Electromagnetic Simulation Software

Increasing Realism in Auto Radar Drive Scenario Simulation with Multipath, Diffuse Scattering, and Micro-Doppler

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European Microwave Week 2021

Virtual Validation of Automotive Sensors

Introduction: Requirements and Challenges for Auto Radar Drive Scenario Simulation

Drive scenario simulation can offer significant benefits for early testing of sensor designs and as a complement to operational road tests.

Focusing on mmWave radar sensors, there are several challenges to simulation of a realistic automotive scenario:

- Near-field conditions that invalidate traditional RCS concepts
- Densely-faceted vehicle models; complex for traditional "propagation" ray-tracers
- Complex multipath from roadside structures (guard rails, signs, parked vehicles, etc.)
- Dynamic scenarios with multiple vehicles in motion, potentially with moving parts

This presentation uses Remcom's WaveFarer® Radar Simulation Software to describe challenges, solutions, and recent R&D to address key aspects of the problem, including target scattering, multipath and clutter, and micro-Doppler from motion such as the moving limbs of a walking pedestrian.

WaveFarer Radar Simulator

High fidelity radar simulator

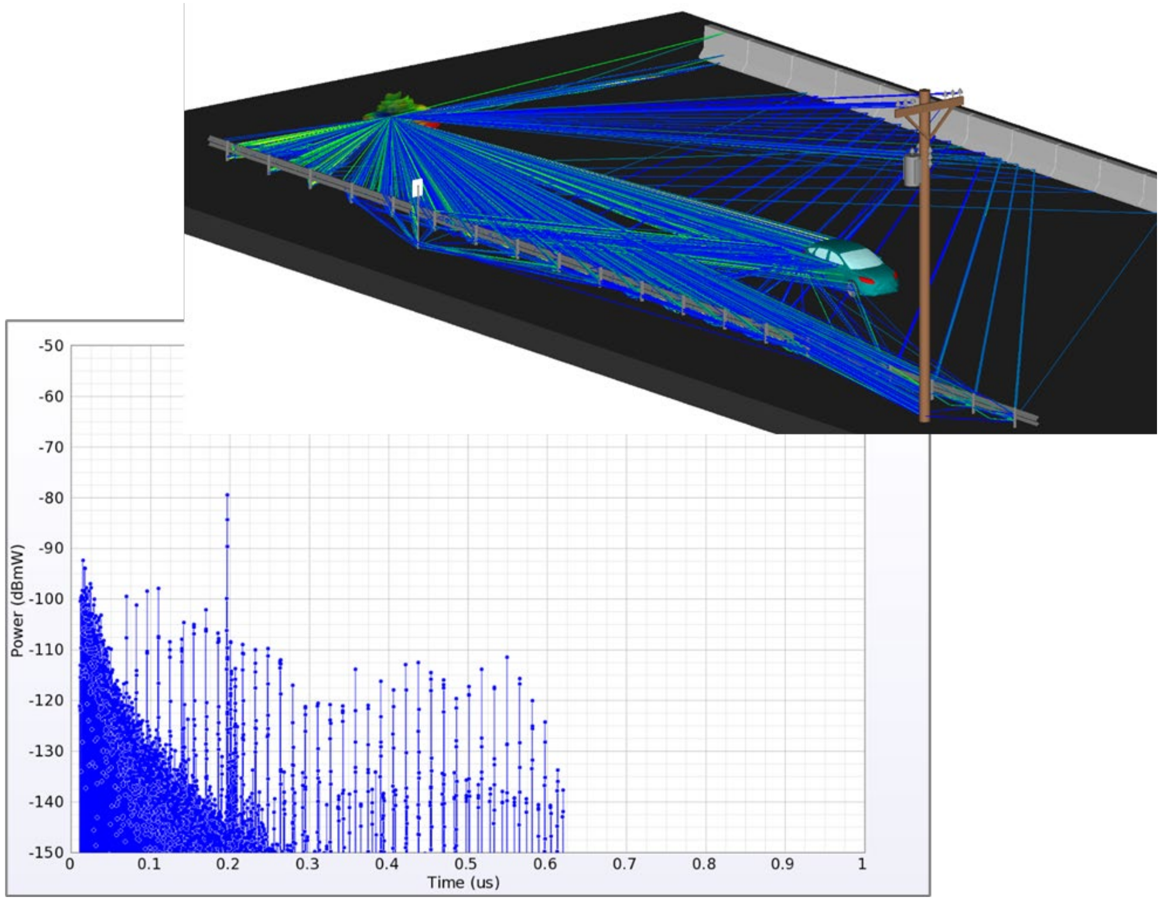
- Designed for close-ranges within cluttered multipath environments

Key capabilities

- Scattering from complex models of vehicles, structures and people
- Multipath with the environment
- mmWave propagation
- Detailed 3D path, polarization, phase data to support Doppler analysis

Applications

- Automotive radar
- Indoor sensors
- Far-field radar cross section (RCS)



Innovative Ray-Tracing Enhancements

Targeted ray-casting

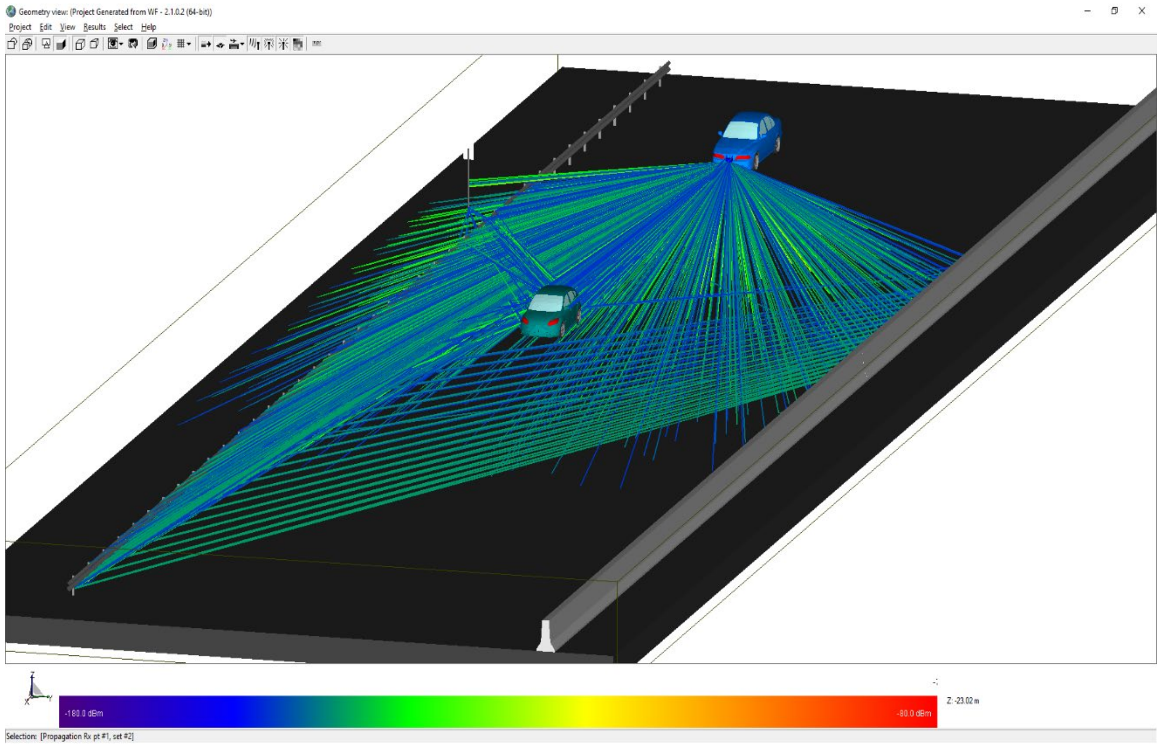
- Launches rays directly at target facets, and extends multipath hits
- Unlike standard SBR, ensures full illumination for surface integration

Exact path correction

- Accurate magnitude, phase, polarization, and time of arrival

Spherical wave incidence to eliminate far-field assumptions

Multipath on way to and from scattering objects



Electromagnetic Methods

Physical Optics (PO) for backscatter

- Surface integration technique accurately predicts backscatter from highly faceted vehicle models in full, 4-π steradians
- Does not make far-field assumptions, allowing for spherical wave incidence

Method of Equivalent Currents (MEC) for edge effects

- Specially derived for Remcom's PO technique to find electric and magnetic line currents
- Included as line integrals to supplement PO surface integral

Geometric Optics and Uniform Theory of Diffraction (GO/UTD)

- Used to propagate to scattering surfaces to provide incident electric and magnetic fields for surface integration
- Used to propagate back to ensure reciprocity

Clutter from Diffuse Scattering

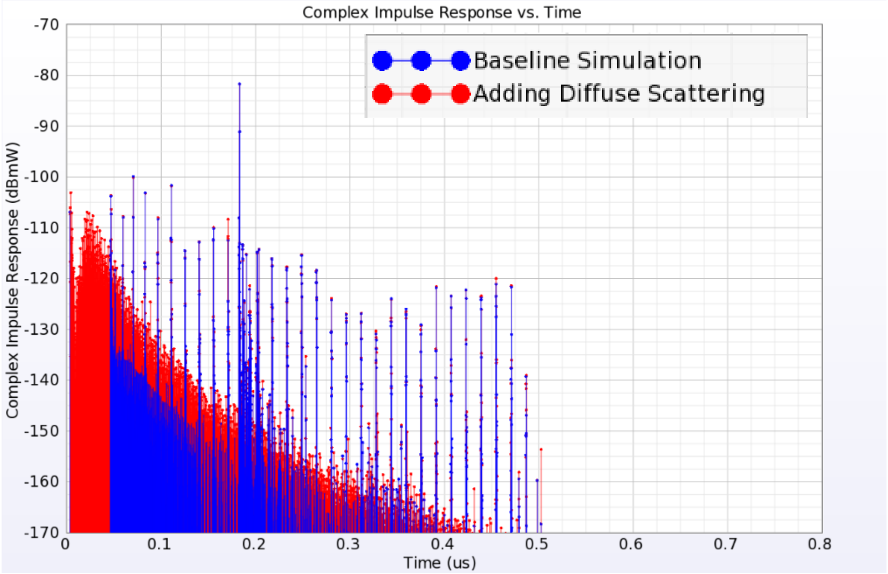
Rough surfaces on roads, walls, and other structures can contribute significant clutter to radar returns

Diffuse scattering models offer a way to capture these effects

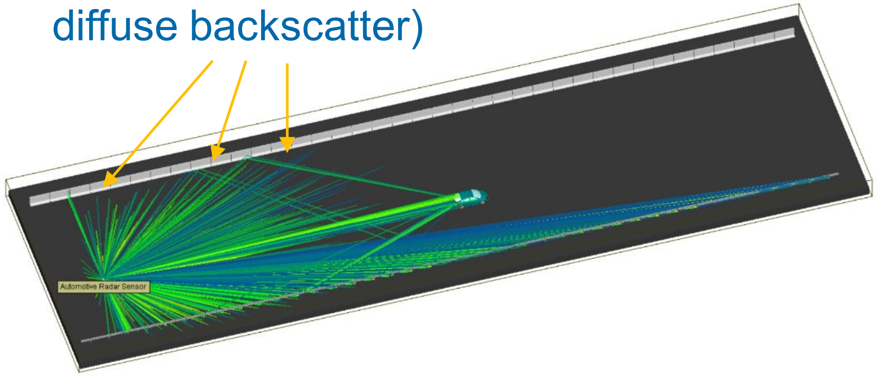
Remcom extended traditional methods to retain relative phase between chirps

