GKN DRIVELINE

Vehicle Dynamics Expo 2006

Integration of Active Limited-Slip Differentials (eLSD) with Vehicle Dynamic Control Systems

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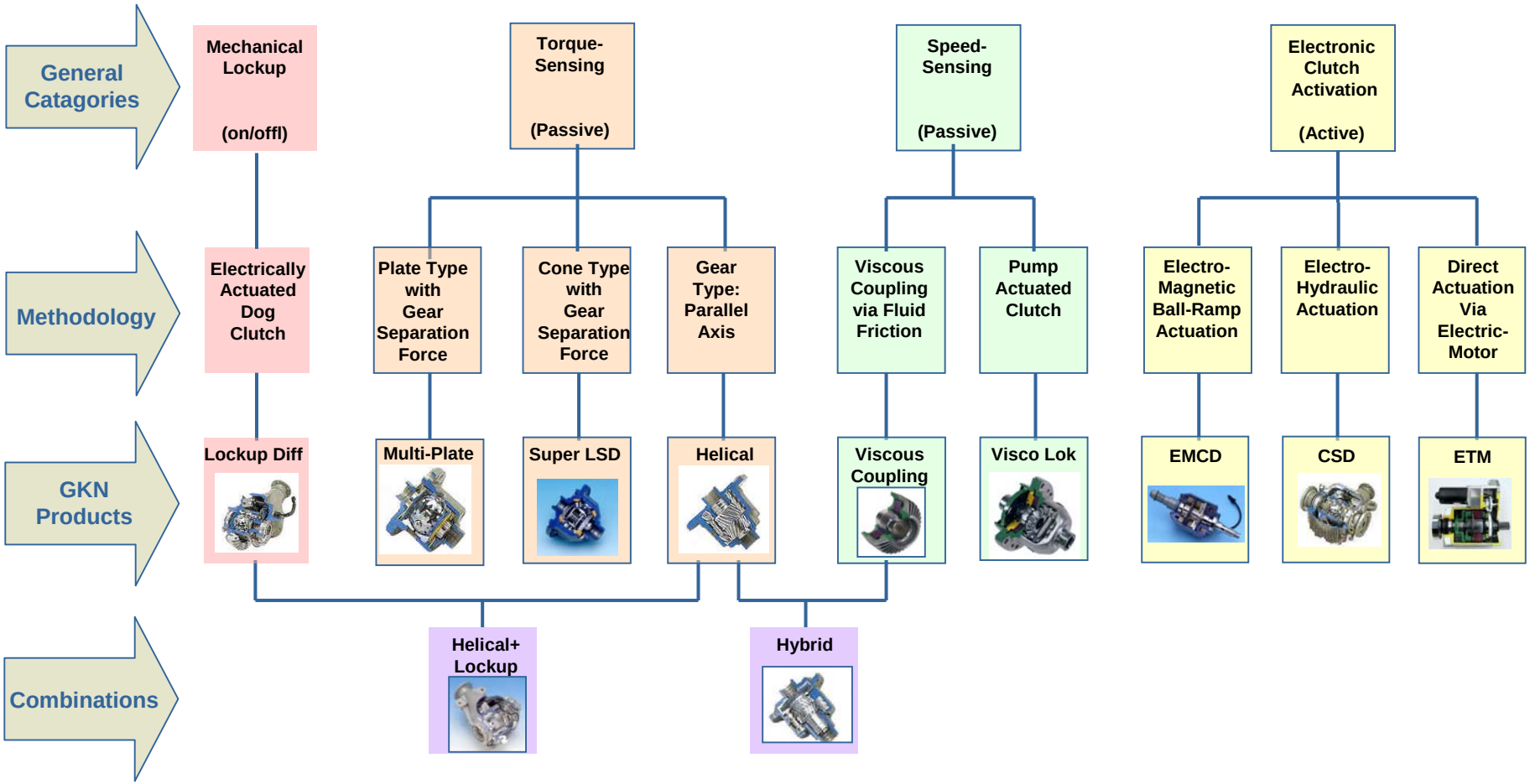
Integration of Active Limited-Slip Differentials (eLSD) with Vehicle Dynamic Control Systems

- Introduction
  - Torque Management Portfolio Overview
  - Limited Slip Differential – Mechanical Properties
- Development of TASC Control Strategy for eLSD
- Vehicle Control Hierarchy
- Vehicle Integration and Interaction with Vehicle Dynamic Control Systems
  - Steering and Suspension
  - Interaction of eLSD with Vehicle Dynamic Control Systems
    - Traction Control Module
    - Active Cornering Support Module
  - TASC Summary of Functions and Limitations
- Conclusions

GKN Torque Management Portfolio Overview



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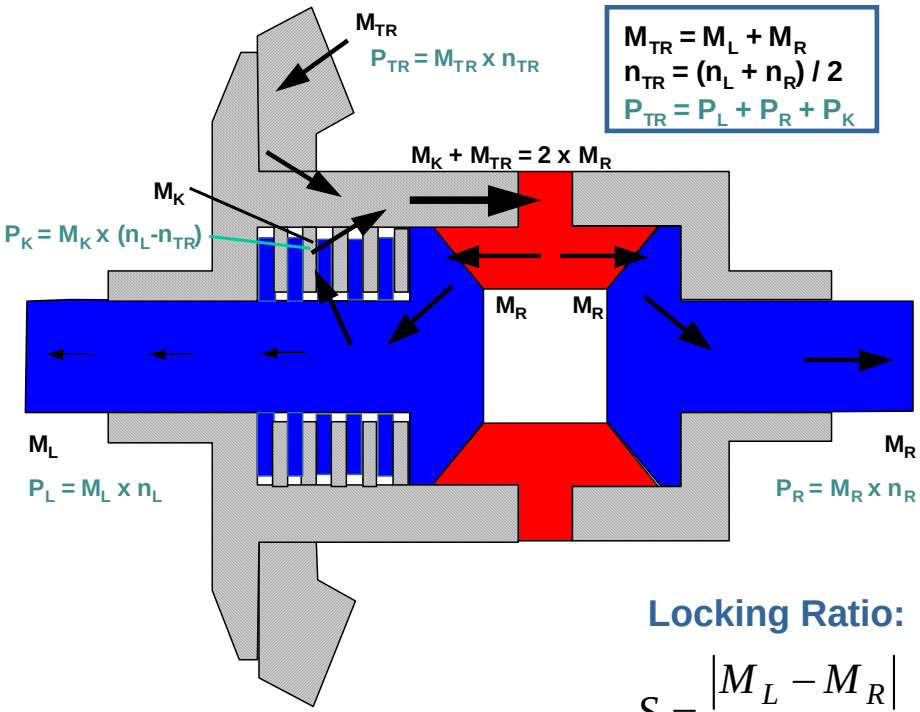
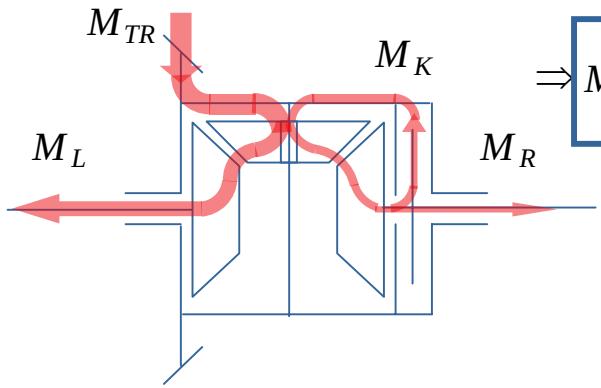
Limited Slip Differential – Mechanical Properties

