# Driving Intelligence Validation Platform (DIVP®) for AD Safety Assurance

## - Radar modelling and Applications -

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*Weather Forecast*

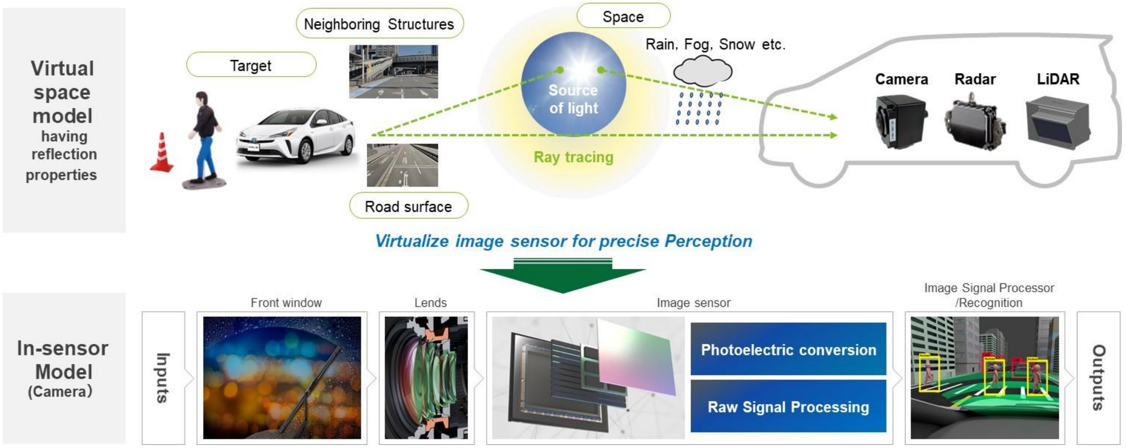
*AD* safety Assurance*

*For Validation & Verification Methodology*

# Building a virtual space simulation platform having highly consistent sensor models with real-world phenomena to contribute to the safety assessment of automated driving.

## DIVP motivation

- Sensor modeling that is highly consistent with physical phenomena.
- Platform that enables AD-evaluations throughout “scenario creation” , “verification of recognition” ,  “validation of vehicle control”.
- Enhanced connectivity with existing simulation software.



**Virtual space model** having reflection properties

Target

Neighboring Structures

Space

Rain, Fog, Snow etc.

Source of light

Ray tracing

Road surface

Camera

Radar

LiDAR

*Virtualize image sensor for precise Perception*

**In-sensor Model** (Camera)

Inputs

Front window

Lends

Image sensor

Photoelectric conversion

Raw Signal Processing

Image Signal Processor /Recognition

Outputs

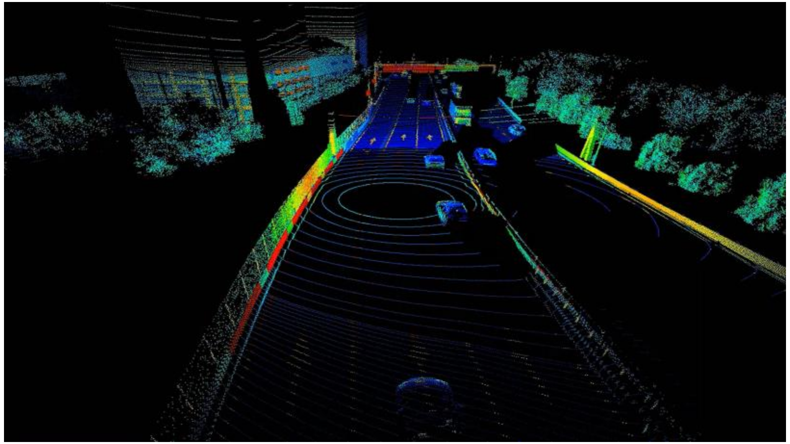
**Real world**

**Virtual space and Sensor model**

# DIVP Simulation results

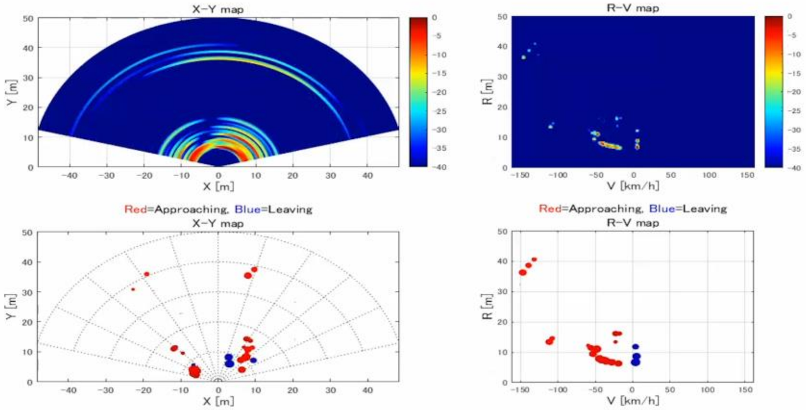
## Virtual sensor views on CI expressway & Odaiba AD-FOT area produced by DIVP simulator

**Camera**



**LiDAR**

Time=0[sec]



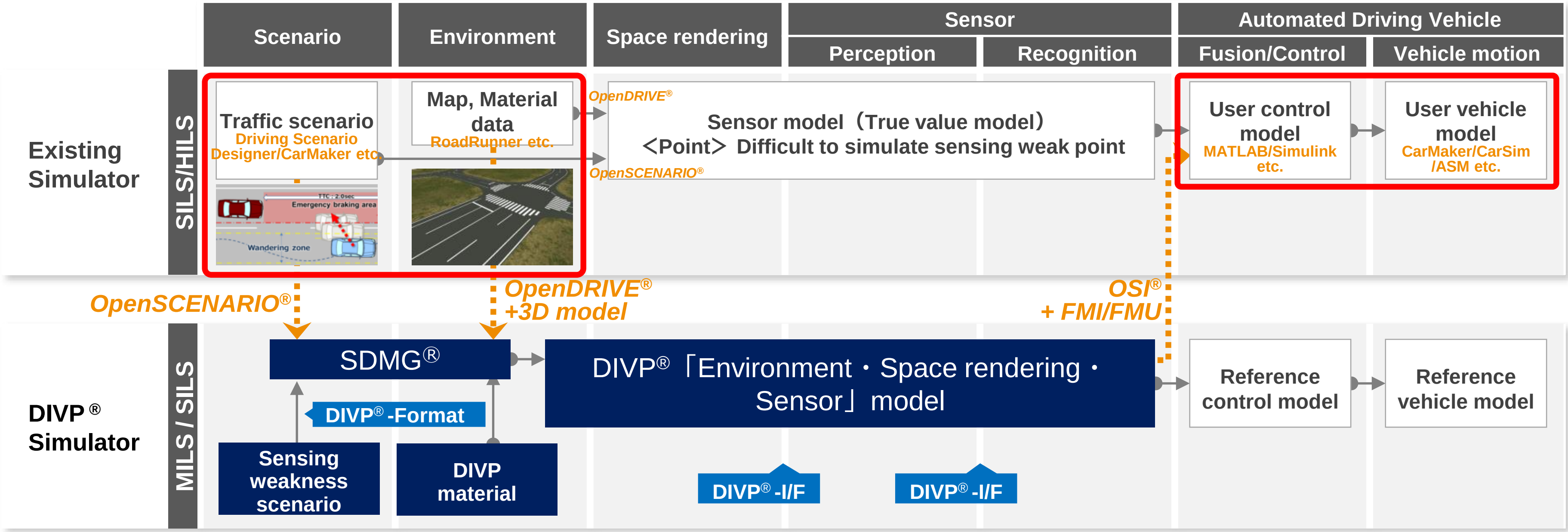
**Radar**

# Comply with OpenSCENARIO® , OpenDRIVE® and other standards of ASAM. Ensure the connectivity with existing simulation software to provide tool chain.

