MATLAB EXPO 2021

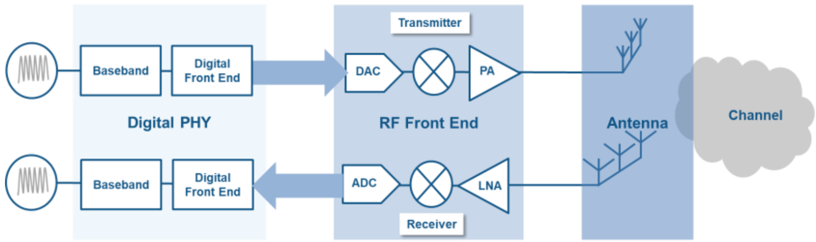
5G and Wireless Design

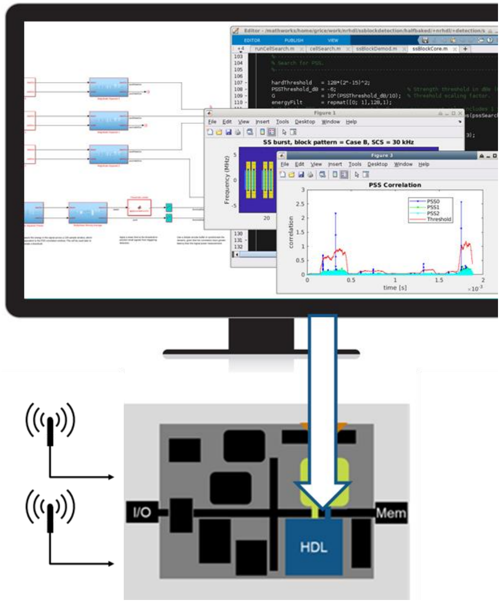
Houman Zarrinkoub

John Wang

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**

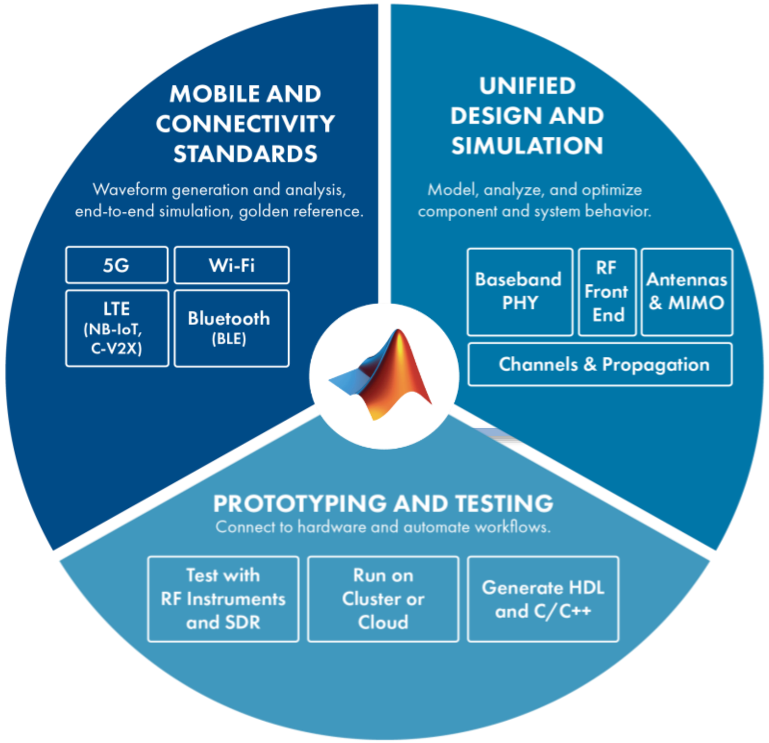
Common Challenges of Wireless Design

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

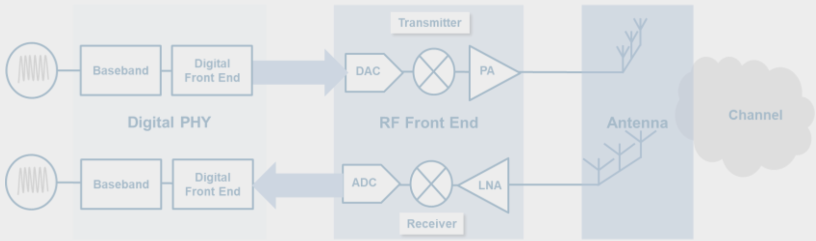
Design Complexity

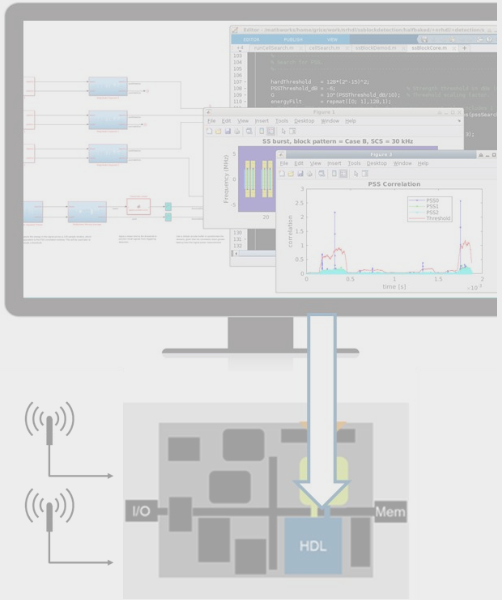
Deployment & Verification

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

Efficiency

Efficient deployment & testing





Ubiquity

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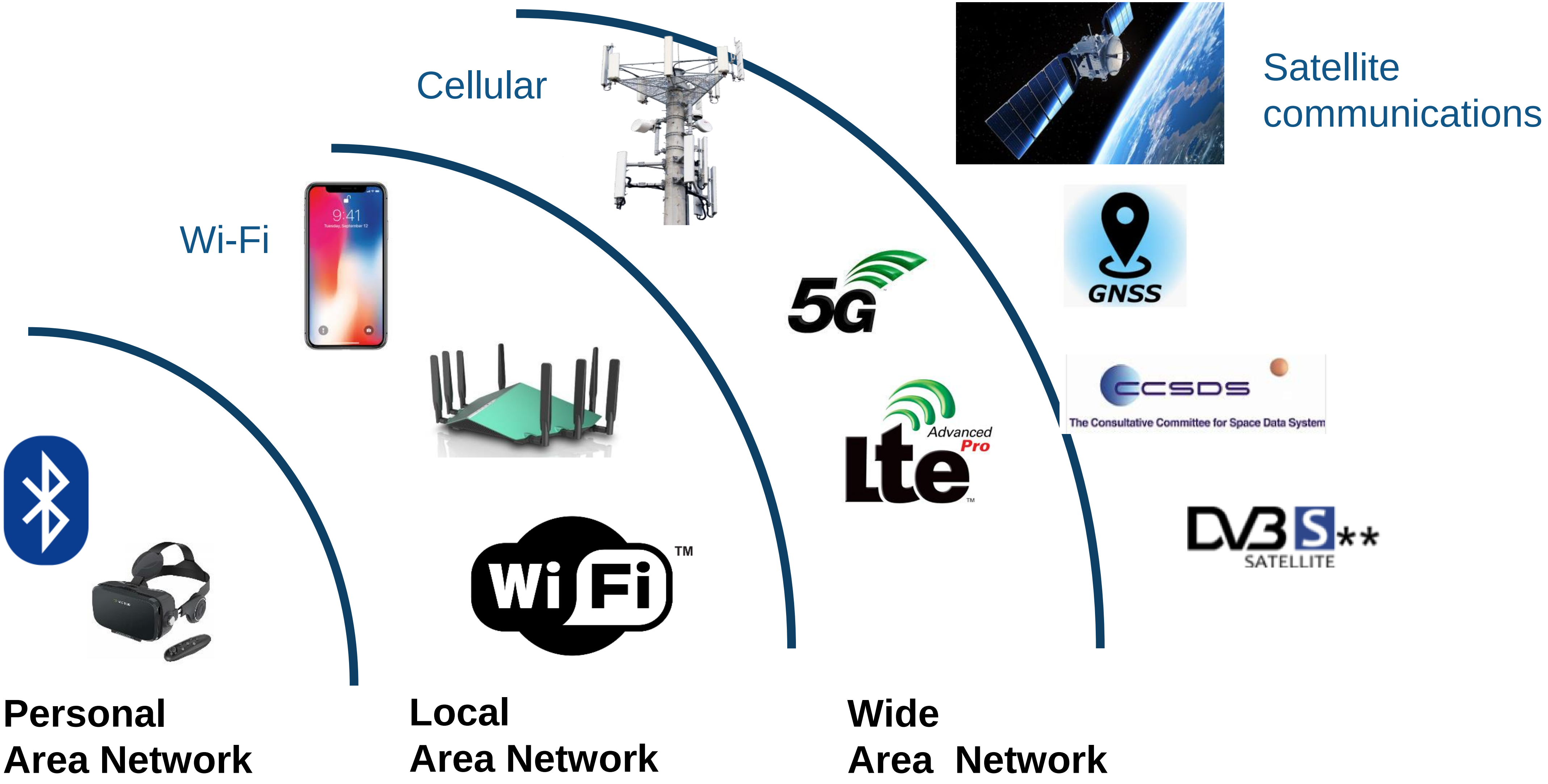
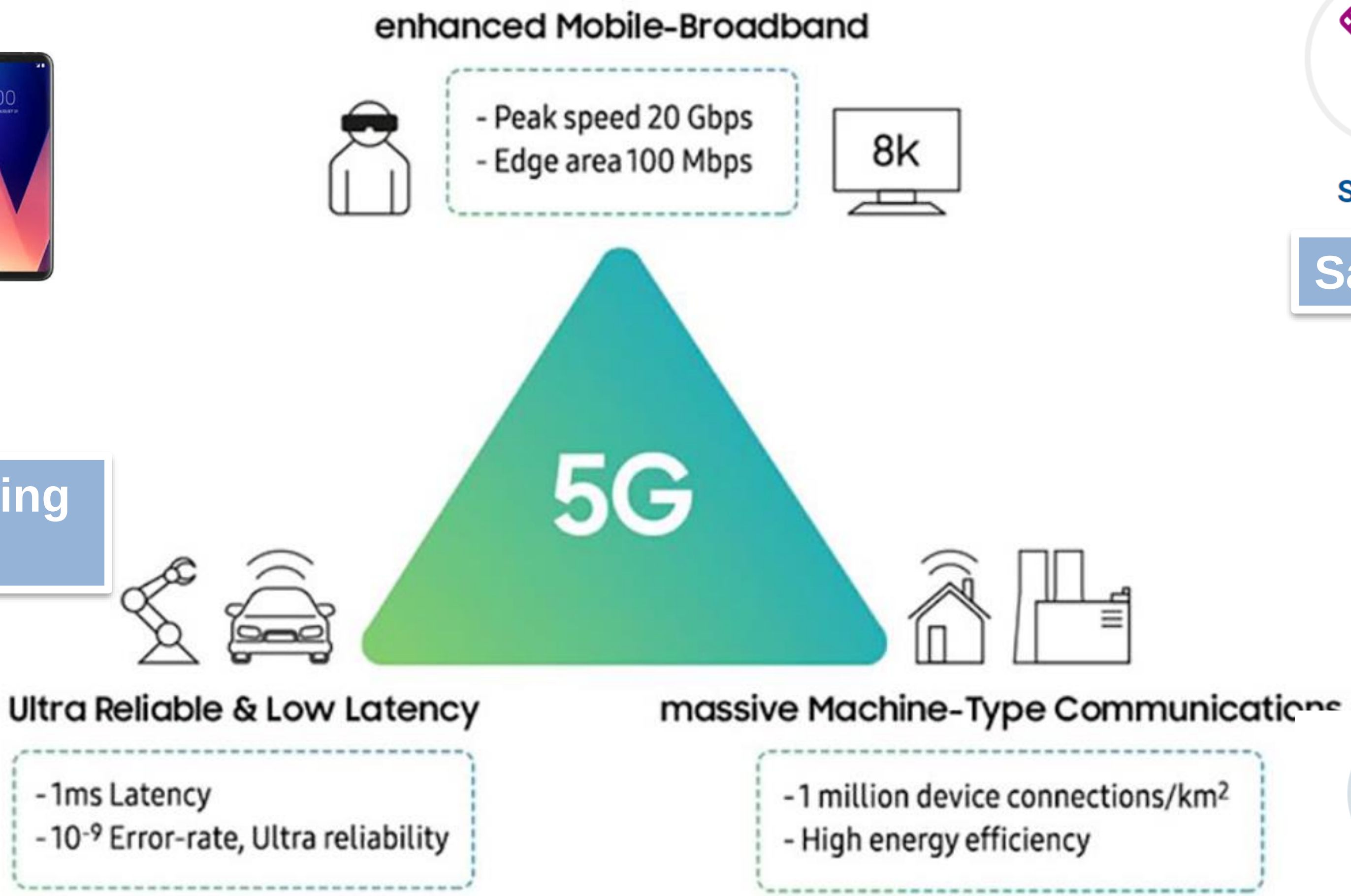
Ubiquitous connectivity – technologies & standards



