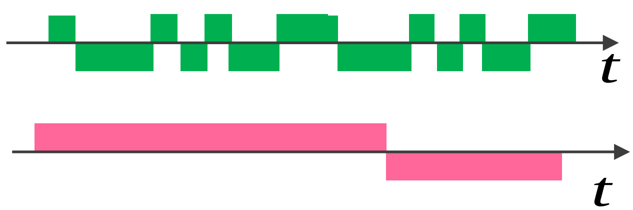
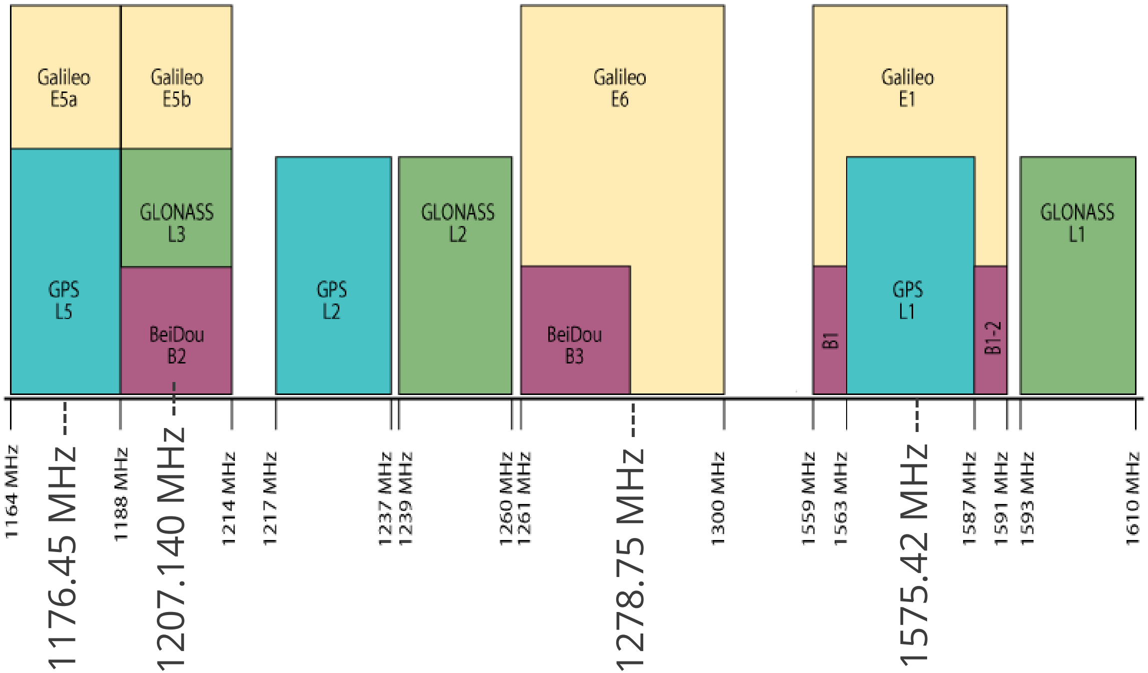


GNSS SIS - FREQUENCIES AND BANDS



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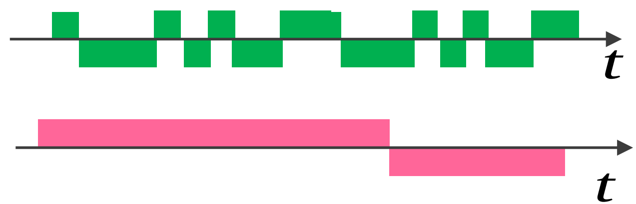
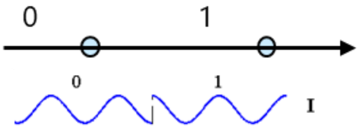


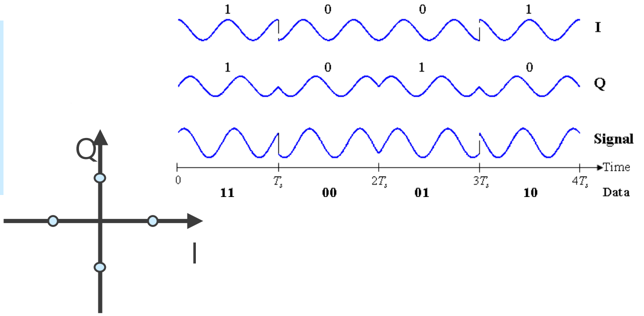
GNSS SIS - MODULATION SCHEMES

- In legacy navigation SISs, the used modulation schemes are:
  - BPSK
  - QPSK
- In new and modernized SISs, innovative modulation schemes have been proposed (BOC, MBOC, …)

BPSK is the simplest form of phase shift keying (PSK).
It uses two phases which are separated by 180°.
Low data rate (1 bit/symbol)
Best BER performance among PSK modulations



