Spread Spectrum Channel Sounder Implementation with USRP Platforms

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SUPELEC

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SUPELEC - Campus de Rennes
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Presentation outline

- Past experience on channel sounding
- Student project on channel sounding
- USRP 1 experiments
- N210 experiments
- Conclusion

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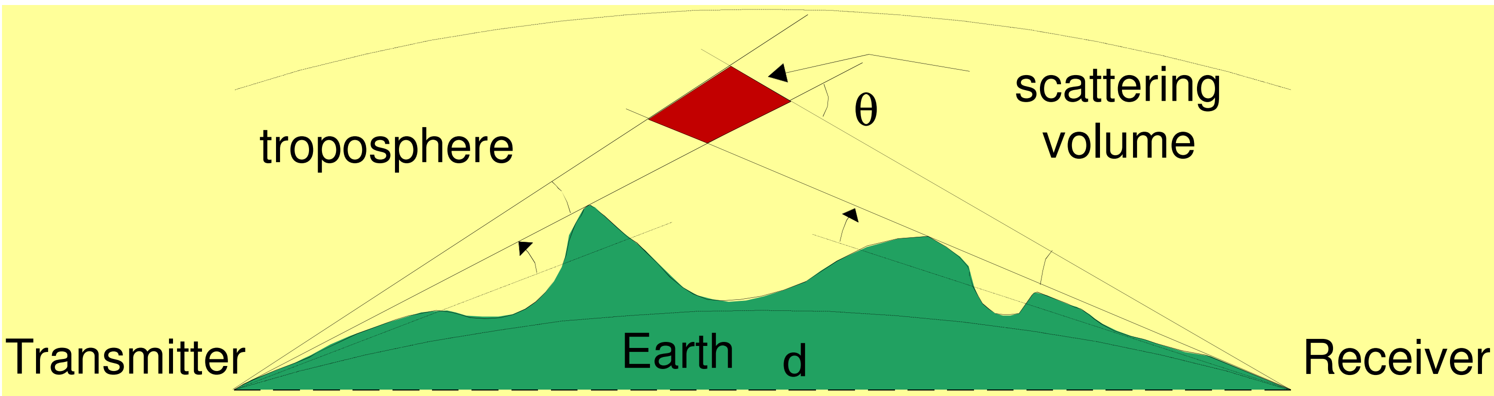
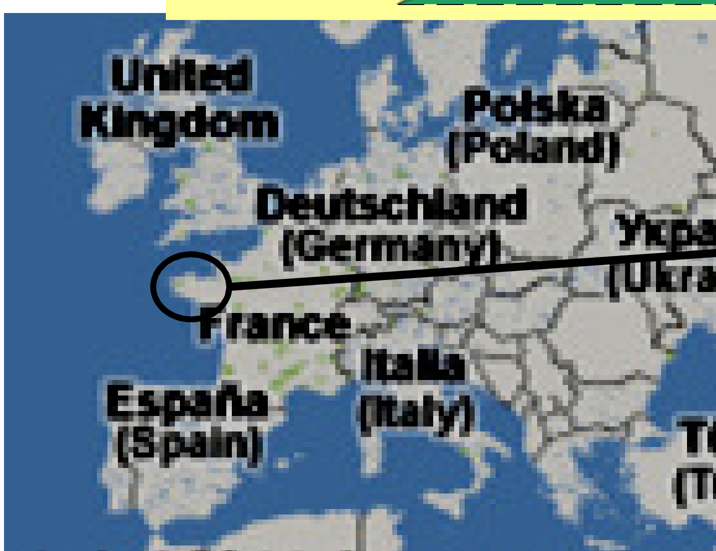
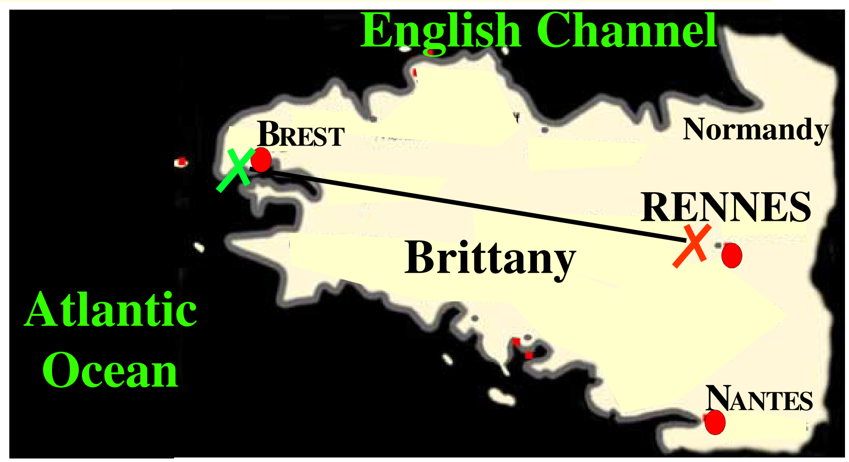
15 years ago

