Optimal energy efficiency, vehicle stability and safety on the OpEneR EV with electrified front and rear axles

Berlin, Monday 17 June 2013

Dr. Stephen Jones, AVL
Emre Kural, AVL
Alexander Massoner, AVL
Dr. Kosmas Knödler, Robert Bosch
Jochen Steinmann, Robert Bosch

Contents

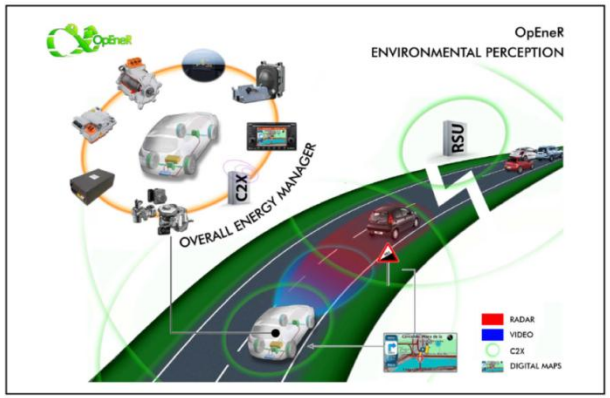
- OpEneR Project Overview
- Introducing the Advanced Co-simulation Platform
- Cooperative Regenerative Braking System
- Simulated Use Cases:
  - Standard Braking Manoeuvre
  - Split-μ Braking
  - Hill climbing on 10% split-μ
- Conclusion and Outlook

EU OpEneR Project, Aim & Project Partners

Consortium

Partner	
Robert Bosch GmbH (Germany, Project Coordinator)	BOSCH Invented for life
Peugeot Citroën Automobiles S.A. (France)	PSA PEUGEOT CITROËN
Robert Bosch Car Multimedia GmbH (Germany)	BOSCH Invented for life
AVL List GmbH (Austria)	AVL
Centro Tecnológico de Automoción de Galicia (Spain)	CTAG Centro Tecnológico de Automoción de Galicia
FZI Forschungszentrum Informatik (Germany)	FZI

- OpEneR is developing driving strategies & assistance systems, that increase electric vehicle efficiency, driving range & safety.
- This is achieved by merging data from on-board & off-board sources. A particular focus lies on an optimal cooperation between the electric drivetrain and the regenerative braking system, supported by data from radar, video, satellite navigation, car-to-infrastructure & car-to-car systems.
- Overall project budget: 7.7 Million €

