UK-China (B)4G Wireless MIMO Testbed: Architecture and Functionality

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Outline

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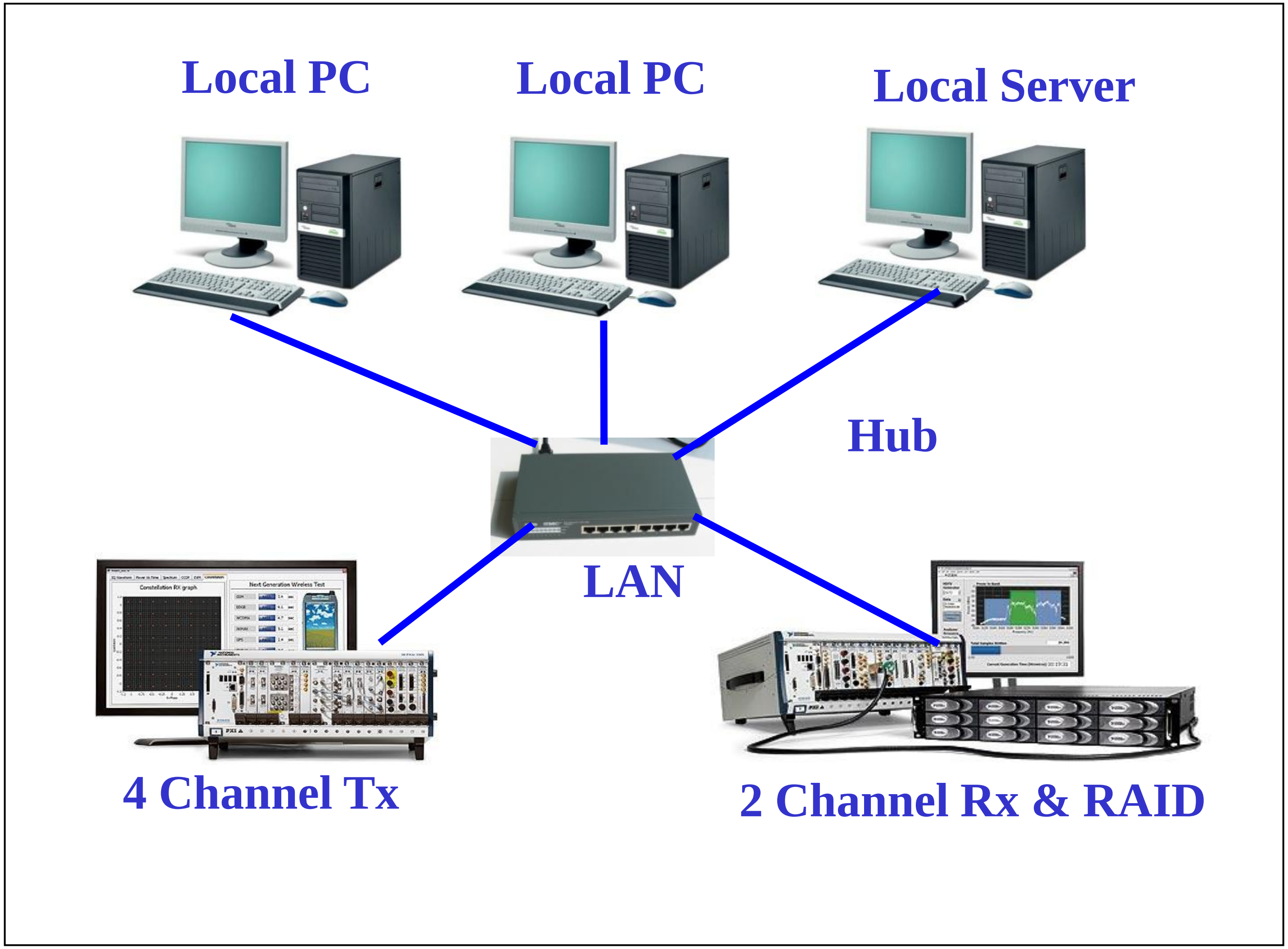
UoB: University of Bristol (UK), UoE: University of Edinburgh (UK), XU: Xiamen University (China) UoT: University of Tabuk (Saudi Arabia); SU: Shandong University (China); SEU: South-East University (China); WiCO : Shanghai Research Centre for Wireless Communications (China).

II. Specifications of Testbed

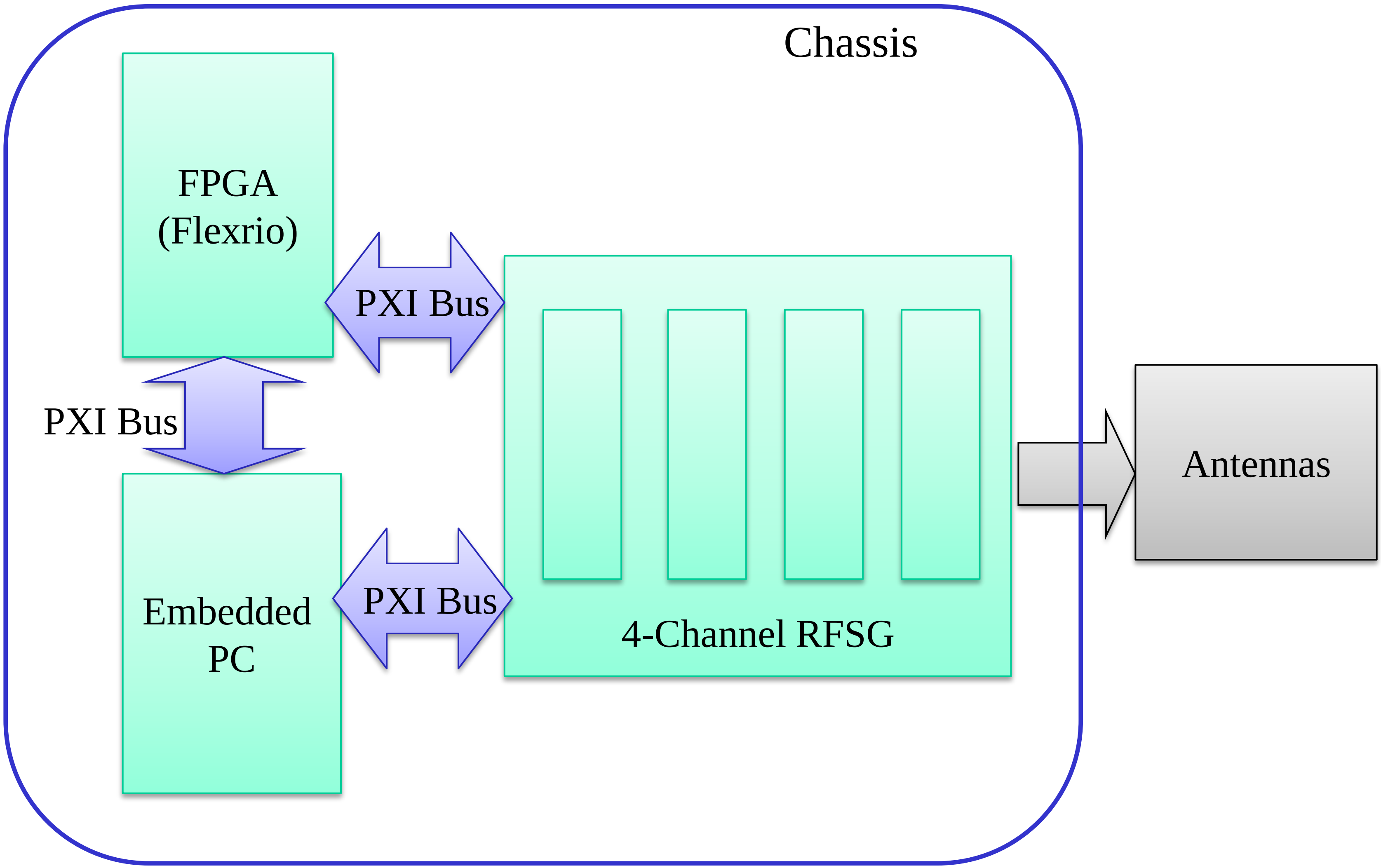
- **Hardware specifics (NI PXI products):**
- Rx ⟶ Left-hand side – 2 RF chains
- Tx ⟶ Right-hand side – 4 RF chains
- Hard-drive array (RAID)⟶ Extreme left-hand side: 6 TBs memory
- Tx frequency range (85 MHz – 6.6 GHz)
- Rx frequency range (10 MHz – 6.6 GHz)
- Tx RF bandwidth: 100 MHz
- Rx bandwidth (3dB): 50 MHz
- Embedded FPGA (Xilinx Virtex 5) at the Tx & Rx for real-time signal processing
- Embedded PCs at the Tx & Rx with Windows 7, LabView , Matlab, & NI software

- **Current capabilities/demos:**
- Real-time simplex SISO-WLAN system
- Offline Spatial Modulation
- Offline MIMO LTE
- Channel Emulator
- **Currently developing:**
- Open access interface

