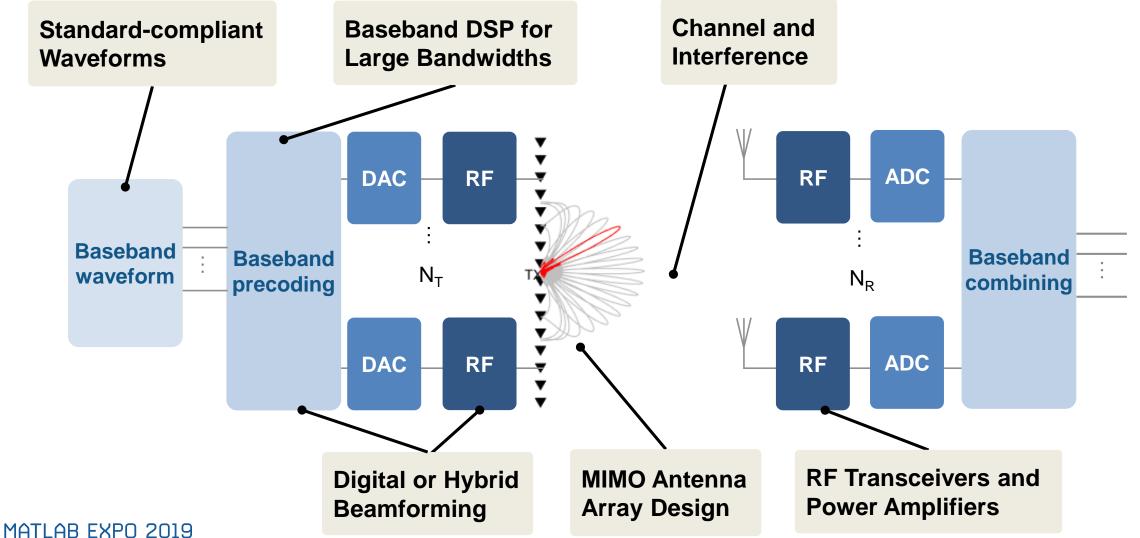
# MATLAB EXPO 2019

Seamless System Design of RF Transceivers and Antennas for Wireless Systems

Vidya Viswanathan Application Engineer – Signal Processing & Communication



# Multi-Domain Engineering for Advanced Wireless Systems Subsystems must be designed and tested together



2

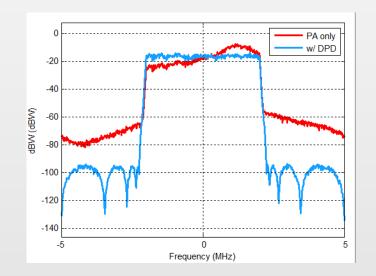


# Agenda



# Beamforming for Multi-User Operation

# Power Amplifier & Digital Pre-distortion

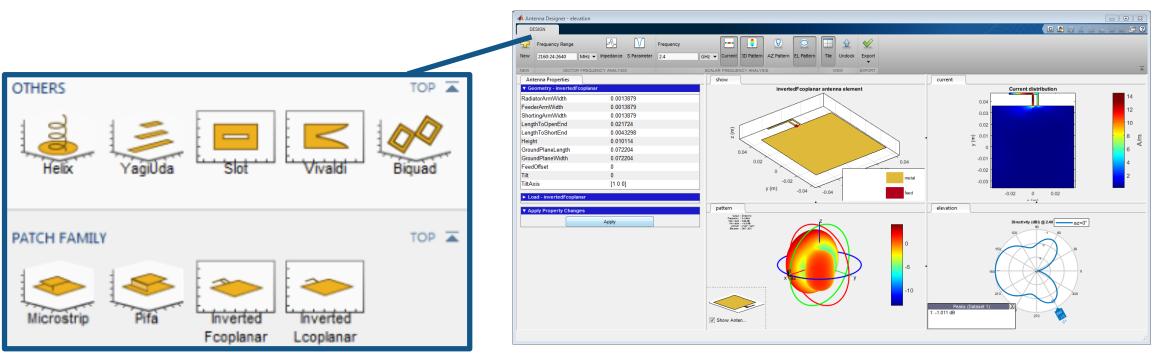




# **Antenna Design – Where To Start?**

## **Antenna Designer App**

- Select an antenna based on the desired specifications
- Design the antenna at the operating frequency
- Visualize results and iterate on antenna geometrical properties
- Generates MATLAB scripts for automation



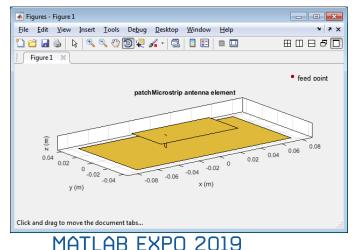


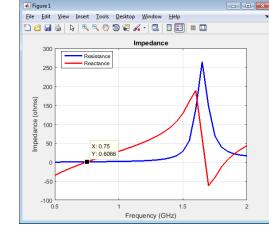


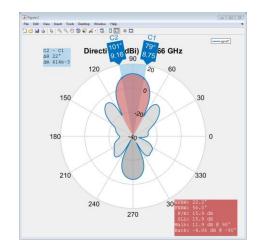
# **Building your First Antenna and Antenna Array**

