Model-Based RF Development in Complex Radio Systems – case: Power Amplifier Digital Pre-distortion

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Outline

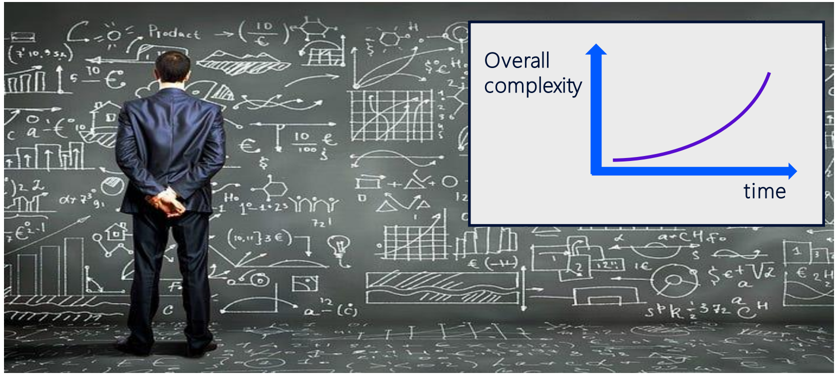
- Background and Motivation
- Trend for digital transformation in engineering
- Iterative model-based radio design flow – high level view
- Use-Case: PA linearization with DPD technique
  - Accurate PA behavioural modelling
  - PA-DPD sub-system design & verification flow
- Importance of simulation confidence and how to build it
- Comparison of virtual PA-DPD simulation results with measurements

Background – ever increasing complexity

Moving towards 6G communications

Complexity of massive MIMO radio systems is getting higher

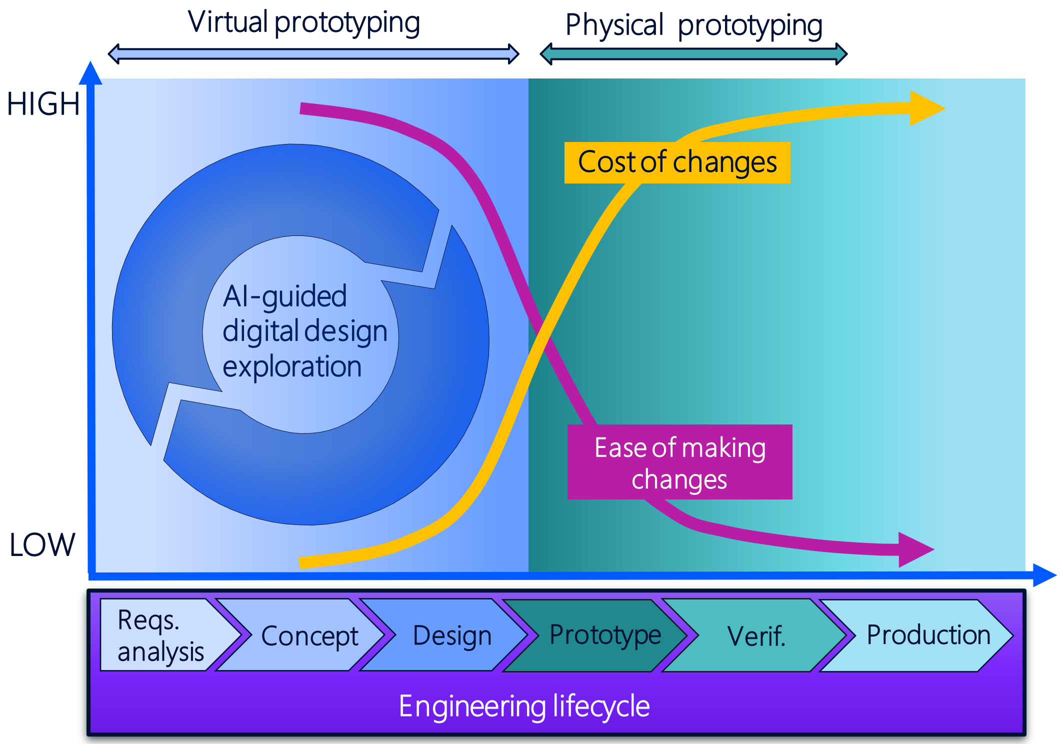
- SW code lines per radio > hundreds of millions…
- HW component count per radio > 30k…
- More signal processing at the radio
- Higher operating frequencies up to sub-THz range
- 2.5/3D SoC chiplet designs & higher power densities
- Product requirements > 1k….
- Customer use-cases > 1k…
- ML/AI embedded inside a radio



