STEERING SYSTEMS

BOSCH

Agenda

- Steering Requirements
- Steering Systems Design
- Electric Power Steering
- Driver Assistance System Functions
- All Wheel Steering
- Steer by Wire
- Superimposed Steering System

Source:

Steering Handbook**,** Editors: Manfred Harrer, Peter Pfeffer

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STEERING REQUIREMENTS

Steering Requirements
Steering behaviour, Steering response

- **Steering behavior** –vehicle response to driver intention
  - the steer-angle has to correlate to the angle of the wheels by a continuous function
    - steering transmission may not produce any jumps

- **Steering response** – information transmitted by the steering system
  - useful information supporting the vehicle control
    - feedback on the limit of adhesion of the wheels
  - disturbing information
    - fluctuations of the braking power

Steering Requirements
Steering function targets

- **Steering precision** - instantaneous response to steering input; synchronous behavior of steering angle input, steering torque increase, and vehicle response

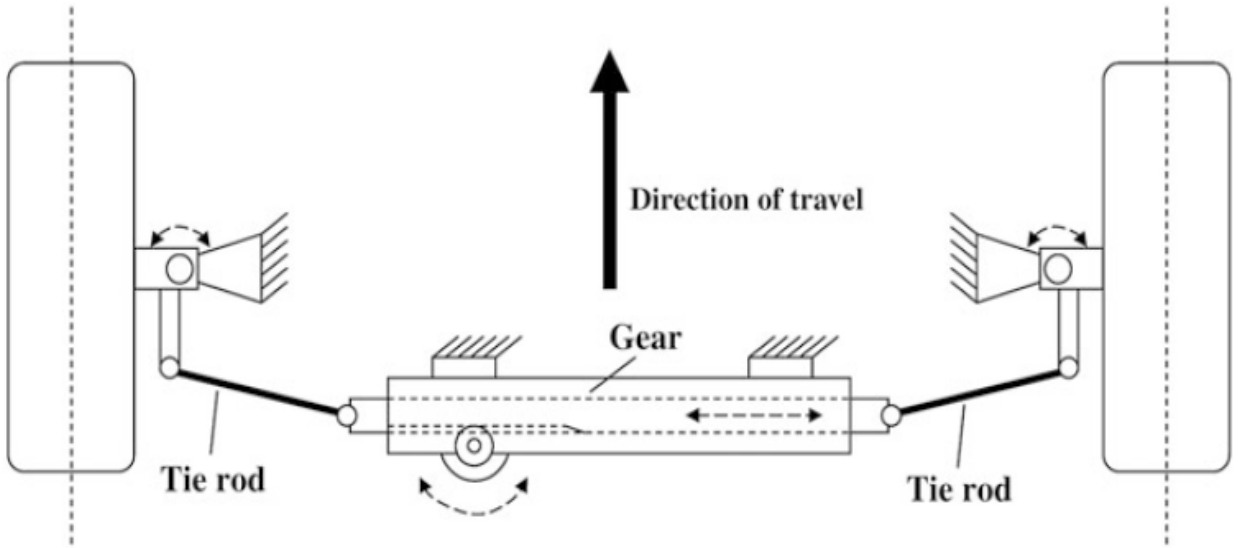
- **Steering comfort** - steering wheel torque adapted to particular driving situations; low steering angle required for parking, cornering, and handling; automatic steering return with an adapted angular velocity of the steering wheel

- **Steering feedback** of driving state and road information in a balanced relationship with possible interfering variables

- **Steering dynamic** sufficient for quick maneuvering; a sudden evasive manoeuvre

Steering Requirements

- Steering behavior and response depend on
  - tyres
  - axle kinematics
  - design of the steering system



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STEERING SYSTEMS DESIGN

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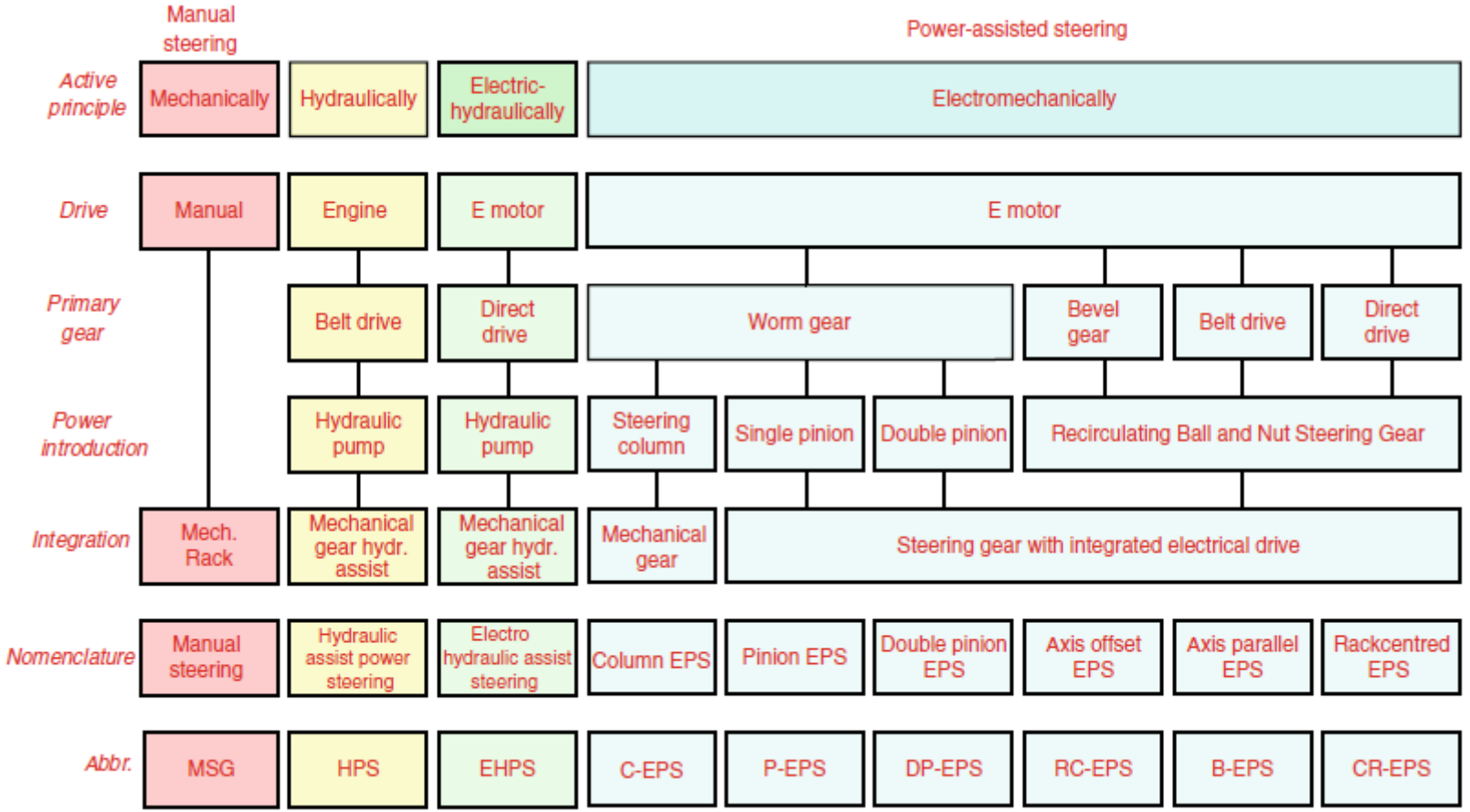
Steering Systems Design
Classifications of steering systems design



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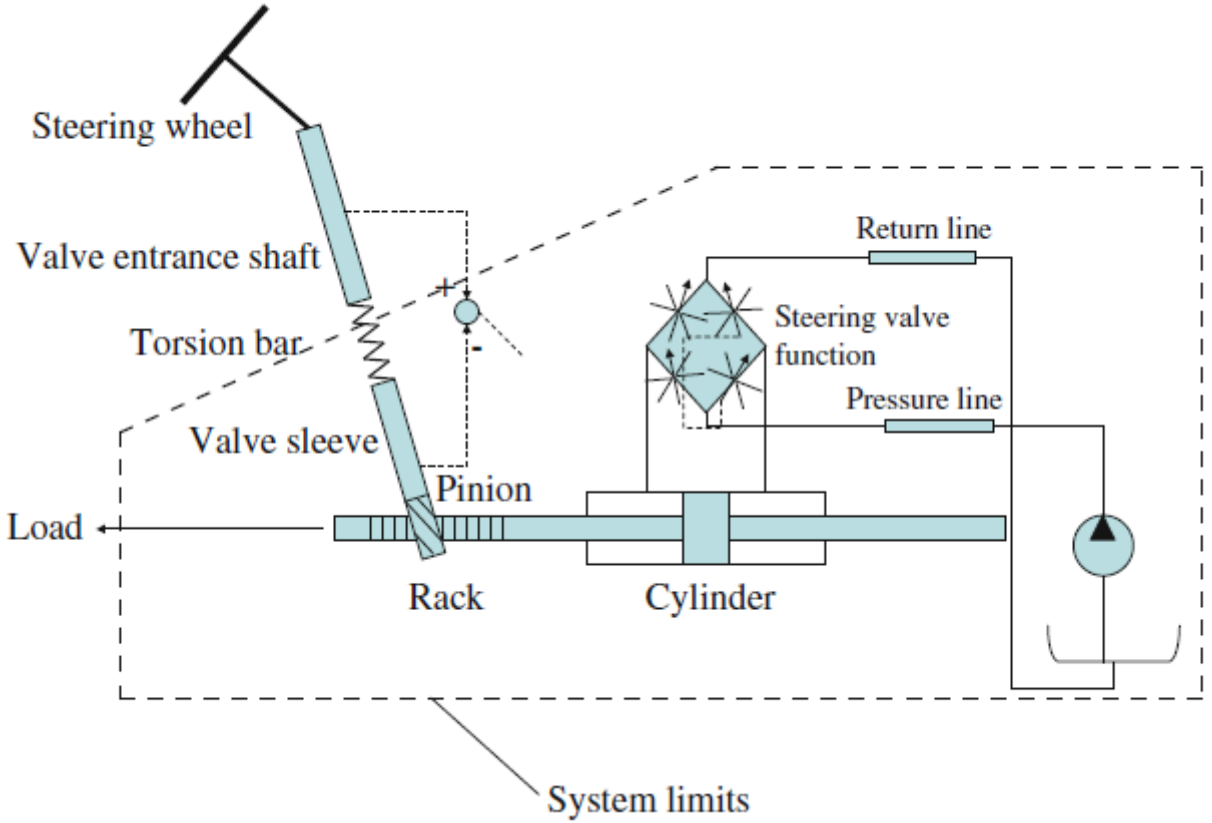
Steering Systems Design
Hydraulic power steering (HPS)

- In a HPS system, the power-assist is activated by opening valve connected to the torsion bar
- the level of the power-assist is a mechanical function of the valve characteristic