QPSK can be obtained as the combination of 2 BPSK signals: one in-phase and the other in quadrature (90° phase shift)
Data rate: 2 bits/symbol

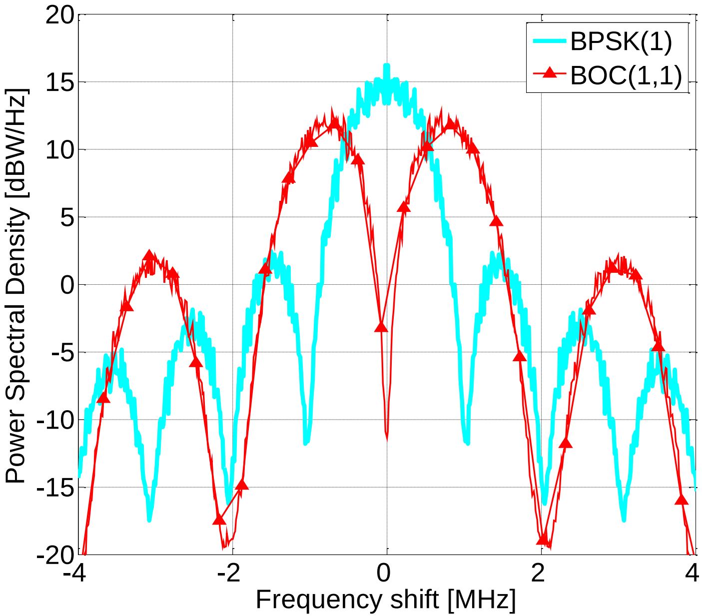


SPLIT SPECTRUM MODULATION

- One way to reduce mutual interference between signals modulated over the same carrier is to **introduce a frequency shift**, modulating one of the signals with a subcarrier

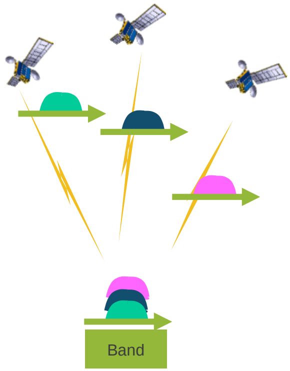
- In the navigation field this technique has been named **Binary Offset Carrier** (BOC) modulation

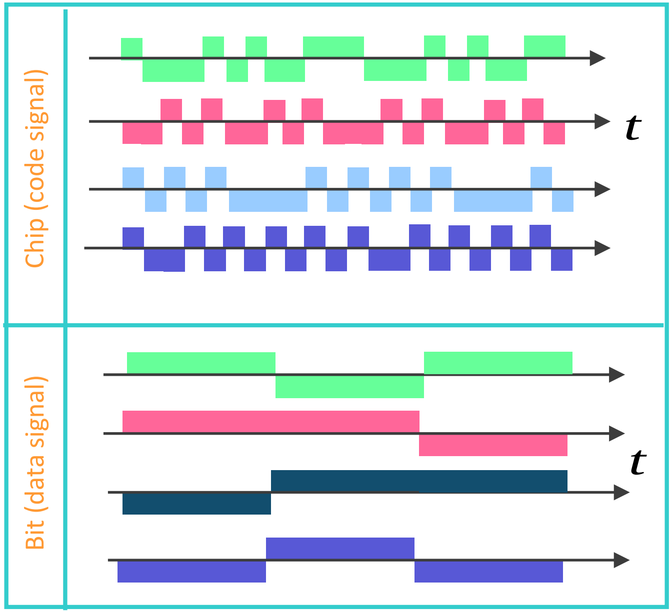
- **Split spectrum**:
  the energy is allocated around BOC subcarrier frequency and not at the central frequency



GNSS SIS - CDMA

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



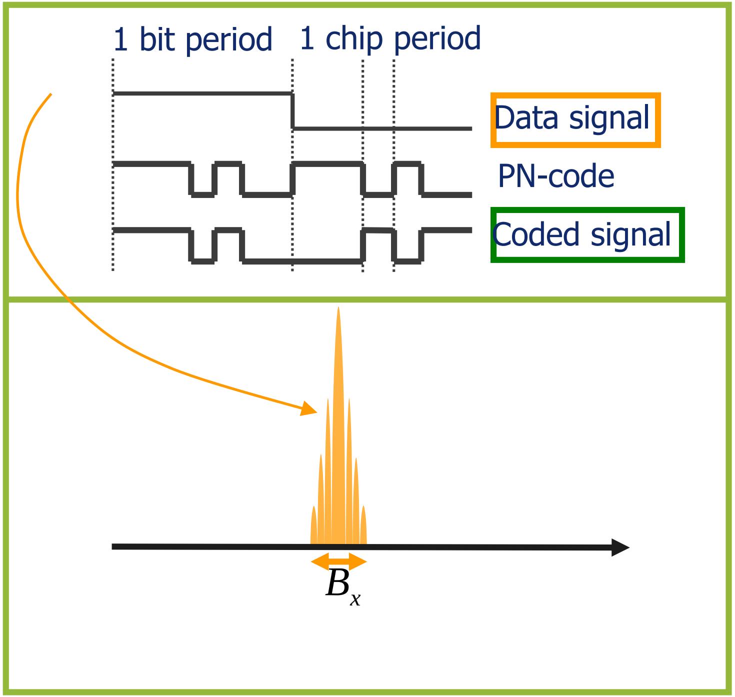


The code signal is a binary sequence, generally referred to as pseudo noise (*PN*)