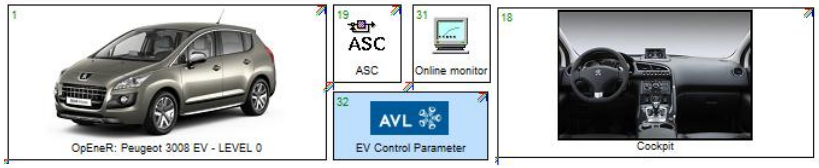


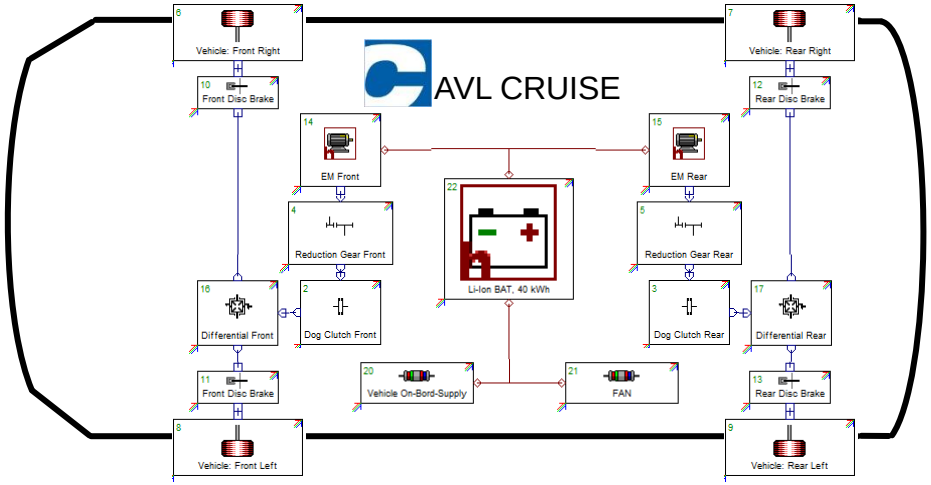
OpEneR

SEVENTH FRAMEWORK PROGRAMME

Contents

OpEneR Vehicle & Simulation Model





OpEneR Simulation Toolchain

AVL

BOSCH
Invented for life

ESP®*hev*

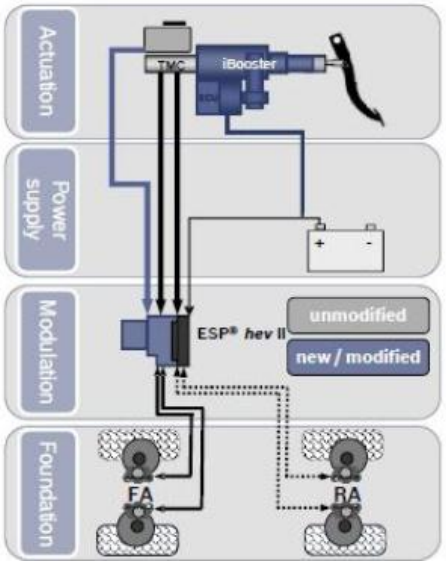
iBooster

- 40kwh battery package (200km range)
- 110kw discharge and charge (depending on temp.)
- Front & Rear Axle e-traction i.e. e-4WD
- Recuperation (e-braking) with ESP®*hev* + iBooster

Contents

- OpEneR Project Overview
- Introducing the Advanced Co-simulation Platform
- Cooperative Regenerative Braking System
- Simulated Use Cases:
  - Standard Braking Manoeuvre
  - Split-μ Braking
  - Hill climbing on 10% split-μ
- Conclusion and Outlook

Cooperative Regenerative Braking System (CRBS)

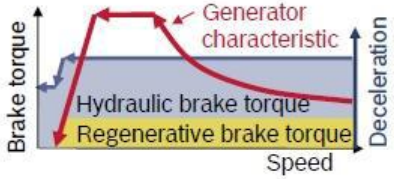


- **ESP®*hev* with rear axle by-wire brake circuit**
  - Rear axle brakes decoupled from brake pedal in normal operation
  - Brake pressure at the axle electronically i.e. by-wire adjusted by ESP®*hev* system during so called torque blending between recuperation & frictional braking torques

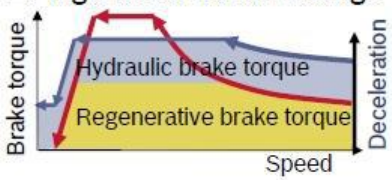
- Regenerative braking is replaced by conventional friction braking in case of system degradation or vehicle stability controller interventions
- The by-wire brake circuit is used to compensate changes of the recuperation torque due to the e-machine characteristics

Regenerative Braking w/o cooperation (blending)

