Testbeds and Rapid Prototyping in Wireless Systems

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Infineon technologies
seibersdorf research

Outline

- Problems in the Design of Wireless Systems
  - Complexity Gap
  - Lack in Tool Support
  - When is a Technology Mature?
- Testbeds and Prototypes
  - Prototype, Demonstrator, or Testbed?
  - Testbed Examples
  - Automatic Design Tools
  - Prototyping Examples
- Conclusions

What makes mobile communication a difficult task?

- Limited Spectrum

  Most of the spectrum is used by public TV stations!

- Limited Battery Power

  Battery capacity increases 2% per year.

- Multi-path Propagation

- Complexity

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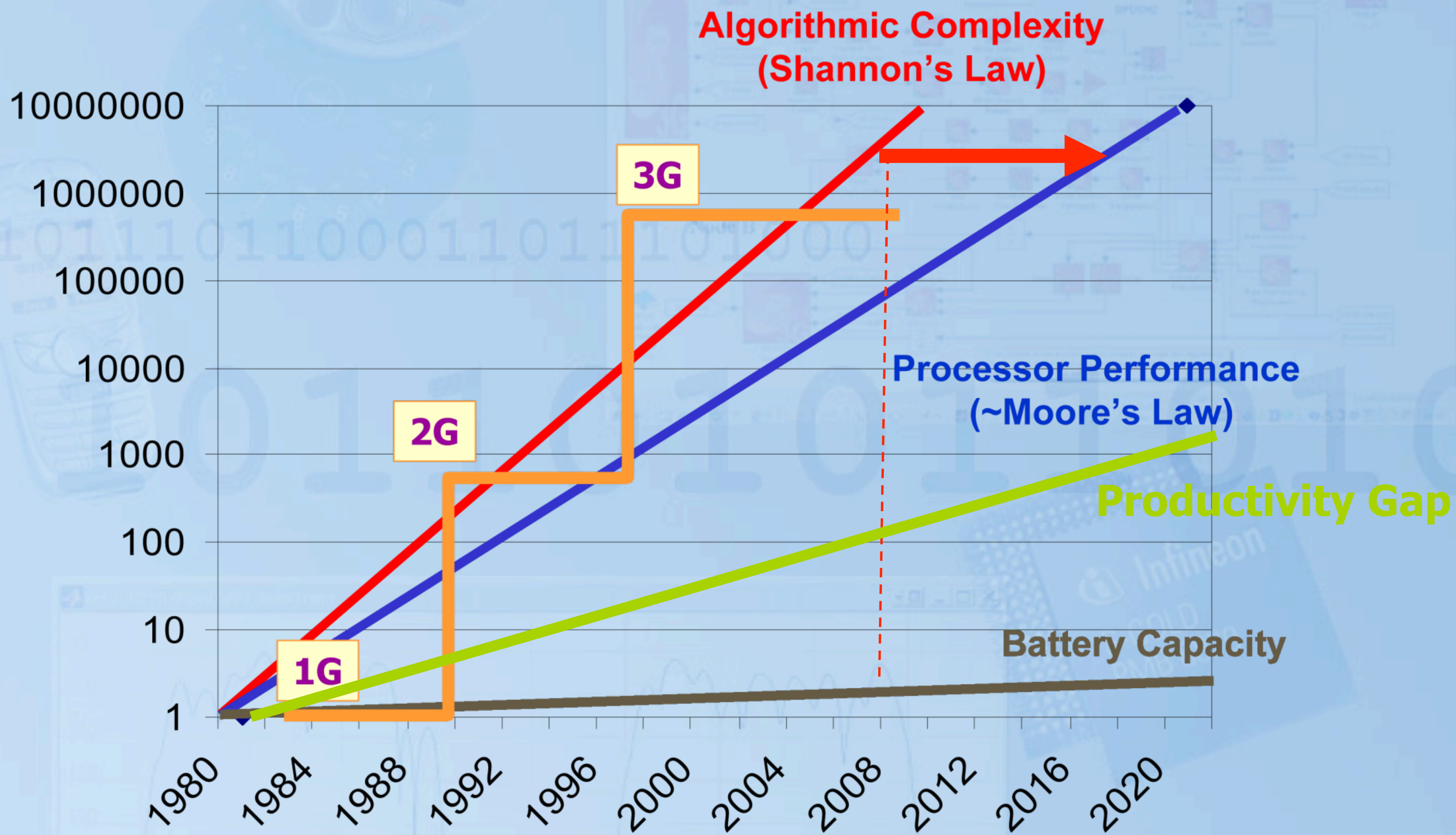
Complexity Gap in 3rd G. wireless



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Lack in Tool Support

- Productivity gap:

  Incompatibility is a major disadvantage of existing EDA tools!

- Prototyping experiences very little tool support due to small market.

- Basic lack exists in:
  - Float-to-fixed point conversion
  - HW/SW/FW partitioning
  - Platform based designs
  - Power aware design at high level description

When is a Technology Mature?

- Prototyping was used to…

  … build a first (set of) working demonstrator(s) to proof that a new theory could really be applied and to learn how cumbersome and expensive it could become once turning it into a product.

- Prototyping today is used to…

  … check on new and crucial parts of a new concept. Building an entire demonstrator is much too cumbersome, costly and slowly.

When is a Technology Mature?

- Many industries (especially wireless) have more and more abandoned prototyping due to tight time to market pressure.

- Failures have caused big losses:
  - Ariane rocket exploded after its start due to overflow problem.
  - HiperLAN I ended early (one product only) after it was realized that simply an equalizer is to be built.

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Now what?

- Prototyping is desired (in a way a nice asset to have a demonstrator) but…

- **Rapid Prototyping** is a real need, especially in wireless designs.

- Testbed, Demonstrator, or Prototype:
  What are we talking about?

Let's look it up

- A **Prototype** is the initial realization of a research idea or a standard, either as a reference, a proof of concept or as a vehicle for future developments and improvements. As opposed to a "simulation" it is not an "imitative representation" of the device. Instead it has significant similarities. In industry a migration into a product is often intended.

- A **Demonstrator** mainly serves as a sales vehicle and to show technology to customers. In general it will implement a new idea, concept or standard that has already been established and has been finalized to some degree. Requirements on scalability are therefore less important than its functionality and often the required design time.

- A **Testbed** on the other hand is generally used for research. It is a vehicle for further developments or for verification of algorithms or ideas under real-world or real-time conditions. This results in the requirement for scalability, modularity and extendibility.

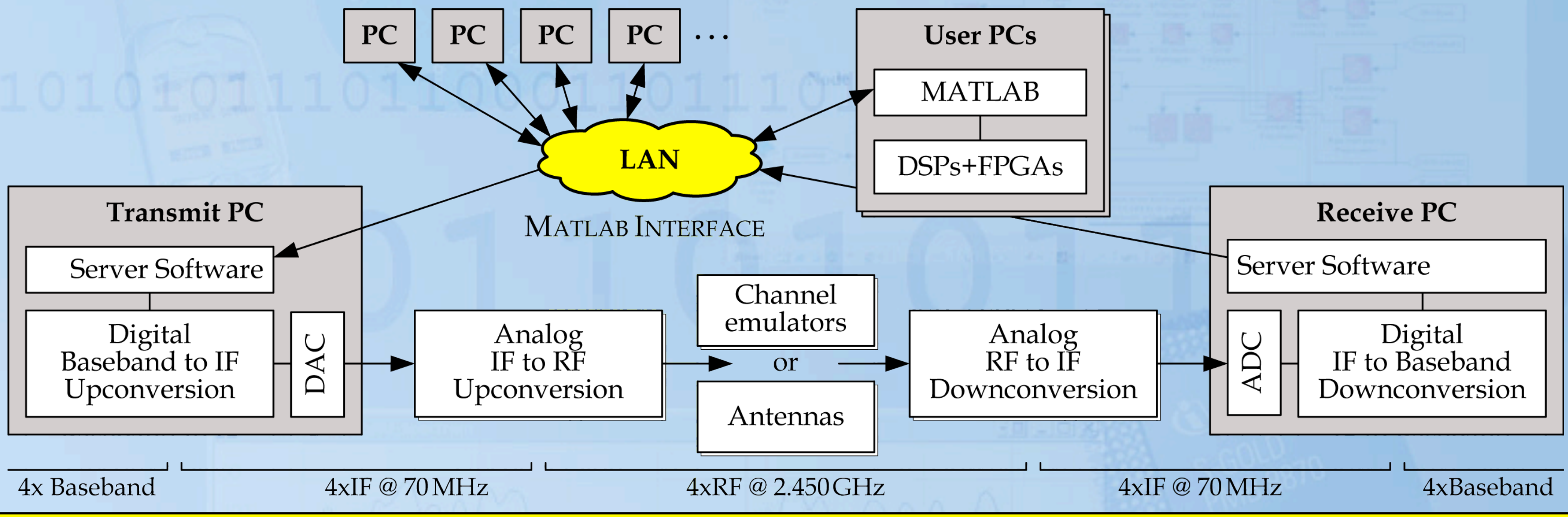
A. Burg, M. Rupp: "*Demonstrators and testbeds*"; in: "*Smart Antennas State of the Art*", Hindawi, 2005, S. 705 - 723., 2006.