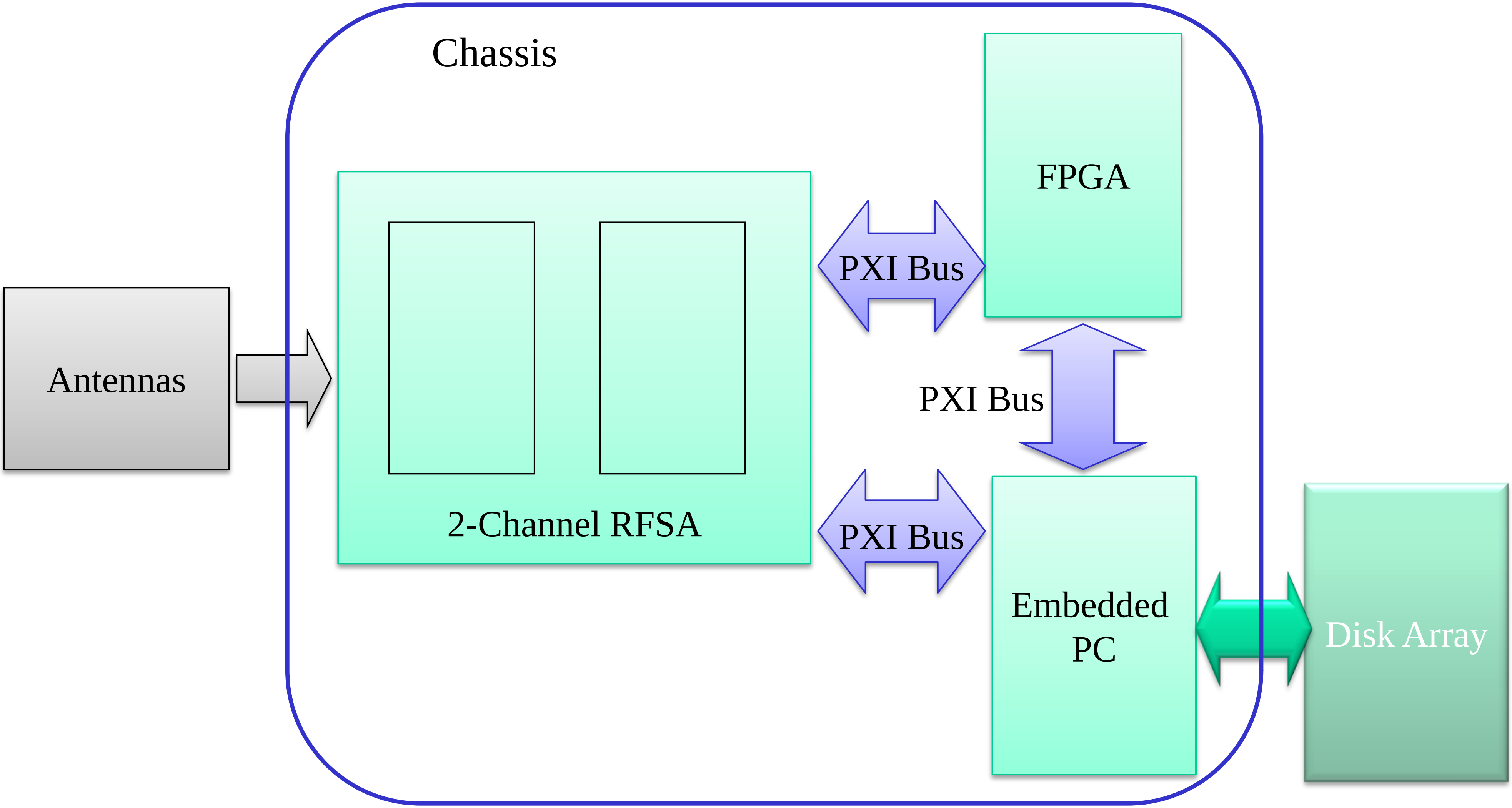
III. Testbed Architecture and Functionality



Transmitter Hardware Architecture



Receiver Hardware Architecture



Software Architecture

MATLAB SIMULINK

XILINX SYSTEM GENERATOR For DSP

XILINX ISE DESIGN SUITE

Software

Offline signal processing

Real-time signal processing

NATIONAL INSTRUMENTS LabVIEW

Instrument control

Hardware

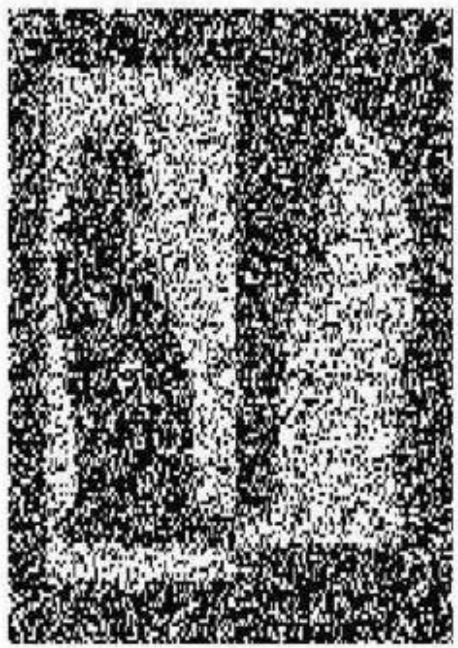
IV. Testbed Functionality

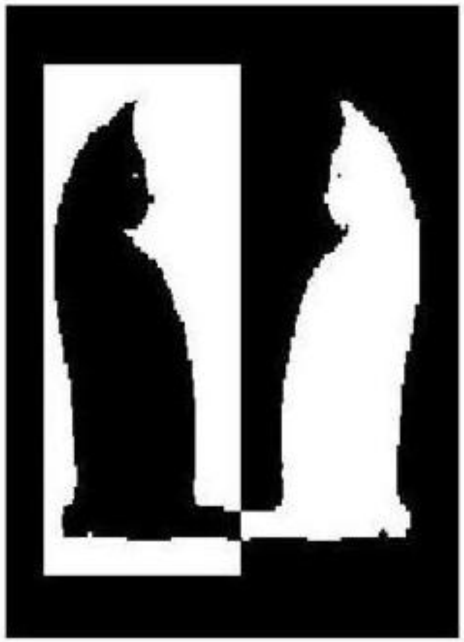
1: Offline MIMO LTE

- LTE: Long-term evolution (3.9G)
- System model: 4x2 MIMO diversity & multiplexing
- Diversity -> Space-frequency block codes
- Multiplexing (Open Loop) -> Cyclic delay diversity (CDD)
- Testing parameters (20MHz bandwidth, 2.3GHz centre frequency)
- Results: Transmitted Images, Constellation, BER

1: Offline MIMO LTE – Image Transmission Results

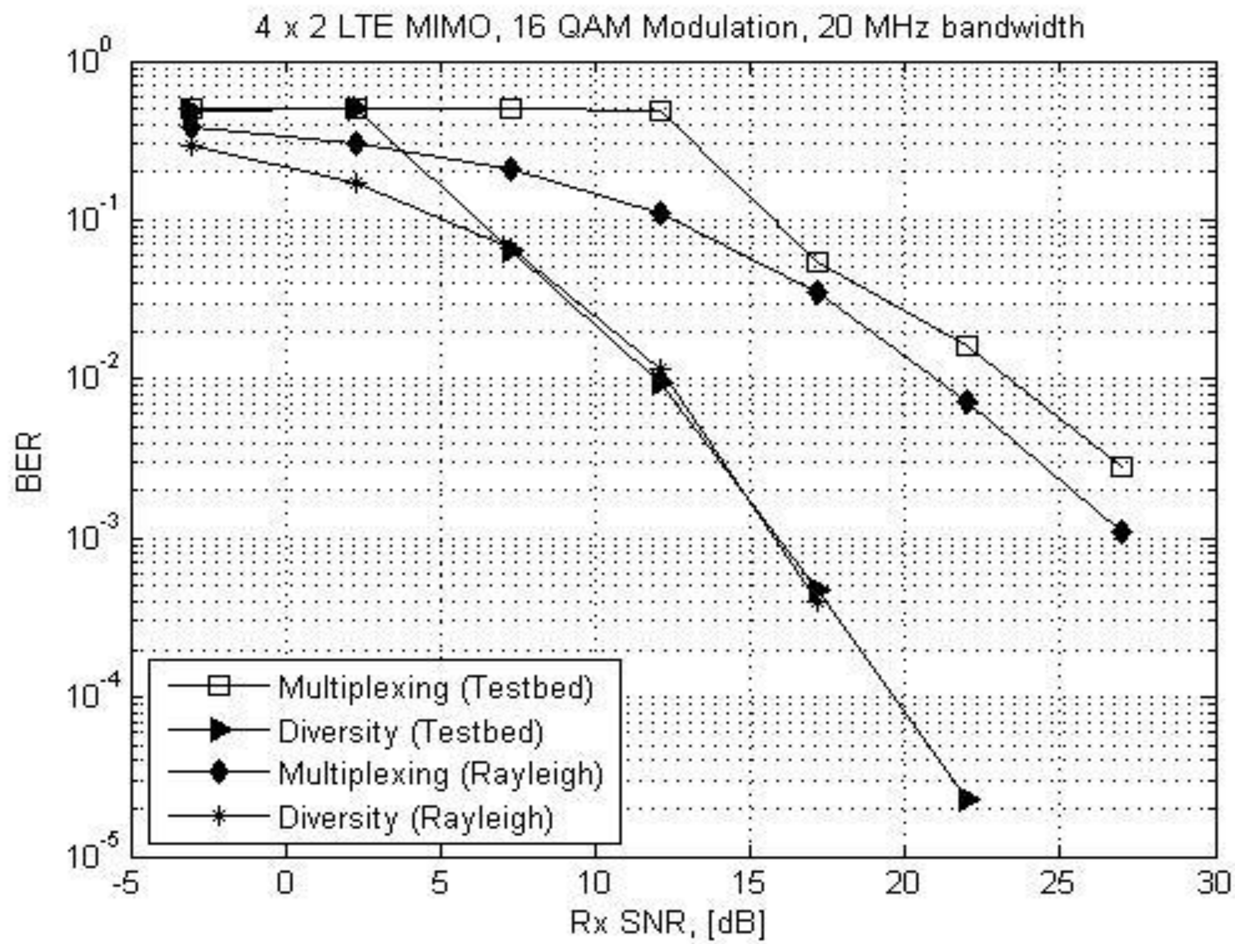
- Tx Power: -15 dBm;
- Received SNR: 7.7 dB
- Turbo coding





