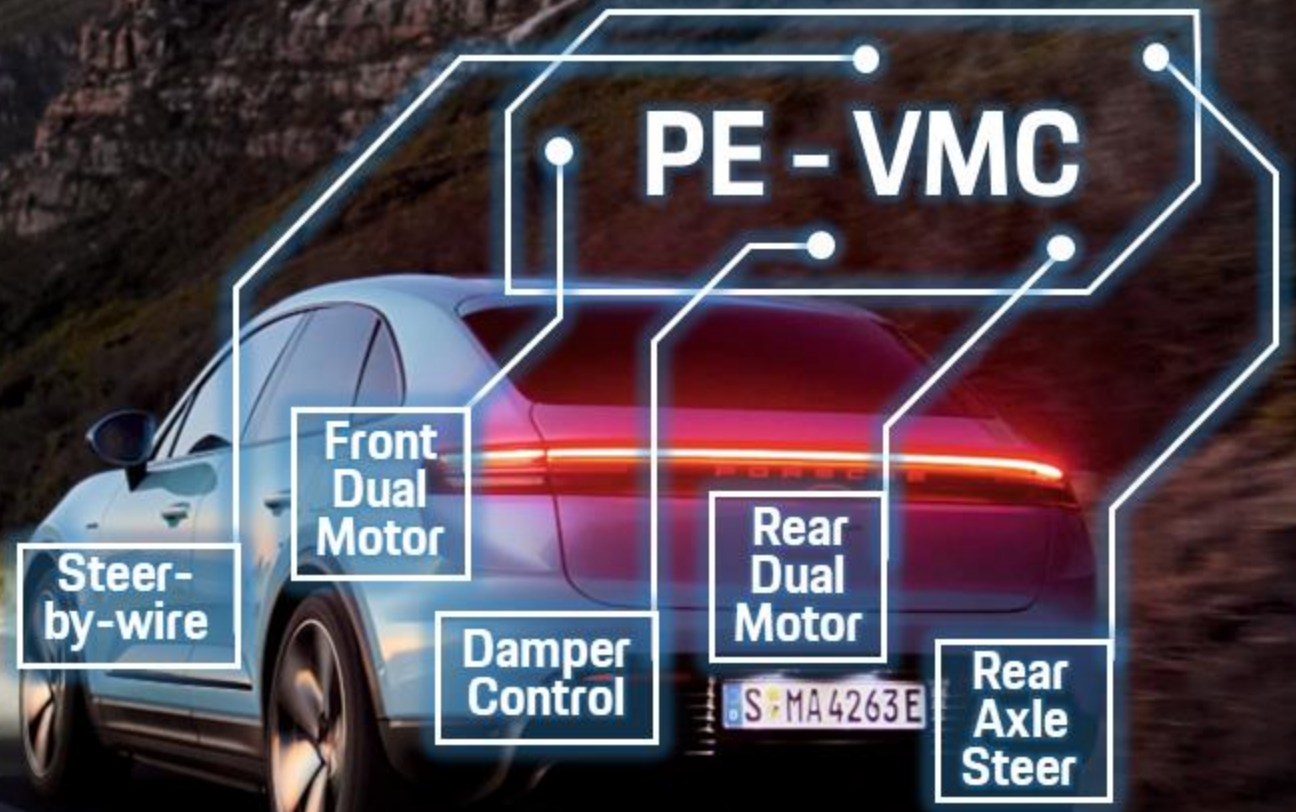
100% Virtual Development of a Vehicle Motion Controller using VI-Grade Driving Simulators

Vehicle Motion Controller

Agenda

- Introduction
- Concept
- Implementation
- Results
- Discussion



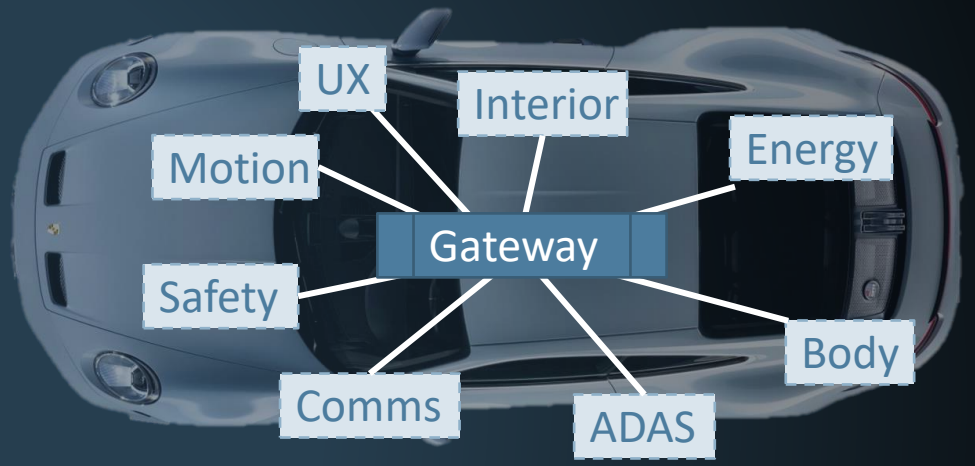
What is a Vehicle Motion Controller?

Centralised controller for the complete motion domain

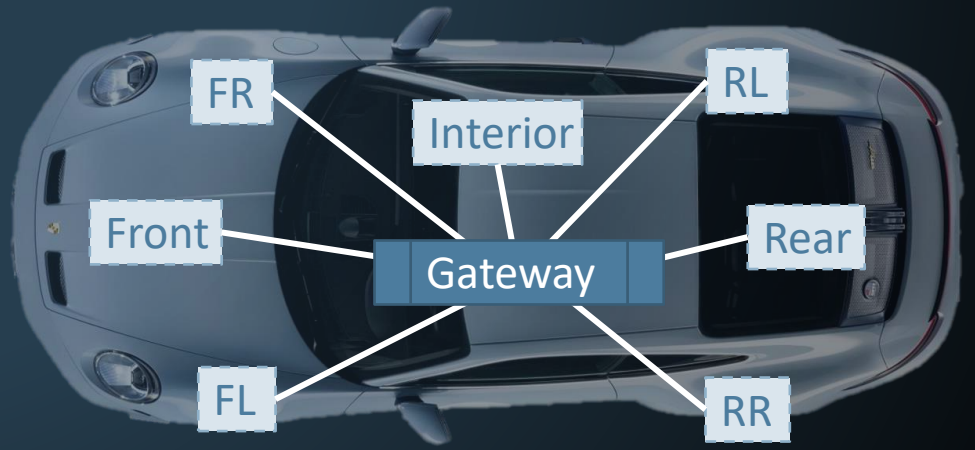
A **domain** is a set of **functionalites** that share a **common** technical **discipine**

- Energy
- UX
- **Motion**
- Communication
- Interior
- Safety
- Body/Comfort
- ADAS/Autonomy

Domain Architecture



Zonal Architecture



Porsche Engineering‘s Vehicle Motion Controller Project

Chassis + Powertrain

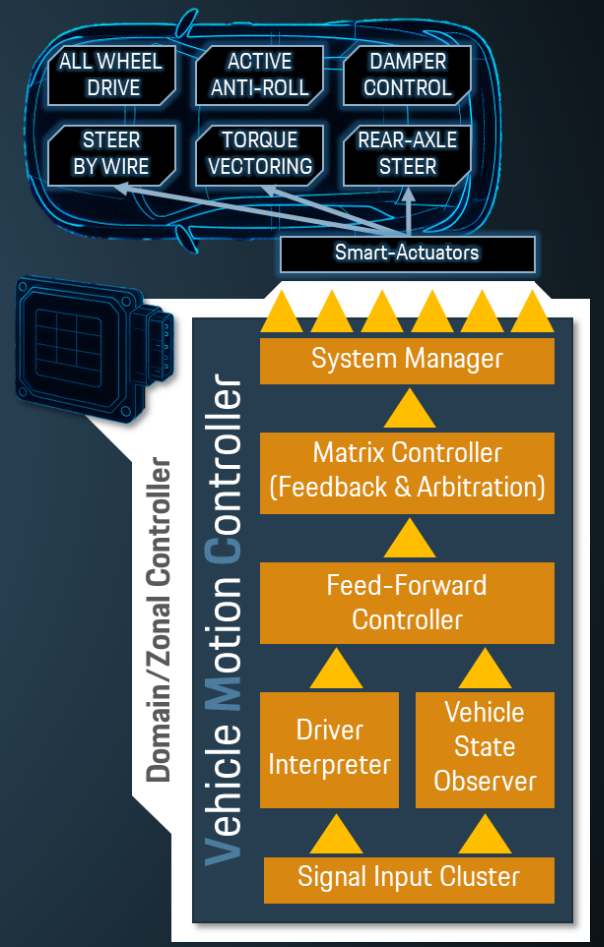
Drive Systems

Controller Software Development

for Customer Projects

Application-Level Software
Vehicle Performance Relevant
Hardware via Customer or Partner

