

Design of vehicle platooning controller with V2V communication

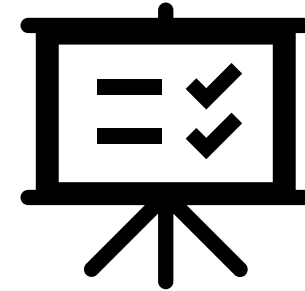
October 20, 2022 | Stuttgart

Advait Valluri



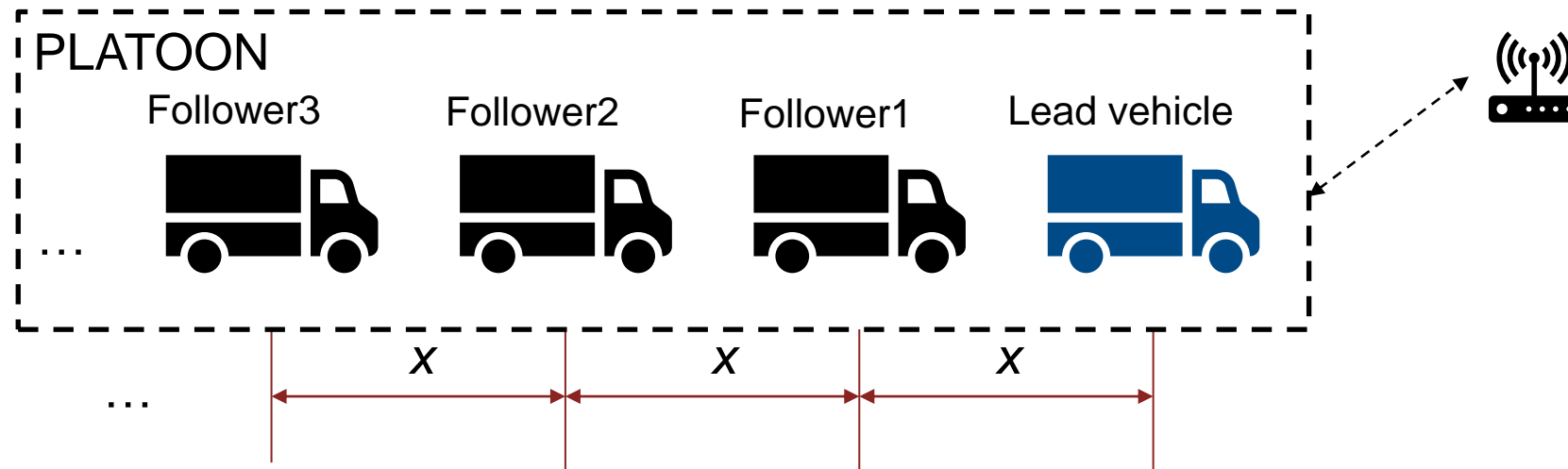
What will you learn today?

- How you can develop end-to-end **multi-domain systems** using MATLAB & Simulink, with platooning and V2V as example
- Understand how to **customize components** to various level of **complexity**
- Use **realistic 3D environments** to enable **sensor modelling (perception, tracking)** and algorithm development
- Leverage the power of **virtual development to identify problems** early before physical prototyping



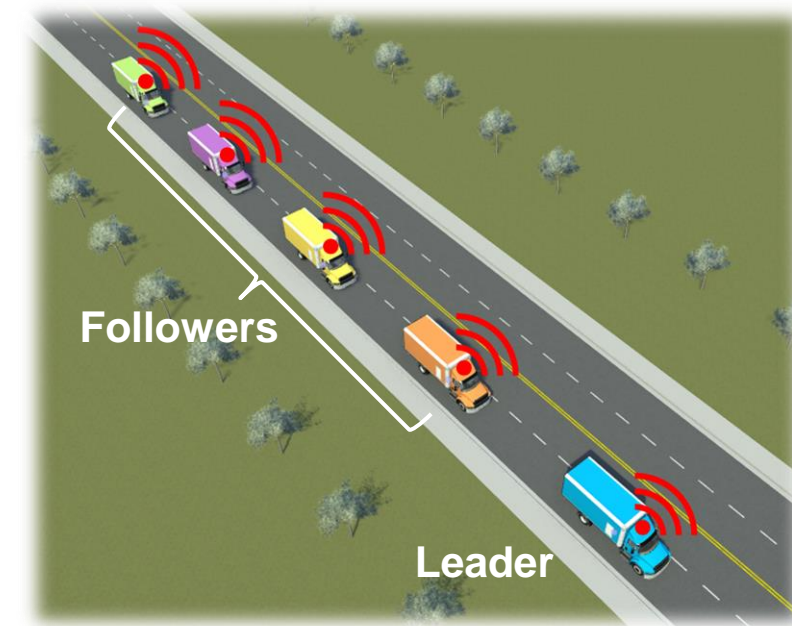
What is platooning?

- Platoon is a group of (autonomous) vehicles moving behind each other, being led by a lead vehicle dictating the motion of the entire group.
- It can reduce fuel consumption, emissions and improve traffic flow, safety.




What is V2V? How does V2V work?

- **Vehicle-to-vehicle (V2V) communication**
 - enables wireless exchange of safety information of surrounding vehicles
- **V2V communications systems**
 - use **Dedicated Short-Range Communication (DSRC)** or **Cellular Network** to exchange messages containing vehicle information (e.g., vehicle's speed, heading, braking status).



Design of vehicle platooning controller with V2V communication

Platooning Controller example



Design Controller for Vehicle Platooning

Tune spacing controller for trailing vehicles in a platoon using PID Tuner.

[Open Live Script](#)

Simulink Control Design™
 Model-Based PID Controller Tuning
R2021b

V2V example



Intersection Movement Assist Using Vehicle-to-Vehicle Communication

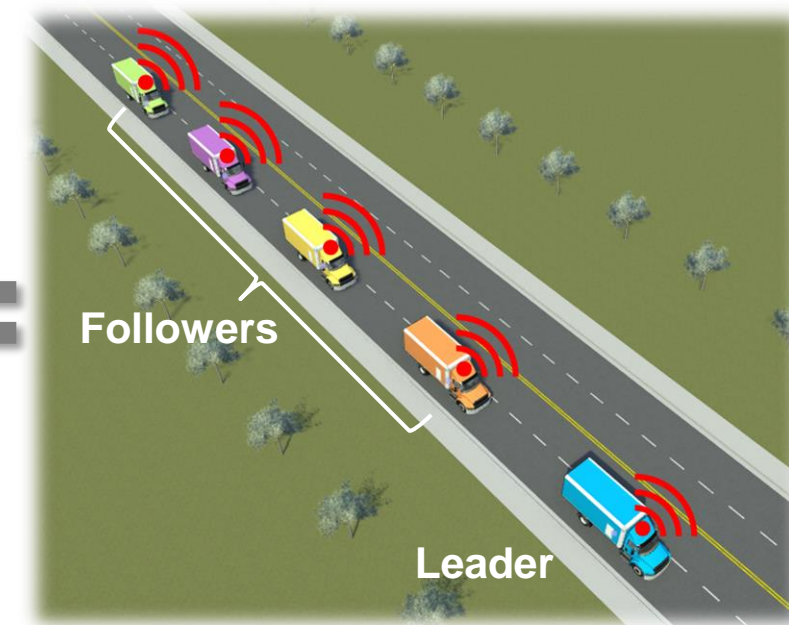
Design intersection movement assist application using V2V communication.

[Open Example](#)

Automated Driving Toolbox™
R2022a



Platooning with V2V



Simulation of vehicle platooning controller with V2V communication

The image displays the MATLAB R2022a Simulink environment used for simulating a vehicle platooning controller with V2V communication. The main window shows the Simulink model, which consists of a Leader vehicle and four Follower vehicles (Follower1 to Follower4). The Leader vehicle receives acceleration inputs and outputs its position (ActorPose) to the BSM (Basic Safety Message) block. The BSM block outputs BusBSM signals to the Follower vehicles. Each Follower vehicle receives BusBSM signals and outputs its position (ActorPose) to the PackAct block. The PackAct block outputs the positions of all vehicles to the workspace.

The workspace contains the following variables:

- ActorPose
- actorProfiles
- ans
- BusAccelerationSet4Way
- BusActorInfo
- BusActorPose
- BusActorsInfo
- BusBrakeSystemStatus
- BusBSM
- BusBSMCoreData
- BusPositionalAccuracy
- BusVehicleSize
- C1
- channelAttributes
- Cr
- Figure
- figureName
- Gap
- InitialBSM
- Iz
- K1
- K2
- K2tuned
- L
- L1
- L2
- lf
- logsgout
- lr
- m
- ...

The Command Window shows the following command history:

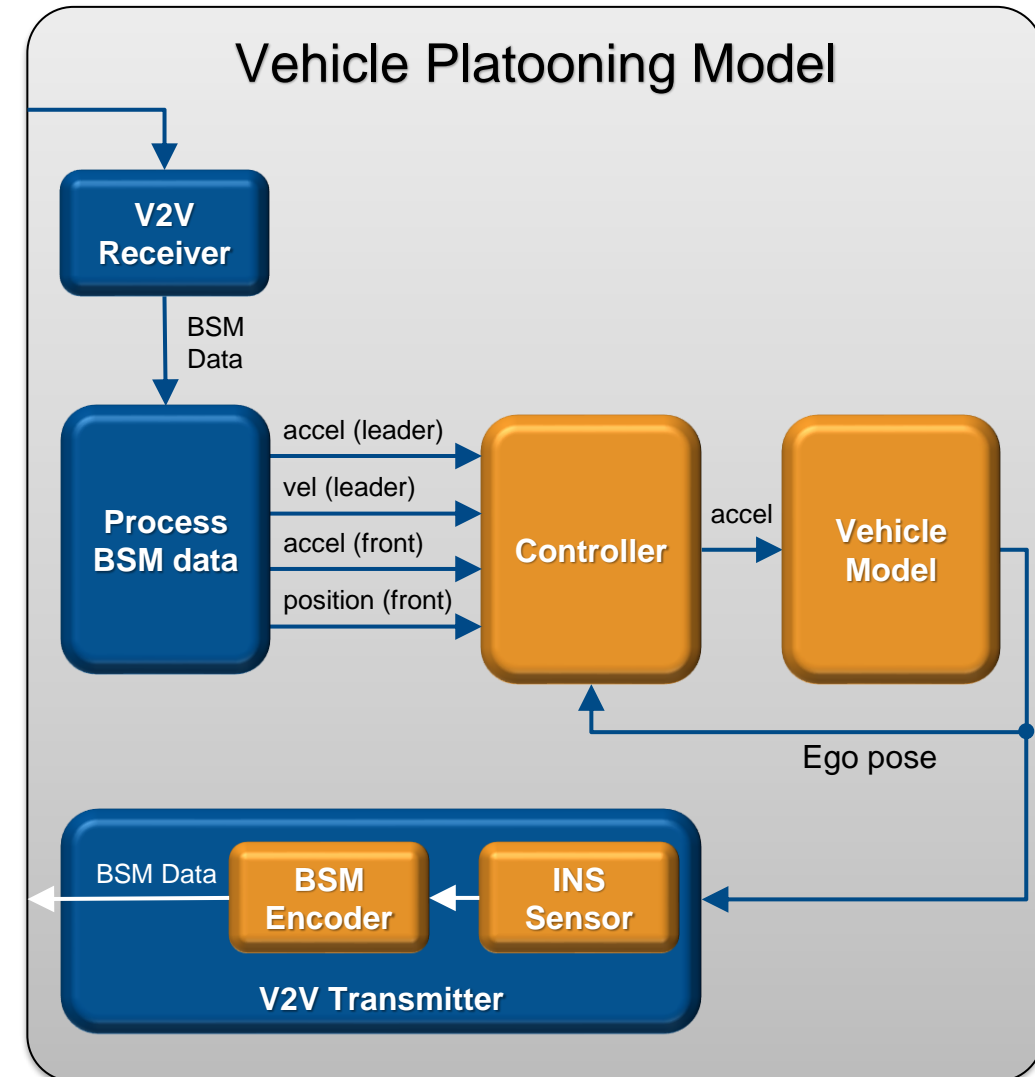
```
Figure = findobj(...
Figure.Position
screenSize = doub...
1920/2
1080-42
figureName = 'Pla...
Figure = findobj(...
Figure.Position
clc
```

The MATLAB R2022a interface shows the current folder containing the following files:

- Folder: .git
- Folder: AddVehicleDynamics
- Folder: bak
- Folder: doc
- Folder: resources
- Folder: slprj
- Folder: study
- Text Document: .gitattributes, .gitignore
- Class: HelperV2VReceiver.m, HelperV2VTransmitter.m, PackActorsInfo.m, VisualizePlatoon.m
- Function: helperActorInfo.m, plotPlatoonResults.m, setInitialBSM.m, stateFcnTruckTrailer.m
- Script: createBus.m, helperCreateV2VEnumDa..., helperFiveVehiclePlatoon..., helperFiveVehiclePlatoon..., helperFiveVehiclePlatoon...
- MAT-file: V2XChannellInfo.mat
- Project: PlatooningControlWithV...
- Simulink Model: dynamics.slx, dynamics_2.slx, fiveVehiclePlatoonDigital..., fiveVehiclePlatoonDigital..., fiveVehiclePlatoonInitial..., fiveVehiclePlatoonInitial..., fiveVehiclePlatoonTuned..., fiveVehiclePlatoonTuned...
- Simulink Cache: fiveVehiclePlatoon.slxc

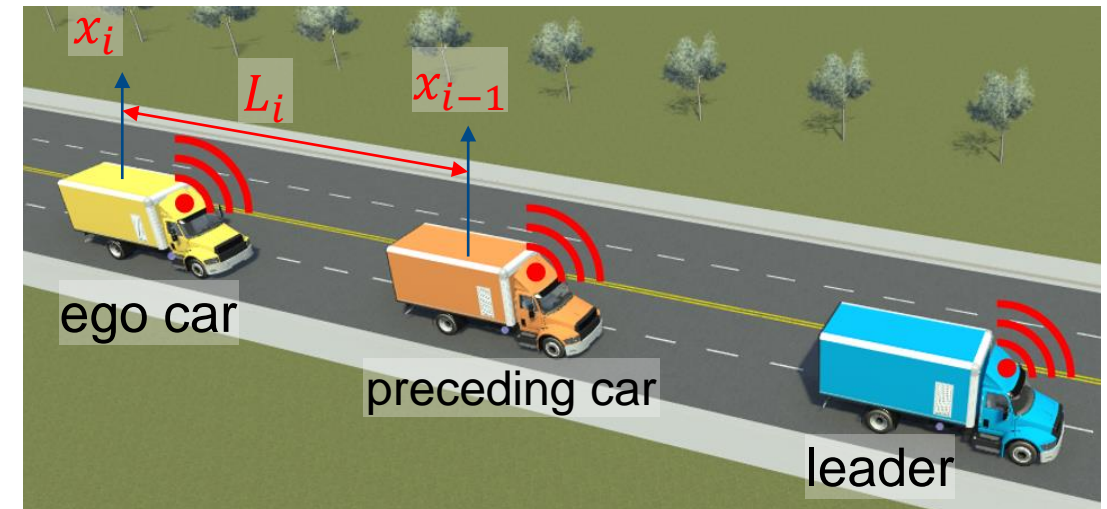
Platooning: components

- Information flow via V2V
 - Obtains the position and movement information of the other vehicles in the platoon via V2V
- Distributed controller
 - Sliding mode control: every controller share the same structure and parameters
 - Constant spacing: every car maintains a constant spacing from the preceding car
- Vehicle model
 - Truck-trailer kinematic model
 - A single track 3DOF rigid vehicle body (bicycle model)



Platooning: problem statement

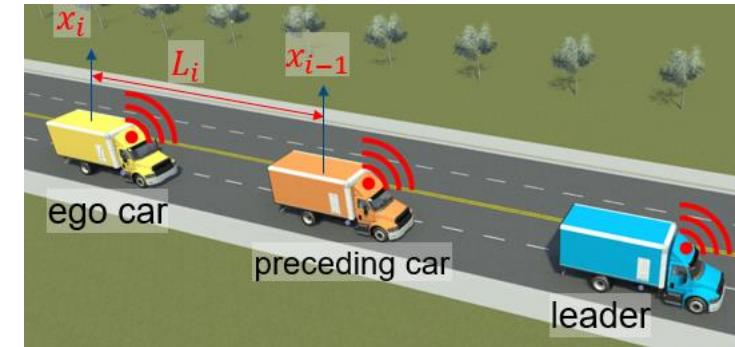
- Problem setup:
 - A given acceleration profile drives the lead vehicle
 - Every trailing vehicle is controlled by a controller based on the position and movement information of the other vehicles in the platoon
- Requirement:
 - Define spacing error: $\varepsilon_i = L_i - (x_{i-1} - x_i)$
 - Individual stability
 - $\varepsilon_i \rightarrow 0$: spacing error goes to zero if predecessor maintains constant speed.
 - String stability
 - spacing error does not amplify downstream.



where L_i is the desired spacing that includes the vehicle length.

Controller with sliding mode control

$$a_{ego} = C_1 a_{lead} + (1 - C_1) a_{front} - K_1 (v_{ego} - v_{lead}) - K_2 (x_{ego} - x_{front} + L)$$



Trade off between lead car and preceding car

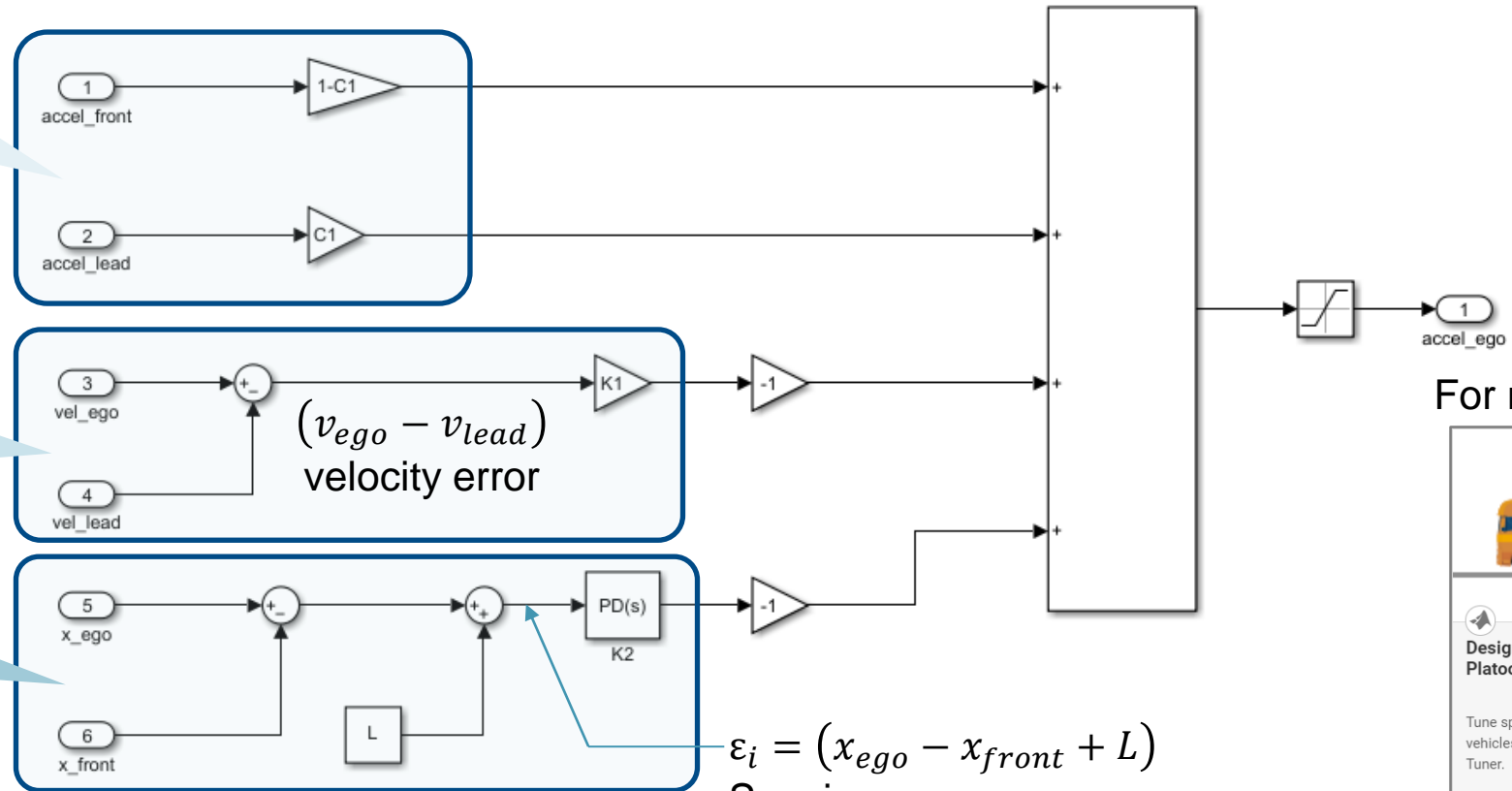
$$C_1 a_{lead} + (1 - C_1) a_{front}$$

Ego velocity will converge to lead velocity

$$-K_1 (v_{ego} - v_{lead})$$

Spacing error will converge to zero

$$-K_2 (x_{ego} - x_{front} + L)$$




$\epsilon_i = (x_{ego} - x_{front} + L)$
Spacing error
= ego - preceding car position