Multiplexing Diversity

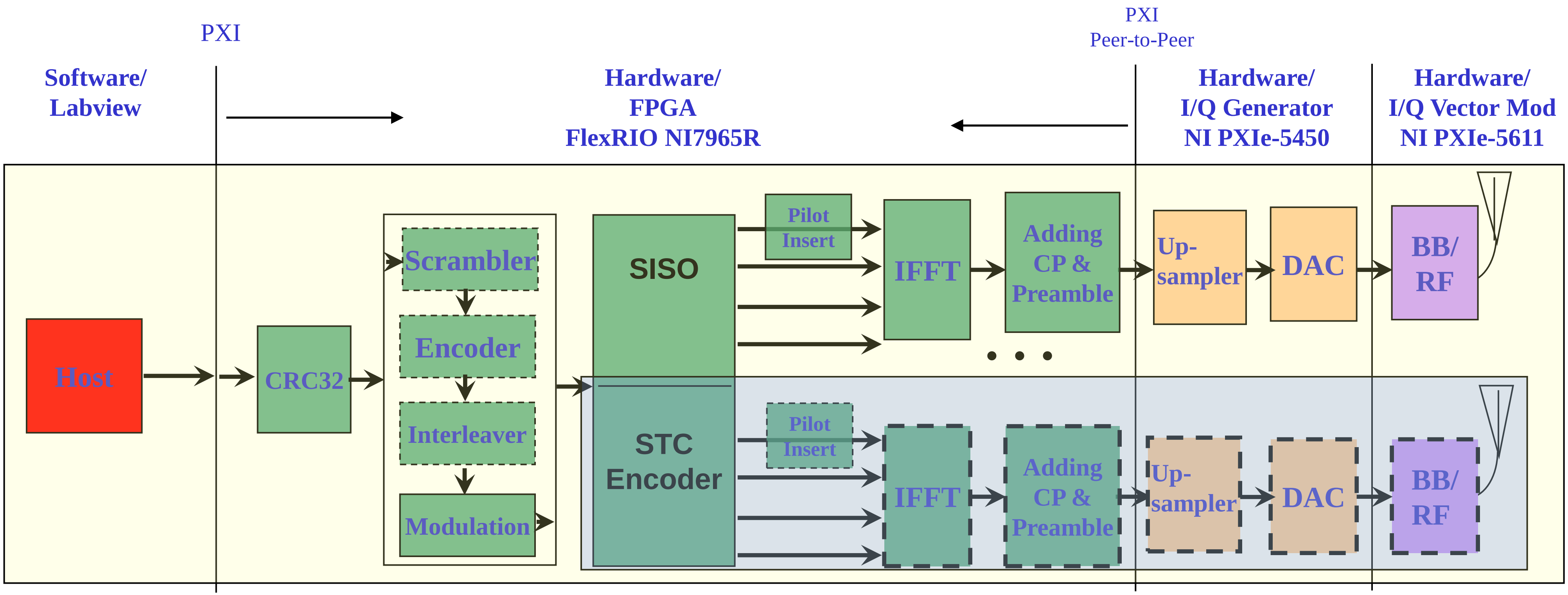
1: Offline MIMO LTE – BER Curves

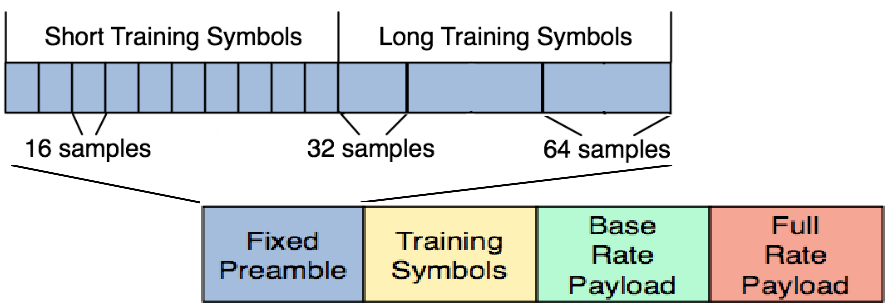


2: Real-Time SISO WLAN

- **Testing parameters**:
  - System bandwidth: 20 MHz
  - Centre frequency: 2.3GHz
  - 64 point FFT
  - Base Rate modulation: QPSK
  - Full Rate modulation: QPSK/16QAM/64QAM/256QAM
  - No channel coding
- **Results**: Constellation diagram, Channel estimation

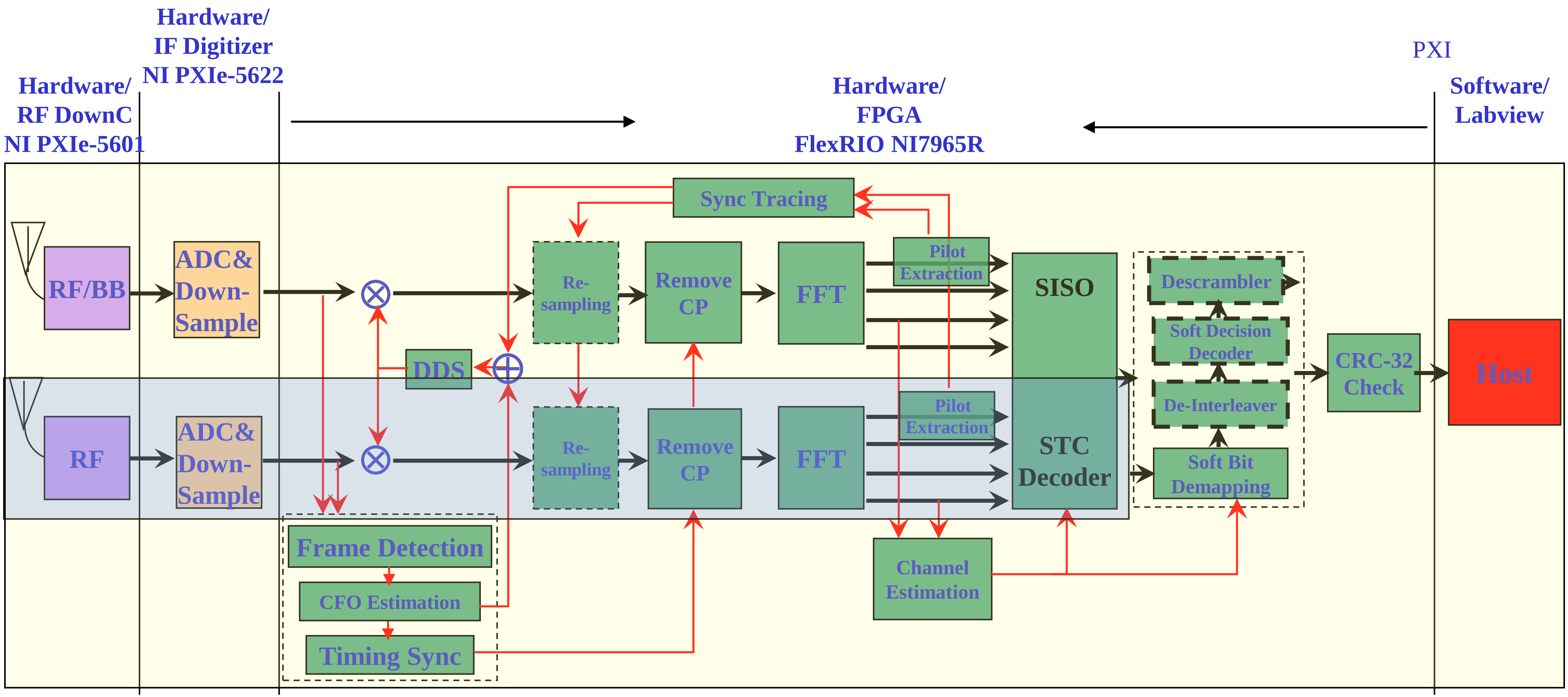
2: Real-Time SISO WLAN – Transmitter





SISO-OFDM Frame Structure

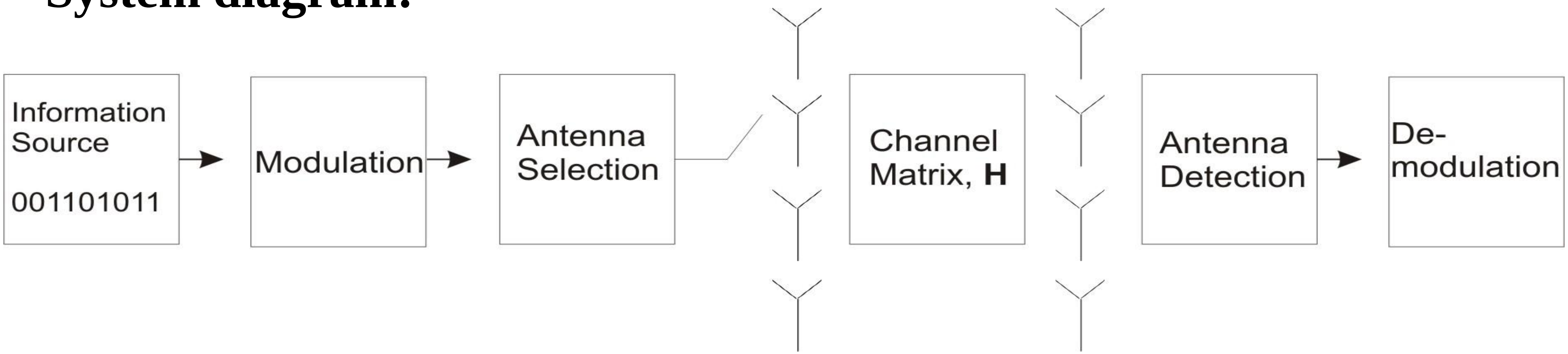
2: Real-Time SISO WLAN – Receiver



Key Techniques: Frame detection and time Sync, Coarse/fine Carrier Sync and tracing, Soft De-mapping and decision

