CNES contribution to GALILEO signals design

JC2

Jean-Luc Issler

INTRODUCTION

➢**GALILEO Signals have been designed by the members of the "GALILEO Signal Task Force(STF)" of the European Commission.**

➢**CNES was (is) the official French delegate inside the GALILEO STF (now CSI) with French Ministry of transports.**

➢**CNES has widely contributed to the Galileo signal design (the air-interface of the biggest European space project !)**

➢**The GALILEO signal plan has been designed to :**

- **Ease the joint use of GPS and GALILEO, for mass market and other cases**
- **Provide signals offering the best positioning accuracy,**
- **Provide a very secured and robust navigation service thanks to PRS (Public Regulated Service)**
- **Respect internationnal agreements.**

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GALILEO downlink frequency bands

GALILEO signals seeks several goals :

Performances :
- Important bandwidth (BOC-type signals); maximum competitiveness
- Dual frequency services for removing ionosphere bias
- Three frequency to support high precision accuracy applications

Interoperability:
- Dual frequency signal common with GPS (E1/L1 & E5a/L5); cooperation with USA

Reliability:
- Two frequency bands different from GPS (E6 & E5b); no common mode of failure

Safety:
- 3 aeronautical bands (E5a/L5, E5b, E1/L1), frequency diversity mitigating interferences

Security:
- Secured governmental signals provided with antispoofing and other security features : PRS

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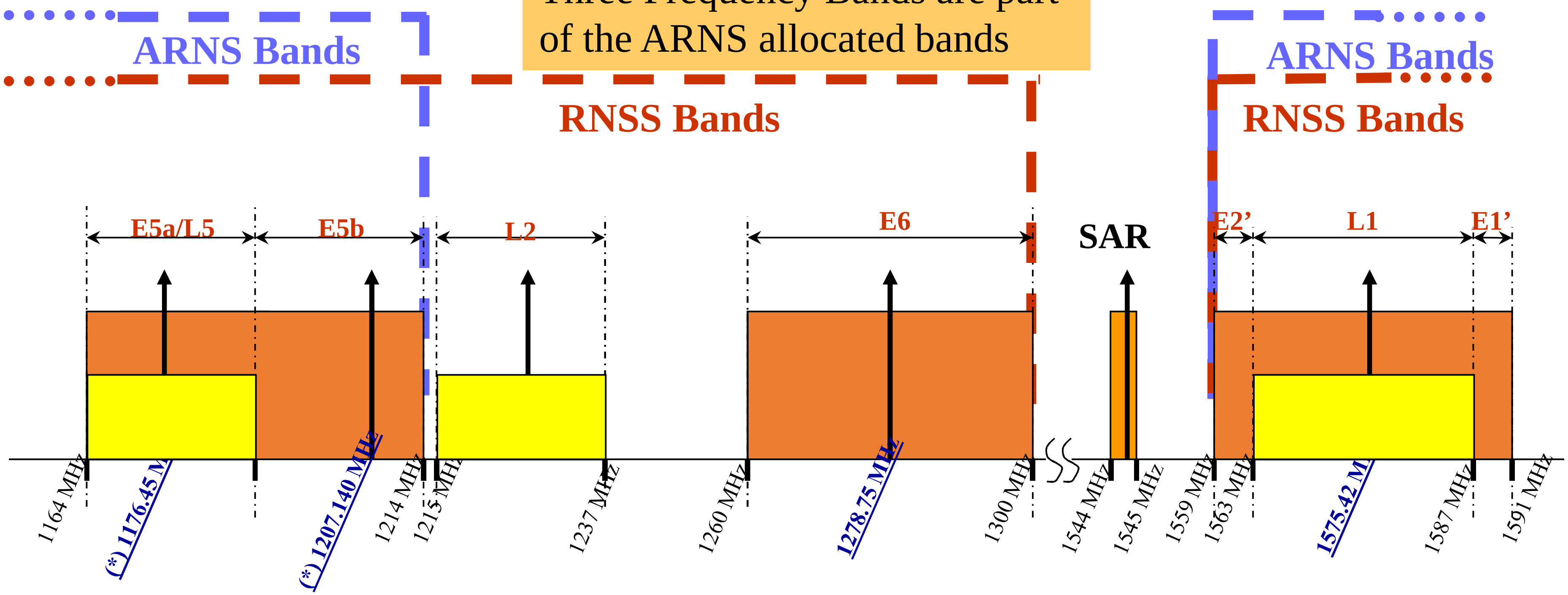
GALILEO downlink frequency bands (2)

Three Frequency Bands are part of the ARNS allocated bands



GALILEO Bands (Navigation)

GALILEO SAR Downlink

GPS Bands

L1 and E5a/L5 are common to
GPS Frequency bands for interoperability

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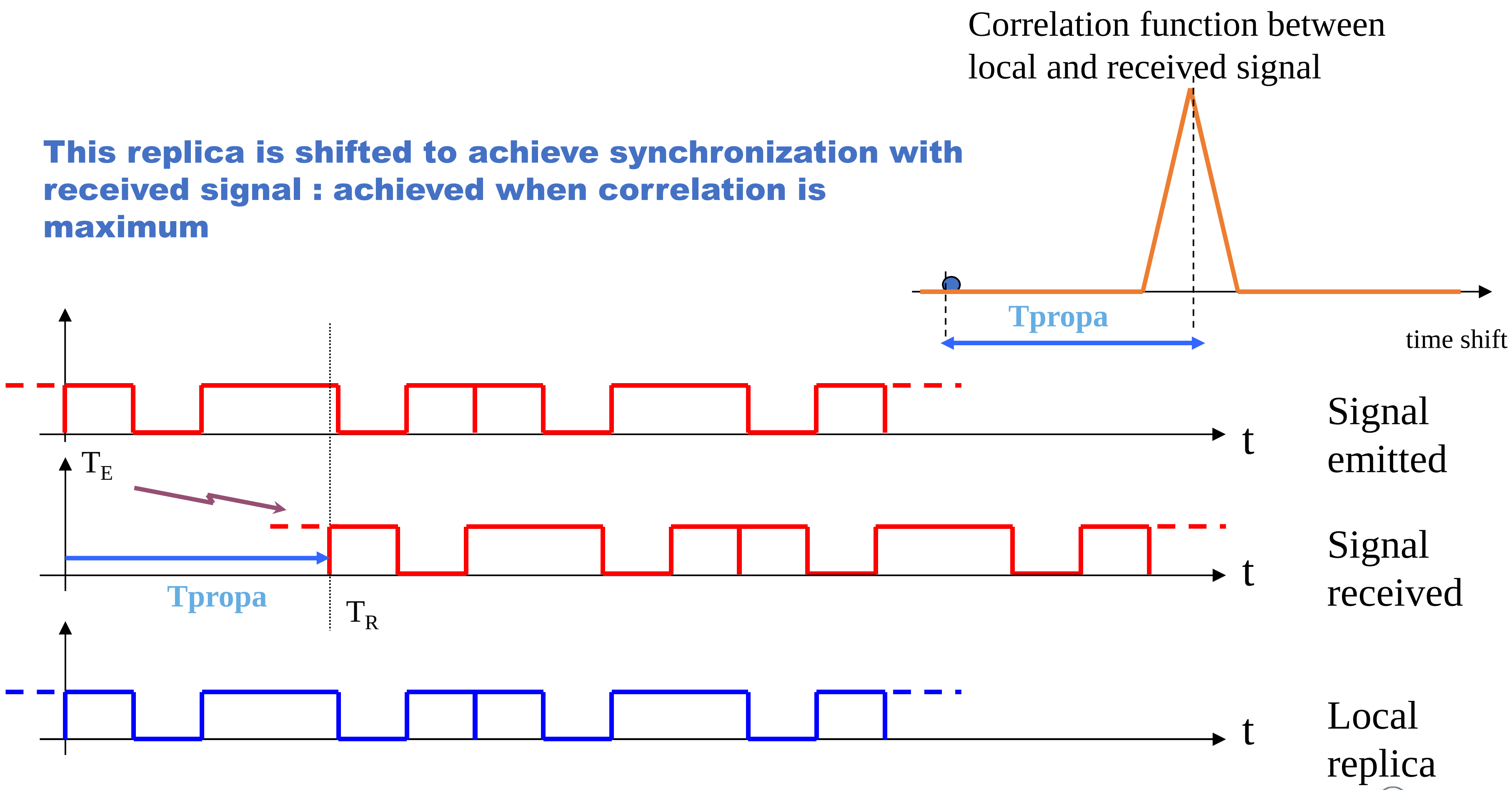
Range measurement with PRN codes

