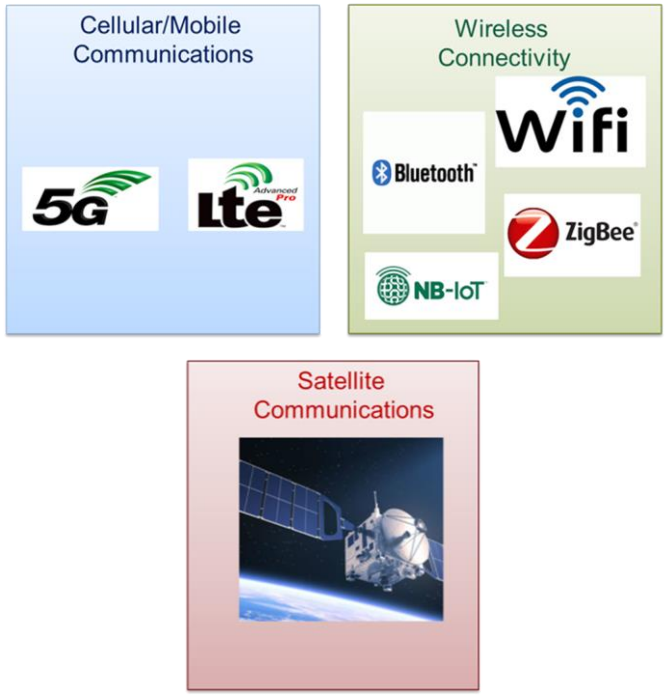
MATLAB EXPO 2021

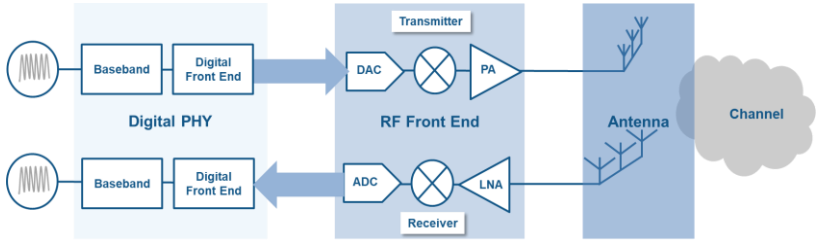
5G and Wireless Design

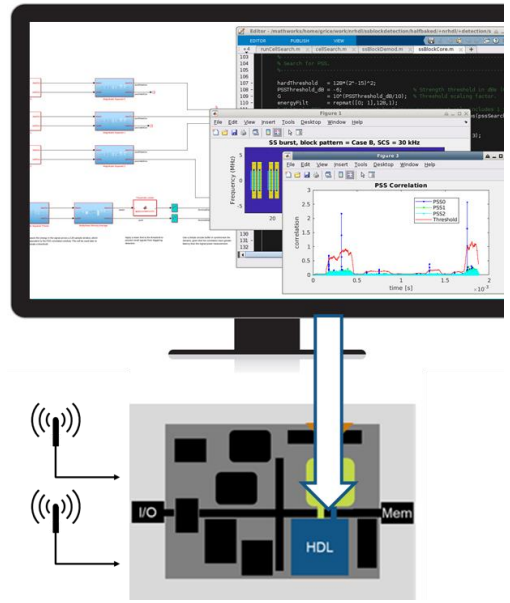
서기환 차장

MathWorks®

3 Topics We Cover Today







Ubiquity

Model 5G/Wireless connectivity systems and standards

Complexity

Integrate and simulate multi-domain designs from antenna-to-bits

Efficiency

Iterate, optimize and verify design implementations

Wireless Communication is Everywhere

Mobile devices

Communications Infrastructure

Semiconductors and components:
Baseband, RF, Antenna

Connected Devices
- **Automotive**
- **Industrial**
- **Smart home**
- **Smart city**
- **Medical**

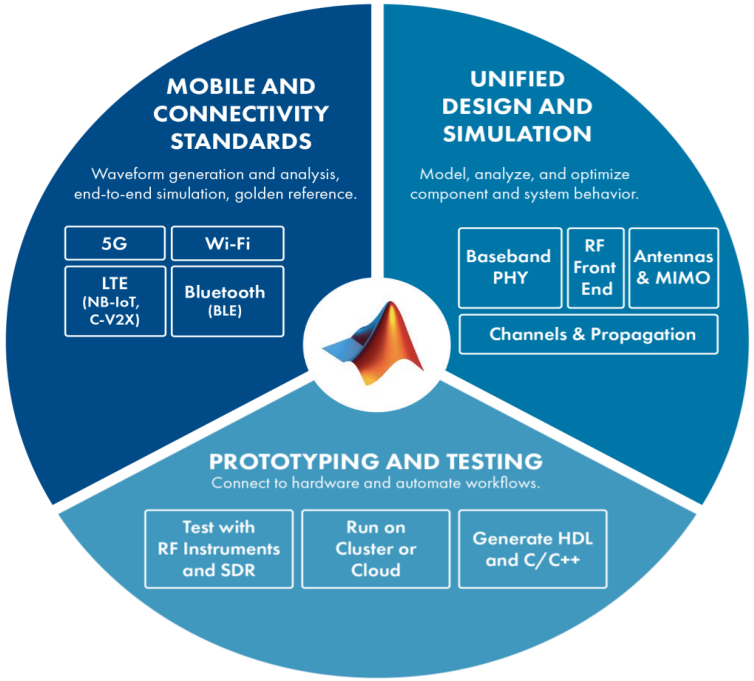
Common Challenges of Wireless Design

Physical Layer Design

- OFDMA
- Mu-MIMO
- Channel estimation/Equalization
- Modulation & Coding
- RF Linearization (PA and DPD)

Ubiquity

Ubiquitous Connectivity



System Engineering

- mmWave
- Link Budget Analysis
- Capacity & throughput
- System-level simulation
- Co-Existence and Interference

Complexity

Design Complexity

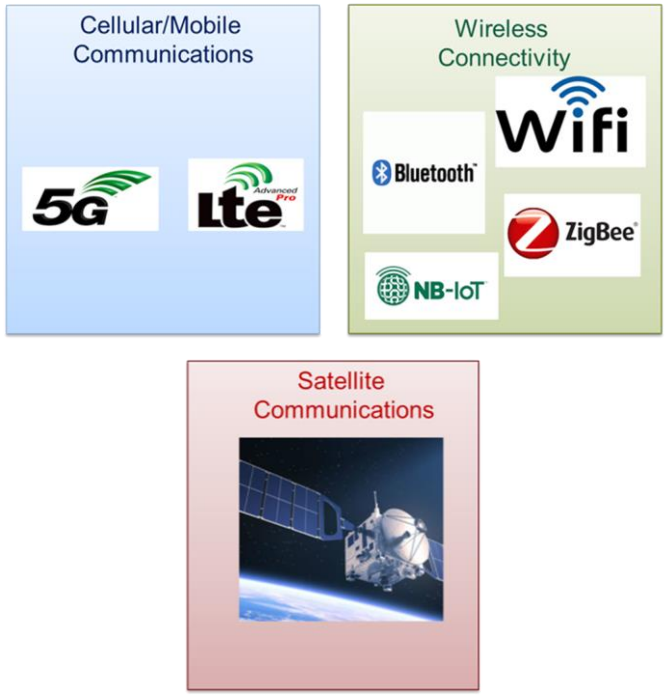
Deployment & Verification

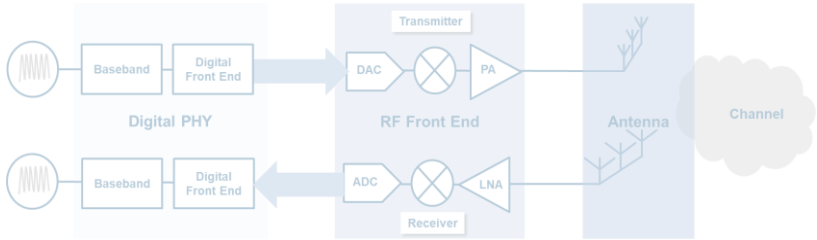
Efficiency

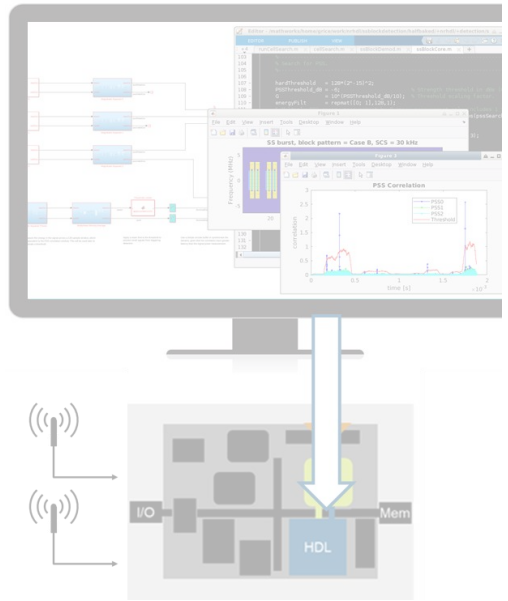
Efficient deployment & testing

- Fixed-point design
- Parallelism
- Area-speed tradeoffs
- Over-the-air testing
- Rapid Prototyping and IP design

3 Topics We Cover Today







Ubiquity

Model 5G/Wireless connectivity systems and standards

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Ubiquitous Connectivity – Technologies & Standards

Cellular

Satellite communications

Wi-Fi

GNSS

5G

CCSDS
The Consultative Committee for Space Data System

Advanced Pro
Lte

Wi Fi™

DVB S** SATELLITE

Personal Area Network

Local Area Network

Wide Area Network

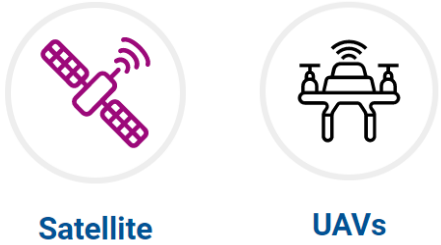
5G: A Megatrend & Driving Force

5G Cellular

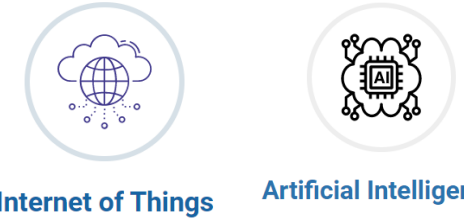
Connectivity & Positioning (UWB, BLE, Wi-Fi)

Connected Car

Autonomous Driving / V2X



SatCom and UAVs

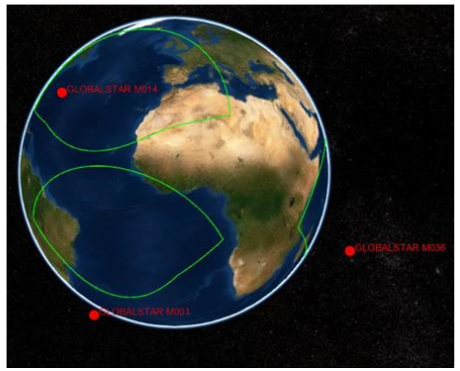


Smart Factory

Trend: Emerging Satellite Communications

Driven by development of high-speed internet connectivity

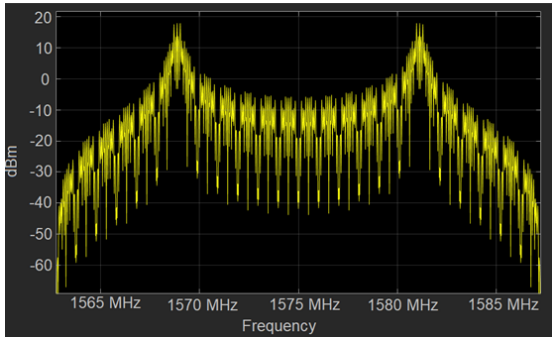
Orbit Propagation and Visualization; Access and Link Analysis



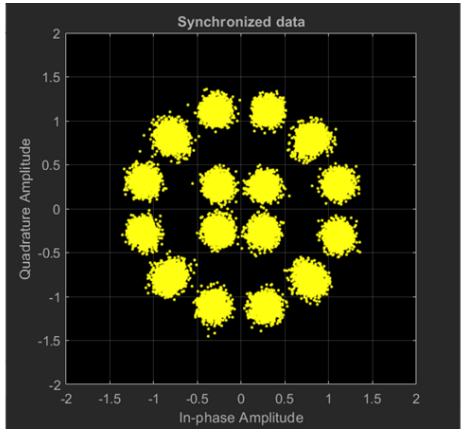
Link Budget Analysis

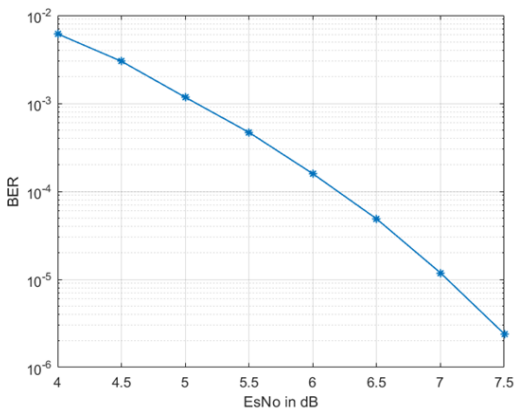
Name	L1
Distance (km)	3.6595e+03
Elevation (deg)	20.2176
Tx EIRP (dB)	51
Polarization loss (dB)	3.0103
FSPL (dB)	186.6387
Received isotropic power (dBW)	-141.6490
C/No (dB-Hz)	87.9502
C/N (dB)	20.1687
Received Eb/No (dB)	17.9502
Margin (dB)	5.9502