F. Kordon and J. Henkel, “An overview of rapid system prototyping today,” *Kluwer Journal on Design Automation for Embedded Systems, vol. 8, pp. 275–282, 2003.*

Testbed and Prototype

- Testbed:
  - Fast to program due to high level language
  - Includes wireless channels
  - Allows for measurements of real-time transmissions
  - DSP functions may be replaced by prototype
- Prototype:
  - Considerable time required to build
    → Methods to speed up required
  - True fixed-point design
  - Allows for design space exploration

Experimental Testbed Setup



- S. Caban, C. Mehlführer, R. Langwieser, A.L. Scholtz, and M. Rupp: "Vienna MIMO Testbed," EURASIP Journal on Applied Signal Processing, March 2006.
- C. Mehlführer, S. Geirhofer, S. Caban, and M. Rupp: "A Flexible MIMO Testbed with Remote Access," EUSIPCO, Antalya, Turkey, Sept. 2005.

Experimental Testbed Setup

Video

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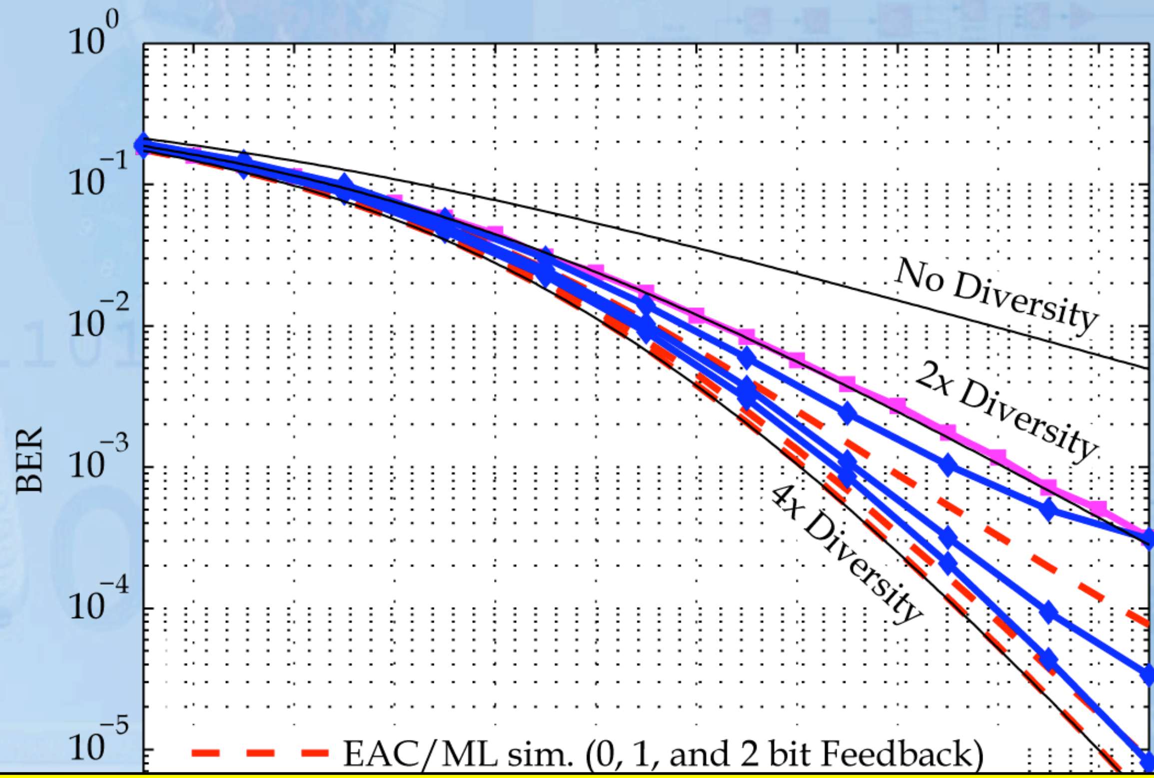
Testbed Example: Space-Time Codes

- **Question:**

  Can recently proposed Space-Time Block Codes really achieve the performance proposed in literature?

- **Answer:** Let's use a Testbed,
  - program codes in MATLAB,
  - transmit them over true channels,
  - receive them and see what we get when comparing to theoretic results.

Experimental Validation



- S.Caban , R.Langwieser, C.Mehlführer, E.Aschbacher, W.Keim, G.Maier, B.Badic, M.Rupp, A.L.Scholtz, "Design and Verification of a Flexible and Scalable 4x4 MIMO Testbed," Workshop on MIMO Implementation Aspects, RAWCON 2004.
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- A. Hottinen, Y. Hong, E. Viterbo, C. Mehlführer, C. Mecklenbräuker: "A Comparison of High Rate Algebraic and Non-orthogonal STBCs, " ITG/IEEE Workshop on Smart Antennas, Wien, Austria, 2007.

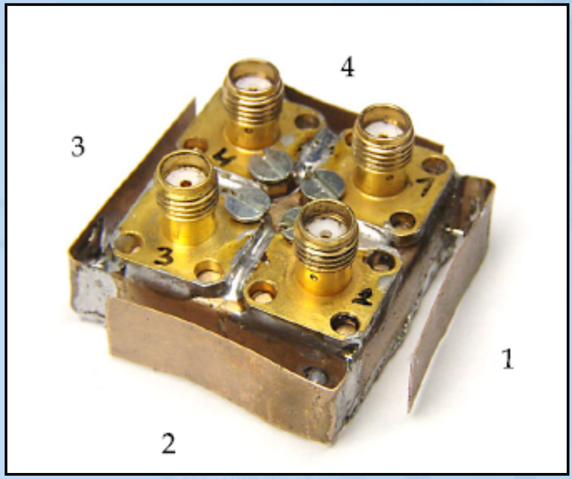
Testbed Example: MIMO Antenna Design

- **Question:**

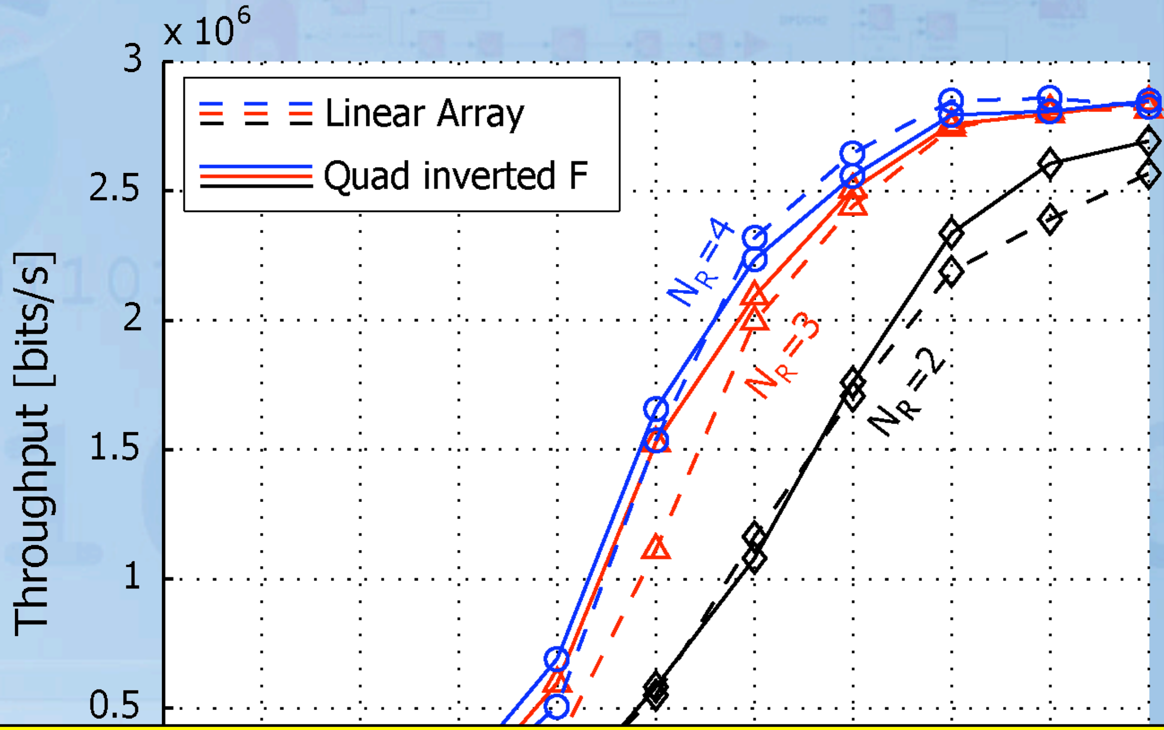
  MIMO HSDPA allows for even higher data rates in UMTS. However, only small antenna designs can be used in mobile phones.
  What is the impact of such small MIMO antenna designs on the data rate achieved?

- **Answer:** Let's use a Testbed,
  - program MIMO HSDPA in MATLAB,
  - transmit the signals over true channels applying various antenna designs,
  - and compare the results.

MIMO Antenna Design



Quad Inverted F Antenna



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- C. Mehlführer, L. Mayer, R. Langwieser, A.L. Scholtz, and M. Rupp: "Free Space Experiments with MIMO UMTS High Speed Downlink Packet Access," IEE Conference on DSP enabled Radio, Southampton, UK, Sept. 2005.

