

# Enhancement Of Digital Control Systems And Tire Model For Automotive Development

Mercedes-AMG | EE/FI | Driving Dynamics, Integration/ Simulation

Alessandro Porro, Maximilian Eberle

Rebecca Lirsch, Michael Bidlingmaier

15.05.2024



# Digital Control System Development At Mercedes-AMG

*Motivation*



„In order to achieve a high **level of maturity** in the early digital development of a vehicle for the design of **hardware**, as well as **software** and **control systems**, AMG is working on solutions to create the best possible **digital prototype**.

To this end, we are using **modern** and **sophisticated methods** to ensure **reliability** and **reproducibility** in the digital development.

This requires not only the handling of the **model** and **signal complexity**, but also the enhancement of the **tire model** to make valid statements about the **control system behavior** in the digital phase and to take the step towards **virtual validation**.”

# Digital Control System Development – Action Plan



- 1 **Base Model Handling In The AMG - Virtual Garage**
- 2 Implementation Of Active Systems
- 3 Dynamic Model Configuration
- 4 Advanced AMG Tire Model
- 5 Automated Testing Environment In Offline And Online Simulation

# 1 – Model Handling – Vehicle Model Configuration

Vehicle model configuration

- platform
- - car series
- - - car
- - - - development type
- - - - - version type
- - - - - spring system
- - - - - tire dimension
- - - - - tire model
- ...



**AMG Components**  
„MiL – model in the loop“



**Active Systems**  
„SiL – software in the loop“



**VI-CRT Base Model**  
„ViL – vehicle in the loop“

# 1 – VI-CarRealTime – Base Model Handling

## AMG Virtual Garage

### Local

**AMG\_Car.cdb:**

**System:**

AMG\_Car\_system.xml

**Subsystems:**

Front suspension:

AMG\_Car\_front\_suspension.xml

Rear suspension:

AMG\_Car\_rear\_suspension.xml

Steering system:

AMG\_Car\_steering.xml

Front wheel:

AMG\_Car\_front\_wheels.xml

Rear wheel:

AMG\_Car\_rear\_wheels.xml

Brakes:

AMG\_Car\_brakes.xml

Powertrain:

AMG\_Car\_powertrain.xml

Aux1, Aux2 ... AuxN:

AMG\_Car\_FMI\_Master.xml

...

**Additional files:**

Springs:

AMG\_Car\_front\_suspension\_spring.xml

Dampers:

AMG\_Car\_front\_suspension\_damper.xml

Tires:

front\_tire.tir, rear\_tire.tir

Torque Property file:

AMG\_engine\_map.pwr

Aero Property file:

AMG\_aero\_map.aer

...



# 1 – VI-CarRealTime – Base Model Handling

## AMG Virtual Garage

Local

Cloud – based



systems.tbl: AMG\_Car\_system.xml

subsystems.tbl: ...

BoM  
Bill of Materials

chassis



dampers



springs



tires



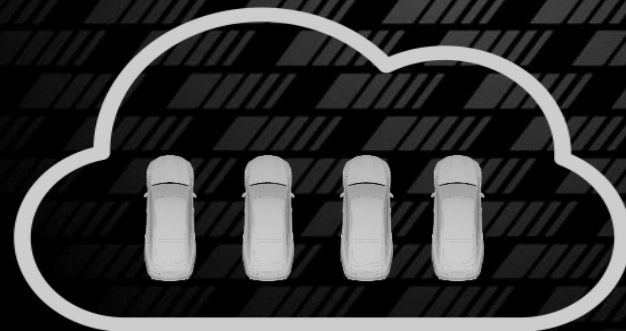
powertrains



...