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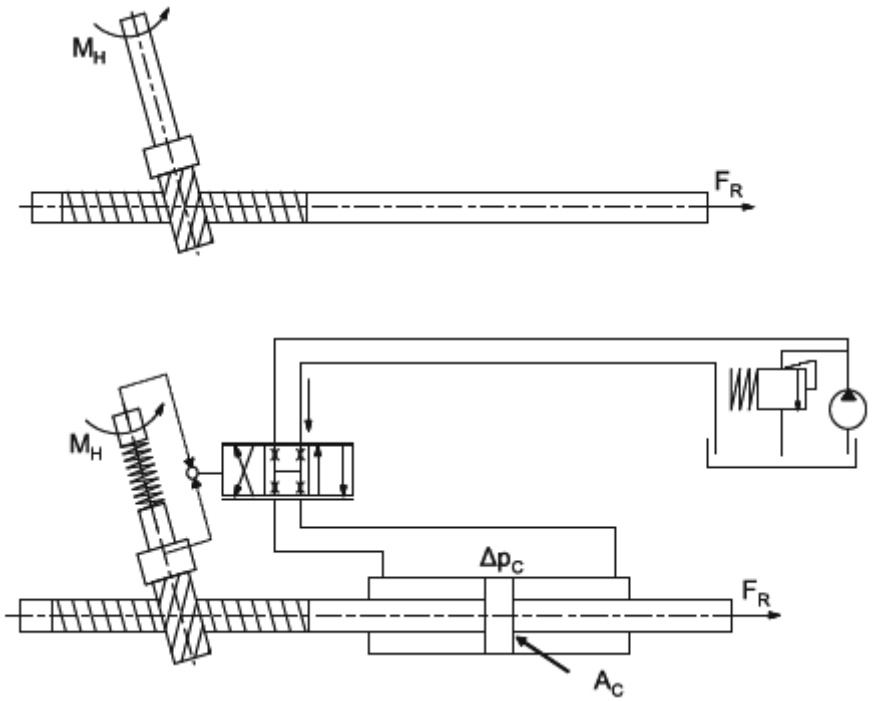
Steering Systems Design
Comparison between mechanical and hydraulic steering

- HPS advantages:
  - reduce steering force
  - reduce steering ratio
  - increase the damping of the steering system



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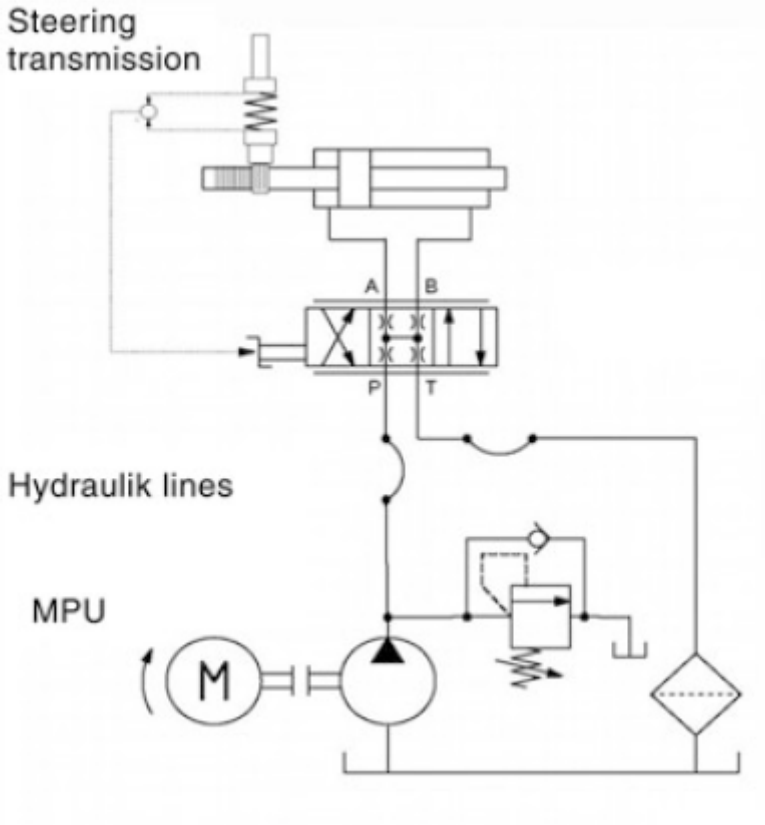
Steering Systems Design
Electrically powered hydraulic

- the hydraulic pump is controlled by an electric motor



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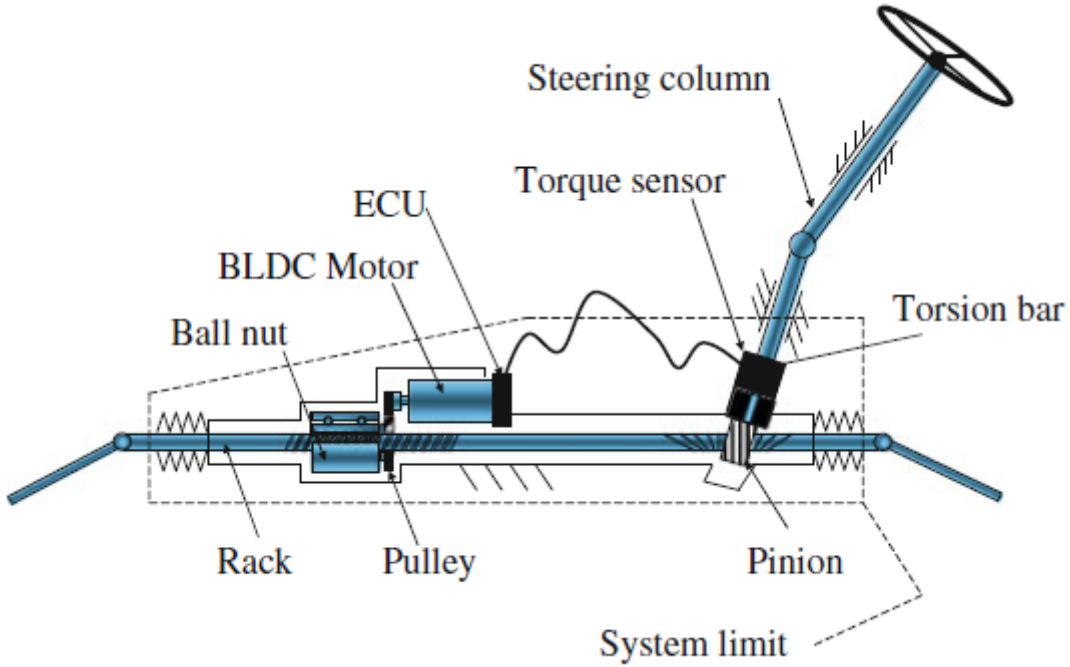
Steering Systems Design
Electric power steering

- EPS generates the power-assist by means of an electric motor whose force is fed into the rack or steering column by a servo gear unit
- EPS uses torque sensors to measure the torsion bar torque
- the power-assistance is computed in the EPS-ECU using the measured torsion bar torque



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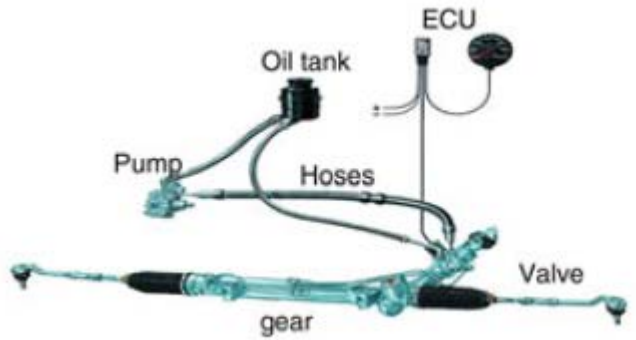
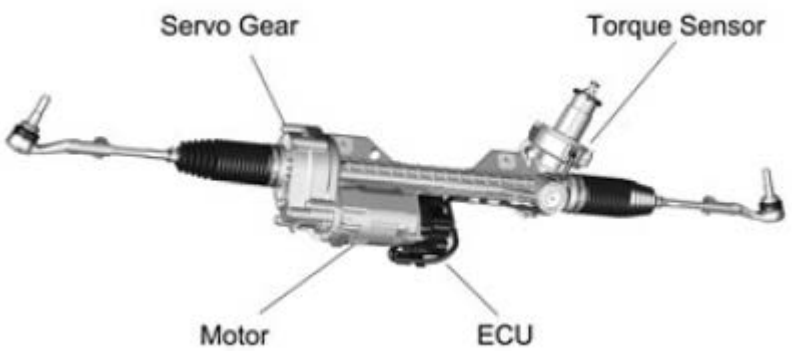
Steering Systems Design
Comparison between hydraulic and electric power steering

- HPS has many individual pats that are usually assembled on-board; the system has to be hydraulically filled and the connections tested for leakage
- EPS is supplied to the vehicle manufacturer as a complete unit
- EPS has additional functions





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Steering Systems Design
Comparison between hydraulic and electric power steering

- EPS is a power on demand system, activated only when the car is steering
  - fuel and CO_2 reduction

- Savings on fuel and CO_2 of EPS compared with HPS
  - NEDC- New European Driving Cycle
  - measurements on BMW 320i

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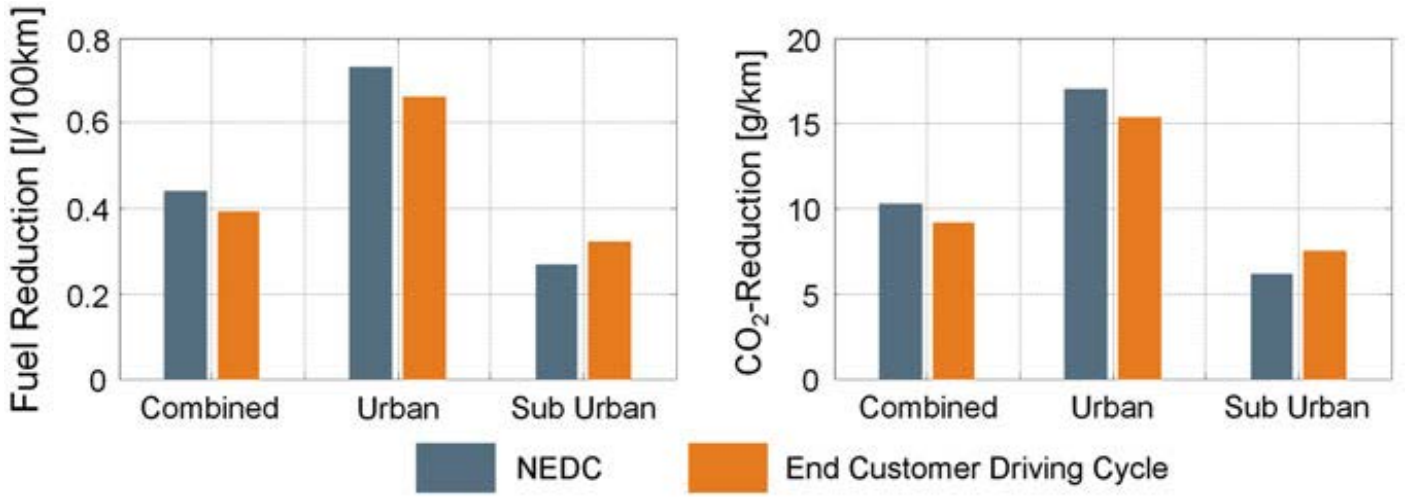