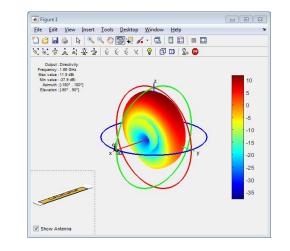
```
p = patchMicrostrip
p.Height = 0.01;
impedance(p, (500e6:10e6:2e9));
current(p, 1.7e9);
pattern(p, 1.7e9);
```

```
a = linearArray
a.Element = p;
a.ElementSpacing = 0.1;
a.NumElements = 4;
show(a);
patternElevation(a, 1.7e9,0);
```







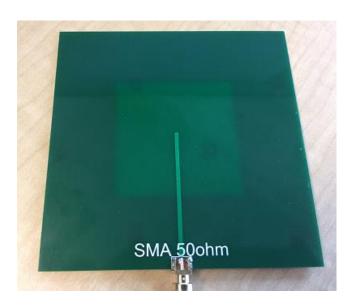




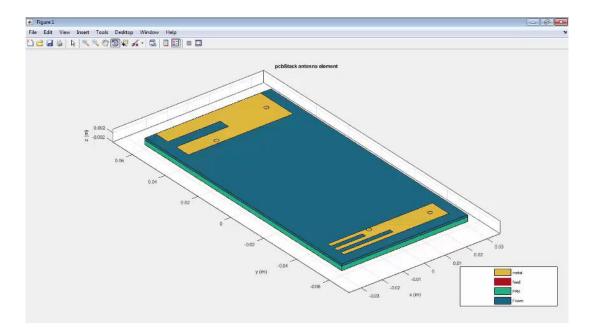
# **Printed Antenna Designing and Fabrication**

Suitable for low cost applications requiring high antenna integration

- Design printed antennas with pcbStack
- Arbitrary dielectric and metal layers
- Define vias and feed structures
- Generate Gerber files



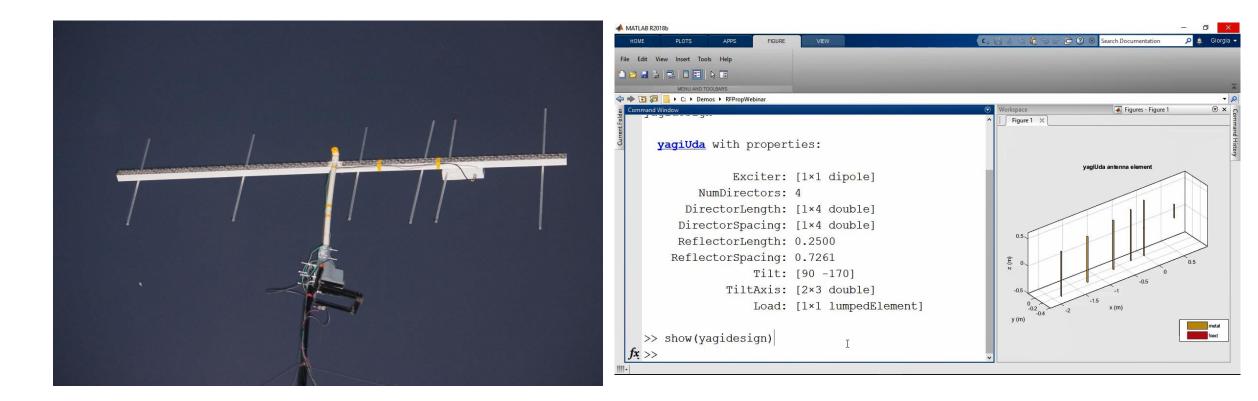






# **Antenna Design and Analysis**

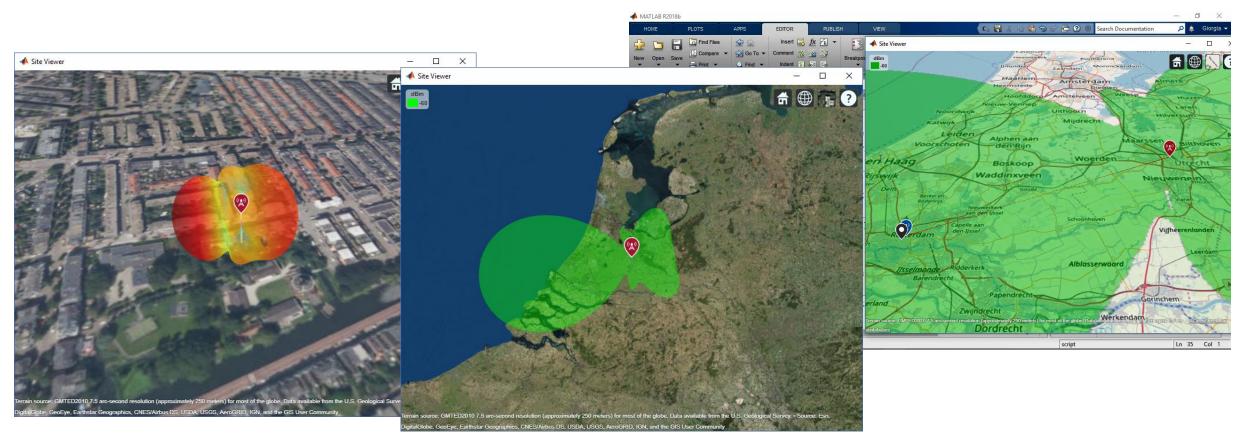
VHF YagiUda antenna designed with Antenna Toolbox to operate at 144.5MHz





# **Antenna Placement and Coverage Analysis**

- Position the antenna at a specific geographical location
- Show coverage of the antenna using Ideal free-space propagation model