For more details

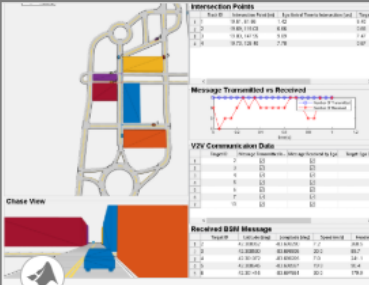
Basic Safety Message (BSM) by SAE J2735

- SAE J2735 – Data and message set dictionary
- Defines the **Basic Safety Message (BSM)**
 - Latitude, longitude, Elev
 - Speed
 - Heading angle
 - Steering wheel angle
 - Lat, long acceleration
 - Vehicle length, width

	SURFACE VEHICLE STANDARD		J2735®	JUL2020
	Issued	2006-12		
	Revised	2020-07		
Superseding J2735 MAR2016				
(R) V2X Communications Message Set Dictionary				

```
BSMcoreData ::= SEQUENCE {
  msgCnt          MsgCount,
  id              TemporaryID,
  secMark        DSecond,
  lat             Latitude,
  long            Longitude,
  elev            Elevation,
  accuracy        PositionalAccuracy,
  transmission    TransmissionState,
  speed           Speed,
  heading         Heading,
  angle           SteeringWheelAngle,
  accelSet        AccelerationSet4Way,
  brakes          BrakeSystemStatus,
  size            VehicleSize
}
```

For more details



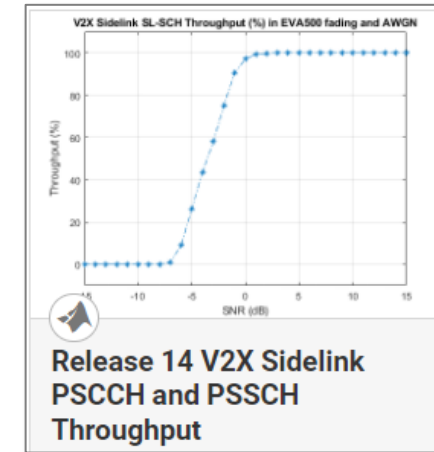
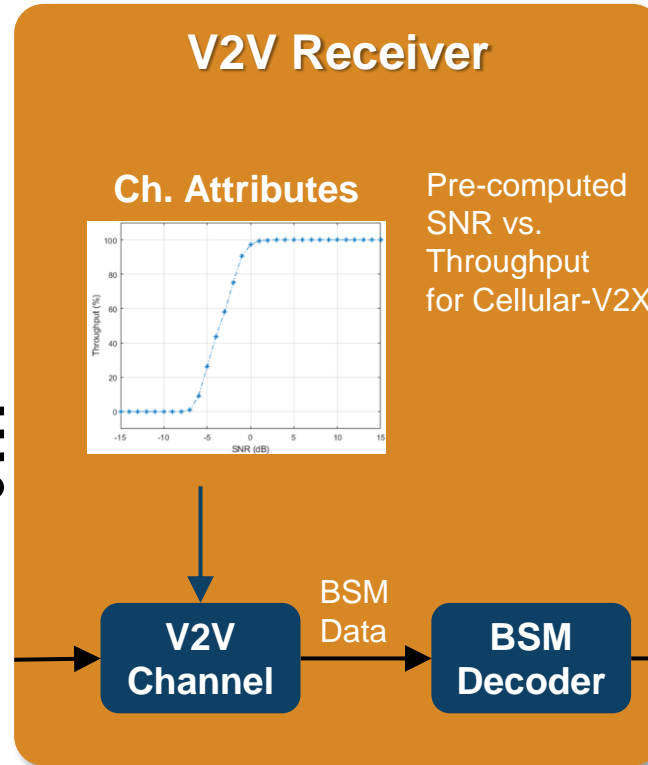
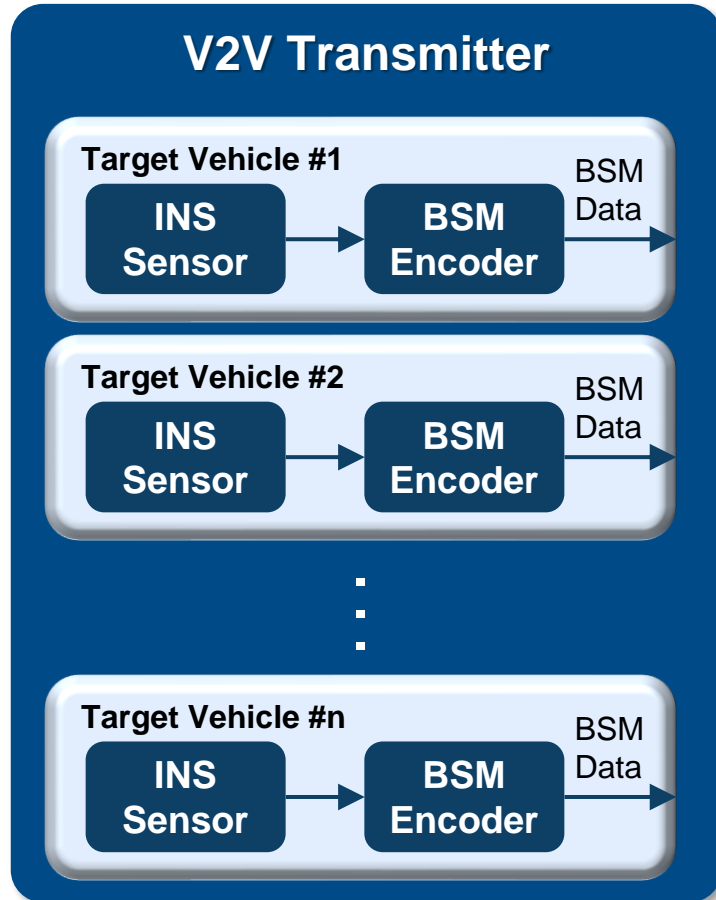
Intersection Movement Assist Using Vehicle-to-Vehicle Communication

Design intersection movement assist application using V2V communication.

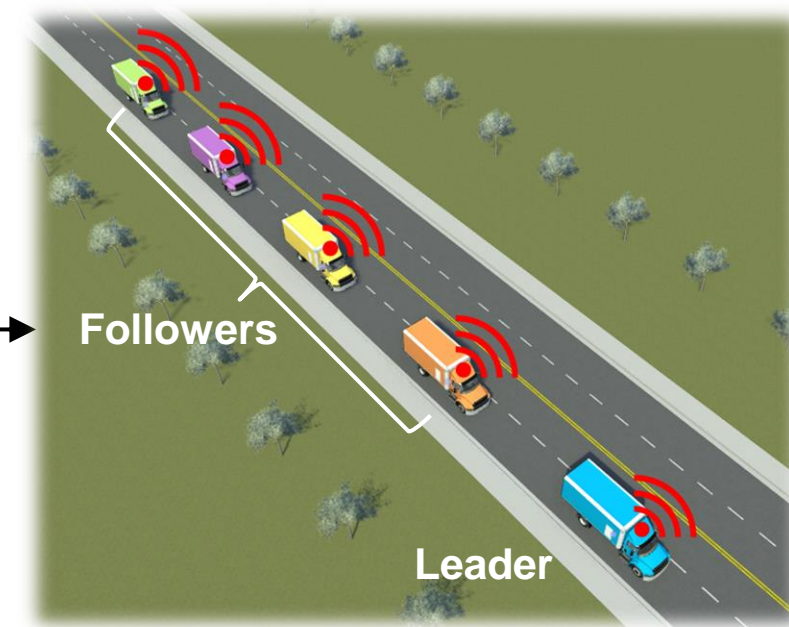
[Open Example](#)

