Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Mechatronics -A better way to get functionality.

by Dr. Karl Reisinger

- Overview of the training
- From functionality to signal flow

FOR EDUCATIONAL PURPOSE ONLY

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598710-EPP-1-2018-1-AT-EPPKA2-CBHE-JP

Overview

- Monday: Khon Kaen,
  - Training
- Tuesday: **Mahararakam**
  - Pick up at the hotel 7:30
  - Welcome & Opening Ceremony
  - Training
  - Short Lab Tour & Welcome Dinner – MSU
- Wednesday: **Site Visit**
  - Pick-Up 8:30
  - CTV
  - Atipong
  - Khon Kaen – Ton Tan Market & City Tour
- Thursday: Khon Kaen
  - Training

Trainings

- Monday, Tuesday morning: **Mechatronics**
  - Presentations by
    Karl Reisinger, (Thomas Lechner)
  - Workshop by ALL of us.
- Tuesday, Thursday: **Testing**
  - Presentations by
    Karl Reisinger, (Thomas Lechner)
  - Workshop by ALL of us.
- Thursday: **EKTU Concept**
  - Intro by Thomas Esch
  - Workshop by ALL of us

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Overview - Mechatronics

What is Mechatronics? – A better way to get functionality

- From functionality to signal flow by means of case studies

Teaching Mechatronics & Software Development 1

- Mechatronics at FHJ – development of a clutch control
- Automotive software development process, V-Model, Model-In-The-Loop, Hardware-In-The-Loop
- Application via CAN: CCP/XCP – a key to watch signals and set parameters in real time

Teaching Mechatronics & Software Development 2

- Setting up a mechatronic system
- Simulink as a program language and it's environment
- CCP/XCP integration

**Hands-on training:
a teaching concept for each partners' university**

- Introduction
- **ALL**: Preparation + Q&A
- **ALL**: presentation of results and

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What is Mechatronics?

A better way to get “smart” Machines with new functionalities…

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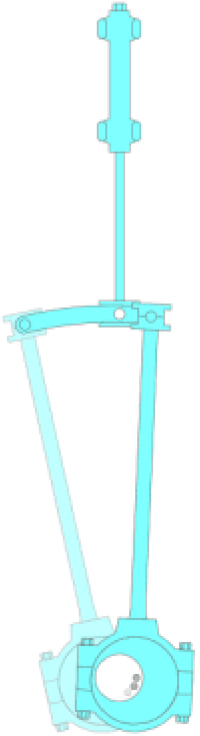
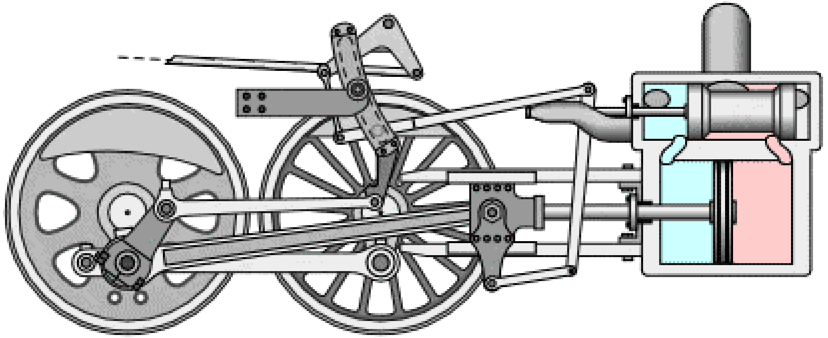
Stephenson didn‘t have Mechatronics …

- Functionality
  - Valve control with adjustable timing
- Solution
  - mechanically
- Advantage
  - robust
- Disadvantage
  - wear out, complex = high unit costs
  - change of timing = change of parts!

→ only limited intelligence is possible





https://www.wikiwand.com/en/Stephenson_valve_gear

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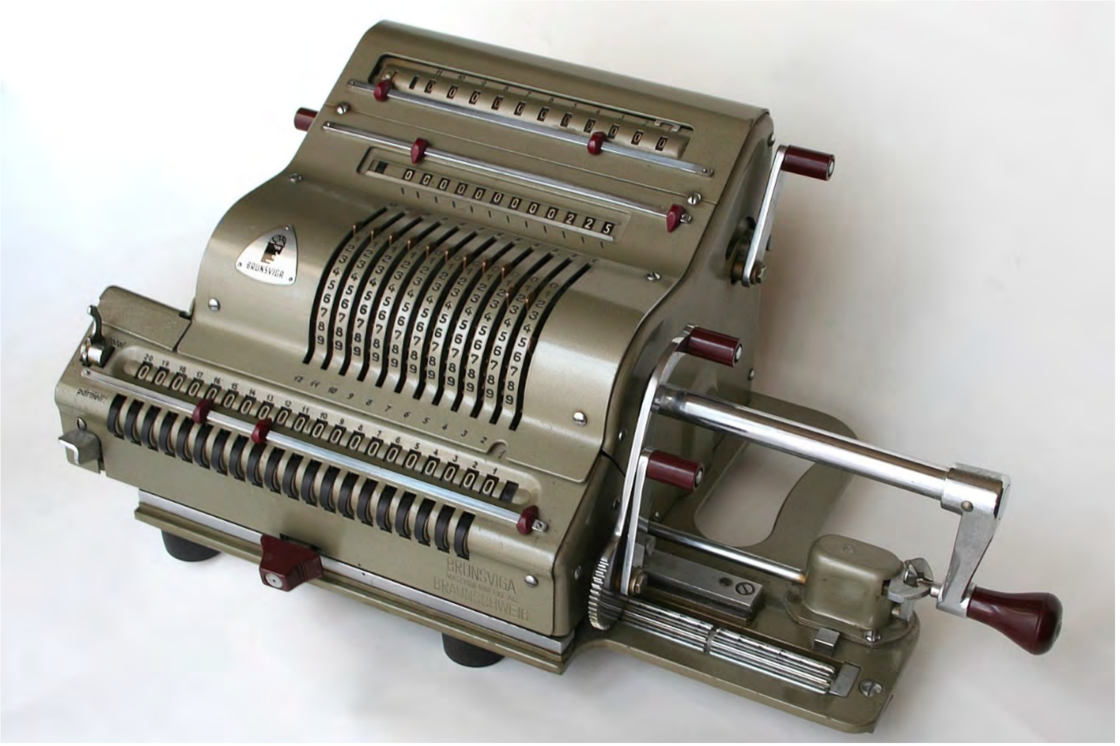
Limited Intelligence?