LSD: Torque (M) and Power (P) Flow ($n_L > n_R$)



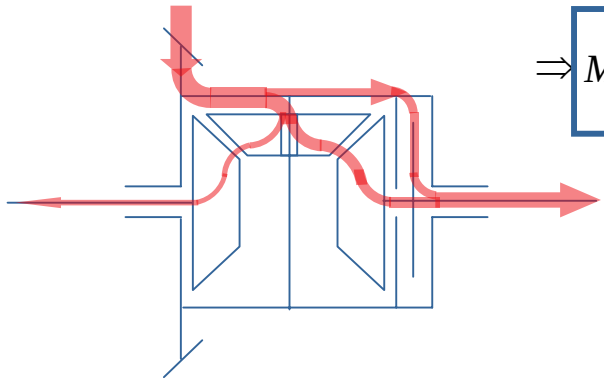
$M_{TR} = M_L + M_R$
$n_{TR} = (n_L + n_R) / 2$
$P_{TR} = P_L + P_R + P_K$

Torque Bias Compensation of Differential
Case 1: Drive, $n_L < n_R$



$$\Rightarrow M_K = \frac{M_{req}}{1 + S_D}$$

Torque Bias Compensation of Differential
Case 2: Drive, $n_L > n_R$, $|M_K| < |M_{TR}|$



$$\Rightarrow M_K = \frac{M_{req}}{1 - S_D}$$

Locking Ratio:

$$S = \frac{|M_L - M_R|}{|M_L + M_R|}$$

Basic mechanical principle of torque transfer inbetween shafts

List of abbreviations:

M_{TR} = Torque Ring Gear
M_L = Torque Wheel Left
M_R = Torque Wheel Right
M_K = Torque Clutch (abs. value)
M_{req} = Required Locking Torque
S_D = Locking Ratio Differential in Drive

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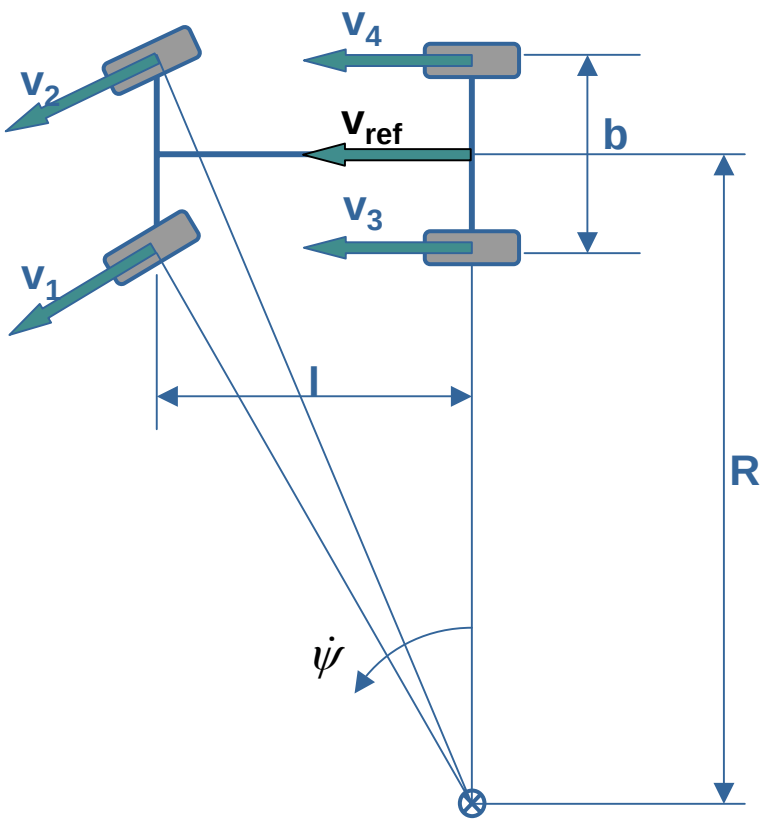
Development of Control Strategy eLSD

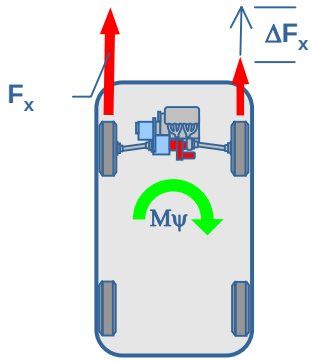
Approach:

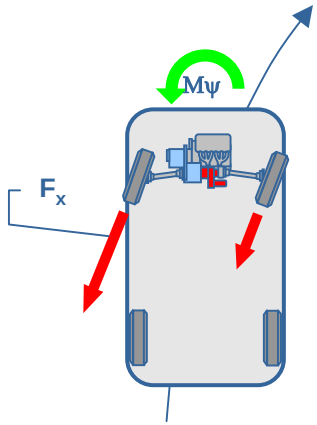


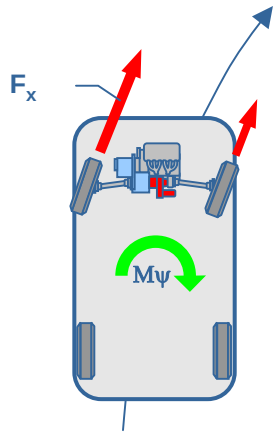
1. Wheel speed differences occuring on non-driven/non-braked axles can be calculated
2. Wheel speed differences occuring on a driven axle deliver essential information about the load condition of the wheels, thus can be used as controler input
   → speed sensing approach
3. Direction (sign) of wheel speed differences directly indicates the direction of torque flow of a limited-slip differential, thus can be used as further constraint for a controller