5G: A Megatrend & Driving Force

5G Cellular

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



Satellite

UAVs

SatCom and UAVs

Connected Car

Autonomous Driving / V2X

Internet of Things

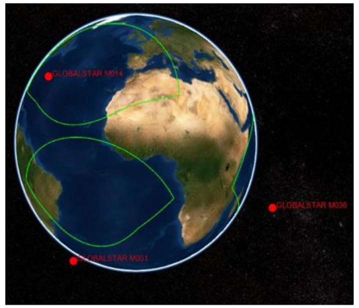
Artificial Intelligence

Smart Factory

Trend: Emerging Satellite communications

Driven by development of high-speed internet connectivity

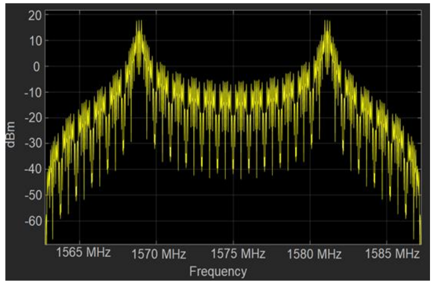
Orbit Propagation and Visualization; Access and Link Analysis

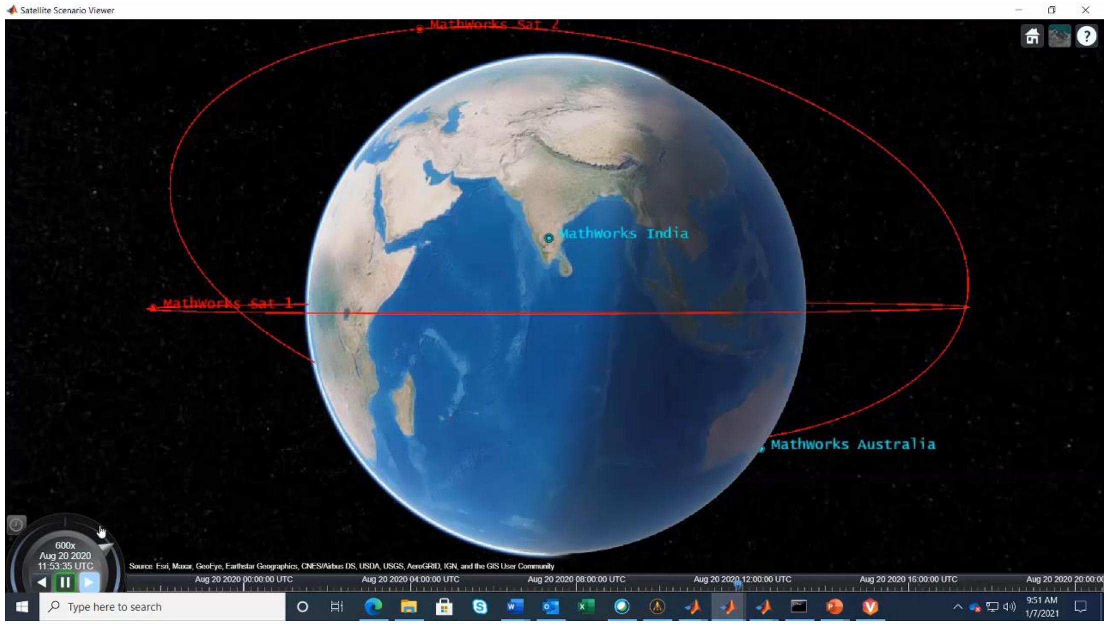


Link Budget Analysis

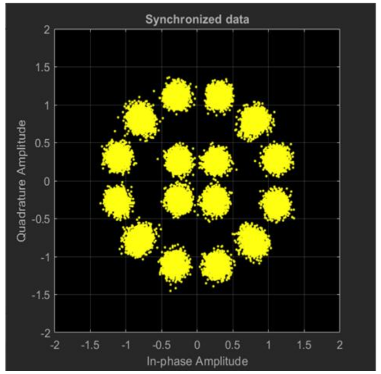
Name	L1
Distance (km)	3.6595e+03
Elevation (deg)	20.2176
Tx EIRP (dB)	51
Polarization loss (dB)	3.0103
FSPL (dB)	186.6387
Received isotropic power (dBW)	-141.6490
C/No (dB-Hz)	87.9502
C/N (dB)	20.1687
Received Eb/No (dB)	17.9502
Margin (dB)	5.9502

Waveform Generation





End-to-End Simulations



Trend: Wi-Fi evolution – Driven by IoT

More devices & dense environments

802.11ac → 802.11ax Wi-Fi 6

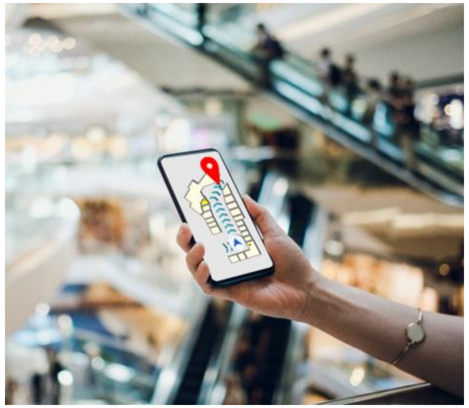
100s of Mbps, high efficiency with lots of devices