# 1 – Advantages Of The AMG Virtual Garage

- ✓ Central location for all vehicle models of AMG
- ✓ Accessibility to the latest vehicle update for all simulation engineers
- ✓ Versioned and revised systems, subsystems and property files
- ✓ Usage of concepts blocking components between car series
- ✓ Possibility to export open or obfuscated models by „one click“ for internal or external usage



„I want to start a VI-CRT simulation with the latest model.“



„I want to transfer the model to an external partner in the obfuscated format.“



„I want to use the model on the driving simulator.“



„I want to know how my colleague sets up the front suspension.“

# Digital Control System Development – Action Plan



- 1 Base Model Handling In The AMG - Virtual Garage
- 2 **Implementation Of Active Systems**
- 3 Dynamic Model Configuration
- 4 Advanced AMG Tire Model
- 5 Automated Testing Environment In Offline And Online Simulation

## 2 – Implementation Of Active Systems

### Automated CI/CD – Pipeline For Different Model Sources And Fixed Software Releases

#### Local

TargetLink - Models

AmeSim - Models

C-Code

Fix Datasets (txt, csv-files)

...



#### Automated CI/CD – Pipeline

#### Cloud – based



JFrog Artifactory

AMG\_FMU1:  
AMG\_FMU1\_V01.fmu  
AMG\_FMU1\_V02.fmu



AMG\_FMU2:  
AMG\_FMU2\_V01.fmu  
AMG\_FMU2\_V02.fmu

AMG\_FMUUn:  
AMG\_FMUUn\_V01.fmu  
AMG\_FMUUn\_V02.fmu

- ✓ Automated triggered pipeline for different kinds of model sources
- ✓ Supplying fixed software release
- ✓ Building up platform independent FMUs (win and linux)
- ✓ Usage of the easy connection format in VI-CRT and SimWB

# Digital Control System Development – Action Plan

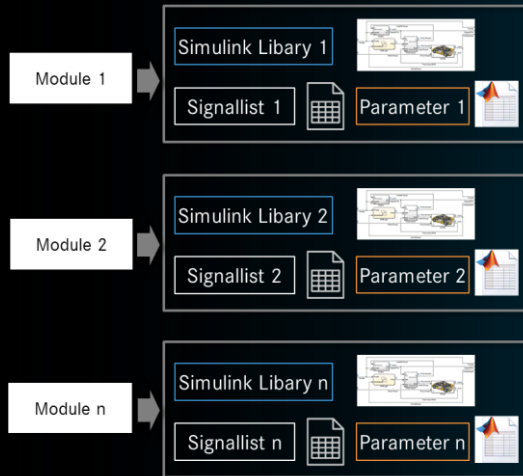


- 1 Base Model Handling In The AMG - Virtual Garage
- 2 Implementation Of Active Systems
- 3 **Dynamic Model Configuration**
- 4 Advanced AMG Tire Model
- 5 Automated Testing Environment In Offline And Online Simulation

# 3 – Dynamic Model Configuration

## Model Integration For Extended Vehicle Dynamic Models

### Module library AMG Components



### Motivation for creating the AMG Components database

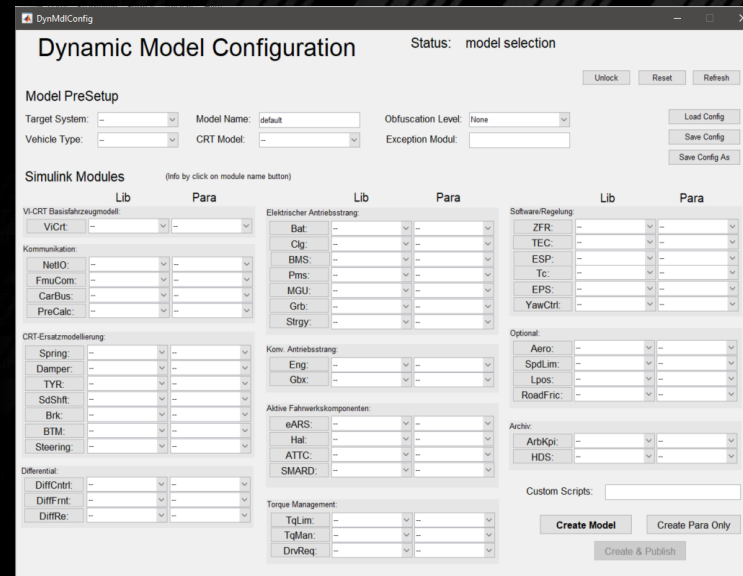
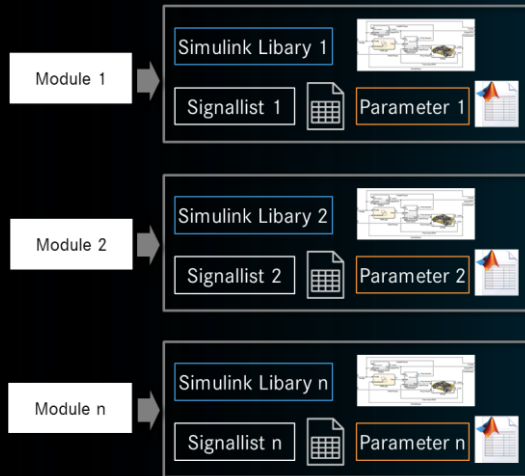
- Higher and more detailed simulation accuracy than in the VI-CRT base model
- Digital integration of modules, controllers, additional models etc. during development
- Use of co-simulation in control system development for a more detailed investigation at signal level

