Transforming Wireless System Design with MATLAB and NI

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MATLAB EXPO

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rgetz

robinlgetz

rgetz

What are we going to talk about

- Learn how to use MATLAB and NI to optimize wireless design processes and improve your product quality
- Discover the latest features and updates from both platforms that will help you achieve your design goals
- Get insights on how to tackle common wireless design challenges and find innovative solutions

Transforming Wireless System Design with MATLAB and NI

Wireless Standards

Design, analyze, and test standards-based 5G, Wi-Fi, LTE, satellite communications, and Bluetooth systems.

AI for Wireless

Apply deep learning, machine learning, and reinforcement learning techniques to wireless communications applications.

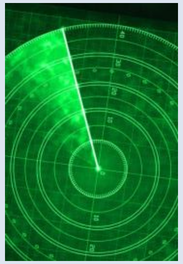
Digital, RF, and Antenna Design

Jointly optimize digital, RF, and antenna components of an end-to-end wireless communications system.

Hardware Design, Prototyping, and Testing

Implement and verify your designs on hardware. Test your algorithms and designs over-the-air with RF instruments and SDRs.

Radar Applications

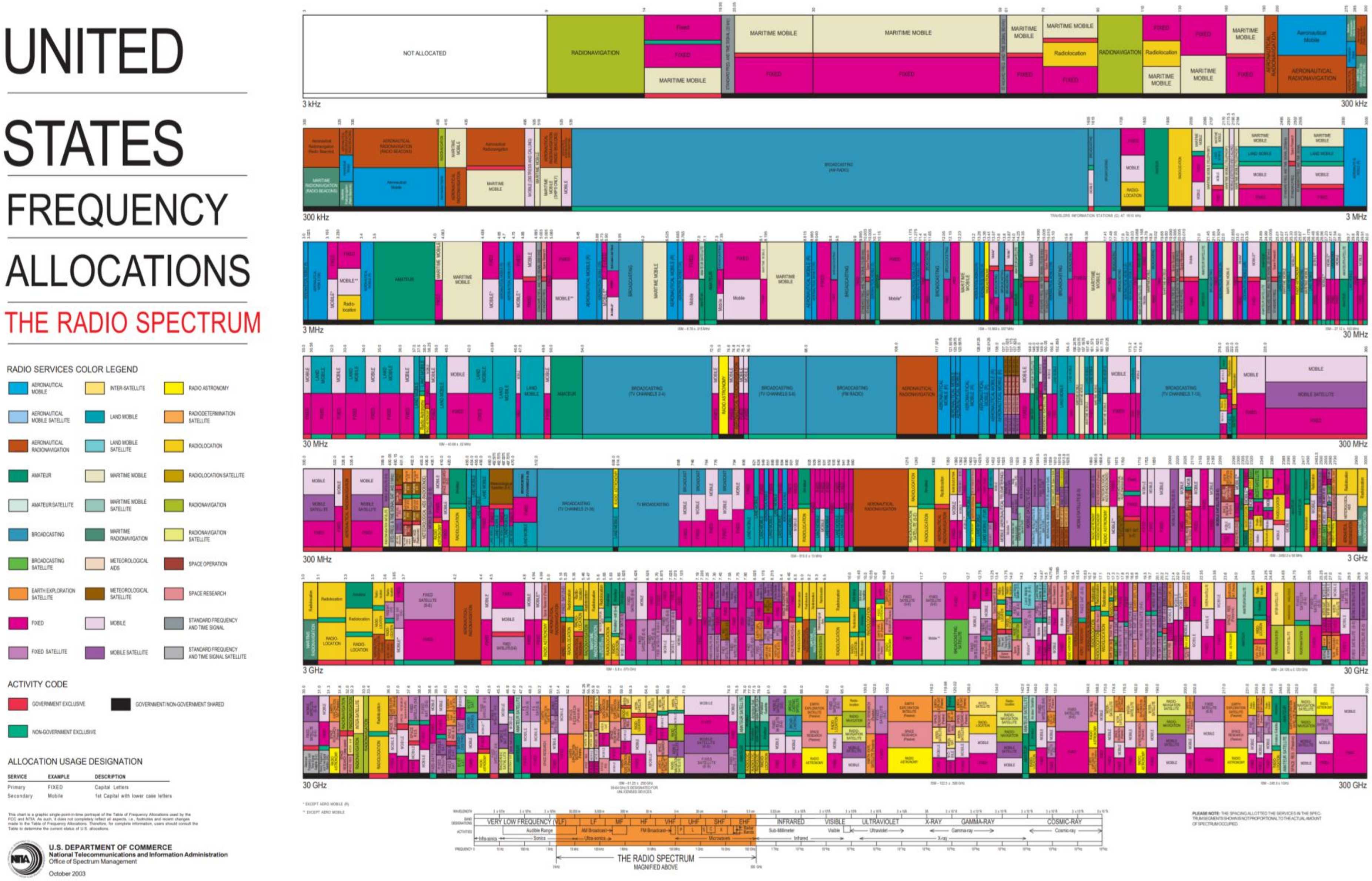


Simulate multifunction radars for automotive, surveillance, and SAR applications. Synthesize radar signals to train machine and deep learning models for target and signal classification.

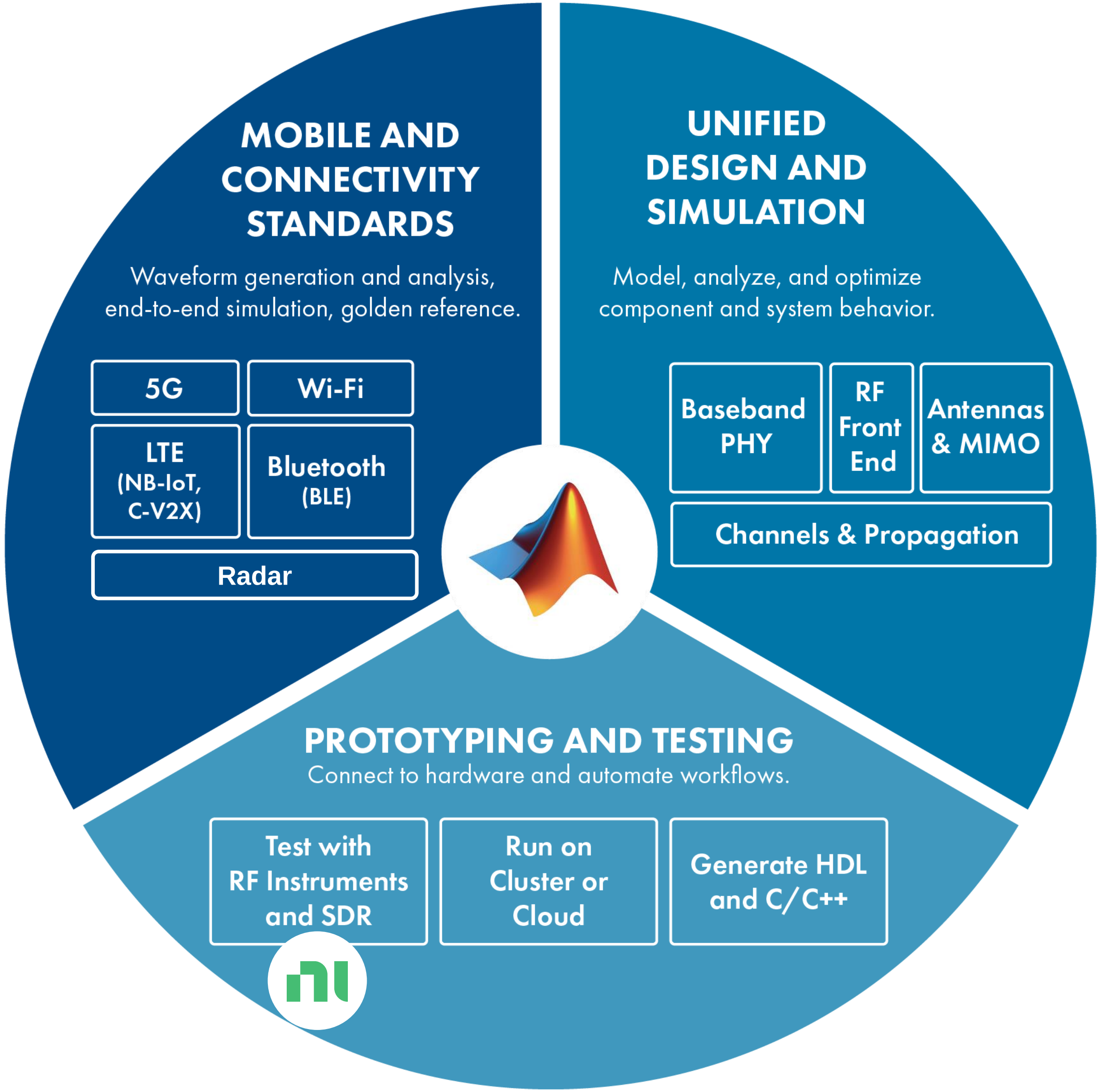
Hands-On Learning

Jump-start learning online or in the classroom. Download interactive teaching content developed by MathWorks and educators from leading universities.