## Enhanced connectivity with existing simulation software

**Legend**

⇢ Connect by standard IF



Scenario | Environment | Space rendering | Sensor: Perception, Recognition | Automated Driving Vehicle: Fusion/Control, Vehicle motion

**Existing Simulator** — SILS/HILS

Traffic scenario
Driving Scenario Designer/CarMaker etc.

Map, Material data
RoadRunner etc.

OpenDRIVE®

Sensor model（True value model）
＜Point＞ Difficult to simulate sensing weak point

OpenSCENARIO®

User control model
MATLAB/Simulink etc.

User vehicle model
CarMaker/CarSim /ASM etc.

OpenSCENARIO®

OpenDRIVE® +3D model

OSI® + FMI/FMU

**DIVP® Simulator** — MILS / SILS

SDMG®

DIVP®「Environment・Space rendering・Sensor」model

Reference control model

Reference vehicle model

DIVP® -Format

Sensing weakness scenario

DIVP material

DIVP® -I/F

DIVP® -I/F

**Contribute to international standardization activities, for example, proposing standard format to ASAM utilizing Japan=German cooperation flamework.**

ASAM2）：Association for Standardization of Automation and Measuring Systems / OSI3) : Open Simulation Interface

# For safety assessment, it is essential to materialize scenarios, tools and indicators that enable validation of the two indicators

## Validation system required for AD safety assessment

Assessment Scenario

Validation Tool (Verification)

Metrics (Metrics)

**Won't you bump into me? Evaluating**

- Geometric **traffic flow scenarios** based on analysis of accident data, etc.

**Can you see it? validation of.**

- **Sensing weakness scenarios** based on expert knowledge

**Consistent** sensor models

**Camera**

**RADAR**

**LiDAR**

Automatic driving control model

***Simulation***

***HILS / VILS***

***PG / Public road***

- **Tool chain** according to validation purpose and target

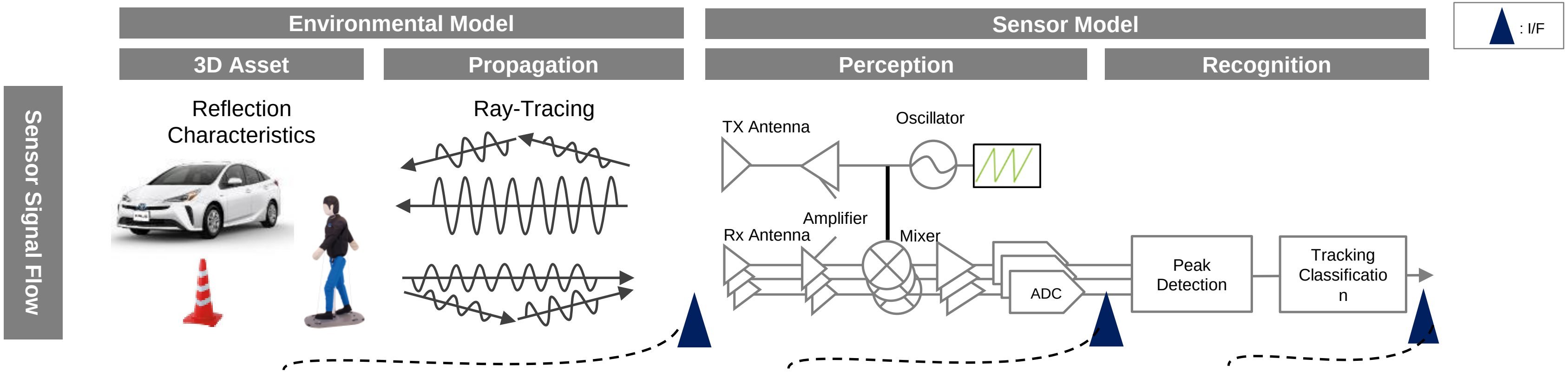
- Accurate prediction of vehicle position allows **margin for accident** and determination

- **Virtual Validation of Recognition Performance** Based on a Consistency Model of Measurable Perceptual Outputs

1. DIVP overview
2. **Radar modeling and validation**
3. Radar model applications
4. Summary

# DIVP models physical phenomena based on the sensor principle and achieves high consistency by verifying each modules I/F.

## Sensor Model (Radar)



: I/F

Sensor Signal Flow

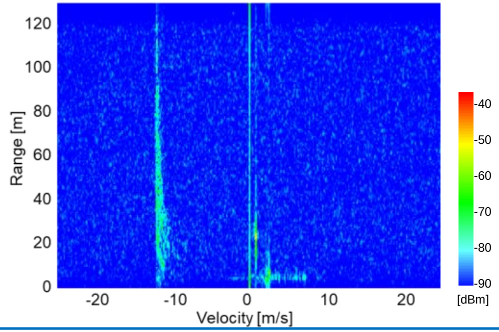
**Environmental Model**
- **3D Asset**: Reflection Characteristics
- **Propagation**: Ray-Tracing

**Sensor Model**
- **Perception**: TX Antenna, Oscillator, Amplifier, Rx Antenna, Mixer, ADC
- **Recognition**: Peak Detection, Tracking Classification

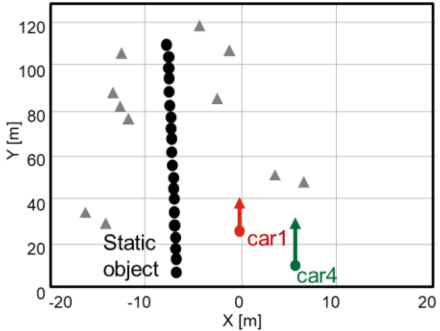
Output I/F

### Ray-Tracing Output

### Perception IF (RV-map)



### Recognition Output



Source : SOKEN, INC

# DIVP models 3D maps and assets based on precise measurements.

## 3D modeling based on measurement results

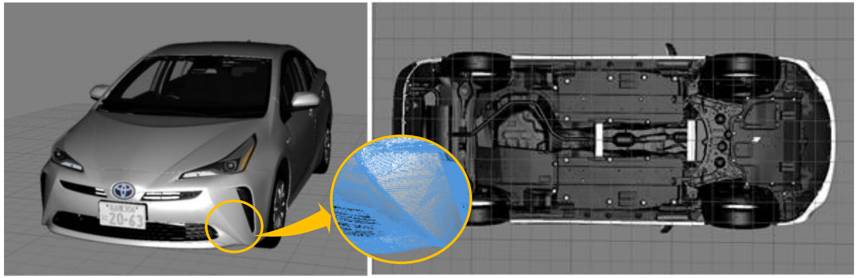
- MMS(Mobile Mapping System) measurement results

- Laser 3D measurement with an accuracy of 1 mm or less

- Virtual Proving Ground (Tokyo Waterfront City)

- High-precision polygons

Modeling the underbody for millimeter-wave multipath reflection

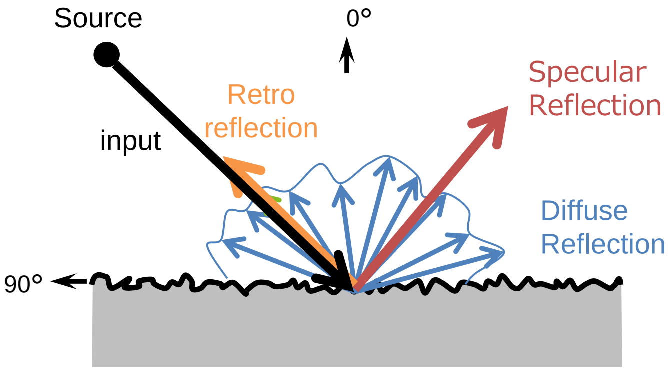


Source : Mitsubishi Precision Co. Ltd.