Approach for Development of Function eLSD

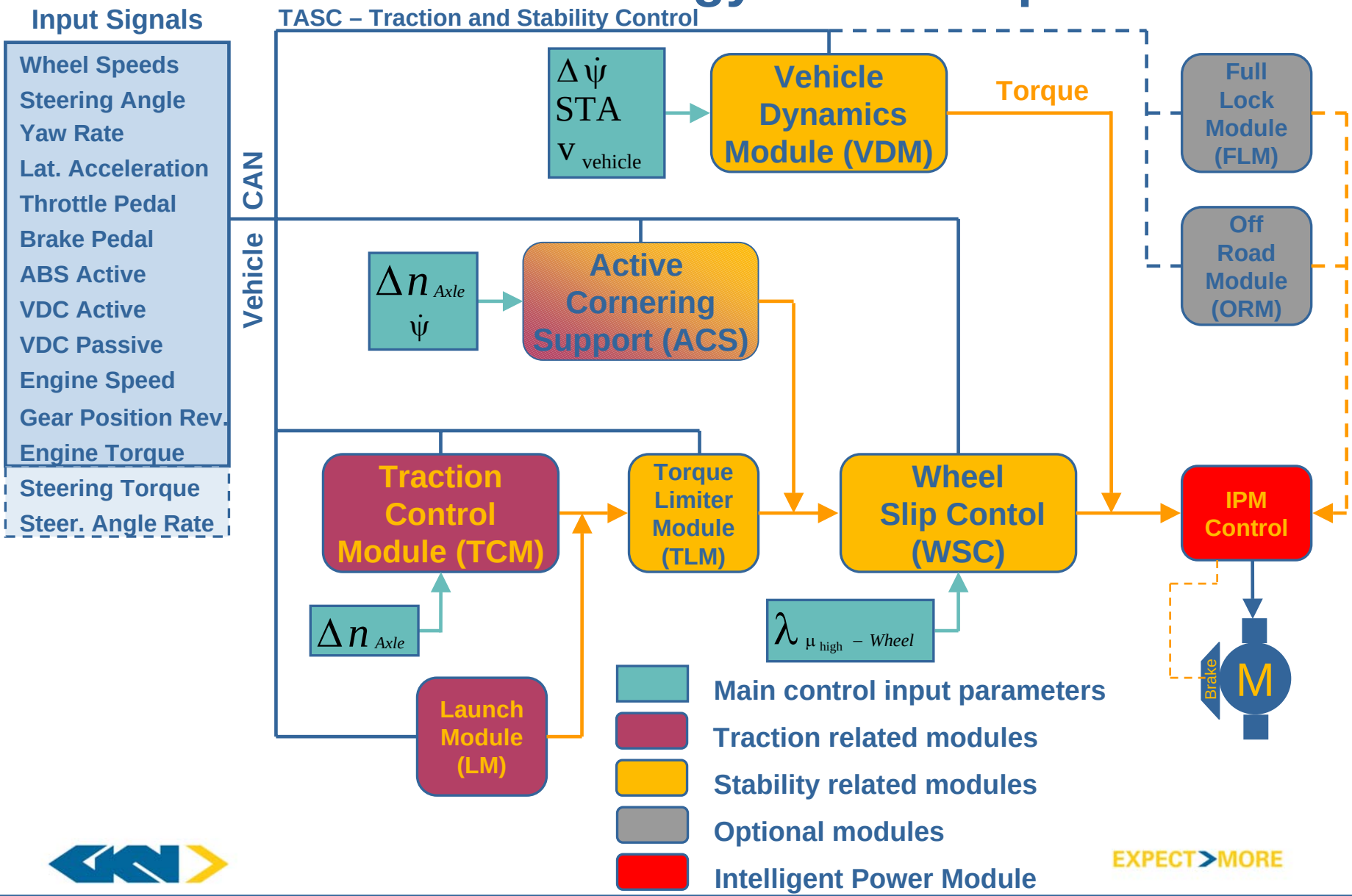
	Traction	Stabilizing	Handling
Driving Situation	➢ Starting on μ-Split / in a curve	➢ Throttle-off in a bend ➢ Lane change	➢ Acceleration in a bend
Approach	➢ Desired torque flow by speed difference	➢ Speed difference creates understeering momentum	➢ Desired torque flow only, if inside wheel spins faster than outside wheel







TASC Control Strategy eLSD + Options



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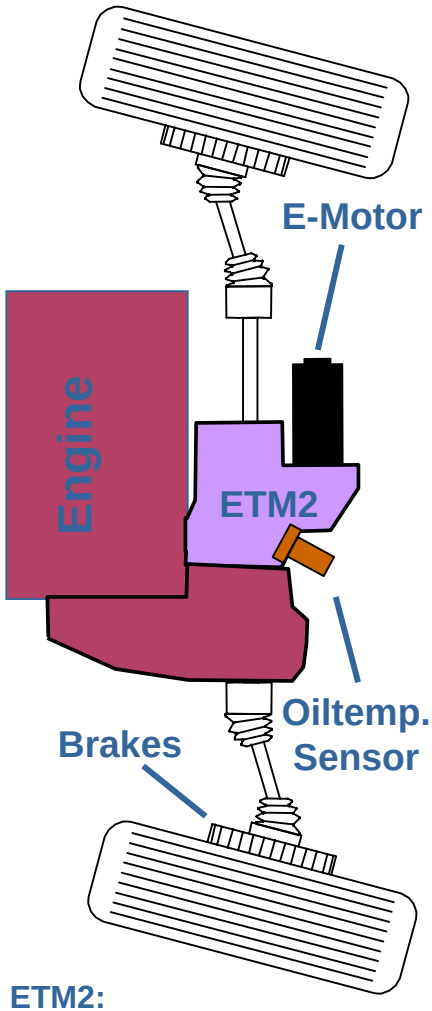
Vehicle Control Hierarchy



ETM2:
Electronic Torque Manager

- Definition of vehicle stability borderline
- Calculates vehicle model
- Sensor input of basic signals
- Communication