GNSS SIS – CDMA AND SPREAD SPECTRUM

Data signal with a narrow band B_x is combined with a PN code (wider band)

The bandwidth B_y of the resulting signal is the sum of band B_x and the large band of the code (Fourier transform property)



GNSS SIS – CDMA AND SPREAD SPECTRUM

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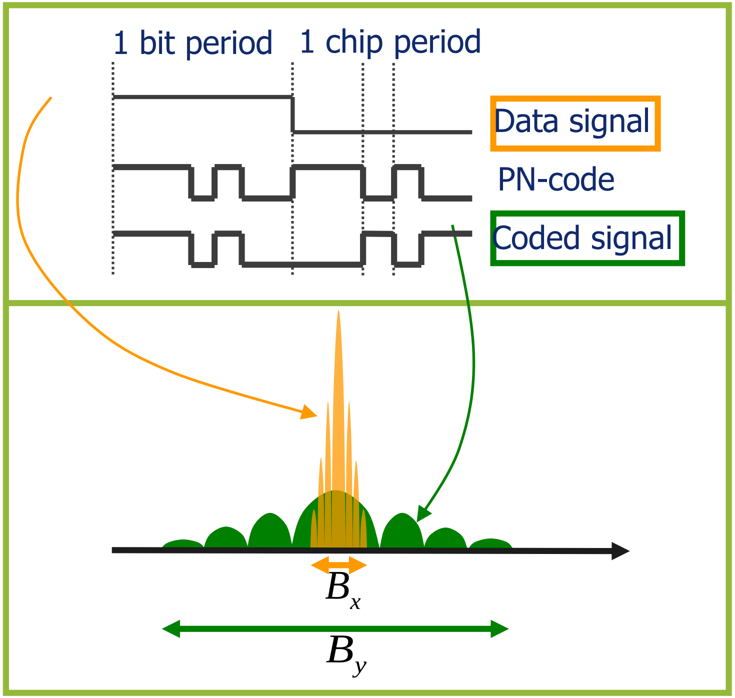
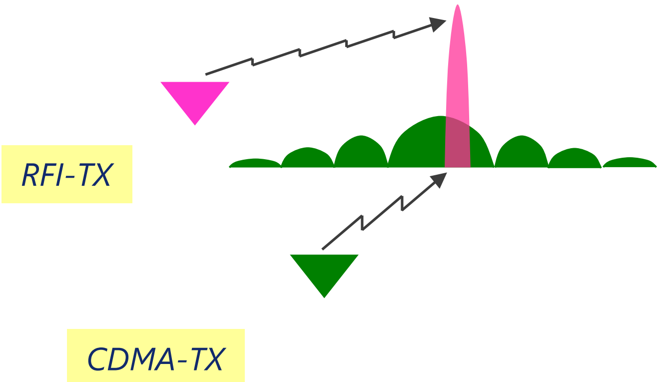
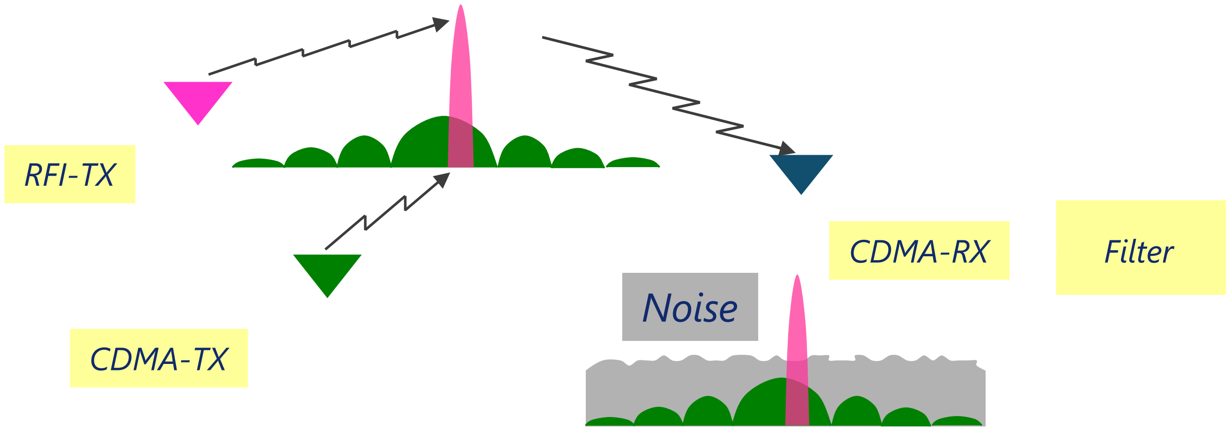