# 3 – Dynamic Model Configuration

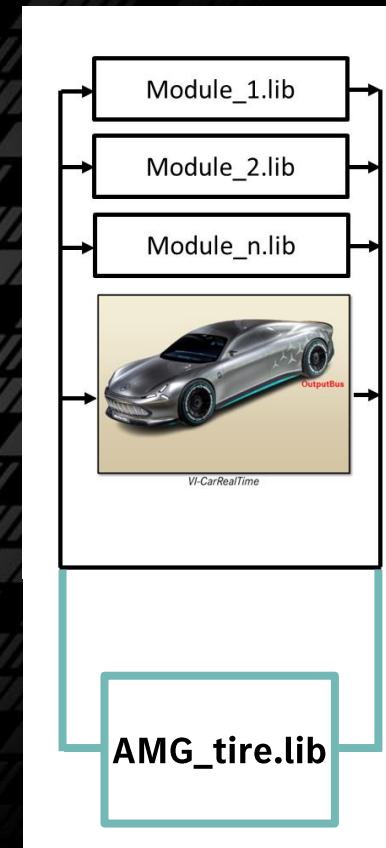
## Model Integration For Extended Vehicle Dynamic Models

Dynamic model configuration

Module library  
AMG Components



Handling of signal compatibility



DiL



HiL



SiL



MiL



# Digital Control System Development – Action Plan



- 1 Base Model Handling In The AMG - Virtual Garage
- 2 Implementation Of Active Systems
- 3 Dynamic Model Configuration
- 4 **Advanced AMG Tire Model**
- 5 Automated Testing Environment In Offline And Online Simulation

## 4 – Tire Model – Requirements

What are the requirements for a tire model at AMG for Control Systems Development?



Real-time efficiency

**Maintain / Improve**



Standstill (flat road and incline/decline)



Decision-making in an early development stage



Different road conditions (high- $\mu$ , low- $\mu$ ,  $\mu$ -split)

**Goals for improvement**



Response to slip control intervention (with different road conditions)