OEM/VDC Supplier

ABS/VDC/TCS ECU

- Master Control for vehicle dynamics
- Engine and brake traction control
- Brake control

- Functional part of eLSD control
- Basic application and tuning
- Communication

GKN or OEM

Driveline Control

- Controls eLSD for vehicle dynamics and traction
- Gets signals from vehicle CAN
- Works in „Closed Loop“ control with feedback from the car

- System response
- Control accuracy
- Torque Bias Compensation
- eLSD sensor input
- Power stage
- Communication
- Diagnosis/Fail safe

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Intelligent Power Module ECU

- Controls eLSD as „Smart Actuator“
- Gets torque requests from master by CAN and sensor signals from eLSD
- Works in „Open Loop“ control w/o torque feedback from the eLSD

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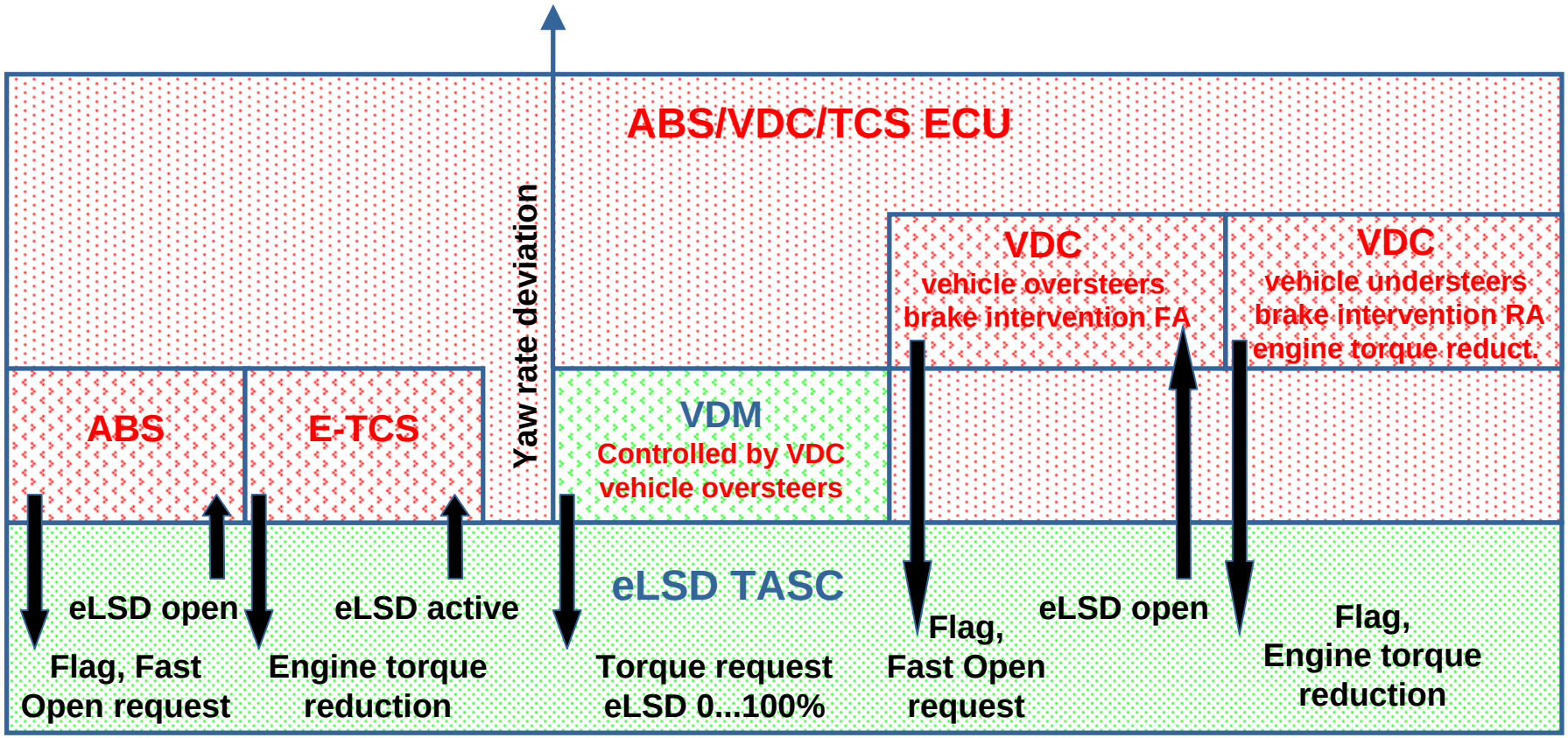
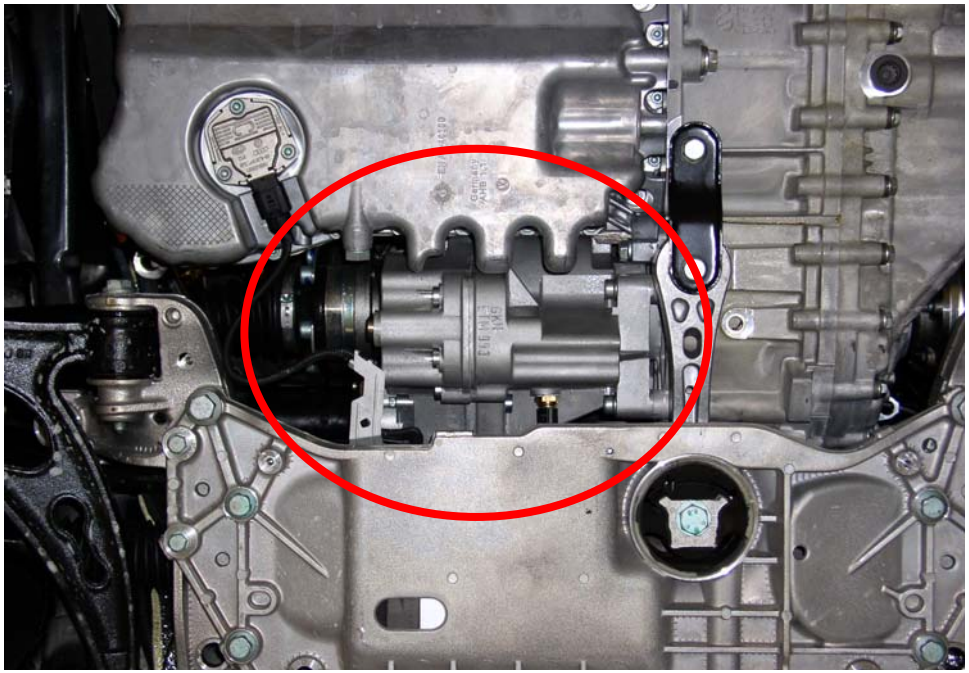
Communication VDC ECU – eLSD Example



eLSD Demonstrator Vehicles



Bottom view of engine and gearbox

- ETM2 combined with AWD gearbox
- ETM2 fits into space of PTU
- Driveshaft inner joint position identical with PTU
- Option for LSD hardware integration into transmission