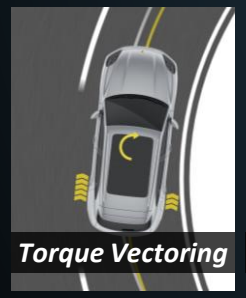
Targeted development
for white-box delivery to
customer markets

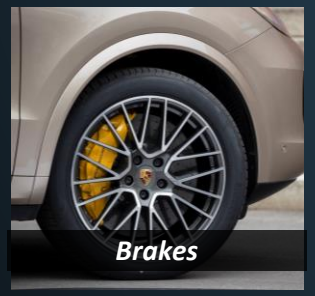


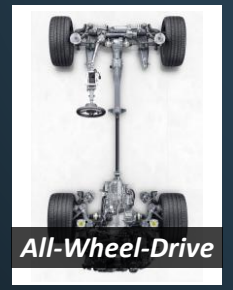
Vehicle Motion Controller – Why?

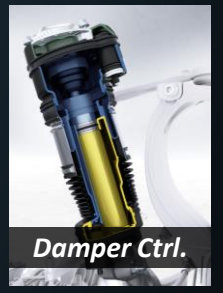
Current Architecture: Overlapping/duplicated domains

	Torque Vectoring	*Brakes*	*All-Wheel-Drive*	*Steer-by-Wire*	*Active Anti-Roll Bar*	*Rear-Wheel-Steering*	*Damper Ctrl.*
DRIVER STATE	Driver inputs Driver interpreter	Driver inputs Driver interpreter	Driver inputs Driver interpreter	Driver inputs Driver interpreter	Driver inputs Driver interpreter	Driver inputs Driver interpreter	Driver inputs Driver interpreter
VEHICLE STATE	Yawrate / Lat. Acc. State observer	Yawrate / Lat. Acc. State observer	Yawrate / Lat. Acc. State observer	Yawrate / Lat. Acc. State observer	Yawrate / Lat. Acc. State observer	Yawrate / Lat. Acc. State observer	Yawrate / Lat. Acc. State observer
SYSTEM CTRL LOGIC	Actuator Request	Actuator Request	Actuator Request	Actuator Request	Actuator Request	Actuator Request	Actuator Request
ACTUATOR	Component Controller	Component Controller	Component Controller	Component Controller	Component Controller	Component Controller	Component Controller









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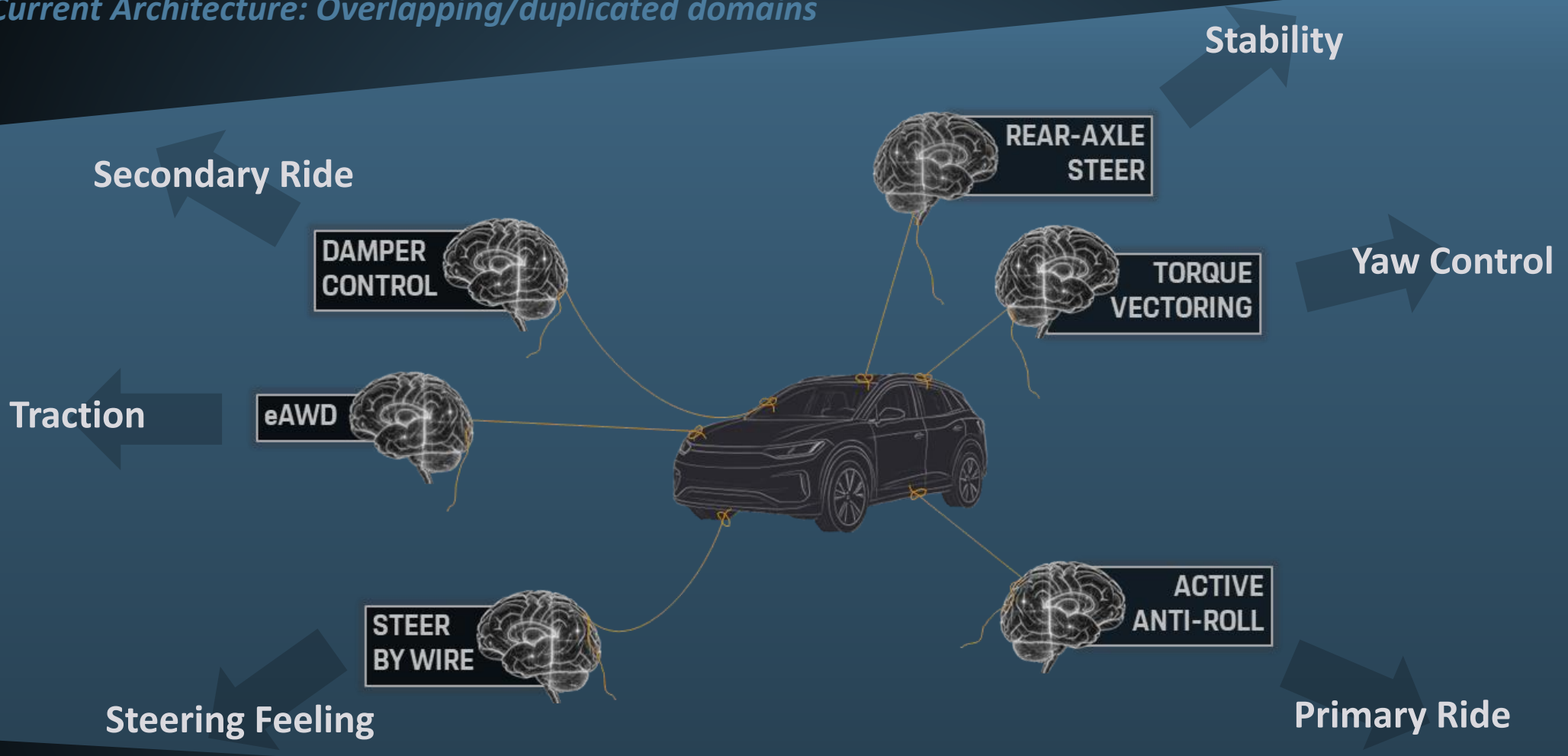

Vehicle Motion Controller – Why?

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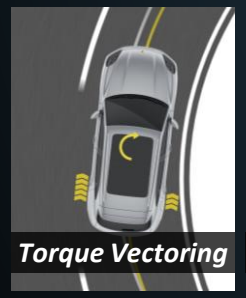
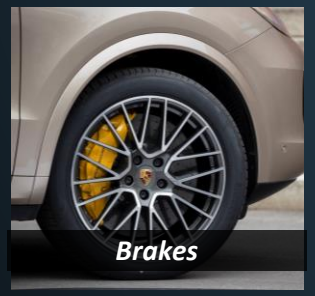
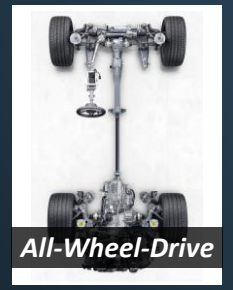
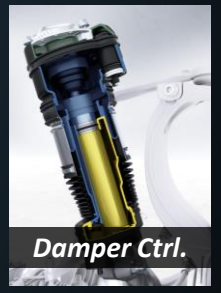








Vehicle Motion Controller – Why?