## 4 – Tire Model – low- $\mu$ Scaling

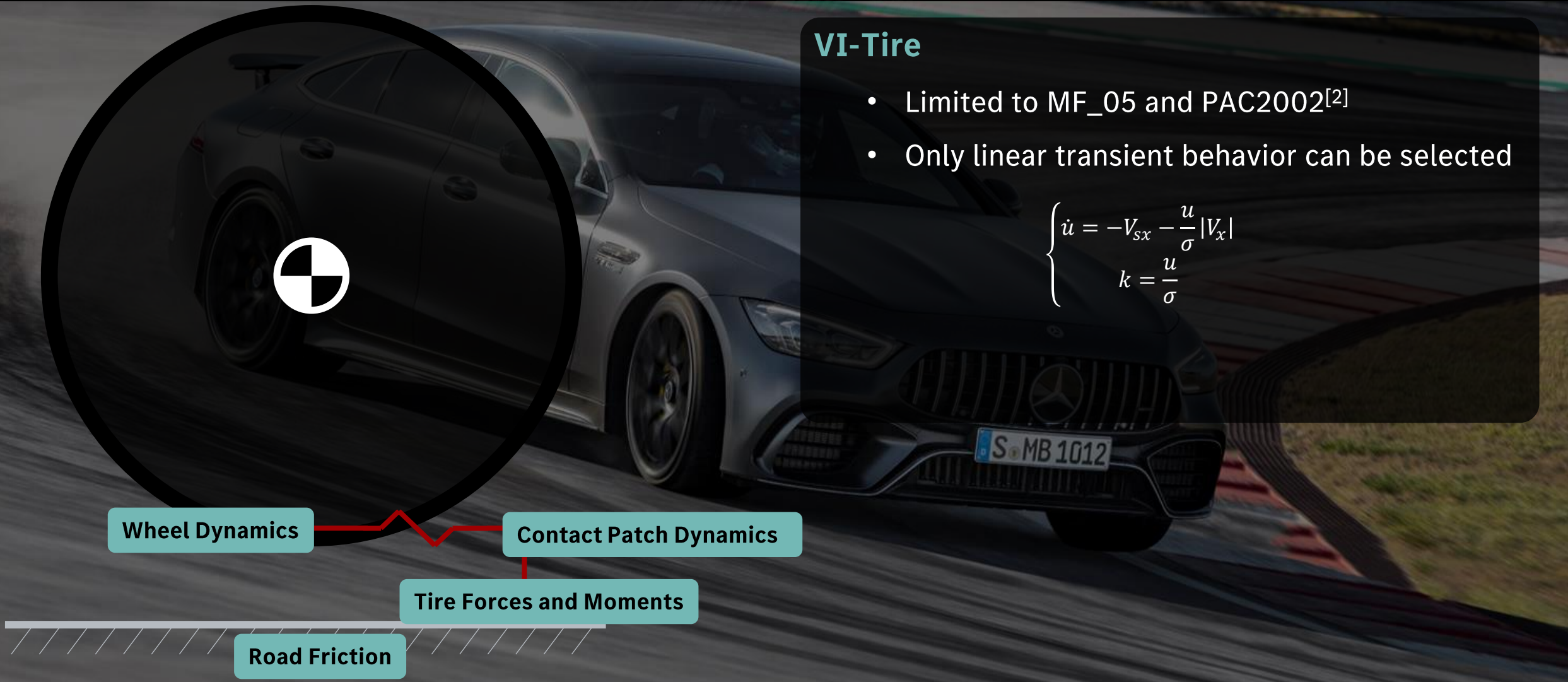
### Different Road Conditions (high- $\mu$ , low- $\mu$ , $\mu$ -split)

1. Typical tire scaling (high- $\mu$  and low- $\mu$ )  $\rightarrow$  linear scaling  $\rightarrow$  not realistic
2. Tire OEM  $\rightarrow$  2 datasets (high- $\mu$  and low- $\mu$ )  $\rightarrow$   $\mu$ -variation online not possible
3. Literature research  $\rightarrow$  improved scaling<sup>[1]</sup>  $\rightarrow$  online scaling possible



