Design of vehicle platooning controller with V2V communication

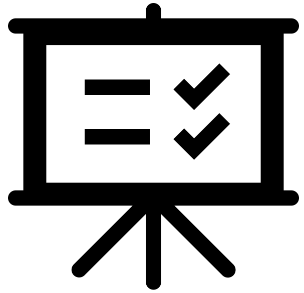
October 20, 2022 | Stuttgart

Advait Valluri

MathWorks®

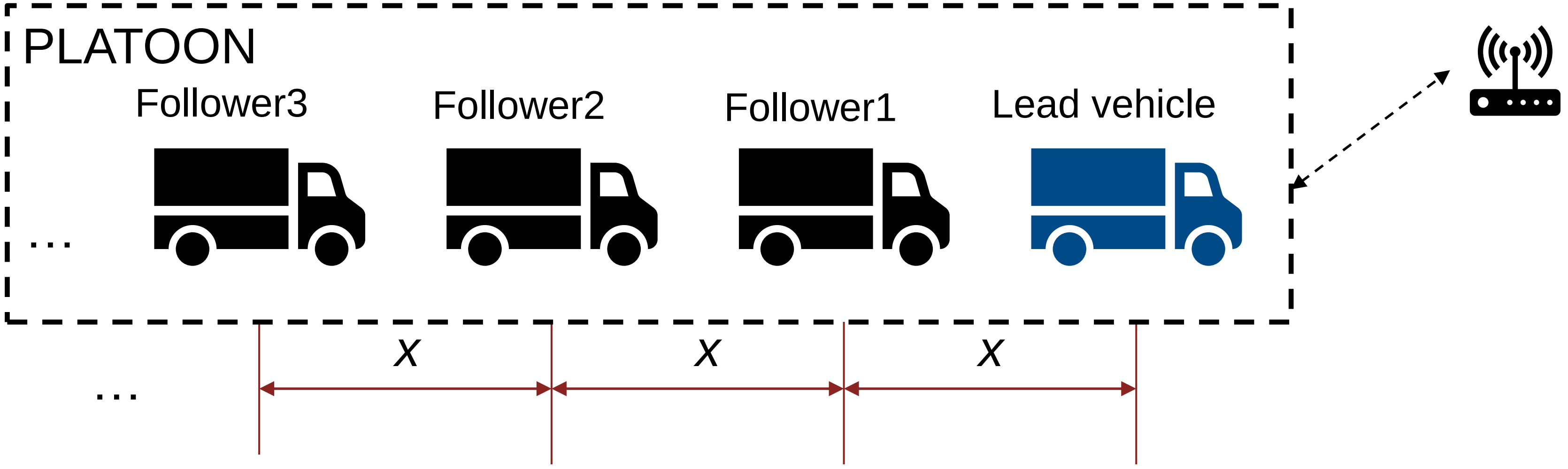
What will you learn today?

- 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?

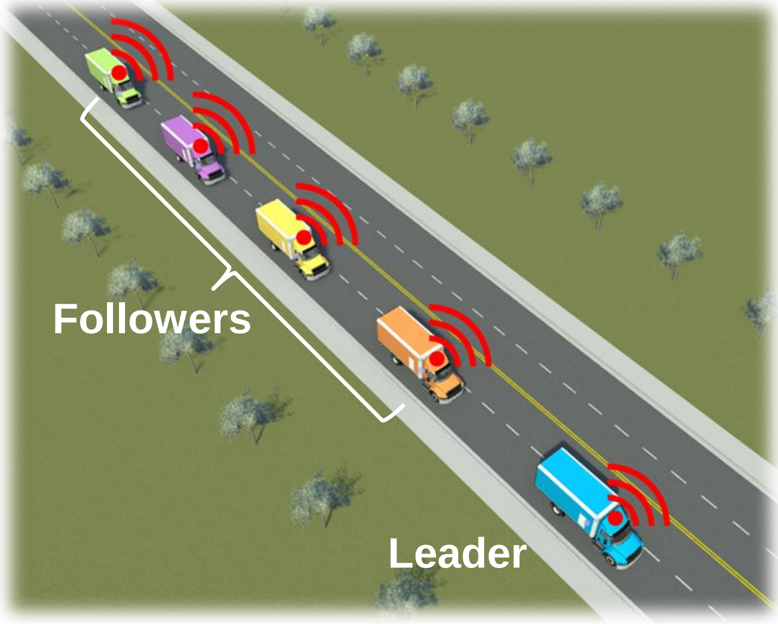
- Platoon is a group of (autonomous) vehicles moving behind each other, being led by a lead vehicle dictating the motion of the entire group.
- It can reduce fuel consumption, emissions and improve traffic flow, safety.



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

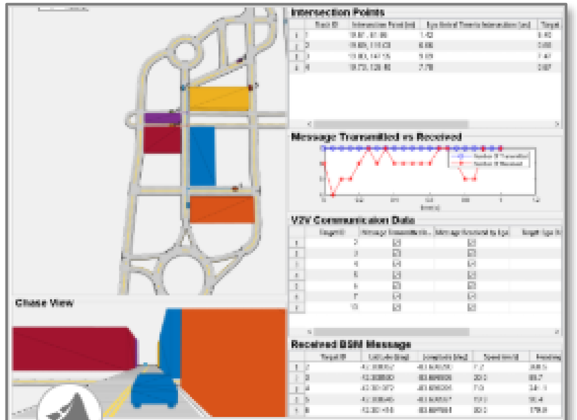
Tune spacing controller for trailing vehicles in a platoon using PID Tuner.

Open Live Script

Simulink Control Design™
Model-Based PID Controller Tuning
R2021b

+

V2V example



Intersection Movement Assist Using Vehicle-to-Vehicle Communication

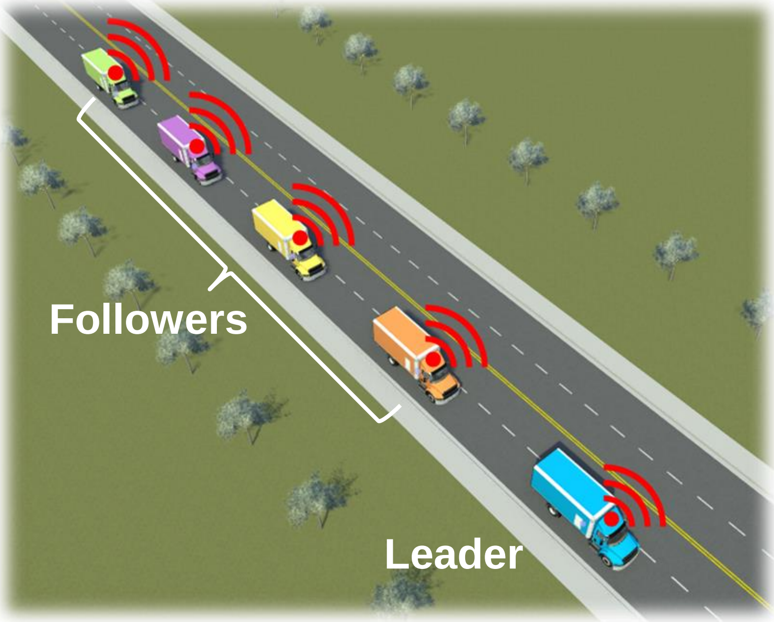
Design intersection movement assist application using V2V communication.