  AI-powered 6G networks will reshape digital interactions | MIT Technology Review

Solution – Digital Engineering

Model-based & automated AI guided design processes



Engineering transformation to digital era

Digital Twins

Digital Thread

Agile HW & SW development

AI powered data analytics

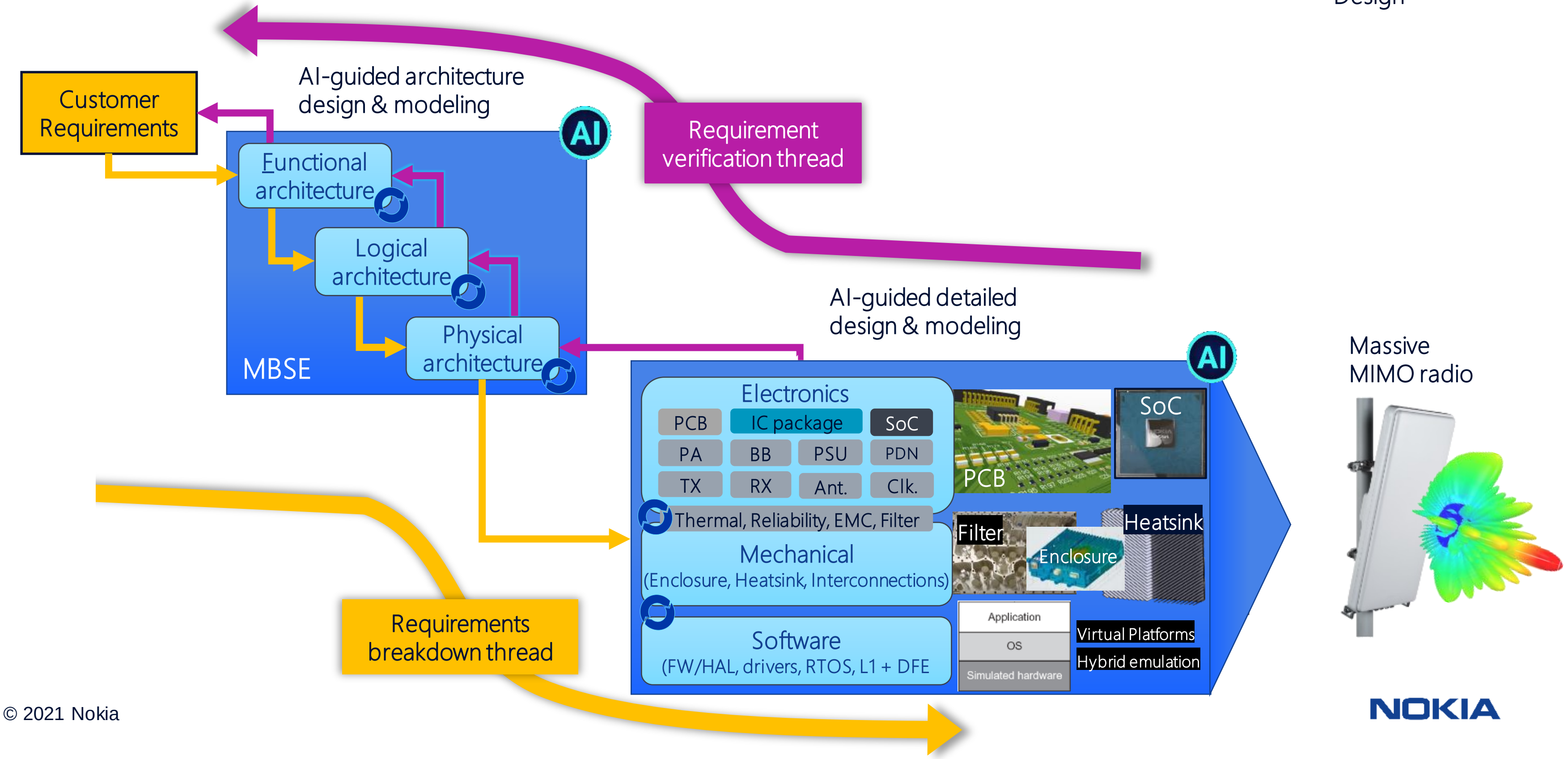
Cloud Computing

Industrial Metaverse

COST-BENEFIT ANALYSIS IN MODEL-BASED SYSTEMS ENGINEERING: STATE OF THE ART AND FUTURE POTENTIALS

