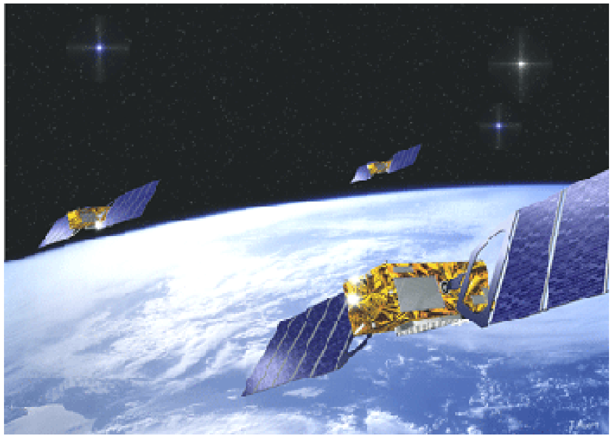
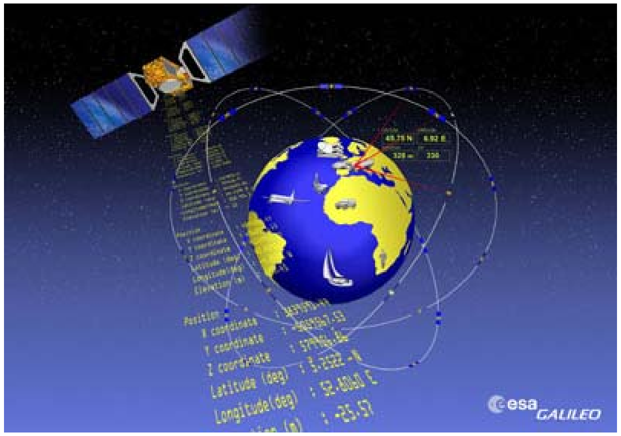
Past and On-going Galileo Research Projects at EPFL-IMT-ESPLAB

Navigare'09

Dr. Cyril Botteron



June 17, 2009

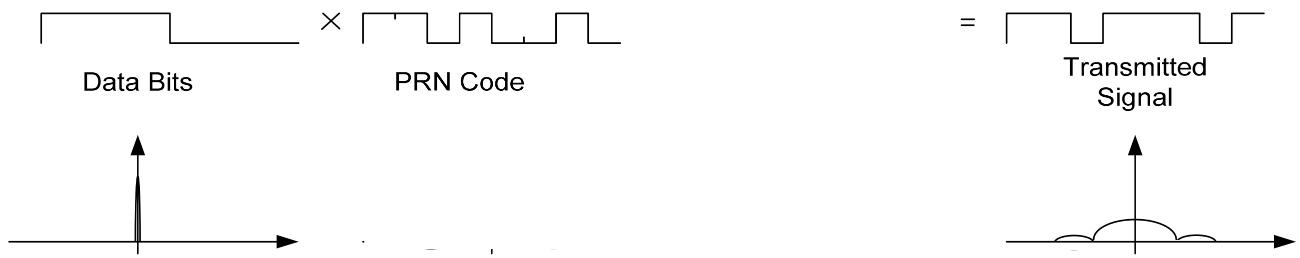


Agenda

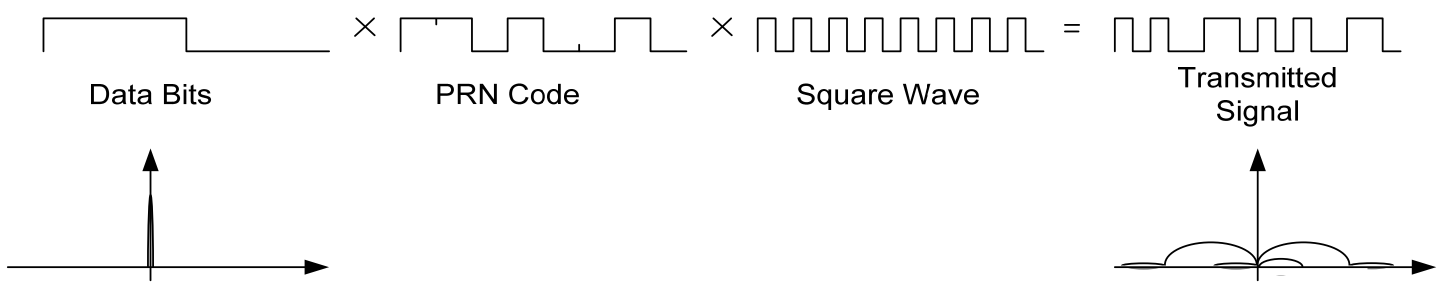
- Intro to GNSS
  - GNSS modulations, main receiver blocks, ...
- Selected past projects
  - GPS Watch, GRDB, GPS L1/L2 rx, ...
- Some current projects
  - GAMMA-A, Signature, SARBACAN, SNSF GNSS, SoftRx, ...
- From GNSS to UWB

BPSK versus BOC Modulation

- Example of BPSK(m)
  - PRN code rate: m x 1.023 MHz

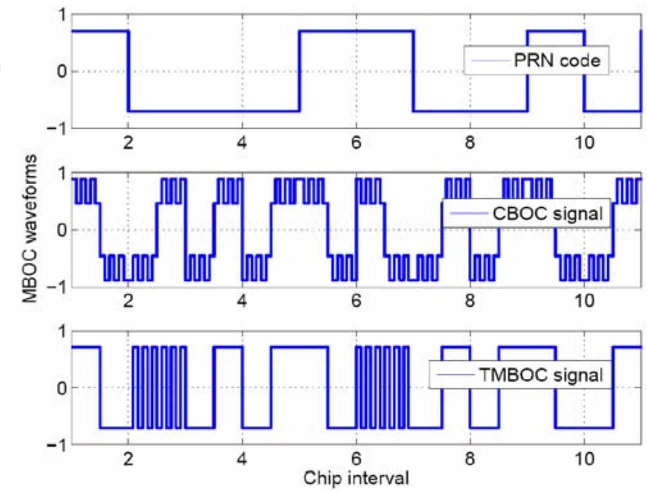


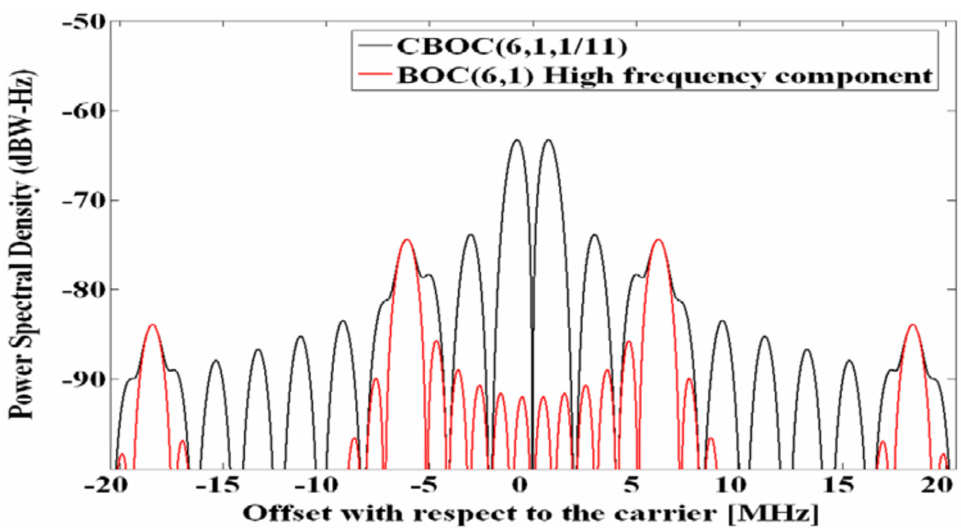
- Binary Offset Carrier: BOC(n,m)
  - The code is modulated by a square wave
  - subcarrier frequency: n x 1.023 MHz
  - PRN code rate: m x 1.023 MHz
- Example of a BOC(1,1)

