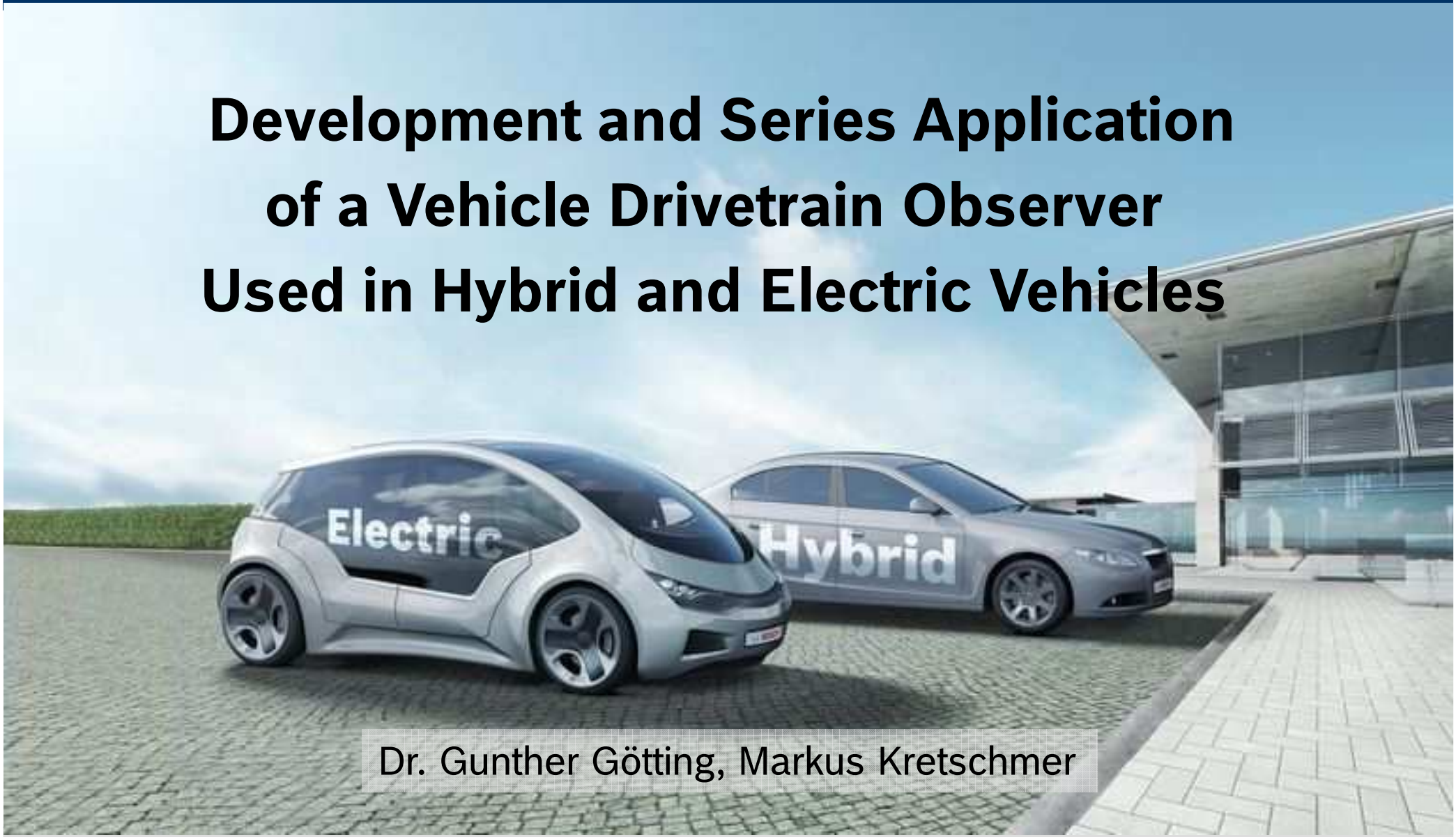
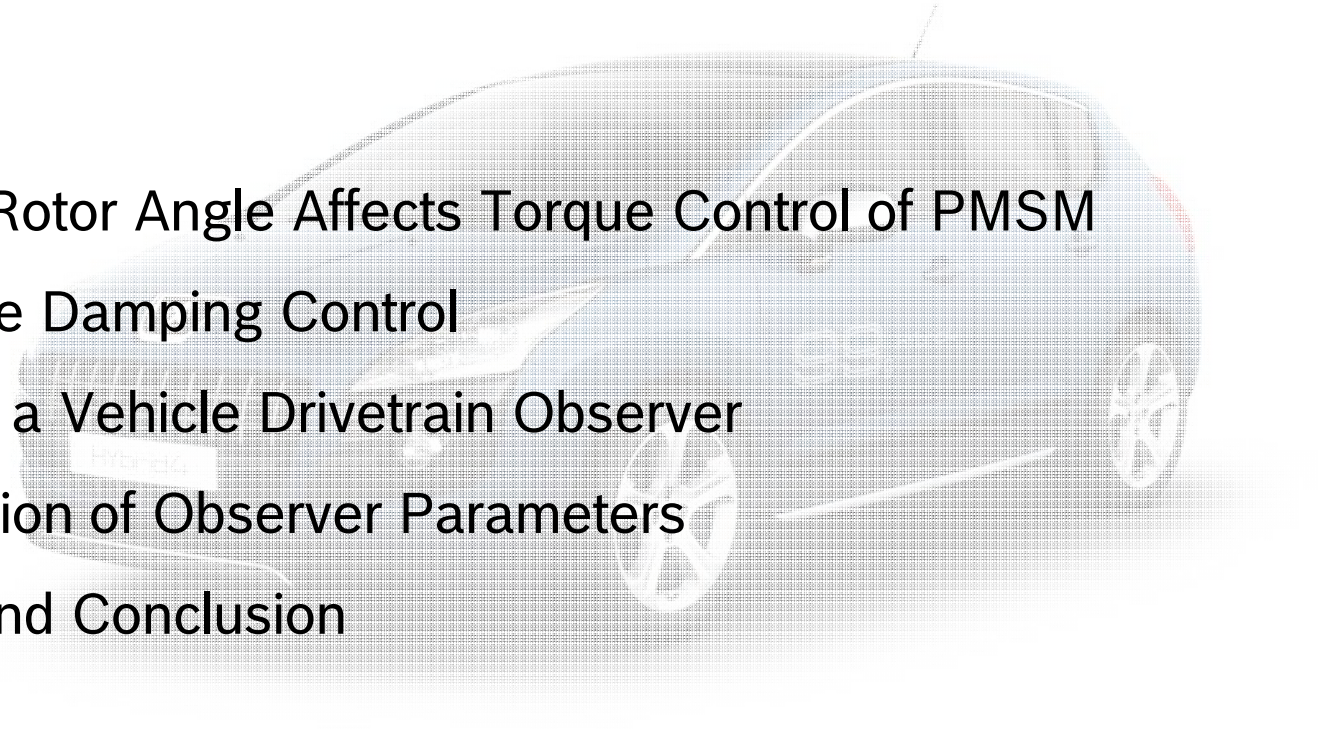
Development and Series Application of a Vehicle Drivetrain Observer Used in Hybrid and Electric Vehicles



