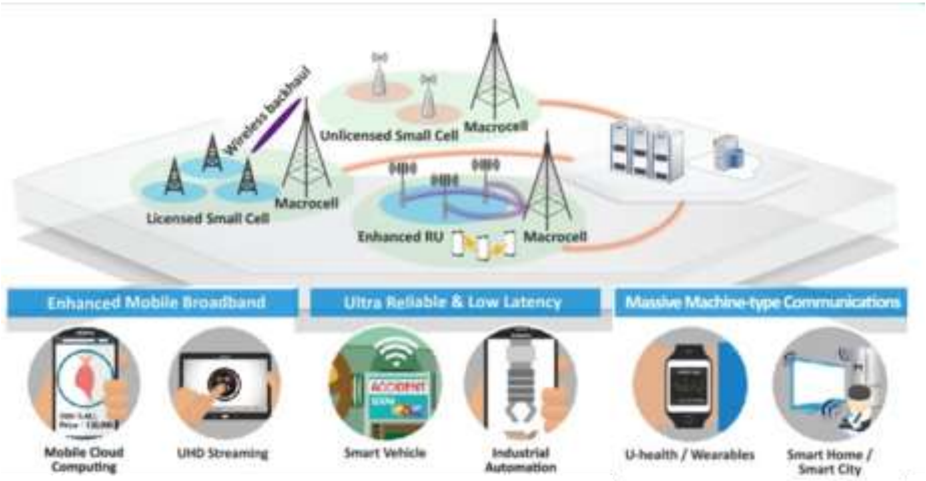
MATLAB EXPO 2018

What's Behind 5G Wireless Communications?

Tabrez Khan
Application Engineering Group

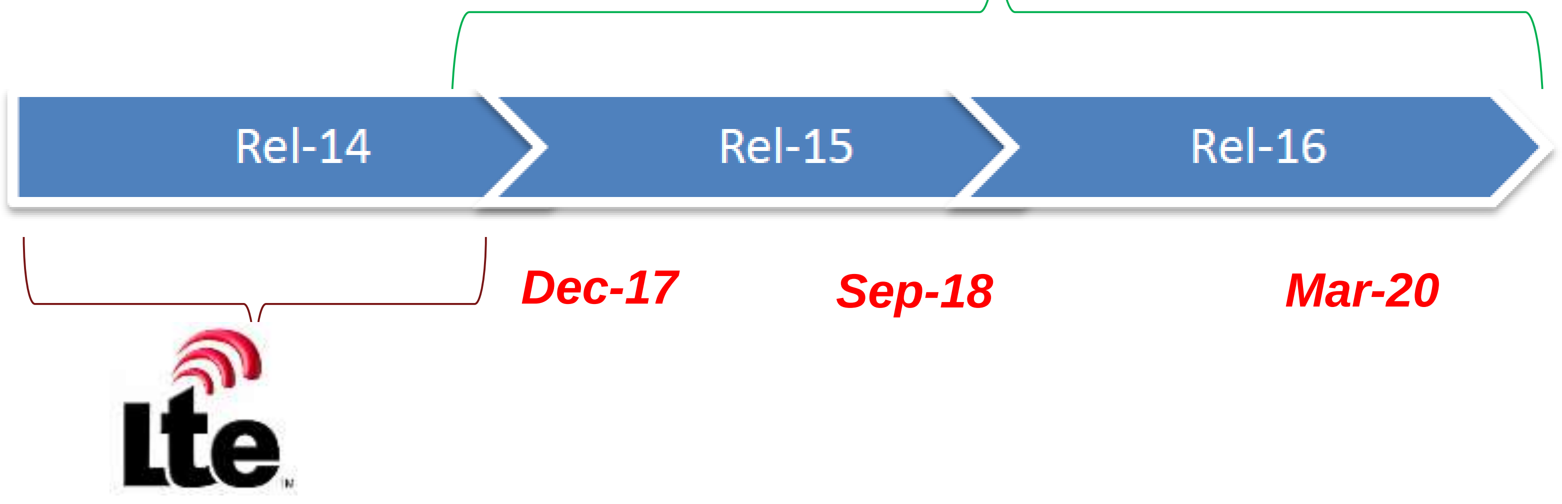
Agenda

- 5G goals and requirements
- Modeling and simulating key 5G technologies
- 5G development workflow
- Learn more…



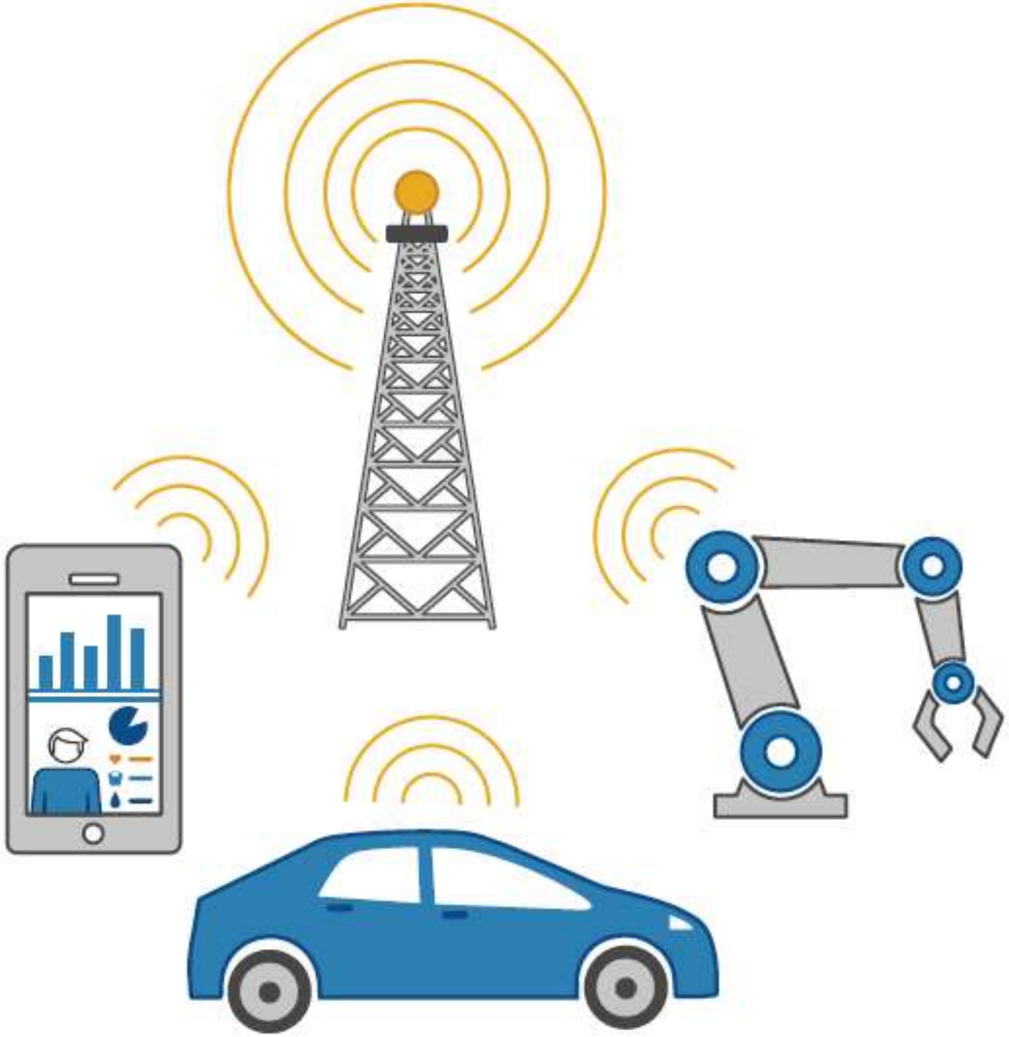
Timeline of 5G standardization

- 3GPP releases



- Two phases for 5G
  1. First release of 5G specification: **Sep 2018/Release 15**
  2. Second release of 5G specification: **Mar. 2020/Release 16**

5G Applications and Requirements



New Applications

4K, 8K, 360° Video

Virtual Reality

Connected Vehicles

Internet of Things

5G Requirements / Use Cases

Enhanced mobile broadband (>10 Gbps)

Ultra reliable & low latency (<1 ms)

Massive machine-type communication (>1e5 devices)

Achieving Higher 5G Broadband Data Rates

Technical Solutions

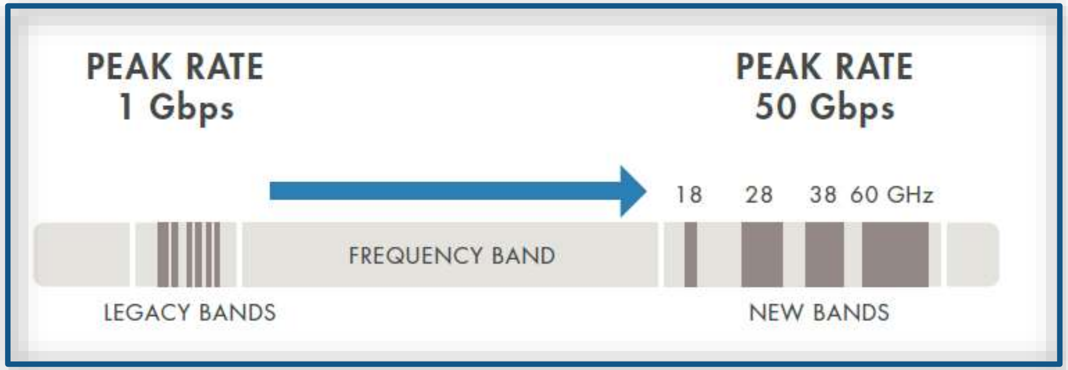
Increased bandwidth

Better spectral efficiency

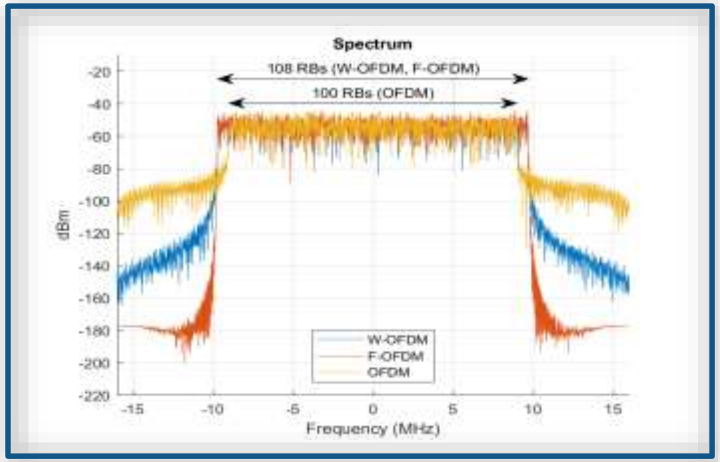
Flexible air interface

Densification

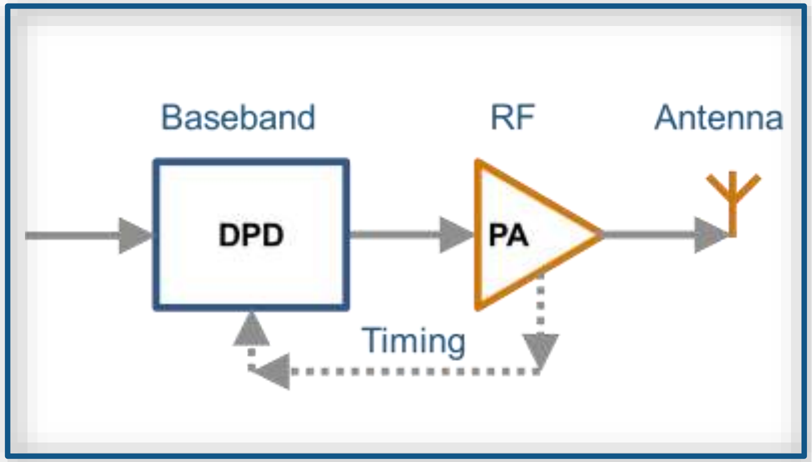
Higher Frequency Bands



New Physical Layer



New RF Architectures

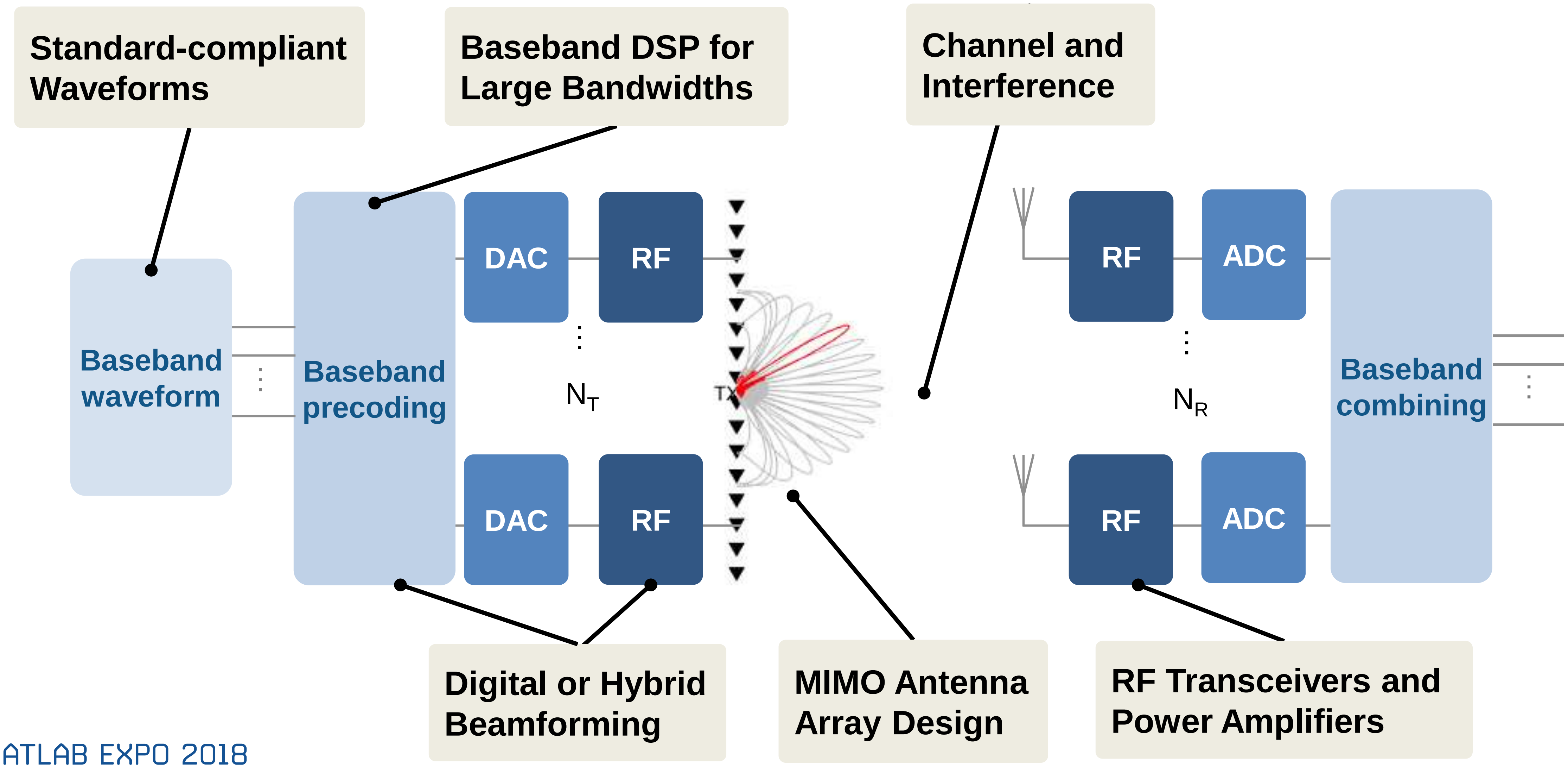


Massive MIMO

Massive MIMO antenna array for a Huawei 5G field trial.