3: Spatial Modulation

- A novel technique that utilises multiple–antenna transmission to realise an entirely new modulation concept.
- **System diagram:**



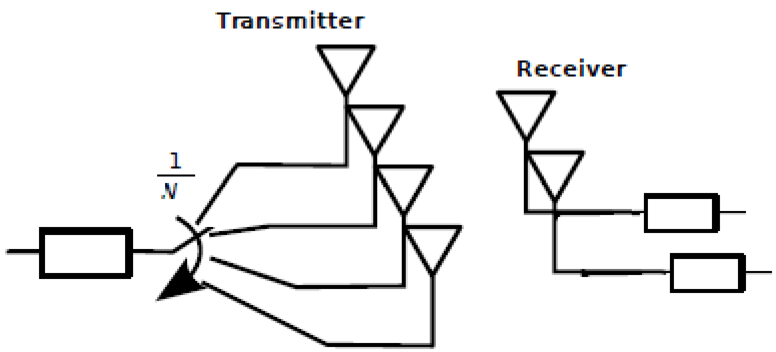
  - Only one Tx antenna is activated at a time: a ‘**green**’ MIMO solution.
  - Data is encoded into the Tx antenna position within the Tx array.
  - Antenna detection stage at Rx ascertains antenna, ‘spatial signature’.

3: Spatial Modulation – UC4G

- **Patent** supported by the UC4G project:
  - H. Haas, R. Mesleh, I. Stefan, and P. M. Grant, "A method and system of enhanced performance in communication systems," international publication number: WO 2010/094960 A1.
- The UC4G project has been the first to demonstrate this new technique experimentally.
- Expected to be a key contender for physical layer techniques for B4G wireless communications standards

4. Channel measurements: Introduction

- **Consider multiple-input/multiple-output (MIMO) radio channel.**
  - **M = 2 receive radio frequency (RF) chains and N = 4 transmit RF chains.**
- **Develop sounding sequence to scan MIMO channel in time.**

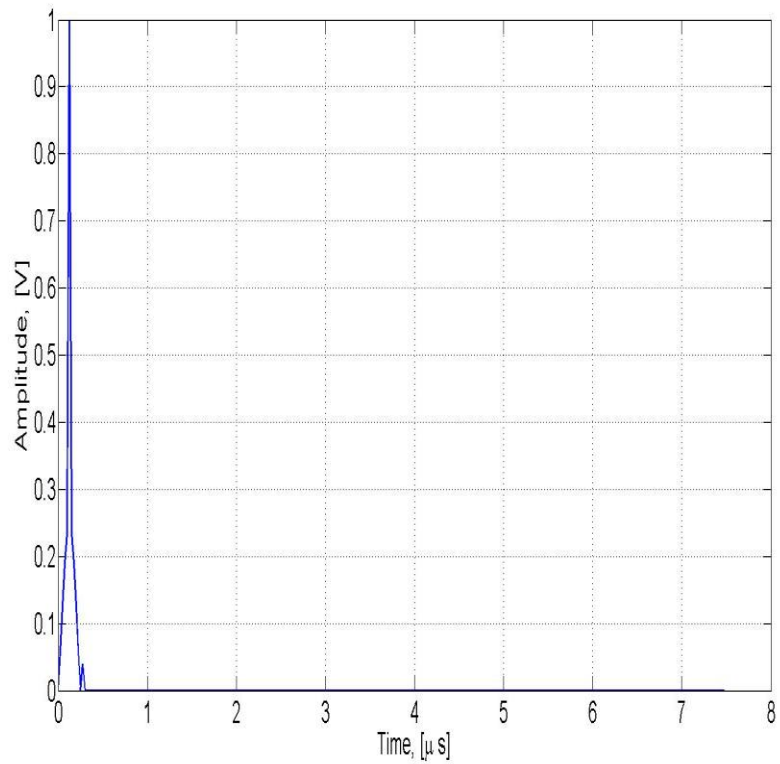


- **Semi-switched sounder:**
  - **Each antenna has its own RF chain.**
  - **2 Rx RF chains are active, each Tx chain is activated in turn**

4. Channel measurements: Transmit pulse

- **Design a time domain transmit pulse in the frequency domain.**

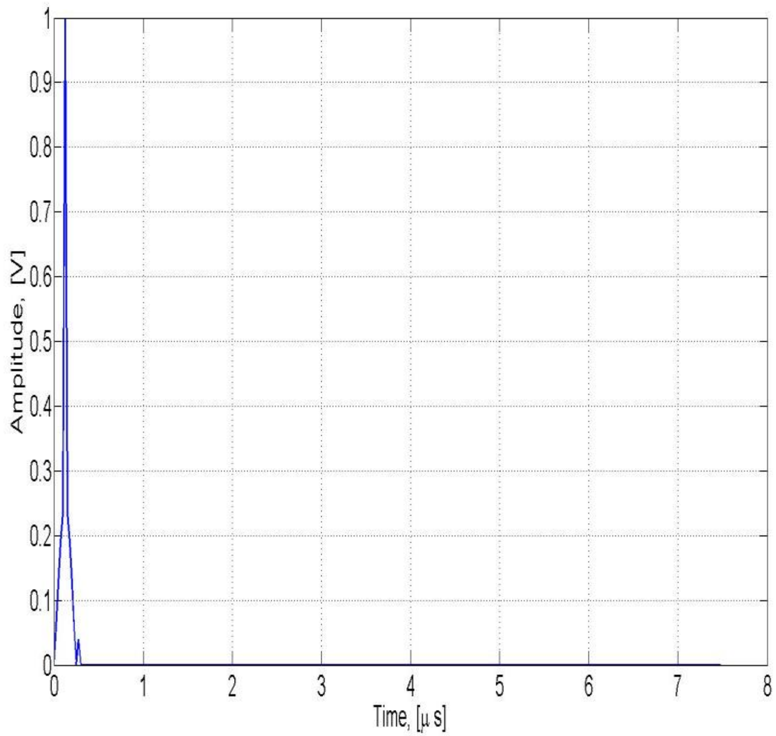
Bandwidth	40 MHz.
Centre frequency	2.3GHz.
Number of tones	64.
Power per tone	-34 dBm.
Frequency between tones	500 kHz.