- The total transmitted power does not change
- The bandwidth B_y of the resulting signal is larger than B_x. The name "spread spectrum" indicates that the spectrum is spread
- The level of the power spectral density decreases

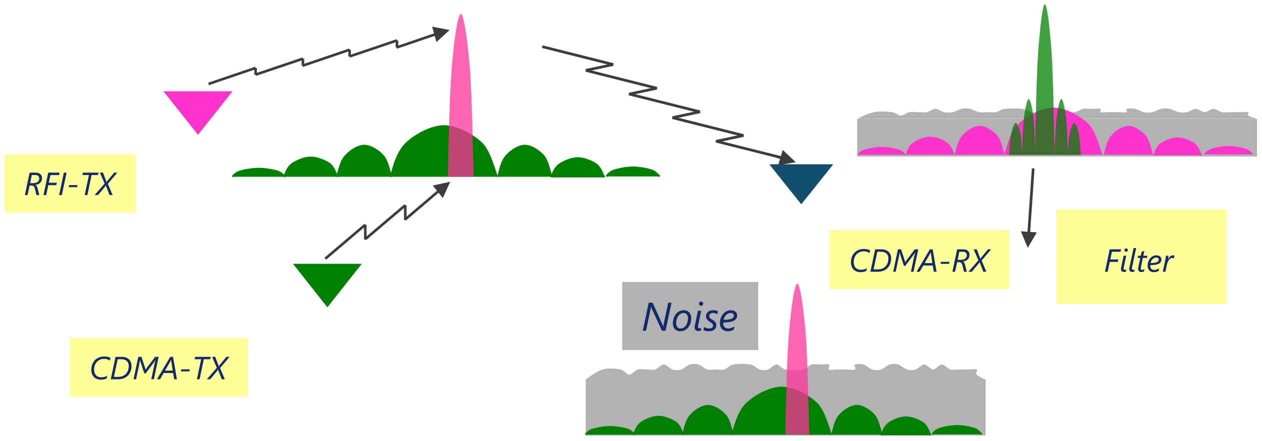
GNSS SIS – CDMA AND INTERFERENCE



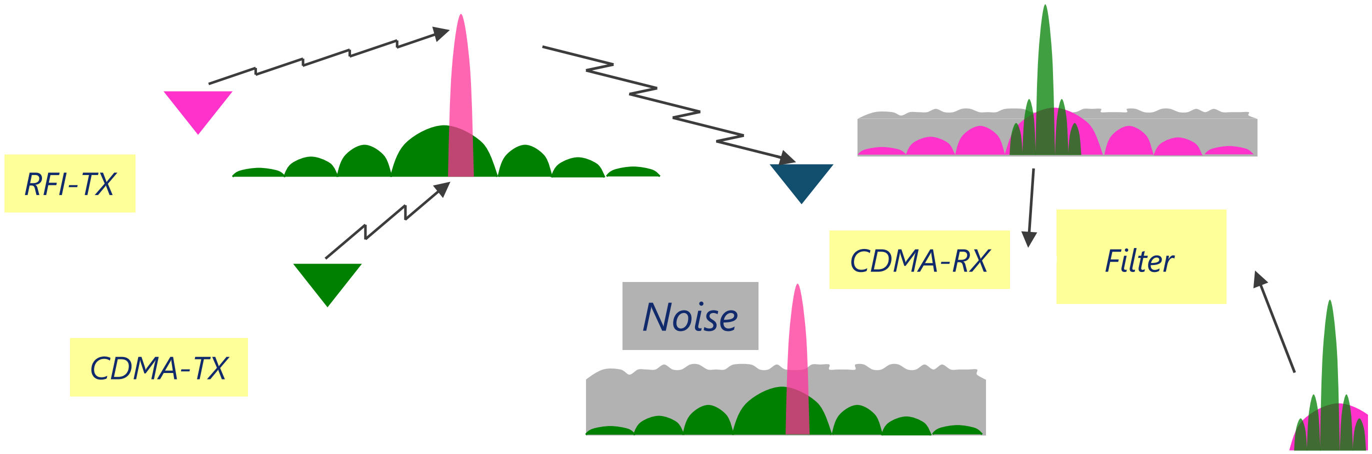
GNSS SIS – CDMA AND INTERFERENCE



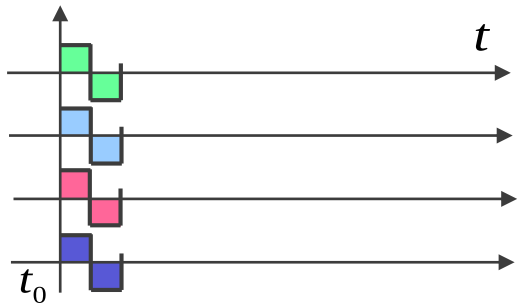
GNSS SIS – CDMA AND INTERFERENCE

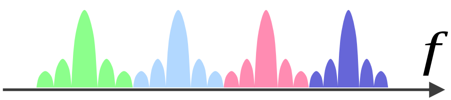


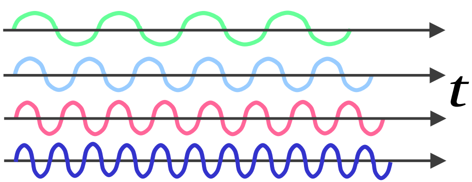
GNSS SIS – CDMA AND INTERFERENCE



GNSS SIS - FDMA







Frequency domain

Time domain