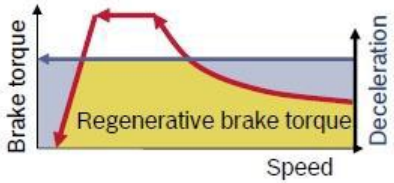
low regeneration



higher regeneration
⇒ high deceleration change



Cooperative Regenerative Braking with ESP® *hev*



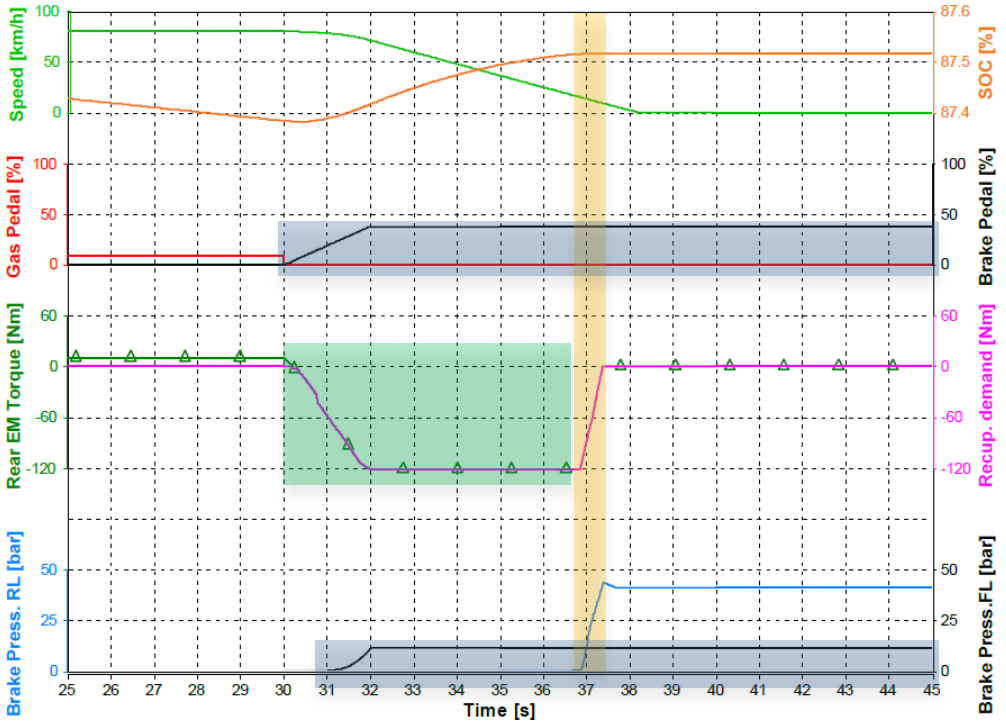
- Highest Regeneration
  - with constant brake pedal position
  - equal to today's pedal feel

Contents

- OpEneR Project Overview
- Introducing the Advanced Co-simulation Platform
- Cooperative Regenerative Braking System
- Simulated Use Cases:
  - Standard Braking Manoeuvre
  - Split-μ Braking
  - Hill climbing on 10% split-μ
- Conclusion and Outlook

Standard Braking Manoeuvre

- **Virtual investigation of new energy management functions with respect to safety**
- **Brake pedal is pressed 40% at 80 km/h**
  - Electronic coordination of regenerative braking and friction brake torque
  - Regenerative brake torque request down to -120Nm
  - Torque blending at low speed

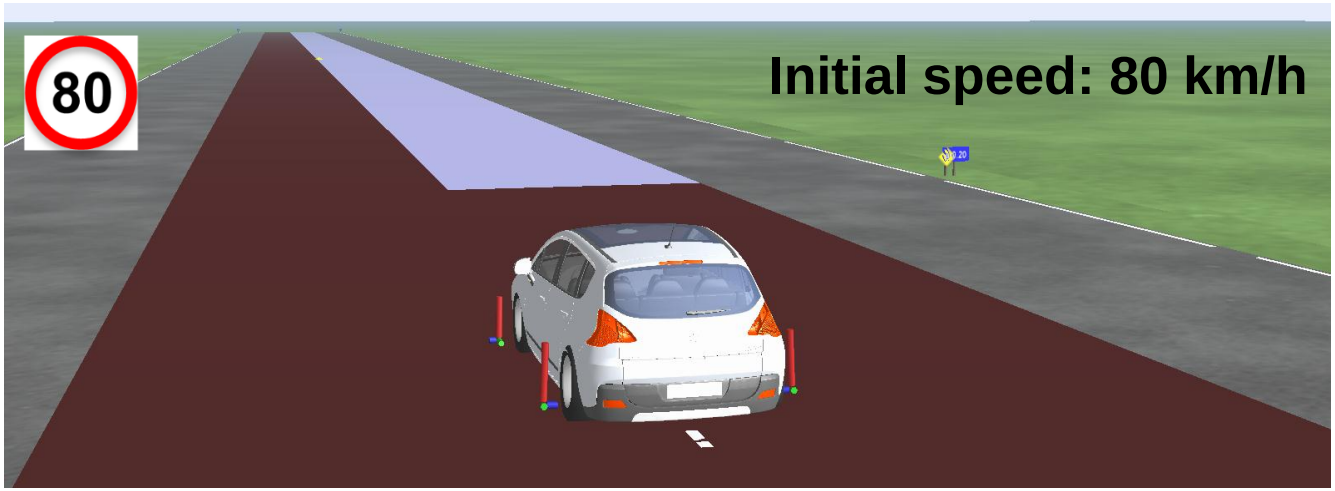


Contents

- OpEneR Project Overview
- Introducing the Advanced Co-simulation Platform
- Cooperative Regenerative Braking System
- Simulated Use Cases:
  - Standard Braking Manoeuvre
  - Split-μ Braking
  - Hill climbing on 10% split-μ
- Conclusion and Outlook