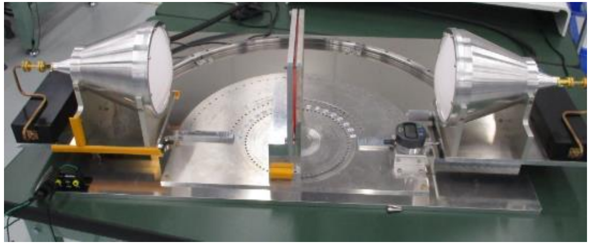
# Detail characteristics Measurement based on Environmental & Space designed modeling

## Reflection characteristics modeling based on measurement results

- Measurement characteristics

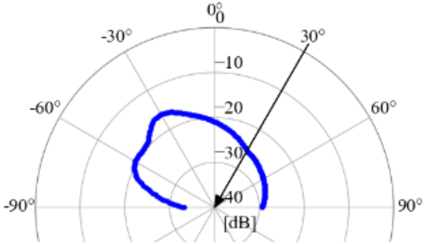


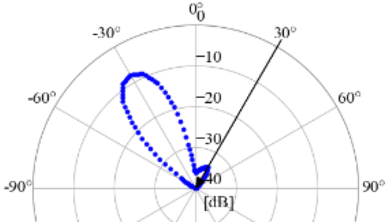
- Measurement system



- Measurement example

asphalt road surfaces with different surface roughness





Source : SOKEN, INC

# Three reflection models are defined and used according to the behavior of radio waves at reflective targets

## Features of the radar reflection model

### Scattered model

For small target (vehicle、person etc.)
Radar equation (distance 4th power)
Physical Optics approximation

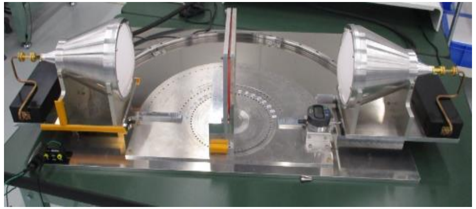
**Multi-layer model**
(Transfer Matrix Method)

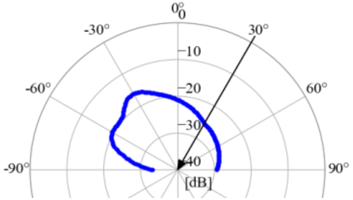
**Input parameters**

Dielectric constant,
Magnetic permeability, Thickness
(from reflection characteristics)

### Reflector model

For large target (Building, road surface etc.)
Friis equation (distance squared rule)
Geometrical Optics approximation

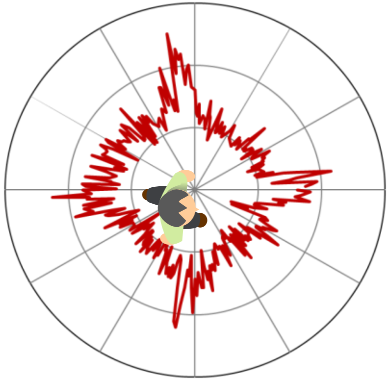




Angle characteristics of reflection characteristics

### RCS model

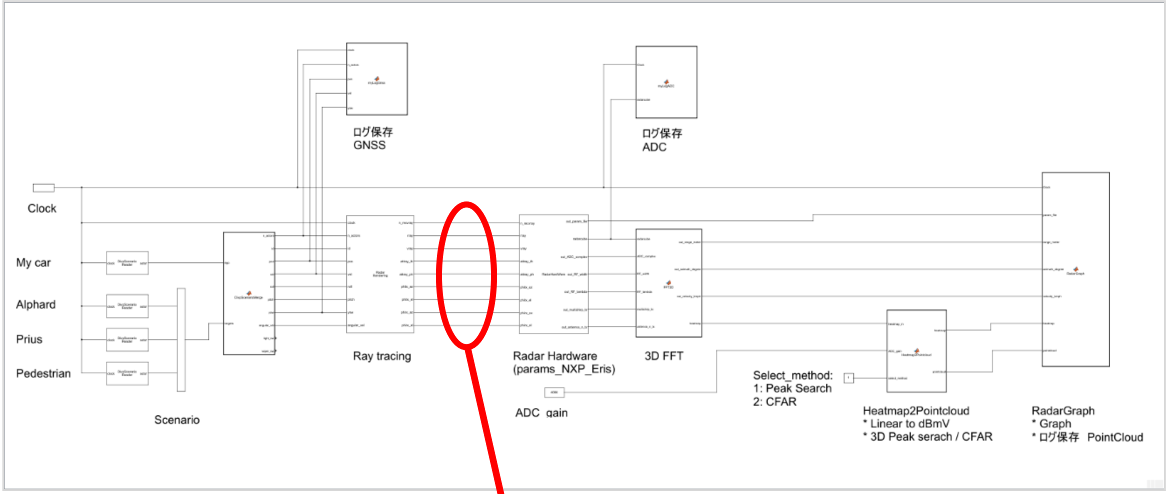
For analysis duration reduction
Radar equation (distance 4th power)