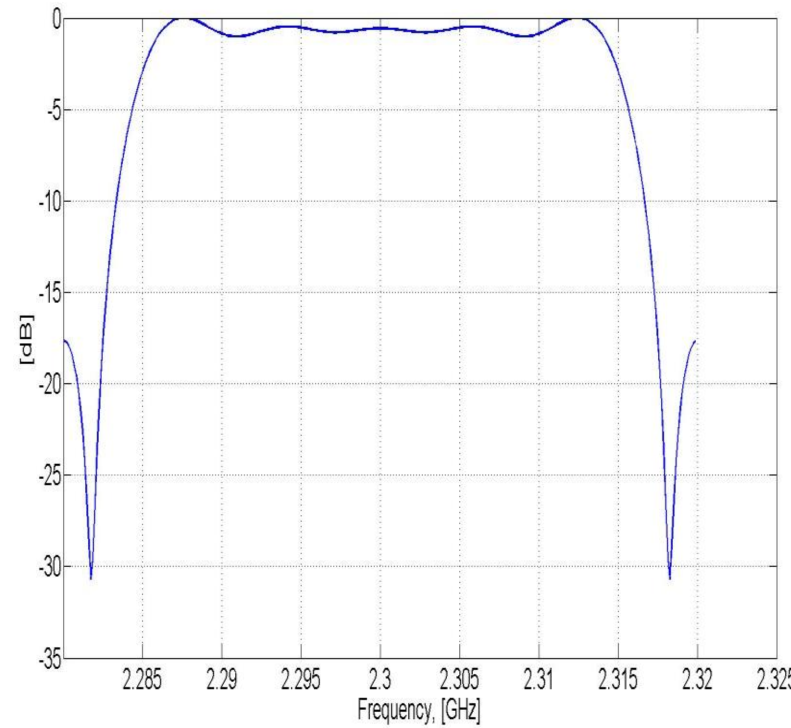
4. Channel measurements: Transmit pulse

- **Pulse is then processed in Matlab (Removal of artefacts, etc).**

Time domain

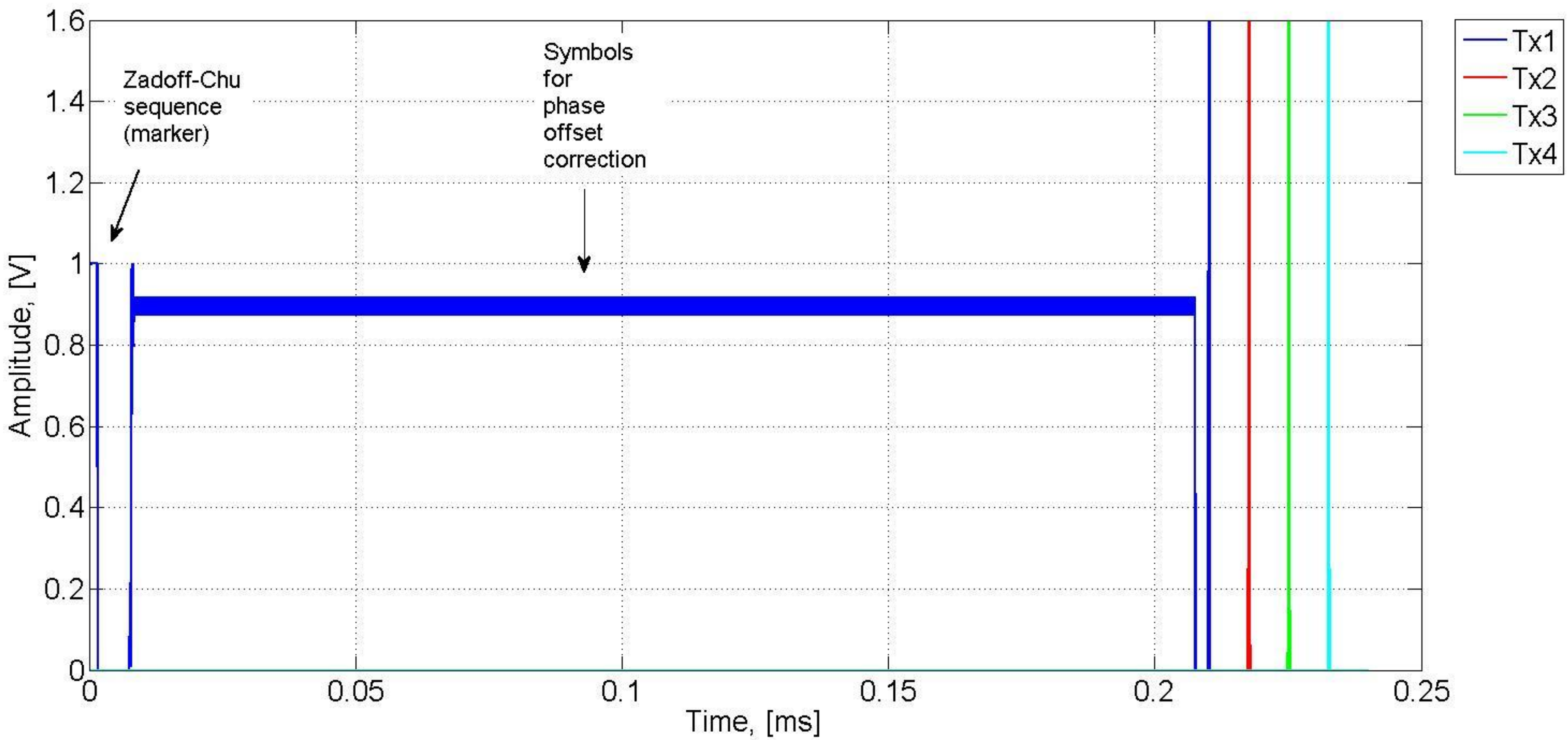


Frequency domain



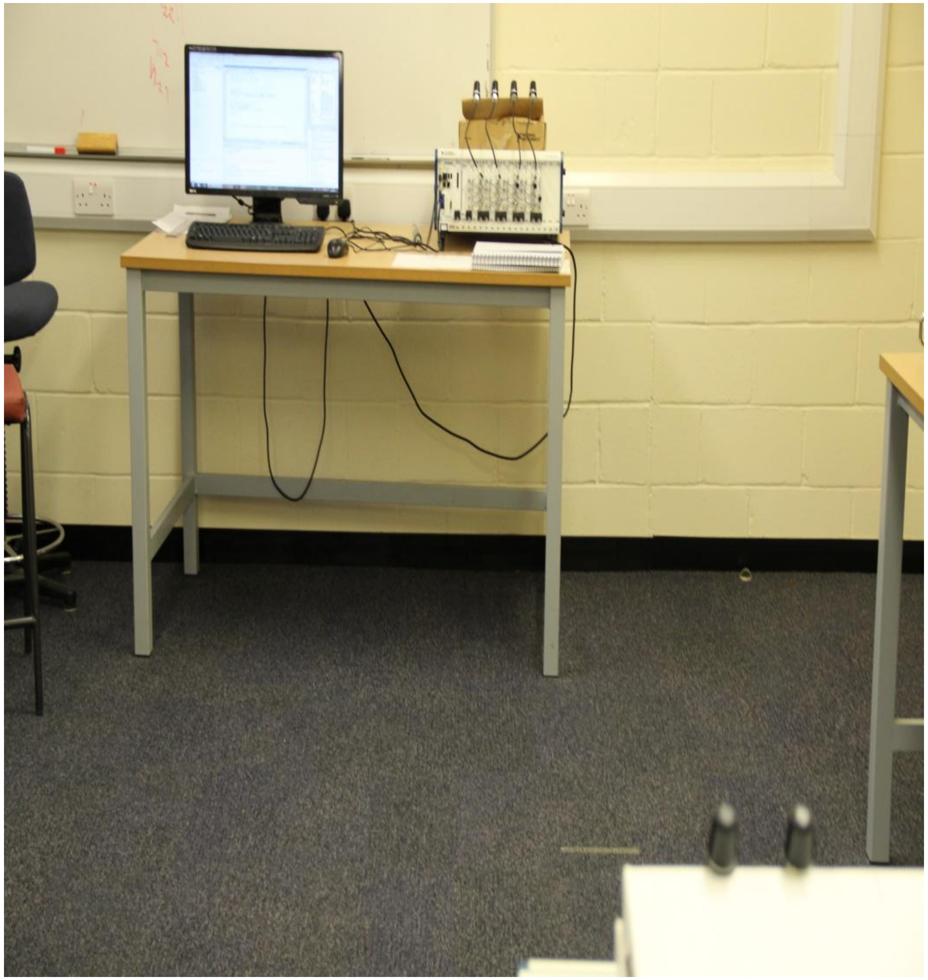
4. Channel measurements: Transmit sequence

- **Incorporate pulse into a sounding sequence**



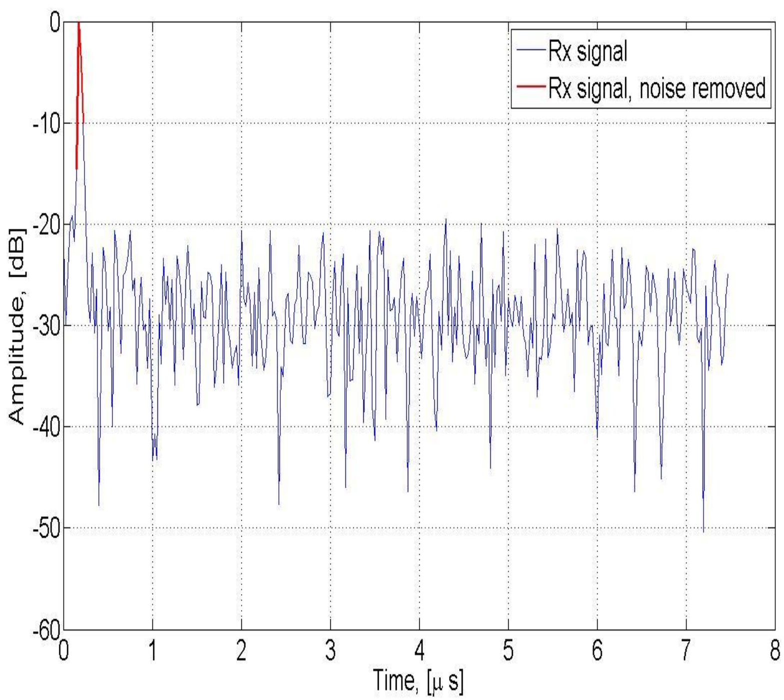
4. Channel measurements: Set-up

- Laboratory
  - Tx on bench, Rx on trolley
  - Measure at various distances from the Tx (1M, 2M, 3M, etc)
- Antennas spaced λ/2 apart (2.3 GHz)