Spectrum is a high demand, non-renewable natural resource

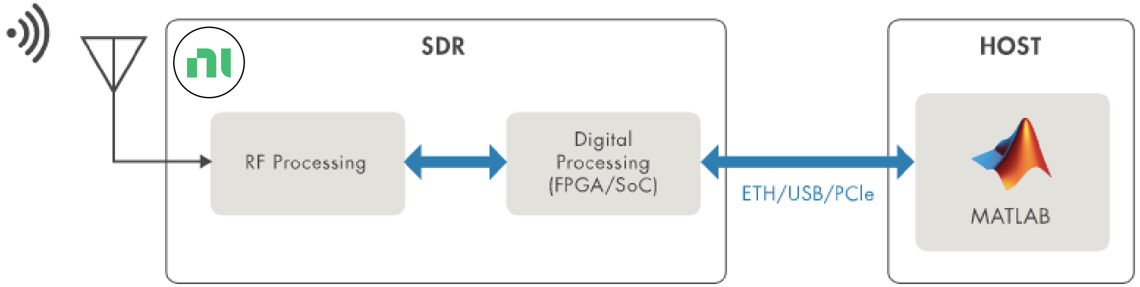


Common Platform for Wireless Development

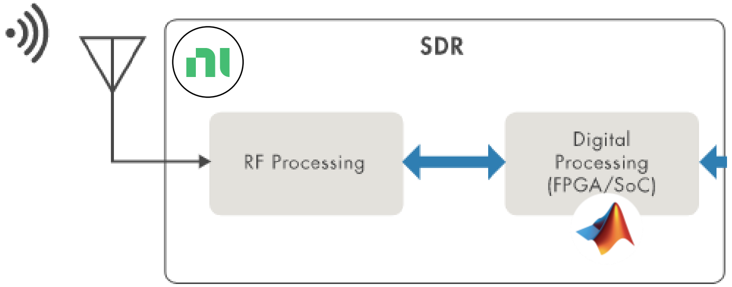


Wireless System Design Based on SDRs

- A software-defined radio (SDR) is a wireless device that typically consists of a configurable RF front end with an FPGA or programmable system-on-chip (SoC) to perform digital functions.



- Prototype: Radio I/O to host



- Deployed: Operates independently

Wireless Research, Design, Prototyping, and Deployment Portfolio

Highly-Portable to High-Performance

KINTEX

USRP 2901
56 MHz BW
6 GHz Fc

B200mini
56 MHz BW
6 GHz Fc

Host based (USB)
Low SWaP

USRP X310
160 MHz BW
6 GHz Fc

FlexRIO
200 MHz BW
4.4 GHz Fc

Large FPGA SDRs

VIRTEX

VST
1 GHz BW
6 GHz Fc

VIRTEX

mmWave VST
1 GHz BW
44 GHz Fc

3rd-Gen VST
2 GHz BW
23 GHz Fc

High Frequency / Wide Bandwidth
Instrument Grade + Calibration

ZYNQ

USRP E31X & E320
56 MHz BW
6 GHz Fc

USRP RX310
Pixus Technologies

Deployable

ZYNQ

N321
200 MHz BW
6 GHz Fc

ZYNQ RFSoC

NI Ettus USRP X410
400 MHz BW
8 GHz Fc

NI Ettus USRP X440
1.6 GHz BW
4 GHz Fc

Stand Alone
FPGA + Embedded Processor

VIRTEX

ATCA-3671
Massive BB
Processing

High Performance and Inline Processing

NI Ettus USRP X410 Product Overview

RF Capabilities

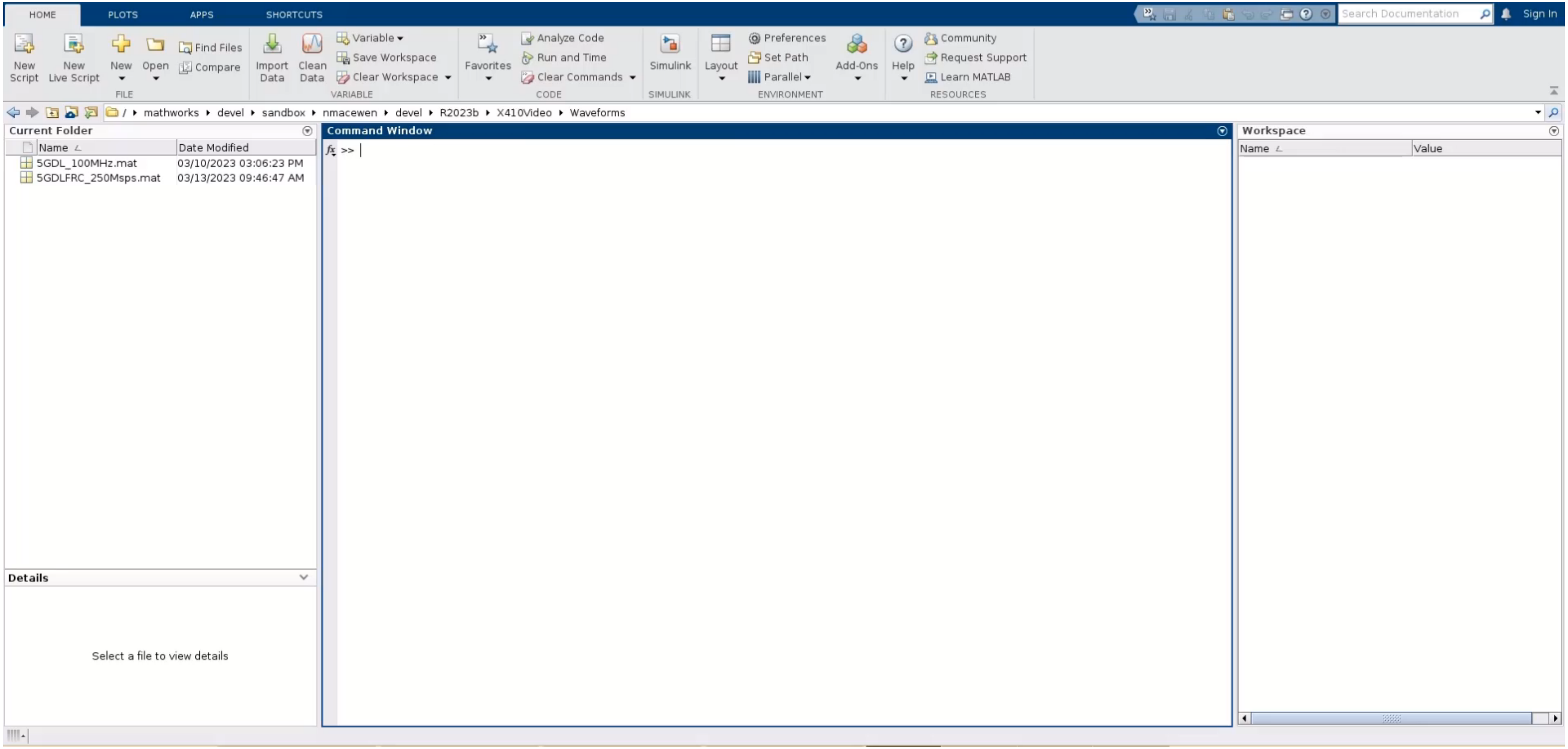
- Frequency Range: 1 MHz - 8 GHz
- Signal Bandwidth: 400 MHz
- Receive Channels: 4X
- Transmit Channels: 4X
- Max TX Power: up to 22 dBm[1]
- Max RX Power: 0 dBm