Testbed Example: Adaptive Equalizers for HSDPA Mode

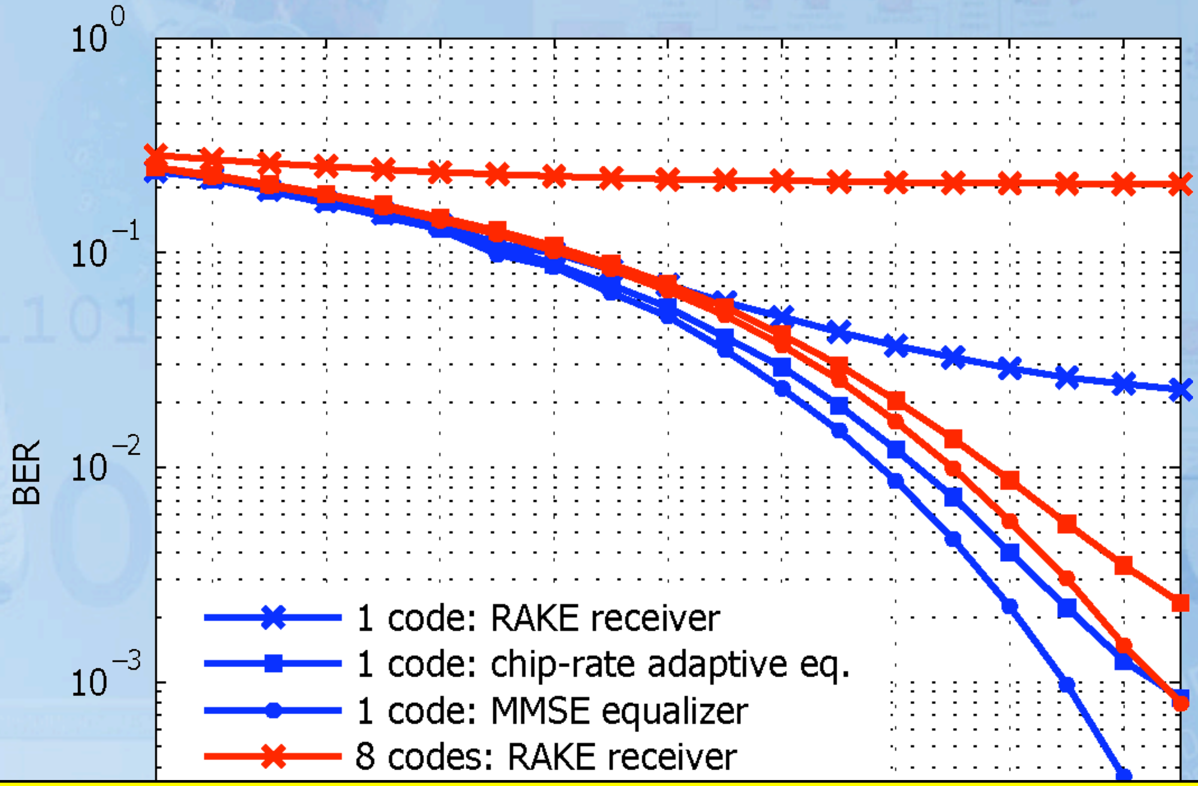
- **Question:**

  HSDPA allows for high data rates in UMTS. However, equalizers are required to guarantee orthogonality of codes. Which equalizers work in a real environment?

- **Answer:** Let's use a Testbed,

  - program HSDPA in MATLAB,
  - transmit the signals over a channel emulator with specific channel profiles,
  - receive them and see what we get when comparing to theoretic results.

Impact of Equalizers in HSDPA



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  "A Flexible MIMO Testbed with Remote Access,"
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- S. Geirhofer, C. Mehlführer, and M. Rupp:
  "Design and Real-Time Measurement of HSDPA Equalizers,"
  SPAWC, New York City, USA, June 2005.

Testbed Example: Antenna Distance

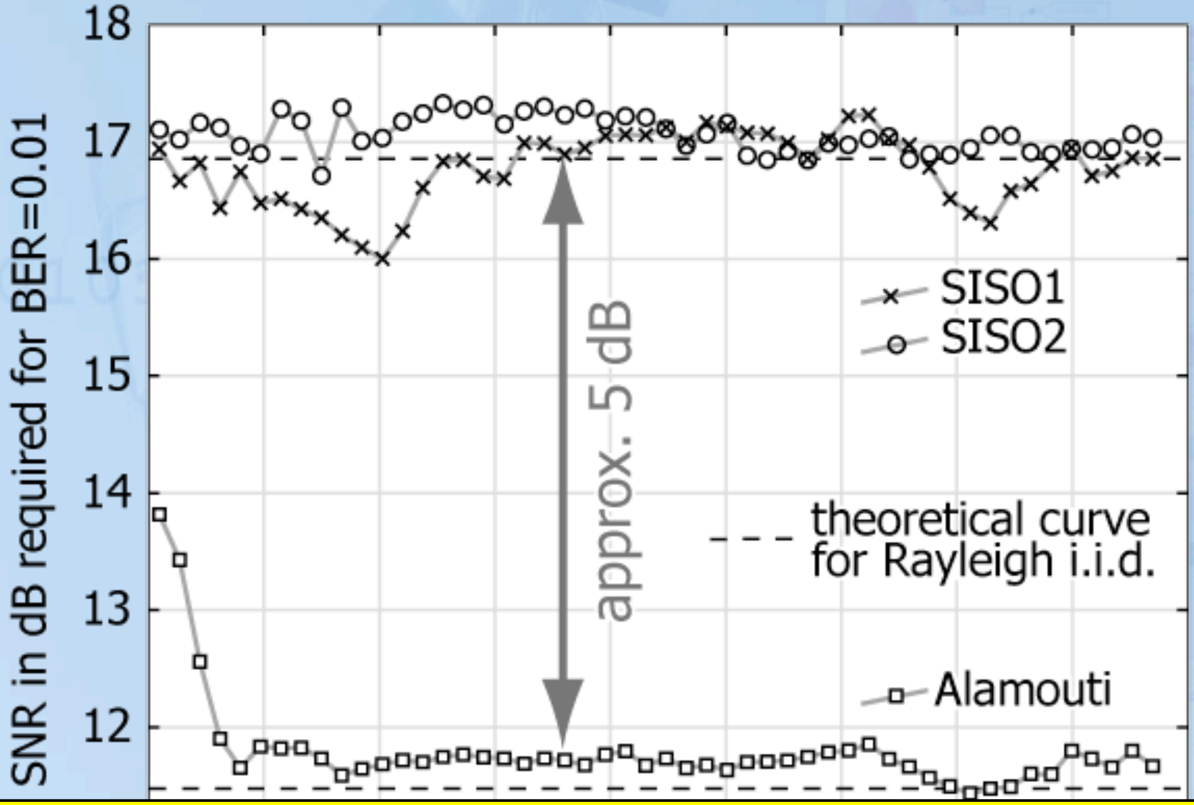
- **Question:**

  What is the impact of Transmit Antenna Spacing on a 2x1 Alamouti Radio Transmission?

Answer: Let's use a Testbed,

and measure BER over antenna distance.

Experimental Validation



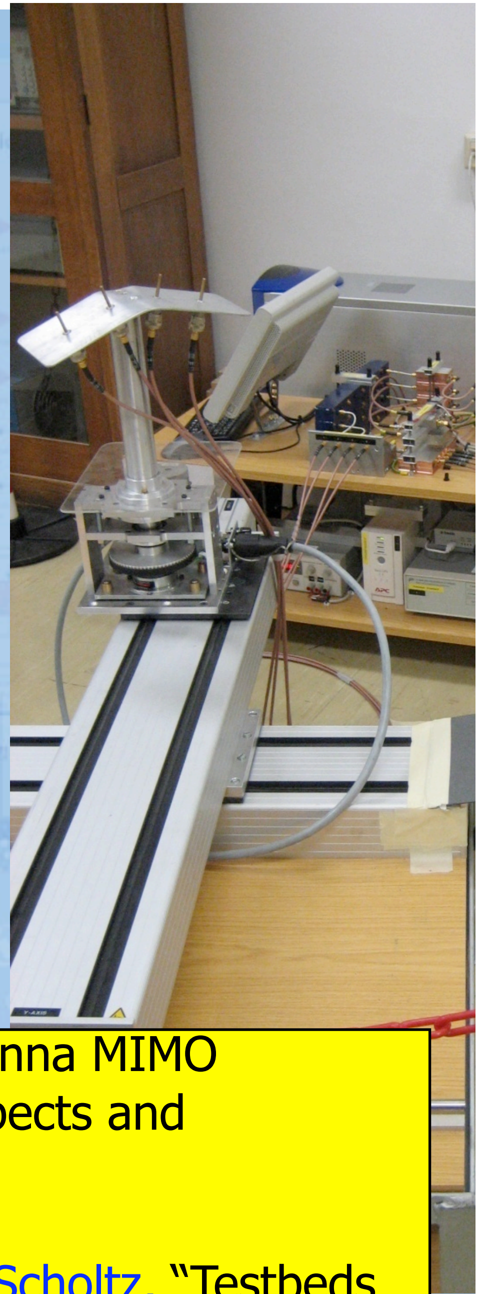
Parameters:
Modulation: 4 QAM
Center Freq.: 2.5 GHz
Bandwidth: 5 MHz
SISO: 100 Symbols
2x1 Alamouti: 100 Symbols
Channel Realizations: 83.521

- S. Caban and M. Rupp:
  "Impact of Transmit Antenna Spacing on 2 x 1 Alamouti Radio Transmission,"
  in IEE Electronics Letters, Vol. 43 (2007), pp. 198-199.
- S. Caban , C. Mehlführer, L. W. Mayer, and M. Rupp:
  "2 x 2 MIMO at Variable Antenna Distances," VTC 2008 Spring, May 2008.

