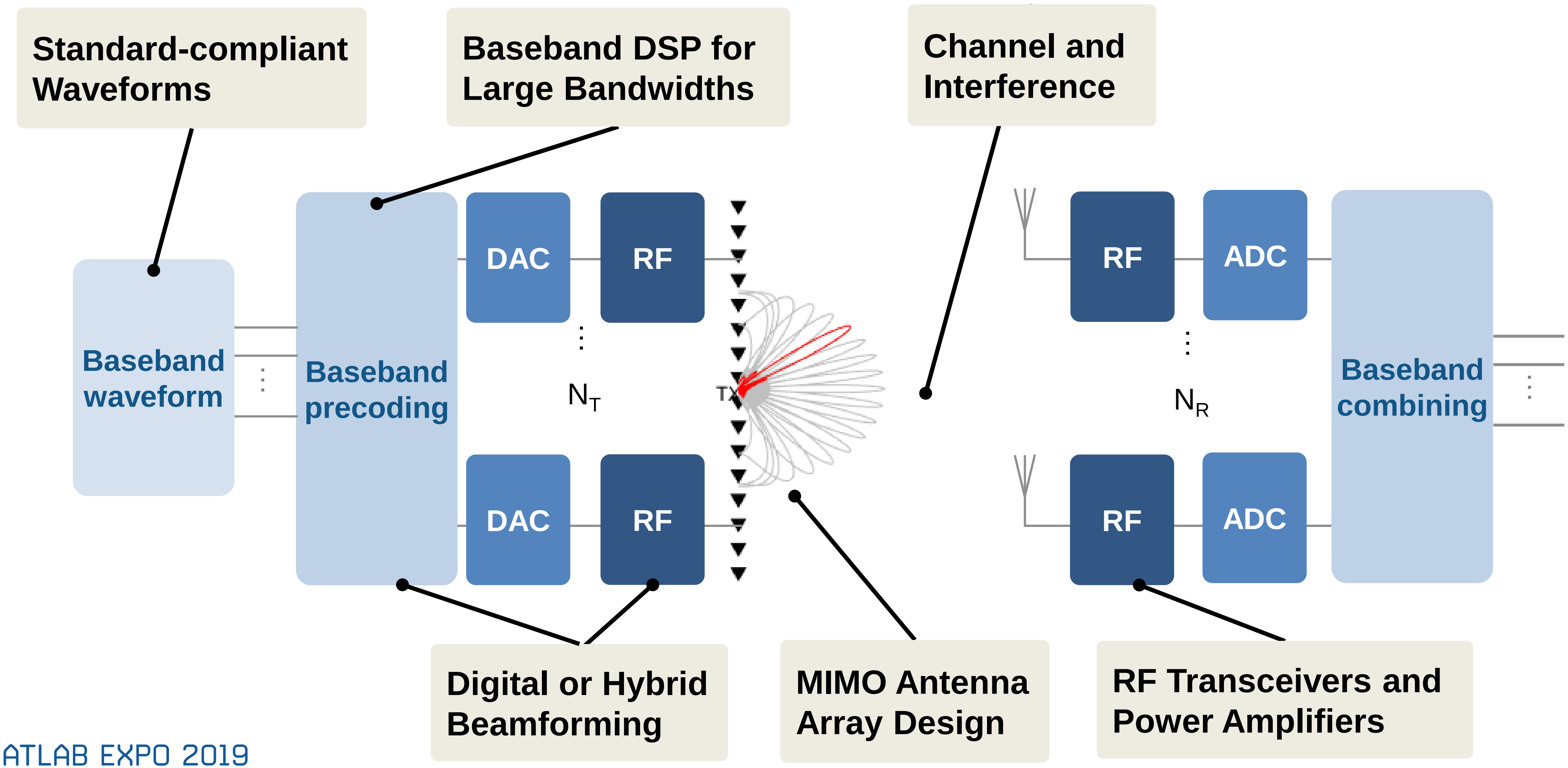
MATLAB EXPO 2019

Seamless System Design of RF Transceivers and Antennas for Wireless Systems

Vidya Viswanathan
Application Engineer – Signal Processing & Communication

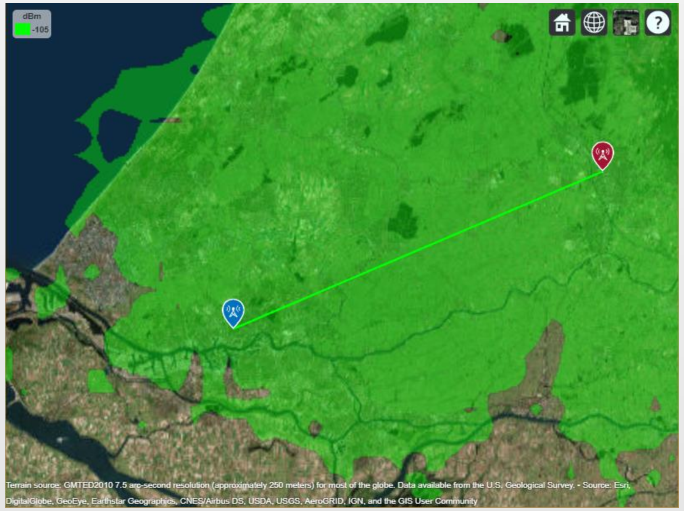
Multi-Domain Engineering for Advanced Wireless Systems

Subsystems must be designed and tested together

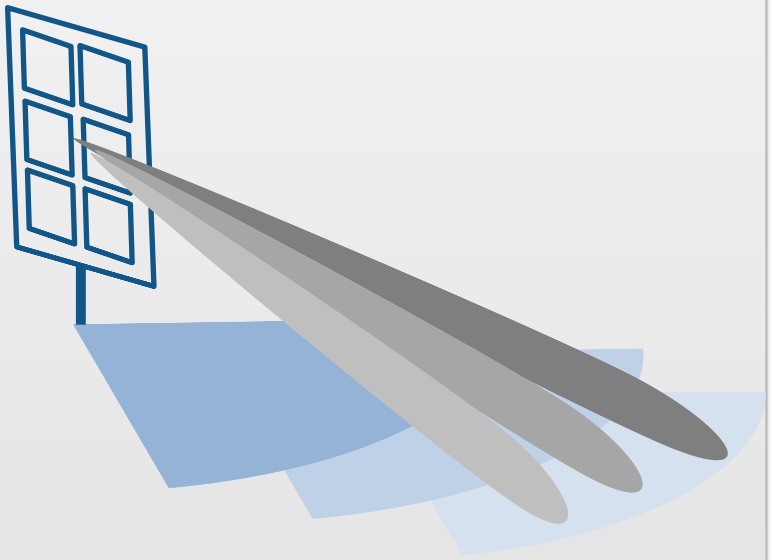


Agenda

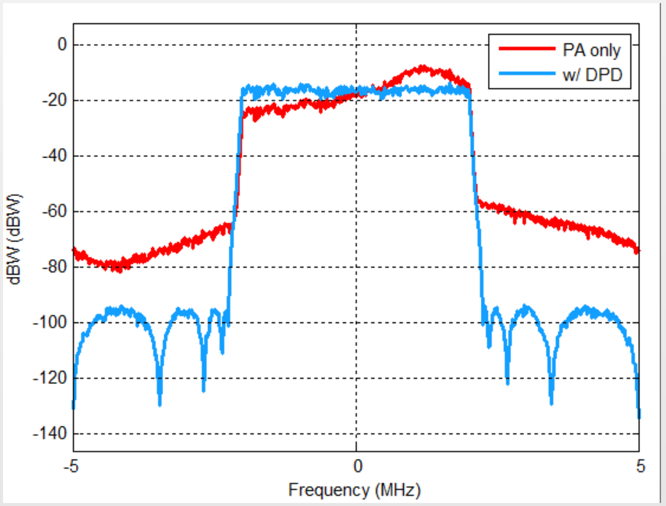
RF Propagation & Network Coverage



Beamforming for Multi-User Operation



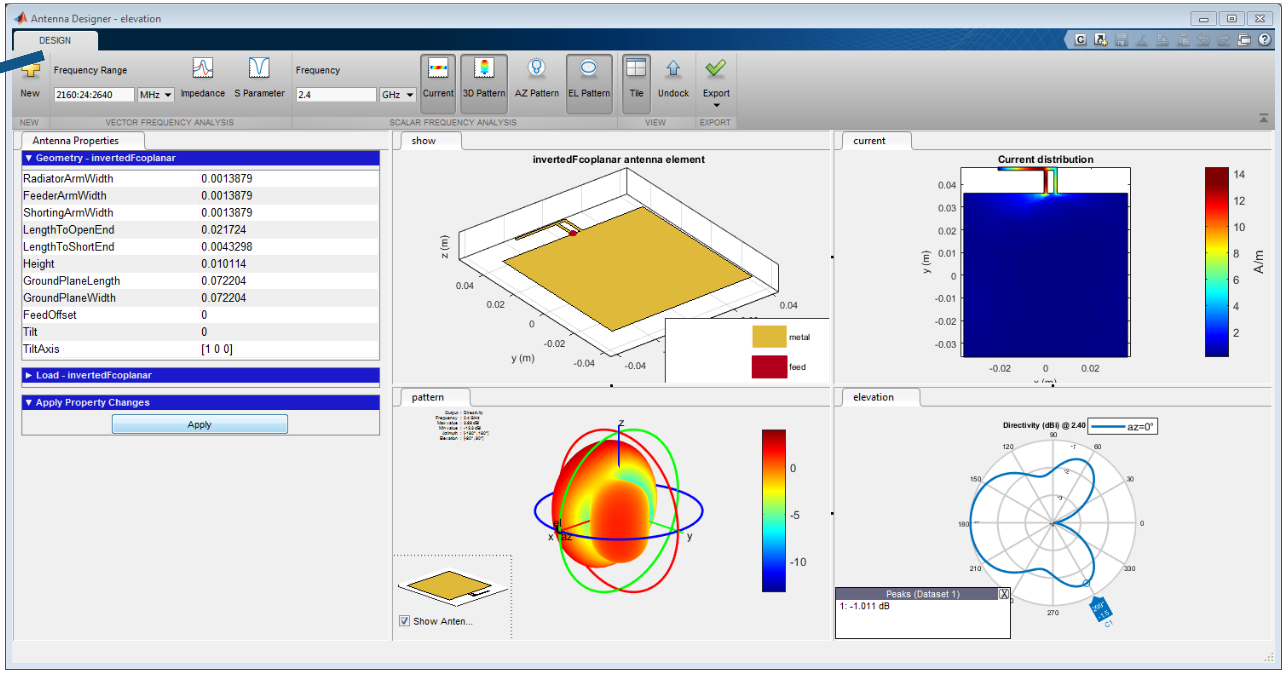
Power Amplifier & Digital Pre-distortion



Antenna Design – Where To Start?

Antenna Designer App

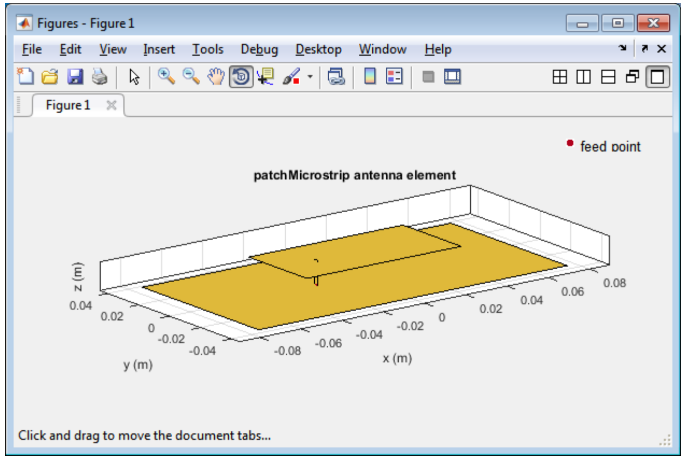
- Select an antenna based on the desired specifications
- Design the antenna at the operating frequency
- Visualize results and iterate on antenna geometrical properties
- Generates MATLAB scripts for automation

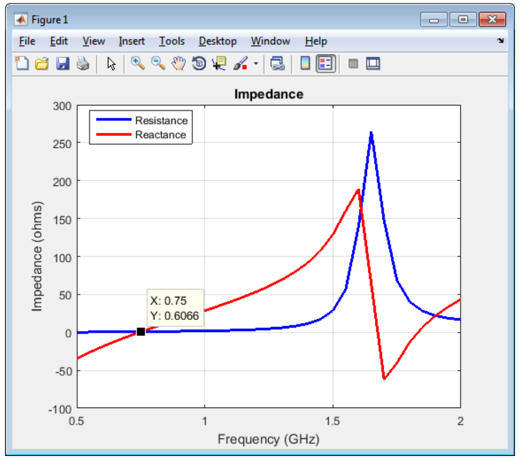


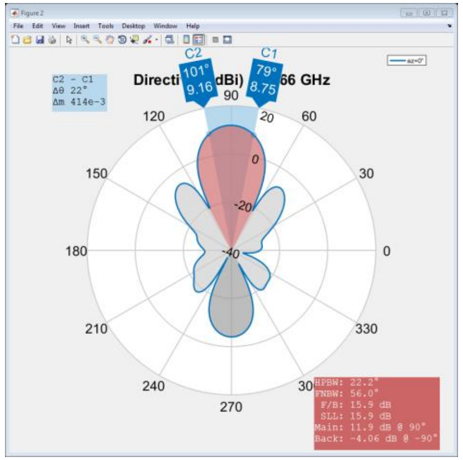
Building your First Antenna and Antenna Array