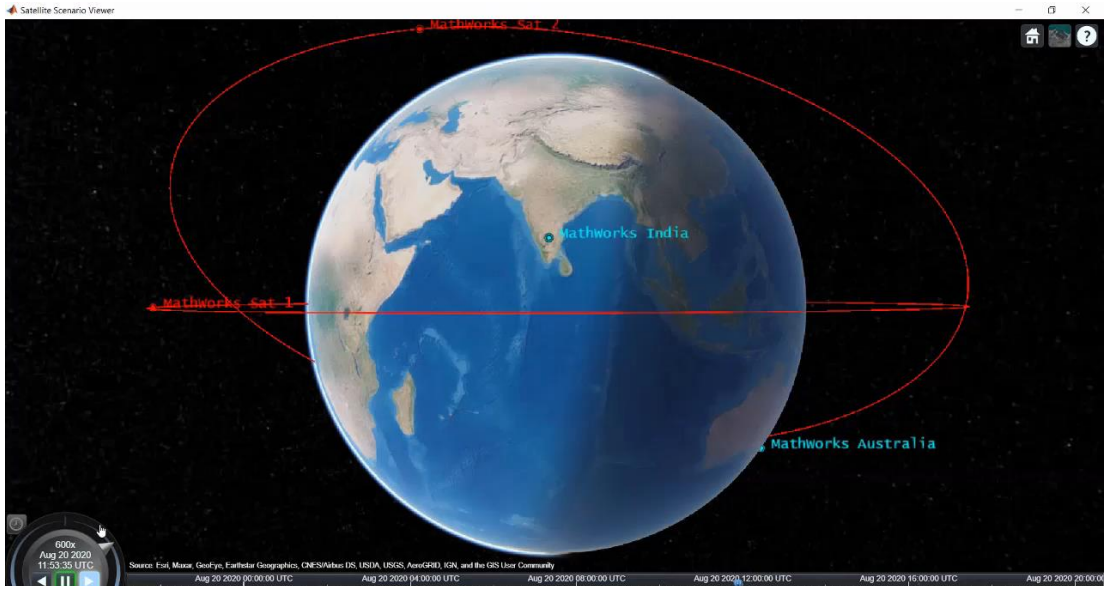
Waveform Generation



End-to-End Simulations







Trend: Wi-Fi Evolution – Driven by IoT

802.11ac → **802.11ax Wi-Fi 6**

100s of Mbps, high efficiency with lots of devices

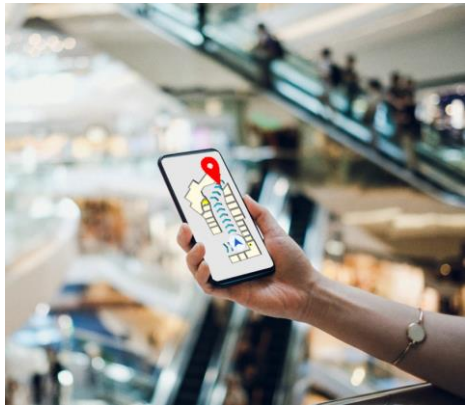
More devices & dense environments

Industry 4.0

802.11ax → **802.11be Wi-Fi 7**

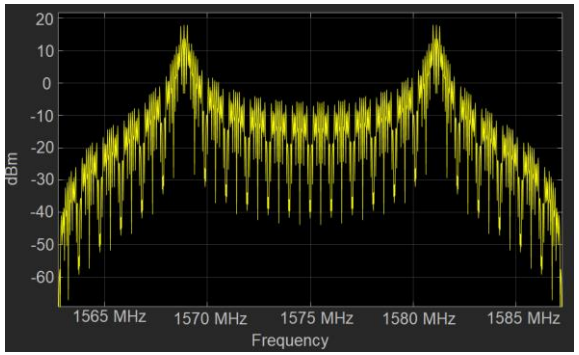
Gbps, reduced latency and jitter

802.11az - Positioning

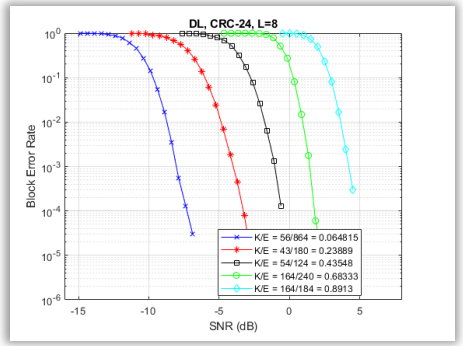


Direction Finding & Localization

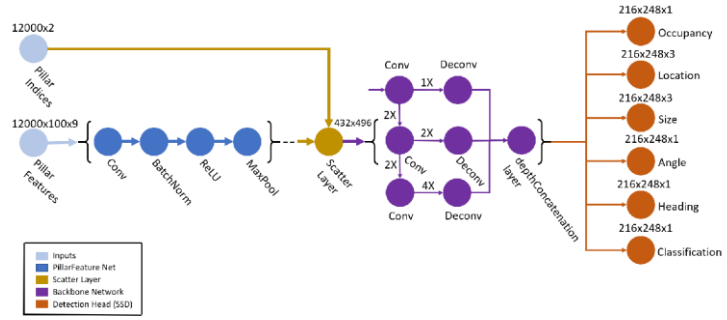
Common Use-Cases of Standard-Based Connectivity Design



Waveform Generation

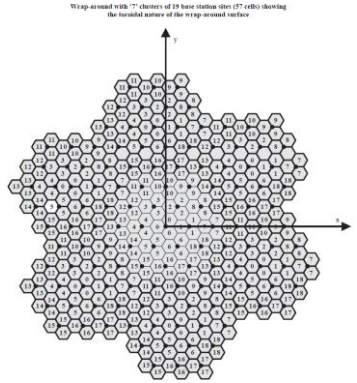


Link-level Simulation



AI Workflow
Pre-trained models, training, evaluation, validation

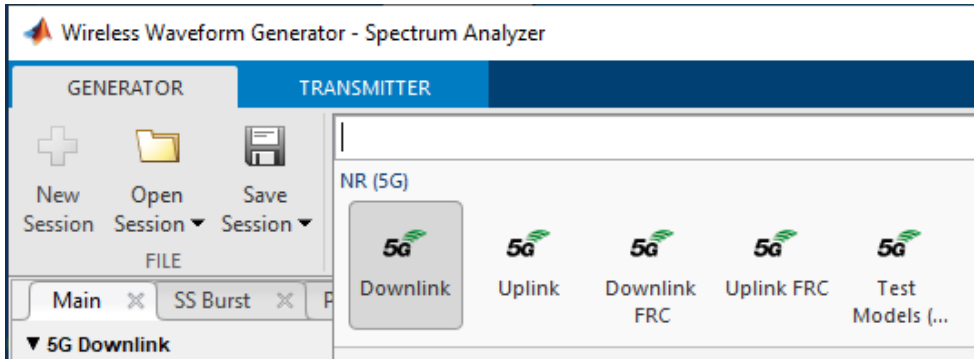
Interference & Coexistence

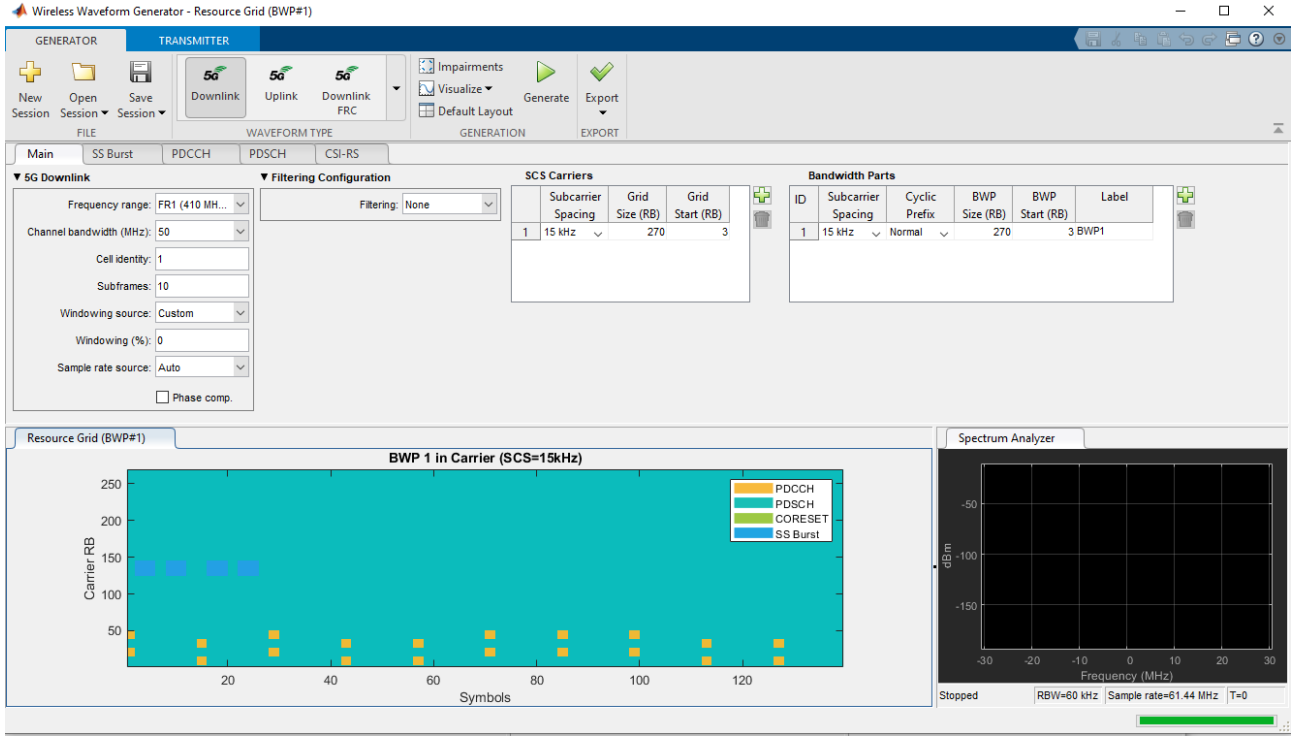


Network Simulation

Wireless Waveform Generator App

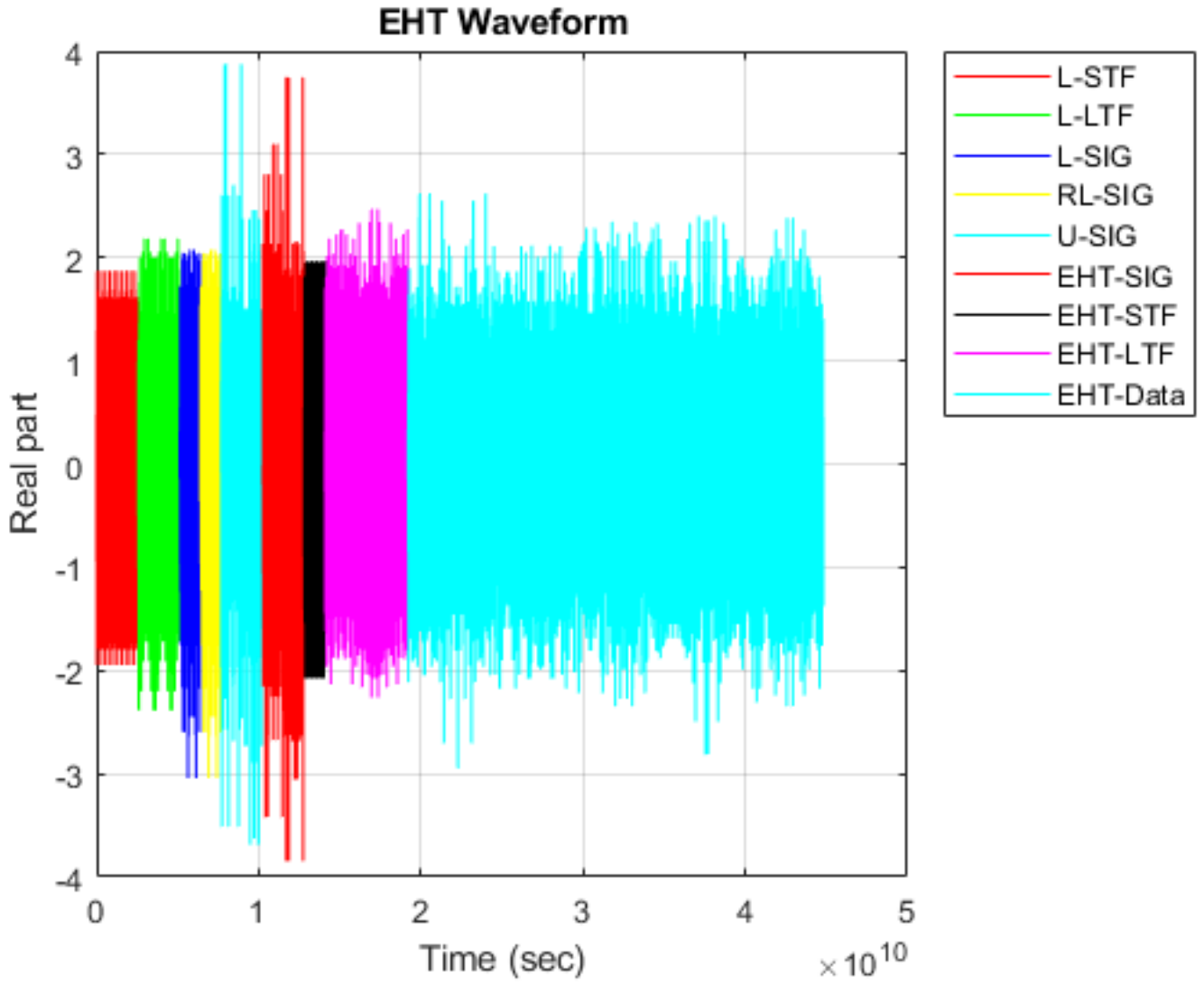
- Interactive waveform generation
- 5G NR off-the-shelf waveforms:
  - NR-TMs / FRCs
- Custom downlink & uplink waveforms
  - New in the App in R2021a