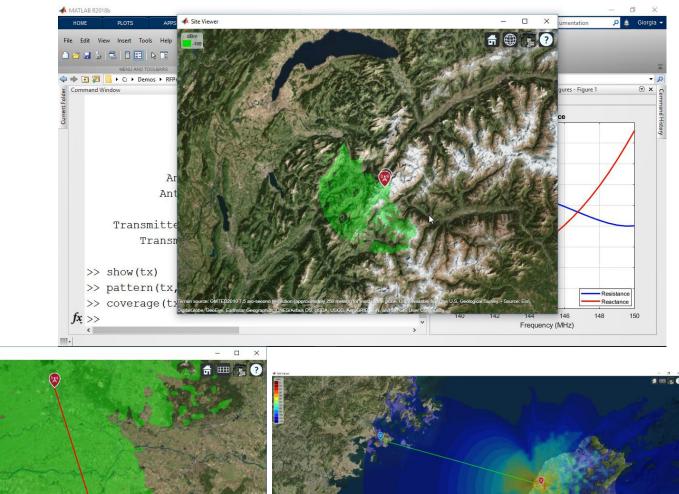




# **Visualize the Antenna on the Terrain**

A Site Viewe

- Terrain Based Propagation Model: Longley-Rice
  - Statistical model taking into account diffraction and scattering
  - Operates between 20MHz and 20GHz
- Include atmospheric effects like rain, fog and gas

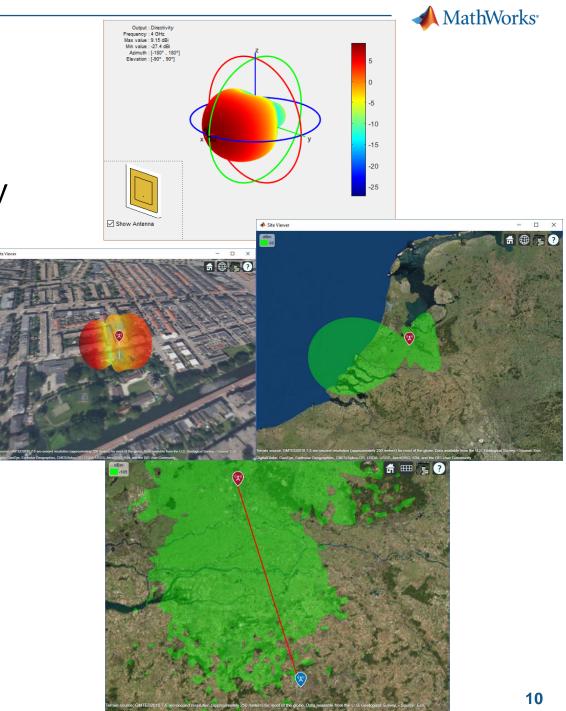


# What did we see in this example?

 Antenna elements and arrays described by electromagnetic based solutions

 Terrain based coverage modeling with realistic antenna models

 Method can be extended to include RF propagation along with channel models

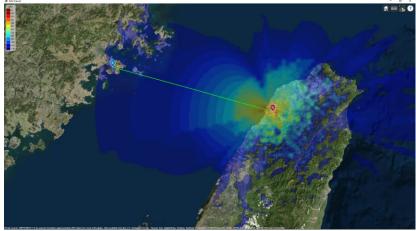




# What's New? Propagation Models

- TIREM
  - Statistical model taking into account reflection, diffraction, and absorption
  - Operates between 1MHz and 40GHz
- Include atmospheric effects like rain, fog and gas





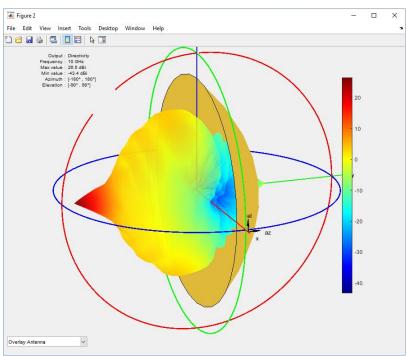


## What's New?

## **Platform-Installed Antennas and Large Structures**

- Import CAD files (STL) to describe large structures such as planes, ships, or cars
- Install antennas and arrays on a platform
- Analyze the effect of the large structure on the antenna performance
- Use physical optics in conjunction with the method of moments





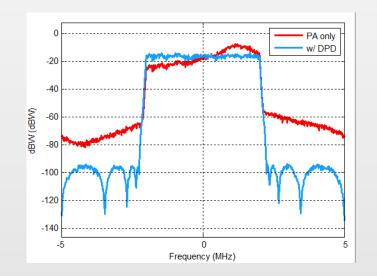


# Agenda



# Beamforming for Multi-User Operation

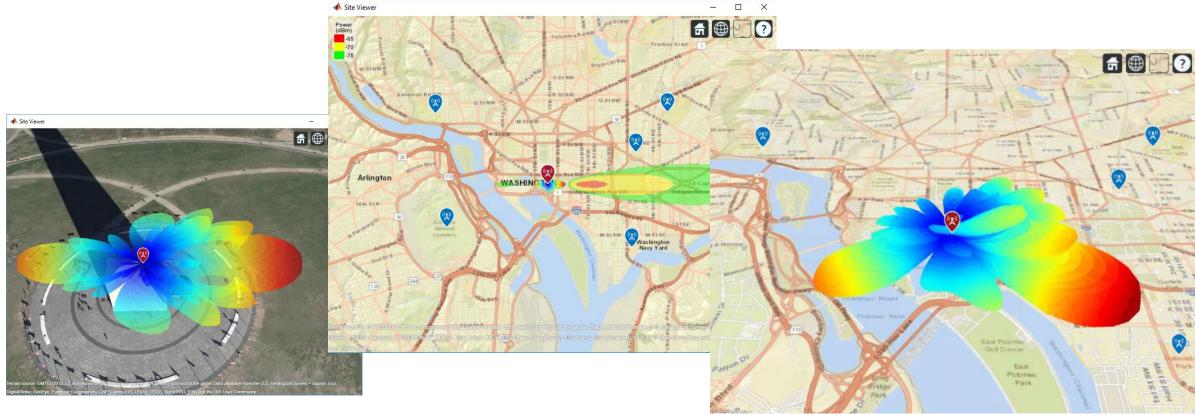
# Power Amplifier & Digital Pre-distortion