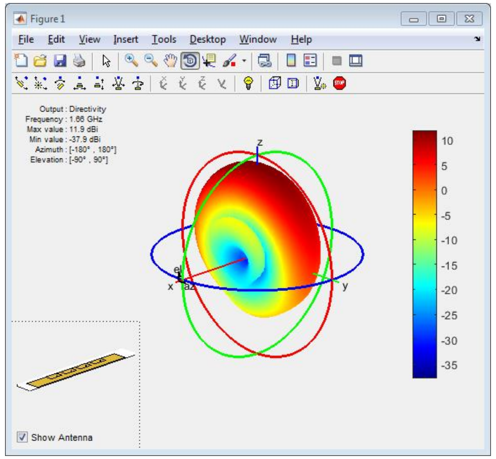
```
p = patchMicrostrip
p.Height = 0.01;
impedance(p, (500e6:10e6:2e9));
current(p, 1.7e9);
pattern(p, 1.7e9);
```

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





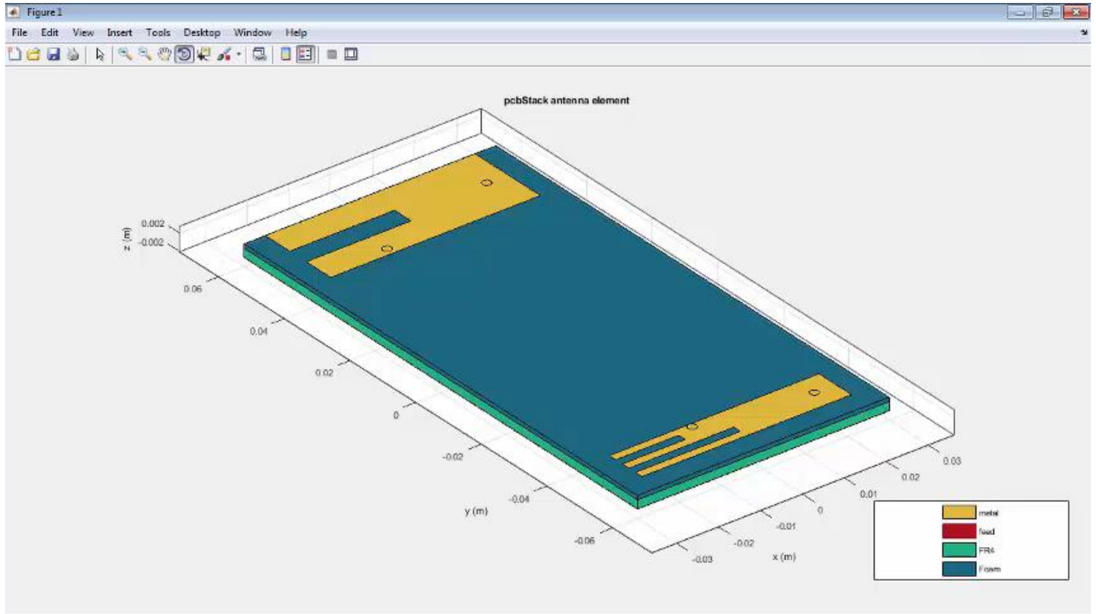


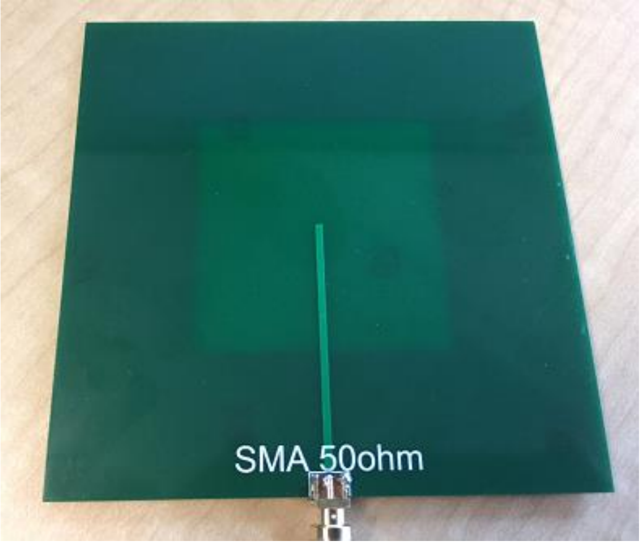


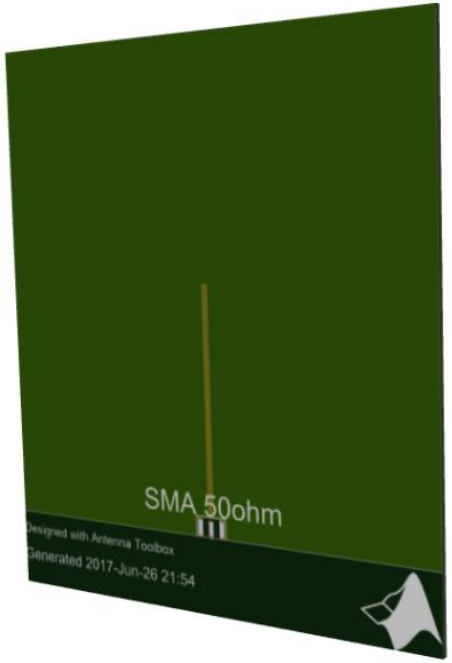
Printed Antenna Designing and Fabrication

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

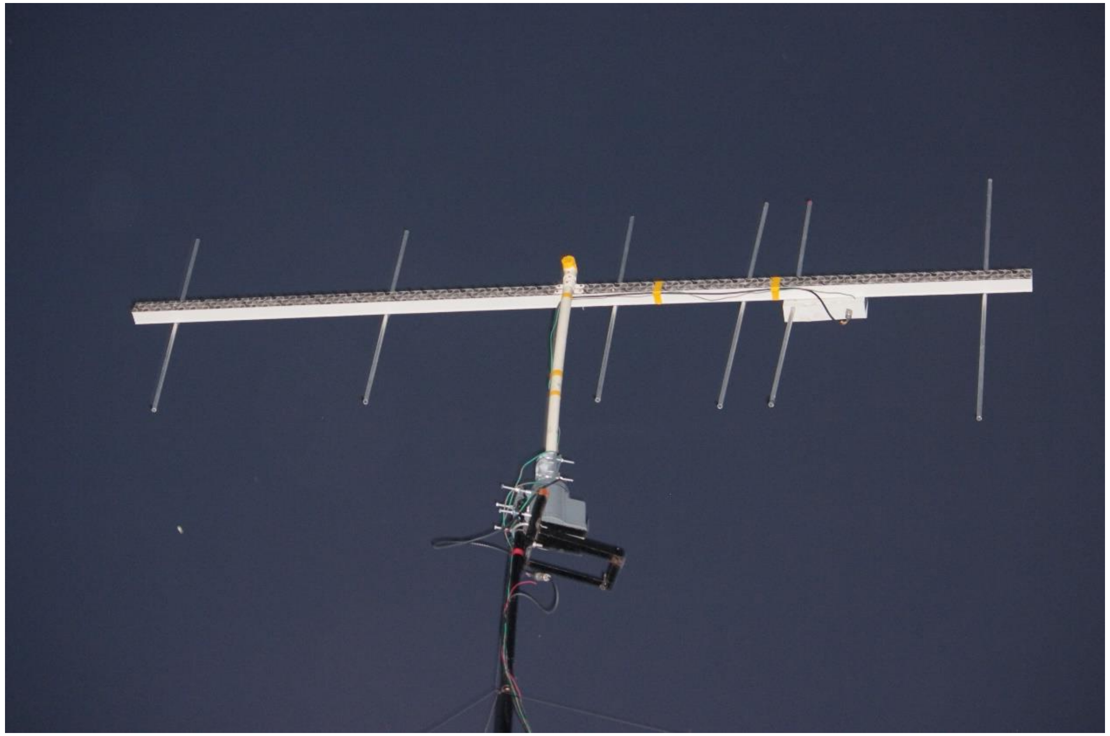


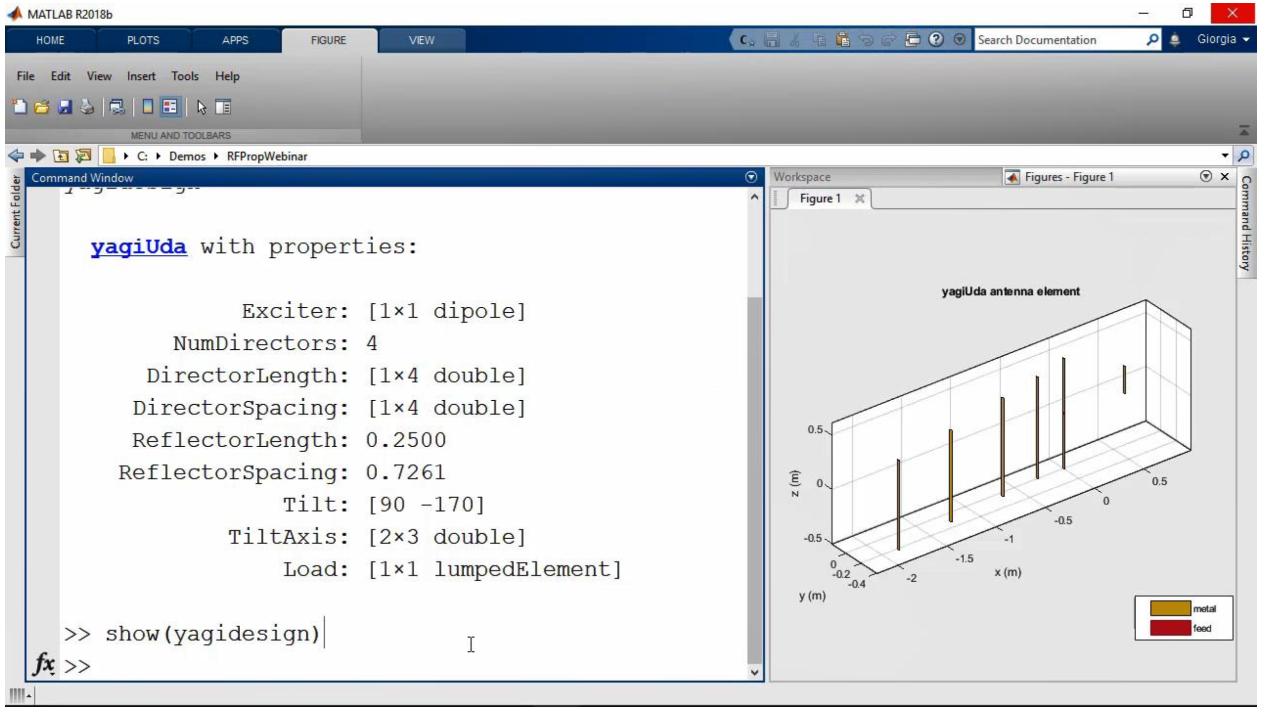




Antenna Design and Analysis

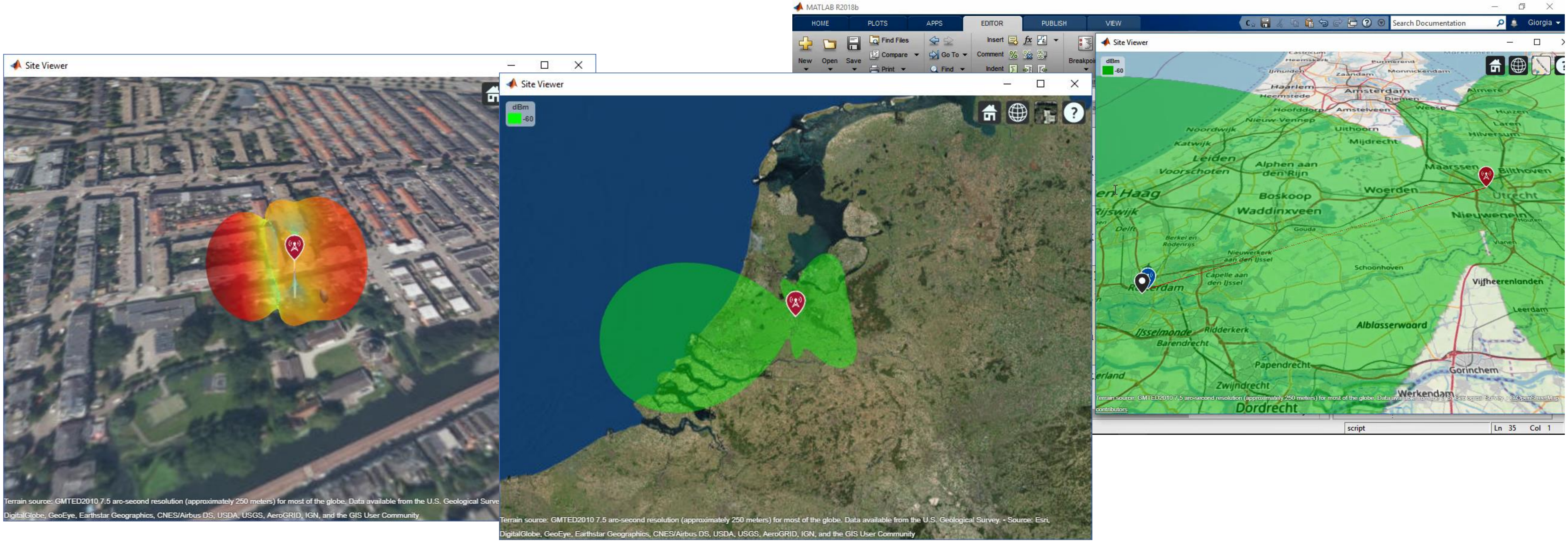
VHF YagiUda antenna designed with Antenna Toolbox to operate at 144.5MHz