Centralised Domain Controller

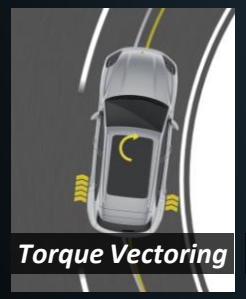
Vehicle Motion Controller

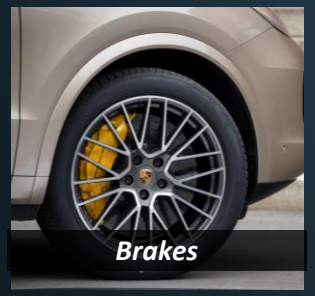
DRIVER STATE
- Driver inputs
- Driver interpreter

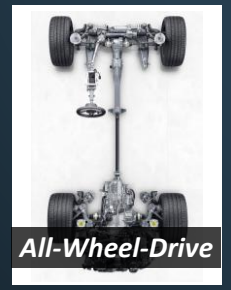
VEHICLE STATE
- Yawrate / Lat. Acc.
- State observer

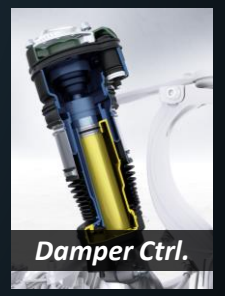
SYSTEM CTRL LOGIC
- Actuator Requests

ACTUATOR Component Controller | Component Controller | Component Controller | Component Controller | Component Controller | Component Controller | Component Controller







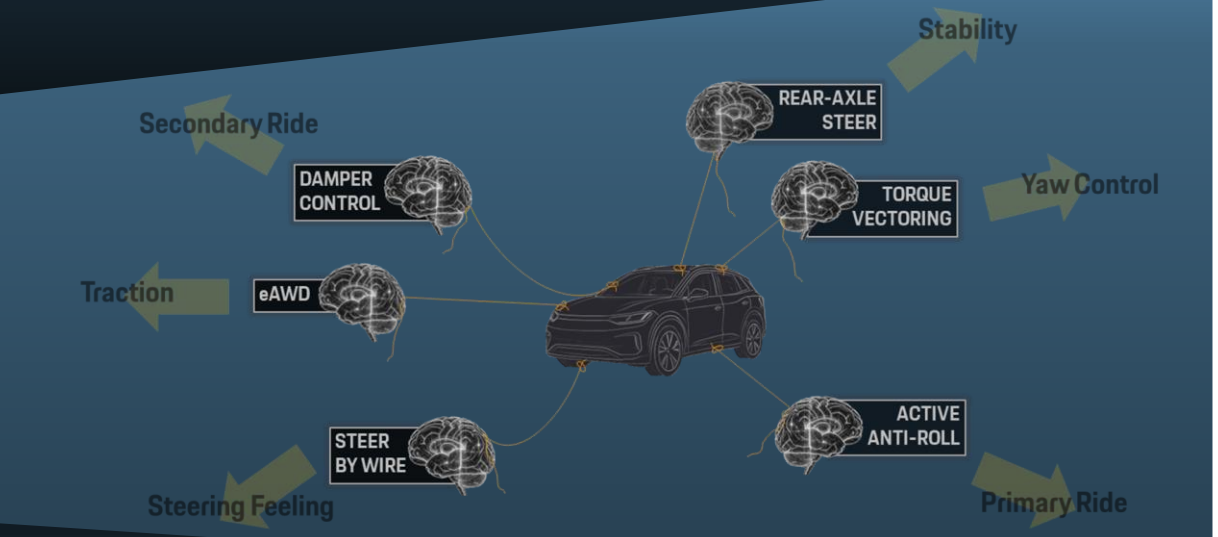


Vehicle Motion Controller – Why?

Centralised Domain Controller

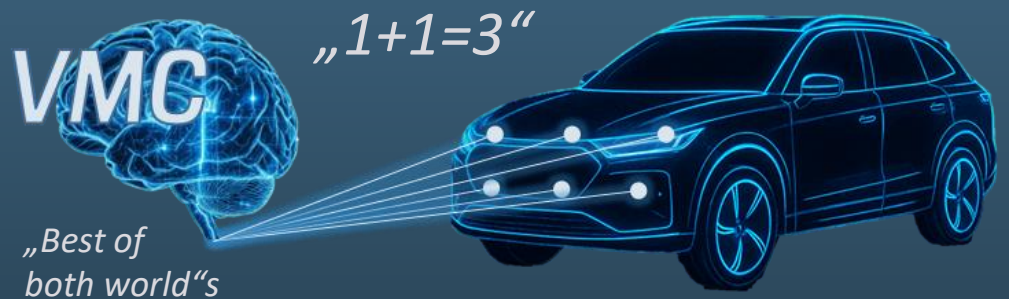
Distributed Architecture

Multiple controller targets
„Every system for itself!“



Domain Architecture

One-Brain to control the Motion Domain
„All for one and one for all!“



„Best of both world“s

„All for one, one for all“…

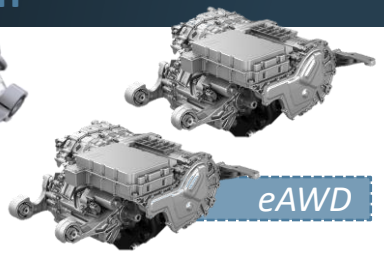
Porsche Engineering‘s Vehicle Motion Controller

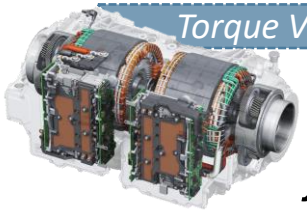
- Porsche Engineering are developing a **Vehicle Motion Controller** (Internal name: MDC - Motion Domain Controller)
- Target: **New generation** of vehicles with **domain** or **zonal** architecture and centralised, **high-power controller-units**

- The **building blocks** are the software functions and technical know-how we have developed over several controller projects:
- …in **serial production**