# **Array Beam Steering and Map Visualization**

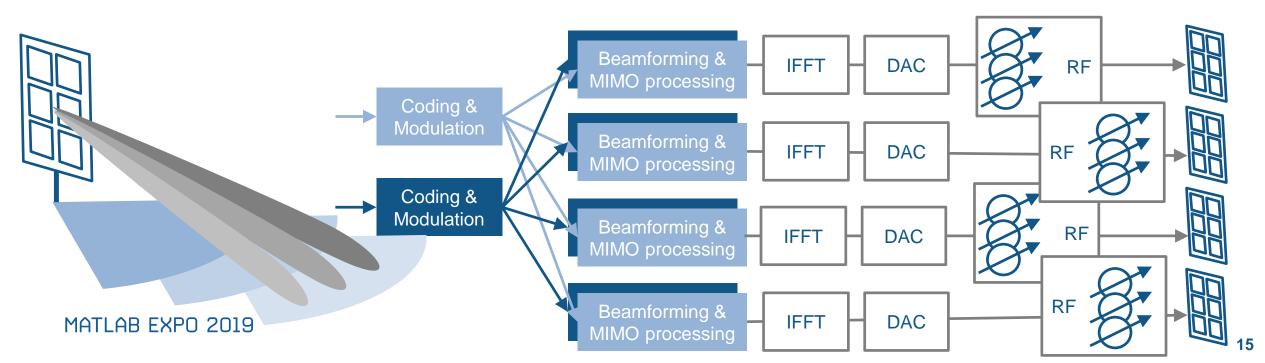
- 7x7 rectangular array of dipoles reflector-backed, operating at 10GHz
- Steer the array beam and assess coverage and links





# **Beamforming for multi-user operation**

- Coarse analog RF beamforming is the same for entire bandwidth
  - Subarray modules (panels) allow coarse elevation angle adjustment (by phase shifters)
  - MU groups are arranged by distance (ring structure)
- Fine beamforming in baseband is performed for OFDM mode in frequency domain
  - Fine horizontal separation of the users is done with baseband processing





×10<sup>-3</sup>

/sart(50

linearArray of patchMicrostrip antennas

# **RF Front End Modelling using Circuit Envelope**

- Direct conversion to IF (5GHz) and superhet up-conversion to mmWave (66GHz)
- Non-linearity (e.g. IP2, IP3, P1dB)
- Power dividers (e.g. S-parameters)

OK Cancel Help

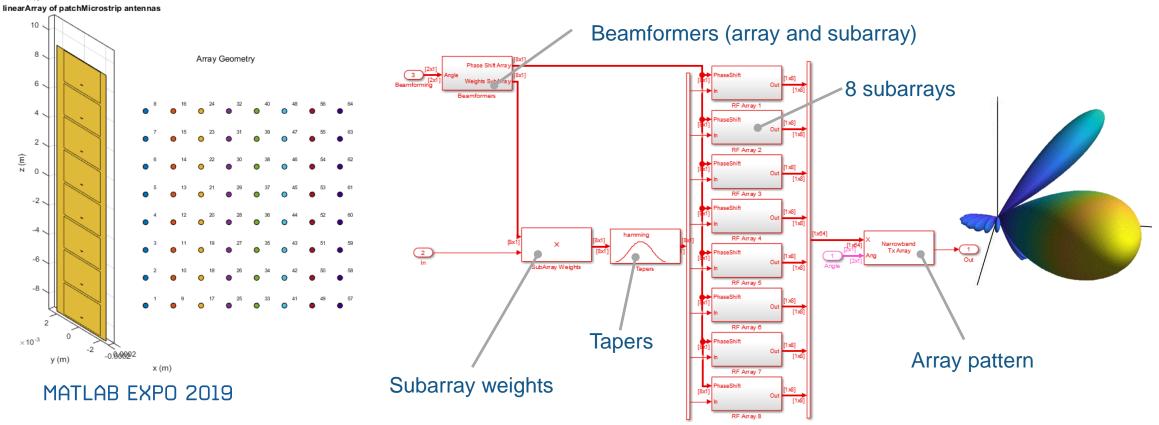
Apply

(1)PhaseShift 10 Variable phase-shifters Amplifier 8 8 8 8 8 8 പ്പ 8 Model an amplifier. 坠 唜 臣 龁 墅 氒 Main Nonlinearity 6 Odd order Nonlinear polynomial type: Intercept points convention: Output IP3: 20 1-dB gain compression power: 33 2 inf Output saturation power z (E) Gain compression at saturation: inf 400 0 <u>, ti</u> -2 Mod **+⊗+** 400 Block Parameters: IQ Modulato 83 23 IQ Modulator 400 -6 Model an IQ modulator Main Impairments Nonlinearity hase : dB 🔹 23 I/Q gain mismatch: 0.1 4000 I/O phase mismatch: 2 🗄 deg 👻 60 LO to RE isolation. : dB ABO. Noise floor (dBm/Hz): -168 ×10<sup>-3</sup> -0 0,0002 S parameters y (m) Antenna Array 19 x (m)