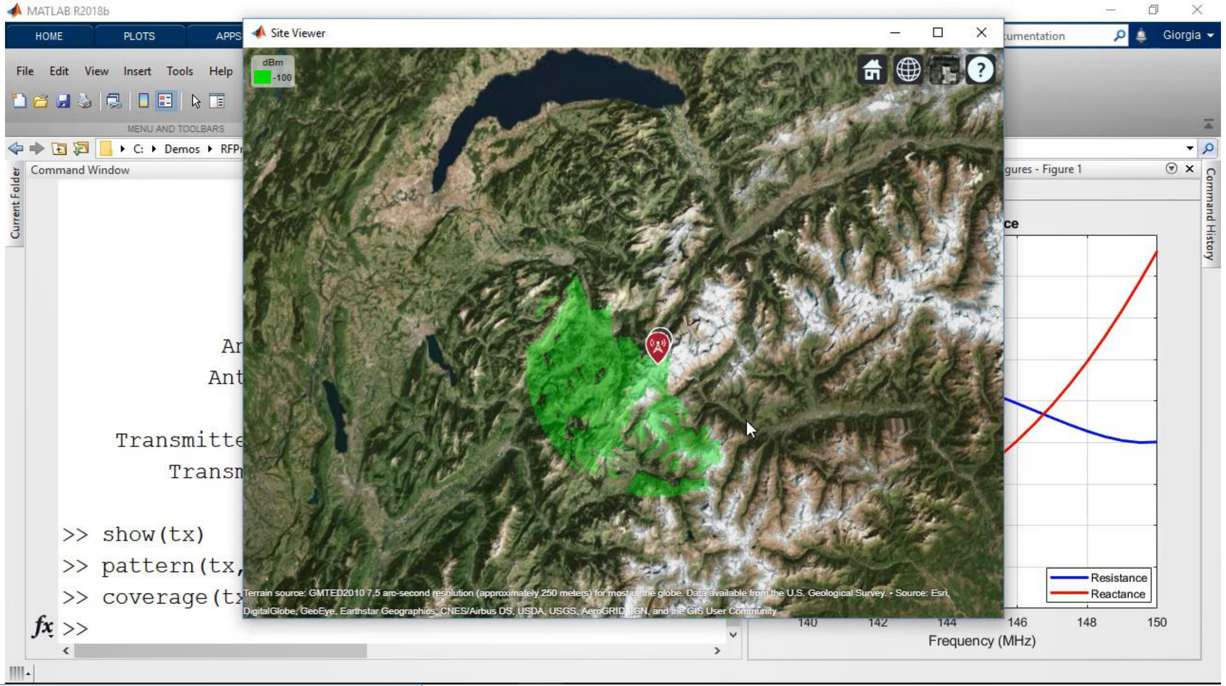
Antenna Placement and Coverage Analysis

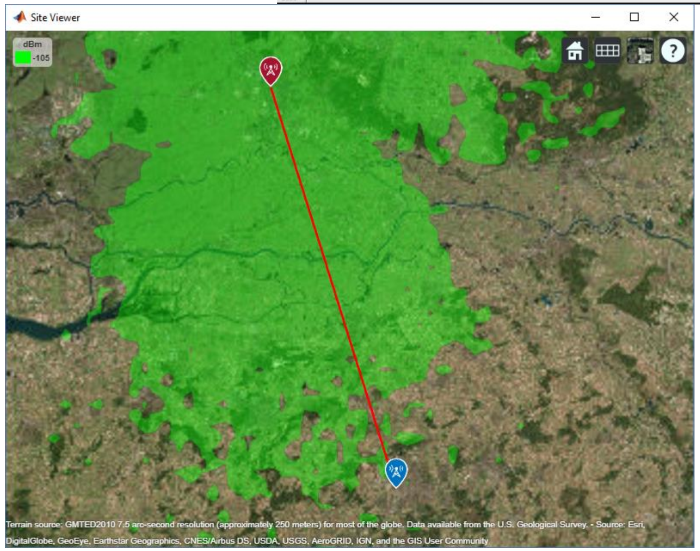
- Position the antenna at a specific geographical location
- Show coverage of the antenna using Ideal free-space propagation model

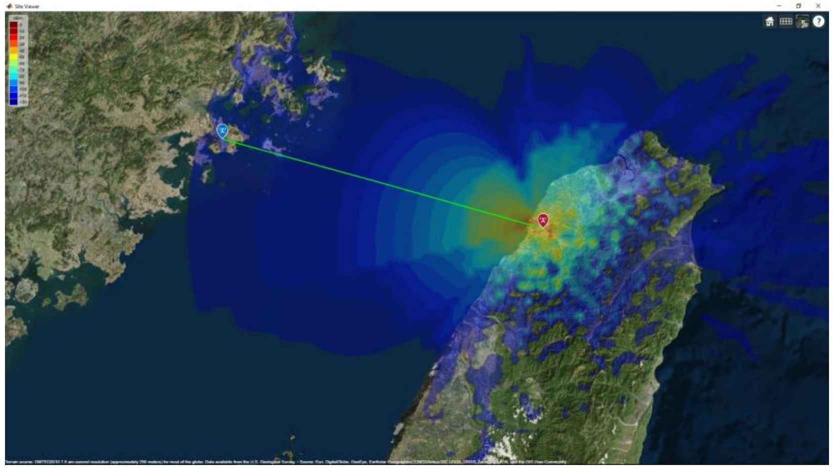


Visualize the Antenna on the Terrain

- 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

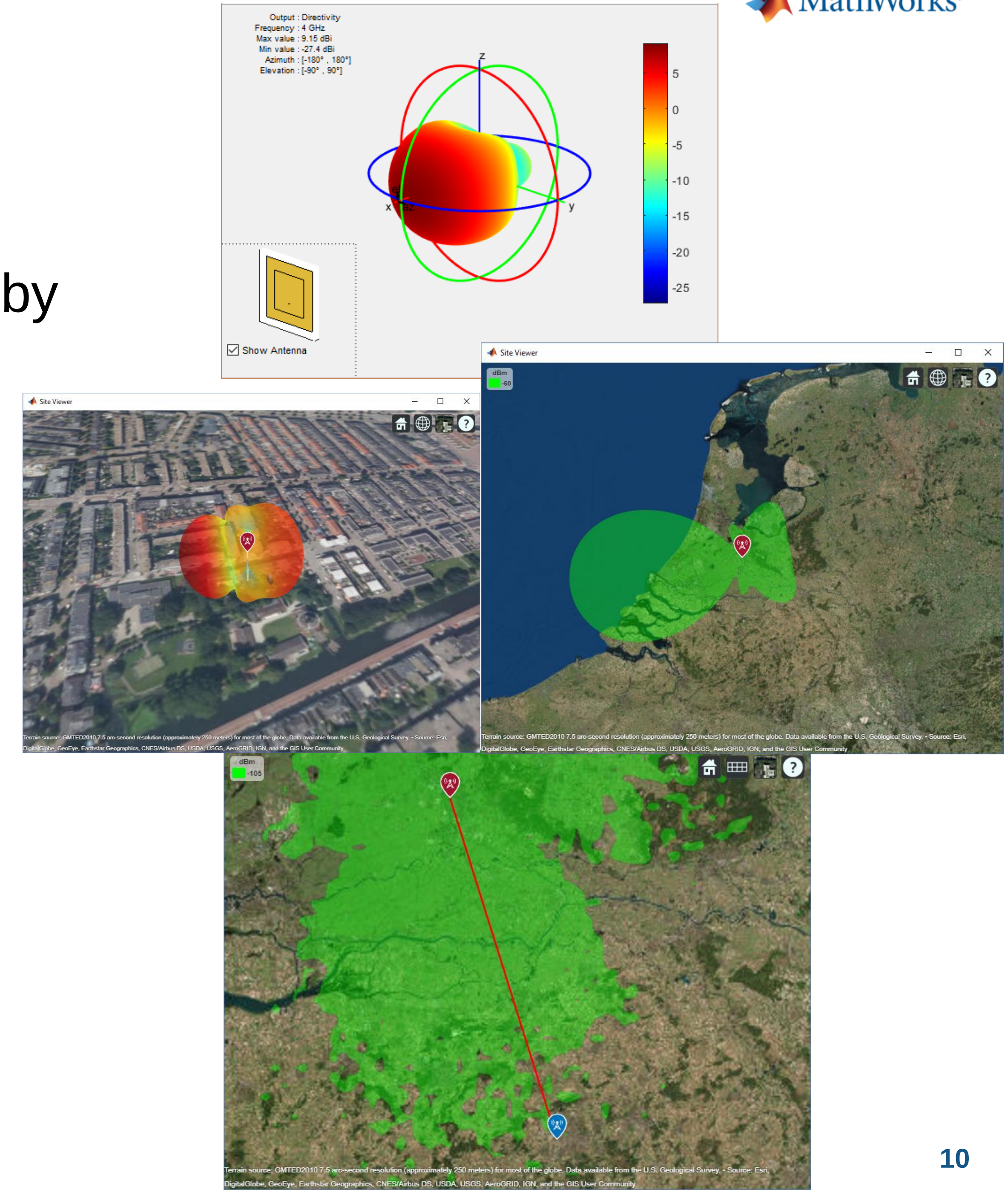






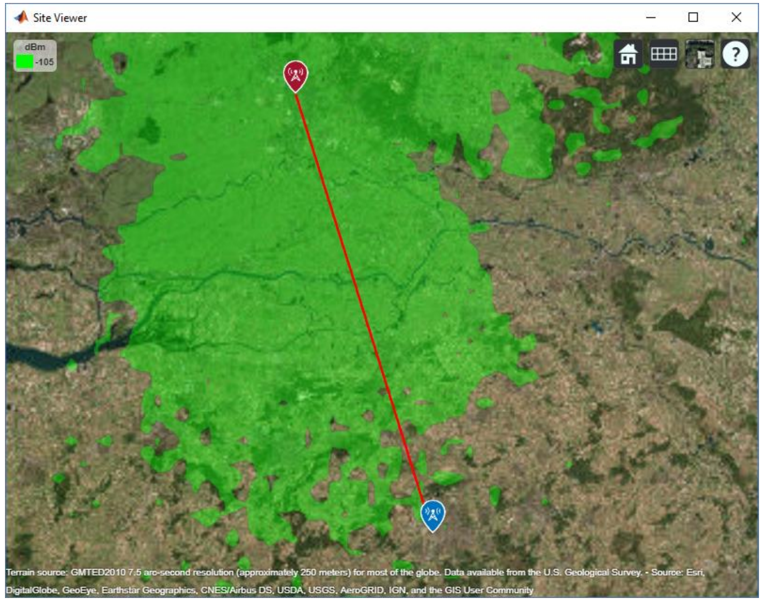
What did we see in this example?