Dr. Gunther Götting, Markus Kretschmer

BOSCH

Agenda



- Basics
- How the Rotor Angle Affects Torque Control of PMSM
- The Active Damping Control
- Design of a Vehicle Drivetrain Observer
- Identification of Observer Parameters
- Results and Conclusion

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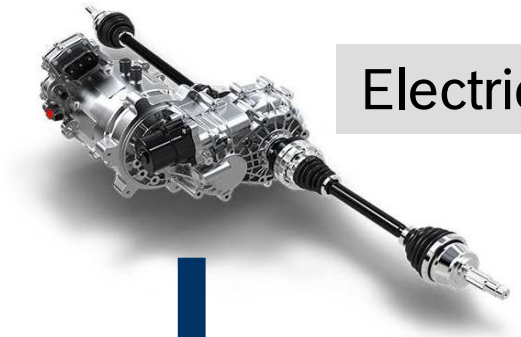
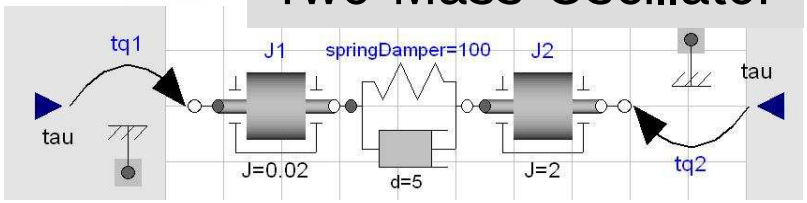
Modeling the Electric Axle Drivetrain

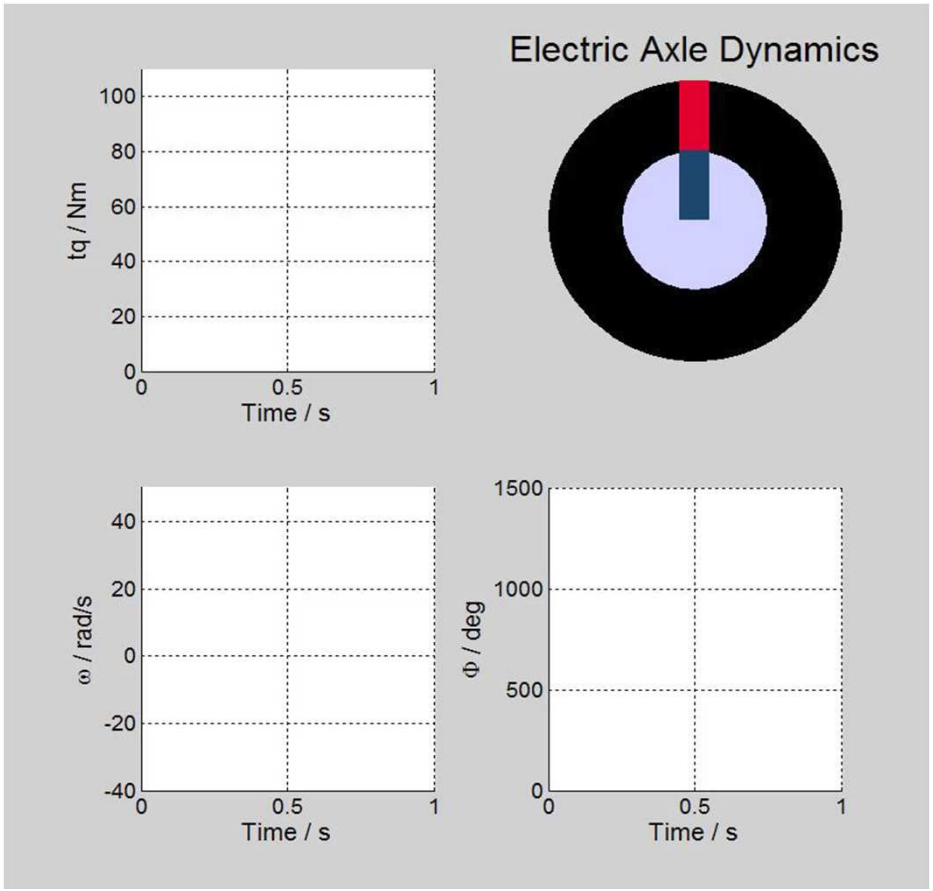
- Axle Split Hybrid / Electric Vehicle applications
- Electric machine installed inside final drive unit housing