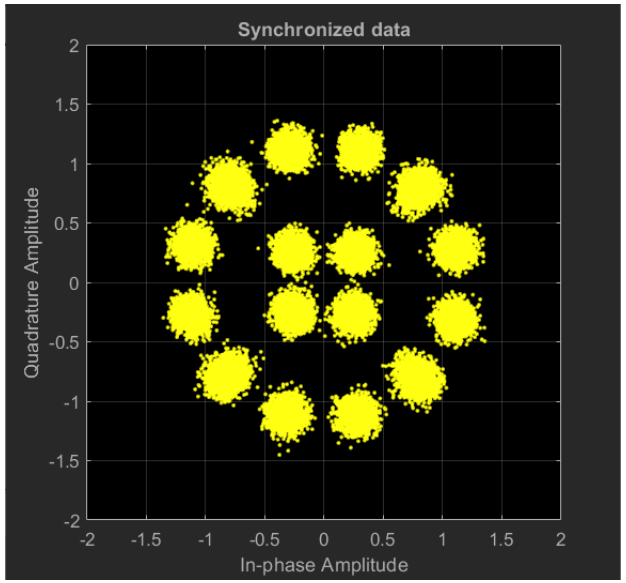


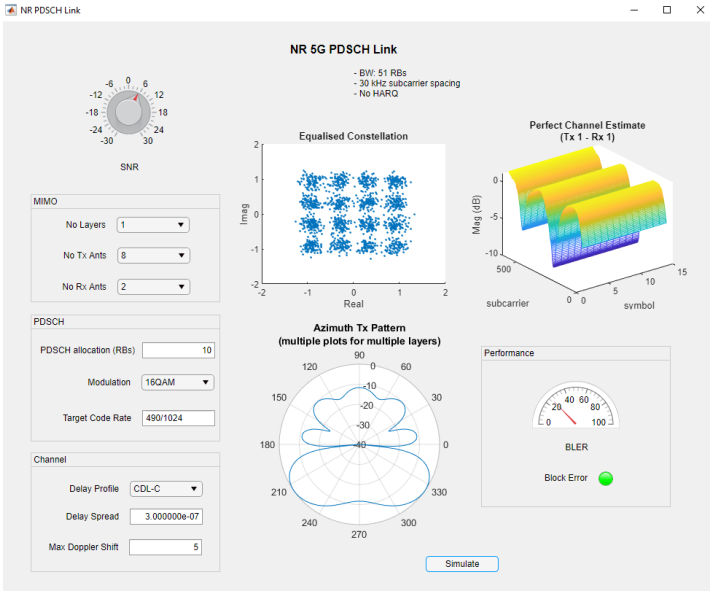
IEEE 802.11be Waveform Generation

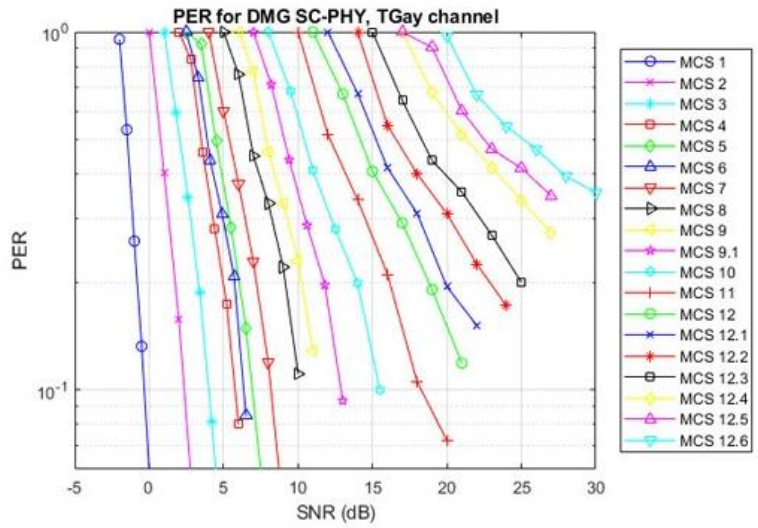
R2021a



End-to-End Link-Level Simulation







End-to-End DVB-S2 Simulation with RF Impairments and Corrections

5G NR PDSCH Throughput

802.11ax Downlink OFDMA and Multi-User MIMO Throughput Simulation

Interference & Coexistence

- 2.4 GHz

BLE

ZigBee

Wi Fi™

- 5/6 GHz

Wi Fi™

Advanced Pro Lte™

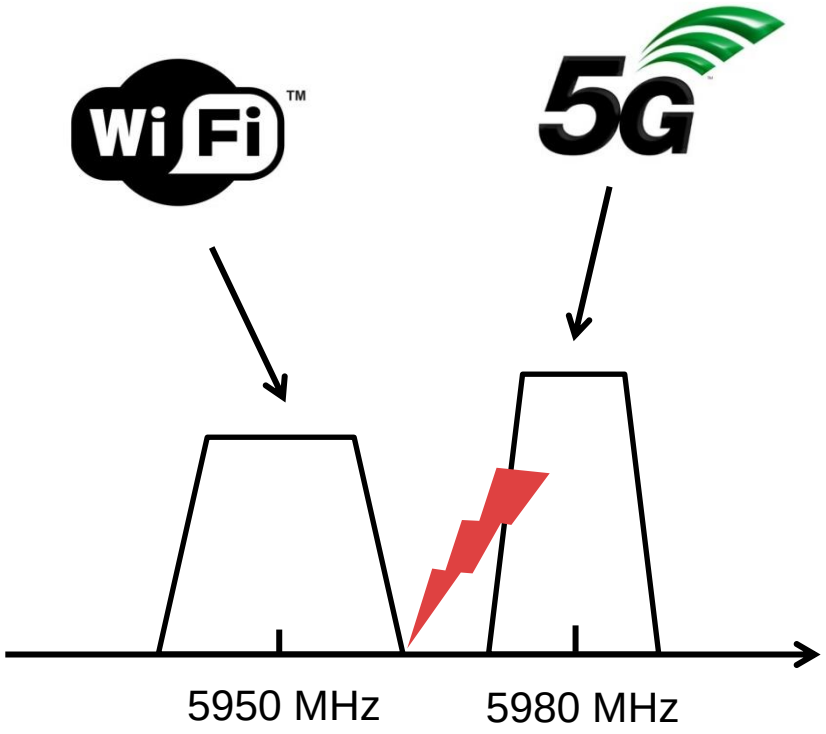
5G

- 60 GHz

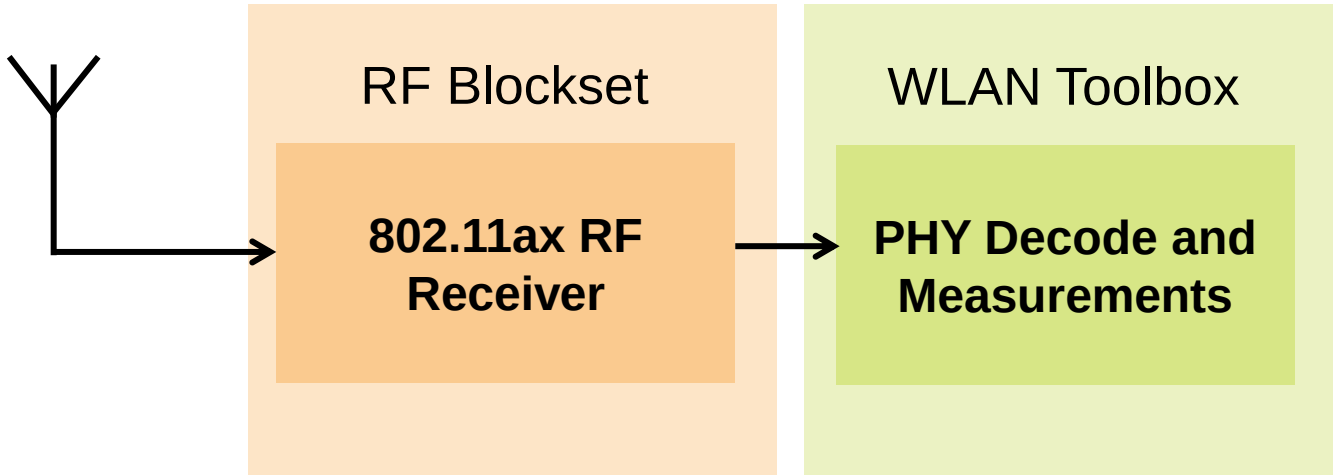
Wi Fi™

5G

Example - 802.11ax RF Receiver with 5G Interference

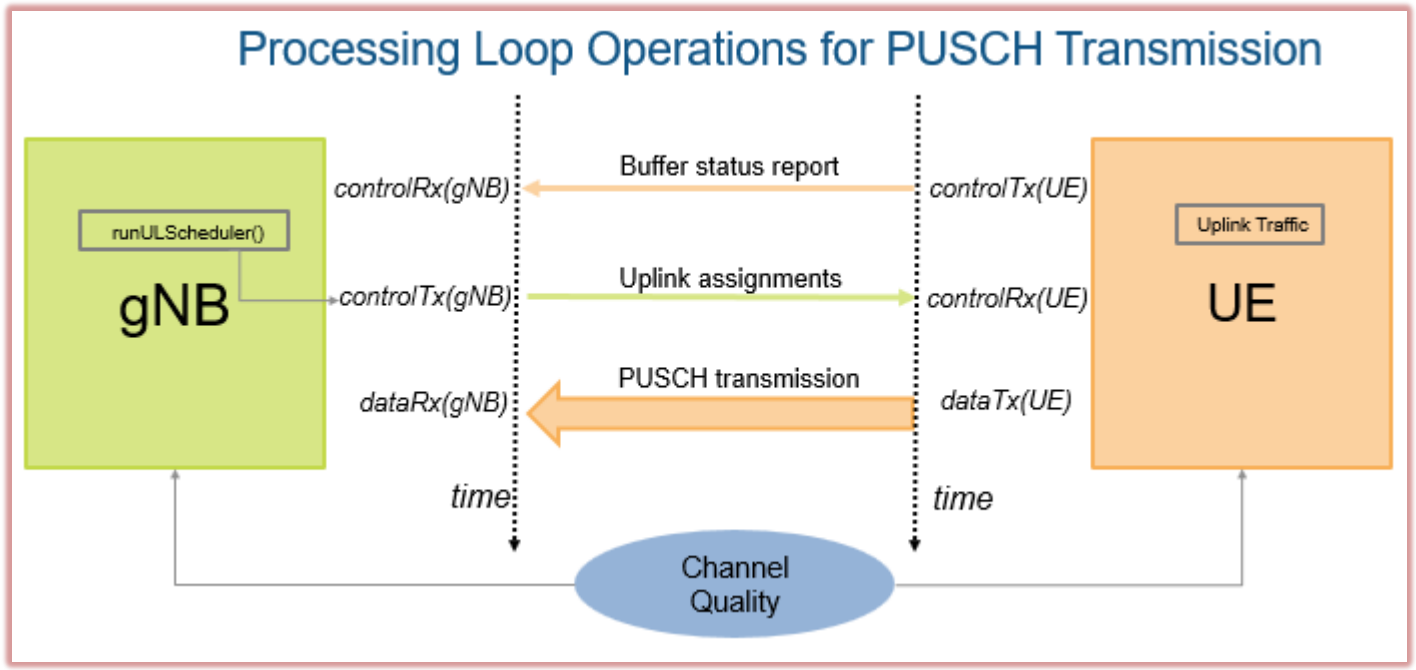


Transmitted waveform	802.11ax at 5950MHz
Interferer	NR-TM at 5980MHz
Tests	- Channel power - EVM per subcarrier - EVM per OFDM symbol



5G NR System-Level Simulations

- Evaluating performance of different schedulers
  - Round-robin, proportionally fair, best CQI