Multi-Domain Engineering for 5G

Subsystems must be designed and tested together



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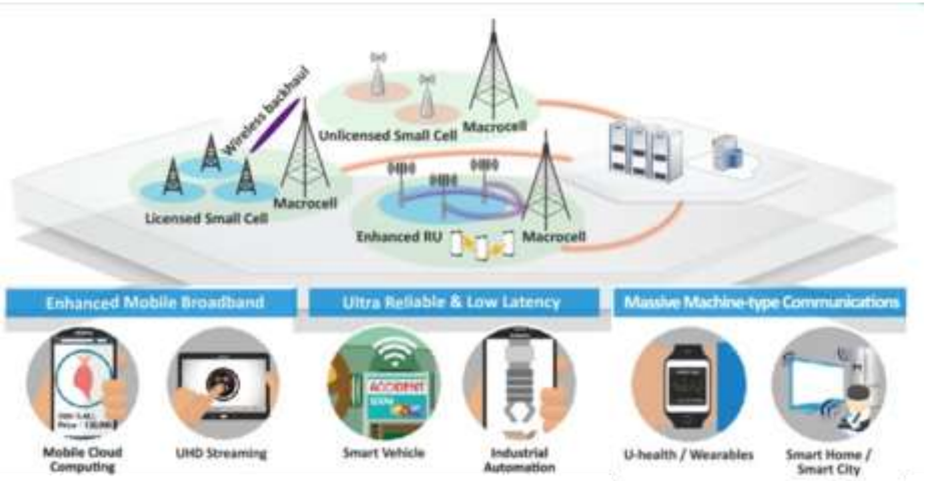
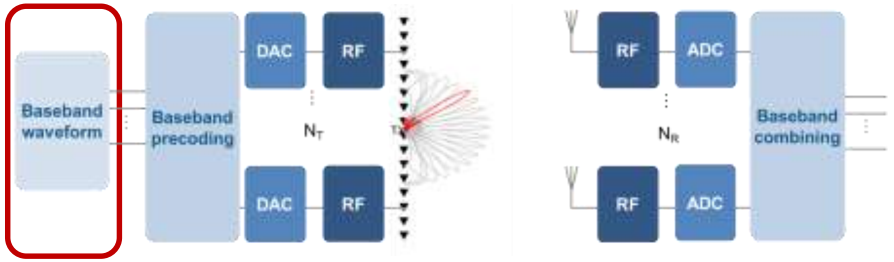


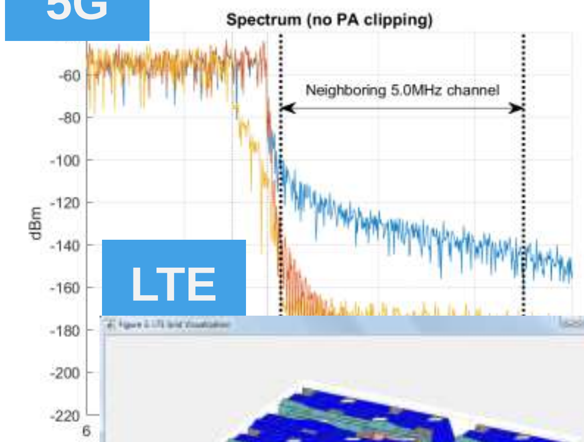
Waveform Generation

- Test with standard-compliant waveforms
- Generate all physical channels and signals
- Off-the-shelf and full custom waveforms

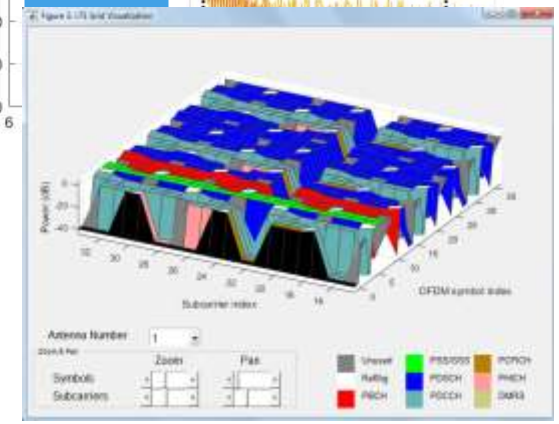
Standard compliance



5G



LTE



3GPP
✓ LTE & LTE-Advanced
✓ NB-IoT
✓ D2D Sidelink
✓ V2X Sidelink
✓ *5G New Radio*

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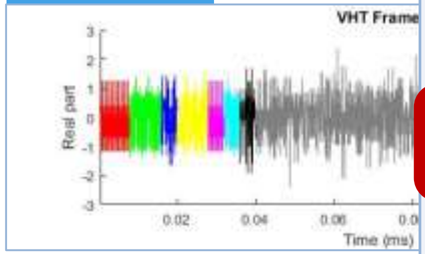
WLAN



IEEE 802.11
✓ *802.11ax*
✓ 802.11ad
✓ 802.11ah
✓ 802.11ac
✓ 802.11a/b/g/n
✓ 802.11p/j

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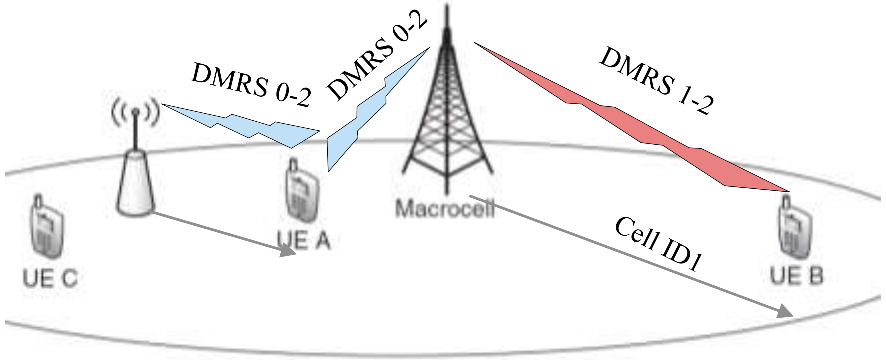
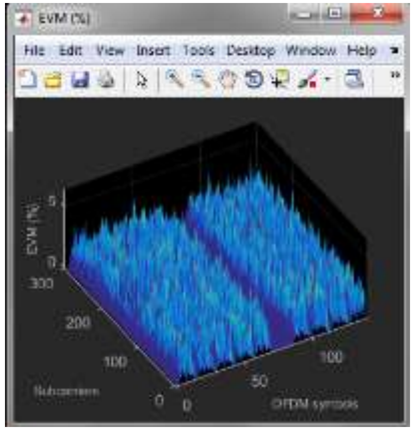
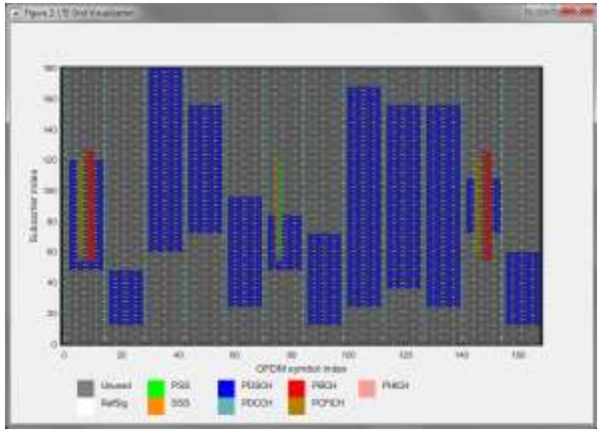
What's LTE System Toolbox?

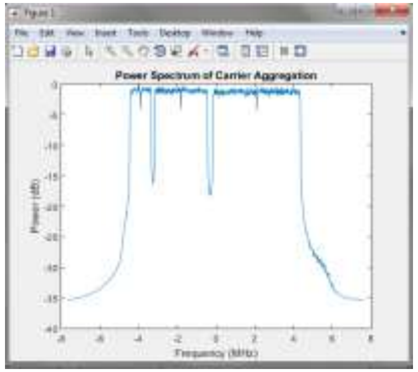
- Over 230 functions for physical layer (PHY) modeling
- LTE, LTE-Advanced, LTE-Advanced Pro (Rel-8 through Rel-14)
- Scope
  - FDD/TDD
  - Uplink/Downlink/Sidelink
  - Transmitter/Receiver