This replica is shifted to achieve synchronization with received signal : achieved when correlation is maximum



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BPSK or QPSK(n)

« Rectangular » time-form of the signal

n : chip rate (multiple of 1,023 MHz)

BOC(m,n)

BOC : Binary Offset Carrier

The PRN code is mixed with a square sub-carrier

Subcarrier frequency = m * 1.023 MHz

PRN code rate = n * 1.023 MHz

Choice of m and n to minimise interferences

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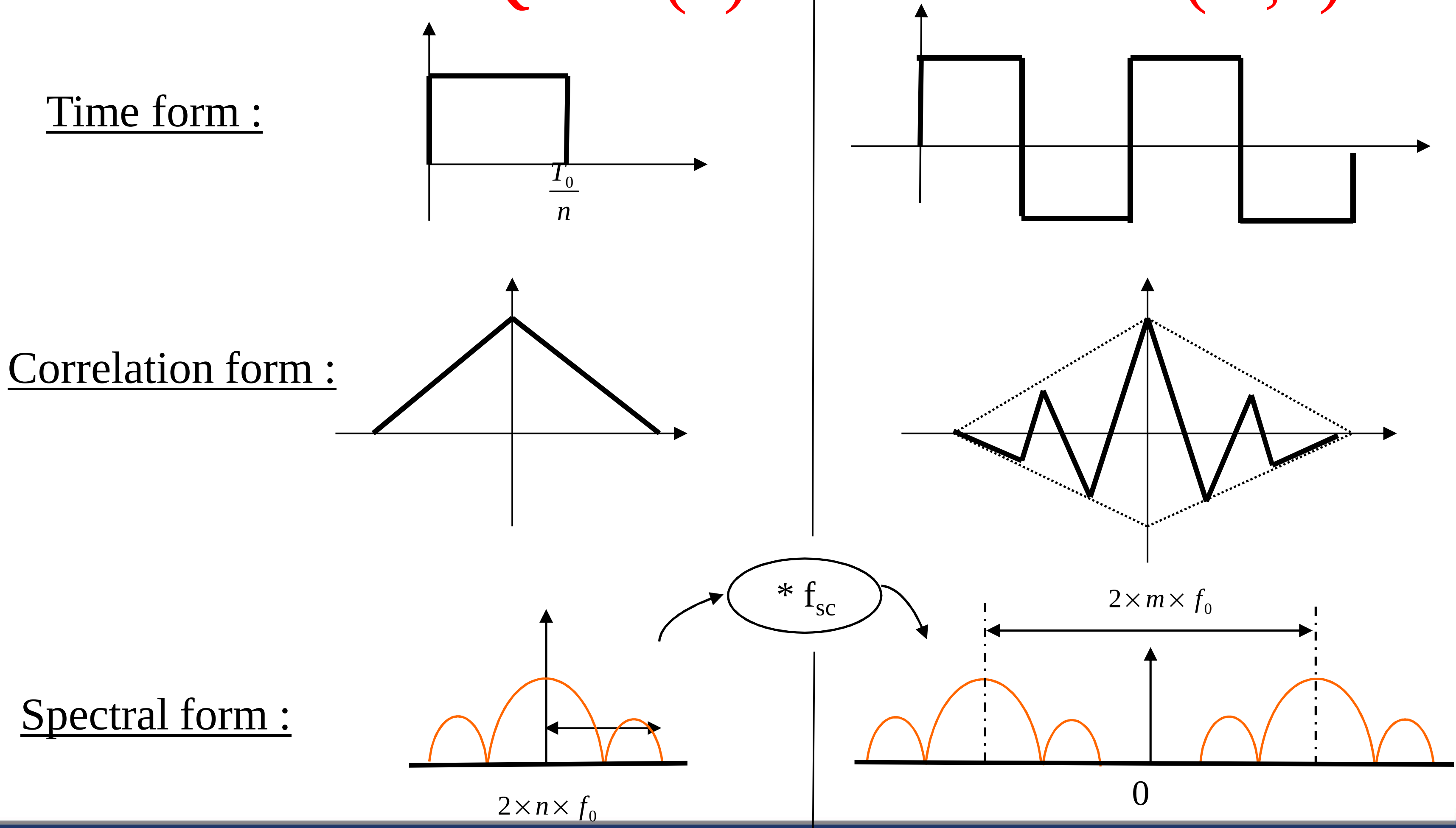
Basic types of GNSS signals (2)

BPSK or QPSK(n) | BOC(m,n)