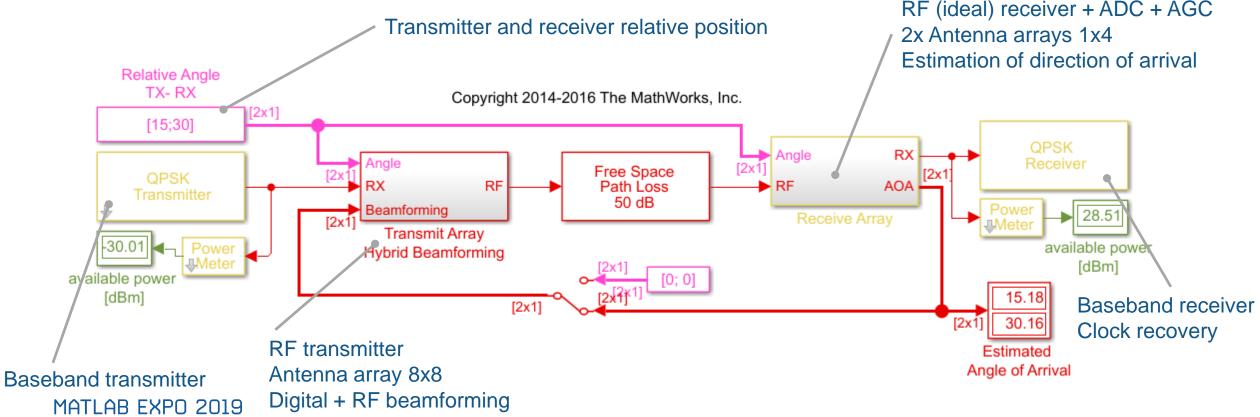
# Hybrid Beamforming Transmitter Array

- 8 subarrays of 8 patch antennas operating at  $66GHz \rightarrow 8x8 = 64$  antennas
- Digital beamforming applied to the 8 subarrays (azimuth steering)
- RF beamforming (phase shifters) applied to the 8 antennas (elevation steering)



# **System Architecture for Hybrid Beamforming**

- The transmitter uses a larger array to perform beamforming towards the receiver
- The receiver estimates the direction of arrival with small orthogonal arrays and communicates it to the transmitter