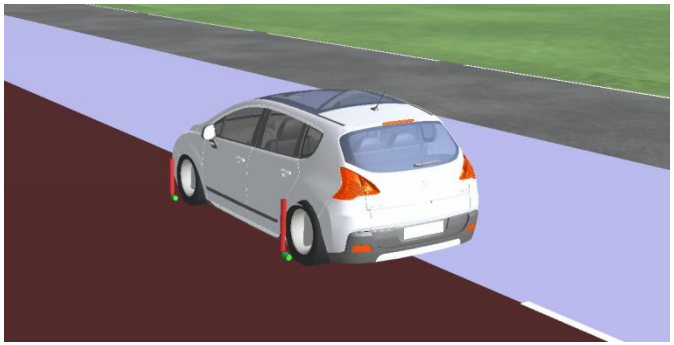
Split-μ Braking with ESP®*hev* Overview

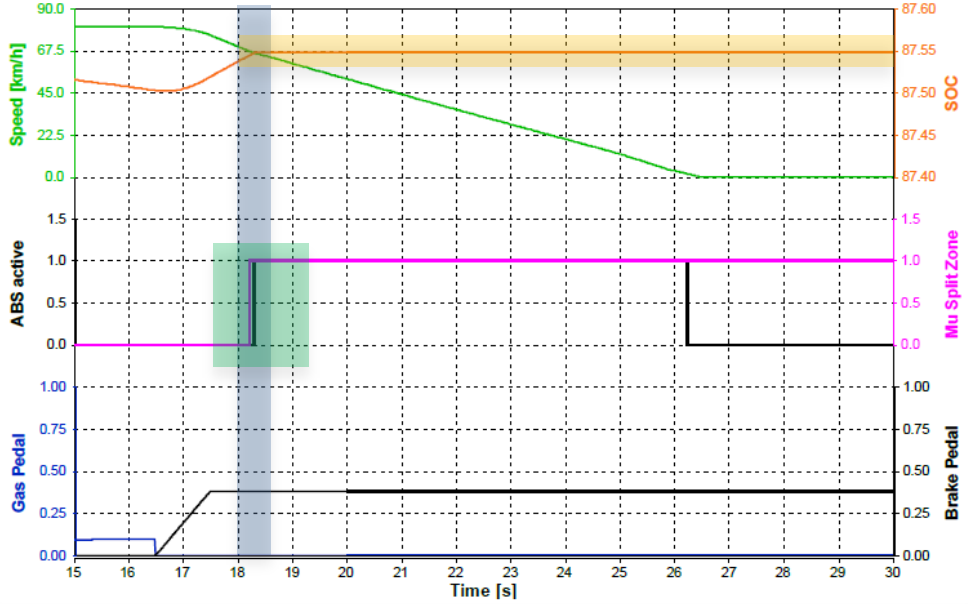
- **The electric machines cannot control the distribution of the torque between left and right wheels**
  - Regenerative braking is disabled on split-μ surface
  - ESP®*hev* controls the brake torque of every wheel individually
  - Vehicle stability is maintained throughout the entire manoeuvre



Split-μ Braking with ESP®*hev*
Part I

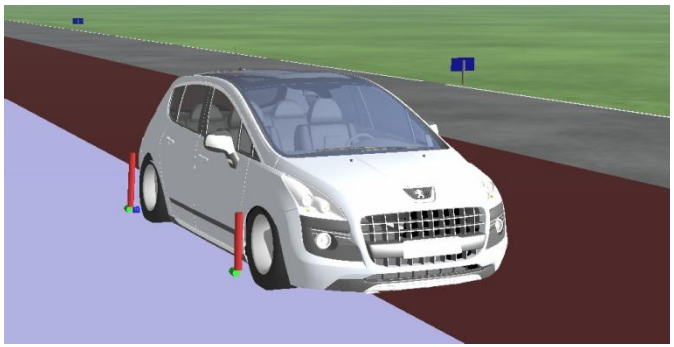
- Start of split-μ after normal braking
- ABS is activated due to high slip of right wheels
- Regenerative braking is instantly disabled (SOC remains constant)