Air Spring

CDC Damper

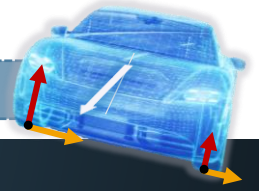

eAWD


Torque Vectoring

$f(x)$ Roll Control

Traction Control

State observer



AUTOMOTIVE SPICE®

ISO 26262

- …in **prototype development**


Steer-by-Wire

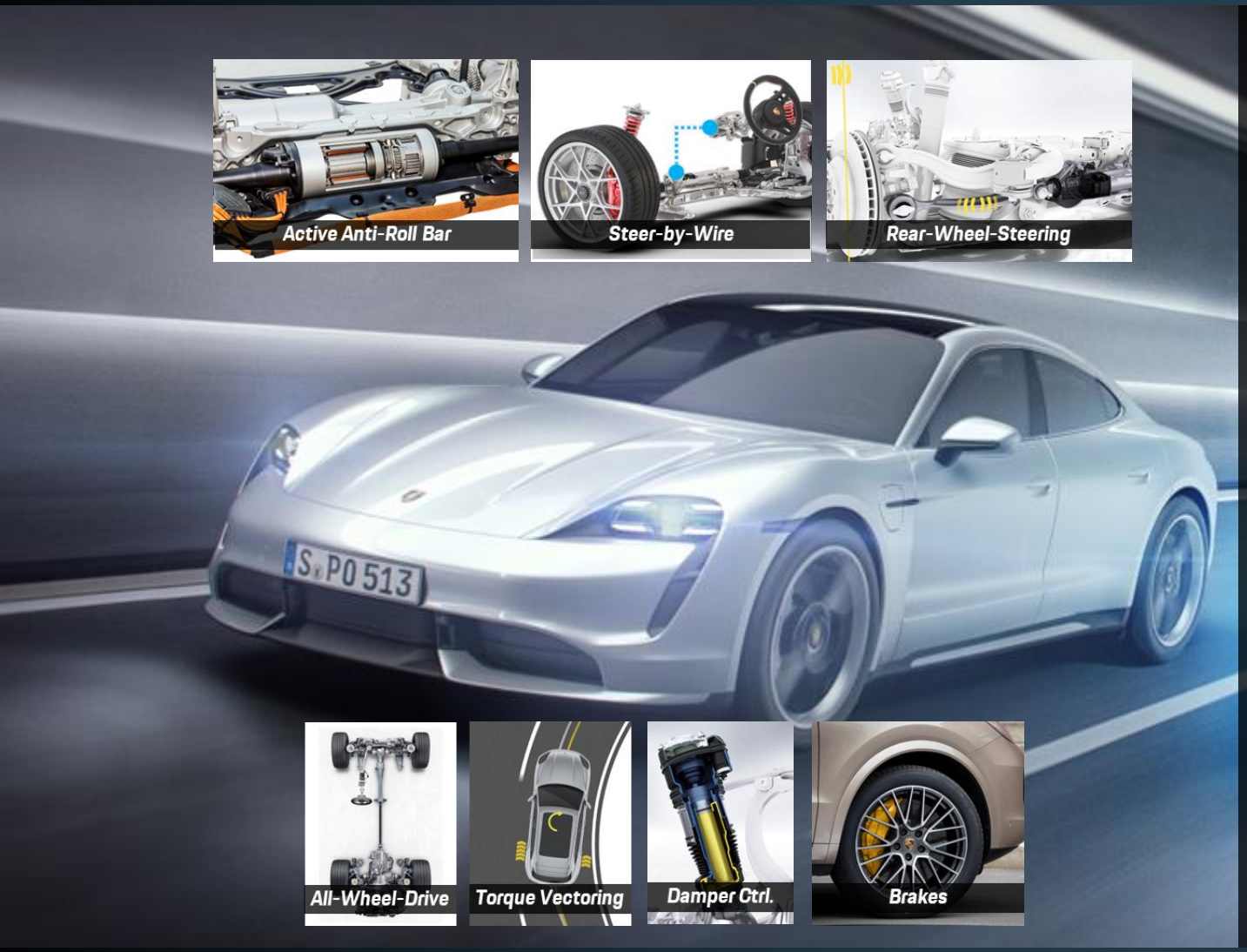

Rear-wheel-steering


Active Anti-roll-bar


Full Active Suspension

- Architecture is up and running in **digital prototypes**

Realisation: Demo Car?



- Donor Car
- 3 or 4 e-Motor Drivetrain
  - *Battery + BMS + Charging Controller*
  - *Cooling*
  - *Power Electronics*
  - *Safety functions*
- Open brake system interface with 4 wheel independent brake torque control
- Active vertical forces (controlled damper, active ARB)
- Steer-by-wire
- Rear-wheel-steering
- Rapid Prototyping ECU, 6 d.o.f. IMU

Realisation: Virtual Prototype

- Donor Car
- 3 or 4 e-Motor Drivetrain
  - *Battery + BMS + Charging Controller*
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VI-CarRealTime model from existing project

4x wheel motors with moment control from external controller

Basic hydraulic model with wheel-specific user input from VMC controller

External damper forces to model active damper and anti-roll-bar

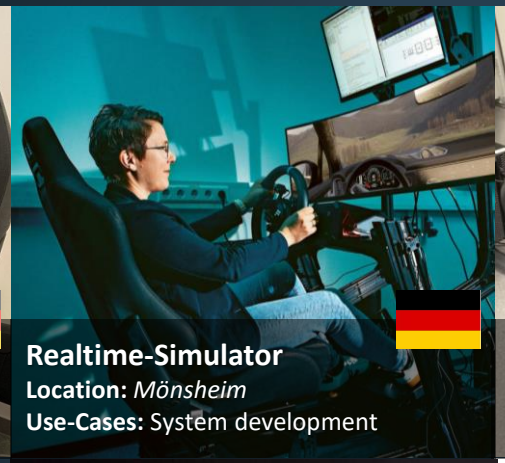
Internal steering deactivated, rack control via VMC controller

Toe angle offset on rear axle kinematics

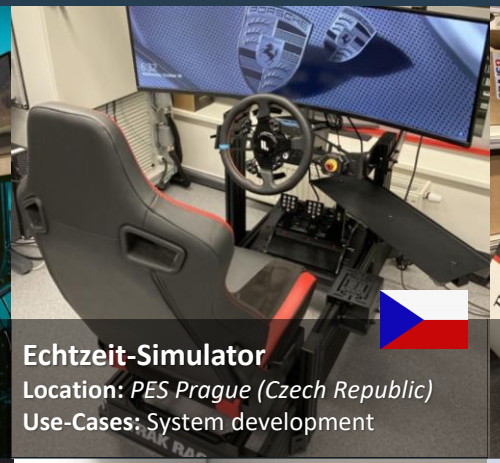
Simulation Workbench & SpeedGoat with Canape Tuning Configuration

Driving Simulators in Porsche Engineering

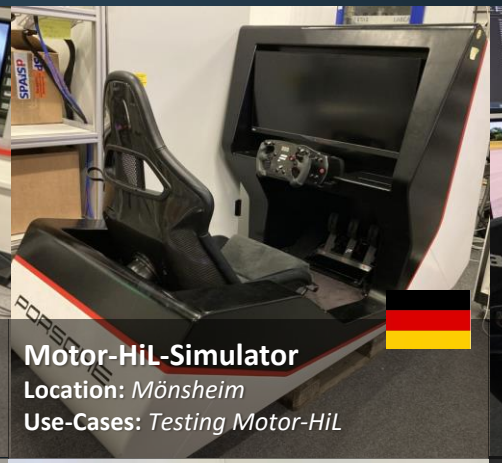
ADAS-Simulator
Location: *Mönsheim*
Use-Cases: *Driver Training*



Realtime-Simulator
Location: *Mönsheim*
Use-Cases: System development



Echtzeit-Simulator
Location: *PES Prague (Czech Republic)*
Use-Cases: System development



Motor-HiL-Simulator
Location: *Mönsheim*
Use-Cases: *Testing Motor-HiL*

Echtzeit-Simulator
Location: *PES China (Shanghai)*
Use-Cases: System development

Porsche Engineering Magazine

HMI-Simulator
Location: *PES China (Shanghai)*
Use-Cases: *HMI-Development*

Fahrertrainingssimulator
Location: *Mönsheim*
Use-Cases: *Driver Training*

Echtzeit-Simulator
Location: *PES Nardo Technical Center*
Use-Cases: *Digital Testing*

Driver-in-Motion Simulator
Location: *PES Nardo Technical Center*
Use-Cases: *Digital Testing*

Porsche Engineering Desktop Simulators

Realtime Simulator Mönsheim P800

VI-Grade Desktop Simulator
Location: *Porsche Engineering Mönsheim*
Use-Cases: System development

Hardware Details

- Concurrent Realtime / Windows Graphic
- VI-Grade Steering Actuator (Phase)
- Custom cockpit with multiple screens
- Speedgoat Rapid Prototyping Machine

Software Details

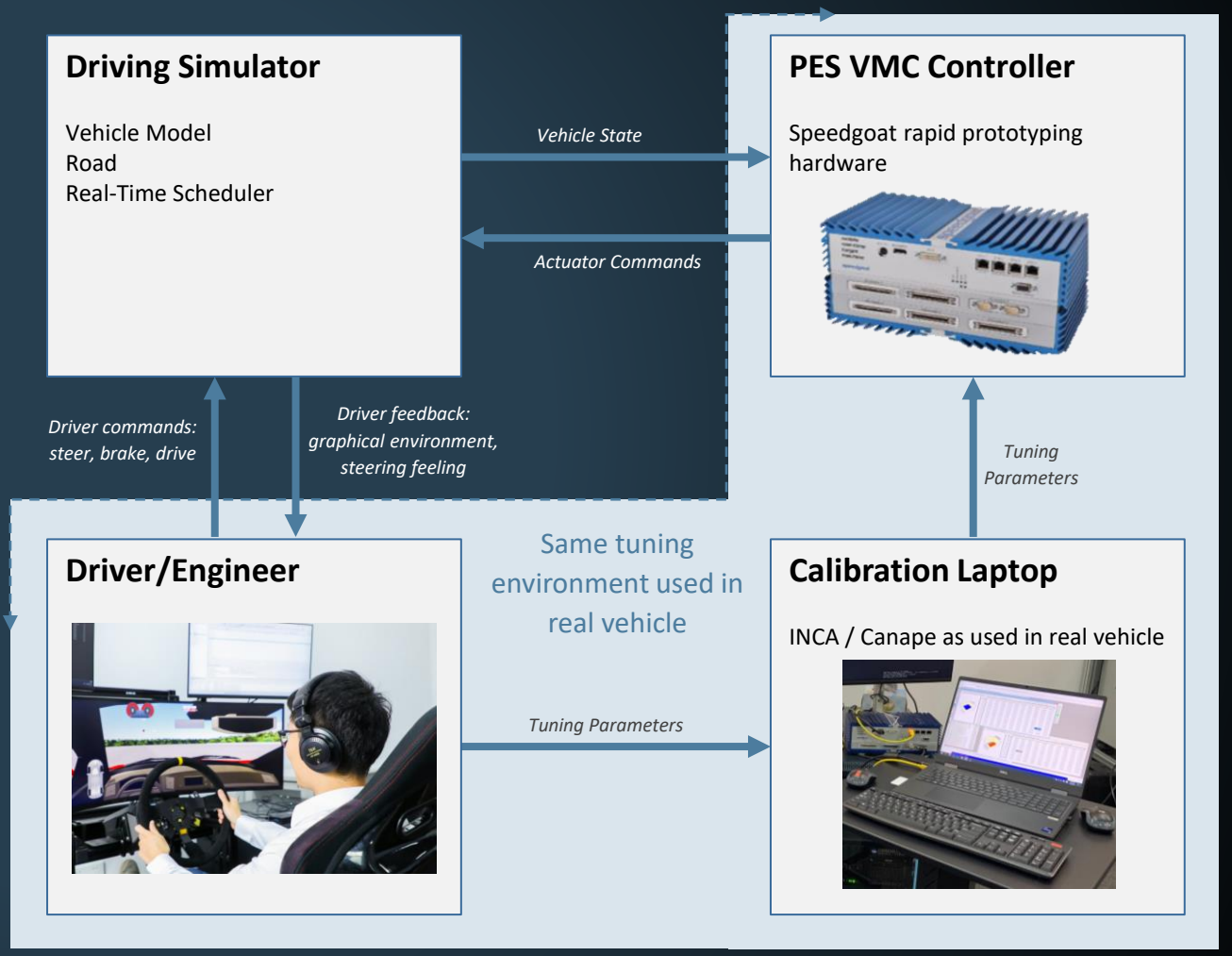
- VI-Grade Suite (CarRealTime, DriveSim, WorldSim)
- Simulation Workbench Real-Time Scheduler
- WinTAX Live Telemetery