- Initial phases are random, but consistent between scenarios and positions
- Predictable phase shifts allow inclusion in Doppler calculations

Clutter from Diffuse Scatter



(additional returns from diffuse backscatter)



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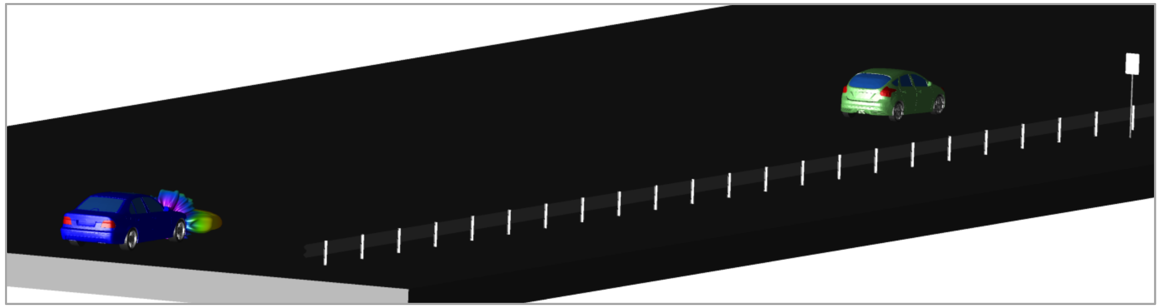
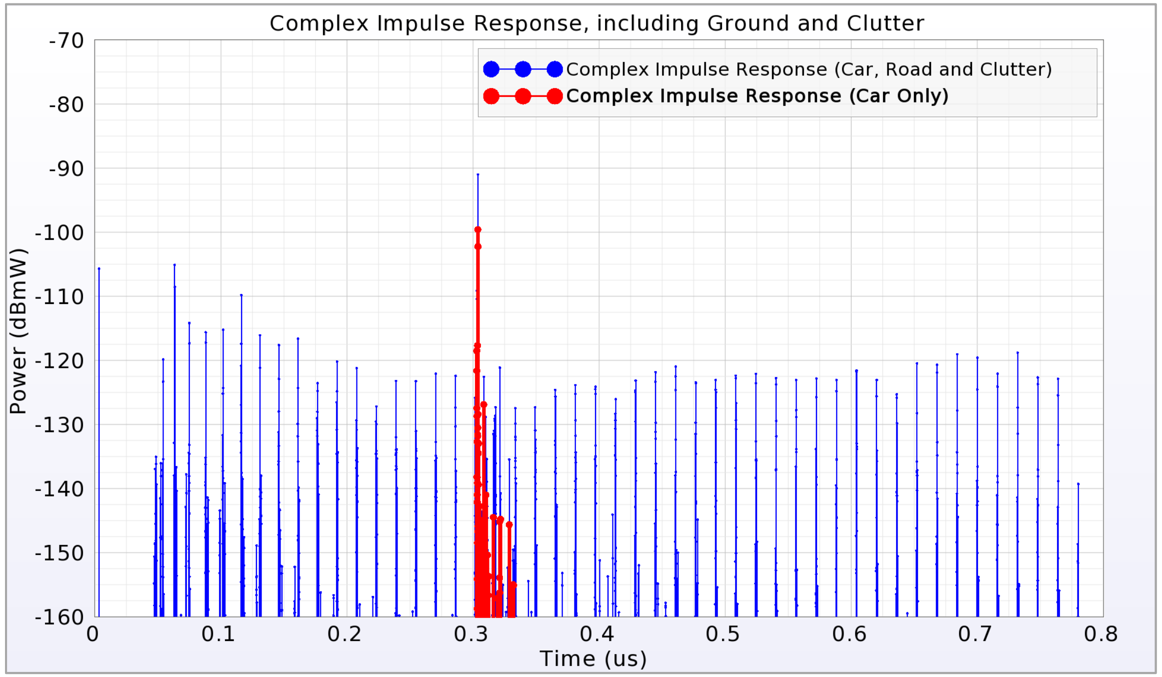
Drive Scenario Modeling





Drive scenarios typically include roadside clutter, other structures

- Examples: guard rails, street sign
- Maybe buildings, walls, poles

Complex impulse response (CIR) shows mag and phase of returns vs. time of arrival

- Figure compares (a) car alone vs. (b) car with ground and clutter
- Ground bounce affects car return, while guard rail posts and sign add numerous secondary returns

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Chirped Waveforms

WaveFarer's script-driven utilities to simulate and process linear chirps

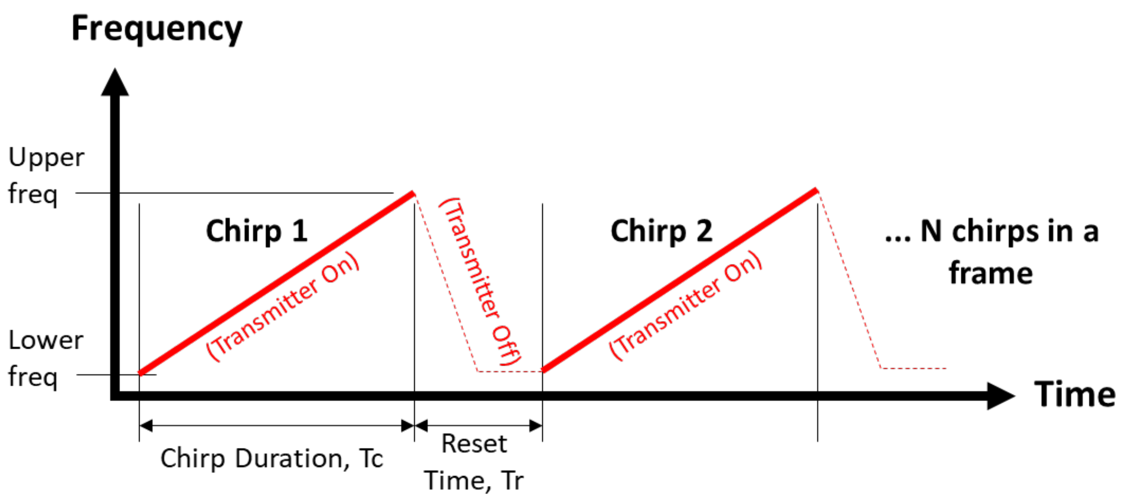
- Define and simulate linear chirp frames
- Post-process to calculate I&Q, range-Doppler

Key Optimization

- Extract detailed path data, mapping shifting interactions between chirps
- Adjust paths to generate impulse response for each sample point of each chirp
- Minimizes required simulations while retaining accuracy via detailed path data

Result: orders of magnitude faster than simulating every sample point of every chirp

Sequence of Chirps in a Frame



Request a demonstration of WaveFarer here.

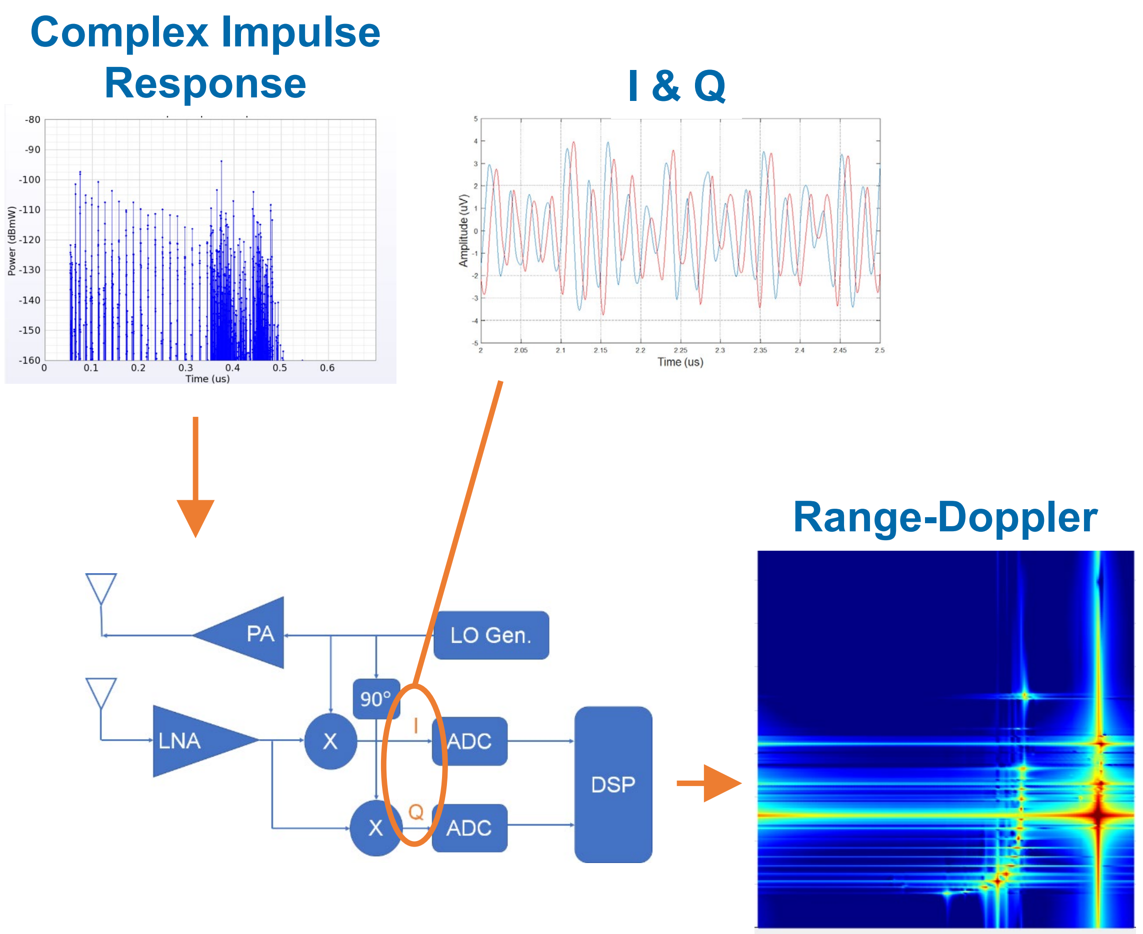
Range-Doppler Post-processing

Range-Doppler post-processing steps

- Extract detailed path data and map between simulations bounding frames
- Adjust path mag and phase to calculate CIR for each sample point of each chirp
- Calculate I&Q at sample points
- Perform 2D FFT to generate range-Doppler

Key Assumptions:

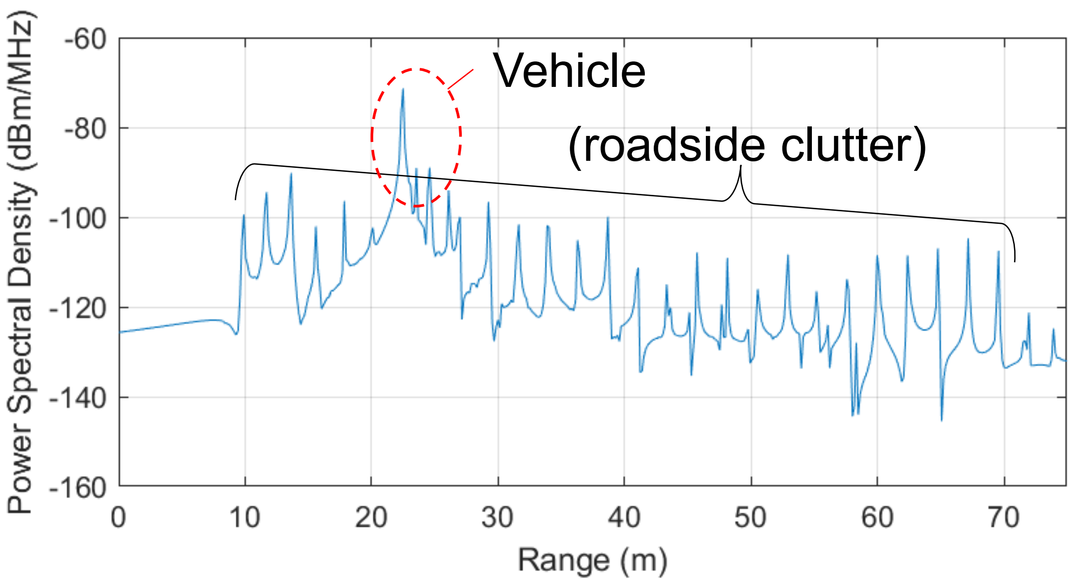
- Motion short during frame (~few ms), so paths between sensor and geometry can be captured with just a few bounding sims
- Frequency dispersion is driven mostly by phase shift due to path length
  - Phase shifts from interactions (reflection, diffraction, scattering) assumed constant over band



Range-Doppler Results

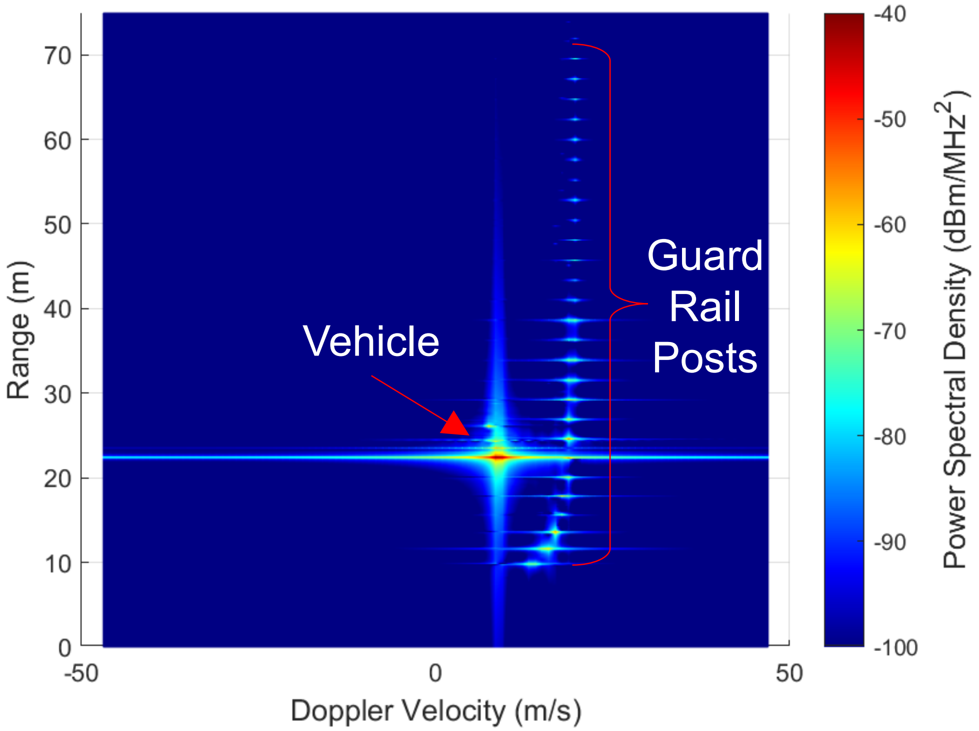
FFT of I&Q from One Chirp:

Power vs. Range (from Beat Frequencies)



FFT across Chirps in Frame:

Range-Doppler (from Phase Shifts)



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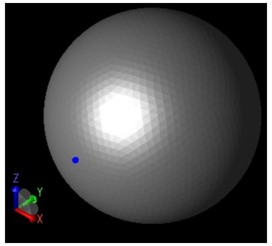
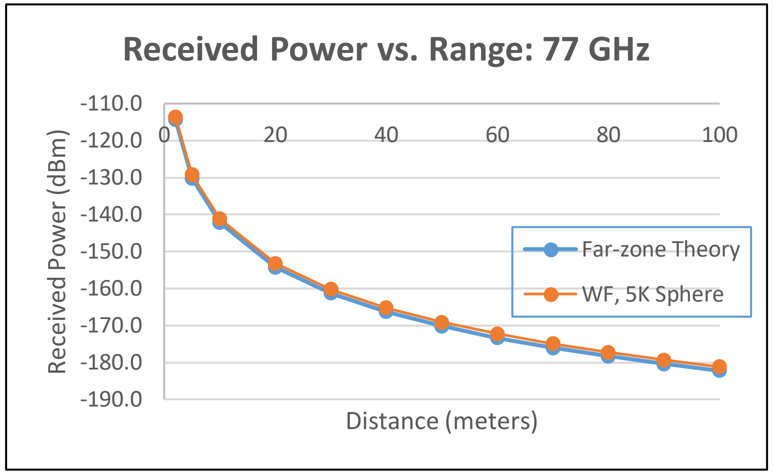
Validation: Theory and Full-Wave Sim

Example 1: Sphere (vs. Theory)

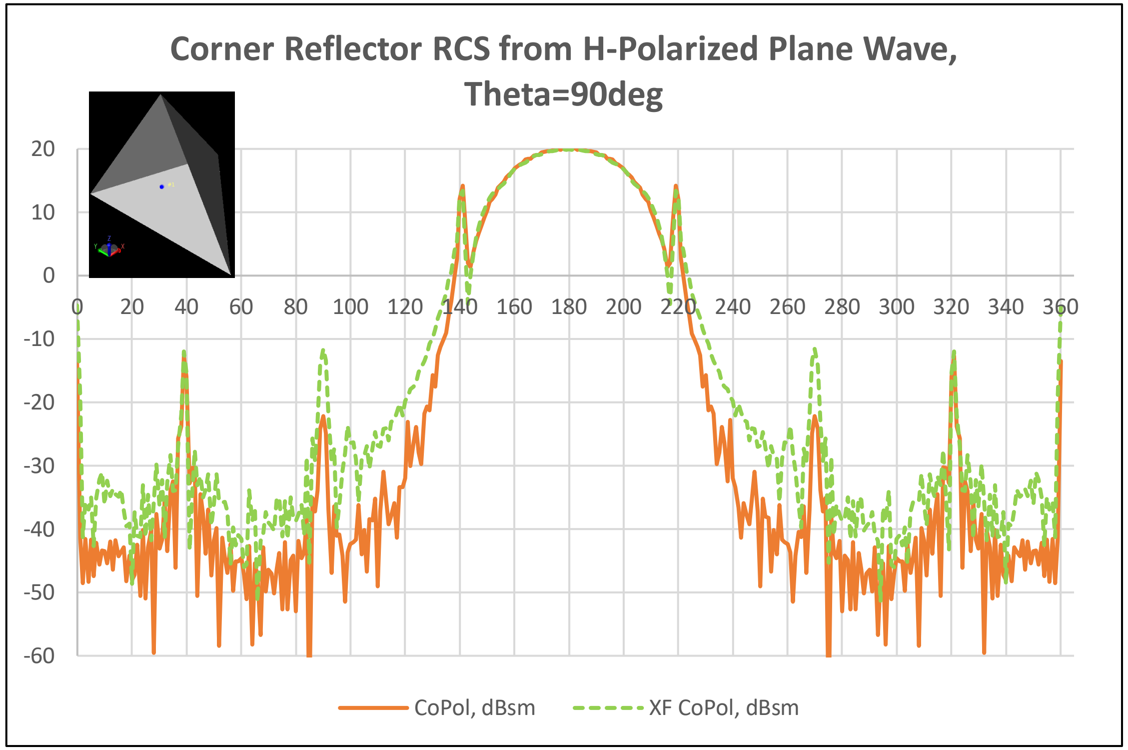
- Far-zone RCS at 77 GHz
  - Theory: -21.05 dBsm
  - WaveFarer: -20.94 dBsm
- RCS vs Range
  - Theory: RCS + radar range equation

PEC Sphere





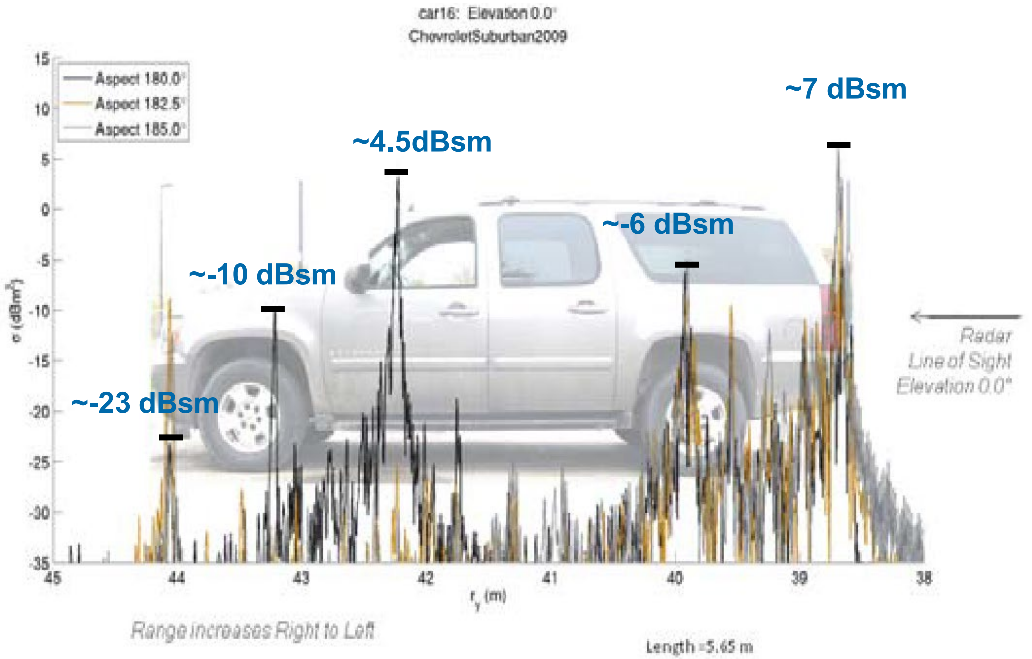
Example 2: Corner Reflector at 24 GHz (vs. FDTD simulation)