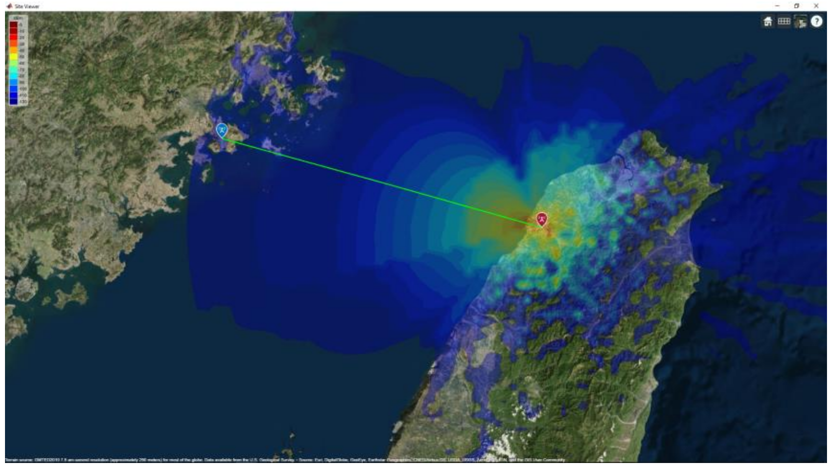
- Antenna elements and arrays described by electromagnetic based solutions
- Terrain based coverage modeling with realistic antenna models
- Method can be extended to include RF propagation along with channel models



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

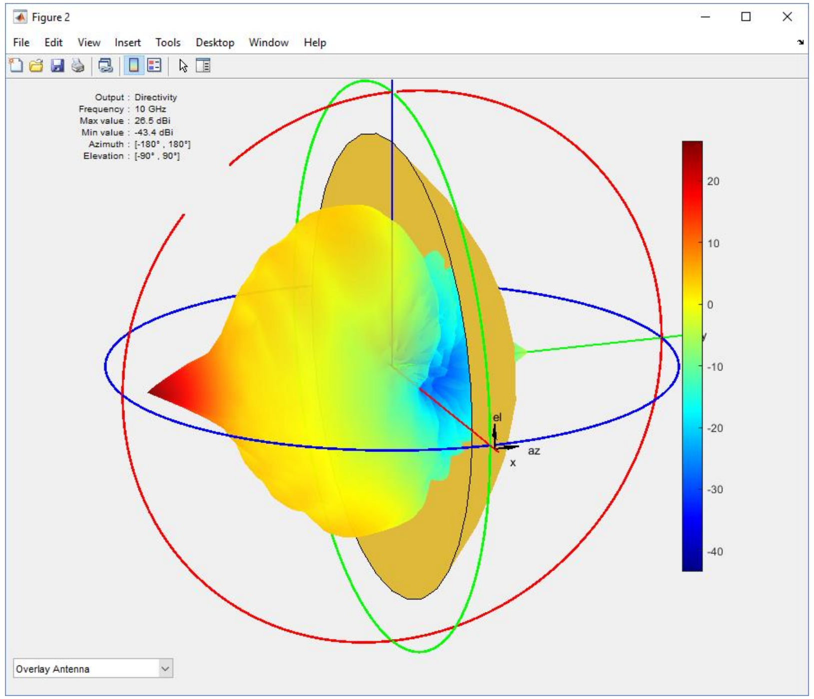




What’s New?

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



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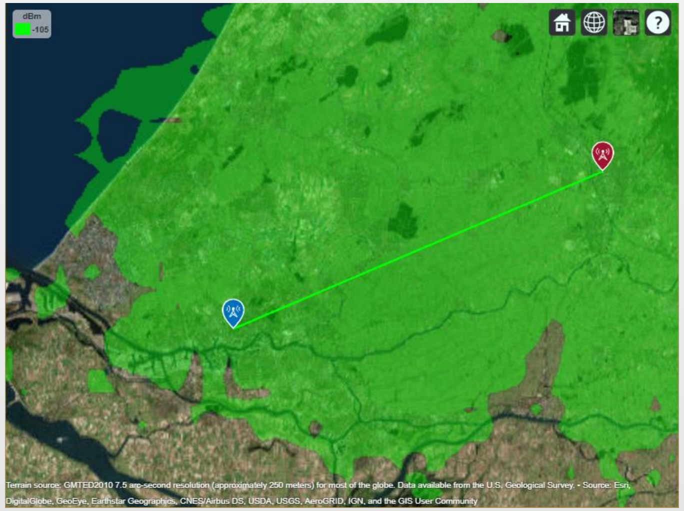
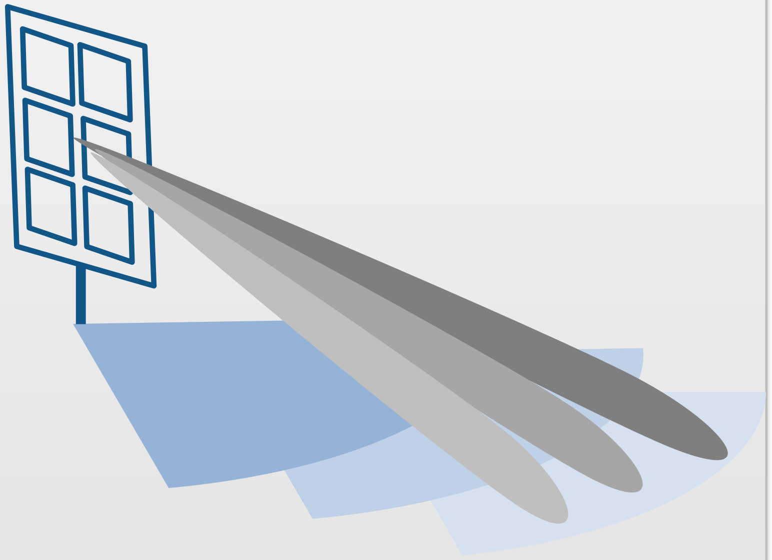
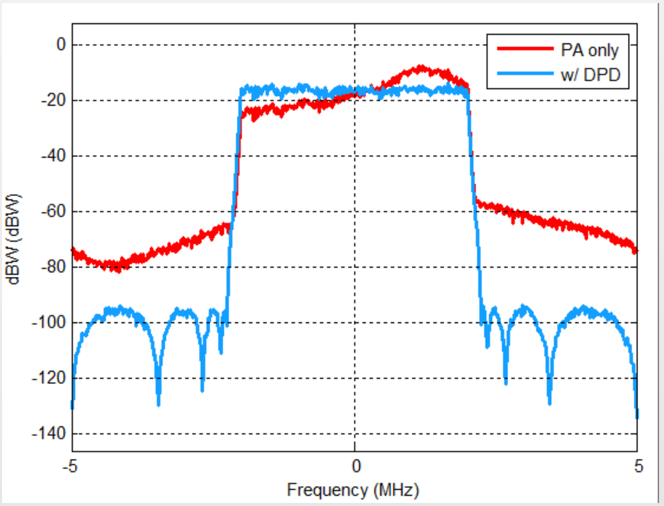
RF Propagation & Network Coverage



Beamforming for Multi-User Operation

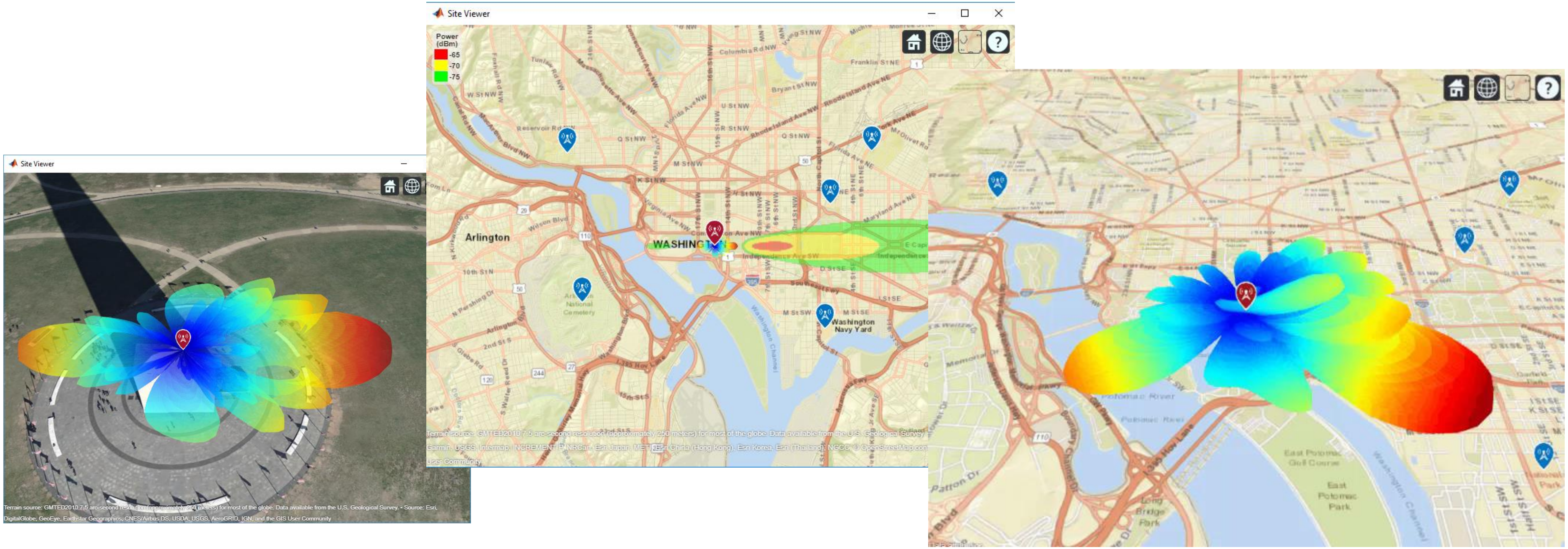


Power Amplifier & Digital Pre-distortion



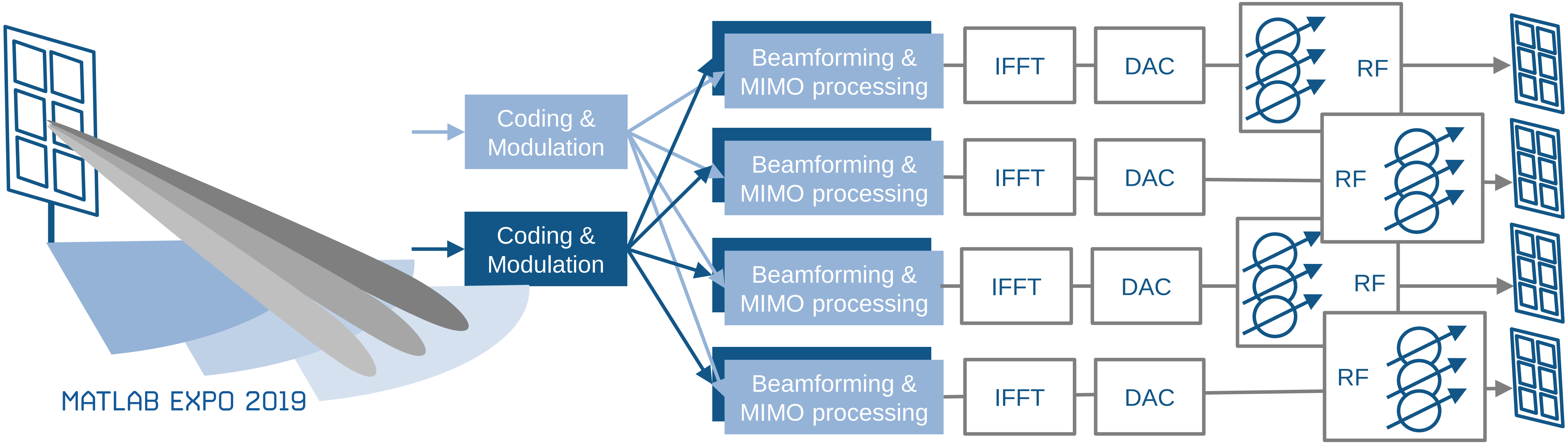
Array Beam Steering and Map Visualization

