Radar System Design Using MATLAB and Simulink

김용정 부장(James.kim@mathworks.com)
Application Engineer
MathWorks
Outline

- Introduction
- Radar System Design and Analysis
- ADAS Radar Systems
- Increasing the fidelity of RF and Antenna models
- Summary
Radar System Design: From Antenna to Algorithms

Antenna, Antenna arrays
- type of element, # elements, configuration
  - Antenna Toolbox
  - Phased Array System Toolbox

Channel
- interference, clutter, noise
  - Communications System Toolbox
  - Phased Array System Toolbox

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

Mixed-Signal
- Continuous & discrete time
  - Simulink (Simscape)
  - DSP System Toolbox
  - Control System Toolbox

Algorithms
- beamforming, beamsteering, MIMO
  - Phased Array System Toolbox
  - Communications System Toolbox
  - DSP System Toolbox

Signal and Data Processing
- TX
  - LNA
  - ADC
  - DAC
- RX
  - PA

Waveforms and Task Scheduling
- SimEvents
  - Phased Array System Toolbox
  - Signal Processing Toolbox
  - Instrument Control Toolbox
  - SimEvents
Radar System Design with Phased Array System Toolbox

Waveforms
Pulse, LFM, FMCW, etc.

Transmitter
Monostatic and Bistatic

Tx Antenna Arrays
ULA, URA, UCA, etc.

- Specify radar requirements
- Research and design new algorithms
- Test algorithms with realistic data
- Simulate end-to-end radar systems

Environment effects, impairments, interferences

Beamforming, Matched Filtering, Detection, CFAR, STAP, etc.

Receiver
Monostatic and Bistatic

Rx Antenna Arrays
ULA, URA, UCA, etc.

Environment effects, impairments, interferences
Benefits of Flexible Modeling and Simulation Framework

- Rapidly model and simulate phased array systems in the MATLAB and Simulink environments
  - Interactive development with algorithms and tools specifically for phased array systems
  - Explore alternative system architectures and make system level trade-offs
  - Access to MATLAB’s visualization and analysis tools
  - Capture system requirements in an executable model
  - Common “language” and interface across teams and projects

- Re-use and extend existing code and IP
  - Use existing C, MATLAB, and other code
  - Open API lets you include proprietary target models and environment models

- Process offline data in the same environment
  - Re-use the same algorithms and test benches
What’s New in Radar Modeling?

Waveform Generator → Transmitter → Transmit Array

Signal Processing → Receiver → Receive Array

Wideband support

GCC-PHAT DOA

Array orientation & Phase shift quantization

Wideband Transmit Array

Range-time Intensity

Doppler-time Intensity
What’s New in Targets, Platform and Environment?

**Platform acceleration**
- Model the motion of platforms such as aircrafts or ground vehicles.
- Parameters: Velocity, Initial position (m), Acceleration, Source of velocity, etc.
- Simulate using: Interpreted execution

**Angle dependent backscatter**
- Compute the reflected signal from a backscatter target.
- Parameters: Azimuth angles, Elevation angles, RCS pattern, Propagation speed, Operating frequency, etc.
- Simulate using: Interpreted execution

**Two-ray**
- Propagation Path
- Two-ray model
- \( L_1 \) and \( L_2 \)
- \( \theta_1 \) and \( \theta_2 \)

**Fractional Delay**
- Delay between rays
- Integer delay vs. expected delay

**Rain, fog and gas**
- Environment
- Wideband free space

**Scenario Viewer**
End-to-End Wideband Radar System – Example Summary

- Tx/Rx Array
  - Transmitter, Receiver, Antenna array
- Propagation channel
  - Path loss, environment
- Signal Processing
  - Beamformer, Matched filter, Stretch processing and Integration
- Target model
  - Custom function with angle and frequency inputs

Built with blocks from Phased Array System Toolbox
User-defined MATLAB function
Pulse Compression in the Wideband Example

- **Pulse Compression**
  - Maximizes peak SNR
  - Convolution in time domain with matched filter
  - Multiply in frequency domain with matched filter