Industry 4.0

802.11ax → 802.11be Wi-Fi 7

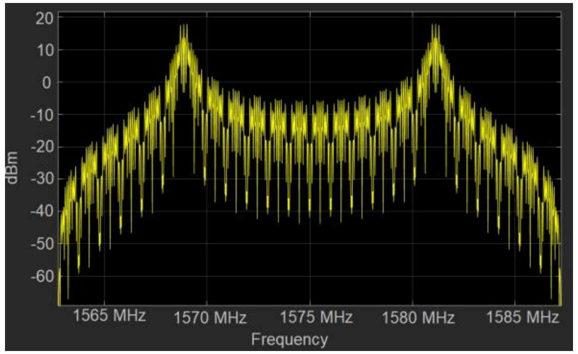
Gbps, reduced latency and jitter

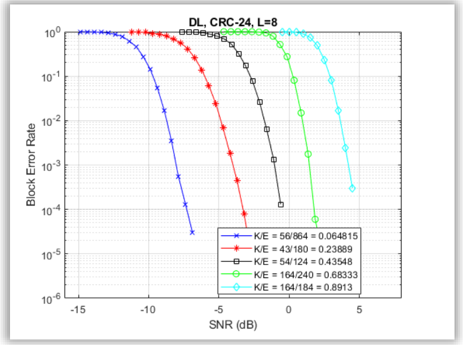
802.11az - Positioning

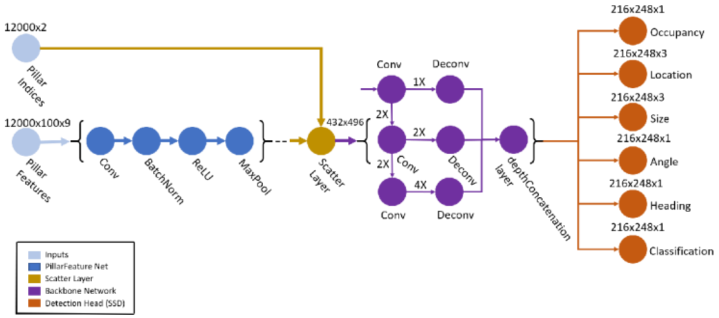


Direction Finding & Localization

Common use-cases of standard-based connectivity design





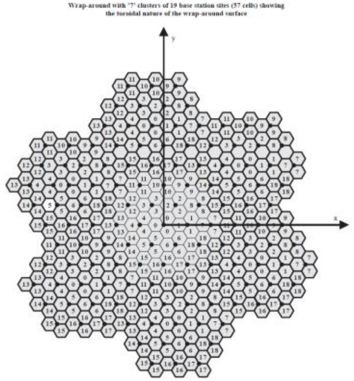


Waveform Generation

Link-level Simulation

AI Workflow

Pre-trained models, training, evaluation, validation

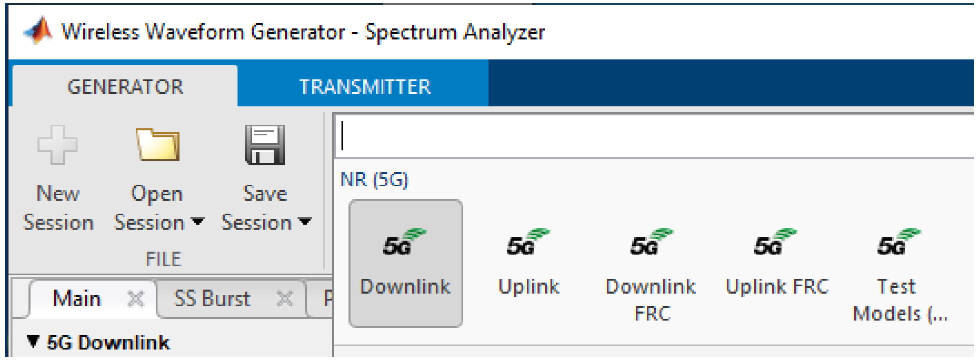


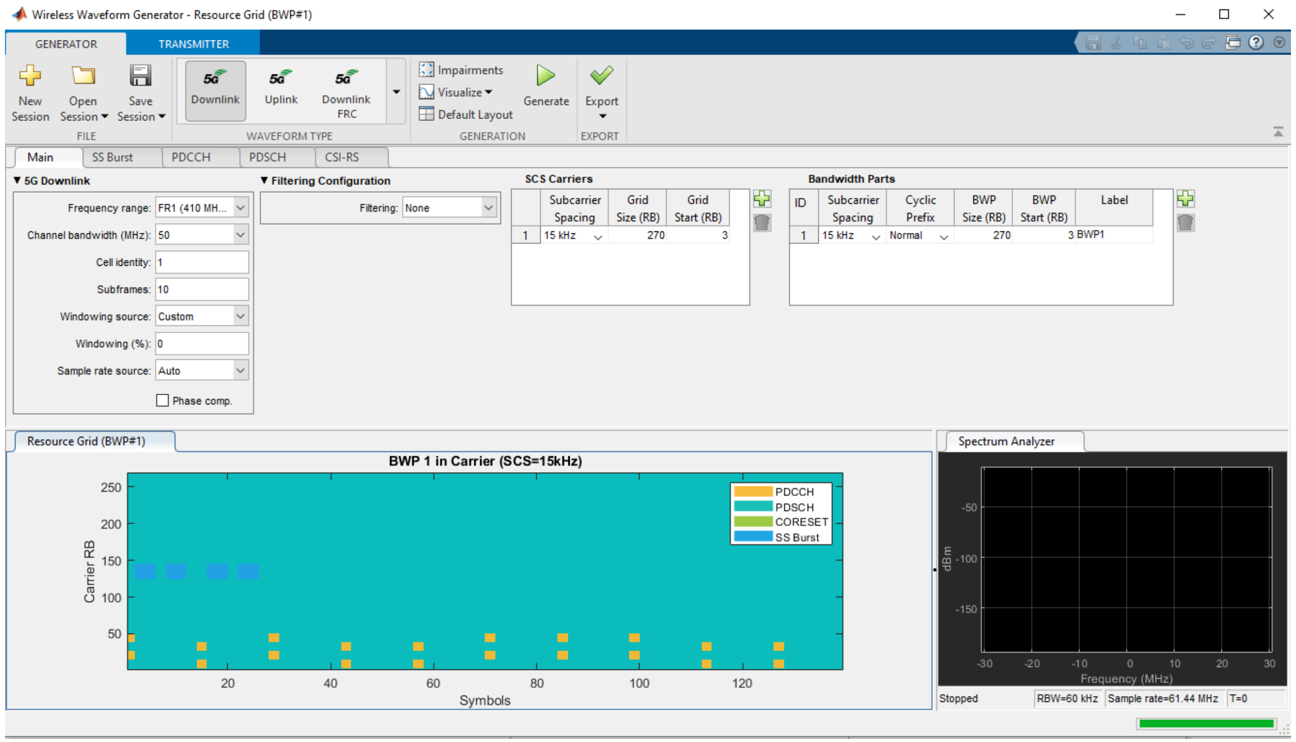
Interference & Coexistence

Network Simulation

Wireless Waveform Generator App

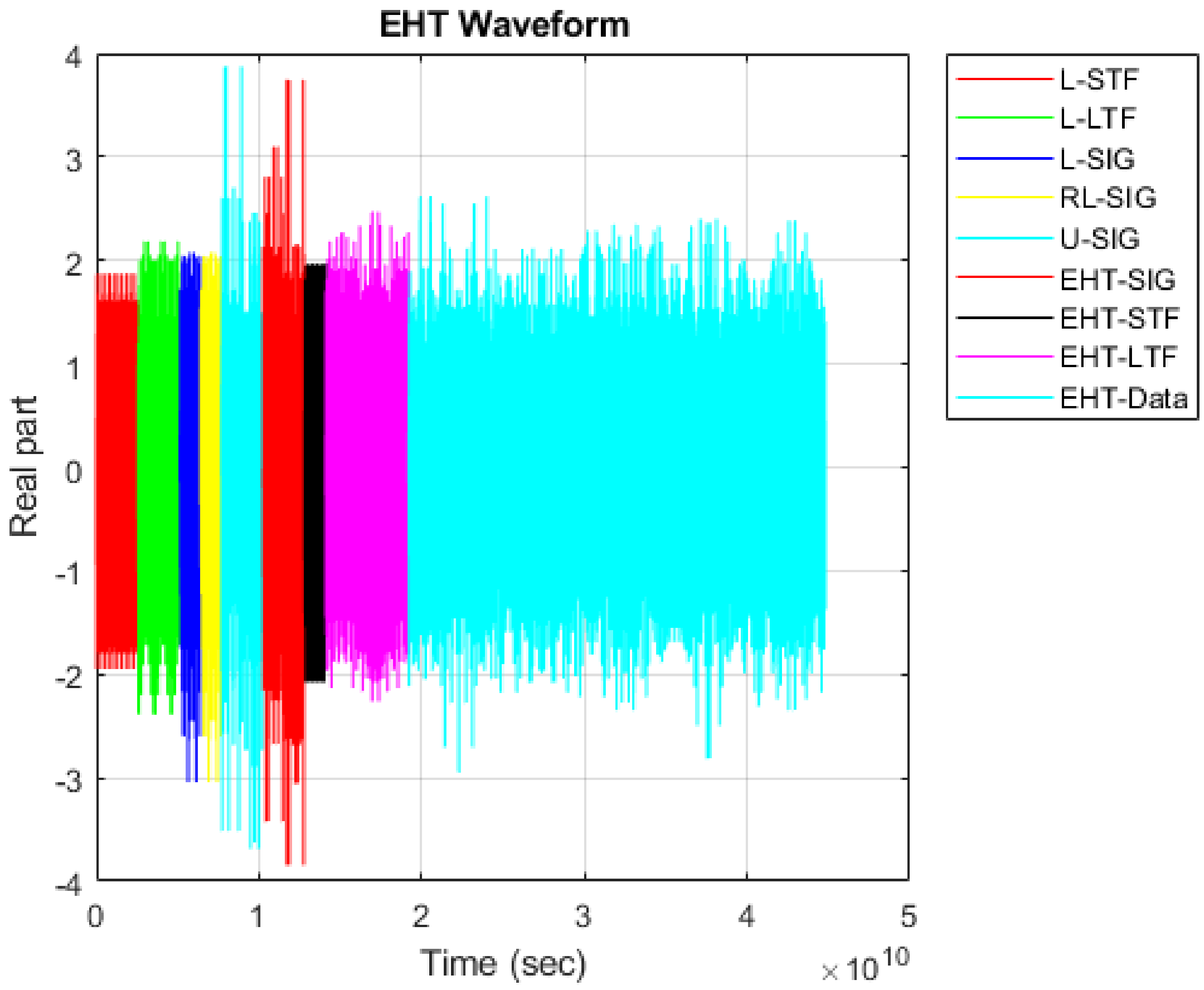
- Interactive waveform generation
- 5G NR off-the-shelf waveforms:
  - NR-TMs / FRCs
- Custom downlink & uplink waveforms
  - New in the App in R2021a