Iterative Model Based Radio Design Flow

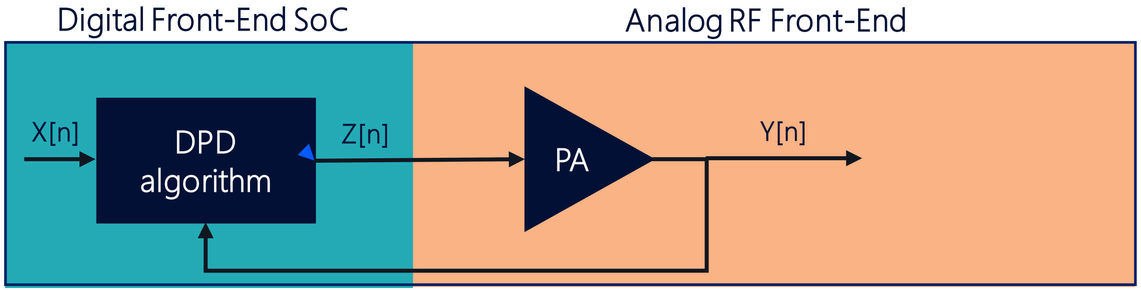
Requirement and design decomposition and close-loop verification

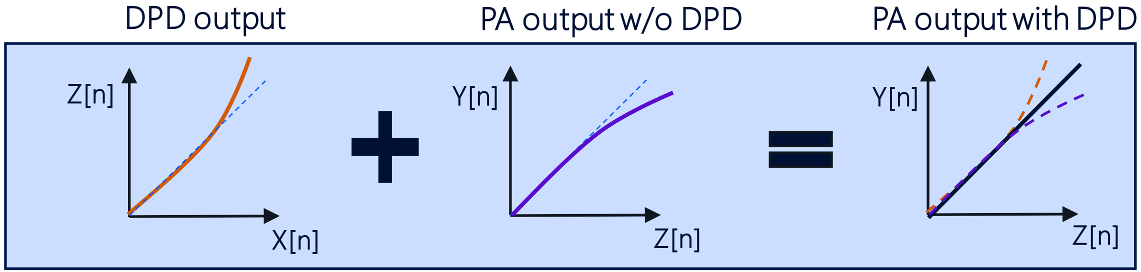


MBD case: Power Amplifier (PA) linearization with DPD technique

Why Digital Pre-Distortion (DPD) is needed ?

The DPD signal processing algorithm compensates for an amplifier's nonlinearities, letting it operate in its nonlinear region for maximum power efficiency.