Electric Axle Drive Unit

Two-Mass-Oscillator

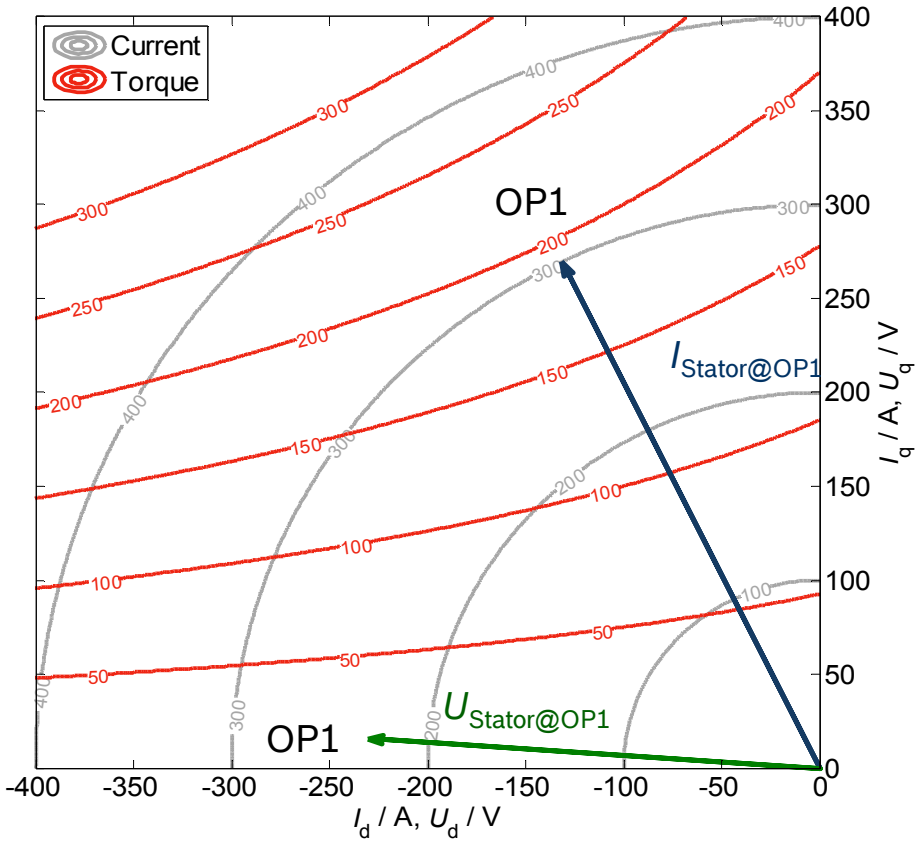




Drivetrain might be exposed to severe oscillations.

Influence of Rotor Angle on PMSM Torque Control

- Field oriented control (FOC)
- $T_{em} = f(I_d, I_q)$
- Angle error (here: ±5°el.):
  - Wrong current phasor
  - Torque error
  - Voltage error (disturbance)
- OP1 (on MTPA, at low speed):
  - Torque error: <1%
- OP2 (field weaken., high speed):
  - Torque error: -7 ... +10%



PMSM: Permanent Magnet Synchronous Machine

Accurate electric machine rotor angle is essential.

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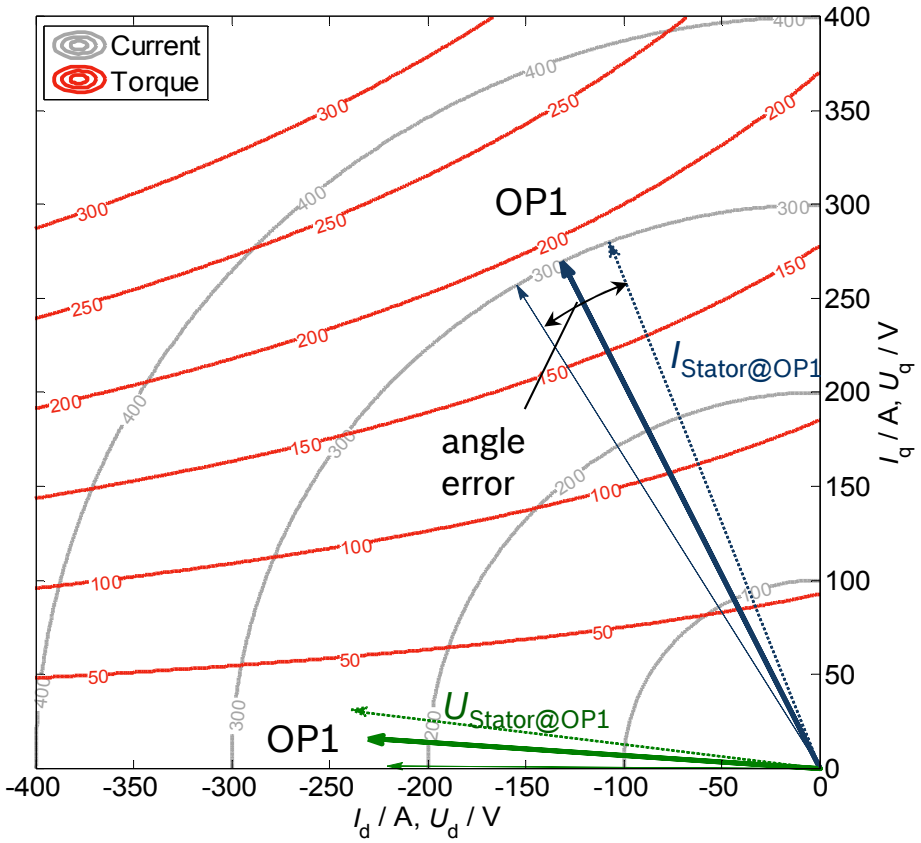

