MathWorks
AUTOMOTIVE
CONFERENCE 2019

MATLAB을 활용한 자동차 레이더 개발

서기환

Agenda

- Different Usage for Radar Modeling
- Radar Design Workflow
  - DSP Design and Simulation
  - RF/Antenna Modeling
- High Level Simulation with Probabilistic Model

Agenda

- Radar Modeling with Fidelity Control
- Radar Design Workflow
  - DSP Design and Simulation
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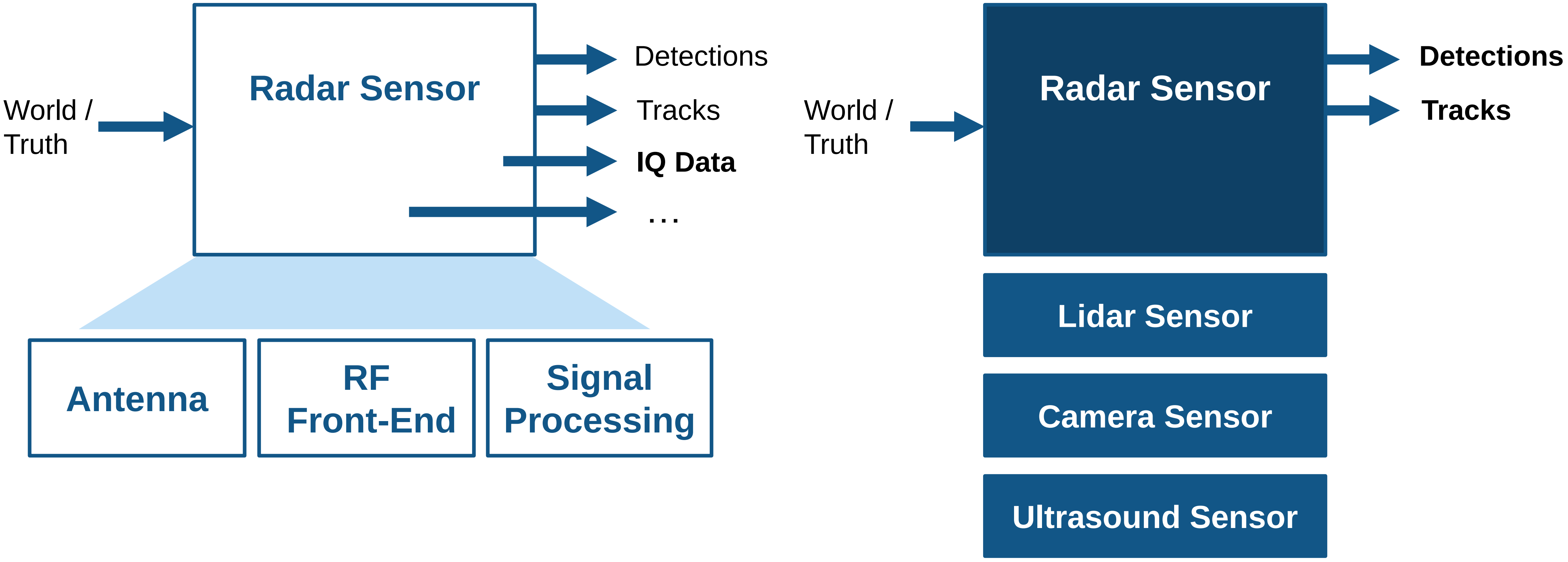
- High Level Simulation with Probabilistic Model

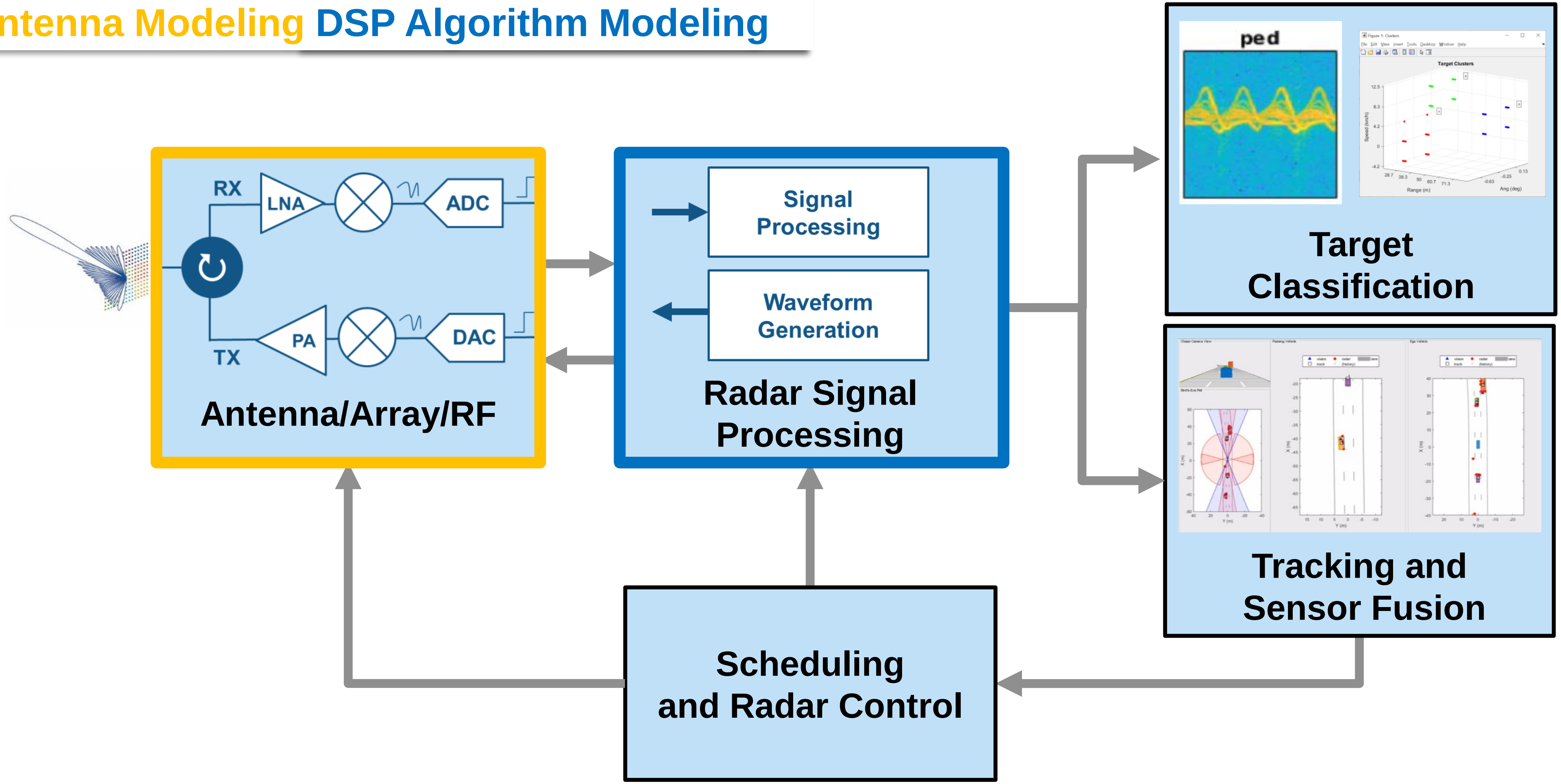
Two Personas using Automotive Radar Sensor Models

Radar Designers ***Radar Users***



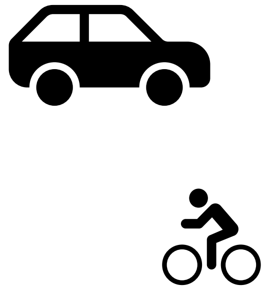
Radar Modeling and Simulation

RF/Antenna Modeling DSP Algorithm Modeling

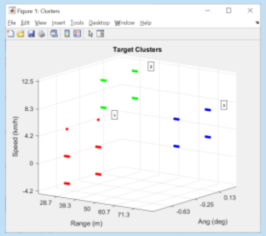


Radar Modeling and Simulation

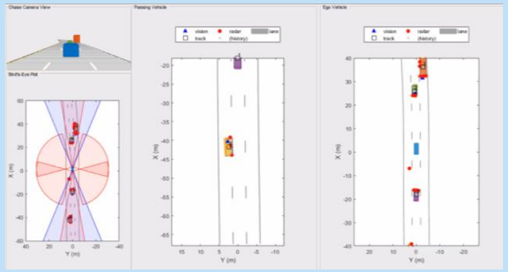
Probabilistic Model



Radar Sensor



Target Classification



Tracking and Sensor Fusion

Automotive Radar Sensor Models

	DSP algorithm Model	RF/Antenna Model	Probabilistic Model
Engineers	Radar Designers	Radar Designers	Radar Users
Model usage	Radar Algorithms	Analog-mixed Signal Simulation	Sensor Fusion, Controller
Outputs	IQ Data or Detections	IQ Data	Detections or Tracks
Benefit	-	Highest Fidelity	Simulation Speed
Disadvantage	-	Simulation speed	Can’t Access IQ Data

Agenda

- Radar Modeling with Fidelity Control
- Radar Design Workflow
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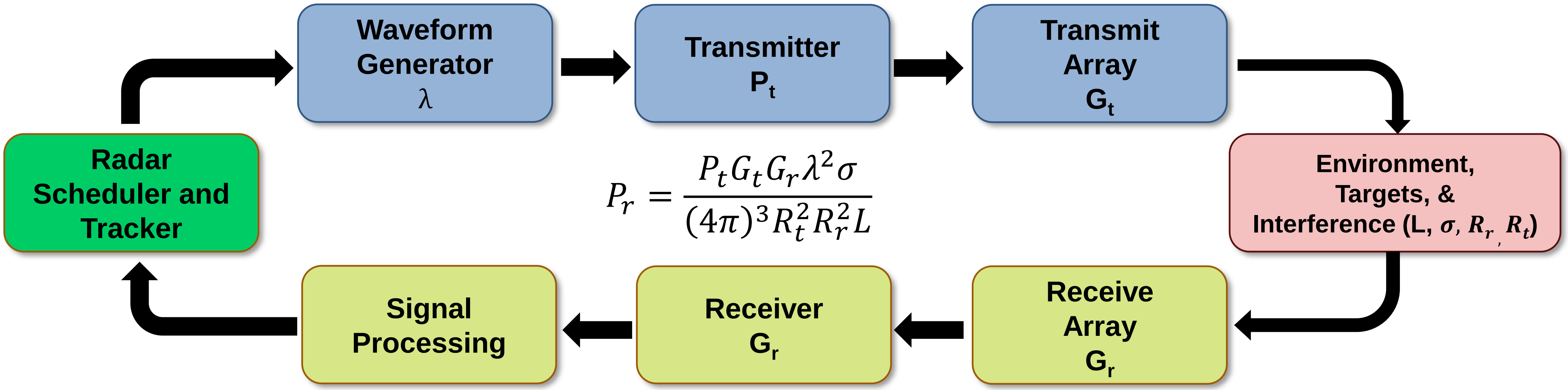
Radar Simulation and Modeling Architecture



- Functions for calculations and analysis
- Apps for common workflows
- Parameterized components for system modeling
- Easy path to increased fidelity for antenna and RF design
- Code generation for deployment

Radar Model to Simulate High Fidelity Raw Data

Antenna, Antenna arrays
type of element, # elements, configuration

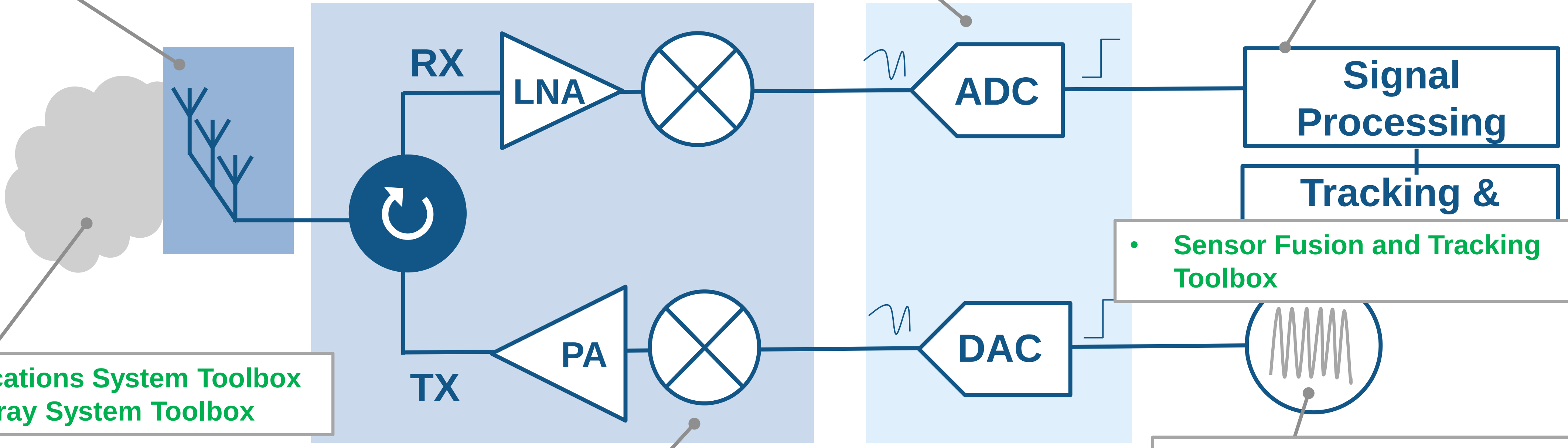
- Antenna Toolbox
- Phased Array System Toolbox

Mixed-Signal
Continuous & discrete time

- Simulink
- DSP System Toolbox
- Control System Toolbox

Algorithms
beamforming, beamsteering, MIMO

- Phased Array System Toolbox
- Communications System Toolbox
- DSP System Toolbox



- Sensor Fusion and Tracking Toolbox

- Communications System Toolbox
- Phased Array System Toolbox

Channel
interference, clutter, noise

- RF Blockset
- RF Toolbox

RF Impairments
frequency dependency, non-linearity, noise, mismatches

- Phased Array System Toolbox
- Signal Processing Toolbox
- Wavelet Toolbox

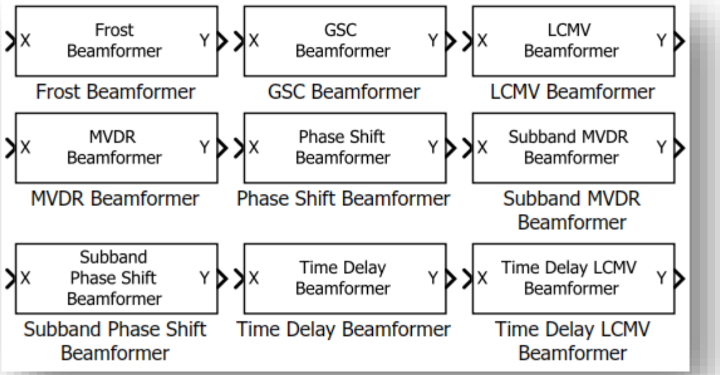
Waveforms & Resource Scheduling

Path to Higher Fidelity

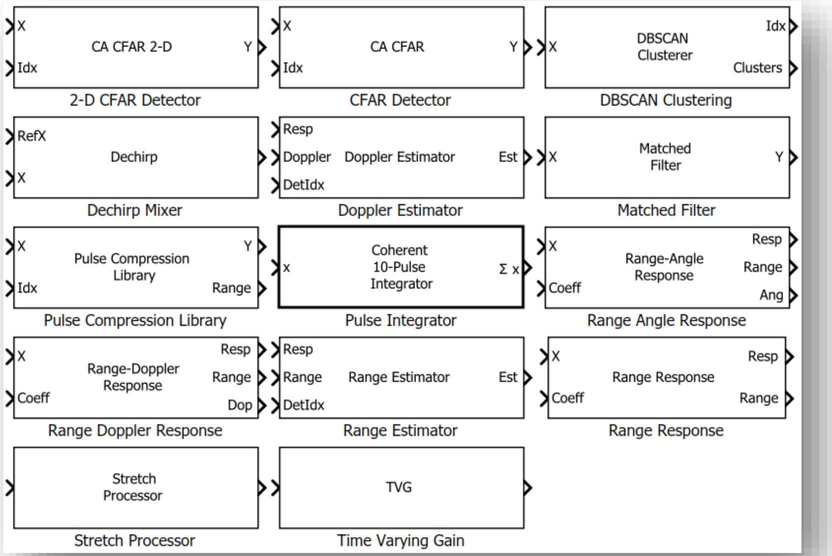
- Extend model fidelity over project evolution
- Simple interface to replace off-the-shelf components with custom ones