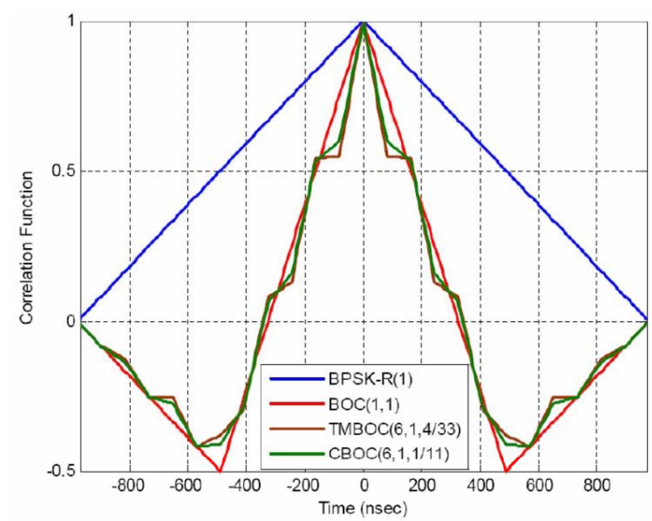


MBOC Modulation

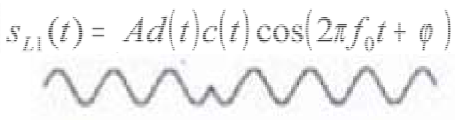
- MBOC Modulation: $G_{MBOC}(f) = \frac{10}{11} G_{SinBOC(1,1)}(f) + \frac{1}{11} G_{SinBOC(6,1)}(f)$
- Galileo E1 CBOC
  - CBOC(6,1,1/11) for both pilot and data
  - 50%/50% power split pilot/data
- GPS L1 TMBOC
  - TMBOC(6,1,4/33) for pilot
  - BOC(1,1) for data
  - 75%/25% power split pilot/data