Open Example

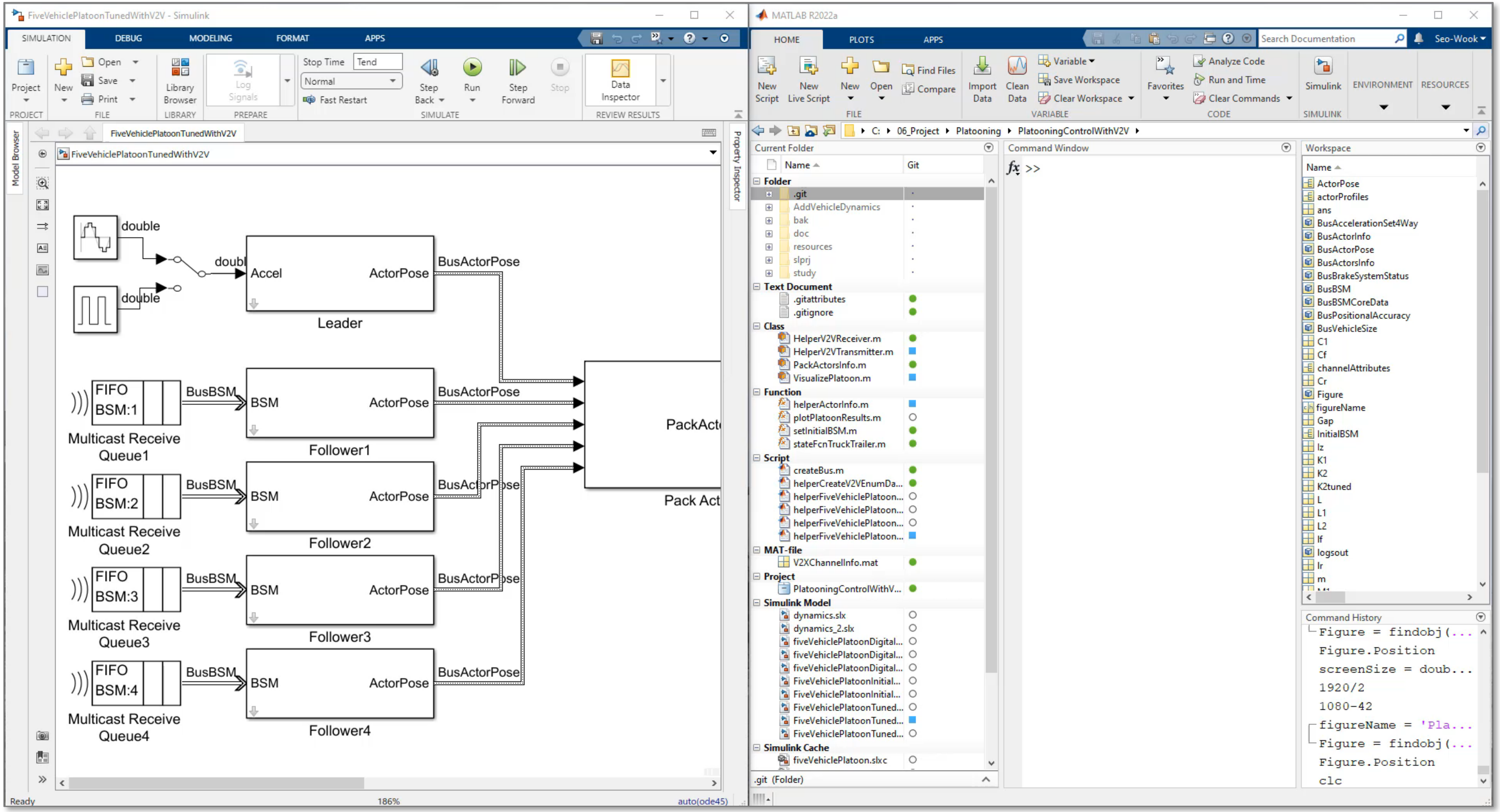
Automated Driving Toolbox™
R2022a

=

Platooning with V2V

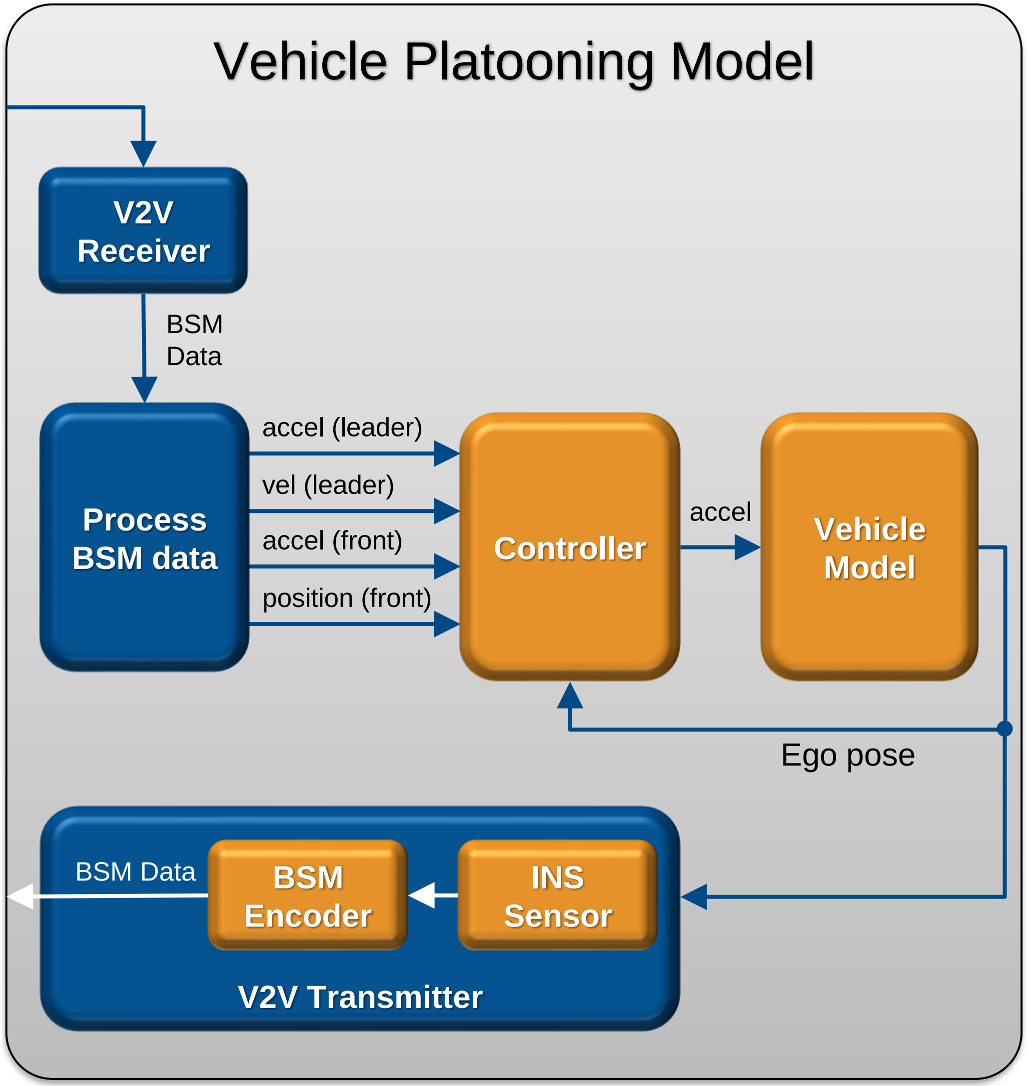


Simulation of vehicle platooning controller with V2V communication



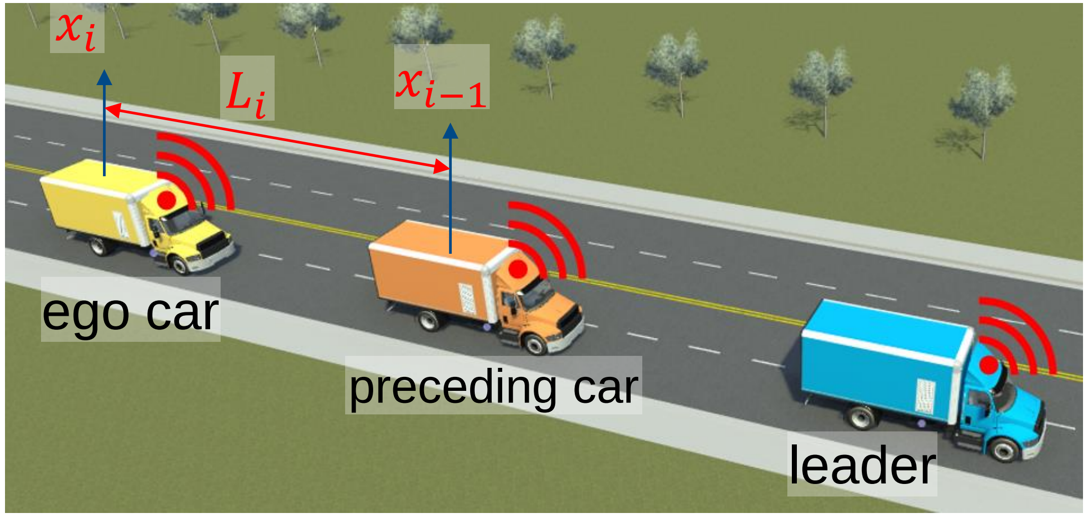
Platooning: components

- 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

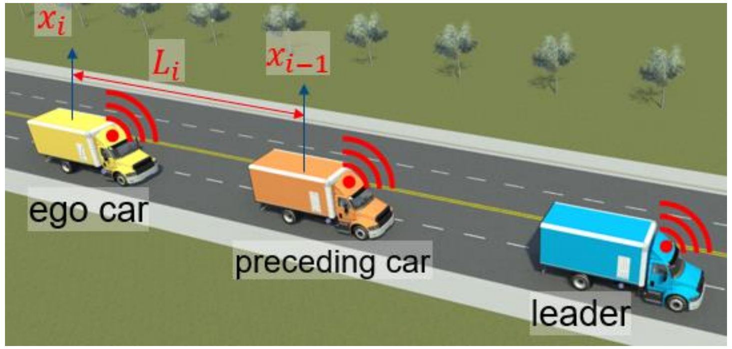
- Problem setup:
  - A given acceleration profile drives the lead vehicle
  - Every trailing vehicle is controlled by a controller based on the position and movement information of the other vehicles in the platoon
- Requirement:
  - Define spacing error: $\varepsilon_i = L_i - (x_{i-1} - x_i)$
  - Individual 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