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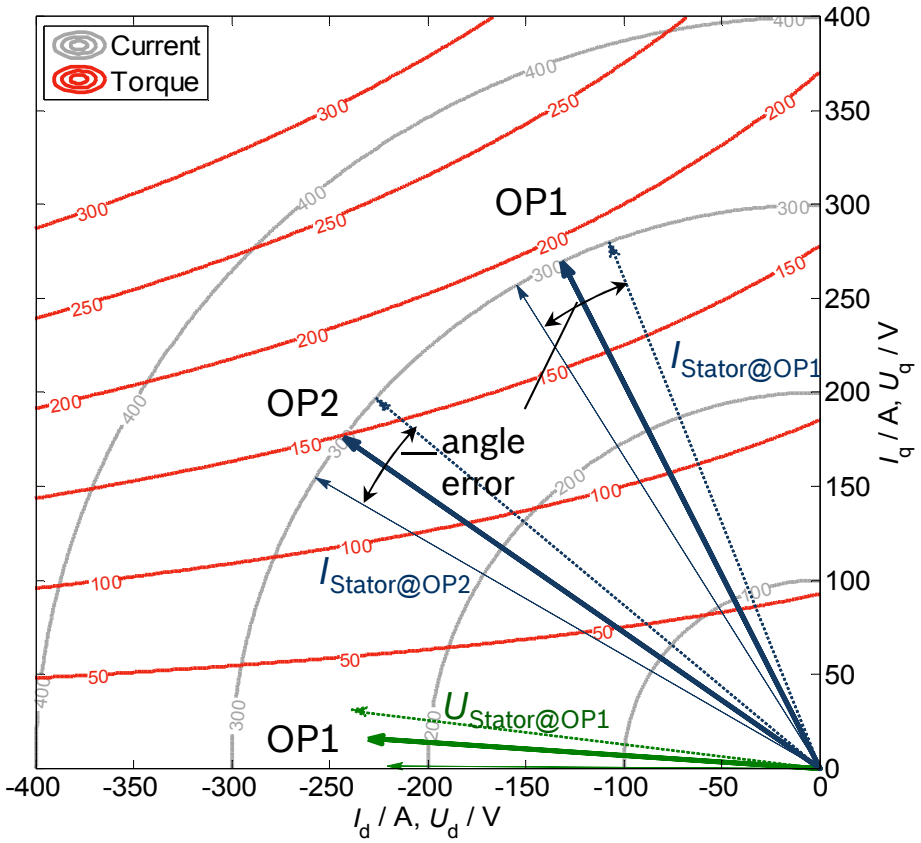

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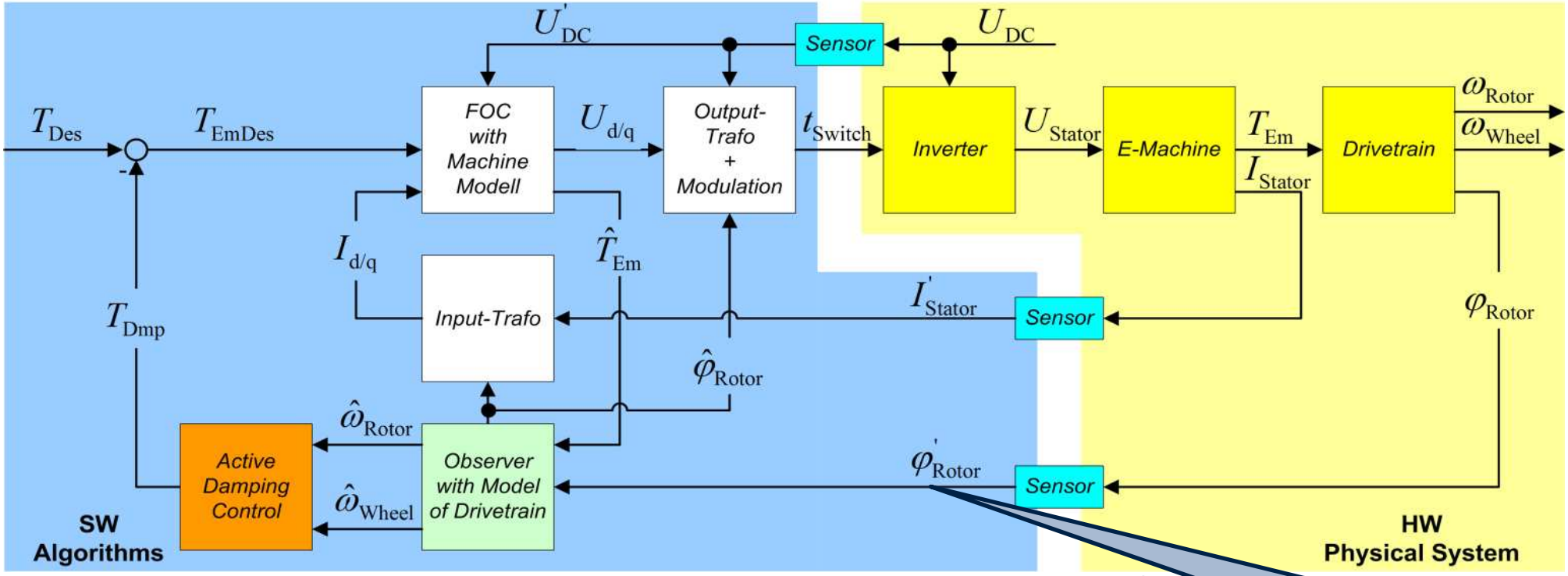
Accurate electric machine rotor angle is essential.