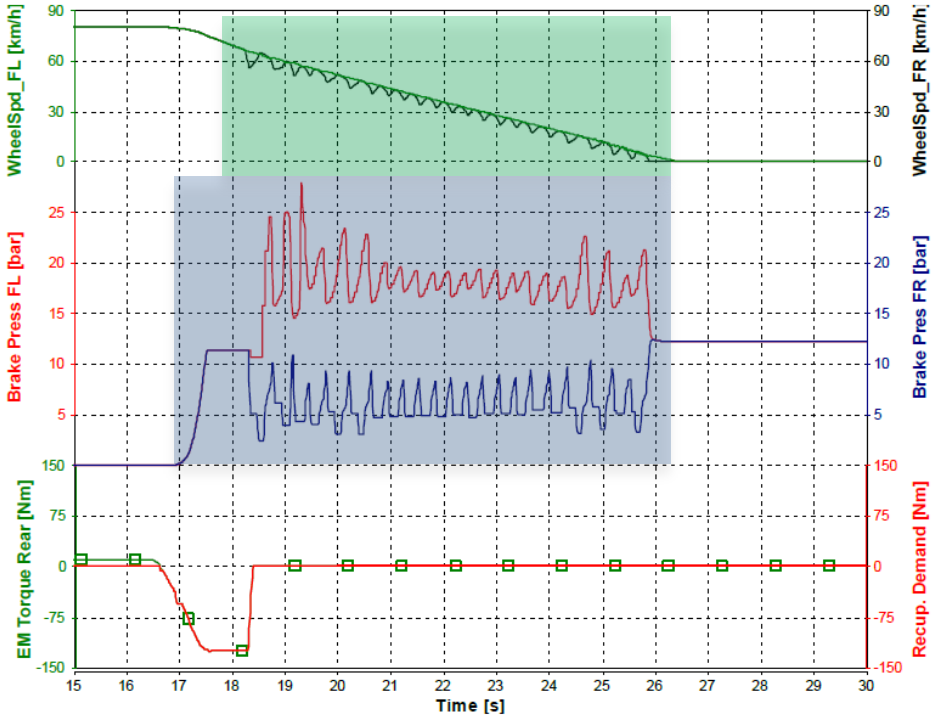




Split-μ Braking with ESP®*hev*
Part II

- Different brake pressure levels for front-left and front-right wheels
- Wheel slip for front-right wheel is higher than for front-left wheel
- The same holds for the wheels on the rear axle