- **Implement a troposcatter channel sounder on a 200 km link @ 4.47 GHz**

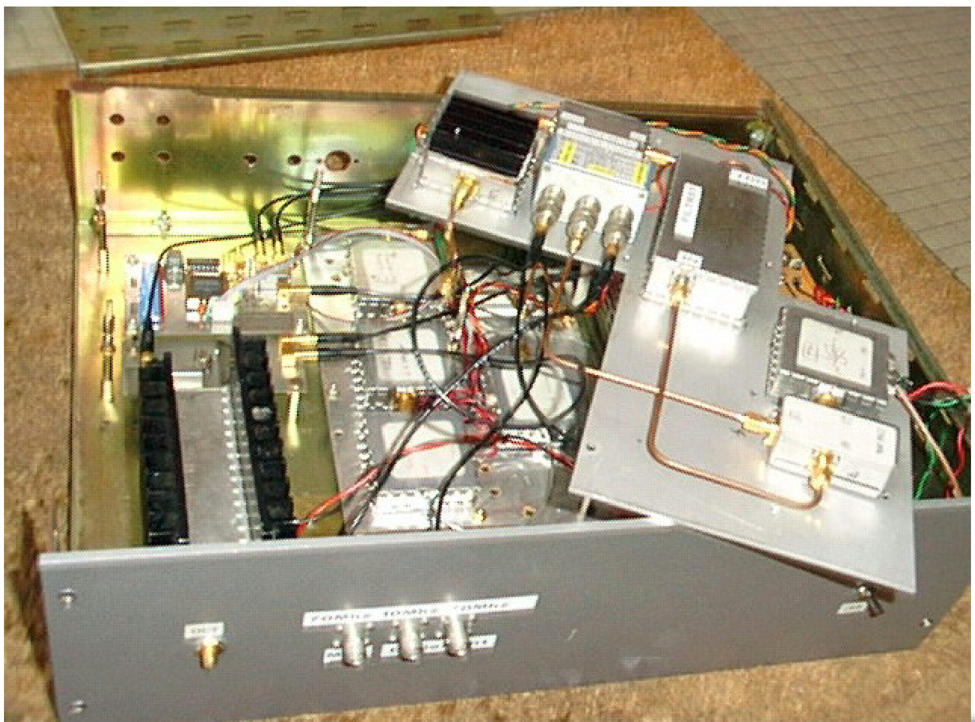


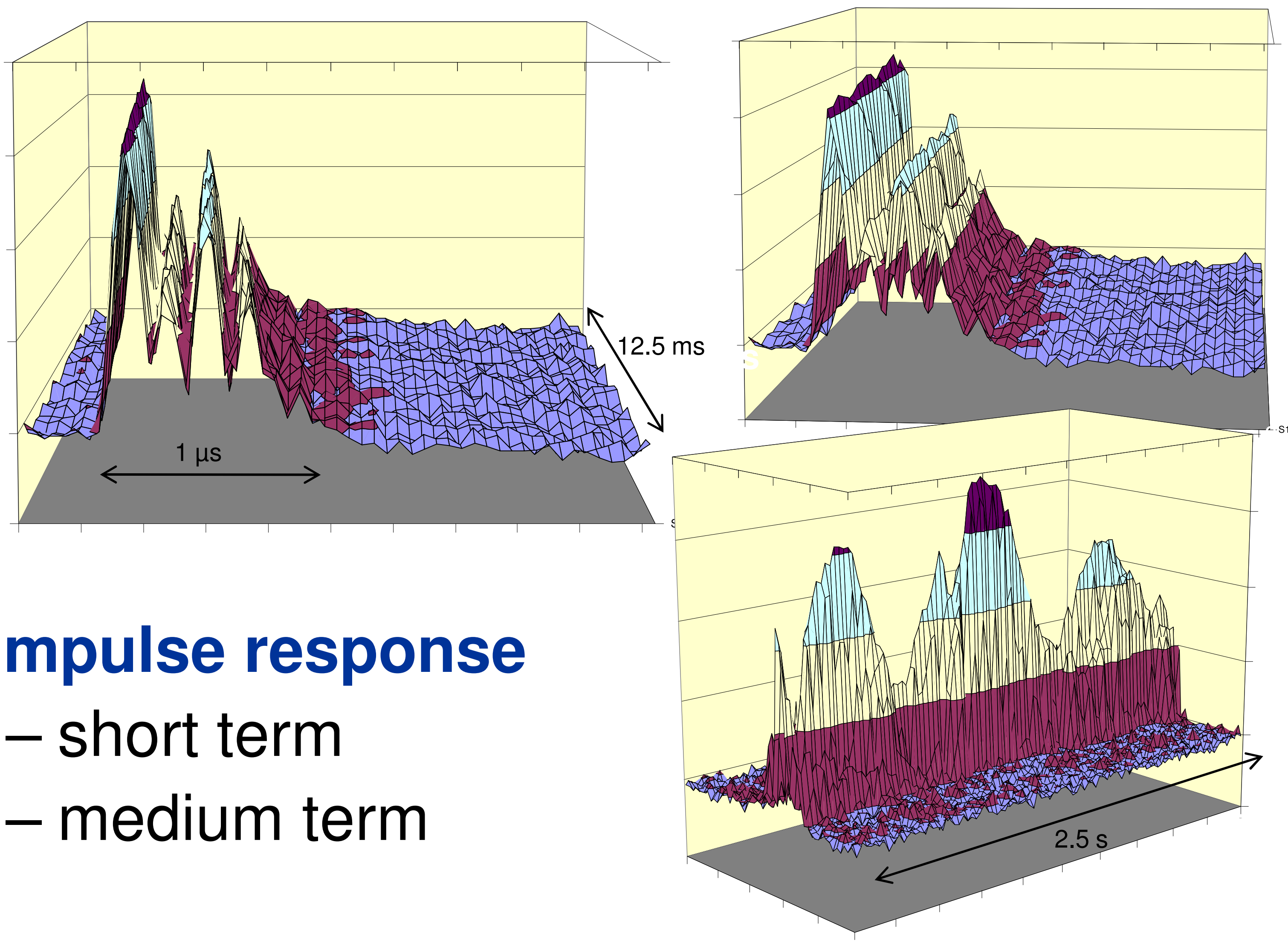




A lot of HW development

- RF
- frequency translation
- digital baseband

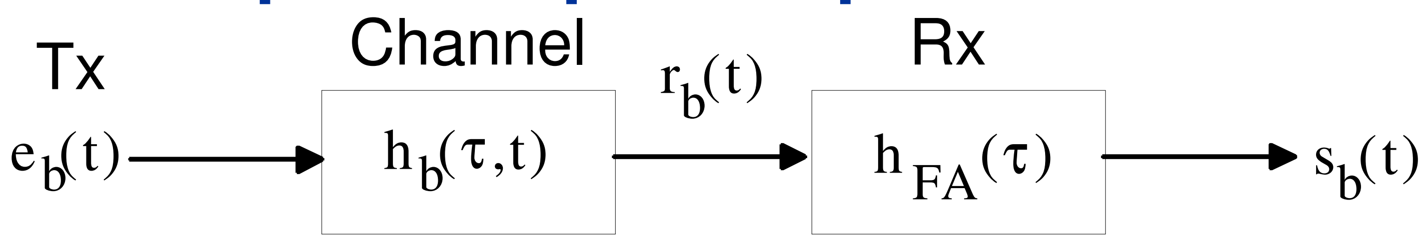




- **Impulse response**
  - short term
  - medium term

Theoretical background (I)

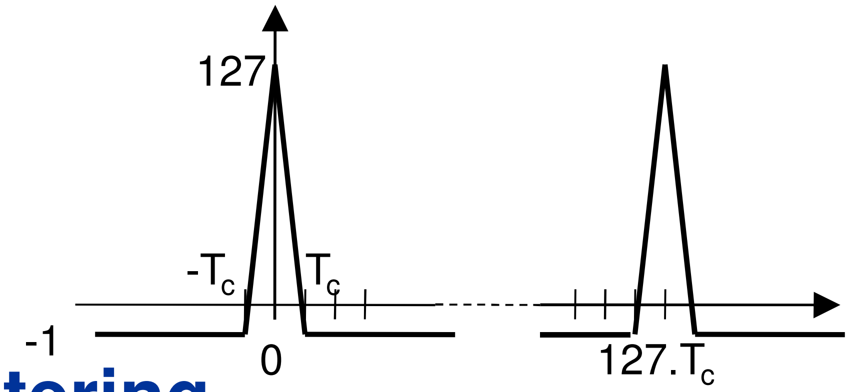
- **Direct Sequence Spread Spectrum sounder**



  – a m-sequence code is transmitted: $e_b(t) = c(t)$
  – matched filter at reception: $h_{FA}(t) = c(\xi\text{-}t)$
    - $\xi = L_c.T_c$
    - L_c is the number of chips of a code sequence
    - T_c is the chip length
  – $r_b(t) = (c \otimes h_b)(t)$
  – $s_b(t)=(c\otimes h_b\otimes h_{FA})(t)=(c\otimes h_{FA}\otimes h_b)(t)=(R_c\otimes h_b)(t)$
  – where R_c is the code autocorrelation fonction

Theoretical background (II)

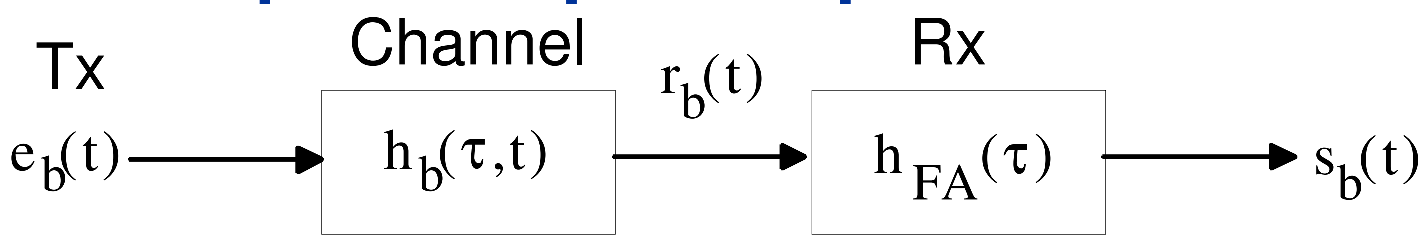
- **Autocorrelation of m-sequence pseudo-random codes**
  - example of a 127 chips long code sequence



- **Method: matched filtering**
- **Consequence for sounding**
  - the larger the signal bandwidth
  - the shorter the chip duration

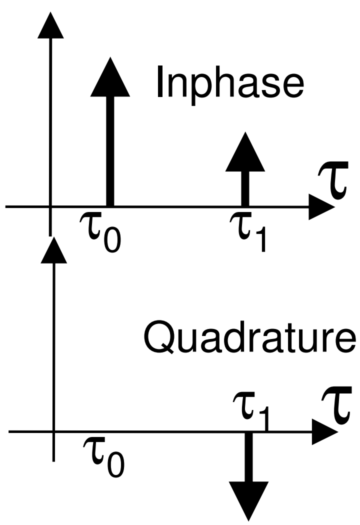
  ➔ the closer to the "real" impulse response
    - thiner peaks
    - lower secondary lobes

