Electric Torque Vectoring

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AGENDA

- Introduction – Torque Vectoring Systems
- Motivation
- Background – Project MEHREN
- Torque Vectoring
  - Examples
- Unsprung Mass
- Conclusions

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INTRODUCTION

Torque Vectoring (TV) is now an established driveline & brakes technology, being offered in various forms by a number of vehicle manufacturers, and with a wide range of offerings right across the supply base.

In order to control such systems, increasing effort has been put into adapting existing or developing new vehicle dynamics control algorithms.

Just to use Ford as an example, a range of increasingly sophisticated TV technologies have been developed:

- AWD based (front – rear) TV was introduced in 2008 in the Ford Kuga.
- Brake based TV was introduced in production vehicles in 2010, & is now included across the range.
- In 2013 a study on the integration of mechanical and brake based TV systems was presented at the EAWD Congress, using an eLSD as an example of a mechanical TV system.
- The Focus RS with TV-AWD (clutch based side-to-side TV on the rear axle and brake based TV on the front axle) was introduced to the market in 2015.
- Since 2013 Ford has been working on electric TV as part of the publicly funded project “MEHREN” and the follow-on project “RABBIT”.

MOTIVATION

- Energy efficiency and reduction in air pollution are driving the electrification of the global vehicle fleet.
- Electrification has a number of challenges (weight, package, …).
- Many of the available technologies are aimed at the best energy efficiency for the lowest on-cost, and not performance.
- Higher performance In-Wheel electric Drives (IWDs) are starting to become available in the market. These have the advantage of being:
  - nearly package neutral – the direct drive motors, power electronics & ECUs fit inside a standard rim. It is only required to find space for the battery, cooling & charging systems.
  - A pair of newer IWDs also tends to weigh less than a central electric drive system.
- Individual wheel drive systems have the inherent advantage that they can be used for torque vectoring, and the traction limitation of one wheel has no effect on the torque that can be applied on any other wheel.

BACKGROUND – PROJECT MEHREN

- The **MEHREN** project (multi-motor electric vehicle with highest space and energy efficiency) was partially funded by the German Federal Ministry of Economics and Energy (BMWi) and ran from 2013 through to 2017.
  - Development of electric in-wheel drive system for a B-car BEV application
  - Use of electric in-wheel drives as actuators for vehicle dynamics control, including integration with ESC
  - Investigation of vehicle architecture benefits of in-wheel drive technology
- Sub-projects and Partners
  - Vehicle Integration and Vehicle Dynamics Control (Ford)
  - In-Wheel Drive System (Schaeffler)
  - Friction brake control, brake blending and motor slip control (Continental)
  - Functional Safety (las3, Regensburg University of applied Sciences)
  - Vehicle Concept Study (ika, RWTH Aachen University)

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SCHAEFFLER

Continental

LaS3 Laboratory for Safe and Secure Systems – a discipline of software engineering

ika INSTITUT FÜR KRAFTFAHRZEUGE RWTH AACHEN UNIVERSITY

Gefördert durch:

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aufgrund eines Beschlusses des Deutschen Bundestages

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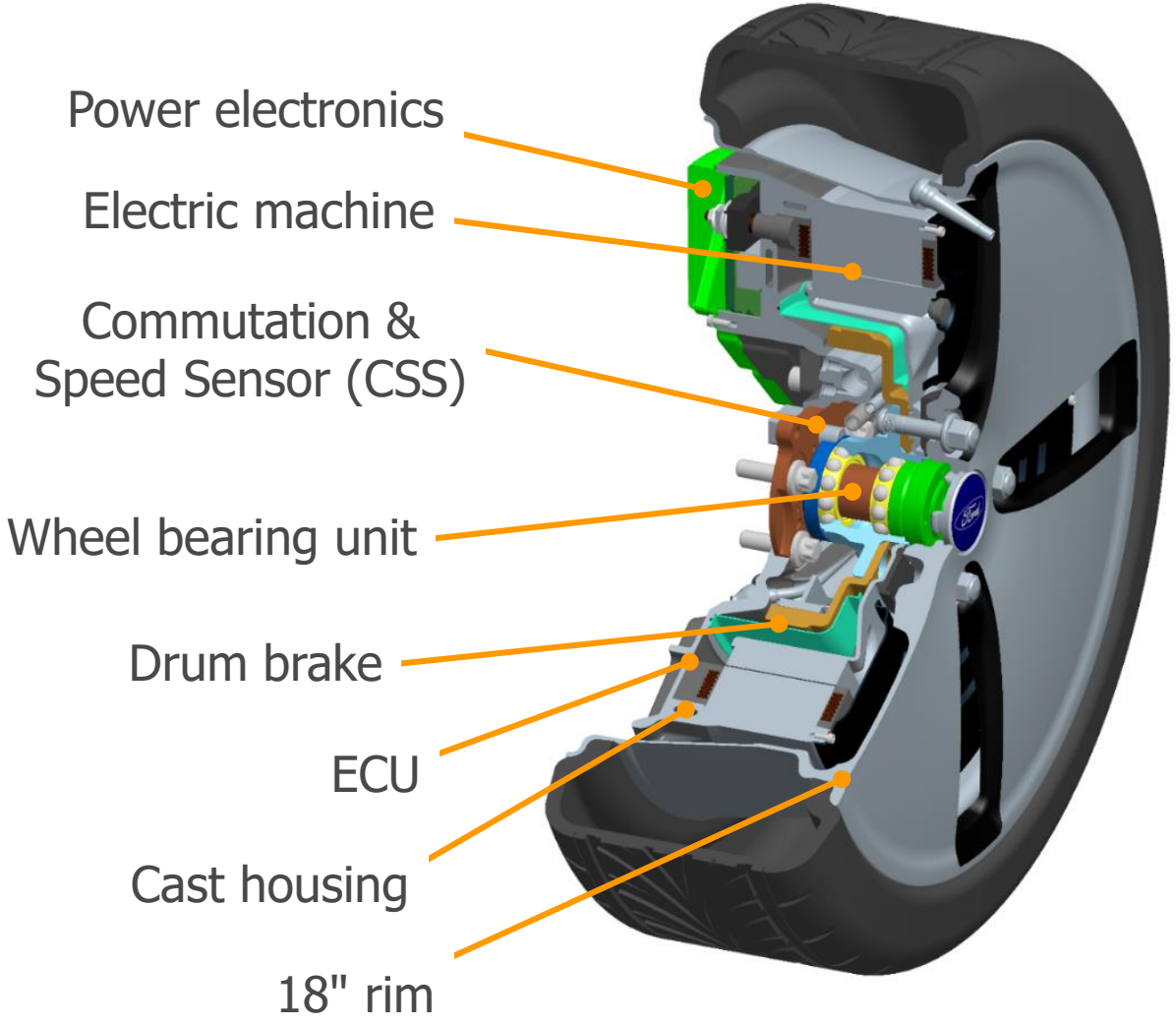
SCHAEFFLER IN-WHEEL DRIVE SYSTEM