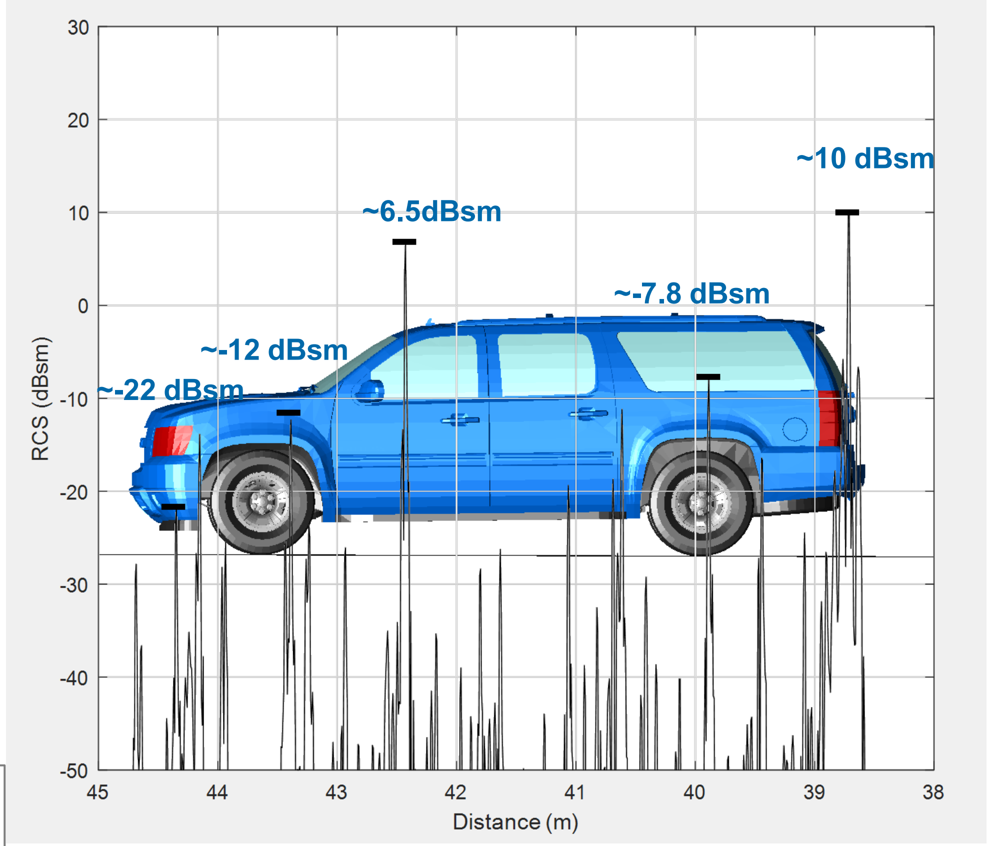
Validation vs. NHTSA Measurements[1]

Compared high-range resolution (complex impulse response) RCS

- 94 GHz with 8 GHz bandwidth
- Good agreement for key RCS peaks



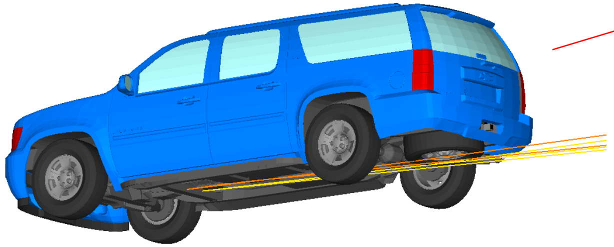
Chevrolet Suburban (2009) returns at 0.0° in elevation from [1] Figure 25(a)

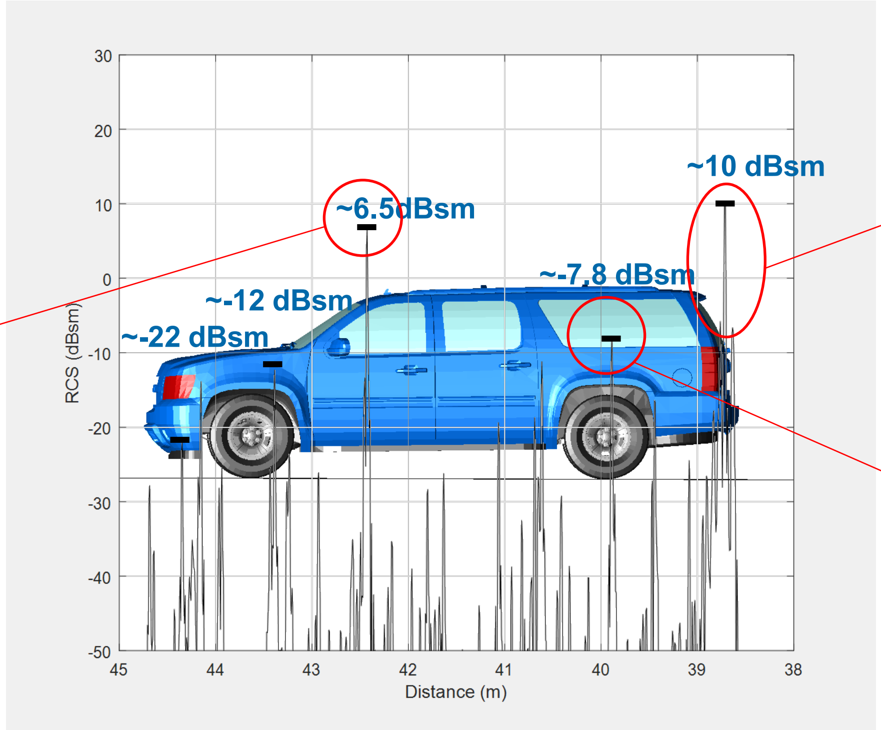


1. Buller, W., et al., "Radar Measurements of NHTSA's Surrogate Vehicle SS_V," National Highway Traffic Safety Administration (NHTSA), U.S. Dept. of Transportation Report DOT HS 811 817, August 2013.

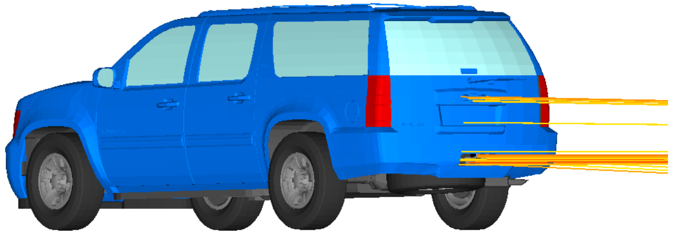
Path Data Pinpoints Potential Sources of Key Returns

2. Cross bar under front passenger area

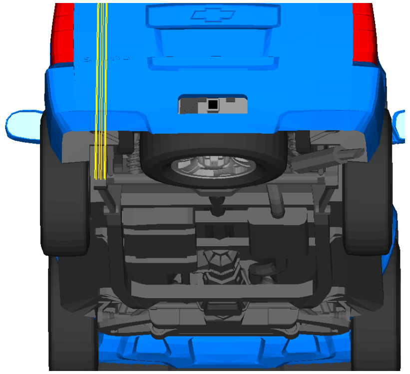




1. Tow-hitch and area around license plate



3. Rear axles



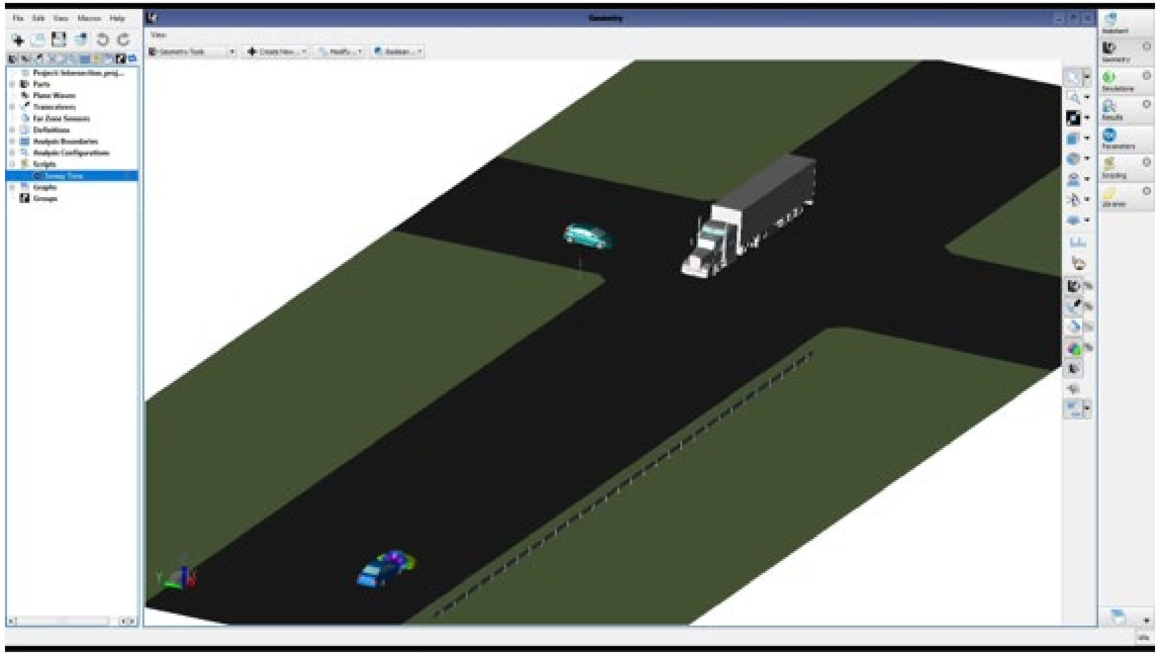
Automotive Radar Example: Vehicle Crossing Scenario

Scenario

- Intersection of local road with two-lane highway
- Large truck in opposite lane obscures crossing car (hatchback), accelerating from full stop at stop sign

TABLE I. DRIVE SCENARIO PARAMETERS

Category	Parameter	Value
Simulated Time	Time	5 Seconds
Host Vehicle	Velocity	15 m/s
Oncoming Truck	Velocity	15 m/s
Accelerating Vehicle	Initial Velocity	0 m/s
	Acceleration	4 m/s^2



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Simulating Linear Chirp

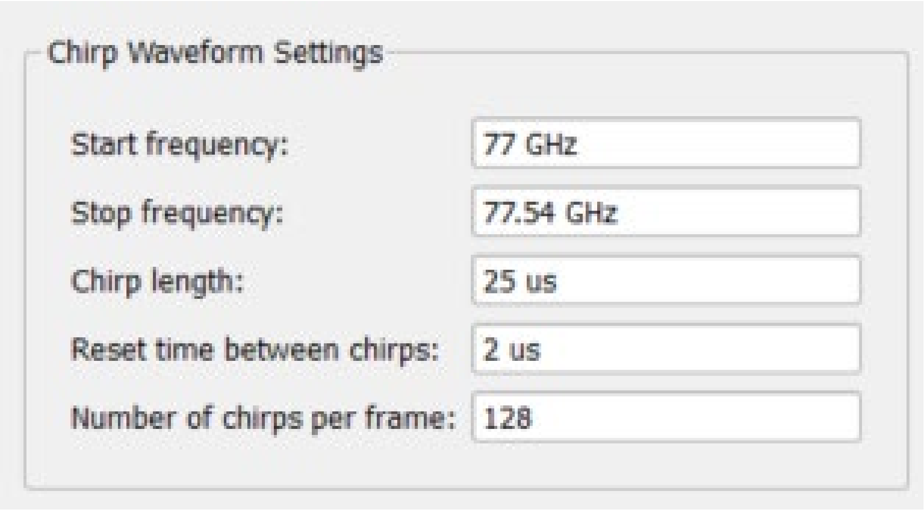
Auto Radar System Parameters

- Power: 10 dBm (24.9 dBmi EIRP)
- Frequency: 77 GHz, 540 MHz BW
- Nominal parameters based on data from ITU, vendors, etc.
- Adjusted for mid-range radar scenario