MIMO Testbed

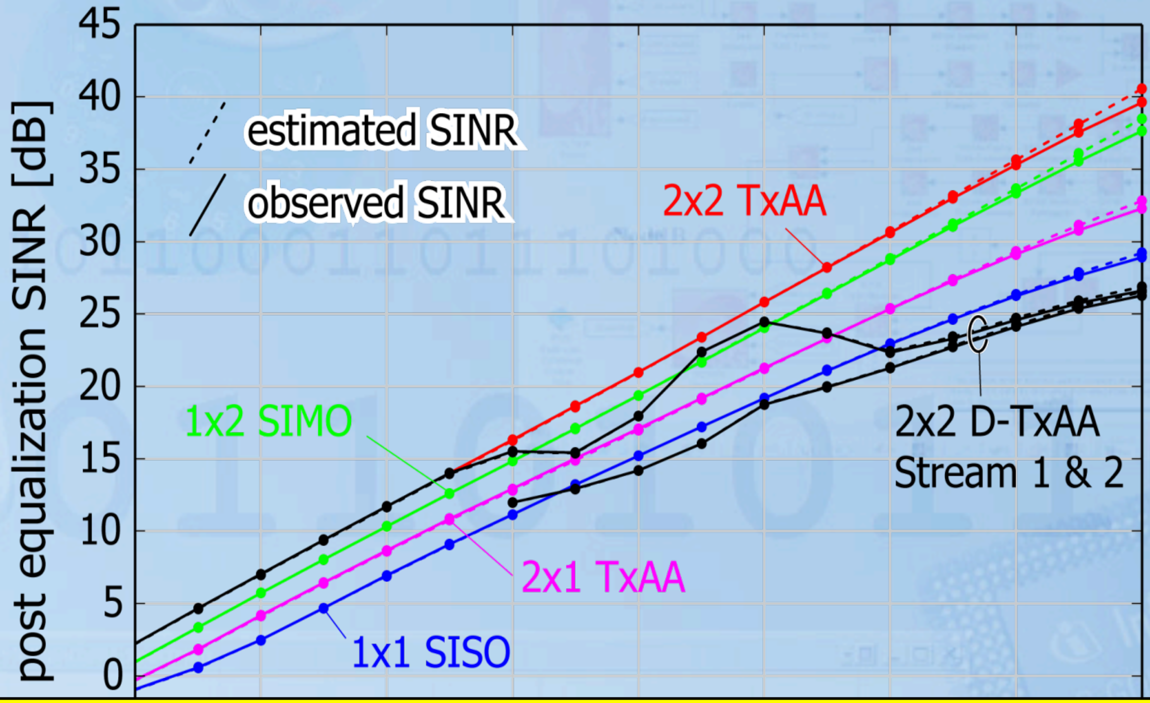
- MIMO WiMAX 802.16-2004
  OFDM physical layer
  - including channel coding and decoding
  - SISO and MIMO

- MIMO HSDPA (TxAA, DTxAA)
  CDMA physical layer
  - including channel coding and decoding
  - SISO and MIMO

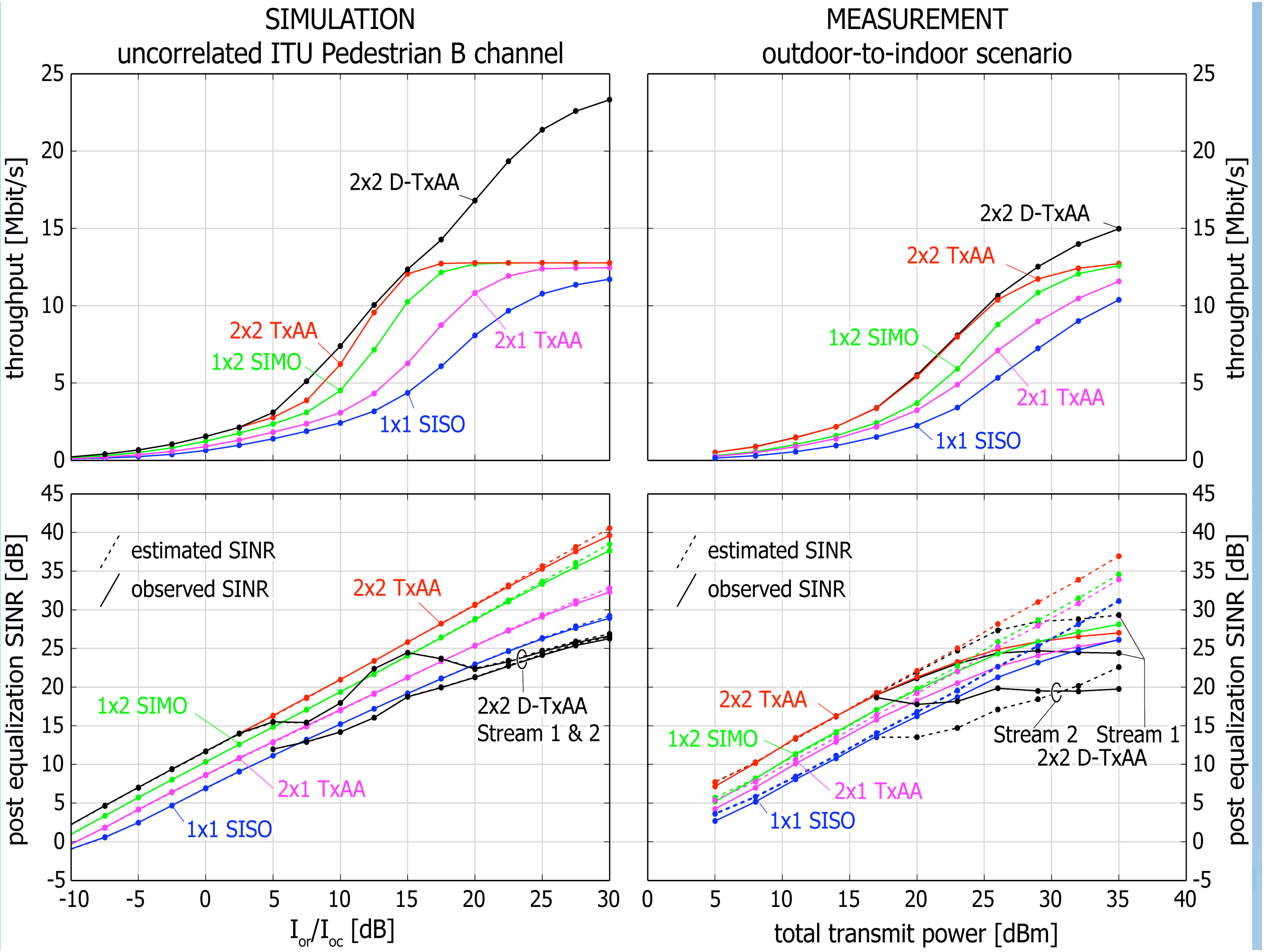


- S.Caban, C.Mehlführer, R.Langwieser, A.L. Scholtz, M.Rupp, "Vienna MIMO Testbed," in EURASIP JASP Special Issue on Implementation Aspects and Testbeds for MIMO Systems,Vol. 2006, Article ID 54868 (2006), http://publik.tuwien.ac.at/files/pub-et_10929.pdf.
- M.Rupp, C.Mehlführer, S.Caban, R.Langwieser, L.W. Mayer, A.L. Scholtz, "Testbeds and Rapid Prototyping in Wireless System Design," in EURASIP Newsletter, pp. 32-50,17 (2006)

Verification of the SINR Estimation in the Simulation



- C.Mehlführer, S.Caban, M.Rupp, "Experimental Evaluation of Adaptive Modulation and Coding in MIMO WiMAXwith Limited Feedback," in EURASIP JASP Special Issue on MIMO Transmission with Limited Feedback,Vol. 2008, Article ID 837102
- C.Mehlführer, S.Caban, M.Wrulich,M.Rupp, "Joint Throughput Optimized CQI and PrecodingWeight Calculation for MIMO HSDPA," 42nd Asilomar Conference on Signals, Systems and Computers, 2008, Pacific Grove, CA, USA, Oct. 2008.



SIMULATION
uncorrelated ITU Pedestrian B channel
MEASUREMENT
outdoor-to-indoor scenario
throughput [Mbit/s]
2x2 D-TxAA
2x2 TxAA
1x2 SIMO
2x1 TxAA
1x1 SISO
post equalization SINR [dB]
estimated SINR
observed SINR
2x2 D-TxAA
Stream 1 & 2
Stream 2
Stream 1
I_{or}/I_{oc} [dB]
total transmit power [dBm]

Automatic Tools

- Some tools allow for automatic conversion of algorithms onto a hardware platform:
  - TIs C6x DSPs (and some others by now) can fully and efficiently be programmed in ANSI-C.
  - MATLAB supports several platforms with C6x DSPs!
  - Xilinx and Altera FPGAs can be programmed directly from a fixed-point MATLAB box.

Automatic Tools

- However, such tools are often inconsistent and inefficient.
- Mixed DSP-FPGA solutions are not supported!
- We therefore developed our own method to support mixed DSP and FPGA designs directly from MATLAB.