Antenna element	Target model	Propagation model	RF signal chain
Ideal elements	Point target	Free space	Baseband
EM solver with mutual coupling	Synthesized backscatter (angle & frequency)	Line of sight atmospheric effects	RF components
Measured pattern import	Measured return (angle & frequency)	Multipath, terrain and ducting effects	Analog-mixed simulation

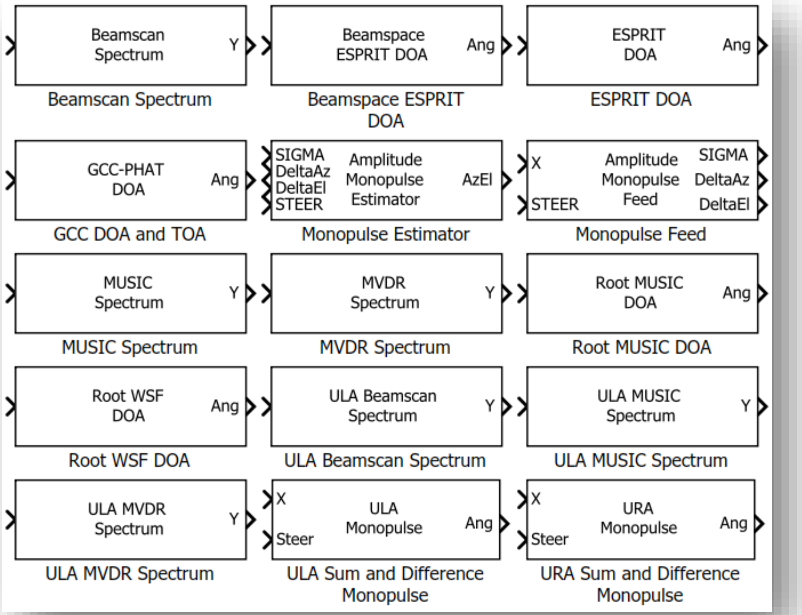
DSP Algorithms for Radar Systems



Beamforming

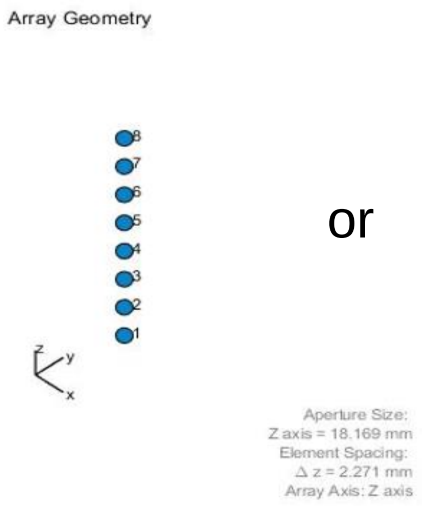


Detections

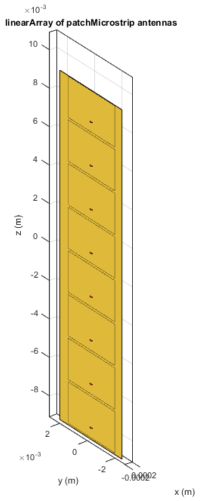


Direction of Arrival

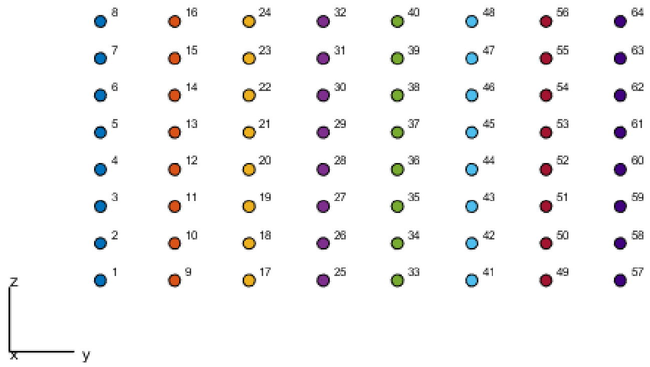
Antenna Array Design



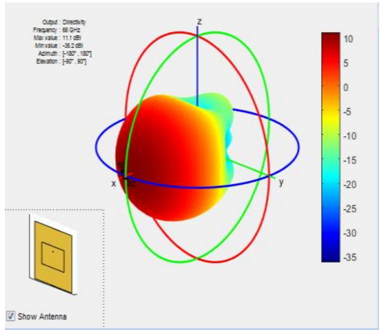
or



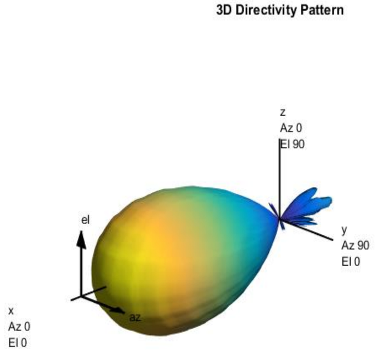
Design subarray with desired fidelity



Replicate to build array

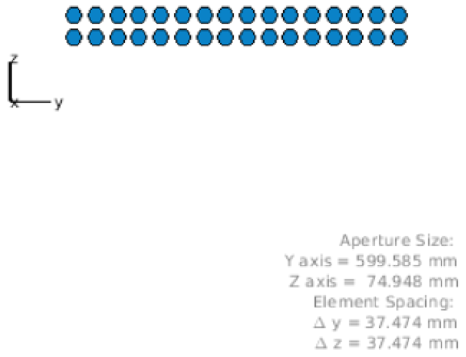


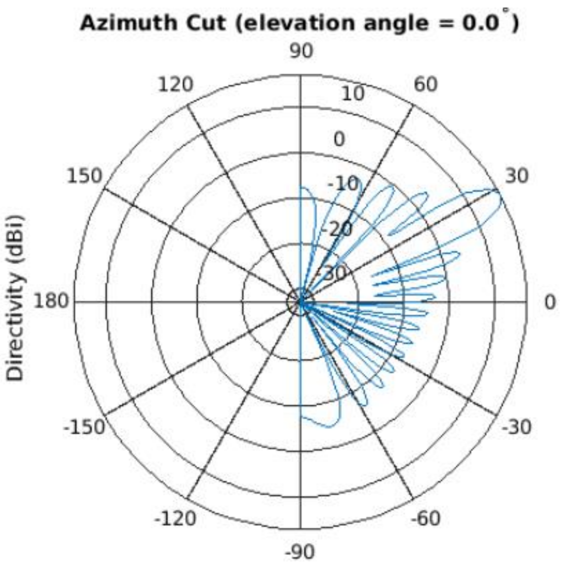

```
p = design(patchMicrostrip,66e9)
```

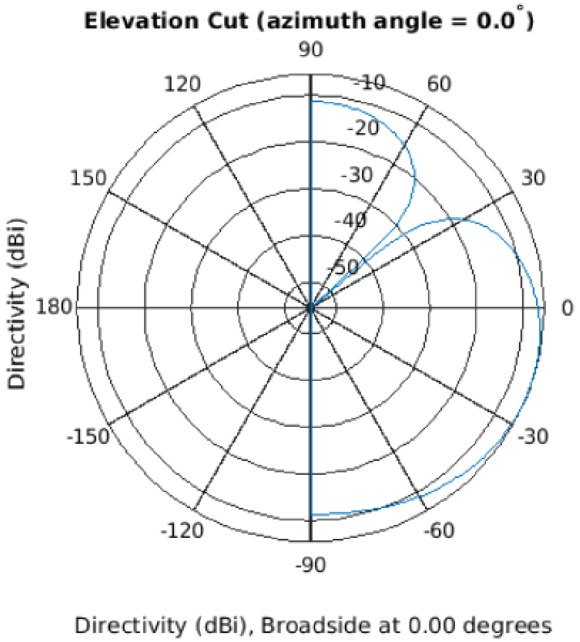


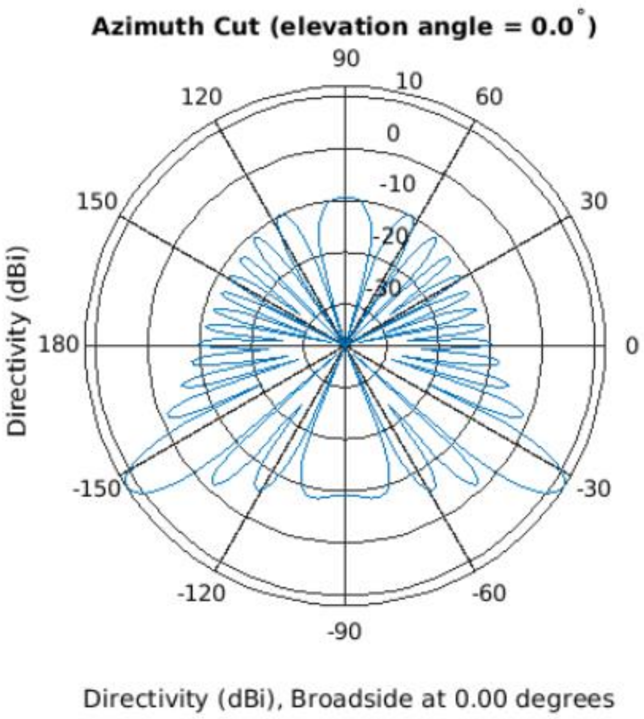
Assess resulting pattern

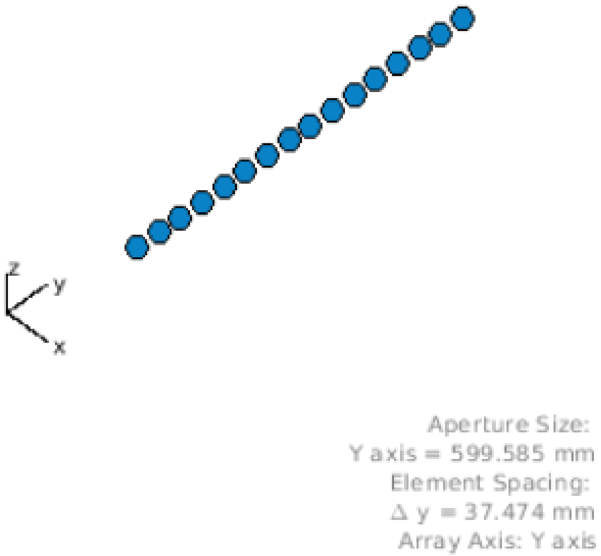
Beam Steering





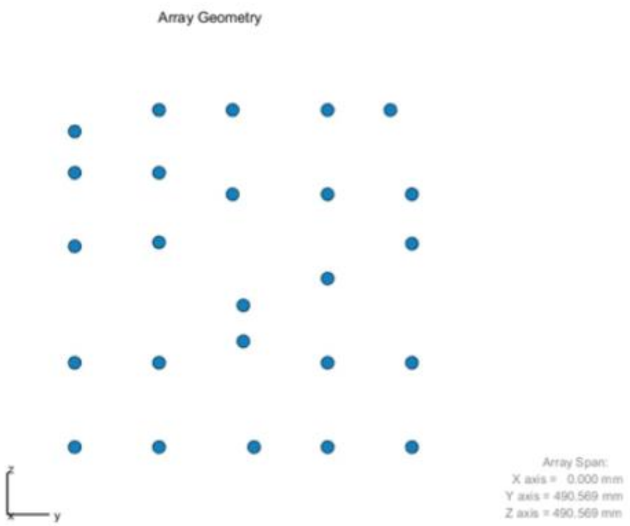


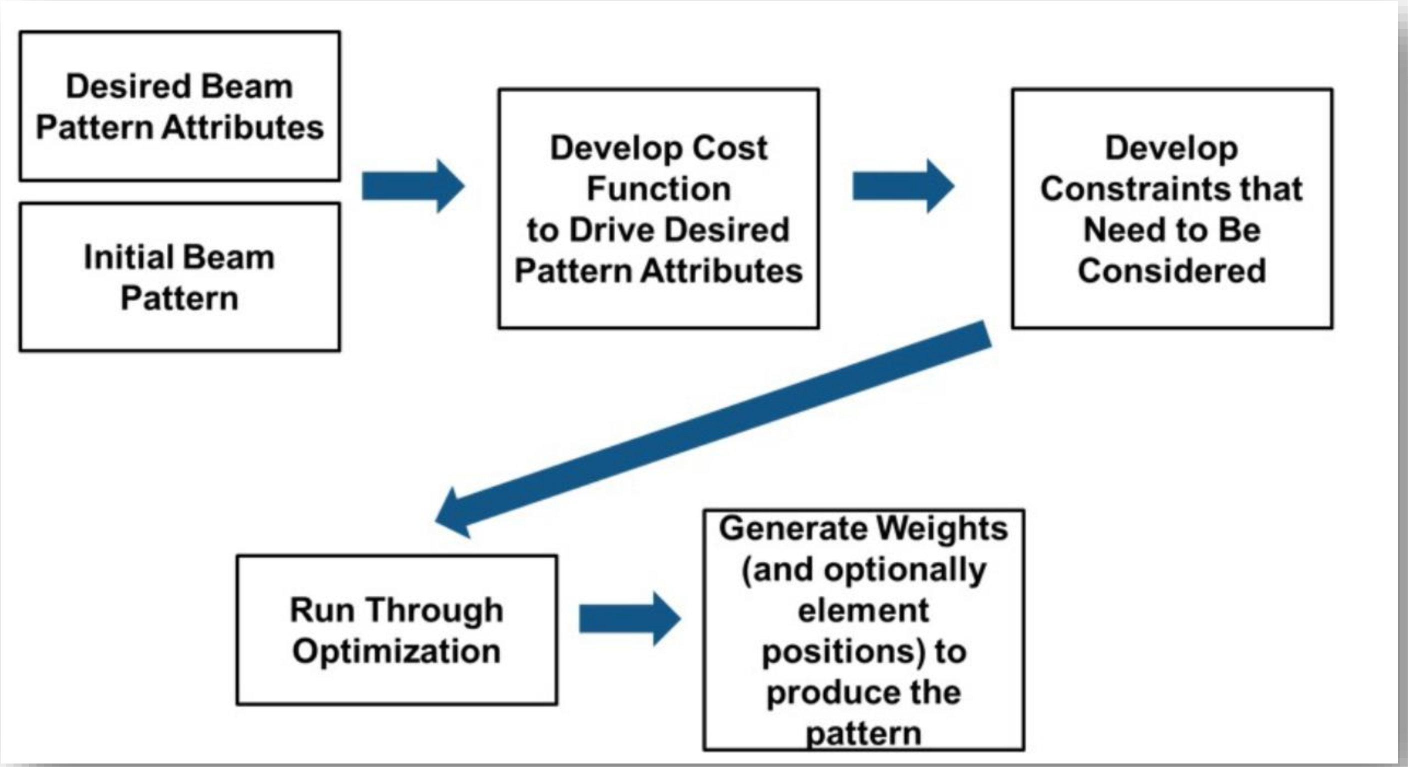




Synthesizing an Array from a Specified Pattern

- Introduce optimization workflow



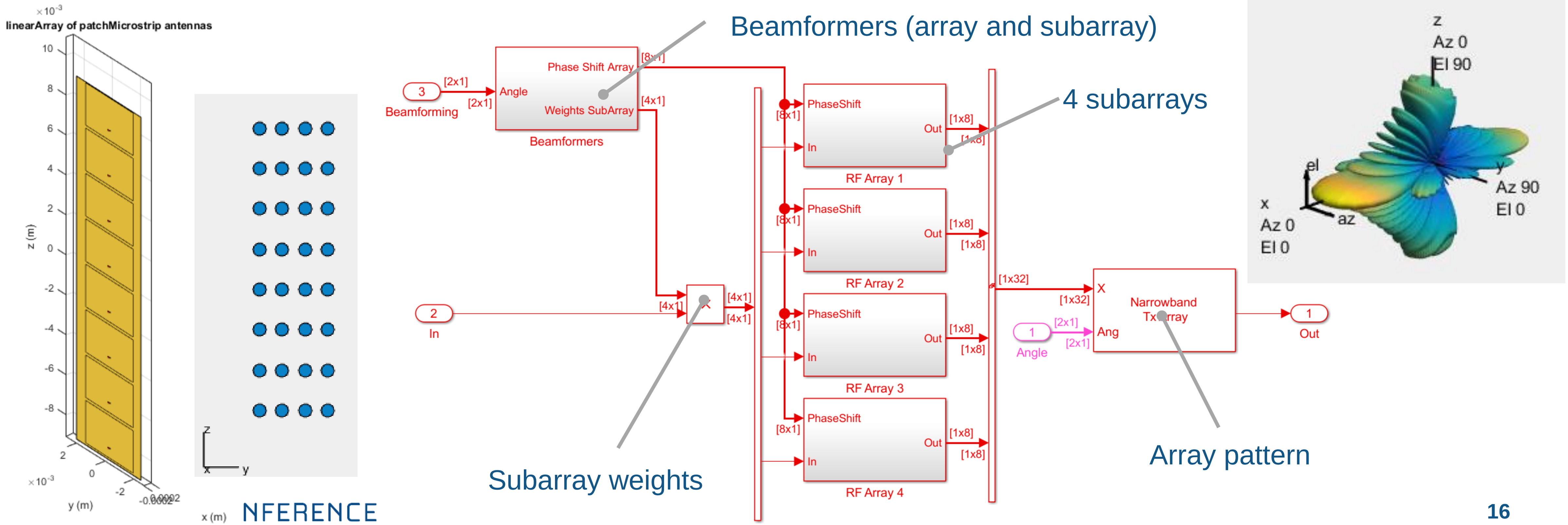


https://blog.naver.com/matlablove/221205030640

https://kr.mathworks.com/company/newsletters/articles/synthesizing-an-array-from-a-specified-pattern-an-optimization-workflow.html