New in R2017b:
- V2X
- NB-IoT

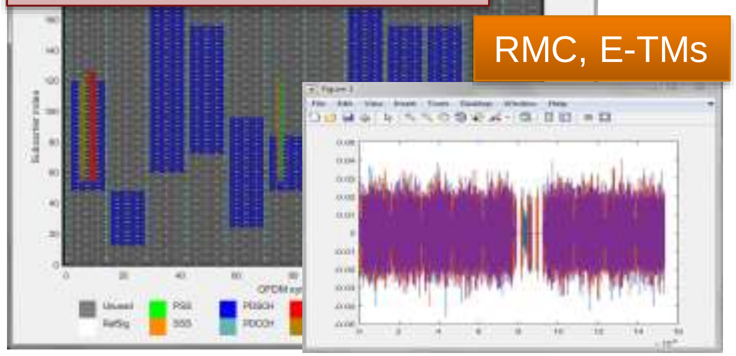




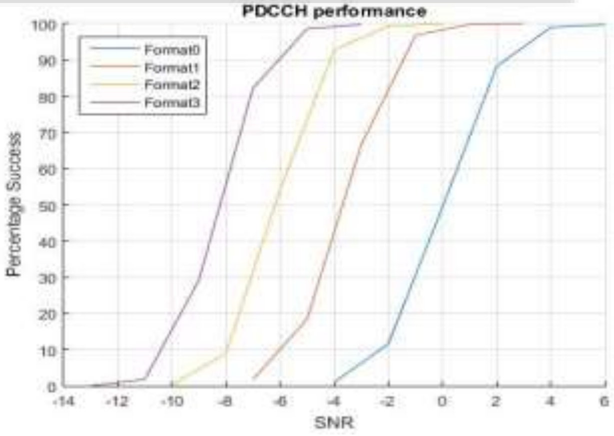


Use Cases

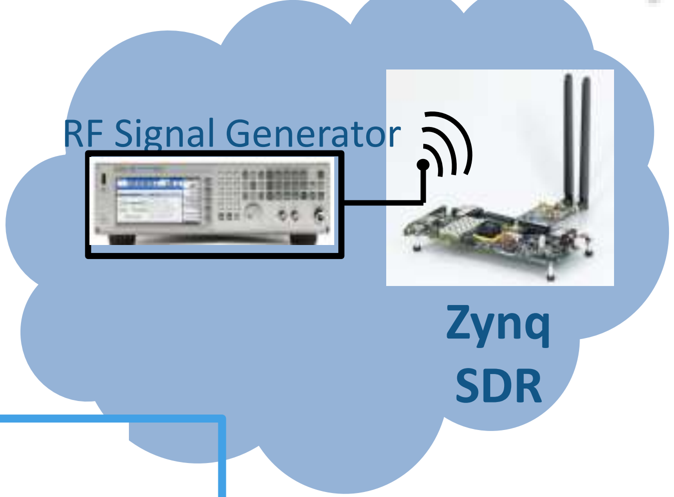
Signal Generation



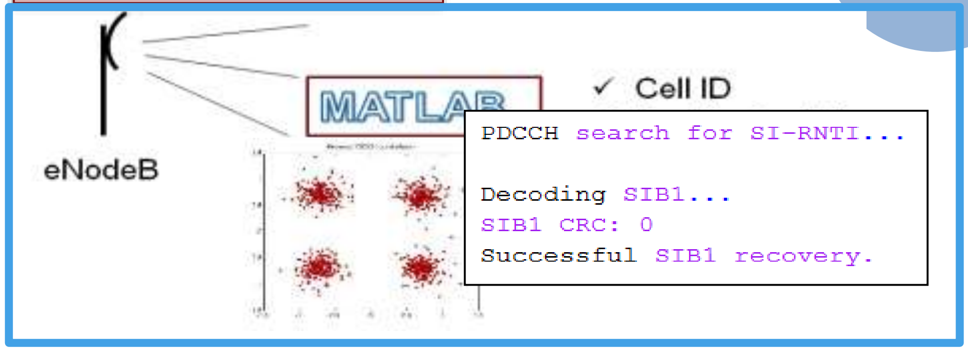
End-to-End Simulations



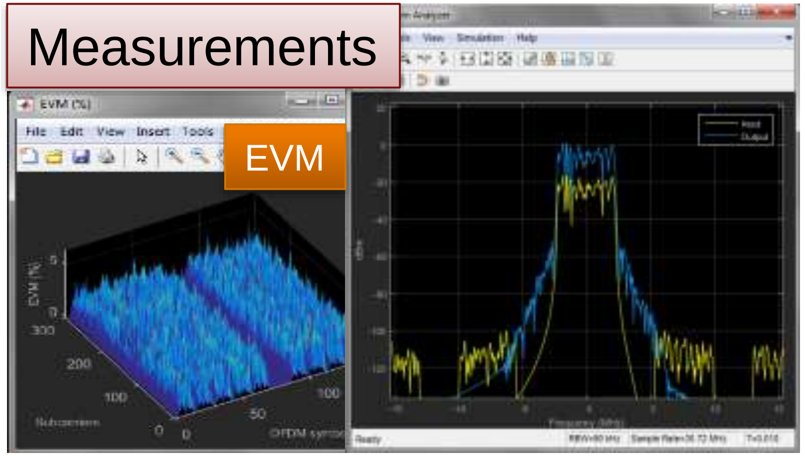
HW & Radio Connectivity



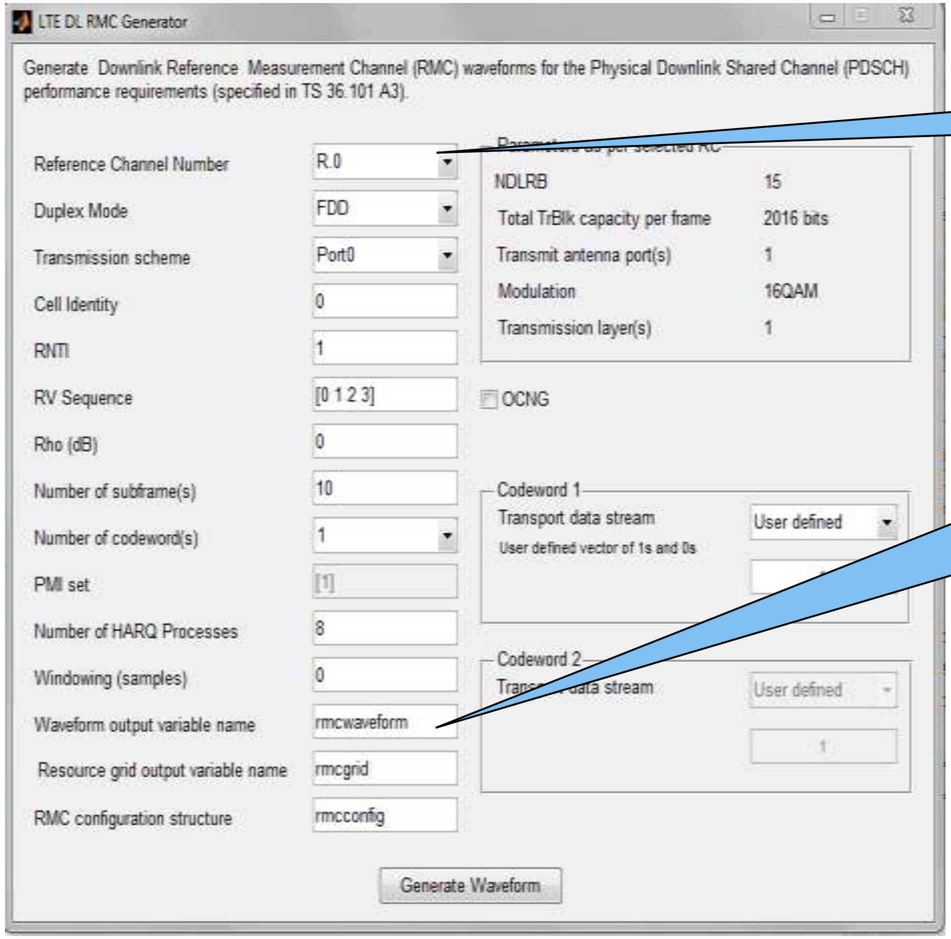
Signal Detection

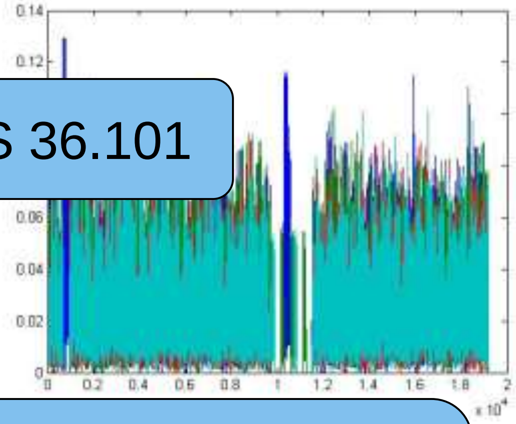


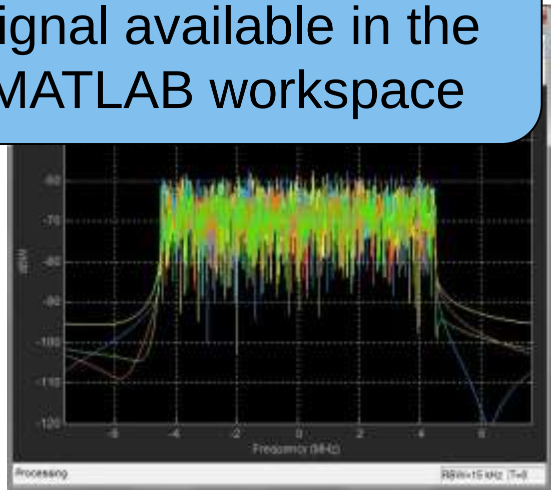
Measurements



Signal Generation and Analysis
Reference Measurement Channels





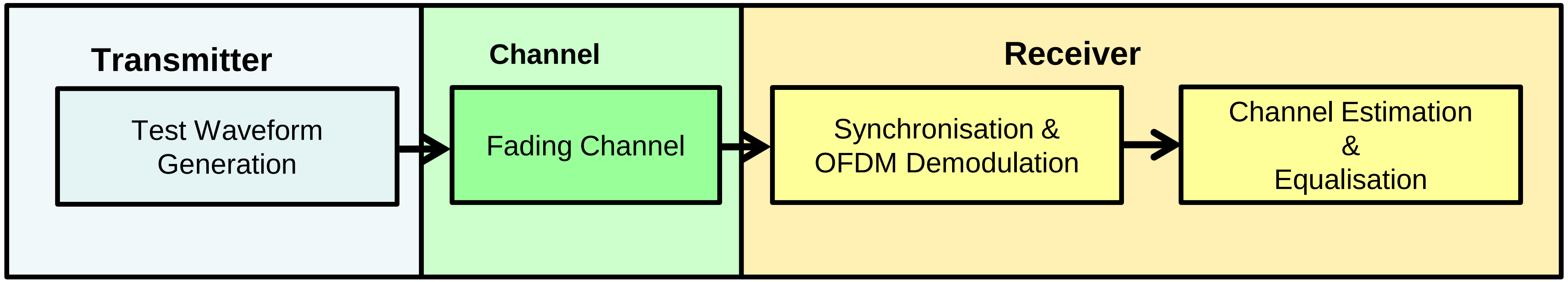


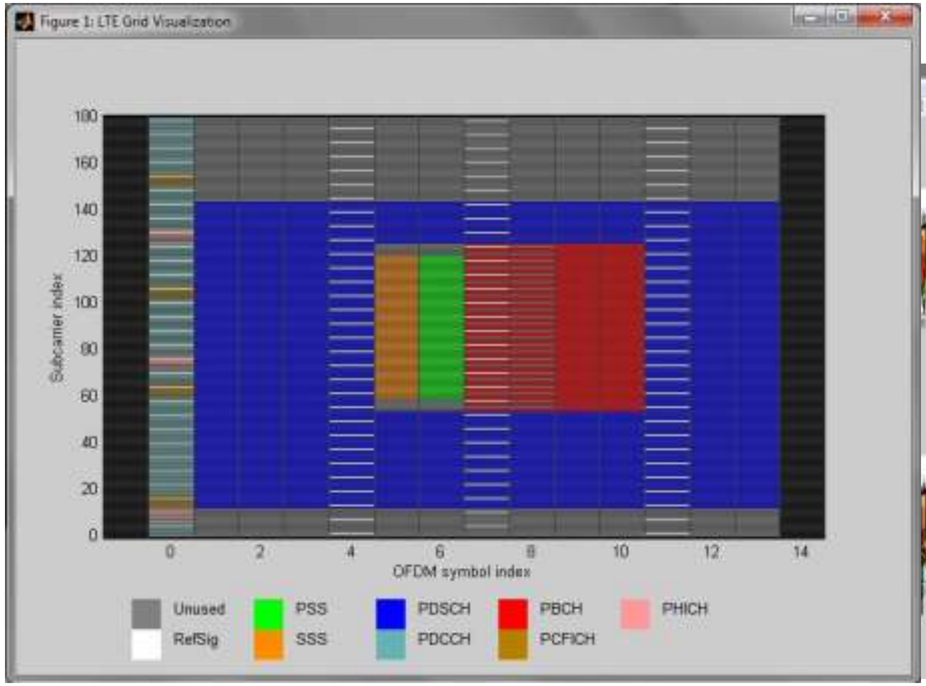
TS 36.101

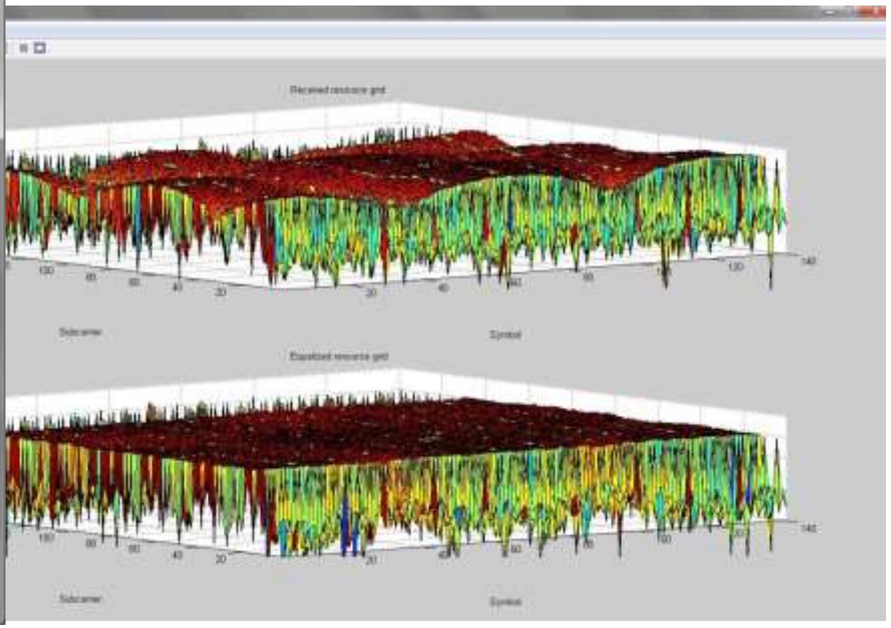
Standard-compliant signal available in the MATLAB workspace

>> lteRMCDLTool

Demo: Equalizing the Downlink Grid







Documentation

Shipping Examples

Functions

LTE System Toolbox Examples

On this page...

Downlink LTE Modeling
Uplink LTE Modeling
Downlink End to End Simulation
Uplink End to End Simulation
Downlink Waveform Generation and Analysis
Uplink Waveform Generation and Analysis

Downlink LTE Modeling

LTE Waveform Modeling Using Downlink Transport and Physical Channels

PDSCH Transmit Diversity Throughput Simulation

PDSCH Port 5 UE-Specific Beamforming

Release 10 PDSCH Enhanced UE-Specific Beamforming

Functions in LTE System Toolbox

LTE Modeling Basics

lteResourceGrid	Subframe resource array
lteResourceGridSize	Size of subframe resource array
lteDLResourceGrid	Downlink subframe resource array
lteDLResourceGridSize	Size of downlink subframe resource array
lteULResourceGrid	Uplink subframe resource array
lteULResourceGridSize	Size of uplink subframe resource array
lteDuplexingInfo	Duplexing information

Downlink Channels

Physical Signals

ltePSS	Primary synchronization signal
ltePSSIndices	PSS resource element indices
lteSSS	Secondary synchronization signal
lteSSSIndices	SSS resource element indices
lteCellRS	Cell-specific reference signal
lteCellRSIndices	CRS resource element indices

5G New Radio and the 5G Library

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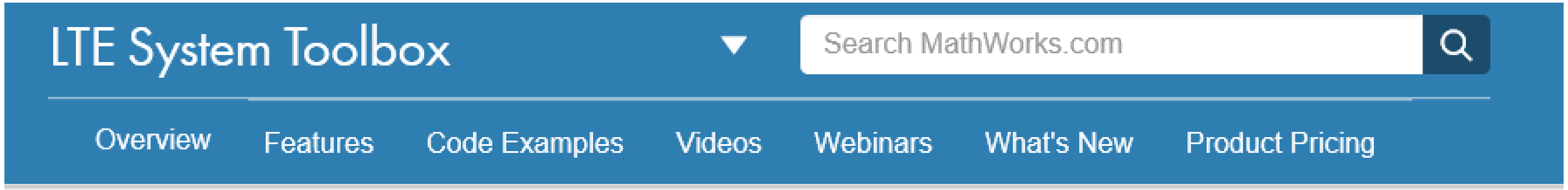
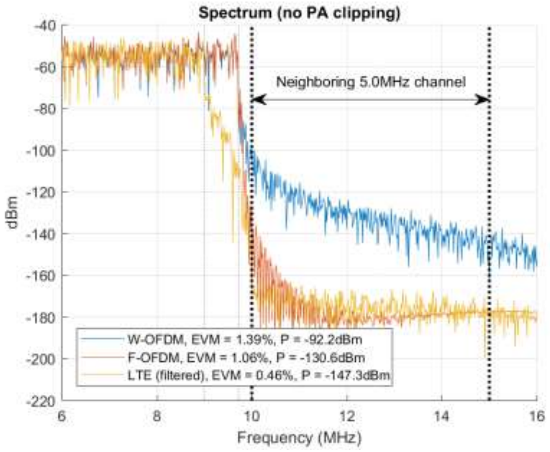
LTE System Toolbox & 5G Library

- The 5G Library is a free downloadable Add-On for LTE System Toolbox
- It builds on the infrastructure of LTE System Toolbox
- It is based on the January 2018 version of the 38.2xx documents



5G Library

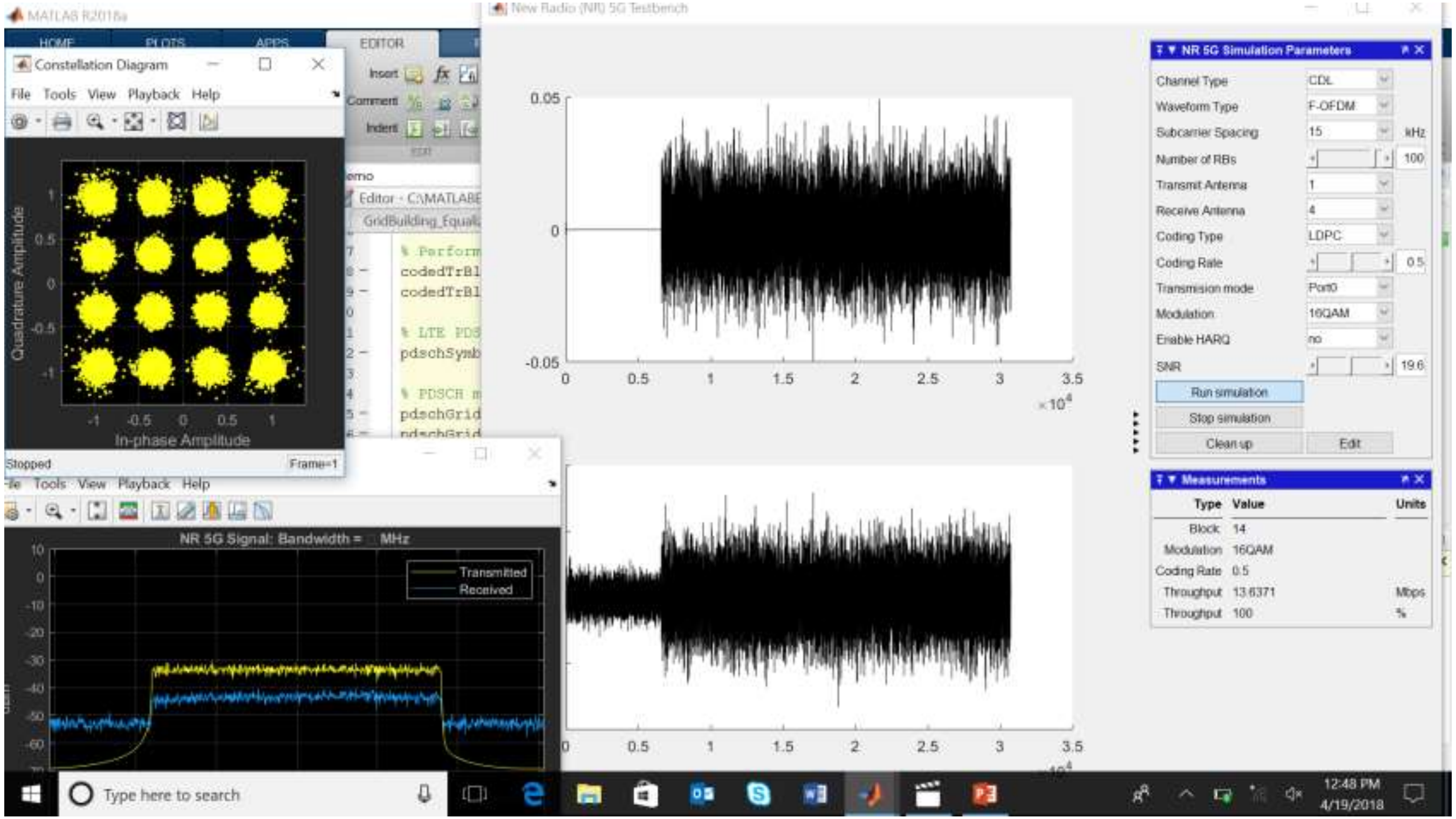
5G Library



[Download the 5G Library]

New Radio (NR) 5G Testbench

Demo

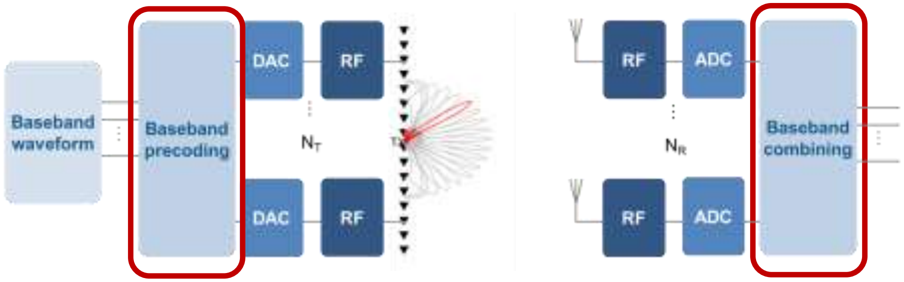


New Physical Layer in Release 15

- Enhanced Mobile Broadband (eMBB):
  - Larger bandwidth
  - Greater spectral efficiency

- PHY techniques used to achieve goals
  - Flexible frame structure and carrier spacing
    - Shorter latency
    - Variable bandwidth
  - Higher capacity coding schemes
  - Channel models: sub-6GHz to mmWave

5G Baseband Processing
- Increased bandwidth
- Greater spectral efficiency



Baseband DSP for Large Bandwidths

- 5G waveform same as LTE: Cyclic-Prefix OFDM (CP-OFDM)
- New baseband techniques for higher capacity

μ	Subcarrier Spacing $\Delta f = 2^{\mu} * 15\text{kHz}$	Bandwidth (MHz)
0	15	49.50
1	30	99
2	60	198
3	120	396
4	240	397.44
5	480	397.44

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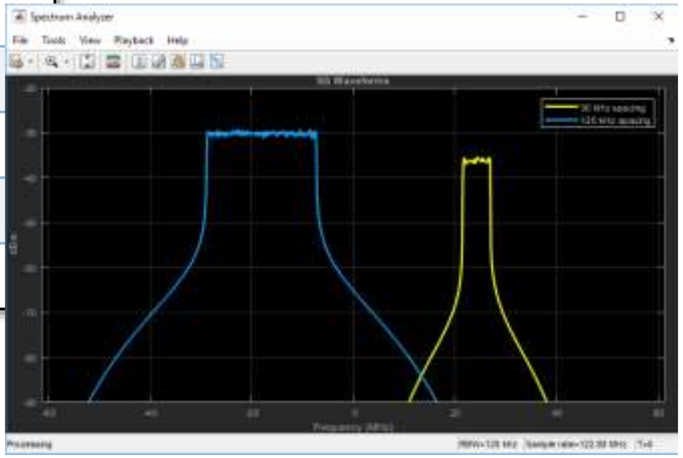
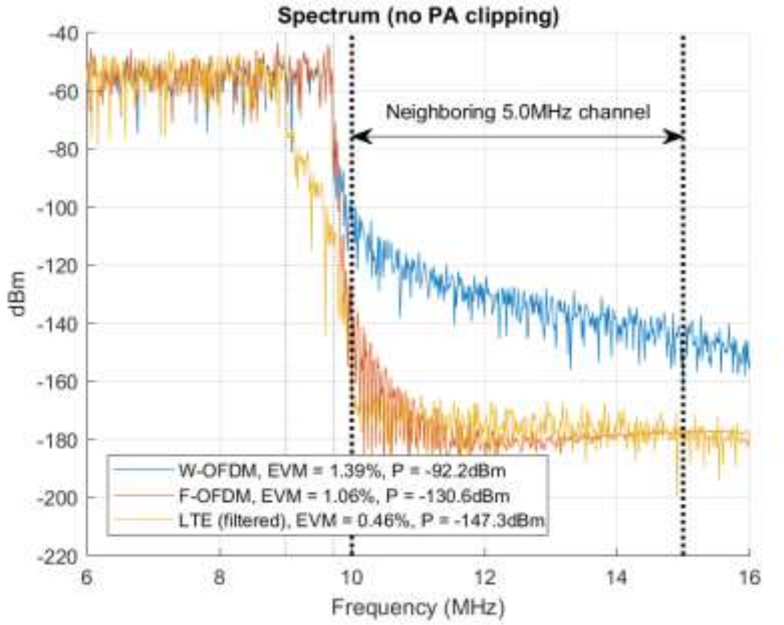