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  "Rapid Prototyping for Wireless Designs: The Five-ones Approach,"
  Signal Processing, Vol. 83, Issue 7, July 2003.
- G. Brandmayr, G. Humer, and M. Rupp:
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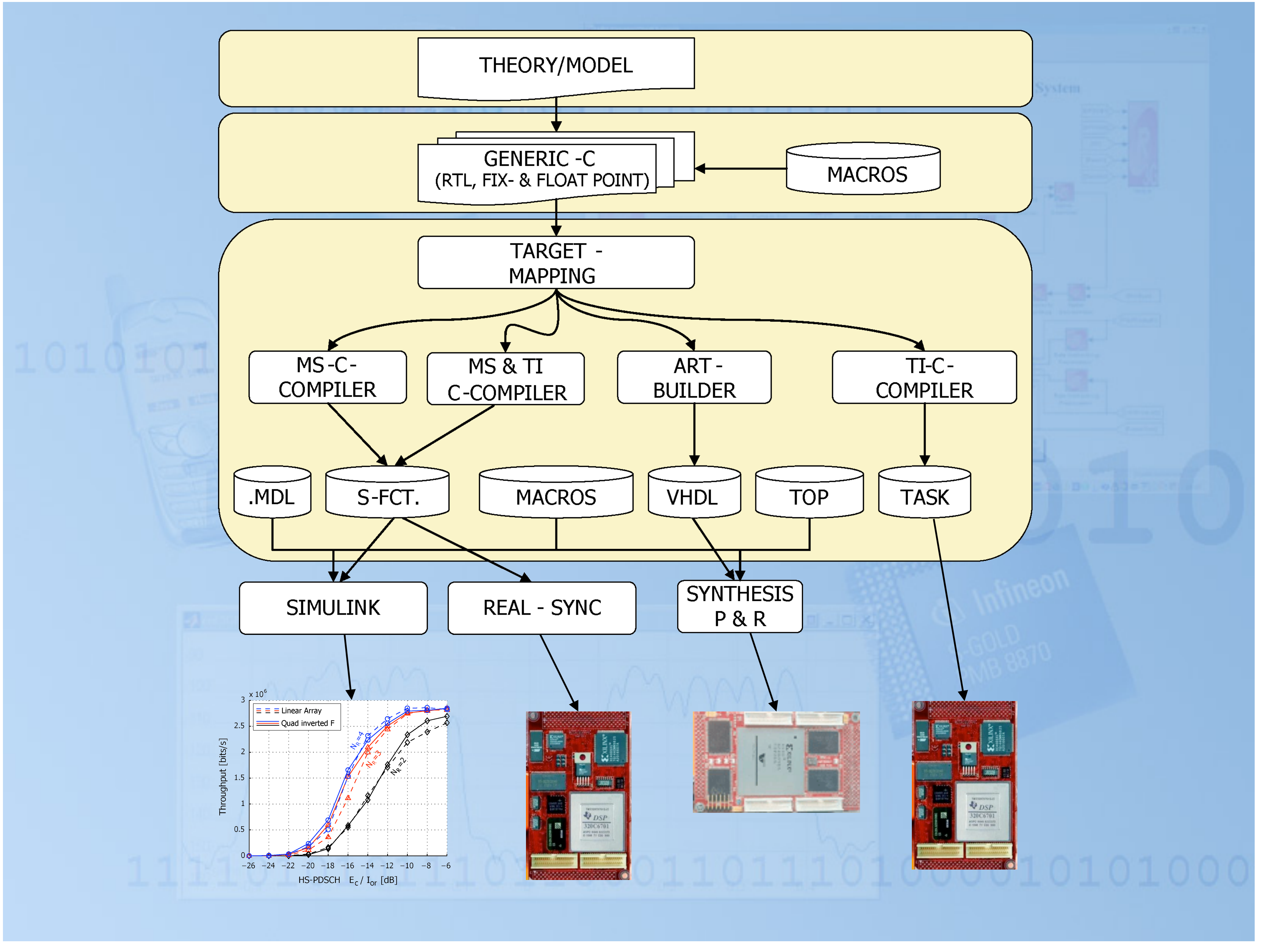
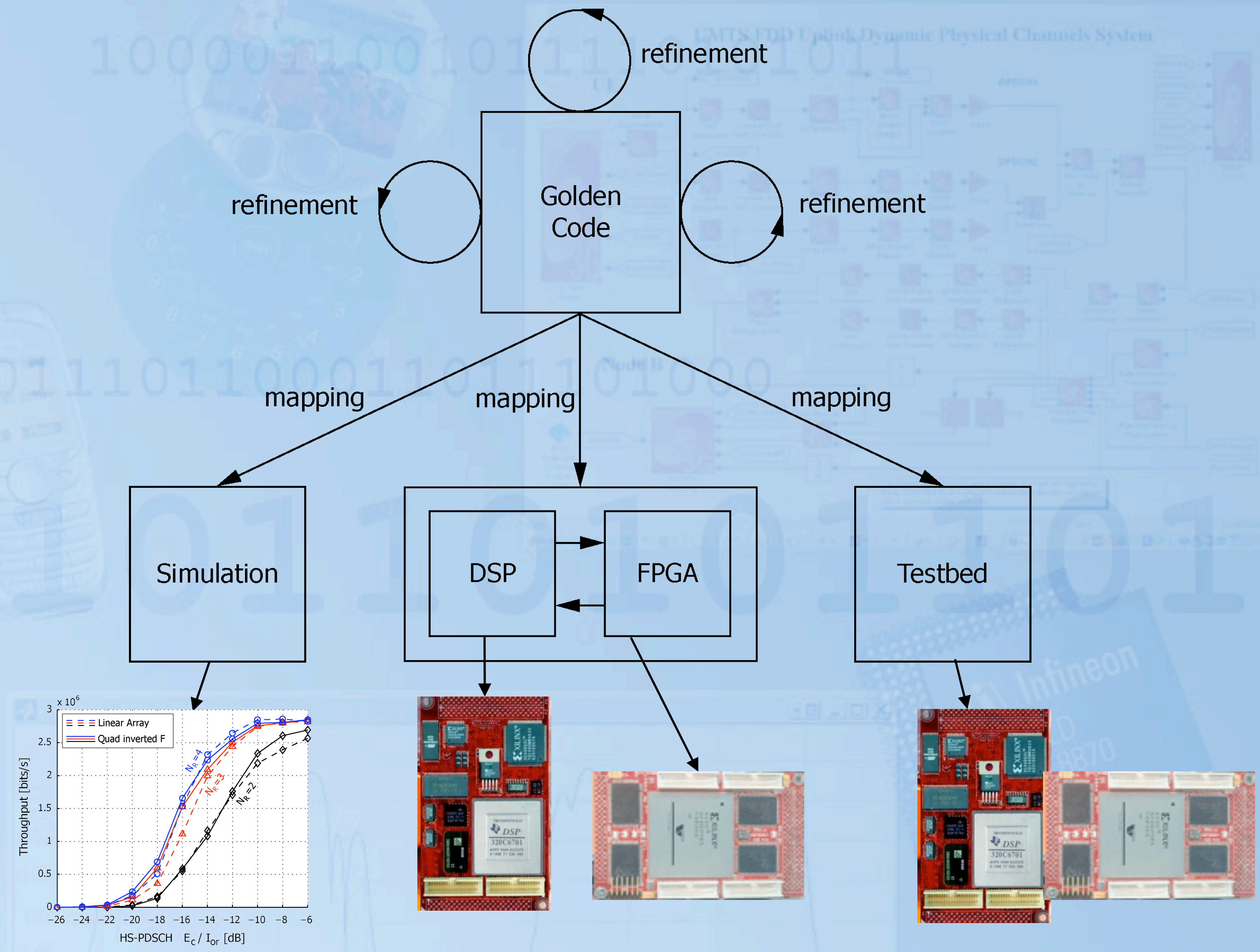


THEORY/MODEL
GENERIC -C
(RTL, FIX- & FLOAT POINT)
MACROS
TARGET -
MAPPING
MS -C -
COMPILER
MS & TI
C-COMPILER
ART -
BUILDER
TI-C -
COMPILER
.MDL
S-FCT.
MACROS
VHDL
TOP
TASK
SIMULINK
REAL - SYNC
SYNTHESIS
P & R
Linear Array
Quad inverted F
Throughput [bits/s]
HS-PDSCH E c / I or [dB]