Typical DPD challenges in 5G/6G systems

- Wide iBWs
- Multiband & Multi-carrier operation
- Massive MIMO
- TDD operation

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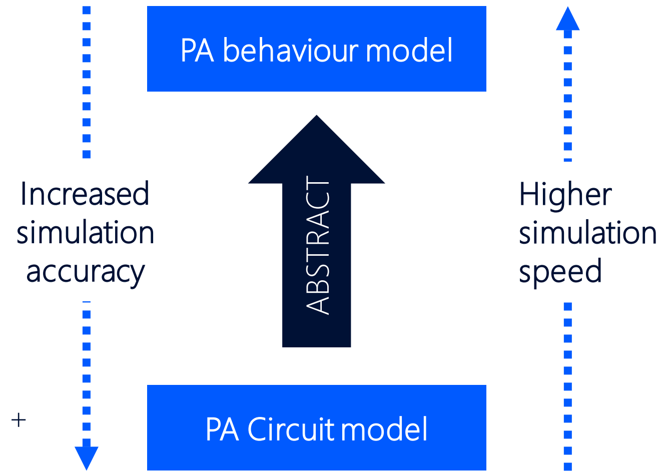
Power Amplifier (PA) modelling

Raising the model abstraction level for speeding up the system simulations

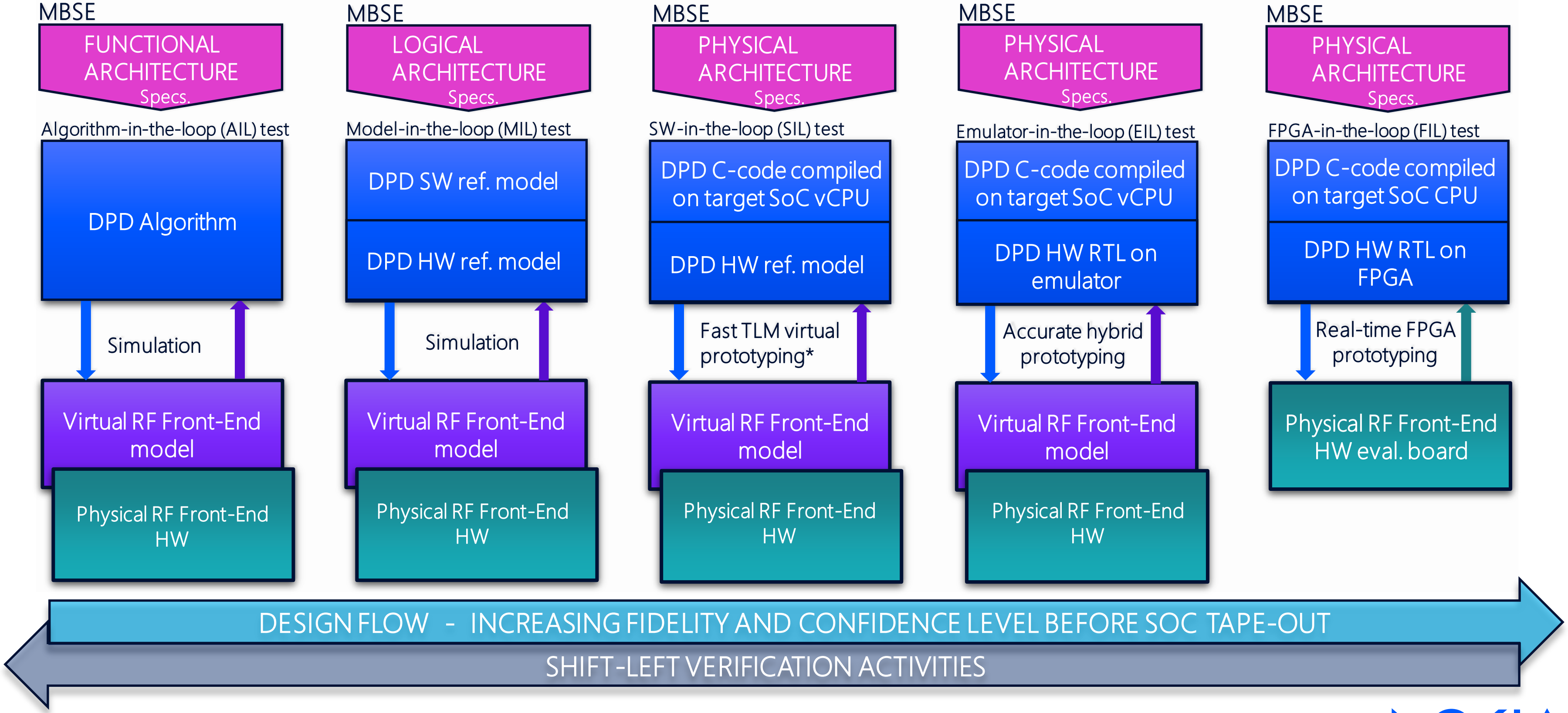
- The models of PA transistors or integrated modules are typically provided as compact circuit models from the device vendors
- The compact circuit models are computationally very slow for sampled communication systems
- It is possible to generate a fast behavioral model from a circuit-based PA simulations or measurements, and still provide sufficient accuracy including following important RF impairment effects:
  - Non-linearities
  - Short & long-term memory effects
  - Load-pull effects (optional)
- The PA-DPD sub-system simulation time can be reduced from <u>tens of hours to minutes</u> with the use of a behavioral model.