ELECTRIC POWER STEERING

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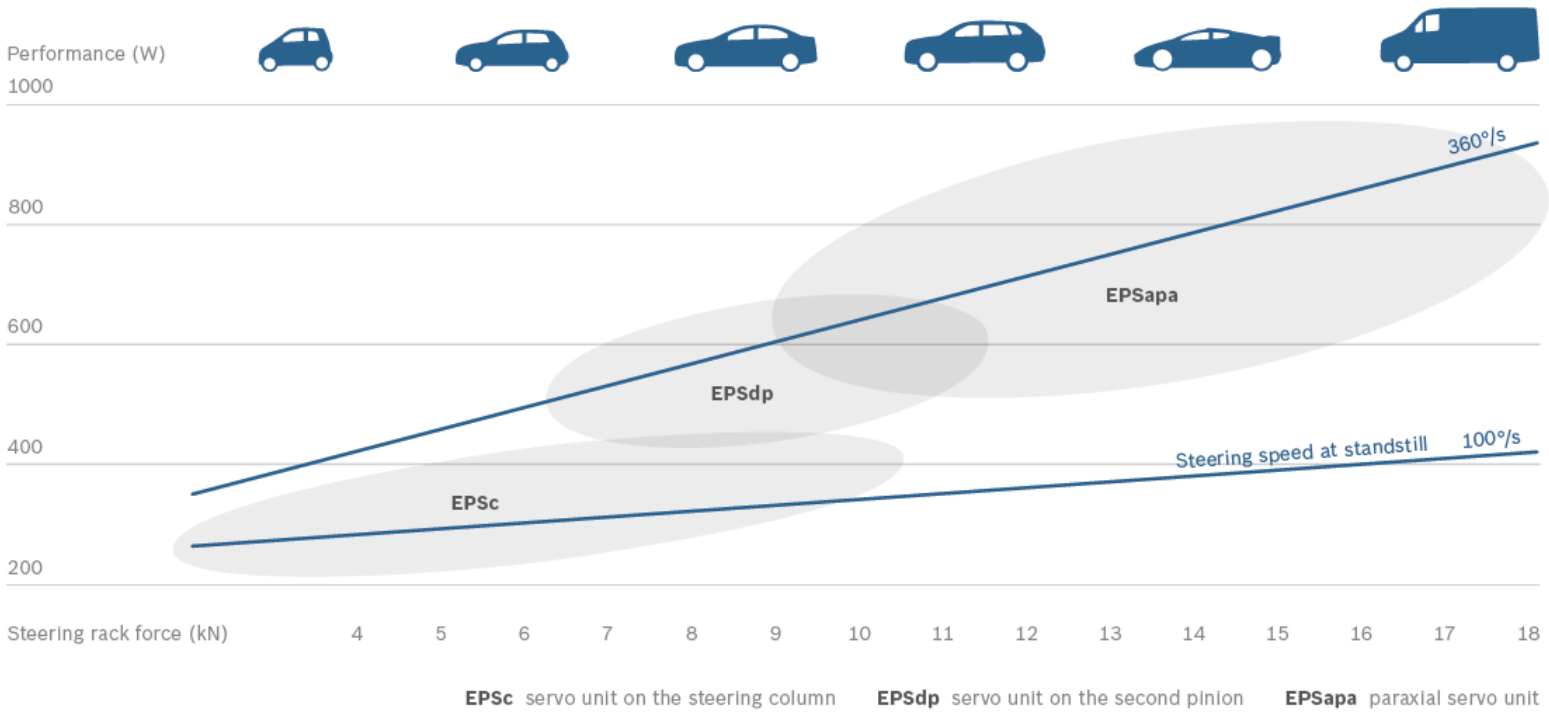
Electric Power Steering
Application range of EPS



Electric Power Steering
Designs of EPS Systems

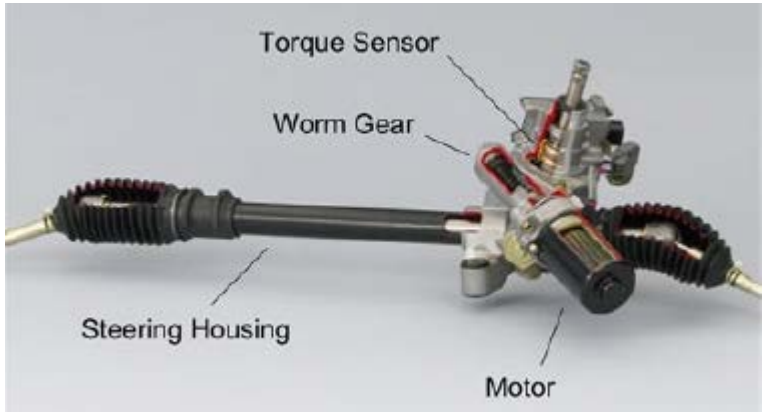
- EPSc: Column
- EPSp: Pinion
- EPSdp: Dual Pinion
- EPSapa: Axle Parallel
- EPSapa Fail-operational
- EPSrc: Rack Concentric

Electric Power Steering
EPSc

- the forces of the power-assist unit are transferred along steering column
- high steering forces are not accessible; limiting factors are intermediate steering shaft and pinion
- for vehicles up to lower mid-range
- low weight and minimal space requirements

Electric Power Steering
EPSp

- The power-assist unit is placed right at the steering pinion
- The forces do not need to be transferred along steering column and intermediate steering shaft
- Higher steering powers than an EPSc



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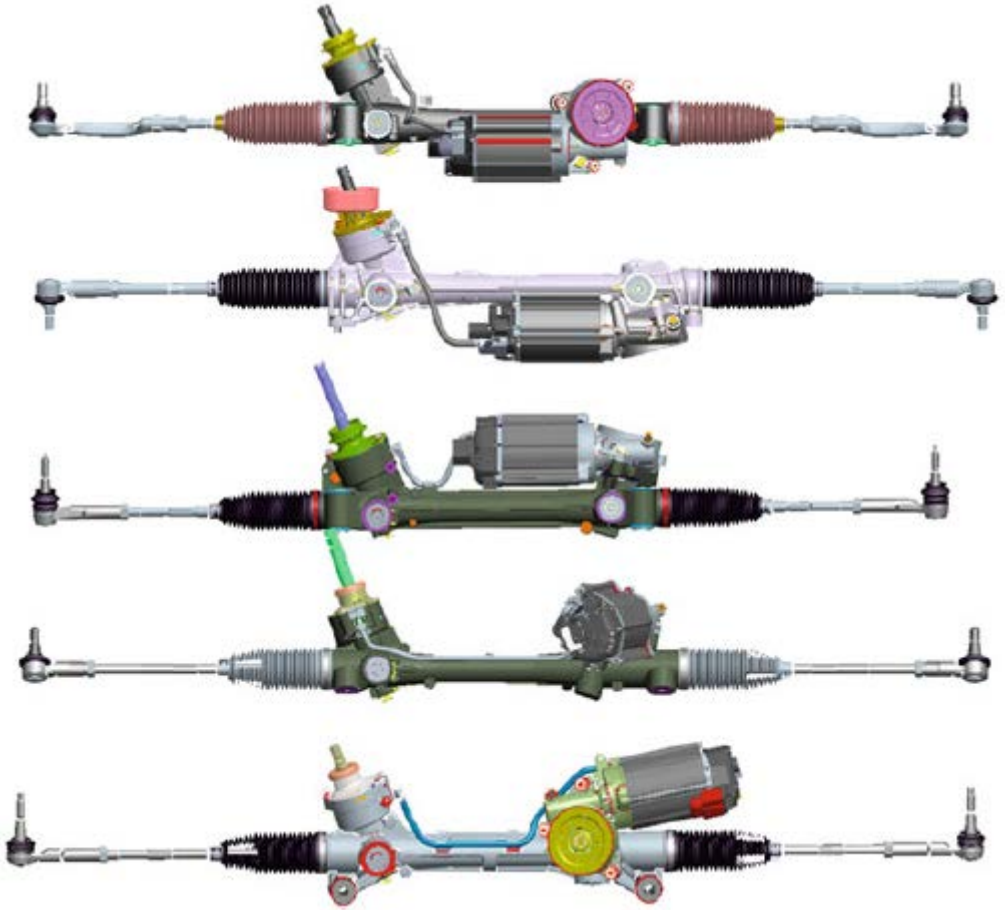
Electric Power Steering
EPSdp

- the power-assist unit is mounted at a second pinion
- sensor unit and drive unit can be separated
- system power is 10–15 % higher than that of an EPSc or EPSp
- fror mid-range vehicles
- versatile installation possibilities

Electric Power Steering
EPSdp

- the servo unit can be positioned to rotate 360 degrees about the axes of the rack and the drive pinion through use of a suitably designed worm gear

- adapting the steering to very difficult installation space



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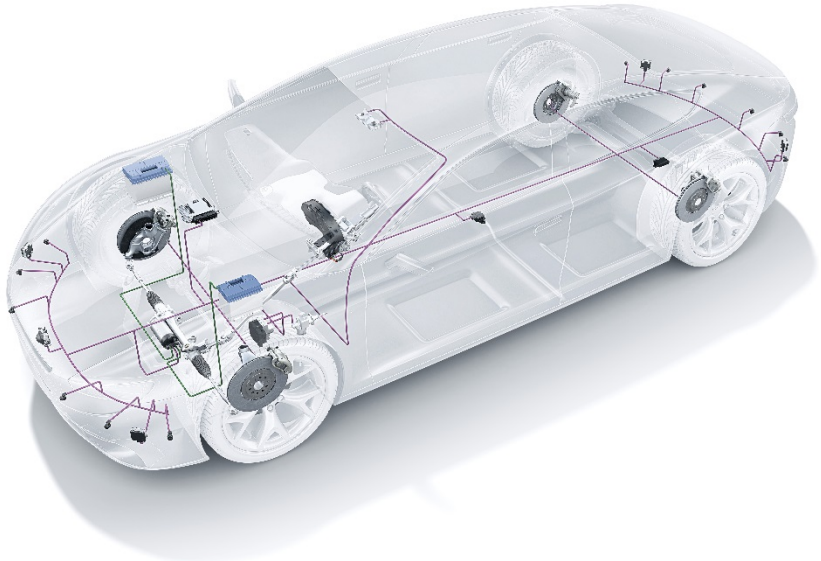
Electric Power Steering
EPSapa

- the power-assistance is transferred to the rack by a combination of ball screw and timing belt gearbox
- the ball screw converts the rotation of the engine into a translation of the rack
- for luxury-class vehicles, sports cars, SUVs and light commercial vehicles
- high efficiency and low system friction

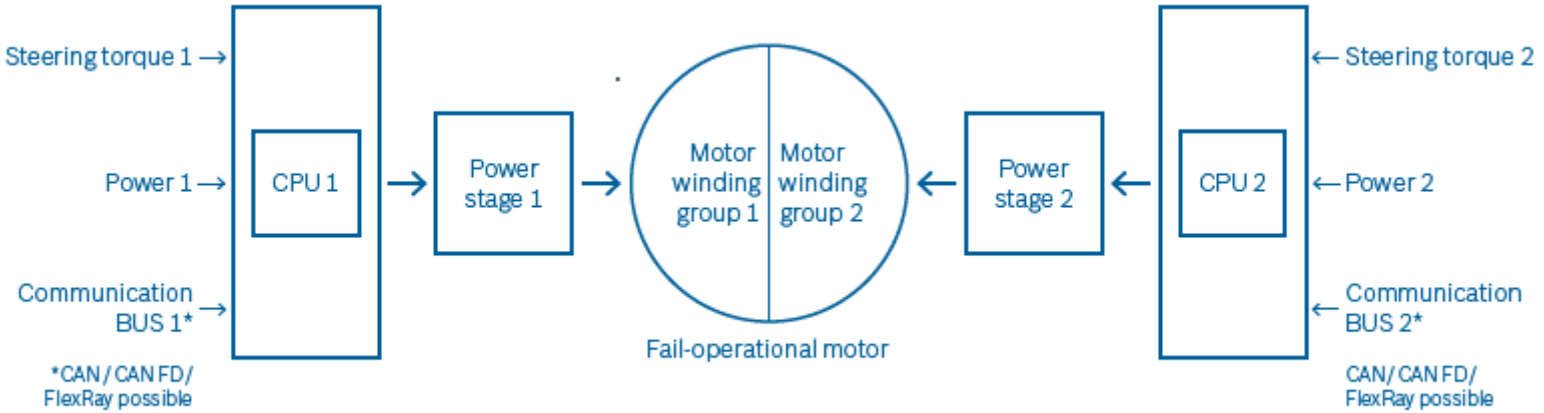
Electric Power Steering
EPSapa Fail-operational