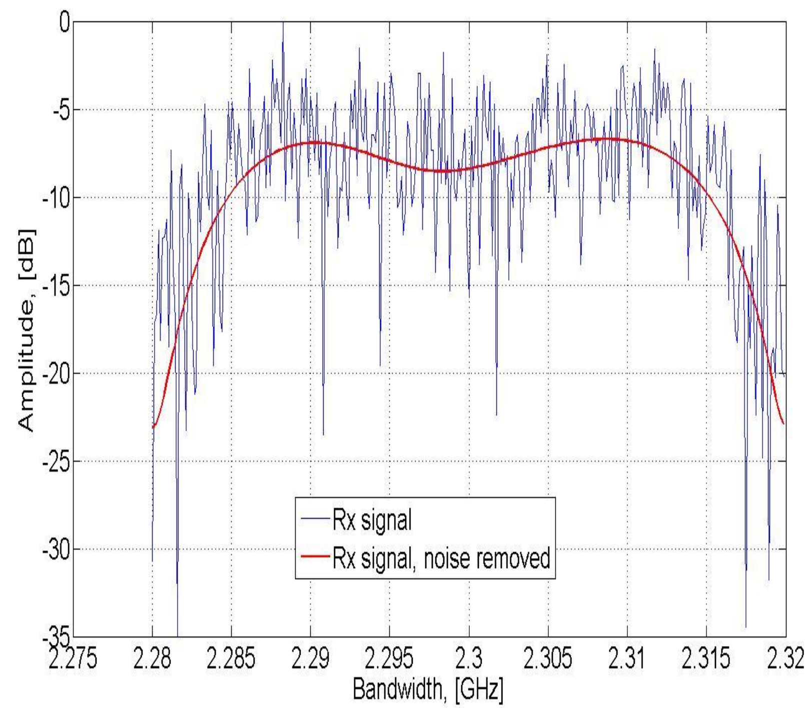


4. Channel measurements: Receiver noise removal

- **Time domain:before and after noise removal**



- **Frequency domain: before and after noise removal**



4. Channel measurements: PDFs & CDFs

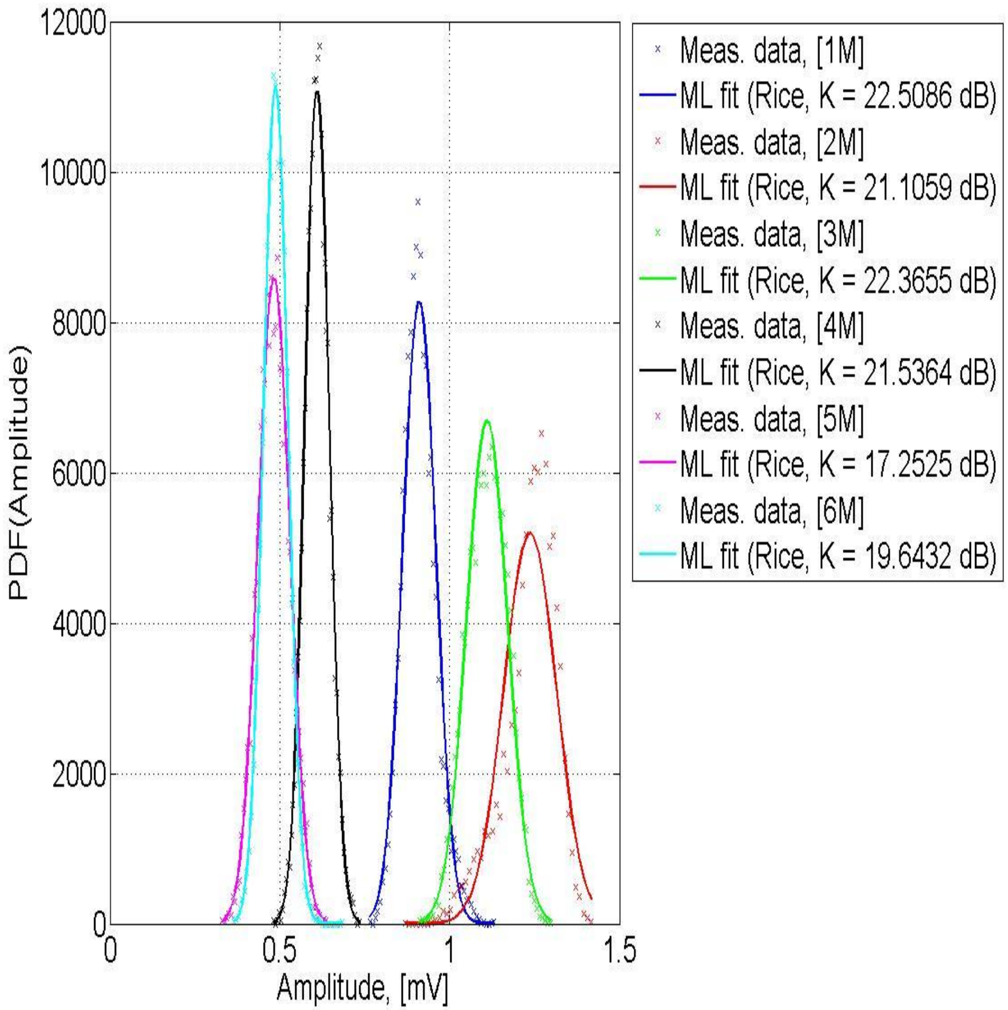
- Acquire 4 dimensional channel matrix **H**

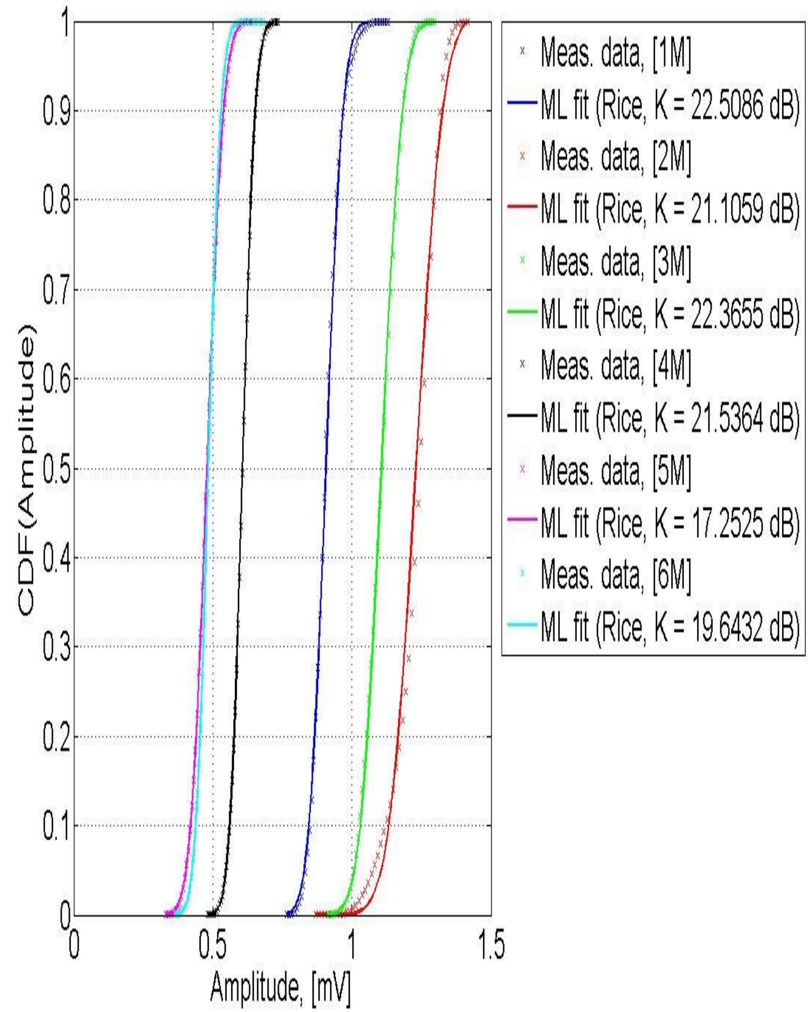
$$\mathbf{H}(\text{dim1}, \text{dim2}, \text{dim3}, \text{dim4})$$

$$M = 2 \qquad N = 4 \qquad Snapshot \qquad \#_{snapshots}$$

- For a given pair $\{M, N\}$:
  - Take FFT of dim3 and mean along dim4.
  - Calculate probability density function (PDF).
  - Use curve fitting to deduce channel statistics.

4. Channel measurements: PDFs & CDFs





4. Channel measurements: Autocorrelation function

- Acquire 4 dimensional channel matrix **H**

$$\mathbf{H}(\text{dim1}, \text{dim2}, \text{dim3}, \text{dim4})$$

$$M = 2 \qquad N = 4 \qquad Snapshot \qquad \#_{snapshots}$$

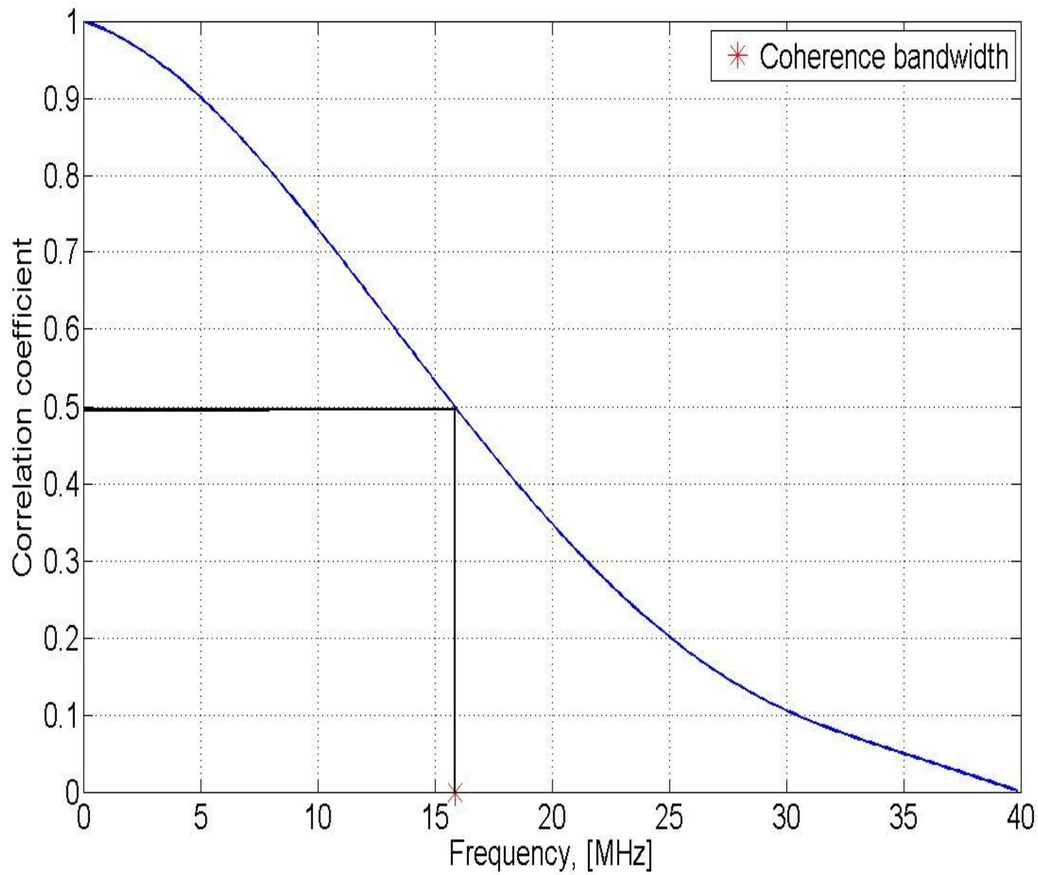
- For a given pair $\{M, N\}$:
  - Take FFT of dim3.
  - Compute the cross correlation function
  - Take mean along dim4

4. Channel measurements – Autocorrelation functions

- **Take 6 M measurement as an example**

- **Compute autocorrelation function**

- **Coherence bandwidth is point at which this falls to 0.5 of its original value**