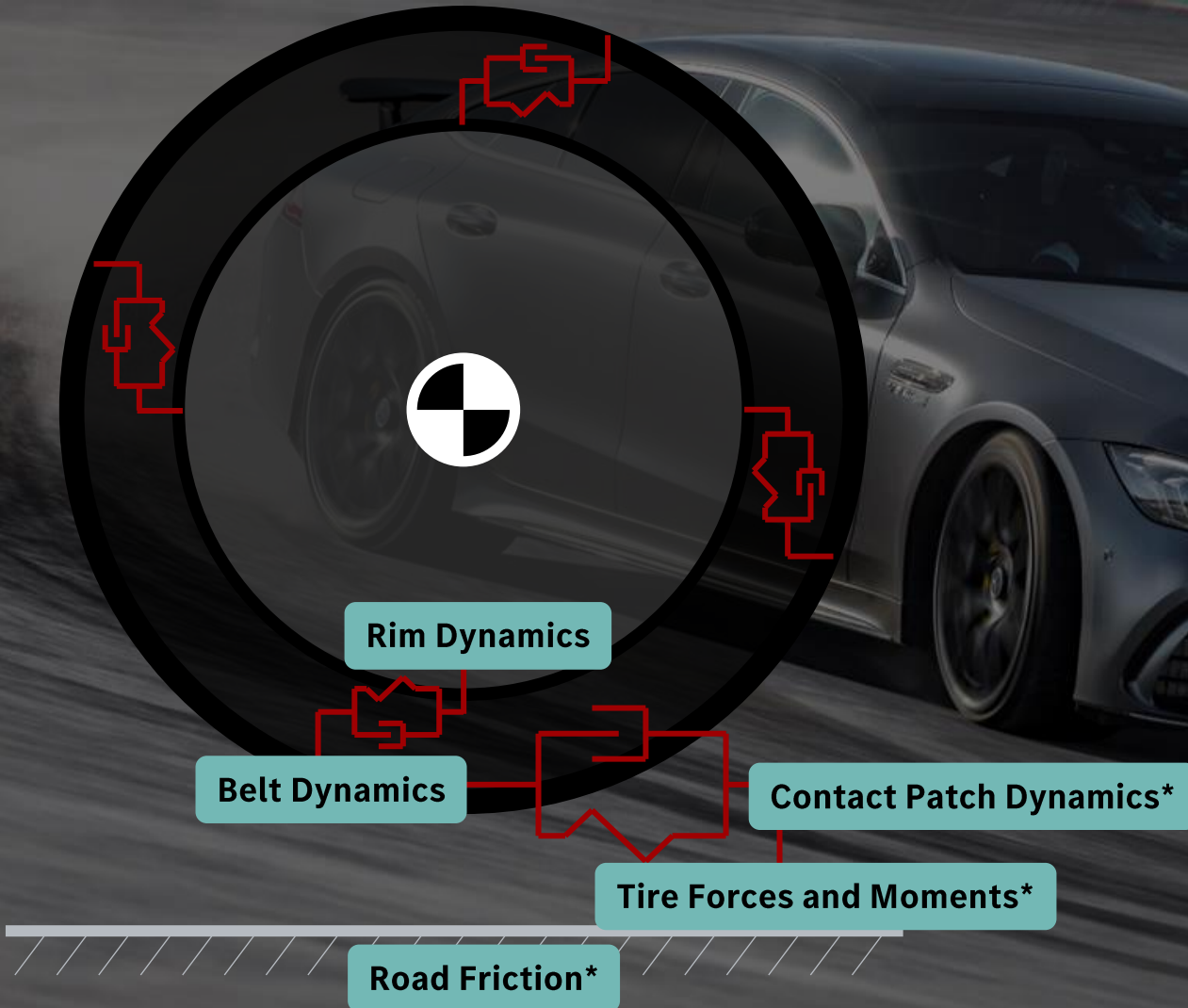
# 4 – Tire Model – Structure

## Response To Slip Control Intervention



# 4 – Tire Model – Structure

## Response To Slip Control Intervention



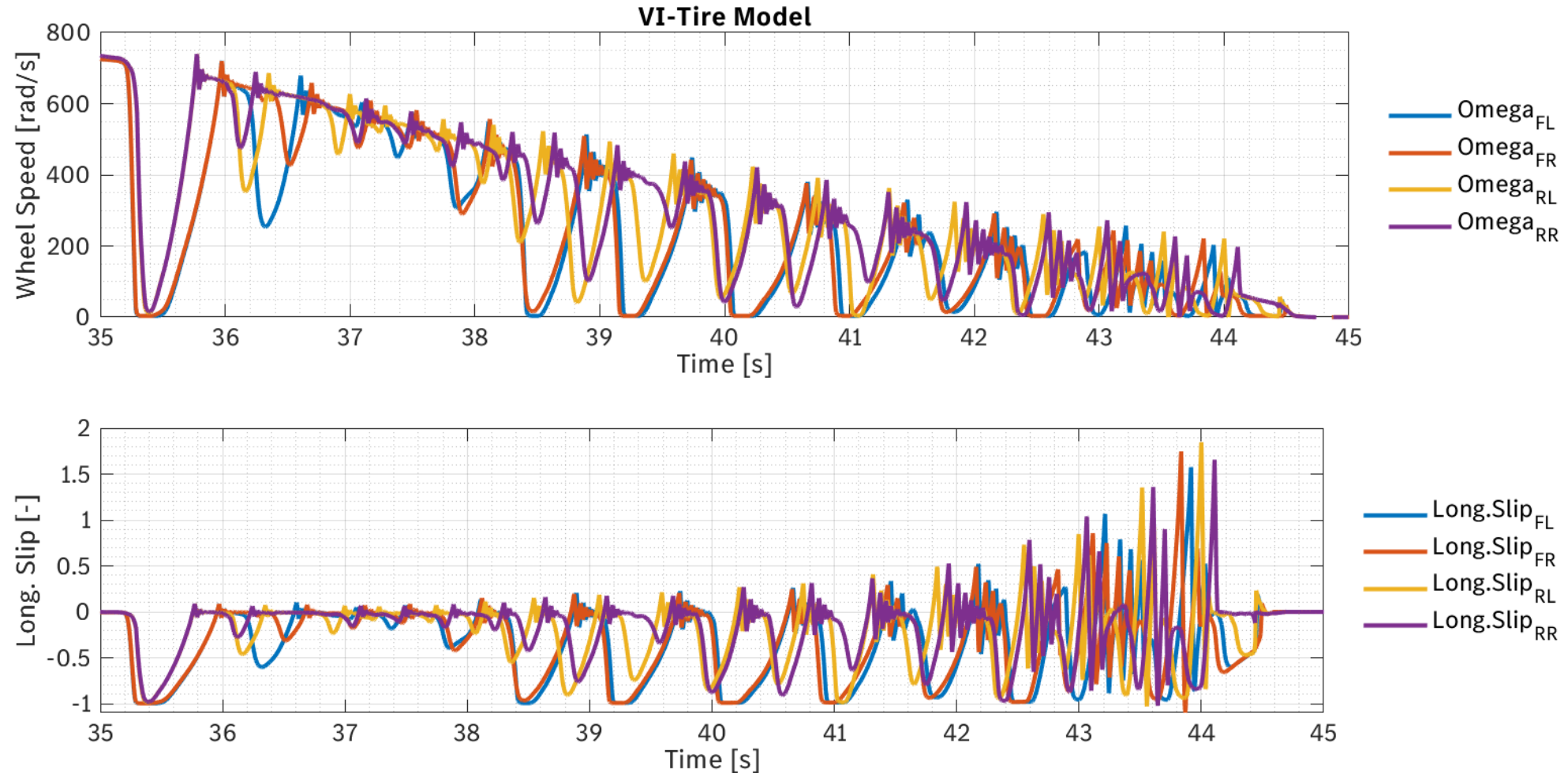
### AMG Tire Model

- MF\_05, PAC2002 and newer versions
- Different transient behaviors can be selected<sup>[3]</sup>
- Turnsip<sup>[3]</sup>
- Belt rotation around the Y-Axis<sup>[3]</sup>
- Tire pressure dependency<sup>[4]</sup>
- Low- $\mu$  scaling<sup>[1]</sup>

$$\left\{ \begin{array}{l} M_y + F_x R = c_{b\theta} \theta_b^r + k_{b\theta} \dot{\theta}_b^r + I_{by} \dot{\omega}_b \\ V'_{sx} = V_x - \omega_b R_{eff} \\ F_x = c_{cx} \varepsilon + k_{cx} \dot{\varepsilon} + m_{cp} \dot{V}_{sx}^* \\ V_{sx}^* = V'_{sx} + \dot{\varepsilon} \\ \dot{u} = -V_{sx}^* - \frac{u}{\sigma} |V_x| \\ k = \frac{u}{\sigma} \end{array} \right.$$