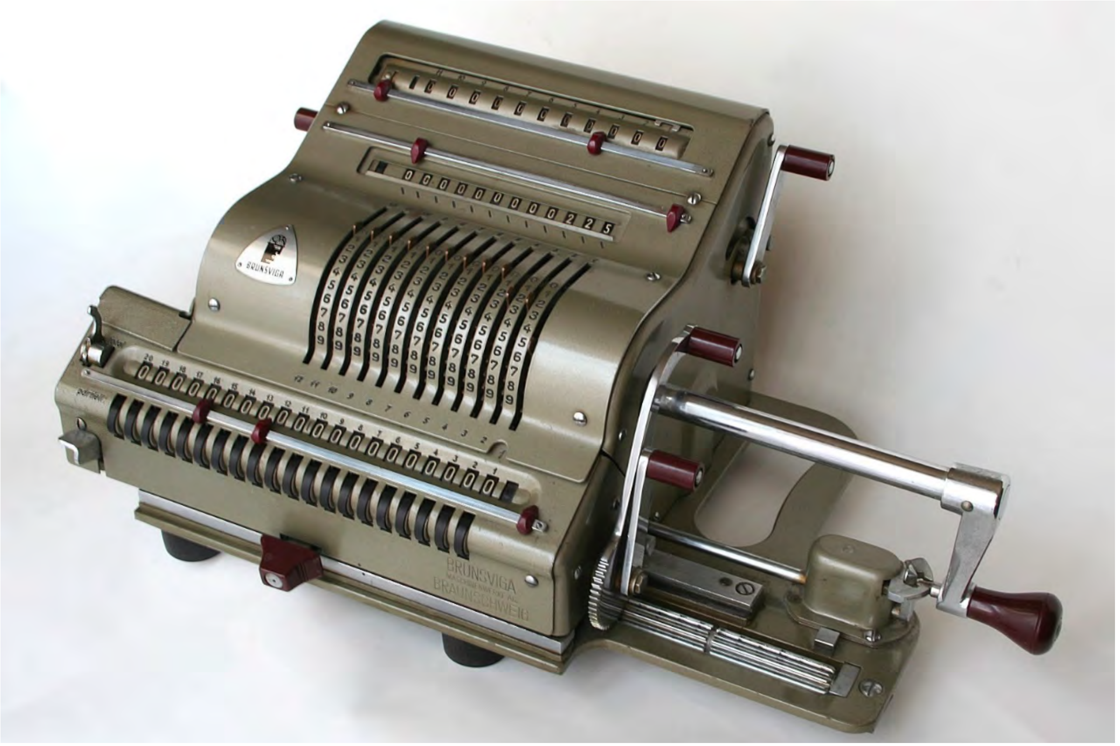


https://de.wikipedia.org/wiki/Vier-Spezies-Maschine

https://de.wikipedia.org/wiki/Samsung_Galaxy_Note

Limited Intelligence?

YES, intelligence was limited …



https://de.wikipedia.org/wiki/Vier-Spezies-Maschine

https://de.wikipedia.org/wiki/HP-41C

https://de.wikipedia.org/wiki/Samsung_Galaxy_Note

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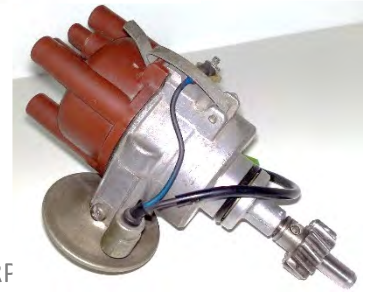
How do you want to solve this task?

Optimization of combustion process

- fuel mixture
  - Bernoulli equation
  - temperature sensitive switch
  - …
- Ignition
  - membrane
  - centrifugal force



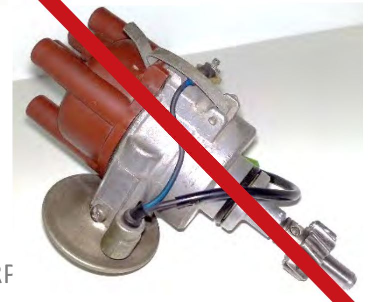
Accurate enough?

Pictures [Wikipedia]

How do you want to solve this task?
Solve complex tasks by software

Optimization of combustion process

- Measure/estimate all significant state variables
- Model based processing
- Set Action
  - ignition
  - throttle
  - injection,
  - …

Pictures [Wikipedia]

Measure air mass and Temperature

Measure residual oxygen

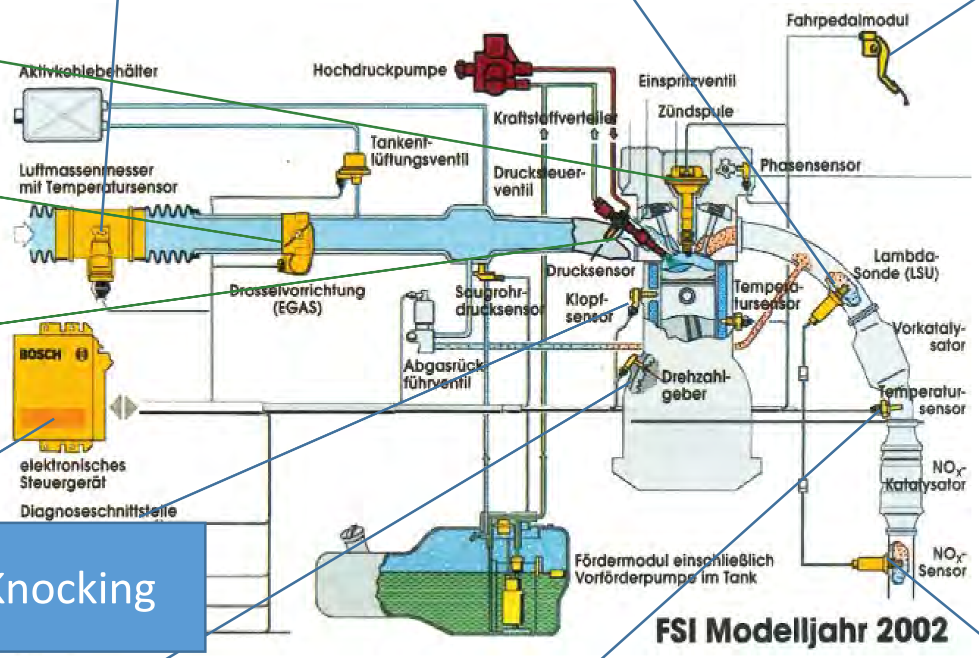
Measure Drivers Request

Set ignition timing

Set air mass e-Throttle

Set fuel mass Injection

CPU + SW



Detect Knocking

Measure Speed & Crank Angle

Measure Exhaust Gas Temp.