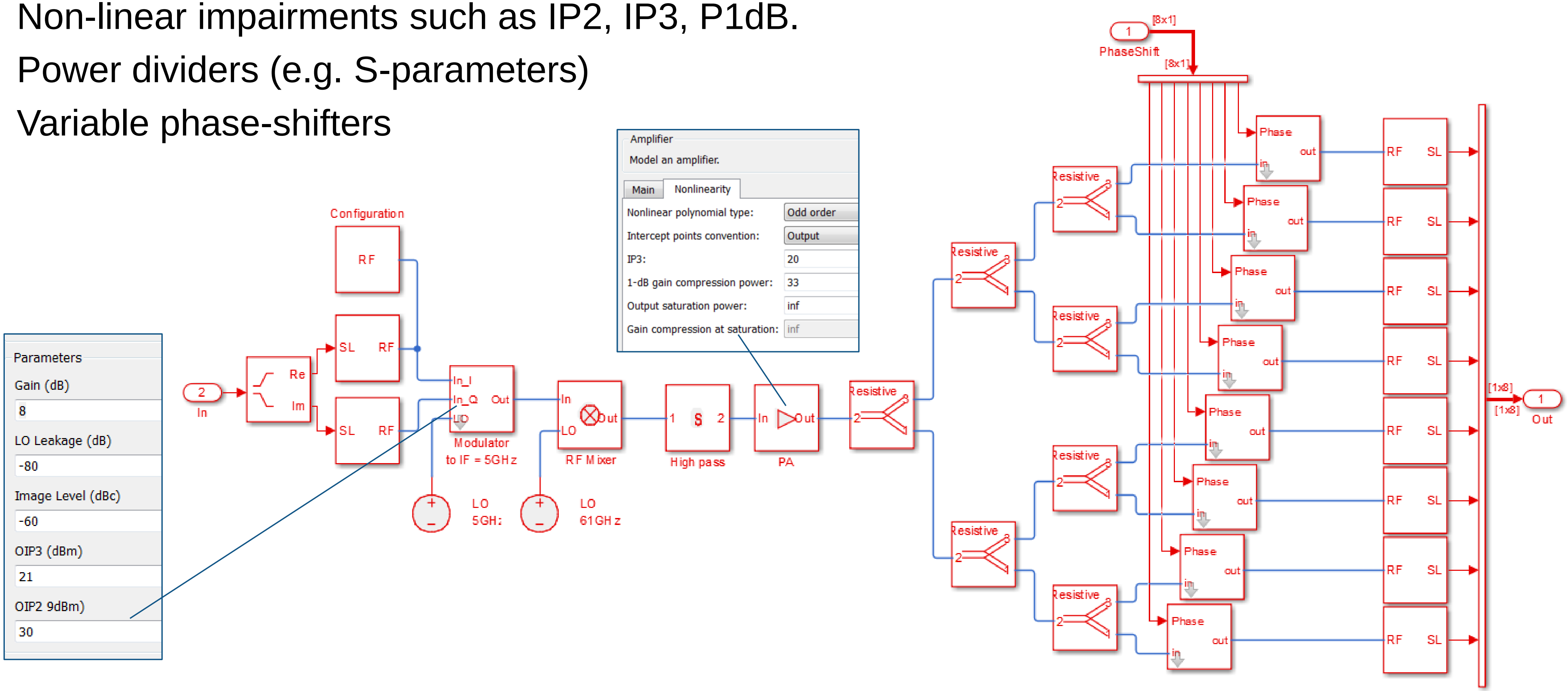
Hybrid Beamforming

- 4 subarrays of 8 patch antennas operating at 66GHz → 4x8 = 32 antennas
- Digital beamforming applied to the 4 subarrays (azimuth steering)
- RF beamforming (phase shifters) applied to the 8 antennas (elevation steering)

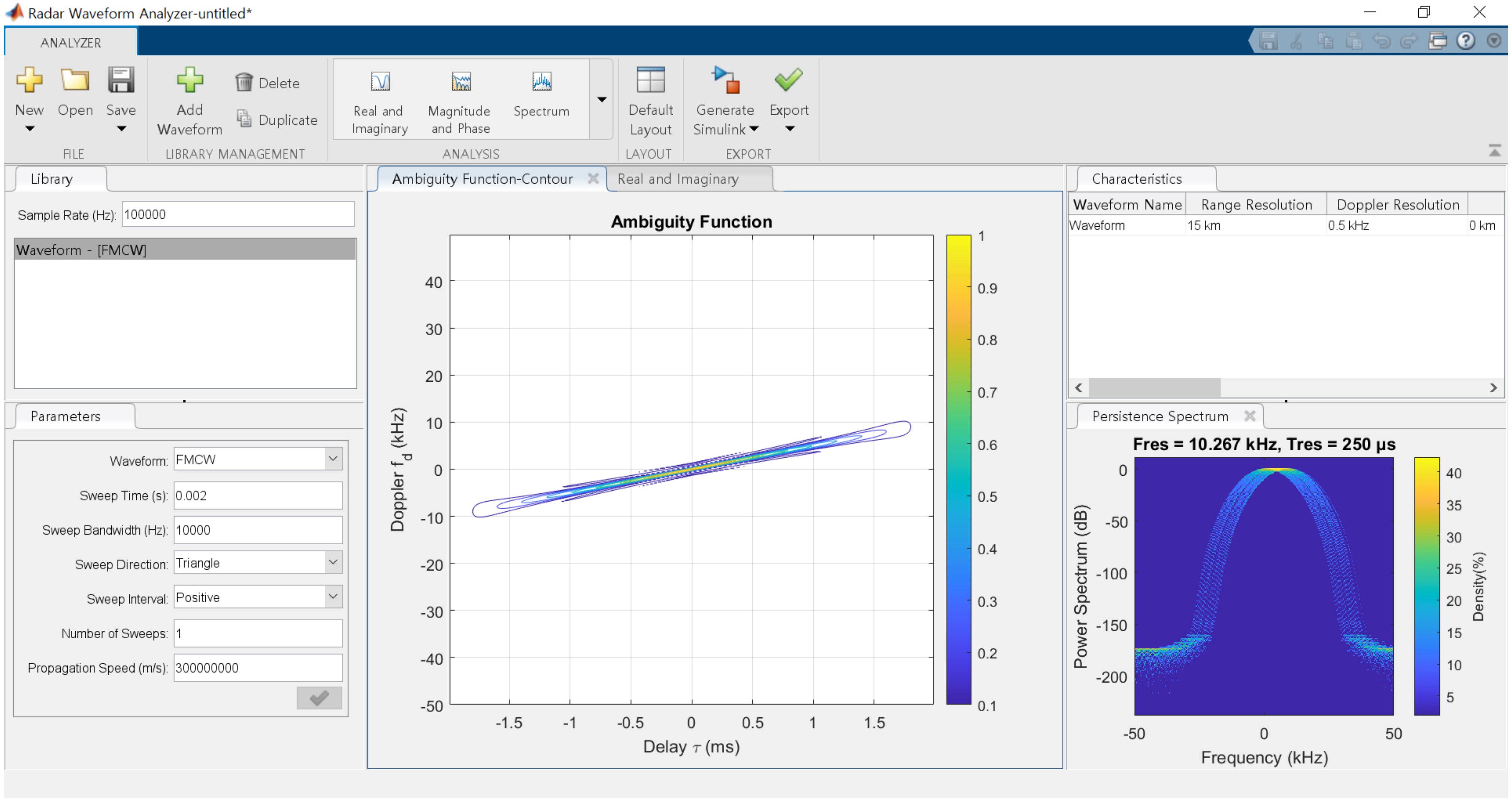


RF Front End Modelling using Circuit Envelope

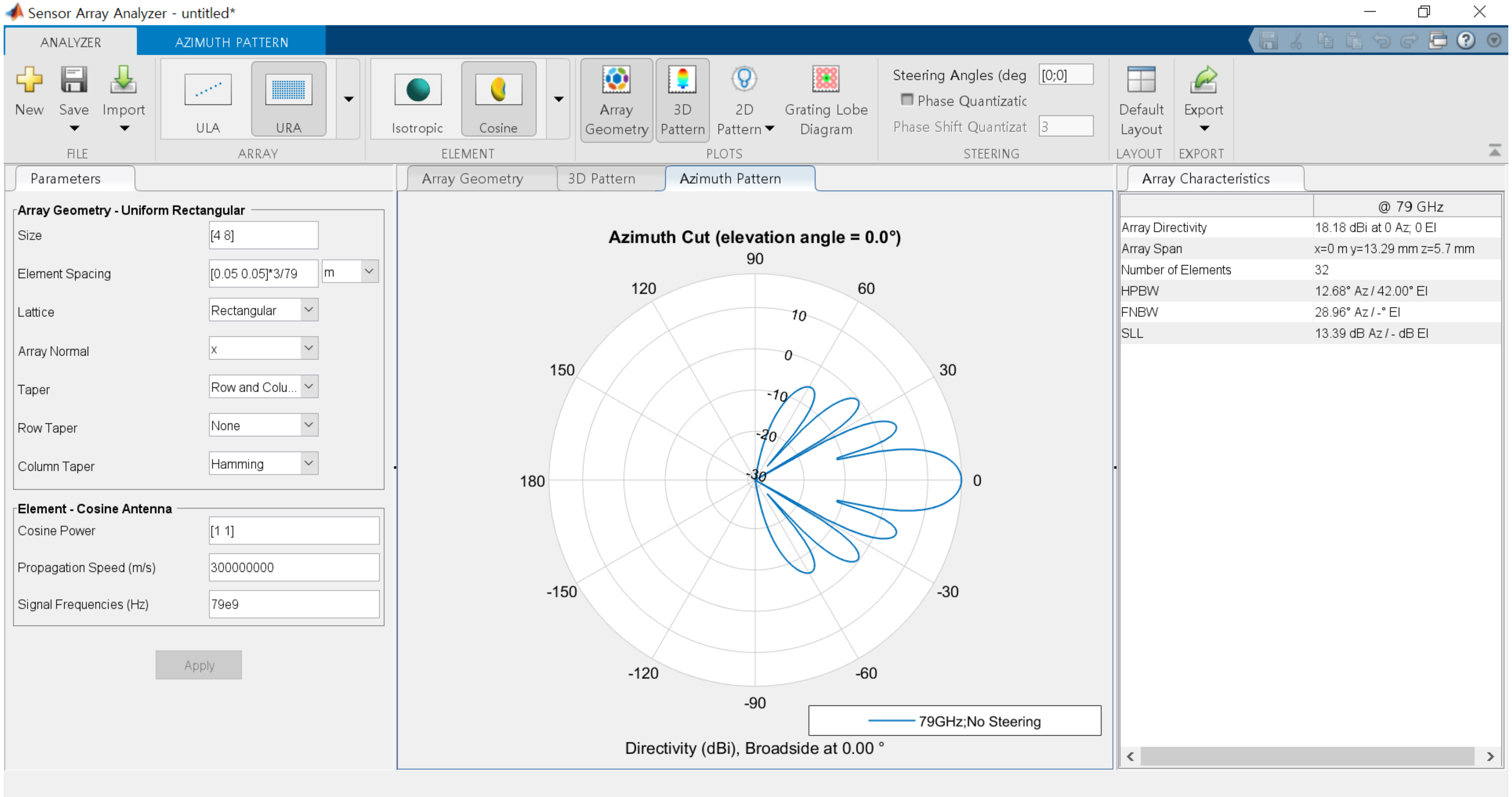
- Direct conversion to IF (5GHz) and superhet up-conversion to mmWave (79GHz)
- Non-linear impairments such as IP2, IP3, P1dB.
- Power dividers (e.g. S-parameters)
- Variable phase-shifters