• Direct Sequence Spread Spectrum sounder

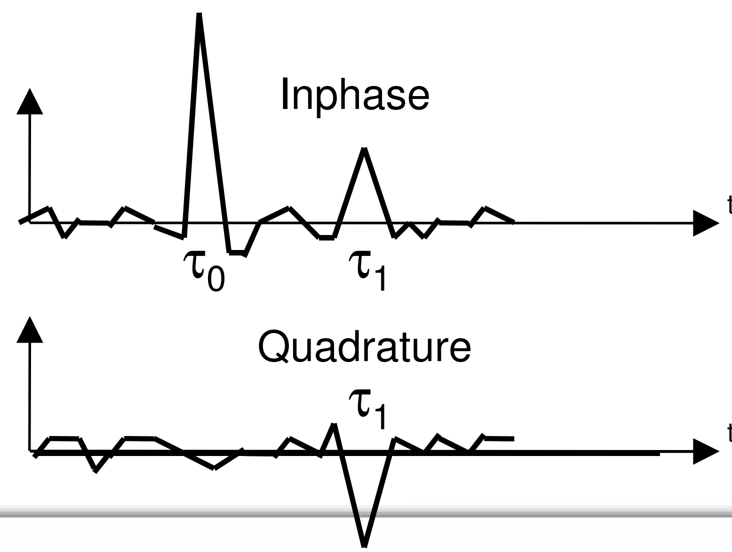


$$- s_b(t) = \sum_{k=0}^{K-1} \alpha_k(t) \cdot e^{-j\cdot\theta_k(t)} \cdot R_c(t-\xi-\tau_k) \cdot d\tau$$

Theoretical "perfect" impulse response (infinite bandwidth)



Obtained band-limited noisy impulse response



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- **Student project on channel sounding**
- USRP 1 experiments
- N210 experiments
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Student project goals

- How to make it now, thanks to SDR facilities?
- Even with undergraduate students
- Only 8 time slots of 4 hours (plus free time) year 1, and the same year 2
- Make students touch implementation difficulties
- Not only a (long and fastidious) theoretical approach as usual when making first steps in radio
- But directly in the reality so that it motivates to study theoretical explanations then

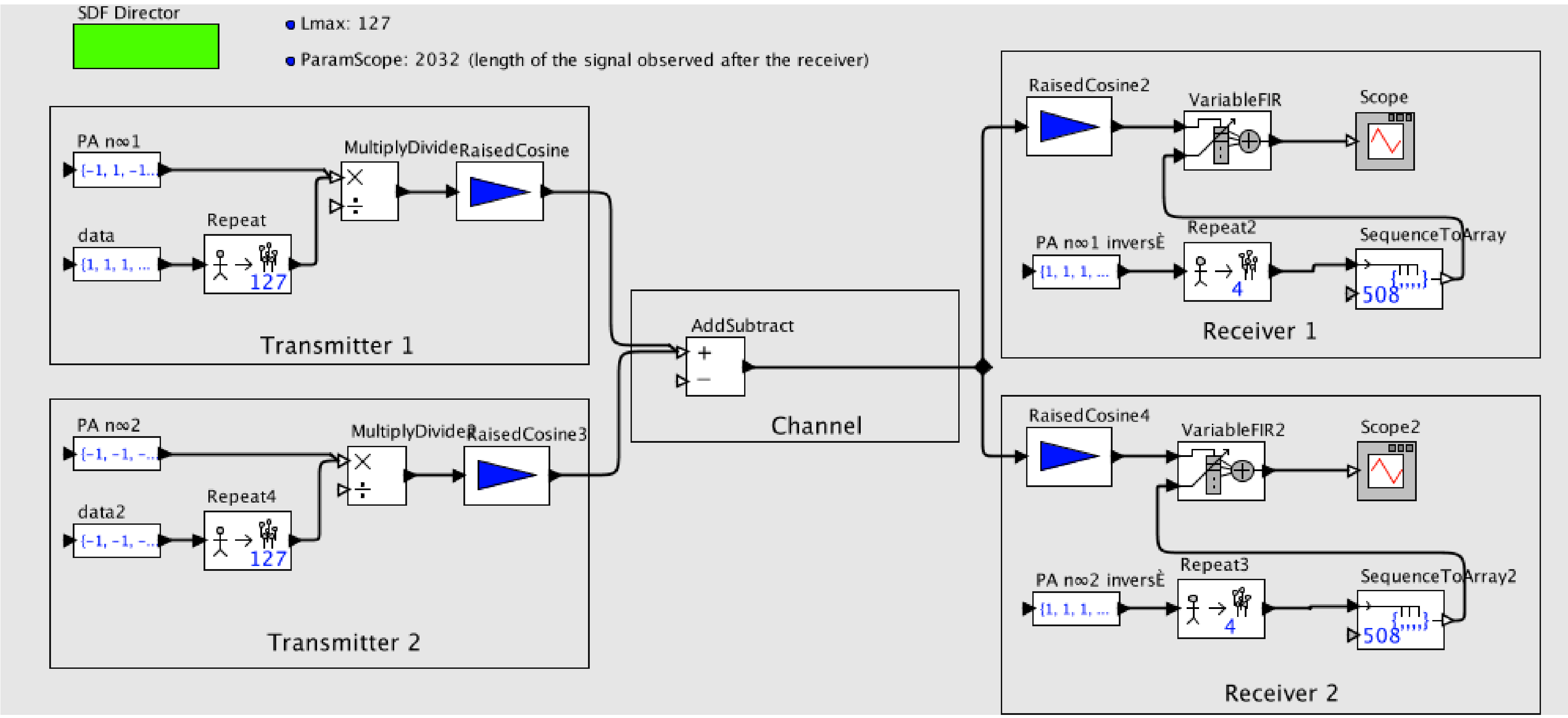
Simulations

- **First step: understand (year 1)**
- **Design Environment**
  - Ptolemy II
  - Ptolemy project of Berkeley
  - Edward LEE lab
  - multi-domains desing (continuous time, discret time, state machine, SDF, etc.)
  - any application field: automatic, wireless, electronics, etc.