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



Trade off between lead car and preceding car

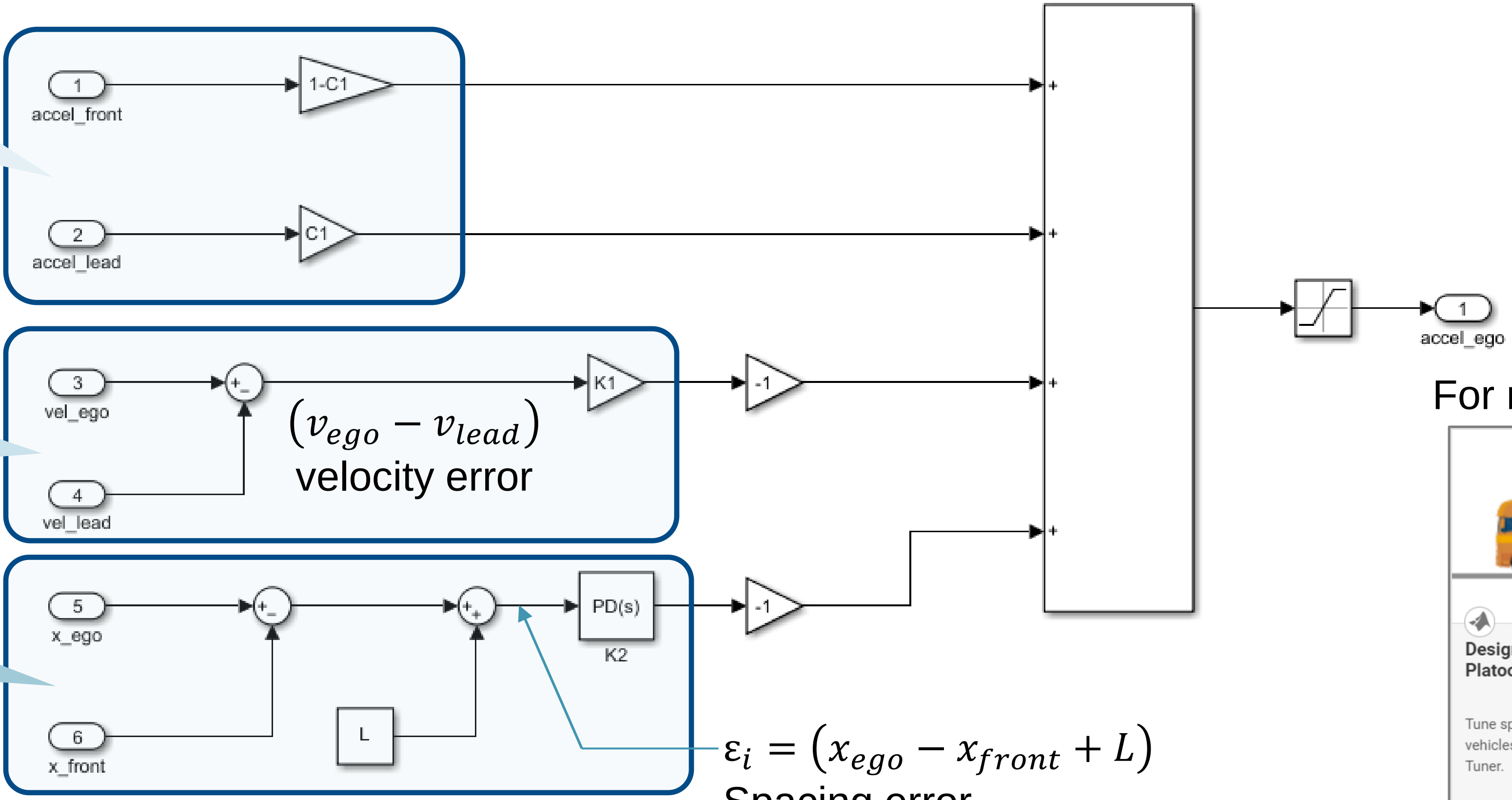
$C_1 a_{lead} + (1 - C_1) a_{front}$

Ego velocity will converge to lead velocity

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

Spacing error will converge to zero

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



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

For more details

Simulink Control Design™

Basic Safety Message (BSM) by SAE J2735

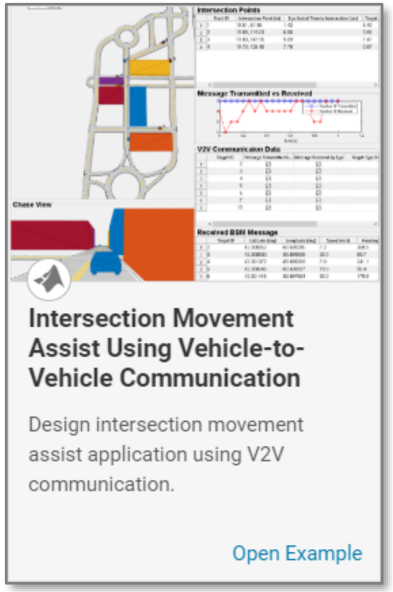
- SAE J2735 – Data and message set dictionary
- Defines the **Basic Safety Message (BSM)**
  - Latitude, longitude, Elev
  - Speed
  - Heading angle
  - Steering wheel angle
  - Lat, long acceleration
  - Vehicle length, width