- Two in-wheel drives take the place of a central electric motor & inverter, a transmission, differential and halfshafts.
- The inverters and ECUs are integrated into the drives and they package completely inside a 7J x 18 rim.
- Torque and power density:
  - 810 Nm peak, 500 Nm continuous
  - 43 KW peak, 25 KW continuous
- Max speed: 130 km/h
- 58 kg additional unsprung mass
- Water cooled eMachine and electronics
- Integrated drum brake & park brake

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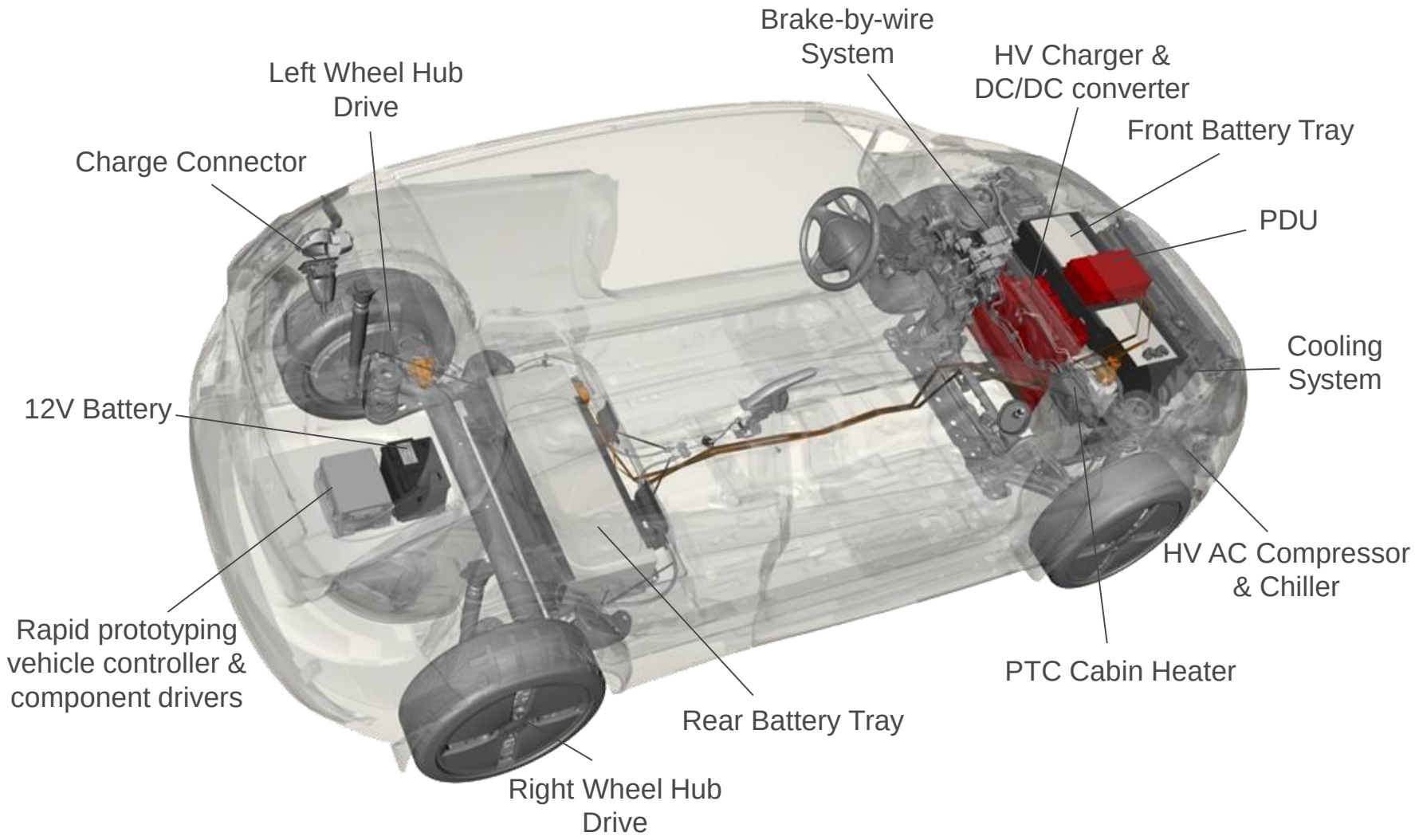
DEMONSTRATOR VEHICLE