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



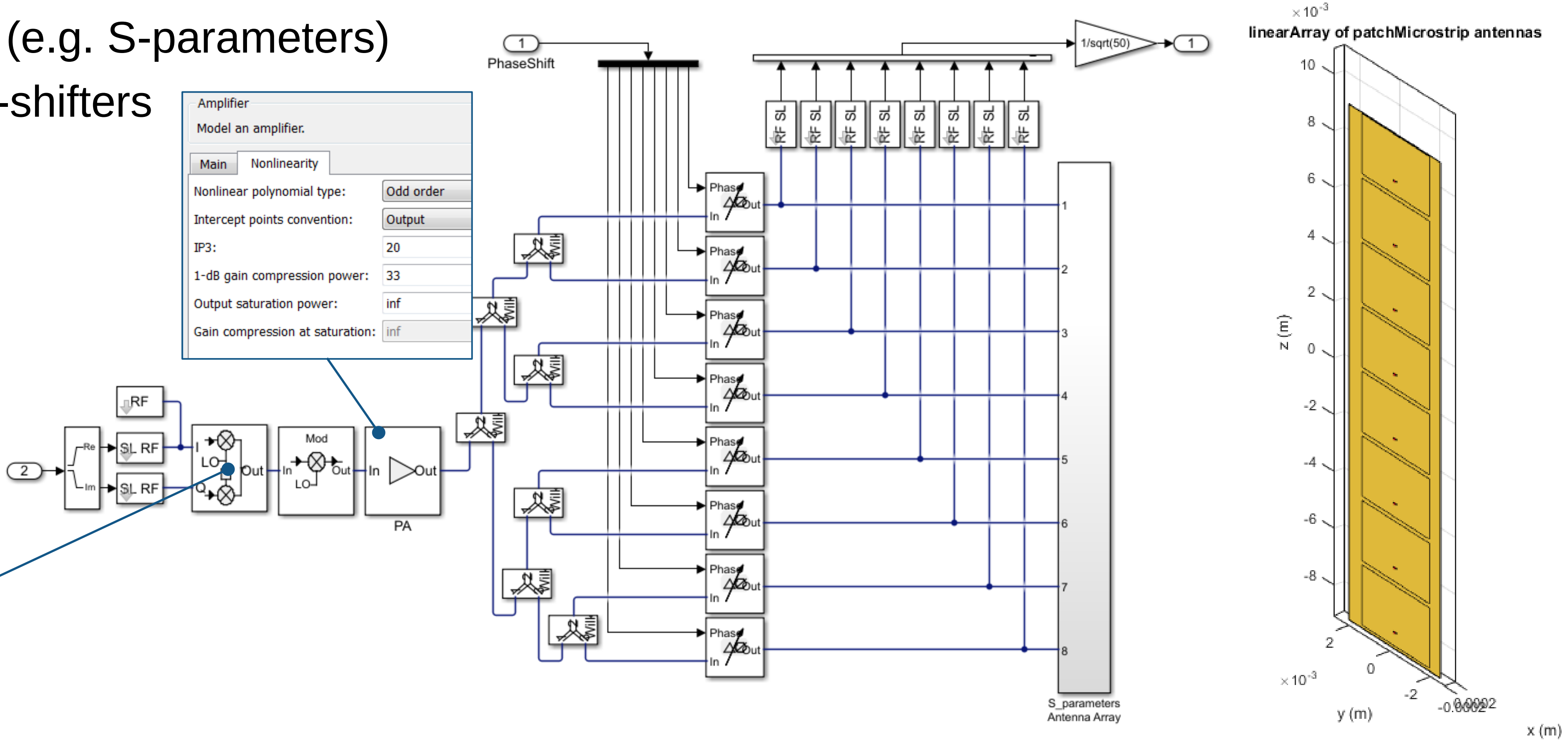
Beamforming for multi-user operation

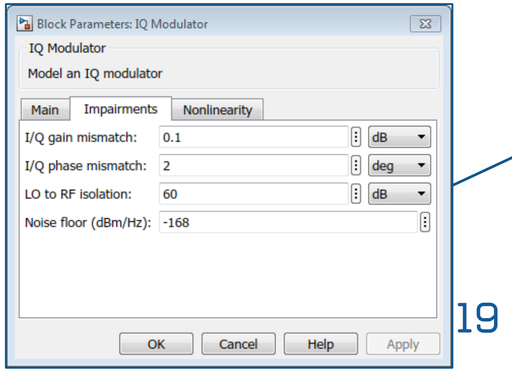
- Coarse analog RF beamforming is the same for entire bandwidth
  – Subarray modules (panels) allow coarse elevation angle adjustment (by phase shifters)
  – MU groups are arranged by distance (ring structure)
- Fine beamforming in baseband is performed for OFDM mode in frequency domain
  – Fine horizontal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



RF Front End Modelling using Circuit Envelope

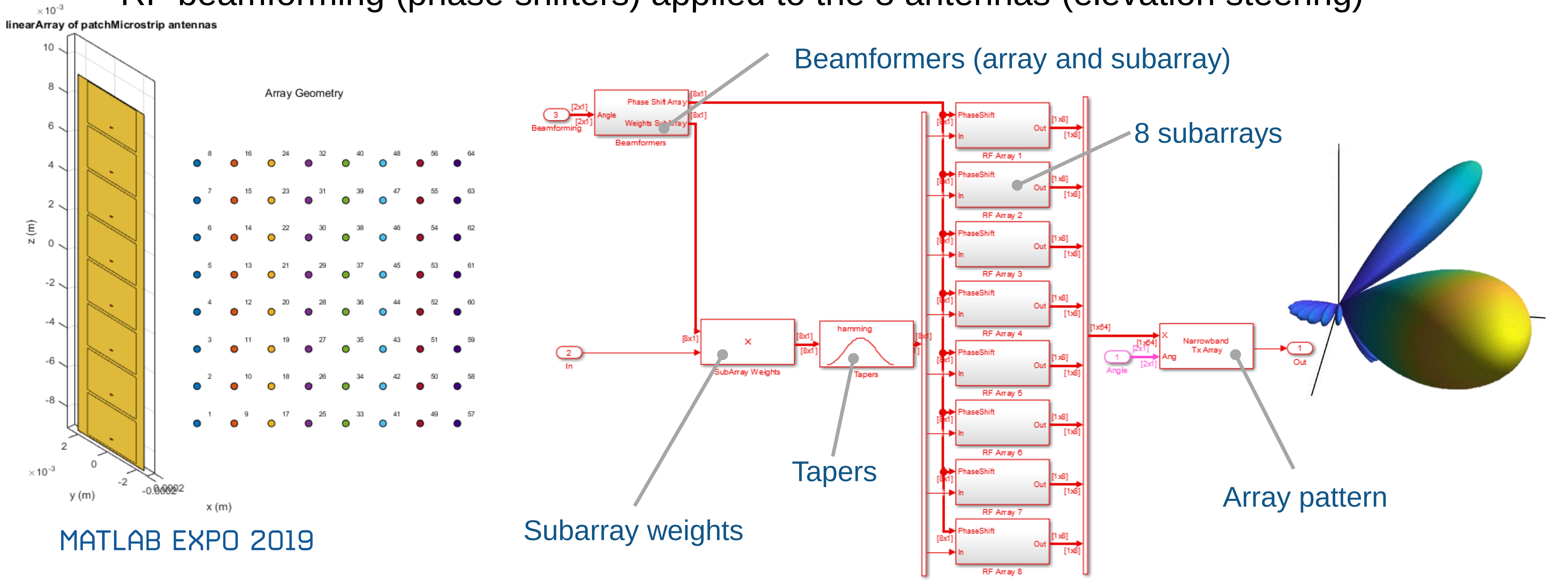
- Direct conversion to IF (5GHz) and superhet up-conversion to mmWave (66GHz)
- Non-linearity (e.g. IP2, IP3, P1dB)
- Power dividers (e.g. S-parameters)
- Variable phase-shifters





Hybrid Beamforming Transmitter Array

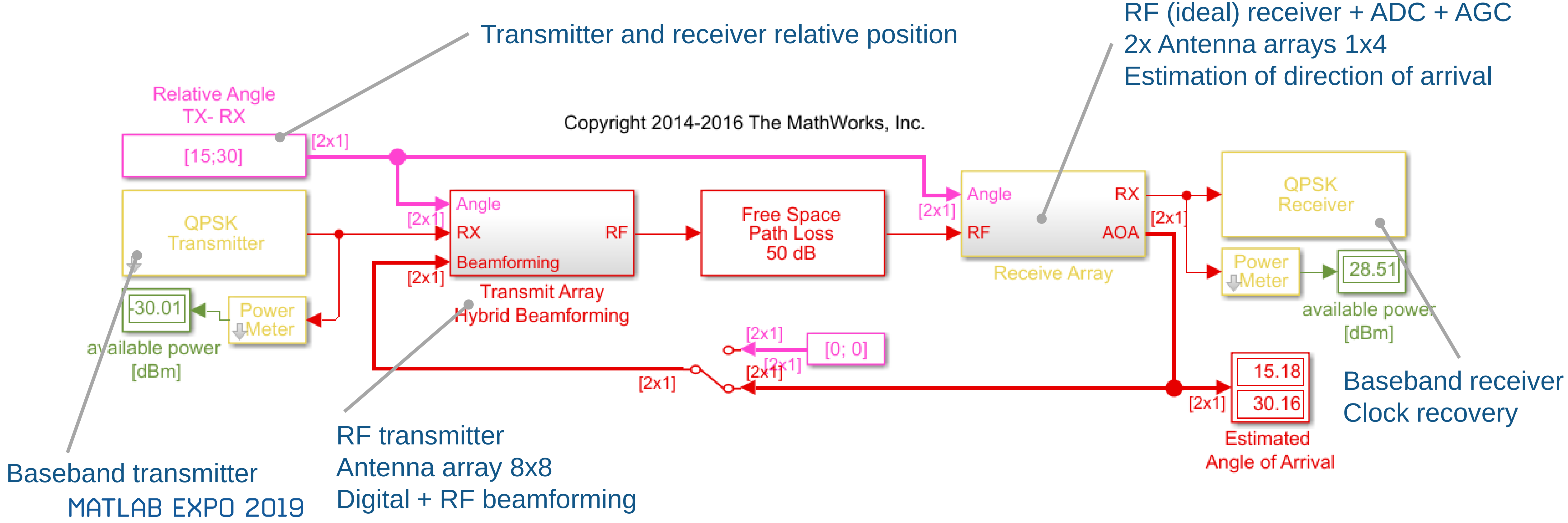
- 8 subarrays of 8 patch antennas operating at 66GHz → 8x8 = 64 antennas
- Digital beamforming applied to the 8 subarrays (azimuth steering)
- RF beamforming (phase shifters) applied to the 8 antennas (elevation steering)



System Architecture for Hybrid Beamforming

Download Whitepaper

- 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



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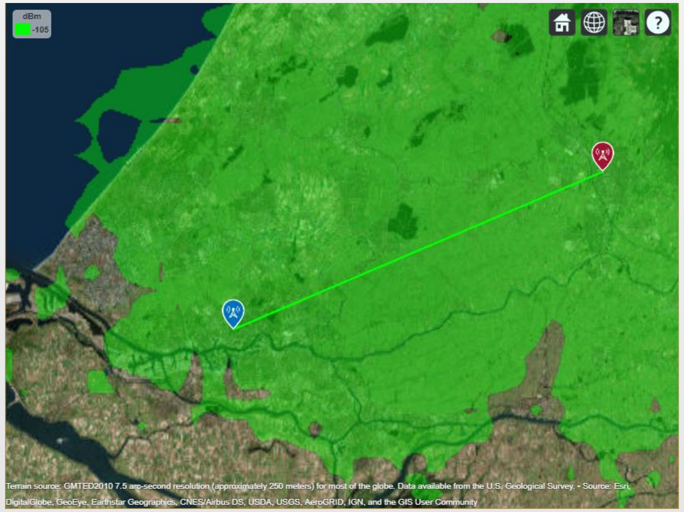