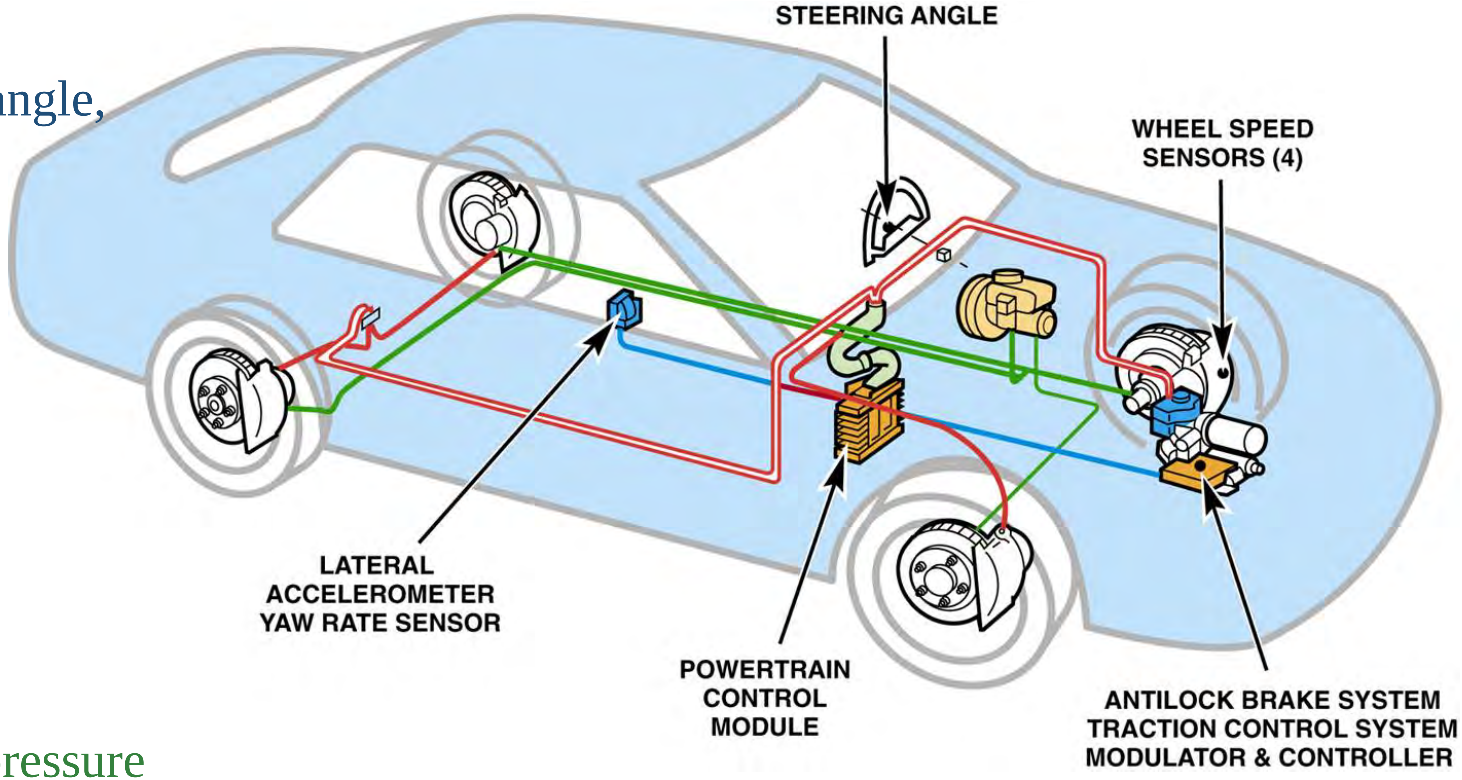
Measure residual NOx

[Base Picture: VW, Bosch, Internet, ZAWM Belgien]

Example: Antilock-brake-system

avoid exceeded slip to be able to steer while emergency brake

- Vehicle State Estimation
  - wheel speeds, steering wheel angle, lateral acceleration,
- Drivers Request
  - steering wheel angle
  - brake pressure
- ECU
  - Estimation of wheel slips
  - Compare to requested slips
  - Limit brake pressure
  - Safety
- Actors
  - controlled valves limit brake pressure
  - pump for continuous braking



https://www.bwigroup.com/product/antilock-brake-systems/

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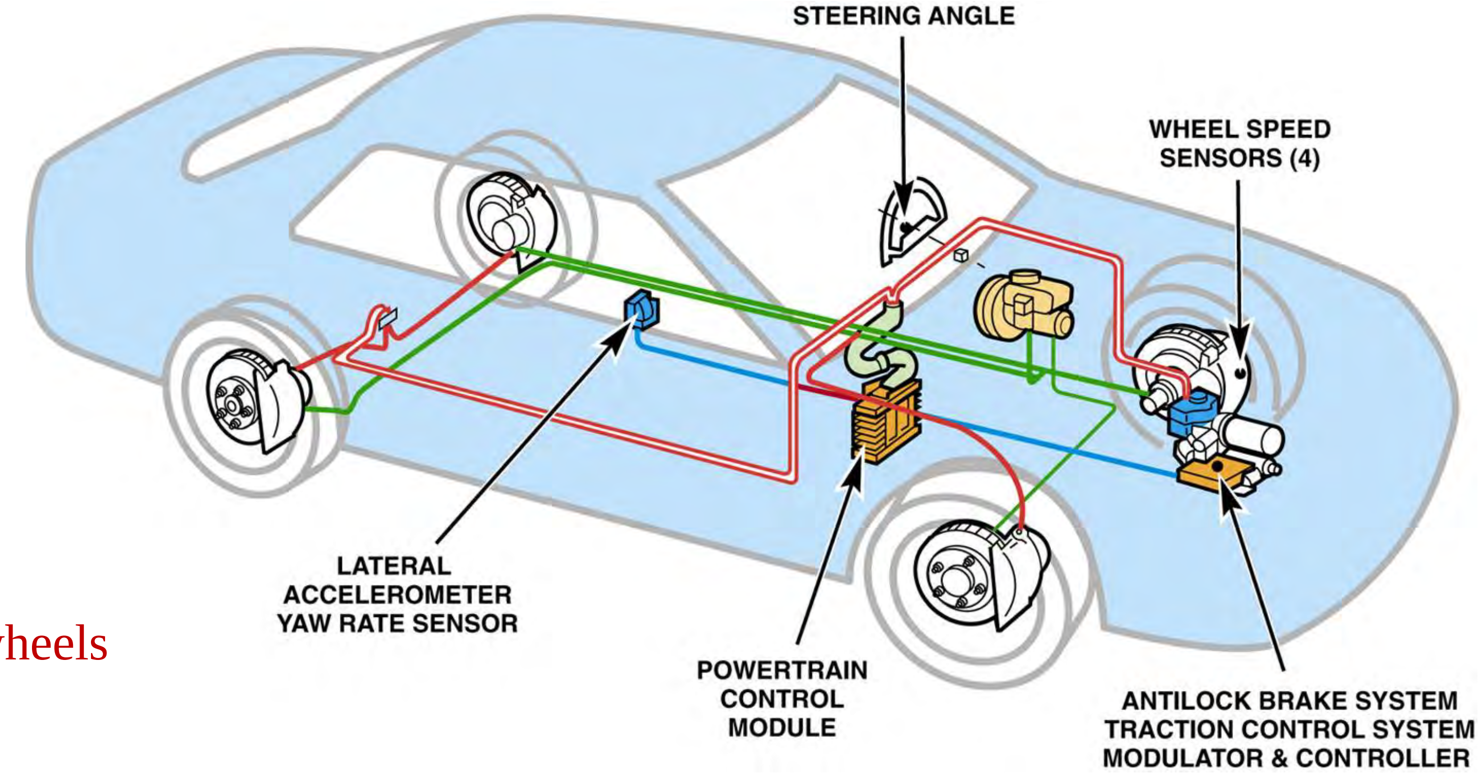
Example: Electronic Differential Lock