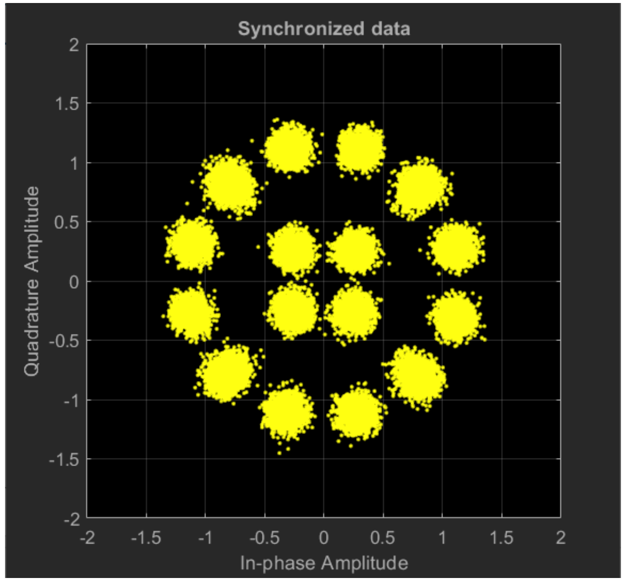


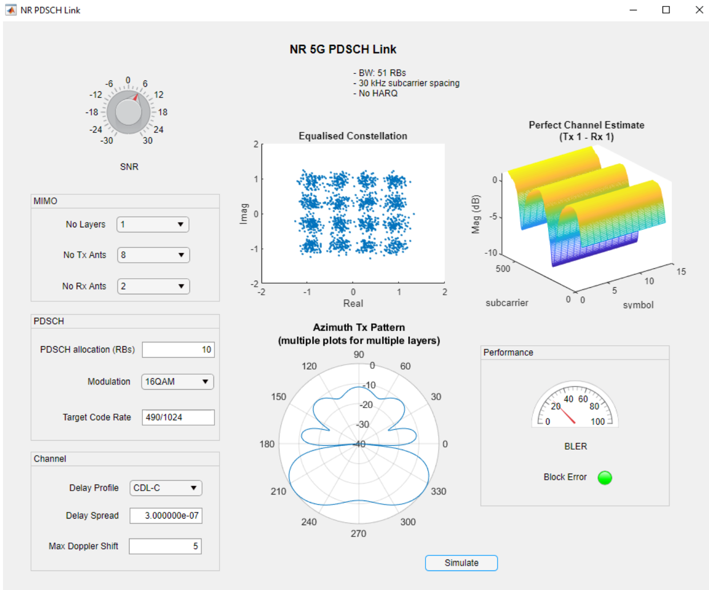
IEEE 802.11be Waveform Generation

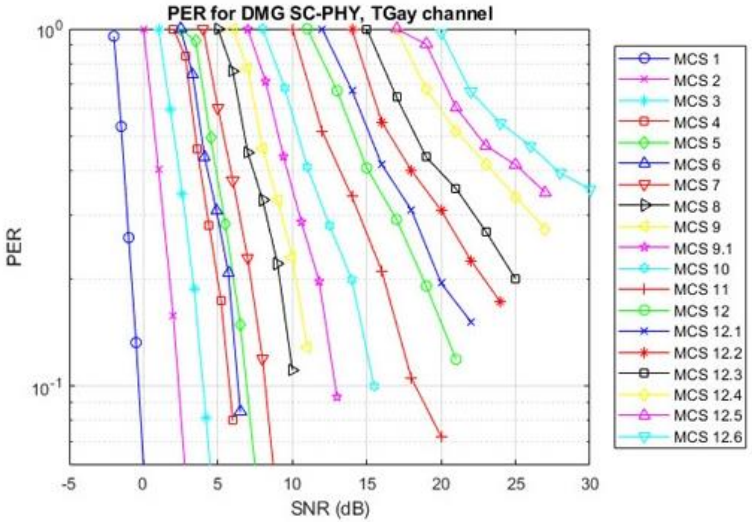
R2021a



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

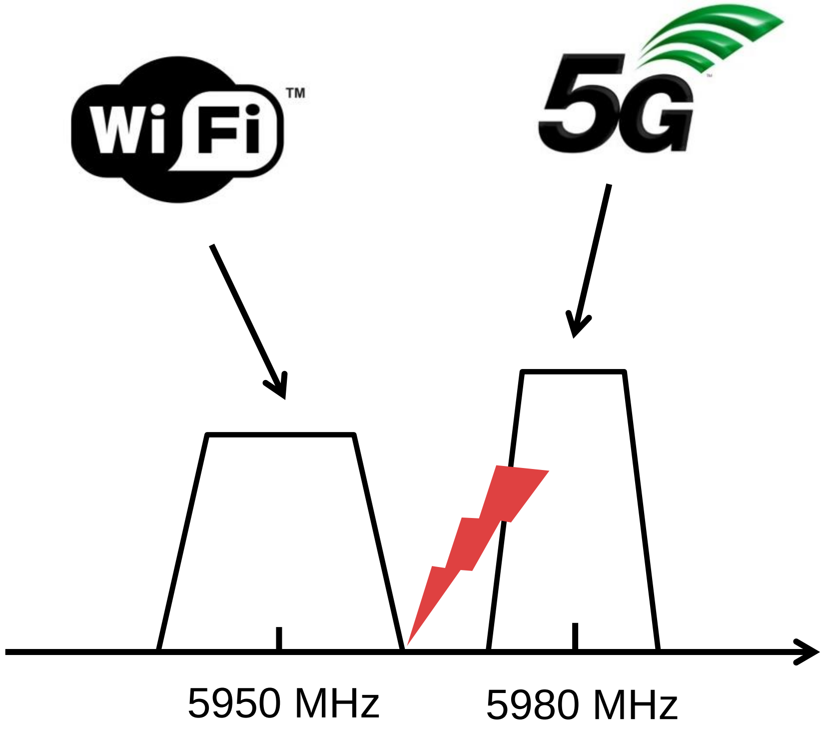
Interference & Coexistence

- 2.4 GHz BLE ZigBee

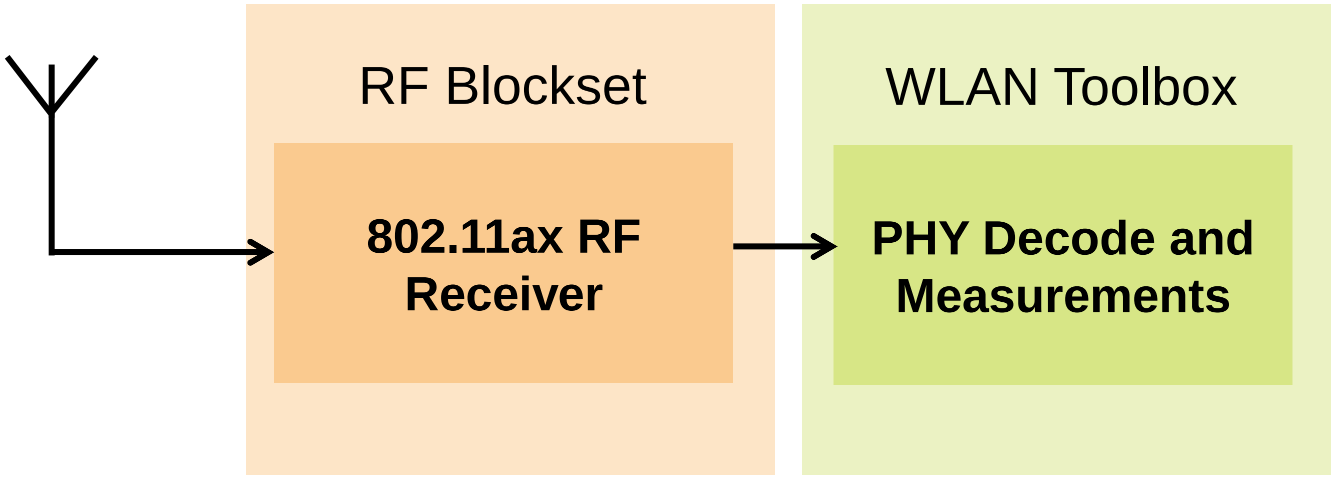
- 5/6 GHz

- 60 GHz

Example - 802.11ax RF receiver with 5G interference

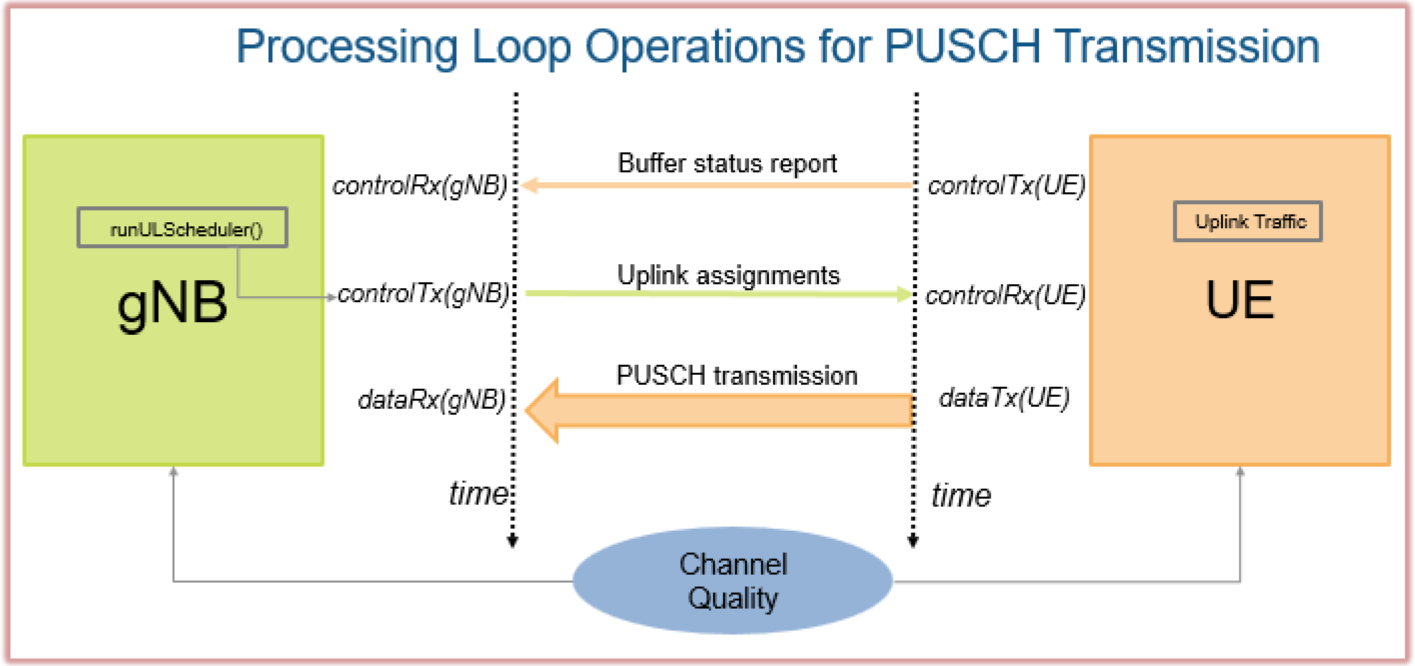


Transmitted waveform	802.11ax at 5950MHz
Interferer	NR-TM at 5980MHz
Tests	- Channel power - EVM per subcarrier - EVM per OFDM symbol

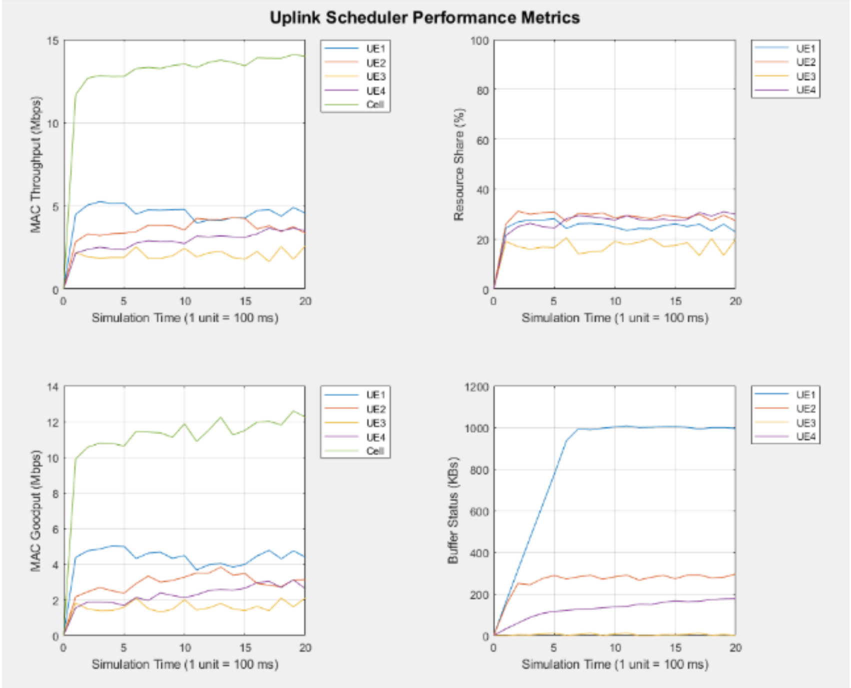


5G NR System-level Simulations

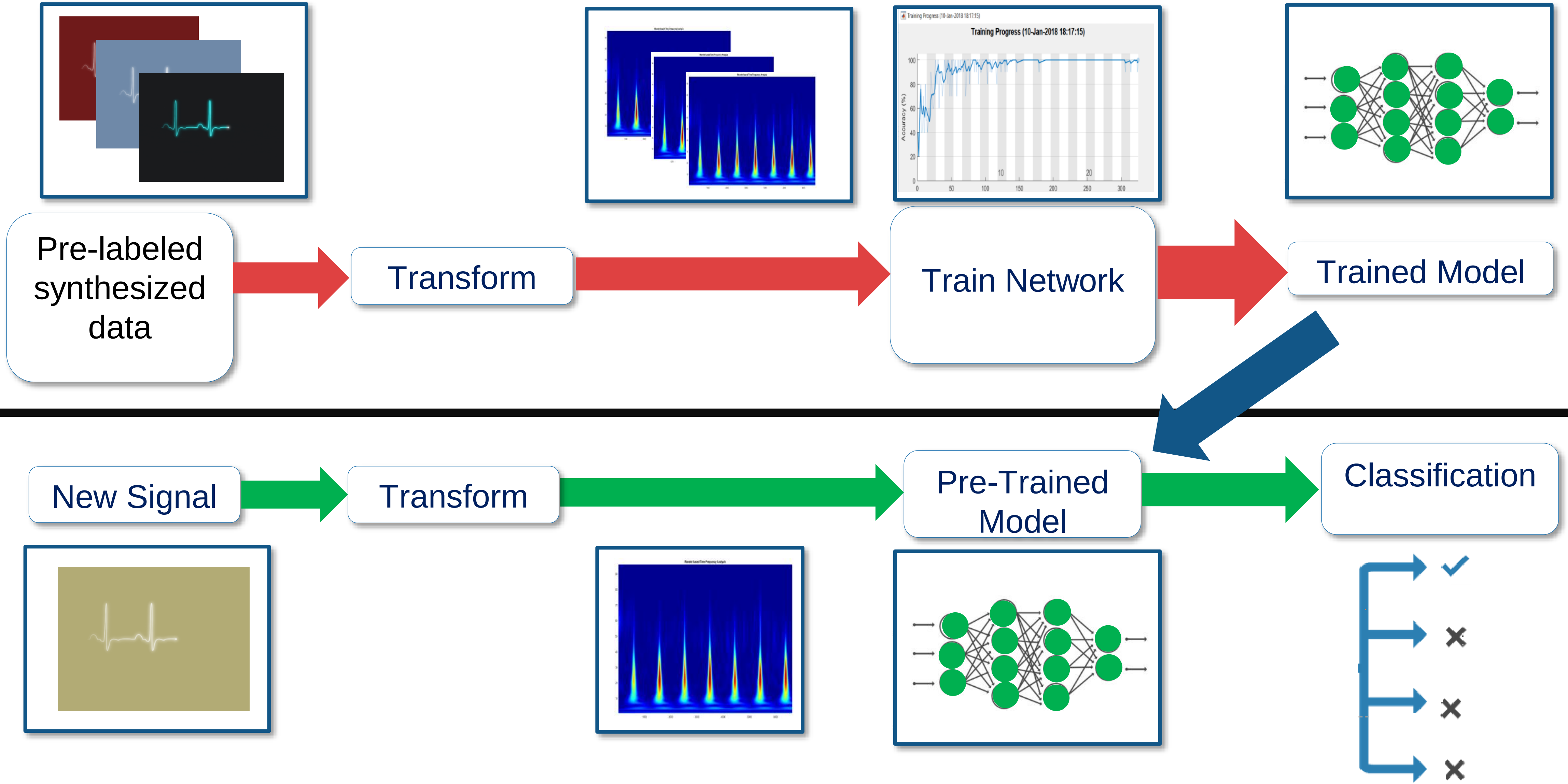
- Evaluating performance of different schedulers
  - Round-robin, proportionally fair, best CQI