Driveable demonstrator with production level functionality

- Fully functional Electronic Braking System with all production features (ABS, ESC, TCS, HSA, …).
- In-wheel drives fully integrated into EBS controls.
- Fully usable interior, including luggage space (slight reduction in luggage space height due to rapid prototyping controller).
- Fully functional climate control system.
- …

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TORQUE VECTORING

The asymmetric distribution of the torque to the driven wheels creates a yaw moment about the vehicle centre of mass so that the vehicle is supported with:

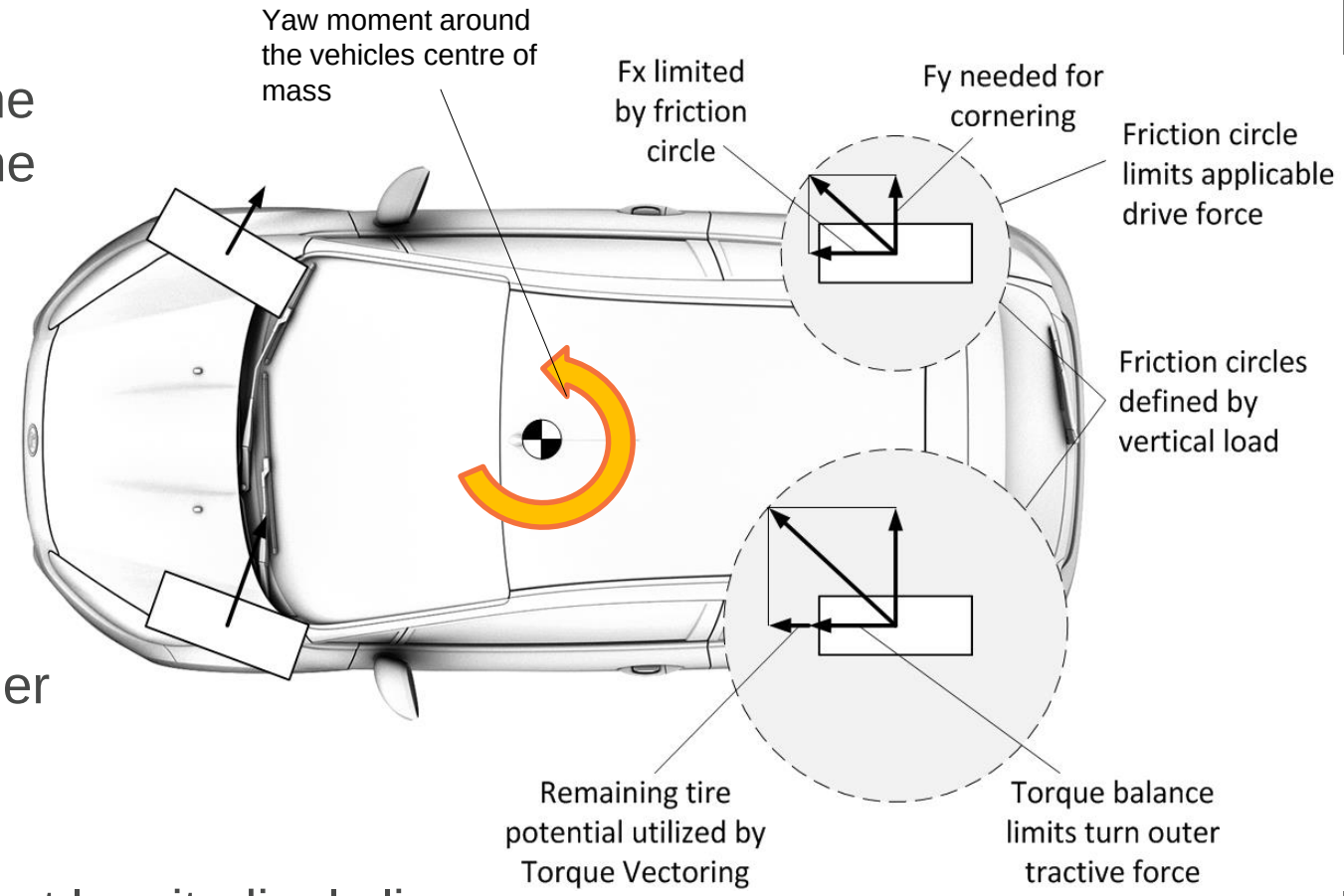
- steering into a curve,
- steering out of a curve or
- stabilisation during dynamic manoeuvres