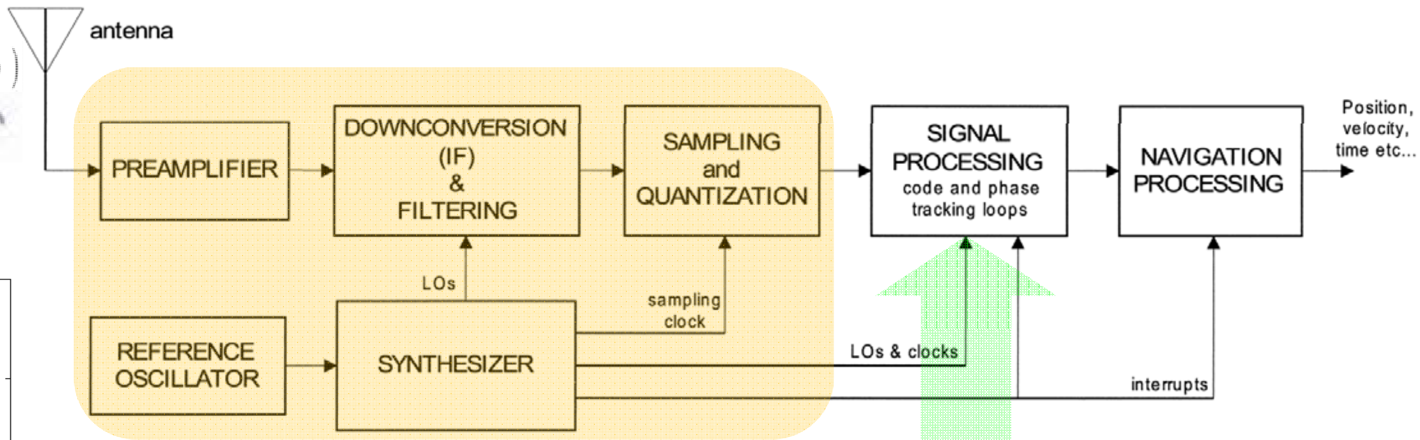


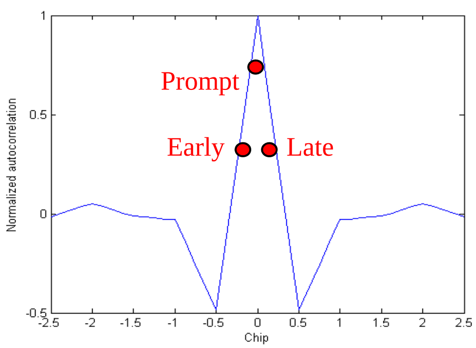


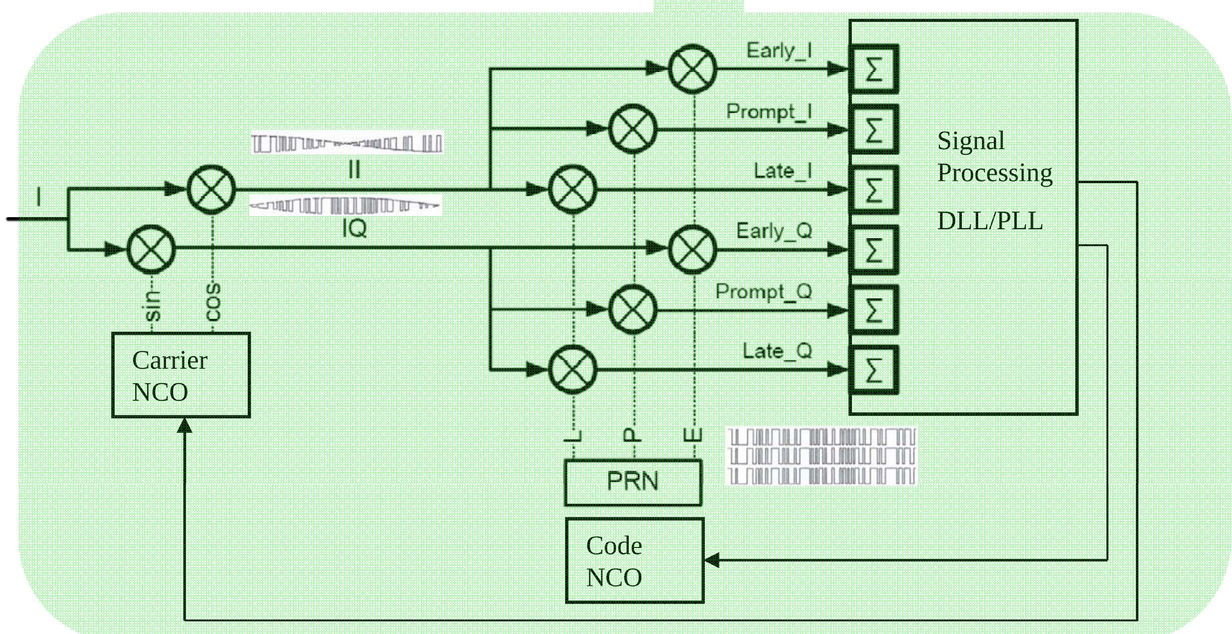


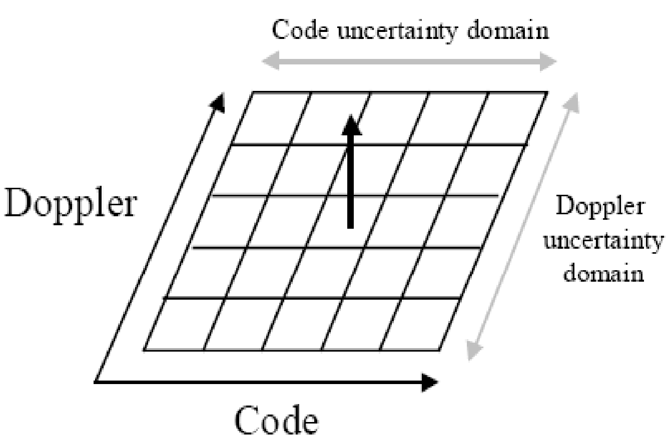
Main GNSS Receiver Blocks



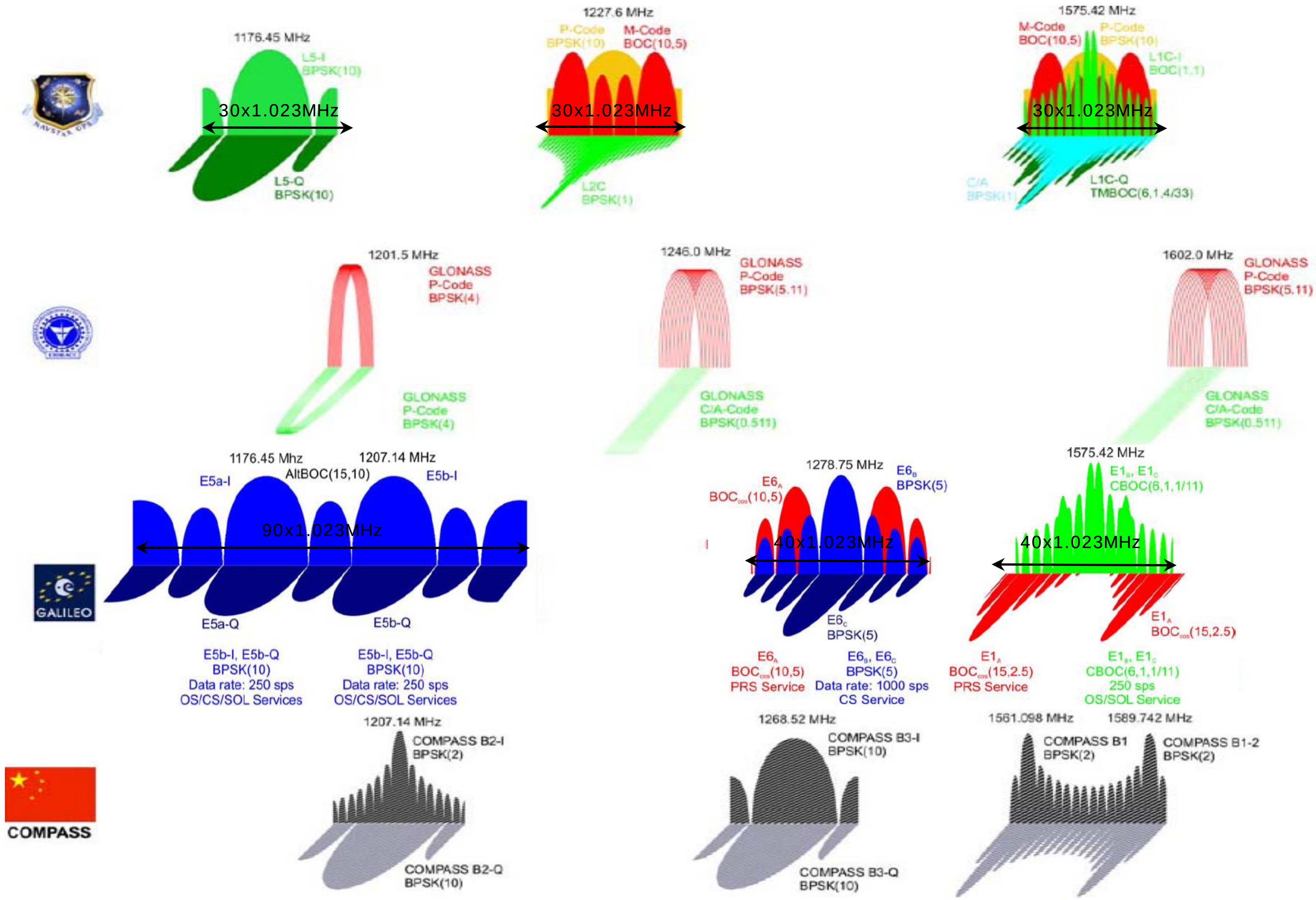








GNSS - Current and intended signals



Green and blue signals: Open or commercial signals
Red signals: Military signals, Public Regulated Services
Grey signals: Usage of filed signal not yet defined officially

Source: "GNSS Signals and Spectra," ICG ICG-4-02, Sept.4-7, 2007

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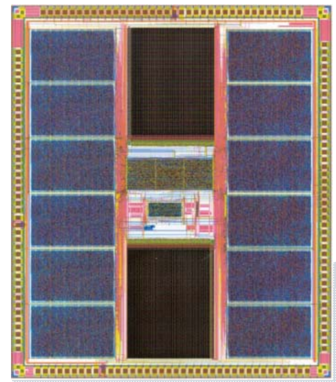
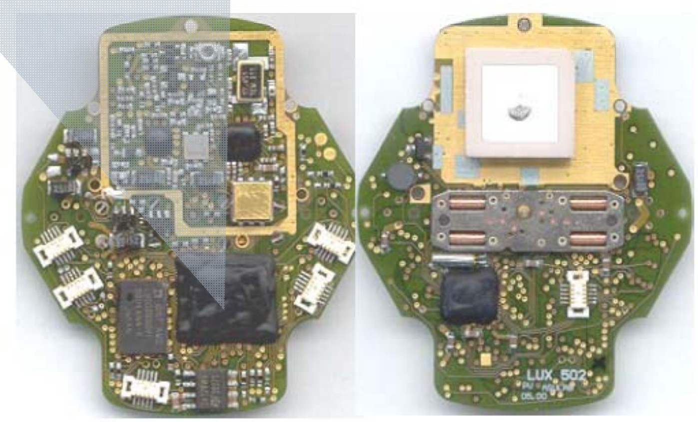
GPS Watch

- The beginning of the GNSS adventure at IMT! (from ~ 1995 to 1998)
  - GPS watch's goals:
    - Dimensions: 57 × 47 × 20 mm3
    - Autonomy>1 year (watch)
    - Low power GPS rx
  - IMT's contributions:
    - Low power receiver architectures and algorithms
    - Realization of a low power 12 channels GPS L1 C/A baseband ASIC (<40mA using TSMC CMOS 0.5um)





[Far00] "GPS Watch -An Analogue Watch Including a Very Low Power GPS Receiver," ION GPS 2000
[Fir01] "Design & Realization of a Low Power DSP Architecture for GPS Receivers", PhD Thesis, IMT 2001

ASULAB SA SWATCH GROUP

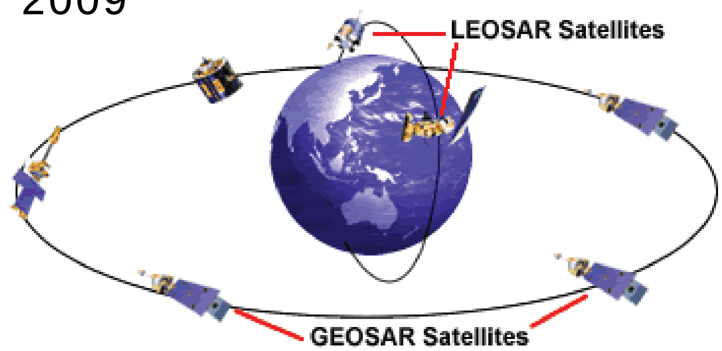
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

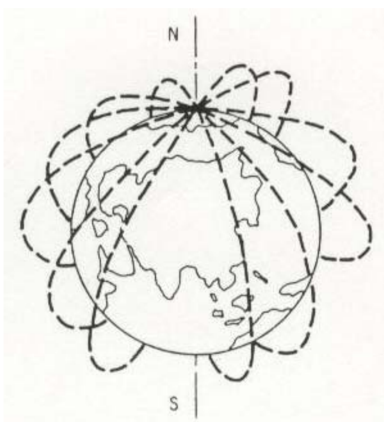
imt

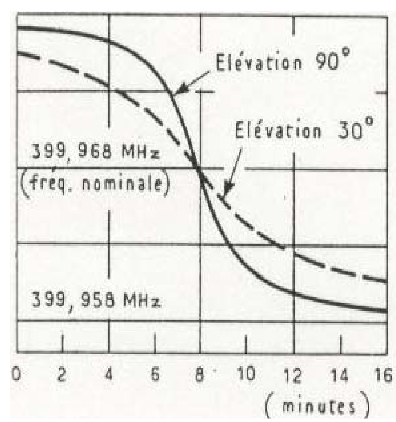
KTI/CTI

GRDB – Galileo Receiver for Distress beacon (1/3)

- Cospas-Sarsat status (05.2009):
  - 5 low-altitude earth orbit satellites (LEOSAR)
  - 4 geostationary earth orbit satellites (GEOSAR)
  - 29 mission control center (MCC)
  - 406MHz beacon population: > 600’000
  - 121.5/243 MHz processing ceased on Feb. 01, 2009
  - Persons rescued in 2007: 2386 (562 distress)
  - Since inception in 1982: 24798 persons
- Localization by LEOSAR (Doppler effect):