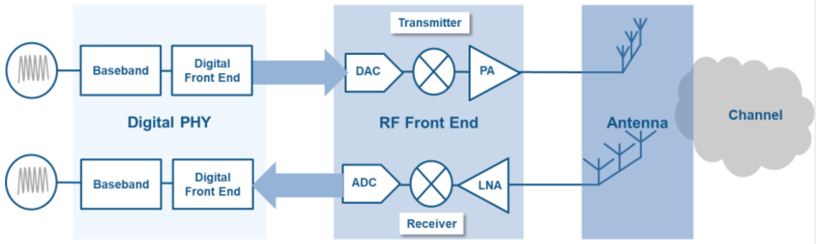
Throughput, goodput, buffer status

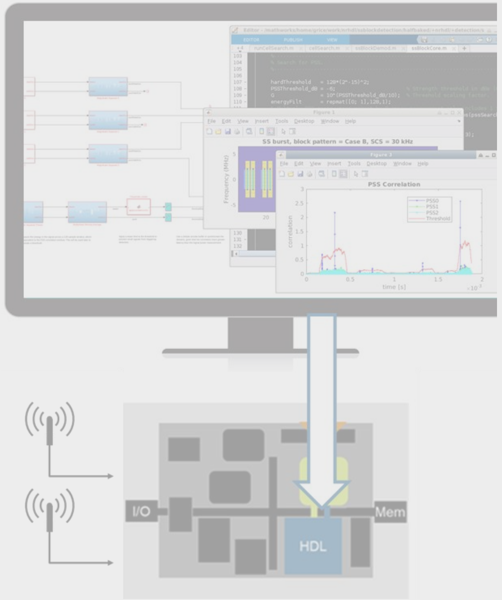


Deep Learning for Wireless Workflow



3 Topics We Cover Today





Ubiquity

Model 5G/Wireless connectivity systems and standards

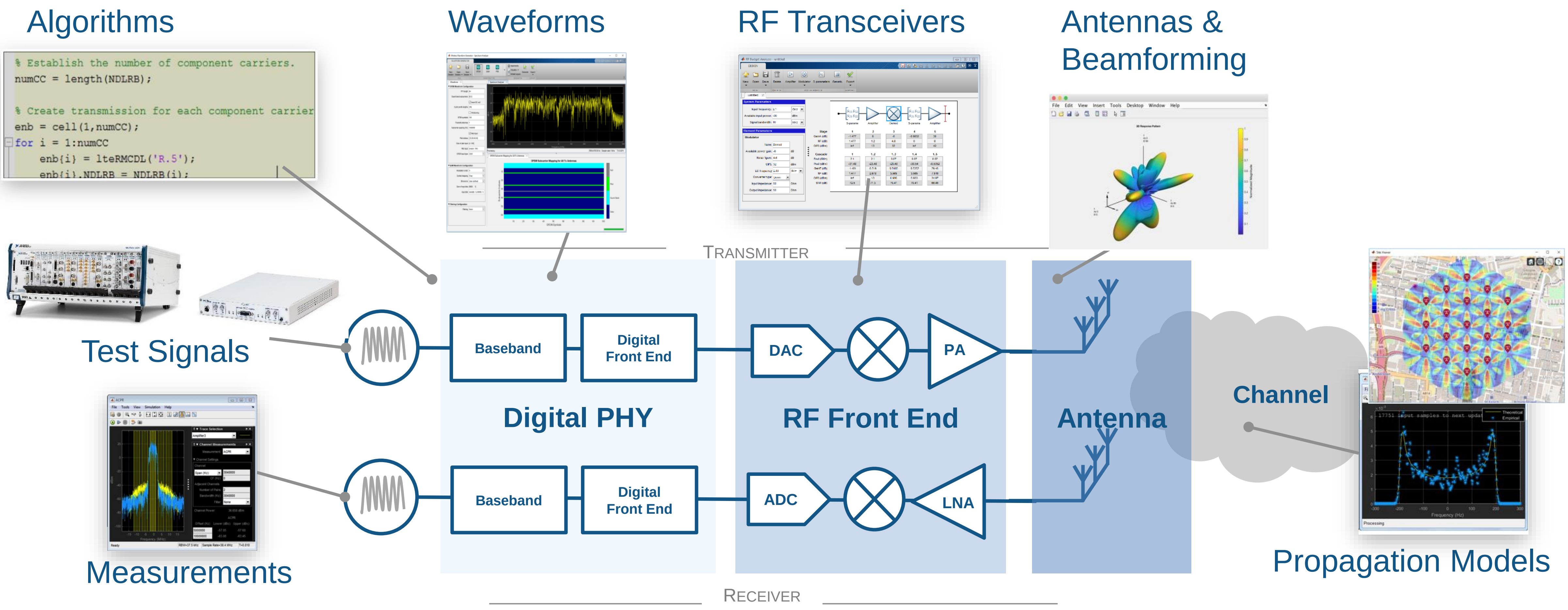
Complexity

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

Efficiency

Iterate, optimize and verify design implementations

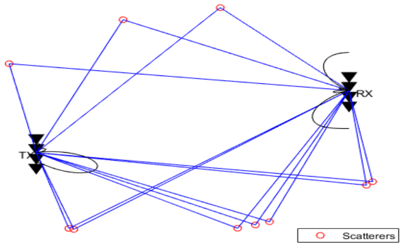
Integrated Multi-domain Modeling Complexity



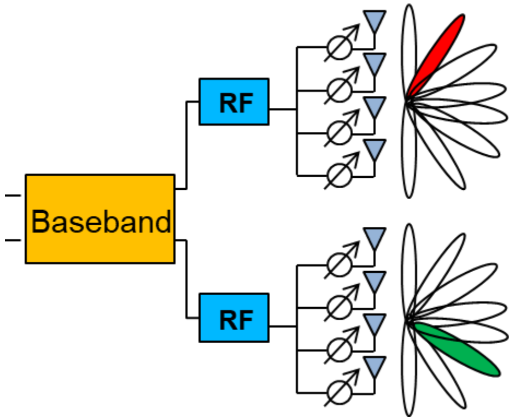
Workflow for Antenna-to-Bit Multi-Domain Design