SAE INTERNATIONAL

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
  }
```

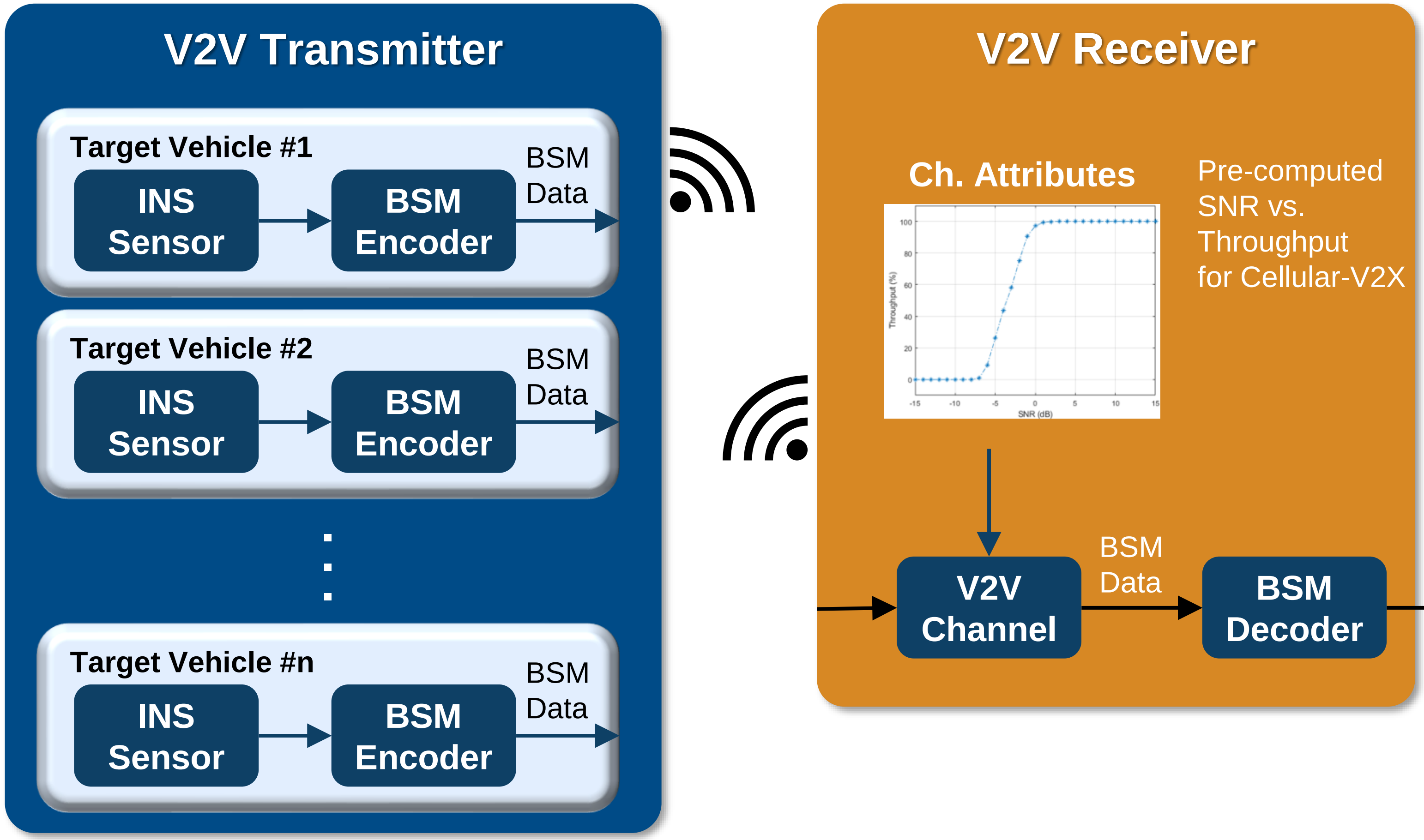
For more details

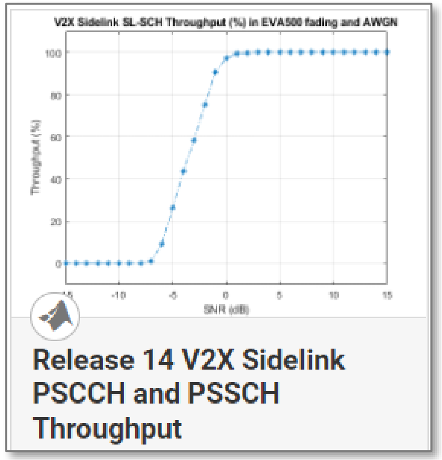


Automated Driving Toolbox™

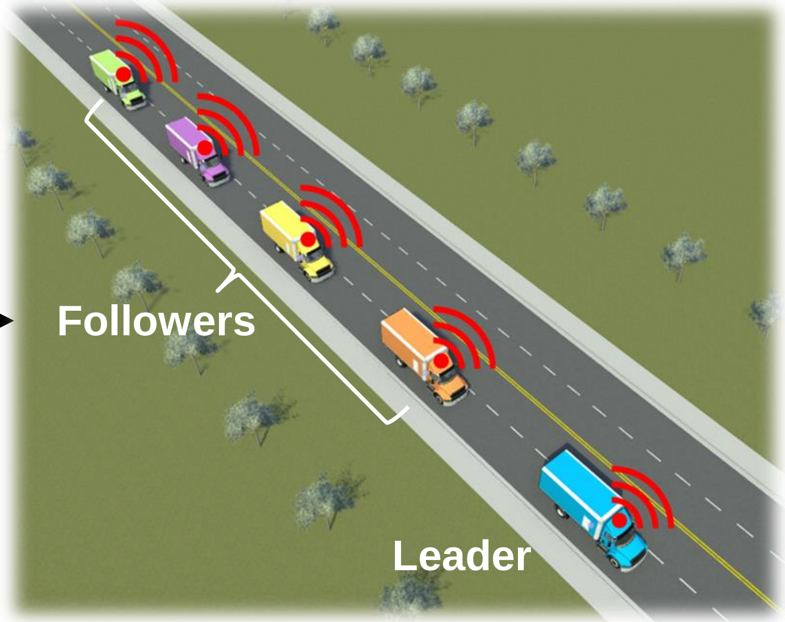
R2022a

Design V2V Transmitter and Receiver



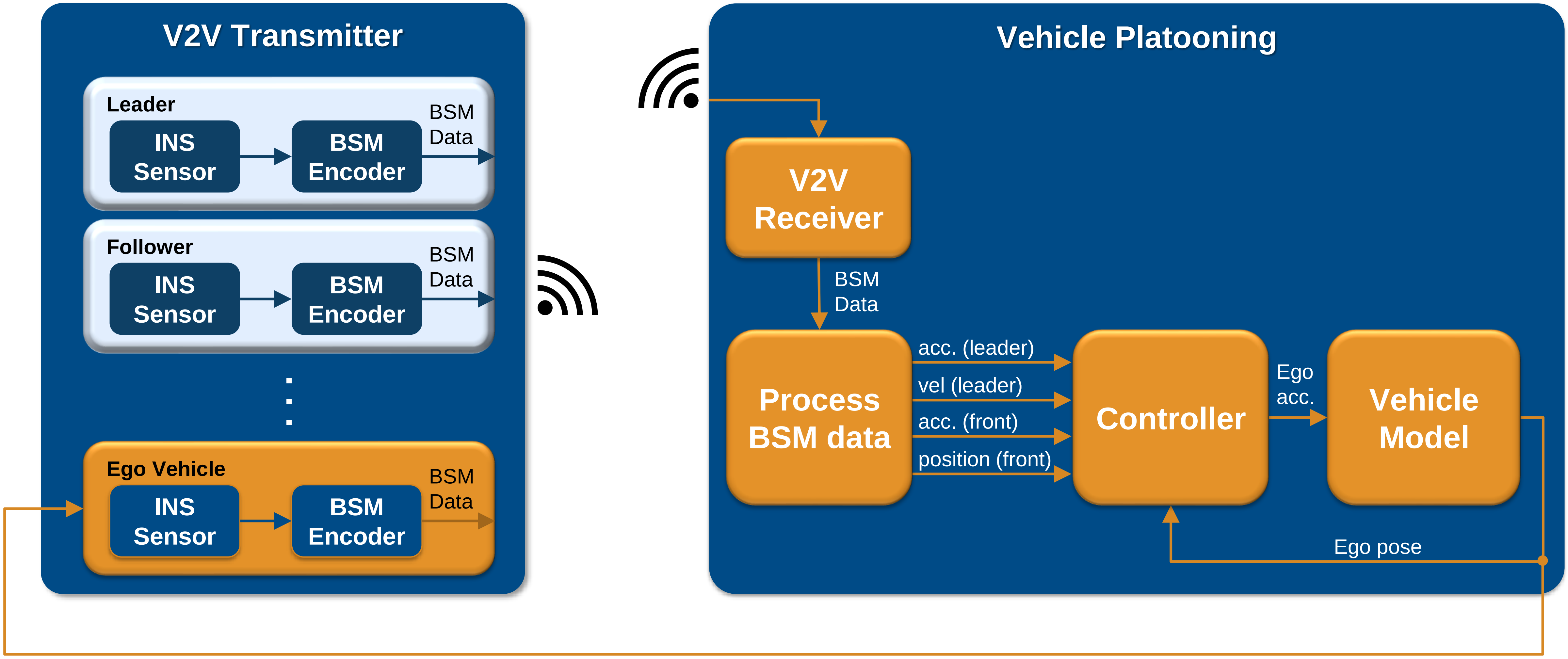


LTE Toolbox™

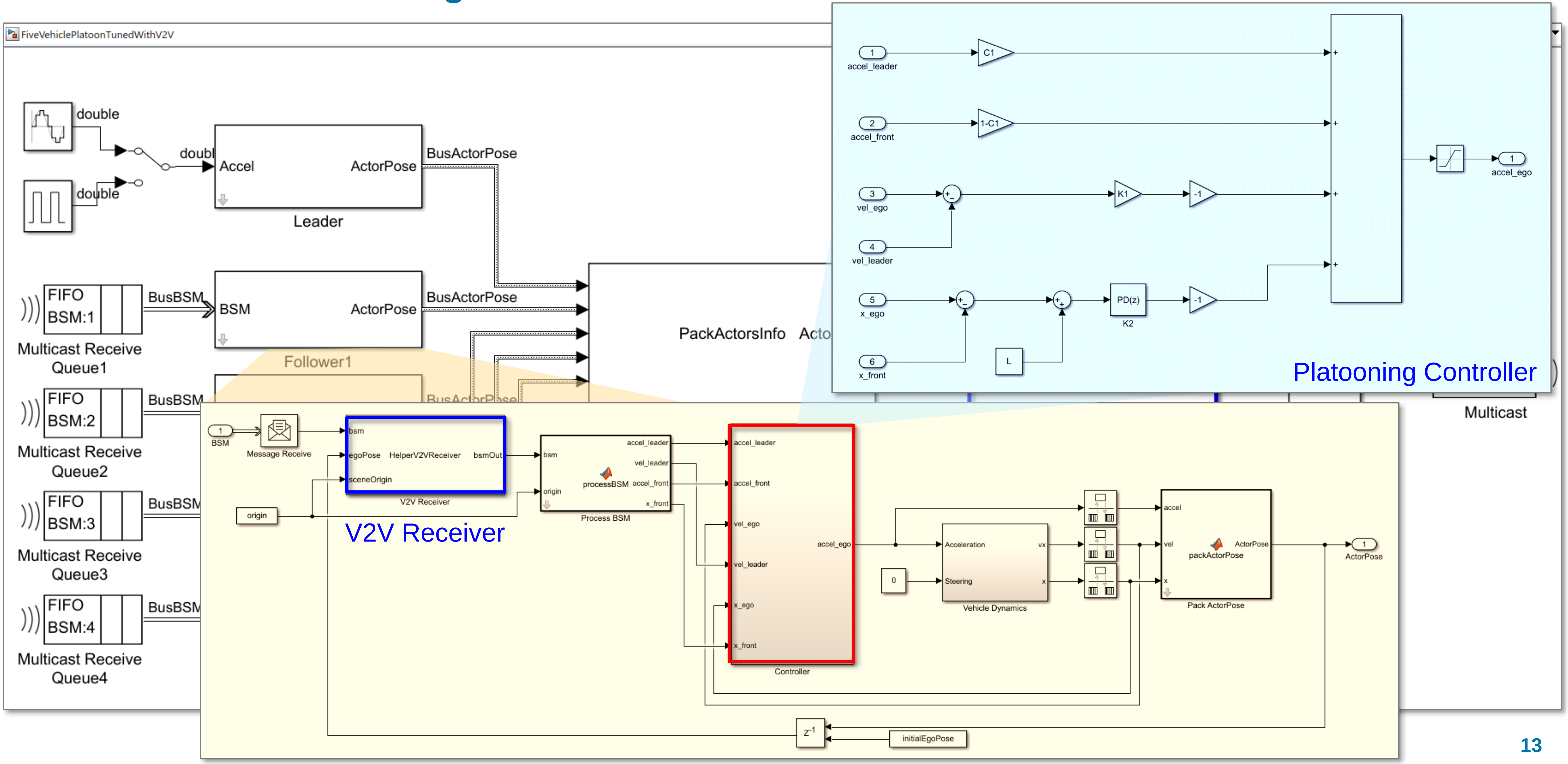


Platooning with V2V