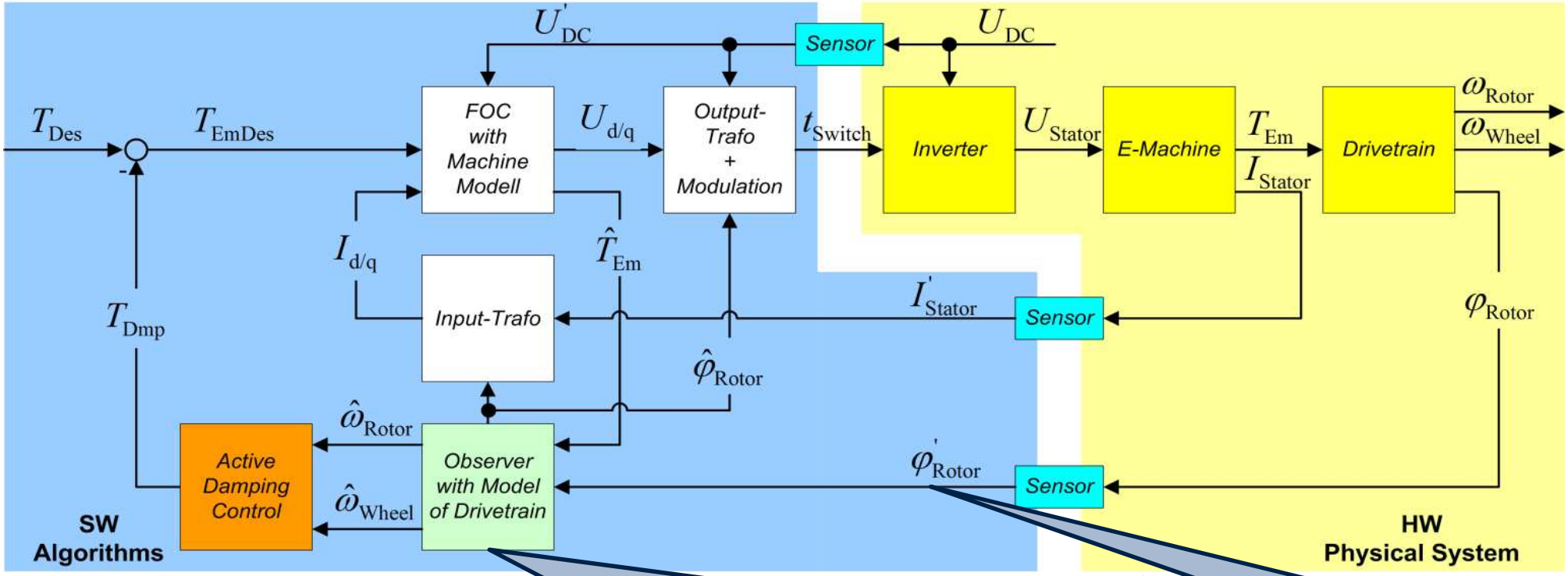
Torque Control Loop, with Observer



Measured angle with high-frequency errors

FOC: Field Oriented Control
ADC: Active Damping Control

Torque Control Loop, with Observer

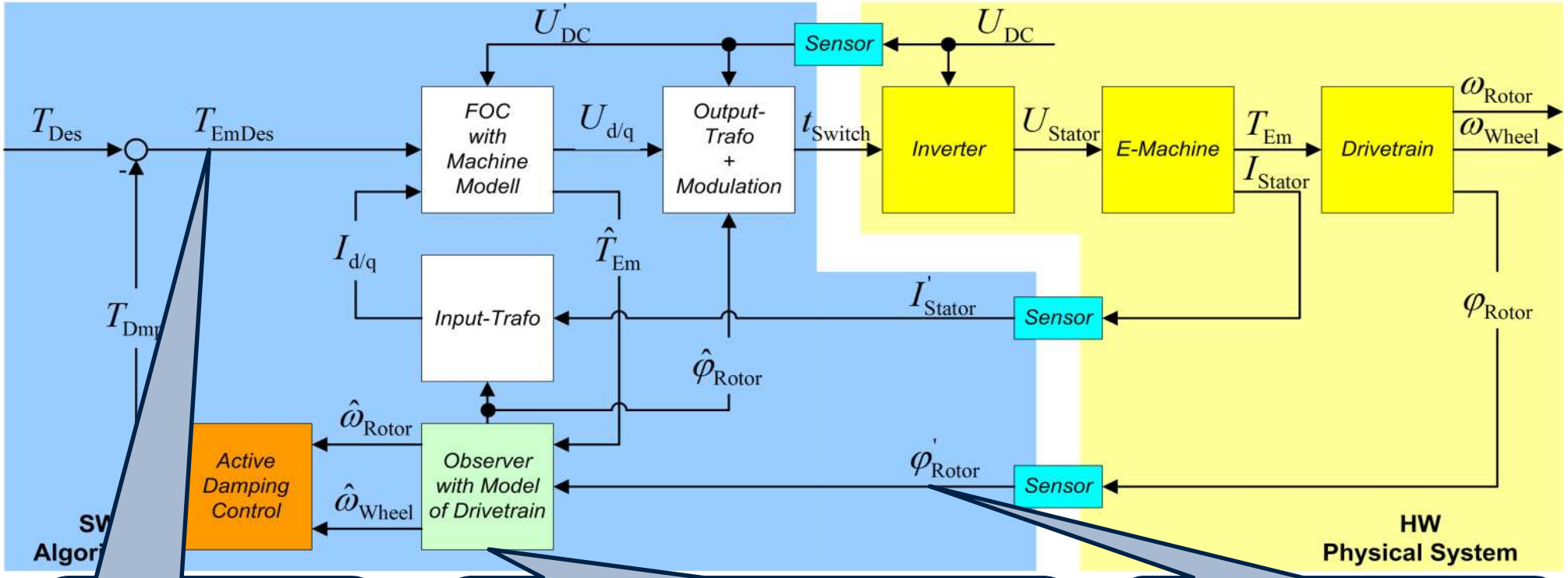


Observer delivers:
- Improved angle signal for FOC (reduced ripple, no phase delay)
- Oscillation speed for ADC

Measured angle with high-frequency errors

FOC: Field Oriented Control
ADC: Active Damping Control

Torque Control Loop, with Observer



Desired Torque is modified by ADC

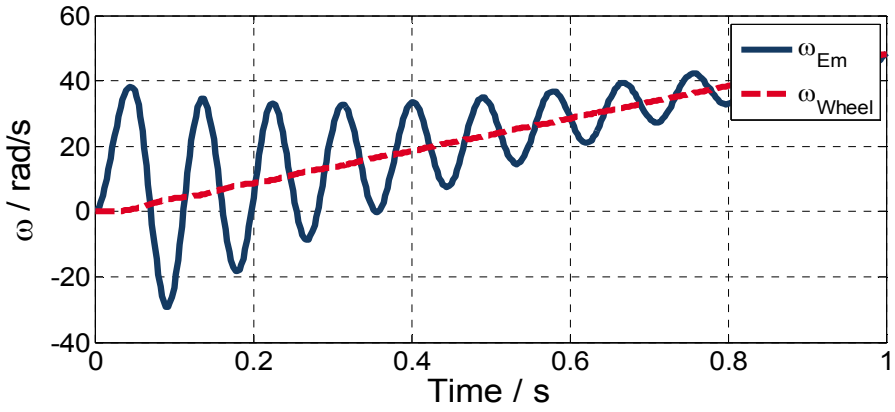
Observer delivers:
- Improved angle signal for FOC (reduced ripple, no phase delay)
- Oscillation speed for ADC