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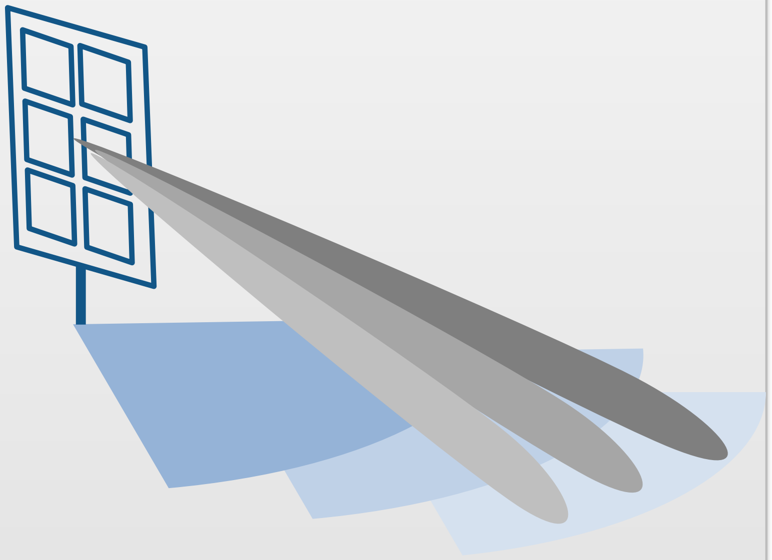
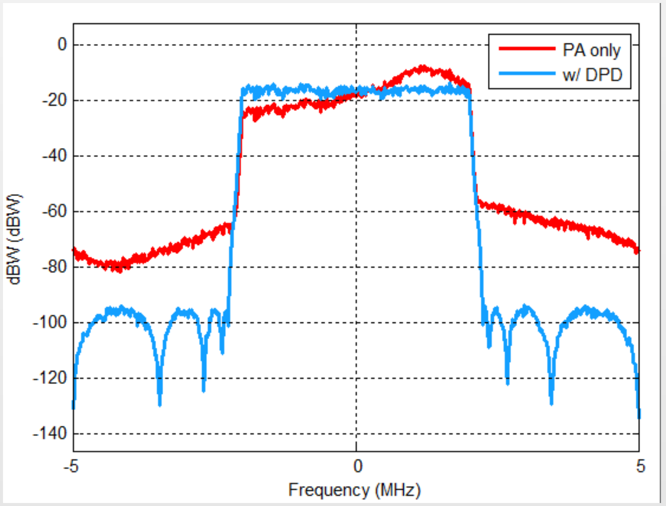
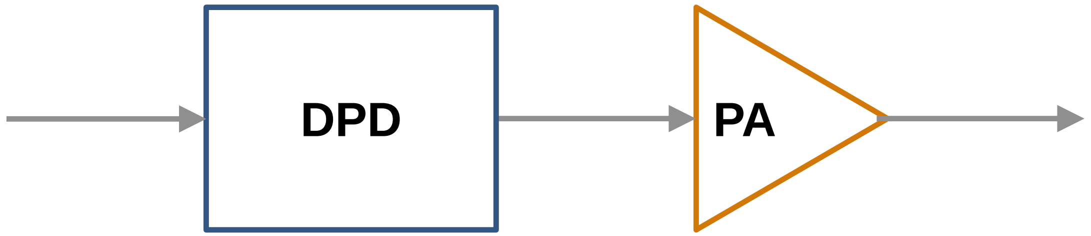
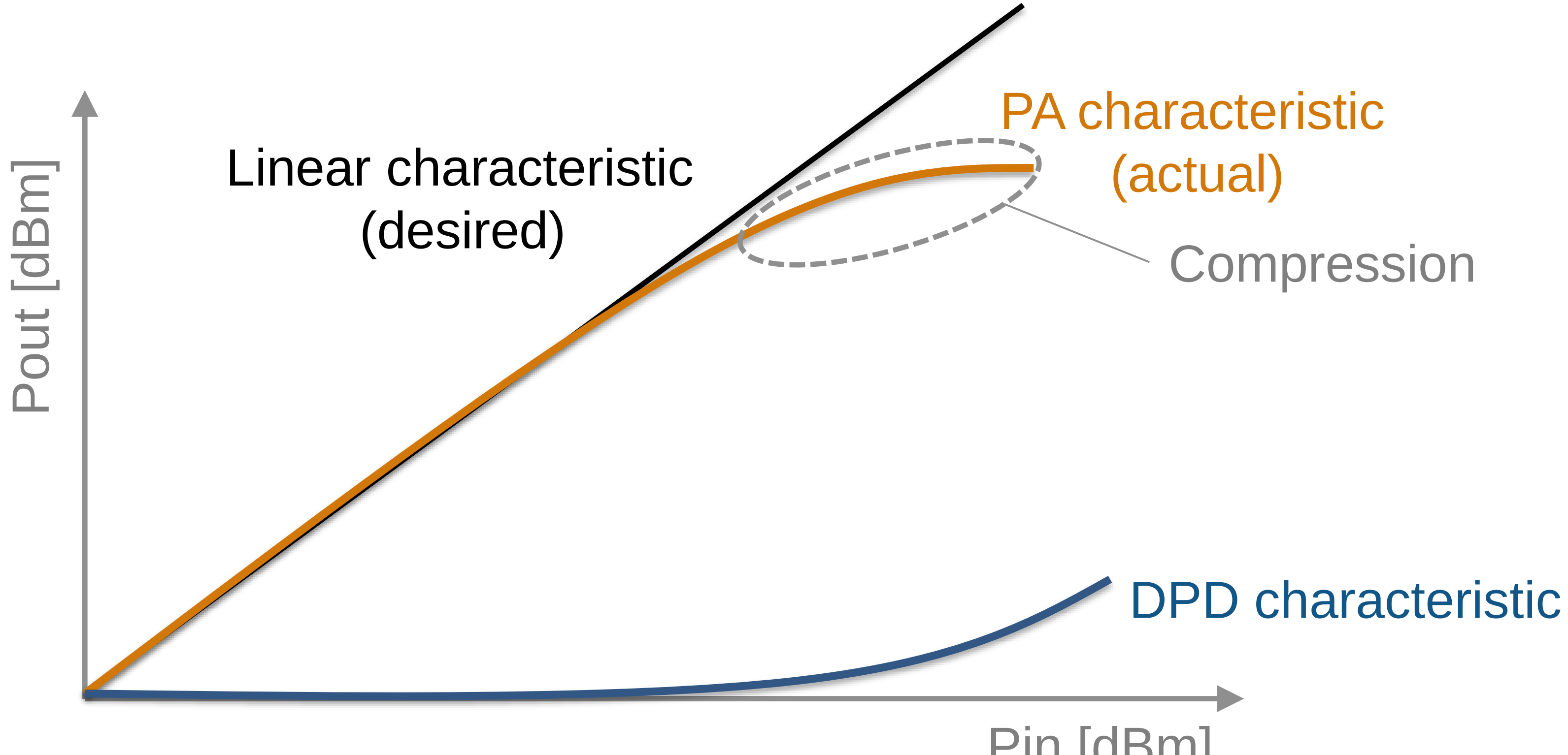


Power Amplifier & Digital Pre-distortion

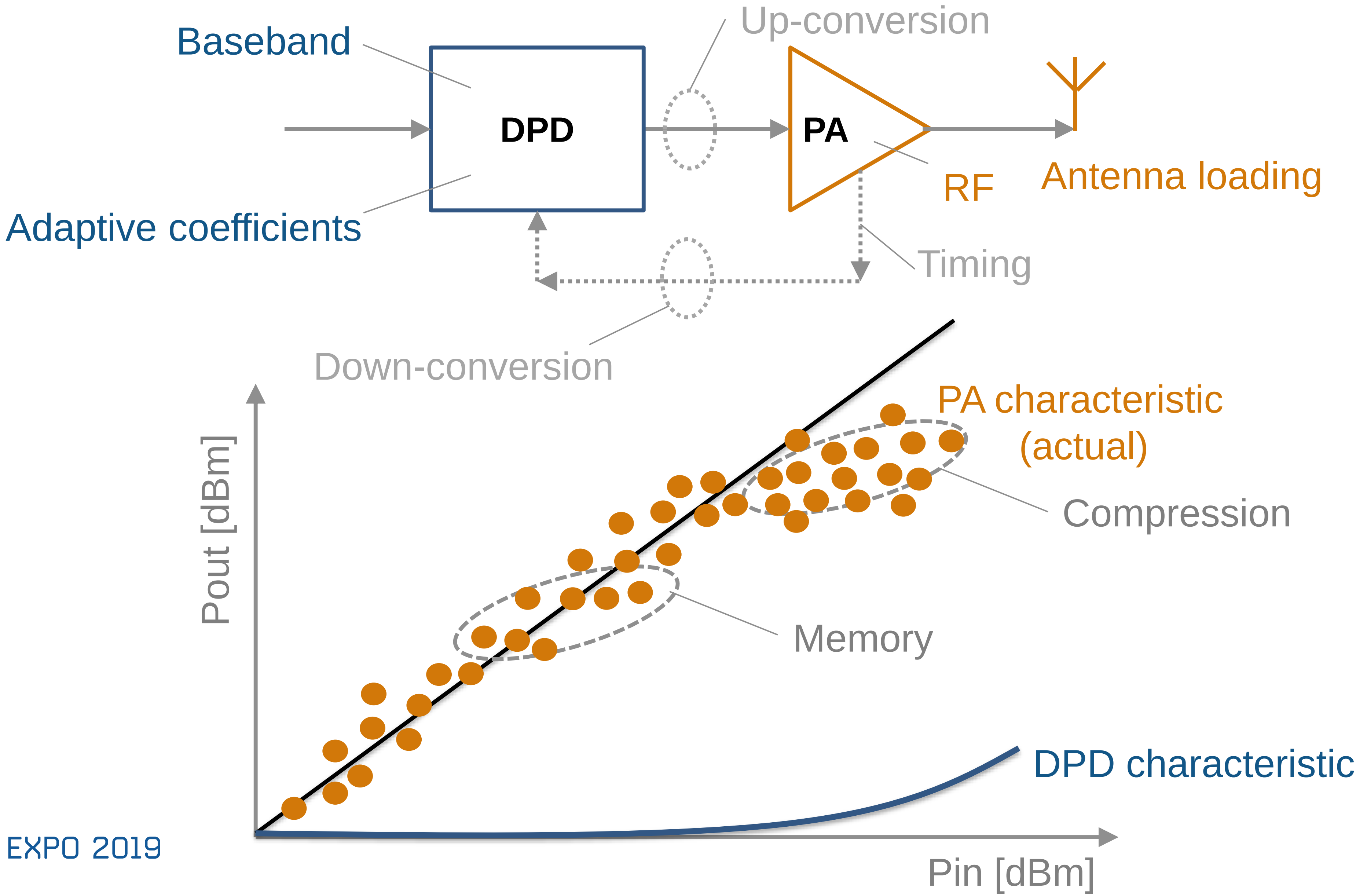


PA Linearization: Digital Pre Distortion (DPD) in Theory



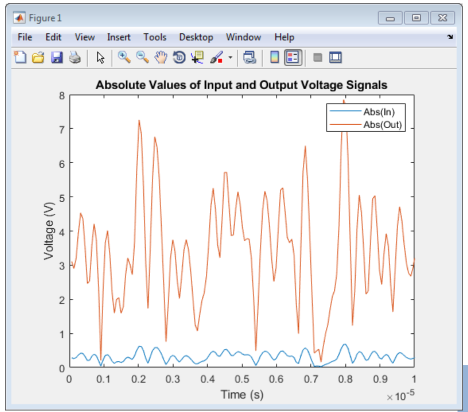


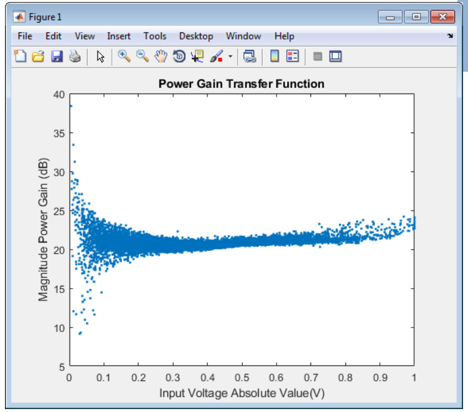
PA Linearization: Digital Pre Distortion (DPD) in Practice



What resources are available to characterize a PA Model?

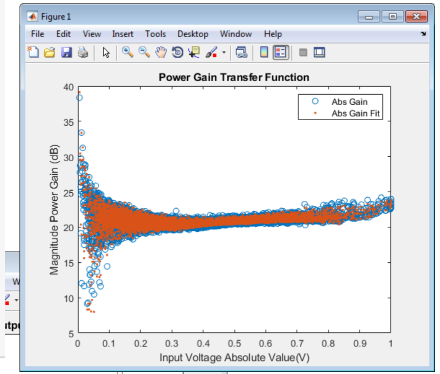
PA Data

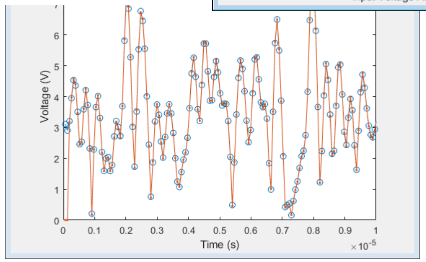




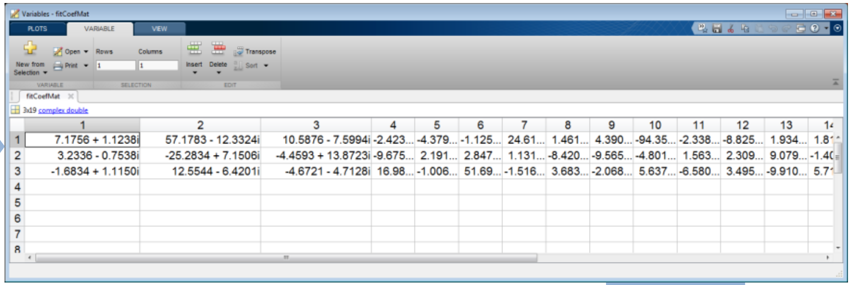
MATLAB fitting procedure (White box)

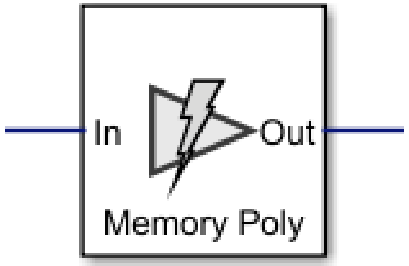
```
function a_coef = fit_memory_poly_model(x,y,memLen,degLen,modType)
% FIT_MEMORY_POLY_MODEL
%   Procedure to compute a coefficient matrix given input and output
%   signals, memory length, nonlinearity degree, and model type.
%
%   Copyright 2017 MathWorks, Inc.

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

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);
```