- allows highly automated driving
- functions and characteristics of standard steering are retained in the non-automated mode
- based on paraxial electromechanical steering
- redundant system design
- in case of a fault in the electronics, at least 50% of steering assistance is retain

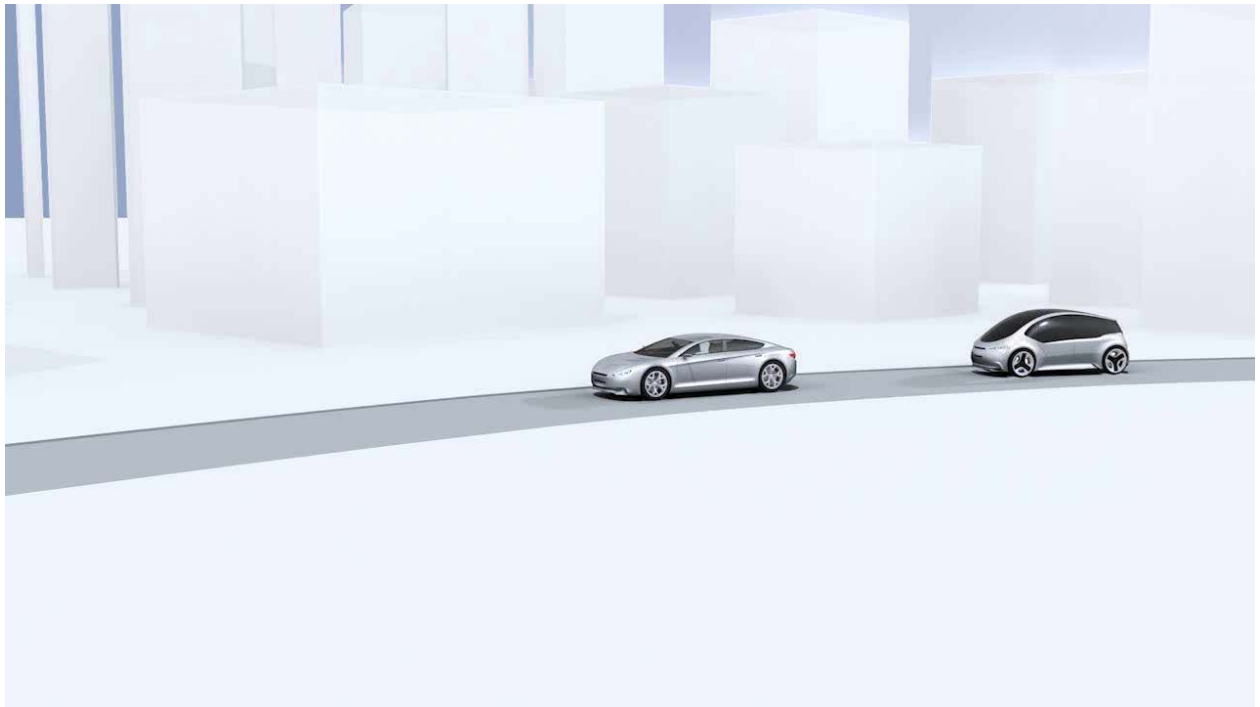


Electric Power Steering

Structure of a Fail-operational steering system

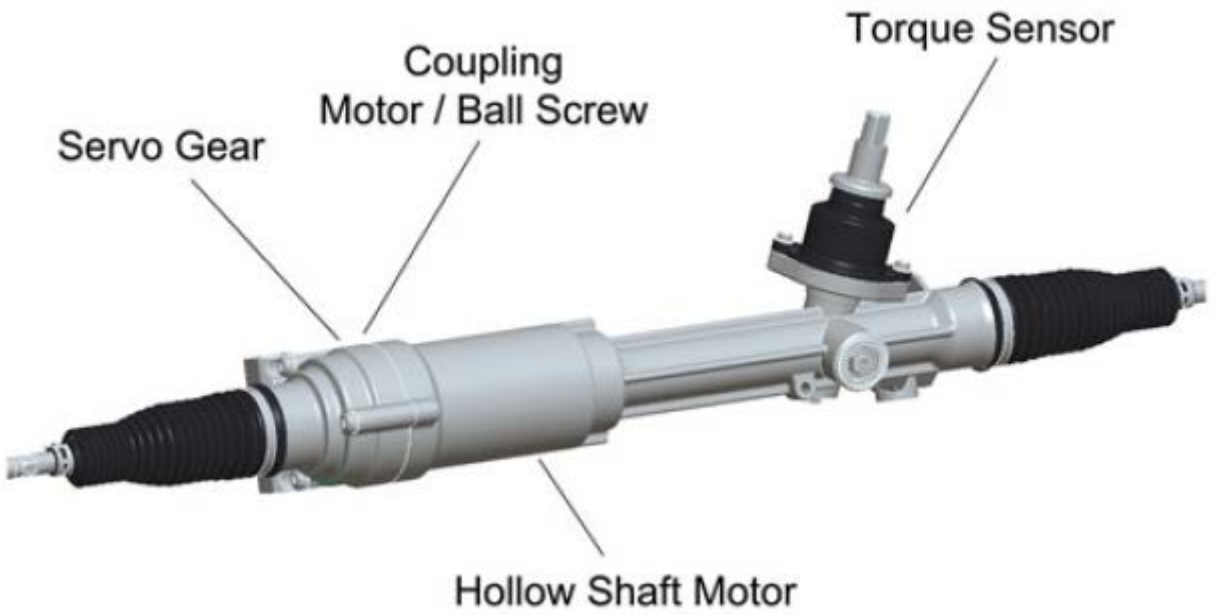


Electric Power Steering
EPSapa Fail-operational



Electric Power Steering
EPSrc

- concentric configuration requires a special servo motor with hollow shaft rotor; the rack of the steering passes through the motor
- uses a ball screw as a gear to convert the rotation of the engine into a translation of the rack
- the ball screw is here directly driven by an electric motor



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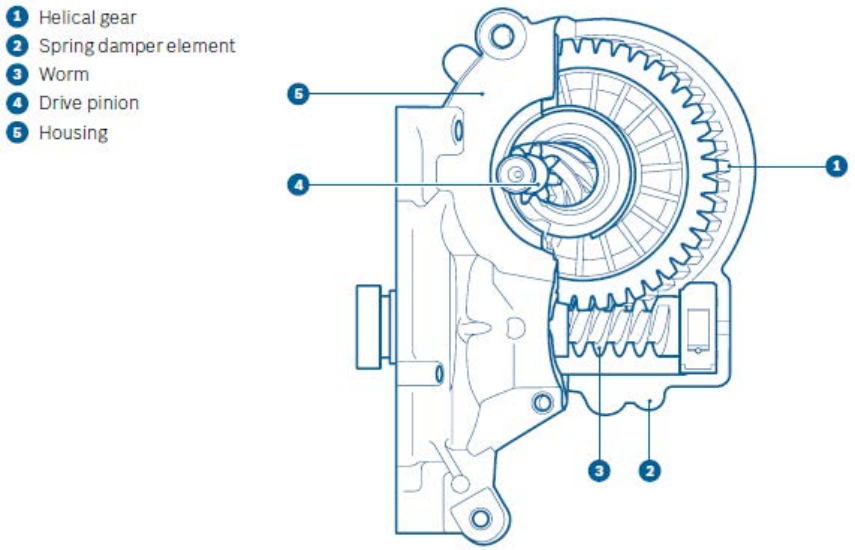
Electric Power Steering
Power-Assisted Gear

- establishes the connection between steering wheel, drive unit and wheels
- convert the rotation of the power- assist into a translation of the rack
- high transmission ratios can be achieved by a combination of two gearbox layers.
- power assisted gears used for EPS:
  - Worm Gear
  - Ball Screw Drive
  - Toothed Belt Drive

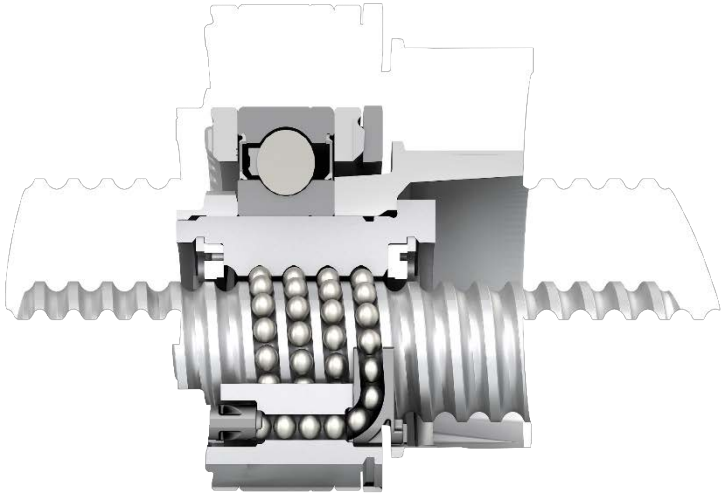
Electric Power Steering
Worm Gear

- used in the EPSdp to transmit power between electric motor and main drive pinion
- used in EPSc and ESPp to transfer the motor power to the steering column

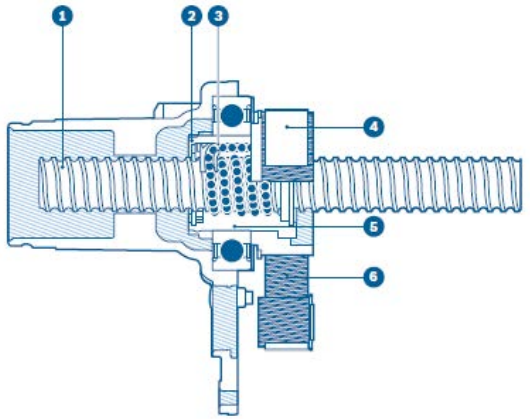


Electric Power Steering
Ball Screw Drive

- transform the rotation of the electric motor in an EPSapa or an EPSrc system into a translation of the rack
- the drive comes either directly (EPSrc) or via a belt gearbox (EPSapa) from the motor

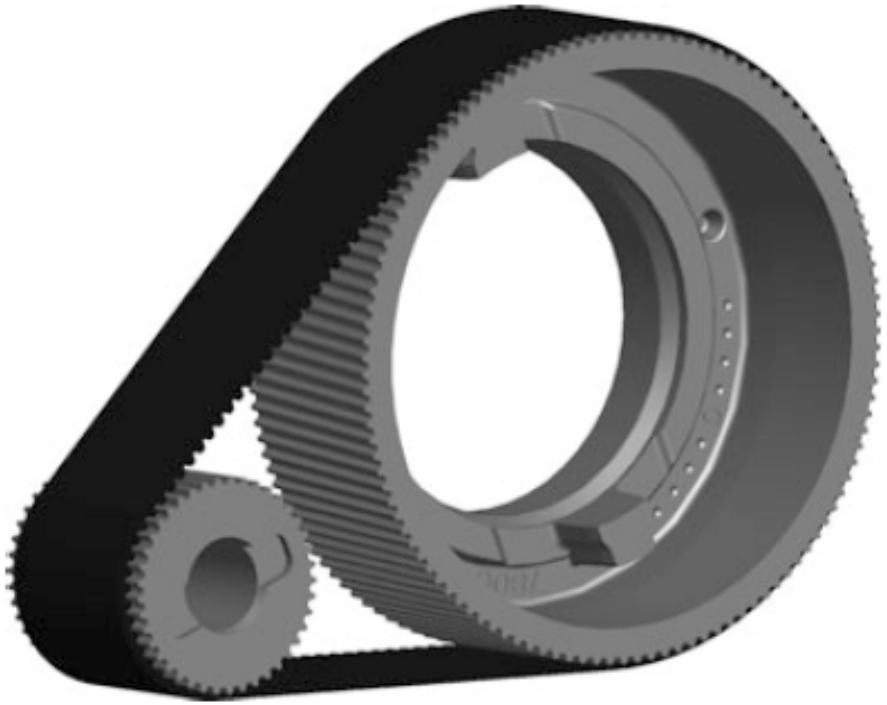


1. Steering rack
2. Ball return channel
3. Ball chain
4. Toothed disc
5. Ball recirculating nut
6. Toothed belt



Electric Power Steering
Toothed Belt Drive

- used in ESPapa, transfer the motor power to the rack
- motor axle and rack are axle-parallel
- the toothed belt drives consist of a belt and two serrated pulleys