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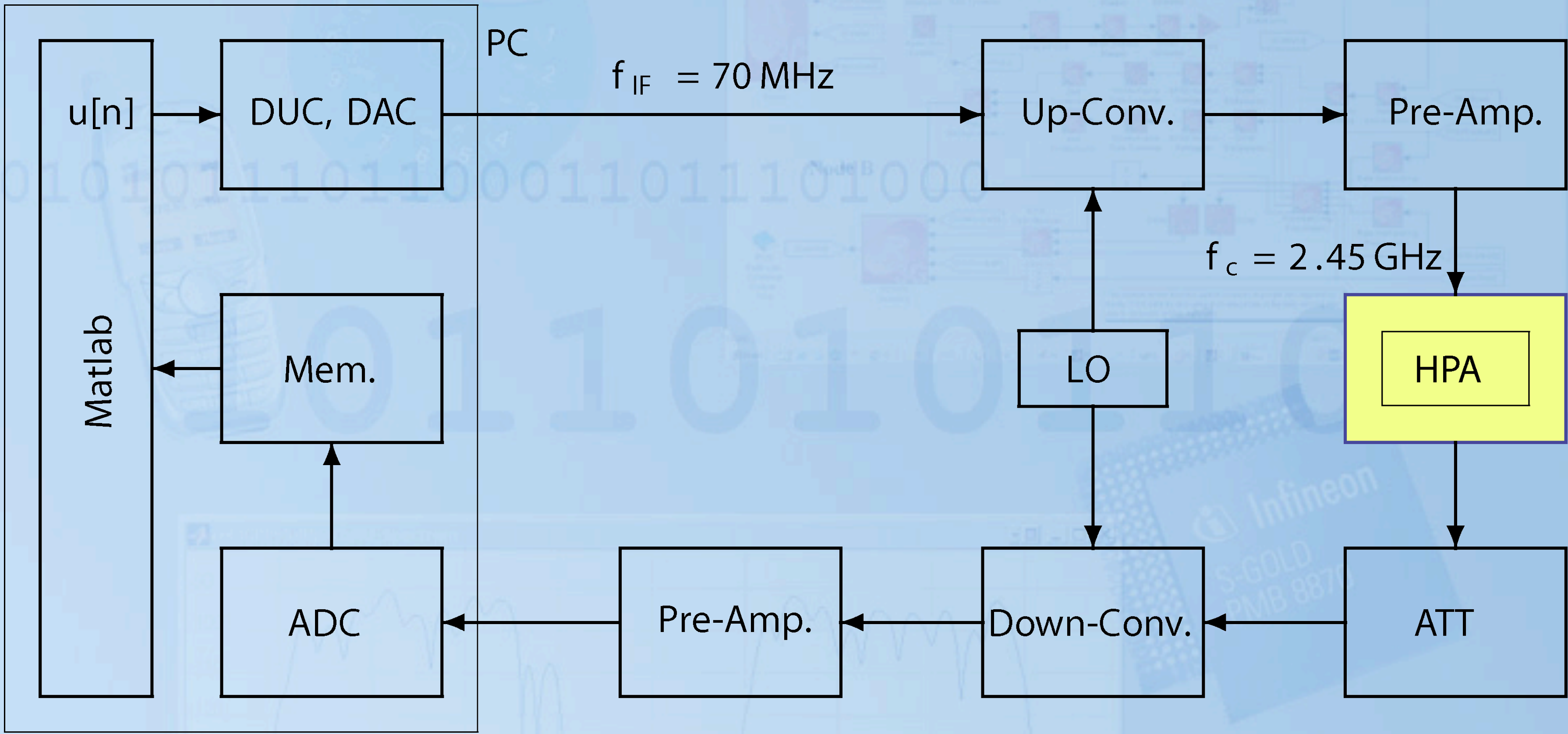
Prototype Example: Adaptive Predistortion Technique



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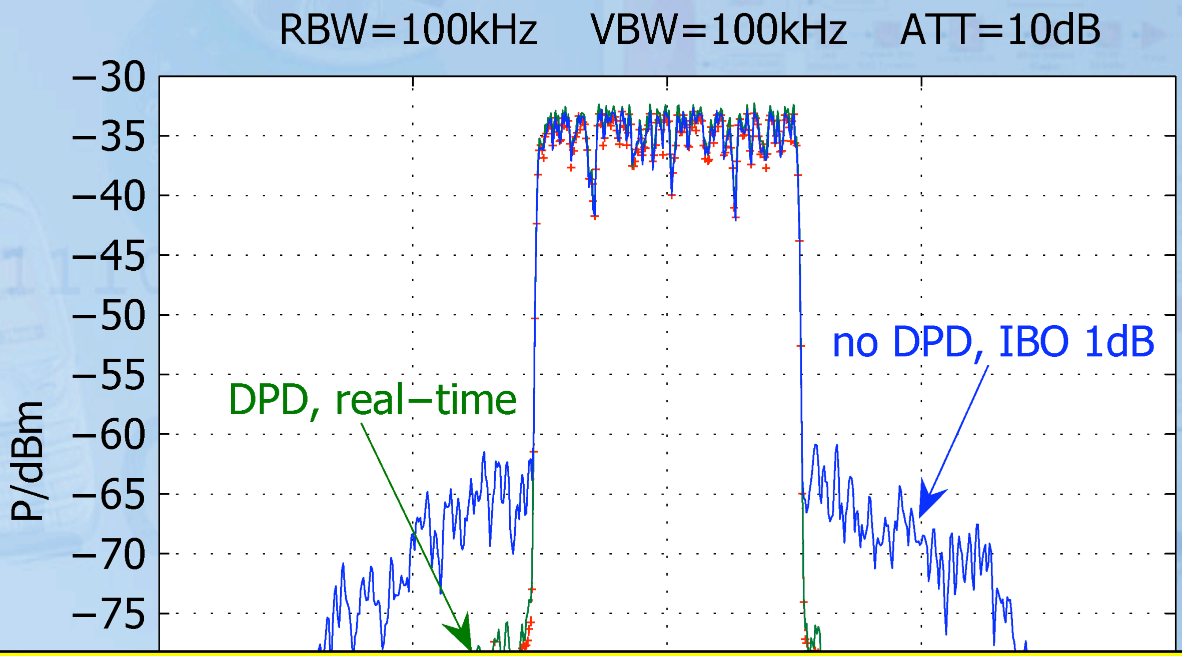
Prototype Example: Adaptive Predistortion Technique



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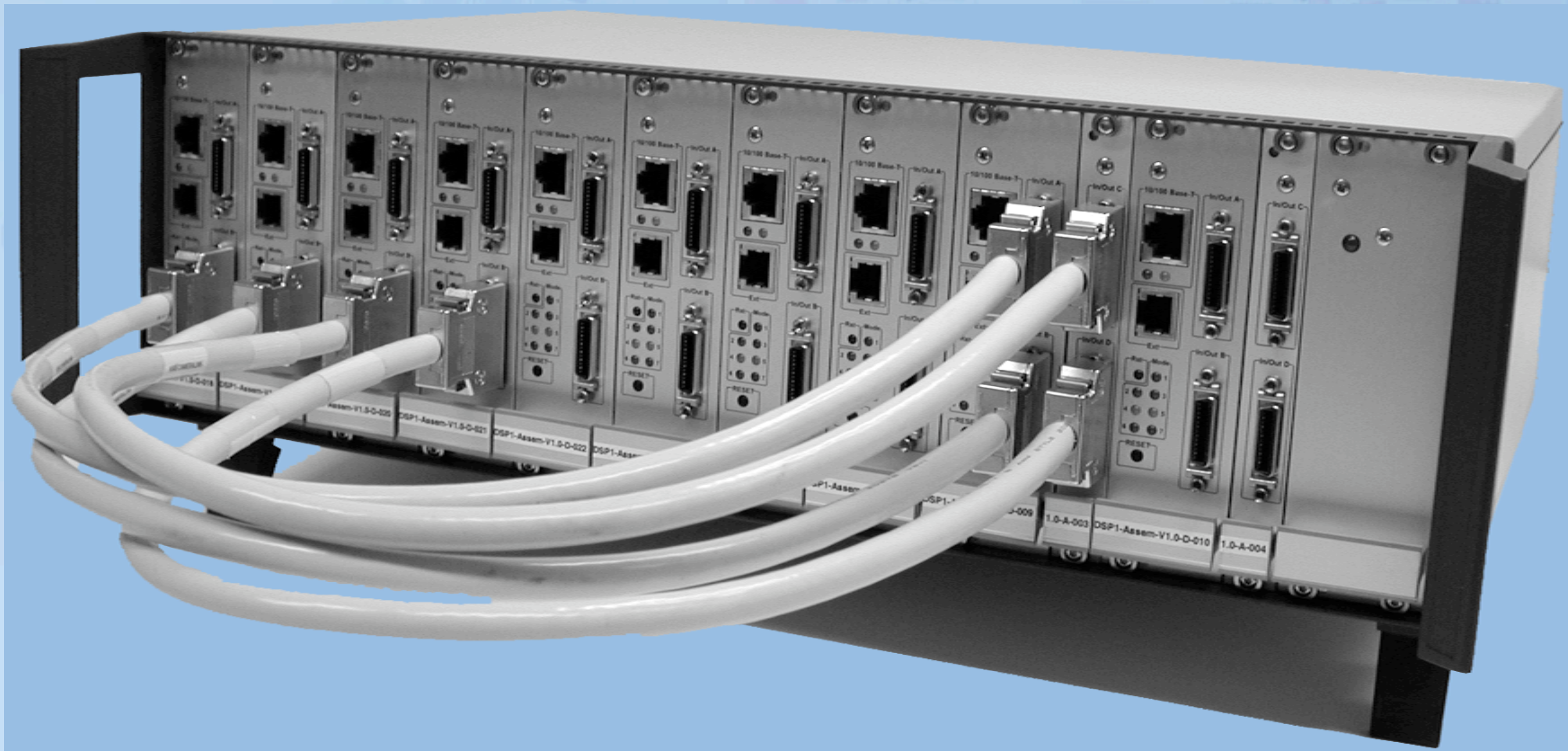
- M.Y.Cheong, E.Aschbacher, P.Brunmayr, M.Rupp, T.Laakso, "Comparison and Experimental Verification of Two Low-complex Digital Predistortion Methods," Proc. of Asilomar Conference, Oct. 2005.
- E.Aschbacher, M.Y.Cheong, P.Brunmayr, M.Rupp, T.Laakso, "Development and Prototype Implementation of Two Efficient Low-Complexity Digital Predistortion Algorithms," EURASIP Journal on Advances in Signal Processing, vol. 2008.