Design an array

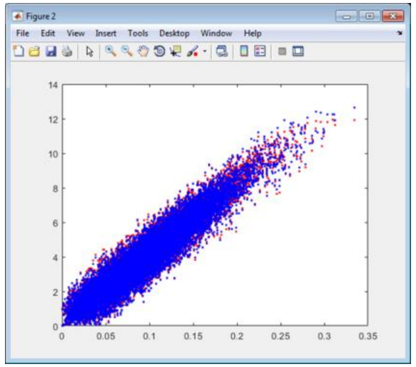
Add channel model



Hybrid beamforming

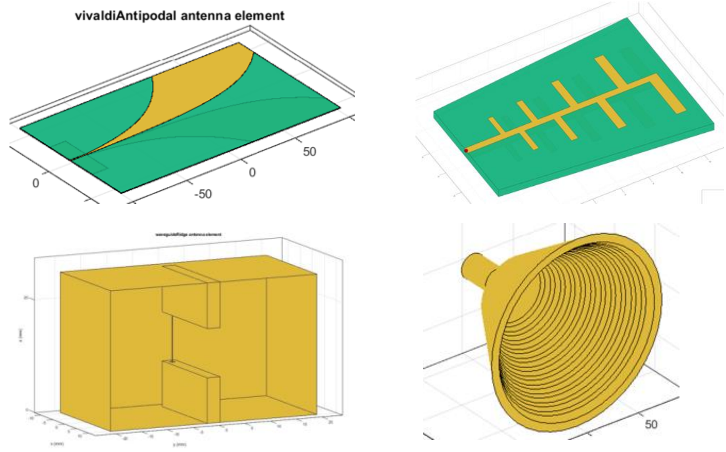


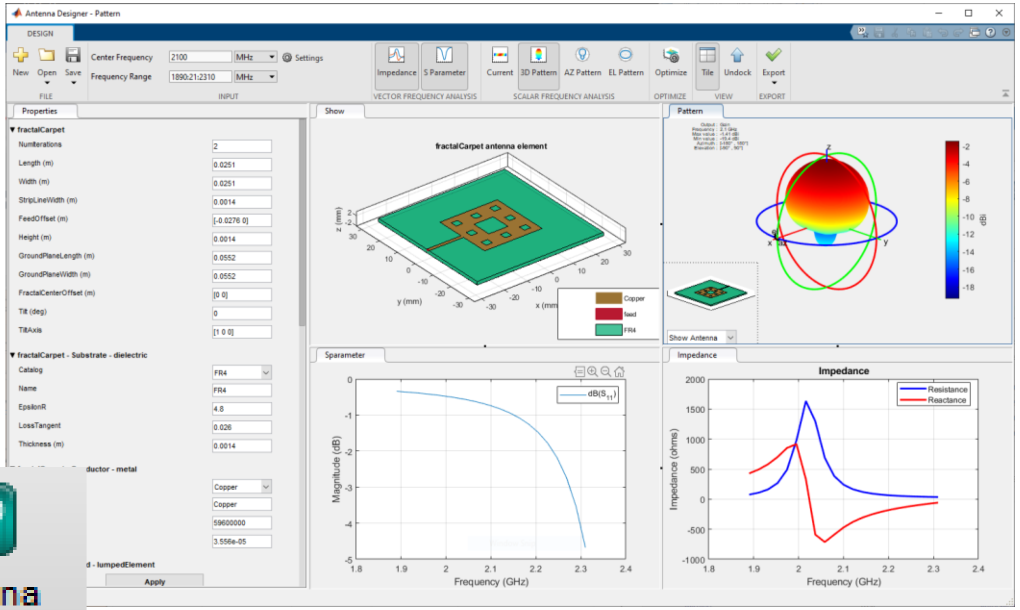
Specify RF front end

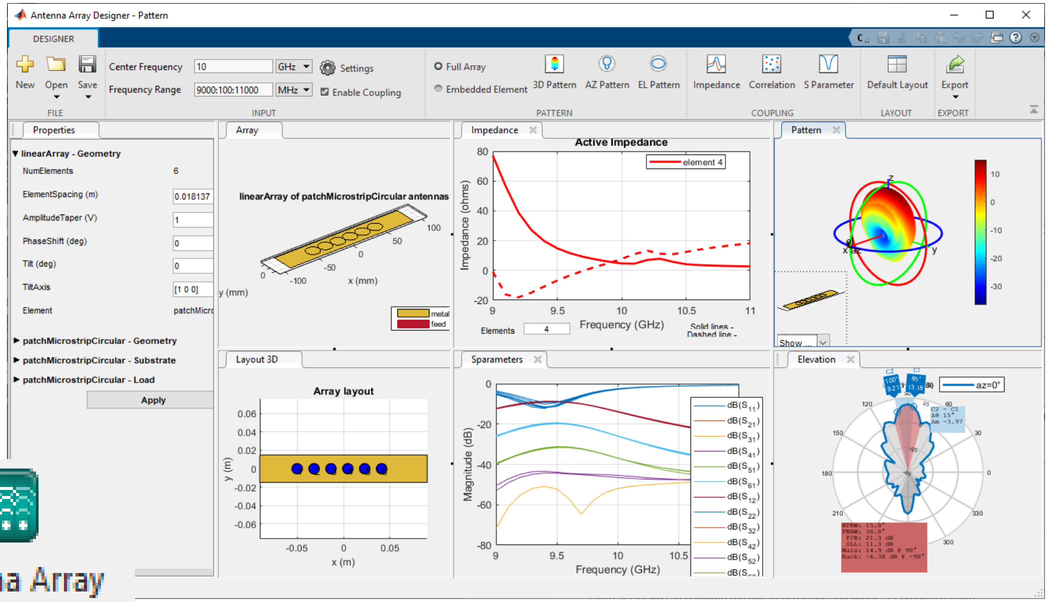


Design, Analyze and Visualize Antenna Elements and Arrays

- 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

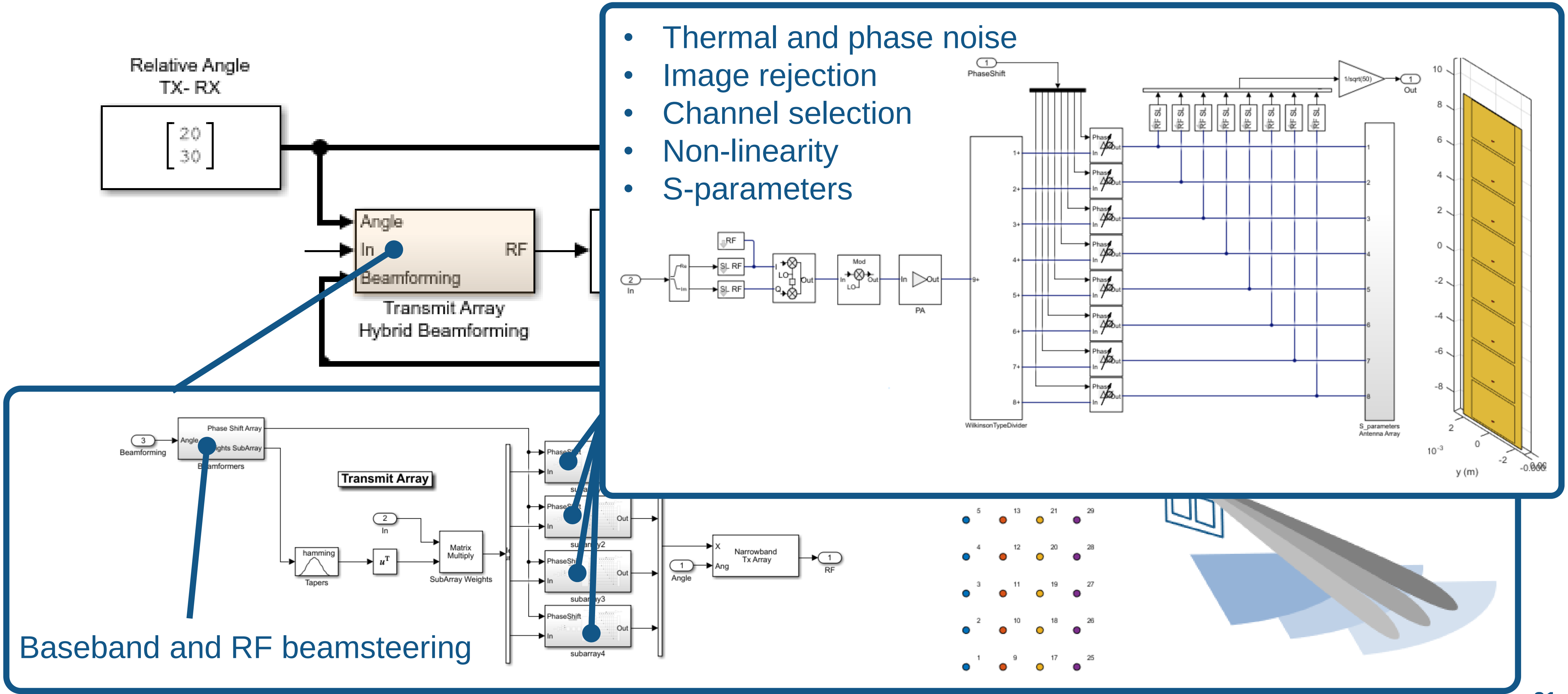






Architecture Exploration for Hybrid Beamforming

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



Baseband and RF beamsteering

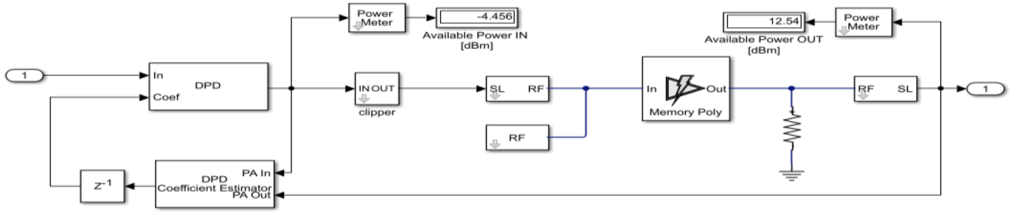
Power Amplifier Linearization: 5G Simulation Results

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

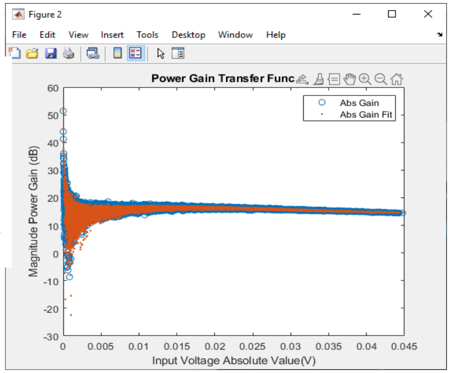
```
rxWaveform_dpd = rf_dpd(txWaveform);
```



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

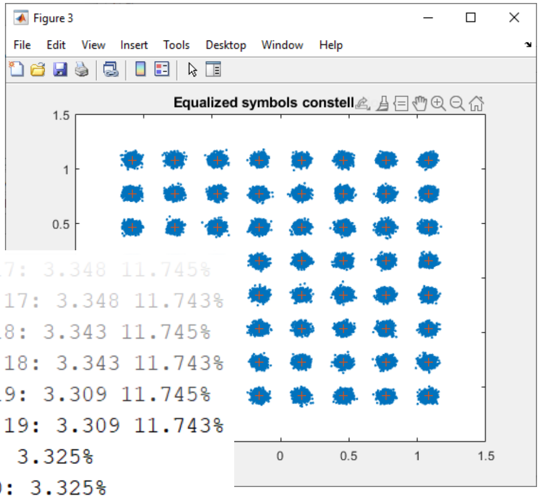
Memory depth

Degree of non-linearity



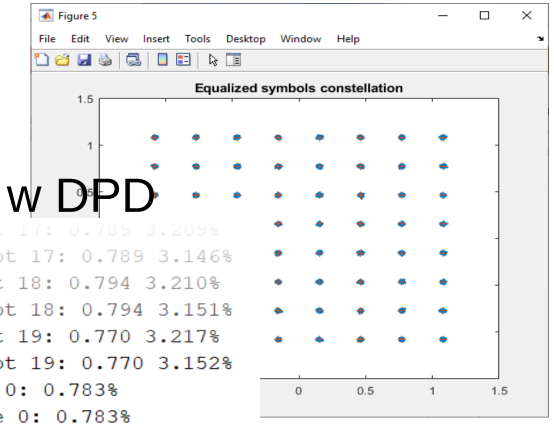
4. Create a RF system including DPD

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

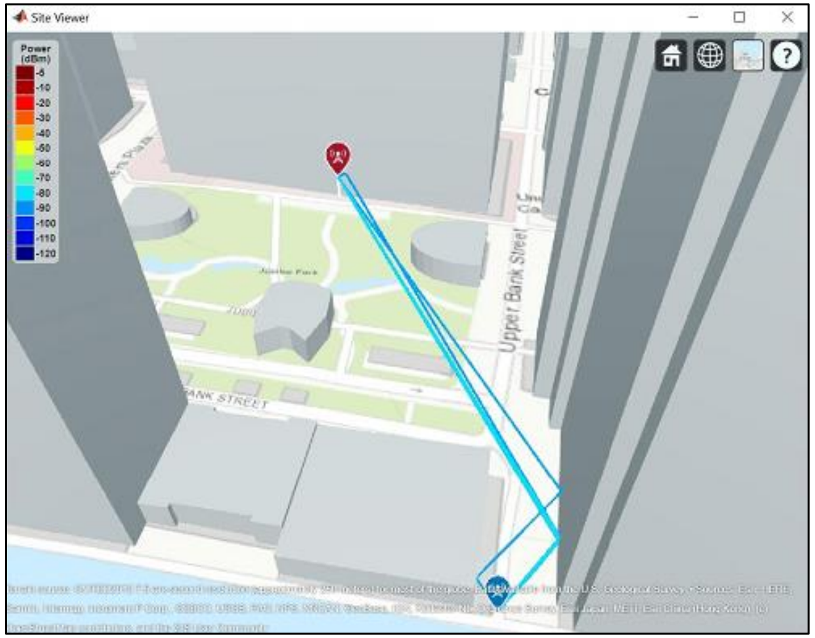



```
Low edge RMS EVM, Peak EVM, slot 17: 0.789 3.209%
High edge RMS EVM, Peak EVM, slot 17: 0.789 3.146%
Low edge RMS EVM, Peak EVM, slot 18: 0.794 3.210%
High edge RMS EVM, Peak EVM, slot 18: 0.794 3.151%
Low edge RMS EVM, Peak EVM, slot 19: 0.770 3.217%
High edge RMS EVM, Peak EVM, slot 19: 0.770 3.152%
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%
```

Propagation Channels

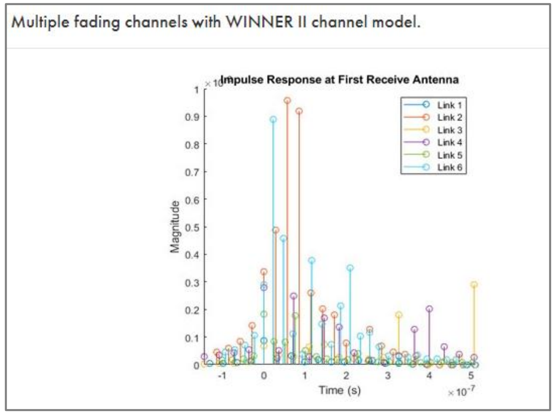
- Scattering MIMO channel
- Free space path loss