  - http://ptolemy.berkeley.edu/ptolemyII/

Understand spread spectrum and CDMA

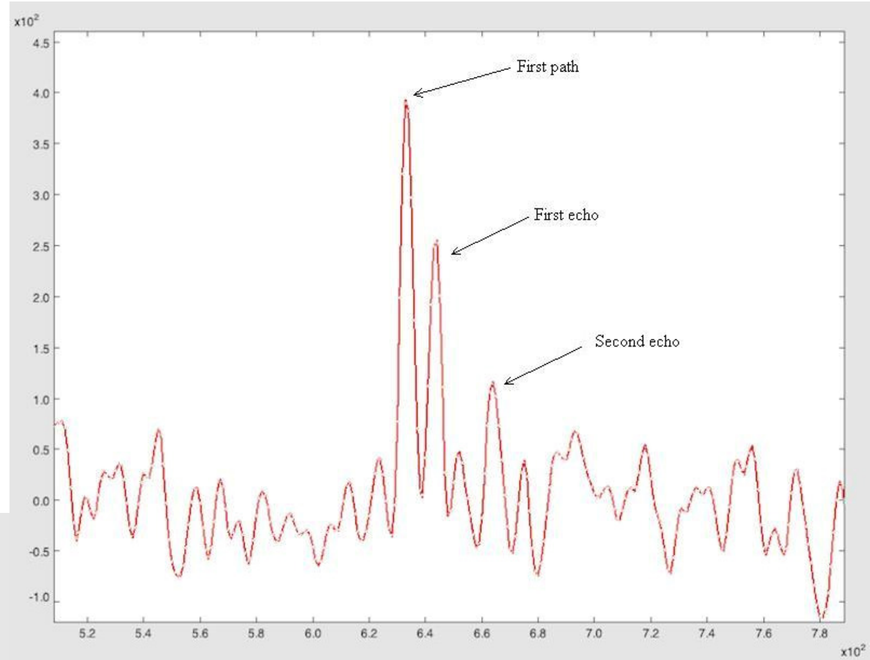
- **Basic CDMA**

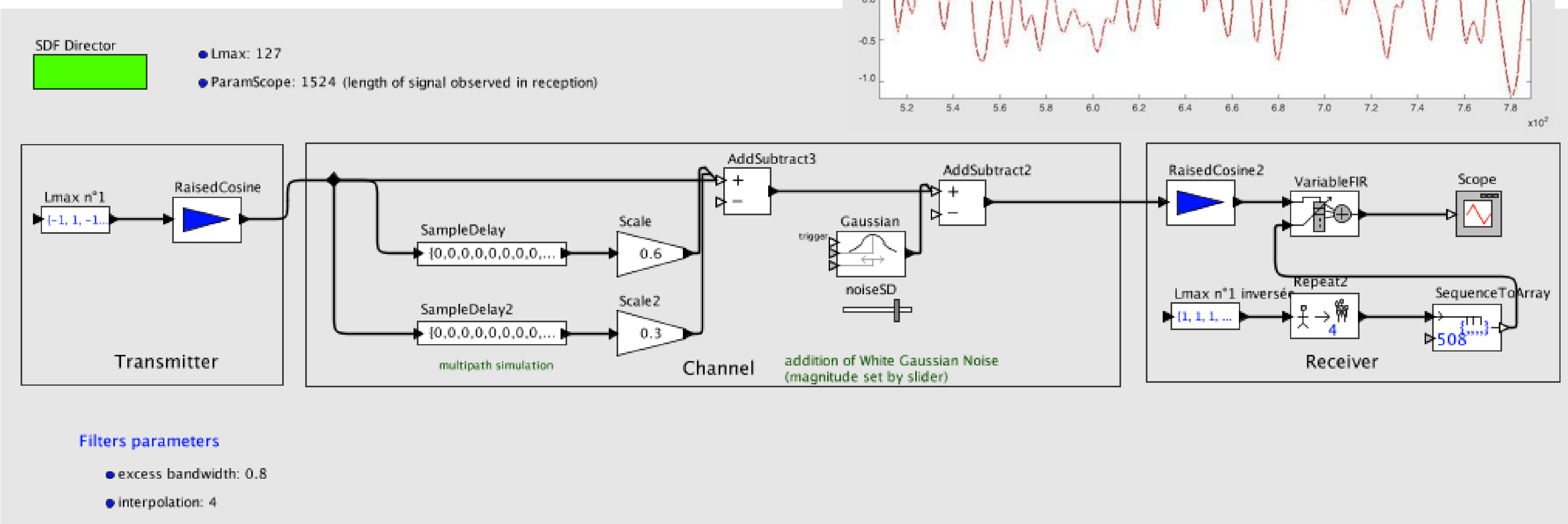


- **Matched filter based at Rx**

Spread spectrum for channel sounding

- **Insert channel effects**
  - AWGN
  - Multipath





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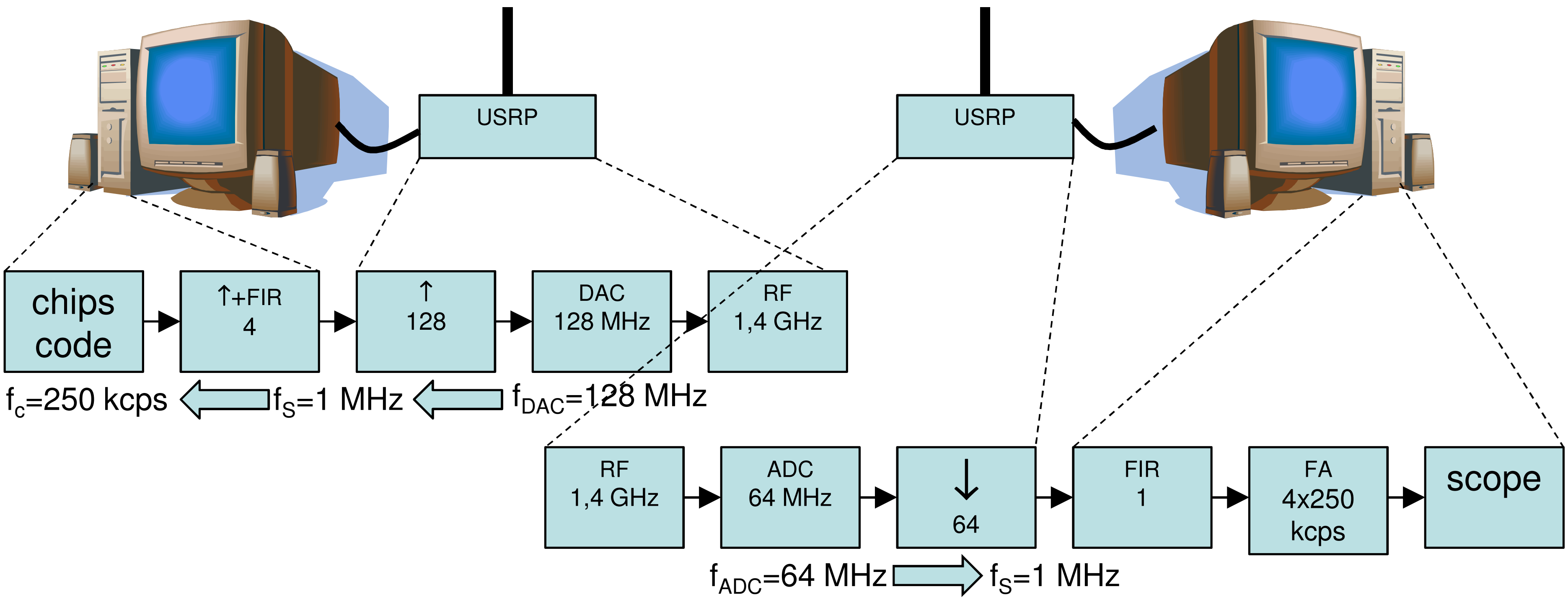
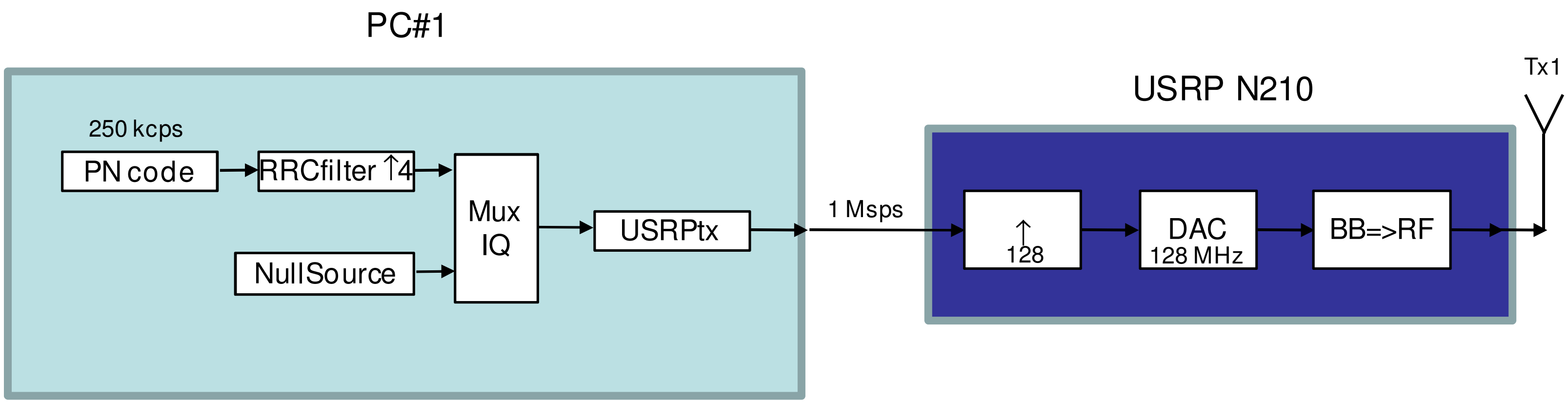
Real channel sounder

- Tx
- Rx

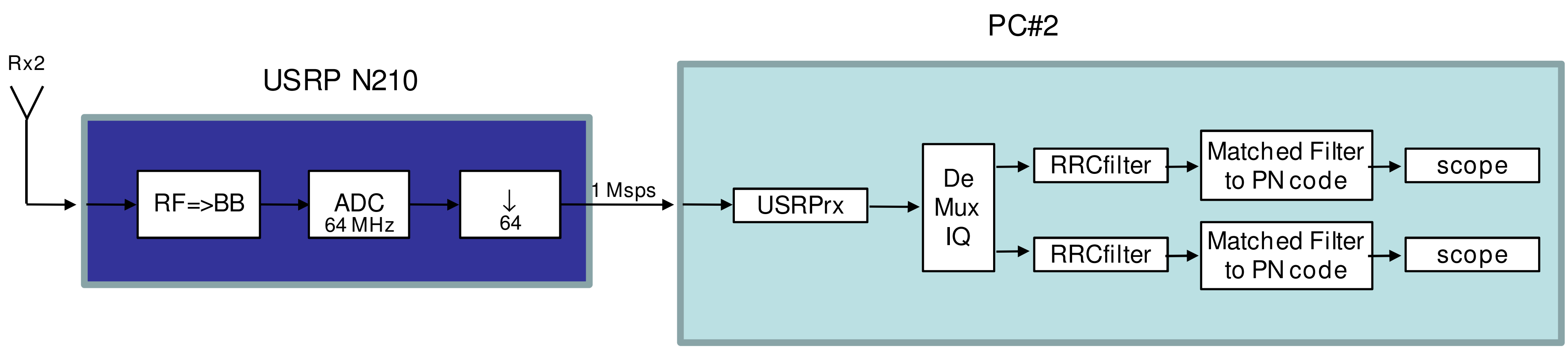


Block diagram

- **Tx radio chain**



- **Rx radio chain**



USRP 1

- **Development Environment**
  – GRC (GNU Radio Companion)
- **USB link** **(max data transfer rate we obtained: 1 Msps)**