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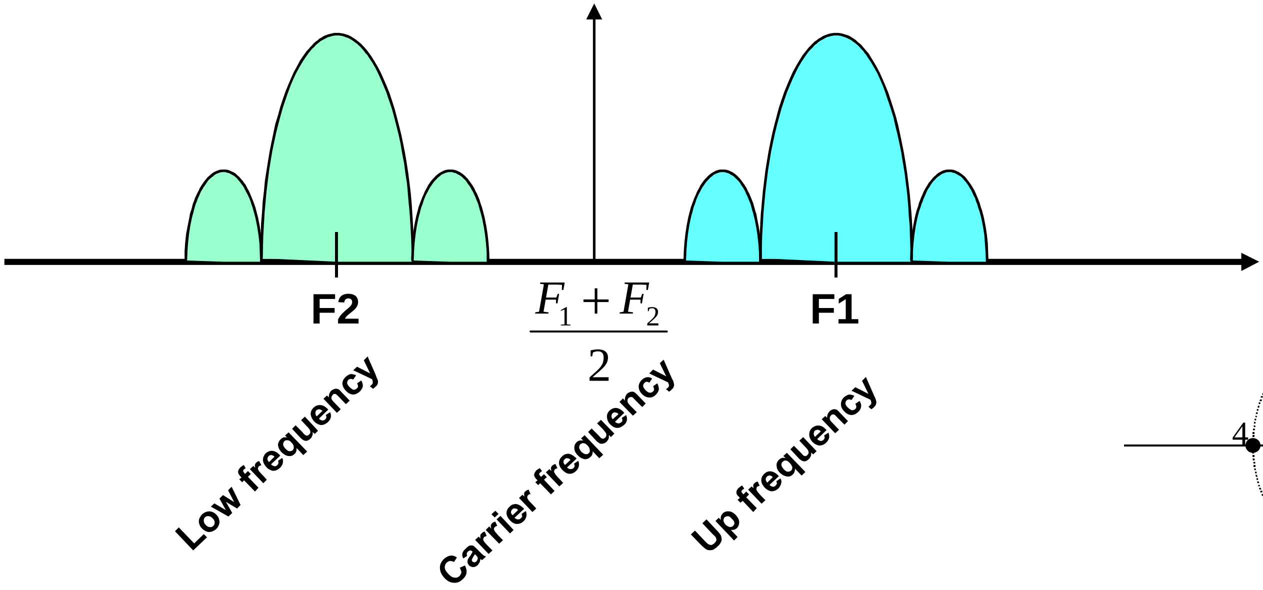
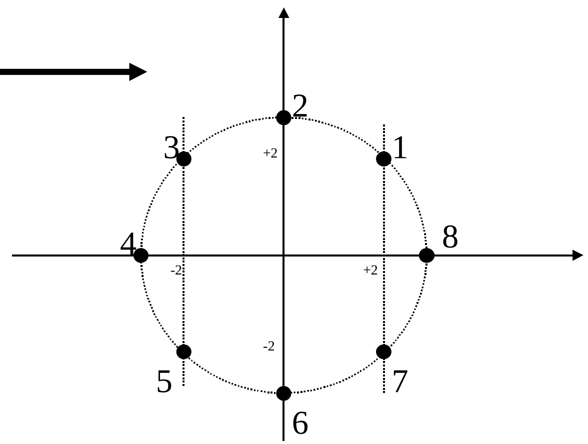
WHAT ALTERNATIVE BOC (ALT-BOC) is ?

Objective : Generate 4 navigation signals at 2 frequencies (lobes) using only one carrier frequency, and using a constant enveloppe





Interest of ALT-BOC : Easy transmission; transmission of 4 signals using the same carrier

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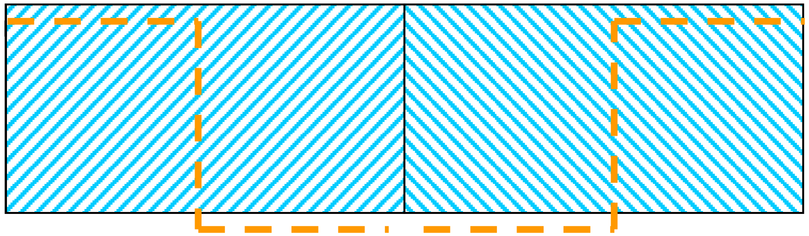
What BOC SIN or COS phasing is ?

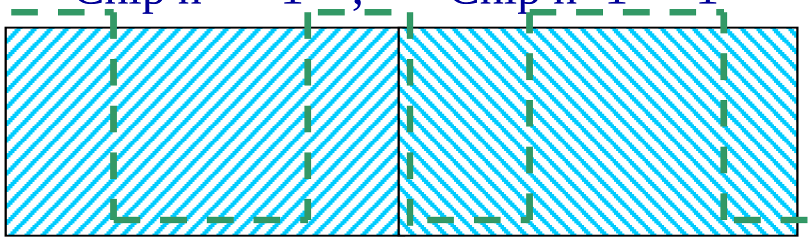
Standard BOC :
"SINUS" sub-carrier :

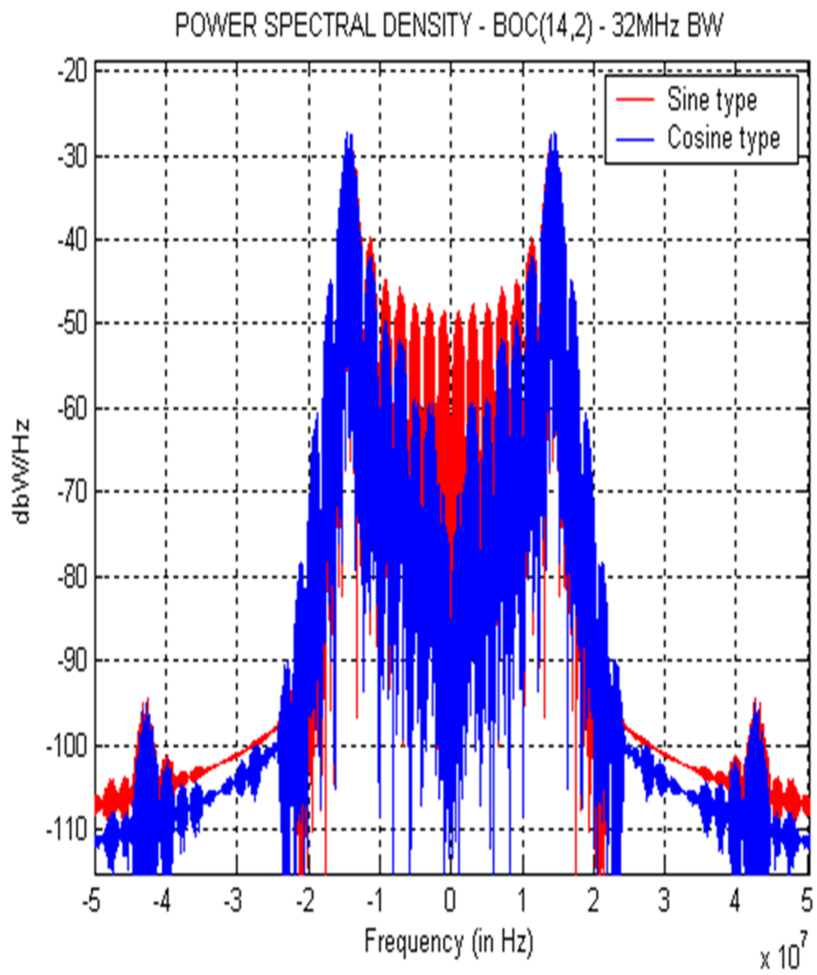
Chip n = +1 , Chip n+1 = -1



"COS" sub-carrier :