- FWD with Power >154 kW / Torque 320 Nm
- McPherson type front suspension
- Hydraulical and electro-mechanical steering assistance, steering rack ratio 16,2 - 16,4 :1
- Manual gearbox

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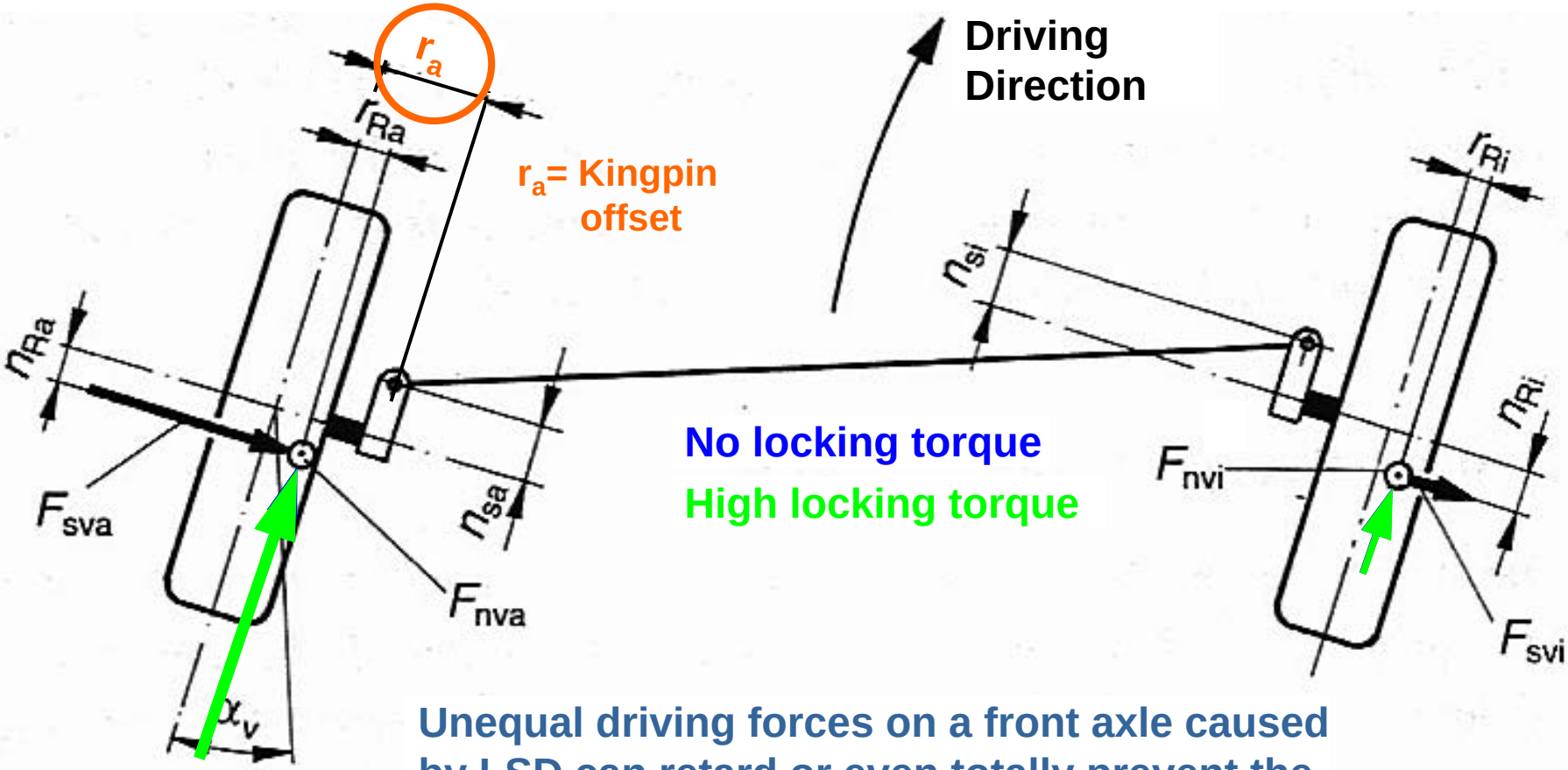
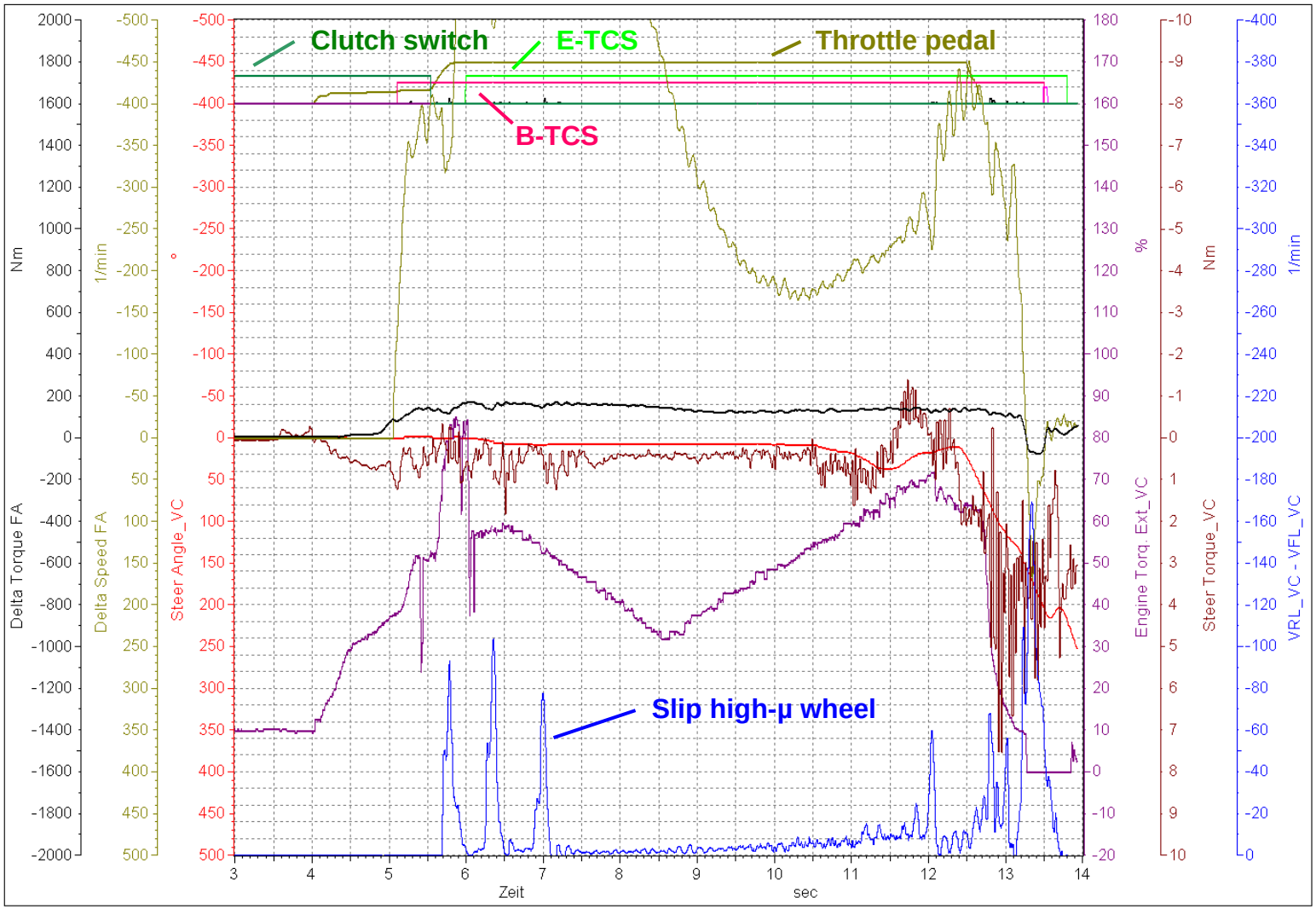
Forces and Moments at the Front Axle