Prototype Example: RFID Reader

- Current state:
  - Different standards for different applications

- Demands:
  - Multi standard, multi frequency
  - One tag / reader system for many application scenarios
  - Rapid implementation: highly automated code generation, simulation and exploration on different levels
  - Evaluate influence of parameters (link timings, codings etc.)

Prototype Example: WLAN



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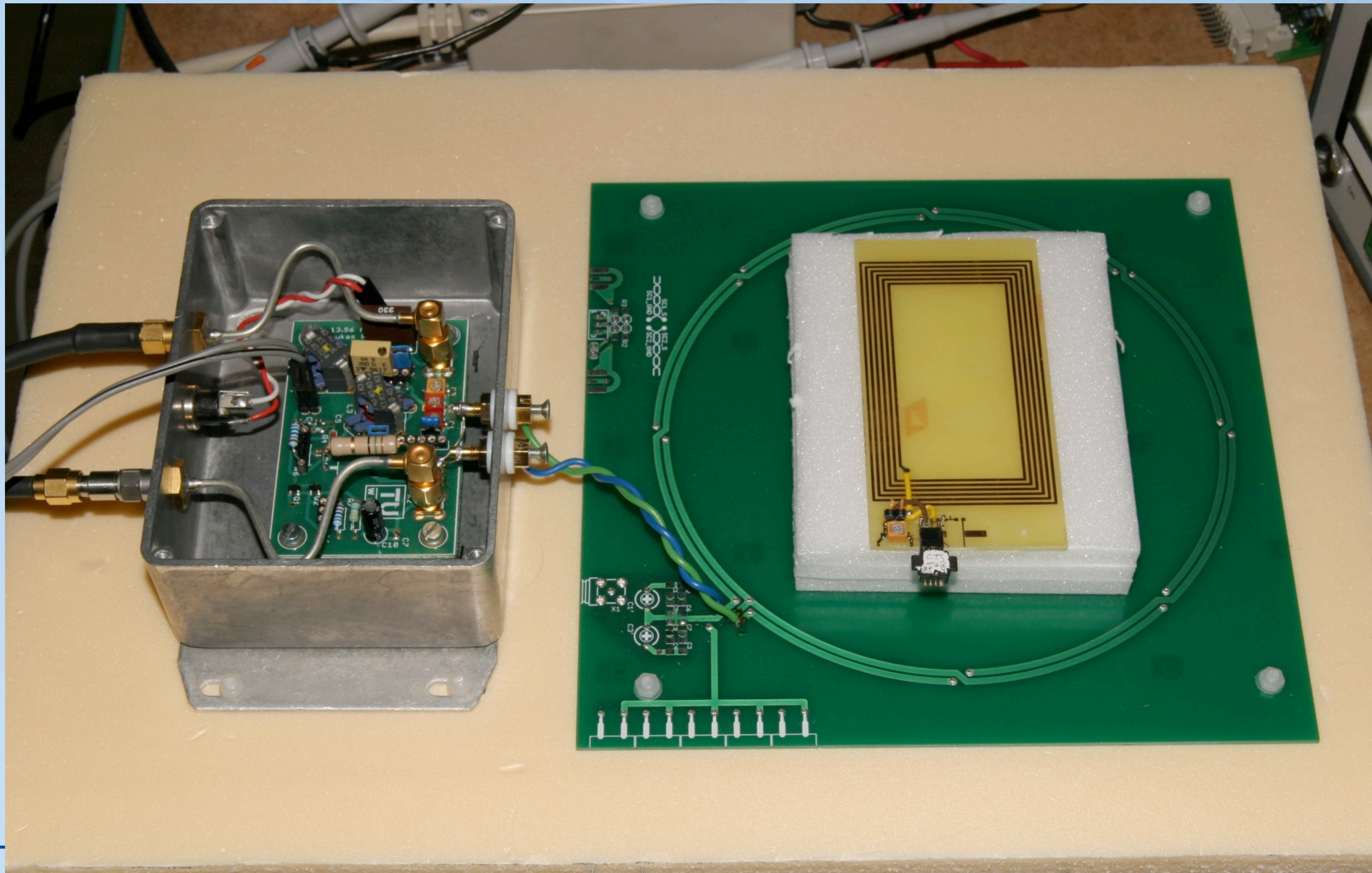
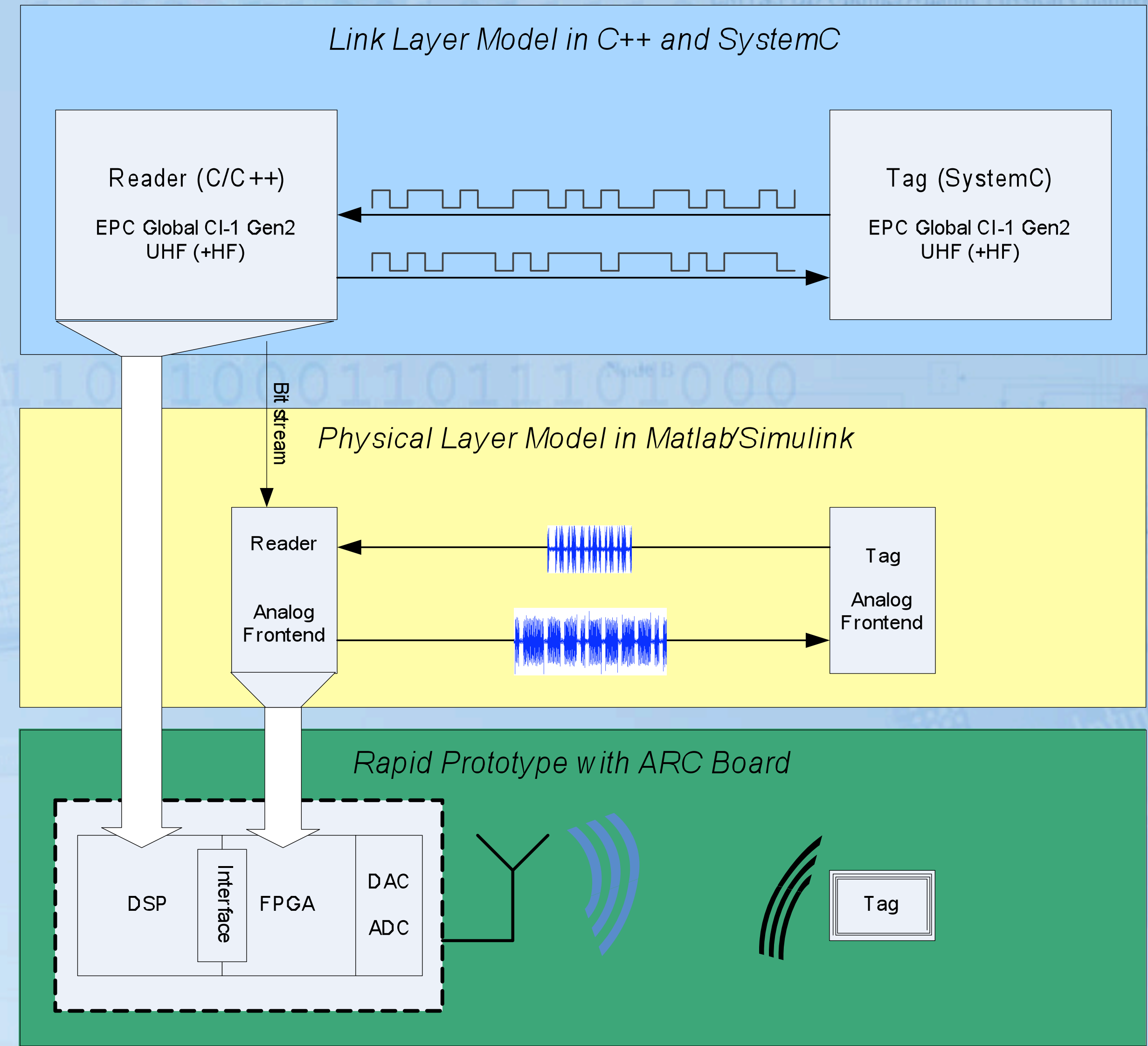
HF-Frontend with Tag



Design flow



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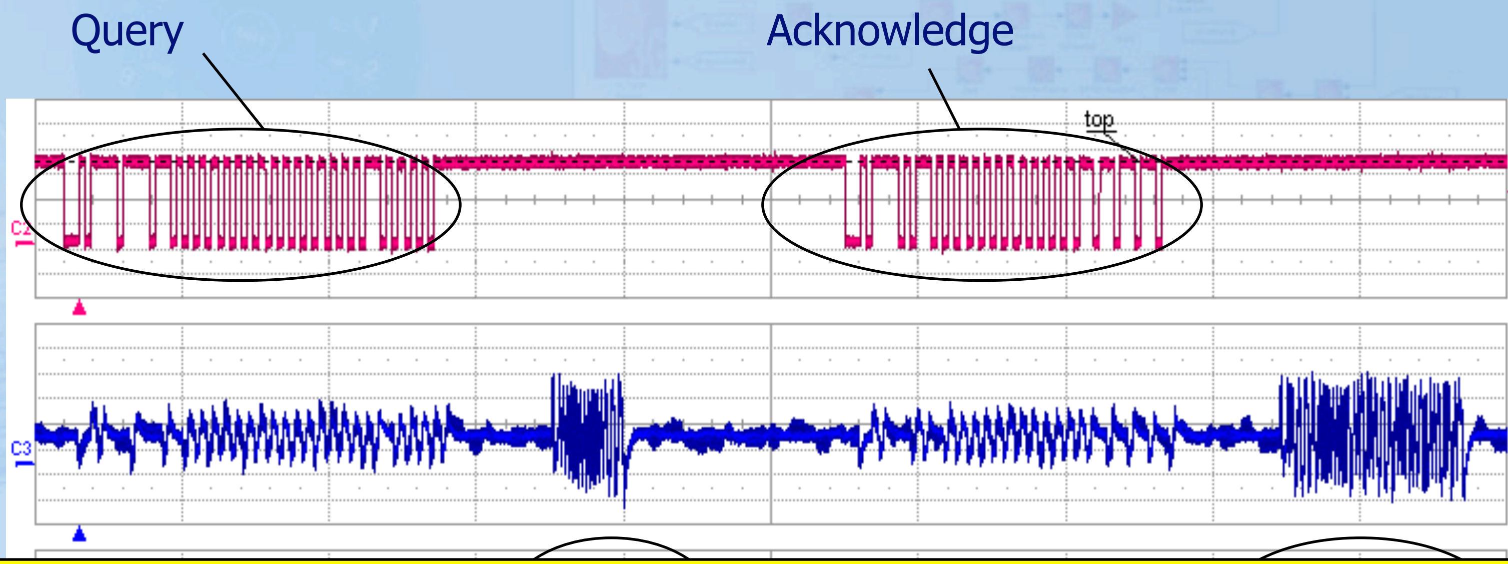
Query + Acknowledge