GALILEO SIS

- One of the major driver in the Galileo signal design has been **the interoperability with GPS**
- Interoperability means that receivers have to be potentially able **to deal with both the systems**, thus with both the Signals-In-Space
- As a consequence, SIS must be in close bandwidths, without interfering each-other
- The open access service (free and unencrypted) signal share the same carrier of GPS C/A code (L1)
- BOC modulation introduced to reduce inter-system interference

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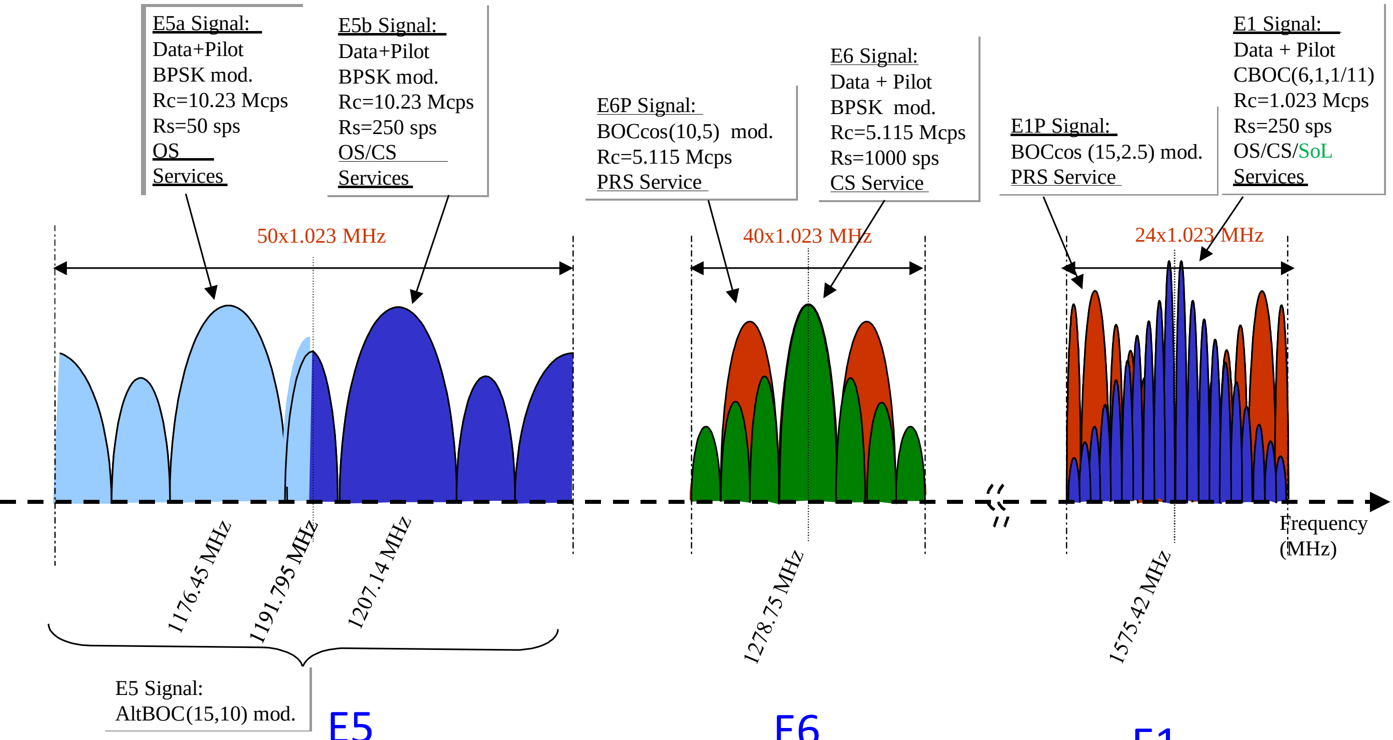
GALILEO BASELINE SIGNAL AND FREQUENCY PLAN