- Ray-tracing channel

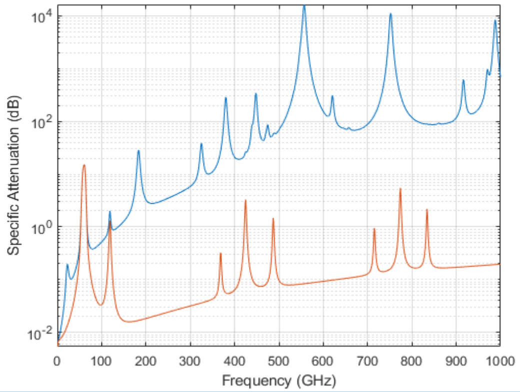


R2021a : Up to 10 reflections

- Winner II fading channel



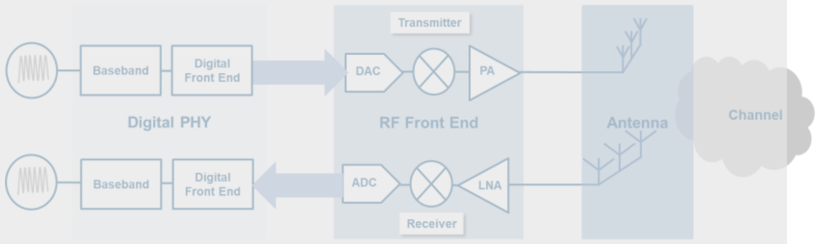
- Loss due to gases, fog, clouds

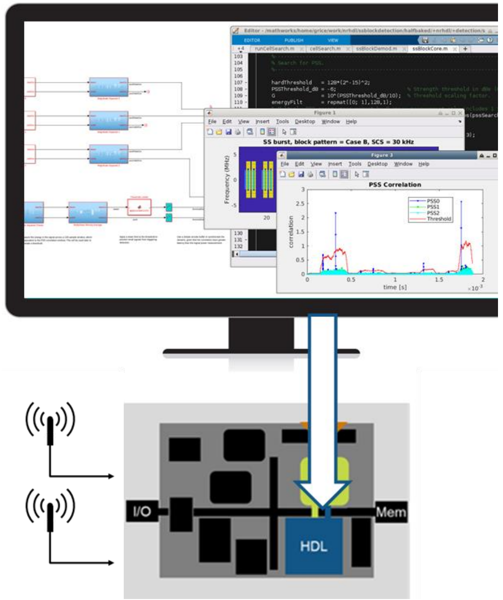


Array Beam Steering and RF Propagation

- 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





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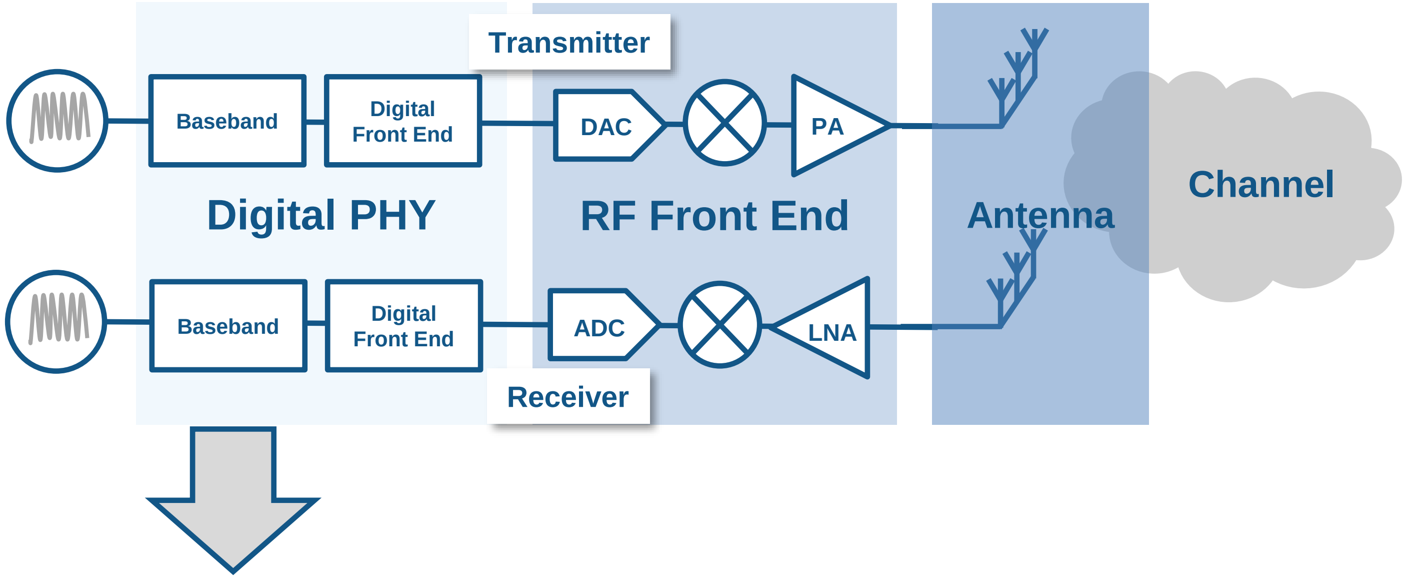
Hardware Deployment, Verification and Testing



Prototyping
SDR, FPGA, SoC

Simulink

HDL Coder

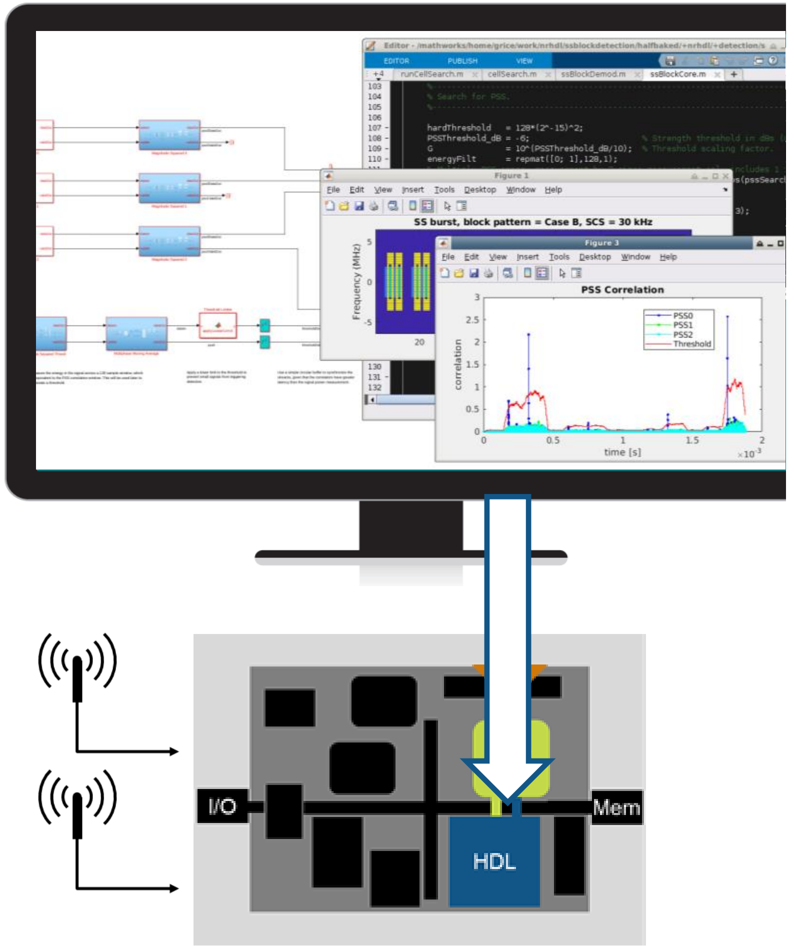
Wireless HDL Toolbox

HDL Verifier

Wireless HDL Toolbox

Mission statement:

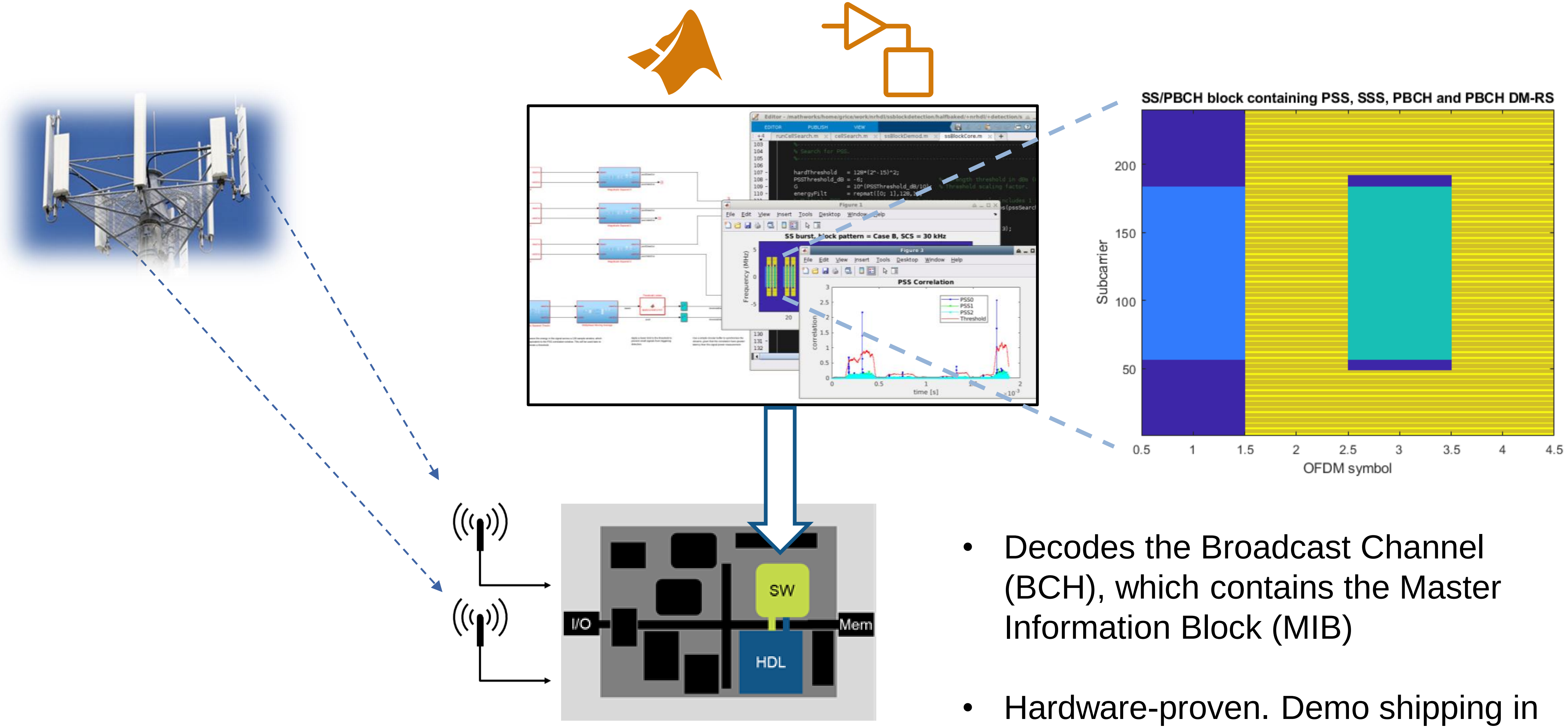
Provide high value reference applications and HDL IP blocks to accelerate the pace of design, implementation and verification of communication systems.