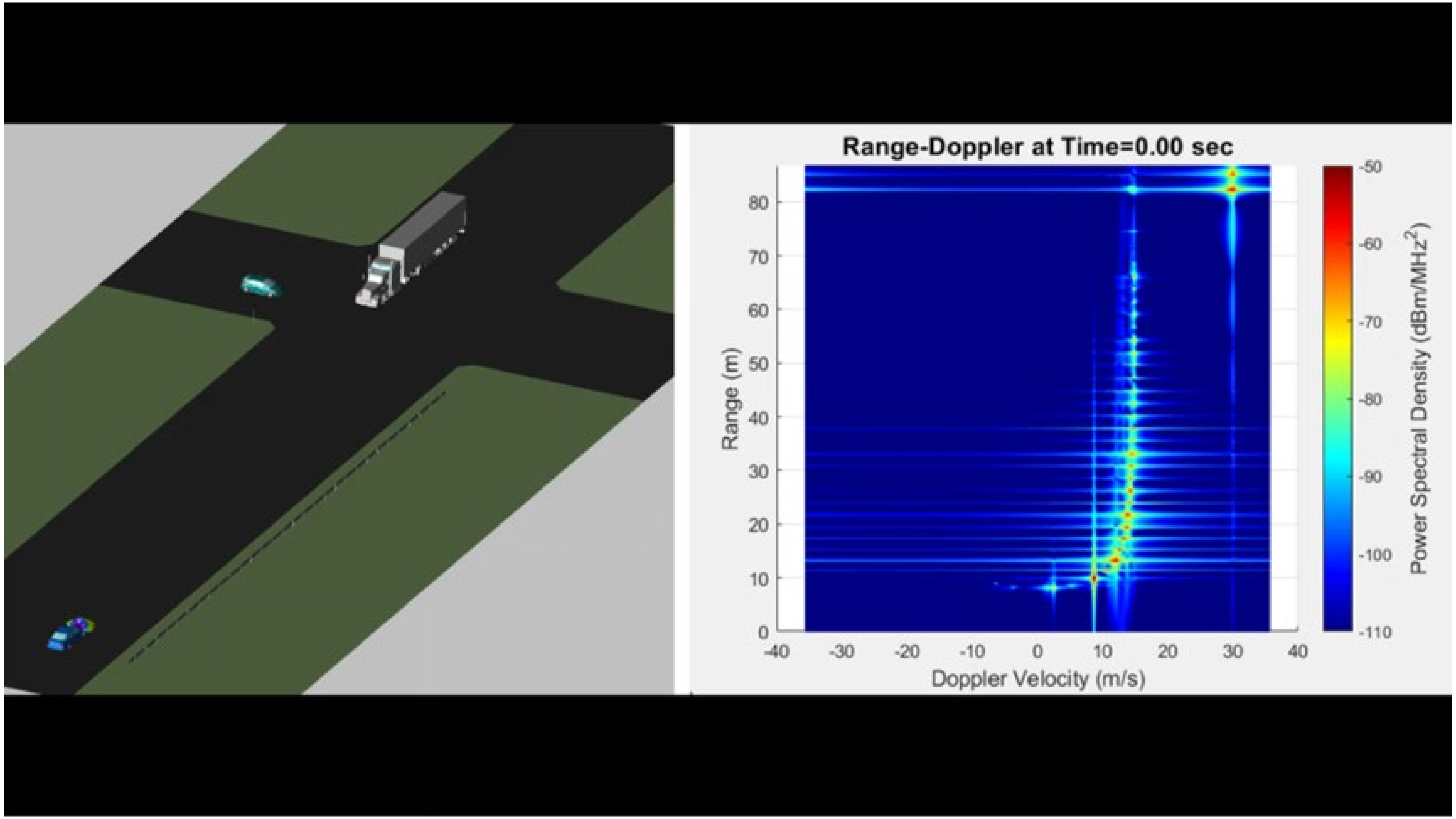
TABLE II. CHIRP PARAMETERS

Category	Parameter	Value
Chirp Waveform	Frequency	77 – 77.54 GHz
	Modulation	Sawtooth
	Chirp Duration	25 us
	Reset Time	2 us
	Chirps / Frame	128
Chirp Sampling Parameters	First Sample	40 ns
	Sample Spacing	40 ns
	# Samples	500

Chirp Waveform and Sampling Parameters



Range–Doppler at 1-Second Snapshots



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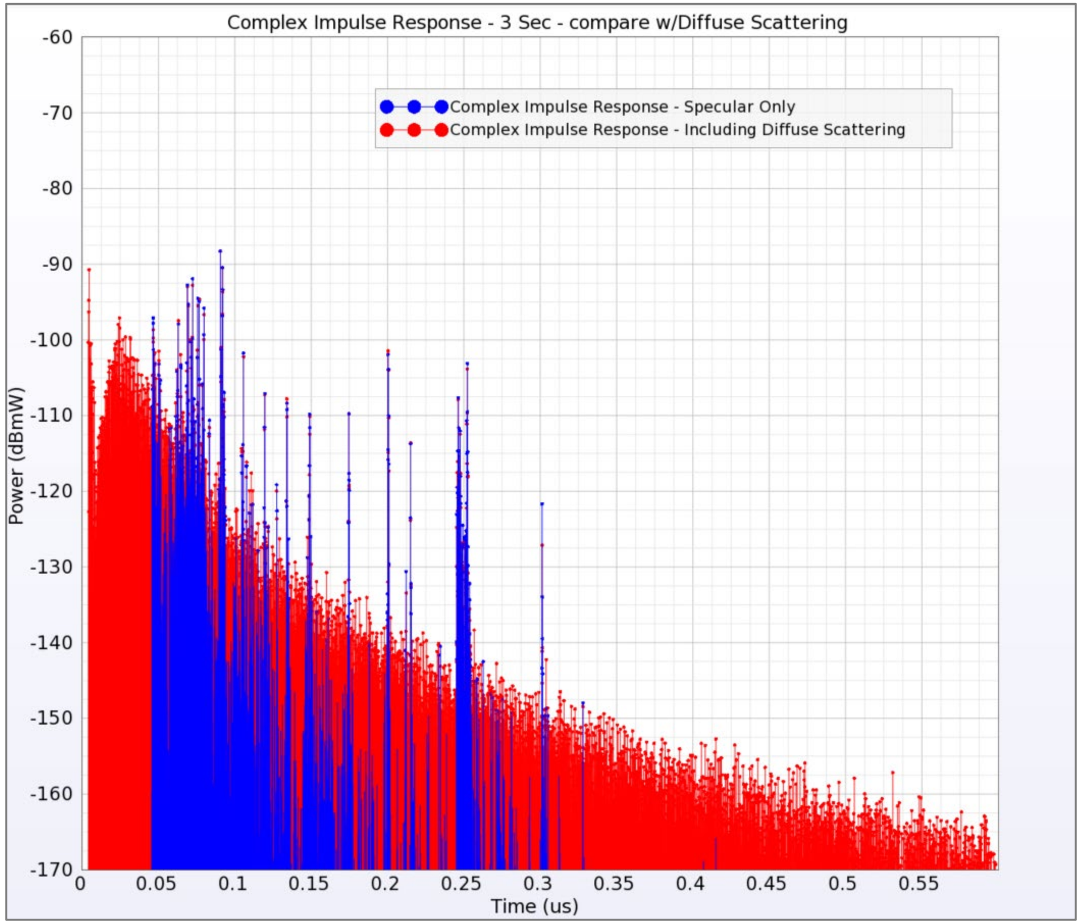
Diffuse Scattering

Roughness of road and ground add clutter to radar returns

Diffuse scattering model can be used to simulate these effects

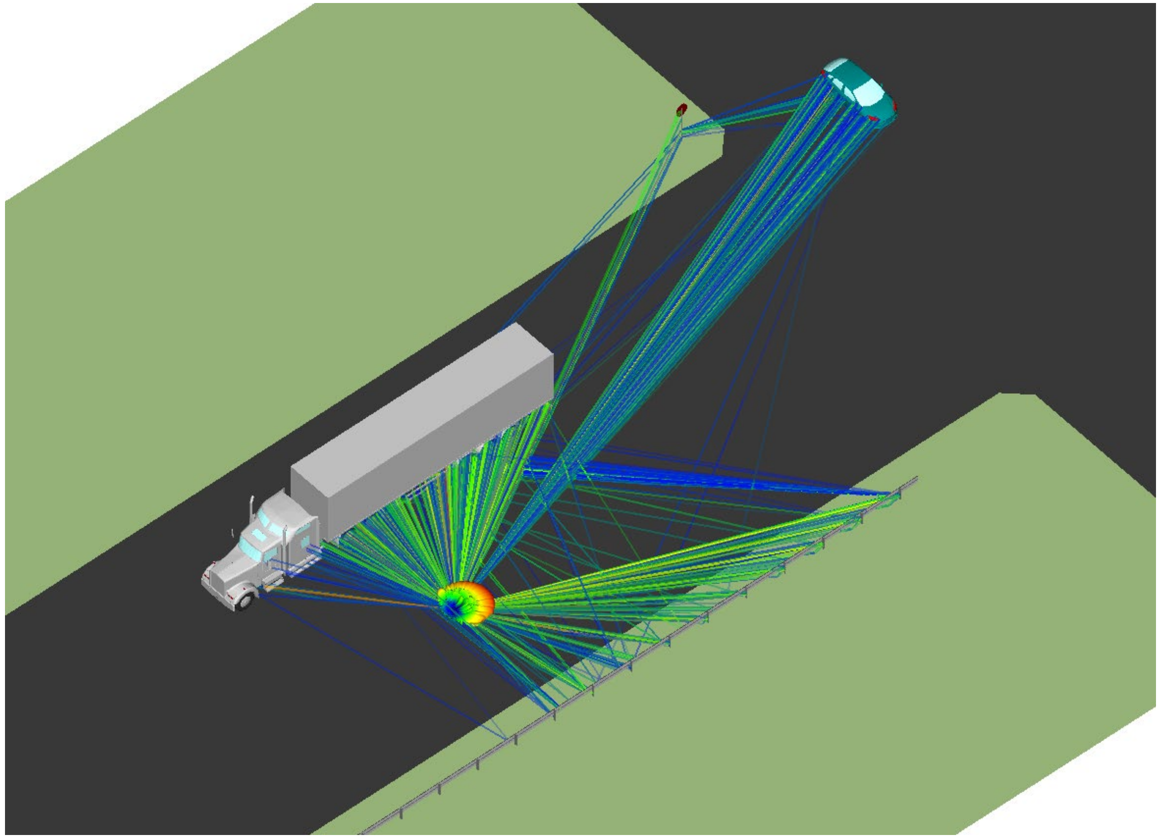
Result:

- Significant clutter across field of view, particularly at shorter ranges

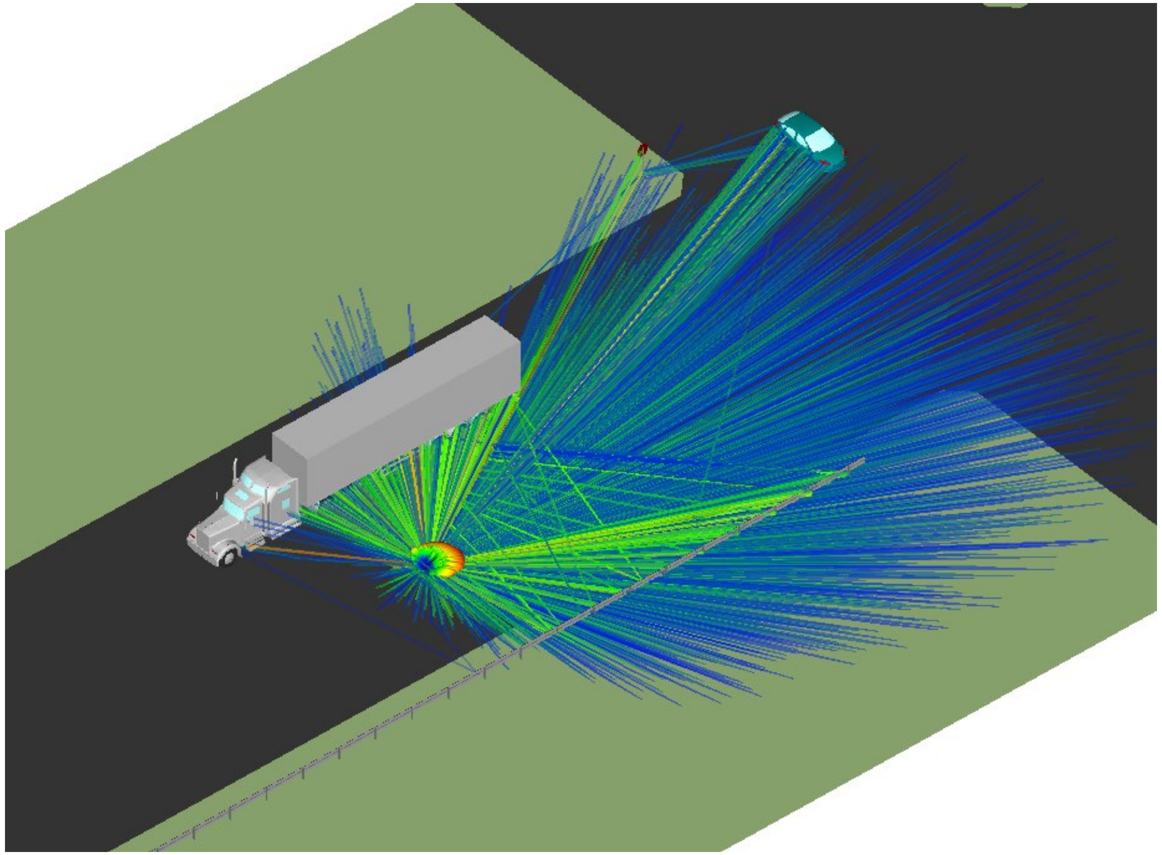


Diffuse Scattering: Path Comparison

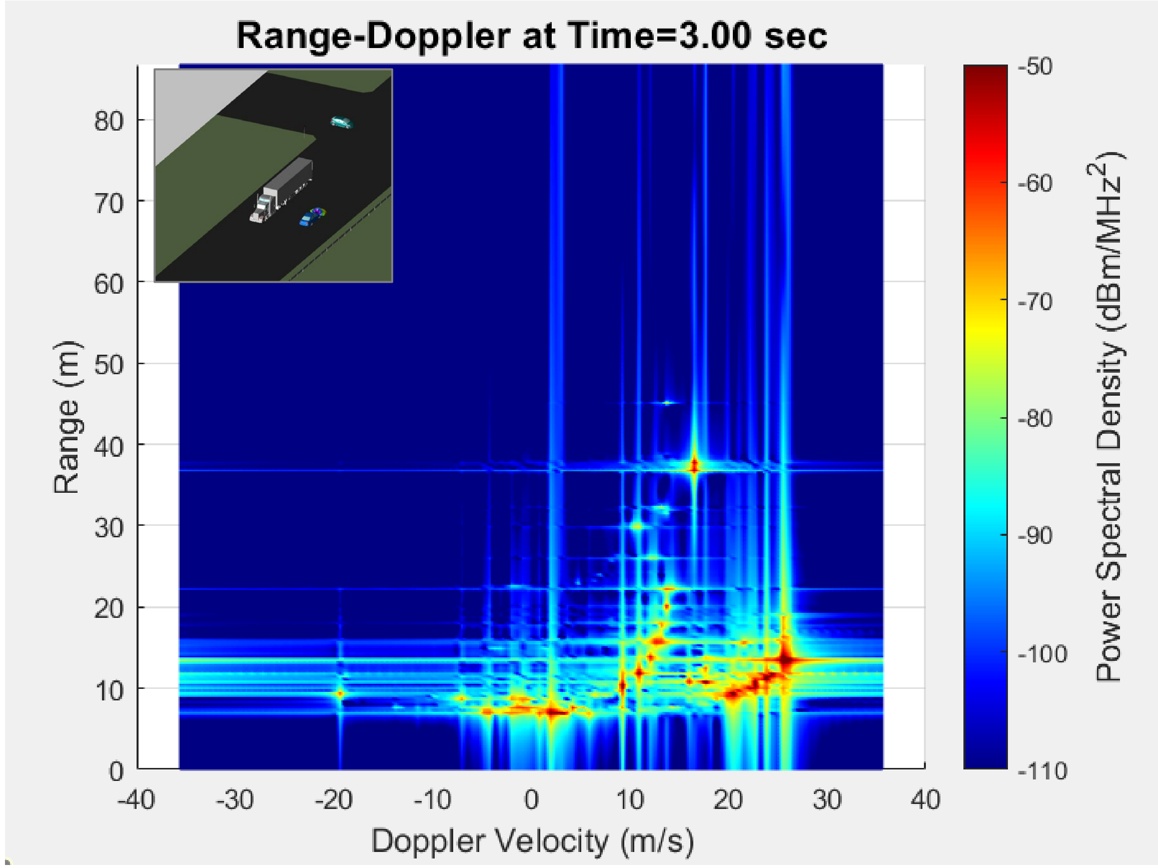
PO Scatter and UTD interactions only

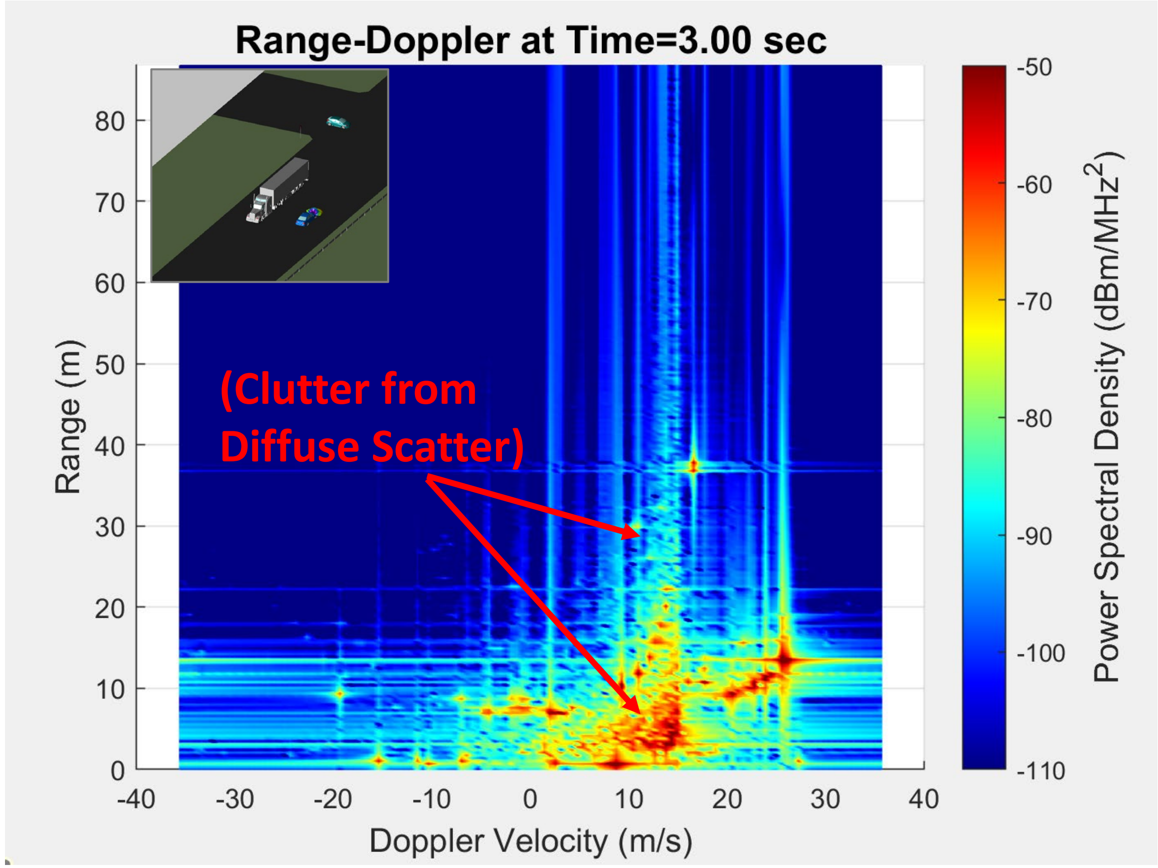


With Diffuse Scatter



Diffuse Scattering: Range-Doppler





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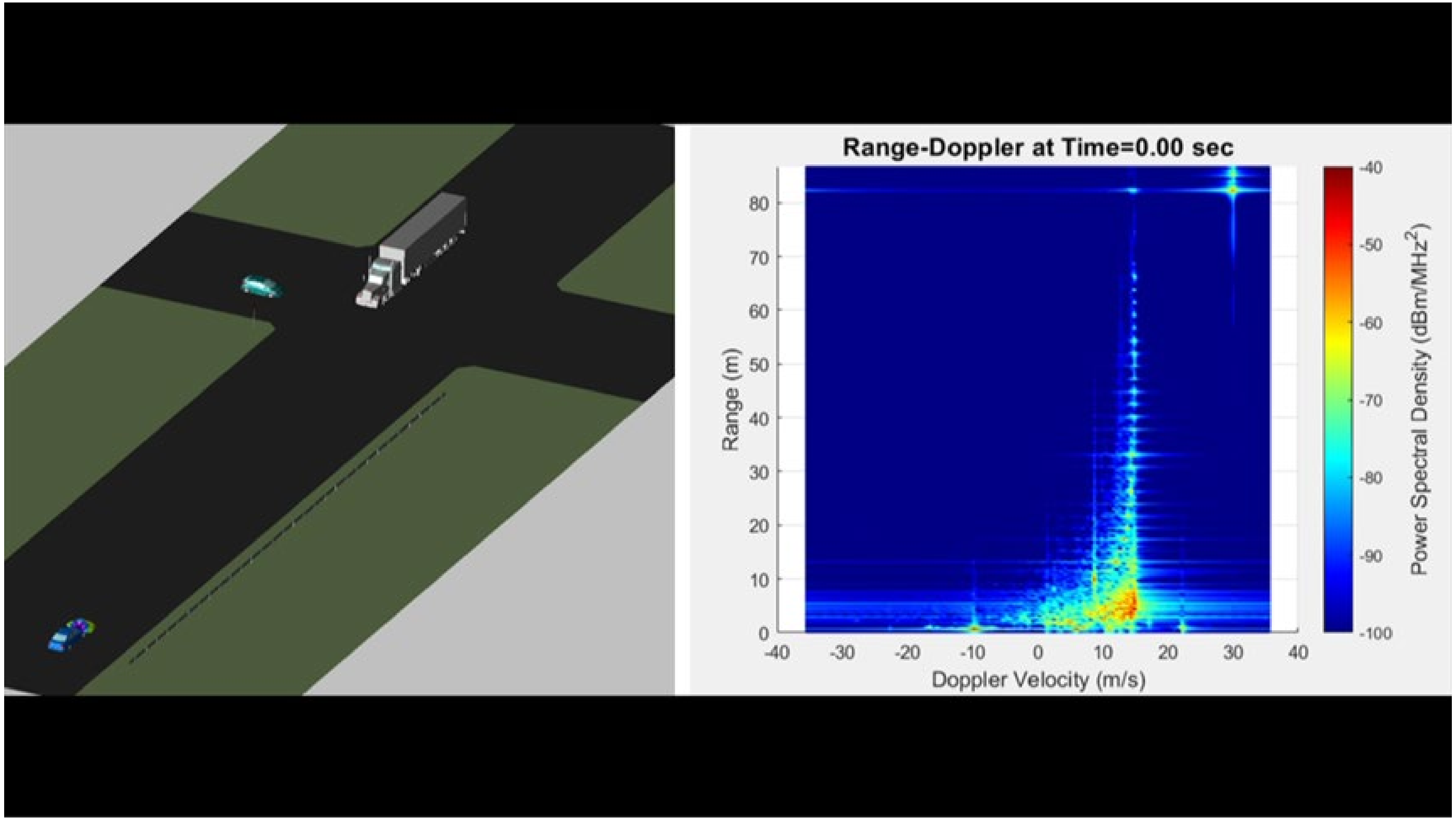
Range–Doppler at 1-Second Snapshots (with Diffuse Scatter)