Automated Driving Toolbox™
R2022a

Design V2V Transmitter and Receiver

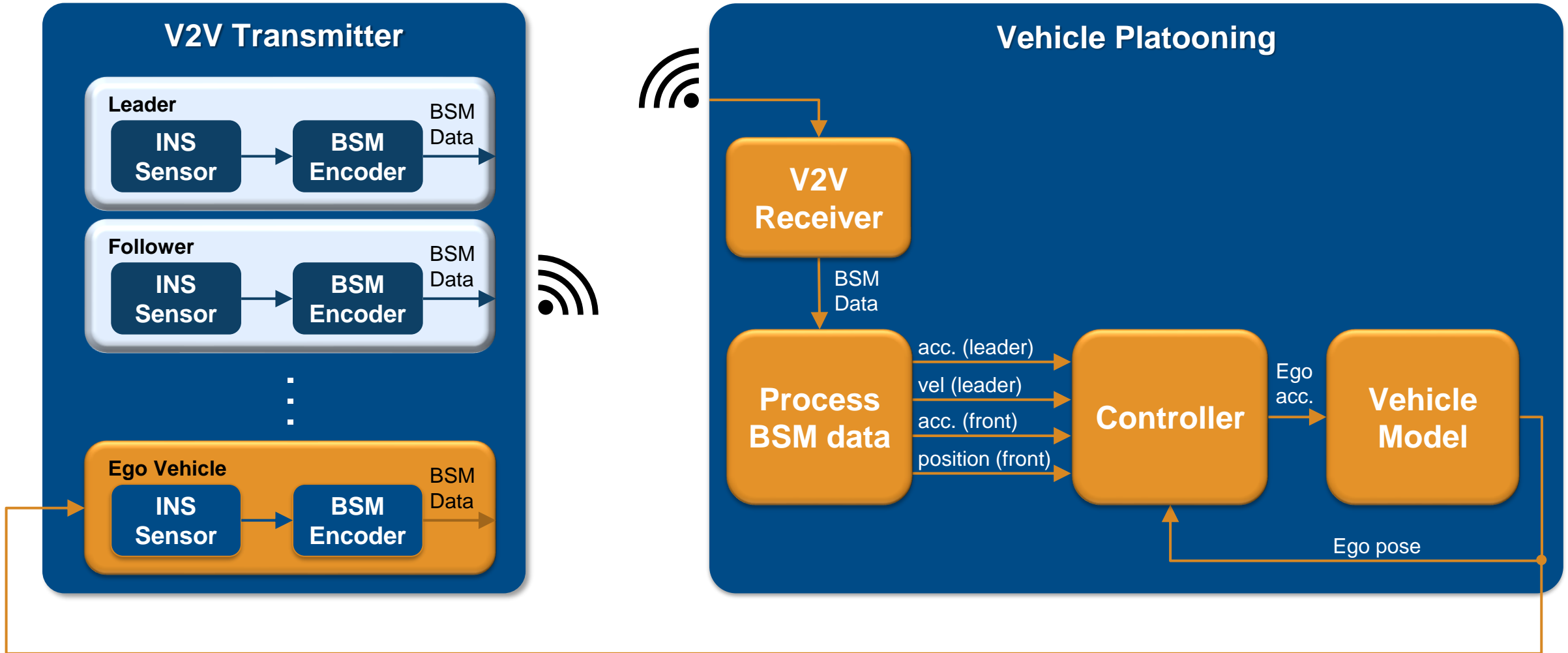


LTE Toolbox™

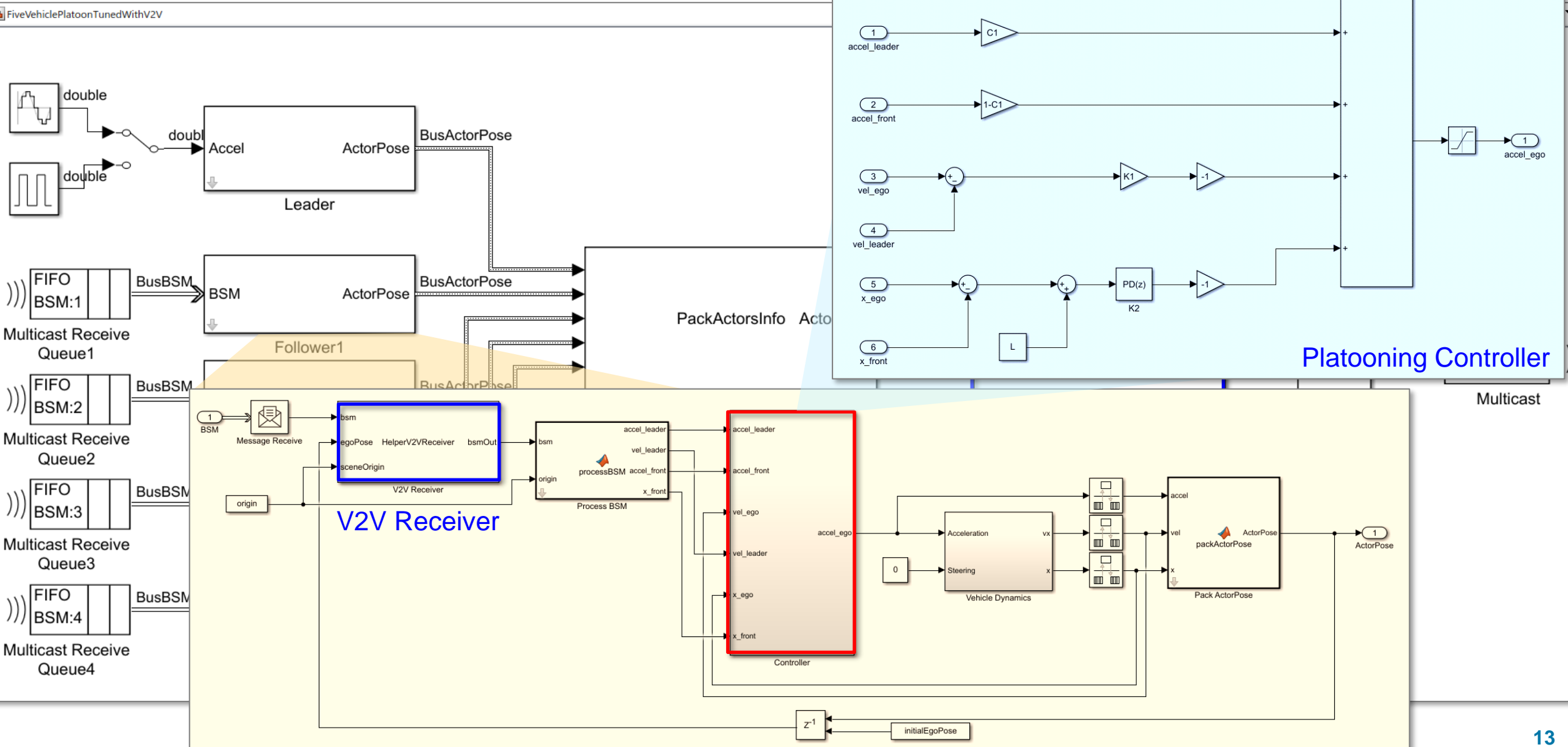


Platooning with V2V

Vehicle Platooning Controller with V2V Communication

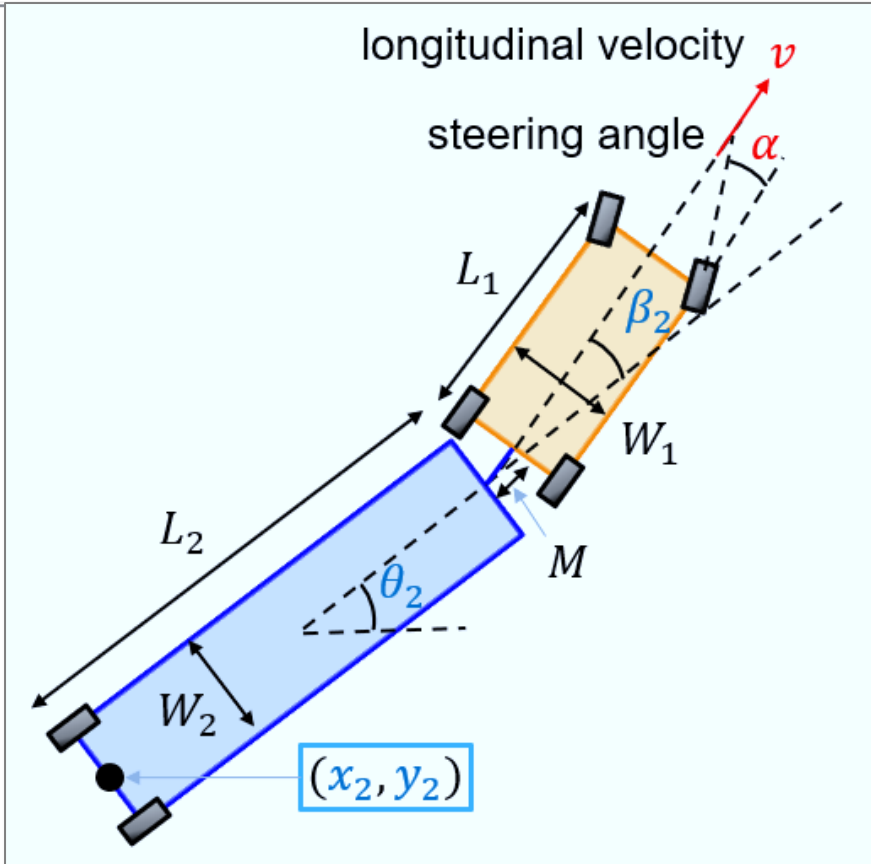


Vehicle Platooning Controller with V2V Communication

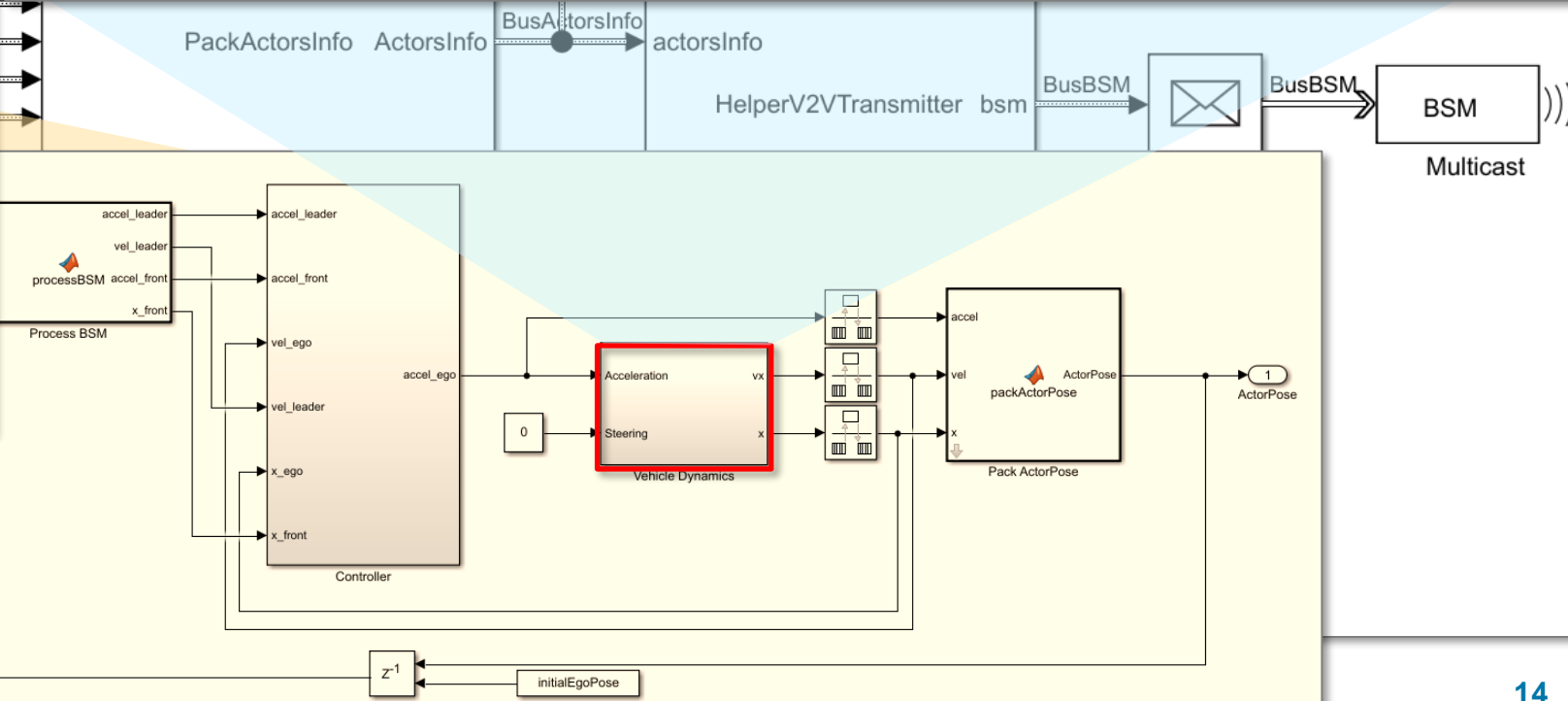
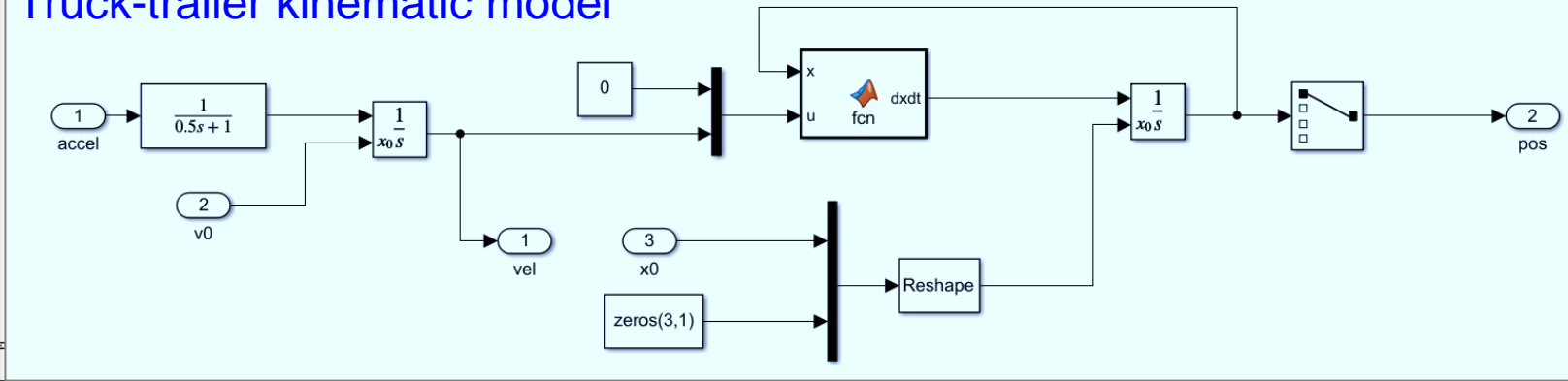