[1] see specification for details

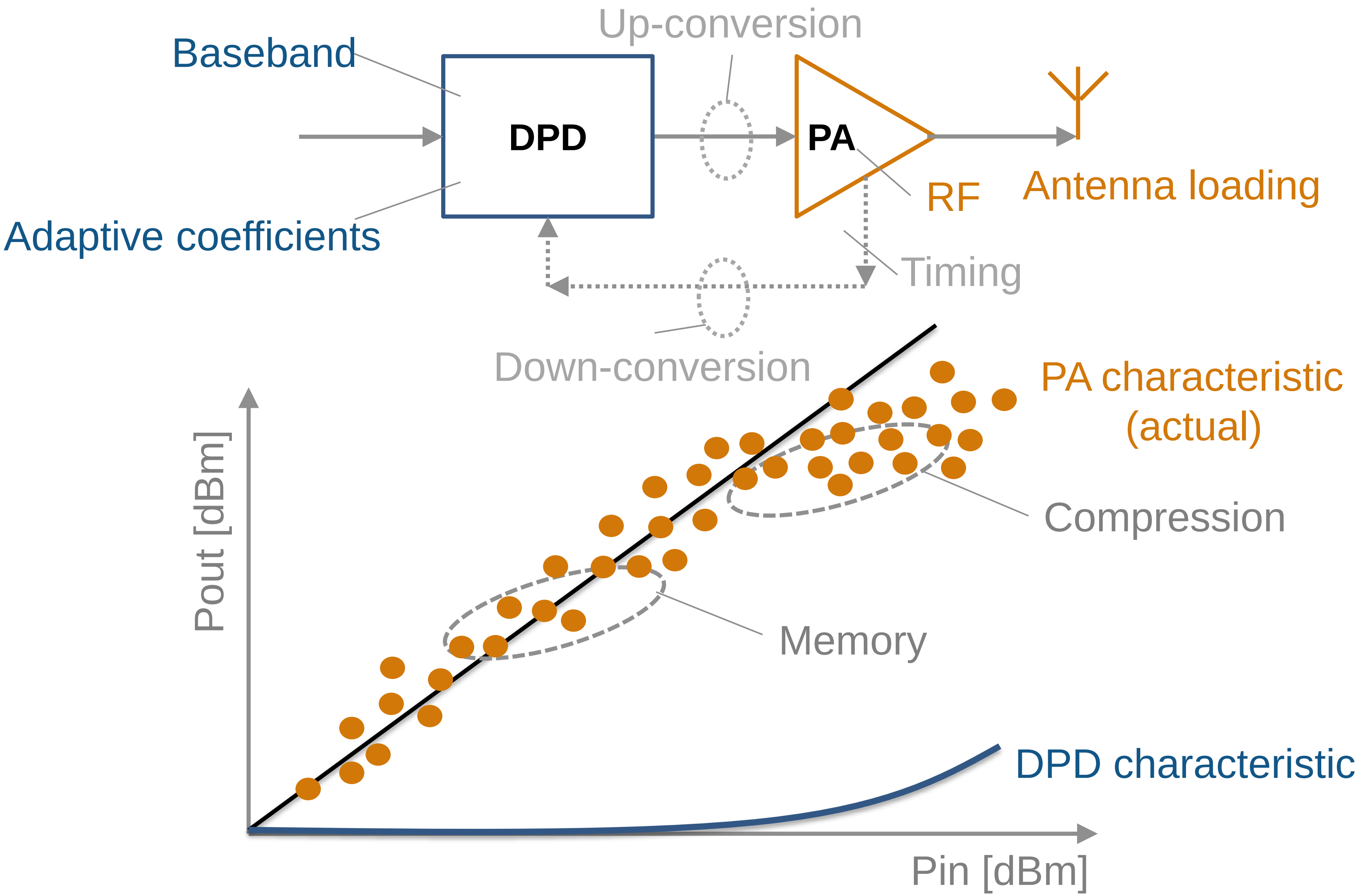
Digital Capabilities

- Xilinx Zynq UltraScale+ RFSoC
  - Built-in quad core ARM processor
- Onboard IP: Fractional DDC, DUC
- Interface options: dual QSFP28 (10G), 1G
- Synchronization: 10 MHz / PPS, GPSDO option
- Software:
  - MATLAB, Wireless Testbench
  - NI-USRP, LabVIEW FPGA
  - USRP Hardware Driver (UHD)

Wireless Testbench plus USRP X410



PA Linearization: Digital Predistortion (DPD) in Practice



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)

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

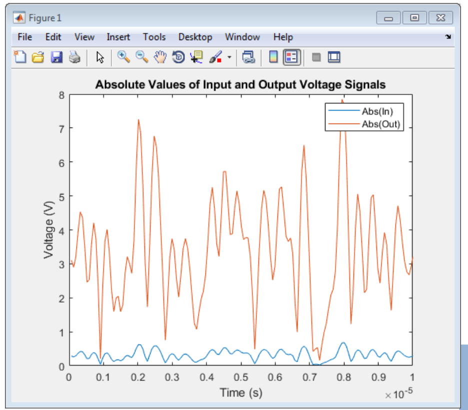
Memory length →

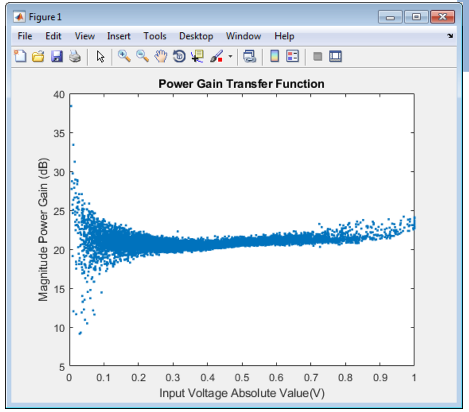
Order ↓

9.4522 + 24.3710i	8.3372 + 22.5027i	-7.6555 - 17.8049i	5.2338 + 12.8109i	-3.5523 - 8.3659i	1.4949 + 4.0988i	-0.6511 - 1.0900i
15.8350 + 25.6405i	3.8876 + 1.8345i	-3.1046 + 0.5440i	2.1230 + 0.9708i	1.0384 - 2.0353i	2.5988 + 0.4408i	1.6011 - 0.5171i
-67.4772 - 80.6146i	-20.3301 - 13.0211i	13.5985 + 0.1138i	-6.0557 - 2.5104i	-2.4325 + 4.5629i	-7.4792 - 0.7205i	-4.3852 - 0.3074i

What resources are available to characterize a PA Model?

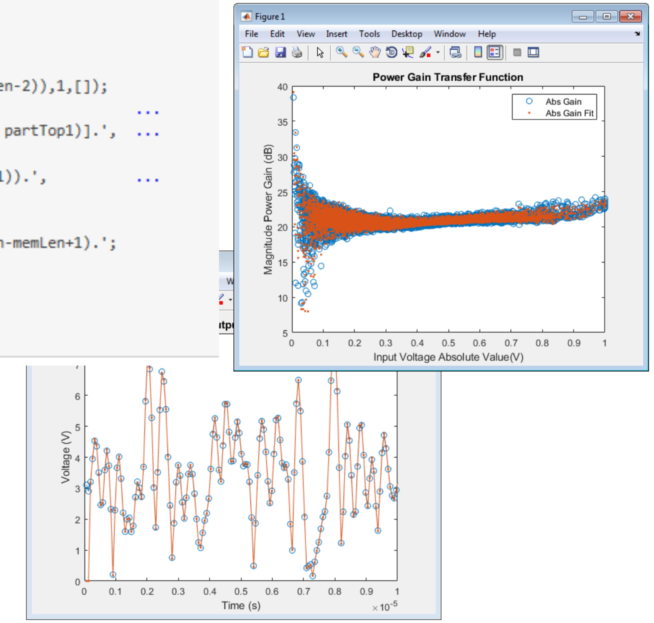
PA Data



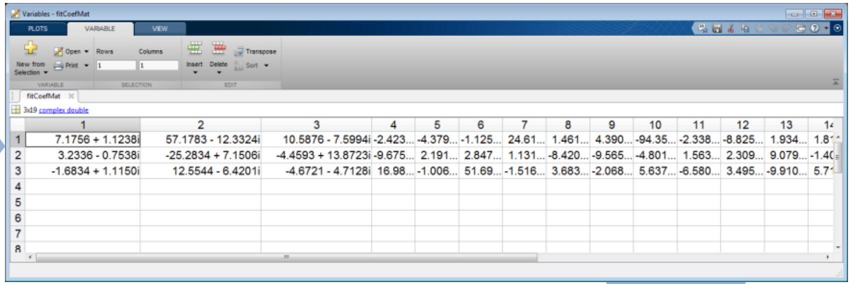


MATLAB fitting procedure (White box)