Use-Cases

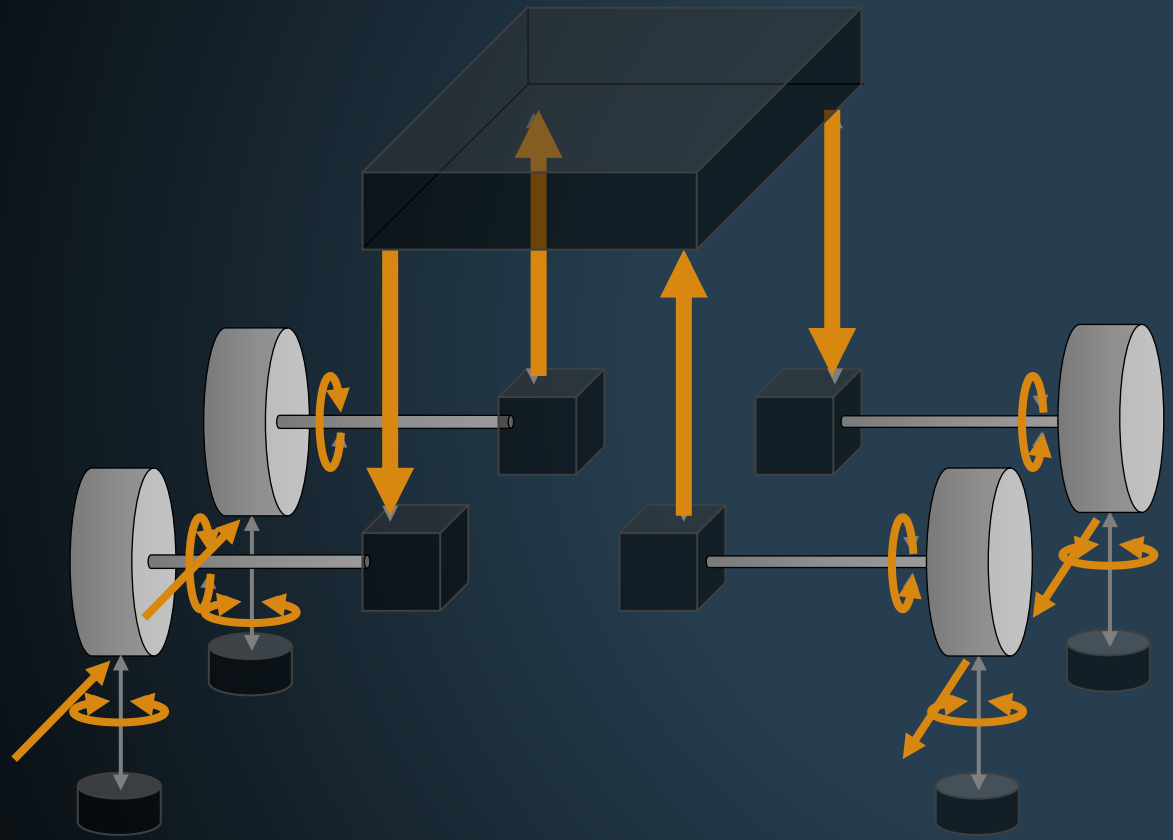
- Development of controller strategies
- Digital commissioning of SWCs
- System/Software troubleshooting
- Pre-Calibration
- Testing of safety functions

Deployment on VI-Grade Desktop Simulator

- VI-CarRealTime vehicle physics
- All control systems in Co-Simulation
- Extensive use of VI-Proving Ground



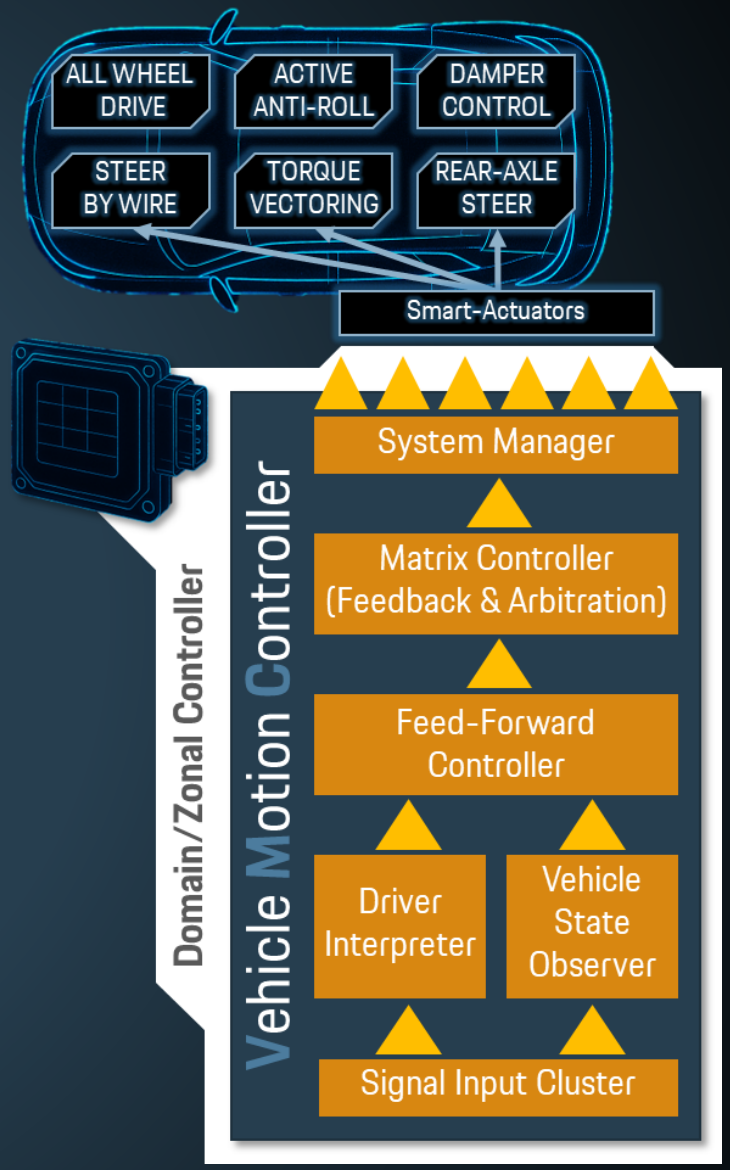
Lateral Handling: Strategy Investigation



- **Kinematic Steer**
  - Front axle steering
  - Rear axle steering
- **Yaw-Moment Steer**
  - Differential moment front axle
  - Differential moment rear axle
- **Warp-Steer**
  - Active damper
  - E-Anti-Roll-Bar