- EPC global HF draft



Dig. output signal

RX signal before slicer

Dig. RX sig

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Conclusions

- Rapid Prototyping and testbeds are a real need in wireless industry.
- Available methods for Rapid Prototyping are rare, cover only fractions of the entire design flow, and are typically not consistent, delaying the design process.
- Let's put more focus on design methods rather than algorithmic design.

Thank you for your attention!

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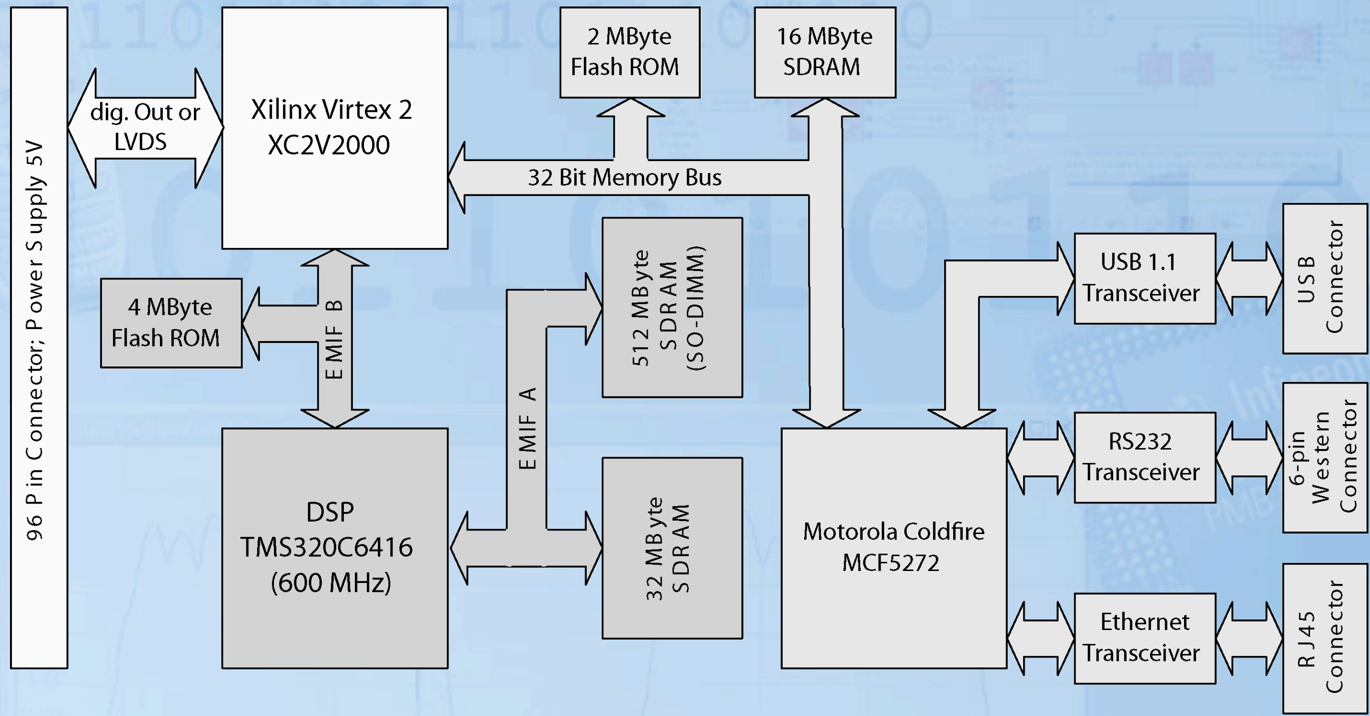
Prototype Example: WLAN

- OFDM based wireless systems like WLAN and WiMAX are currently a hot topic for standardization, working at 2.4, 3.5, 5.2, 5.8 and 11.0 GHz.
- Flexible hardware prototypes are required not only for testing the anticipated behavior in physical wireless channels but also to gain experience in building such devices.
- For this reason, ARCS has extended their rapid prototyping environment towards OFDM.
  - Scalable 802.11n MIMO system
  - Scalable 802.16 MIMO system
  - Channel emulator implementing I-Metra Model
  - Flexible, modular RF front end

Prototype Example: WLAN

- Multiple boards with C6416 and Virtex-2
- Working either stand-alone or in connection



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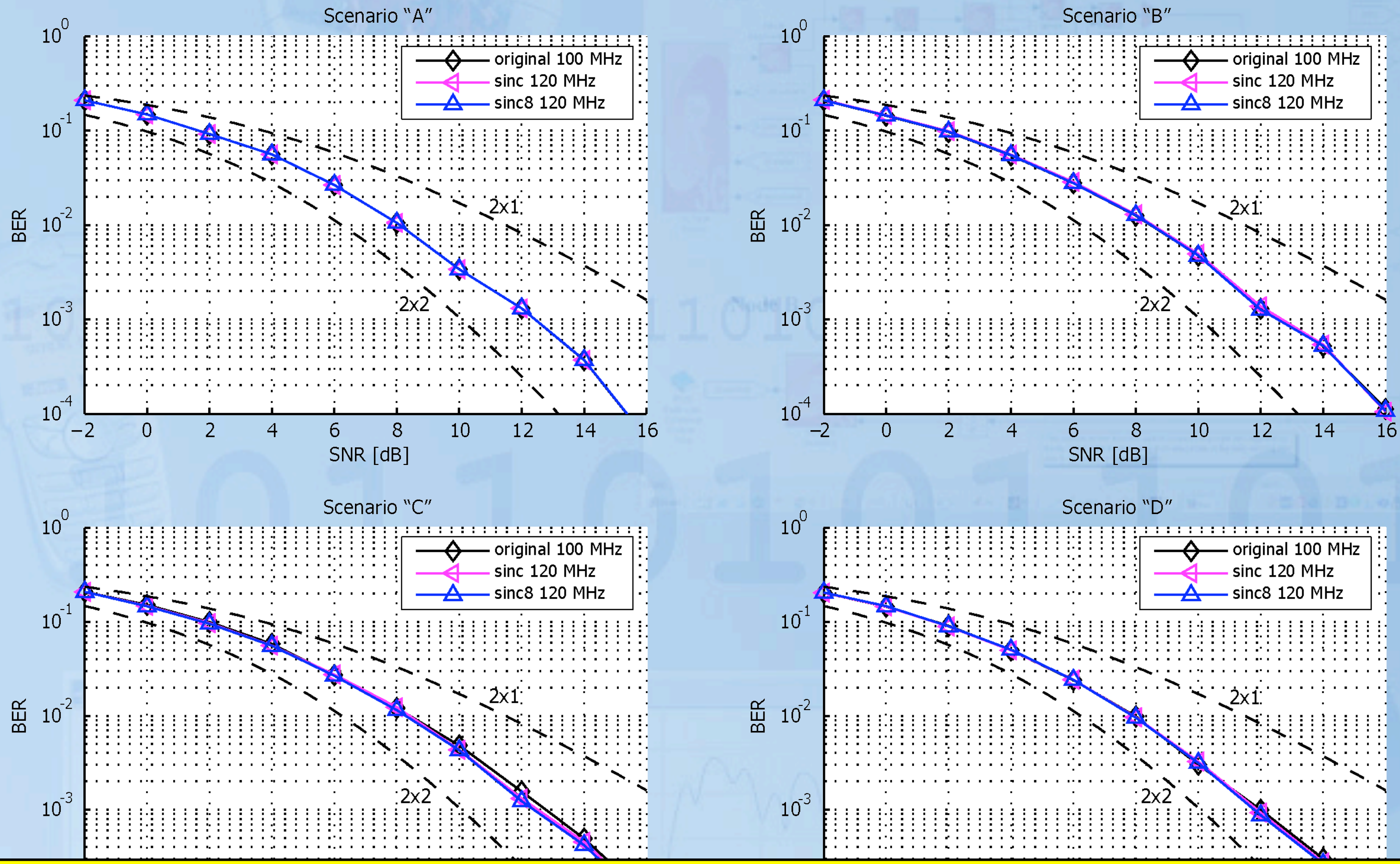
Prototype Example: WLAN



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