Throughput, goodput, buffer status

Deep Learning for Wireless Workflow

1 Data Preparation

- Data cleansing and preparation
- Human insight
- Simulation-generated data

2 AI Modeling

- Model design and tuning
- Hardware accelerated training
- Interoperability

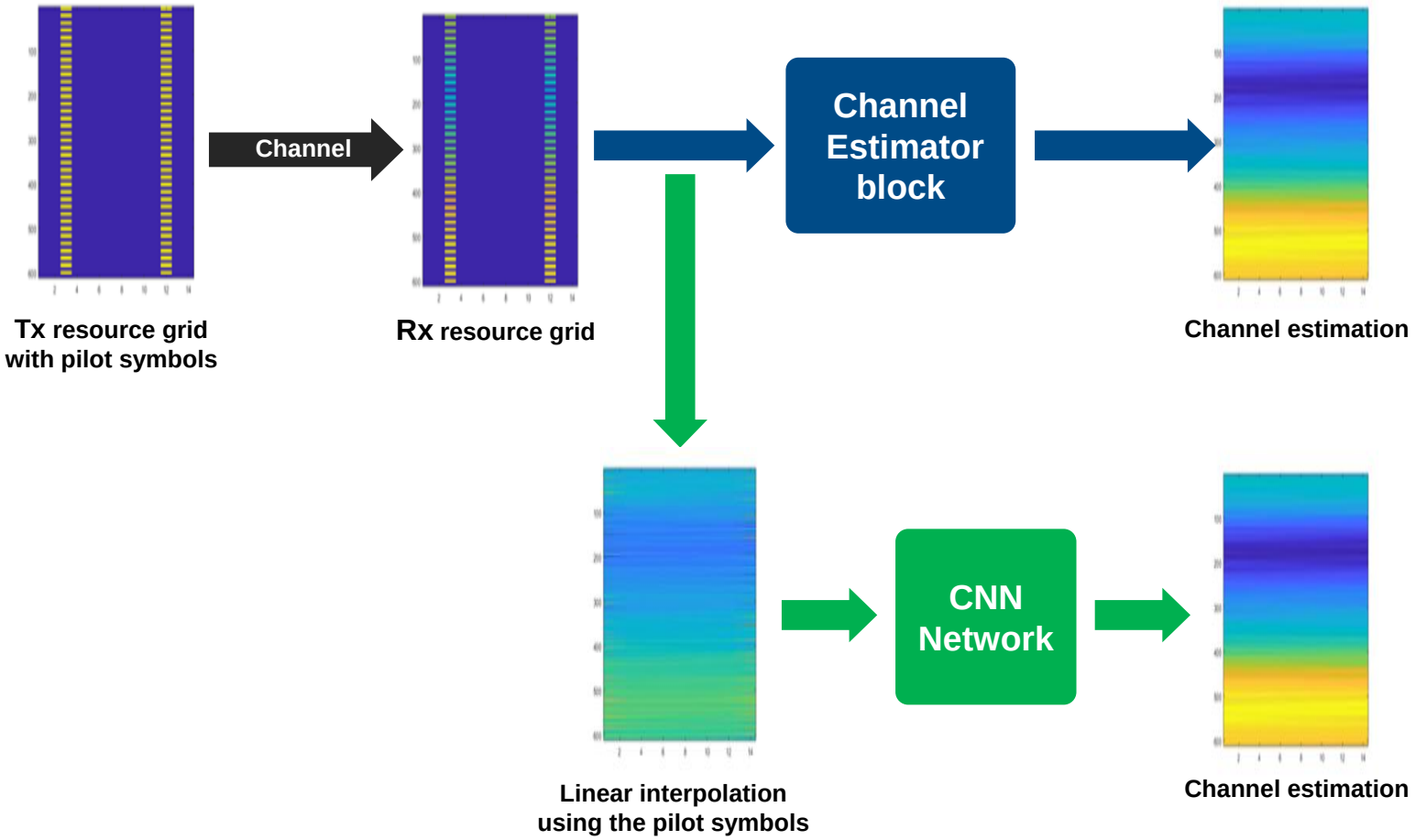
3 Simulation and Test

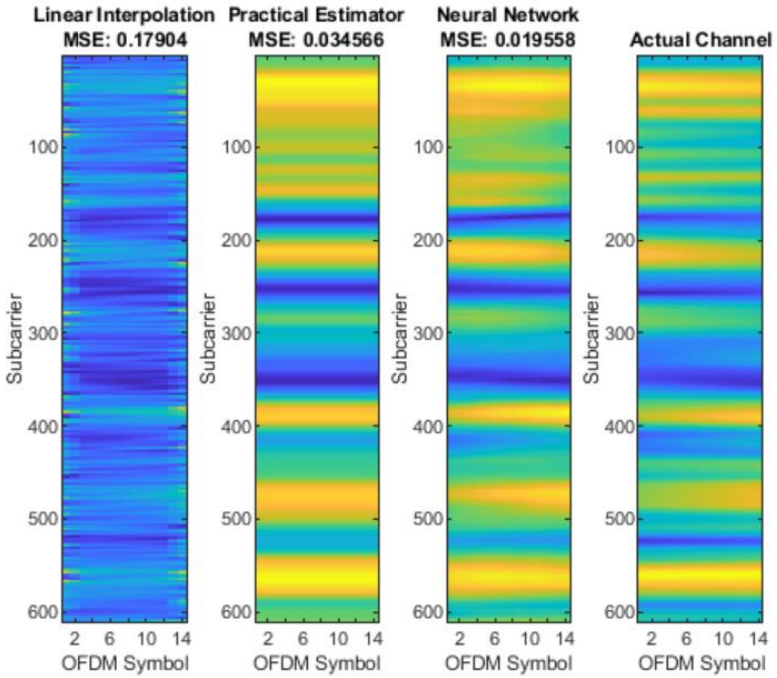
- Integration with complex systems
- System simulation
- System verification and validation

4 Deployment

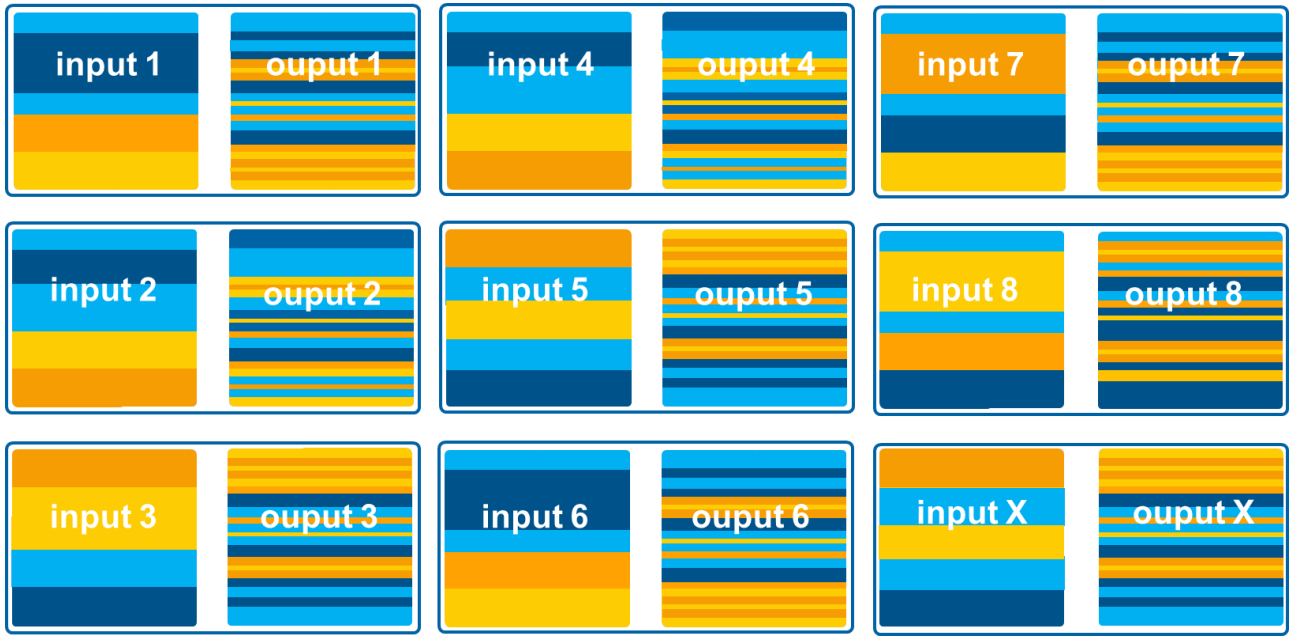
- Embedded devices
- Enterprise systems
- Edge, cloud, desktop

Example - 5G Channel Estimation



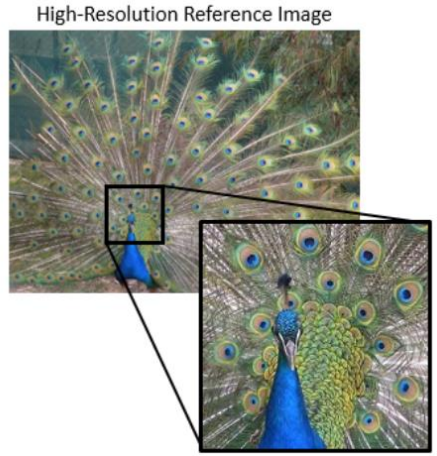


Example - 5G Channel Estimation



Estimate a high-resolution image

Image denosing



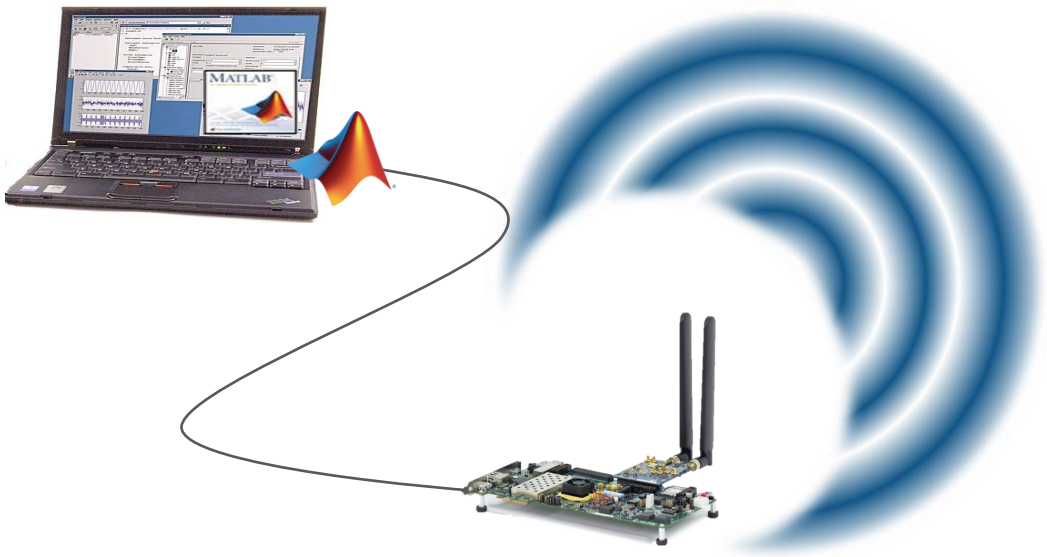
Example - Modulation Classification

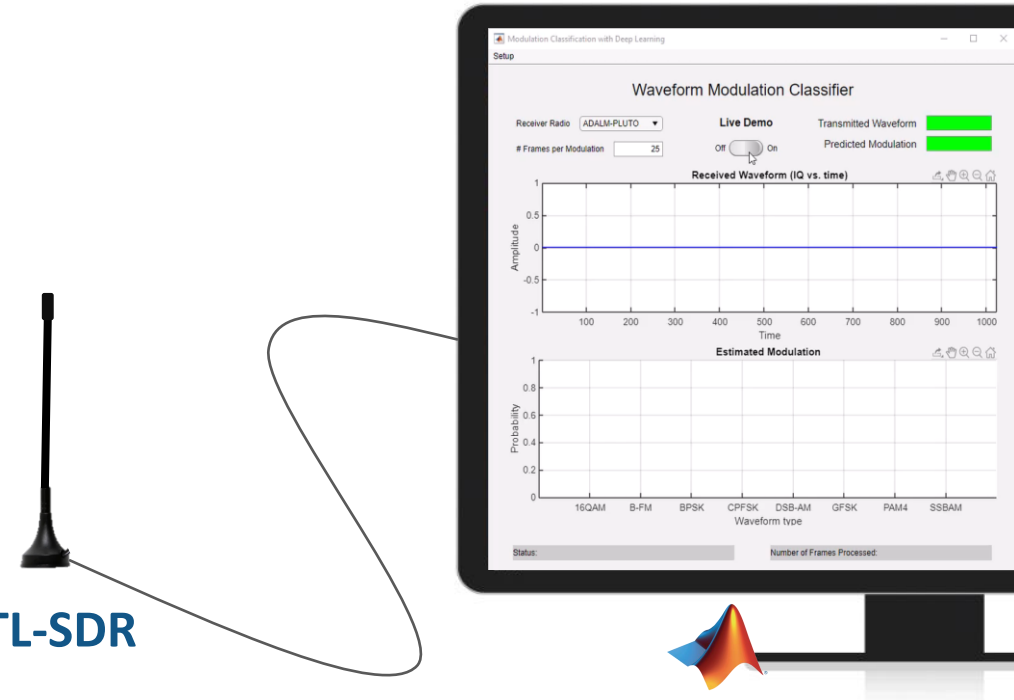
With MathWorks wireless communications tools

- **Synthetize data** (5G waveforms, Radar, Lidar, GPS…)
- Benefit from standard compliant **channel models**
- Build **link-level simulation** (PHY layers + RF front end)
- From Matlab to the real world… and back: **Connect to test equipment and SDR**

Workflow example:

- Synthetize data in MATLAB
- Build and train your AI network in MATLAB
- Collect over-the-air data using SDR and test/retrain your network with real-world data
- Deploy AI network to hardware





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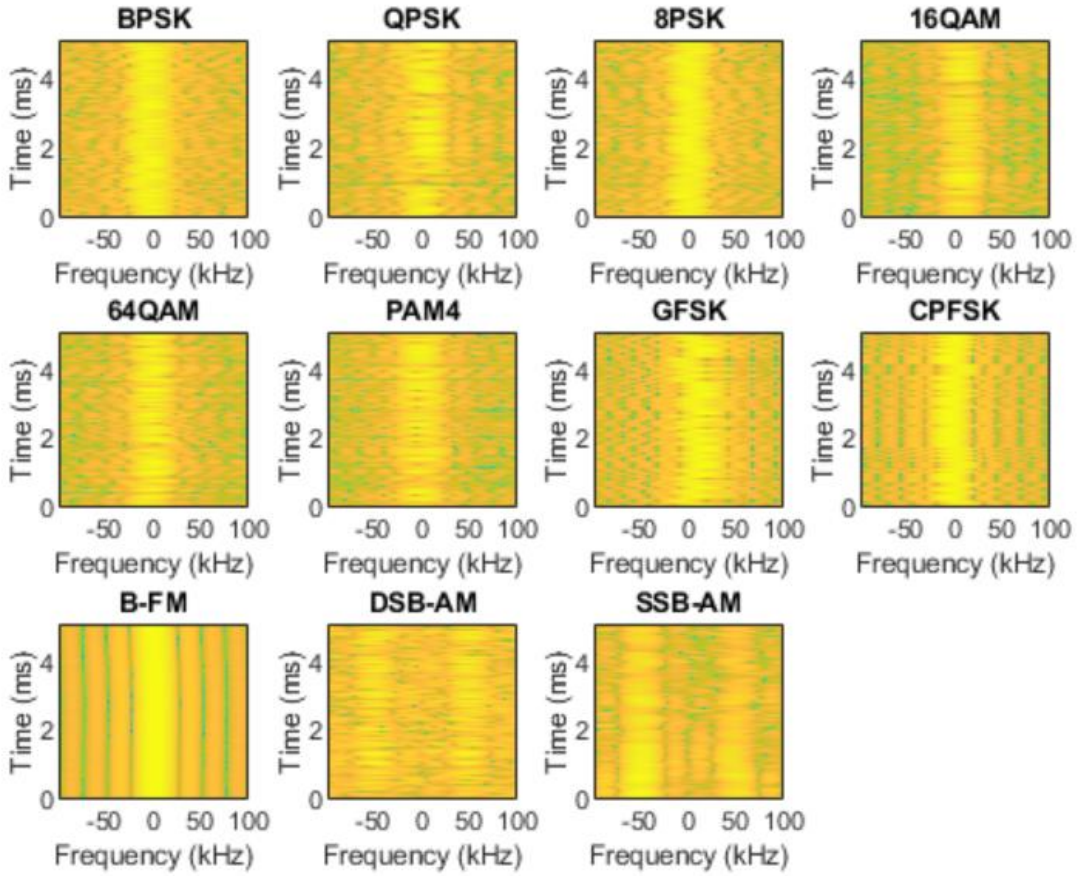
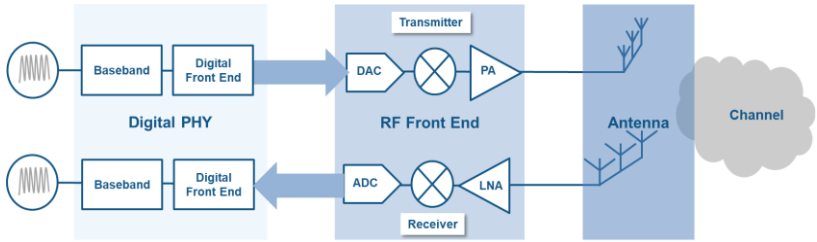
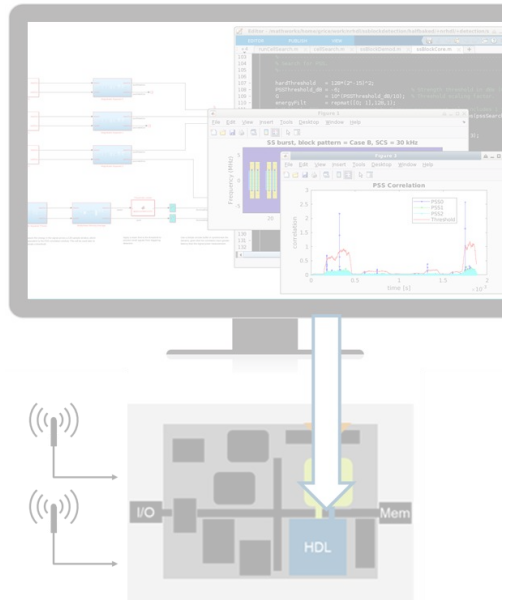