Bi-static RCS

# Format of ray trace output to radar model.

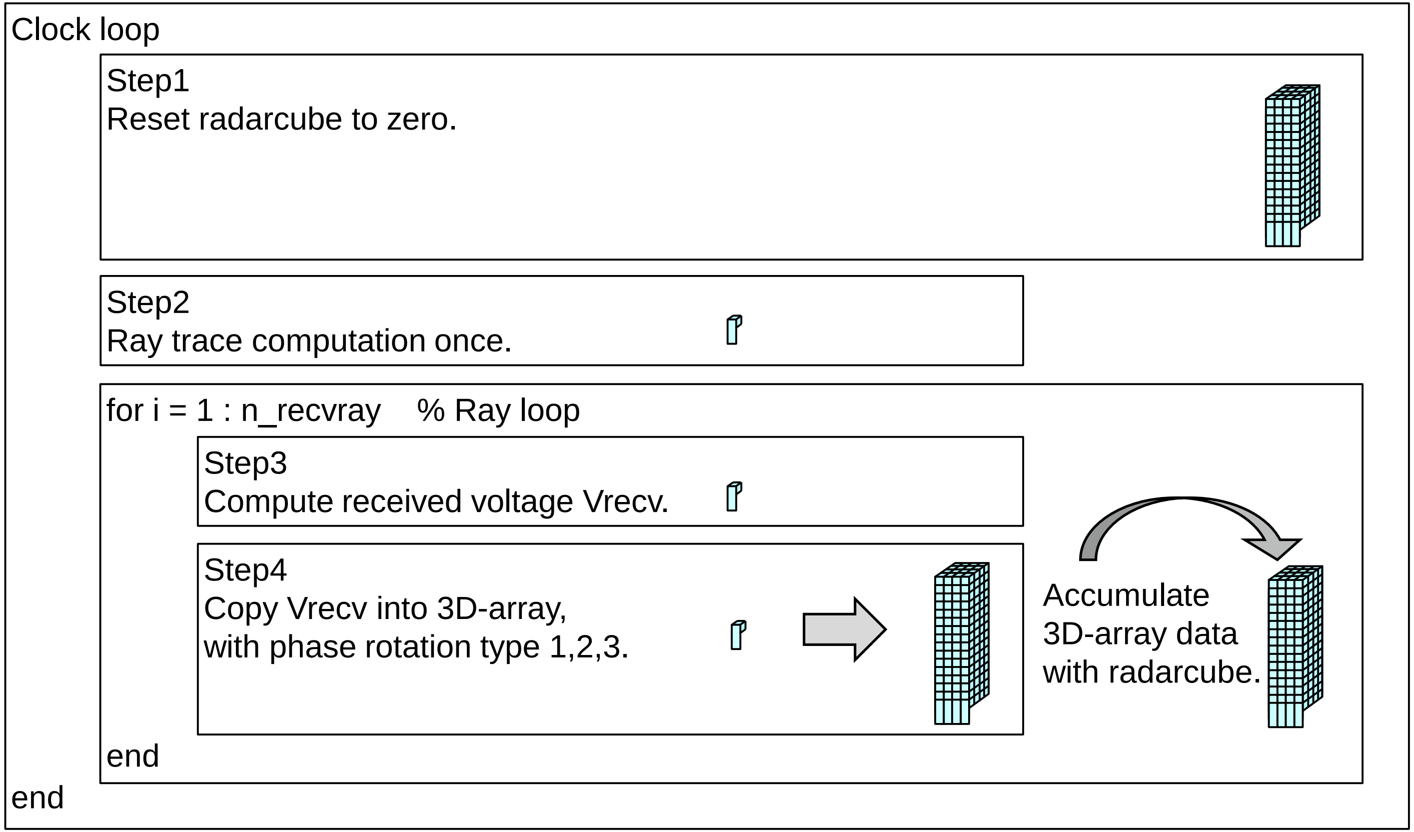
Simulink model



Format of
ray trace output

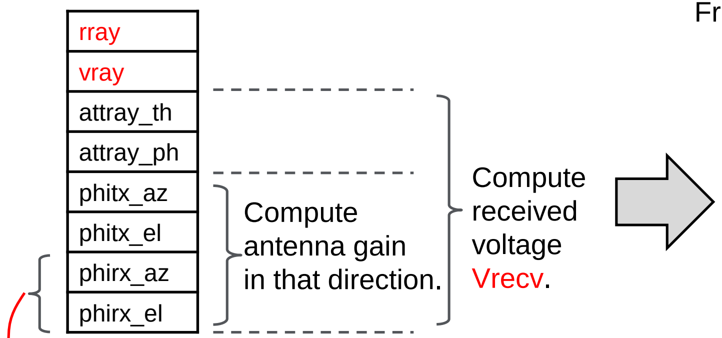
| Name | Content | Data type |
|---|---|---|
| n_recvray | Number of output ray | Uint16 |
| rray | Propagation distance of ray [m] | Double, 1D-array |
| vray | Relative radial velocity of the reflected points [m/s] | Double, 1D-array |
| attray_th | Loss factor (Complex, Propagation and reflection) [linear] *(Horizontal polarization)* | Double, 1D-array |
| attray_ph | Loss factor (Complex, Propagation and reflection) [linear] *(Vertical polarization)* | Double, 1D-array |
| phitx_az | Angle of radiation from TX antenna [rad] *(Horizontal)* | Double, 1D-array |
| phitx_el | Angle of radiation from TX antenna [rad] *(Vertical)* | Double, 1D-array |
| phirx_az | Angle of receiving to RX antenna [rad] *(Horizontal)* | Double, 1D-array |
| phirx_el | Angle of receiving to RX antenna [rad] *(Vertical)* | Double, 1D-array |

# Algorithm to compute radarcube



```
Clock loop
    Step1
    Reset radarcube to zero.

    Step2
    Ray trace computation once.

    for i = 1 : n_recvray    % Ray loop
        Step3
        Compute received voltage Vrecv.

        Step4
        Copy Vrecv into 3D-array,
        with phase rotation type 1,2,3.

        Accumulate
        3D-array data
        with radarcube.
    end
end
```

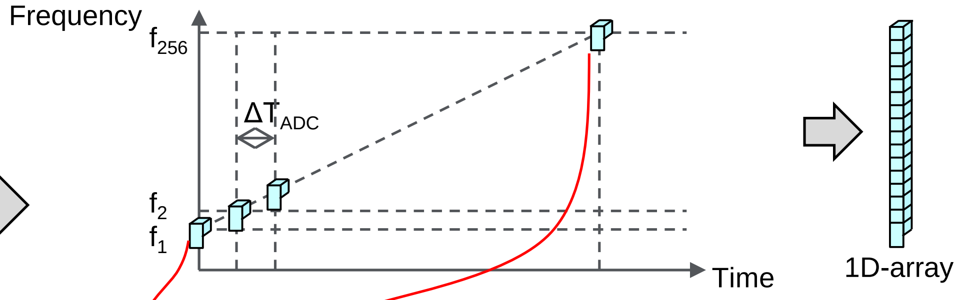
# Three types of phase delay



- rray
- vray
- attray_th
- attray_ph
- phitx_az
- phitx_el
- phirx_az
- phirx_el

Compute antenna gain in that direction.

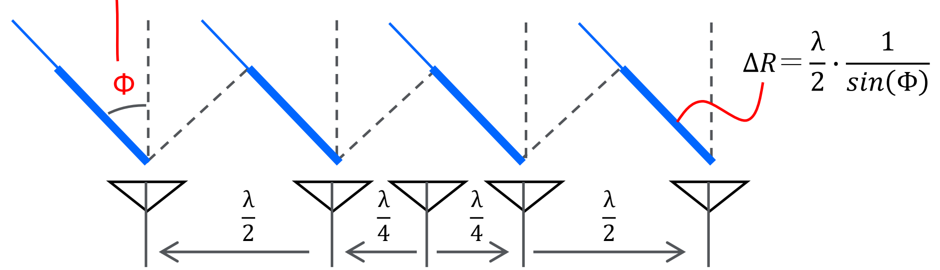
Compute received voltage Vrecv.



**Phase delay (type 1)**

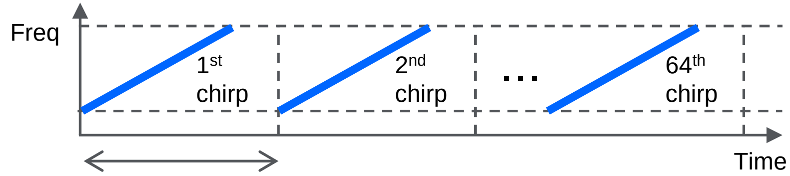
$$V_{256} = V_{recv} \cdot e^{-j\cdot\beta_{256}\cdot R_{256}} \qquad \beta_{256} = \frac{2\pi \cdot f_{256}}{c} \qquad R_{256} = rray + vray \cdot (254 \cdot \Delta T_{ADC})$$

$$V_1 = V_{recv} \cdot e^{-j\cdot\beta_1\cdot R_1} \qquad \beta_1 = \frac{2\pi \cdot f_1}{c} \qquad R_1 = rray$$