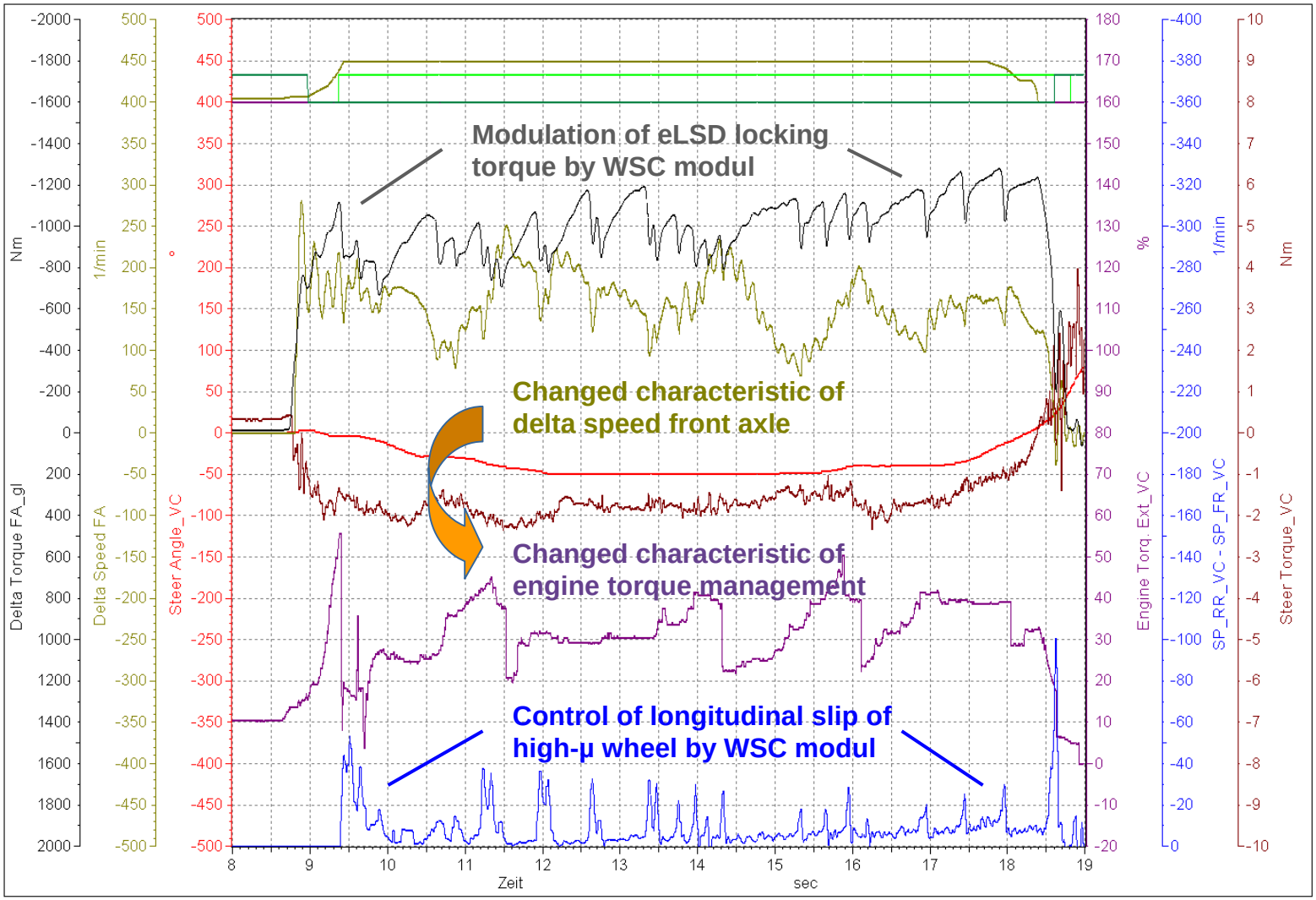
Unequal driving forces on a front axle caused by LSD can retard or even totally prevent the steering return every driver is expecting when cornering and accelerating.