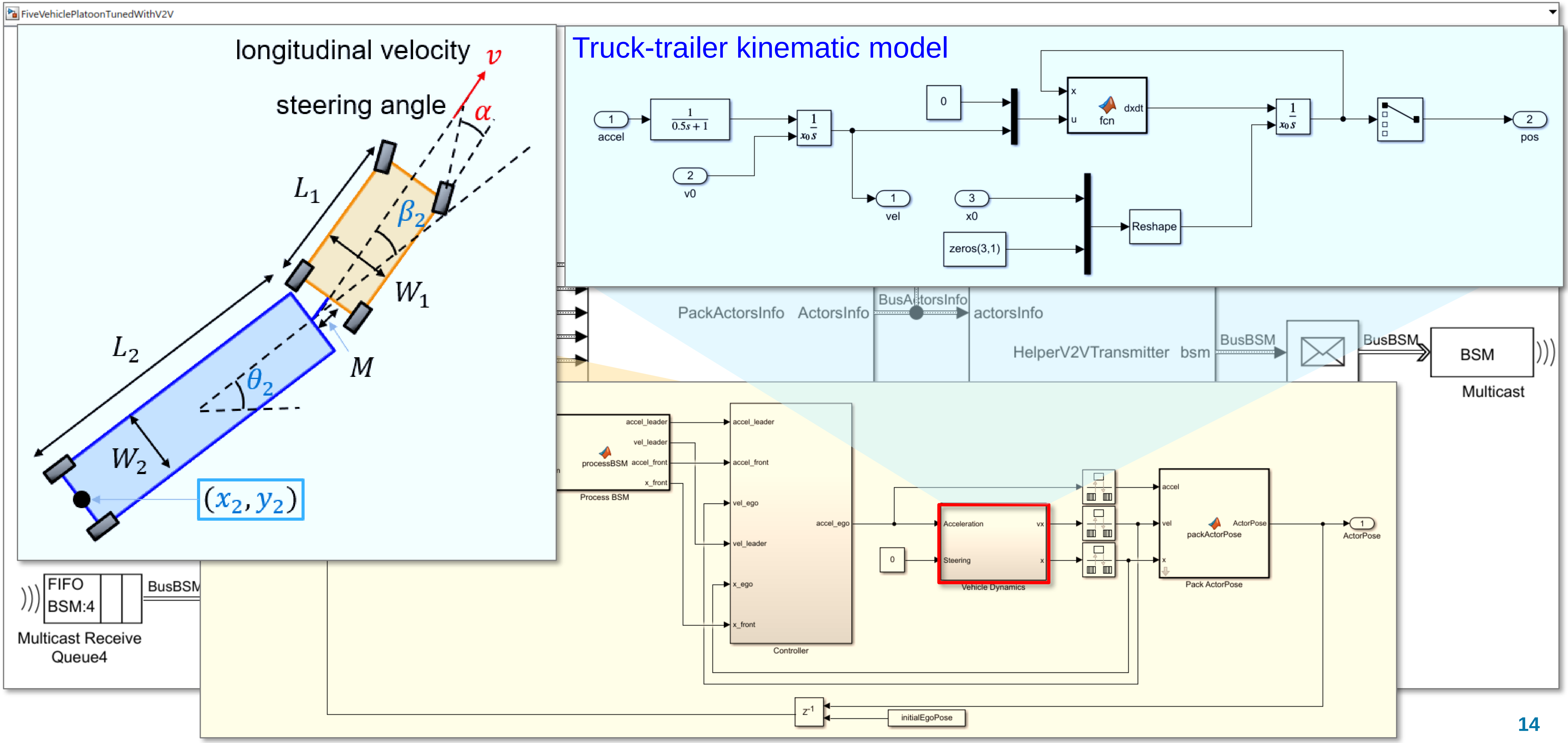
Vehicle Platooning Controller with V2V Communication



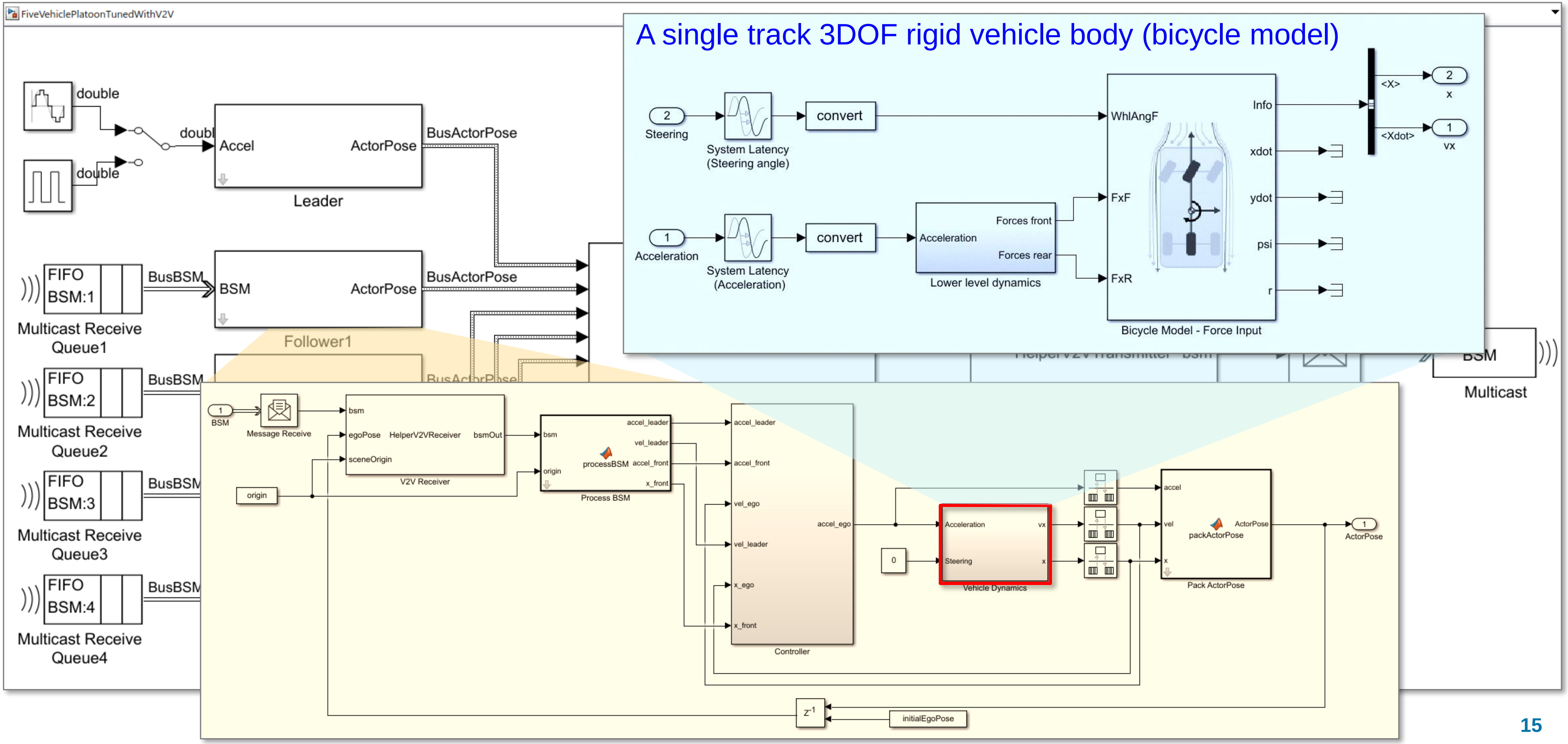
Vehicle Platooning Controller with V2V Communication



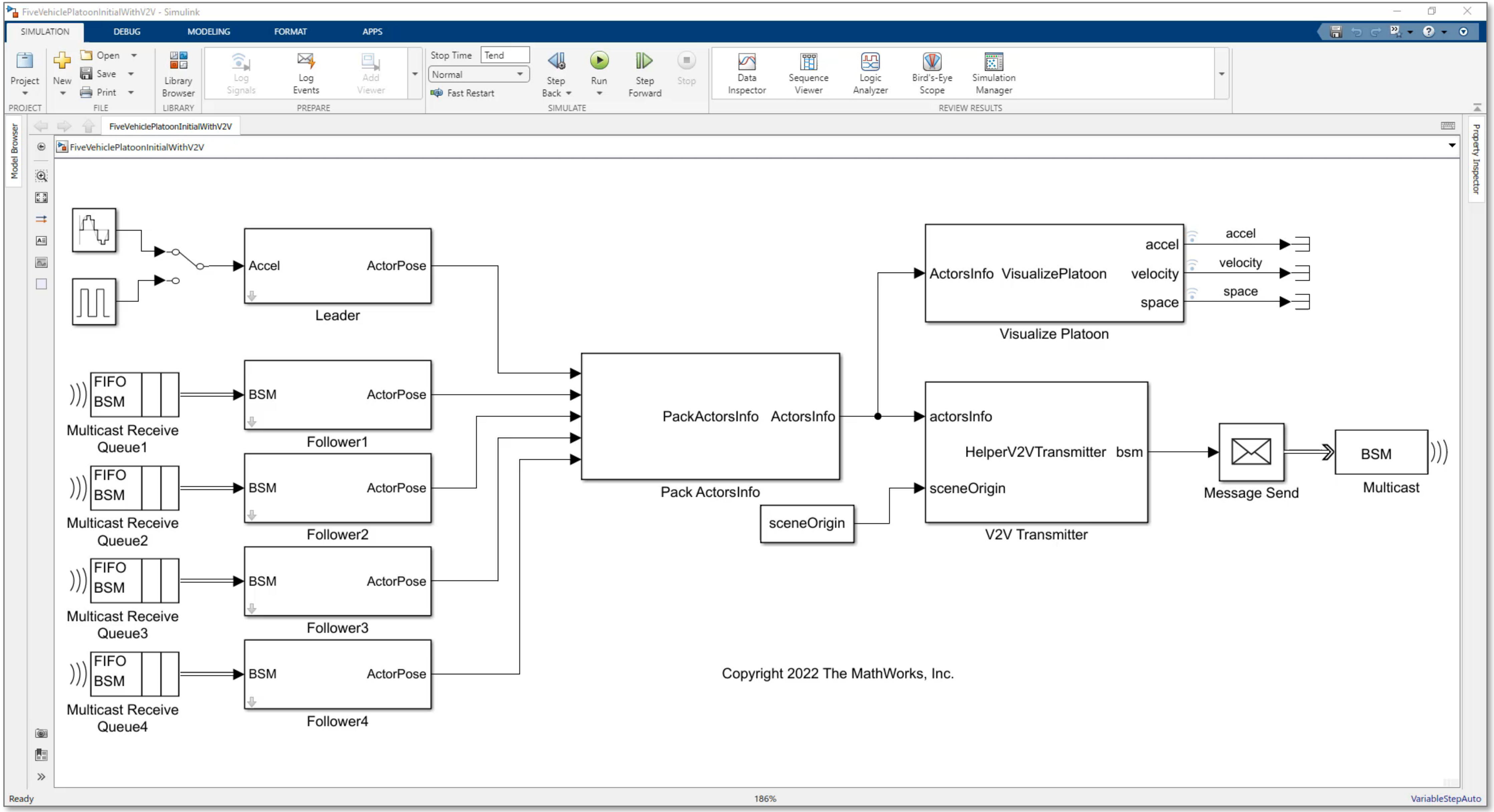
Vehicle Platooning Controller with V2V Communication



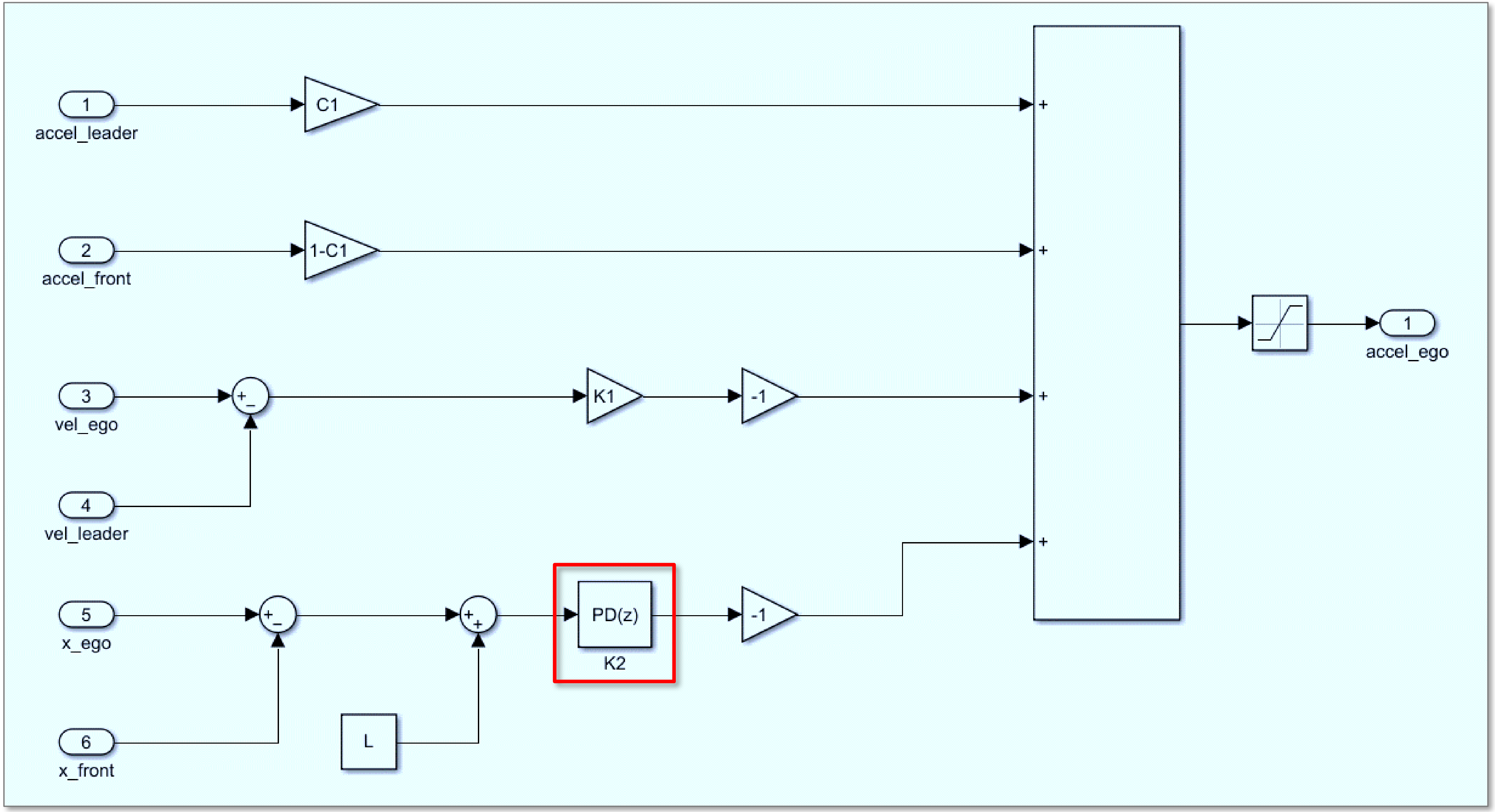
Vehicle Platooning Controller with V2V Communication



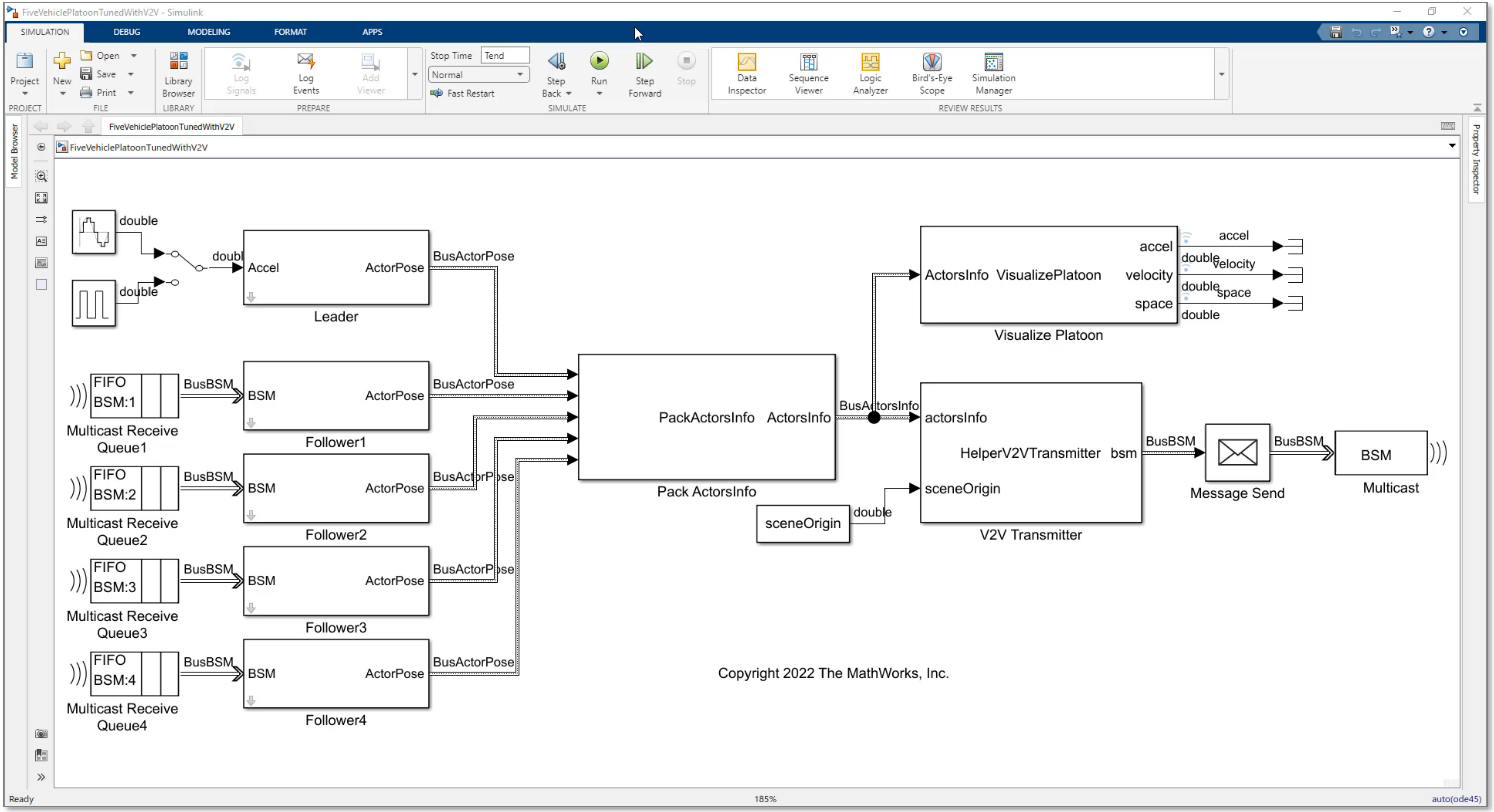