MathWorks<sup>®</sup>

**Download Whitepaper** 

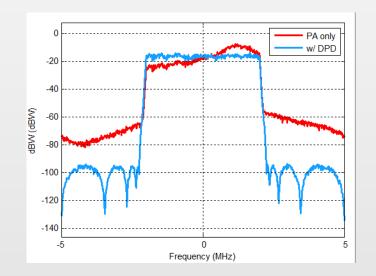


# Agenda



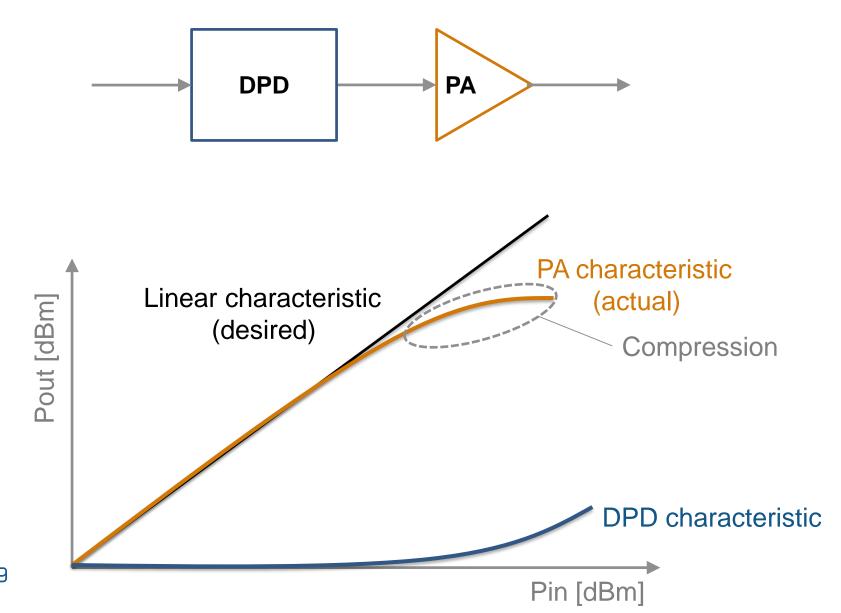
# Beamforming for Multi-User Operation

# Power Amplifier & Digital Pre-distortion

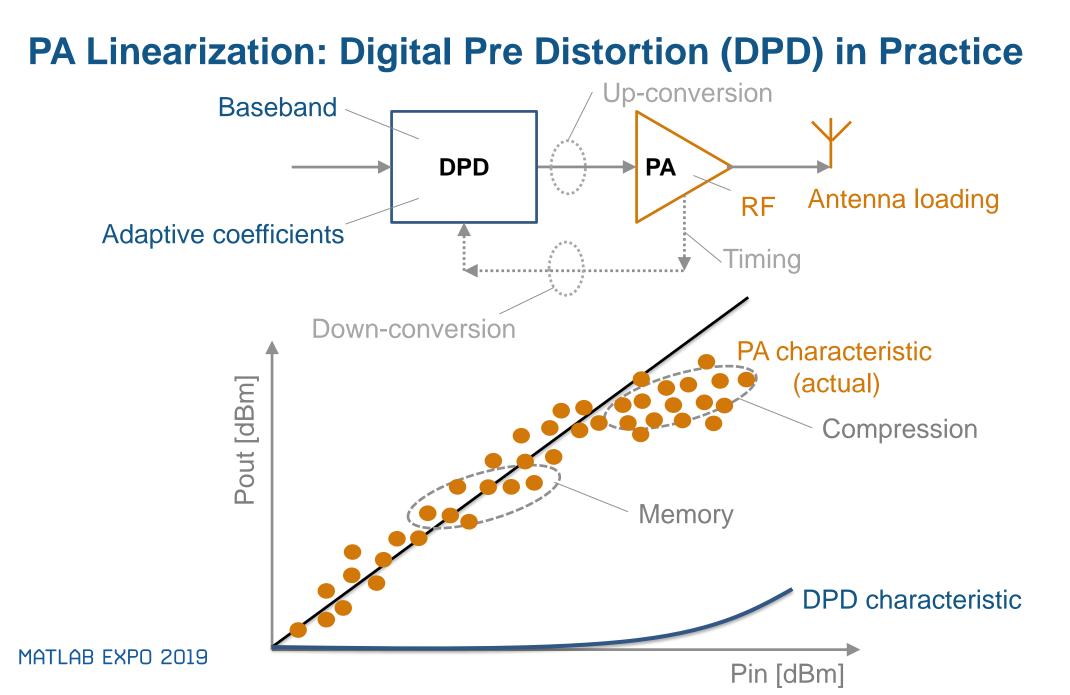




# PA Linearization: Digital Pre Distortion (DPD) in Theory





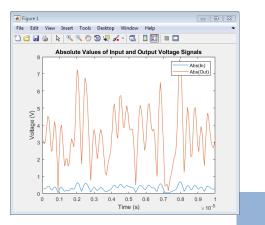


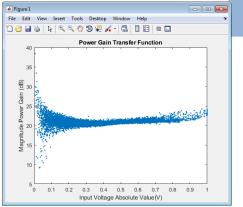
#### 



## What resources are available to characterize a PA Model?

## 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);

S.

#### 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);

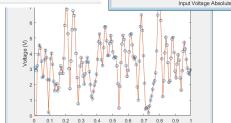
#### case 'ctMemPoly' % Cross-term memory polynomial

- 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);

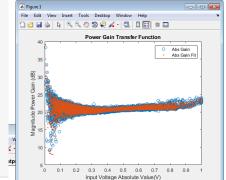
a\_coef = reshape(coef,memLen,numel(coef)/memLen);



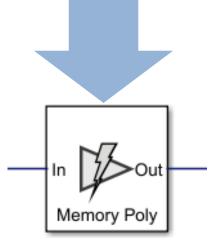
Time (s)

## PA model coefficients

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H	3x19 complex double													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
1	7.1756 + 1.1238i	57.1783 - 12.3324i	10.5876 - 7.5994i	-2.423	-4.379	-1.125	24.61	1.461	4.390	-94.35	-2.338	-8.825	1.934	. 1
2	3.2336 - 0.7538i	-25.2834 + 7.1506i	-4.4593 + 13.8723i	-9.675	2.191	2.847	1.131	-8.420	-9.565	-4.801	1.563	2.309	9.079	-1
3	-1.6834 + 1.1150i	12.5544 - 6.4201i	-4.6721 - 4.7128i	16.98	-1.006	51.69	-1.516	3.683	-2.068	5.637	-6.580	3.495	-9.910.	. 5
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~ 10-5



## PA model for circuit envelope simulation



# **PA + DPD Simulation**

Pre-distort a complex baseband signal using a memory polynomial to

Cancel

compensate for nonlinearities in a power amplifier.

OK

Memory polynomial

- Circuit Envelope for fast RF simulation
- Low-power RF and analog components
  - Up-conversion / down-conversion
  - Antenna load

Block Parameters: DPD

Coefficient source: Input port

Help

Apply

DPD

Block Parameters: DPD Coefficient Polynomial type:

distortion of a nonlinear power am Simulate using: Code generation

DPD Coefficient Estimator

Desired amplitude gain (dB):

Source code

Parameters

Degree:

Polynomial type:

Memory depth

Forgetting factor

Forgetting factor source:

Initial coefficient estimate:

Simulate using: Code generation

OK

Algorithm:

Estimate the coefficients of a mem

Source code

Parameters

Memory polynomial

Recursive least squares

Least squares

Cancel

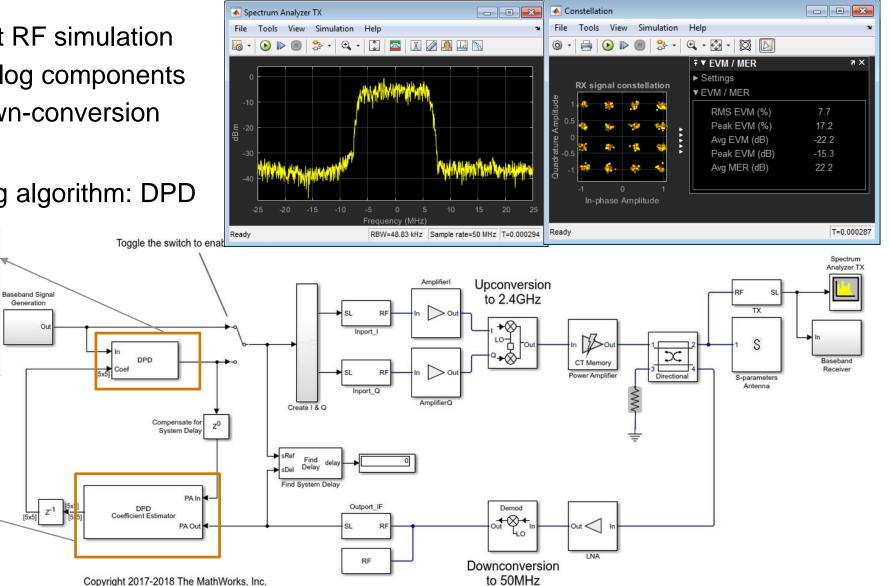
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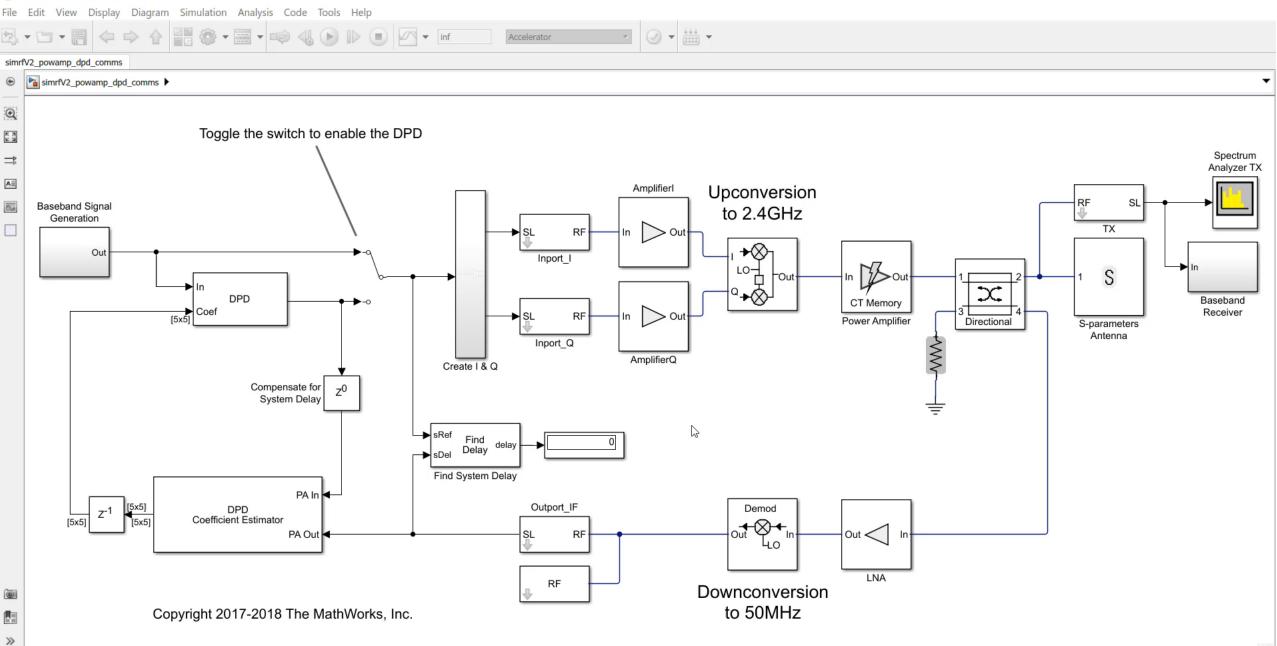
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- Digital signal processing algorithm: DPD

Help

Apply





Ready



# **RF System Simulation Must Be Fast**

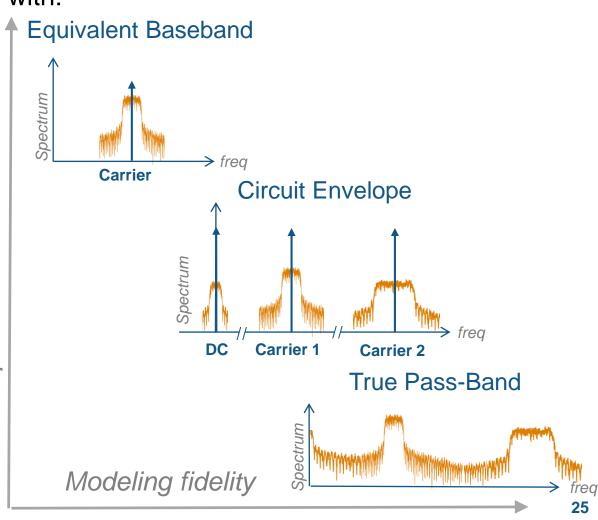
RF Blockset allows you to deal with RF complexity with:

- Models at high levels of abstraction
- Solvers that use larger time-step

Deeper understanding of:

- Non-linear effects
- Noise generation
- Sources of signal distortion
- Impedance mismatches

Simulation speed





## Developing a Radio Frequency System for Wireless at Huawei

Erni Zhu, Huawei

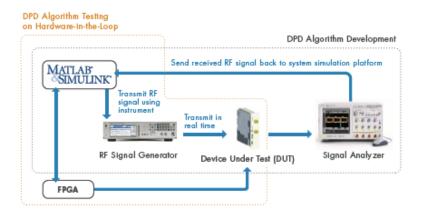
Huawei, in collaboration with MathWorks, developed an intermediate frequency (IF) and radio frequency (RF) system for 5G wireless base stations to achieve greater capacity, higher speed, lower latency, and more energy efficiency.