$$\Delta R = \frac{\lambda}{2} \cdot \frac{1}{sin(\Phi)}$$

| | |
|---|---|
| Phase delay (type 2) | $e^{-j\beta\cdot\Delta R}$ |

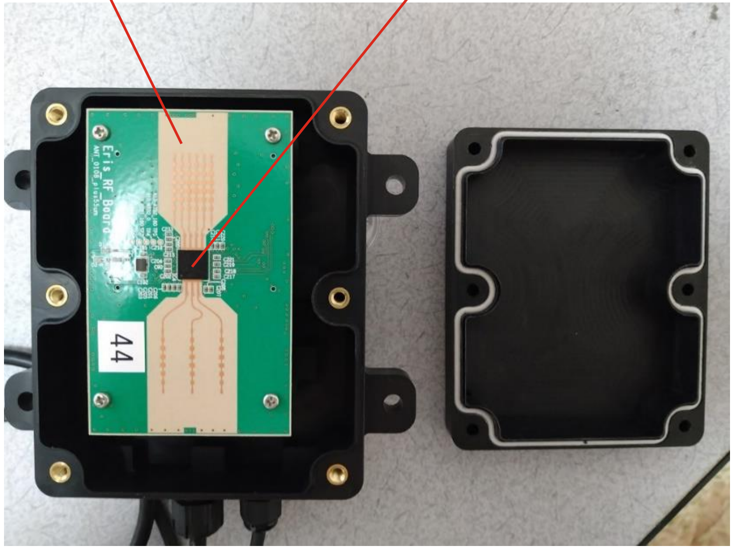


| | |
|---|---|
| Time difference | $\Delta T_{chirp}$ |
| Distance difference | $\Delta R = vray \cdot \Delta T_{chirp}$ |
| Phase delay (type 3) | $e^{-j\cdot\beta\cdot\Delta R}$ |

# Radar module, and experiment scenario.

| | |
|---|---|
| TX antenna | 3 |
| RX antenna | 4 |
| Virtual array | 3 x 4 = 12 |

| | |
|---|---|
| Radar chip | NXP TEF810X (77GHz) |
| MCU chip | NXP S32R274 |



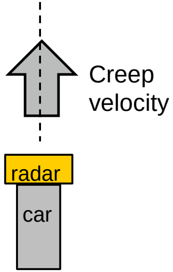
| | |
|---|---|
| in | DC 12V |
| out | Ethernet (100Mbps) |

## Radar setting

| | |
|---|---|
| fc | 76.5 GHz |
| Max range | About 50m |
| Number of ADC sampling | 256 (※) |
| Number of multi-chirp | 64 (※) |

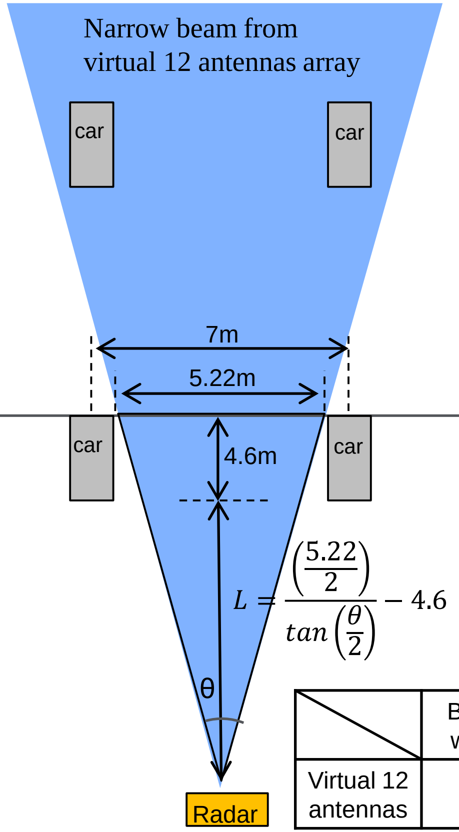
(※) Parameters are reduced in order to suppress the data size to capture all the radarcude in real time.

The antenna board was designed by U-Shin and S-Takaya in Japan.



Very simple experiment
to estimate
angular separation distance

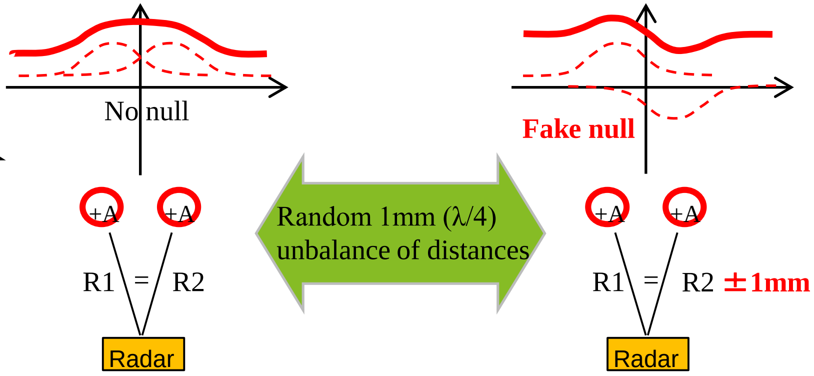
# Complex behavior, predicted from theory.



$$L = \frac{\left(\frac{5.22}{2}\right)}{tan\left(\frac{\theta}{2}\right)} - 4.6$$

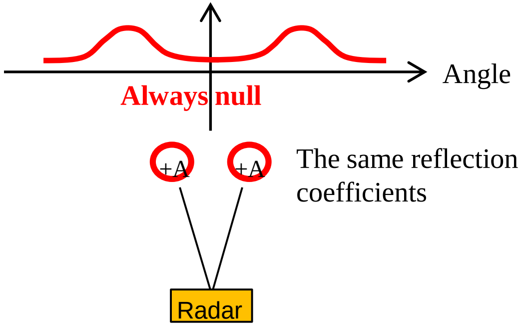
| | Beam width | L |
|---|---|---|
| Virtual 12 antennas | 9.5 deg | 26.4 m |

The radar fails and succeeds to separate two cars **randomly**.



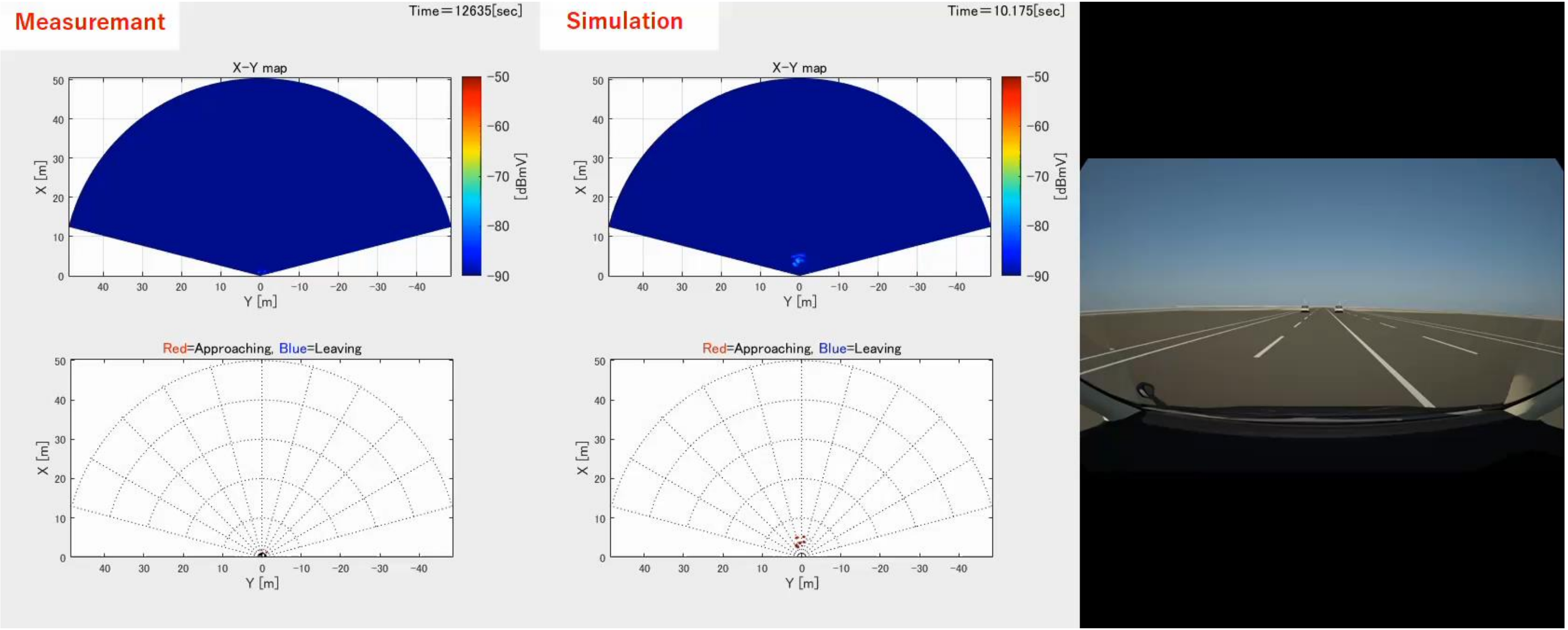
The radar can separate two cars **stably** .