Image classification

3 Topics We Cover Today





Ubiquity

Model 5G/Wireless connectivity systems and standards

Complexity

Integrate and simulate multi-domain designs from antenna-to-bits

Efficiency

Iterate, optimize and verify design implementations

Integrated Multi-domain Modeling Complexity

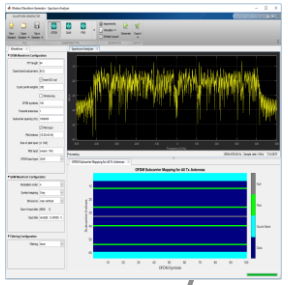
MATLAB® & SIMULINK®

Algorithms

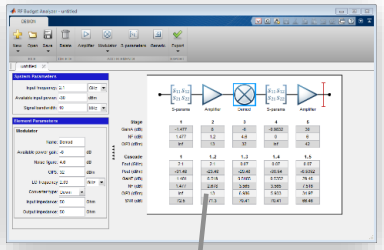
```
% Establish the number of component carriers.
numCC = length(NDLRB);

% Create transmission for each component carrier
enb = cell(1,numCC);
for i = 1:numCC
    enb{i} = lteRMCDL('R.5');
    enb{i}.NDLRB = NDLRB(i);
```

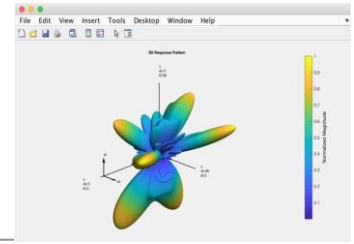
Waveforms



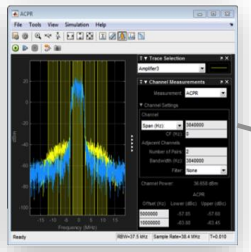
RF Transceivers



Antennas & Beamforming



Test Signals



Measurements

TRANSMITTER

Baseband

Digital Front End

Digital PHY

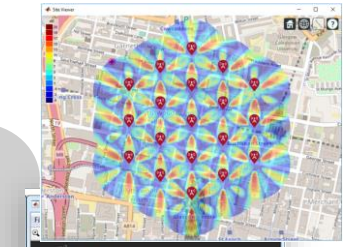
DAC

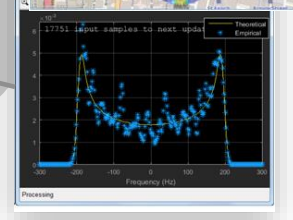
PA

RF Front End

Antenna

Channel





Propagation Models

Baseband

Digital Front End

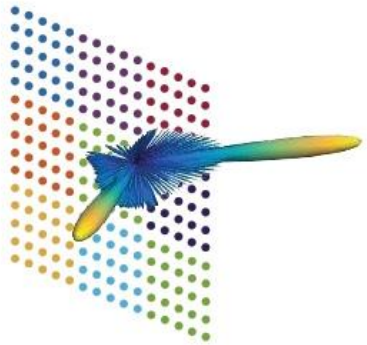
ADC

LNA

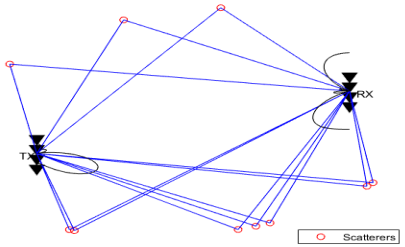
RECEIVER

Workflow for Antenna-to-Bit Multi-Domain Design

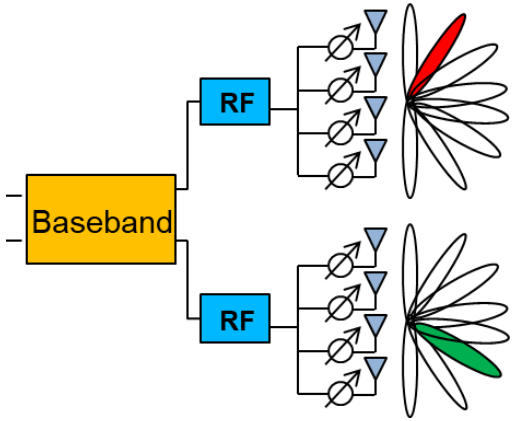
Design an array



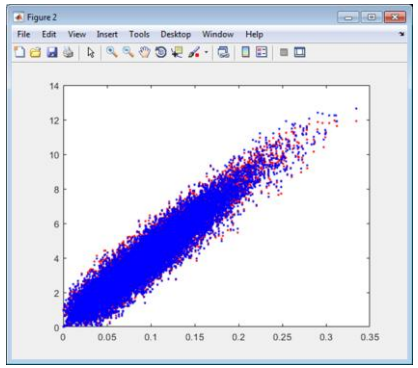
Add channel model



Hybrid beamforming

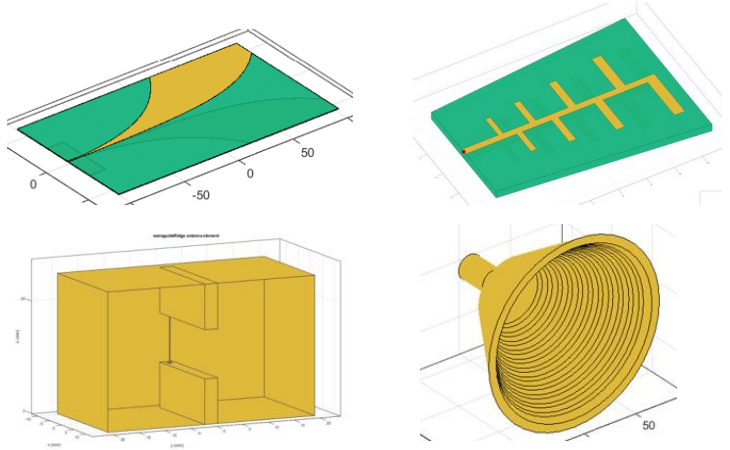


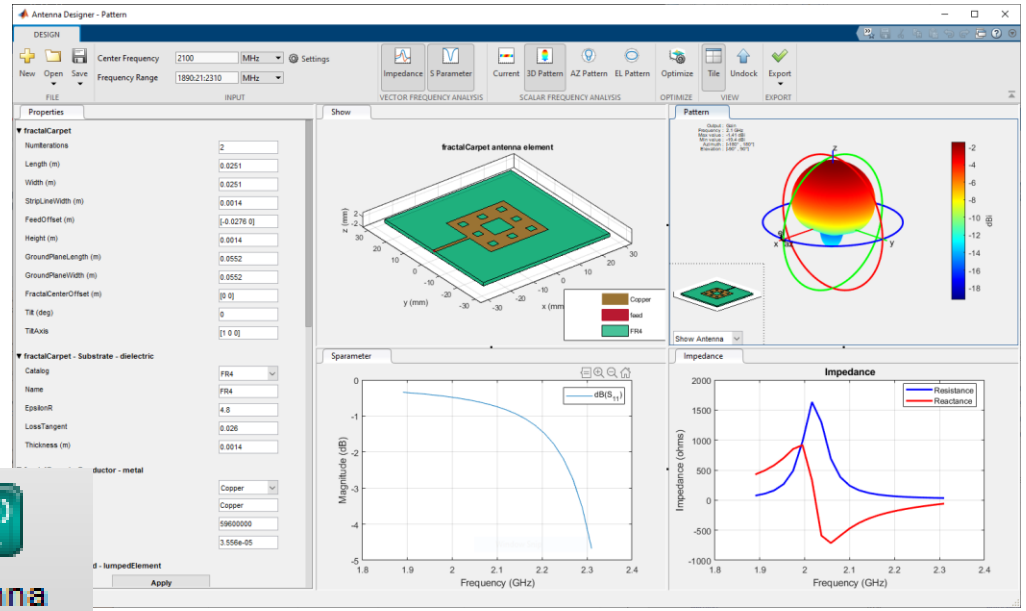
Specify RF front end



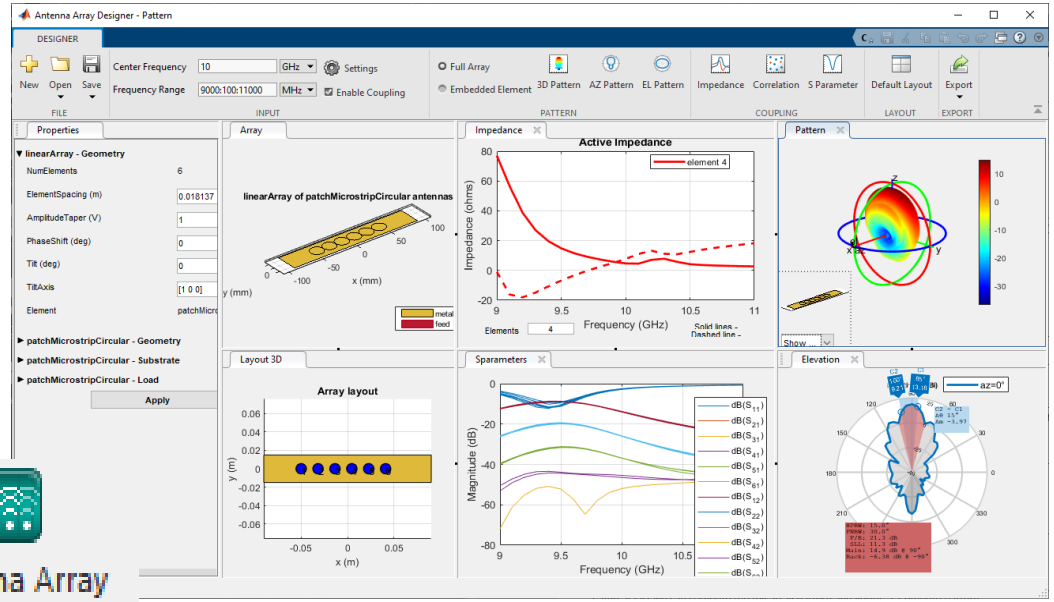
Design, Analyze and Visualize Antenna Elements and Arrays

- Get started with antenna and array catalog, and apps
- Perform full-wave EM simulation
- Improve the performance using surrogate optimization
- Design and fabricate PCBs with Gerber file generation
- Analyze the effects of installation on large platforms