PA model coefficients

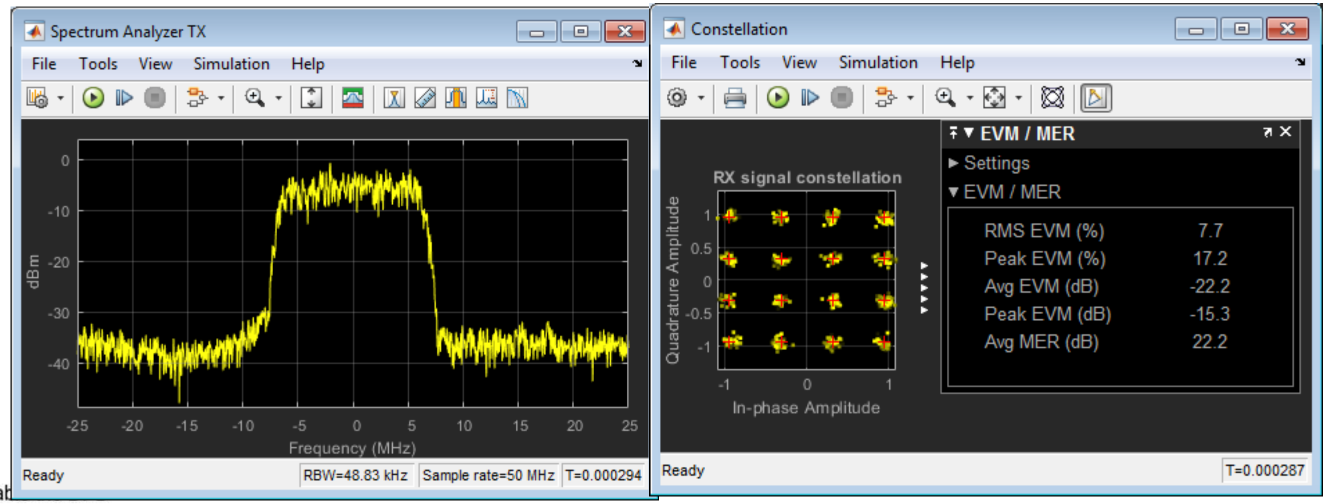


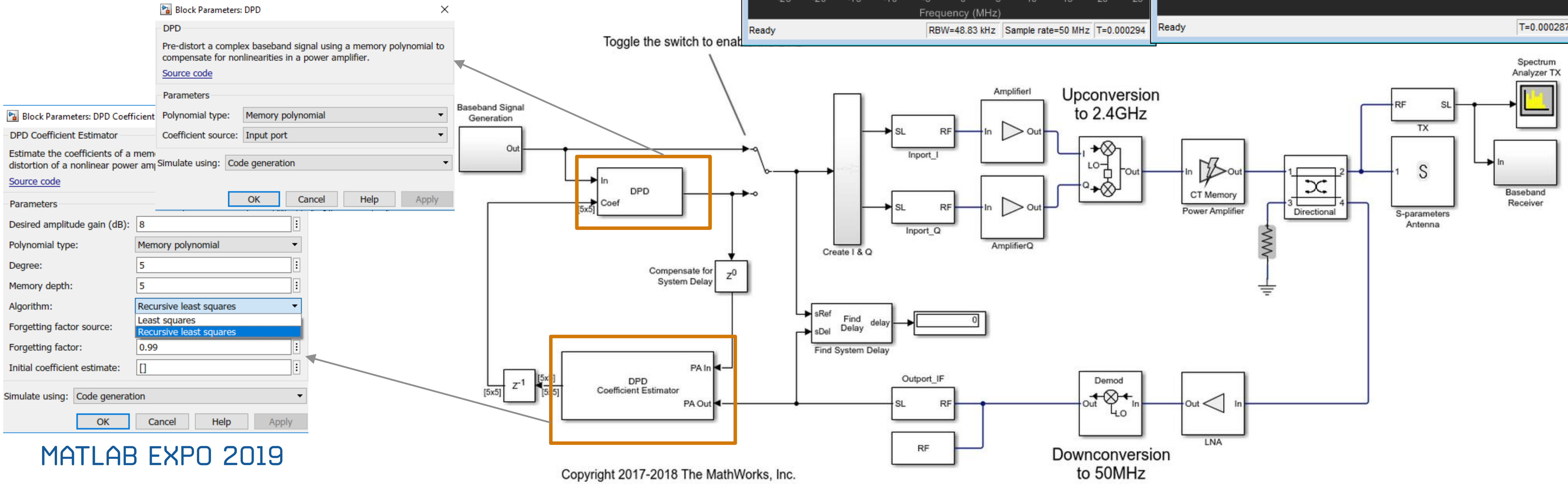


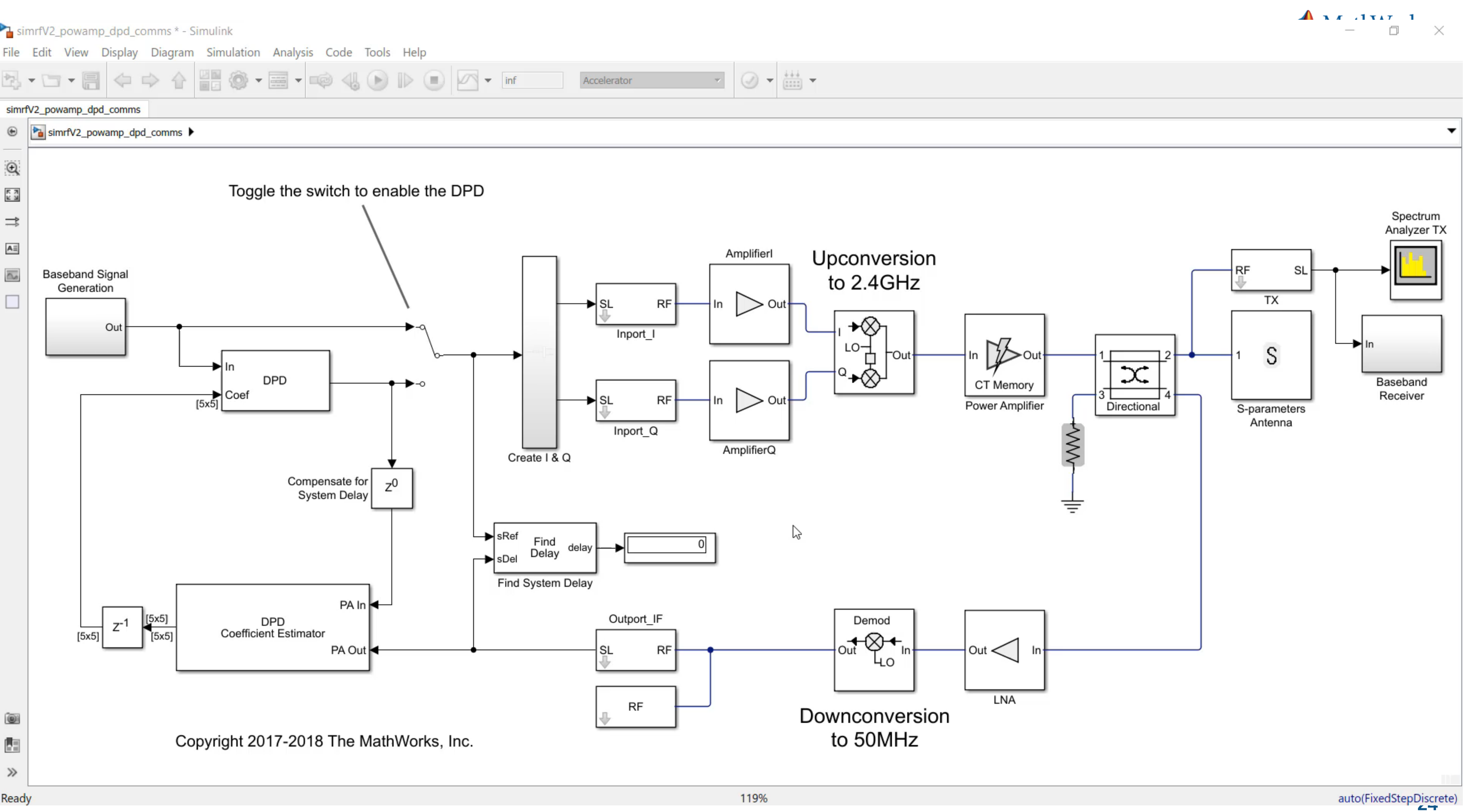
PA model for circuit envelope simulation

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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Copyright 2017-2018 The MathWorks, Inc.
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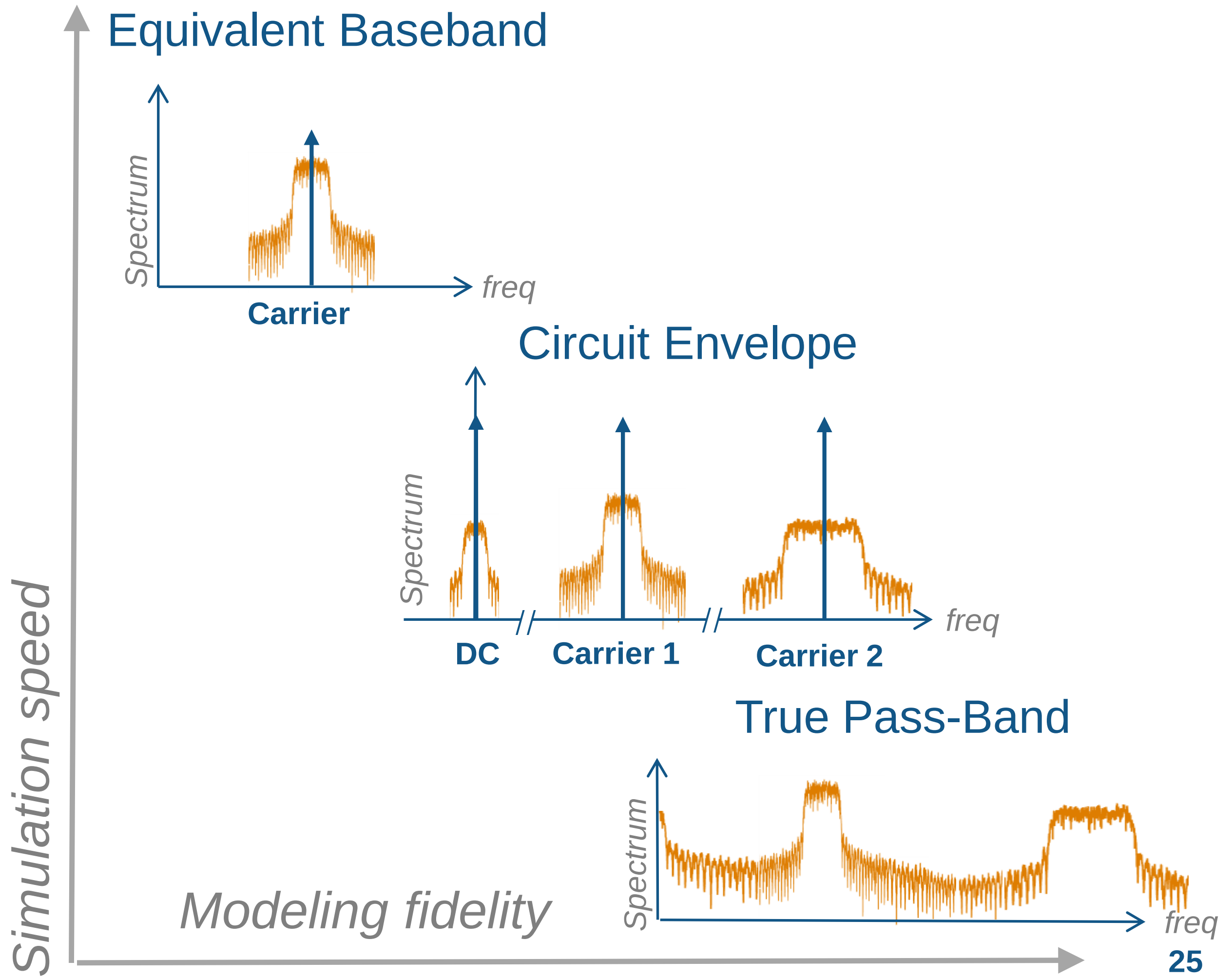
RF System Simulation Must Be Fast

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



Developing a Radio Frequency System for Wireless at Huawei

Erni Zhu, Huawei

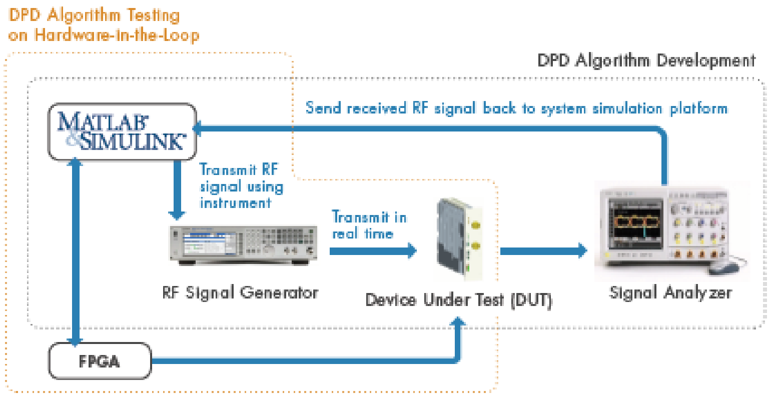
Huawei, in collaboration with MathWorks, developed an intermediate frequency (IF) and radio frequency (RF) system for 5G wireless base stations to achieve greater capacity, higher speed, lower latency, and more energy efficiency.