Simulation result (with initial setting of controller gains)



Simulation result (after tuning K2 for faster response)

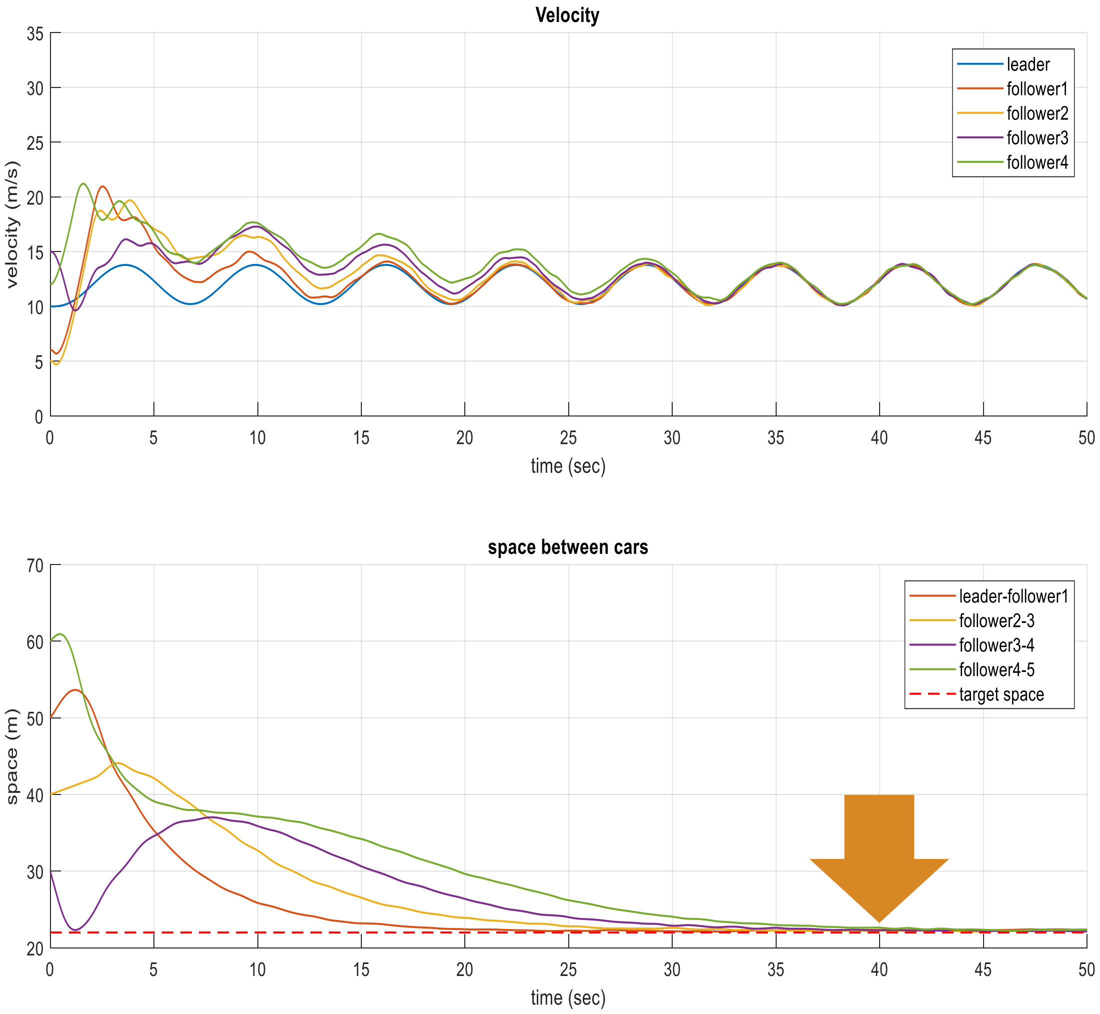


Simulation result (after tuning K2 for faster response)

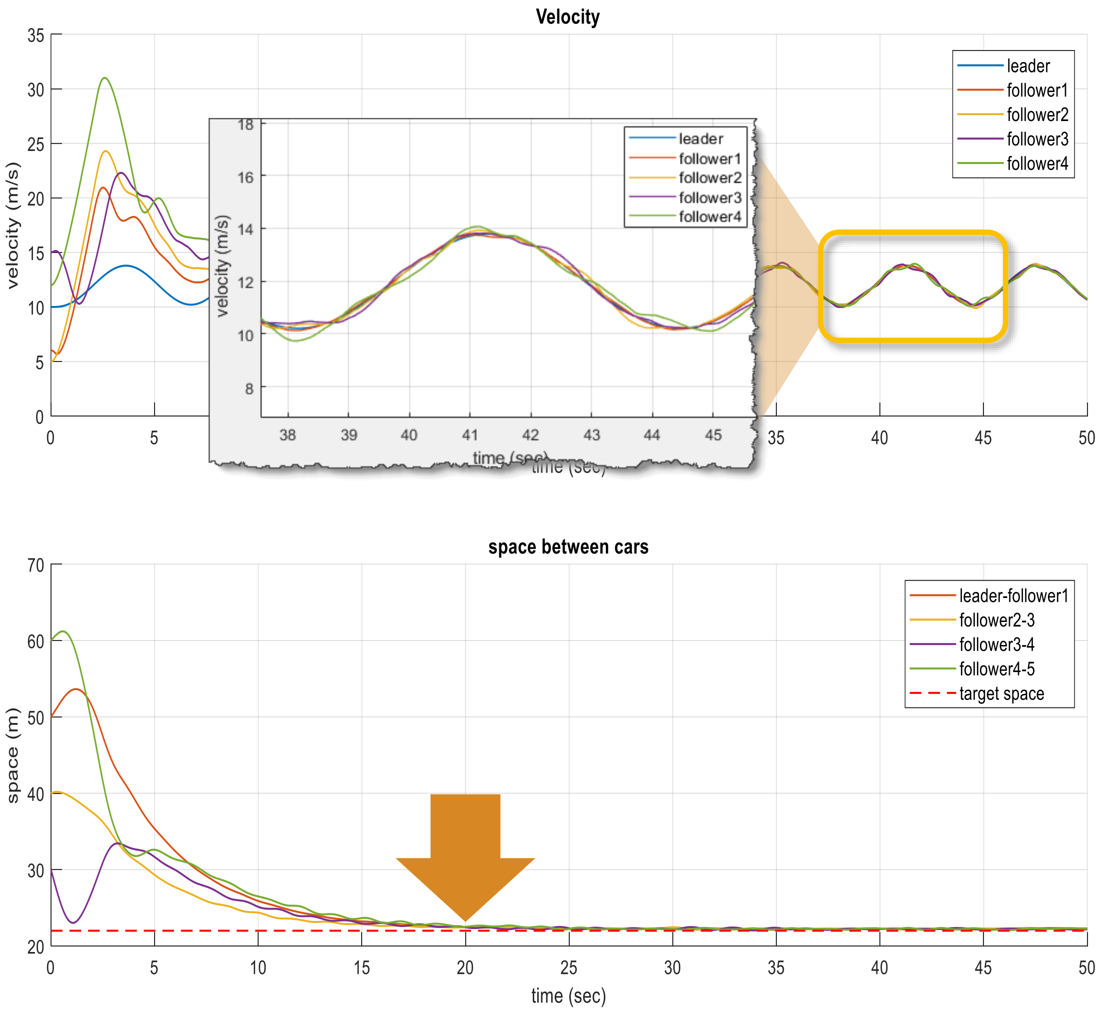


Simulation result (before vs. after tuning K2 for faster response)

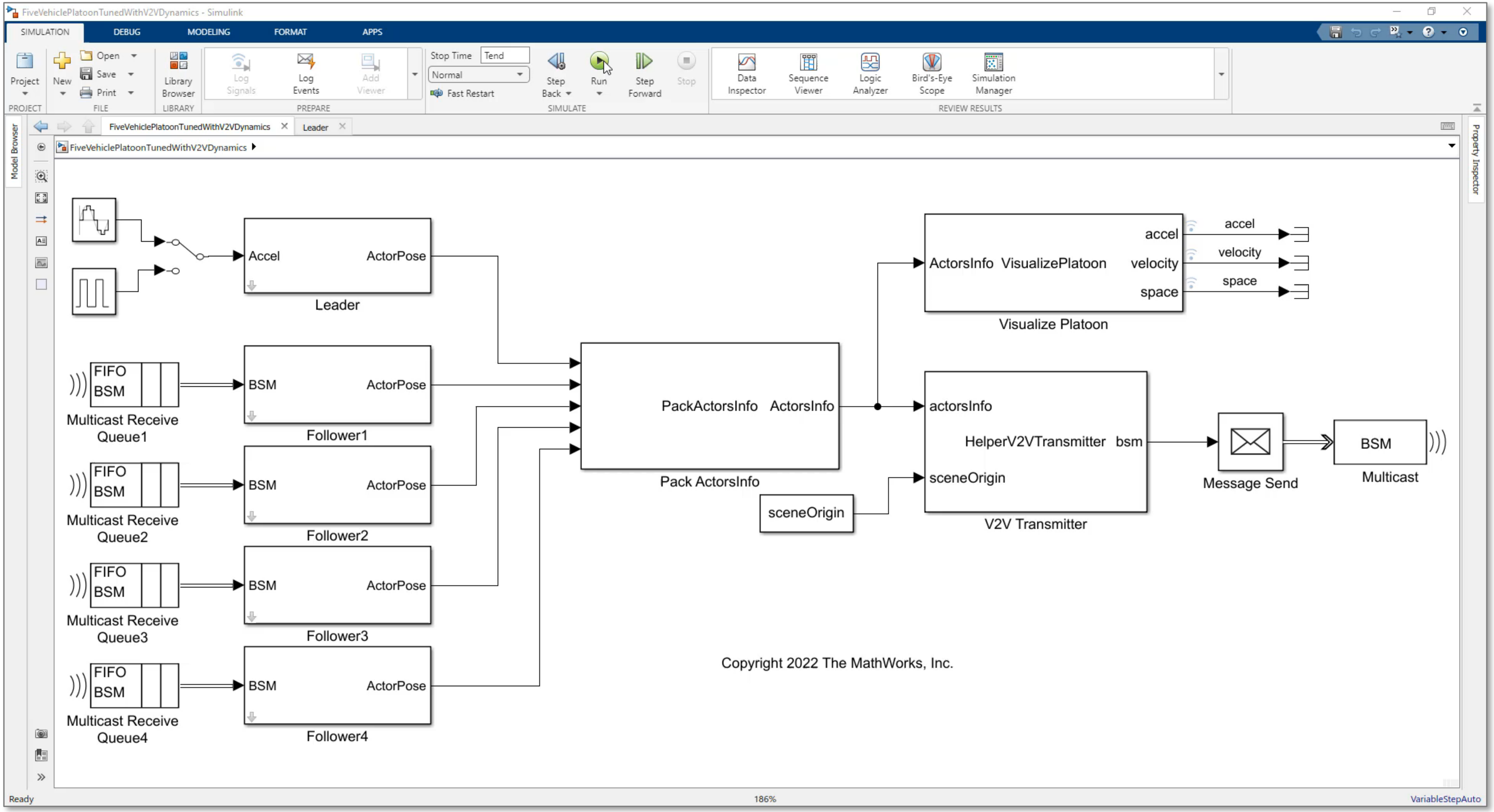
Before



After

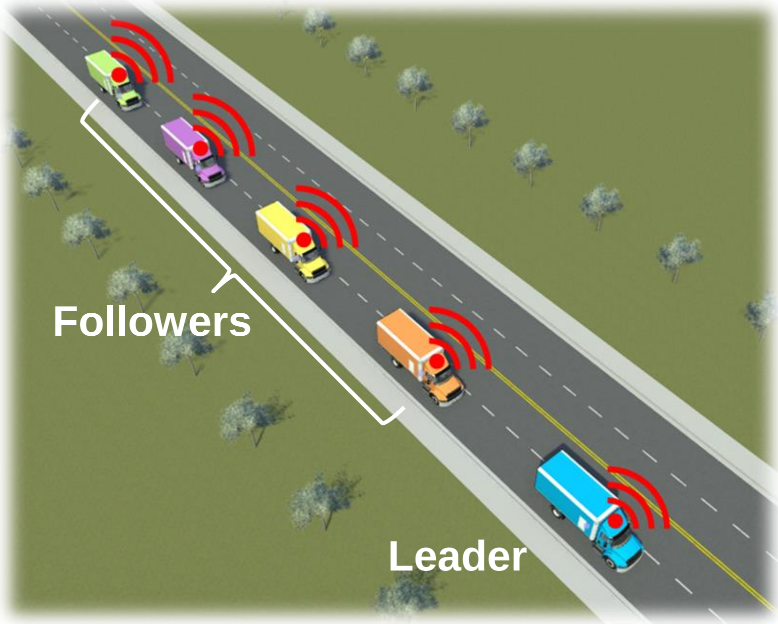