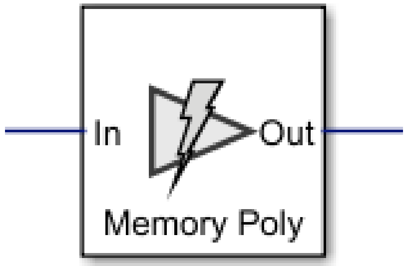
```
function a_coef = fit_memory_poly_model(x,y,memLen,degLen,modType)
% FIT_MEMORY_POLY_MODEL
%   Procedure to compute a coefficient matrix given input and output
%   signals, memory length, nonlinearity degree, and model type.
%
%   Copyright 2017 MathWorks, Inc.

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



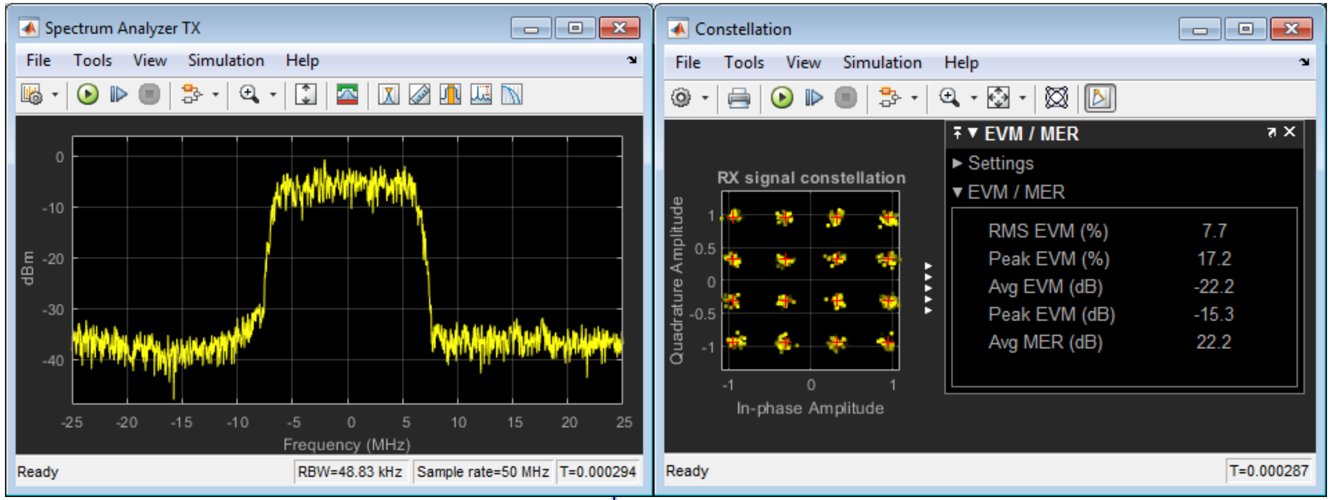
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	7.1756 + 1.1238i	57.1783 - 12.3324i	10.5876 - 7.5994i	-2.423...	-4.379...	-1.125...	24.61...	1.461...	4.390...	-94.35...	-2.338...	-8.825...	1.934...	1.8
2	3.2336 - 0.7538i	-25.2834 + 7.1506i	-4.4593 + 13.8723i	-9.675...	2.191...	2.847...	1.131...	-8.420...	-9.565...	-4.801...	1.563...	2.309...	9.079...	-1.4
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...	5.7
4														
5														
6														
7														
8														

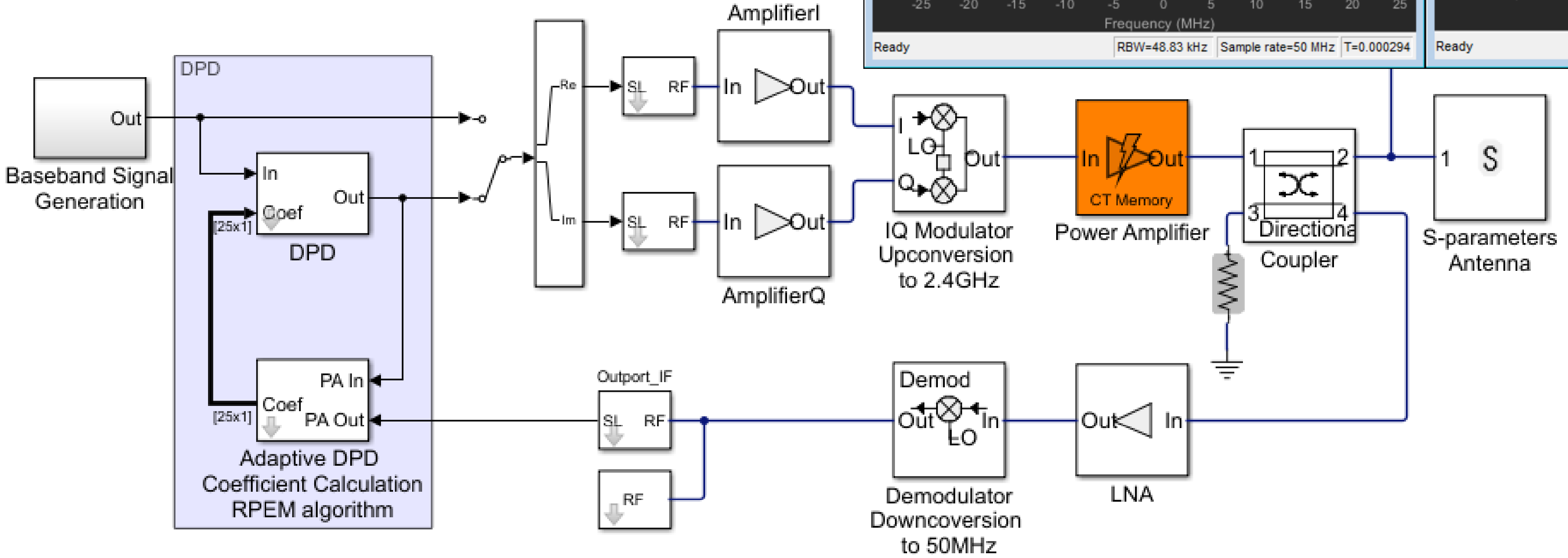


PA model for circuit envelope simulation

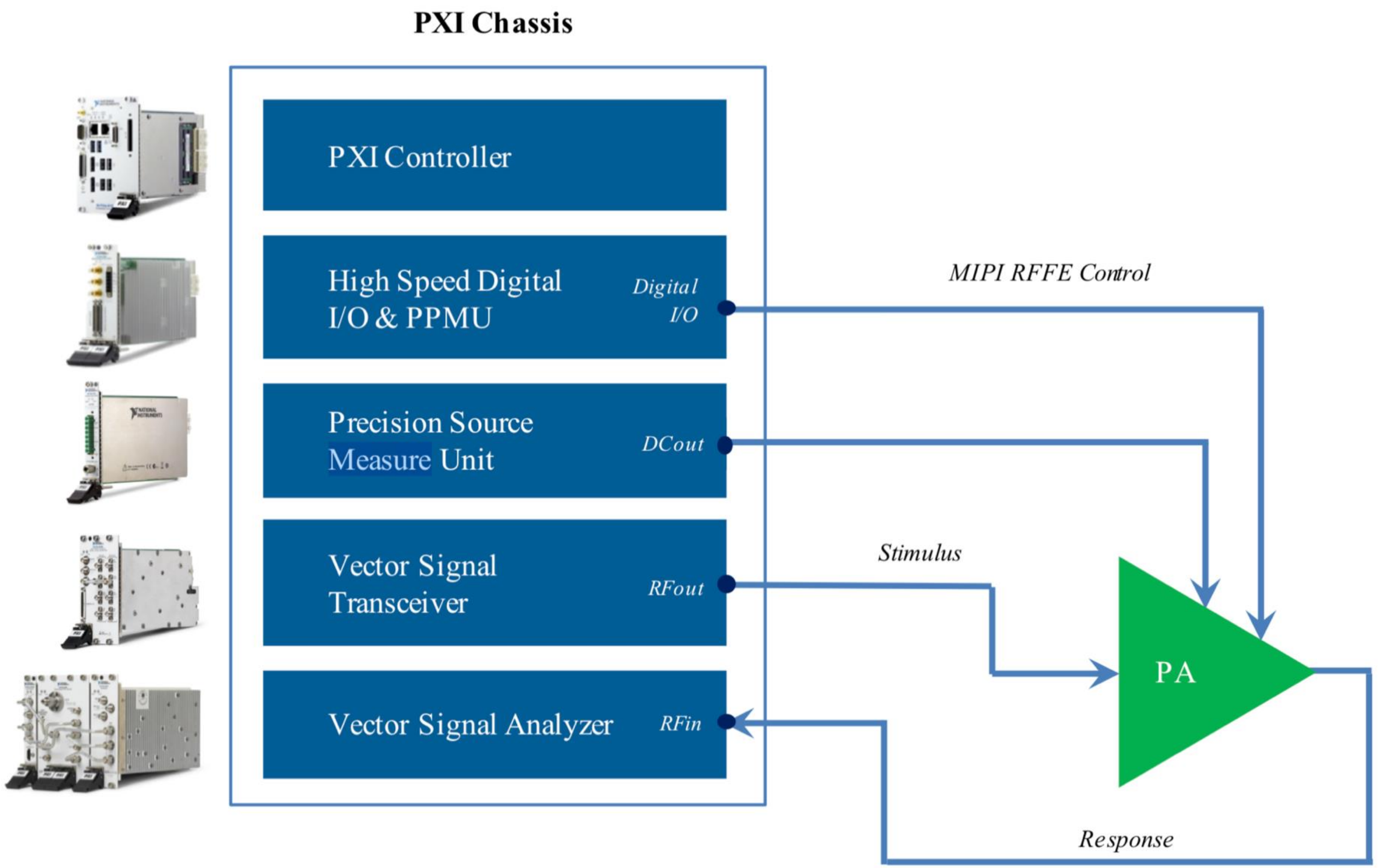
Why is static DPD modeling not enough for 5G systems?

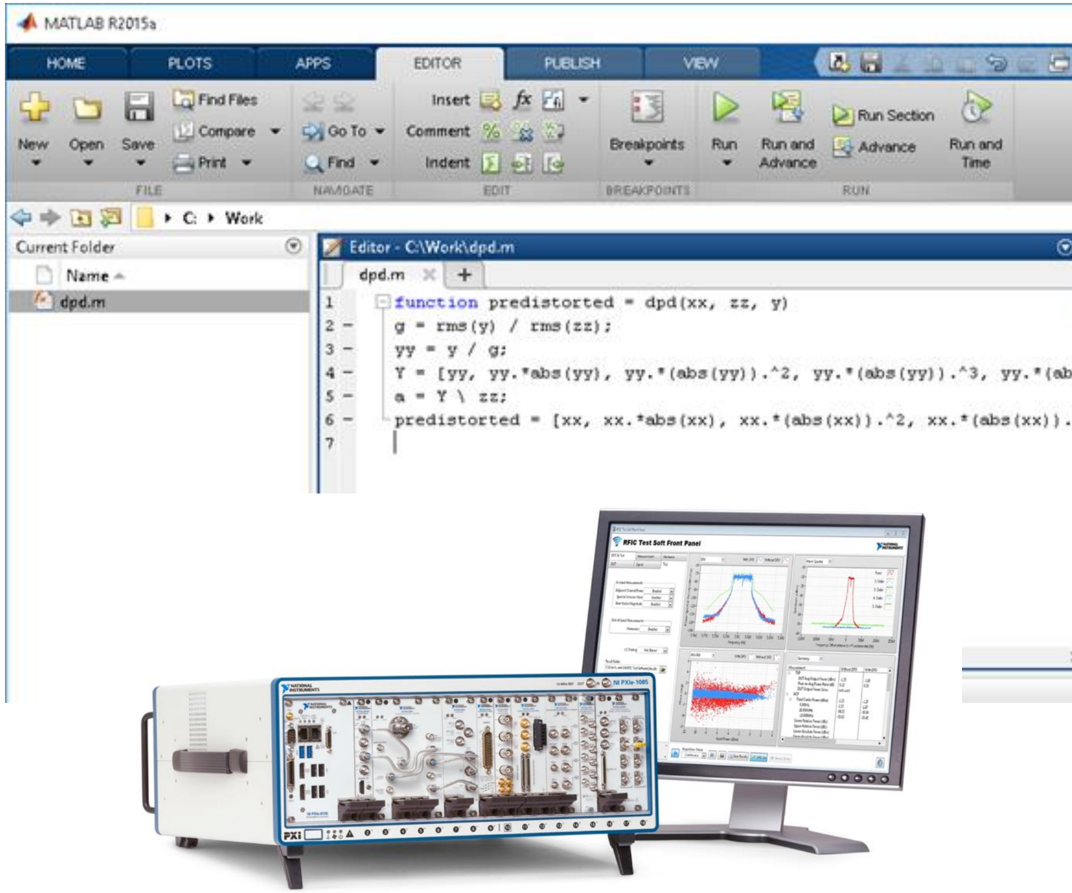
- Circuit Envelope for fast RF simulation
- Low-power RF and analog components
  - Up-conversion / down-conversion
  - Antenna load
- Digital signal processing algorithm: DPD





NI PXI Setup for PA Characterization with DPD & ET Algorithm Running in MATLAB





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

Qualcomm 5G RF front end prototype

"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

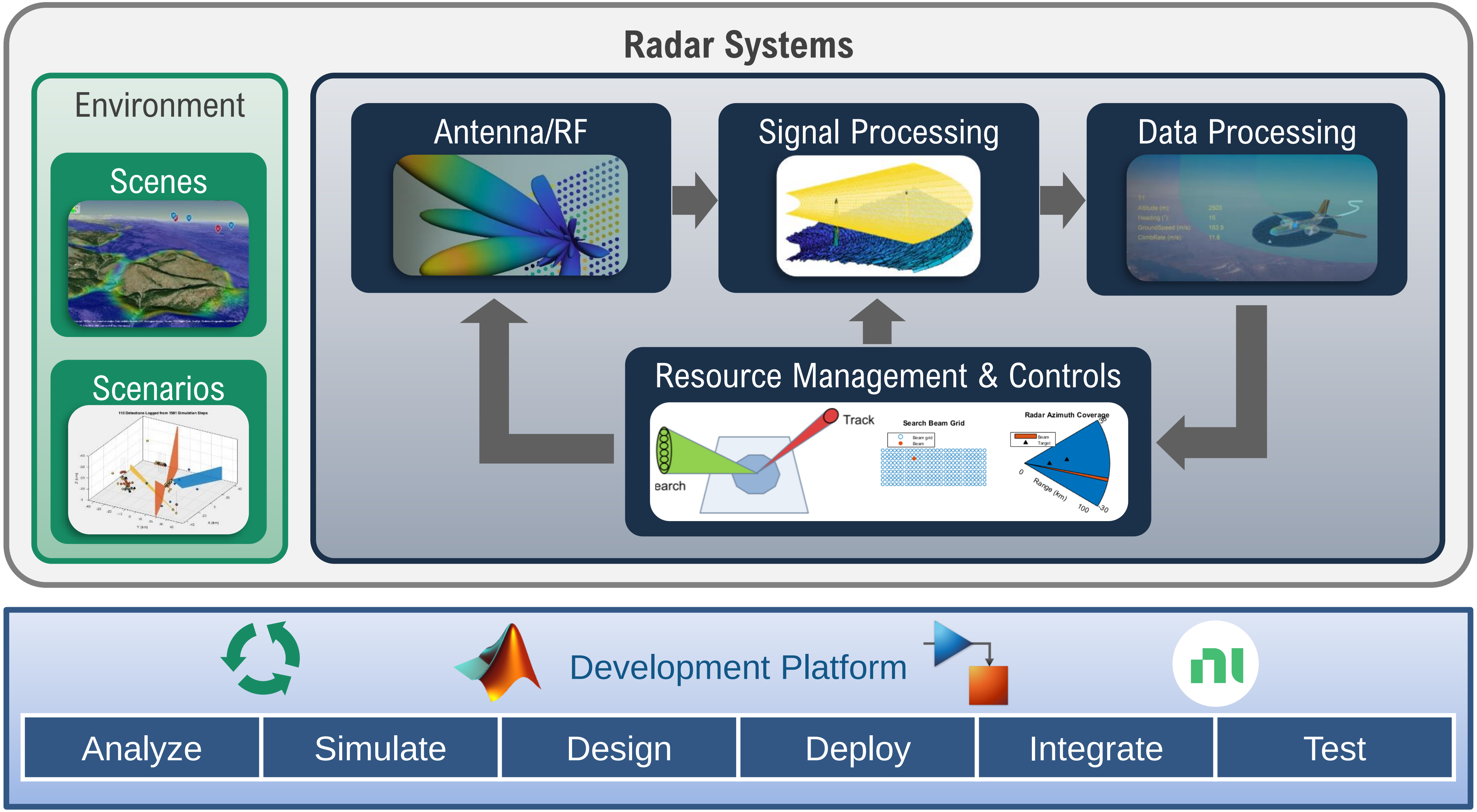
Results
- Development time reduced by 50%
- Iterative verification process accelerated
- Early customer validation enabled

NanoSemi linearization IP development and verification using MATLAB.

"With MATLAB, our team can deliver leading-edge IP faster, enabling our customers to increase bandwidth, push modulation rates higher, and reduce power consumption."

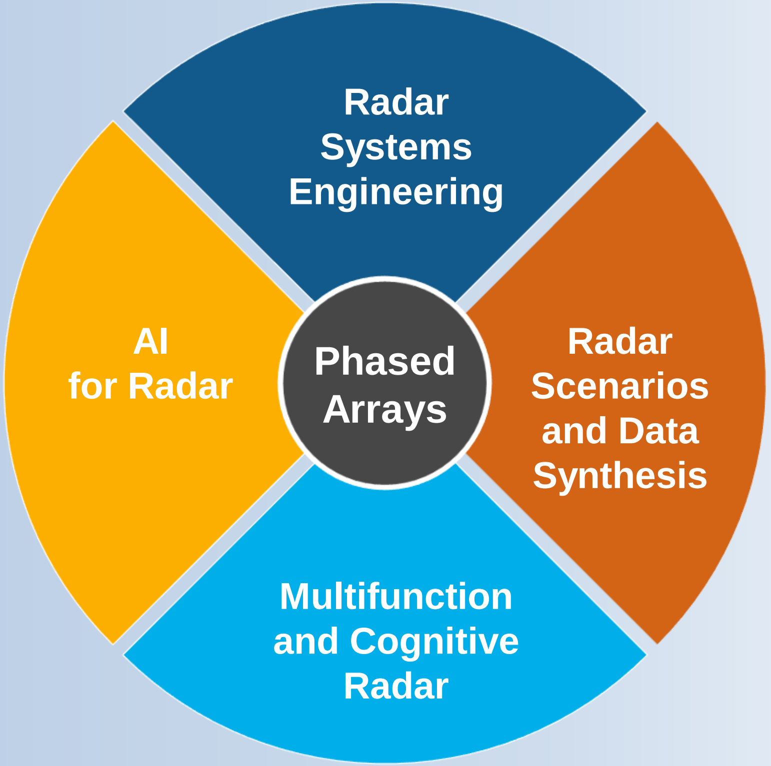
Nick Karter
NanoSemi

Development of Radar Systems
with MATLAB & Simulink



Summary: Support Full Radar Life Cycle