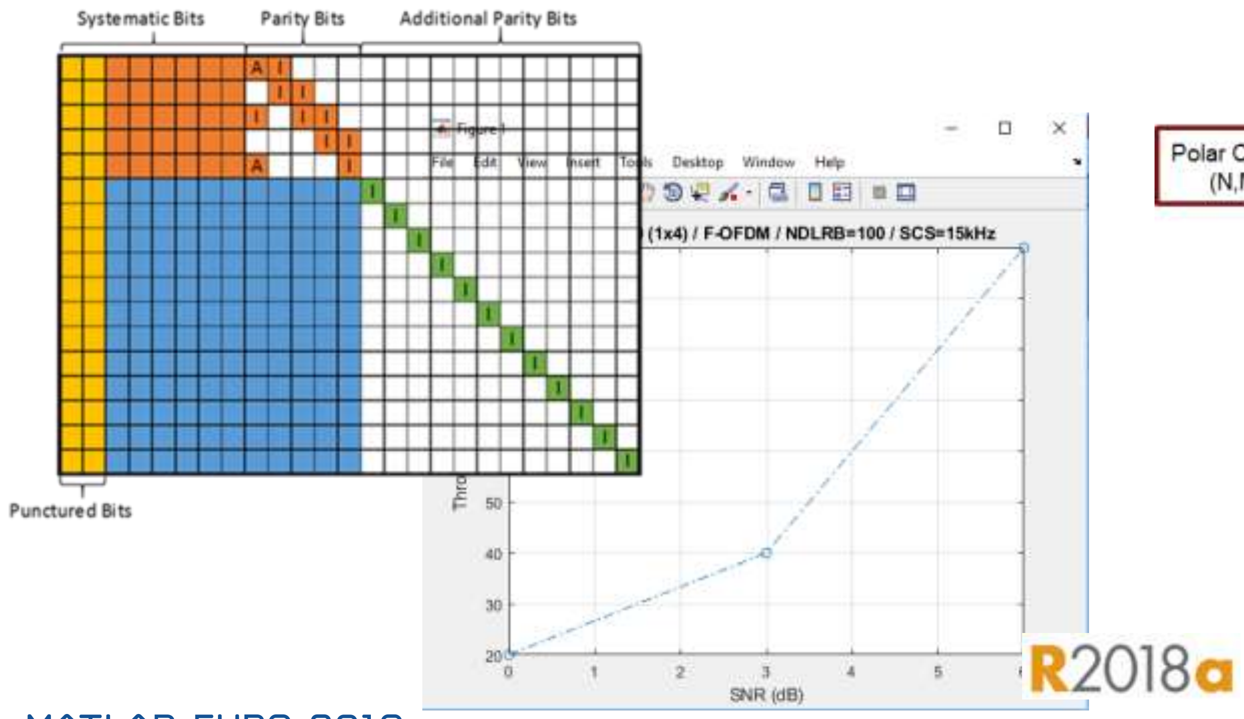
Increase bandwidth and reduce latency with flexible subcarrier spacing



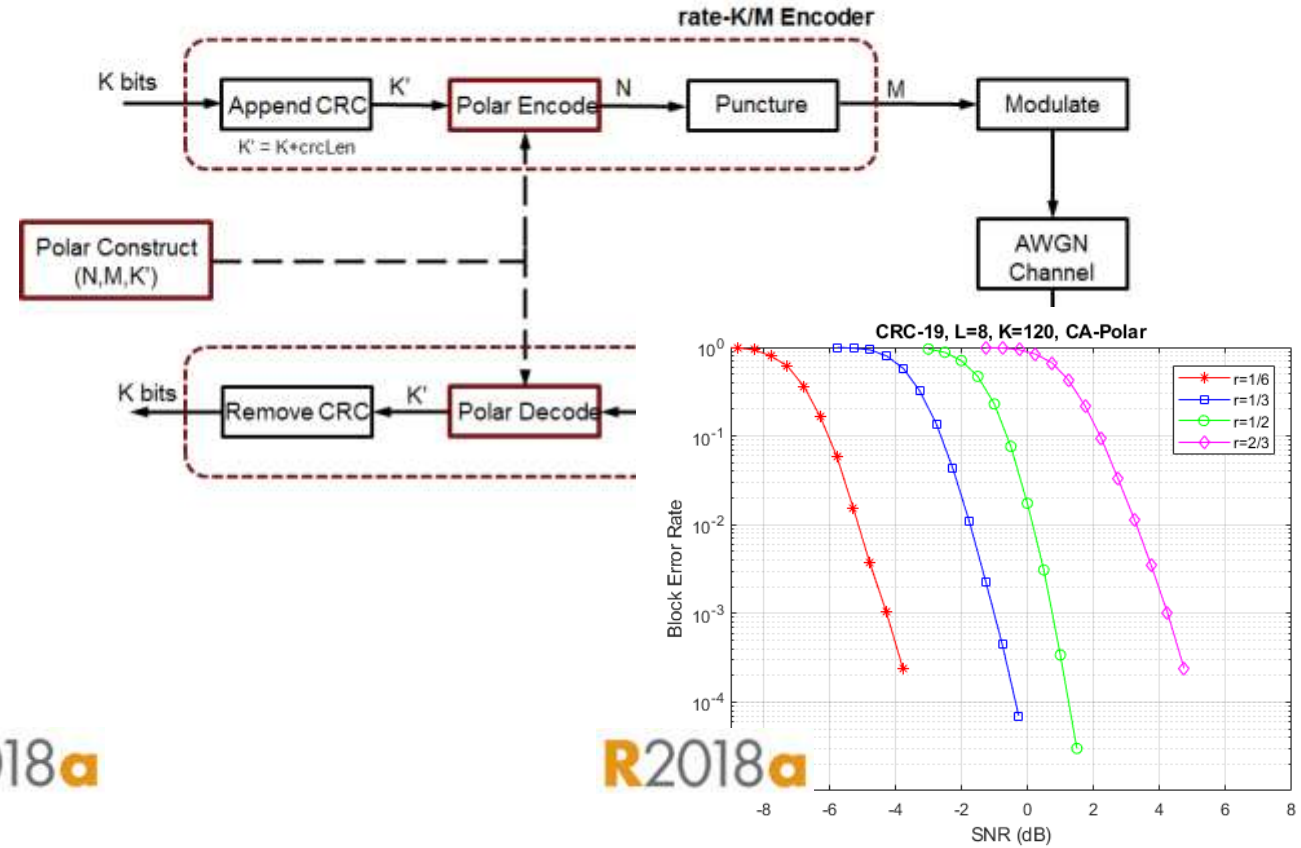
Reduce spectral leakage with filtering or windowing

Efficient Channel Coding Methods

- Low-Density Parity Check (LDPC) for data channel: memoryless block coding



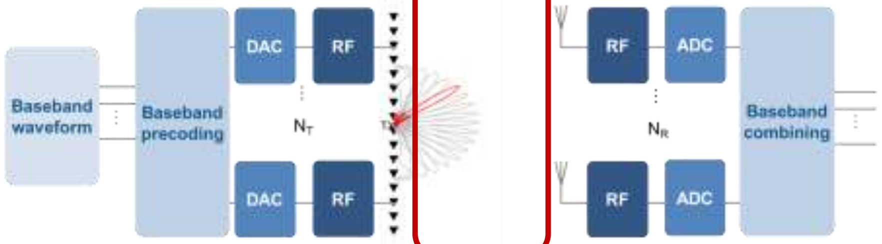
- Polar Codes for control channel: achieve channel capacity

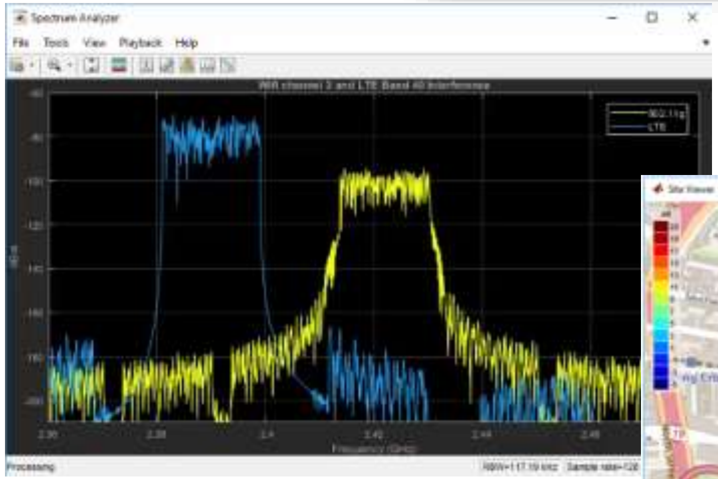


Model Channel and Interference

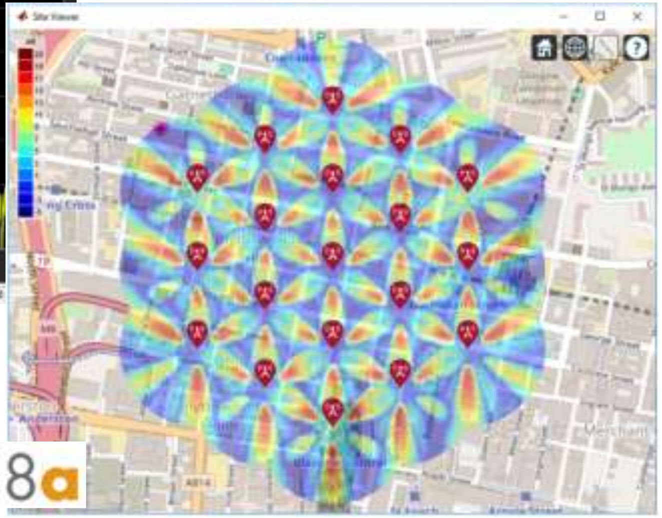
- Interference
  - Multiple standards: 5G/LTE/WLAN
- 3D propagation channels
  - 5G, LTE, 802.11, Scattering MIMO, Custom
- Visualize propagation on maps
  - Rx/Tx location
  - Signal strength and coverage
  - Signal-to-interference-plus-noise (SINR)

Channel and Interference
- Multiple UEs/Base Stations
- Signal propagation





LTE-WLAN interference



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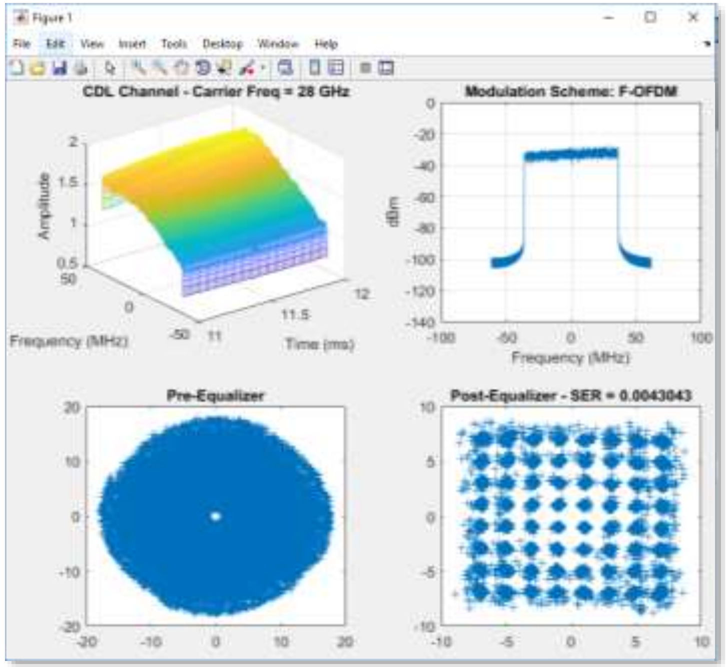
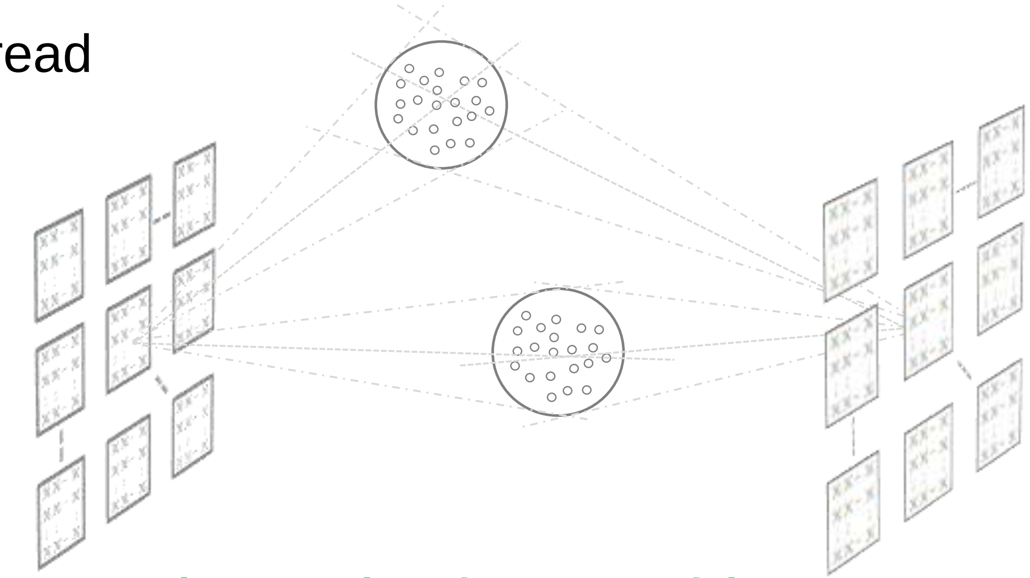
SINR for 5G urban macro-cell

5G Channel Model

- 3GPP TR 38.901: 500 MHz - 100 GHz (mmWave)
- For massive MIMO arrays (>1024 elements)
- Delay profiles:
  - Control delay line (CDL): Full 3D model
  - Tapped delay line (TDL): Simplified for faster simulation
- Control key parameters
  - Channel delay spread
  - Doppler shift
  - MIMO correlation

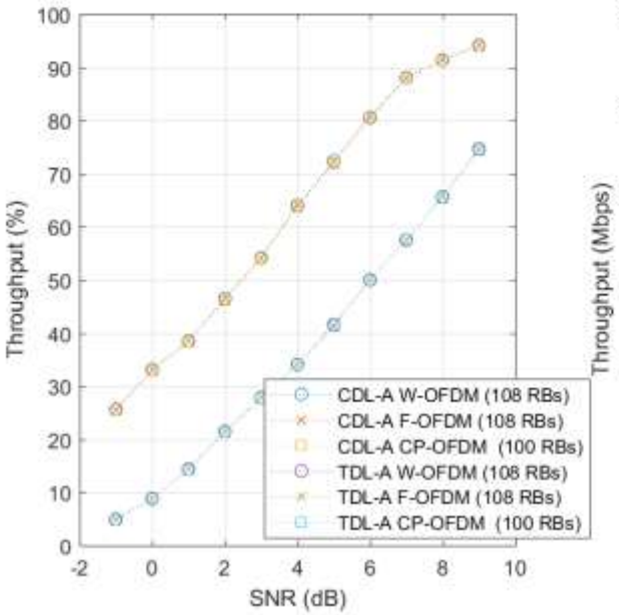


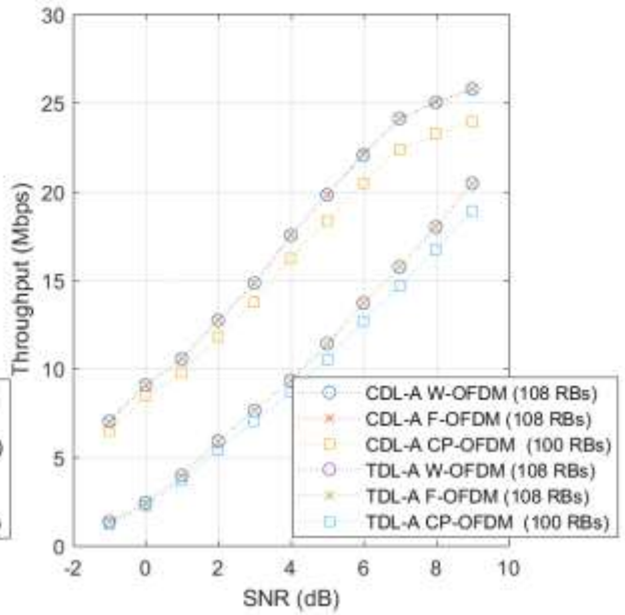


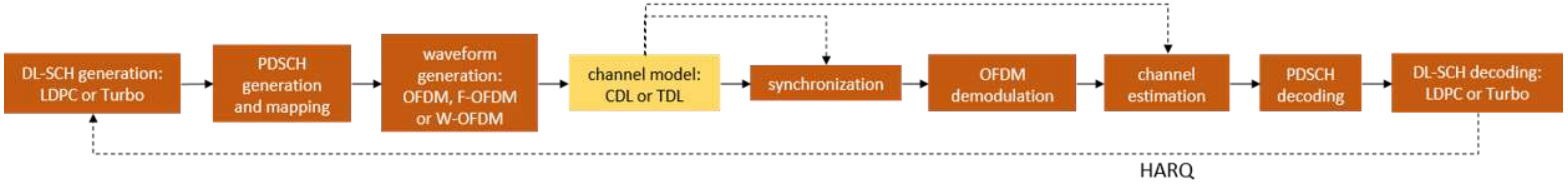
Cluster Delay Line: 3D model

5G Link Level Simulation

- End-to-end physical layer reference model
- Verify implementation
- Evaluate impact of algorithm designs on link performance