Trade-off between models



PA-DPD sub-system design & verification flow

MBSE driving for AIL/MIL/SIL/EIL/FIL verification tests



*) A Virtual TLM prototype can fully mimic the functionality of a target System-on-Chip (SoC) and run embedded SW code on it.

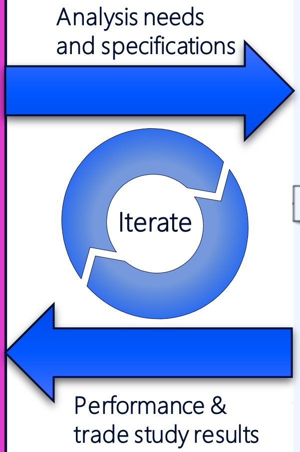
PA-DPD Functional Architecture Verification

Algorithms-in-the-loop (AIL) test with a virtual PA model

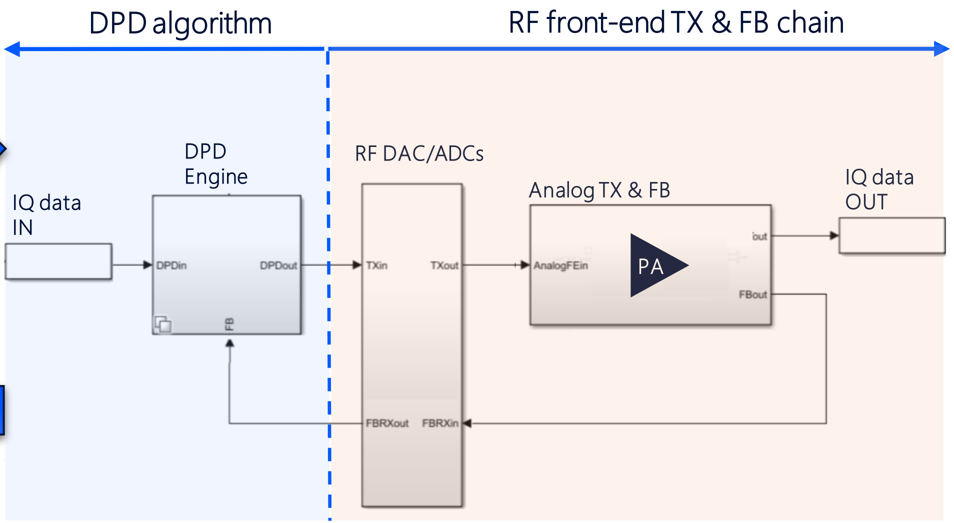
Functional DPD architecture Model

MBSE diagram

- The functional system model of the PA-DPD is verified using the AIL simulation process shown on the right.
- After simulation the system requirements can be validated.