avoid spinning of a wheel at μ-split to increase traction

- Vehicle State Estimation
  - Anti-Lock-System sensors
  - engine torque
  - yaw rate
- Drivers Request
  - Anti Lock Sensors
- ECU
  - Anti Lock Function +
  - Calc. brake torque
  - Avoid hot brakes
  - Set brake pressure at single wheels
- Actors
  - Anti Lock System +
  - 2 additional valves for pressure build up



https://www.bwigroup.com/product/antilock-brake-systems/

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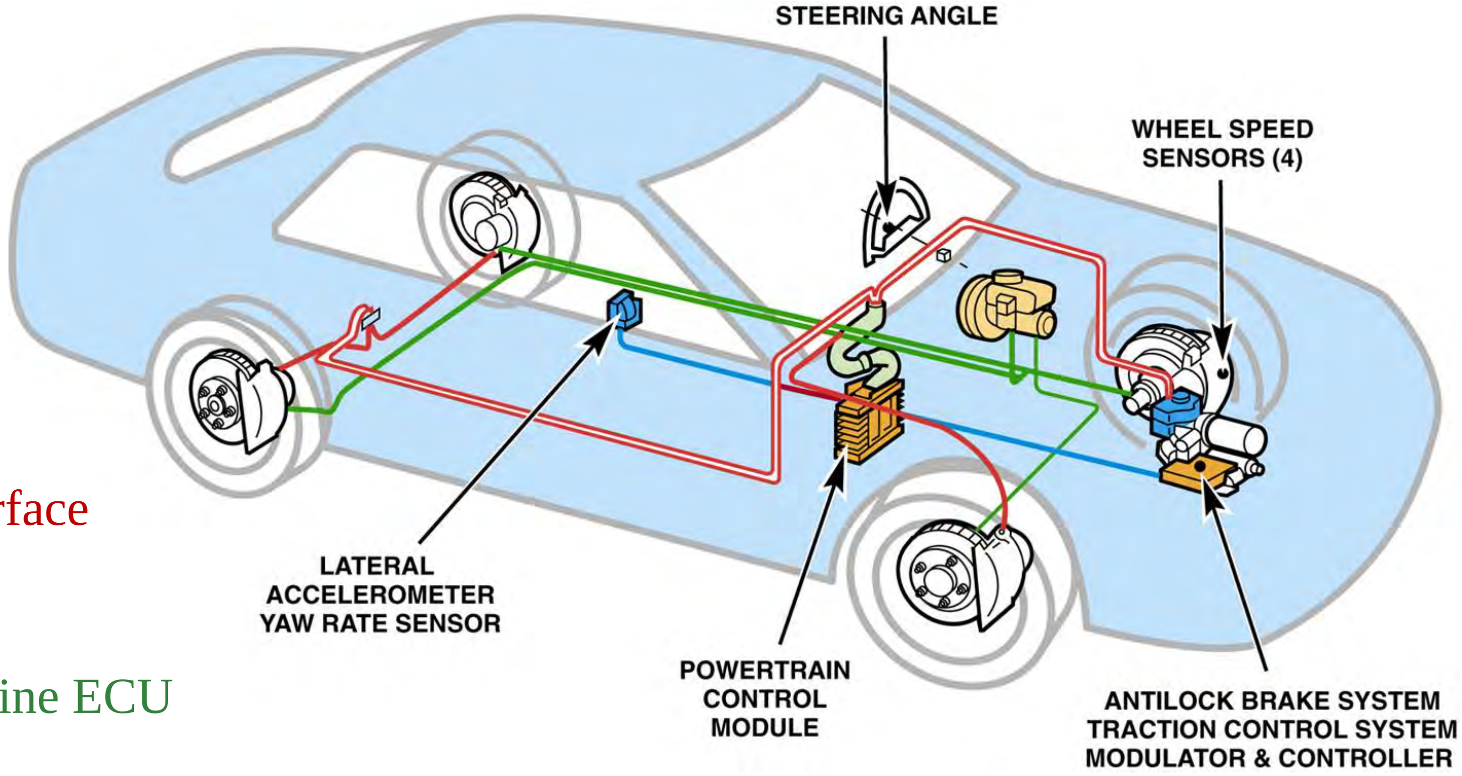
Example: Traction Control

avoid spinning of both driven wheels at µ-low

- Vehicle State Estimation
  - system above
- Drivers Request
  - system above
- ECU
  - system above
  - limit engine torque model
  - Max. engine torque CAN interface
- Actors
  - system above
  - + Max. torque interface at engine ECU
  - + electronic throttle