Vehicle Motion Control - Implementation

- **Signal Input Cluster**
  - Wrapper, processing and integrity checking
- **Driver Interpreter**
  - Interpretation layer for human drivers (deleted for autonomous drive)
- **State observer**
  - Advanced state observation necessary for the matrix controller
- **Feed-Forward Controller**
  - Robust feed-forward actuation, fully tuneable
- **Matrix Controller**
  - Model-based central controller
- **System Manager**
  - Translation of vehicle level requirements to system/actuator level



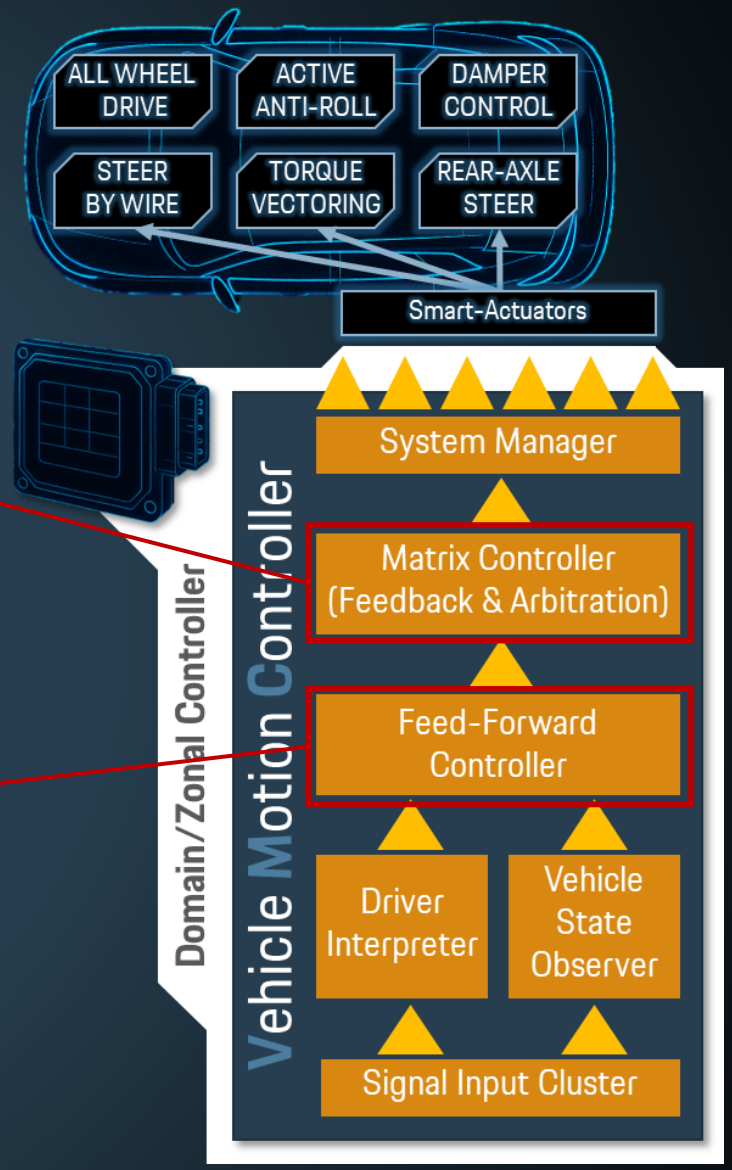
Vehicle Motion Control - Implementation

Matrix Motion Control Concept

- **Optimal control** by minimizing cost function, penalization of both, deviation of system states and control effort applied
- **Centralized MIMO control** – Model based approach is well-suitable for MIMO control system – direct calculation of control effort based on multiple states considering interactions
- **Integrated Control** – natural handling of coupling between systems and motion states e.g., Longitudinal/Lateral

Model-Based Feed-Forward Control

- Improvement of linear range lateral handling via **inverse handling model** based **pre-control** of front axle steering, rear axle steering and yaw moment from torque vectoring.



VMC Use Case: Highway driving

Emulating Sports Car Performance with Comfort Tires + Active Systems

This functionality is impossible with unsynchononised systems! (TV, SbW, RWS)

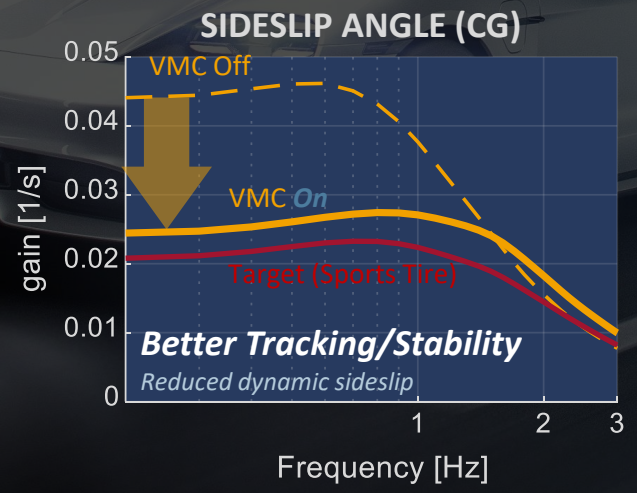
Maneuver: Sinusoidal steering sweep, linear range, highway speed

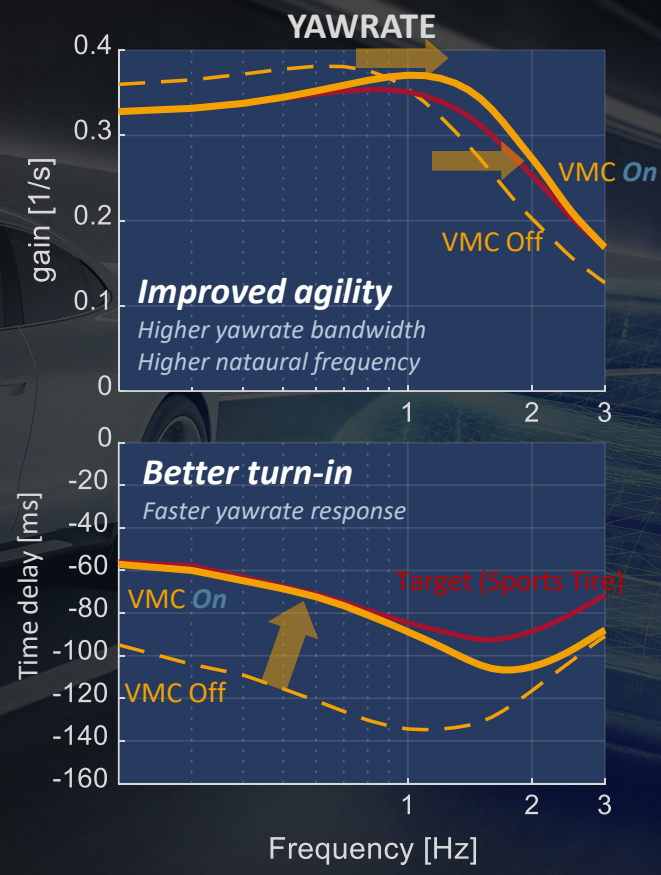
Vehicle: D-Segment Luxury SUV (Comfort Tires)