Virtual executable PA-DPD test setup in Simulink



Typical simulation outputs: SNR, Pave, PAR, ACLR, EVM, AM/AM, AM/PM

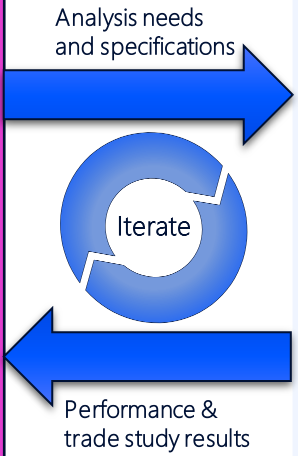
PA-DPD Functional Architecture Verification

Algorithm-in-the-loop (AIL) test with a real physical PA

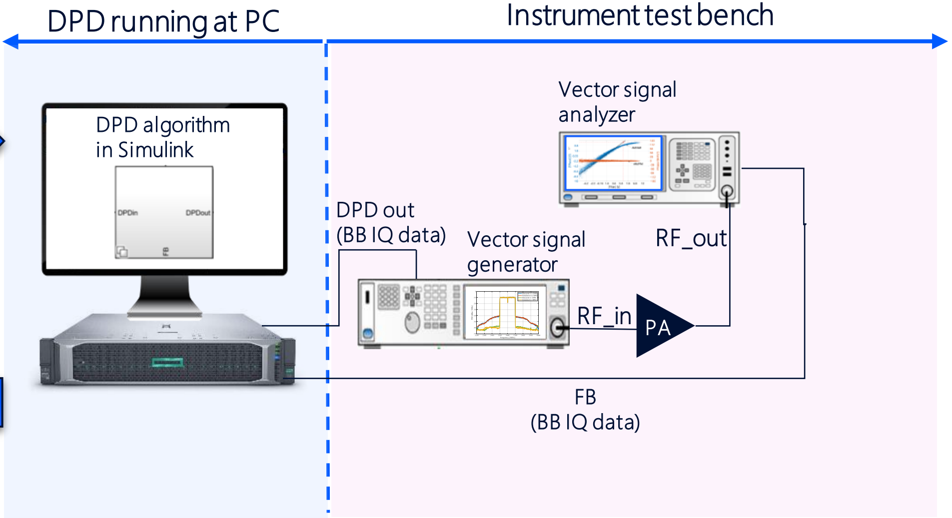
Functional DPD architecture Model

MBSE diagram

- The functional system model of the PA-DPD is verified using the hybrid AIL process shown on the right.
- After simulation the system requirements can be validated.