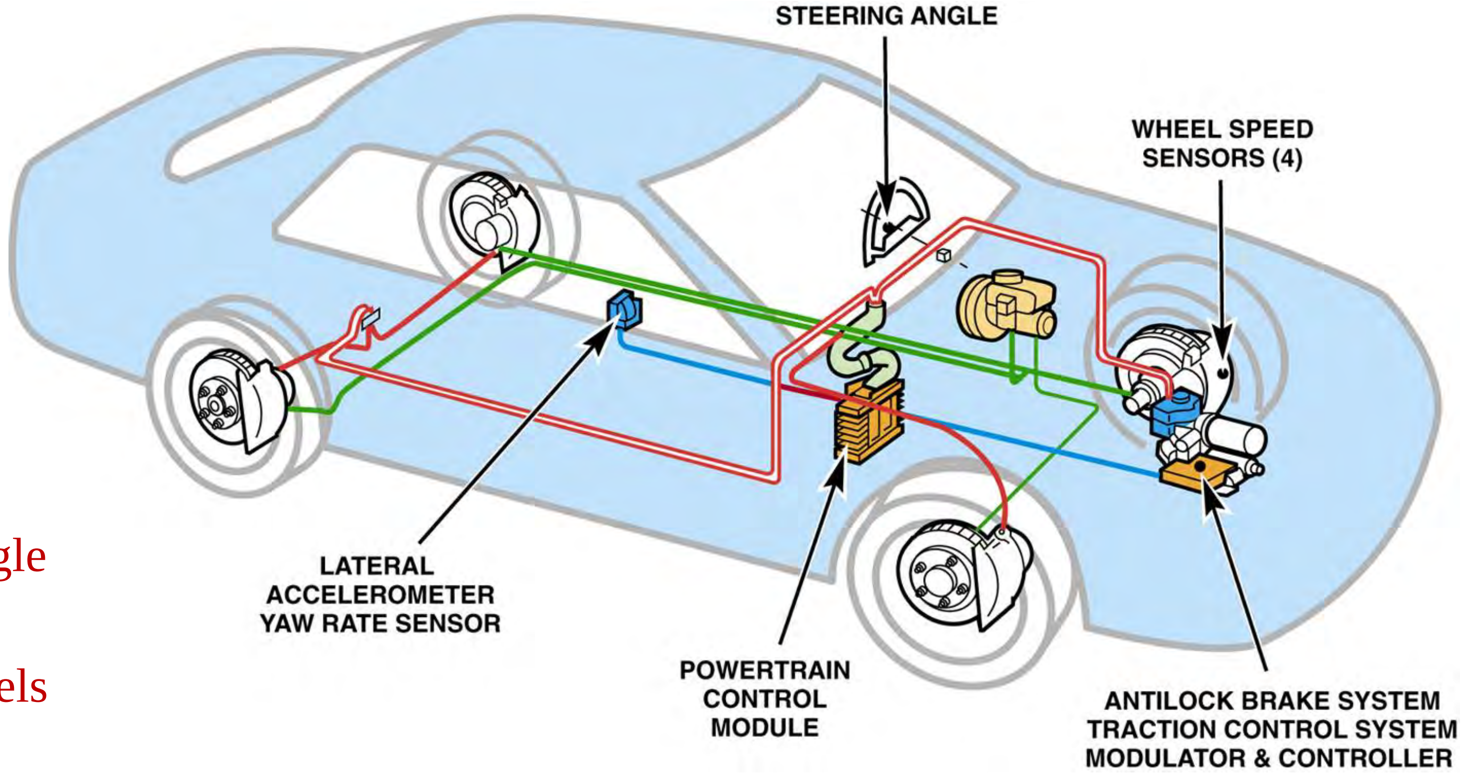


https://www.bwigroup.com/product/antilock-brake-systems/

Example: Electronic Stability Control

avoid excessive over/understeering and skidding

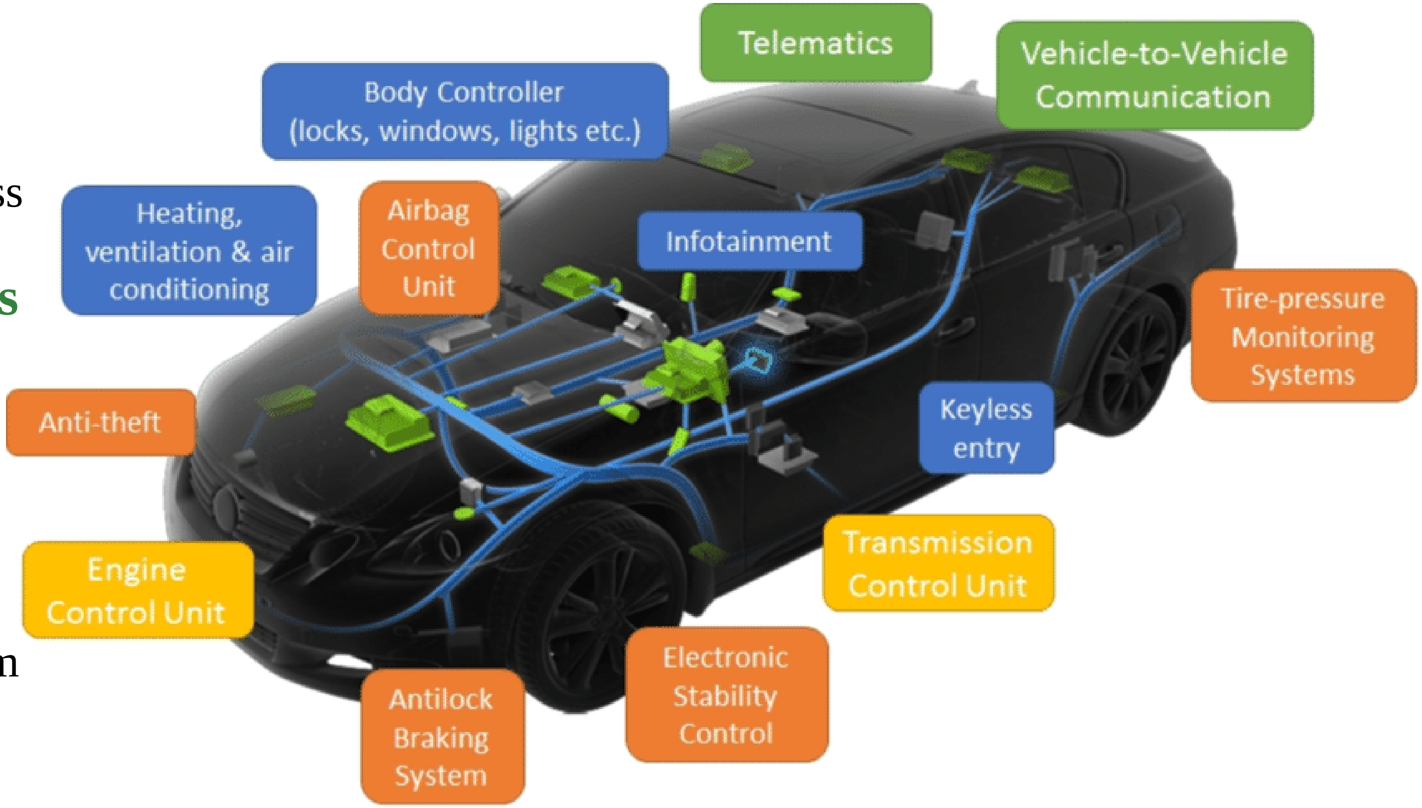
- Vehicle State Estimation
  - system above
- Drivers Request
  - system above
- ECU
  - system above
  - estimate actual body slip angle
  - estimate requested body slip angle
  - limit engine torque
  - set brake pressure at single wheels
- Actors
  - system above



https://www.bwigroup.com/product/antilock-brake-systems/

There are many Subsystems in a modern Car, they are connected.

- **Share Sensors**
  - e.g. wheel speed sensor
  - acquired by Anti Lock - ECU
  - used by speedometer/odometer, gear box control, clutch control, …, loudness of radio
- Simple Interfaces: **Smart Subsystems**
  - power
  - BUS-Connection for signals
- **New functionalities** by smart connection
  - cornering lamp = smart fog lamp lightening inner corner
  - close window by central locking system
  - …
- **Unique Selling Point**



https://www.researchgate.net/publication/320198036_Security_Concerns_in_Co-operative_Intelligent_Transportation_Systems

IEEE/ASME's view of Mechatronics?