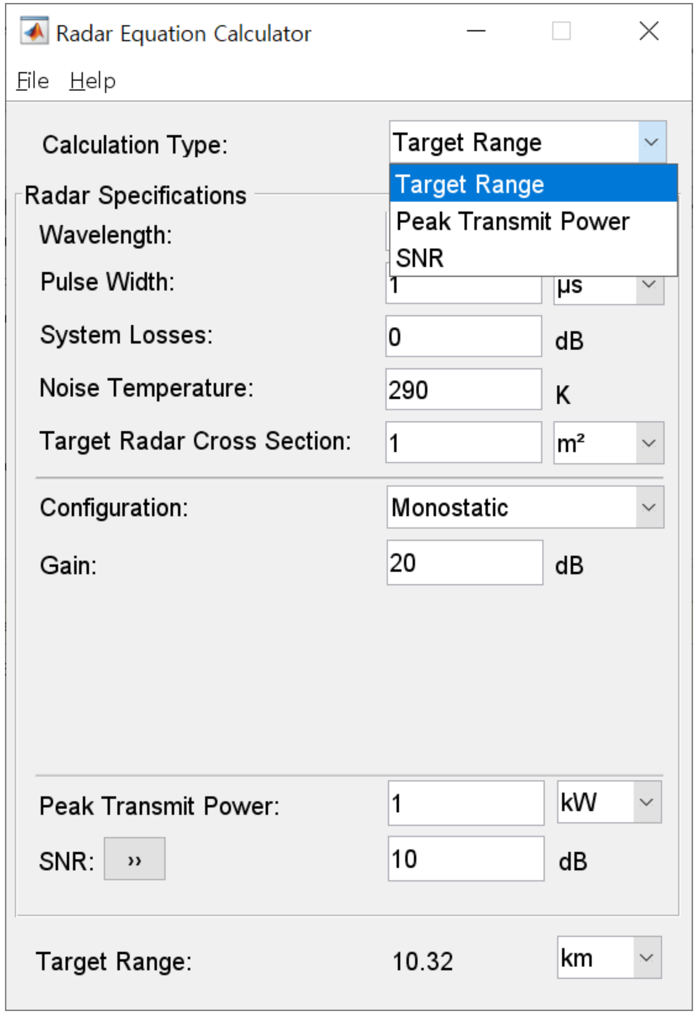
Radar Waveform Analyzer

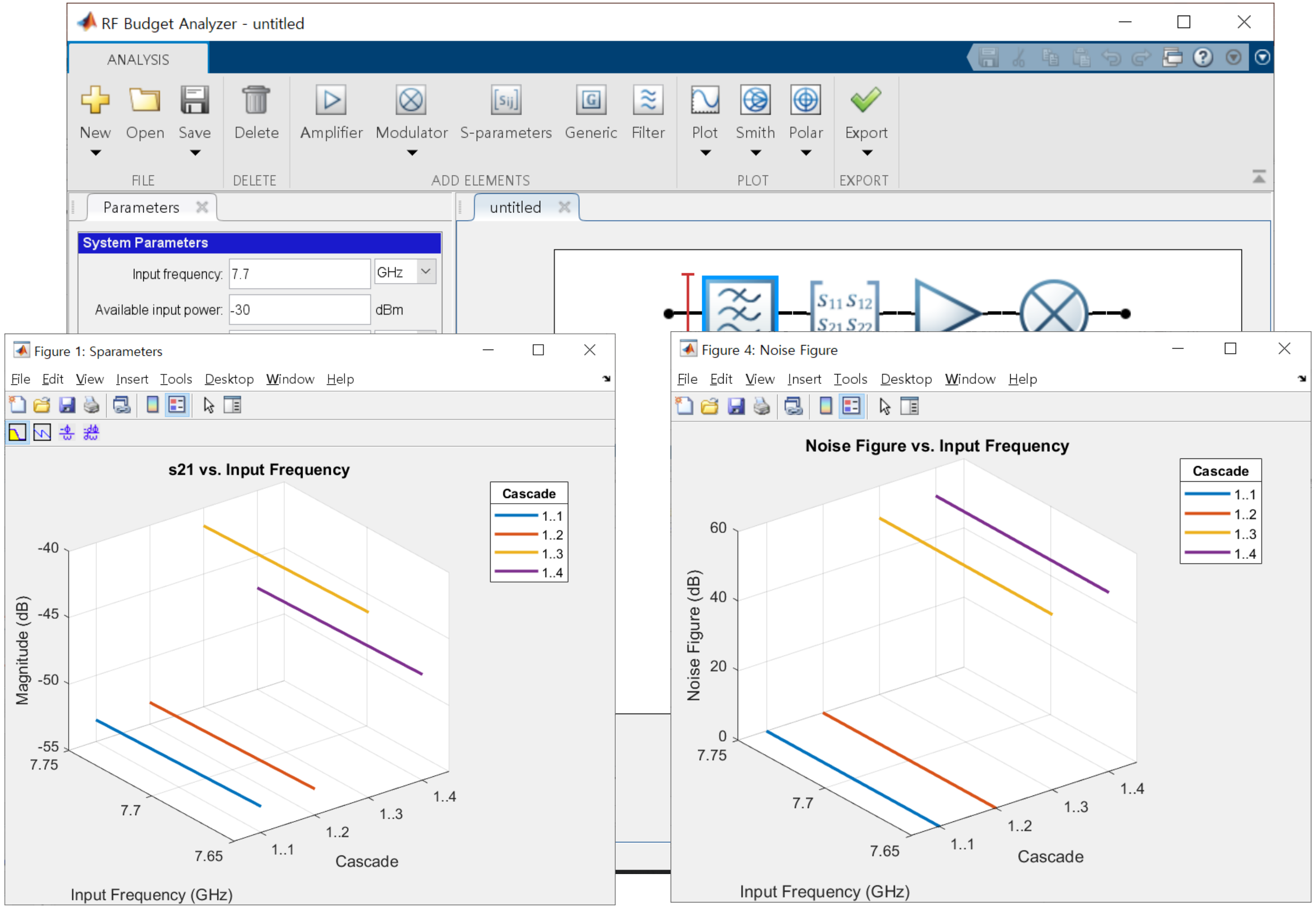


Sensor Array Analyzer

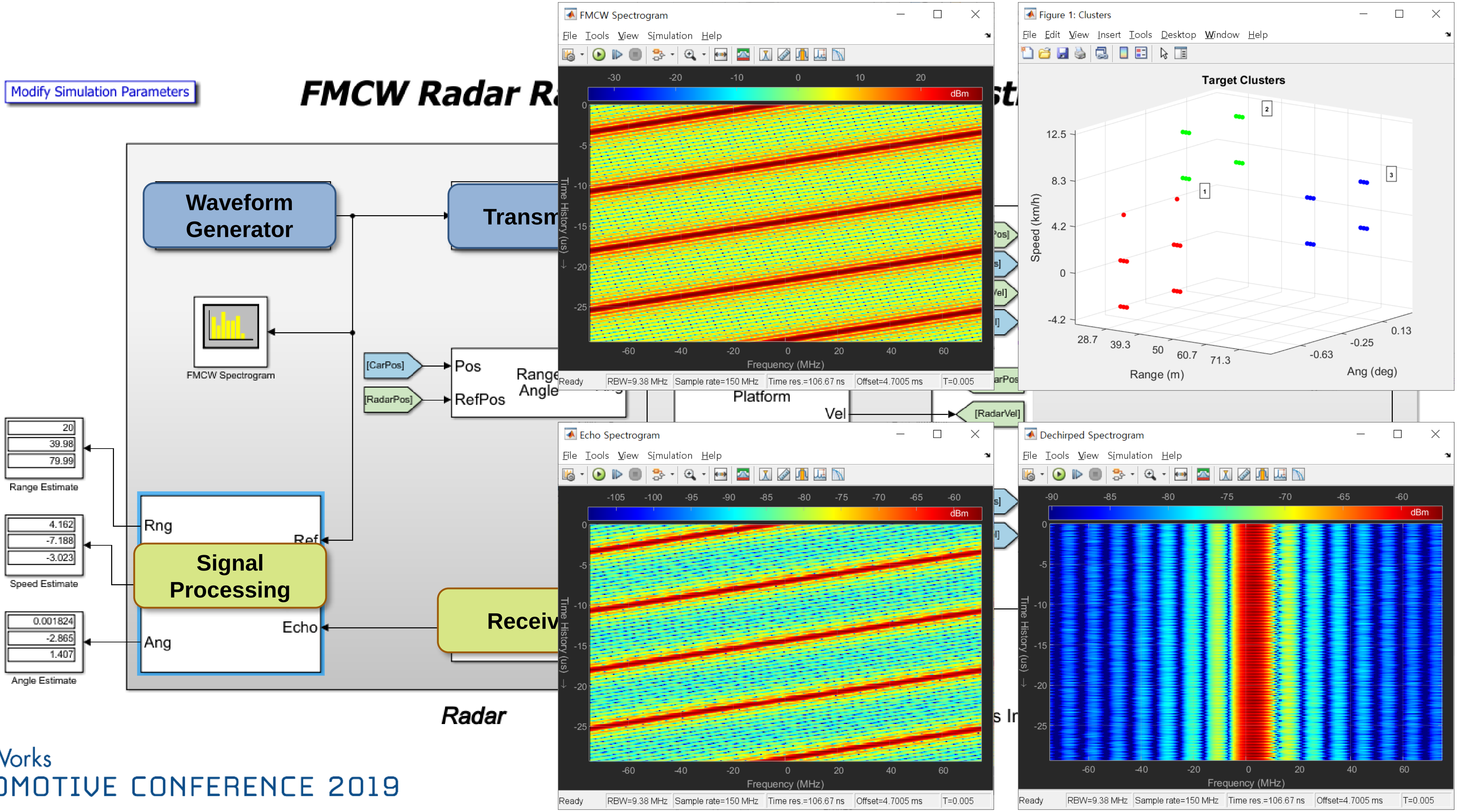


Radar Equation Calculator, RF Budget Analyzer

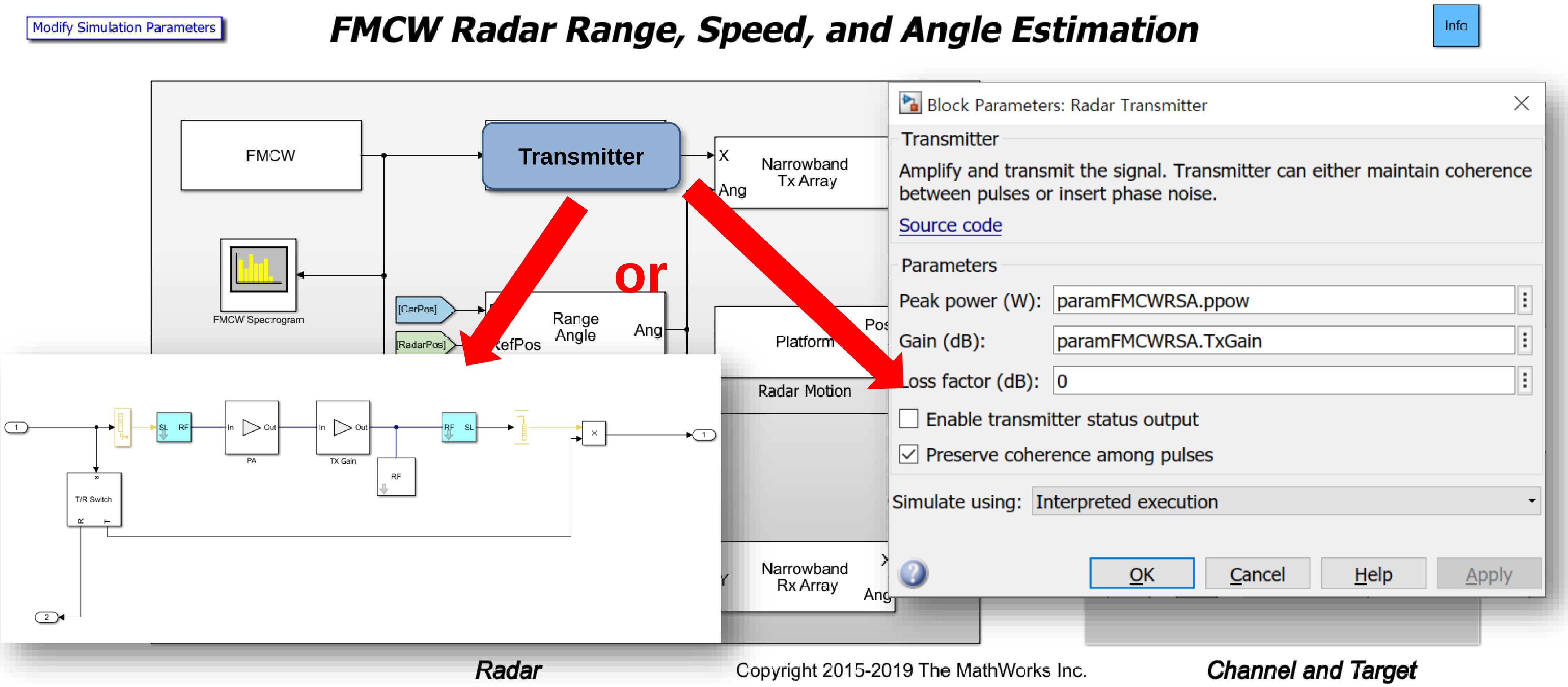




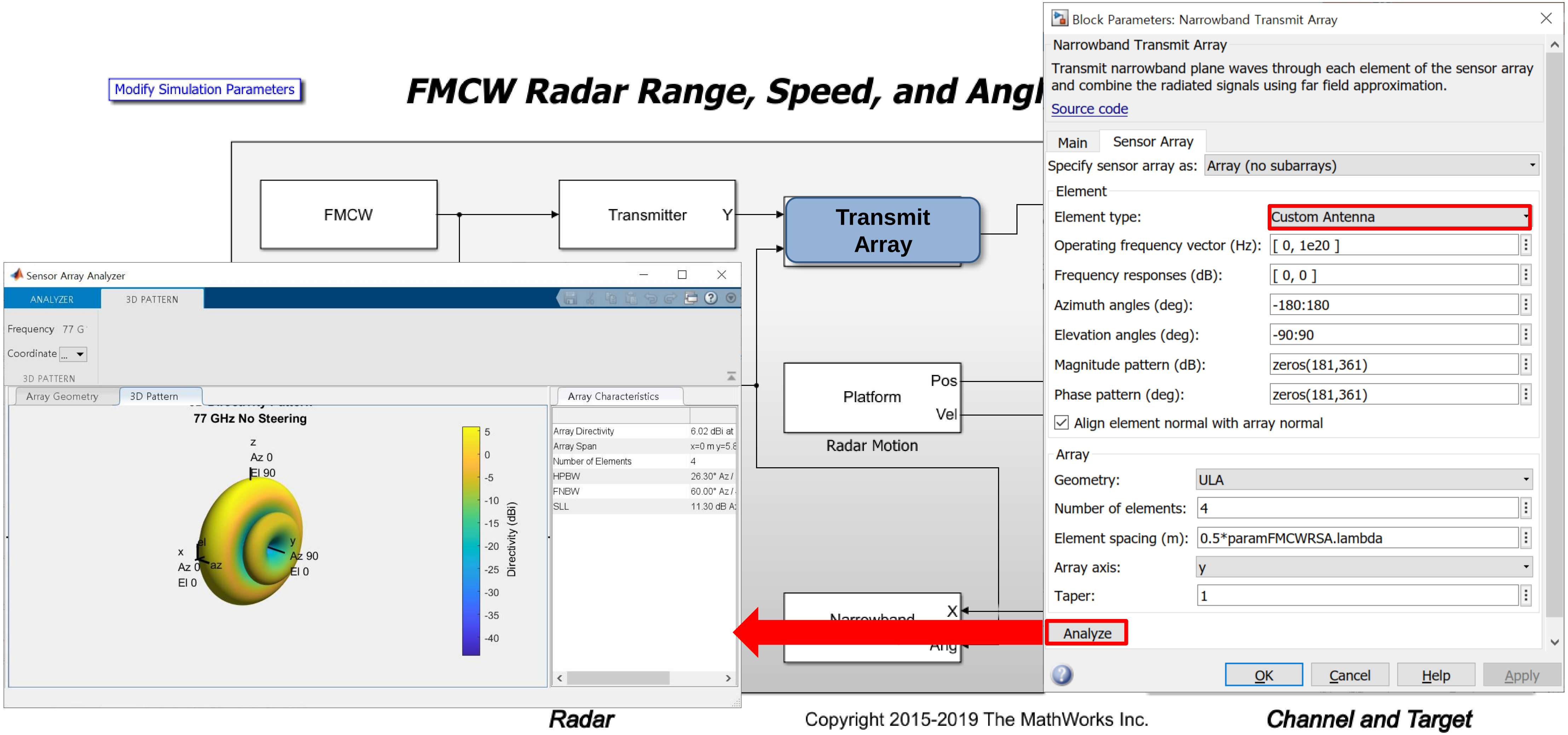
Model FMCW RADARs at mmWave Frequencies



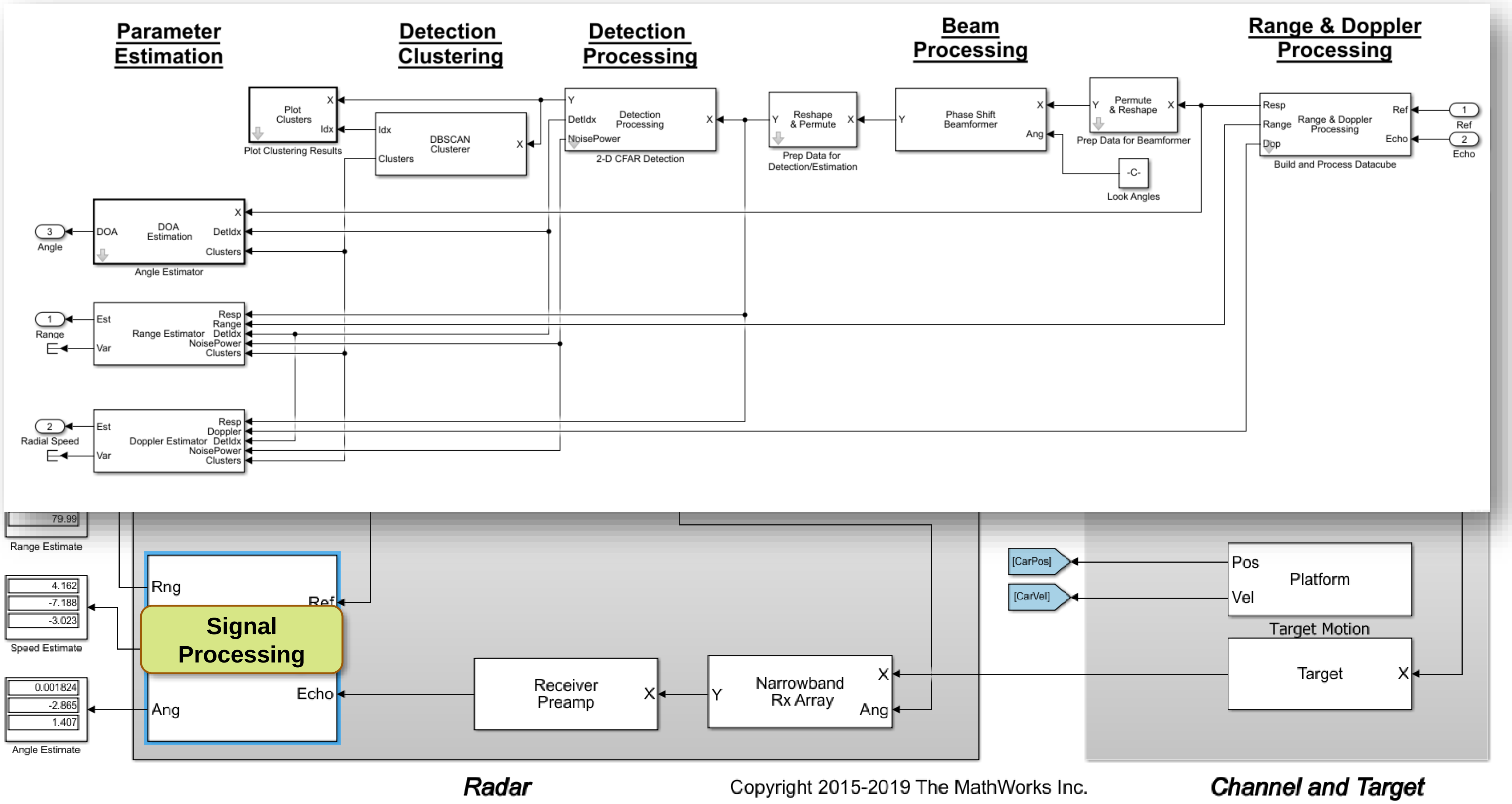
Model FMCW Radar – RF Front-End



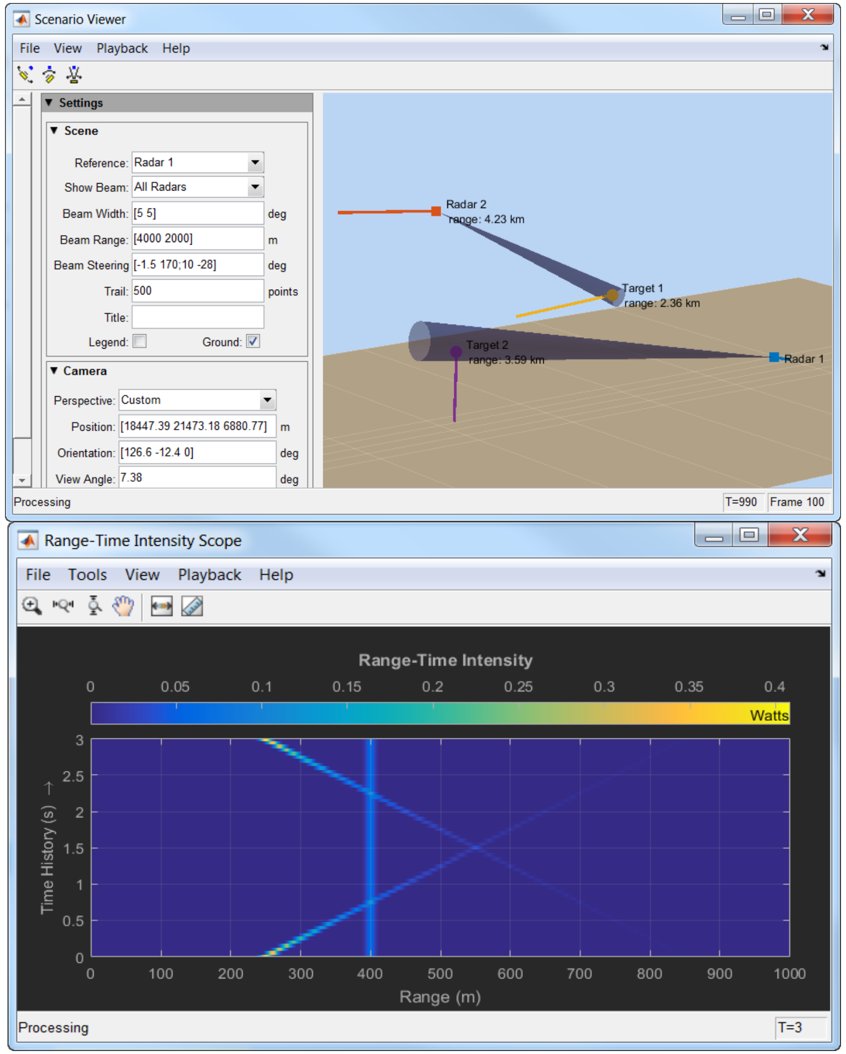
Model FMCW Radar – Transmit Array Antenna