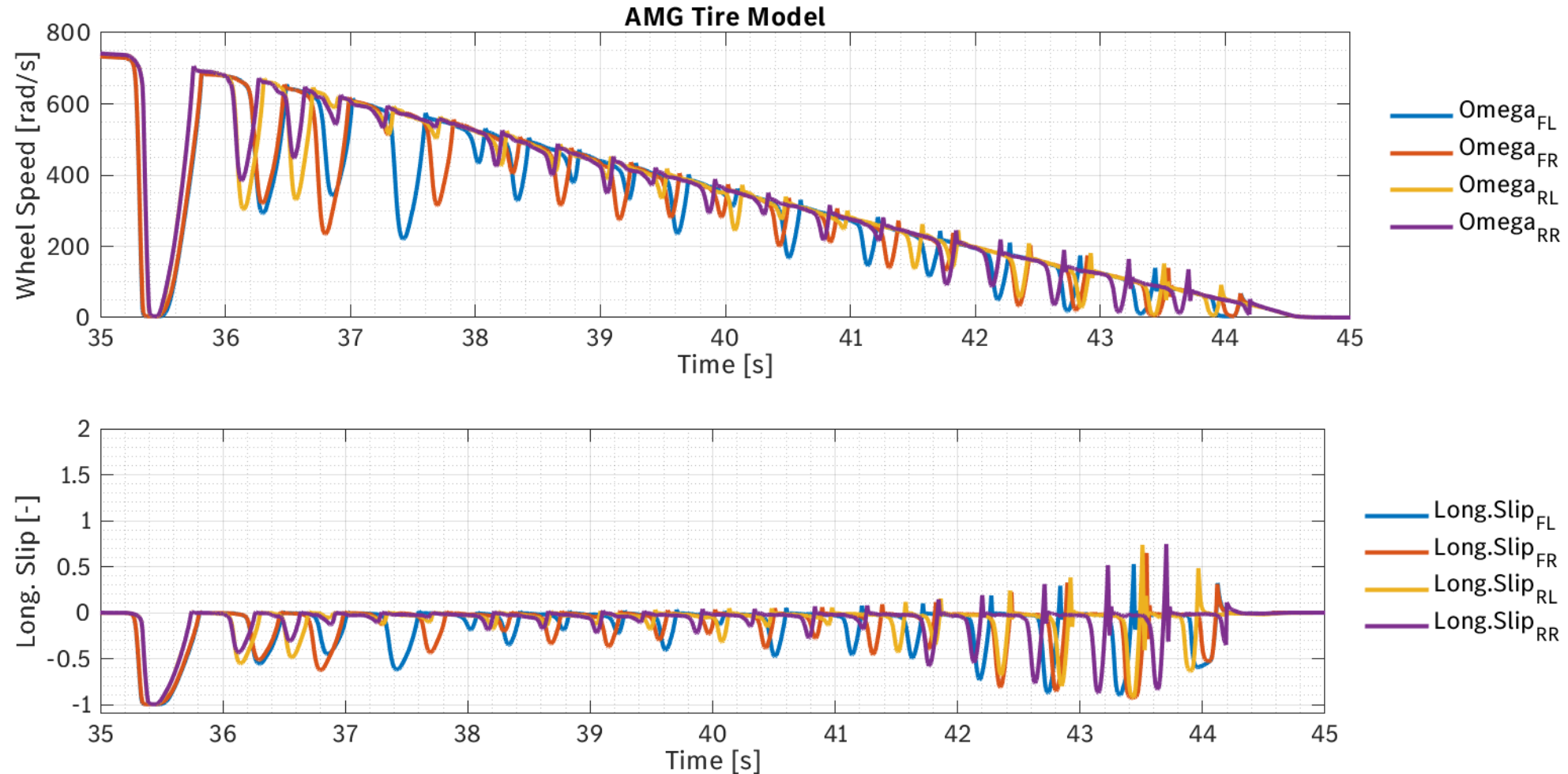
## 4 – Tire Model – ABS Maneuver With VI-Tire (low- $\mu$ )

### Response To Slip Control Intervention



## 4 – Tire Model – ABS Maneuver With AMG Tire Model (low- $\mu$ )

### Response To Slip Control Intervention



## 4 – Tire Model – Summary

What are the requirements for a tire model at AMG for Control Systems Development?