Example: **Acceleration out of turn**:

- Wheels loaded differently → can lead to inner wheel slip

Solution:

- Tractive force of inner wheel limited to prevent longitudinal slip
- Remaining torque potential transferred from inner to outer wheel, if torque capacity exists (otherwise a reduction in total drive torque is required)



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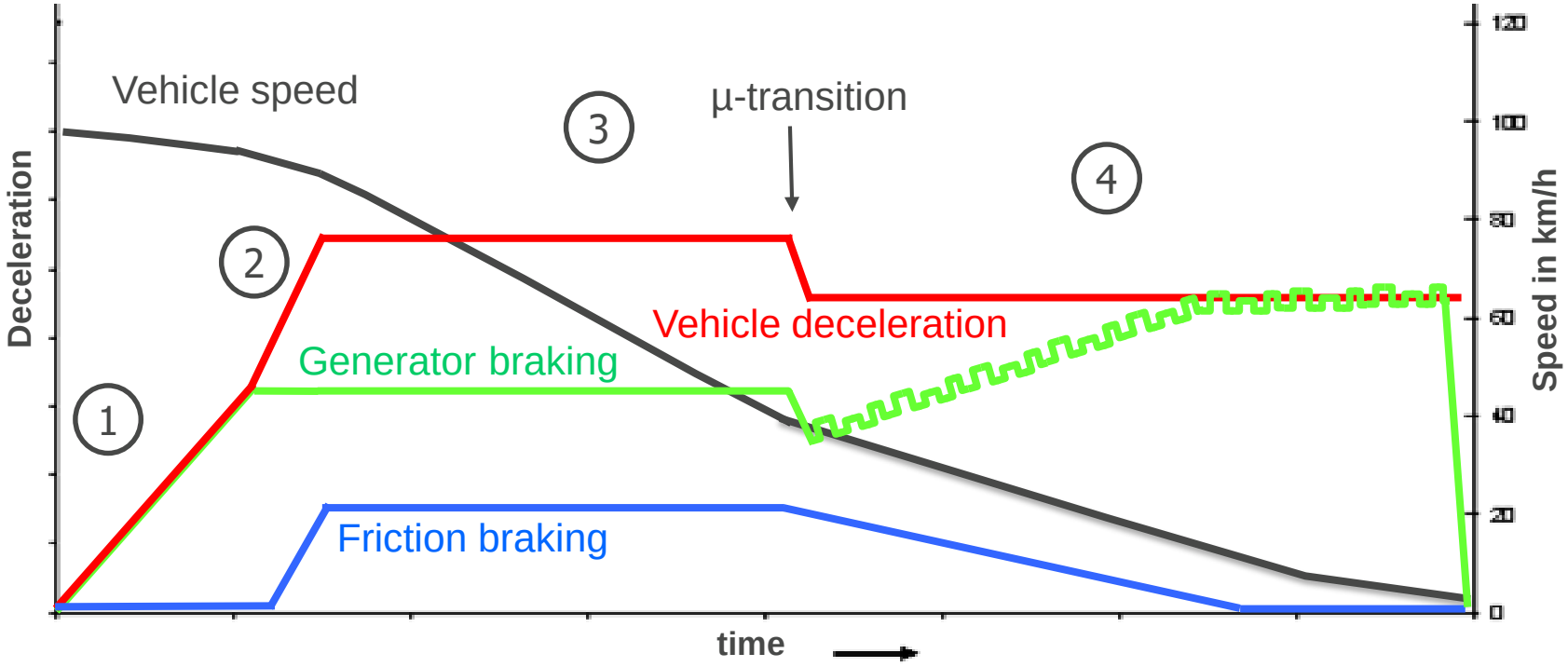
VEHICLE STABILISATION CONTROL & TORQUE COORDINATOR

- ESC and other vehicle stabilisation algorithms are adapted to the IWDs on the rear axle
- Torques are distributed between the wheels and co-ordinated amongst the actuators
- Example: Torque blending while braking on a road surface with a µ-transition



1. Braking by IWD only
2. Higher braking demand supported by friction braking
3. Deceleration from combined friction and IWD braking
4. Advanced torque blending – optimal distribution of the brake torque between IWD and the friction brake system during ABS and optimal slip control