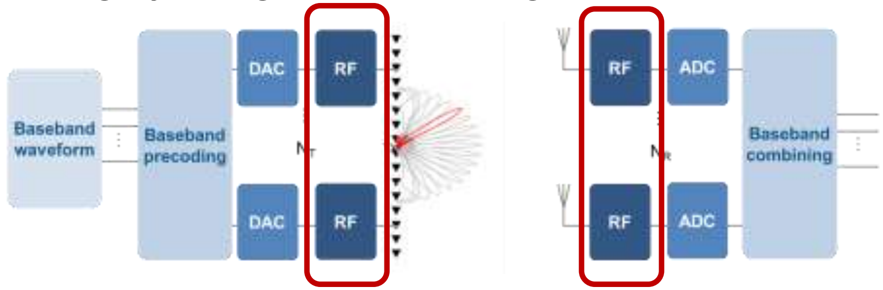






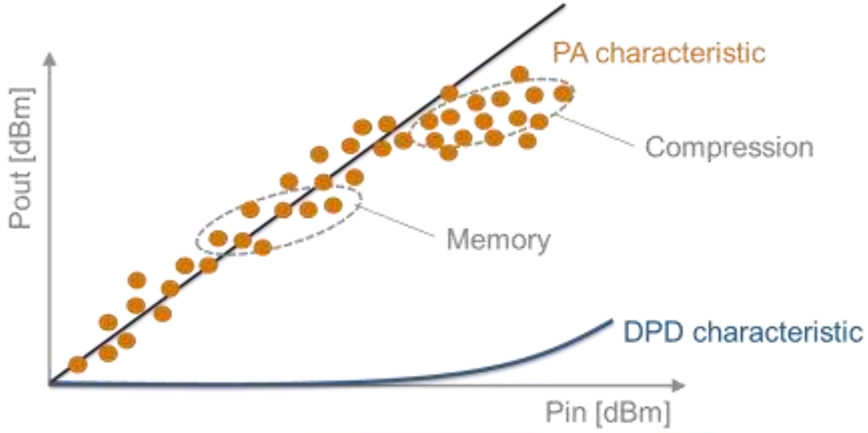
RF Power Amplifier (PA) Linearization

RF challenges in 5G
- Frequency dependent behavior
- Highly integrated RF + digital devices

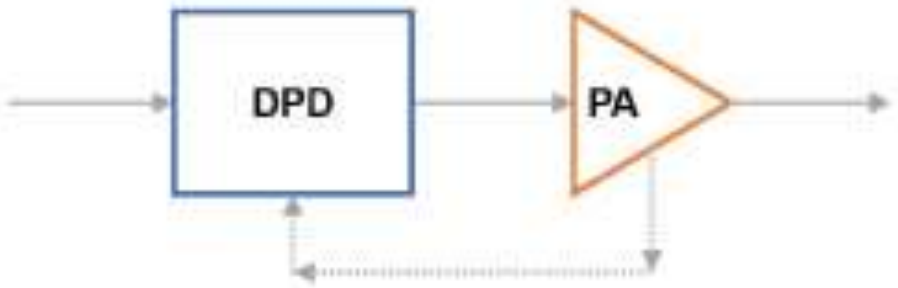


- 5G frequencies and bandwidth put greater requirements on RF transmitter efficiency

- 5G PA's are difficult to model
  - Non-linearity
  - Memory effects

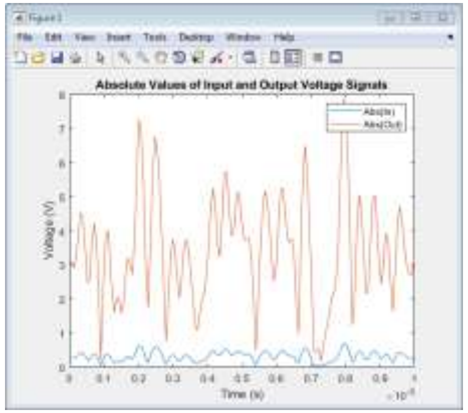


- Solution: Linearization using adaptive digital pre-distortion (DPD)



Characterize PA Model Using Measured Data

PA Data



MATLAB fitting procedure
(White box)

```
function a_coef = fit_memory_poly_model(x,y,memLen,degLen,modType)
% FIT_MEMORY_POLY_MODEL
%   Procedure to compute a coefficient matrix given input and output
%   signals, memory length, nonlinearity degree, and model type.
%
%   Copyright 2017 MathWorks, Inc.

x = x(:);
y = y(:);
xLen = length(x);

switch modType
  case 'memPoly'   % Memory polynomial
    xrow = reshape((memLen:-1:1)' + (0:xLen:xLen*(degLen-1)),1,[]);
    xVec = (0:xLen-memLen)' + xrow;
    xPow = x.*(abs(x).^(0:degLen-1));
    xVec = xPow(xVec);
  case 'ctMemPoly'  % Cross-term memory polynomial
    absPow = (abs(x).^(1:degLen-1));
    partTop1 = reshape((memLen:-1:1)'+(0:xLen:xLen*(degLen-2)),1,[]);
    topPlane = reshape(                                              ...
        [ones(xLen-memLen+1,1),absPow((0:xLen-memLen)' + partTop1)].', ...
        1,memLen*(degLen-1)+1,xLen-memLen+1);
    sidePlane = reshape(x((0:xLen-memLen)' + (memLen:-1:1)).',       ...
        memLen,1,xLen-memLen+1);
    cube = sidePlane.*topPlane;
    xVec = reshape(cube,memLen*(memLen*(degLen-1)+1),xLen-memLen+1).';
end

coef = xVec\y(memLen:xLen);
a_coef = reshape(coef,memLen,numel(coef)/memLen);
```

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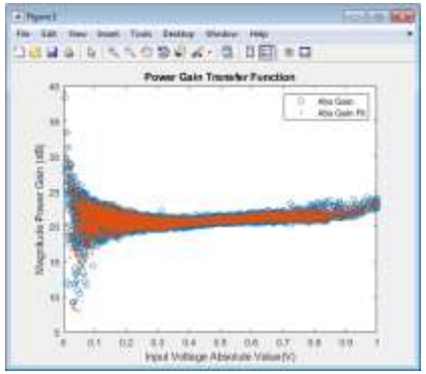
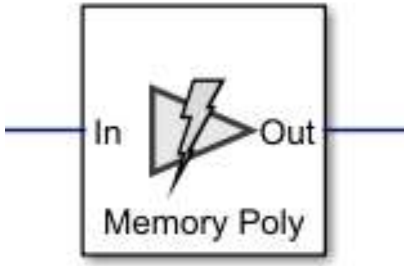
MATLAB PA model

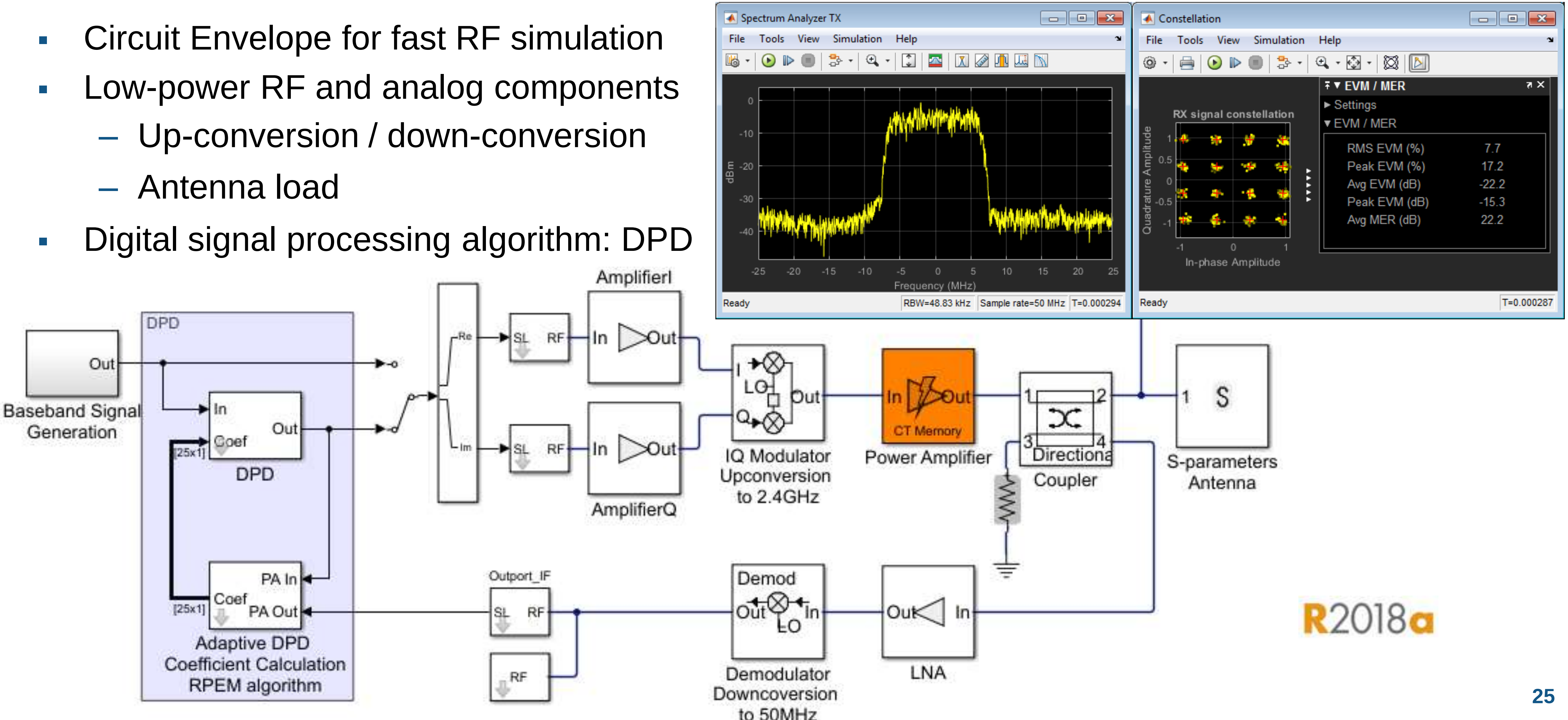




PA model for circuit envelope simulation

PA + DPD Simulation

- Circuit Envelope for fast RF simulation
- Low-power RF and analog components
  - Up-conversion / down-conversion
  - Antenna load
- Digital signal processing algorithm: DPD



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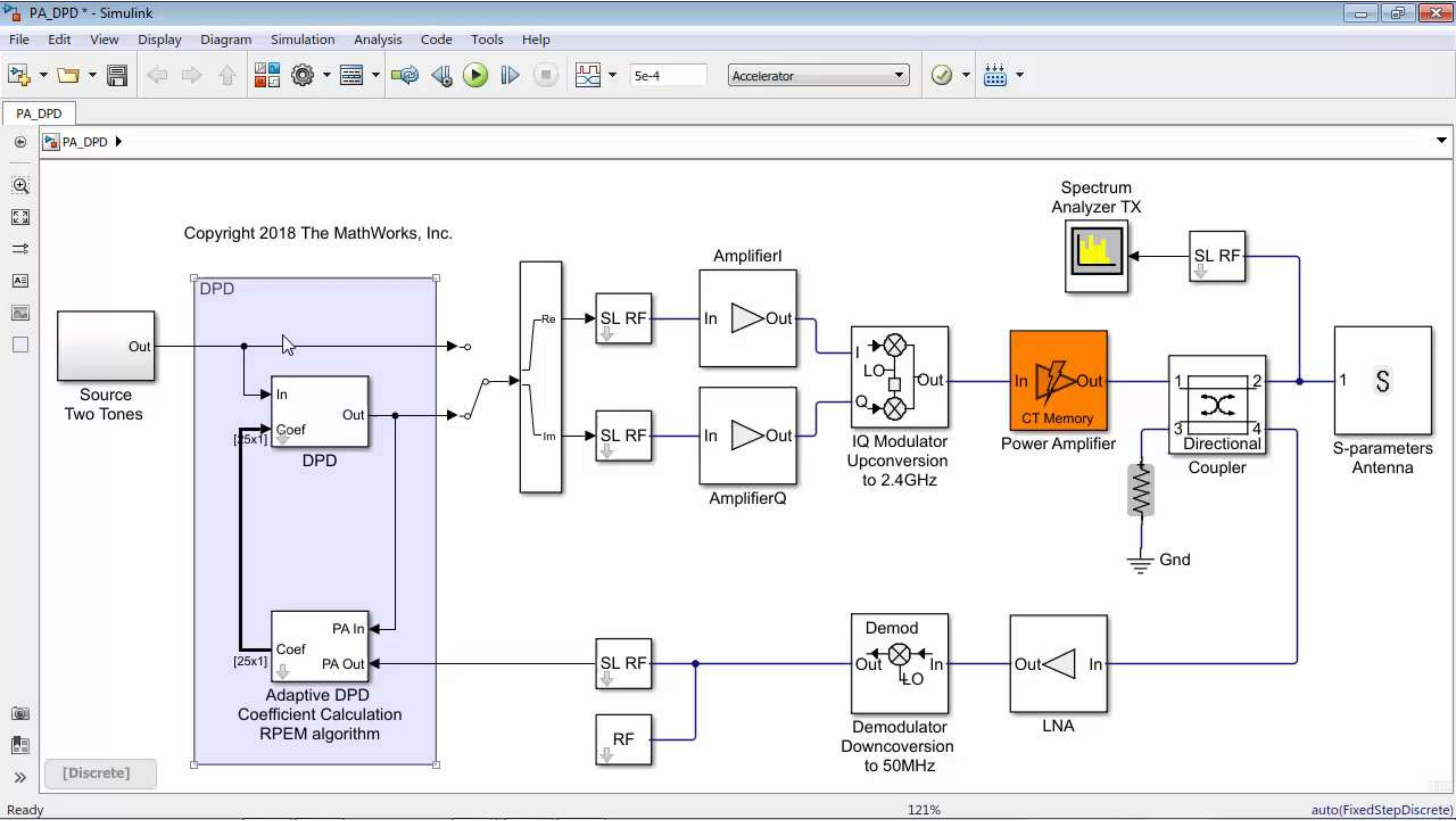

PA_DPD * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
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Accelerator
PA_DPD
Copyright 2018 The MathWorks, Inc.
DPD
Out
Source Two Tones
In
Coef
Out
[25x1]
DPD
Re
Im
SL RF
AmplifierI
In
Out
AmplifierQ
I
LO
Q
Out
IQ Modulator Upconversion to 2.4GHz
In
Out
CT Memory
Power Amplifier
Spectrum Analyzer TX
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2
3
4
Directional Coupler
S-parameters Antenna
Gnd
PA In
Coef
PA Out
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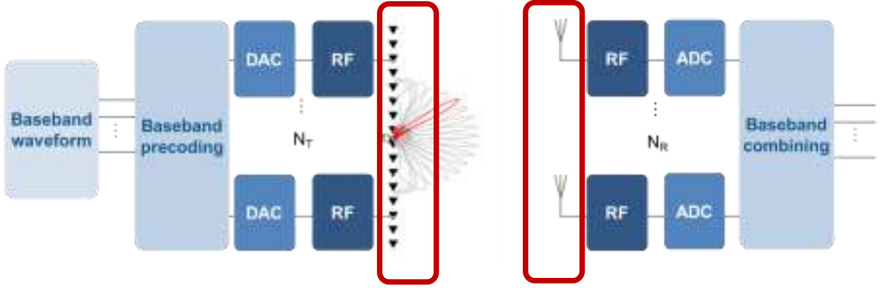
Adaptive DPD Coefficient Calculation RPEM algorithm
RF
Demod
Out
In
LO
Demodulator Downcoversion to 50MHz
LNA
[Discrete]
Ready
121%
auto(FixedStepDiscrete)