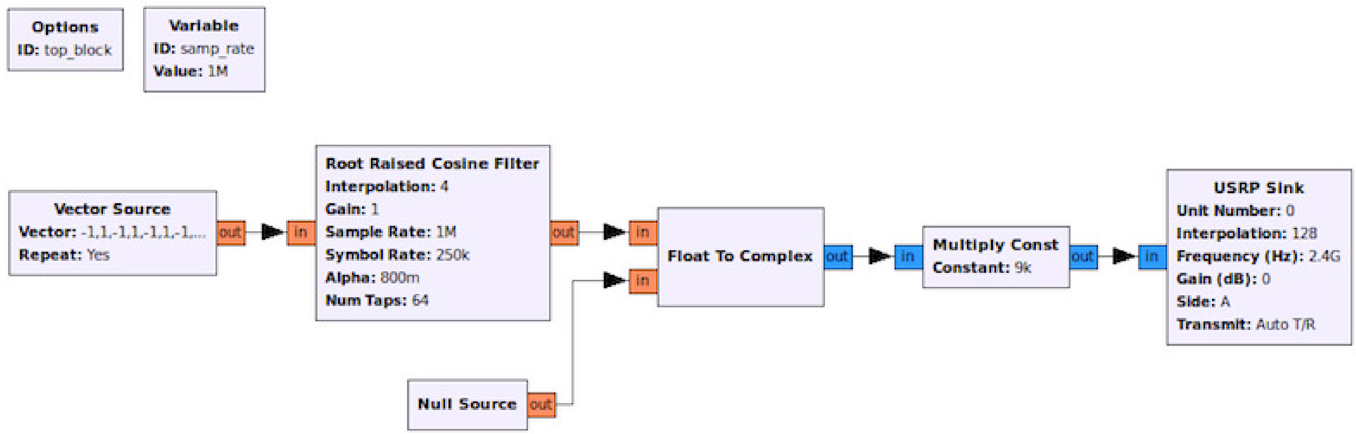
- **With an oversampling of 4 in pulse shaping**

➔ 250 kHz of bandwidth for sounding

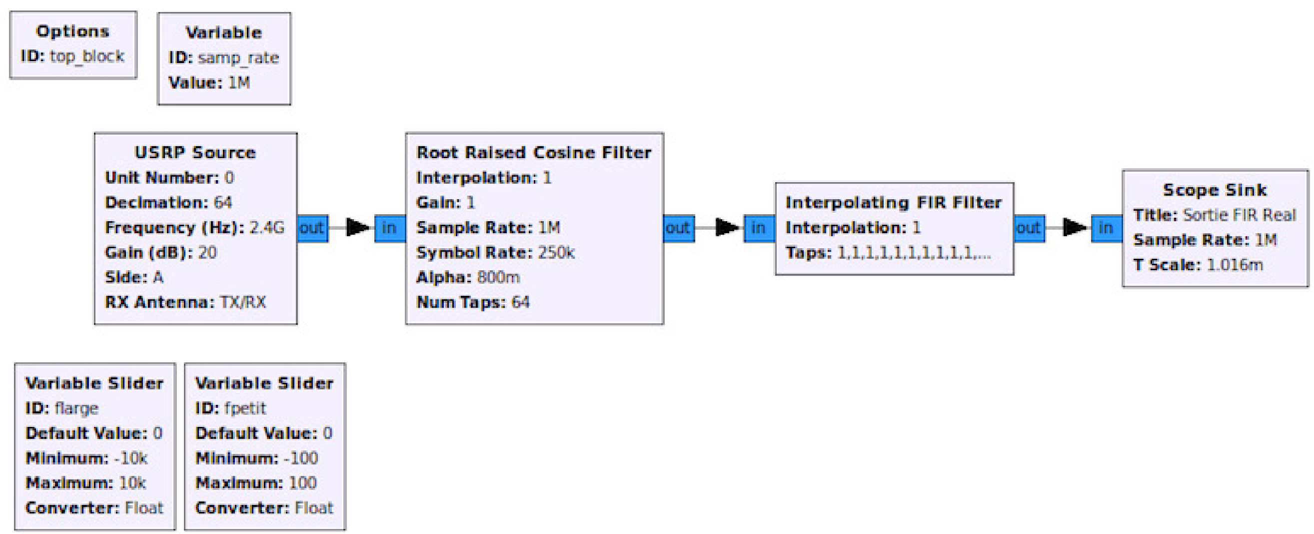
➔ path discrimination of 4 µs

A starting point (enough for getting started in year 2)

- **Tx**


Options
ID: top_block
Variable
ID: samp_rate
Value: 1M
Vector Source
Vector: -1,1,-1,1,-1,1,-1,...
Repeat: Yes
out
in
Root Raised Cosine Filter
Interpolation: 4
Gain: 1
Sample Rate: 1M
Symbol Rate: 250k
Alpha: 800m
Num Taps: 64
out
in
in
Float To Complex
out
in
Multiply Const
Constant: 9k
out
in
USRP Sink
Unit Number: 0
Interpolation: 128
Frequency (Hz): 2.4G
Gain (dB): 0
Side: A
Transmit: Auto T/R
Null Source
out

- **Rx**


Options
ID: top_block
Variable
ID: samp_rate
Value: 1M
USRP Source
Unit Number: 0
Decimation: 64
Frequency (Hz): 2.4G
Gain (dB): 20
Side: A
RX Antenna: TX/RX
out
in
Root Raised Cosine Filter
Interpolation: 1
Gain: 1
Sample Rate: 1M
Symbol Rate: 250k
Alpha: 800m
Num Taps: 64
out
in
Interpolating FIR Filter
Interpolation: 1
Taps: 1,1,1,1,1,1,1,1,1,1,...
out
in
Scope Sink
Title: Sortie FIR Real
Sample Rate: 1M
T Scale: 1.016m
Variable Slider
ID: flarge
Default Value: 0
Minimum: -10k
Maximum: 10k
Converter: Float
Variable Slider
ID: fpetit
Default Value: 0
Minimum: -100
Maximum: 100
Converter: Float