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

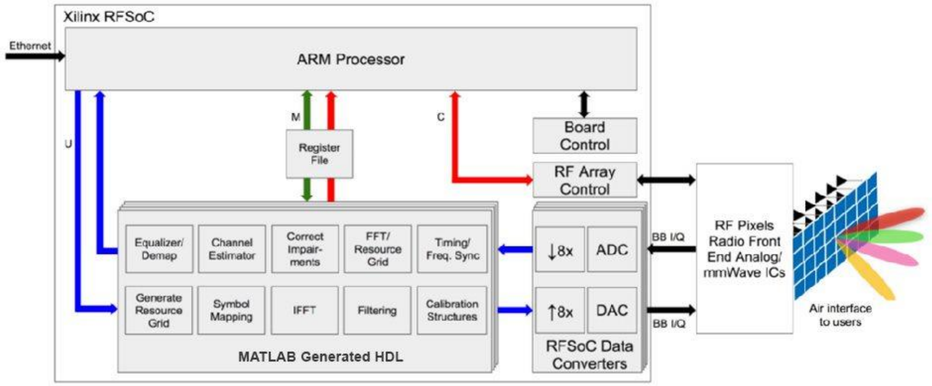
Test and demonstrate radio front-end designs that incorporate specialized RF electronics hardware and millimeter wave spectrum technology

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



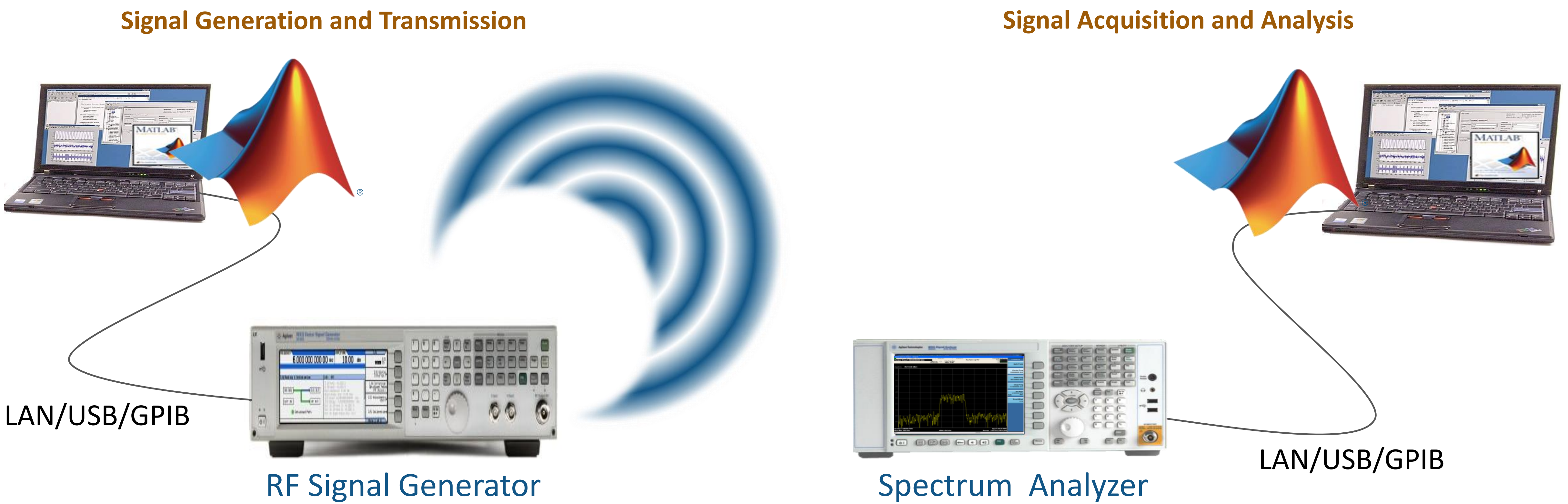
Digital baseband implemented in HDL, used to verify the RF Pixels radio front end.

"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

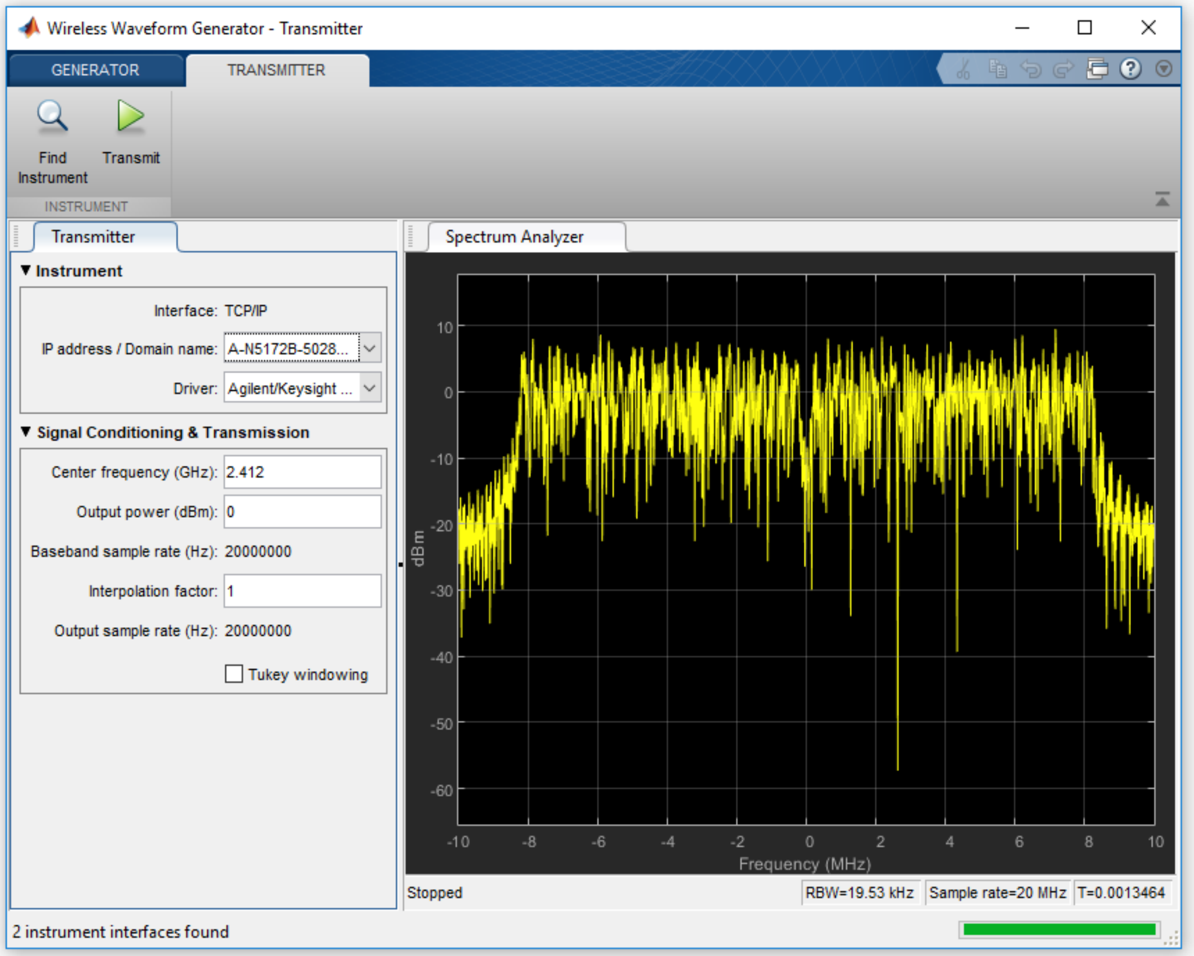


Over-the-air testing: Moving designs to the lab

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

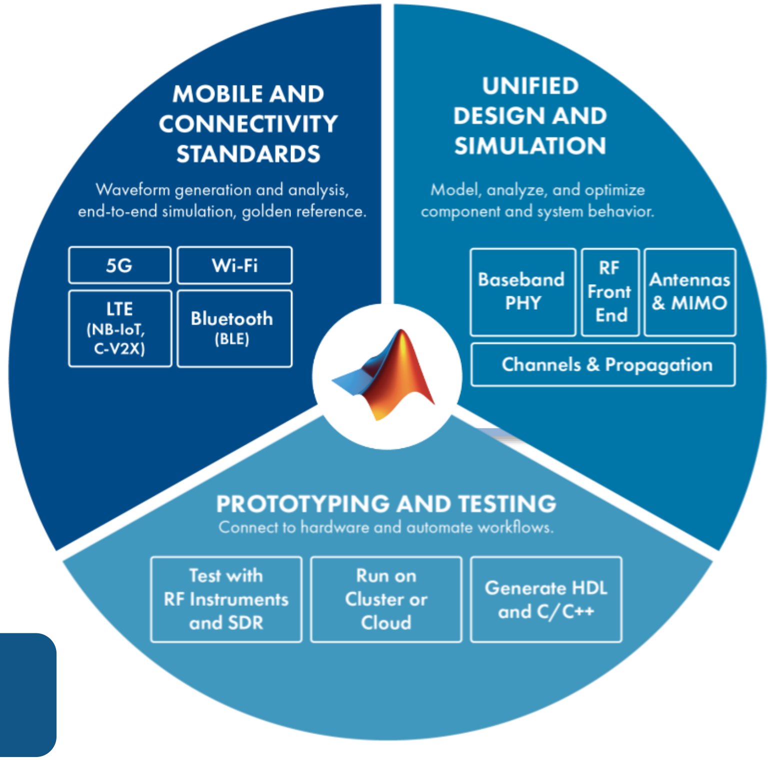
Ubiquity

Ubiquitous Connectivity

System Engineering

Complexity

Design Complexity



Deployment & Verification

Efficiency

Efficient deployment & testing

How to Learn More

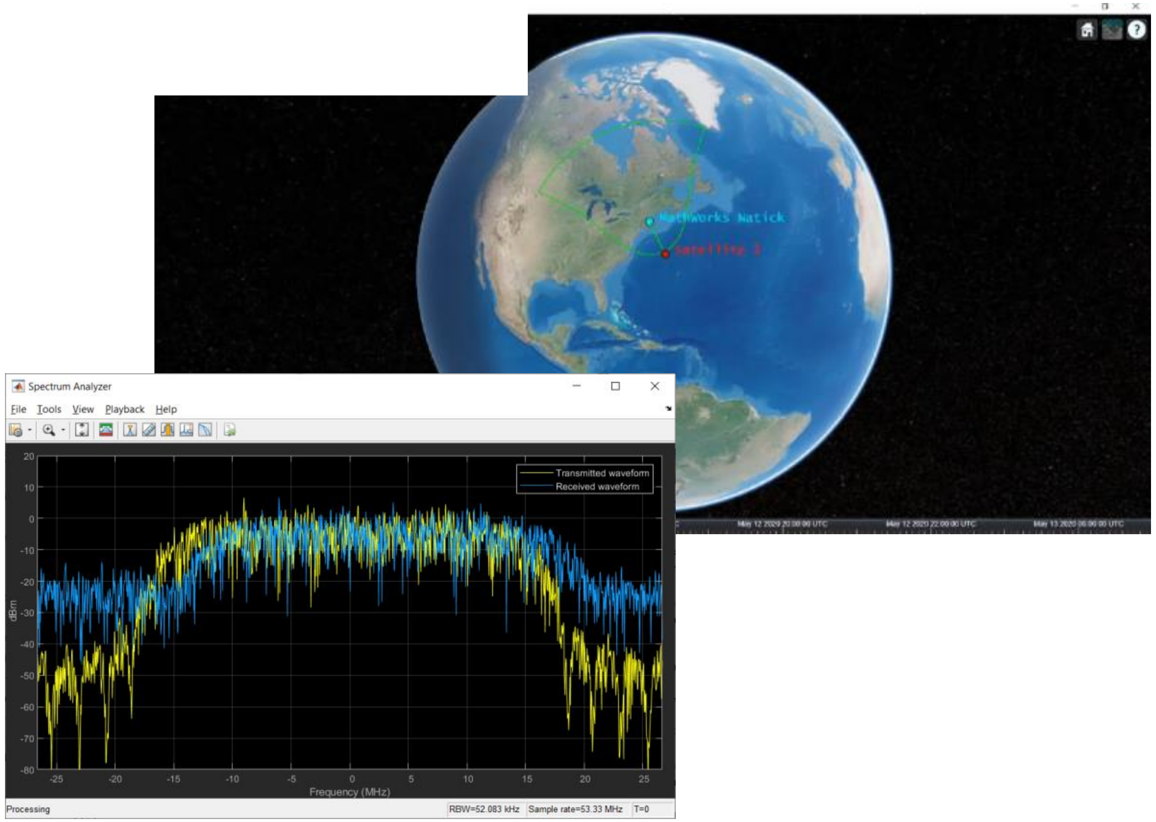
Wireless Communications product pages

mathworks.com/products/

- 5G
- LTE
- WLAN
- Satellite-communications

Wireless communications solution page

mathworks.com/solutions/wireless-communications.html



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2021

Thank you

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