Hybrid PA-DPD test setup



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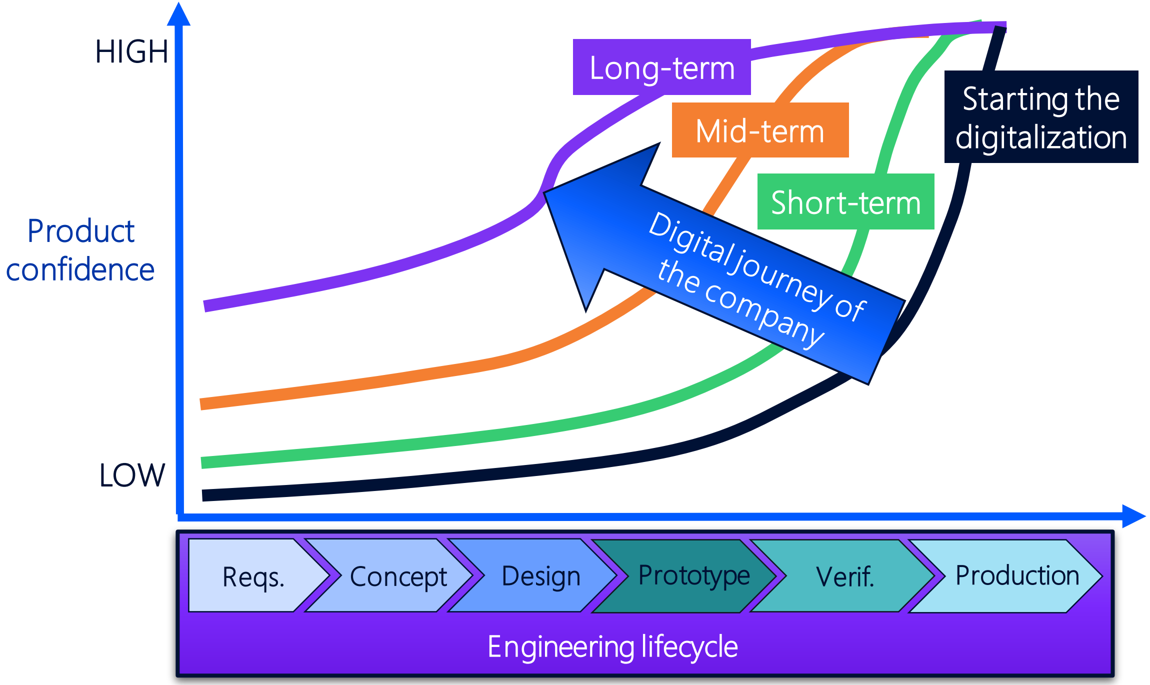
Simulation confidence

Digital engineering success is linked with confidence



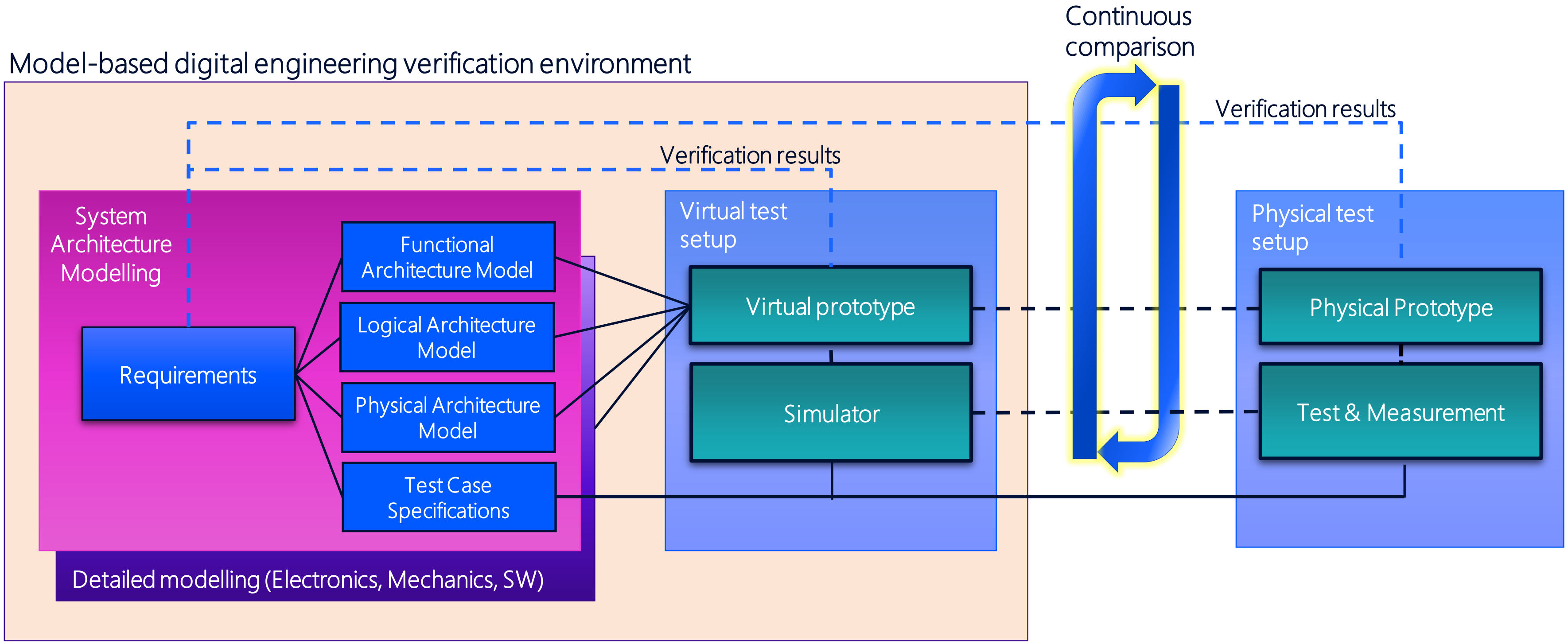
Improving simulation confidence at all design abstraction levels is one of the key goals in digital engineering transformation.