The reflection coefficients observed from the radar



The same reflection coefficients

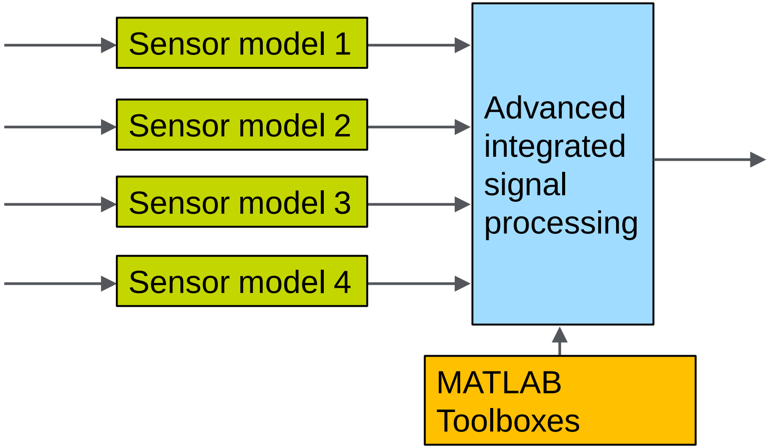
# The complex phenomena correctly computed in simulation.



1. DIVP overview
2. Radar modeling and validation
3. **Radar model applications**
4. Summary

# The Co-Simulation environment of DIVP and MATLAB/Simulink is very effective for studying sensor model applications.

## Co-simulation between DIVP and MATLAB/Simulink



Sensor model 1

Sensor model 2

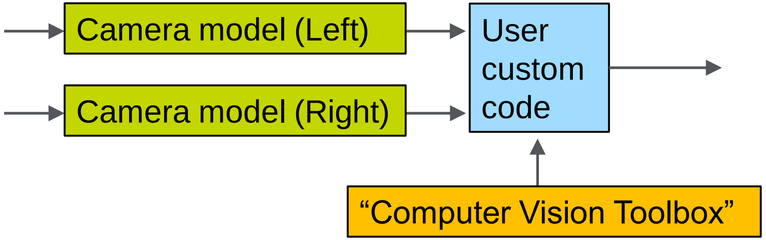
Sensor model 3

Sensor model 4

Advanced integrated signal processing

MATLAB Toolboxes

- Sensor models can be connected in parallel.
- Full access to MATLAB Toolboxes.

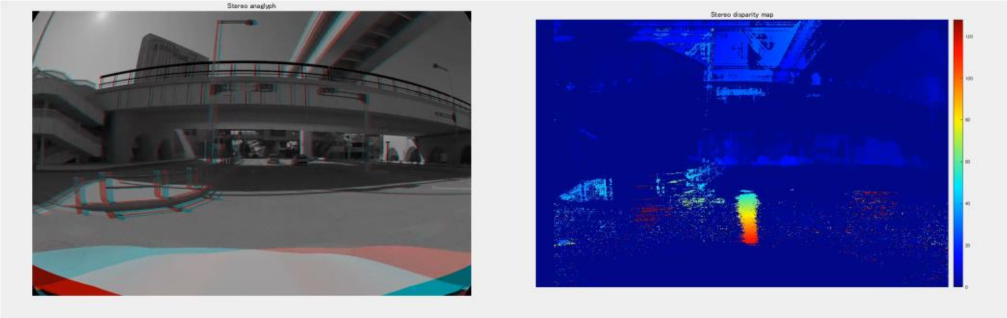


Camera model (Left)

Camera model (Right)