Concept Exploration → Systems Engineering → Design and Test → Operations and Planning → Data Analysis



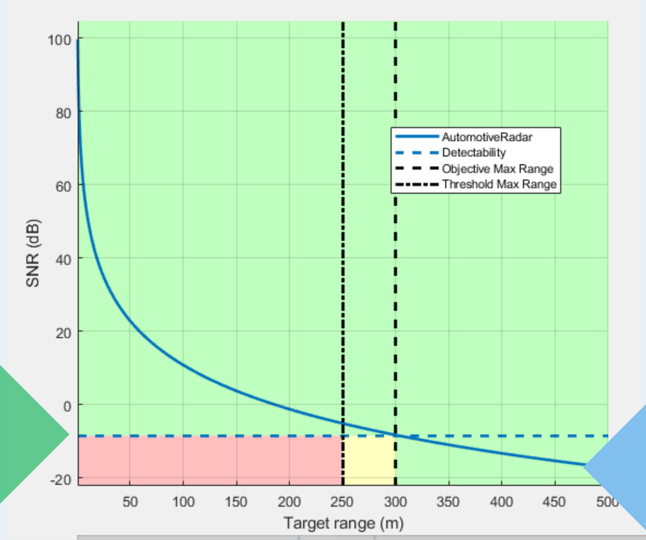
Radar Systems Engineering

Radar Budget Analysis

Stoplight visualizations and metrics

Stoplight chart

Pass
Warn
Fail



Detectability threshold for a given Pd, Pfa

SNR available at the input of the radar receiver

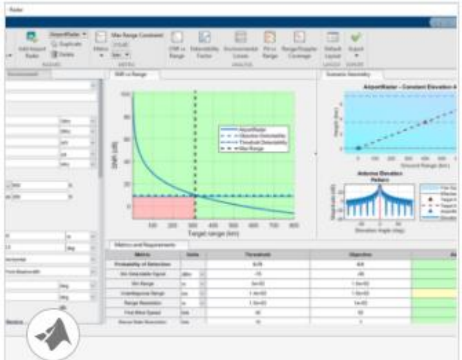
Metrics

minimum detectable signal (MDS)
EIRP
range and Doppler ambiguity
resolution, accuracy
track probabilities

Metric	Units	Threshold	Objective	AutomotiveRadar
Max Range	**km**	**0.25**	**0.3**	**0.3 ✓**
Min Detectable Signal	dBm	-60	-80	-83 ✓
Min Range	m	3e+03	1.5e+02	0 ✓
Unambiguous Range	km	0.25	0.3	7.5 ✓
Range Resolution	m	2.5e+02	1.5e+02	0.5 ✓
First Blind Speed	m/s	30	40	39 ⚠
Range Rate Resolution	m/s	1	0.2	0.15 ✓
Range Accuracy	m	1	0.5	0.54 ⚠
Azimuth Accuracy	deg	60	45	41 ✓
Elevation Accuracy	deg	30	15	14 ✓
Range Rate Accuracy	m/s	5	3	0.16 ✓
Probability of True Track		0.95	0.99	1 ✓
Probability of False Track		1e-08	1e-12	1.1e-11 ⚠
Effective Isotropic Radiated Power	MW	3e-06	3.4e-06	3.2e-06 ⚠
Power-Aperture Product	kW·m²	3.8e-09	4e-09	3.9e-09 ⚠

Pass: measurement meets objective

Warn: violates objective but meets threshold



Radar Link Budget Analysis

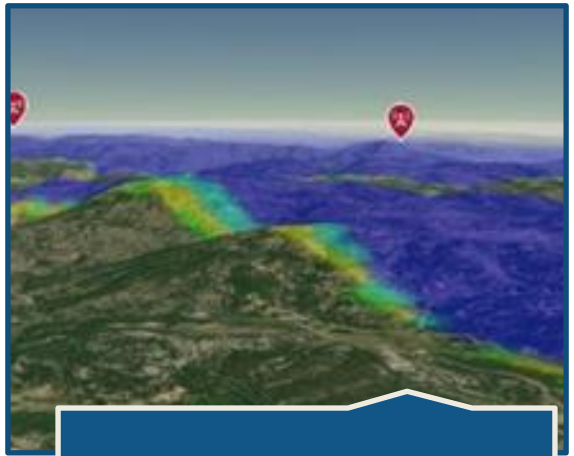
Use the radarDesigner app to perform radar link budget analysis.

Open Live Script

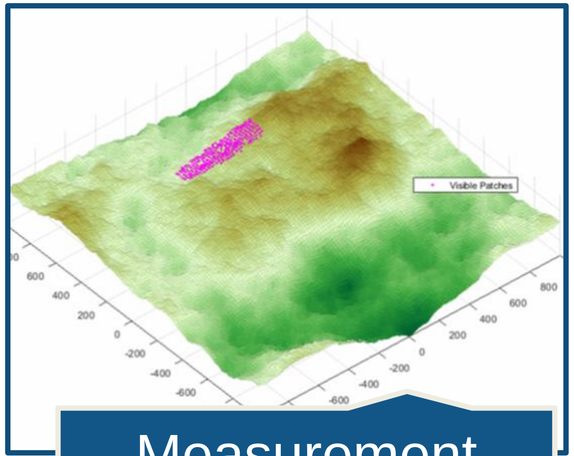
Simulating Clutter Returns

Test signal and data processing algorithms

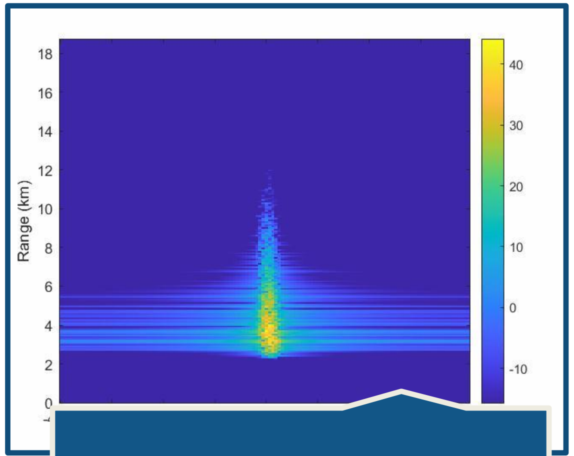
Land and Sea Surface Models → Radar Reflectivity Models → Radar Surface Return



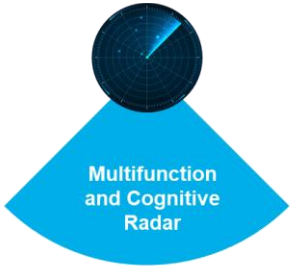
Power Level



Measurement Level



Waveform Level



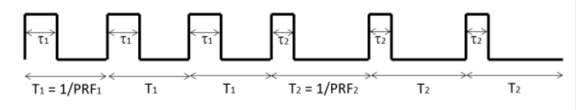
Radar Application

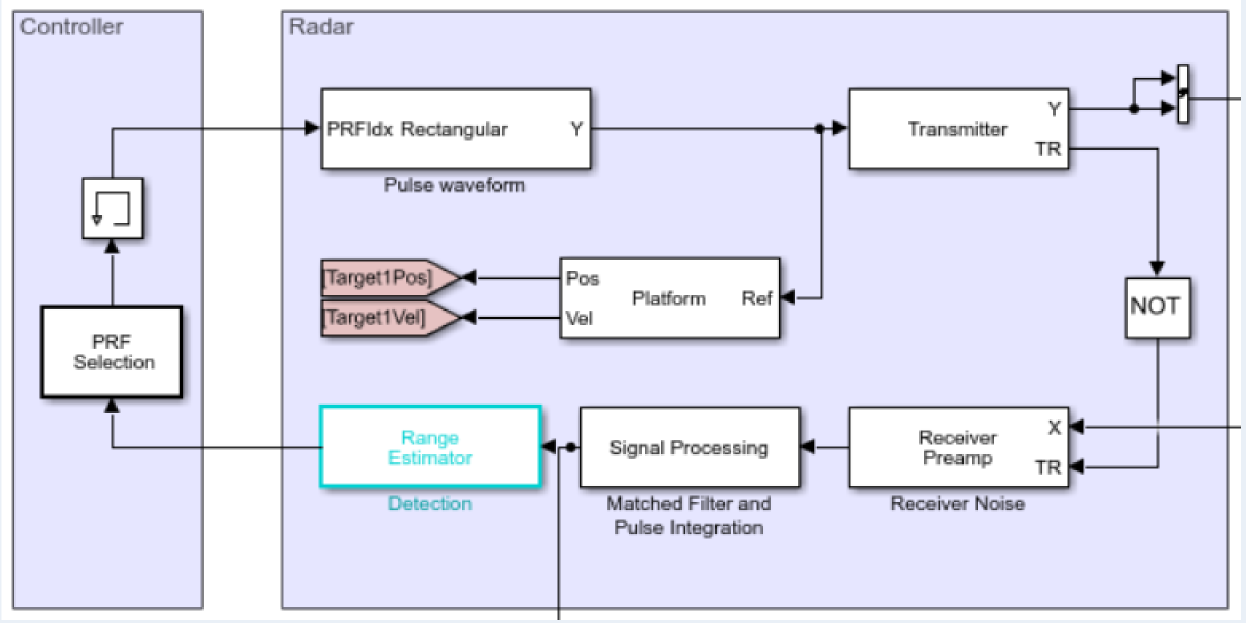
PRF, frequency and waveform agility

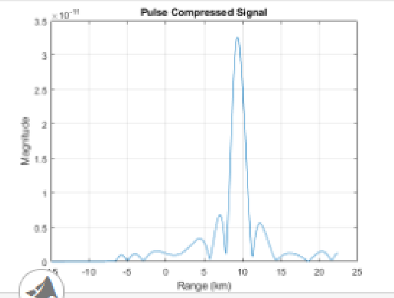
Closing the signal processing loop

Change signal processing chain when an event is detected

- frequency hoping
- PRF selection
- waveform selection
- etc.