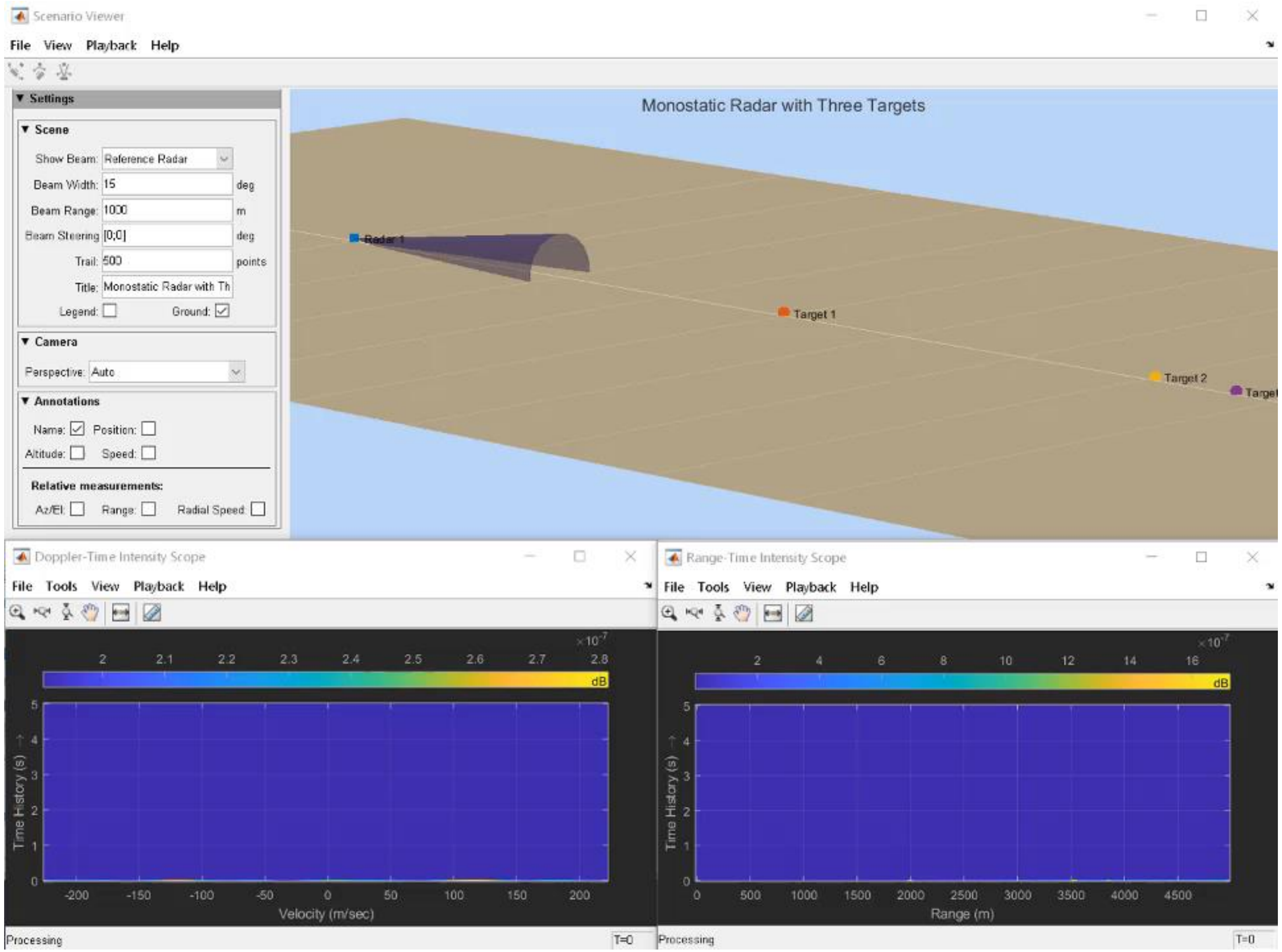


Model FMCW Radar – Signal Processing

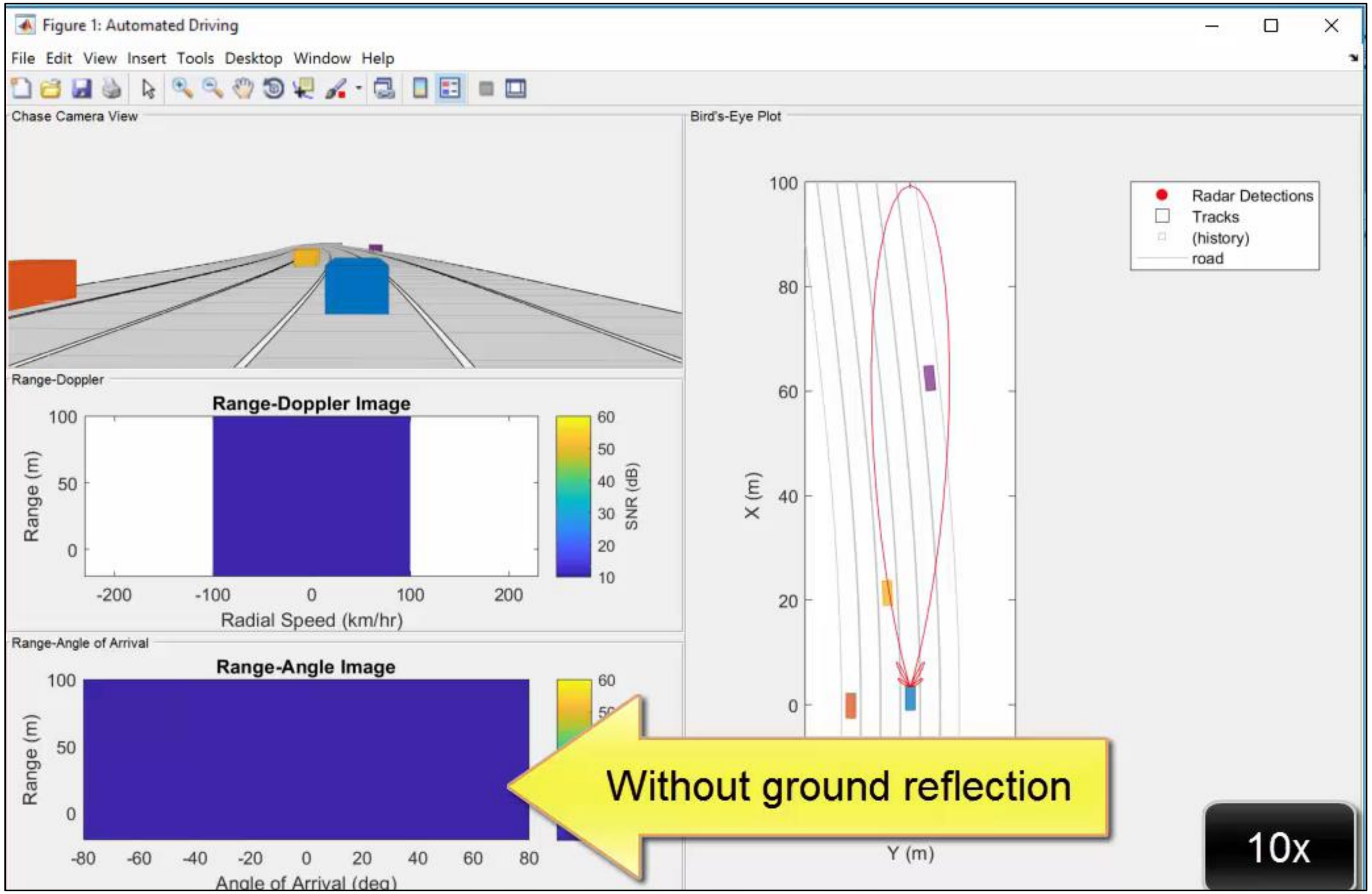


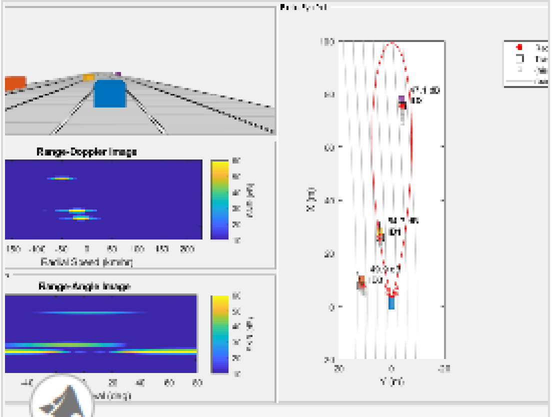
Visualizing Radar and Target Trajectory





Automated Driving Simulation with IQ-level Radar Signal



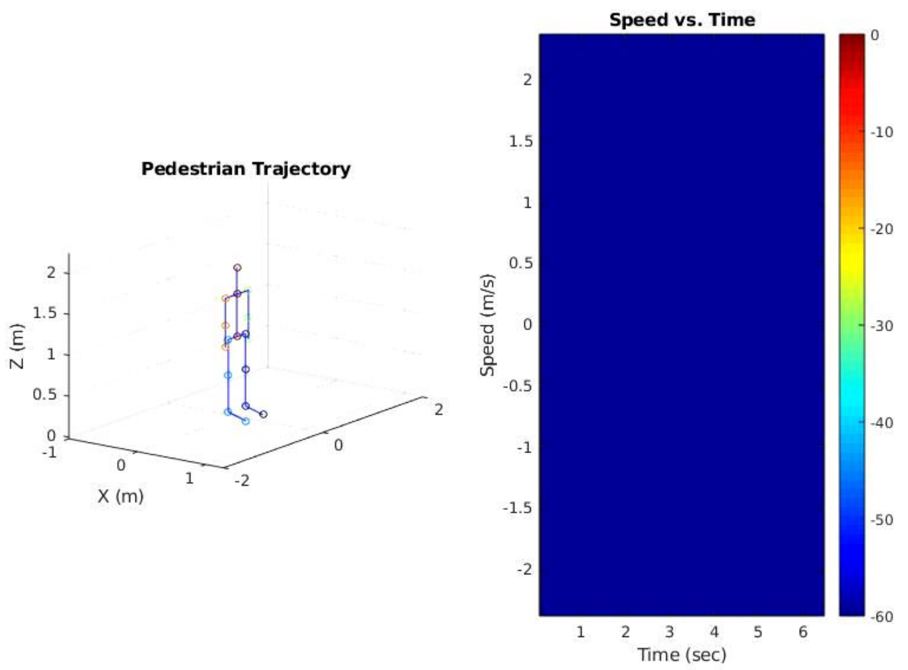


Radar Signal Simulation and Processing for Automated Driving

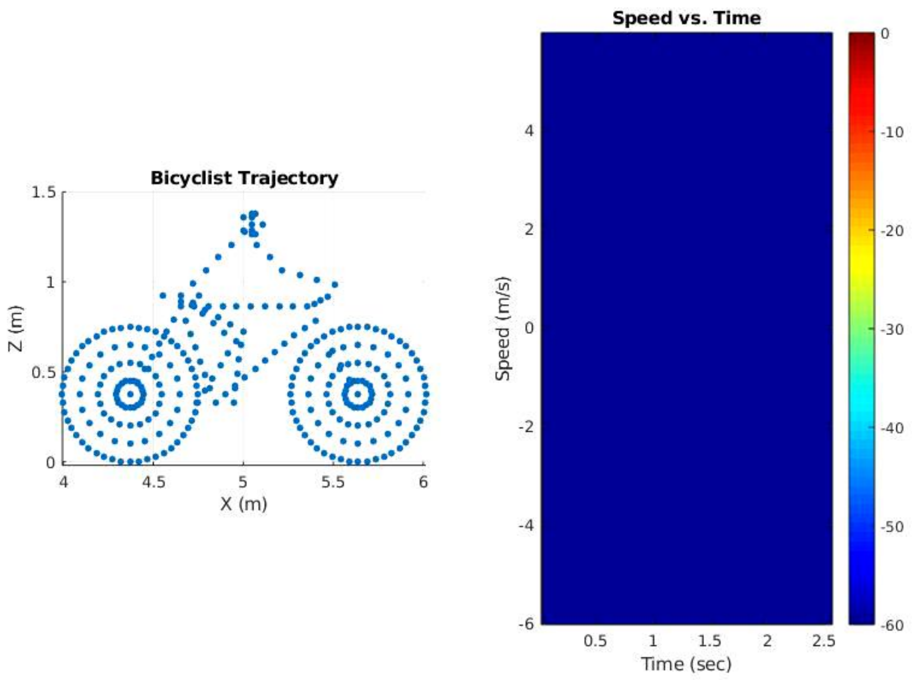
Model a radar's hardware, signal processing, and propagation environment for a driving scenario. First you develop a model of the