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.

> MATLAB and Simulink provide a **unified and efficient** system development platform to **bridge** between analog and digital; software and hardware; and algorithm, implementation, and verification.

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



» Learn more about 5G wireless technology solutions

Presented at MATLAB EXPO 2017 China

Watch video (in Chinese) 28:11

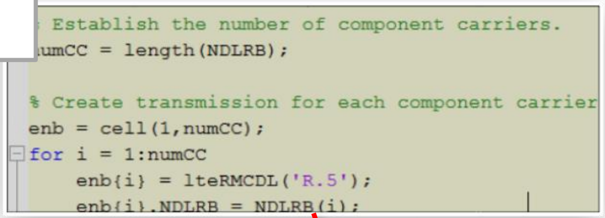
Wireless System Overview

MATLAB & Simulink as a Unified Platform

Demo Station:
Antenna and RF Design

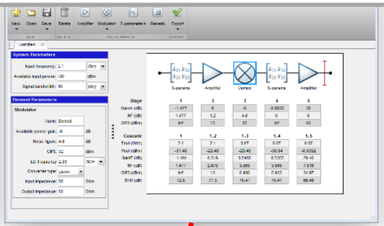
Algorithms, Waveforms, Measurements

- Communications Toolbox
- Phased Array System Toolbox
- LTE, WLAN & 5G Toolbox



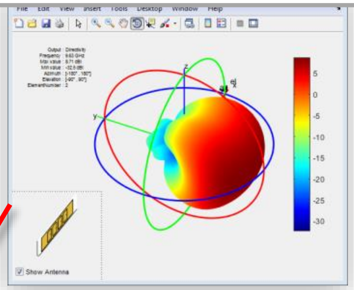
RF Front End

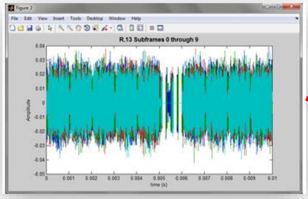
- RF Toolbox
- RF Blockset

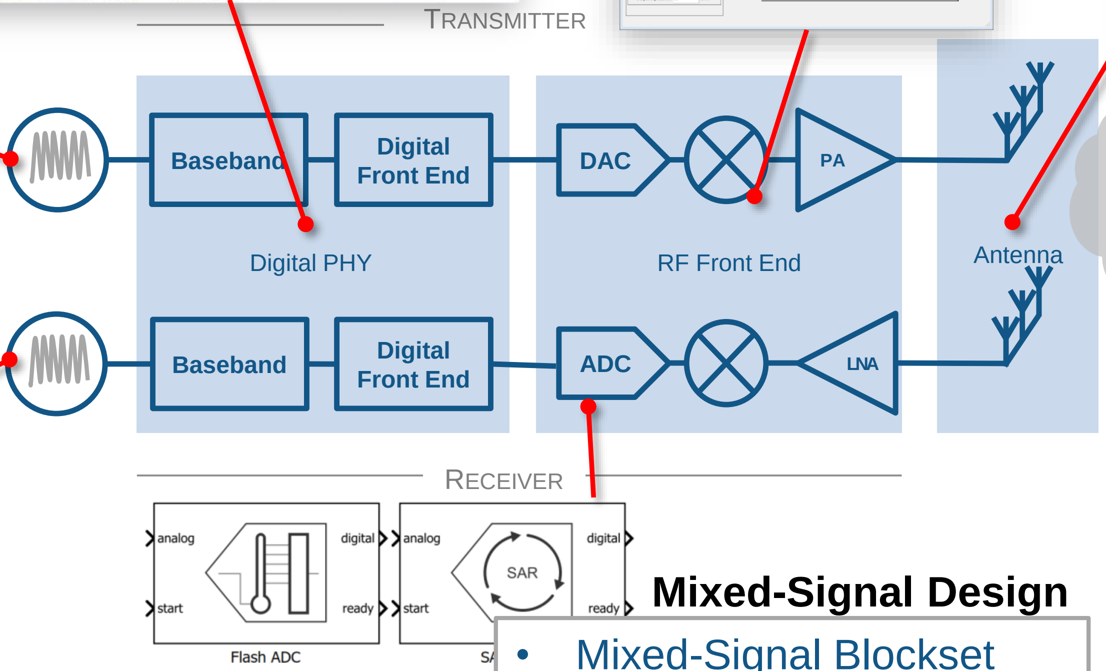


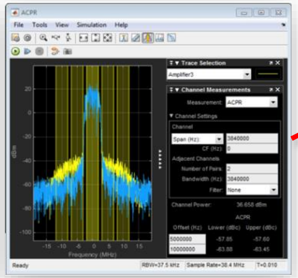
Antennas, Antenna Arrays

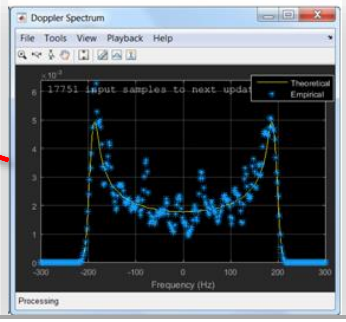
- Antenna Toolbox
- Phased Array System Toolbox











Mixed-Signal Design

- Mixed-Signal Blockset

- Communications Toolbox
- Phased Array System Toolbox
- LTE, WLAN & 5G Toolbox

Channel Modeling

Resources to Help You Get Started

View web resources

[Mapping RF Propagation for Wireless Communications](#) (webinar)

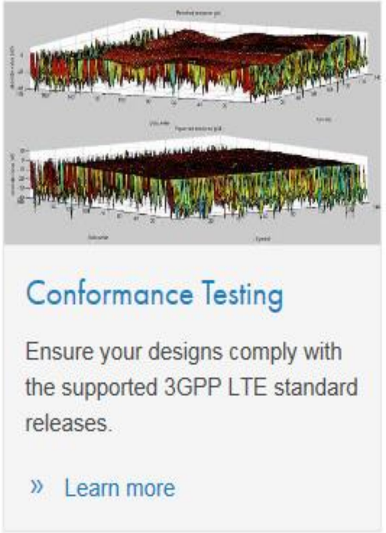
[Modeling RF Power Amplifiers and Increasing Wireless Transmitter Linearity with DPD Using MATLAB](#) (webinar)

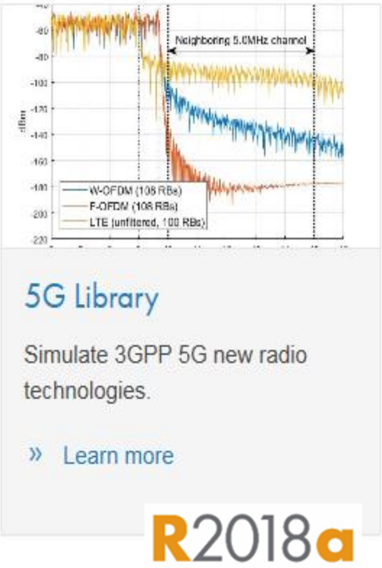
Read eBook and white papers

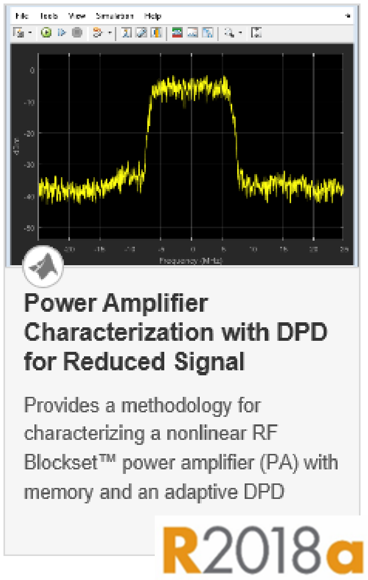
[5G Development with MATLAB](#) (eBook)

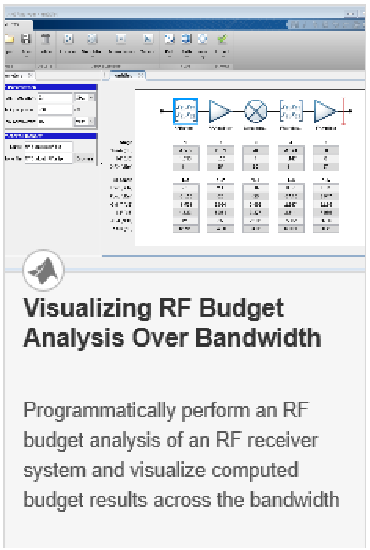
[Hybrid Beamforming for Massive MIMO Phased Array Systems](#) (white paper)

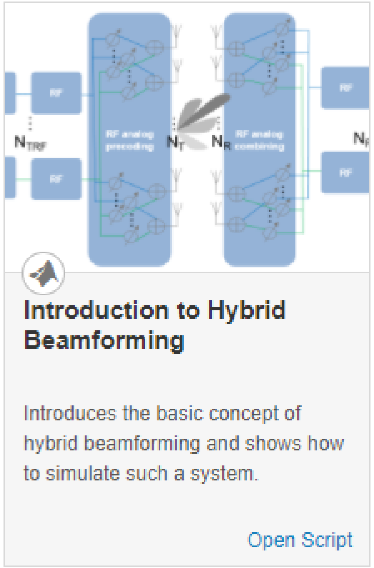
[Four Steps to Building Smarter RF Systems with MATLAB](#) (white paper)

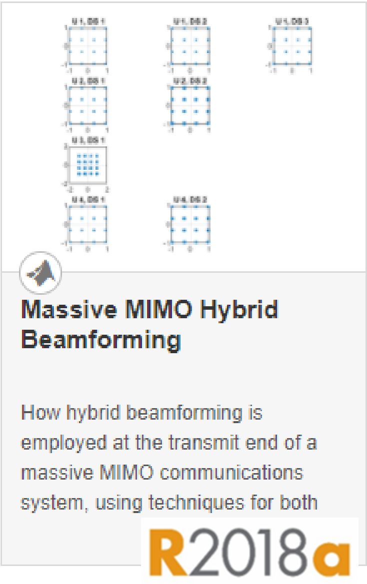








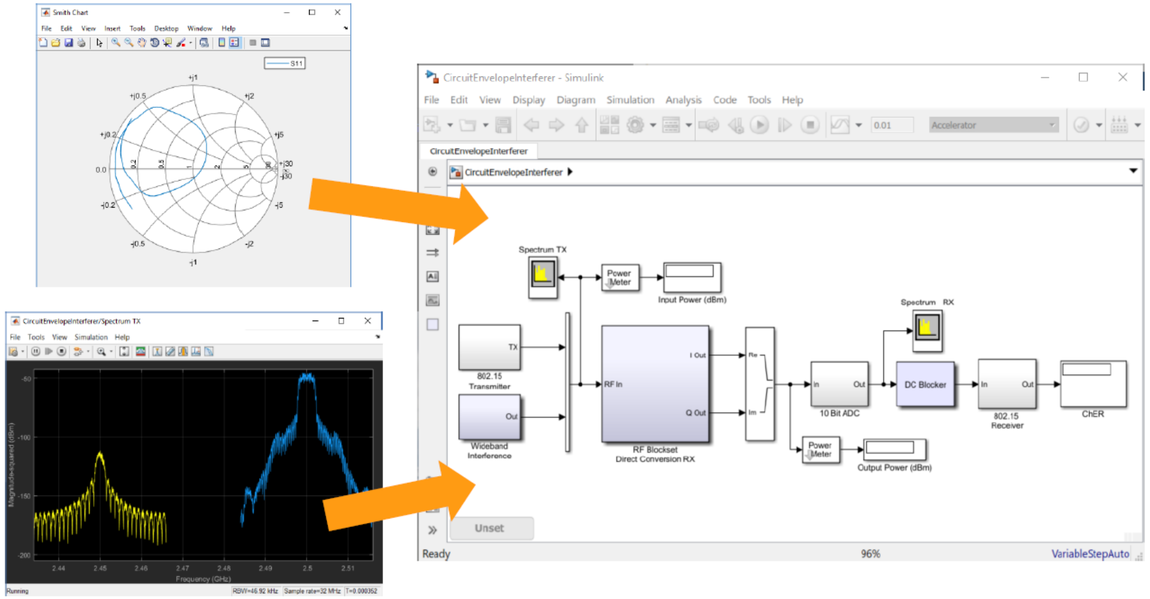




MathWorks | Training Services

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



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