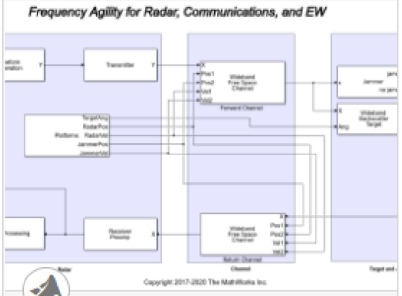




Frequency Agility in Radar, Communications, and EW Systems

Model frequency agility in radar, communications and EW systems to counter the effects of interference.

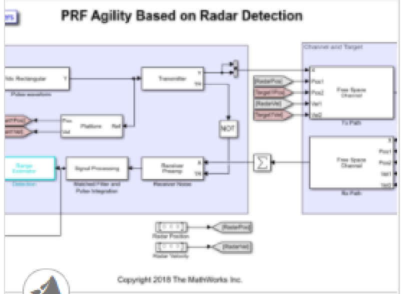
Open Live Script



Interference Mitigation Using Frequency Agility Techniques

Model frequency agility techniques to counter the effects of interference in radar, communications, and EW systems.

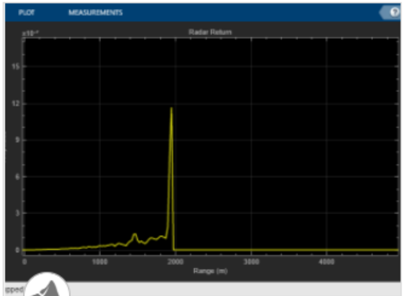
Open Model



PRF Agility Based on Target Detection

Model a radar that changes its pulse repetition frequency (PRF) based on the radar detection.

Open Model

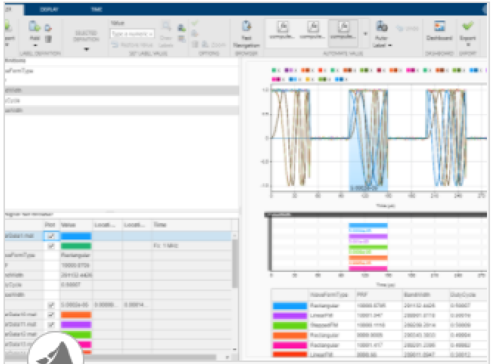


Waveform Scheduling Based on Target Detection

Model a radar that changes its pulse repetition frequency (PRF) based on the radar detection.

Open Script

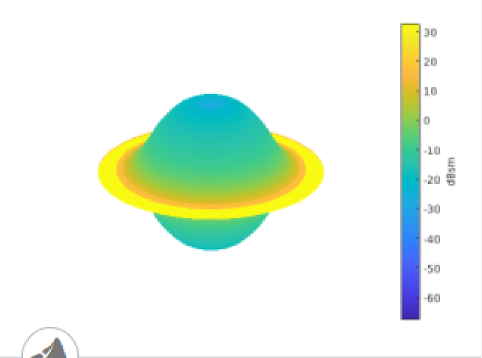
AI for Radar



Labeling Radar Signals with Signal Labeler

Label the time and frequency features of pulse radar signals with added noise.

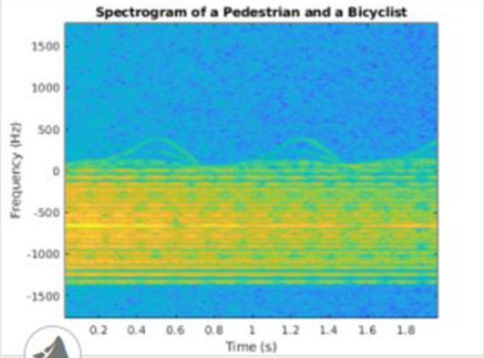
Open Live Script



Radar Target Classification Using Machine Learning and Deep Learning

Classify radar returns using machine and deep learning approaches.

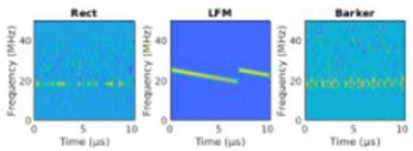
Open Live Script



Pedestrian and Bicyclist Classification Using Deep Learning

Classify pedestrians and bicyclists based on their micro-Doppler characteristics using a deep learning network and time-frequency

Open Live Script



Radar and Communications Waveform Classification…

Classify radar and communications waveforms using the Wigner-Ville distribution (WVD) and a deep convolutional neural network (CNN).

Open Live Script

Software Setup for Radar Prototyping

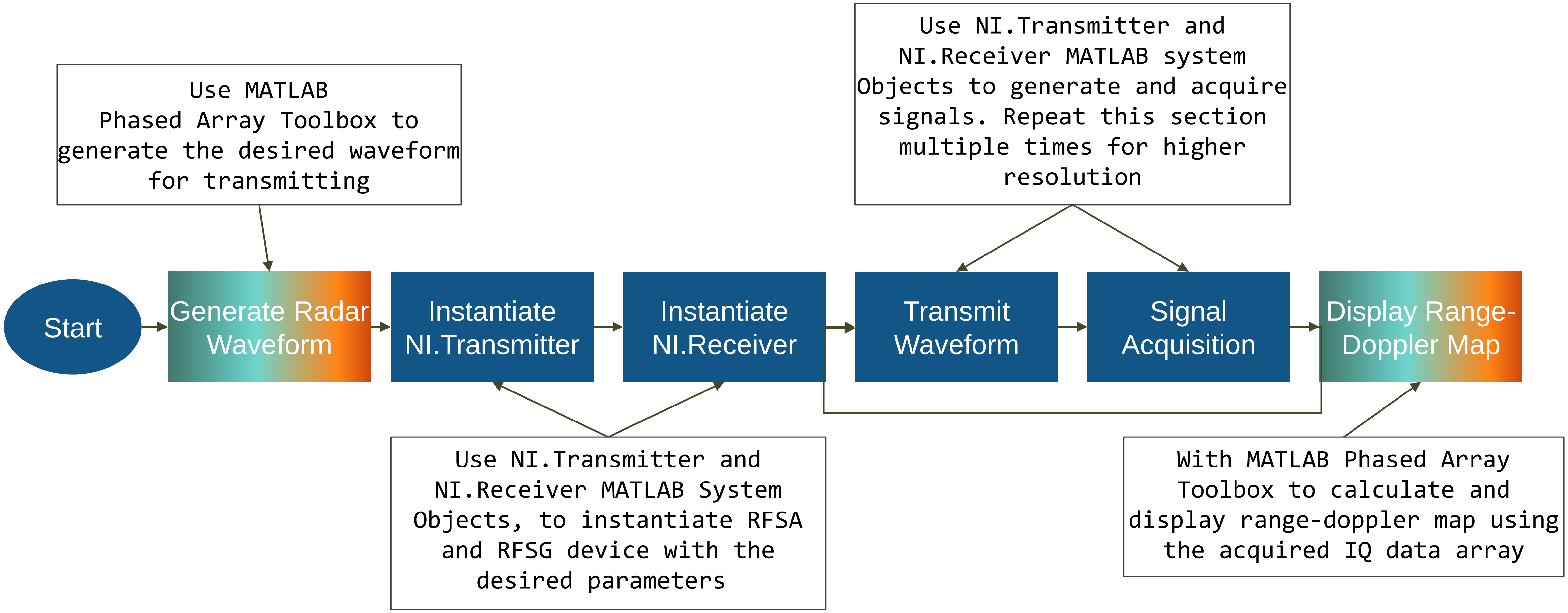
Software stack

Application	MATLAB Example Code	
MATLAB	NI.Receiver System Object	NI.Transmitter System Object
LabVIEW	RFSA.dll RFSA LabVIEW Wrapper	RFSG.dll RFSG LabVIEW Wrapper
Driver	RFSA Driver	RFSG Driver
Hardware	RFSA	RFSG
	PXIe Vector Signal Transceiver	

23 GHz* VSA with up to
2 GHz Instantaneous BW
* 26.5 GHz available in H2.2023