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Micro-Doppler from Pedestrians

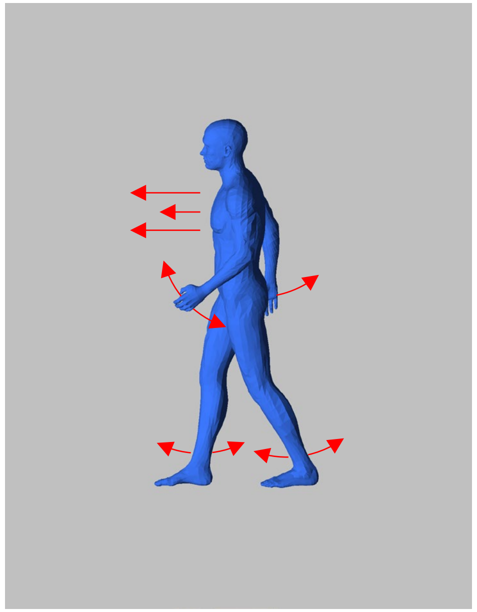
Many objects in an auto radar scene have moving parts

These can result in micro-Doppler that varies about the Doppler of the object

Pedestrian

- Torso motion is somewhat sinusoidal during walking
- Arms and legs swing forward and back
- Interactions between limbs and body can cause sudden phase shifts
- Resultant micro-Doppler can vary several meters-per-second about the overall velocity (see next slide)

Sources of Micro-Doppler



Micro-Doppler from Walking

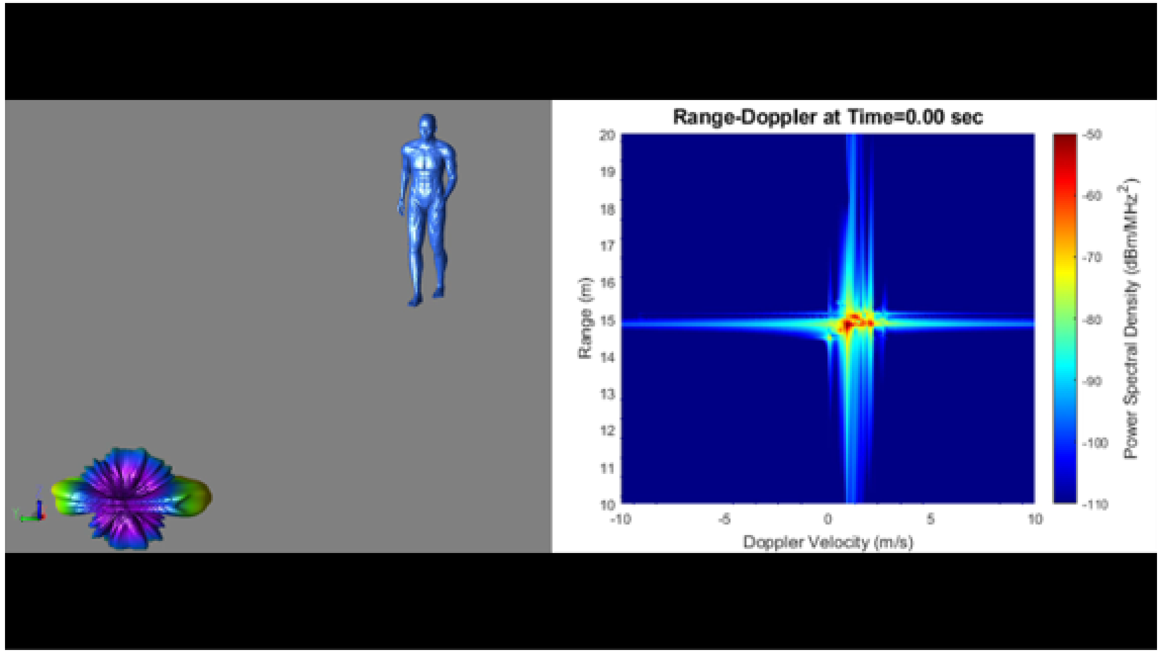
To evaluate pedestrian micro-Doppler, obtained a rigged CAD model with specified walking motion

As pedestrian cycles through steps at 1.4 m/s velocity:

- Doppler spread periodically extends out to between 0 and 4.5 m/s
- Peak Doppler fluctuates between 0.6 m/s and 2.8 m/s

Variations due to micro-Doppler caused by:

  - Swinging arms and legs
  - Sinusoidal motion of torso while walking



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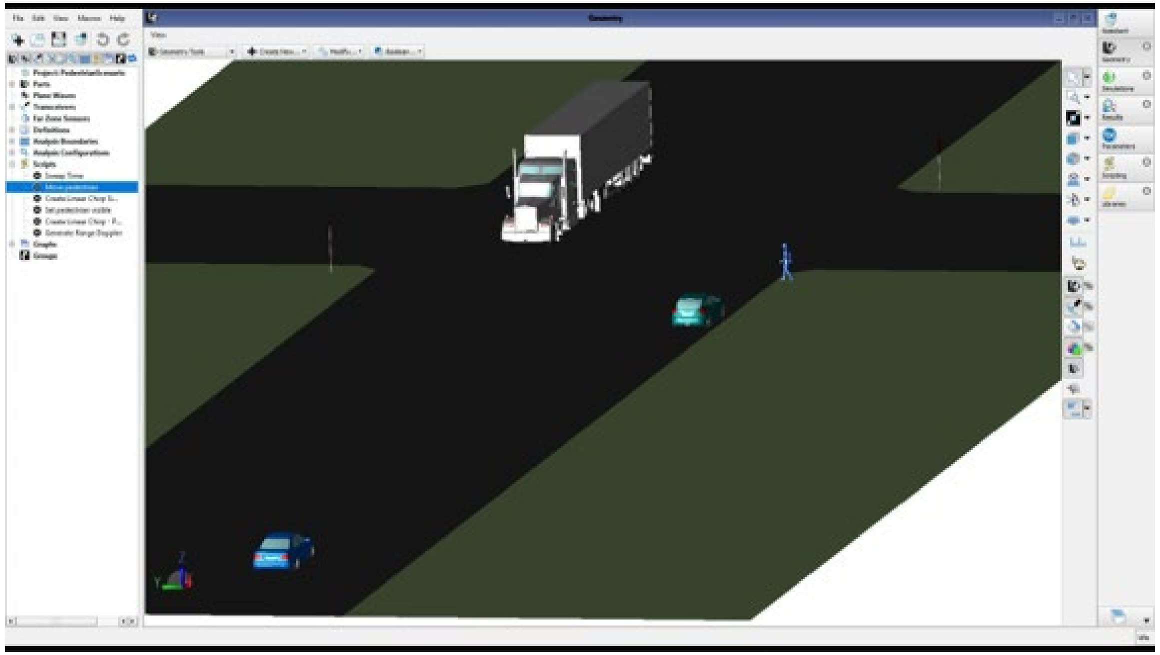
Pedestrian Crossing Scenario

Crossing Scenario

- Pedestrian crosses intersection
- At first partially obscured by stopped vehicle before coming into full view
- Calculate range-Doppler as vehicle and pedestrian progress



CLICK to see video clip

TABLE I. DRIVE SCENARIO PARAMETERS

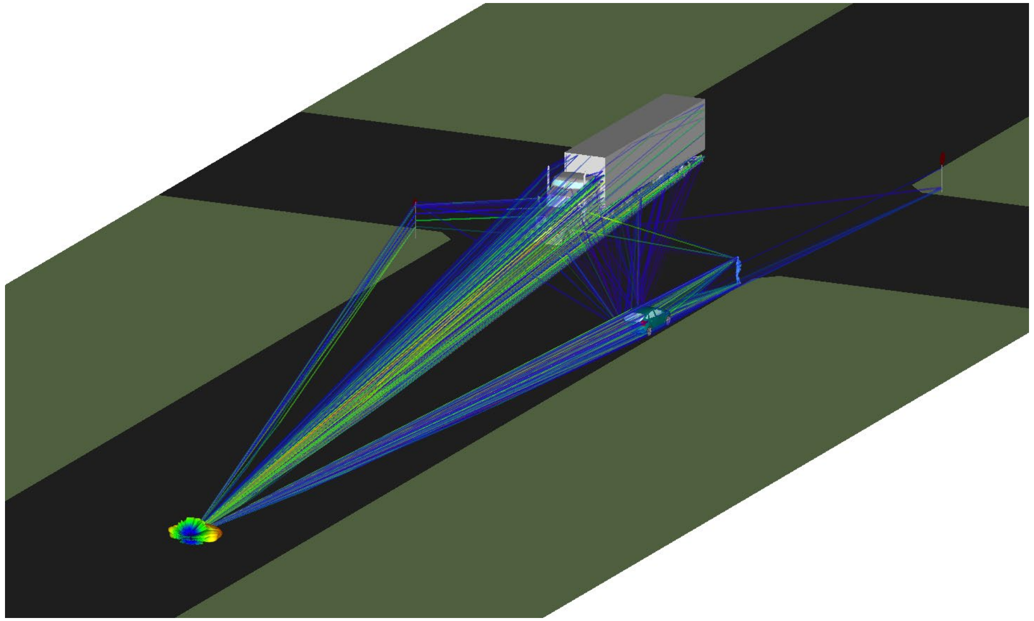
Category	Parameter	Value
Simulated Time	Time	3 Seconds
Host Vehicle	Velocity	15 m/s
Pedestrian	Velocity	1.4 m/s
Oncoming truck	Velocity	12 m/s
Parked Vehicle	Velocity	0 m/s (parked)