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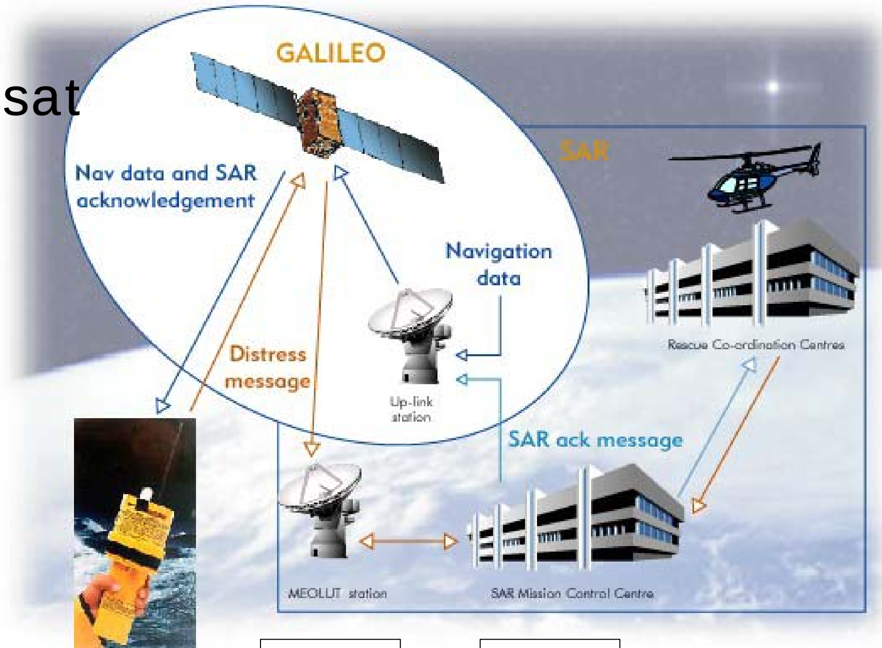
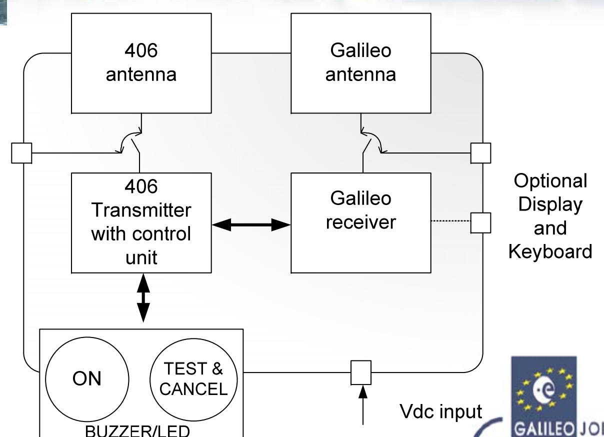
Sixth Framework Programme

GALILEO JOINT UNDERTAKING

GRDB – Galileo Receiver for Distress beacon (2/3)

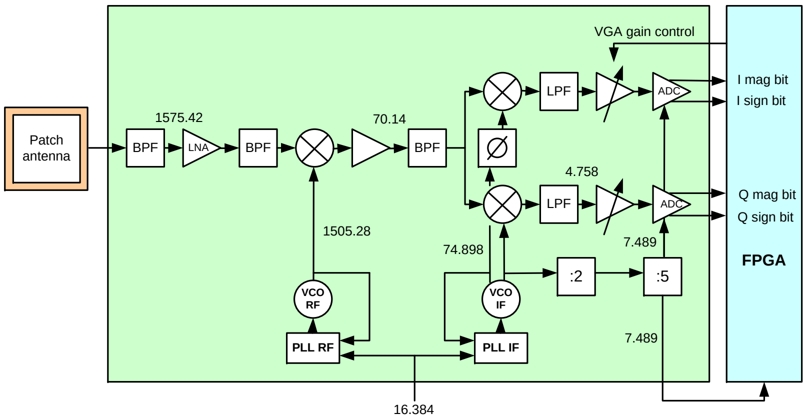
- Galileo Contribution to Cospas-Sarsat
  - Galileo SAR Service
    - Cospas-Sarsat space segment replacment
    - Global and drastic reduction of alert delay
    - New localization based on new principles
    - Reduction of false alert quantity (SAR RLM)
- GRDB’s goals (2005-2007)
  - Beacon prototype platform
    - Galileo BOC(1,1) receiver
    - Operations in presence of 20dBm/406MHz
    - SAR RLM decoding and new operating modes

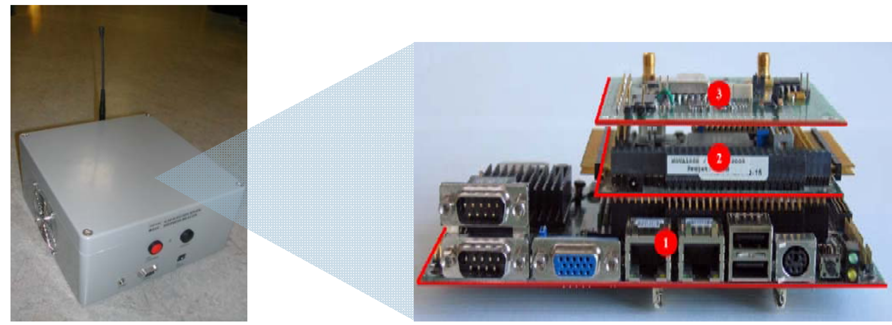




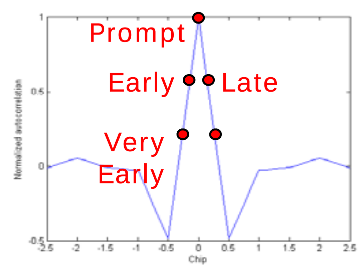
GRDB – Galileo Receiver for Distress beacon (3/3)

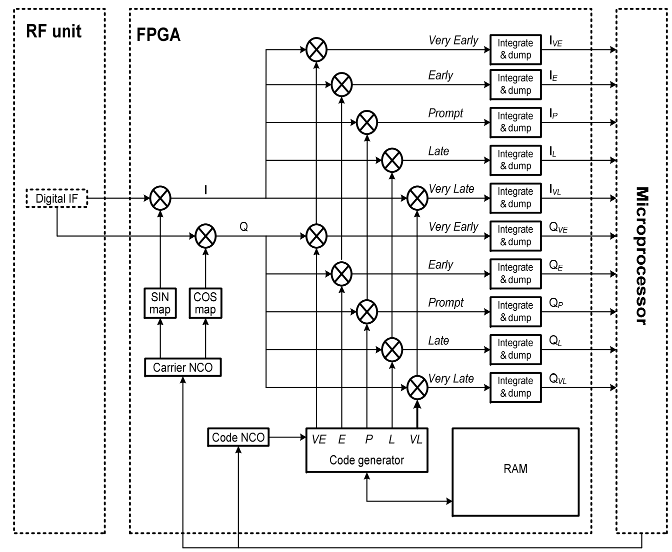
- IMT's contributions:
  - Novel front-end architecture





  - Novel correlator HW implementation

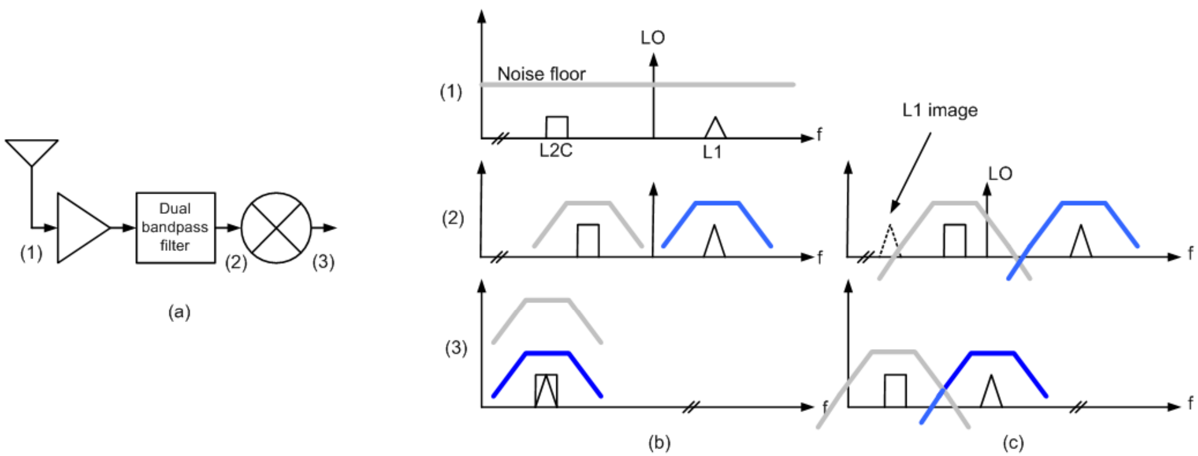




[Cha07] "Galileo E1b,c RF FE for SAR applications," *ENC-GNSS 07*
[Wae07] "Real-time Galileo E1 signal acquisition and tracking scheme", *ENC-GNSS 07*
[Bot06] "Flexible Galileo L1 Rx Platform for Validation of Low Power and Rapid Acqu. Schemes," *ION GNSS 2006*
[Cha06] "Galileo L1 RF FE Optimized for Narrowband Interferers Mitigation," *ION GNSS 2006*