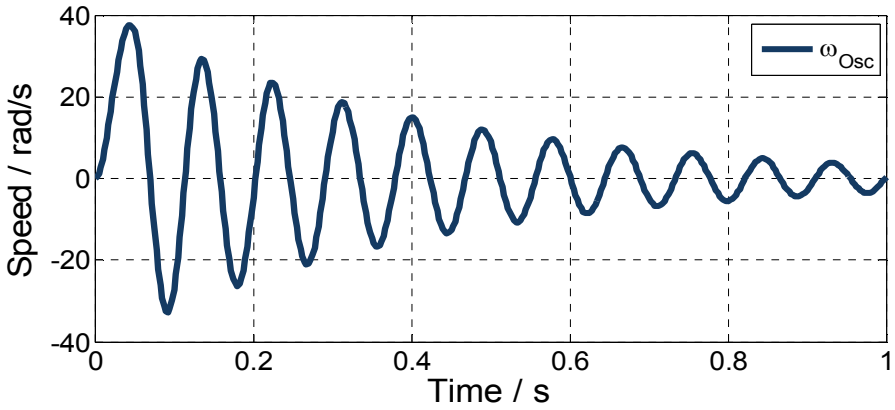
Measured angle with high-frequency errors

FOC: Field Oriented Control
ADC: Active Damping Control

Active Damping Control (ADC)

- Active damping torque is needed to compensate drivetrain oscillations:
  - $T_{Dmp} = k_{Dmp} \bullet \omega_{Osc}$
- Oscillation speed:
  - $\omega_{Osc} = \omega_{Em} - \omega_{Wheel}$
- E-Machine speed ω_{Em}:
  - is computed using rotor angle signal
- Wheel speed ω_{Wheel}:
  - usually not available, especially at low speeds





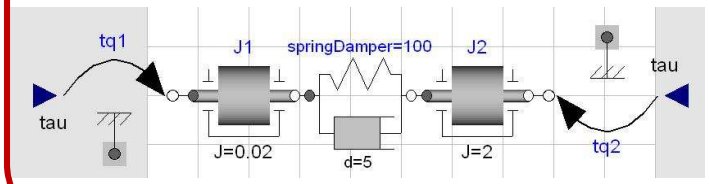
Oscillation speed ω_{Osc} needs to be estimated.

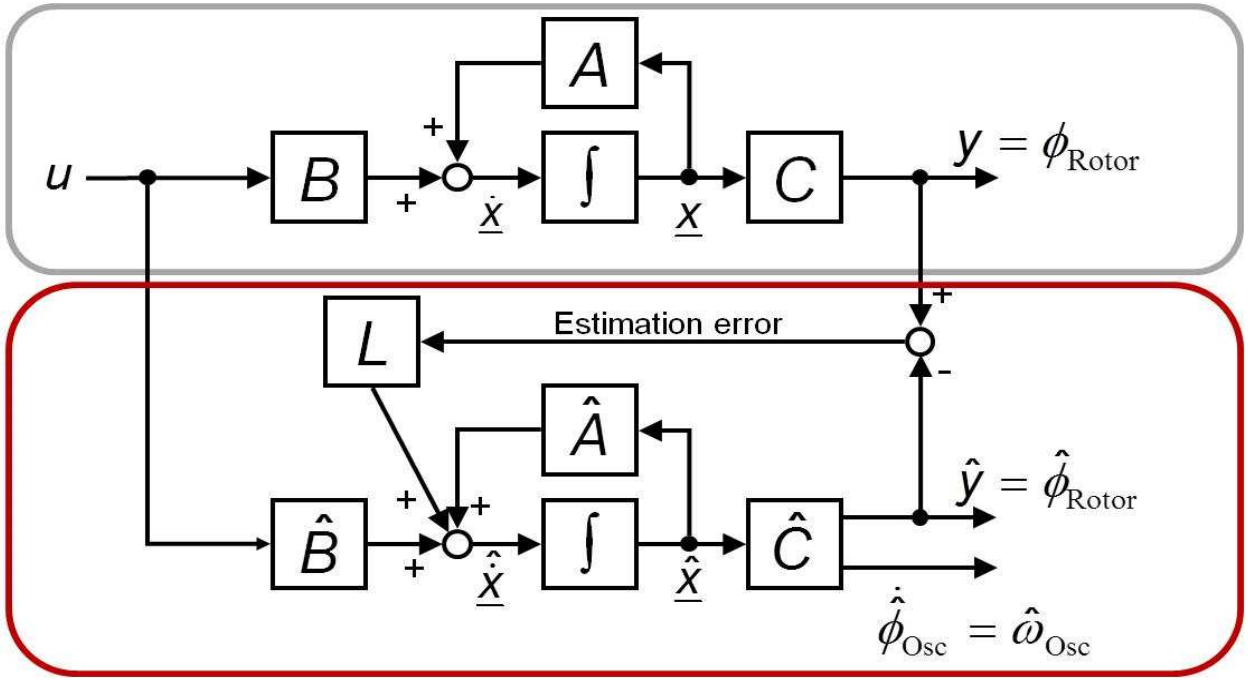
Design of a Vehicle Drivetrain Observer

- Drivetrain is modeled as a two-mass-system
- Luenberger structure with feedback of measurement signal via *L* vector