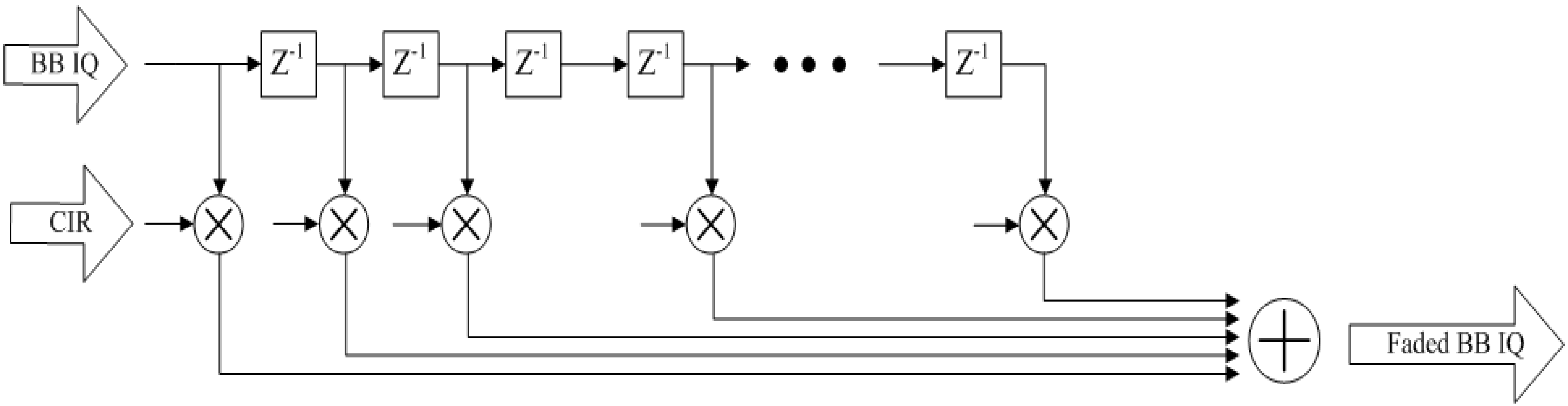


5: Channel Emulator

- **What is channel emulator?**
  - It replaces the real-world radio channel between a Tx and a Rx by providing a faded representation of a transmitted signal to the Rx inputs.
  - Applications: anywhere needing a channel, e.g., receiver algorithms evaluation.
- **Advantages of a channel emulator:**
  - Compared with using a real-world channel (e.g., RF testbed):
    - Scenario creation
    - Repeatability
  - Compared with a software channel simulator
    - Higher speed
- **Our contributions:**
  - A time-domain (tapped-delay-line), SISO channel emulator

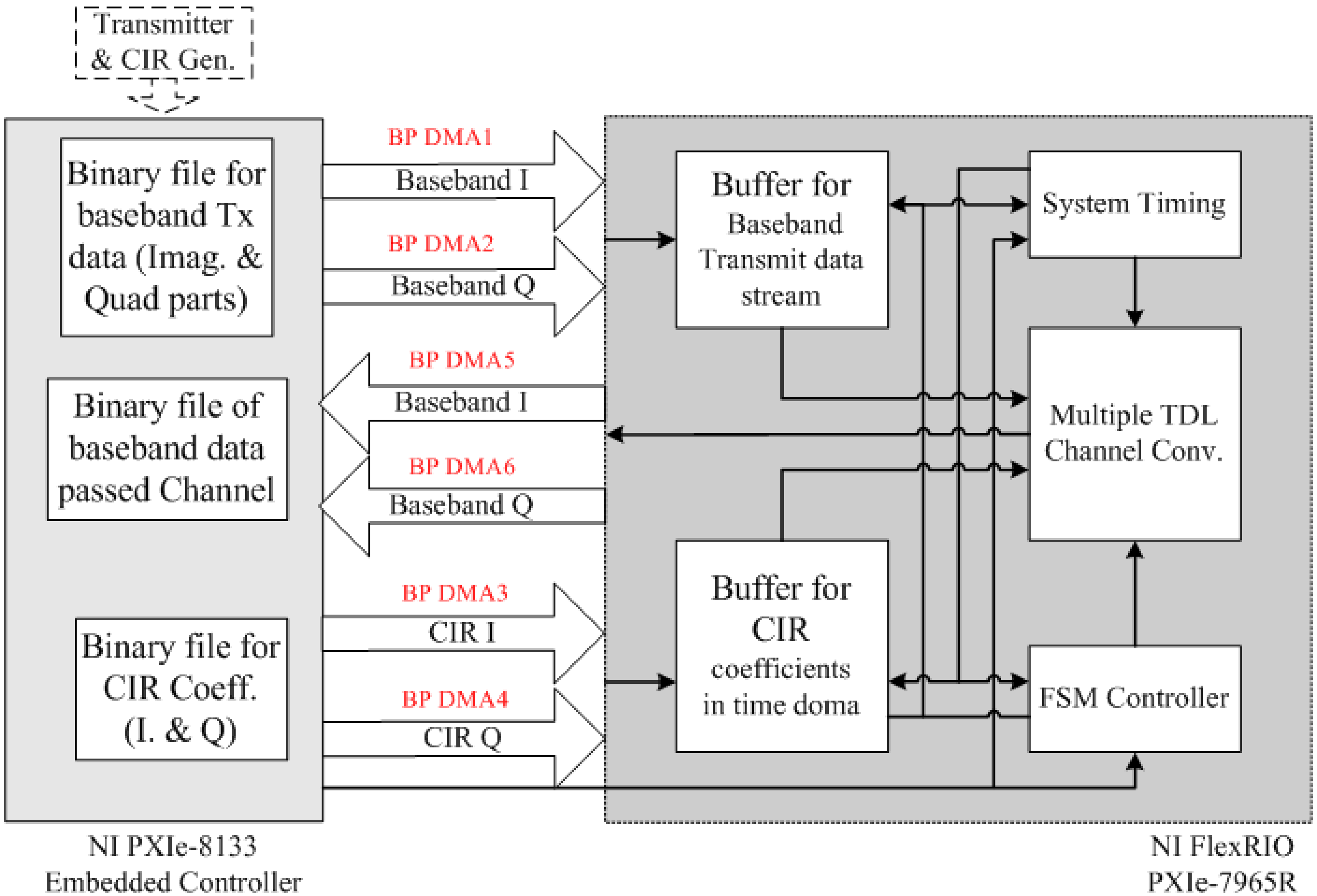
5: Channel Emulator – Channel Representation