Vehicle Platooning Controller with V2V Communication

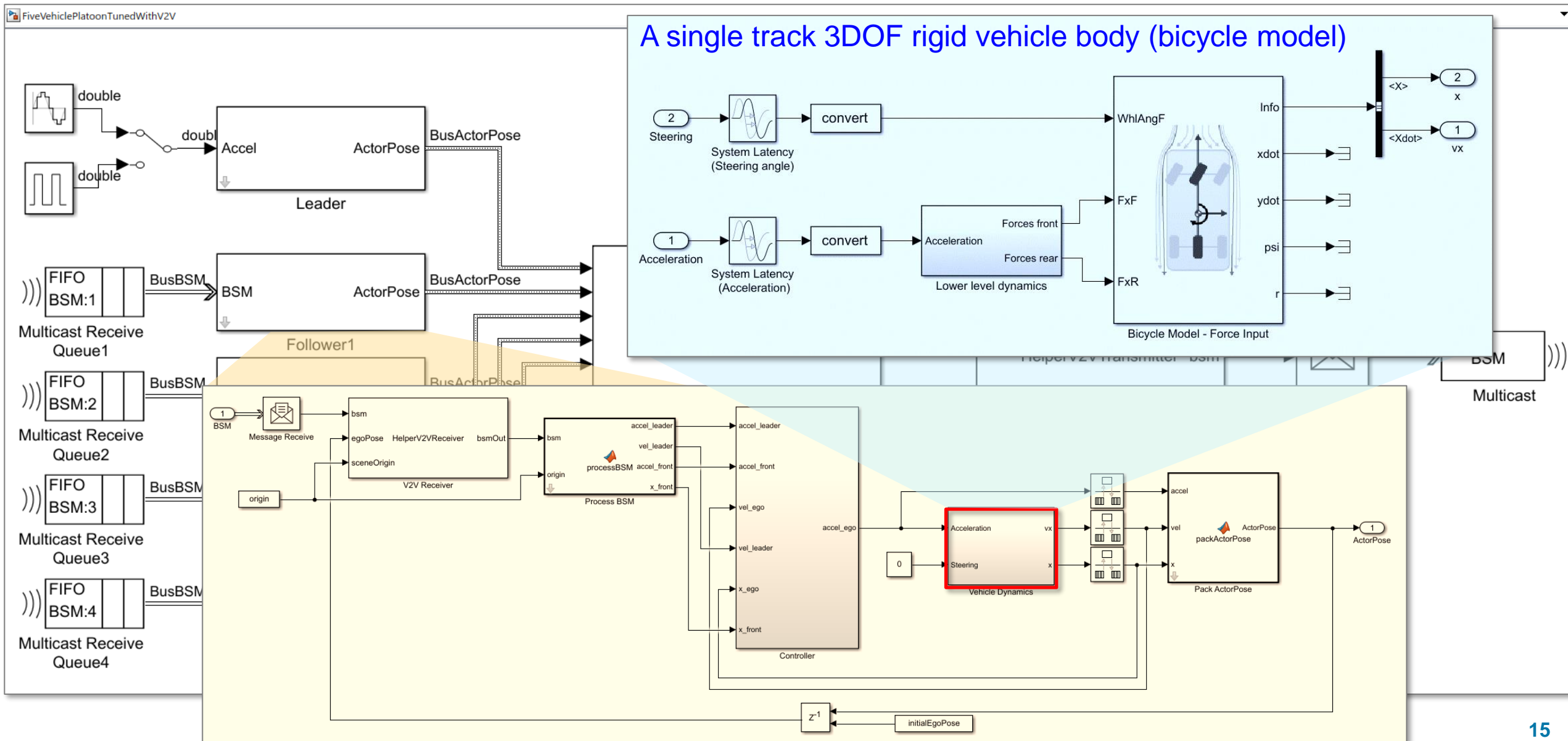
FiveVehiclePlatoonTunedWithV2V



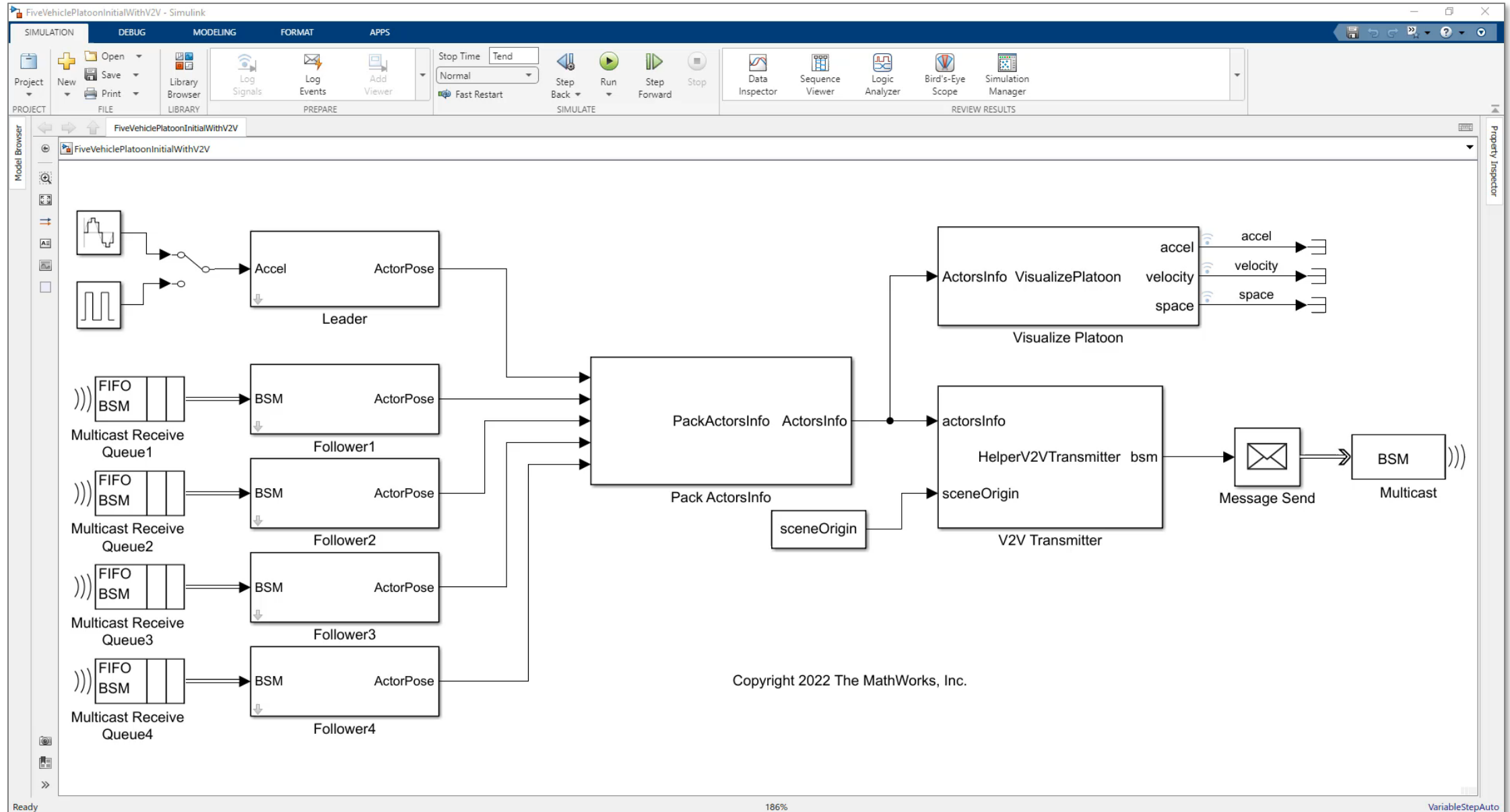
Truck-trailer kinematic model



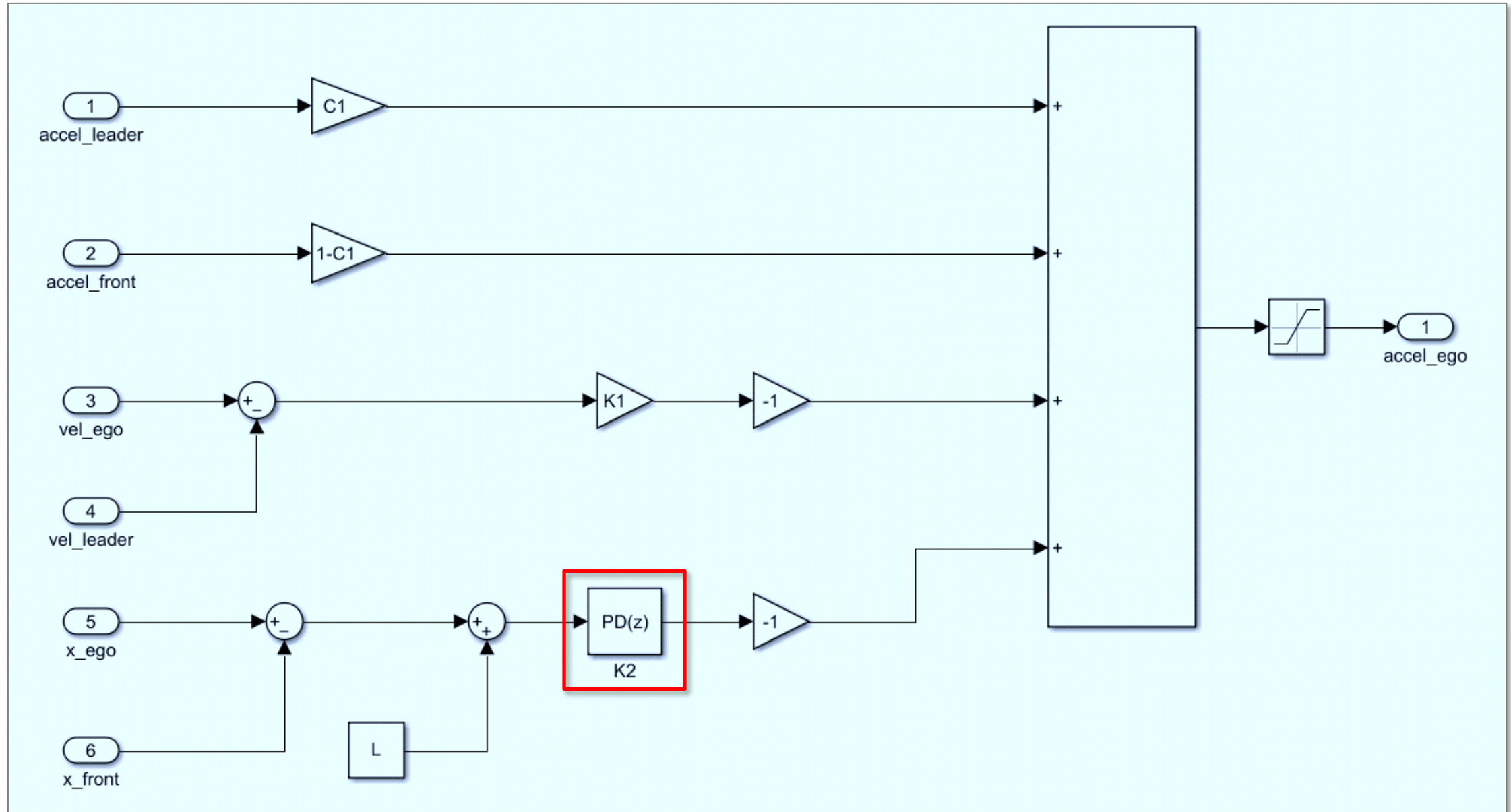