„Mechatronics is the synergetic integration of mechanical engineering with electronic and intelligent computer control in the design and manufacturing of industrial products and processes"

Definition in IEEE/ASME Trans. on Mechatronics (1996)

[Moheimani S.I.R.: Editor-In-Chief, Mechatronics; ELSEVIR https://www.journals.elsevier.com/mechatronics, 20.01.2020]

Synergetic Integration

- Better solutions as each single domain.

Mechanical Engineering

- … designs the body itself.

Electronics

- … to sense and to move.

Intelligent Computer Control

- Makes the mechanical thing intelligent to perform complex tasks automatically
- provides simple interfaces between subsystems

Industrial Products and Processes

- Intelligent products can transact complex processes.

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Embedded System

- Computer embedded in a technical context doing automation tasks
- Often in background, invisible for customer

- Capturing System States
  electronic sensors, fast & accurate,
  transform physical quantities to electrical signals or electronical signals (BUS)
- Information processing
  - Data Acquisition: transforms electrical signals to variables
  - Data Preparation: determines physically based variables
  - Data relationship:
    calculate signals based on logic, equations and characteristics using engineering’s view of physics to get proper function
  - Set Action: Digital output using PWM or BUS-signals
- Actuators
  put energy to the signals to impact the system

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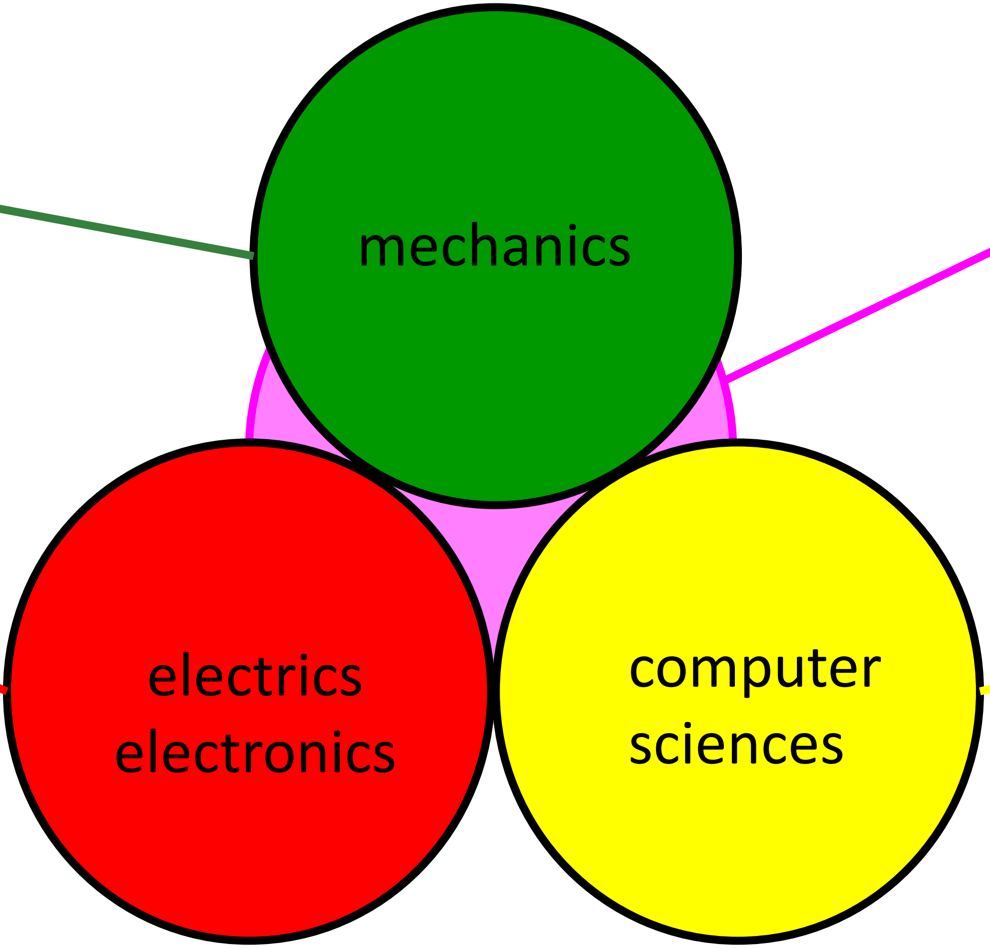
Mechatronics – The Tasks of the Domains

UNITED

MECHANICS = the body
- transfers forces
- covers from environment
- defines the design

ELECTRONICS
- sense/transfers signals
- A/D conversion
- computing of software
- D/A conversion
- signals interfaces (BUS)
- converts signals to power



Mechatronics = "Cement" for a holistic product
- systems engineering
- control theory

Software = Intelligence
- provokes signal conversion
- data preparation
- model based data relationship
- provokes signal outputs

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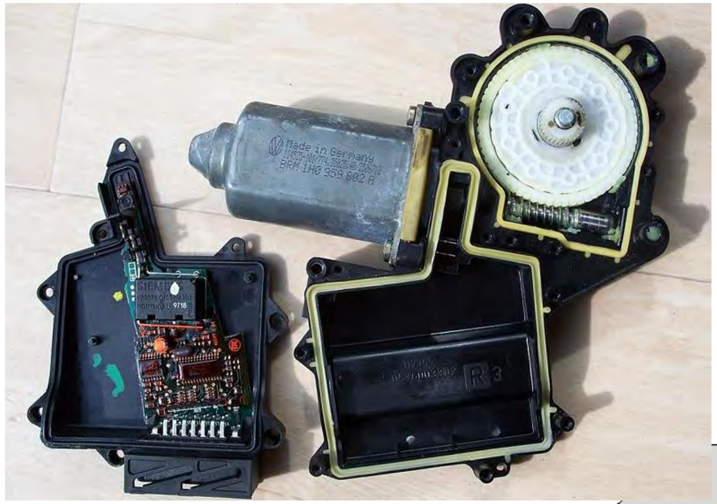
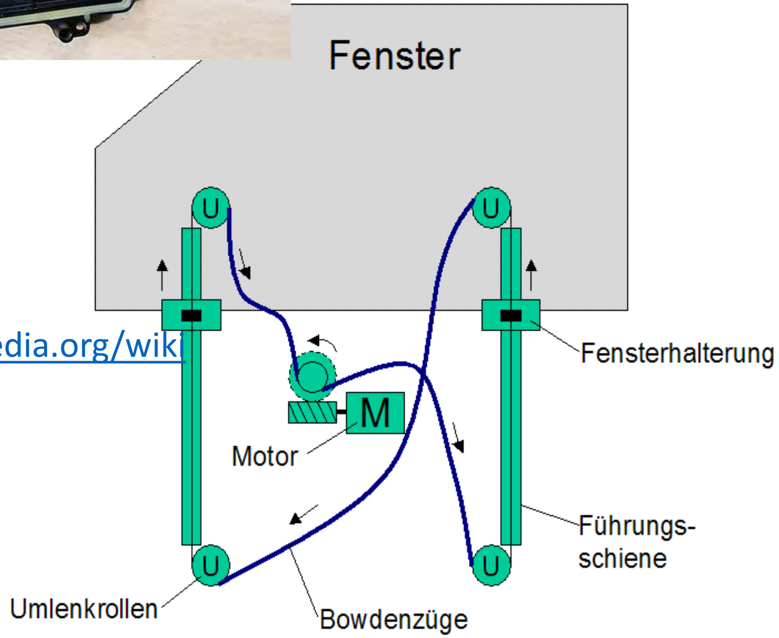
E.g. Power Window

[Picture: K. Reisinger]





[https://de.wikipedia.org/wiki/Fensterheber]

Base Functionality:

- open/close the window as long as a push button is pressed.
- driver or passenger can operate

Hazards

- **clamping hands, heads!**
- the driver takes care
- deactivate when ignition is off (driver is absent)

Solution

- spring loaded switch with opening and closing contacts to avoid shortcut
- **No Mechatronics needed**.