Physical drivetrain

Two-mass model of drivetrain

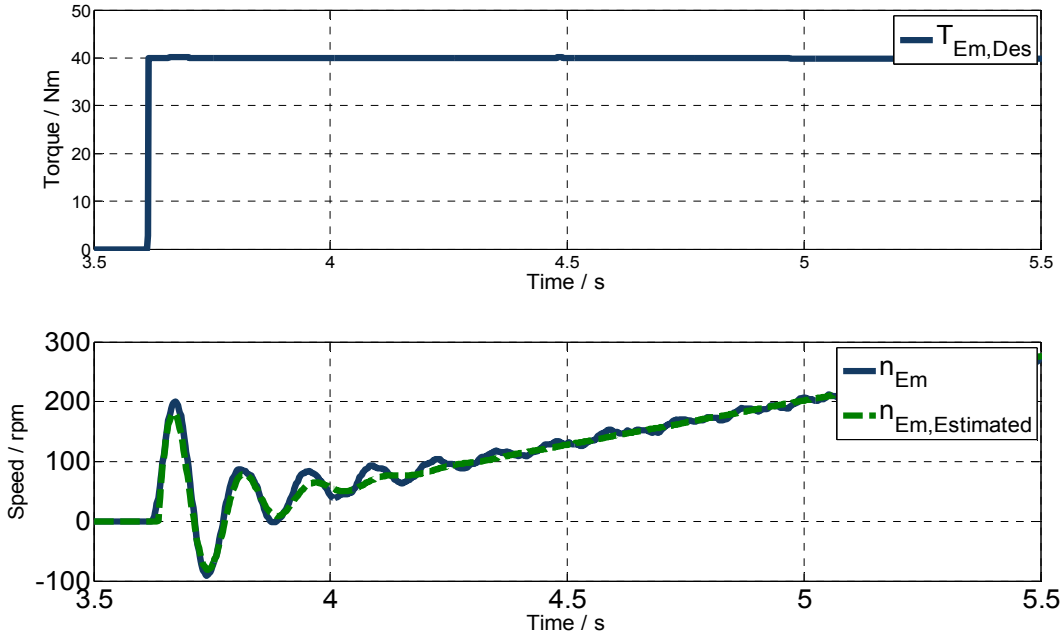


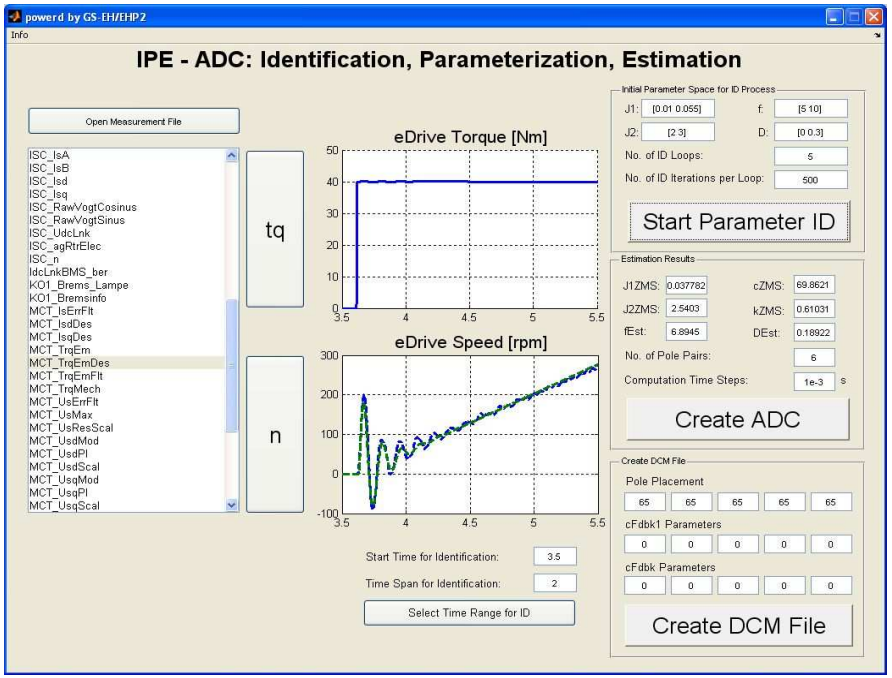


Observer estimates internal system states, e.g. ω_{Osc}.

Identification of Observer Parameters

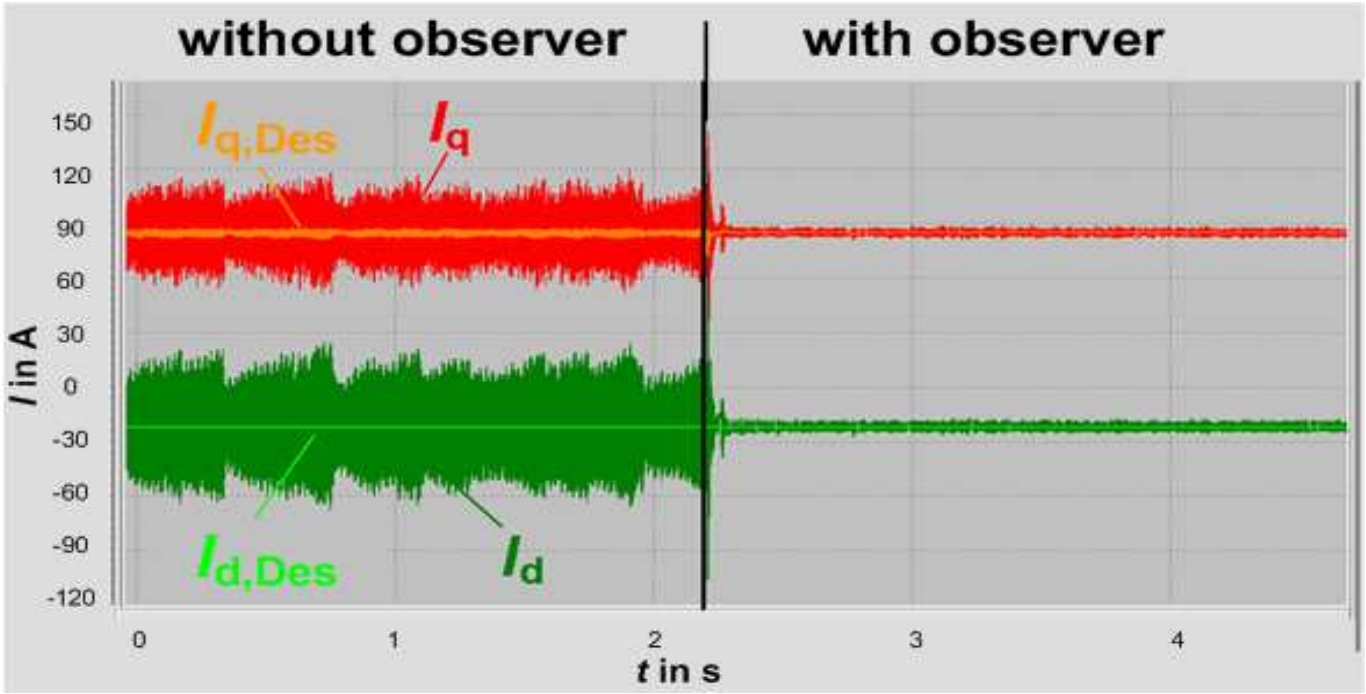
- Perform Vehicle tests, e.g. with torque step
- Use measurement results of EM-torque and -speed as input for automated calibration tool