Vehicle Platooning Controller with V2V Communication



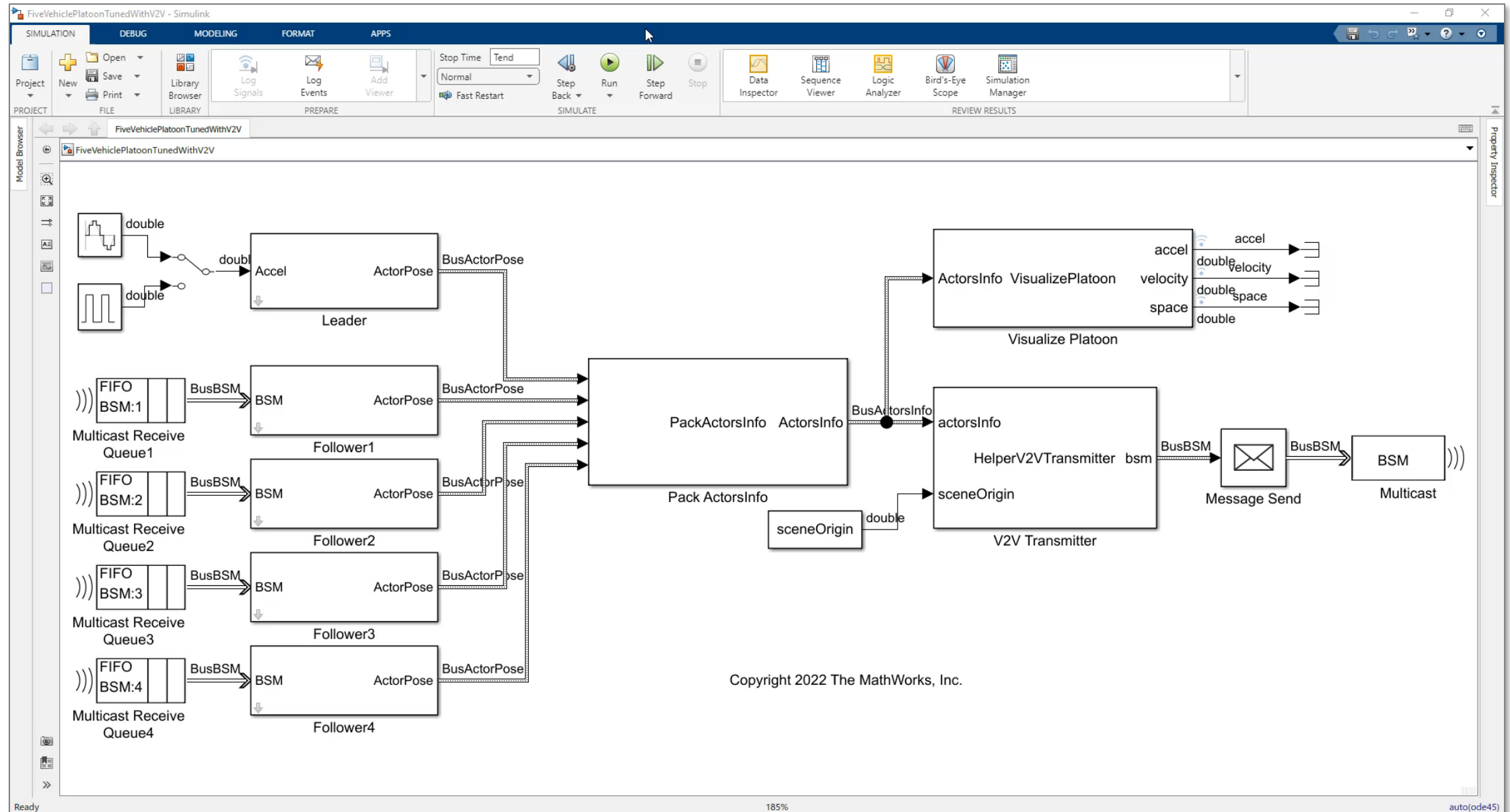
Simulation result (with initial setting of controller gains)



Simulation result (after tuning K2 for faster response)

