What are we going to talk about?

- How MATLAB and Simulink can be used in a wireless system design workflow
- Wireless Scenario Simulation
- End-to-end Simulation of mmWave Communication Systems with Hybrid Beamforming
- Developing Power Amplifier models and DPD algorithms in MATLAB
- Use of National Instruments PXI for PA characterization with DPD
Common Platform for 5G Development

Mobile and Connectivity Standards

Unified Design and Simulation

Prototyping and Testing Workflows
What differentiates high data rate 5G systems from previous wireless system iterations?

- High data rates (>1 Gbps) requires use of previously “under-used” (mmWave) frequency bands
  - mmWave requires MIMO architectures to achieve same performance as sub-6GHz
    - Lower device power and high channel attenuation

- Antenna array, RF, and digital signal processing cannot be designed separately!
  - Large communication bandwidth → digital signal processing is challenging
  - High-throughput DSP → linearity requirements imposed over large bandwidth
  - Wavelength ~ 1mm → small devices, many antennas packed in small areas
How is the presentation set up?

**Scenario Modeling**

**Link Level Modeling**

**TRANSMITTER**

- Baseband
- Digital Front End
- Digital PHY
- DAC
- PA
- RF Front End
- LNA
- Antenna

**RECEIVER**

- RF Chain
- Analog Front End
- WRF
- RF Chain
- WRF
- Digital Combiner

**Hardware**

**MATLAB EXPO 2019**
What is the most basic way we can look at a wireless link?

- **Scenario Level Modeling**
  - RF propagation
  - Multi-transmitter scenarios
  - Coverage
What relevant items need to be included to analyze a realistic 5G coverage scenario?

- Multiple Transmitter Scenario for analyzing SINR
  - Frequency = 4GHz
  - TX power = 44dBm
  - Antenna height = 25m
  - Model 19 adjacent cells
  - Each cell has 3 sectors
What are the different scenarios that can be analyzed?

- Select unique RF propagation scenarios such as ‘Close-in’ and ‘Rain’ propagation models.
- Choose different antenna elements and array configurations to maximize coverage.
What are the different use cases for Antenna Toolbox?

Antenna Element and Array Design

Visualization and Analysis of 3rd party Antenna Data

RF Propagation Visualization and Analysis
What type of fidelity do we want to add to a physical layer model?

- **RF Front End**
  - Noise budget
  - Gain
  - Non-linearity
  - Tx linearization

- **Antennas**
  - Arrays
  - Beamforming
  - Propagation effects
  - Loading
Why do link level modeling for a 5G mmWave system?
What needs to be included in a 5G system model to describe typical operation?

- Include fidelity that comprises of array behavior, channel modeling, spatial multiplexing and pre-coding and basic hybrid beamforming
What comprises the behavior between the Tx and Rx antenna?

- Channel and RF propagation behavior

Signal Attenuation  Wideband performance  Scatter-rich propagation
What is Hybrid Beamforming?

Beamforming done in two stages:
- RF Beamforming (phase shifters in RF front ends)
- Digital Beamforming (digital filtering of baseband signal)
Why do you want to add RF (System-Level) models to your PHY layer model?

- Design the architecture and define the specs of the RF components
- Integrate RF front ends with adaptive algorithms such as DPD, AGC, beamforming
- Test and debug the implementation of the transceiver before going in the lab
- Use models and measured data to gain insights in your design
- Provide a model of the RF transceiver to your colleagues and customers
Circuit Envelope to Trade-off Fidelity and Speed

Equivalent Baseband

Circuit Envelope

True Pass-Band

Modeling fidelity
PA Linearization: Digital Pre Distortion (DPD) in Practice

Baseband

Adaptive coefficients

Up-conversion

Timing

Down-conversion

RF

Antenna loading

Pin [dBm]

Pout [dBm]

PA characteristic

(actual)

Compression

Memory

DPD characteristic

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PA Modeling Workflow

- Get I/Q (time domain, wideband) measurement data from your PA
- Fit the data with a memory polynomial (extract the coefficients) using MATLAB
- Verify the quality of the polynomial fitting (time, frequency)

\[
y_{MP}(n) = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} a_{km} x(n - m) |x(n - m)|^k. \\
\]

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<tr>
<td>-67.4772 - 80.6146i</td>
<td>-20.3301 - 13.0211i</td>
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What resources are available to characterize a PA Model?

- PA Data
- MATLAB fitting procedure (White box)
- PA model coefficients
- PA model for circuit envelope simulation
Why is static DPD modeling not enough for 5G systems?

- Circuit Envelope for fast RF simulation
- Low-power RF and analog components
  - Up-conversion / down-conversion
  - Antenna load
- Digital signal processing algorithm: DPD
Real-Life Example: AD9371 Transmitter + Observer
From Simulation to Implementation: HDL Code Generation

Automatically generate synthesizable HDL (Verilog / VHDL) code
- Make your model hardware “friendly”
- Estimate utilized resources
- Optimize model and generated code (speed, cost)
- Target FPGAs for rapid prototyping
How do we transition from software models to hardware?