Software Setup

Call sequence from MATLAB



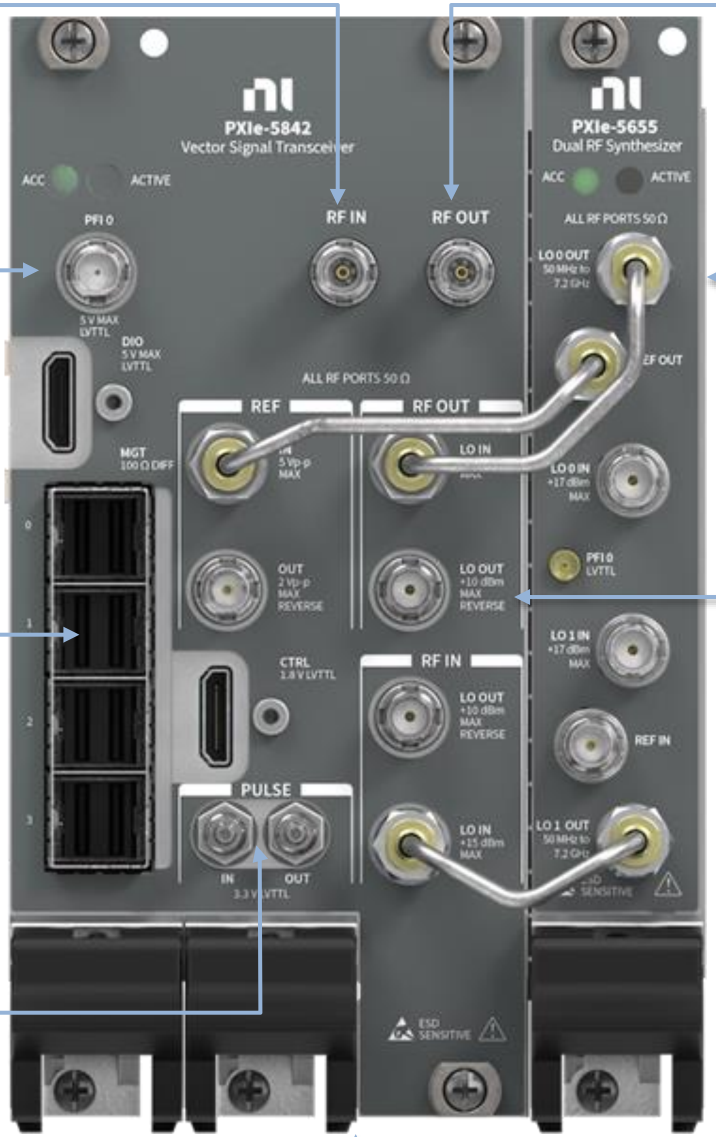
PXIe-5842 Vector Signal Transceiver | Overview

23 GHz* VSA with up to 2 GHz Instantaneous BW
* 26.5 GHz available in H2.2023

PFI 0 (Trigger / Event)

High speed serial interface
MGT - 16 lanes @ 16 Gbps
Full Rate (2 GHz BW) IQ Data Streaming to NI FPGA Co-processor
(*Available H2.2023)*

Integrated RF Signal Chain Pulse Modulation
Allows for optimization of On/Off Ratio versus pulse width
(*Available H2.2023)*



23 GHz* VSG with up to 2 GHz Instantaneous BW
* 26.5 GHz available in H2.2023

High Performance Dual LO Synthesizer
Unique LO chains for RF Out and RF In (from PXIe-5655)

Multi-Instrument Synchronization
Expand channel count with phase coherency LO / REF-sharing and TClk sync across the PXI backplane

Small Footprint
Requires only 4 PXIe slots

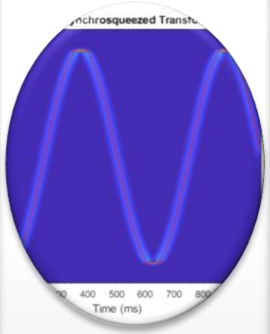
COTS-Based Active and Passive SAR/ISAR Radar Design and Tests

- “One of the most challenging parts of developing any radar system is digital signal processing. In our applications we used real-time SAR processing for an active FMCW radar system and offline processing for passive SAR/ISAR imaging implemented with The MathWorks, Inc. MATLAB® software.”
  - Dr Piotr Samczyński,
    Warsaw University of Technology
    Institute of Electronic Systems

https://www.ni.com/en-gb/innovations/case-studies/19/cots-based-active-and-passive-sar-isar-radar-design-and-tests.html

Electrical / Computer Engineering Education

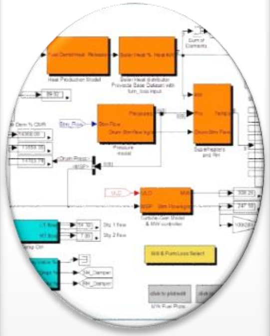
Communications
- Wireless
- Wireline



Signal Pro.
- Signal Processing

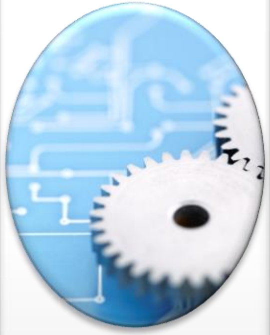
Computer Eng.
- FPGA/ASIC/SoC
- ML/DL/AI
- Comp. Vision
- Data Science
- Embedded
- Microprocessor
- Cryptography

Robotics
- Kinematics/ Dynamics
- Path Plan
- Perception



Controls
- Controls

Electrophysics
- Radiowaves
- Photonics
- Lasers
- Optics
- Quantum Tech.
- Magnetics
- Solar



Microelectronics
- MEMS/NEMS
- Circuits
- VLSI

Electrification
- Power Sys.
- Power Elec.
- Semiconductors
- Renewable Energy