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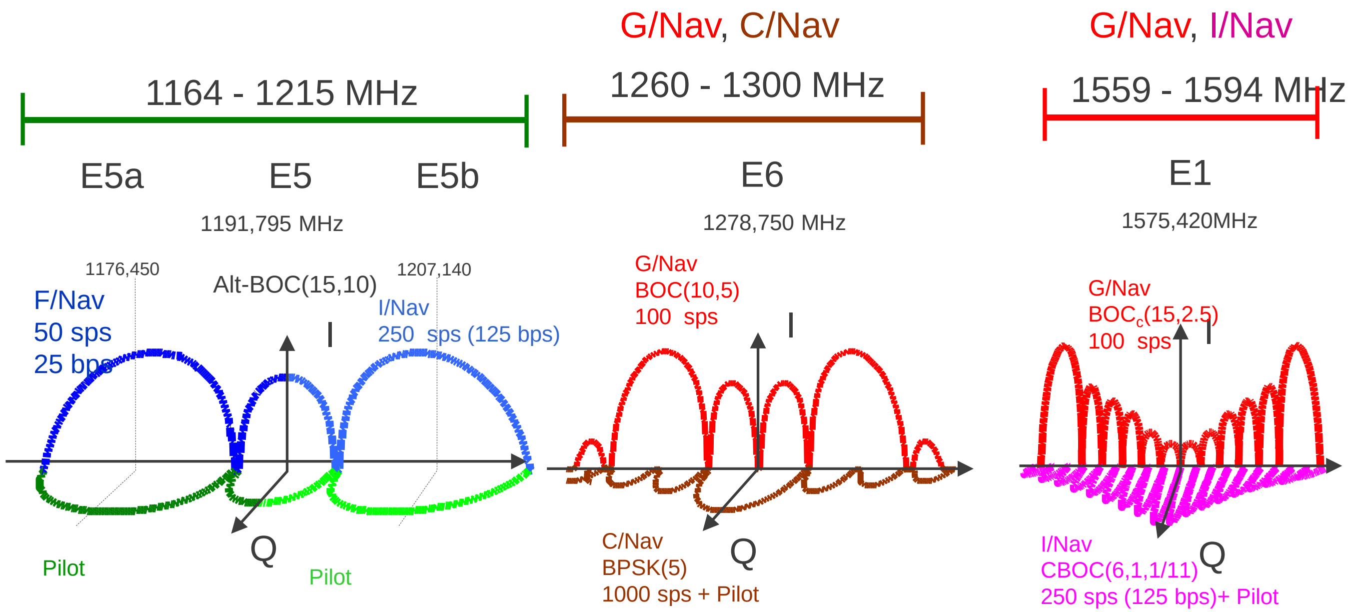
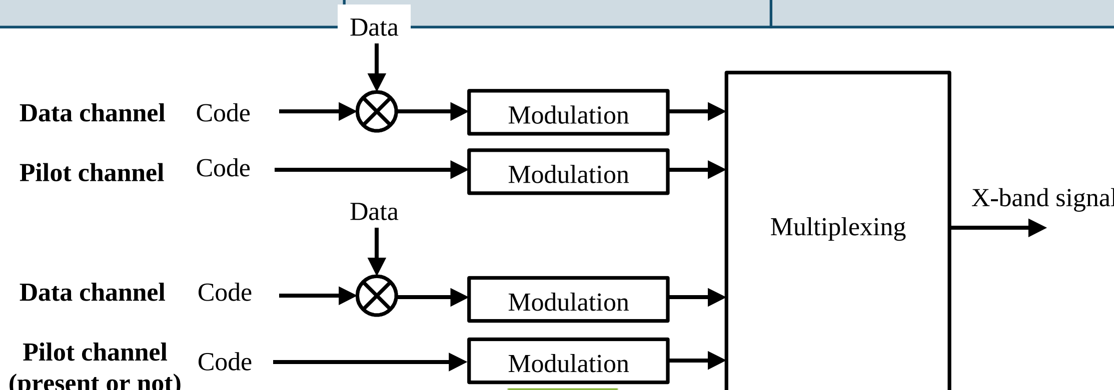


GALILEO BASELINE SIGNAL AND FREQUENCY PLAN

Signal	Carrier Frequency (MHz)	Receiver Reference Bandwidth (MHz)
E1	1575.420	24.552
E6	1278.750	40.920
E5	1191.795	51.150
E5a	1176.450	20.460
E5b	1207.140	20.460



GALILEO E1 SIGNALS

Carrier Frequency (MHz)
1575.420

- **2 Navigation Signals (3 channels)** transmitted in **E1** band:
  - ***E1*** (E1-B, E1-C): open access signals with navigation data
  - ***E1P***: restricted access signal (PRS)
- **Coherent Adaptive Sub-Carrier Modulation (CASM)** multiplexing