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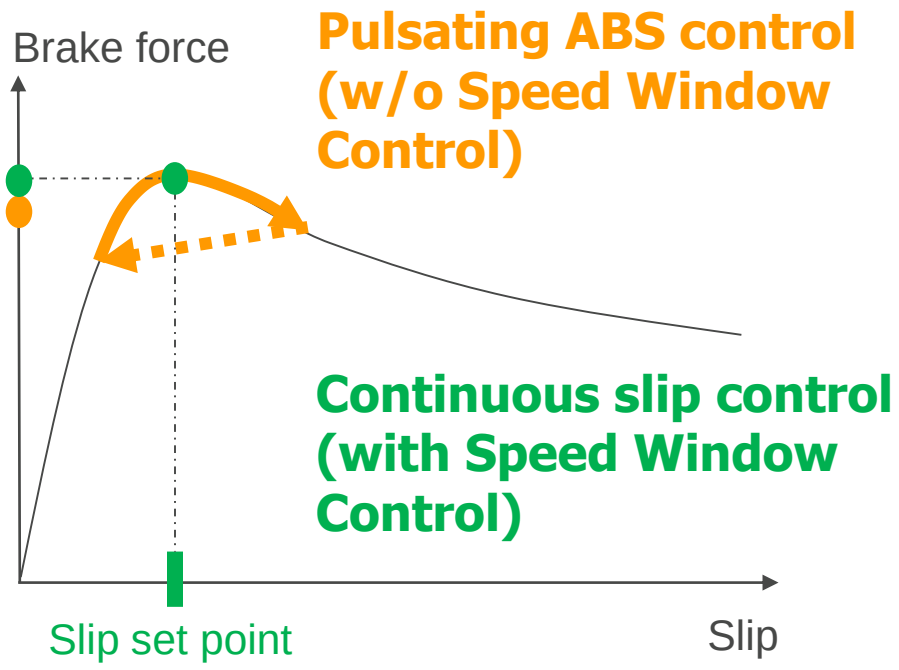
SPEED WINDOW CONTROL

Technical Concept

- Wheel integrated torque control with slip limiter (propulsion and braking)
- Optimisation of required torque according to ideal wheel slip

Advantage

- Quick response of actuators with direct connection to wheels
- Precise torque control
- Optimization of wheel slip control for ABS/TCS/ESC



(a good reference speed is essential. If the reference speed is not good, the setpoint will tend to vary)

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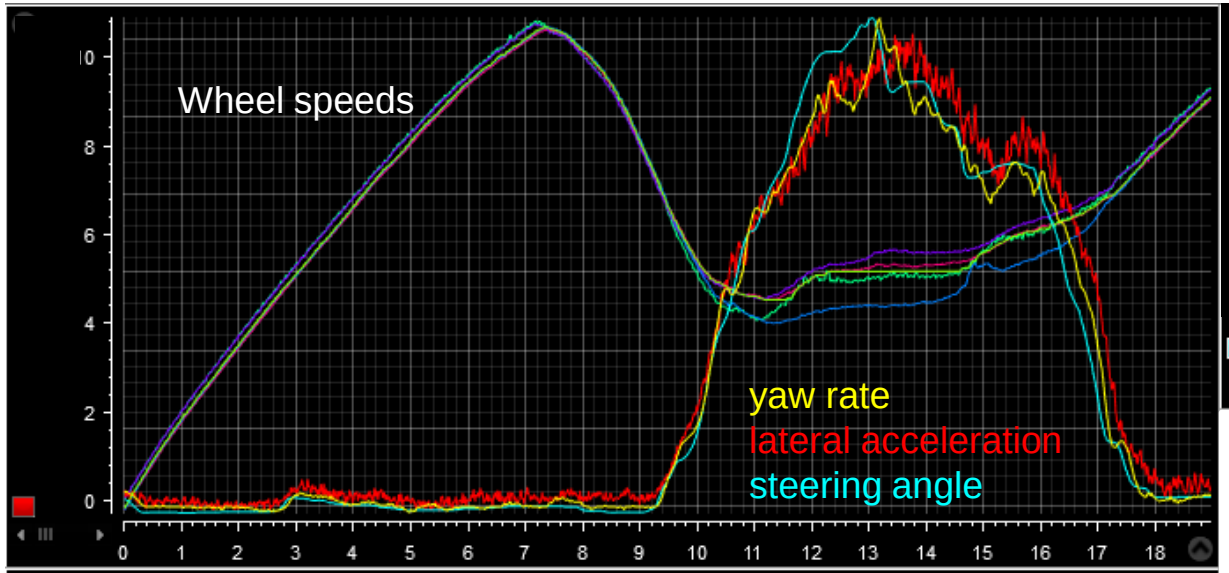
TORQUE VECTORING CONTROLS

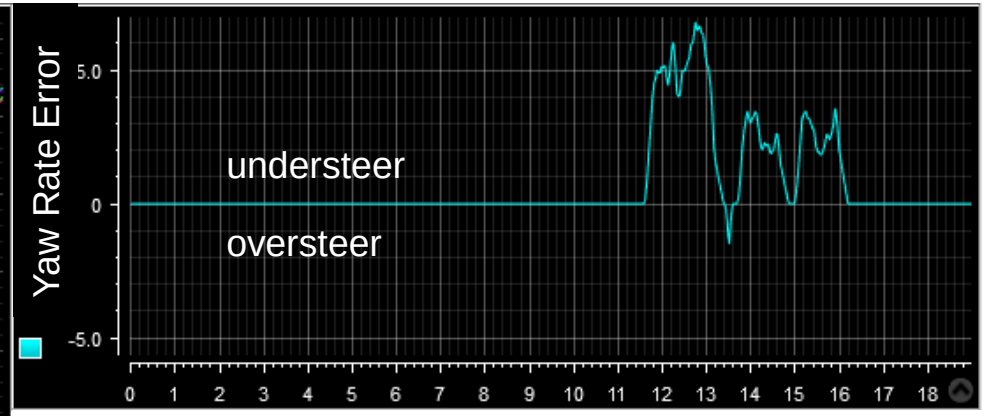
- In-house TV controls already existed from development work carried out for the Focus RS TV-AWD system. These included both feed forward and feed back algorithms.
- Only minor modifications were required to the code to adapt it for use with IWDs
  - This added the ability to apply negative torques to the curve inner wheels, which isn't possible with the mechanical twin-clutch system.
  - It also allowed power-off situations to be handled better than with a clutch based TV system – with a zero nett axle torque a yaw torque can still be generated.