Chip n = +1 , Chip n+1 = -1





Interest : Spectral isolation

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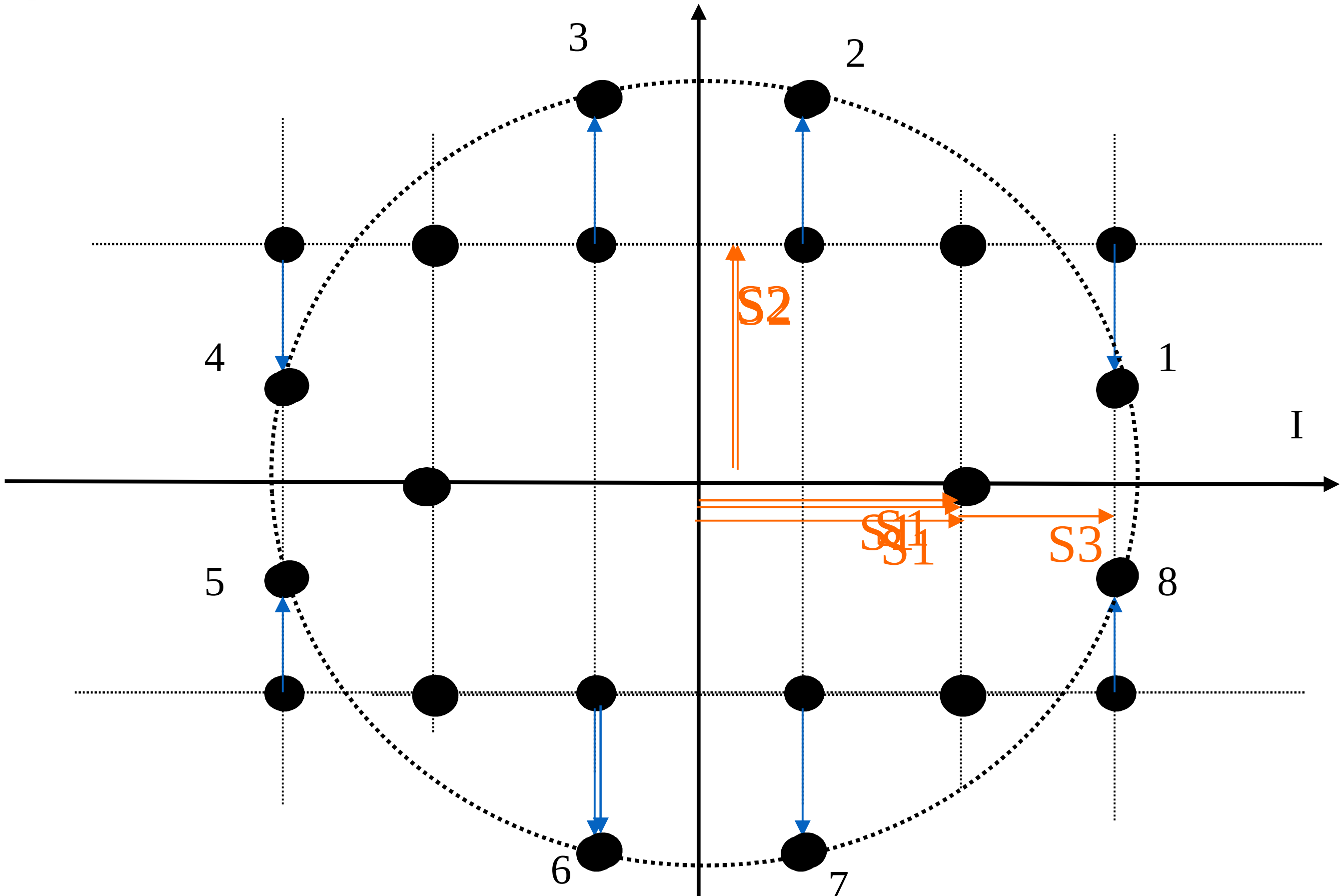
What modified Interplex modulation is ?



A modified interplex modulation is used for GALILEO E6 and E1

Objective : Combine 3 signals with a constant enveloppe, to ease the signal transmission thanks to minimize the back-off at the input of the RF power amplifier to maximize the RF transmitted power

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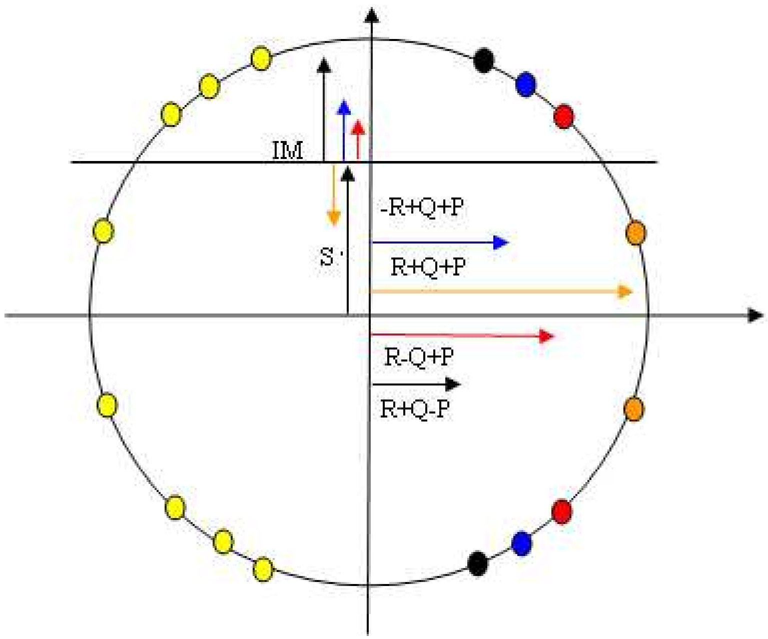
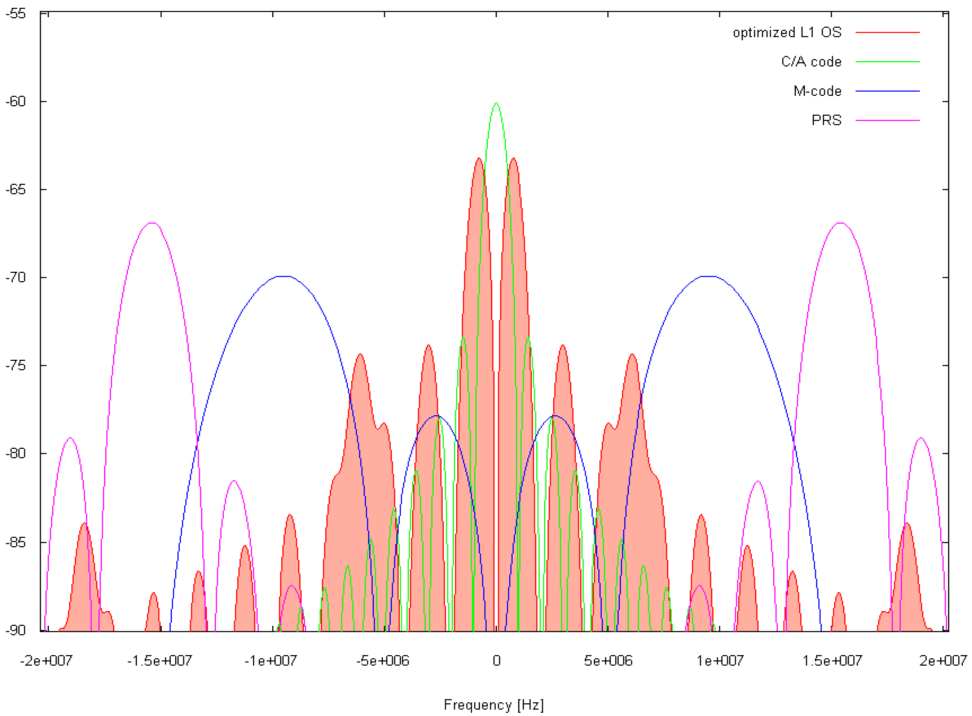
What is MBOC and CBOC ?