Simulation result (With a single track 3DOF rigid vehicle body - bicycle model)



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

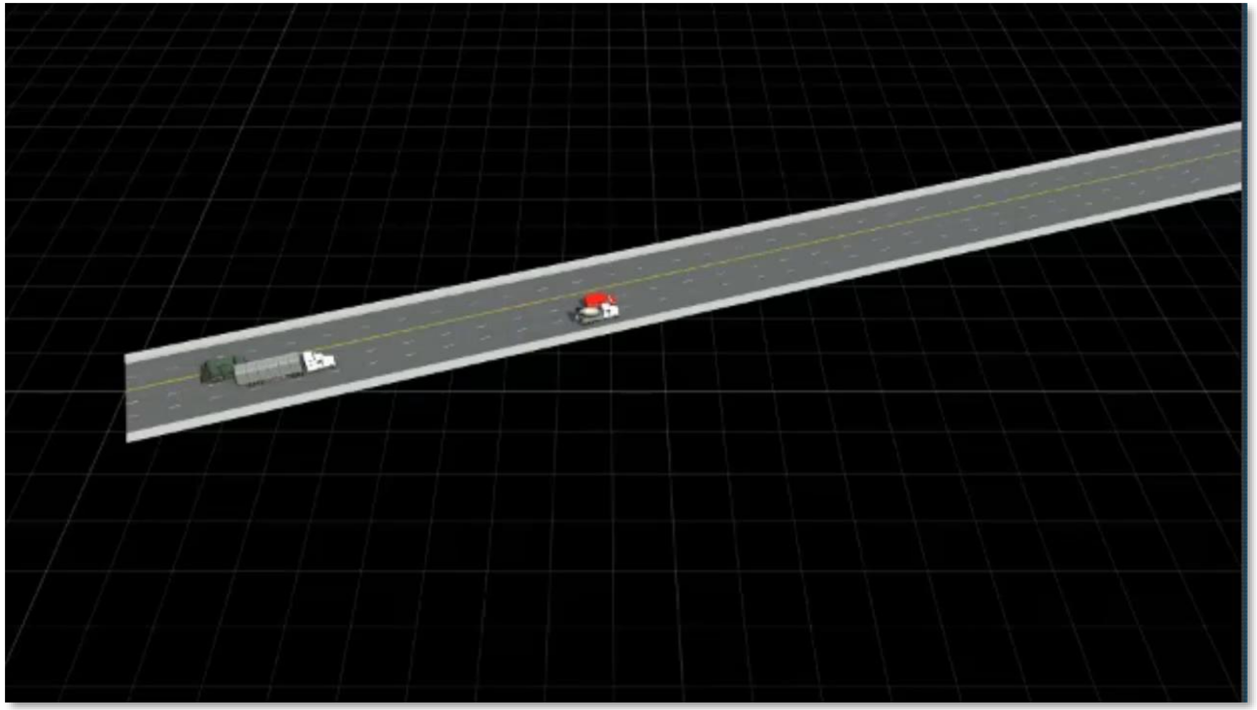


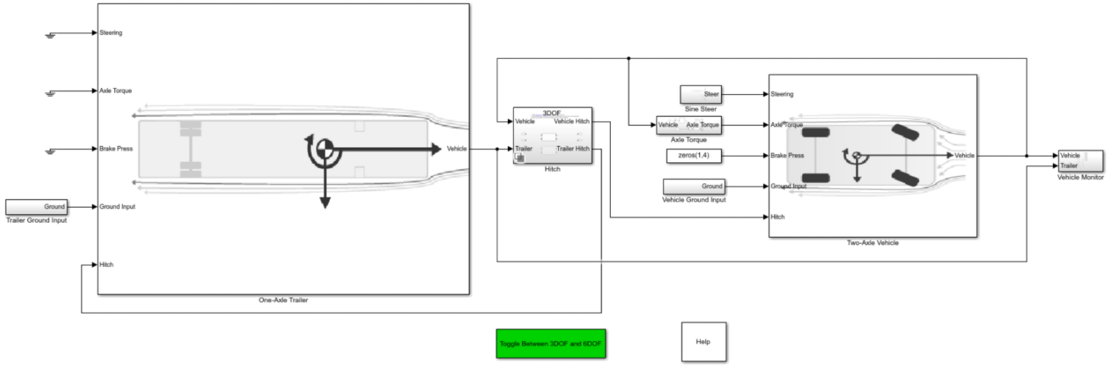
Simulink Control Design™
Automated Driving Toolbox™

R2022a

Further studies

- Scenario authoring using RoadRunner Scenario with truck and trailer meshes





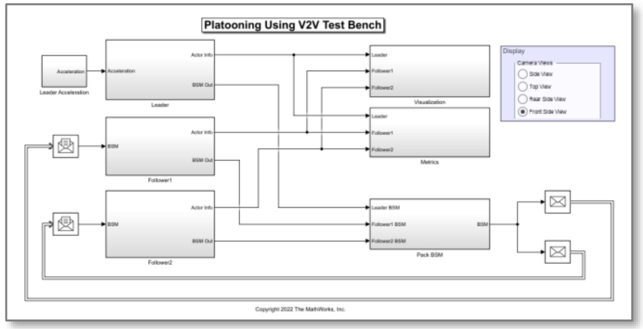