ELECTRICAL & COMPUTER ENGINEERING

NI USRP-290X B-Series Overview

Specs

- Low-cost, all-in-one solution
- Frequency Range: 70 MHz – 6 GHz
- 50-100 mW output power
- USRP B200 / NI USRP 2900
  - XC6LX75 FPGA
  - 1 TX & 1 RX Half or Full Duplex
  - Up to 56 MHz RF Bandwidth
  - USB 3.0 Interface, bus powered
  - 12-bit ADC & DAC
- USRP B210 / NI USRP 2901
  - XC6LX150 FPGA
  - 2 TX & 2 RX Half or Full Duplex, Coherent
  - Up to 30.72 MHz RF Bandwidth in 2x2
  - USB 3.0 Interface, External
  - MICTOR, JTAG, and GPIO connectors

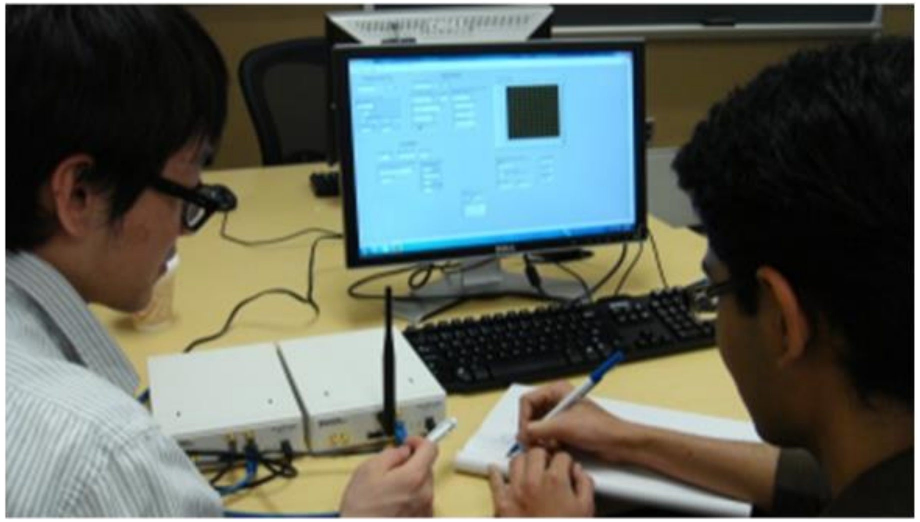
Applications

- FM, TV Broadcast
- Signals Intelligence
- Communications Research

Teaching Wireless Communications with USRP

- “More than four out of five students, 82 percent, said that in the future they would like to make use of the USRP"
  - Robert Maunder, University of Southampton

- “In lab assignments, we could really test out the theory and gain a deeper understanding of how communication systems work.”
  - Student, Rutgers University



Transforming Wireless System Design with MATLAB and NI

Wireless Standards

Design, analyze, and test standards-based 5G, Wi-Fi, LTE, satellite communications, and Bluetooth systems.

AI for Wireless

Apply deep learning, machine learning, and reinforcement learning techniques to wireless communications applications.

Digital, RF, and Antenna Design

Jointly optimize digital, RF, and antenna components of an end-to-end wireless communications system.

Hardware Design, Prototyping and Testing

Implement and verify your designs on hardware. Test your algorithms and designs over-the-air with RF instruments and SDRs.

Radar Applications

Simulate multifunction radars for automotive, surveillance, and SAR applications. Synthesize radar signals to train machine and deep learning models for target and signal classification.

Hands-On Learning

Jump-start learning online or in the classroom. Download interactive teaching content developed by MathWorks and educators from leading universities.

MATLAB EXPO

Thank you

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