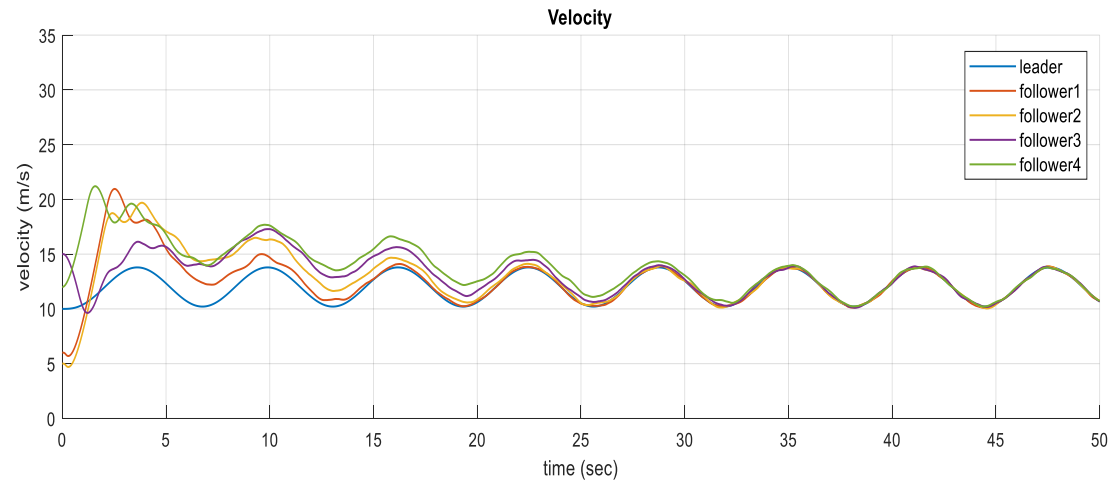


Simulation result (after tuning K2 for faster response)

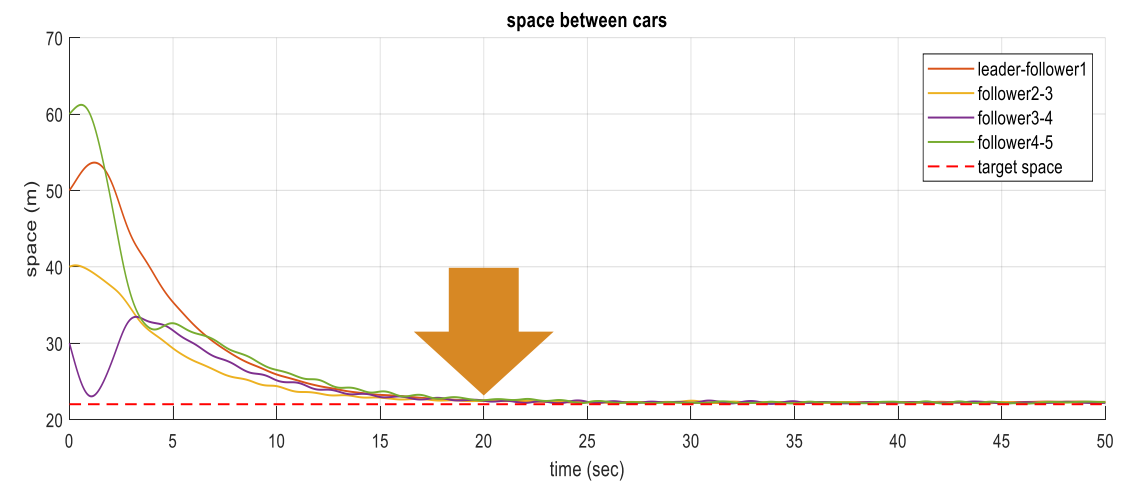
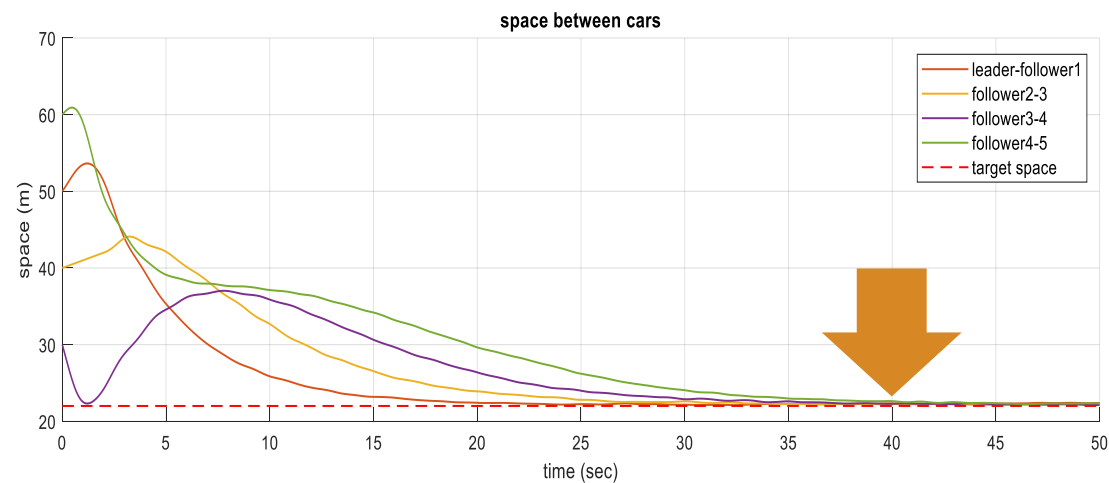
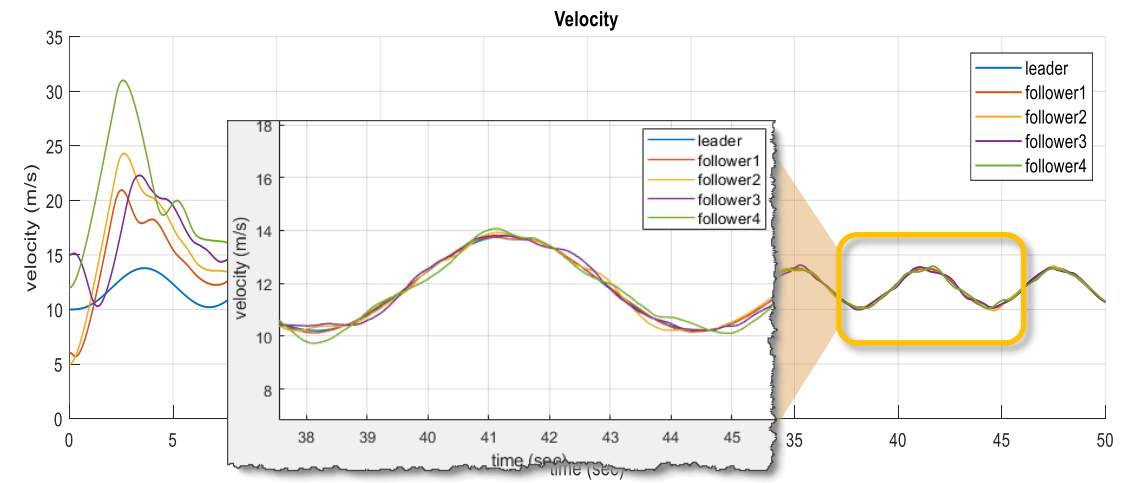


Simulation result (before vs. after tuning K2 for faster response)