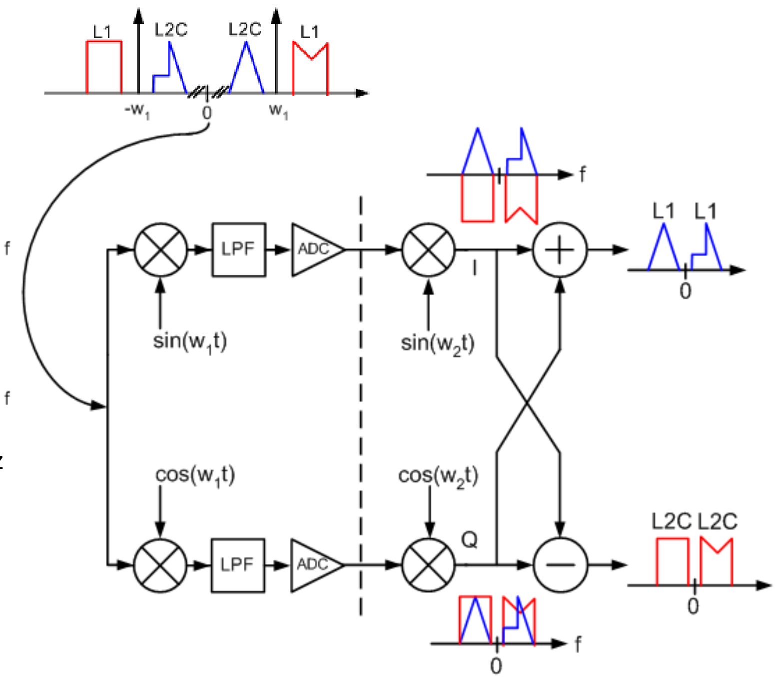
martec imt Sixth Framework Programme GALILEO JOINT UNDERTAKING

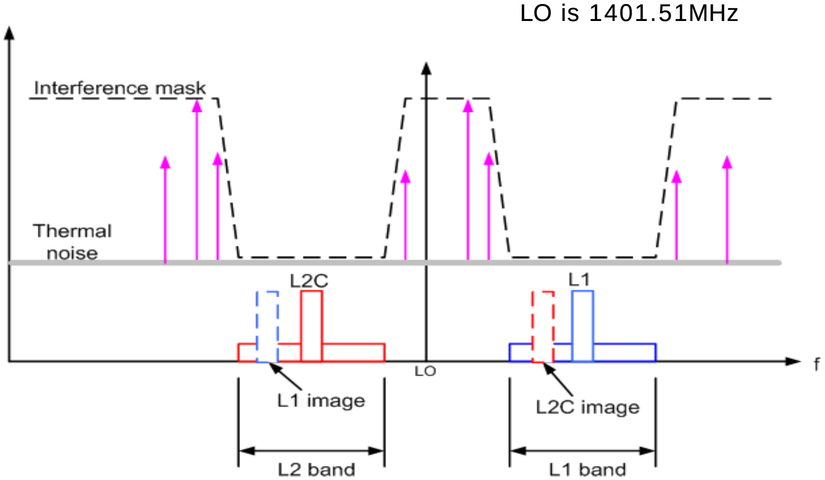
A Low-Power L1/L2C RF FE Architecture



LO is 1401.51MHz

LO is shifted to 1405.5MHz





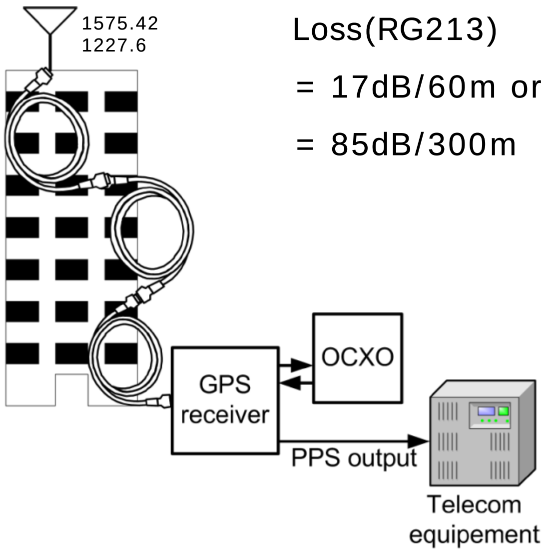
Proposed low power solution:

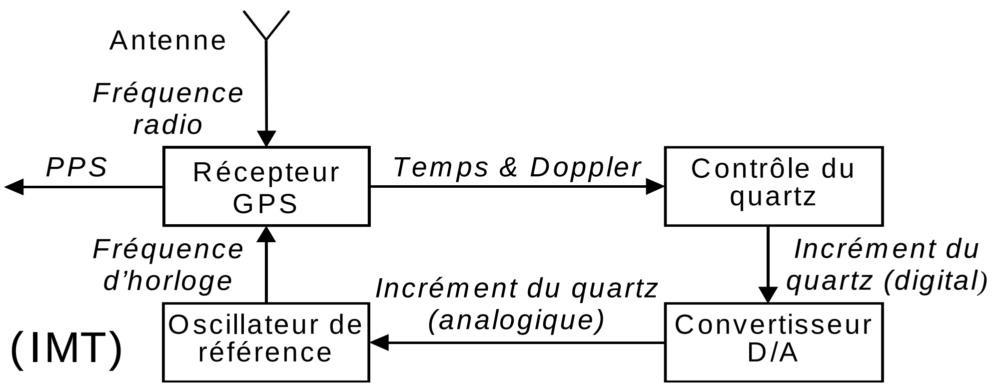
- Shifted LO solution (without quadrature mixer)
- Selection using a Weaver architecture
- Power consumption ~ L1 heterodyne FE

[Cha05] "A Low Power RF Front-End Architecture for an L1/L2CS GPS Receiver," *ION GNSS 2005*

GPS L1/L2 – CTI Project (1/2)

- GPS L1C/A L2C receiver platform for time transfer applications (2004-2007)
  - GPS Disciplined oscillator (GPSDO)
  - Ionospheric delay
  - Accuracy & stability goals:
    - Max PPS error <25ns (over 24 hours w.r.t. UTC)
    - Mean MTIE < 40ns (for interval over 1 week)
    - Holdover error < 7us (after 24 hours, -20°C-70°C)
- Challenges:
  - Small profile double oven OCXO (OSA)
  - RF signal transport (IMT)
  - GPS L1C/A & L2C receiver design (IMT)
  - Ionospheric error corections (IMT)





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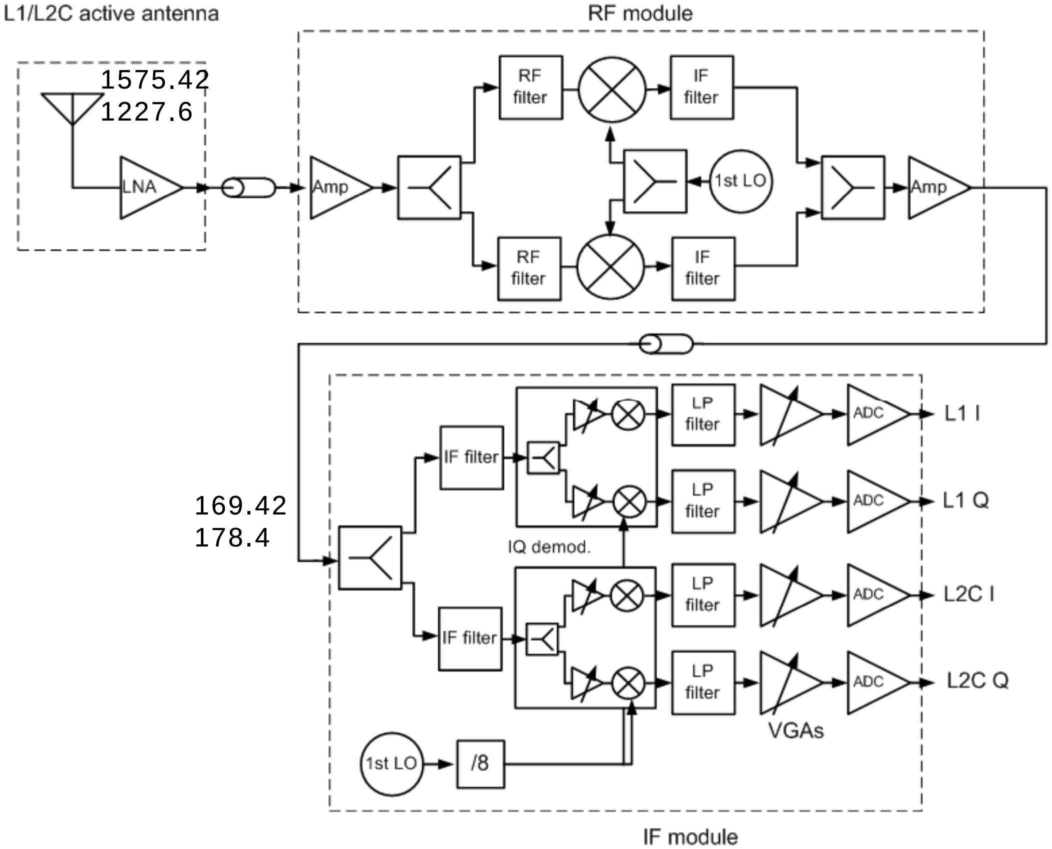
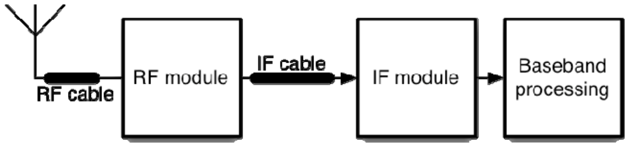
GPS L1/L2 – CTI Project (2/2)