Signal	Channels	Modulation	Rc (Mcps)	Rd (sps)	Power level (dBW)	Services	Multiplex. scheme
E1	E1-B Data	CBOC(6,1,1/11)	1.023	250	Min: -157 Max: -154/-150	OS ,CS (I/NAV)	CASM
	E1-C Pilot	CBOC(6,1,1/11)	1.023	--			
E1P	E1-A Data	BOC_{cos}(15,2.5)	2.5575	N/A	N/A	PRS	

E1 MULTIPLEXING TECHNIQUE

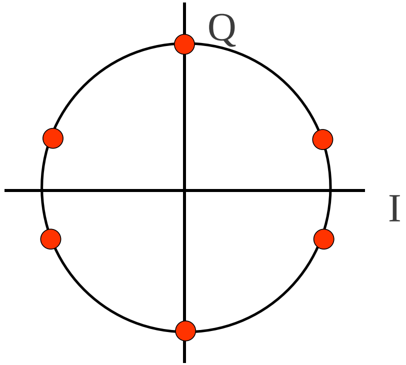
- CASM : Coherent Adaptative Subcarrier Modulation

$$\tilde{S}_{E1}(t) = \frac{\sqrt{2}}{3}\left[e_{E1-B}(t) - e_{E1-C}(t)\right] + j\frac{1}{3}\left[2e_{E1-P}(t) + e_{E1,\text{int}}(t)\right]$$

INTERMODULATION PRODUCT TO ASSURE CONSTANT ENVELOPE

- Relative power levels:

Channels	Before multiplexing	After multiplexing
E1-B data	25%	22%
E1-C pilot	25%	22%
E1-P	50%	44%
IM	--	11%



GALILEO E6 SIGNALS

Carrier Frequency (MHz)
1278.750

2 Navigation Signals (3 channels):

- ***E6*** (E6-B data and E6-C pilot channels): commercial access signal
- ***E6P*** (data channel): restricted access signal (PRS)

Signal	Channels	Modulation	Rc (Mcps)	Rd (sps)	Power level (dBW)	Services	Multiplex. scheme
E6	E6-B Data	BPSK(5)	5.115	1000	Min: -155 Max: -152	CS (C/NAV)	CASM
	E6-C Pilot	BPSK(5)	5.115	--			
E6P	Data	BOC_{cos}(10,5)	5.115		Min: -155 Max: -152	PRS	

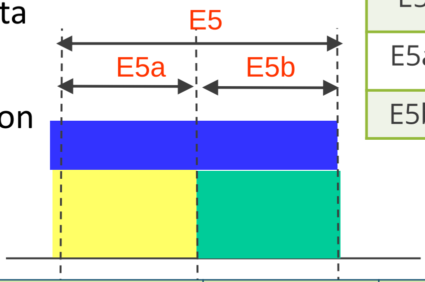
GALILEO E5 SIGNALS

Carrier Frequency (MHz)	
E5	1191.795
E5a	1176.450
E5b	1207.140

2 Navigation Signals (4 channels):

- **E5a**: open access signal containing basic data for navigation and timing
- **E5b**: open access signal containing navigation and integrity data

- **AltBOC** multiplexing



Signal	Channels	Modulation	Rc (Mcps)	Rd (sps)	Power level (dBW)	Services	Multiplex. scheme
E5a	E5a-I Data	BPSK-like	10.23	50	Min:-155 Max: -152	OS (F/NAV)	AltBOC(15,10)
	E5a-Q Pilot	BPSK-like	10.23	---			
E5b	E5b-I Data	BPSK-like	10.23	250	Min:-155 Max: -152	OS/CS (I/NAV)	
	E5b-Q Pilot	BPSK-like	10.23	---			

ALTBOC MODULATION

- AltBOC Modulation allows the use of E5 band in two separate sidebands (E5a and E5b)
- In each sideband: 2 I-Q BPSK = 1 QPSK signal
  - Galileo receivers can use one or both sidebands
  - Multiple codes locally generated and correlated (challenging implementation of RX)
- AltBOC is equivalent to 8-PSK

From the receiver point of view:

BPSK Signals

- One or both sidebands separately
- Received in non-coherent mode
- Triangular correlation
- GPS receivers like

AltBOC architecture

- Entire bandwidth
- Coherently received
- Narrower correlation
- More complex structure

GALILEO SPREADING CODE LENGTHS

- Spreading codes are used to acquire and track a specific satellite. Each channel and satellite has a different code (CDMA)
- Galileo signals features depend on their code properties
- Code carefully selected by considering:
  - length
  - relation to data rates
  - auto/cross-correlation properties of the codes
- Code lengths:
  - Data channels: code period duration is equal to one symbol duration.
  - Pilot channels: long pilot code periods (100 ms) to improve cross-correlation and channel isolation, as well as noise and interference suppression.
  - ***Tiered code construction:*** short primary and long secondary codes used to build the code