Open Script

Simulating Micro-Doppler Signatures

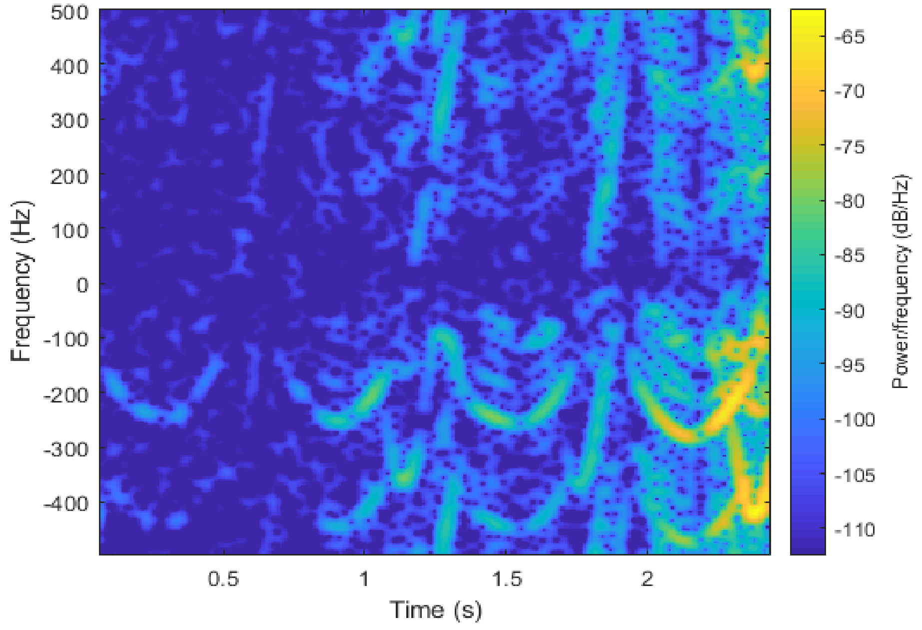


Micro-Doppler for Pedestrian

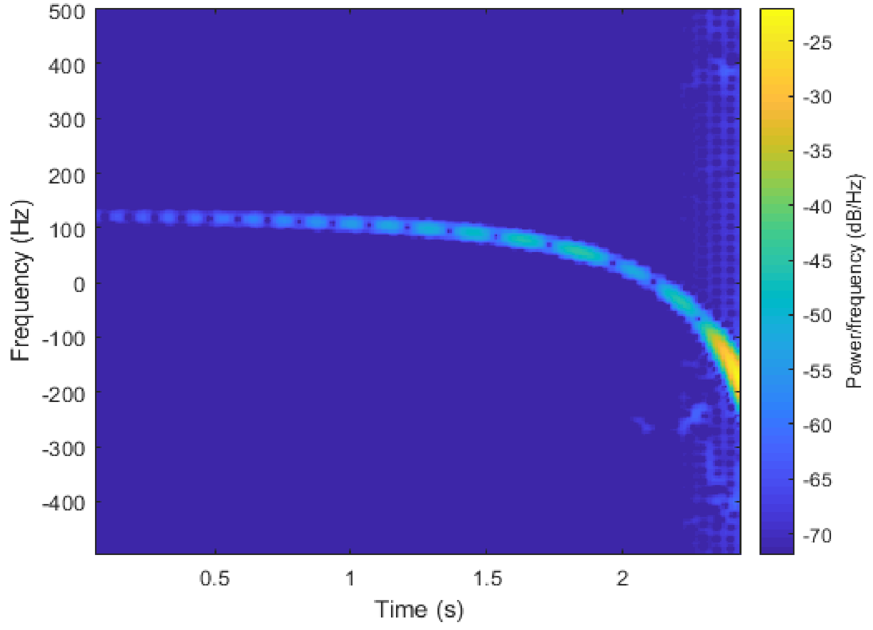


Bicycle

Pedestrian Micro-Doppler with and without Parked Vehicle

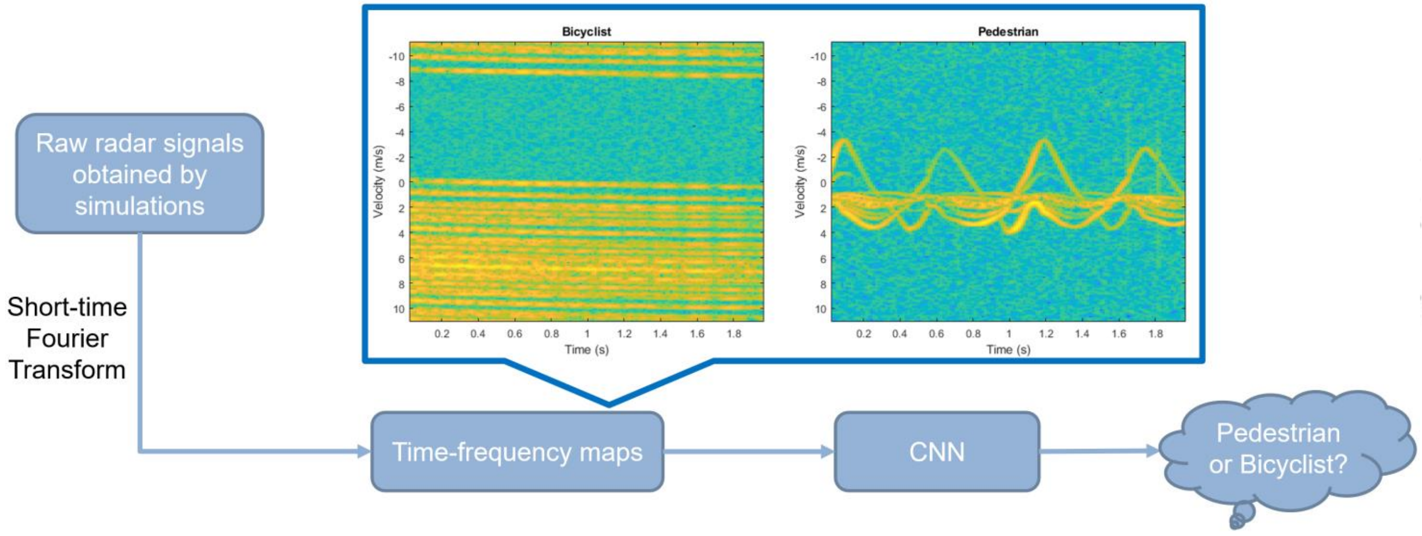


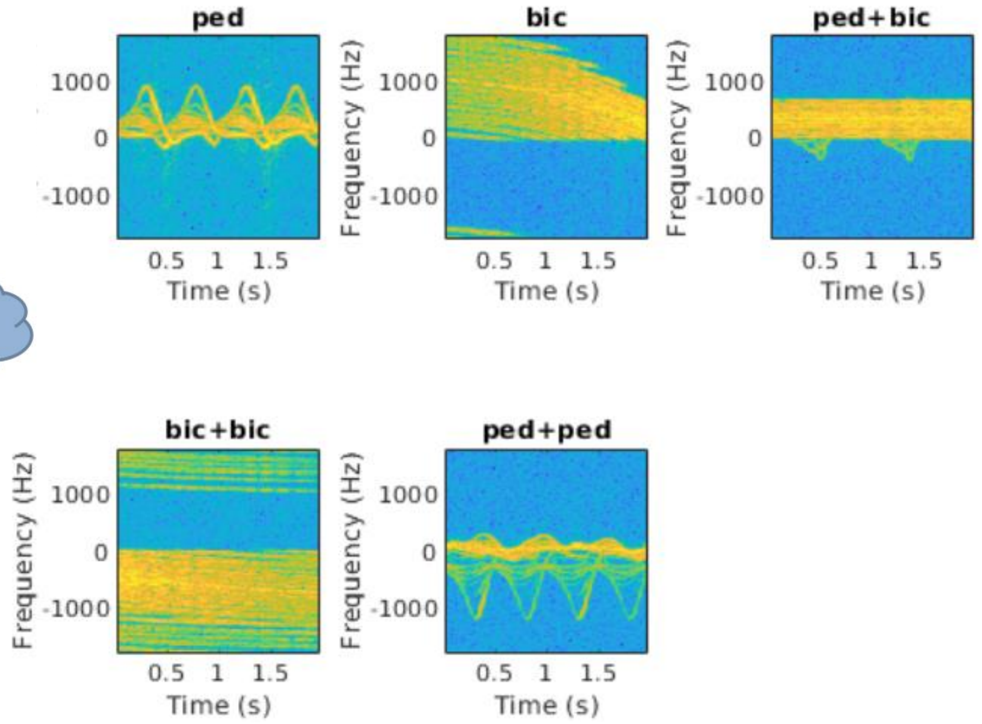
Micro-Doppler for pedestrian (only)



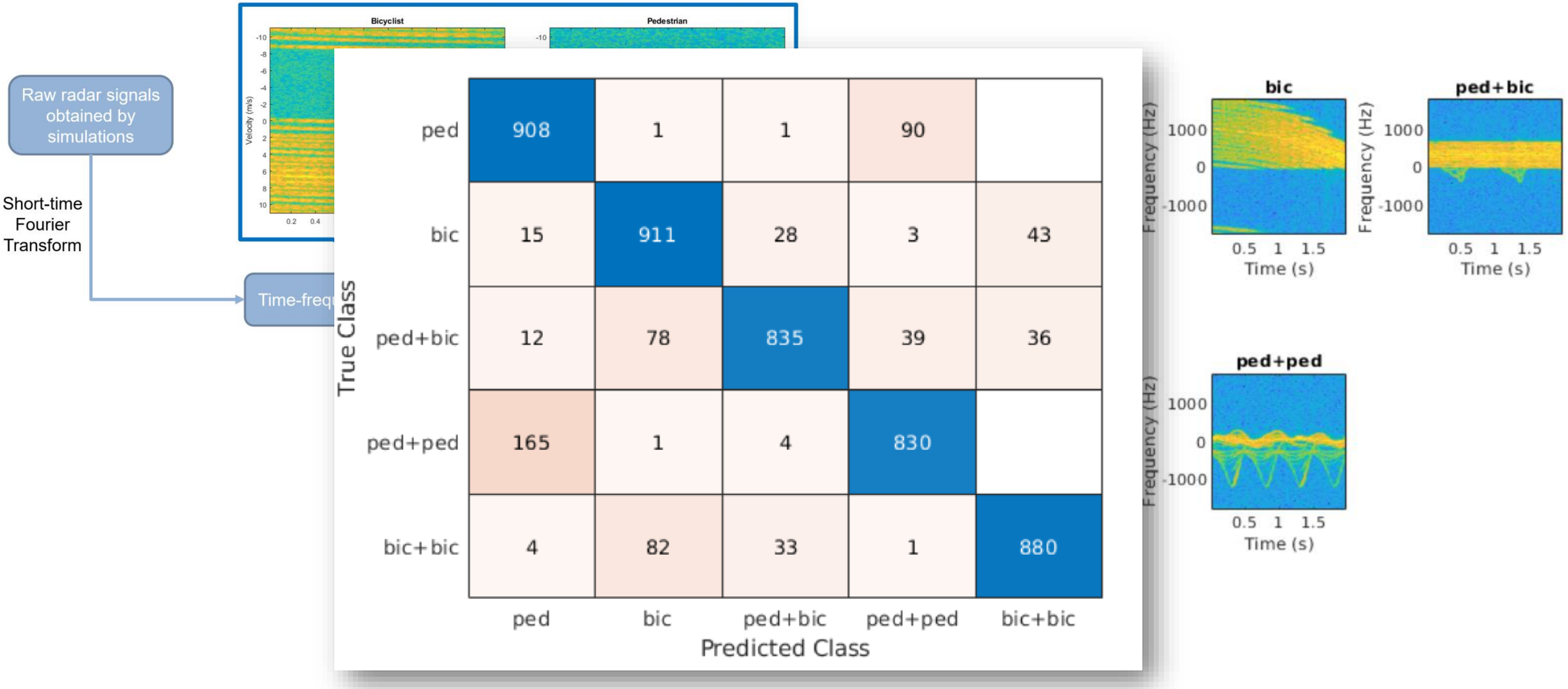
Micro-Doppler for pedestrian and parked vehicle

Pedestrian and Bicyclist Classification Using Deep Learning



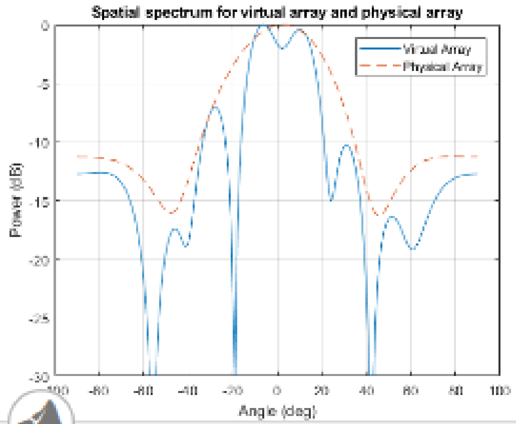


Pedestrian and Bicyclist Classification Using Deep Learning



True Class \ Predicted Class	ped	bic	ped+bic	ped+ped	bic+bic
ped	908	1	1	90	
bic	15	911	28	3	43
ped+bic	12	78	835	39	36
ped+ped	165	1	4	830	
bic+bic	4	82	33	1	880

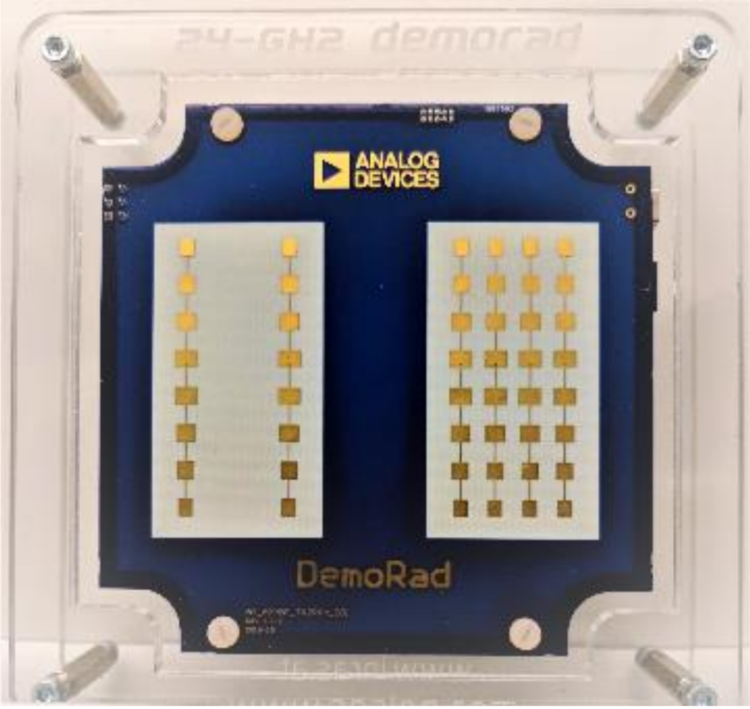
Increasing Angular Resolution with MIMO Radars (Virtual Array)