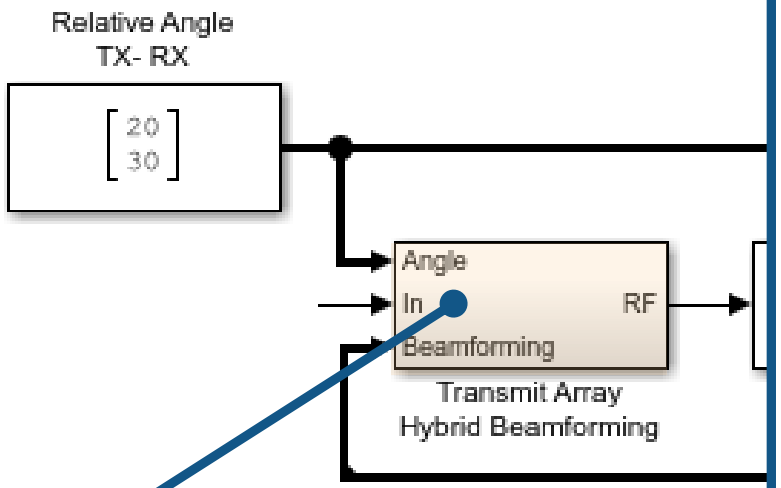


Antenna Designer

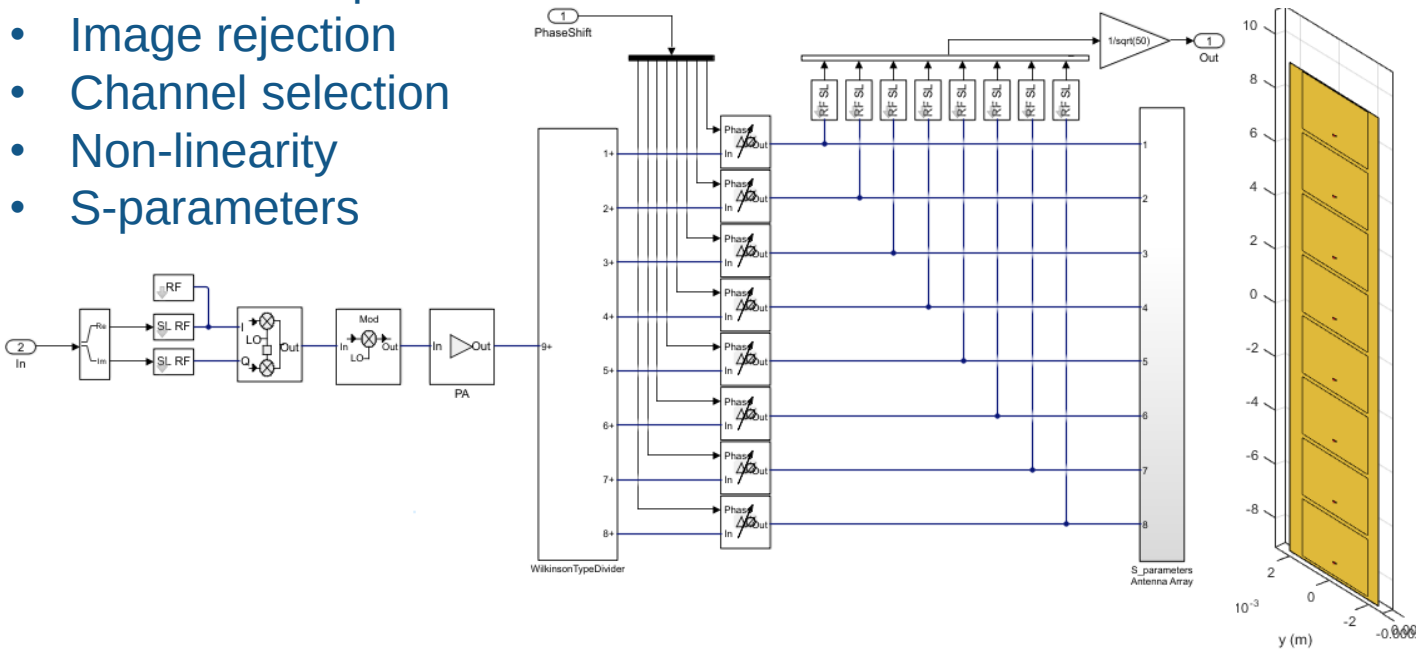


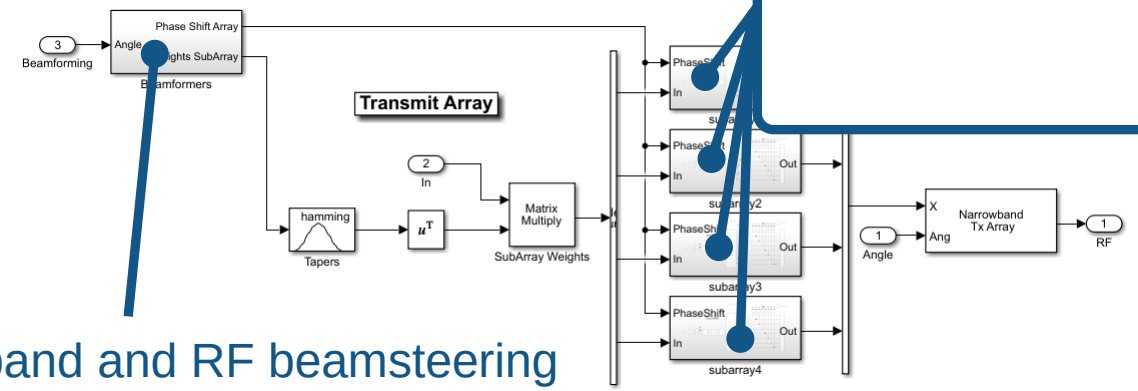
Antenna Array Designer

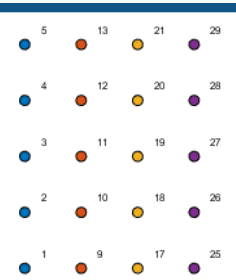
Architecture Exploration for Hybrid Beamforming



- Thermal and phase noise
- Image rejection
- Channel selection
- Non-linearity
- S-parameters







Baseband and RF beamsteering

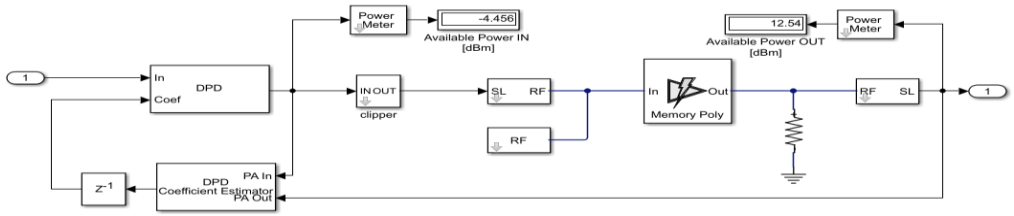
Power Amplifier Linearization: 5G Simulation Results

1. Generate 5G waveforms

```
rc = "NR-FR1-TM3.1"; % Reference channel(NR-TM or FRC)
% Select the NR waveform parameters
bw = "100MHz"; % Channel bandwidth
scs = "30kHz"; % Subcarrier spacing
dm = "FDD"; % Duplexing mode
```

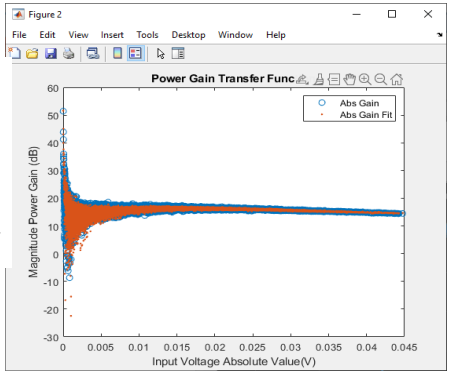
2. Model PA memory and non-linearity

```
rxWaveform_dpd = rf_dpd(txWaveform);
```

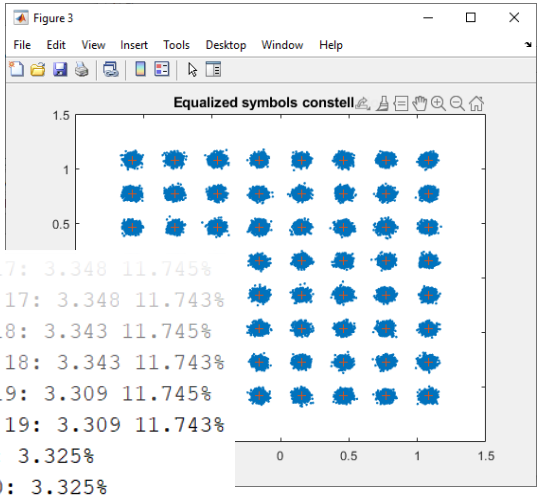


$$y_{\mathrm{MP}}(n) = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} a_{km} x(n-m)\,|x(n-m)|^{k}$$

Memory depth — Degree of non-linearity

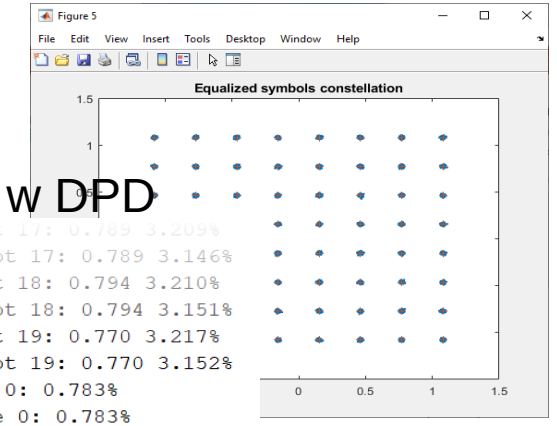


3. Measure EVM




```
Low edge RMS EVM, Peak EVM, slot 17: 3.348 11.745%
High edge RMS EVM, Peak EVM, slot 17: 3.348 11.743%
Low edge RMS EVM, Peak EVM, slot 18: 3.343 11.745%
High edge RMS EVM, Peak EVM, slot 18: 3.343 11.743%
Low edge RMS EVM, Peak EVM, slot 19: 3.309 11.745%
High edge RMS EVM, Peak EVM, slot 19: 3.309 11.743%
Averaged low edge RMS EVM,frame 0: 3.325%
Averaged high edge RMS EVM,frame 0: 3.325%
Averaged RMS 3GPP EVM frame 0: 3.325%
Averaged overall RMS EVM: 3.325%
Peak EVM = 12.1753%
```

4. Measure EVM w DPD



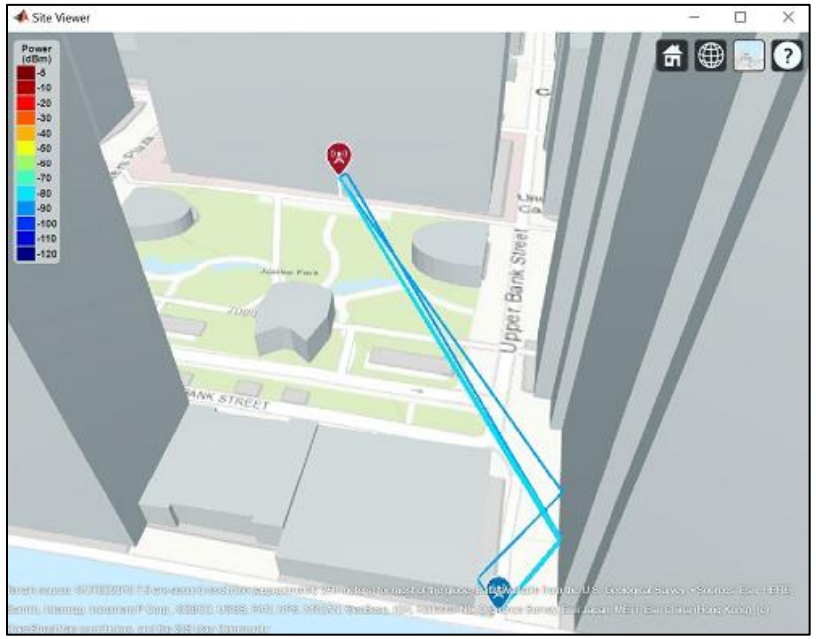

```
Low edge RMS EVM, Peak EVM, slot 17: 0.789 3.209%
High edge RMS EVM, Peak EVM, slot 17: 0.789 3.146%
Low edge RMS EVM, Peak EVM, slot 18: 0.794 3.210%
High edge RMS EVM, Peak EVM, slot 18: 0.794 3.151%
Low edge RMS EVM, Peak EVM, slot 19: 0.770 3.217%
High edge RMS EVM, Peak EVM, slot 19: 0.770 3.152%
Averaged low edge RMS EVM,frame 0: 0.783%
Averaged high edge RMS EVM,frame 0: 0.783%
Averaged RMS 3GPP EVM frame 0: 0.783%
Averaged overall RMS EVM: 0.783%
Peak EVM = 3.7347%
```

4. Create a RF system including DPD

Propagation Channels

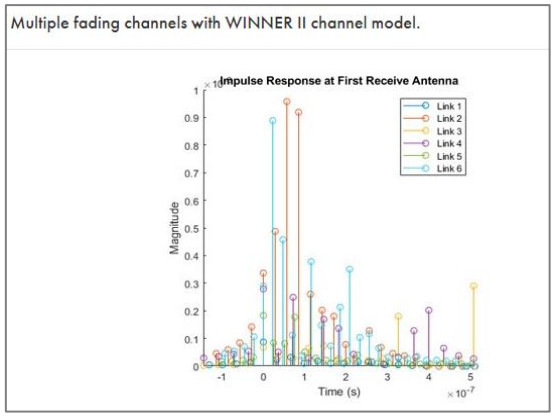
- Scattering MIMO channel
- Free space path loss

- Ray-tracing channel

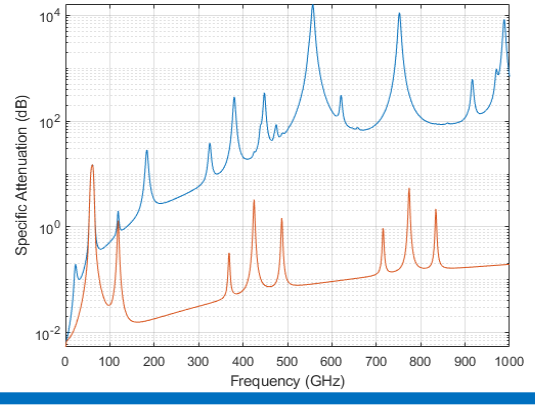


R2021a : Up to 10 reflections

- Winner II fading channel



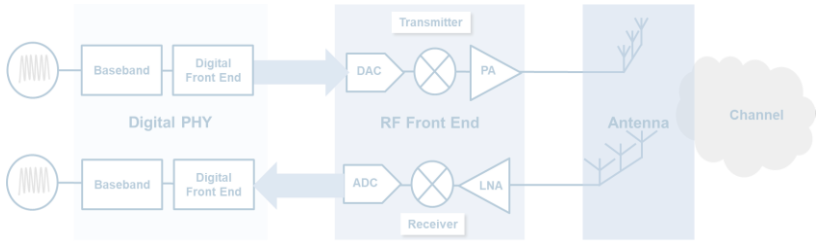
- Loss due to gases, fog, clouds

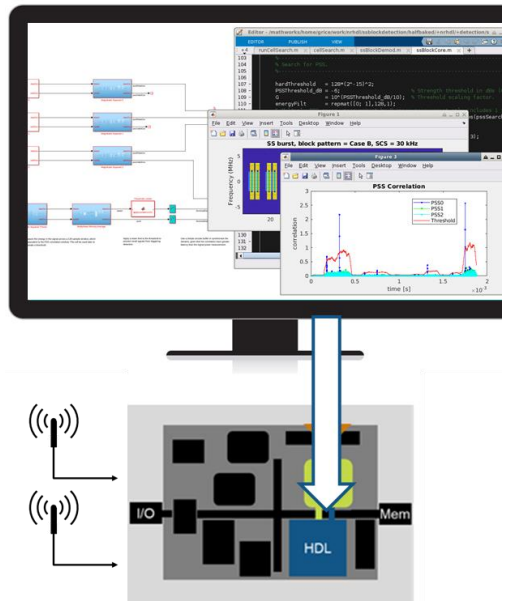


Array Beam Steering and RF Propagation

- Rectangular array of dipoles reflector-backed, operating at desire frequency
- (Electronically) Steer the array beam and assess coverage and links