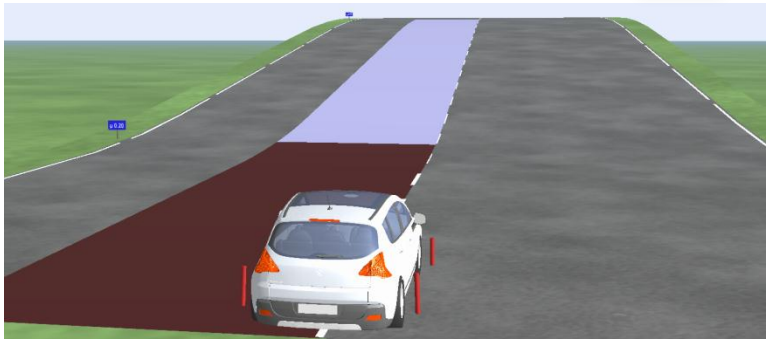


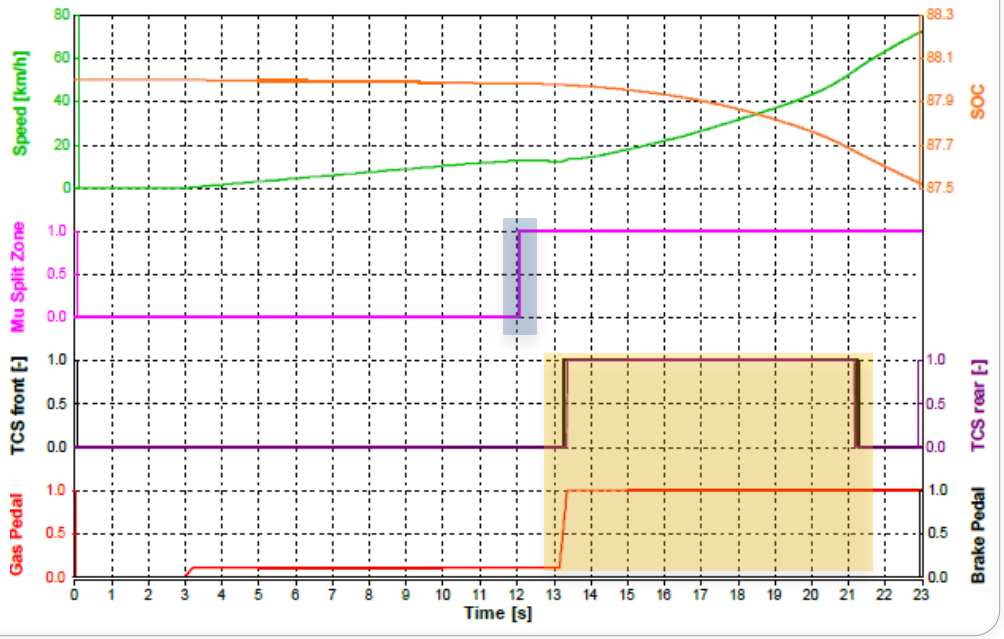
Contents

- OpEneR Project Overview
- Introducing the Advanced Co-simulation Platform
- Cooperative Regenerative Braking System
- Simulated Use Cases:
  - Standard Braking Manoeuvre
  - Split-μ Braking
  - Hill climbing on 10% split-μ
- Conclusion and Outlook

Hill climbing on 10% split-µ Overview

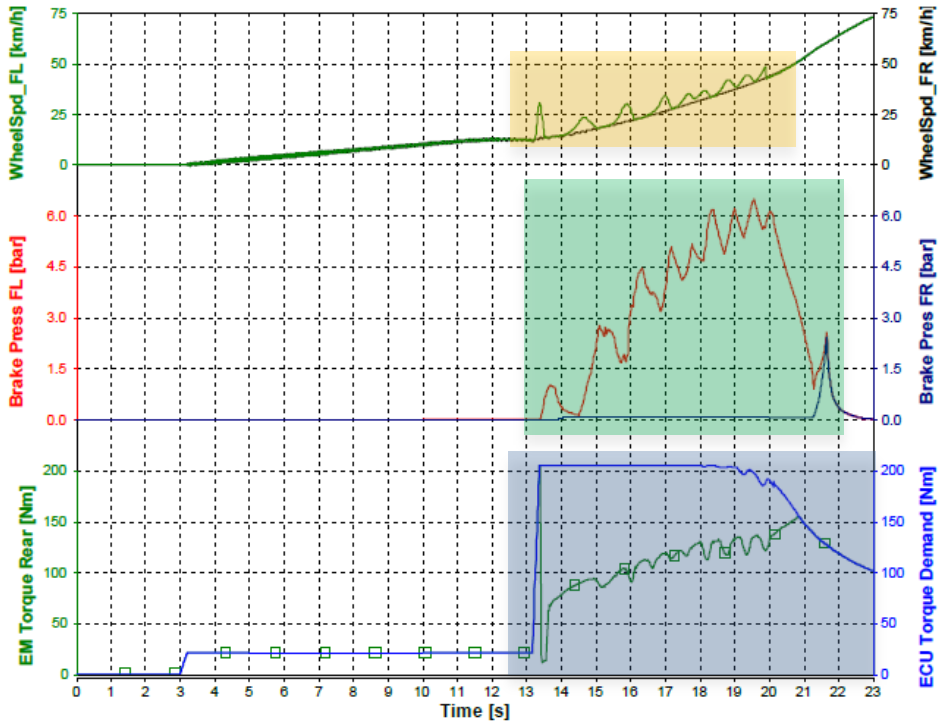
- **Initial speed: 15 km/h**
- **Full throttle on µ-split**
  - ESP®*hev* controls the torque of both EM individually
  - Moderate pressure is applied to stabilize the wheels on the low mue side
- **Start of split-µ**
- **Gas pedal is pushed 100%**
  - TCS front & rear is active