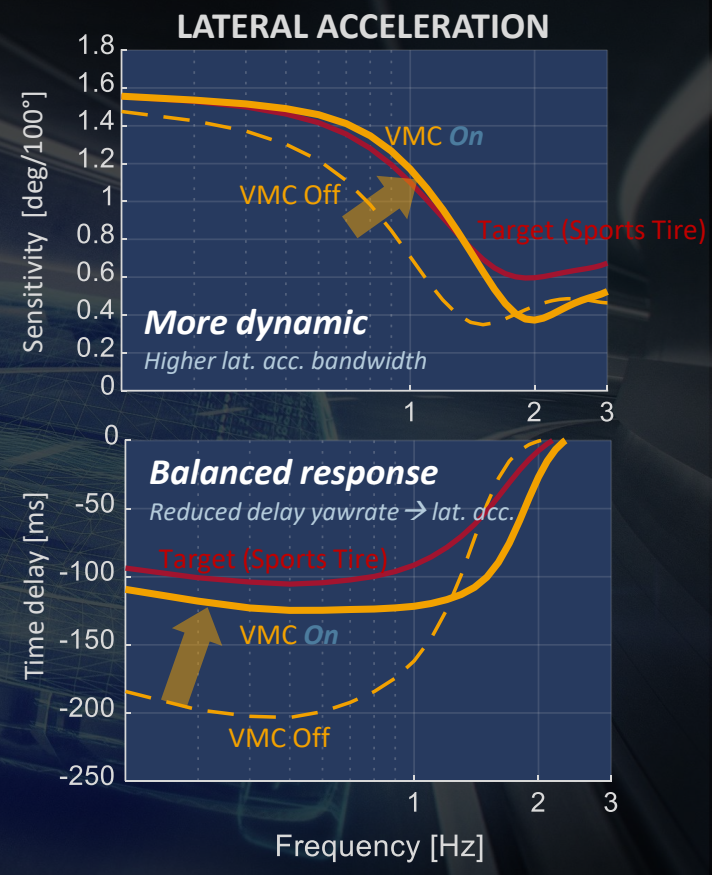
Controller Target: D-Segment Sport SUV (Sport Tires)

Vehicle Systems:

- Steer-by-wire
- Rear wheel steering
- Torque vectoring

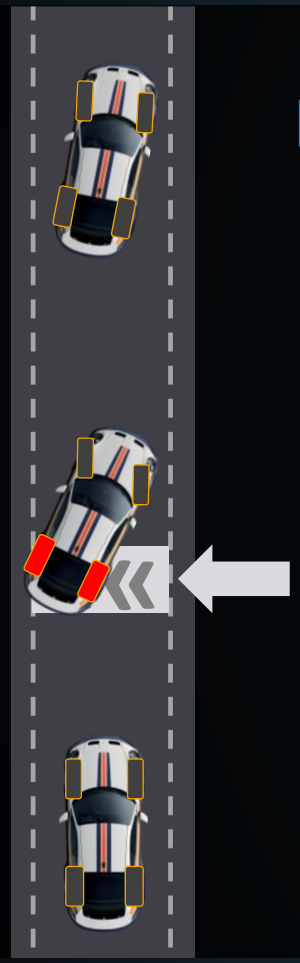




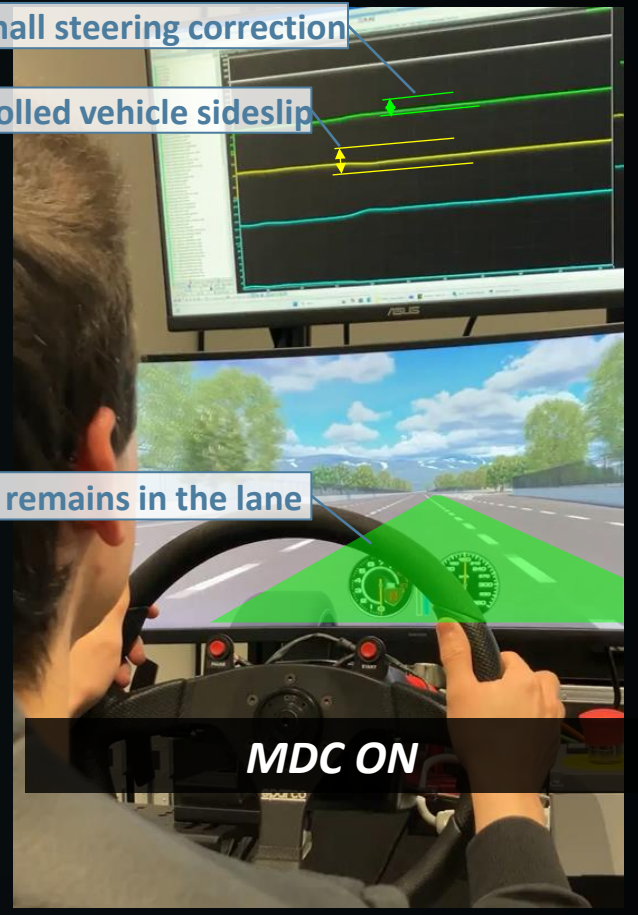


VMC Use Case: Virtual Kick-Plate

Co-ordinated actuator management to improve high-speed vehicle stability



< Disturbance Force
< Drive Steer
< Sideslip
< RWS (inactive)
< TV (inactive)