3 Topics We Cover Today





Ubiquity

Model 5G/Wireless connectivity systems and standards

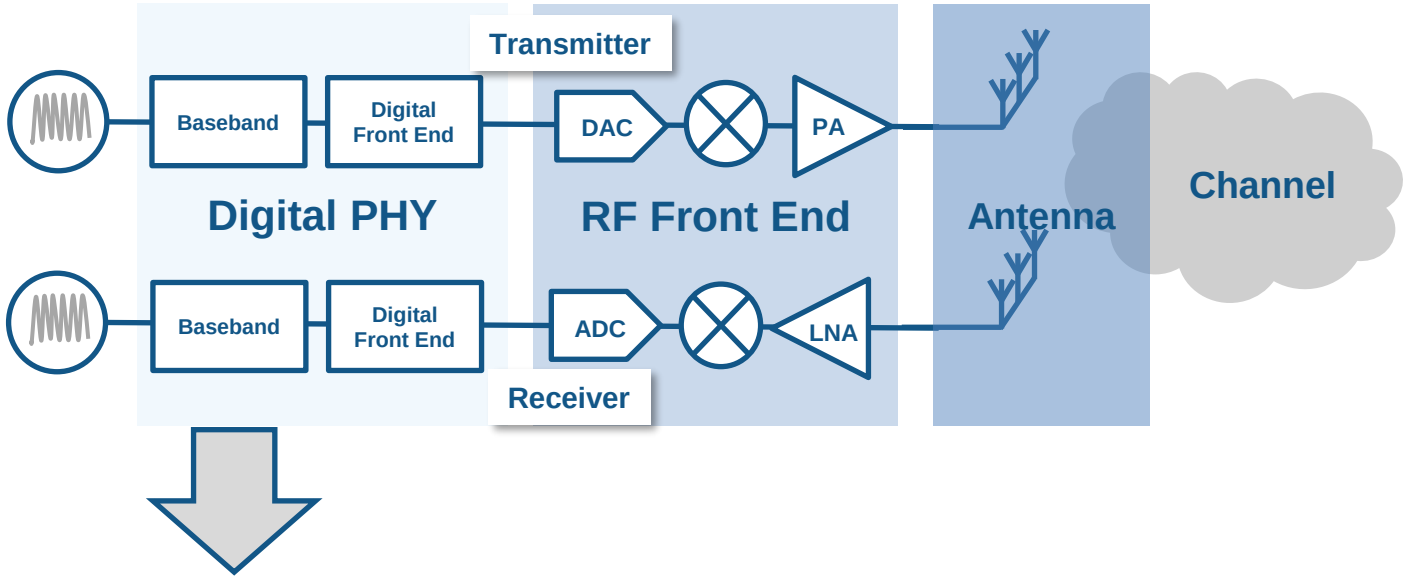
Complexity

Integrate and simulate multi-domain designs from antenna-to-bits

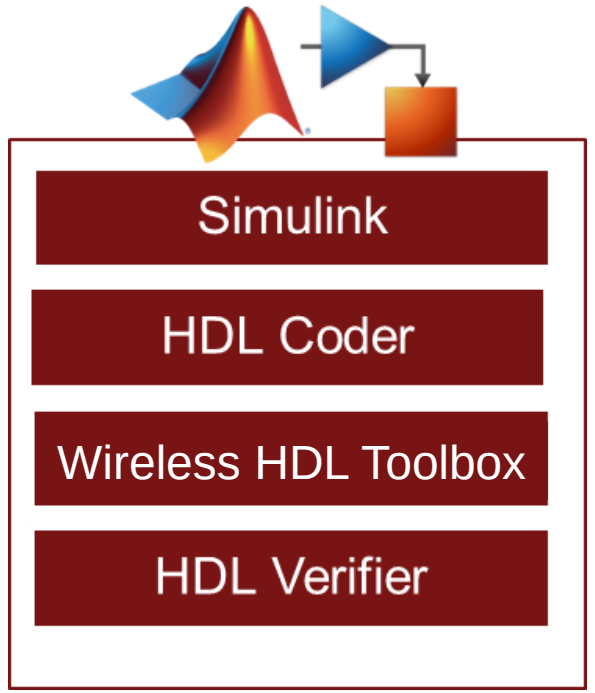
Efficiency

Iterate, optimize and verify design implementations

Hardware Deployment, Verification and Testing



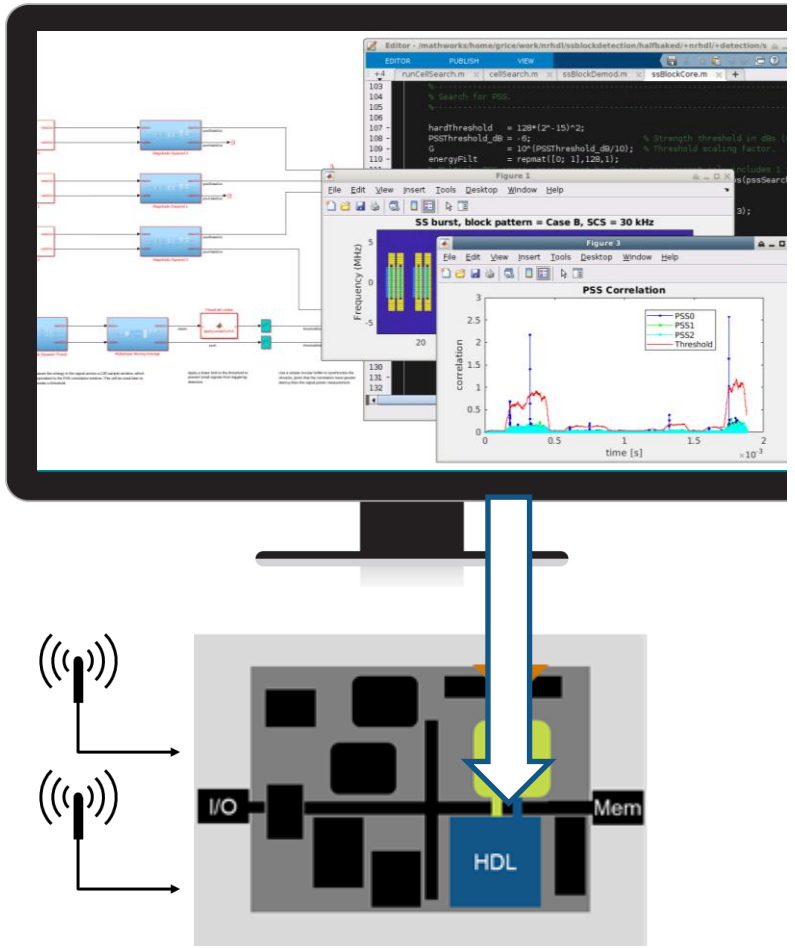
Prototyping
SDR, FPGA, SoC



Wireless HDL Toolbox

Mission statement:

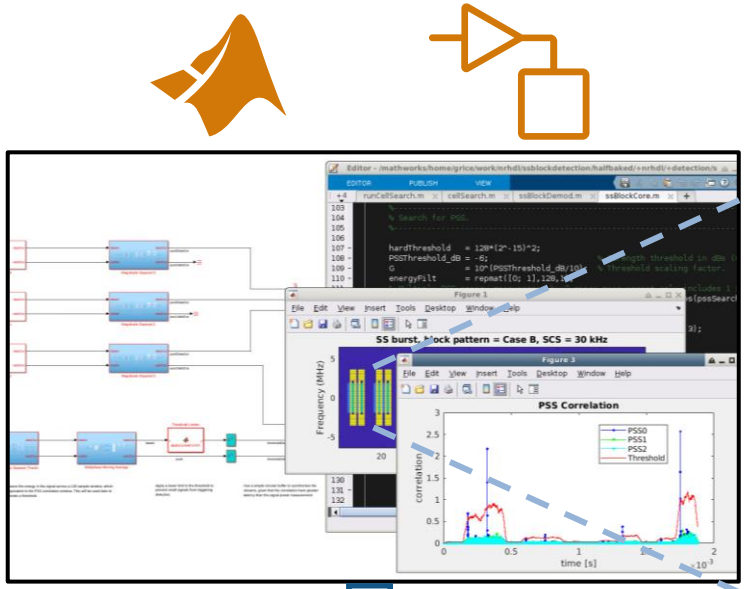
Provide high value reference applications and HDL IP blocks to accelerate the pace of design, implementation and verification of communication systems.

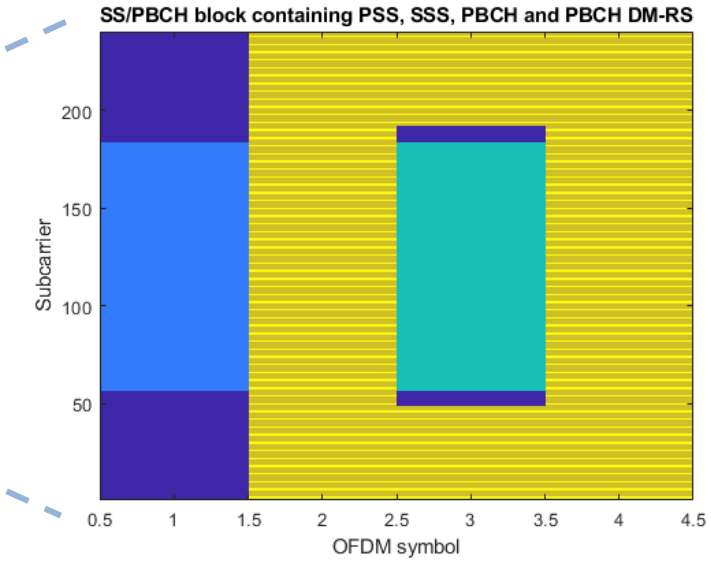


Applications:

1. 5G receiver reference applications
2. Custom OFDM reference applications

5G MIB Recovery Reference Application





- Decodes the Broadcast Channel (BCH), which contains the Master Information Block (MIB)
- Hardware-proven. Demo shipping in Comms Zynq HSP in R2020b

RF Pixels Verifies Millimeter Wave RF Electronics on a Zynq RFSoC Based Digital Baseband

Challenge

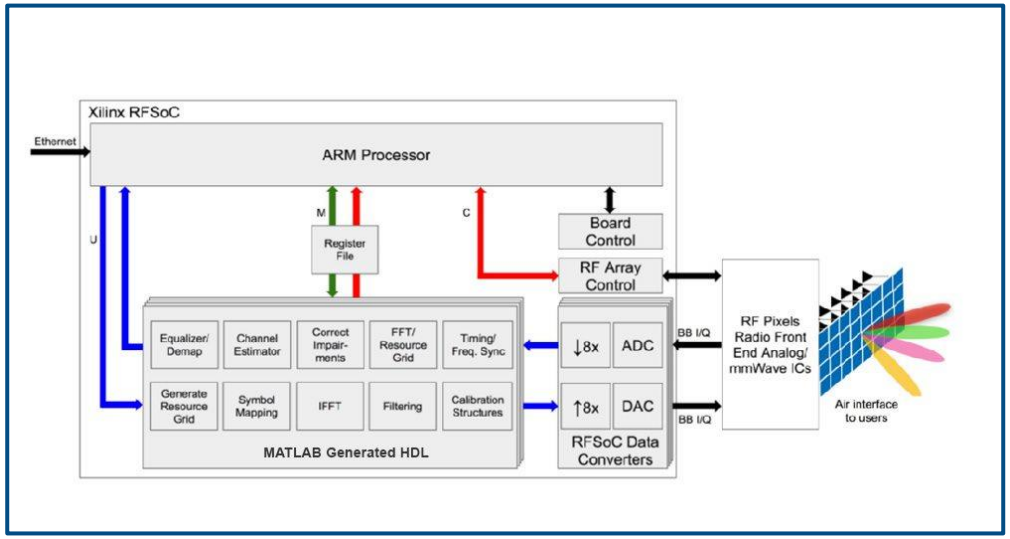
Test and demonstrate radio front-end designs that incorporate specialized RF electronics hardware and millimeter wave spectrum technology

Solution

Use MATLAB and Simulink to implement a digital baseband and deploy it to a Zynq RFSoC board for over-the-air testing

Results

- Engineering effort reduced by one year or more
- Digital baseband implementation completed by a single engineer
- Design iterations reduced from weeks to days



Digital baseband implemented in HDL, used to verify the RF Pixels radio front end.

"By adapting the LTE golden reference model from Wireless HDL Toolbox and deploying it to a Zynq UltraScale+ RFSoC board using HDL Coder, we saved us at least a year of engineering effort—and this approach enabled me to complete the implementation myself, without having to hire an additional digital engineer."