- **Stretch Processing**
  - Apply dechirp processing to a linear FM pulse over a given range span.
    - Resulting sinusoid translates directly to range
  - Alternative for LFM pulses with large bandwidth signals
Wideband Simulink Models

- End-to-End Wideband System Demo
Visualize Radar and Target Trajectories

- Demo
Modeling a Radar Task Scheduler

- Demo

Radar Scheduler Using SimEvents
ADAS Radar

- Modeling an ADAS Radar System
- Long Range Radar Model - Adaptive Cruise Control (ACC)
- Short Range Radar Model - Blind Spot Detection
Background and Motivation

- Consumer demand and legislation drives safety improvements every model year
- Sensor accuracy requirements increase as “passive” safety evolves to “active” system control
- Momentum of autonomous vehicles accelerates ADAS technology

- Reasons for using radar in ADAS:
  - Range and velocity precision
  - Angular resolution and width of view
  - Conditions that impact camera vision do not impact radar view

- Short range radar characteristics
  - Wide bandwidth enables high range resolution at short ranges.

- Long-range radar characteristics
  - Range distance and beam width

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<th>Short/Medium Range</th>
<th>Long Range</th>
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<td>Automatic Cruise Control</td>
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Integrate sensing (radar, vision, etc…) and control algorithms
Designing Radar Systems with Simulink

- **Design** a radar component or system
  - Mix of models with different levels of fidelity
  - Multipath propagation
  - Multiple objects
  - Develop optimal detection algorithms

- **Integrate** a radar component or system
  - Validate radar performance and examine what-if scenarios
  - Simplify system level debug for anomalous data from road-test
  - Evaluate the use of off-the-shelf components to reduce system cost
  - Integrate the radar in a larger system and facilitate sensor integration
Long Range Radar Model - ACC

- FMCW radar model
  - Waveform generation
  - Waveform processing
  - Transmitter and receiver
- Environment model
  - Propagation channel
  - Obstacles
- Vehicle model
  - ACC speed control
  - Vehicle dynamics
- 3D visualization
Blind Spot Detection Model

- Built using Long Range Radar example as a starting point
- Change orientation of the radar
- Modify positioning and velocity of the vehicles
- Update detection algorithm
- Lower transmit power for shorter distance
- Higher range resolution for distance accuracy
Increasing the Fidelity of the RF and Antenna Models
Antenna Toolbox

- Easy design
  - Library of parameterized antenna elements
  - Functionality for the design of linear and rectangular antenna arrays
  - No need for full CAD design

- Rapid simulation setup
  - Method of Moments field solver for port, field, and surface analysis
  - No need to be an EM expert

- Seamless integration
  - Model the antenna together with signal processing algorithms
  - Rapid iteration of different antenna scenarios for radar and communication systems design
Integrating an Antenna Array in a Radar System Model

- You can integrate your antenna into the radar model built in Phased Array System Toolbox

```matlab
% Import antenna element in Phased Array
>> myantenna = dipole;
>> myURA = phased.URA;
>> myURA.Element = myantenna;
```
Antenna Array, Phased Array, and Radiation Pattern

- Phased Array System Toolbox arrays use pattern superposition
  - ULA, URA, UCA and conformal arrays use the same pattern for all elements
  - Heterogeneous arrays have different patterns for different elements
- Antenna Toolbox arrays perform full wave EM analysis
  - Isolated element vs embedded element vs full array

```
Isolated element
pattern(p, 10e9);

Embedded element
pattern(l, 10e9, ... 'ElementNumber', 2);

Full array
pattern(l, 10e9);
```
Wideband Antenna Integration Example

- Demo
Model-Based Design for Radar Systems

- Complete system model
- Requirements traceability
- System behavior exploration
- Cross team collaboration

- Deploy on desktop
- Generate code and HDL
- Integrate into larger systems
- Explore design tradeoffs

- Configuration management
- Automated regression testing
- Report generation
- V&V and security analysis for code
- Support for certification & standards
Summary

- MATLAB, Simulink, Phased Array System Toolbox, Antenna Toolbox and SimRF provide flexible platform for radar system design and simulation
  - Large number of examples to get started with

- MathWorks products also enable design and implementation of radar systems across the workflow

- Thank you very much for your time today