MATLAB® and Simulink® help Huawei address design and verification challenges including modeling and analysis of hybrid analog-digital systems, accelerating algorithm implementation with code generation, and automating verification. Huawei saved development time by efficiently creating designs early in R&D, which reduced debugging and verification effort.

#### Advantages of using MATLAB:

- Perform closed-loop simulation of designs containing both analog/RF and digital components, such as digital predistortion (DPD) for RF power amplifiers
- Quickly develop a flexible, high-performance hardware development platform at the beginning of the R&D process using a seamless interface to RF instruments
- Quickly build an automatic verification platform between software and hardware
- Use a single platform for hardware development, including reference models, fixed-point conversion, and automatic C and RTL code generation
- Reuse models for bit-true verification of floating-point, fixed-point, and RTL code





Presented at MATLAB EXPO 2017 China

Watch video (in Chinese) 28:11

📣 MathWorks

**Demo Station:** 

Antenna and RF Design

# Wireless System Overview MATLAB & Simulink as a Unified Platform

#### **RF Front End** Antennas, Antenna Arrays Algorithms, Waveforms, Measurements Antenna Toolbox • **Communications Toolbox RF** Toolbox . Phased Array System Toolbox Phased Array System Toolbox **RF Blockset** LTE, WLAN & 5G Toolbox Establish the number of component carriers. umCC = length (NDLRB); Output Directivity Prespeny #40.0xx Mox value 871.08 Ministrie 422.5.09 Aprilute 1477.190 Etwalter 1477.197 Demotive 147 % Create transmission for each component carrier enb = cell(1,numCC); Gank (d) N<sup>2</sup> (d) OT3 (d) Trad (d) Pad (d) Del (d) Del (d) Del (d) Del (d) for i = 1:numCC 1.2 1.3 1.4 21 0.07 0.07 423.44 423.44 423.44 6.016 0.0142 620.44 7.0 0.0142 3.005 0.0 6.005 5.053 71.2 10.41 10.41 enb{i} = lteRMCDL('R.5'); enb(i).NDLRB = NDLRB(i); TRANSMITTER at the best link Calley Weden Hep a b b ∿∿⊙⊙∉⊀・₫ □⊟ =□ Digital DAC Baseband Donnier Spectrum Front End File Tools View Playback Helt Channel 1 KH & 19 [13] [24 [24] Antenna **Digital PHY RF Front End** File Tools View Simulation Help Digital **Baseband** ADC LNA Front End RECEIVER **Communications Toolbox** Phased Array System Toolbox digital > analog digital SAR LTE, WLAN & 5G Toolbox **Mixed-Signal Design** ready Start **Channel Modeling** Mixed-Signal Blockset Flash ADC



# **Resources to Help You Get Started**

## View web resources

Mapping RF Propagation for Wireless Communications (webinar) Modeling RF Power Amplifiers and **Increasing Wireless Transmitter** Linearity with DPD Using MATLAB (webinar)

# Read eBook and white

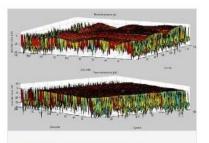
## papers

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)

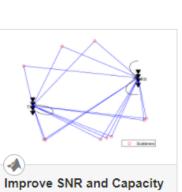
### MATLAB EXPO 2019



### **Conformance** Testing

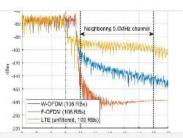
Ensure your designs comply with the supported 3GPP LTE standard releases.

» Learn more



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

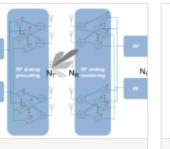


### 5G Library

Simulate 3GPP 5G new radio technologies.

» Learn more

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R2018a
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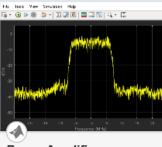


#### Introduction to Hybrid Beamforming

4

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

Open Script



#### **Power Amplifier** Characterization with DPD for Reduced Signal

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

U2.083

....

Massive MIMO Hybrid

How hybrid beamforming is

employed at the transmit end of a

system, using techniques for both

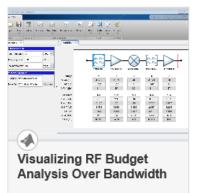
massive MIMO communications

Beamforming

U2.081

U 3, DS





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



#### 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



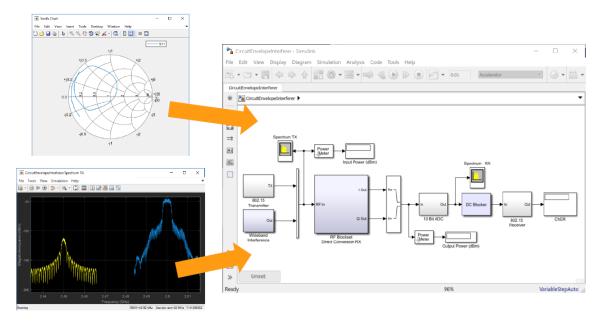
Open Script



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# **RF System Design using MathWorks Tools**

- 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





# Please provide feedback for this block of sessions



- Scan this QR Code or log onto link below (link also sent to your phone and email)
- <u>http://bit.ly/expo19-feedback</u>
- Enter the registration id number displayed on your badge
- Provide feedback for this session

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