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Electric Power Steering
Electric Motor

- power assist is supplied by the electric motor
- it converts electric energy into mechanical energy
- the operating range of an electric motor for EPS can be divided into a
  - speed range with constant torque: parking maneuver (high steering force up to a defined steering speed)
  - speed range with almost constant output power: evasive manoeuvres (high steering speed are required)

1 Control unit
2 Housing
3 Drive shaft

Electric Power Steering
Steering Functions

- define the force that the driver perceives while guiding the steering wheel
- response of the free steering wheel (automatic parking)
- steering functions classifications:
  - basic steering functions
    - power-assistance, friction compensation, inertia compensation, damping
  - extended steering functions (EPS specific)
    - Active Return
  - functions at vehicle level (Driver Assistance System Functions)
    - Park Steering Assistant, Lane Departure Warning, Lane Keeping System, Driver Steering Recommendation(DSR

DRIVER ASSISTANCE SYSTEM FUNCTIONS

BOSCH

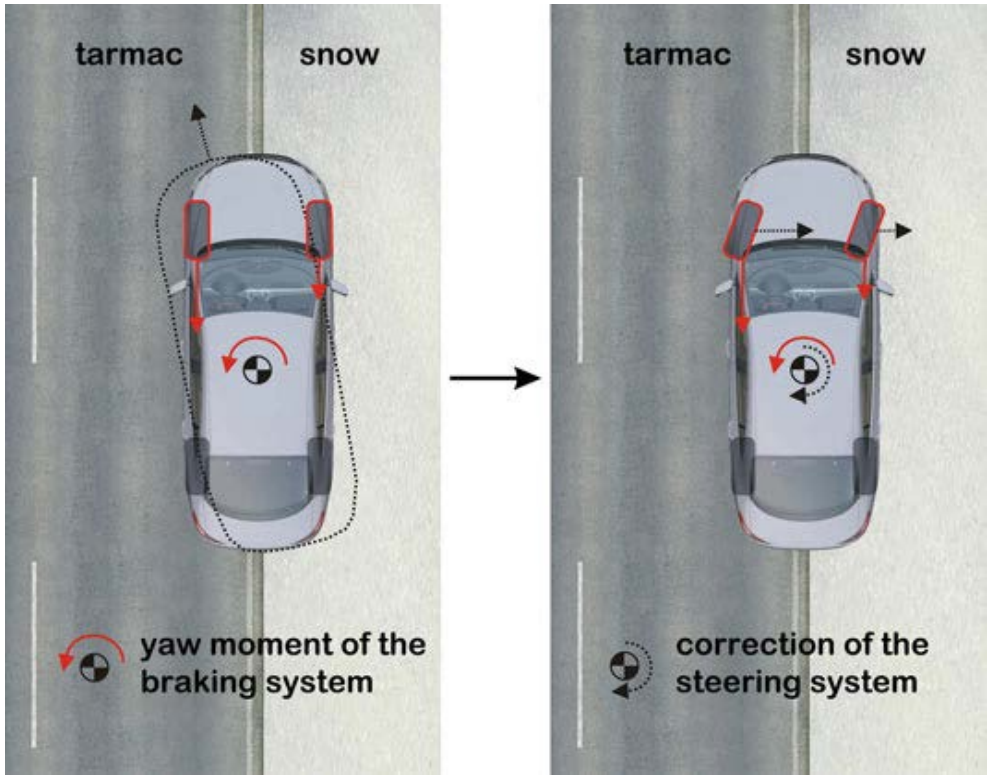
Driver Assistance System Functions
Overview

- determines the current driving situation on the basis of steer-angle, steering torques, lateral acceleration, yaw rate sensors and ESP-computed values
- identifies the best steer-angle for the present driving situation
- is computed and superimposed a steering torque to the steering wheel
- the additional torque should motivate the driver to adapt the self-chosen steering wheel angle to the ideal one
- increase the efficiency of ESP/ABS systems

Header of section
Driver Steering Recommendation(DSR)

- improvement of handling and braking distance

- support the driver in braking maneuvers when there are asymmetrical friction values on the road (μ-split)
  - based on the yaw rate of the vehicle and the brake pressure difference at the front wheels, DSR computes the corrective steering wheel
  - the driver has to steer towards the low friction value to counteract the pull towards higher friction



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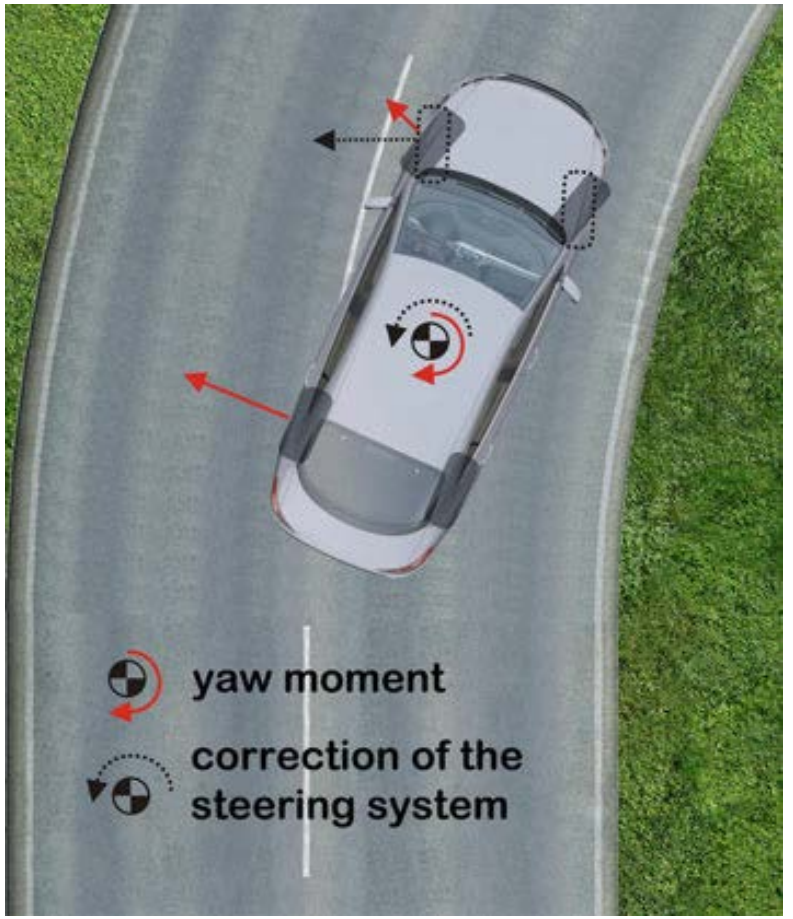
Driver Assistance System Functions
Driver Steering Recommendation(DSR)

- support the driver in oversteering conditions
  - in a oversteerig situation yaw moment is generated pushing the car rear outward
  - the driver has to compensate the yawing movement by counter steering
  - DSR provides a superimposed steering wheel torque to the driver, pointing where to steer
  - the driver's counter steering movement is optimized and ESP interventions can be avoided or reduced.



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Driver Assistance System Functions
Driver Steering Recommendation(DSR)

- Ergonomics Requirements
  - steering wheel torque interventions have to be always continuous (may not include any jumps)
  - possibility to control the steering characteristics by parameters
  - limitation of the highest additional steering wheel torques, the function has to be deactivated if the driver does not agree with the recommended steering wheel torques.

- Safety Requirements
  - the driver should be able to control the driving situation whenever an additional steering wheel torque is applied
  - monitoring and limitation of the steering wheel torques and their gradients

Driver Assistance System Functions
Lane Keeping Systems (LKS)

- support the driver in keeping the lane by intervening with a correcting wheel torque

- components of the lane keeping system:
  - camera and ECU (1)
  - electromechanical steering (2)
  - multi function steering wheel (3)
  - instrument cluster (4)

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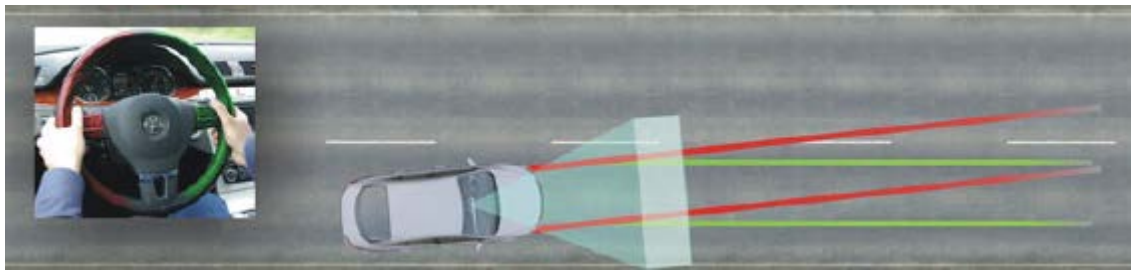
Driver Assistance System Functions
Lane Keeping Systems (LKS)

- the lane keeping system is designed for use on well developed country roads and highways
- the system only switches to the ‘active’ state when the following criteria are fulfilled:
  - lane recognised
  - lane is wide enough
  - curvature of the lane is small enough
  - speed is faster than 65 km/h
- If the vehicle deviates from his lane, the lane assist will countersteer



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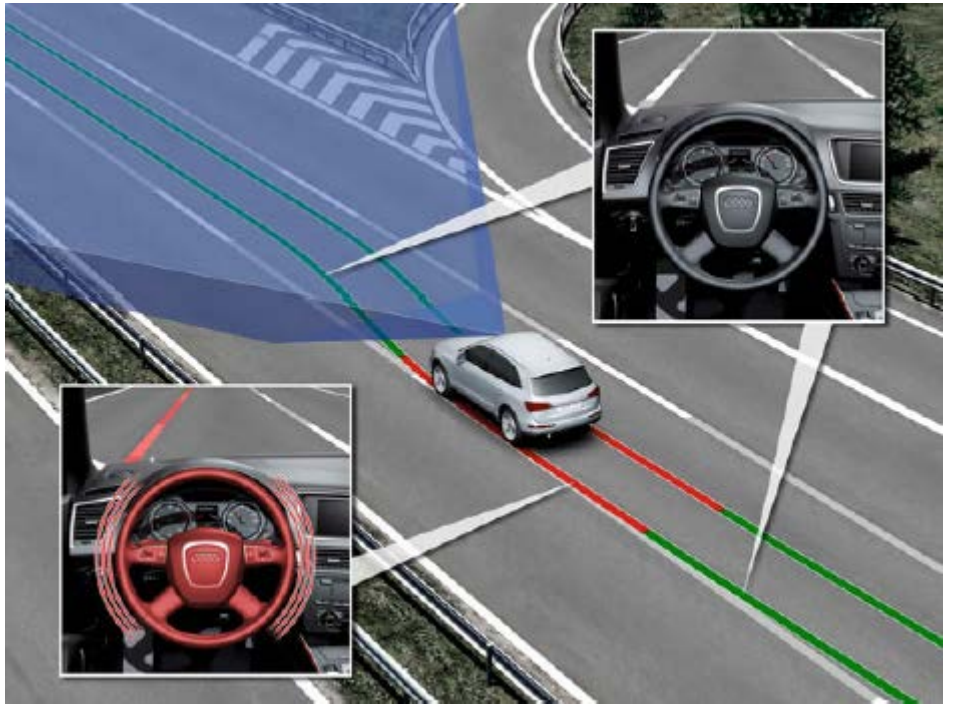
Driver Assistance System Functions
Lane Departure Warning (LDW)