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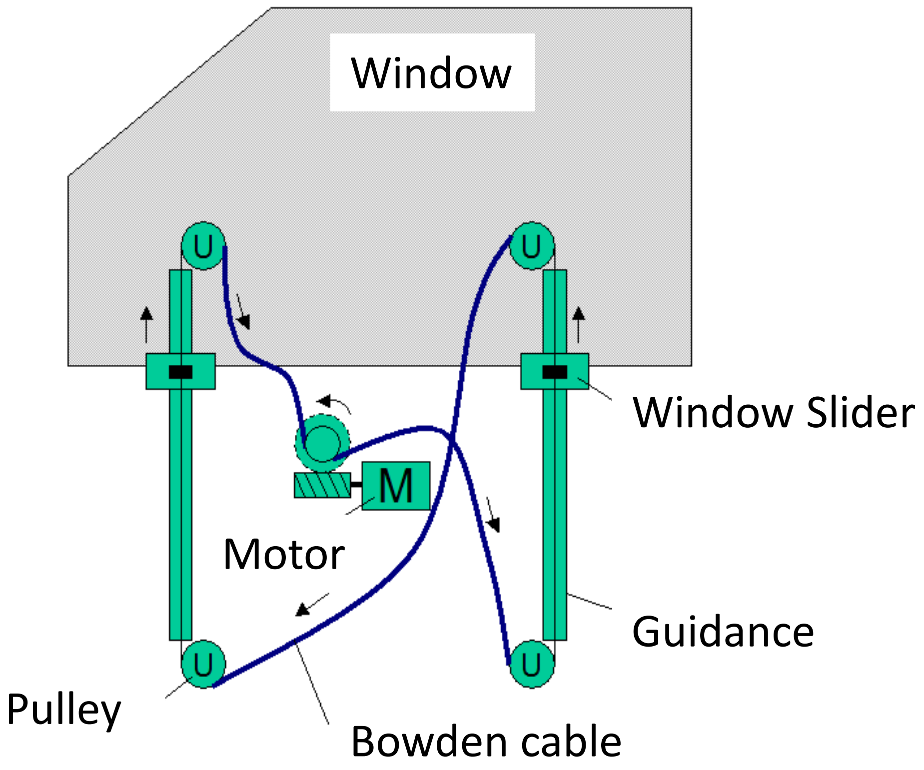
E.g. Automatic Power Window 1



Better Functionality:

- open/close the window automatically triggered by pressing a push button.
- driver or passenger can operate

Hazards

- **clamping hands, heads!**
- the smart system must take care!
- How?

Task break down

- detect clamped objects
- stop closing when detected

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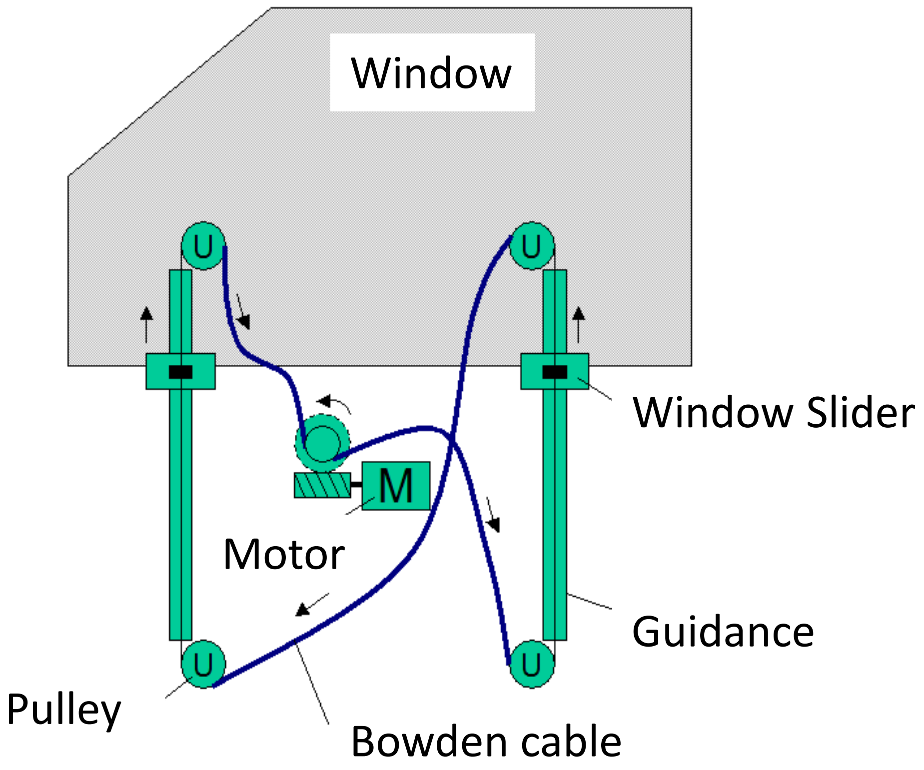
E.g. Automatic Power Window 2



detect clamped objects

- detect force at the frame
  - air filled sensor hose + pressure sensor
  - How to check periodically?
- measure closing force
  - force sensors at the sliding guidance
  - force sensors in Bowden cable
  - measure support torque of motor
  - torque measurement in Bowden wheel
  - determine motor's shaft torque
  - …