MBOC[f] = 10/11*BOC(1,1)[f] + 1/11*BOC(6,1)[f]





Interplexing of PRS with CBOC (data and pilot)

MBOC measurement errors are approximately twice smaller than BOC(1,1)

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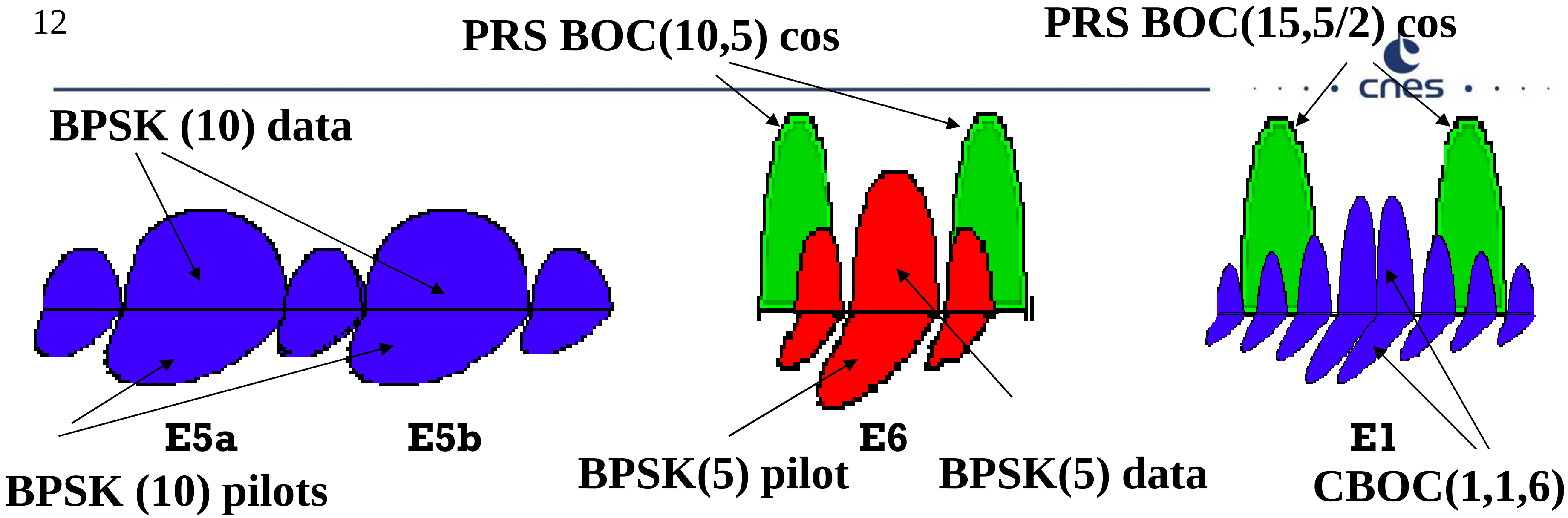

4 signals ALTBOC (15,10) mod	3 signals modif interplex mod	3 signals modif interplex mod

Safety Of Life and Open Services

Public Regulated Service (PRS)

Commercial Service

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Conclusion

- **Main CNES contribution in Galileo signal design was :**

- First filing of Galileo Frequencies in collaboration with ANFR
- Contribution to the choice of E5b and E6 frequency values
- Contribution to definition of ALT BOC, in E5 aeronautical band
- Early definition of CBOC : OS service at GPS/GALILEO frequency L1/E1.
- Early definition of BOC-COSine modulation for the PRS for a better spectral separation between GPS and GALILEO secured and open signals.
- Contribution to the definition of modified interplex modulation
- Definition of the Navigation Signal Generation Unit (NSGU) principles

CBOC, ALTBOC and BOC-COS modulations achieve high navigation performances and fulfil the national security criteria agreed with USA

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Exemple of CNES co-funded PhD Thesis impacting GALILEO program

JC2

Marion Aubault, Jean-Luc Issler

Galileo signals and payloads optimization

Emilie Rebeyrol, defended in 2007

Goal:

To analyse and to improve the implementation of E5 and E1 Galileo signals generation , amplification and filtering in the payload. Consider different possible E1 (resp E5) Open signal waveforms , and their interplexing in the signal generator. Analyse signal distortions, phase noise, and overal related signal performances an receiver level.

Keywords:

GPS, GNSS, Galileo, modulation performance, propagation channel, distortion, interplex, ALTBOC, CBCS, payload, amplifier, filter, distortion, phase noise, spectrum, multipath, CBOC, growth potential

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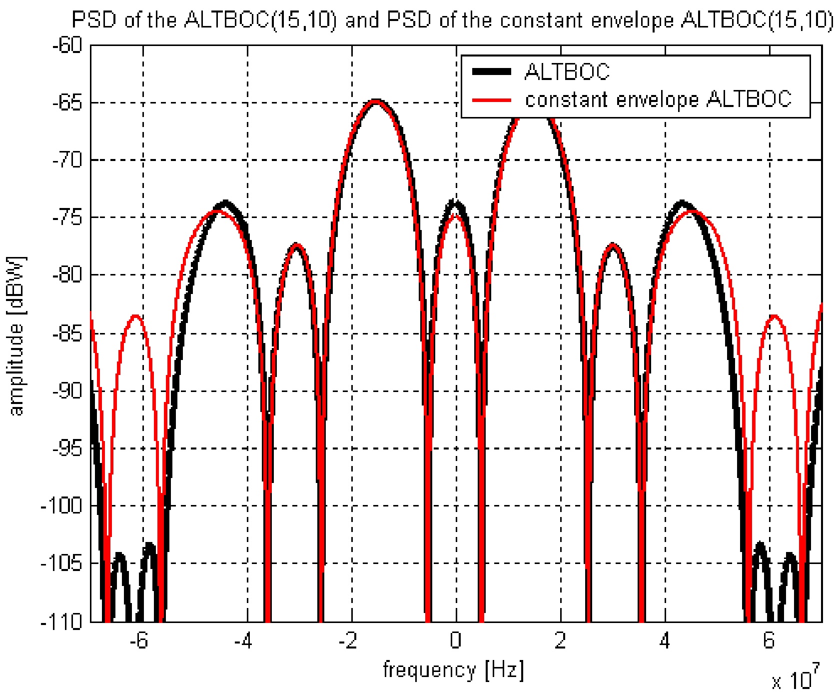
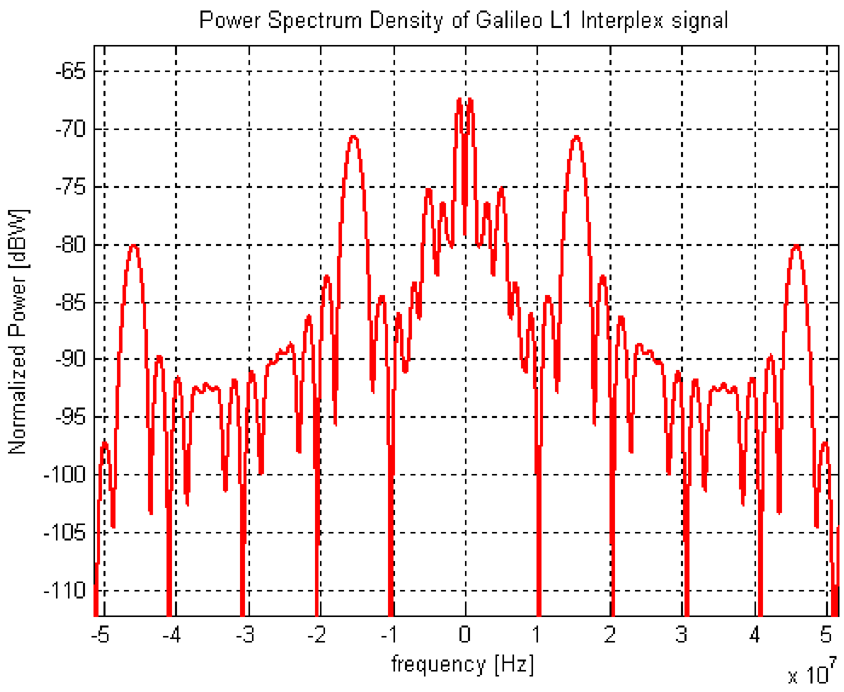
PSD theoretical formulations of complex GNSS signals