Picture (above):
Reimpell, J.: Fahrwerktechnik: Grundlagen
Würzburg: Vogel Buchverlag, 3. Auflage 1995

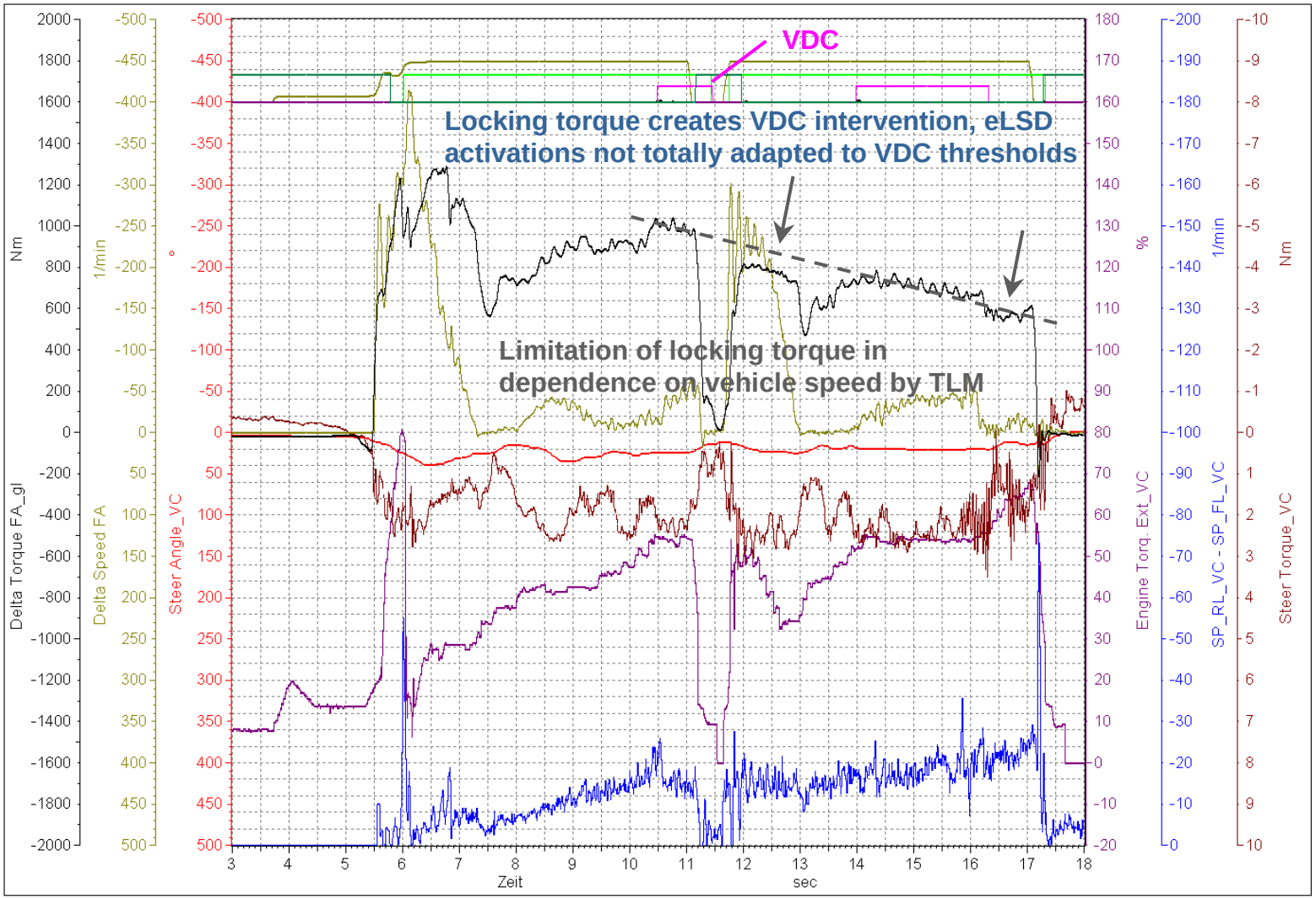
Standard Vehicle, B-TCS & E-TCS
Acceleration on Split-µ Gradient 15%