Hill climbing on 10% split-μ

- **ECU Torque demand is derived from gas pedal position**
  - ESP®*hev* overrules (reduces) torque demand (shown for rear EM)
- **Modest amount of friction braking**
  - Increases torque of the wheels on high-μ surface
  - Control slip/wheel speed of the wheels on low-μ surface
- **Safe and efficient hill climbing performance**



Contents

- OpEneR Project Overview
- Introducing the Advanced Co-simulation Platform
- Cooperative Regenerative Braking System
- Simulated Use Cases:
  - Standard Braking Manoeuvre
  - Split-μ Braking
  - Hill climbing on 10% split-μ
- Conclusion and Outlook

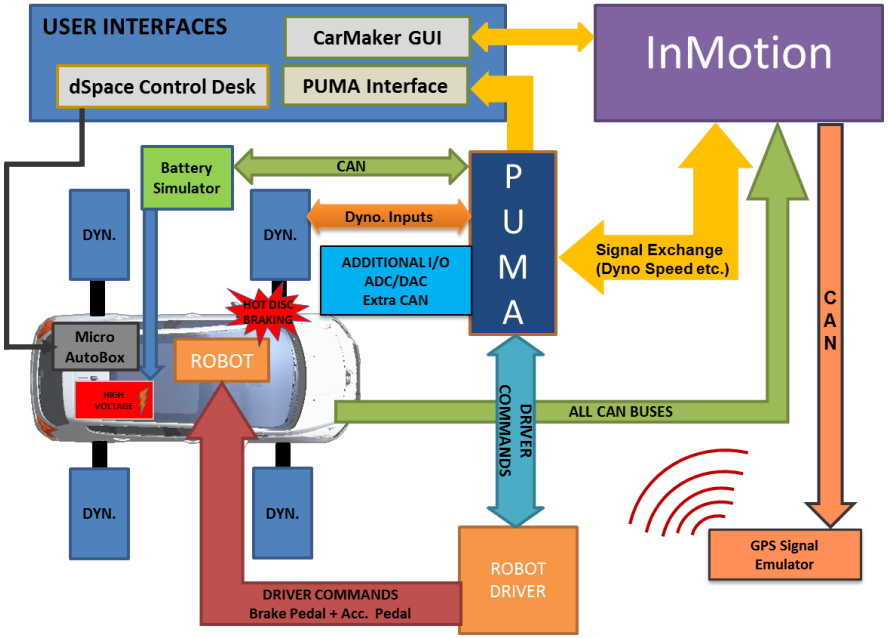
Conclusion and Outlook
Migration from Office PC to Testbed

- **Simulation toolchain extensively supports development process**

Reuse of office simulation environment for AVL InMotion test-bed

Office → Lab → Testbed → Road

- **AVL InMotion test-bed**
  - Fast migration to HiL testing
  - Rapid prototype testing
  - Realistic real-world conditions
  - Complex interface between Unit Under Test, automation and measurement systems



Conclusion and Outlook
Connectivity & the Powertrain

- Off-board or environmental information, allows predictive control of vehicles for more energy efficient, comfortable and safe driving.
- Beyond improving routing and optimizing the vehicle speed profile, off-board data from GPS, Radar, V2X, Video, etc. can be used to better regulate powertrain incl. braking systems, for example:
  - By intelligently & predictively optimizing load point switching between multiple power sources, or via improved thermal management, to improve efficiency, and thus CO2 emissions.
  - And as indicated here today, safely optimizing the cooperation between regenerative braking systems, friction brakes and vehicle dynamic control systems to improve efficiency and thus CO2 emissions and maintaining braking and related vehicle dynamic functions.
- Best facilitated with the use of a highly realistic co-simulation on office PC, and later powertrain testbed which is powered by similar simulation models.

Thanks for your kind attention