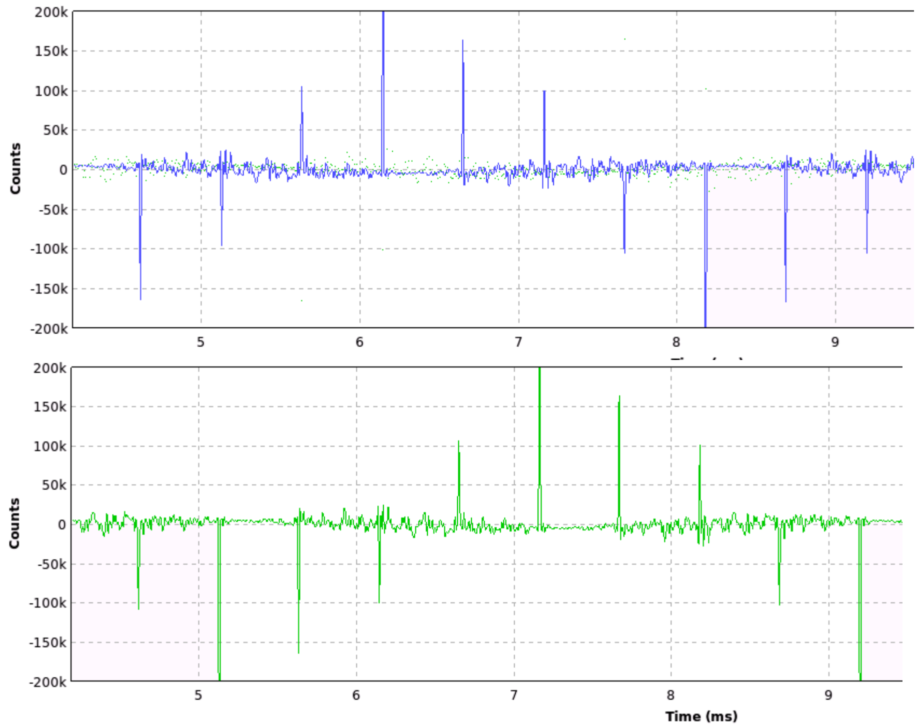
Channel #1 measurements

- W = 250 kHz
- carrier frequency is 2.4 GHz

➔ carrier desynchronization

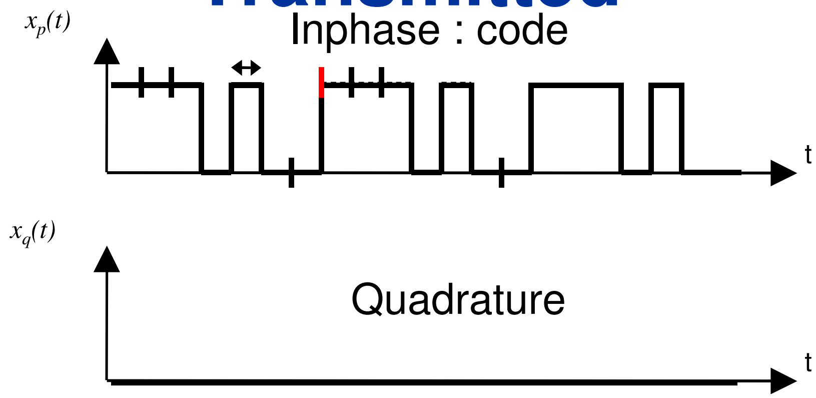
inphase

quadrature

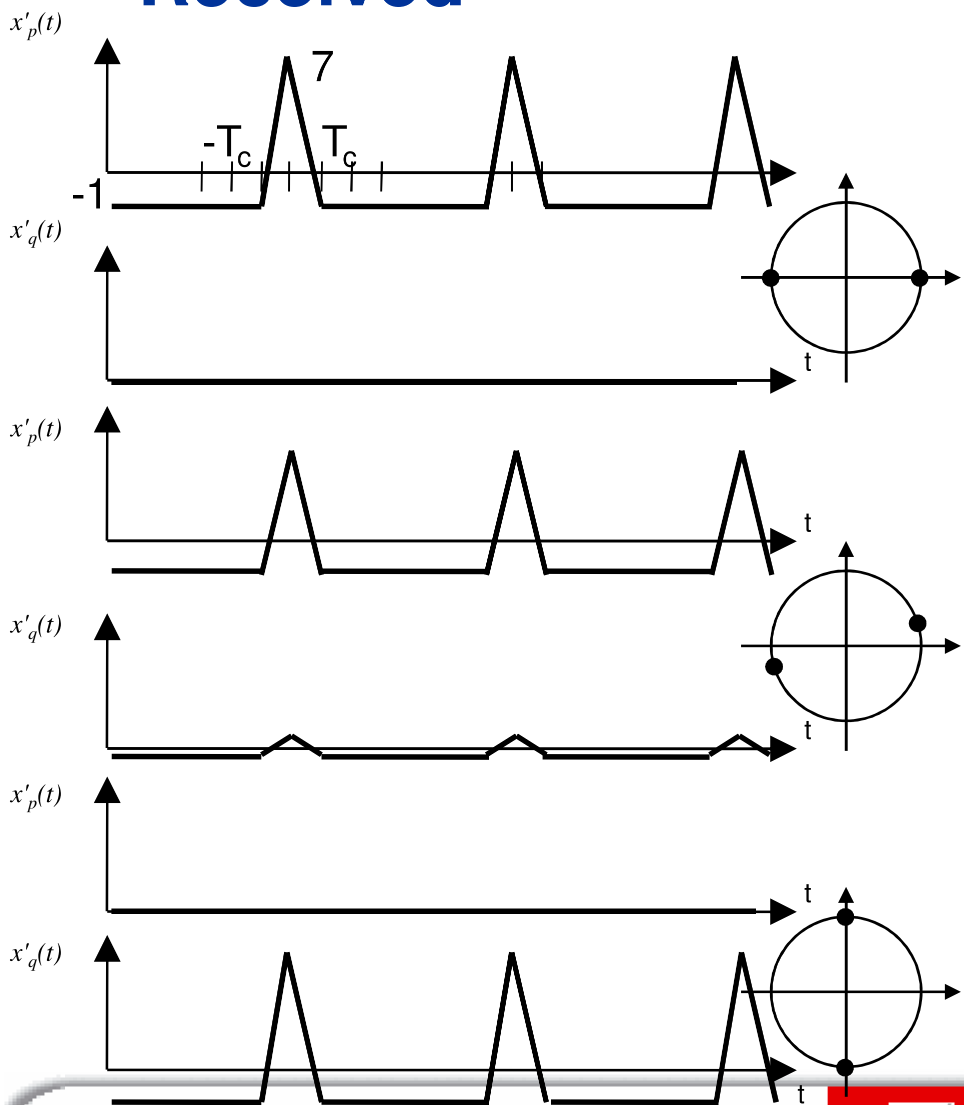


Student expectation

- **Transmitted**



Received



- **versus reality**

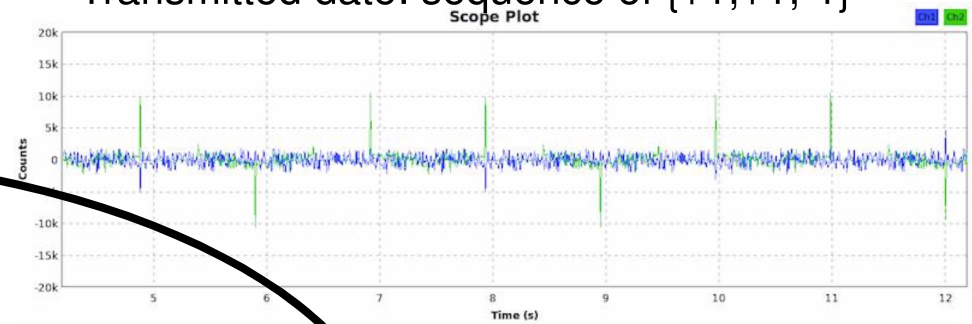
Carrier desynchronization compensation

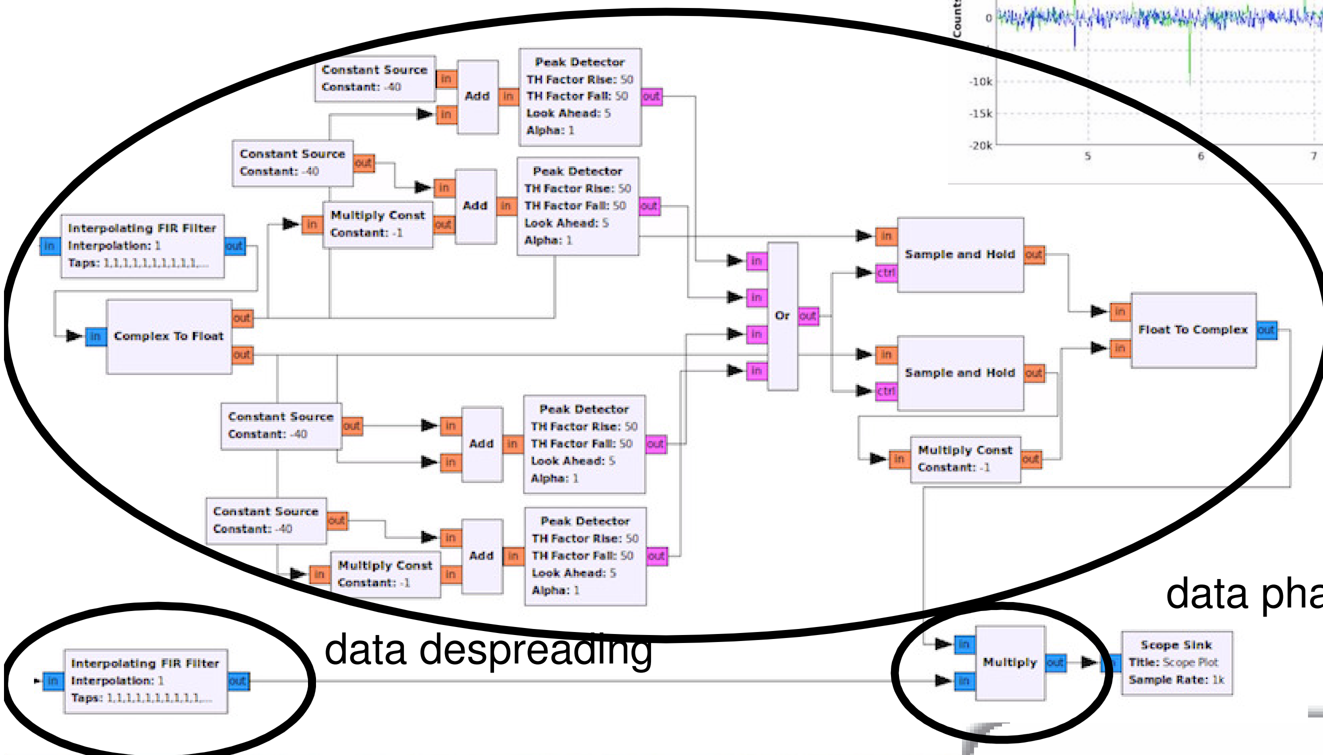
- **In a data transmission perspective: how to compensate carrier desynchronization using a channel sounder?**