- warn the driver by an optical, acoustic or haptic signal that the lane was left, but they do not interfere into the lane guidance
- activation limit 65km/h
- function status displayed in the instrument cluster



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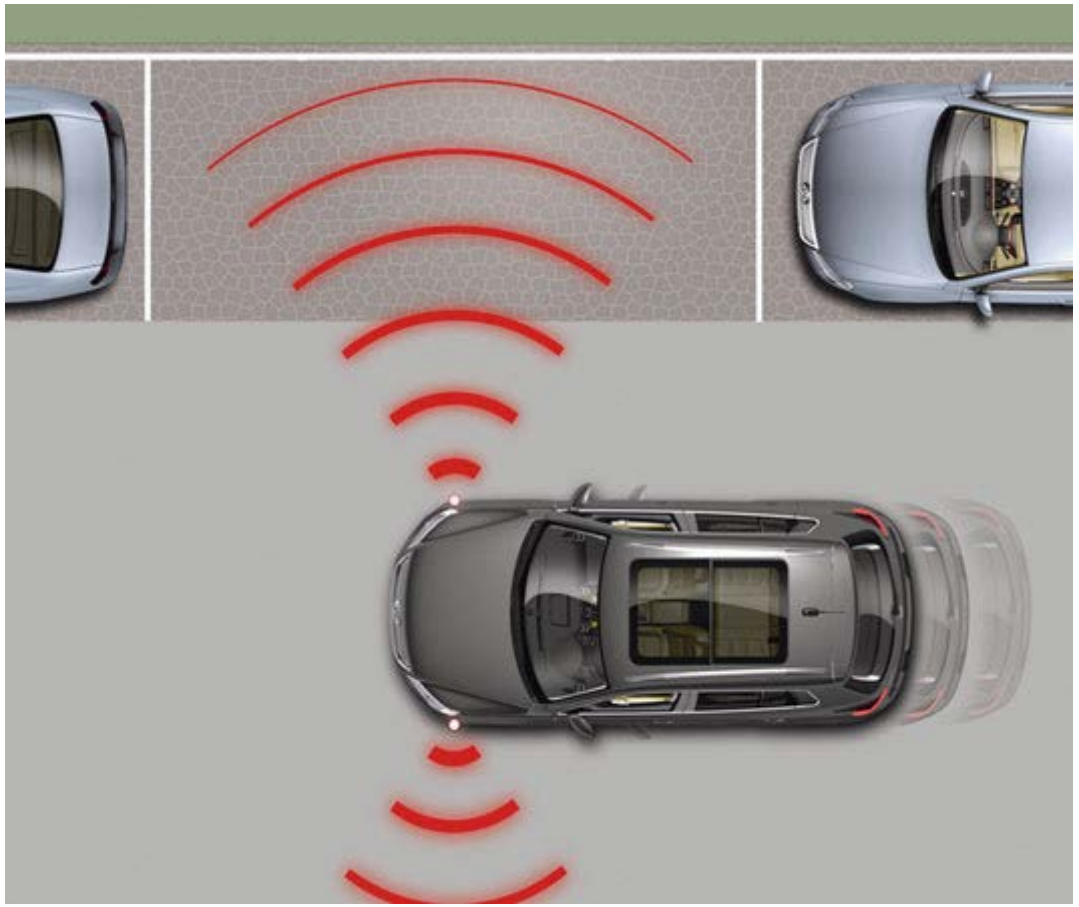
Driver Assistance System Functions
Parking Assist

- support the driver by independent steering into a parking spot
- parking spot detection is made by ultrasonic sensors



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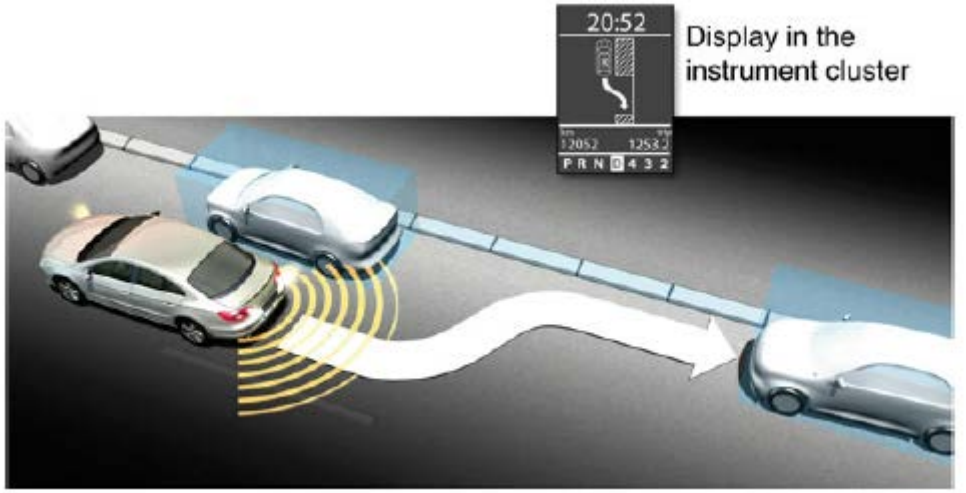
Driver Assistance System Functions
Parking Assist

- parking assist systems:
  - informing systems
    - inform the driver by acoustic and/or visual indication how far away the driver still is from an object within the driving space
  - controlled parking assist systems
    - suggest to the driver specific measures based on evaluated information on the surroundings
  - semiautomatic parking
    - full adoption of a function (automatic steering)
  - fully automatic parking
    - the driver gives a command to park when a parking spot has been detected
    - the vehicle parks automatically in the parking spot

Driver Assistance System Functions
Parking Assist (Semiautomatic parking)

- semiautomatic parking requirements:
  - the vehicle has to achieve a suitable final position, matching the parking situation
  - the time needed for parking should be very short
  - the vehicle may not collide with any object, otherwise the driver has to be warned during the manual longitudinal guidance



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Driver Assistance System Functions
Parking Assist (Semiautomatic parking)

- automatically carry out the best steering wheel movements to park the car on the ideal line, in one backward pull
- survey of the parking spot and the steering movements
- the driver remains responsible for clutch, gas and brake
- the driver may, at any time and by deliberate action, override the function
- the control action shall be automatically disabled if the vehicle speed exceeds the set limit of 10 km/h by more than 20 % or the signals to be evaluated are no longer being received

ALL WHEEL STEERING

BOSCH

All Wheel Steering
Overview

- all-wheel steering provides the possibility to make the back wheels steerable, in addition to the steering at the front axle
- improves of the lateral dynamic driving characteristics of the respective vehicle

- basic concepts of rear-wheel steering
  - mechanical systems $\delta_h = f(\delta_v)$
  - hydraulic systems
  - electromechanical systems $\delta_h = f(v_x, \delta_v)$

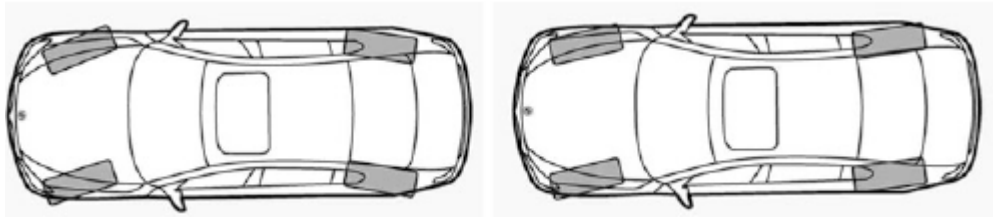
δ_h - rear wheel steer angle

δ_v - front wheel steer angle

v_x - vehicle forward speed

All Wheel Steering
All-wheel steering principles

- parallel direction
  - the rear and front wheels are steered in the same direction
- opposite direction
  - the rear wheels are turned against the steering direction of the front wheels



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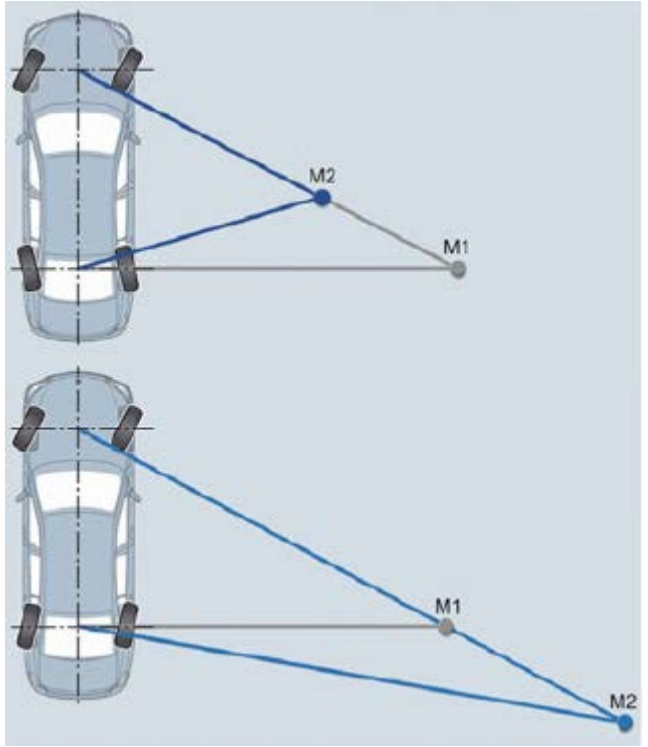
opposite direction

parallel direction

All Wheel Steering

Change of the cornering circle and virtual change of the wheelbase

- opposite direction (upper picture)
  - the instantaneous center of the vehicle moves forwards, this has an effect as if the wheelbase was shortened
  - the cornering circle shrinks, the vehicle is more agile
- parallel direction (lower picture)
  - the instantaneous center moves to the back
  - the virtual extension of the wheelbase increases the stability