Comparison of the ALTBOC Power Spectrum Densities



Galileo baseline E1 Interplex signal normalized power spectrum density



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Identification of CBOC(6,1,1) growth potential for G2G

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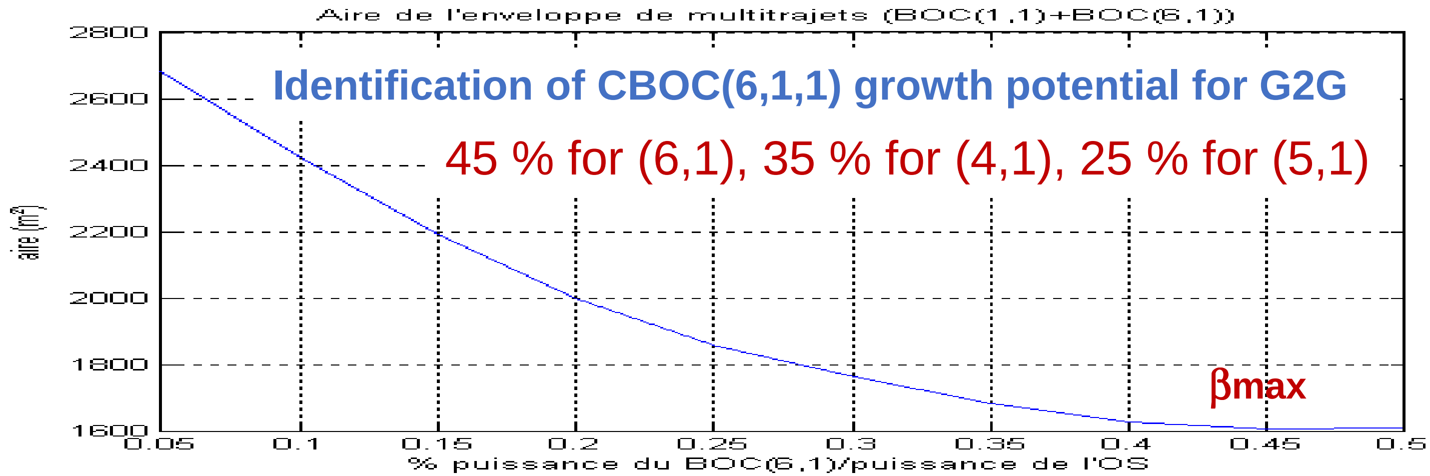
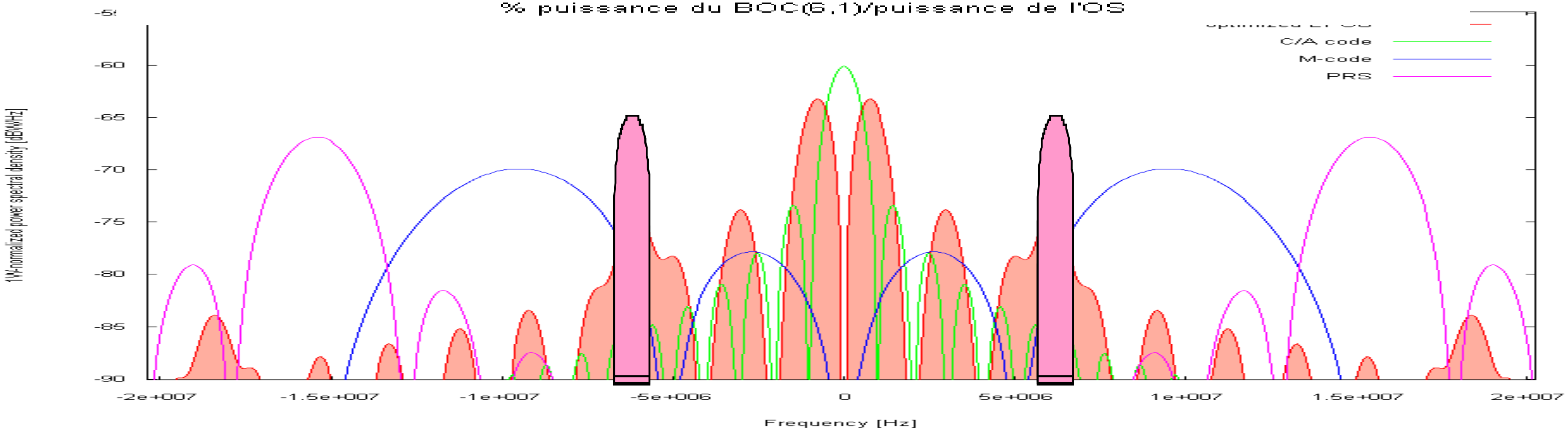
CBOC = α*BOC(1,1) + β*BOC(6,1)   Today : β = 9 % = 1/11, β_{max} = 45 %

Identification of CBOC(6,1,1) growth potential for G2G

45 % for (6,1), 35 % for (4,1), 25 % for (5,1)





Impact of this thesis on European GNSS Programs

Galileo signal and payload optimization
Emilie Rebeyrol, defended in 2007

- ➔ **This work on Galileo 1st generation signal and payload allowed :**
  - ➔ To reinforce CNES know how in GNSS navigation payload
  - ➔ An analytical description of the ALTBOC and interplexed CBOC spectra
  - ➔ To reinforce the CNES proposal for E5 GALILEO ALTBOC signals
  - ➔ To reinforce CNES/UNiBwM proposal E1 GALILEO CBOC signals
  - ➔ To choose the configuration of the GALILEO CBOC signal vis-à-vis multipath mitigation performance
- ➔ **This work is a key input to Galileo 2nd Generation(G2G) studies**
  - ➔ The CBOC(6,1,1) growth potential identified by this thesis could be exploited for a more performing signal still backward compatible with G1G

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Optimization of demodulation performance of the GPS and GALILEO navigation messages

Axel Garcia Pena, defended in 2010

Goal:

To analyse and to improve the demodulation performance of the current open GNSS signals, specifically in indoor and urban environments, and to propose new navigation message structures for GALILEO E1.