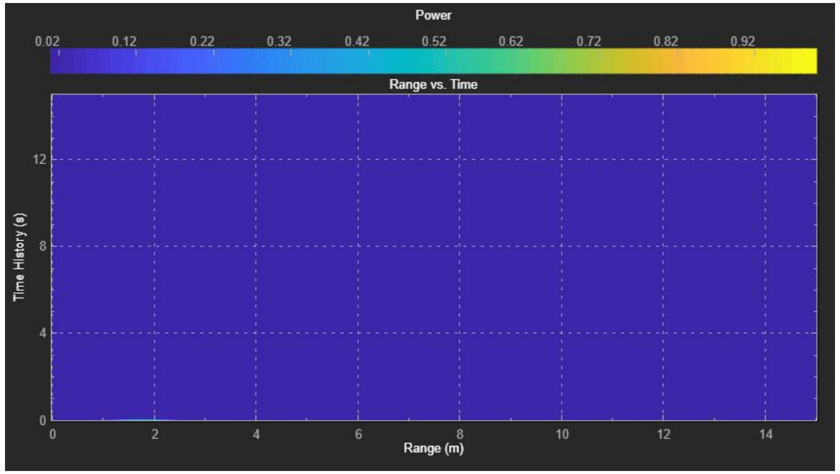
Increasing Angular Resolution with MIMO Radars

Introduces how forming a virtual array in MIMO radars can help increase angular resolution. It shows how to simulate a coherent MIMO

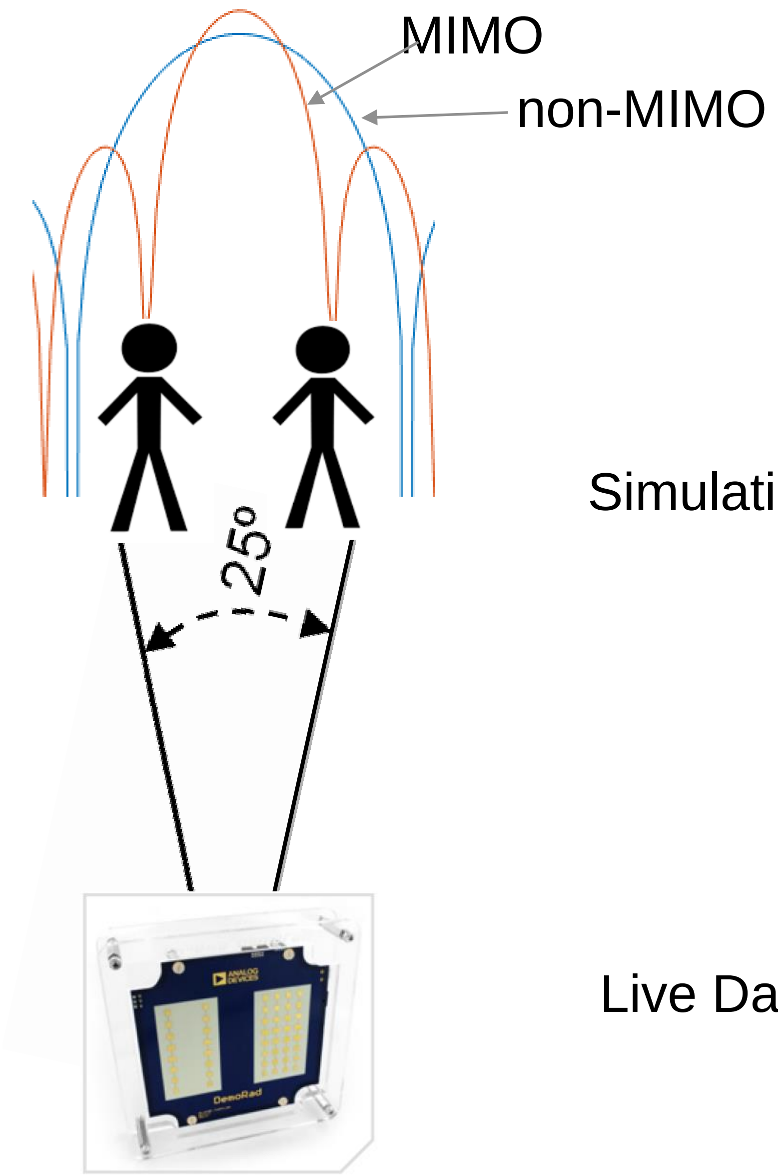
Open Script



2 Tx 4 Rx



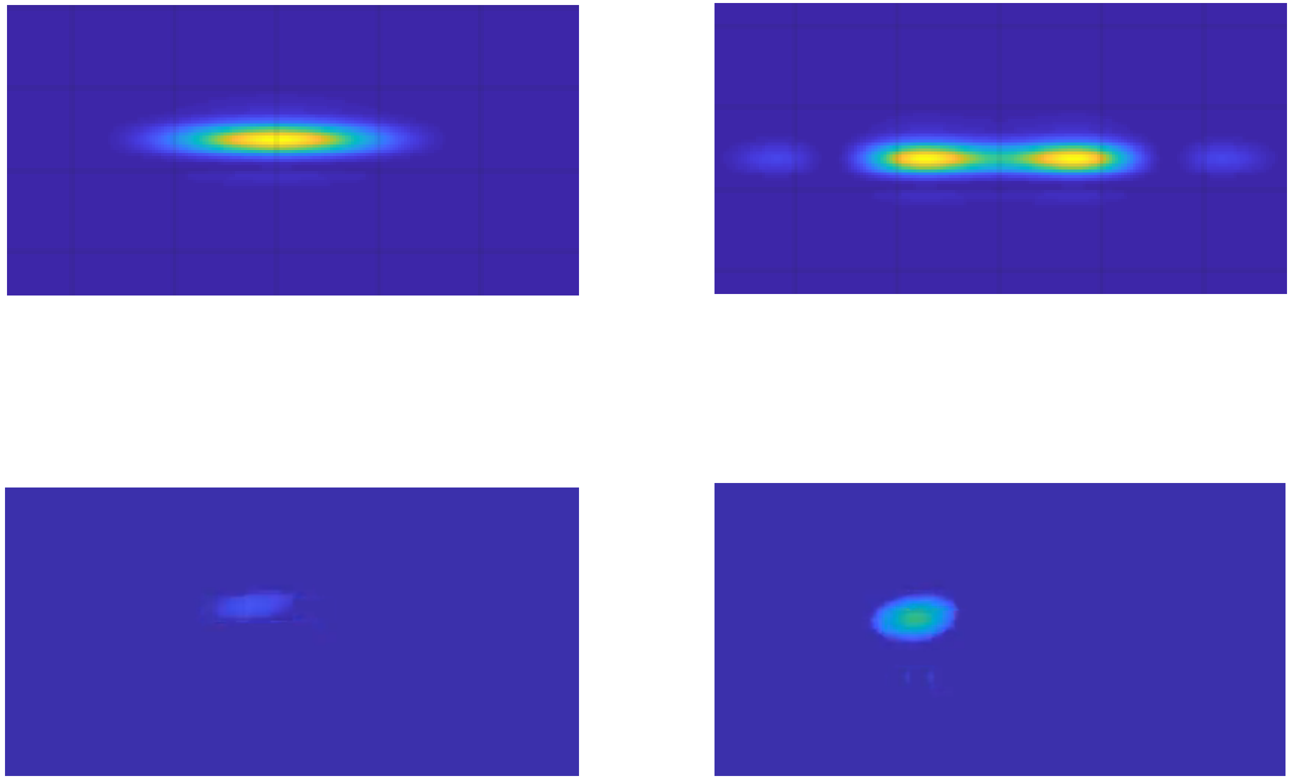
Two options: Increase number of receive elements or perform signal processing



Non-MIMO | MIMO

Simulation

Live Data



Agenda

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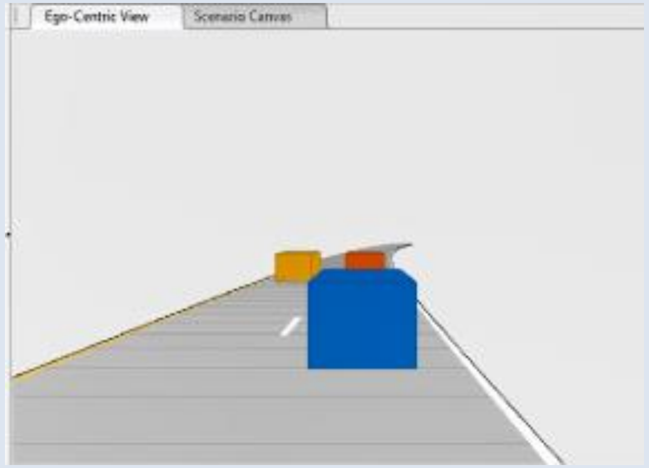
Virtual Driving Scenarios with Radar Sensor

Scenes	**Cuboid** 	**3D Simulation** 
Testing	Controls, sensor fusion, planning	Controls, sensor fusion, planning, perception
Authoring	Driving Scenario Designer App Programmatic API (drivingScenario)	Unreal Engine Editor
Sensing	Probabilistic radar (detection list) Probabilistic vision (detection list) Probabilistic lane (detection list)	Probabilistic radar (detection list) Monocular camera (image, labels, depth) Fisheye camera (image) Lidar (point cloud)

Synthesize Radar Sensor Data

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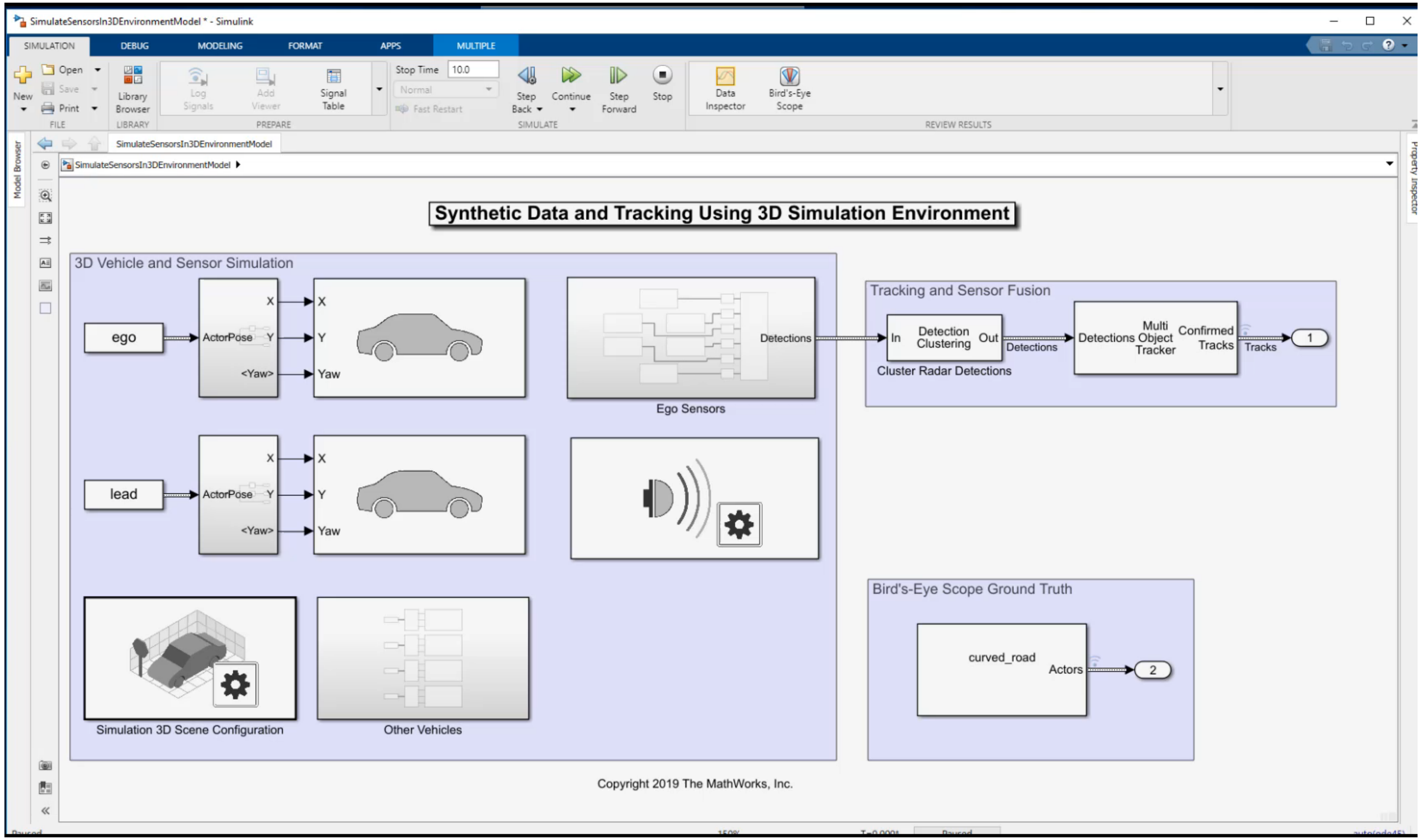
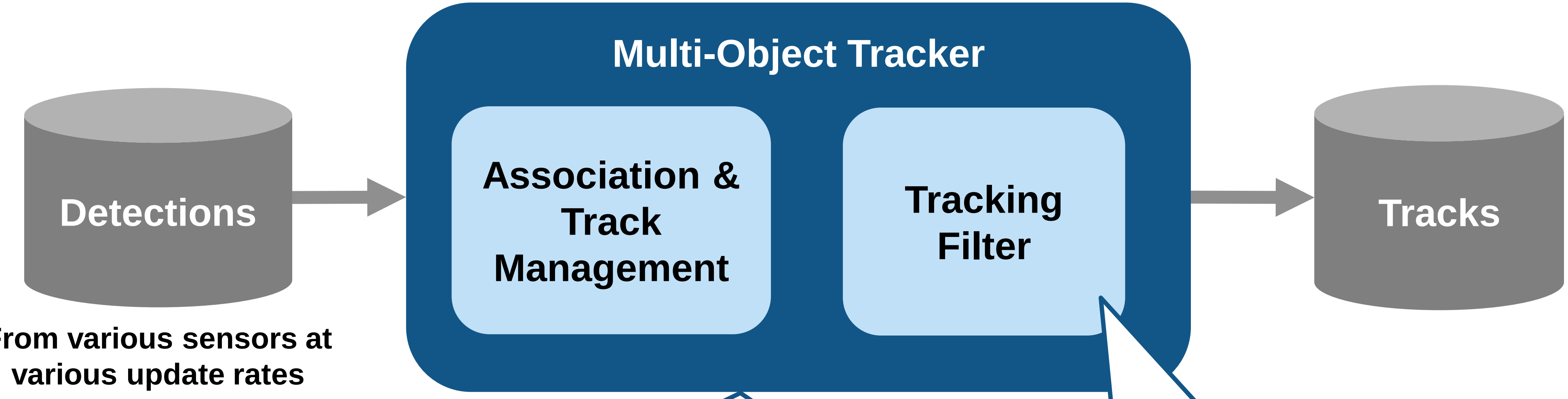
[Simulate Radar Sensors in 3D Environment]

- Extract the center locations
- Use center location for road creation using driving scenario
- Define multiple moving vehicles
- Export trajectories from app
- Configure multiple probabilistic radar models
- Calculate confirmed track

Automated Driving Toolbox™



Design trackers



- Multi-object tracker
- Global Nearest Neighbor (GNN) tracker
- Joint Probabilistic Data Association (JPDA) tracker
- Track-Oriented Multi-Hypothesis Tracker (TOMHT)
- Probability Hypothesis Density (PHD) tracker

- Linear, extended, and unscented Kalman filters
- Particle, Gaussian-sum, and Interacting Multiple Model (IMM) filters