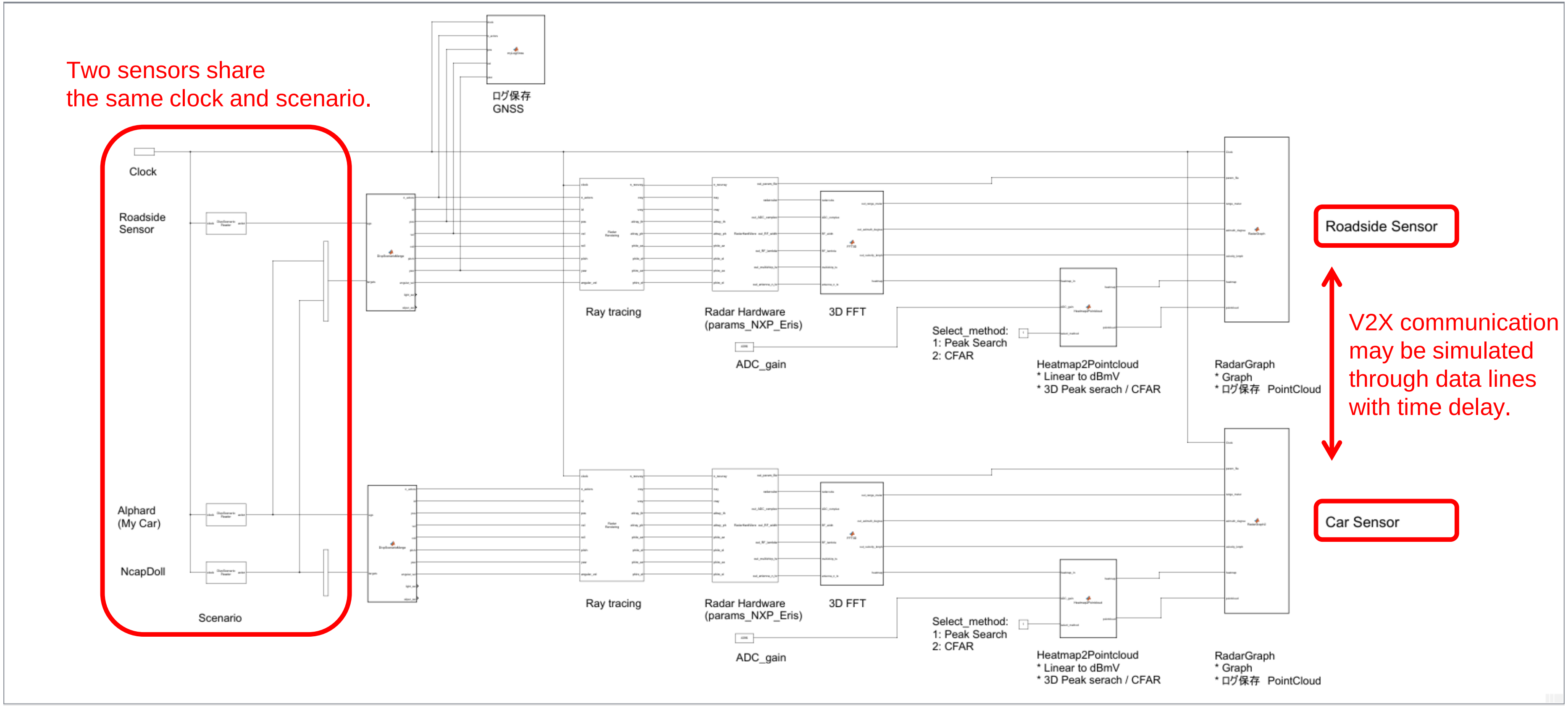
User custom code

“Computer Vision Toolbox”



Example of stereo camera

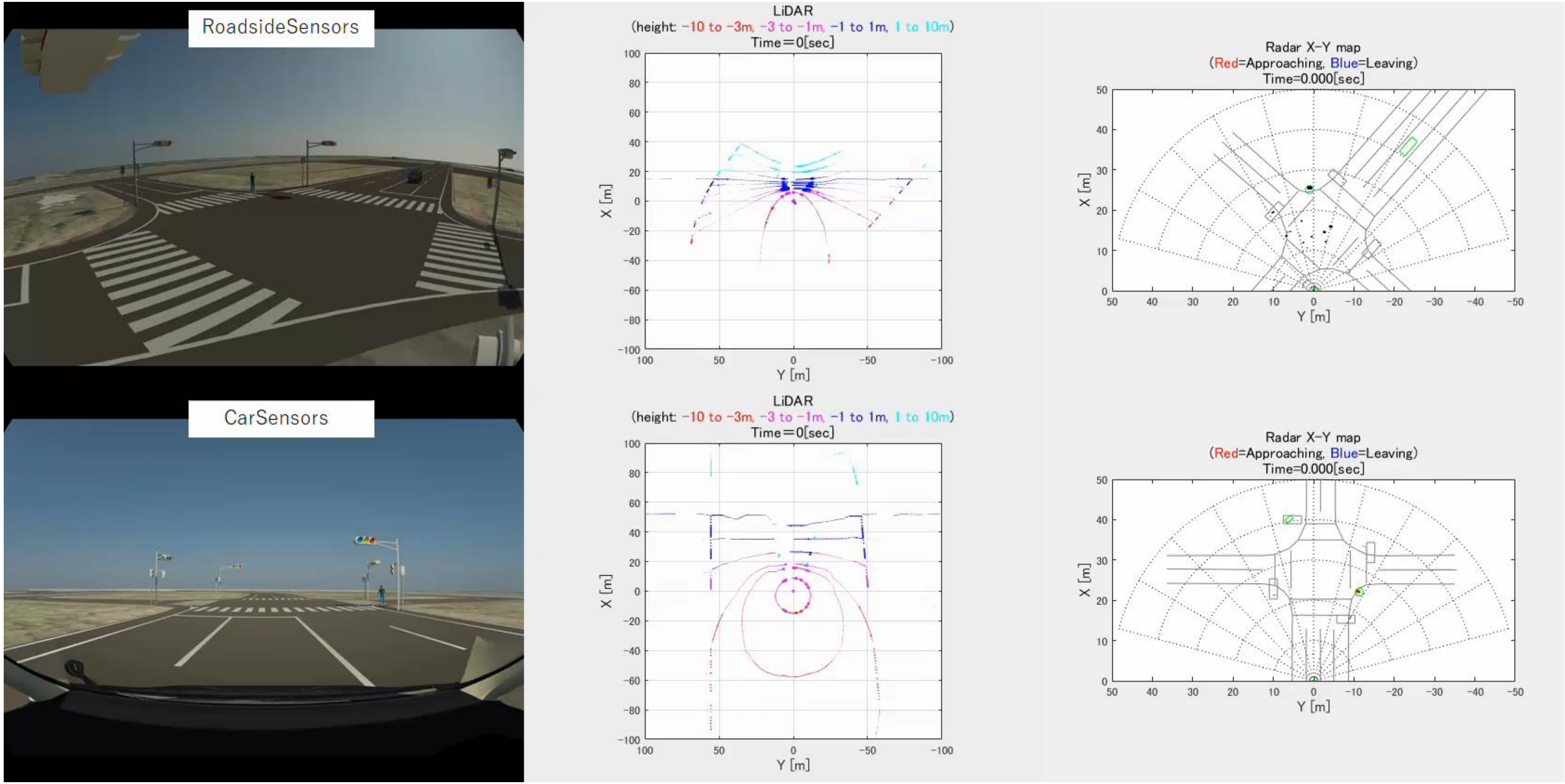
# A radar model application
# on “Vehicle-to-infrastructure cooperative driving system”



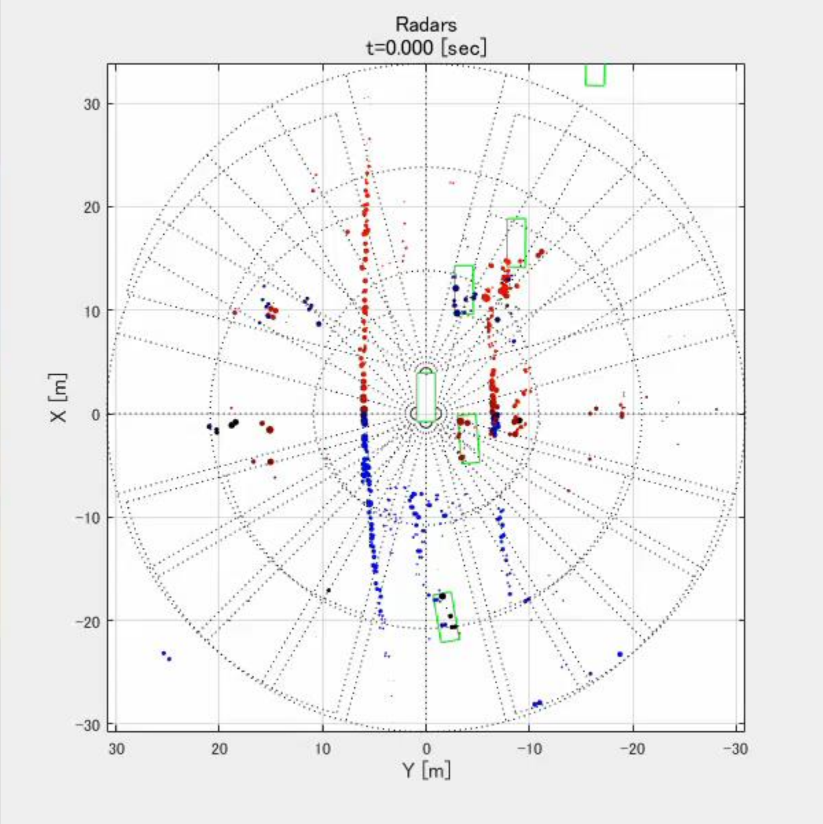
Two sensors share
the same clock and scenario.

V2X communication
may be simulated
through data lines
with time delay.