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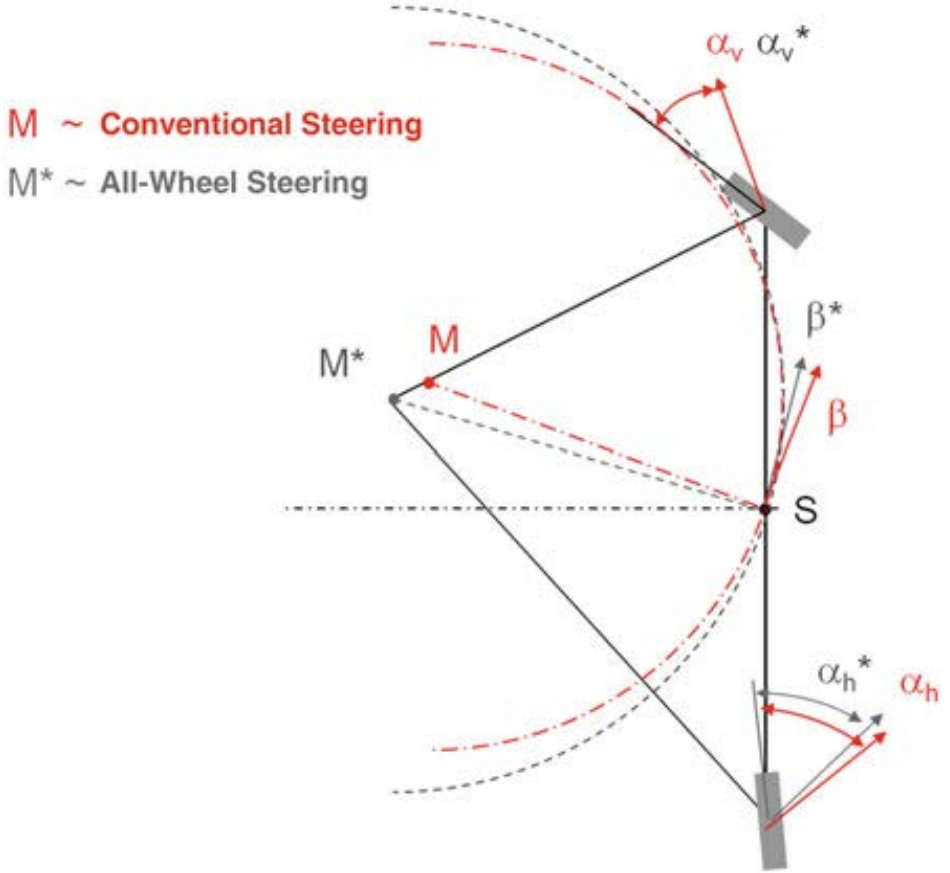
All Wheel Steering
Stationary Vehicle Characteristic (All-Wheel Steering)

- Comparison between vehicle with front and all-wheel steering
  - the same highest lateral acceleration
  - different side slip angles
  - with all-wheel steering the side slip angle of the vehicle can be compensated to improve vehicle stability



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All Wheel Steering
Nonstationary Vehicle Characteristics (All-Wheel Steering)

- ISO lane change
  - all-wheel steering with parallel direction response (blue)
  - Front wheel steering (yellow)
- higher driveability for all-wheel steering vehicle
  - lower side slip angle
  - better correlation between steering angle and yaw rate/lateral acceleration

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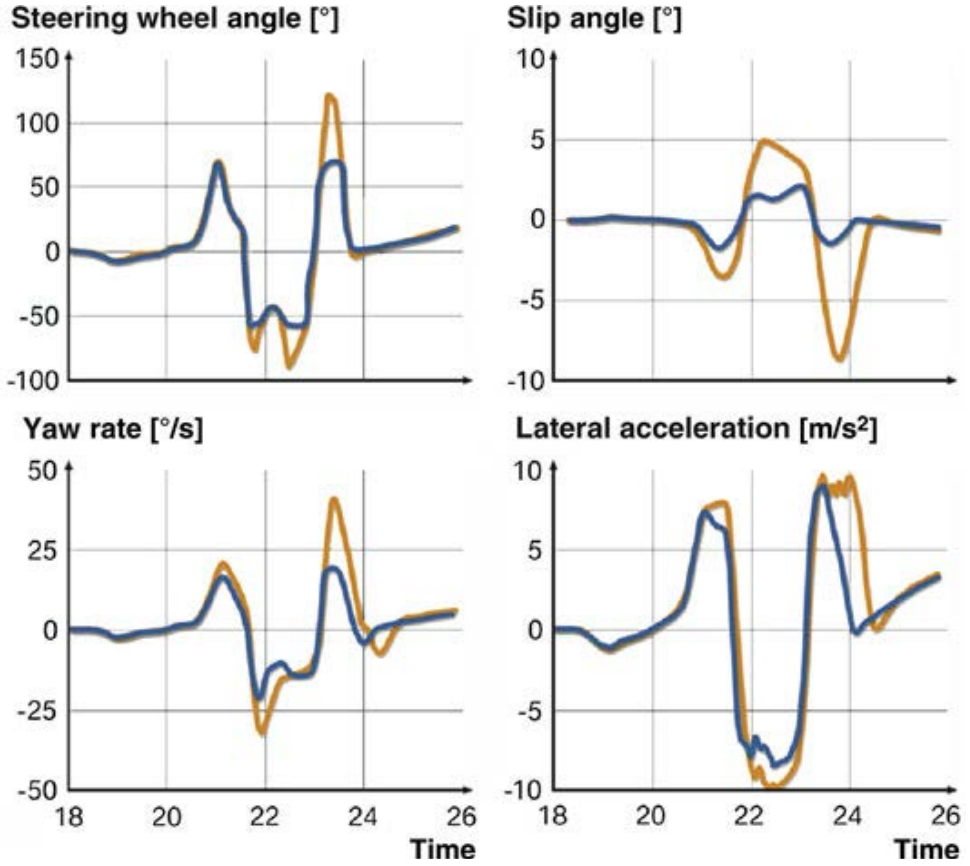

STEER BY WIRE

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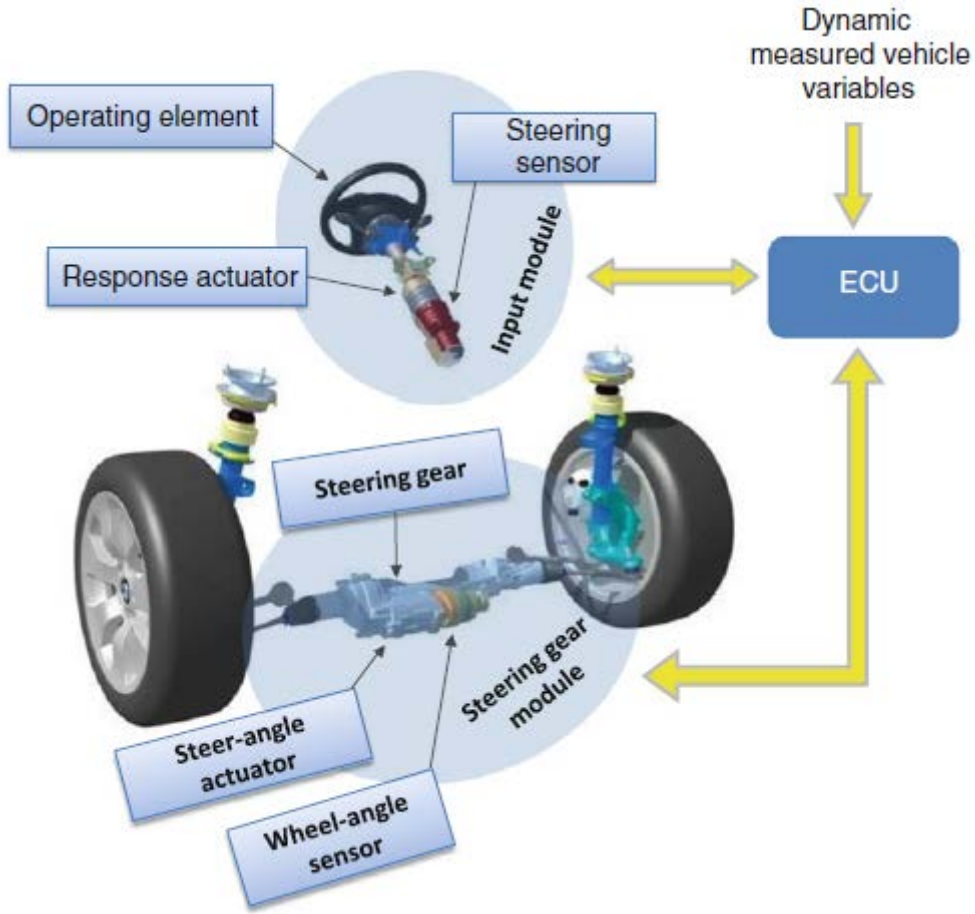
Steer by Wire
Overview

- a system that electrically transmits a steering command from an operating element (steering wheel) by an ECU to an actuator executing the steering command at the driven wheels

- biggest challenge: to meet the safety and reliability requirements



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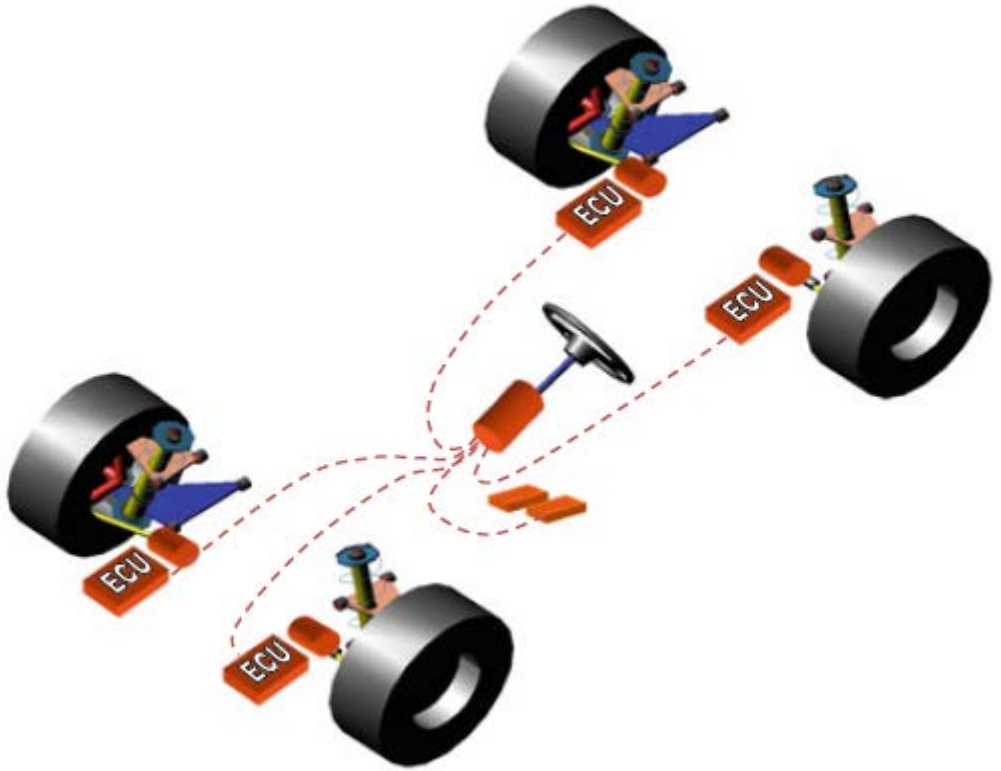
Steer by Wire
Corner module concept

- performs the chassis functions (steering,driving, braking, vertical dynamics) at the individual wheels



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Steering Handbook

SUPERIMPOSED STEERING SYSTEM

BOSCH

Superimposed Steering System
Overview

- introduce an additional angle to the driver's steering input

$$\delta_{H^*} = \delta_H + \delta_M$$

δ_M - freely controllable engine angle (added angle)
δ_H - steer wheel angle
δ_{H^*} - driven shaft

- additional steering functions: steering dynamics and steering stabilization functions