Pedestrian Scenario: Propagation Paths

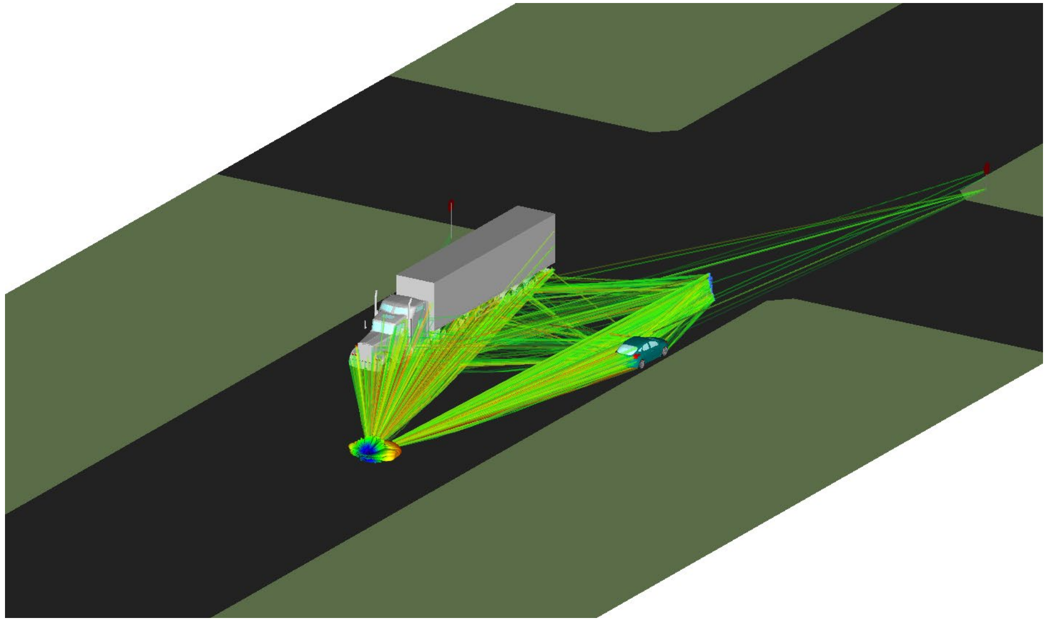
Dominant paths show interactions with vehicle, pedestrian, and stop signs

- When pedestrian partially shadowed, paths primarily from above and below parked car
- Once in full line-of-sight, radar returns are from full body

Pedestrian partially obscured (0.5 s)

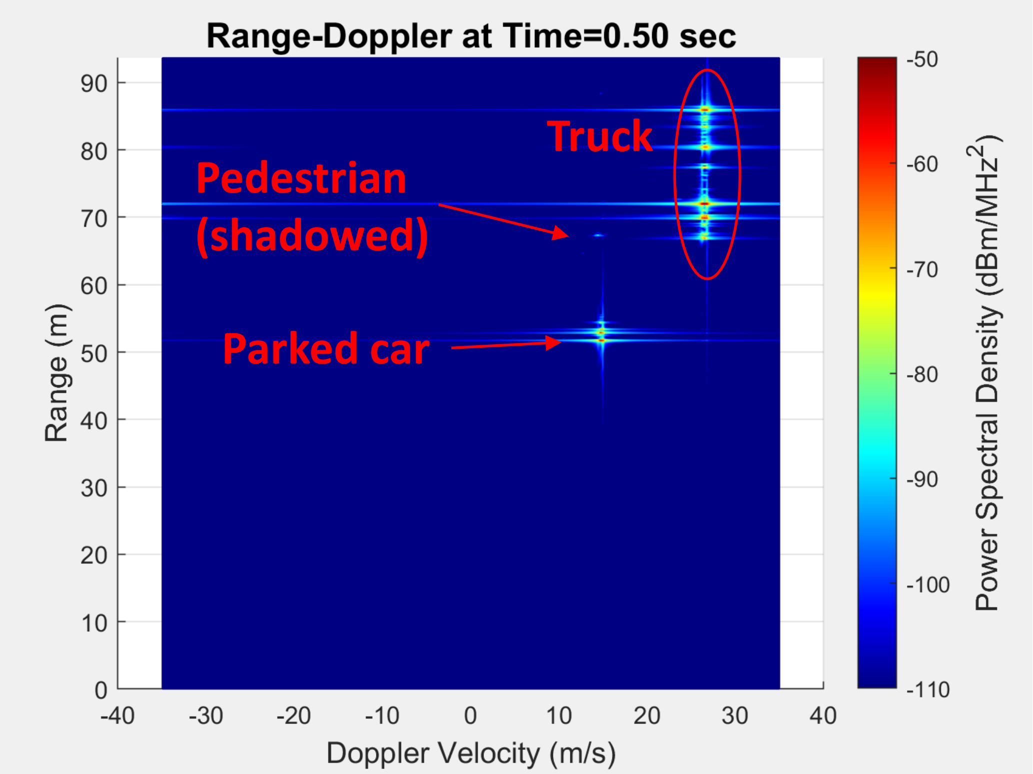


Pedestrian in full line-of-sight (2.5 s)

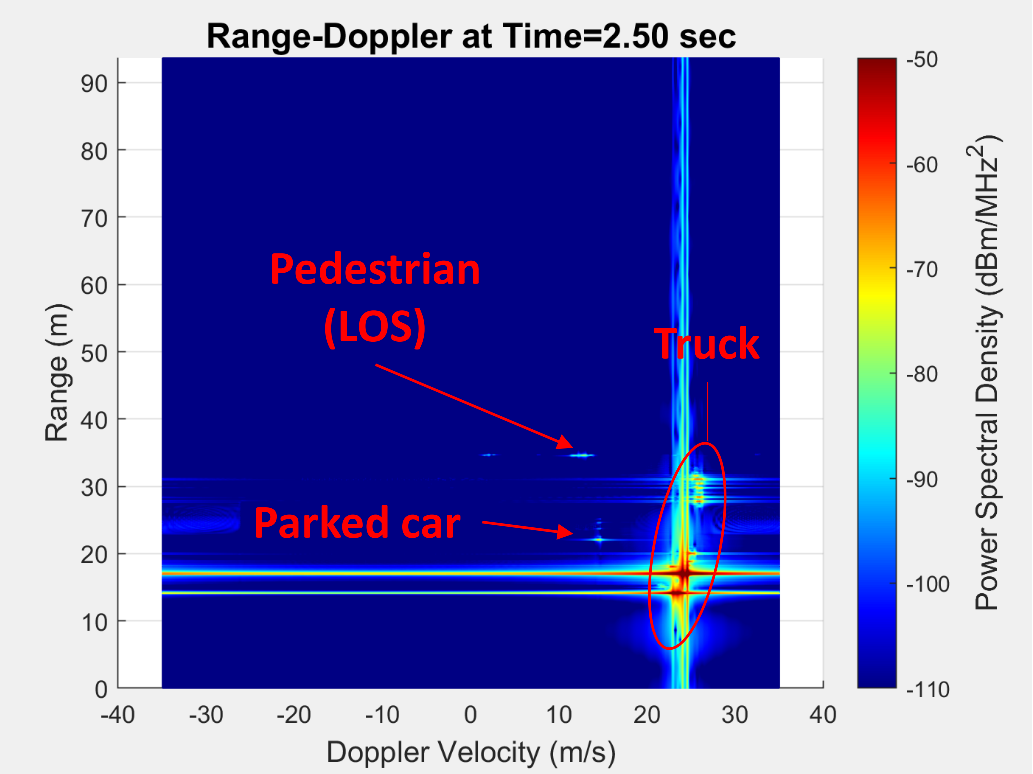


Pedestrian Scenario: Range-Doppler

Pedestrian partially obscured (0.5 s)



Pedestrian in full line-of-sight (2.5 s)



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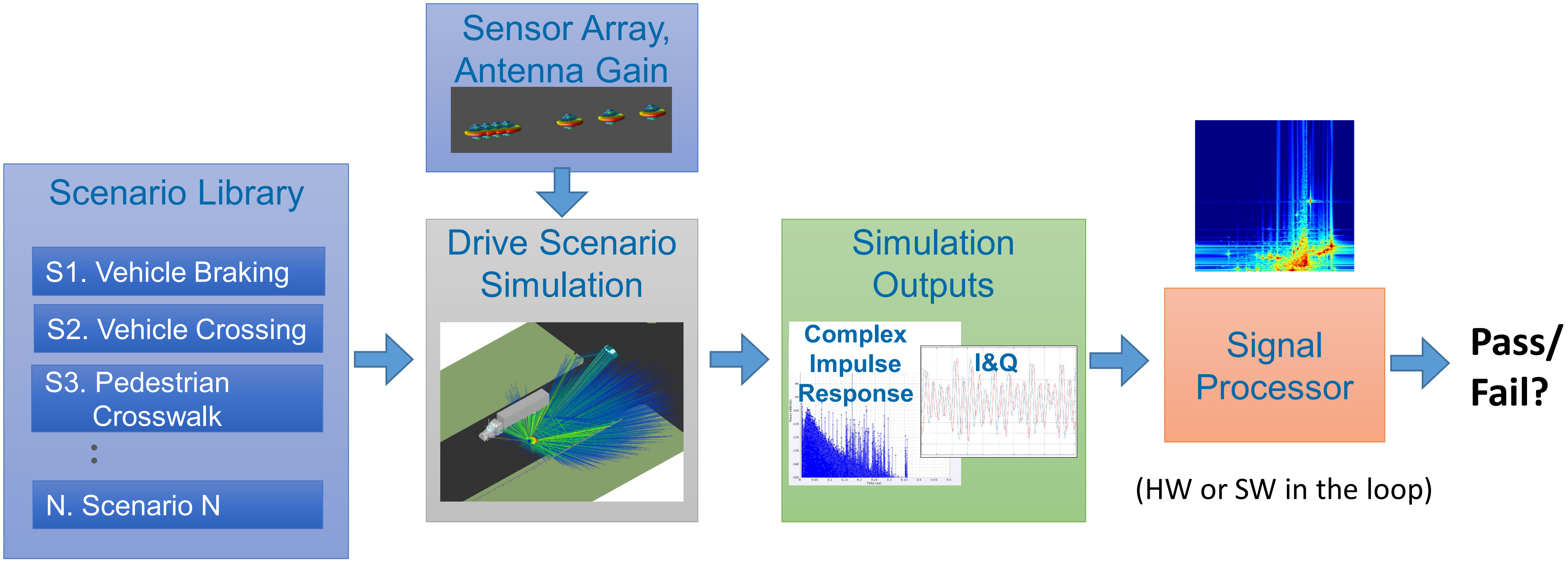
Concept for Virtual Drive Testing



Summary

In this talk, we reviewed some of the challenges for mmWave radar drive scenario simulation and an approach based on ray-tracing and Physical Optics developed to address them.

Results from simulated scenarios show value that predictive simulation can bring to assessment of performance for potential drive scenarios

- Insight into sources of radar returns, impacts of environment, etc.
- Simulated returns, I&Q or range-Doppler for input into testing
- Ability to capture clutter from diffuse scattering and micro-Doppler

For best accuracy, may require detailed CAD model (e.g., undercarriage details) or motion (e.g., pedestrian micro-Doppler)

- But perhaps there can be a tradeoff between fidelity and run-time

Remcom is interested in collaborating with partners in the industry and academia to determine how we can continue to improve these capabilities and integrate with design processes to assist with virtual validation.

Contact

Request a demonstration of WaveFarer here.

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