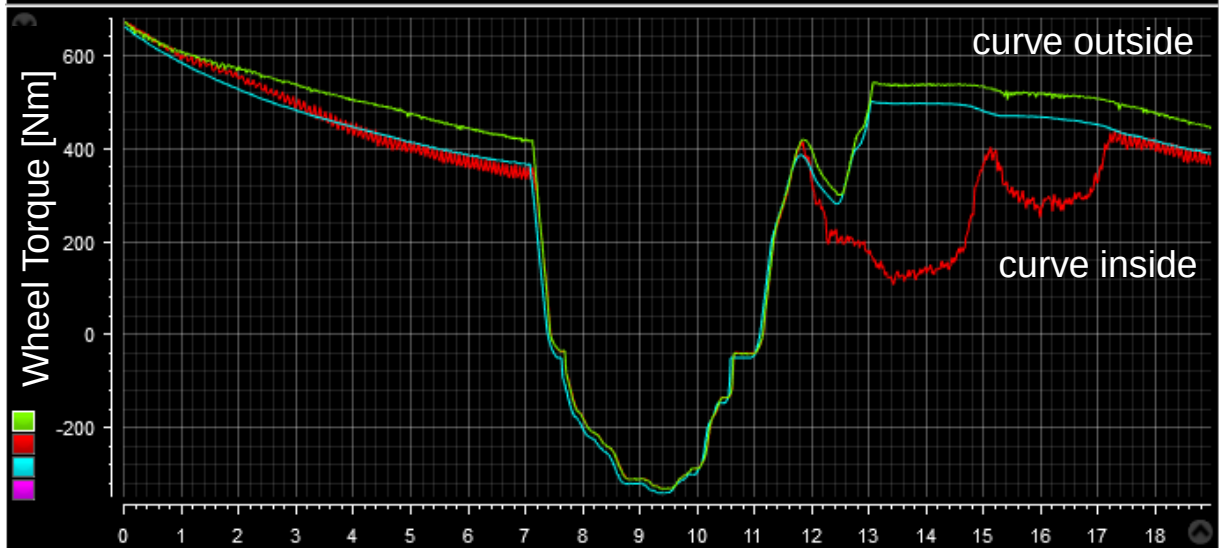
- The following slides show examples of driving manoeuvres with early level controls and tuning.

- Wheel torque control through the electric machine alone can in many cases be as effective as a brake based ESC intervention, reducing yaw error and vehicle speed to stabilise the vehicle and allow it to negotiate the curve.
- It also has the advantage of improved NVH during ESC yaw control. There is no brake activation noise on the driven axle, where the available IWD torque is sufficient.

EXAMPLE: DRIVING THROUGH A CURVE WITHOUT TORQUE VECTORING







- Equal torques are requested from both driven wheels.
- Curve inside wheel torque is limited due to wheel slip as it unloads due to lateral forces, so we do have a slight TV effect.
- In spite of this, the vehicle starts to understeer quite early in the manoeuvre.