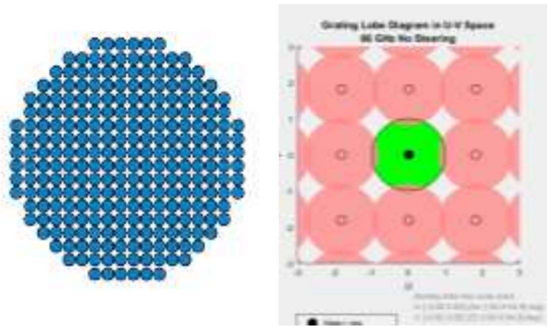
Massive MIMO Antenna Arrays

- Model antenna and array beam patterns
- Model antenna element failures
- Optimize tradeoffs between antenna gain and channel capacity
- Simulate with 3D channel model

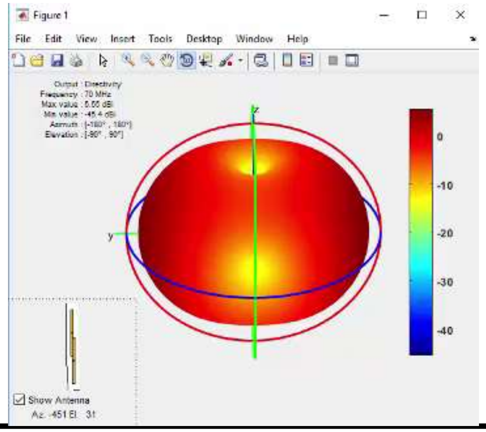
Antenna array design considerations
- Element coupling
- Imperfections



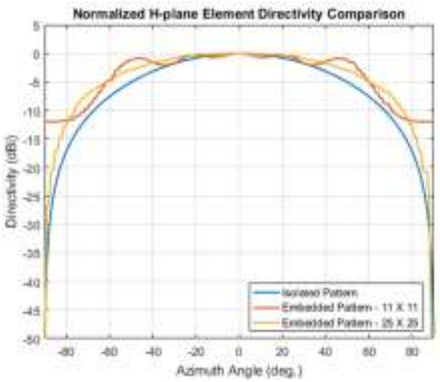
Design an array



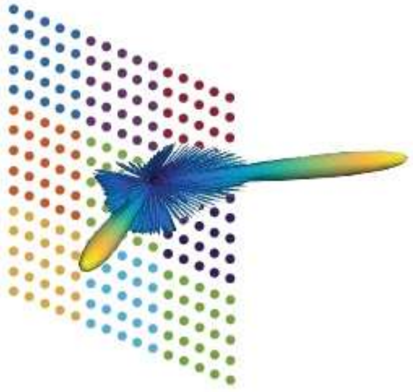
Import antenna patterns



Model mutual coupling



Array beam pattern



Call to Action

Designing and Integrating Antenna Arrays with Multi-Function Radar Systems

15:30 –16:15

In this talk, you will learn how to model antenna and antenna arrays and integrate them with multi-function radar systems. Topics covered include:

- Analyzing the performance of custom printed antennas and fabricating them using Gerber files
- Performing array analysis by computing coupling among antenna elements
- Integrating antenna models with the rest of the system
- Modeling and simulating multi-functional capabilities of radars

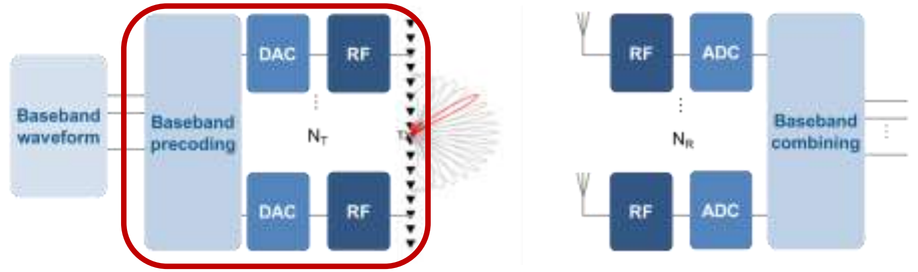
Shashank Kulkarni,
Ph.D., Principal Developer,
MathWorks India

Swathi Balki,
Pilot Engineer,
MathWorks India

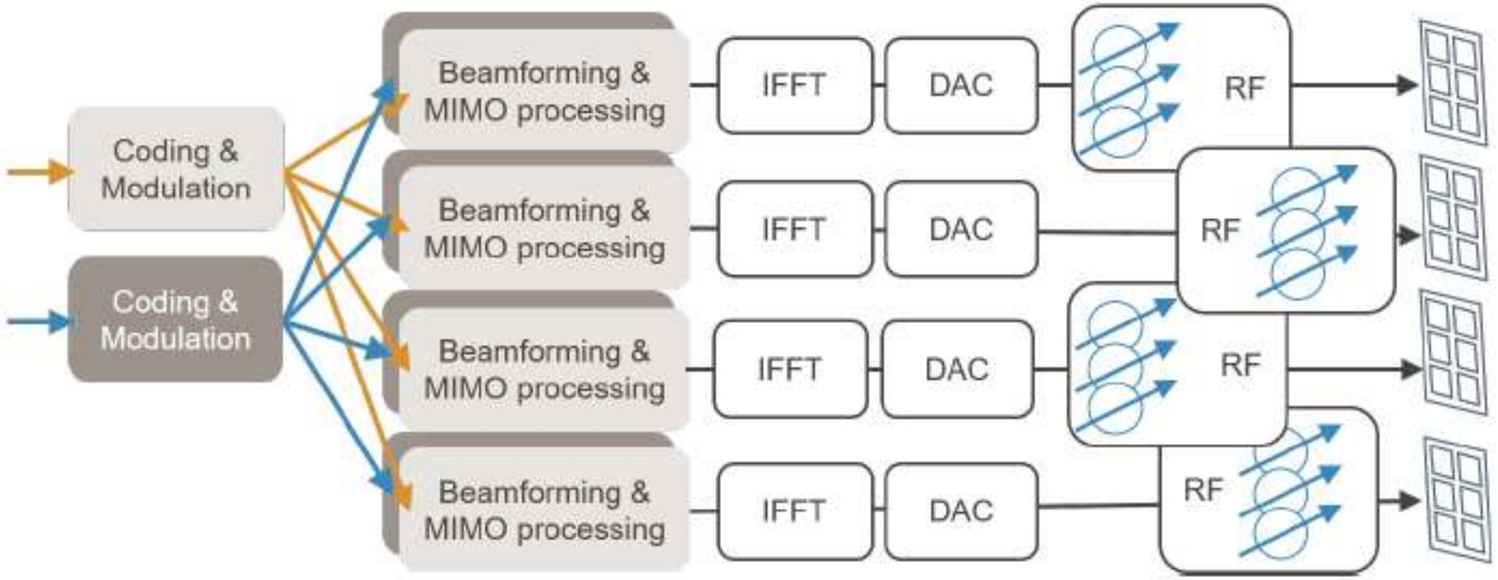
Hybrid Beamforming for Massive MIMO

- Beamforming implemented part in the digital and part in the RF domain
  - Trade-off performance, power dissipation, implementation complexity
- Subarrays contain RF channels with phase shifter
- Digital beamforming performed on signals outside subarrays

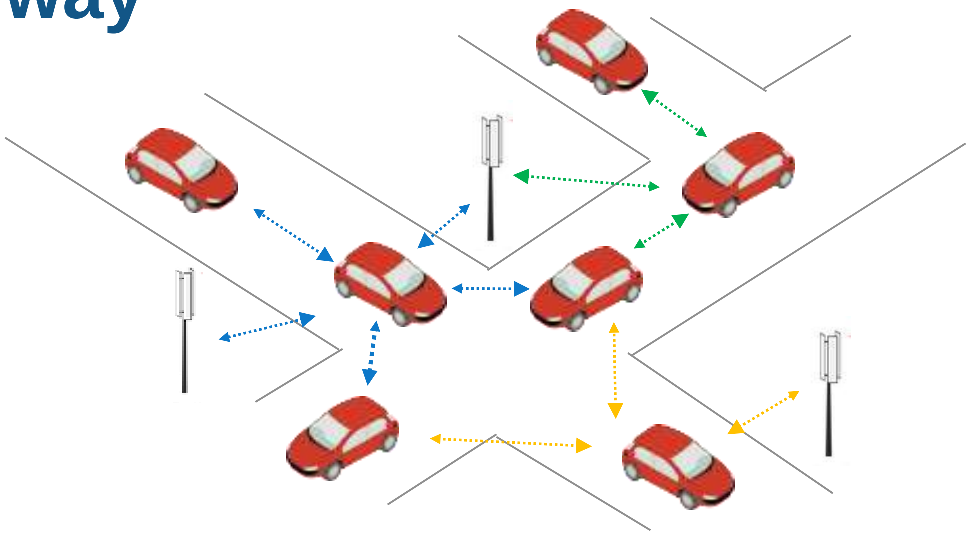
Why Hybrid Beamforming?
- Massive MIMO reduces mmWave propagation loss
- Hybrid beamforming reduces implementation cost



[Hybrid Beamforming for Massive MIMO Phased Array Systems]



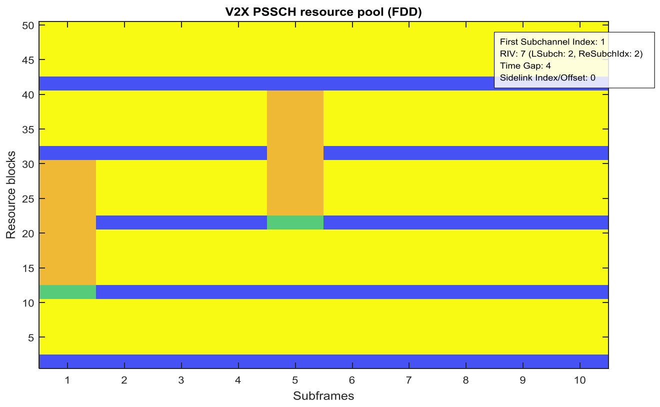
V2X: Building the Connected Car Highway



<u>Standards for V2X</u>

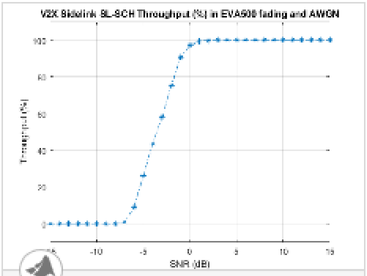
- 5G: Reserved for future release
- Cellular V2X (C-V2X)
  - Release 14 LTE V2X Sidelink
  - **LTE System Toolbox**
- DSRC
  - IEEE 802.11p
  - **WLAN System Toolbox**

PHY Waveform Generation



Throughput Simulation

R2017b



Release 14 V2X Sidelink PSCCH and PSSCH Throughput

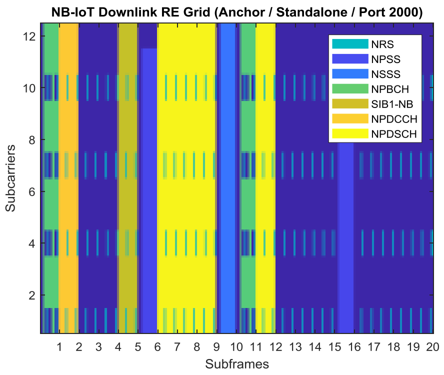
Demonstrates how to measure the Physical Sidelink Shared Channel (PSSCH) and Physical Sidelink Control Channel (PSCCH)

Future 5G Use Case: IoT Connectivity

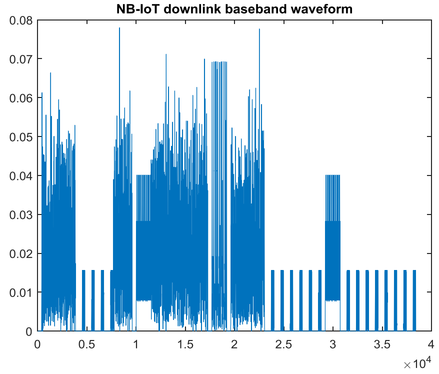
- IoT use case reserved for future 5G release

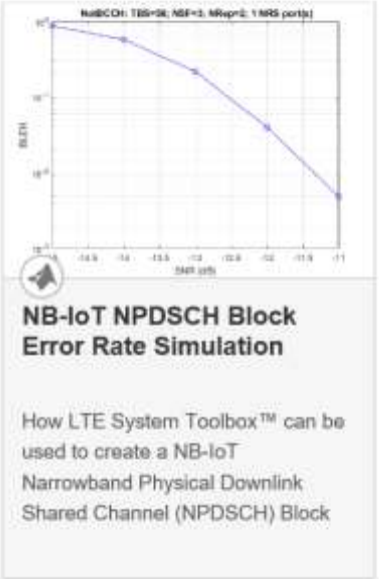
- Cellular long-range standard: LTE NB-IoT
  - Compatible with LTE networks
  - Lower cost and power, extended range

- NB-IoT cost and power reduction techniques
  - Reduced peak rate and bandwidth (180 kHz)
  - Reduced maximum transmit power
  - Single antenna
  - No higher-order modulation (BPSK and QPSK)



Waveform Generation





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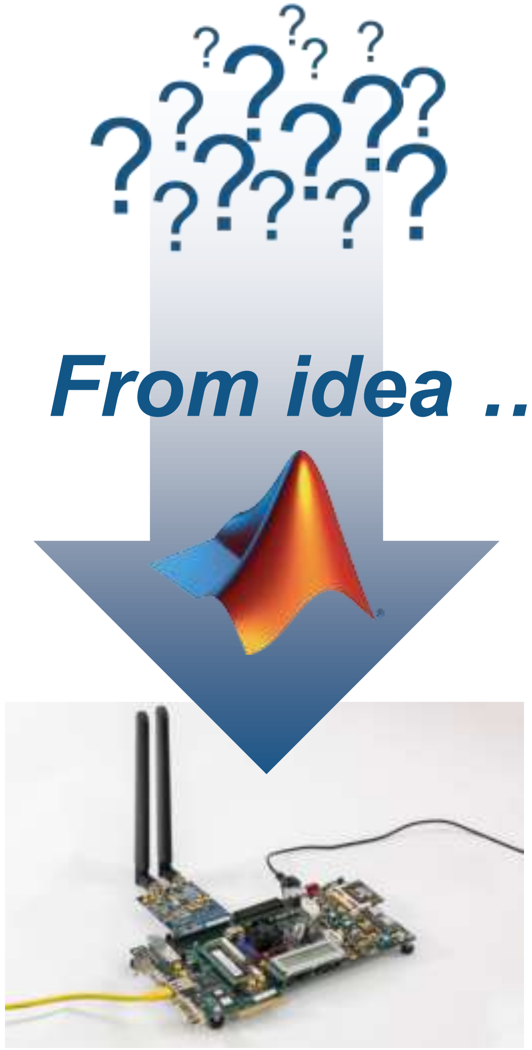
BLER Simulation

Agenda

- 5G goals and requirements
- Modeling and simulating key 5G technologies
- 5G development workflow
- Learn more…



… to implementation

Customer Perspective

"We need a multidomain platform for simulation, rapid prototyping, and iterative verification from the behavior model to testbed prototyping to the industrial product. MATLAB and Simulink are helping us to achieve these goals."

- Kevin Law, director of algorithm architecture and design, Huawei

Can you tell us more about how MATLAB and Simulink are helping you?