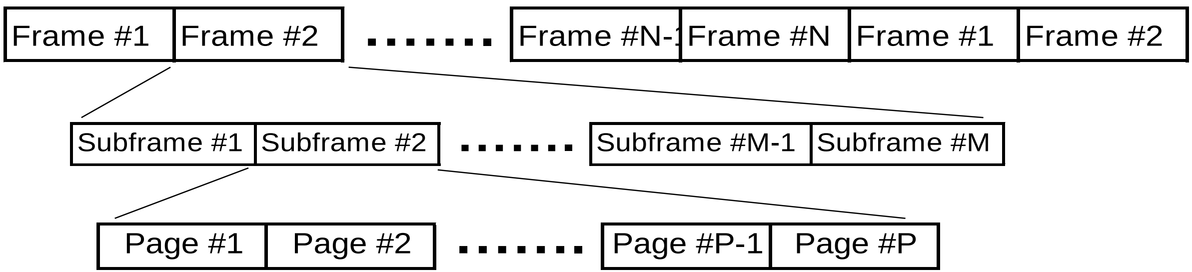
GALILEO SPREADING CODE LENGTHS

Channel	Code rate (Mcps)	Data Rate (symbol/s)	Code period (ms)	Code length (chips)
E5a-I data	10.230	50	20	204600
E5a-Q pilot	10.230	Pilot	100	1023000
E5b-I data	10.230	250	4	40920
E5b-Q pilot	10.230	Pilot	100	1023000
E6-B data	5.115	1000	1	5115
E6-C pilot	5.115	Pilot	100	1023000
E1-B data	1.023	250	4	4092
E1-C pilot	1.023	Pilot	100	1023000

These information are valid for signals excluded PRS service

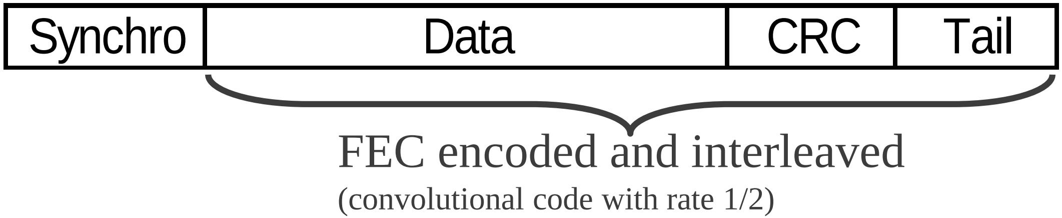
GALILEO NAVIGATION MESSAGE

- **Galileo Message Data Stream :** The navigation message is transmitted in the data stream as a **sequence of frames**.
- Each **frame** consists of a certain number (depending on the signal band) of **subframes** which contain several **pages.**



	Signals	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 E1F	250 sps	1 s	30	18
C/Nav	E6B	1000 sps	1 s	15	8
G/Nav	E6P E1P				

PAGE FORMAT



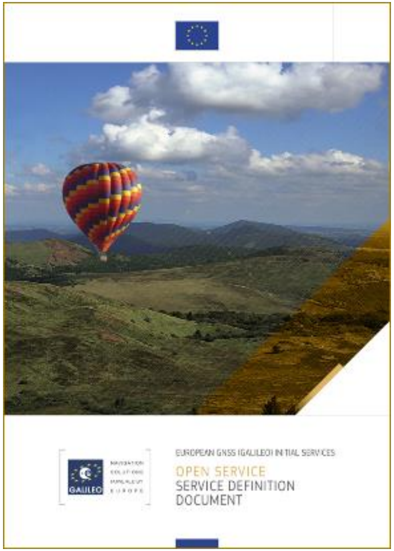
A three levels error coding is applied to the GALILEO Message Data Stream:

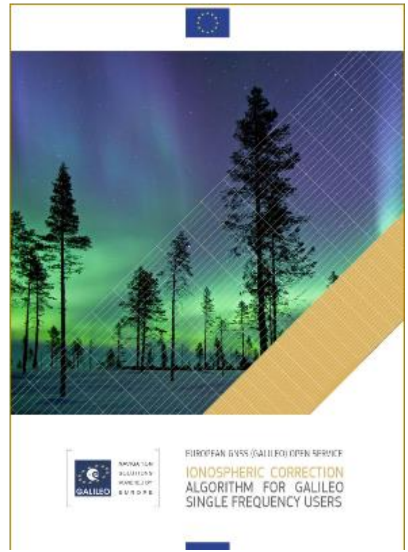
- A **Cyclic Redundancy Check** (CRC) with error **detection capabilities** after recovery of the received data
- A one-half rate **Forward Error Correction** (FEC). Tail Bits (sequence of zeros) to allow Viterbi decoding.
- **Block Interleaving** on the resulting frames: provides robustness to the FEC decoding algorithm by avoiding packets of errors

FEC and CRC are defined according to BER and FER targets.

GALILEO REFERENCE DOCUMENTS

https://www.gsc-europa.eu/electronic-library/





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