Standalone Tool to Identify and Calibrate Drivetrain Observer Parameters.

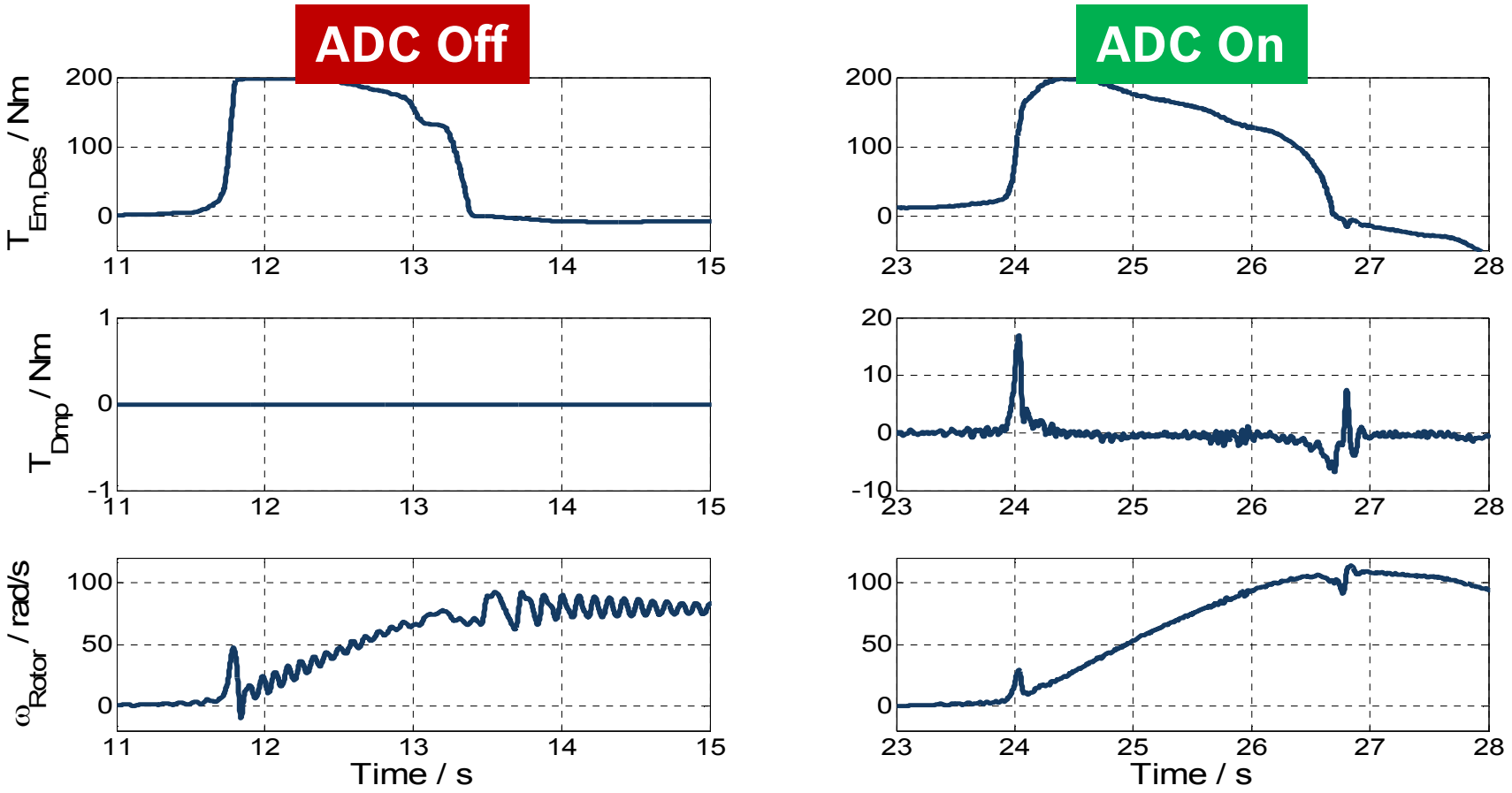
Improvement of Rotor Angle Signal Quality



- High-frequency error of rotor angle signal leads to
  - voltage errors (disturbances)
  - increased current ripple

Observer improves rotor angle signal and reduces current ripple.

Test Results: Series Axle Split Hybrid Vehicle



ADC with observer eliminates drivetrain oscillations.

Conclusions

- Accurate FOC needs a high quality rotor angle signal.
- Robust ADC needs the oscillation speed of drivetrain.
- Drivetrain observer modeled as two mass system is vital for
  - improving rotor angle for FOC and
  - estimating oscillation speed for ADC
- Standalone Calibration-Tool:
  - simple and proper identification of observer parameters
  - in use for several hybrid and electric vehicle series applications

Thank you for your attention!