Automated Driving Toolbox™

Sensor Fusion and Tracking Toolbox™

Design Multi-Object Trackers

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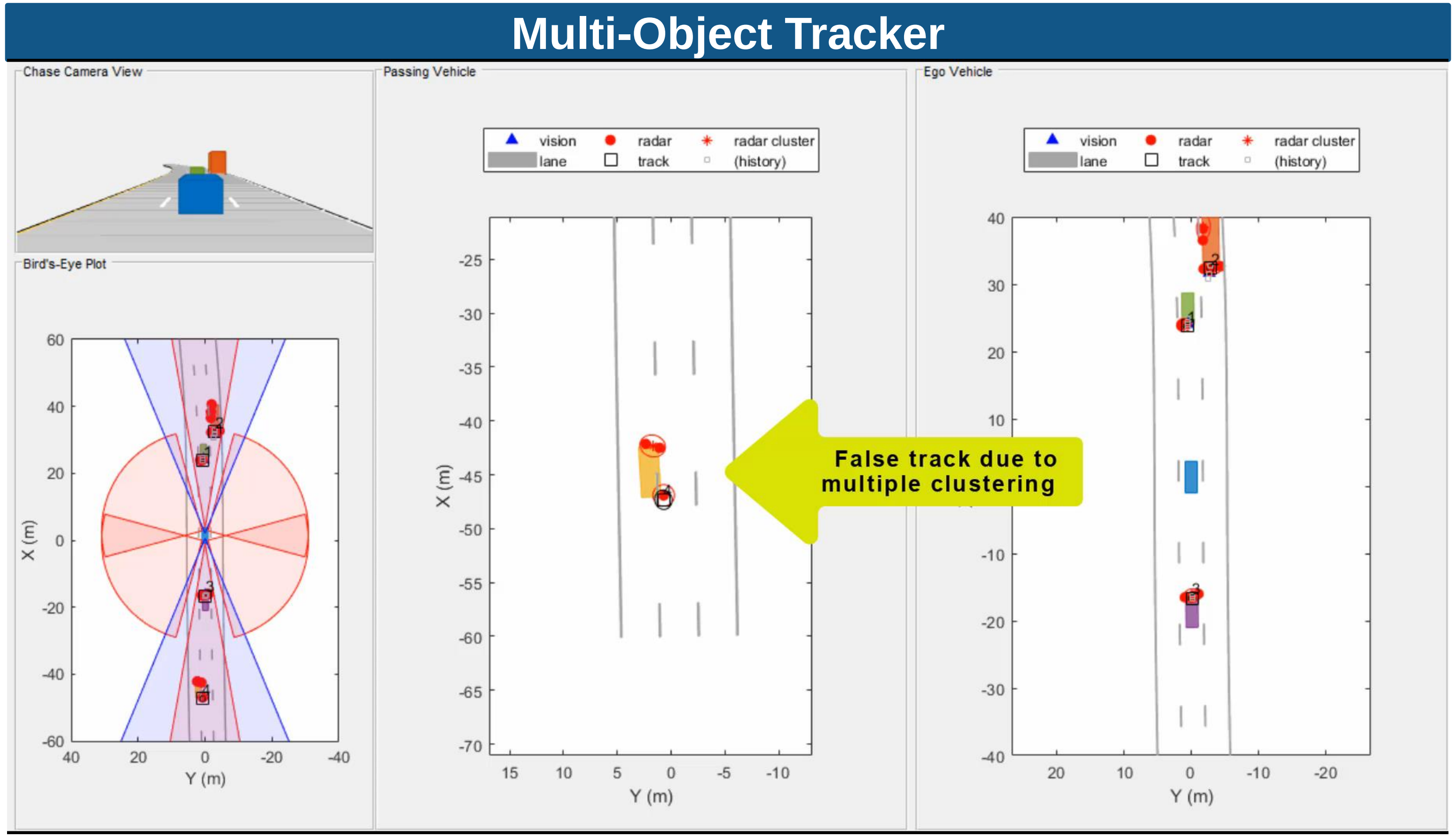
[Extended Object Tracking](#)

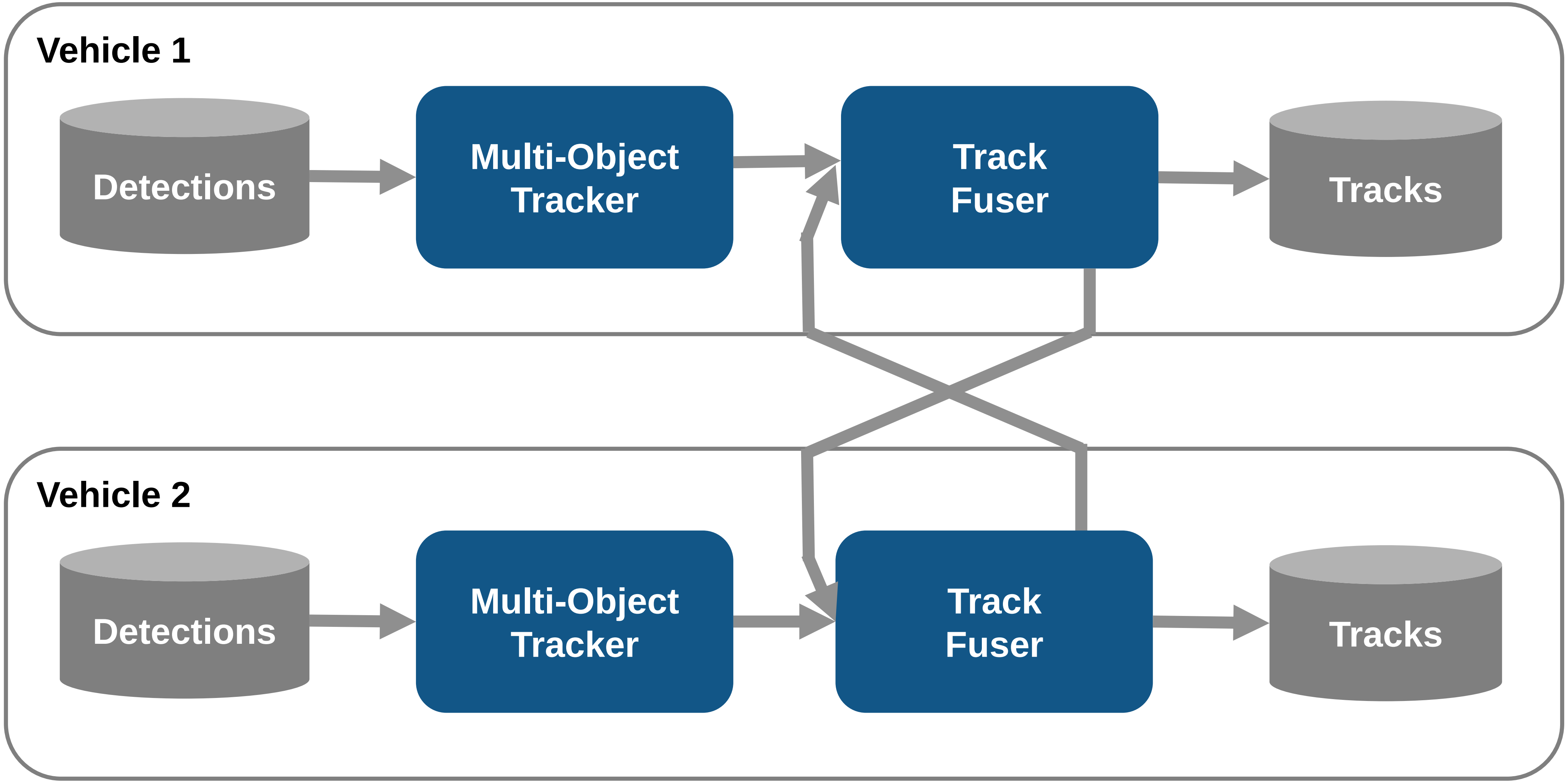
- Design multi-object tracker
- Design extended object trackers
- Evaluate tracking metrics
- Evaluate error metrics
- Evaluate desktop execution time

Sensor Fusion and Tracking Toolbox™

Automated Driving Toolbox™



Design track level fusion systems

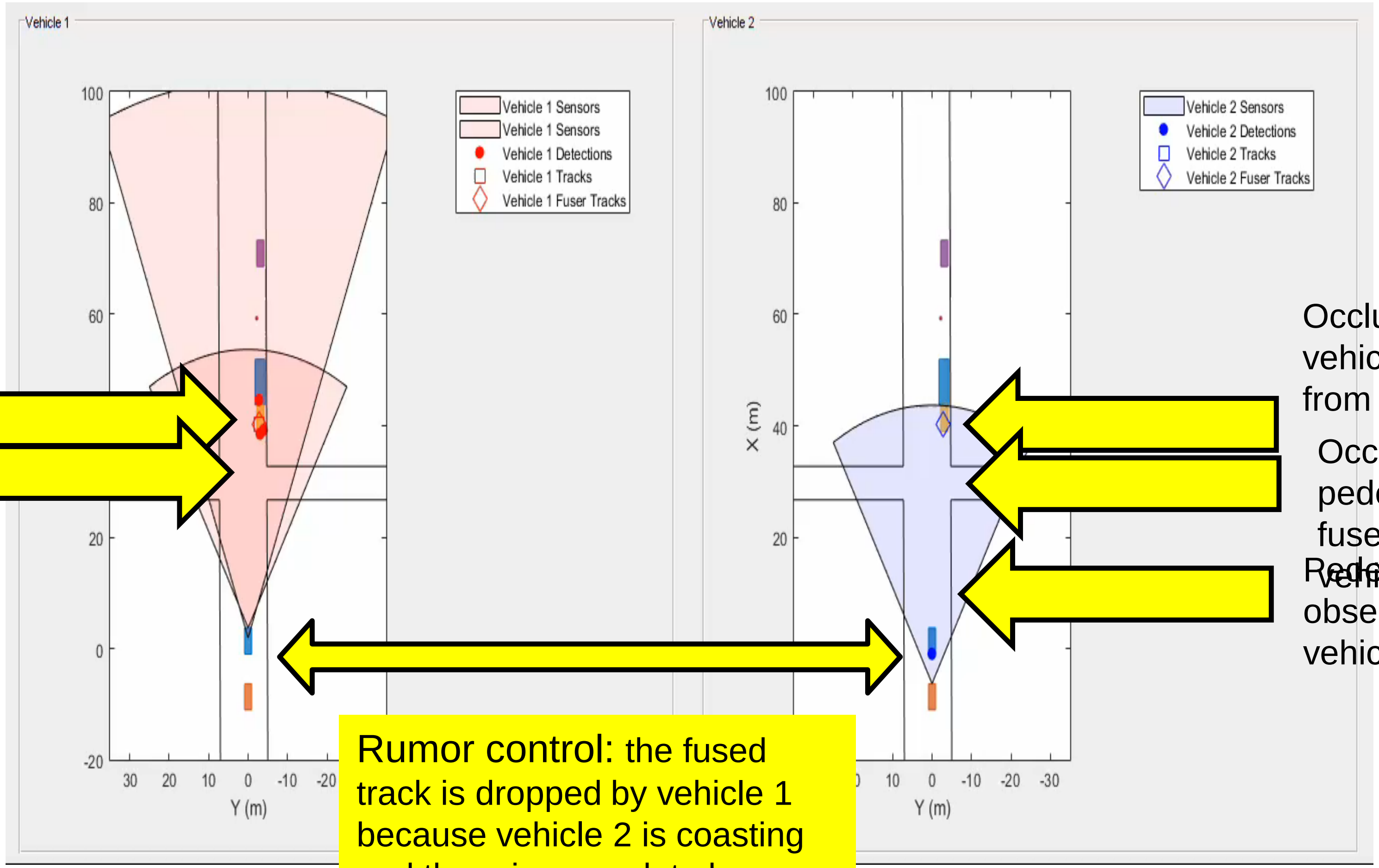


Track-Level Fusion

[Track-to-Track Fusion for Automotive Safety Applications]

Parked vehicles observed by vehicle 1

Pedestrian observed by vehicle 1



Occluded vehicle fused from vehicle 1

Occluded pedestrian fused from vehicle 1

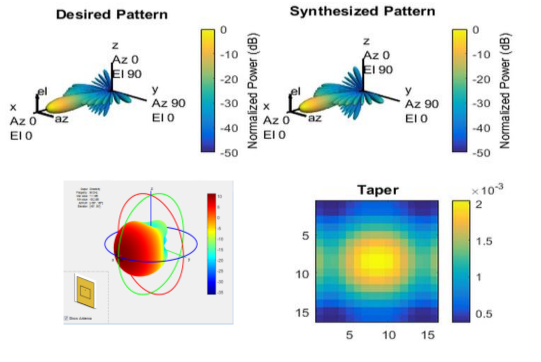
Pedestrian observed by vehicle 2

Rumor control: the fused track is dropped by vehicle 1 because vehicle 2 is coasting and there is no update by vehicle 1 sensors

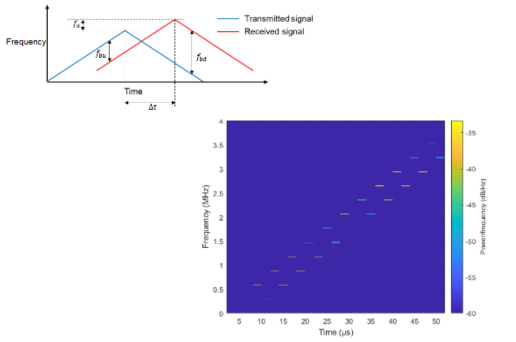
Sensor Fusion and Tracking Toolbox™
Automated Driving Toolbox™

Radar System Modeling for Perception

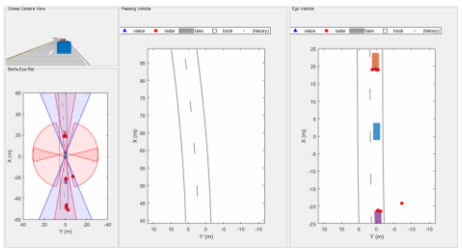
Antenna/RF



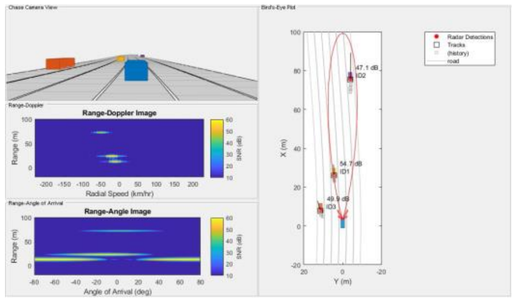
Waveforms



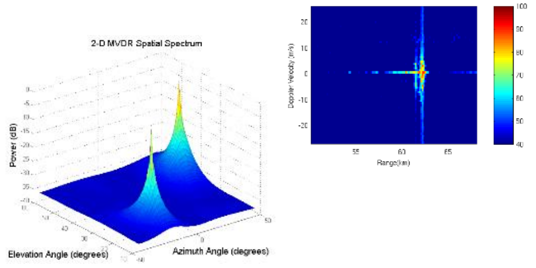
Tracking/ Sensor Fusion



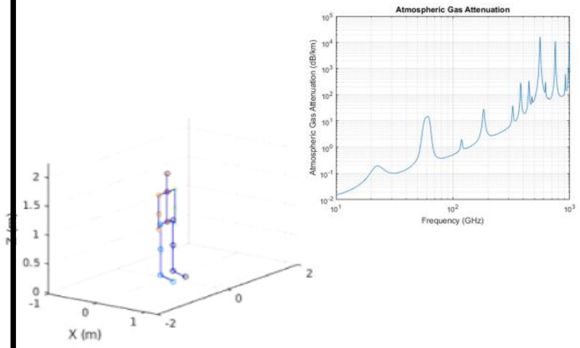
Scenario Generation



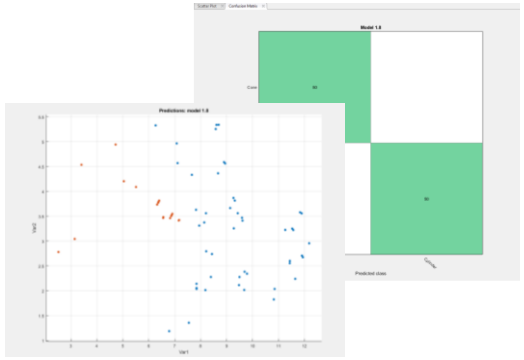
Spatial Signal Processing



Environment



Deep Learning



Code generation

MATLAB

HDL

Key Takeaways

- Choose the Right Modeling Method
  - You can control the fidelity
- Start Your First Radar Design with Various Apps
- High Level Simulation with Probabilistic Model
  - Tracking
  - Control

Thank You!