- **UMTS FDD uplink approach:**
  - transmit spread data with code #1 on Inphase
  - transmit a sounding code #2 on Quadrature
  - use "sounding phase" to "re-phase data"
- **Done by students by simulation only as carrier desynchronisation was too high for the implementation constraints**

- **Synchronisation proposal for a simulated data transmission**
  – continuous phase correction

Transmitted date: sequence of {+1,+1,-1}





channel sounding (just phase recovery here)

data despreading

data phase correction

If we want to implement it

- **Carrier desynchronization is too high with the current system**
  - USRP1 platform
  - carrier at 2.4 GHz
  - spreading factor of 127

➔ phase is changing too much during one code sequence so that correlation is corrupted

- **Solutions**
  - decrease spreading factor (but loss in processing gain)
  - increase chip rate
  - decrease carrier frequency

→ new platform (USRP N210)

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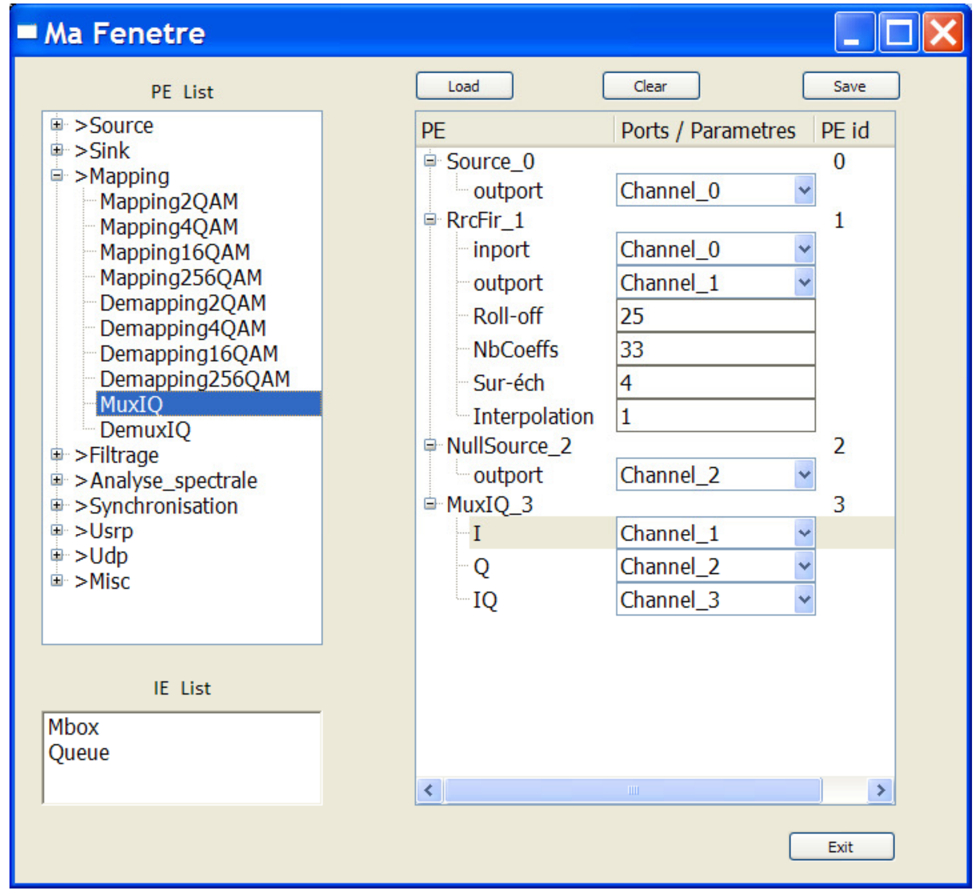
USRP N210

- **Development Environment**
  - SUPELEC proprietary environment (Windows)
- **UHD library**
  - from Ettus Research
- **Supporting HDCRAM**
  - **H**ierarchical and **D**istributed **C**ognitive **R**adio **A**rchitecture **M**anagement [1]
  - HDCRAM is an architecture for the management of reconfiguration and cognitive facilities (metrics capture and decision/learning)
  - for real-time (seemless) auto-adaptation

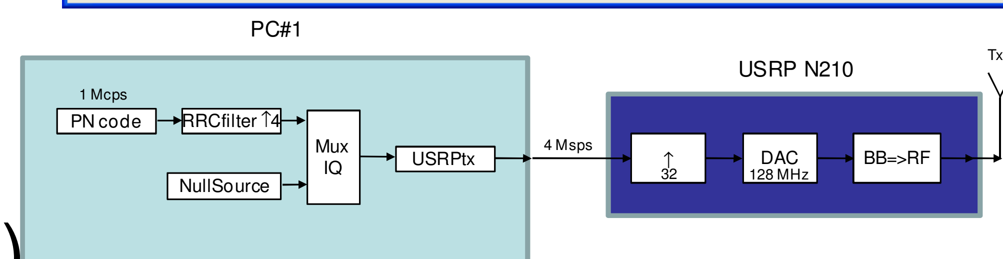
[1] Christophe MOY, "High-Level Design Approach for the Specification of Cognitive Radio Equipments Management APIs", Journal of Network and System Management - Special Issue on Management Functionalities for Cognitive Wireless Networks and Systems, vol. 18, number 1, pp. 64-96, Mar. 2010

USRP configuration

- **GUI (temporary)**
  - not yet graphical capture of the radio chain
  - later: through UML graphs

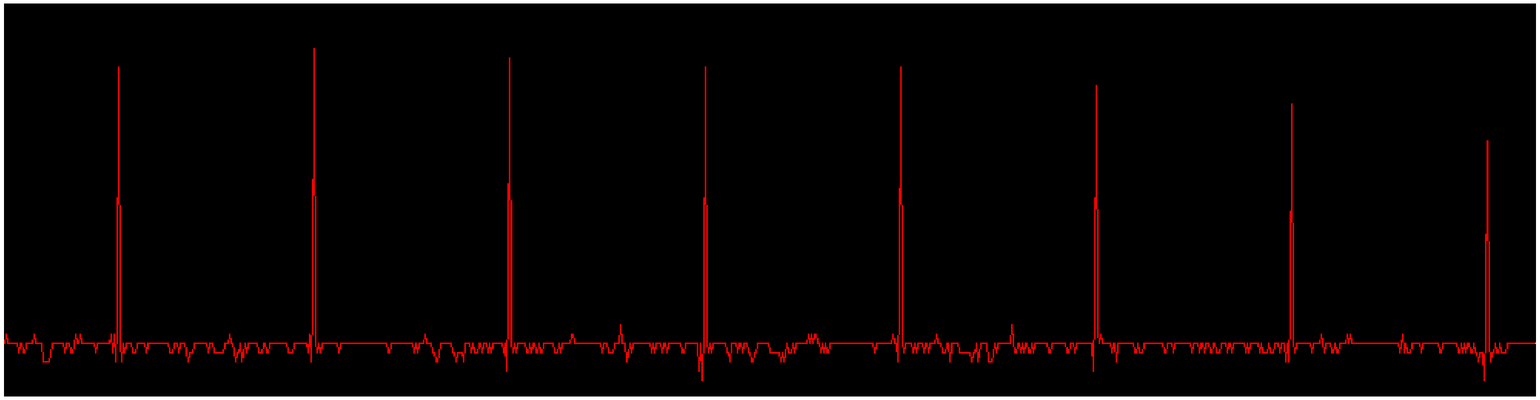


- **Tx radio chain**
  - up to 1 MHz BW
  - more RF flexibility (from 100 MHz to 2 GHz in our case)