- Implementing DPD in hardware
  - Data streaming
  - Prototype on hardware
Connecting System-Level Models to Hardware for Design and Verification
NI Front-End Module Test With DPD

- VST with 1 GHz instantaneous generation and analysis bandwidth
- Free NI-RFmx SpecAn with LUT, MPM, and GMP DPD models
- Free RFIC Test Software with DPD automation examples

1. Generate reference waveform and acquire distorted waveform
2. Create predistortion model by comparing reference waveform to distorted waveform
3. Apply DPD to reference waveform using predistortion model
4. Generate predistorted waveform and make measurements
Traditional T&M Setup for MATLAB Based PA Characterization with DPD Algorithm Running in MATLAB

- Familiar user experience for many engineers
- Slower measurement speed, Large physical footprint
- Expensive to upgrade or replace – even Software
- Difficult to synchronize for ET & DPD
- Tradeoffs between speed and accuracy
NI PXI Setup for MATLAB Based PA Characterization with DPD & ET Algorithm Running in MATLAB

- Similar user experience as box-instruments
- Faster and FPGA-accelerated measurement speed, at a fraction of the physical footprint
- Modularity for incremental upgrades
- Native synchronization technologies at sub nanosecond accuracy
- R&D grade measurement accuracy with production test speed
## Enabling Integrated Semi PA Design & Validation Flow Between LabVIEW & MATLAB

### Design (MATLAB)
- Stimuli
- DPD
- DUT
- Analysis

### Validation (LabVIEW)
- Stimuli
- DPD
- DUT
- Analysis

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High-Power PA w/ DPD HW Demo Setup

Wideband LDMOS Two-stage Integrated Power Amplifier 20 W + 40 W, 28 V, 1805 – 2200 MHz

SKU: PTNC210604MD-V1

The PTNC210604MD is a wideband, two-stage, LDMOS integrated power amplifier. It incorporates internal matching for operation from 1805 to 2200 MHz, and dual independent outputs with 20 W and 40 W of output power each. It is available in a 14-lead plastic overmold package with gull wing leads.

**Features**

- On-chip matching for broadband operation
- Typical CW performance, 2200 MHz, 28 V, combined outputs
  - Output power at P3dB = 63 W
  - Linear Gain = 28 dB
  - Efficiency = 50.5%
- Capable of handling 10:1 VSWR @28 V, 10 W mod avg output power
- Integrated ESD protection
- Human Body Model Class 1A (per ANSI/ESDA/JEDEC JS-001)
- Integrated temperature compensation
- Pb-free and RoHS compliant
PA Design Engineer’s View in MATLAB
Validation Engineer’s View in LabVIEW
Two Distinct Approaches to PA Characterization

Traditional Approach

- **Separate** workflow for design and validation
- **Different** waveforms, PA models, analysis algorithm
- **Expensive, large** footprint, **poor** synchronization

Platform-Based Approach

- **Integrated** workflow for design and validation
- **Same** waveforms, PA models, analysis algorithm
- **Modular, small** footprint, **sub-nanosecond** synchronization
Ultra High Band 5G FEM 3.3 – 4.2 GHz
400 MHz bandwidth
Rapidly tested with a wide variety of waveforms

"The wide bandwidth, excellent RF performance, and the flexibility of NI’s PXI test systems were critical in helping us introduce the industry's first commercially available 5G FEM. Qorvo’s focus on innovation was clearly demonstrated at the 20th GTI Workshop in London."
— Paul Cooper, Director of Carrier Liaison and Standards

5x faster test times
Reduced tester footprint by 50%
Saved Several Million $$$

"The measurement speed of PXI was very attractive to us. In fact, the VST’s measurement speed was about 5 times faster than our previous test equipment. This has allowed us to cut the characterization time for a typical LTE modem from one week to less than 2 days. With the additional testing that we were able to perform using PXI, we estimate that we have saved several million of dollars."
— Eike Rutkowski, Head of RF Cellular Hardware

Sub-6 GHz New Radio Sky5 (3.3 – 5.0 GHz)
200 MHz bandwidth
Tested with the PXIe-5840 VST

"We were able to reduce manufacturing test time of Power Amp (PA) by 5 times compared to existing test system by using NI VST to implement power sourcing on FPGA level."
— New Product Introduction (NPI) Team, Broadcom

"Skyworks is pleased to be utilizing NI’s RF VST to validate performance of our Sky5™ solutions for 5G NR applications. Using NI’s PXI platform, we are able to validate key performance benchmarks."
— Kevin Walsh, Senior Director of Mobile Marketing for Skyworks
Qualcomm UK Uses MATLAB to Develop 5G RF Front-End Components and Algorithms

Challenge
10x more waveform combinations in 5G than in LTE, making device validation much more complex and time-consuming

Solution
Use MATLAB to simulate hardware-accurate Tx and Rx paths to predict system performance and optimize design parameters.

Results
- Fully model RF transceiver and components
- Securely release sensitive IP
- Eliminate the cost of developing separate test suites

“We use MATLAB models to optimize and verify the 5G RF front end through all phases of development.”
Sean Lynch
Qualcomm UK, Ltd.

NanoSemi Improves System Efficiency for 5G and Other RF Products

Challenge
Accelerate design and verification of RF power amplifier linearization algorithms used in 5G and Wi-Fi 6 devices

Solution
Use MATLAB to characterize amplifier performance, develop predistortion and machine learning algorithms, and automate standard-compliant test procedures

Results
- Development time reduced by 50%
- Iterative verification process accelerated
- Early customer validation enabled

“With MATLAB, our team can deliver leading-edge IP faster, enabling our customers to increase bandwidth, push modulation rates higher, and reduce power consumption.”
Nick Karter
NanoSemi
Wrap up

- How MATLAB and Simulink can be used in a wireless system design workflow
- Wireless Scenario Simulation
- End-to-end Simulation of mmWave Communication Systems with Hybrid Beamforming
- Developing Power Amplifier models and DPD algorithms in MATLAB
- Use of National Instruments PXI for PA characterization with DPD
Learn More

- Where can you get more information about MathWorks tools for wireless system modelling?

  - MATLAB and Simulink for 5G Development
  - White paper: RF PA and DPD linearization using MATLAB and Simulink
  - White paper: Hybrid Beamforming for 5G Systems