High-confidence on early results will maximize business value in terms of TTM*, Cost, Quality.

TTM* = Time-To-Market

Building the simulation confidence

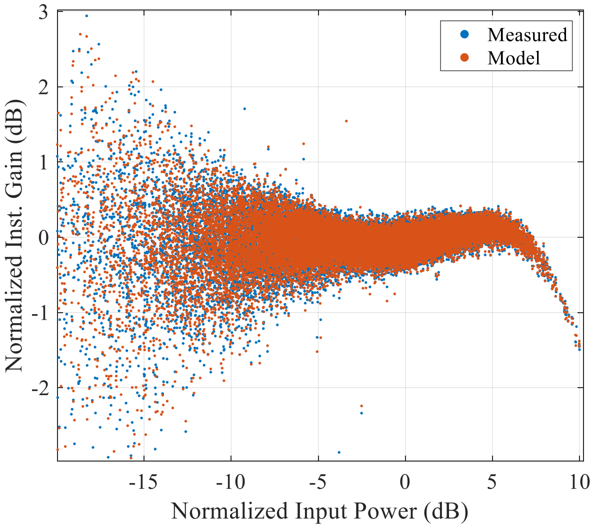
Continuous comparison of virtual prototypes against real prototypes



Practical PA-DPD system analysis example with AIL tests

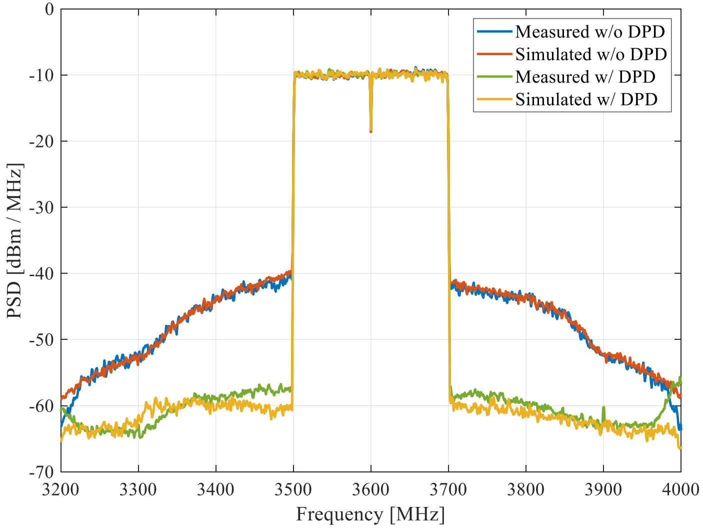
Comparison of simulations and measurements at instantaneous signal BW of 200 MHz

Normalized dynamic gain of a PA, showing its memory and non-linearity effects w/o DPD



Modulated input signal = 2 x 100 MHz 5G-NR

RF spectrum of a PA output with and w/o the DPD algorithm



Modulated input signal = 2 x 100 MHz 5G-NR

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