*Vehicle Dynamics Blockset*TM

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

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

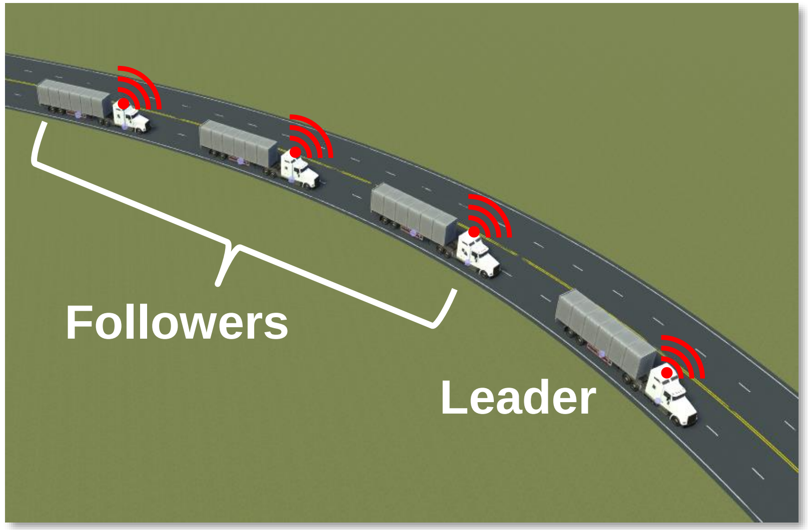


R2022b

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

Future Release

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



- 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

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 ✓