- **Time-domain (Tapped-delay-line) channel representation:**



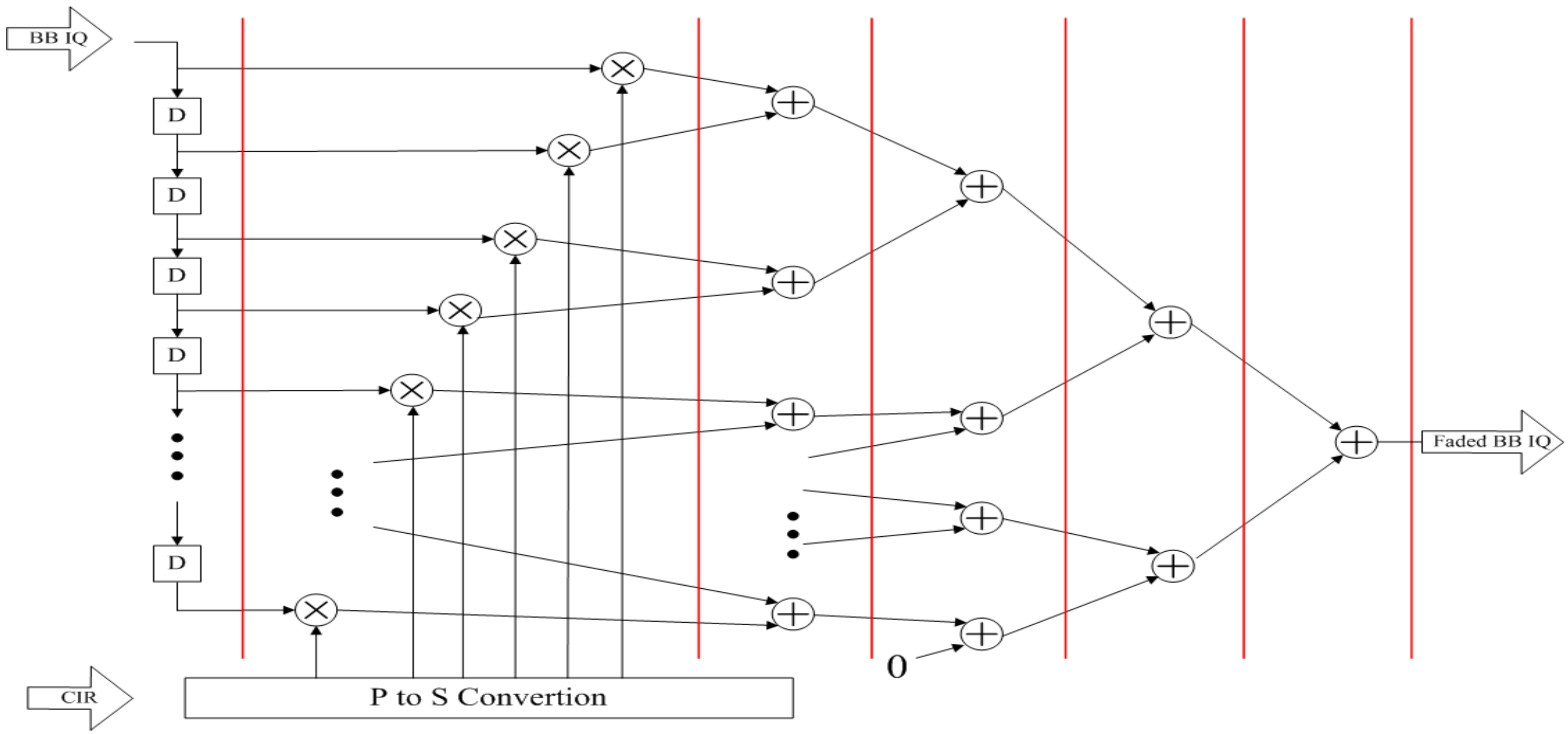
5: Channel Emulator – Schematic

- **Current solution for the channel emulator:**



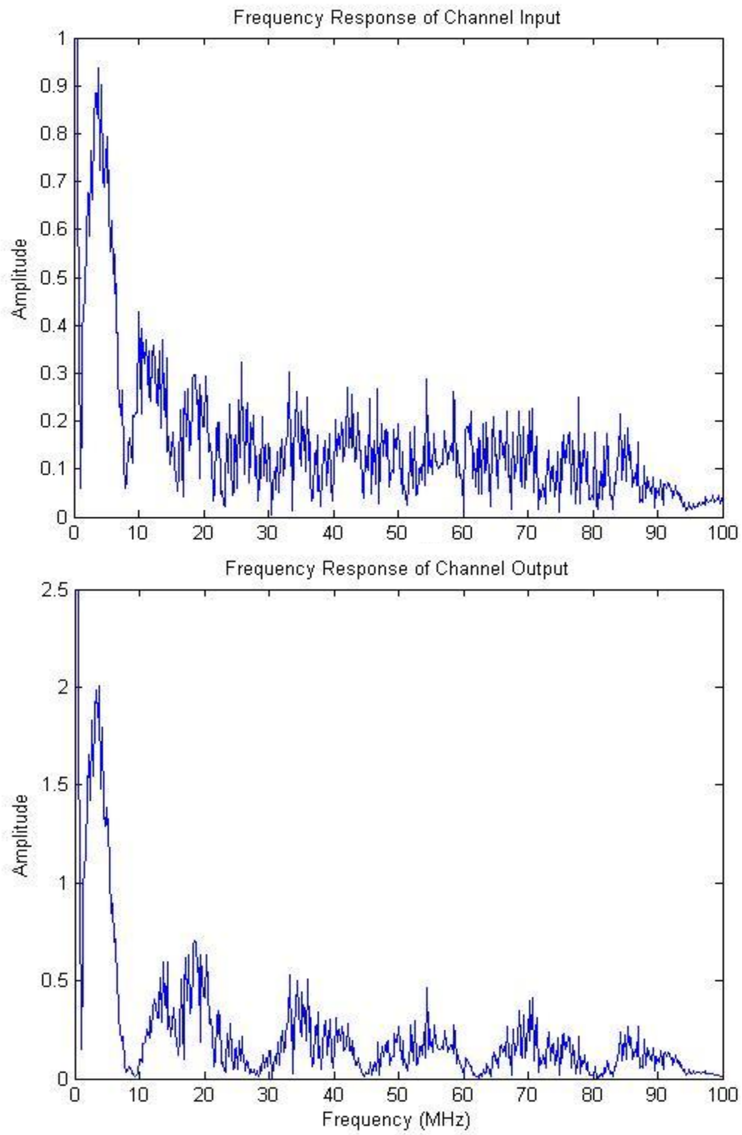
5: Channel Emulator – Convolution

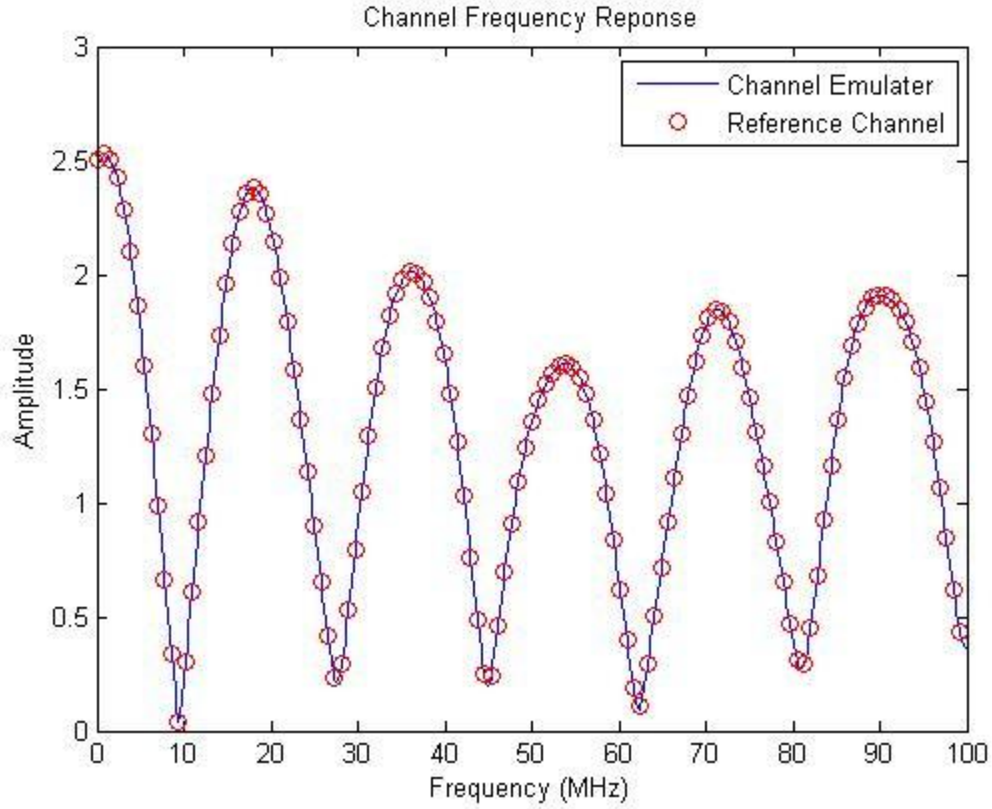
462 delays 16 taps 8 adders 4 adders 2 adders 1 adder



WINNER II: scenario C4

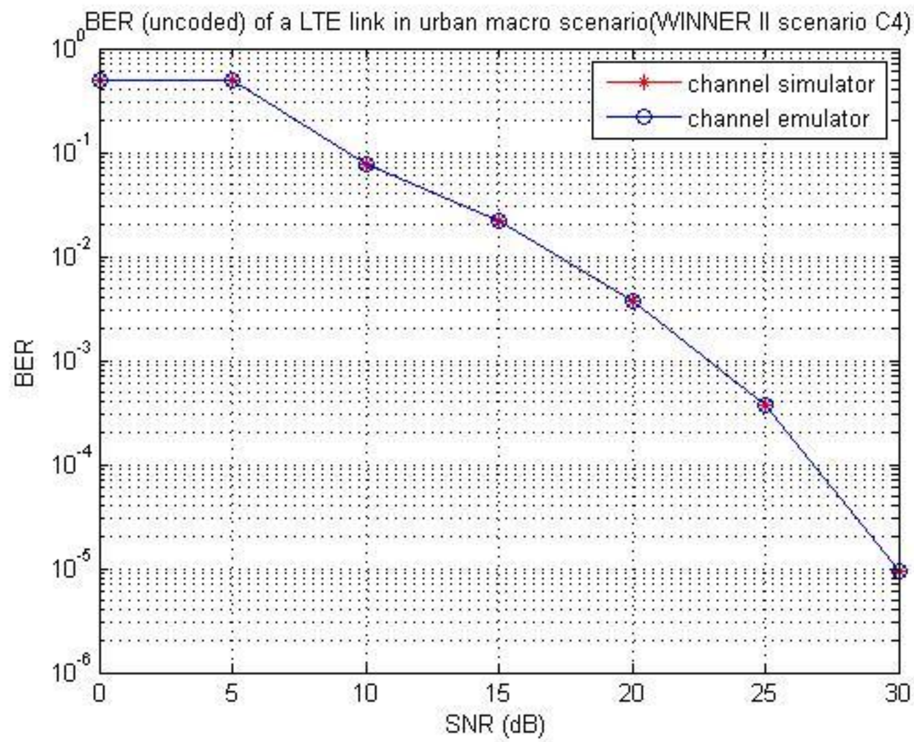
5: Channel Emulator – Evaluation





5: Channel Emulator – Performance

- **FPGA system clock:** 100 MHz
- **FPGA utilisation :** 56.6% (Winner II Scenario C4 in a Xilinx Vertex 5-ST95)
- **LTE link-level comparison**
  - Apply the channel emulator/simulator into a LTE link-level simulator



LTE baseband signals	Channel simulator	Channel emulator	Post-processing @ Rx
26 M samples (100M Byte)	159.097 s	14.682 s	806.394 s

- Winner II Scenario C4 :
  462 effective delays, 16 taps
- Matlab-based channel simulator :
  Matlab 2011 @ Windows 7, Intel Core i7 1.73GHz, 4GB RAM

Future Development of Testbed

- **Testbed vs C8:** Comparison of spatial modulation results from testbed and results from C8 channel simulator (with theory and simulation).
- **'LTE' spatial modulation:** Development of spatial modulation in conjunction with OFDM and compare performance with MIMO long term evolution (LTE) standard.
- **Testbed transceiver design:** Purchase of appropriate modules to develop the testbed from simplex to duplex operation.
- **Testbed relay:** Development of relay system, again purchase of appropriate modules for amplify and forward system.
- **Open access testbed:** Development of a web-based interface:
  - Enable third party access to testbed so that project partners can test signal processing ideas.
  - Establish a network of testbeds that can work together in order to establish a wide variety of results efficiently
- **Channel measurements using testbed:** Examine whether testbed can be used to make RF channel measurements.