- Dual frequency front-end development



- GPS L1C/A L2C receiver development



[Cha05] "Dual-frequ. RF FE for Long Antenna-GPS Receiver Links," *ION GNSS 2005*

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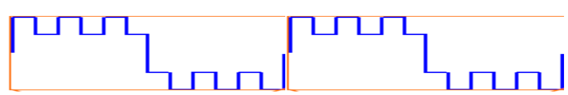
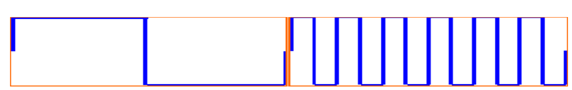
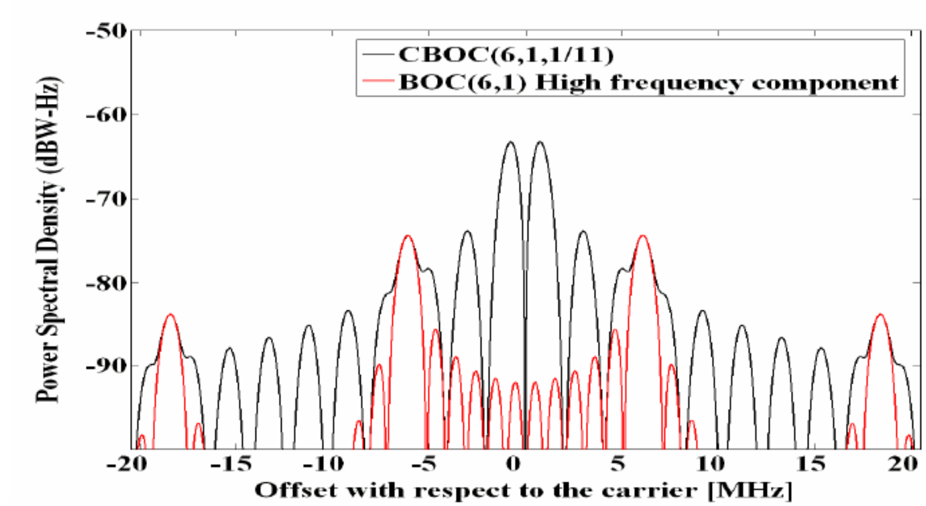
Gamma-A: Galileo Receiver for Mass Market Applications in the Automotive Area

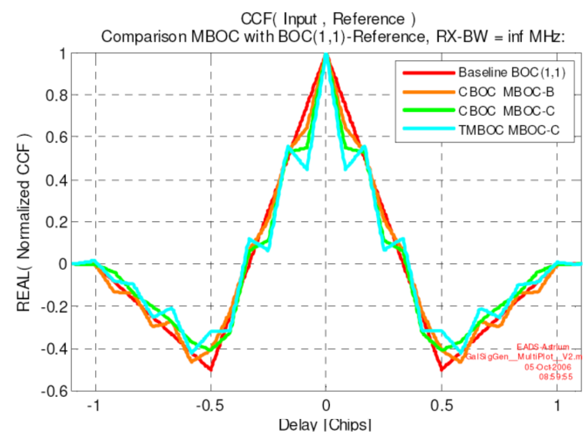
- GAMMA-A's goals:
  - 3-frequency receiver concept for automotive applications
    - L1 GPS/EGNOS/ GALILEO
    - E5a/L5 GPS/GALILEO
    - E5b GALILEO signals
  - Innovation
    - 12 core technologies studied
- EPFL's contribution:
  - Analyze possible tracking algorithms for processing
    - CBOC on Galileo E1 OS



    - TMBOC on GPS L1C OS

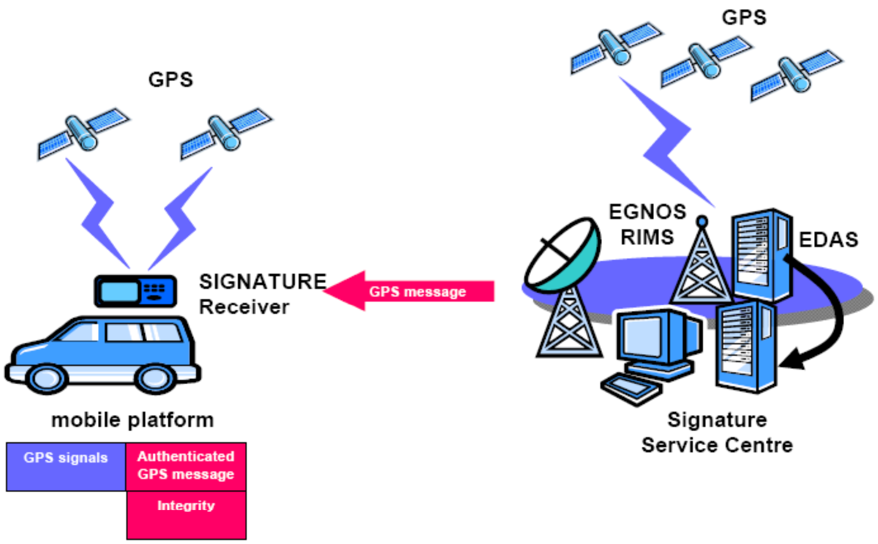






[Jov09] "Analysis of Tracking Schemes for CBOC Signals and Their Performances," ENC-GNSS 2009

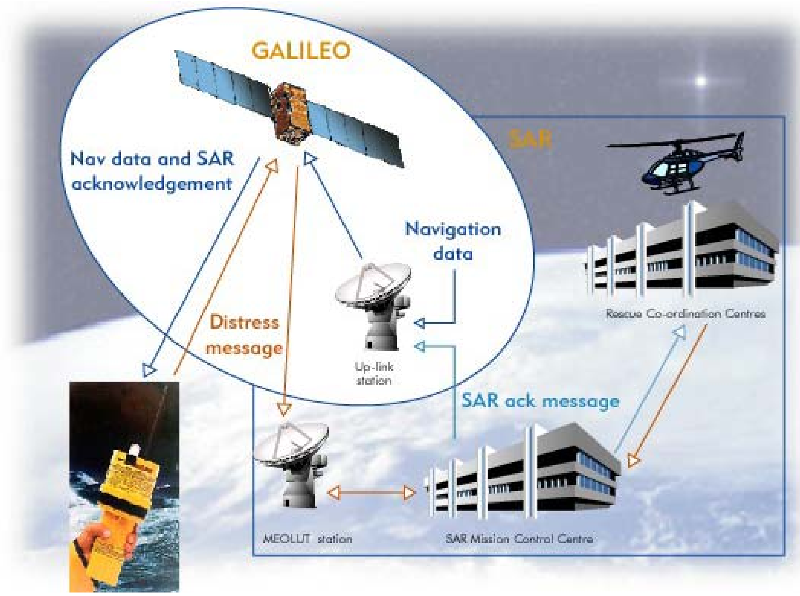
Signature: SImple GNSS Assisted & TrUsted Receiver



- Signature's goals:
  - Prototype a GNSS based solution for flexible road user charging providing high integrity in a cost-effective and scalable manner.
- EPFL's contribution:
  - Development of high-sensitivity assisted receiver prototype