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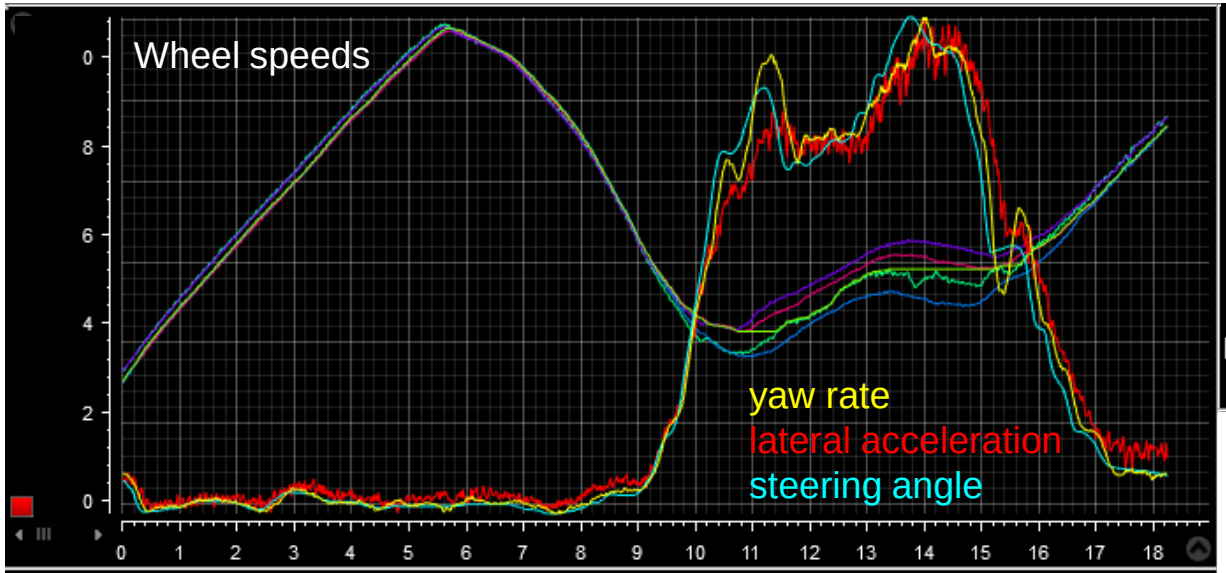
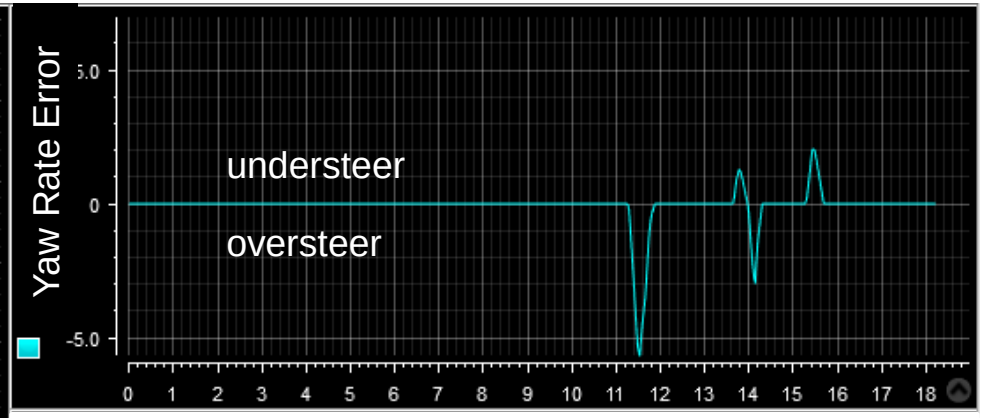
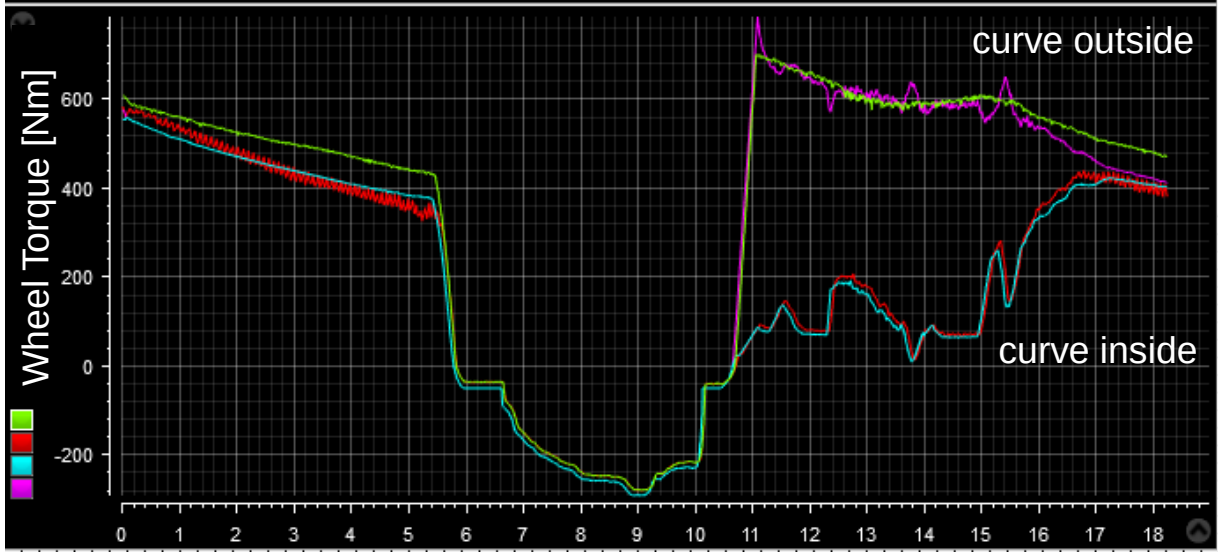
EXAMPLE: DRIVING THROUGH A CURVE WITH TORQUE VECTORING







- TV control distributes the drive torques according to the driver demand and compensates for the vehicle reaction.
- The vehicle stays very neutral throughout the manoeuvre, with any understeer or oversteer tendency being automatically compensated.