eLSD Demonstrator, eLSD & E-TCS
Acceleration on Split-µ Gradient 15%



eLSD Demonstrator, eLSD & E-TCS
Acceleration on Split-μ Flat

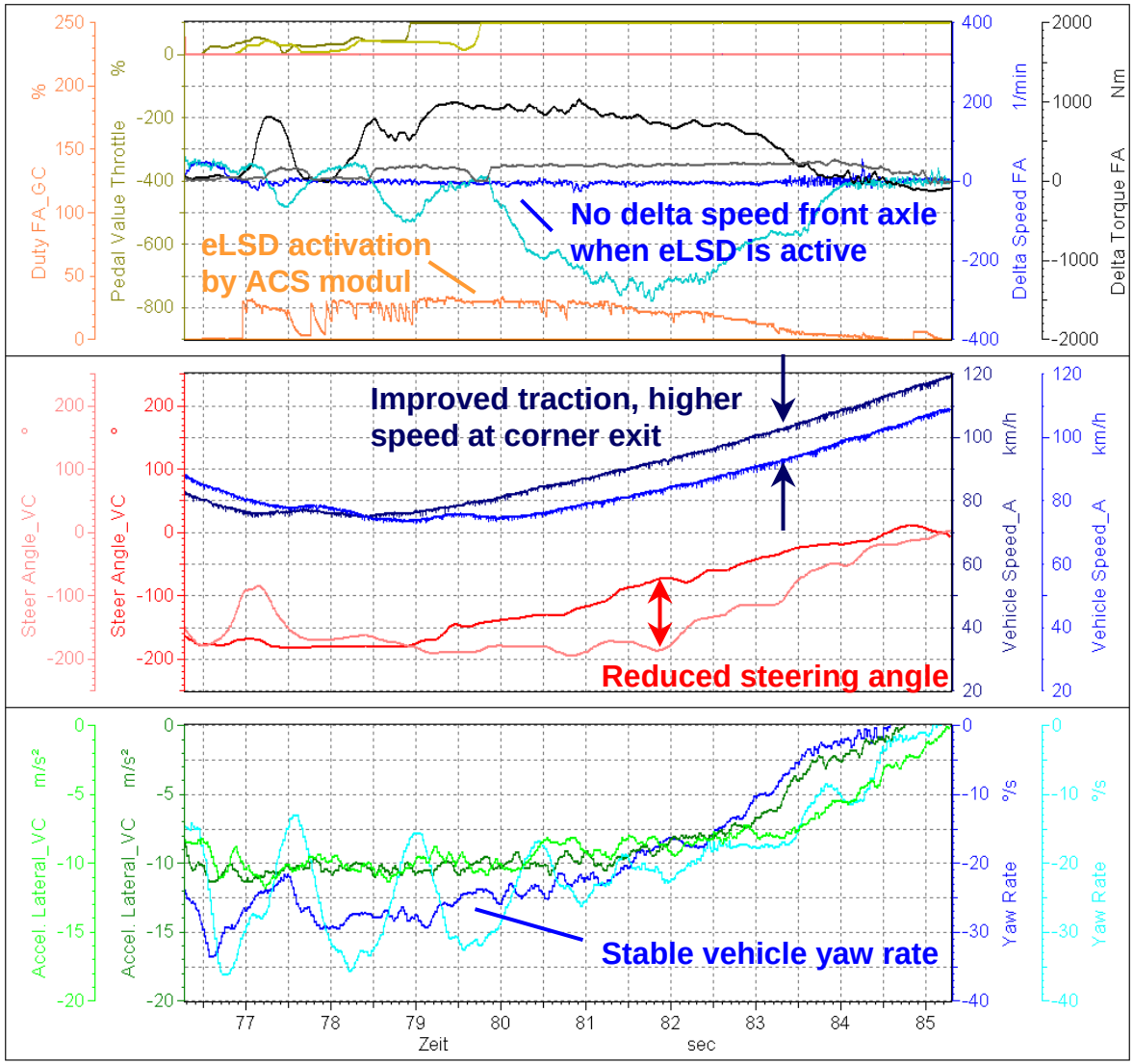


Interaction of eLSD with Vehicle Dynamic Control Systems – Traction Control Module

- Standard Vehicle with B-TCS & E-TCS
  - E-TCS intervention in dependence of command signal ‚Delta Wheel Speed Front Axle‘
  - Stable vehicle behaviour, only small counter steer necessary
  - Low feedback of B-TCS in steering system
- eLSD Demonstrator with E-TCS
  - Characteristic of command signal changed by eLSD, therefore quite aggressive raise of engine torque
  - At higher vehicle speed limitation of locking torque to reduce yaw moment build-up, thus keeping corresponding VDC thresholds
  - Similar stable vehicle behaviour achieved by WSC module limiting the longitudinal slip of the high-μ wheel
  - Slightly increased feedback of eLSD in steering system
  - Only adaption of E-TCS parameters required to reduce energy input in clutch package

eLSD Demonstrator - Handling

VDC/E-TCS passive



Delta Torque =
Torque LH – Torque RH

Dark colour: F-ETM2 on

Bright colour: F-ETM2 off

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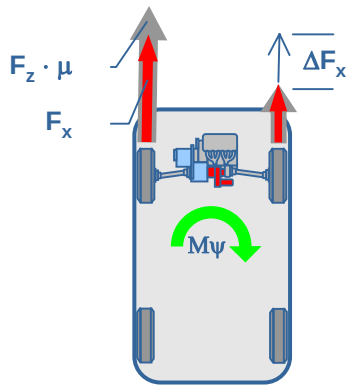
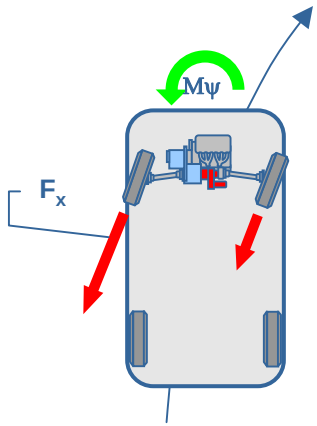
Interaction of eLSD with Vehicle Dynamic Control Systems – Active Cornering Support Module

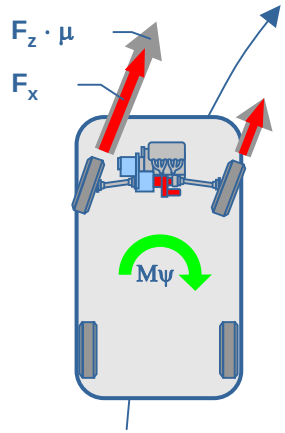
- Standard Vehicle with B-TCS & E-TCS
  - E-TCS intervention in dependence of command signal ‚Delta Wheel Speed Front Axle‘
  - Stable vehicle behaviour, vehicle follows target radius
- eLSD Demonstrator with E-TCS
  - Characteristic of command signal changed by eLSD, therefore engine torque management cannot act appropriate without further measures
  - Stable vehicle behaviour can be achieved by using WSC module to limit eLSD activations e.g. at high lateral accelerations, resulting in an uninfluenced command signal for E-TCS
  - At higher vehicle speed limitation of locking torque to reduce yaw moment build-up

Development of Function

	Traction	Stabilizing	Handling
Driving Situation	➢ Starting/Acceleration on μ-Split / in a curve	➢ Throttle-off in a bend ➢ Lane change	➢ Acceleration in a bend
Strategy	➢ Controlled via wheel speed difference ➢ Limited through slip on μ_{high}-wheel ➢ Reduced over vehicle speed	➢ Controlled via yaw rate difference for detection of oversteering ➢ Pre-emptive activation when throttle-off during cornering is detected	➢ Controlled via wheel slip *inner wheel* ➢ Limited via wheel slip *outer wheel* ➢ Reduced over vehicle speed







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Summary & Conclusions

- More Traction: Complementary with Traction Control Systems
  - On split-μ the maximum traction potential can be used without compromise in terms of vehicle stability
- More Stability: Good Synergy with VDC system
  - Damping of yaw rate for lane change and throttle-off in a bend
- More Fun: Improved vehicle dynamics by
  - Higher cornering speed (improved traction)
  - Reduced on-throttle understeering
  - For vehicle dynamics improvements eLSD can be active during the whole vehicle speed range

Summary & Conclusions

- In opposite to passive devices active LSDs offer the possibility for a certain level of integration into current vehicle dynamic control systems
- A quite high level of overall vehicle performance can already be achieved by using control modules like WSC and simple limitations for eLSD control. In the consequence VDC systems will just require an adaption of their parameters without changing fundamental control algorithms
- Improvements of eLSD control are under development by exchanging some of the limitations with closed-loop control strategies utilizing vehicle dynamic parameters
- Further optimization will follow by using all options for integration with VDC systems and linking eLSD with other active systems, especially steering systems