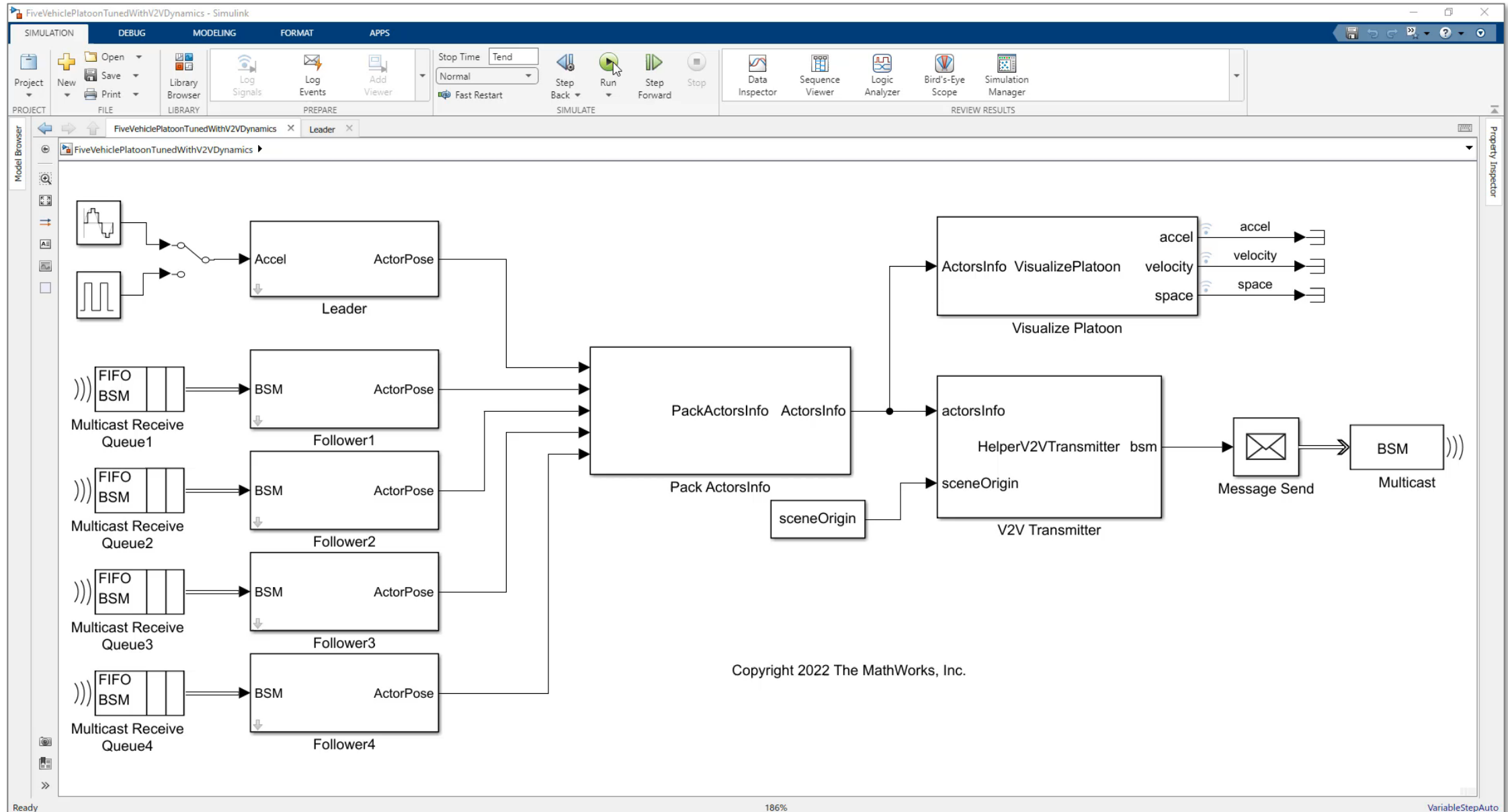
Before



After



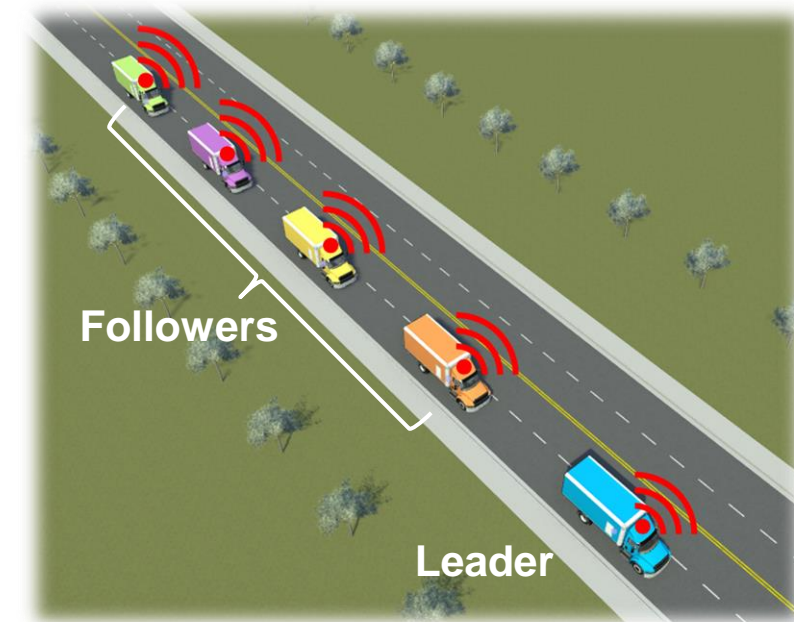
Simulation result (With a single track 3DOF rigid vehicle body - bicycle model)



Key takeaways:

Design of vehicle platooning controller with V2V communication

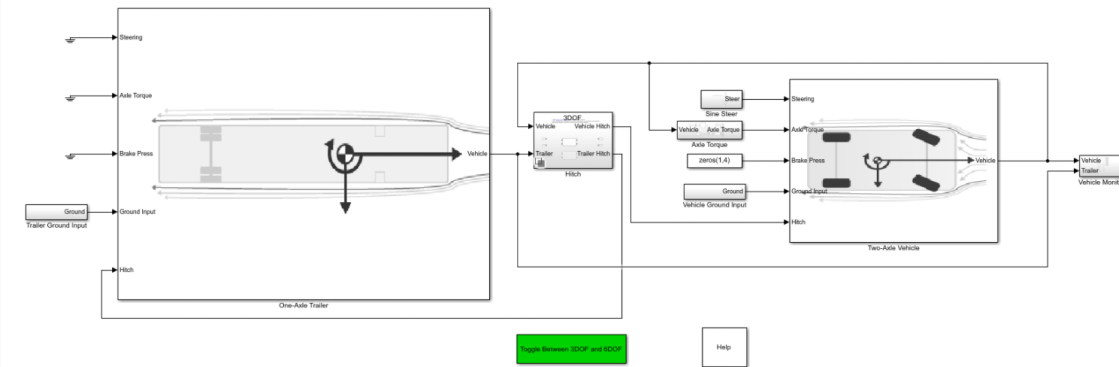
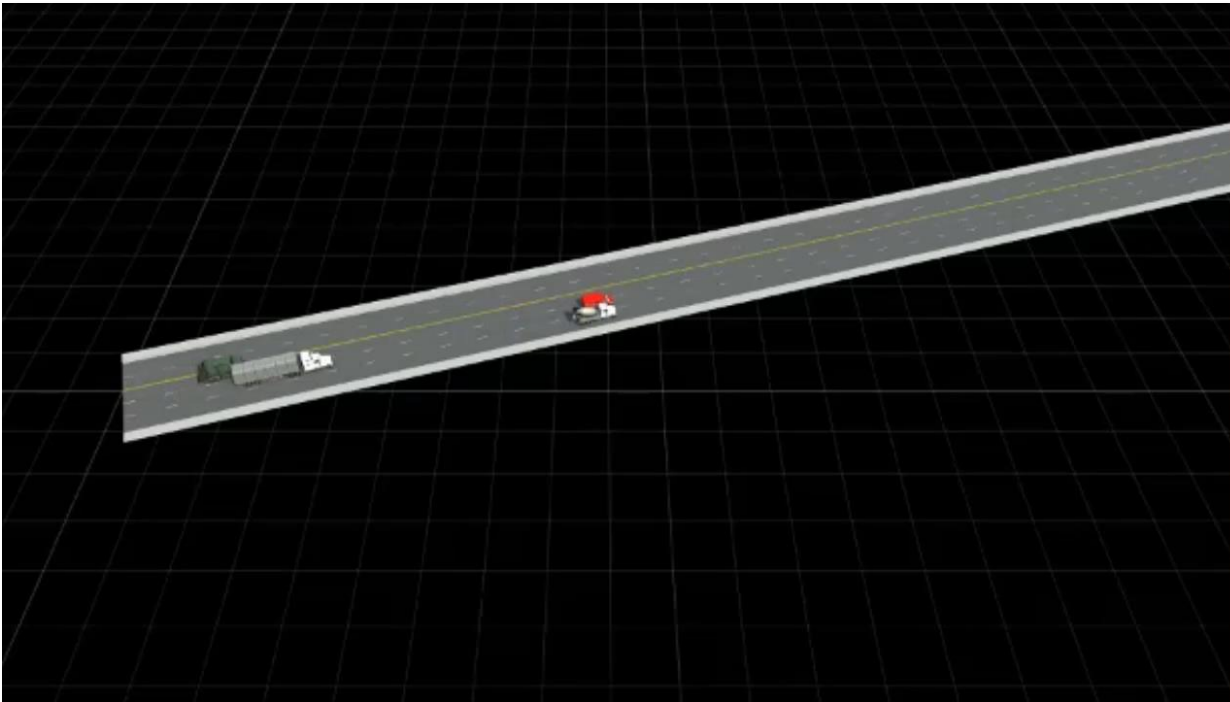
- Demonstrated how to design a vehicle platooning controller with V2V communication using
 - Simulink Control Design™
 - Automated Driving Toolbox™
- The test bench model consists of
 - V2V communication
 - Model characteristics of the V2V communication channel
 - Implement BSM defined by SAE J2735
 - Vehicle model
 - Truck-trailer kinematic model
 - A single track 3DOF rigid vehicle body (bicycle model)
 - Distributed controller implementing sliding mode control



Simulink Control Design™
Automated Driving Toolbox™
R2022a

Further studies

- Scenario authoring using RoadRunner Scenario with truck and trailer meshes



Vehicle Dynamics Blockset™
R2022a

- High fidelity 6 DOF model of a two-axle tractor towing one axle trailer
- Lateral control for curved roads (use Lane keeping control)

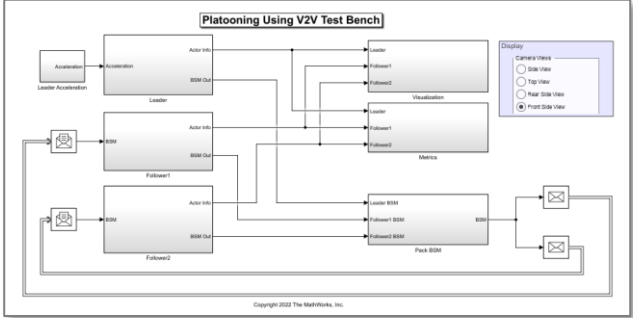
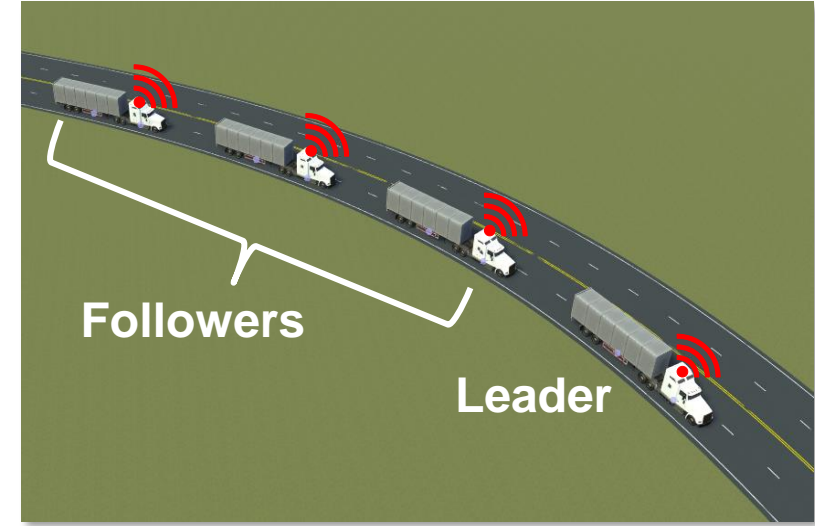
Design of vehicle platooning with lateral control and V2V communication

Design of vehicle platooning controller with V2V communication

October 20, 2022 | Stuttgart

Advait Valluri

- Platooning longitudinal control
- Truck-trailer kinematic model
- V2V communication



R2022b

- Platooning longitudinal control
- High fidelity Three-Axle Tractor Towing Three-Axle Trailer
- V2V communication

- Lateral Control using LKA MPC controller
 - Truck-trailer linearized lateral dynamics model
- Scenario authoring using RRS
- UE visualization
- Command acceleration generation depending on road curvatures
- V2V communication



- Future Release
- Lateral Control using LKA MPC controller
 - Truck-trailer linearized lateral dynamics model
 - UE visualization

What will you learn today?

- How you can develop end-to-end **multi-domain systems** using MATLAB & Simulink, with platooning and V2V as example ✓
- Understand how to **customize components** to **various level of complexity** ✓
- Use **realistic 3D environments** to enable **sensor modelling (perception, tracking)** and algorithm development ✓
- Leverage the power of **virtual development to identify problems** early before physical prototyping ✓