Sarbacan: SAR BeAcon development with CANada

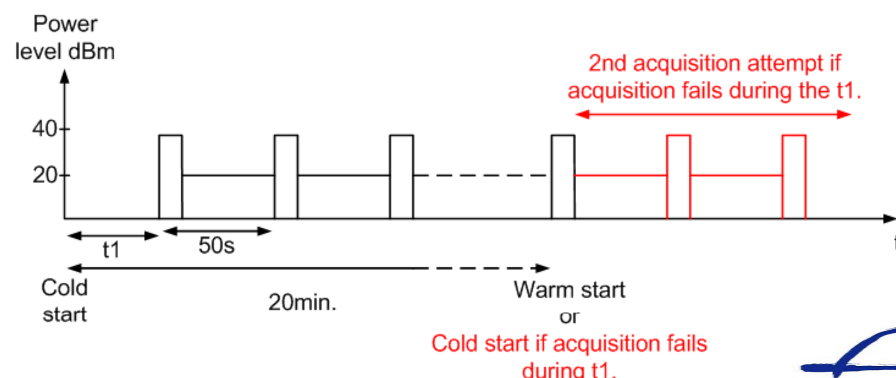
- Sarbacan's goals
  - Development and validation of 3 types of 406MHz SAR beacons prototypes
  - Including SAR RLM processing and new MQPSK generation
- EPFL's Contribution
  - GNSS receiver optimizations
  - Leading GNSS preliminary designs
  - Specific software GNSS rx solution




Aviation beacon

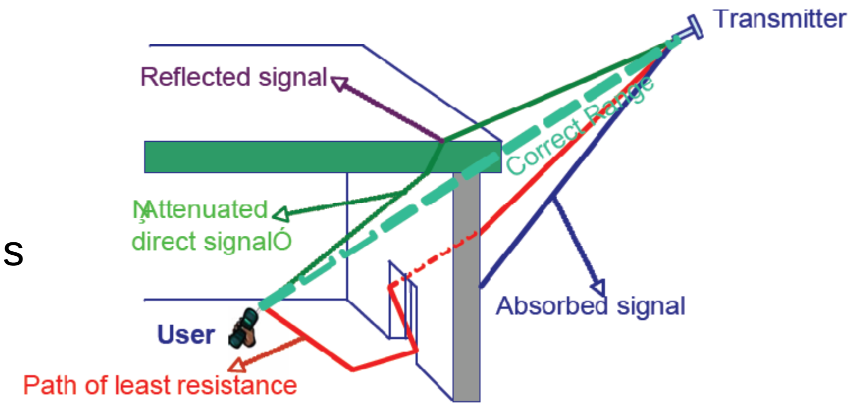

Maritime beacon

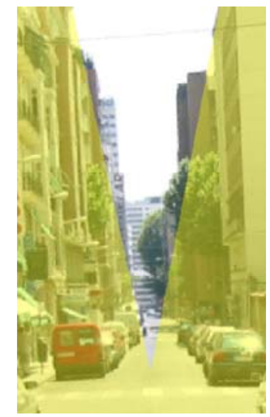

Personal beacon

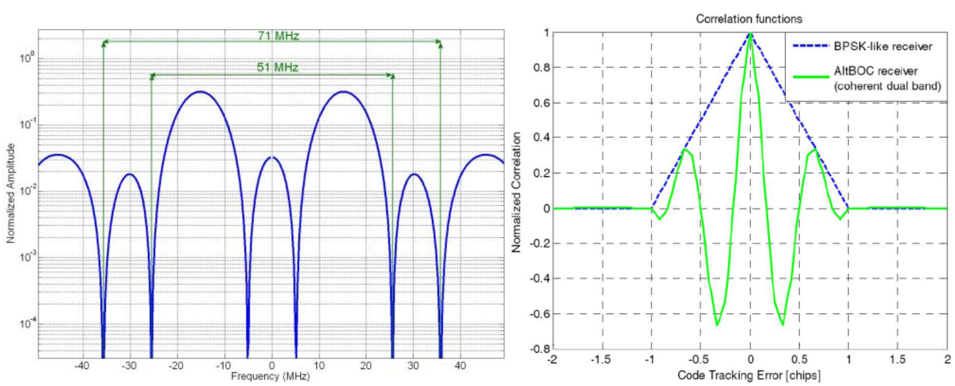


SNSF GNSS - Advanced Algorithmic and Architecture Designs for Future Satellite Navigation Receivers

- Focus on algorithms for:
  - High sensitivity
  - Multipath mitigation
  - => Taking profit of new GNSS signals' structures and properties







E5 AltBOC(15,10) spectrum and correlation peak

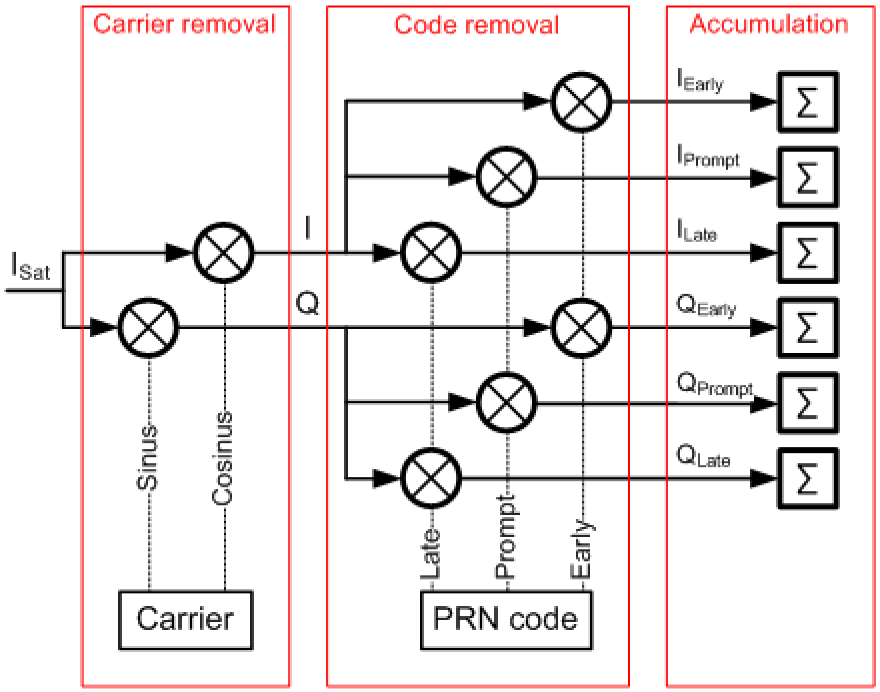
Channel	Code Rate [Mchip/s]	Subcarrier Freq.[MHz]	Symbol Rate [symbols/s]	Service
E5a-I	10.23	15.345	50	F/NAV
E5a-Q	10.23	15.345	No data	Pilot
E5b-I	10.23	15.345	250	I/NAV
E5b-Q	10.23	15.345	No data	Pilot

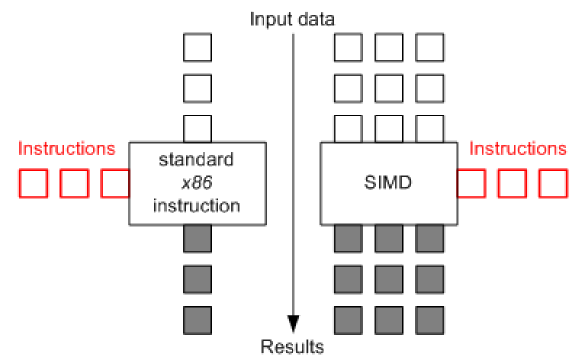
Channel	Code length [chips]		Code length [ms]
	Primary	Secondary	
E5a-I	10230	20	20
E5a-Q	10230	100	100
E5b-I	10230	4	4
E5b-Q	10230	100	100

[Taw09] "Full Design Approach for Non Real Time Galileo E5 Receiver," *ENC-GNSS 2009*
[Par09] "Design of a GPS and Galileo Multi-Frequency Front-End," *VTC 2009*

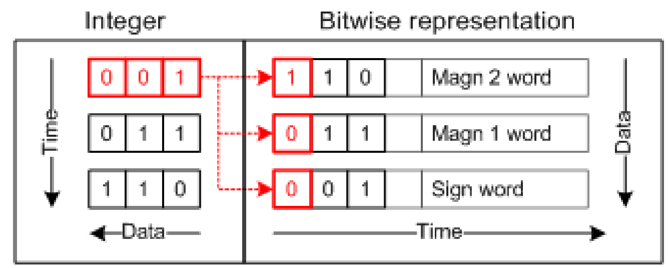
Swiss National Science Foundation

Soft RX - Development of a GPS L1 software receiver





Single Instruction Multiple Data (SIMD)
+ data bit-depth independent
- platform dependent