Real-time efficiency



Standstill (flat road and incline/decline)



Decision-making in an early development stage



Different road conditions (high- $\mu$ , low- $\mu$ ,  $\mu$ -split)



Response to slip control intervention (with different road conditions)

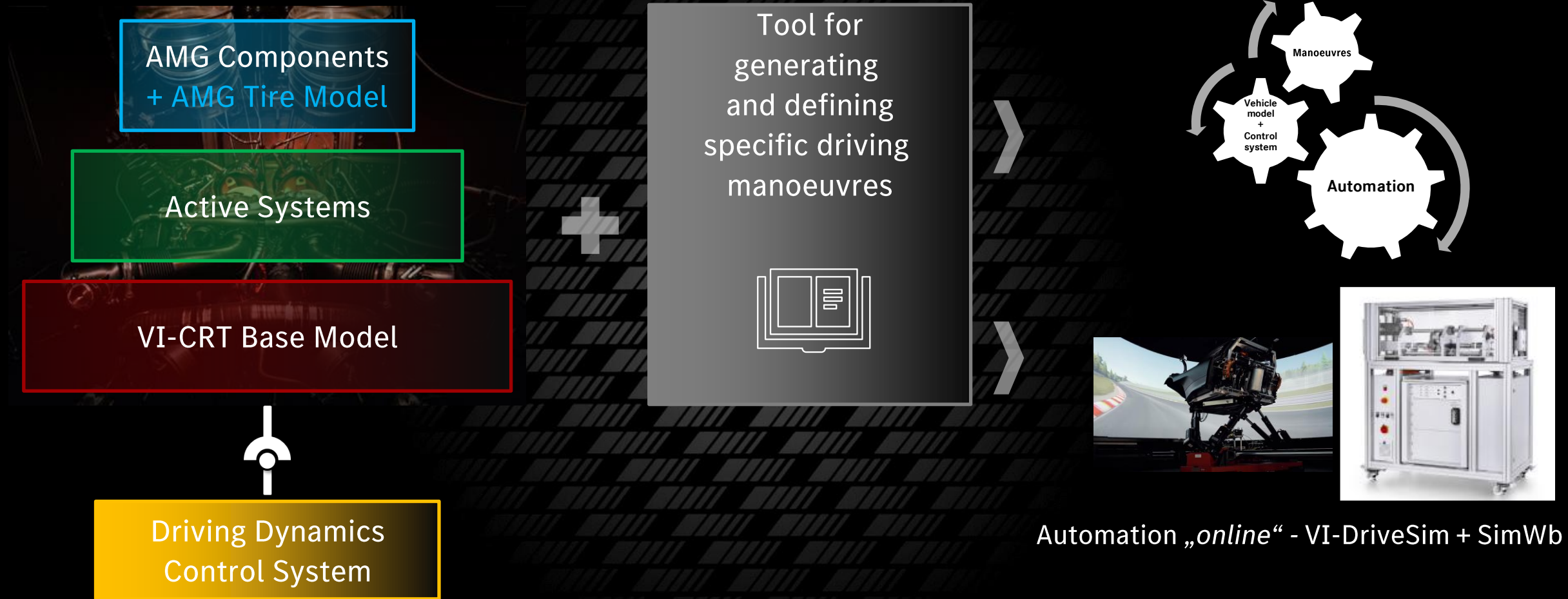


# Digital Control System Development – Action Plan



- 1 Base Model Handling In The AMG - Virtual Garage
- 2 Implementation Of Active Systems
- 3 Dynamic Model Configuration
- 4 Advanced AMG Tire Model
- 5 **Automated Testing Environment In Offline And Online Simulation**

# 5 – Automated Testing Environment – Offline And Online



# Digital Control System Development – Mission Completed!



- 1 **Base Model Handling In The AMG - Virtual Garage**
- 2 **Implementation Of Active Systems**
- 3 **Dynamic Model Configuration**
- 4 **Advanced AMG Tire Model**
- 5 **Automated Testing Environment In Offline And Online Simulation**