Keywords:

GPS, GNSS, Galileo, demodulation performance, propagation channel, AWGN channel, LMS channel, CSK, BER, WER, EER, navigation message

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New GNSS users are appearing involving:

- New needs
- New services

More information is wanted to be transmitted, and faster, implying:

- Higher data rates (PPP, Safety of Life, …)

An important part of new services takes place in urban environment:

- Improved system performance is required

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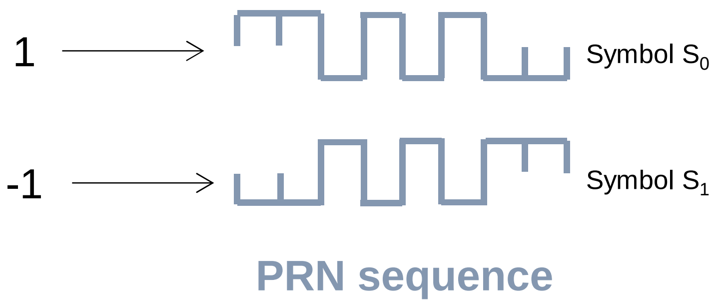
For GNSS signals:

- **Data symbols are spread by a Pseudo-Random Noise (PRN) sequence**
- **Data symbols are BPSK modulated (or equivalent)**



➔ 2 possible symbols per PRN sequence!

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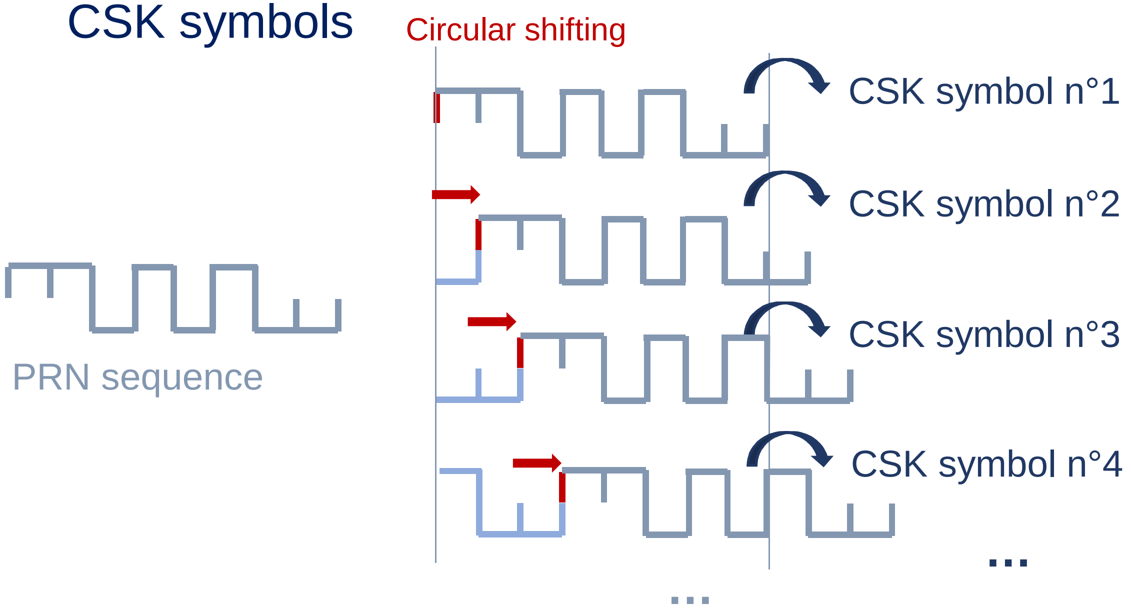
One possible solution to increase the data rate is:

- **The CSK (Code-Shift Keying) modulation**

consisting in circularly shifting the spreading sequence in order to represent CSK symbols



➔ Number of CSK possible symbols per PRN sequence: number of chips constituting the PRN sequence (1023 chips for GPS L1 C/A)

➔ CSK modulation is really promising, it permits to increase the data rate, without modifying the spreading code sequence length or rate.

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Impact of this thesis on European GNSS Programs

Optimization of demodulation performance of the GPS and GALILEO navigation messages
Axel Garcia Pena, defended in 2010

- ➔ **This work on CSK is a key input for G2G studies**
- ➔ **This work allow CNES a significant better know how on CSK modulation**
  - ➔ for future navigation and telecom applications
  - ➔ for CNES inputs to G2G
  - ➔ for potential collaboration with CSK-using GNSS system (QZSS, …)

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Analysis and improvement of GNSS navigation message demodulation performance in urban environments

Marion Aubault Roudier, defended in 2015

Goal:

To improve GNSS signals demodulation performance in urban areas, proposing a new signal

Keywords:

GPS, GNSS, Galileo, demodulation performance, propagation channel, AWGN channel, LMS channel, CSK, LDPC, BER, WER, EER, navigation message, error correcting codes

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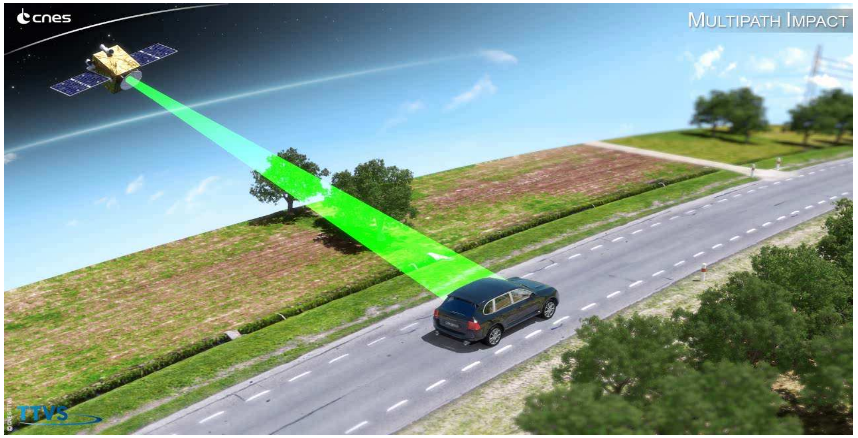
New GNSS users are appearing with :

- **New needs**
- **New services**



More information is wanted to be transmitted, and faster, implying:

- **Higher data rates (PPP, Safety of Life, …)**

An important part of new services takes place in urban environment:

- **Improved system performance is required**

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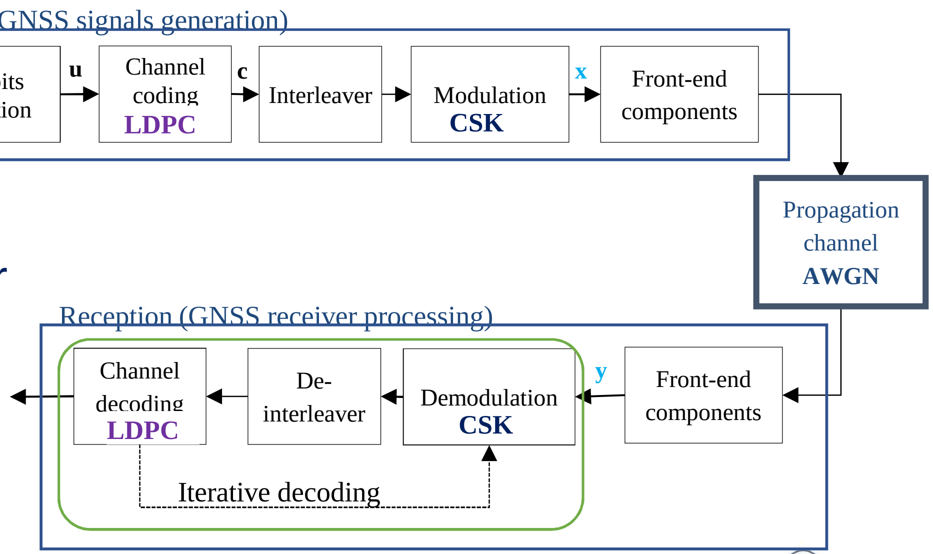
To protect information data against potential errors due to the propagation channel:

An error correcting code is applied, adding redundant bits : CHANNEL CODING

The latest GPS signal, GPS L1C is protected by:

A LDPC channel code



Study goal:

To design a LDPC code adapted for the CSK modulation for the next generation Galileo signals

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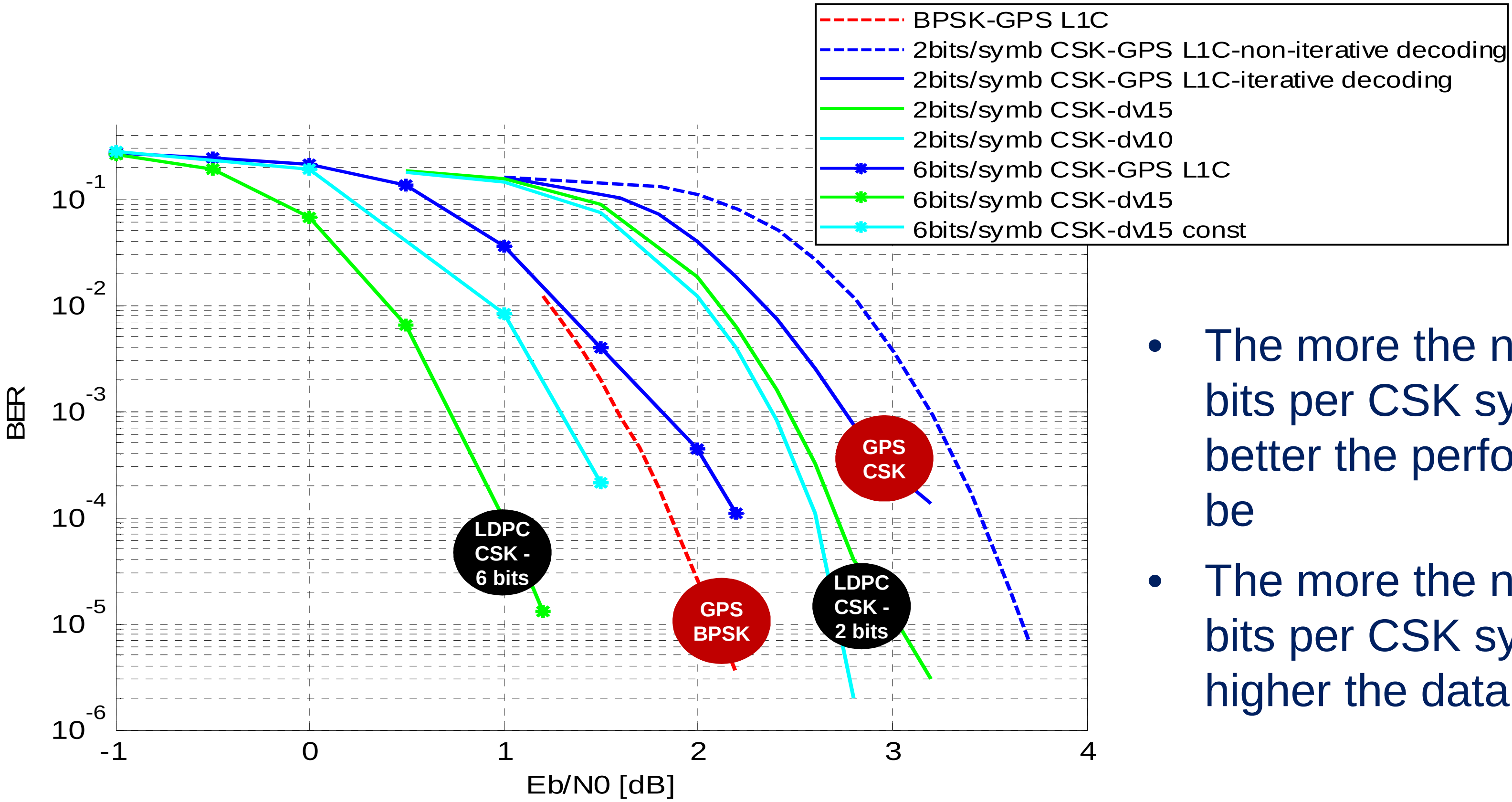

- The more the number of bits per CSK symbol, the better the performance will be
- The more the number of bits per CSK symbol, the higher the data rate will be

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Impact of this thesis on European GNSS Programs

Analysis and improvement of GNSS navigation message demodulation performance in urban environments
Marion Aubault Roudier, defended in 2015

➔ **This work on CSK is a key input for G2G studies**

➔ **This work allow CNES a significant better know how on CSK modulation and coding**

- ➔ for future navigation and telecom applications
- ➔ for CNES inputs to G2G
- ➔ for potential collaboration with CSK-using GNSS system (QZSS, …)

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Signals study and optimization for Galileo evolutions

Lorenzo Ortega, started in 2016

Goal:

To design a new Galileo signal for Galileo evolutions

Keywords:

GNSS, Galileo, demodulation performance, propagation channel, AWGN channel, LMS channel, BER, WER, EER, navigation message, error correcting codes, modulation, interplexing

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Evolutions on Galileo 1st Generation (G1G)

- I/NAV Evolution (SSP, redCED, FEC2)
    - Secondary Synchronization Pattern (SSP): allows for receiver time ambiguity resolution (+/- 3 sec.) and compliance to 3GPP A-GNSS standard
    - Reduced Clock and Ephemeris Data (redCED)
    - Forward Error Correction additional level (FEC2): choice between a LDPC and a Reed Solomon code
- OS-NMA
    - Navigation Message Authentication (NMA): Addition of cryptographic protection in the navigation message for the Open Service through E1-B
- CS Separate Encryption
    - Commercial Service (CS) will provide access to two additional encrypted signals on the E6 band

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Evolutions on Galileo 2nd Generation (G2G)

➢ New component E1-D to design

Identified User Needs:

- Robust data delivery also in challenging environment
- Very low TTFF (Time To First Fix)
- Support enhanced authentication data dissemination needs for message authentication and Anti Replay Protection (at PRN level)
- Allow for improved flexibility and expandability capabilities, to allow the introduction of futures services

Existing constraints:

- Signal provision in E1 (mass market compatible)
- Spectral congestion in the band

Recommended solution:

- Provision of signal at offset carrier aligned to future GLONASS CDMA signals, Processing as META signal in combination with E1-B/C for high multipath suppression

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Impact of this thesis on European GNSS Programs

Signals study and optimization for Galileo evolutions
Lorenzo Ortega, started in 2016

- ➔ **This work is also a key input for G2G studies**

- ➔ **This work allow CNES significant better contribution to G2G signals definition**
  - ➔ Waveform : message, encryption, coding, modulation, interplexing
  - ➔ Frequency : New frequency(ies)

- ➔ **This work is an input for potential Galileo/Glonass collaboration**

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CONCLUSION

- CNES co-funded PhD thesis had a big impact on Galileo G1 Signal design

- CNES co-funded PhD thesis should have a big impact on G2G Signal design

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