These two platforms play an important role in our innovation areas like 5G, optical communication, and wireless terminals. The tools give us top-down Model-Based Design, a product ecosystem that covers multiple domains, and code generation and iterative verification.

https://www.mathworks.com/content/dam/mathworks/tag-team/Objects/h/80861v00_Huawei_QA.pdf

MATLAB & Simulink Wireless Design Environment

for baseband, RF, and antenna modeling and simulation

Algorithms, Waveforms, Measurements

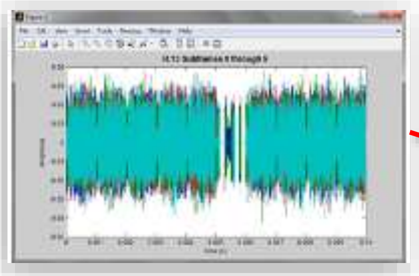
- Communications System Toolbox
- LTE System Toolbox (5G Library)
- WLAN System Toolbox

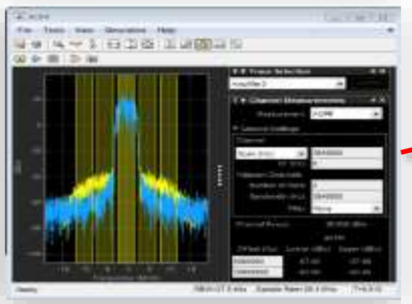
RF Front End

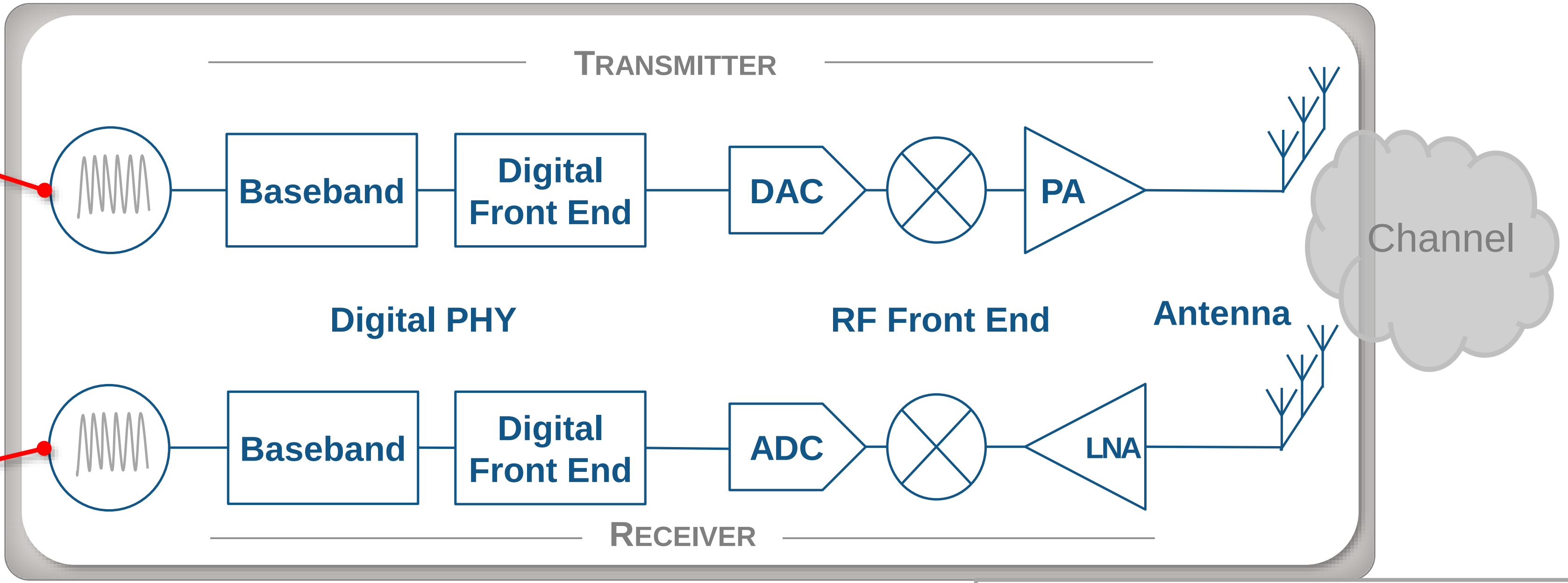
- RF Toolbox
- RF Blockset

Antennas, Beamforming

- Antenna Toolbox
- Phased Array System Toolbox







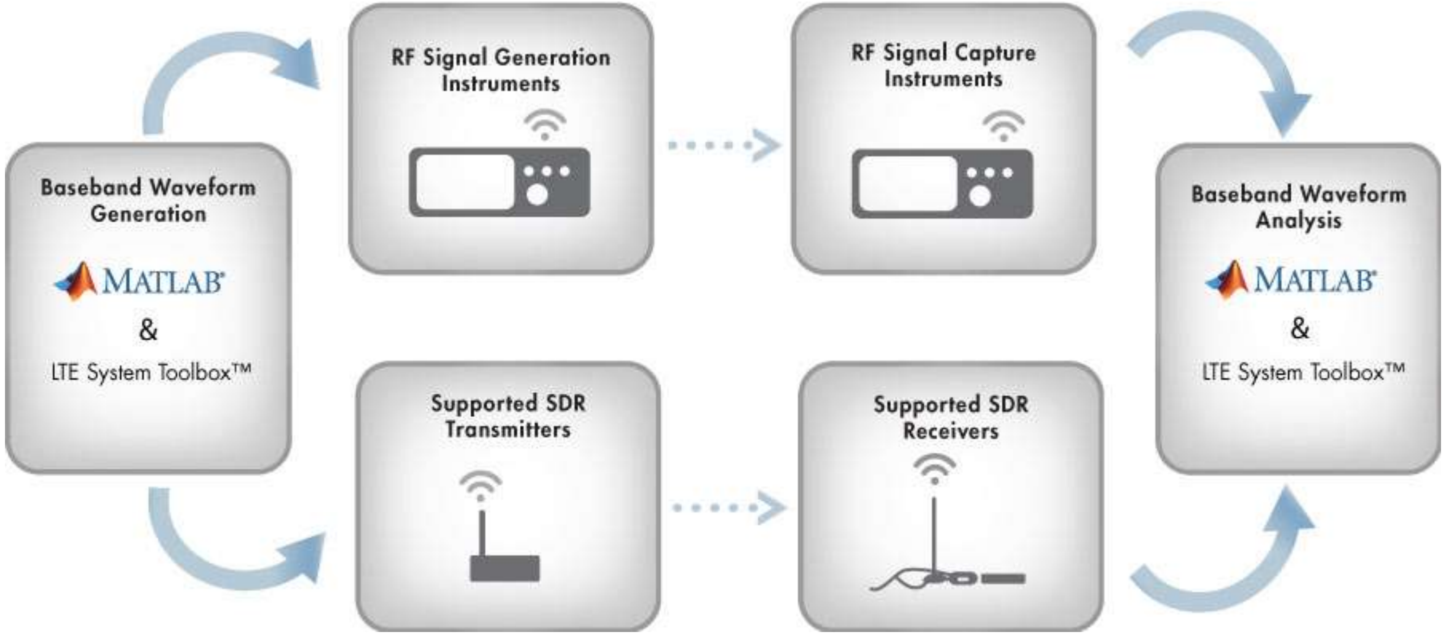
- Simulink
- DSP System Toolbox
- Control System Toolbox

Mixed-signal

- Communications System Toolbox
- Antenna Toolbox
- LTE System Toolbox
- WLAN System Toolbox

Channel and Propagation

Over-the-Air Testing with SDR and RF Instruments



Ettus USRP SDR

RTL-SDR

Pluto SDR

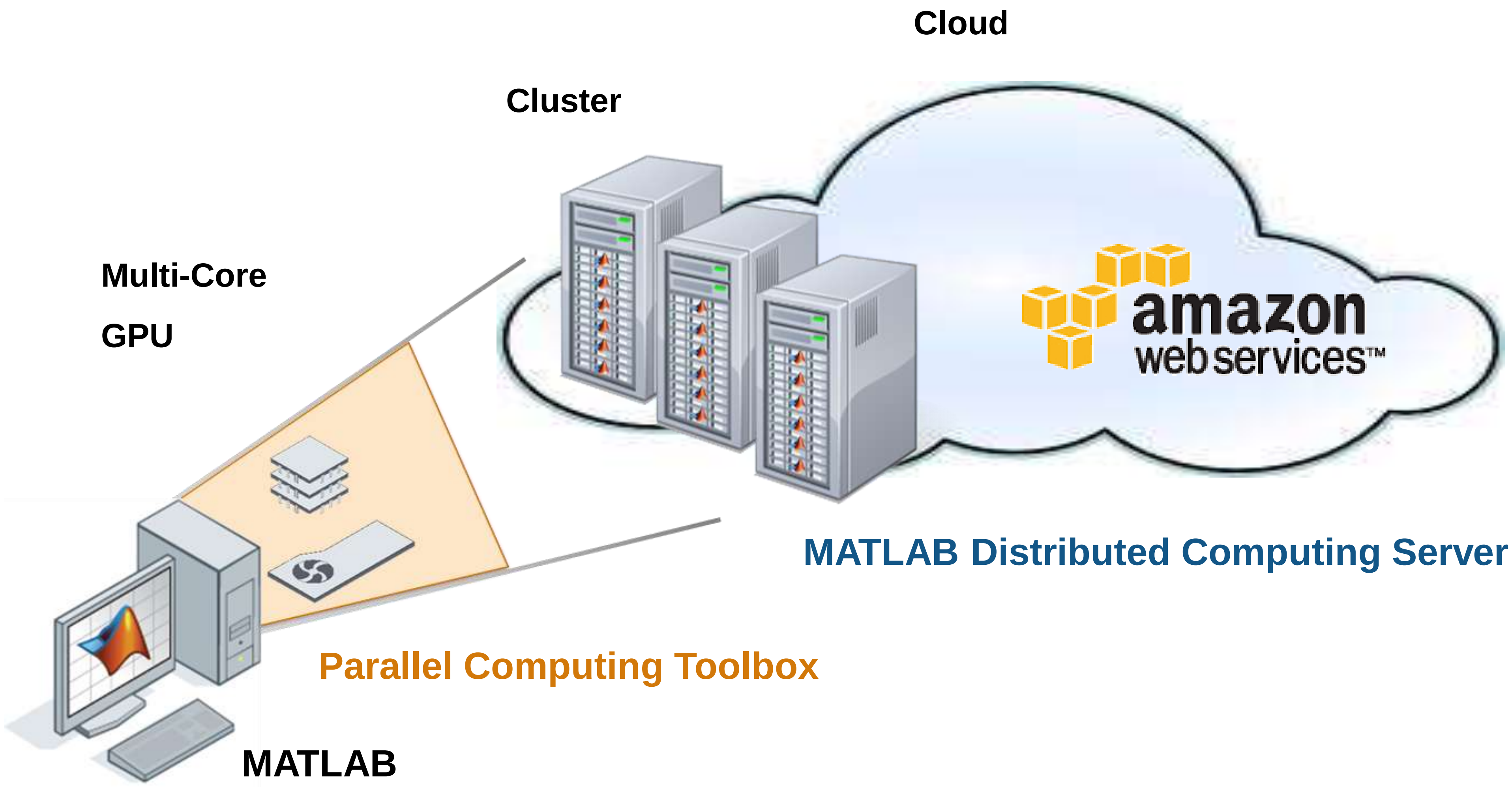
Zynq SDR

RF Signal Generator

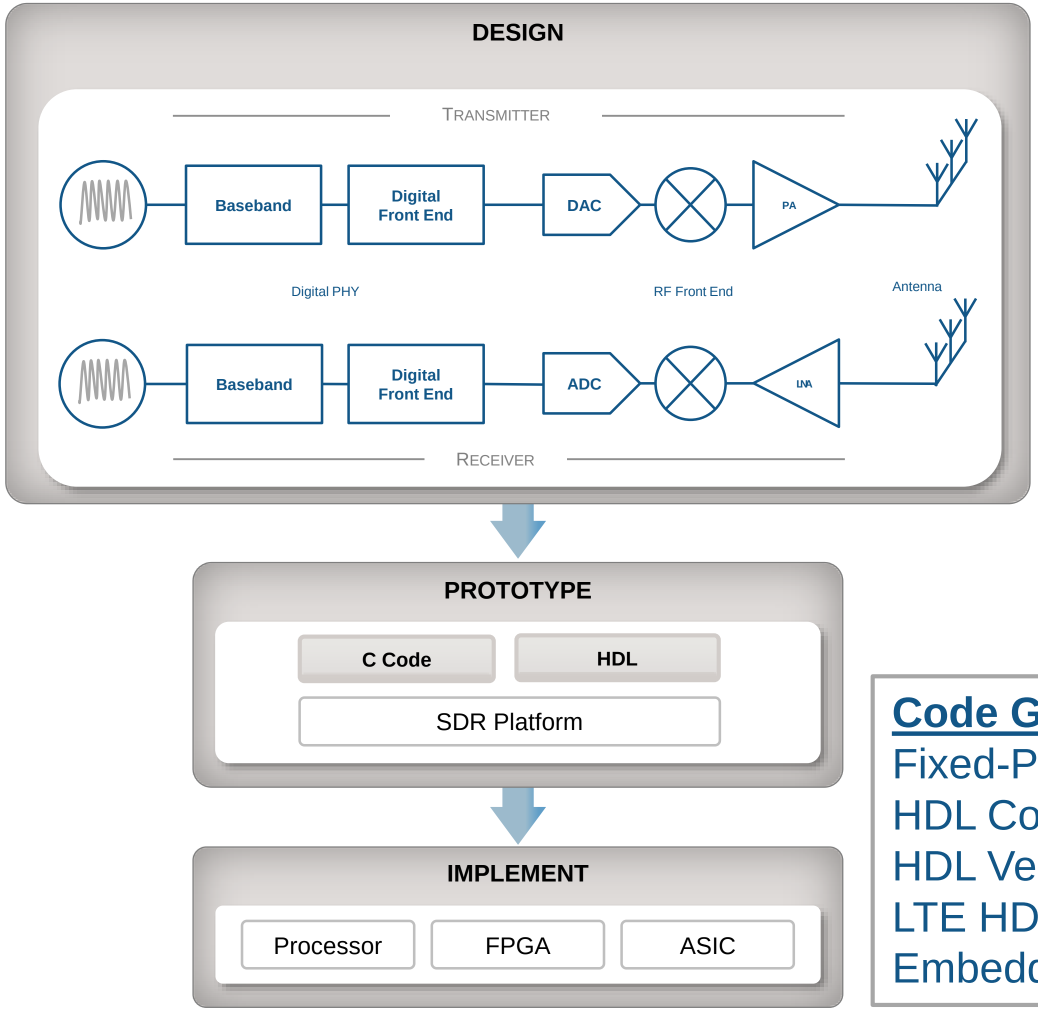
Spectrum Analyzer

Over-the-air Testing
Instrument Control Toolbox
SDR Support Packages
Communications System Toolbox

Accelerate Simulations with Scalable Computing



Common Platform for Wireless Development



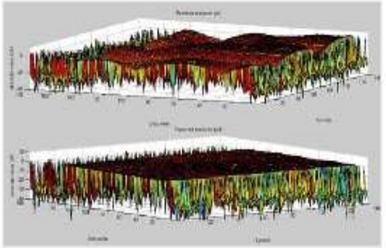
- Algorithm Design and Verification
- RF, Digital and Antenna Co-Design
- System Verification and Testing
- Rapid Prototyping and Production

Code Generation and Verification
Fixed-Point Designer
HDL Coder
HDL Verifier
LTE HDL Toolbox R2017b
Embedded Coder

Agenda

- 5G goals and requirements
- Modeling and simulating key 5G technologies
- 5G development workflow
- Learn more…

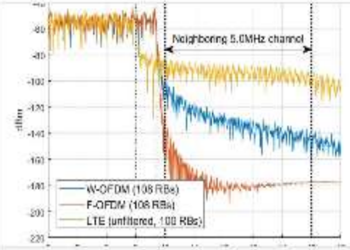
Resources to Help You Get Started



Conformance Testing

Ensure your designs comply with the supported 3GPP LTE standard releases.

» Learn more



5G Library

Simulate 3GPP 5G new radio technologies.

» Learn more

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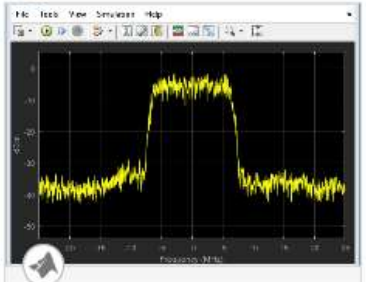

Power Amplifier Characterization with DPD for Reduced Signal

Provides a methodology for characterizing a nonlinear RF Blockset™ power amplifier (PA) with memory and an adaptive DPD

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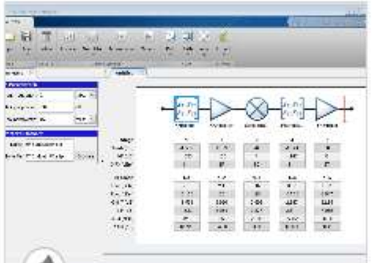
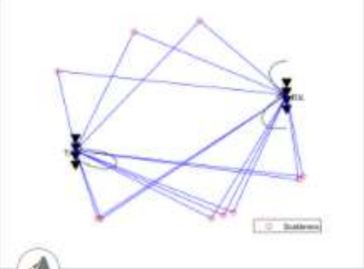


Visualizing RF Budget Analysis Over Bandwidth

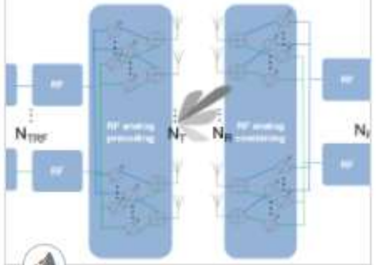
Programmatically perform an RF budget analysis of an RF receiver system and visualize computed budget results across the bandwidth



Improve SNR and Capacity of Wireless Communication Using...