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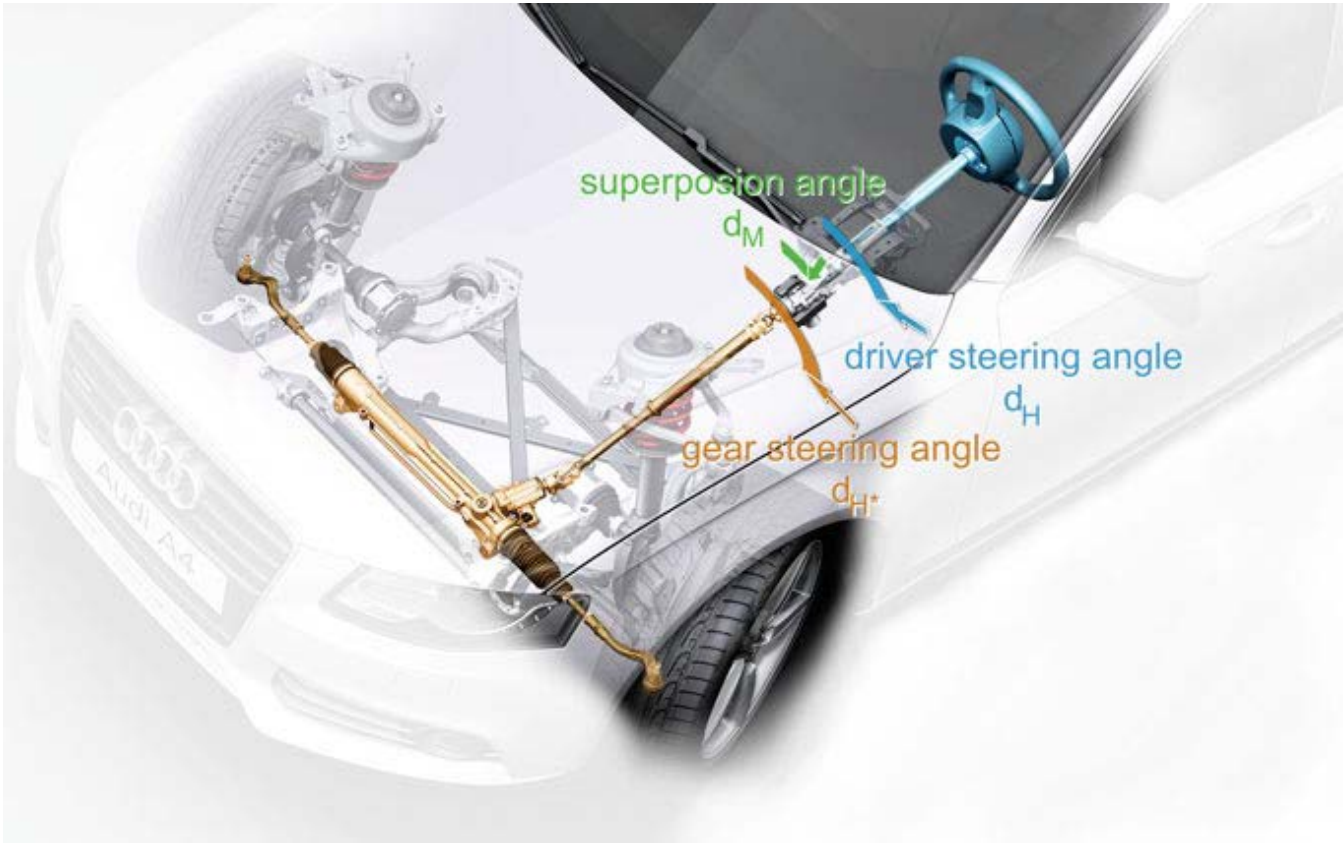
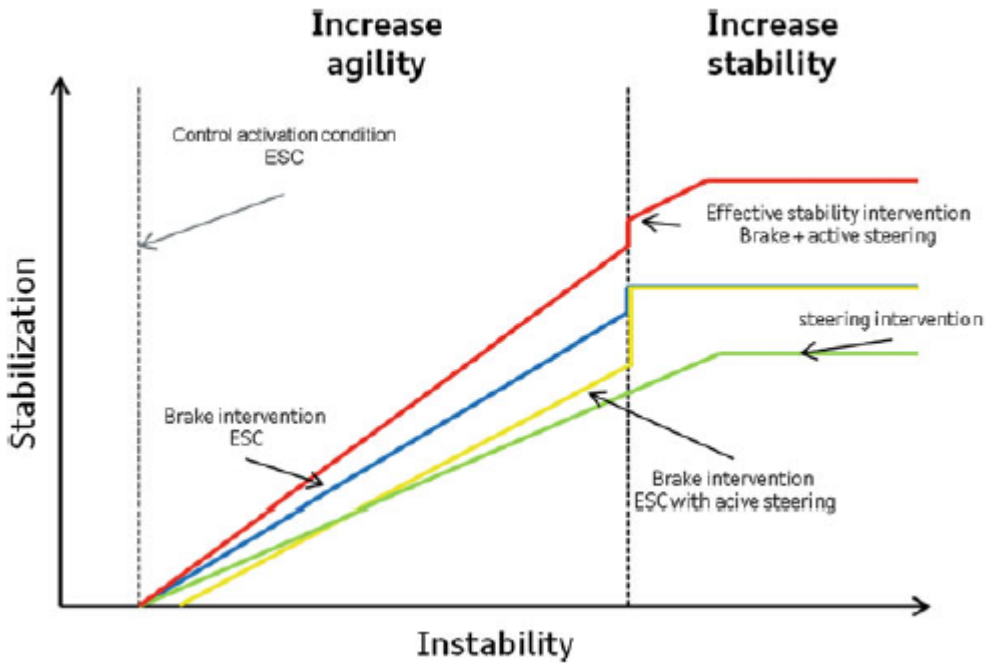


Superimposed Steering System
Steering Stabilisation

- active stabilizing steering corrections that are almost independent from the driver
- stabilize the vehicle in dynamically critical situations
  - overall stability of the vehicle is improved by concurrent braking and steering interventions
  - less critical driving situations, vehicle stability could be achieved only with the superimposed steering system:
  - to achieve the best agility and concurrent stability, the best distribution of the stabilization torque on brake and steering is made by an arbitrating concept.



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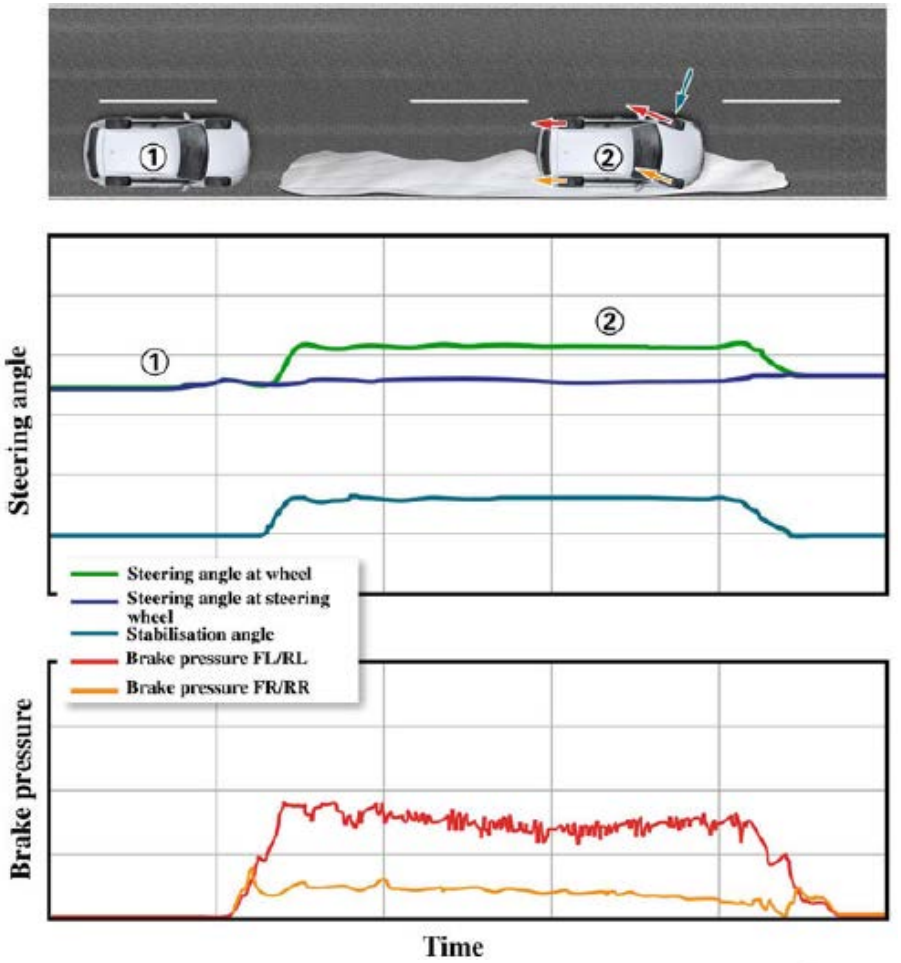
Superimposed Steering System

Steering Stabilization During Braking on Roads with Different Friction Values (μ-split)

- braking on such a road generates a yaw torque from the higher braking powers on the side with more friction
- to continue driving straight, the stabilisation system set a steering wheel angle that compensates the interfering yaw torque



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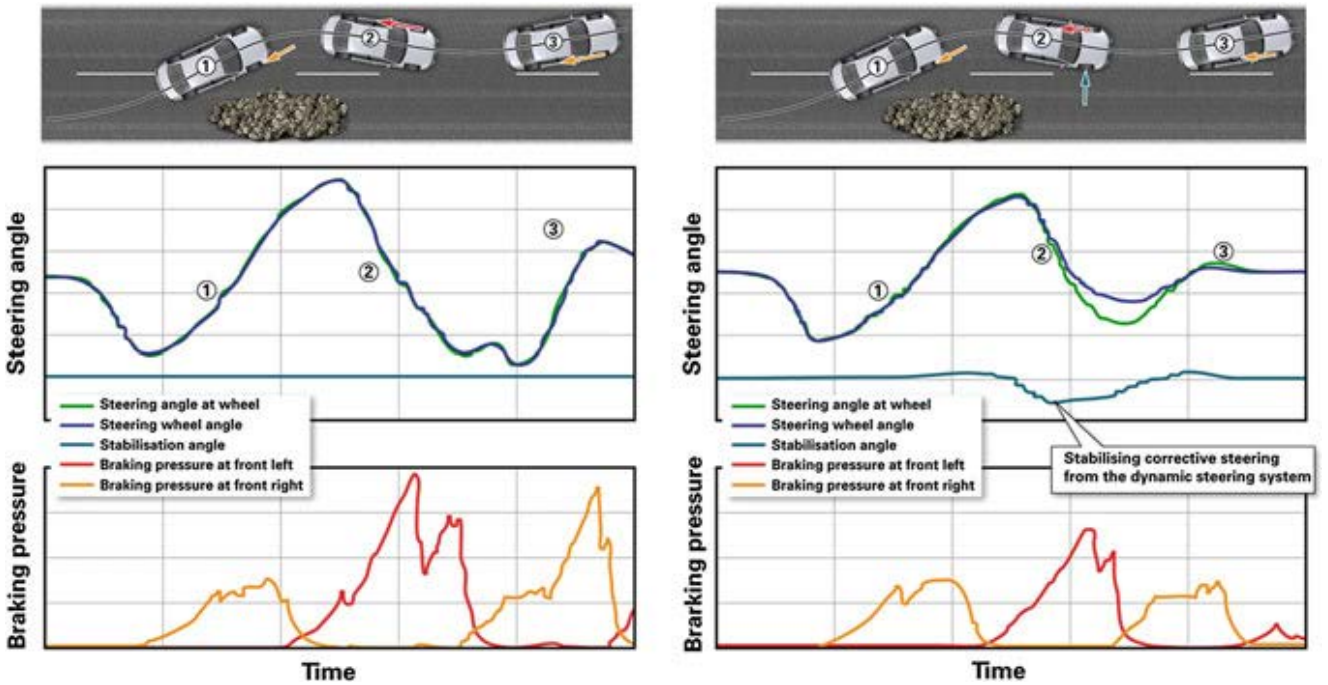
Superimposed Steering System
Steering Stabilisation at Oversteering

- reduce or fully compensate the too high yaw response of the vehicle
- lower number of brake interventions that make the overall stabilization look very harmonious



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