- Matthew Weiner, RF Pixels

[Link to technical article]

Over-the-air testing: Moving designs to the lab

Signal Generation and Transmission

LAN/USB/GPIB

RF Signal Generator

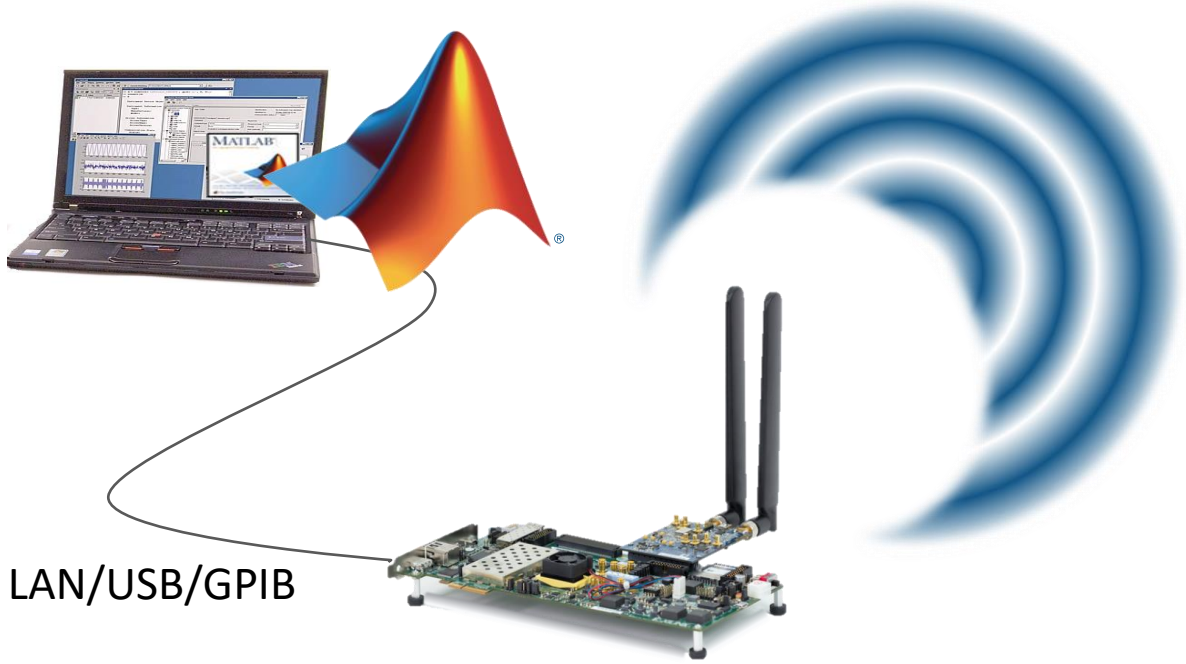
Signal Acquisition and Analysis

Spectrum Analyzer

LAN/USB/GPIB

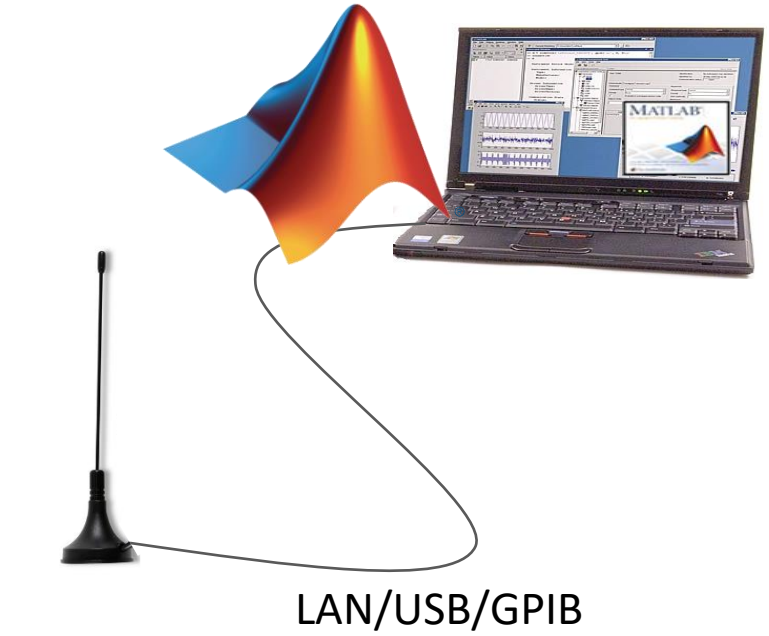
Over-the-air testing: Moving designs to the lab

Signal Generation and Transmission



Zynq SDR

Signal Acquisition and Analysis

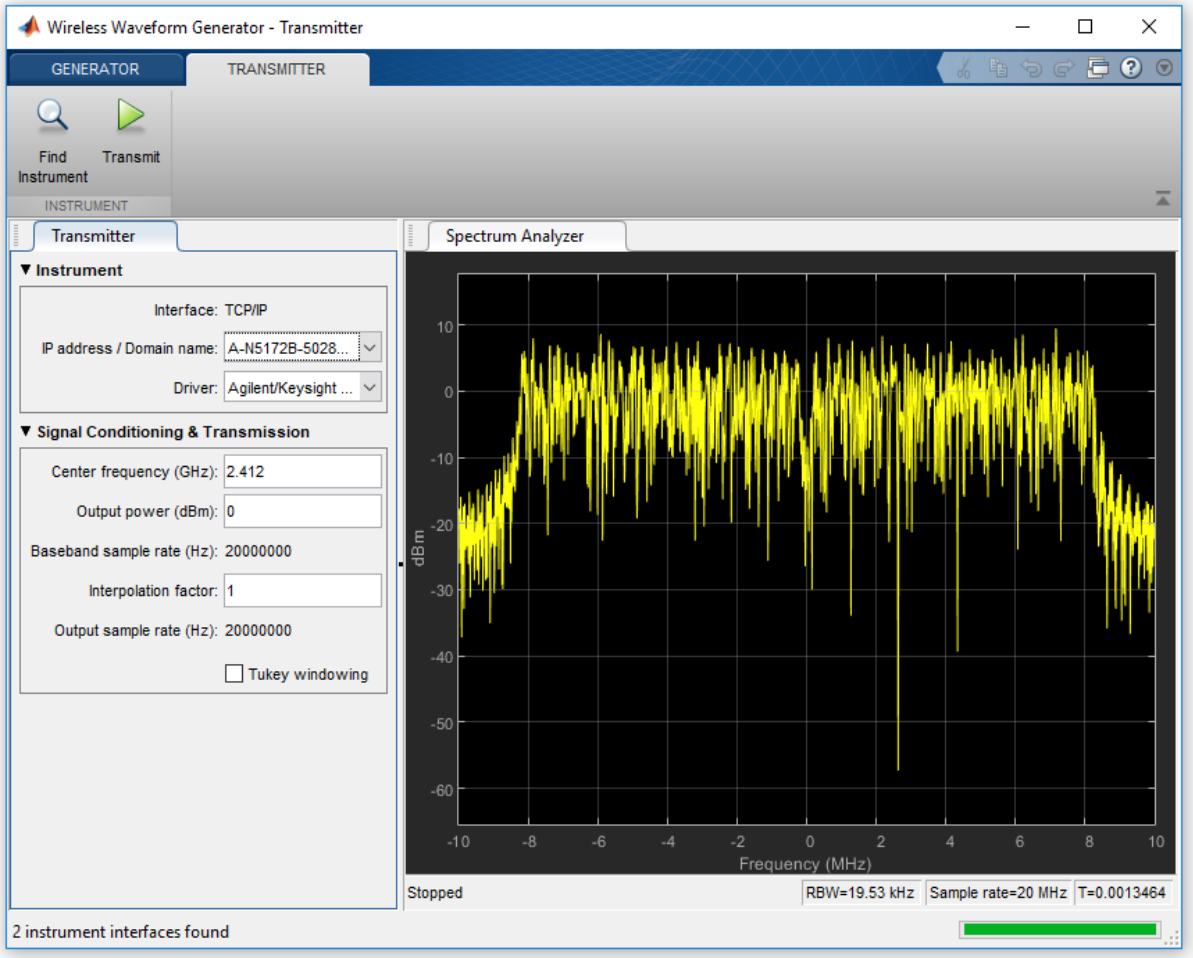


RTL-SDR

RF Instrument Connectivity in Wireless Waveform Generator App

Transmit wireless waveforms with RF instruments (e.g., Keysight/ Agilent, Rohde & Schwarz)

- Need Instrument Control Toolbox
- Automatically discover available instruments
- Transmit/stop infinitely looped waveforms
- Configurable transmission frequency, output power and (integer) interpolation factor



MATLAB & Simulink Tools for Wireless Design

Physical Layer Design

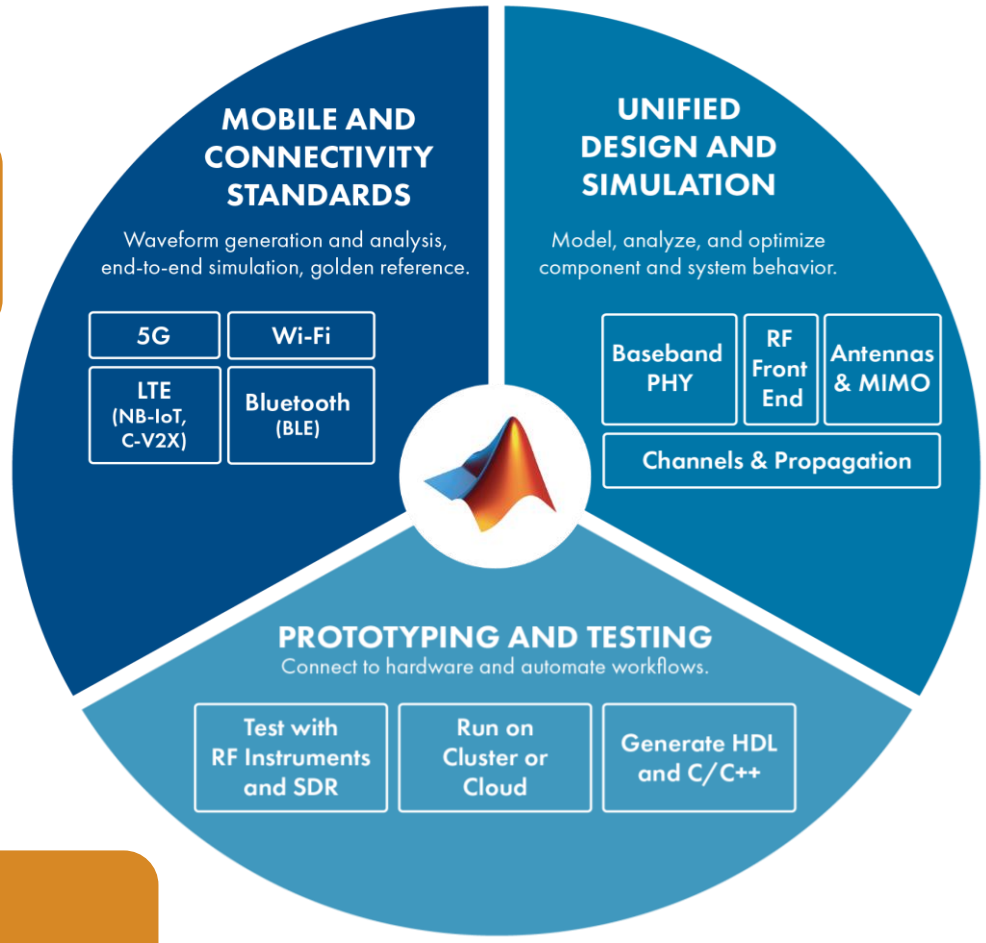
Ubiquity

Ubiquitous Connectivity

System Engineering

Complexity

Design Complexity



Deployment & Verification

Efficiency

Efficient deployment & testing

How to Learn More

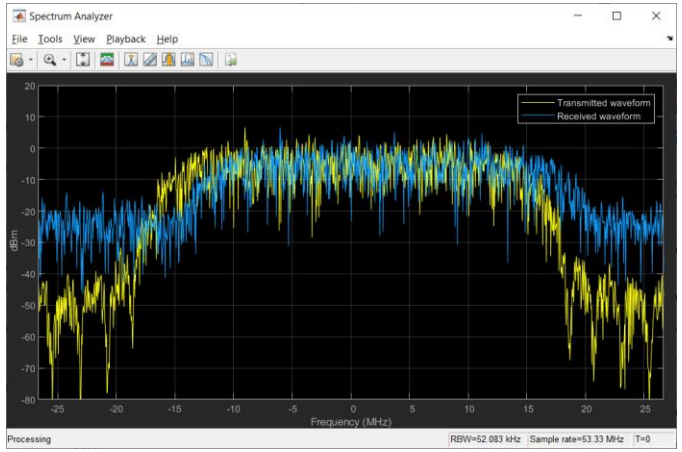
Wireless Communications product pages

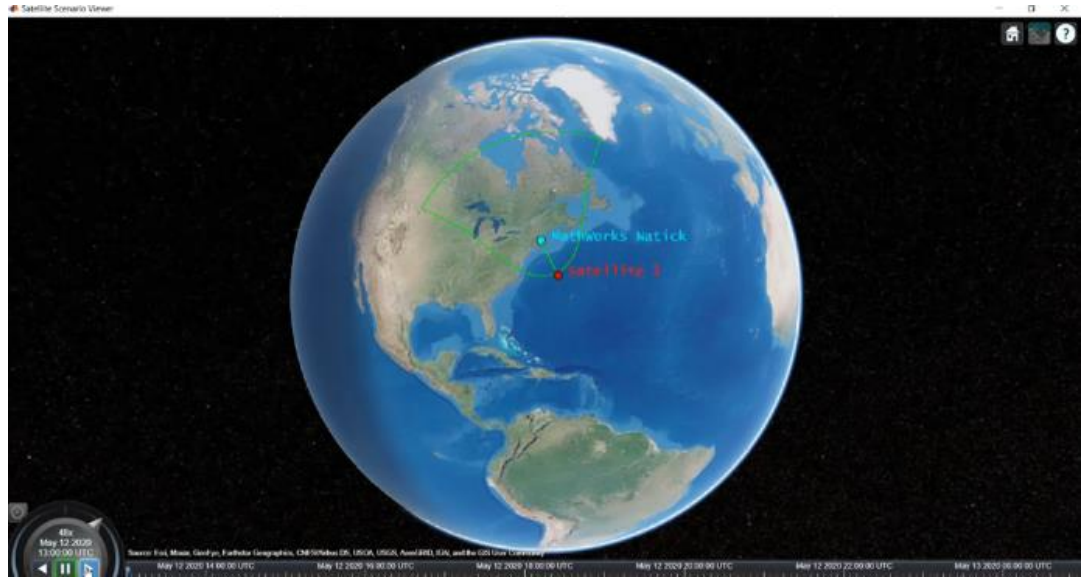
mathworks.com/products/

- **5G**
- **LTE**
- **WLAN**
- **Satellite-communications**

Wireless communications solution page

https://www.mathworks.com/solutions/wireless-communications.html





MATLAB EXPO 2021

Thank you