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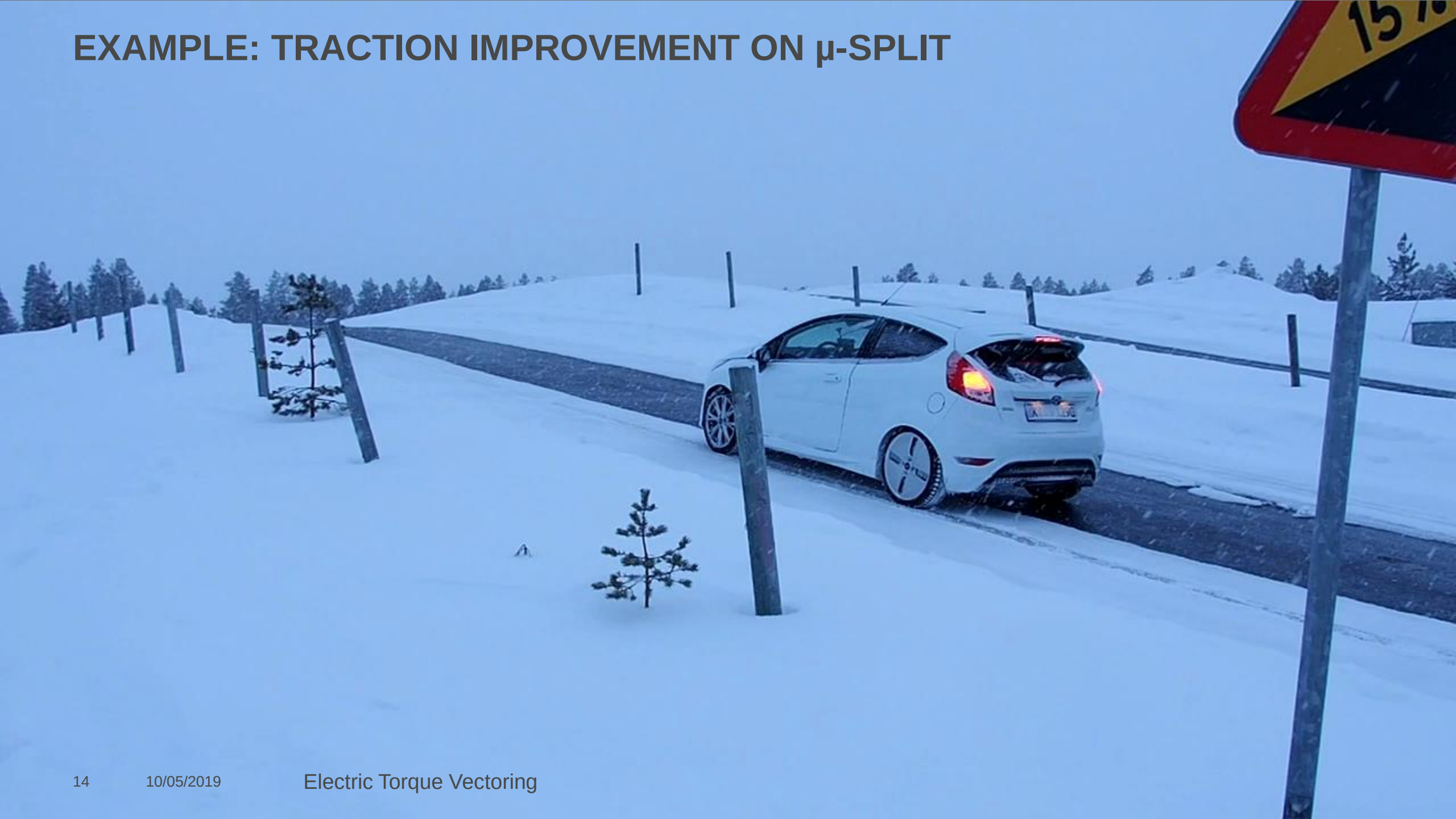
EXAMPLE: TRACTION IMPROVEMENT ON μ-SPLIT



EXAMPLE: TRACTION IMPROVEMENT ON μ-SPLIT

- Vehicle climbs slope easily without the need for brake based TCS interventions required in conventional systems – no heating of the brakes.
- Very fine slip control possible.

- Situation detection is necessary – TV without detection will tend to transfer the torque in the wrong direction.

- One limitation is that only half the installed axle torque is available on the high-μ wheel

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INCREASED UNSPRUNG MASS

- Disadvantage of in-wheel drives predicted by traditional literature.
- Was shown to be much less significant than expected (despite an increase of 58 kg per driven wheel), in the vehicle speed range tested.
- Some ride attributes were *slightly* worse than in original production car, others were actually slightly better.
- Ride quality was rated to be not worse than a Fiesta with optional sport suspension, in spite of the very low profile non-production tyre used (205/40 R18).
- Studies carried out by other parties (e.g. Lotus) have also confirmed this behaviour.

INCREASED UNSPRUNG MASS

Points to consider:

- IWD mass is not completely unsprung – a pneumatic tyre sits between the IWD and the road surface.
- Sprung to unsprung mass ratio also has an effect – the total vehicle mass increased by ~200 kg. Half of this was an increase in the sprung mass.
- Standard suspension tuning techniques can be used to counteract much of the effect of the increased unsprung mass.
- Testing so far has only been at up to 130 km/h.
- There are new IWDs on the market that offer higher power and torque, with lower increase in unsprung mass, in a similar 18” package. (e.g. 1250 Nm peak torque for a 36 kg increase in unsprung mass per wheel).

CONCLUSIONS

- In-Wheel Drives offer the opportunity, besides package and weight advantages, to improve the traction and handling of motor vehicles through the build-in torque vectoring capacity, and the ability to imitate a cross axle locking device.
- Yaw control capability is better than with clutch based devices, particularly power-off, and NVH during yaw control is very good.
- Torque vectoring algorithms developed for use on mechanical TV drivelines were adapted for use in the technology demonstrator vehicle with little effort.
- Through testing on low and high μ surfaces, these were shown to provide an agile, but stable and easily controllable, handling behaviour.
- One of the predicted disadvantages of in-wheel drives – increased unsprung mass – was shown to be of much less significance than expected.
- One limitation of the architecture is that only half the installed axle torque is available on any one wheel.

Q&A

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