# A radar model application on “Vehicle-to-infrastructure cooperative driving system”

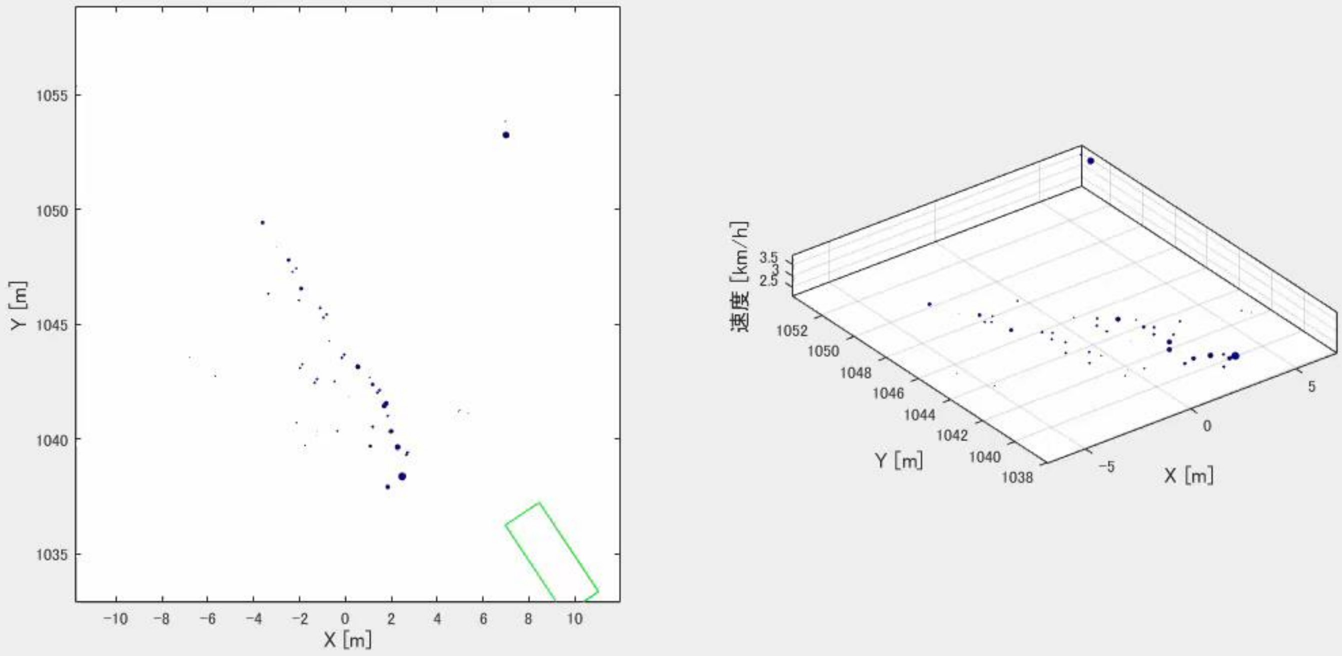


# A radar model application on early fusion with camera image



# A radar model application on "Free space mapping"

Extracting static objects



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# Summary on Radar modelling

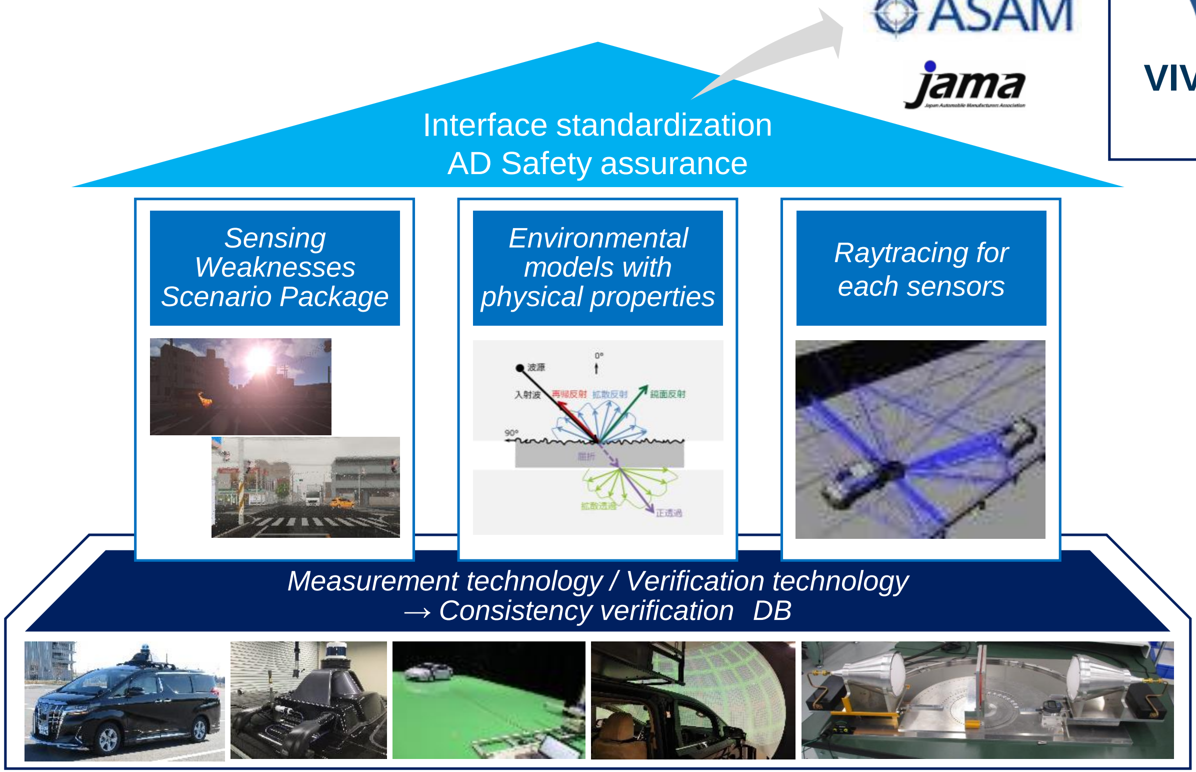
1. DIVP's Radar model can efficiently calculate the radarcube from a single ray tracing result using three different phase differences

2. With 77-GHz millimeter-wave radar, which has a wavelength of only 4 mm, complex phenomena often occur in even the simplest experiments. Using azimuth separation performance experiments as an example, we show that the Radar model can reproduce such complex phenomena.

3. The DIVP simulator enables the study of advanced complex sensor systems while making maximum use of the MATLAB/Simulink Toolbox group. Examples of potential applications are shown in the study of road-vehicle cooperative driving systems, sensor fusion, and free space generation.

# Through VIVID collaboration, DIVP® accelerates its original contributions to global standardization of simulation-based AD safety assurance methodology

## Summary; DIVP® contributions



ASAM

jama

Interface standardization
AD Safety assurance

*Sensing Weaknesses Scenario Package*

*Environmental models with physical properties*

*Raytracing for each sensors*

*Measurement technology / Verification technology*
*→ Consistency verification DB*

VIVALDI + DIVP

= *VIVID_JTs*

- Sensing weakness scenario: JT2
- Environmental models with physical library: JT2
- Interface; JT3
- Sensor models with ray tracing:
  - Camera: JT3.1
  - LiDAR: JT3.2
  - Radar: JT3.3

- Sensor measurements & test metrics: JT4,
- Tool chain: JT1

# *Thank you for your kind attention!*

*Tokyo Odaiba → Virtual Community Ground*

**END**