The goal of a wireless communication system is to serve as many users with the highest possible data rate given constraints

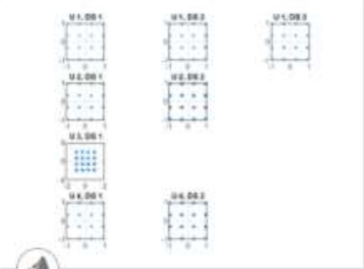
Open Script



Introduction to Hybrid Beamforming

Introduces the basic concept of hybrid beamforming and shows how to simulate such a system.

Open Script



Massive MIMO Hybrid Beamforming

How hybrid beamforming is employed at the transmit end of a massive MIMO communications system, using techniques for both

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SINR Map for a 5G Urban Macro-Cell Test Environment

This example shows how to construct a 5G urban macro-cell test environment and visualize the signal-to-interference-plus-noise

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Call to Action

View web resources

Wireless Communications Design with MATLAB

MATLAB and Simulink for 5G Technology Development

Read eBook and white papers

5G Development with MATLAB (eBook)

Hybrid Beamforming for Massive MIMO Phased Array Systems (white paper)

Four Steps to Building Smarter RF Systems with MATLAB (white paper)

Evaluating 5G Waveforms Over 3D Propagation Channels with the 5G Library (white paper)

Download software

Wireless communications trial package

Download the 5G Library

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- Web-based training with live, interactive instructor-led courses

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- Signal Processing with MATLAB
- Machine Learning with MATLAB
- Parallel Computing with MATLAB
- Programming Xilinx Zynq SoCs with MATLAB and Simulink

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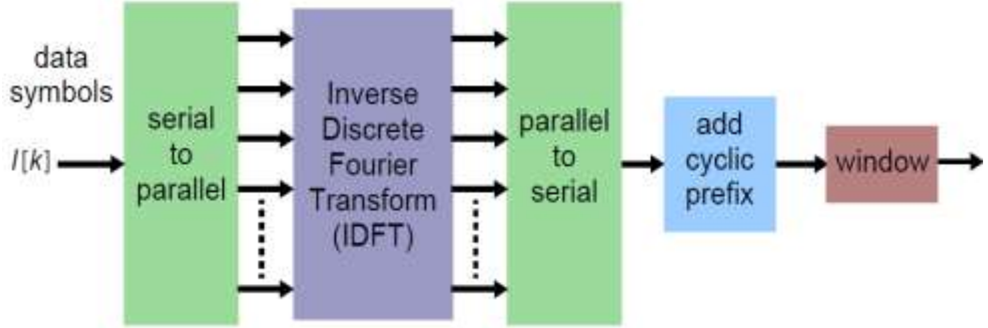
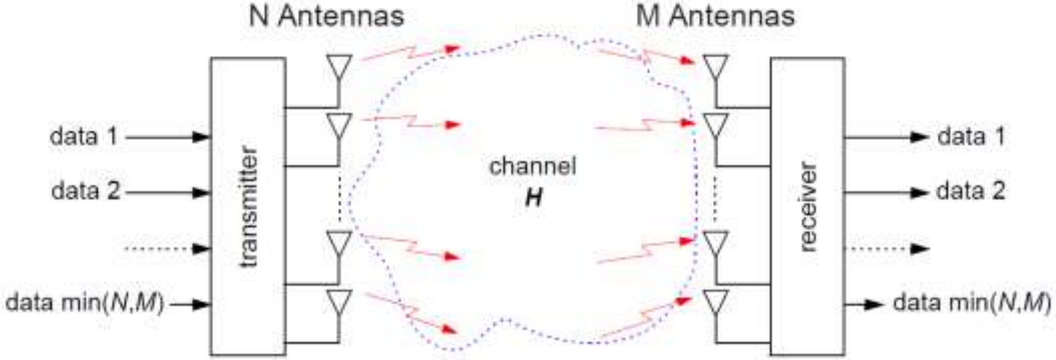
Updated: Communication Systems Design with MATLAB

- Advanced communications topics
  - MIMO / OFDM
  - LDPC / Turbo Codes / OSTBCs
  - Examples using IEEE 802.11 (Wi-Fi) & LTE-based system and waveform parameters

- New hands-on content using Software Defined Radios
  - Radio-in-the-loop using RTL-SDR and USRP B210
  - Build end-to-end OFDM system using a USRP
  - Demonstrate a 2x2 OFDM-MIMO over-the-air system using USRPs





RTL-SDR (RX)

USRP (TX & RX)

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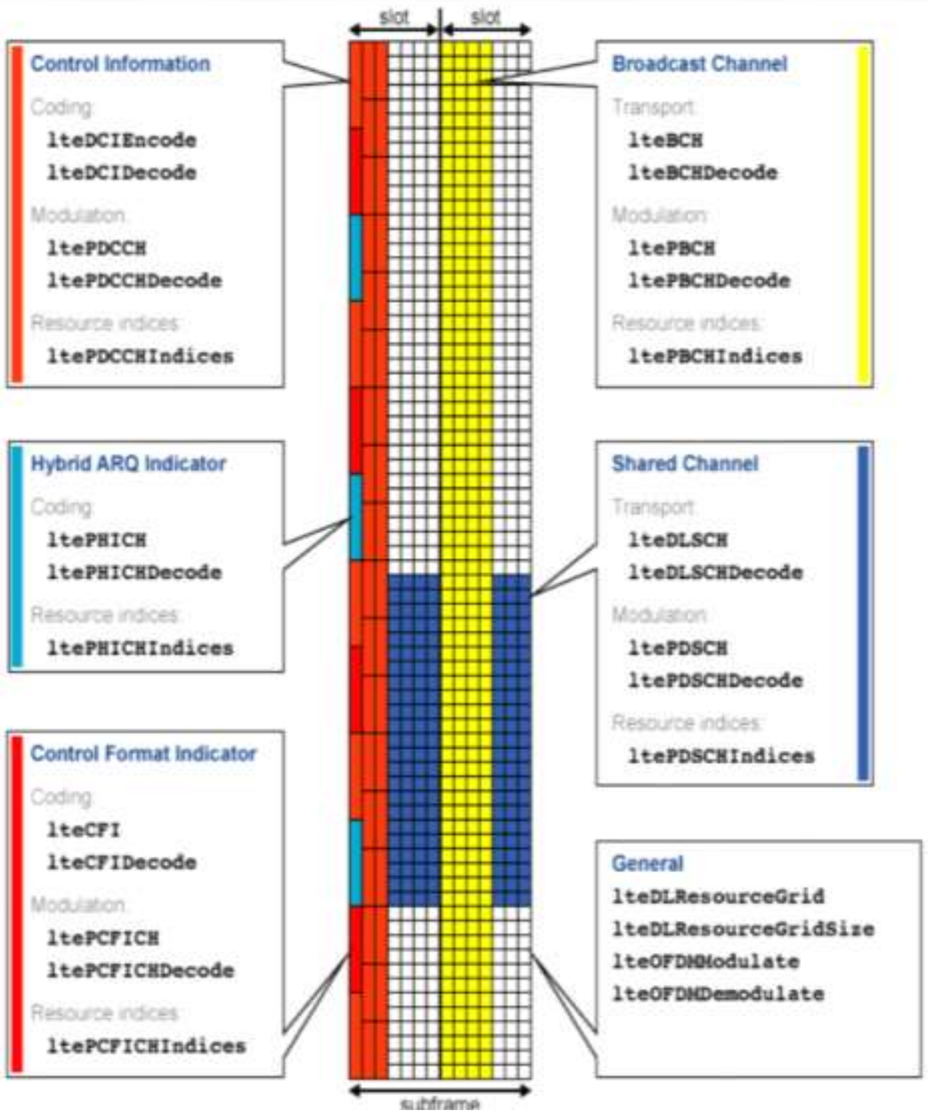
Designing LTE and LTE Advanced Physical Layer Systems with MATLAB

Topics include:

- Review of the advanced communications techniques forming the core of an LTE system: OFDMA and SC-FDMA multi-carrier techniques, and MIMO multi-antenna systems
- Descriptions of all of the signals and elements of the processing chain for the uplink and downlink LTE physical channels
- Methods for golden reference verification with the standard



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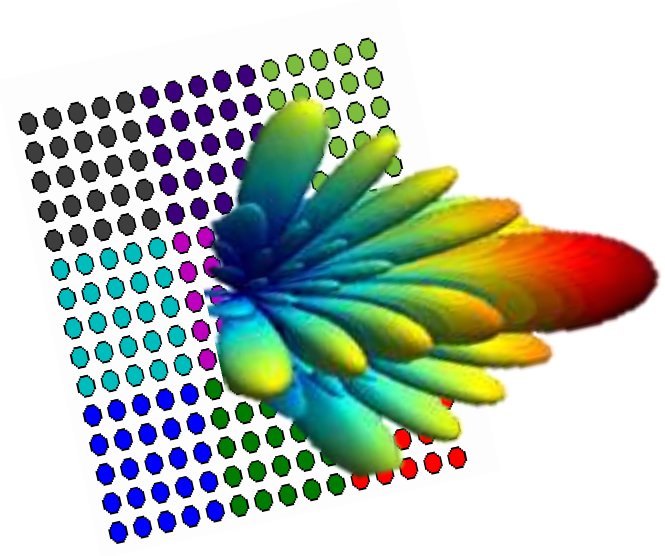
Phased Array System Toolbox Fundamentals

This one-day course provides a comprehensive introduction to the Phased Array System Toolbox™. Themes including radar characterization and analysis, radar design and modeling and radar signal processing are explored throughout the course.

Topics include:

- Review of a Monostatic End-to-End Radar Model
- Characterize and analyze radar components and systems
- Design and model components of a radar system
- Implement a range of radar signal processing algorithms

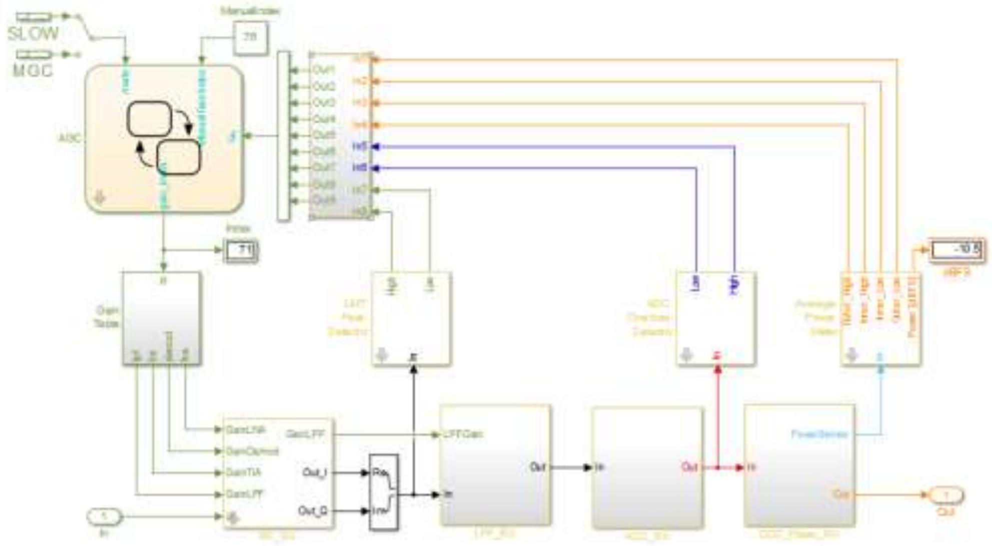


MathWorks | *Training Services*

Modeling RF Systems with RF Blockset

Topics include:

- Introduction to RF simulation using MathWorks tools
- How do I model my RF system with RF Blockset?
- Importing S-Parameters and modeling linear operation
- Fundamentals of noise simulation
- Modeling non-linear devices
- Developing custom models

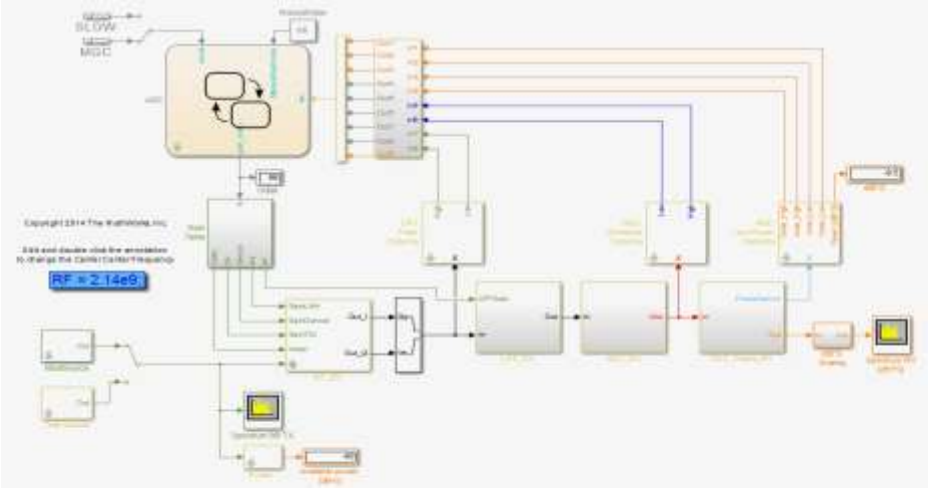


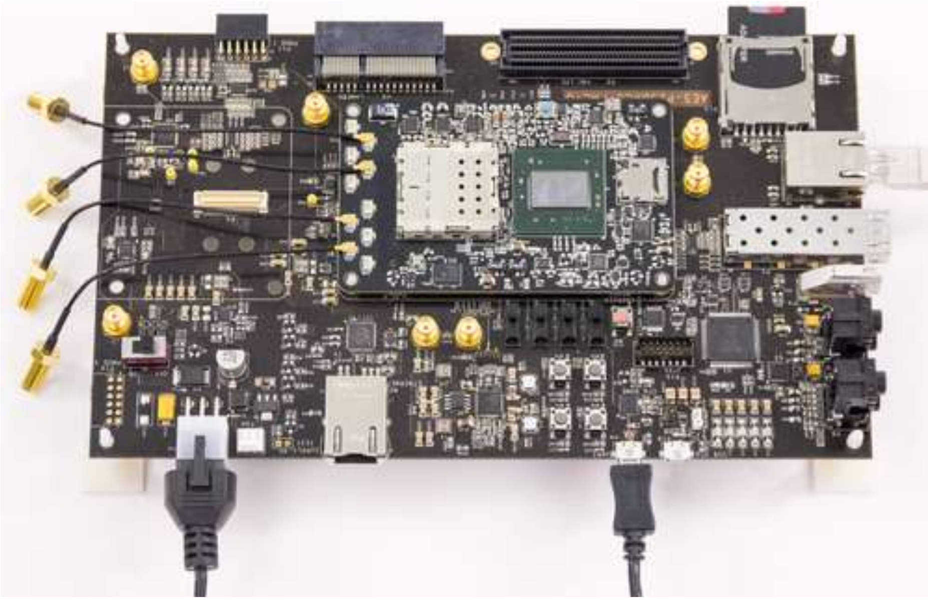
New module:

- Testing and Programming the AD9361 with the RF Blockset Model

MathWorks | Training Services

New: Software Defined Radio with Zynq using Simulink





- Learn the Model-Based Design workflow from simulation of RF chain, testing with Radio I/O to moving design to chip
- Get hands-on experience with PicoZed
  - Setting up and communicating with board
  - Capture over-the-air signal and process in MATLAB
  - AD9361 configuration
  - HW/SW co-design for SDR

Speaker Details

Email: Tabrez.khan@mathworks.in

Contact MathWorks India

Products/Training Enquiry Booth

Call: 080-6632-6000

Email: info@mathworks.in

- **Share your experience with MATLAB & Simulink on Social Media**
  - Use #MATLABEXPO
  - I use #MATLAB because……………………… Attending #MATLABEXPO
  - Examples
    - I use #MATLAB because it helps me be a data scientist! Attending #MATLABEXPO
    - Learning new capabilities in #MATLAB and #Simulink at #MATLABEXPO.

- **Share your session feedback:**

  Please fill in your feedback for this session in the feedback form

Thanks for your attention

Questions?