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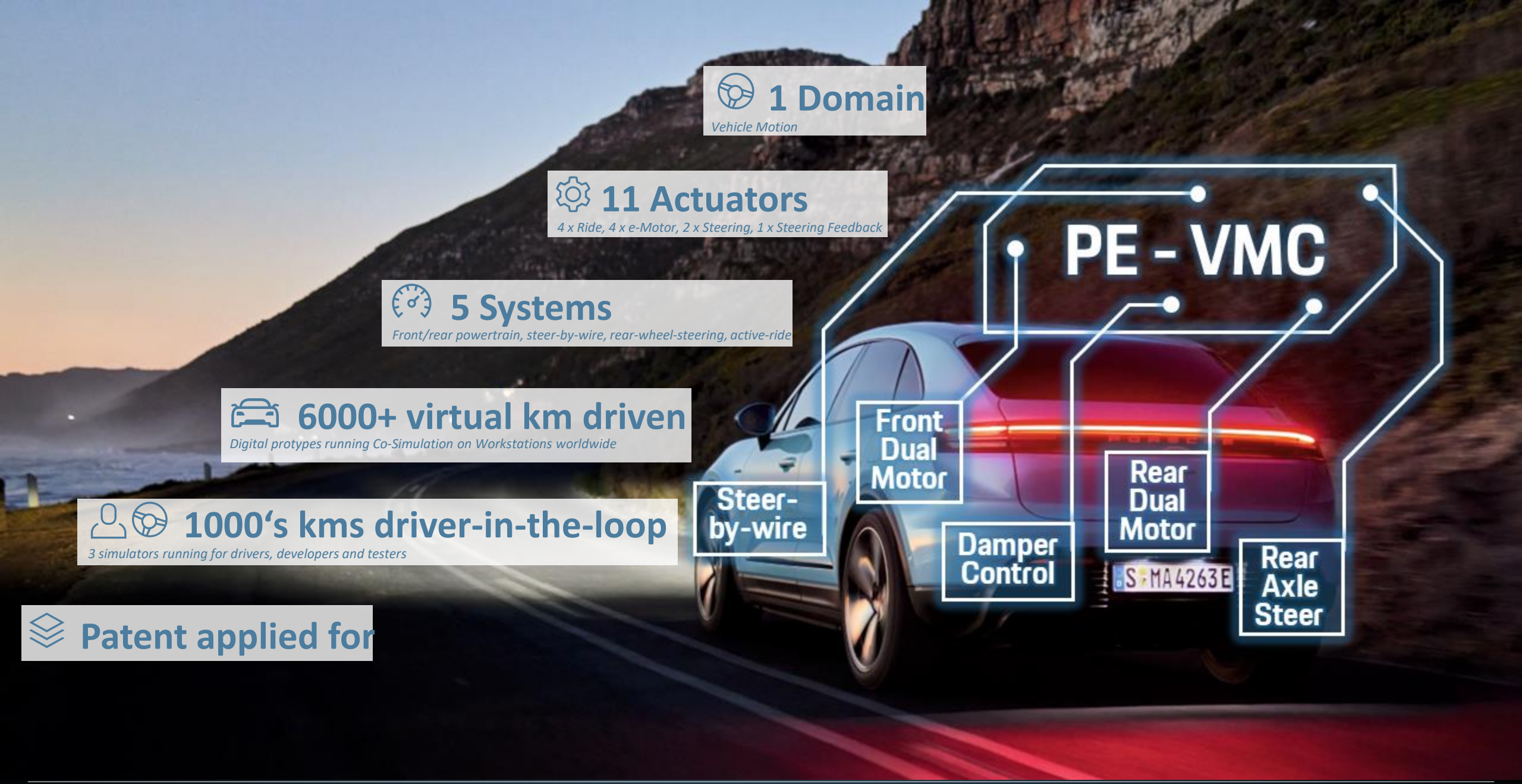
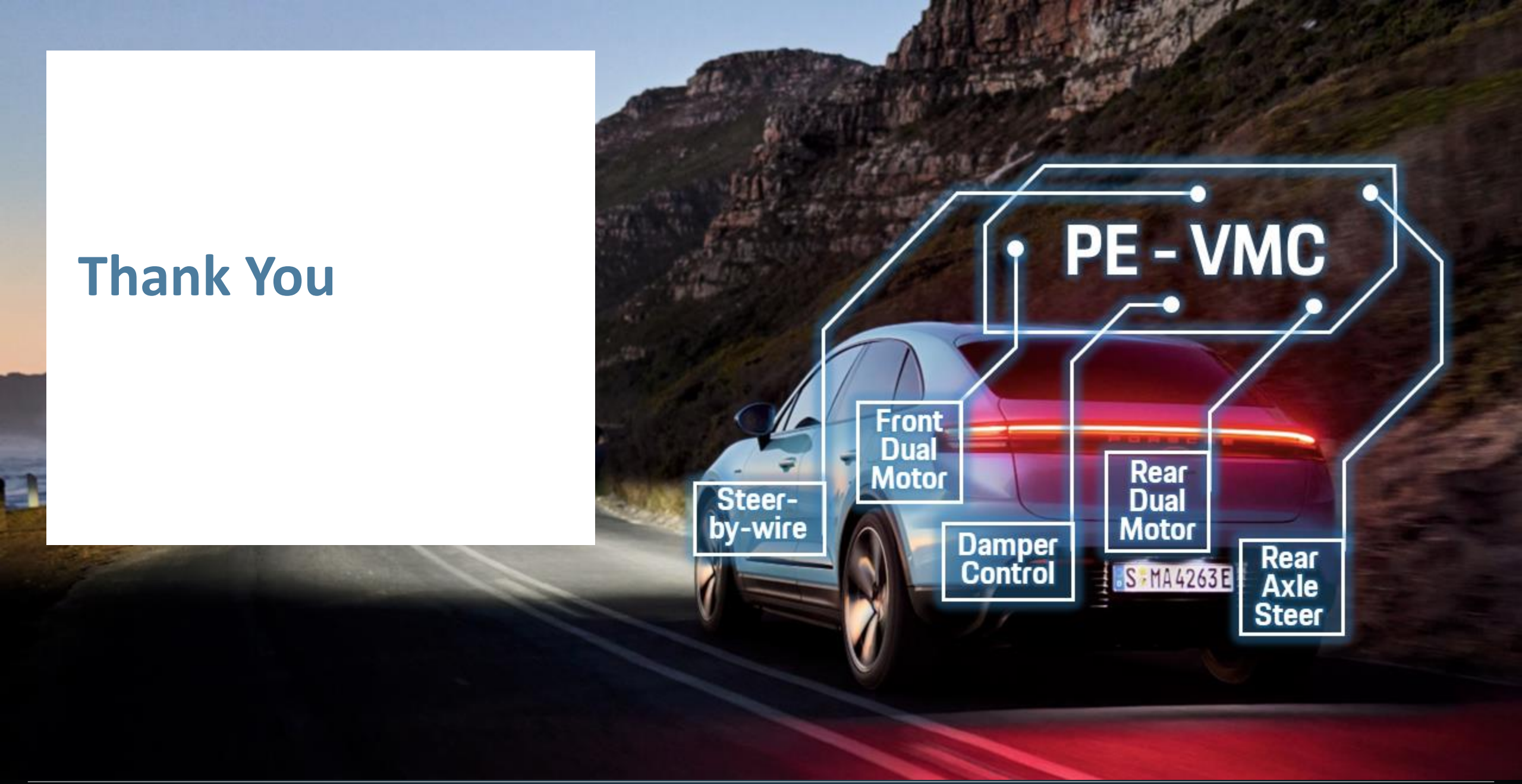
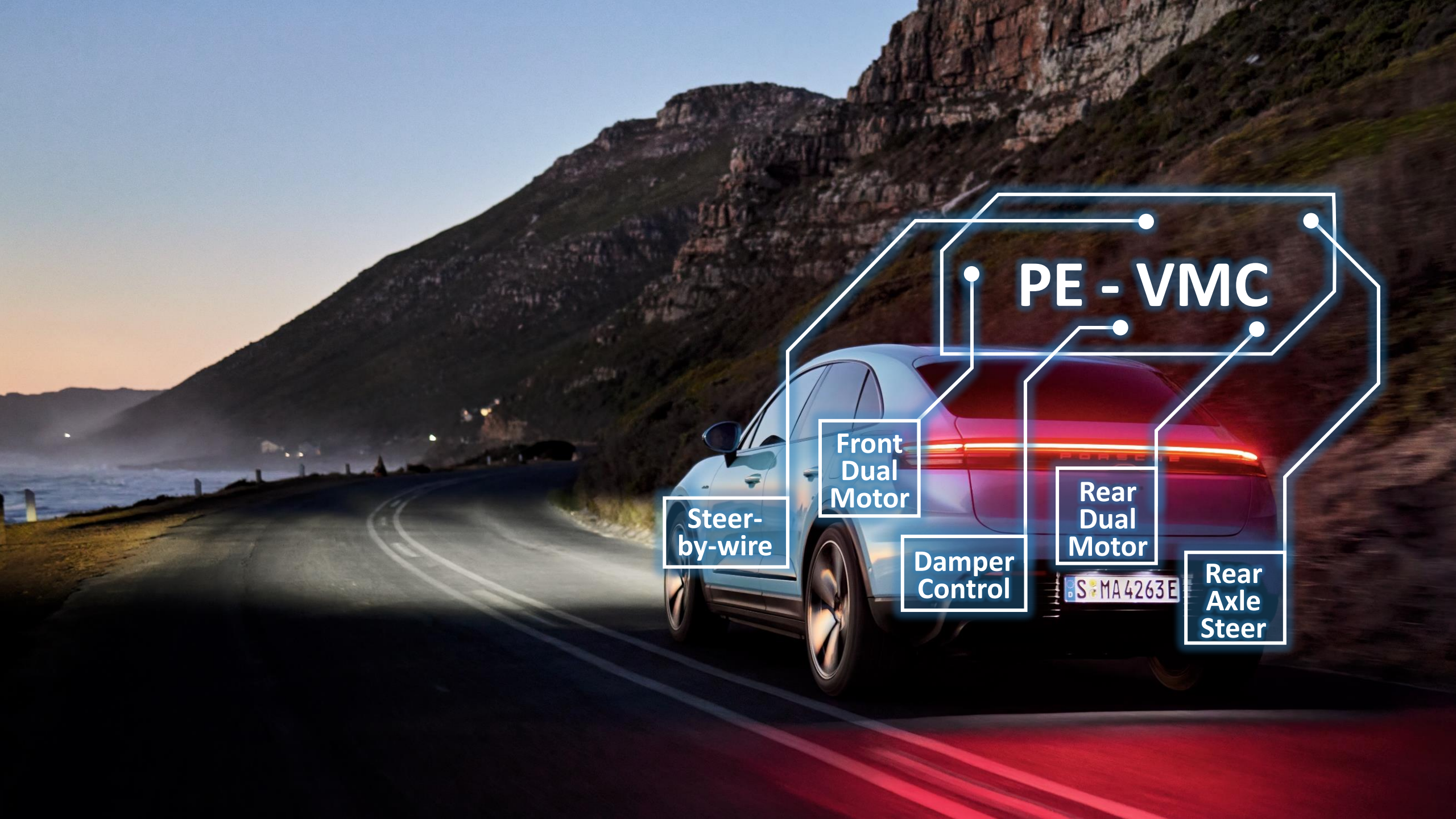

1 Domain
Vehicle Motion
11 Actuators
4 x Ride, 4 x e-Motor, 2 x Steering, 1 x Steering Feedback
5 Systems
Front/rear powertrain, steer-by-wire, rear-wheel-steering, active-ride
6000+ virtual km driven
Digital protypes running Co-Simulation on Workstations worldwide
1000‘s kms driver-in-the-loop
3 simulators running for drivers, developers and testers
Patent applied for
PE - VMC
Steer-by-wire
Front Dual Motor
Damper Control
Rear Dual Motor
Rear Axle Steer

Thank You


PE - VMC
Front Dual Motor
Steer-by-wire
Damper Control
Rear Dual Motor
Rear Axle Steer
S MA 4263E


PE - VMC
Steer-
by-wire
Front
Dual
Motor
Damper
Control
Rear
Dual
Motor
Rear
Axle
Steer