Bitwise Processing (or vector processing)
+high // and speed
- conversion into int

- 12 channel receiver with Fs = 4 MHz requires $3 \cdot 10^8$ additions and $4 \cdot 10^8$ multiplications per second
  => Solution: distributed arithmetic architecture

[Wae09] "Perfo of new correlation algorithm for platform-independent GPS soft rx," ITM 2009
[Fre09] "Real-Time GNSS software receiver: Challenges, Status, and Perspectives," *ENC-GNSS 2009*

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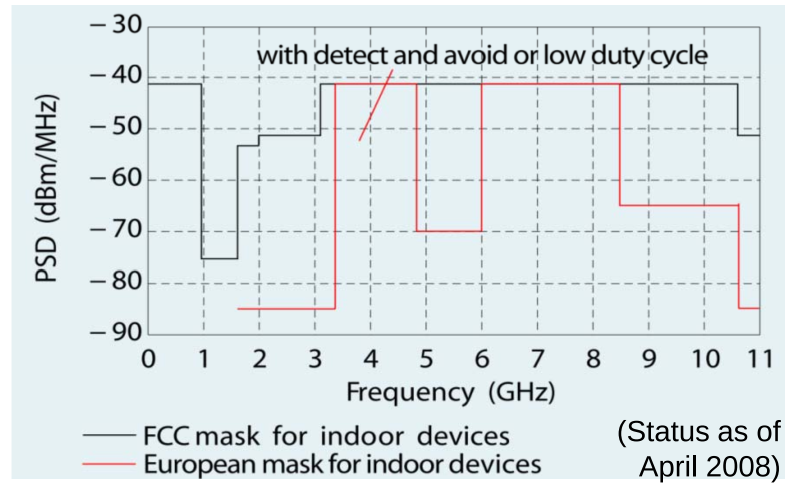
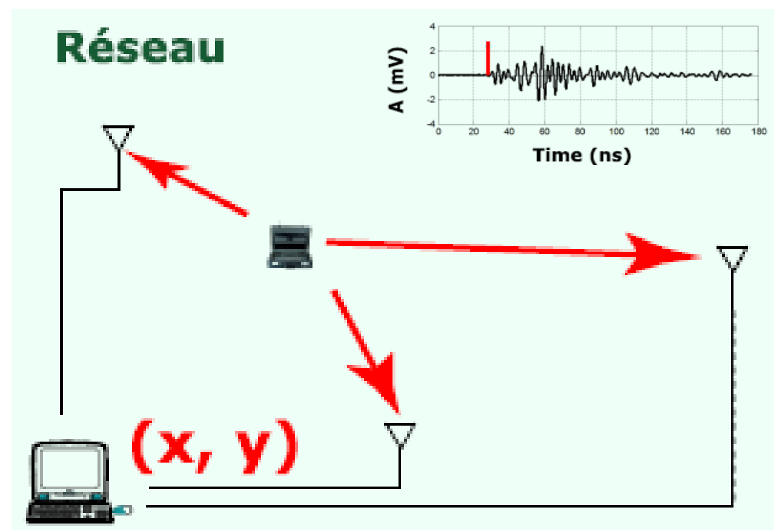
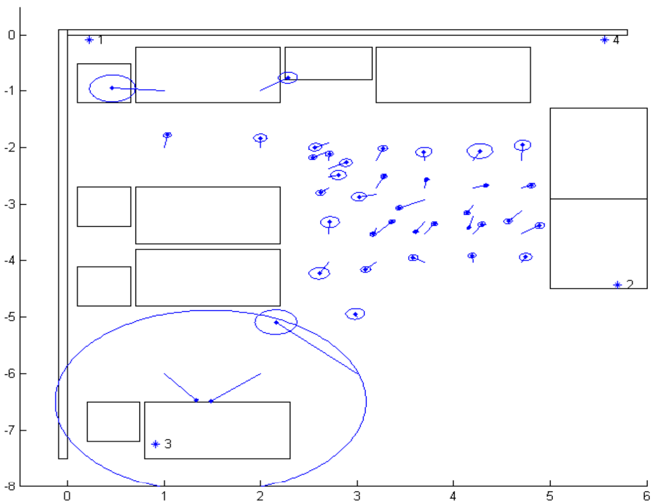
From GNSS rx developments to UWB developments

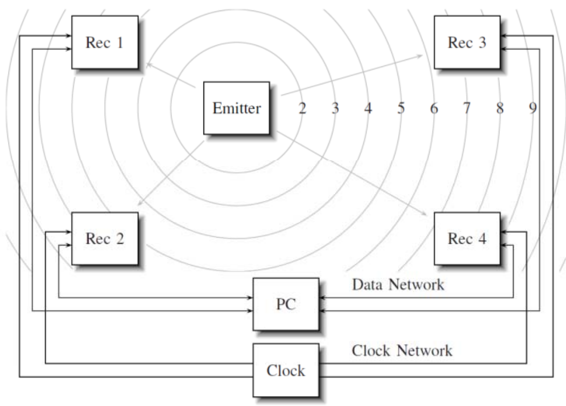
- UWB for high data rates short range communications
  - Shannon capacity theorem: $C \sim B \cdot \log_2[1+P / (B \cdot N_o)]$
  - E.g., for wireless USB, or for other high data rates cables replacement
- UWB for low data rates low power communications
  - E.g., for sensors networks, for Wireless Personal Area Networks (WPAN)
- UWB for locating devices (tags, nodes, etc)
  - E.g., for manufacturing, geo-fencing, etc.

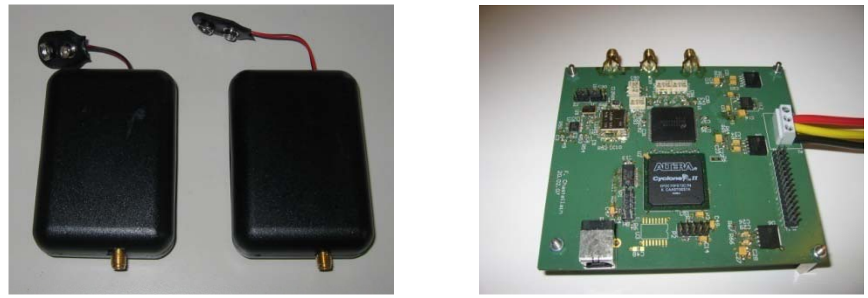




PX PosLoc: UWB-based *Local Positioning System for Locating Tag Transmitters*



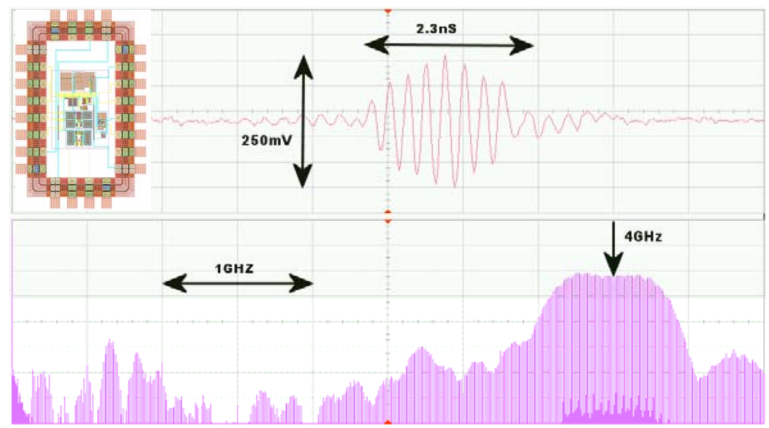




Prototype COTS-based tx and rx

Measured precision:

67% (1 measure)
=> 0 ± 30.5 cm (phys)
=> 17.6 ± 20.7 cm (median)
67% (16 measures)
=> 0 ± 19.7 cm (phys)
=> 17.6 ± 5.5 cm (median)



TX ASIC measurements (CMOS 180nm)

[Mer09] "Programmable Rx for Communication Systems and its Application to Impulse Radio," *Hindawi Research Letters in Communications*
[Mer08] "Experimental Platform for an Indoor Location and Tracking System," *ENC-GNSS 08*

PXGROUP

Dr. Cyril Botteron
GNSS & UWB Team Leader

EPFL–STI–IMT-ESPLAB
Rue A.-L. Breguet 2
CH-2000 Neuchâtel

Email: cyril.botteron@epfl.ch
Tel: +41 32 718 3424