Channel #2 measurements

- W = 1 MHz
- 1.4 GHz



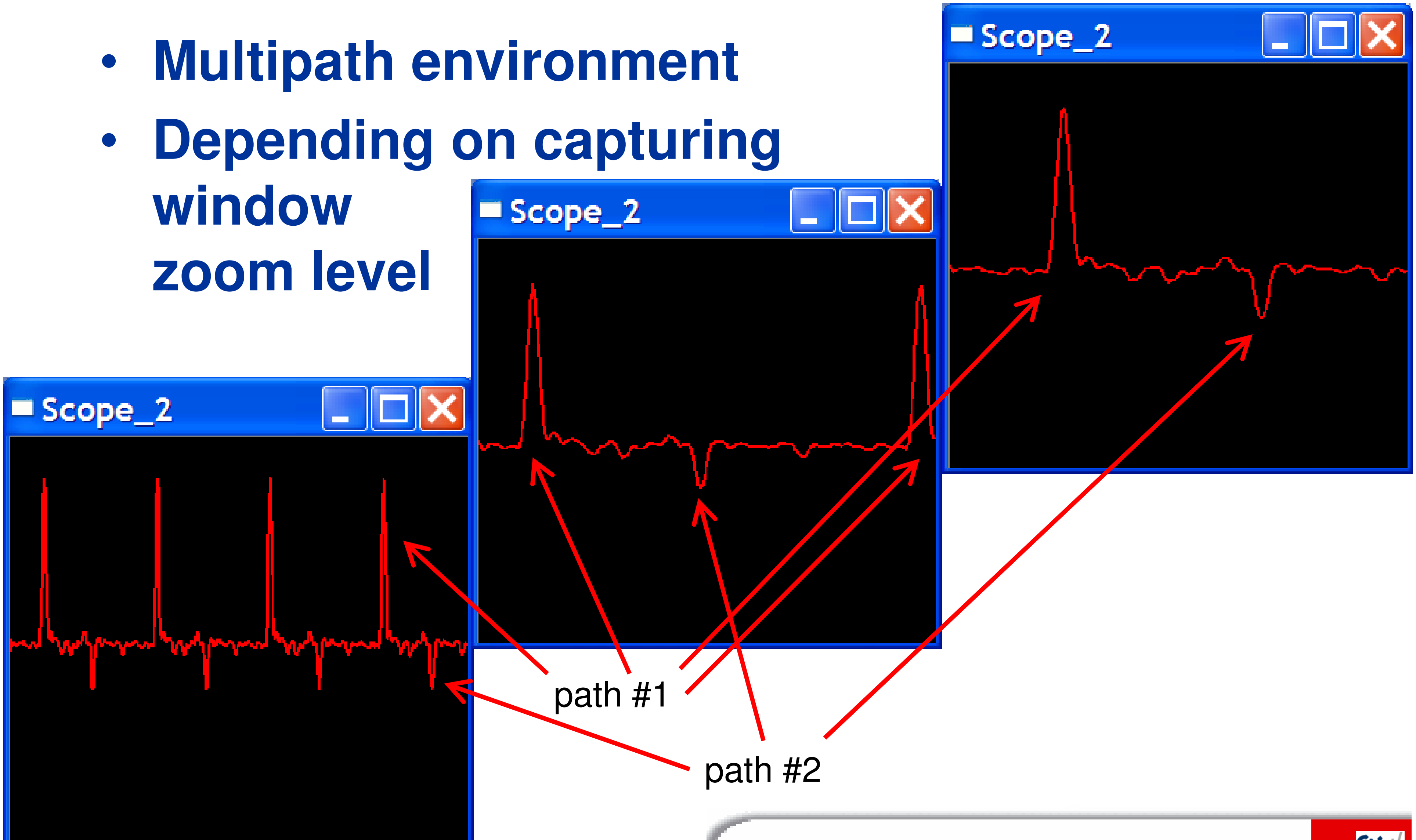
inphase signal

→ no more (less visible indeed) carrier desynchronization (lucky!)

→ no multipath

Channel #2 measurements

- **Multipath environment**
- **Depending on capturing window zoom level**

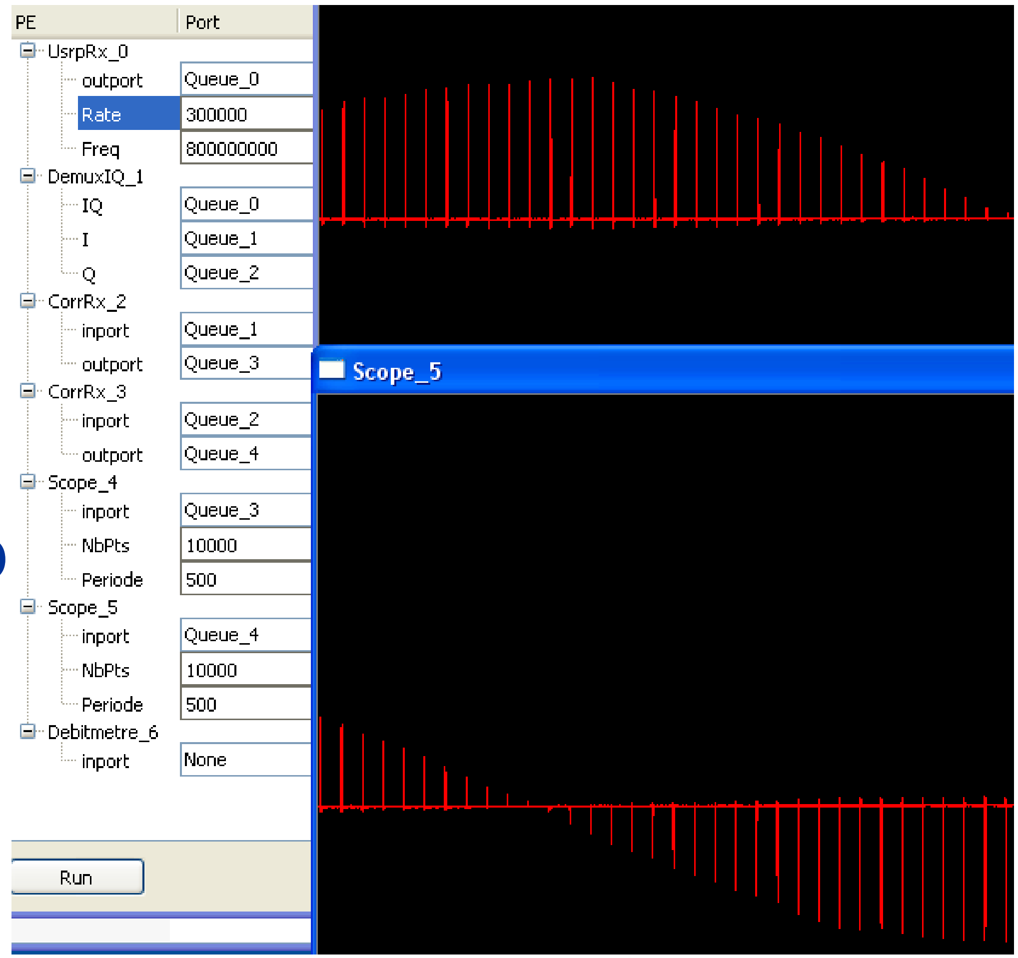


Channel #3 measurements

- Very easy to change of configuration (just do it!)
- W = 300 kHz
- 800 MHz

- That was not that easy 15 years ago with the "old" approach!

➔ flexibility



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Conclusion

- **Teaching level (project benefit for students)**
  - – spread spectrum
  - – digital communications in general, and more (channel sounding is not an easy thing)
  - – (some) implementation limitations
  - – writing a paper for a conference
- **SDR for education**
  - – fast and easy to implement (even for beginner)
  - – very motivating for students compared to
    - analytical analysis
    - simulations more or less deconnected from reality

  ➔ not to replace them, but as as a complement

- **Information can be found:**

http://www.rennes.supelec.fr/ren/perso/cmoy/SCEE-SERI/

- **Thank you to/This is the work of students:**

Olivier GOUBET

Adrien LE NAOUR

Thanks for your attention