stop closing when detected

- open a gap
- switch off the motor

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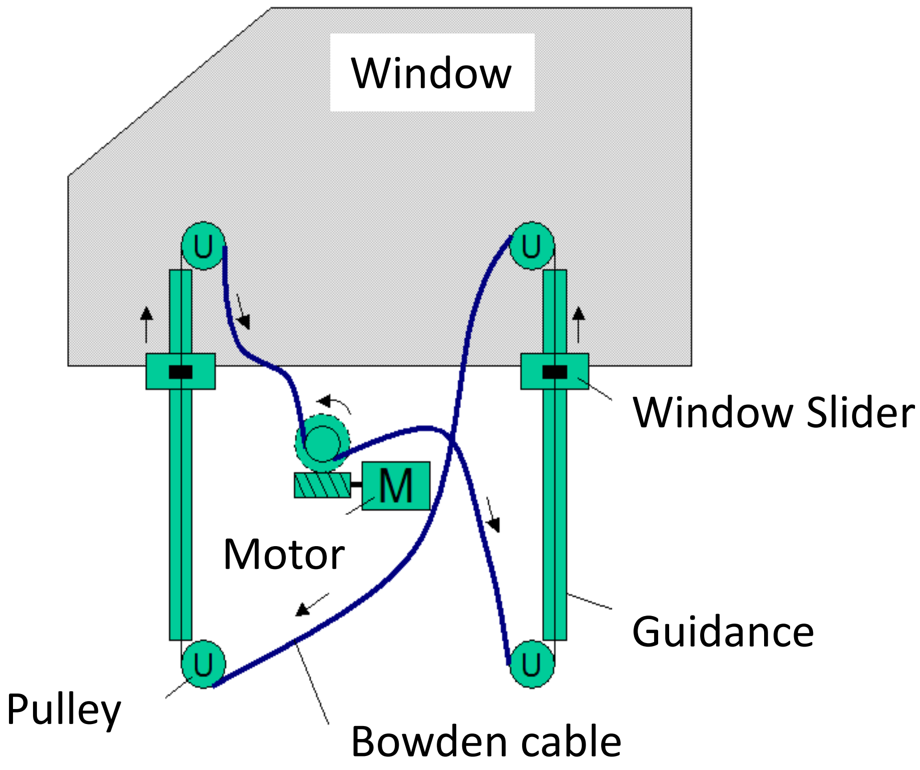
E.g. Automatic Power Window 3



detect clamped objects by determination of motor's torque

- measure motor's shaft torque
- estimate motor shaft's torque
  - $J \frac{d\,\omega}{dt} = +k_t \cdot i(t) + M_{shaft}(t)$
  - Measure motor current $i(t)$
    using a shunt internal in control unit
  - Measure speed ω
    using an incremental speed sensor
  - derive speed numerically in respect to time

  →Control Variable $M_{shaft}(t)$
  →Intelligence in Software of ECU
  →Simple, cheap, robust sensors used

→Mechatronic System with Added Value

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Mechatronic Workflow for new Products

UNITED

- **Disengage yourself from a known solutions!**
- Which **functionality** do we want?
  - define requirements
- Is there dangerous behaviour to avoid
  - **Hazards** → Safety Requirements
- Which signals do we have to sense to know the systems state?
  - **input signals**
  - How can we get them? (directly or using physically laws)
- How can we influence the system in the proper way
  - output signals / actions
  - how can we do that?
- Start designing a concept mechanically …

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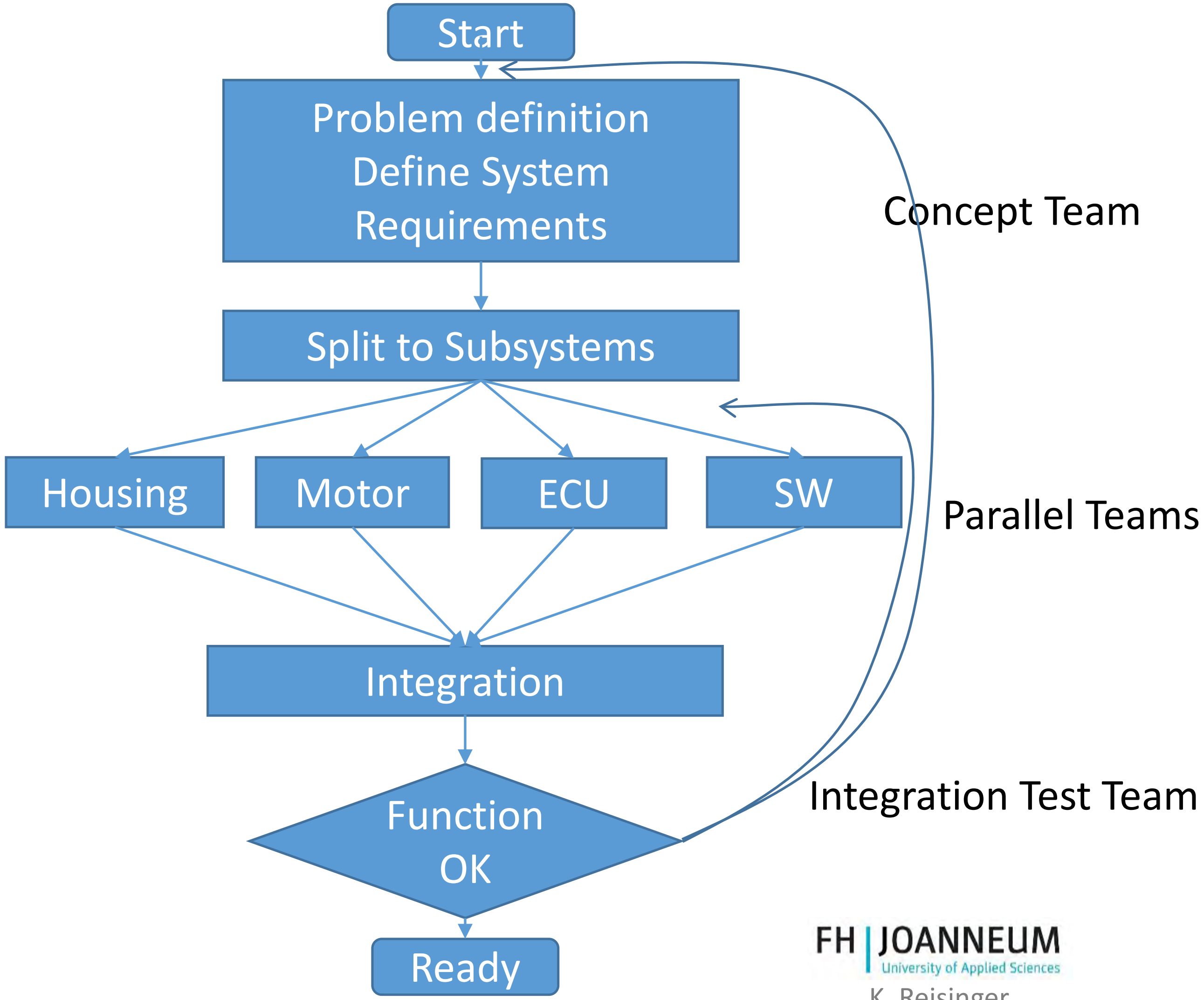
Development of a Mechatronic System

- Automotive Development is done by a lot of teams /companies in parallel
- At the SOP ALL must be ready!
- It is crucial to define, what we want!
- Make safe tiny, safe steps to reach the goal at time.



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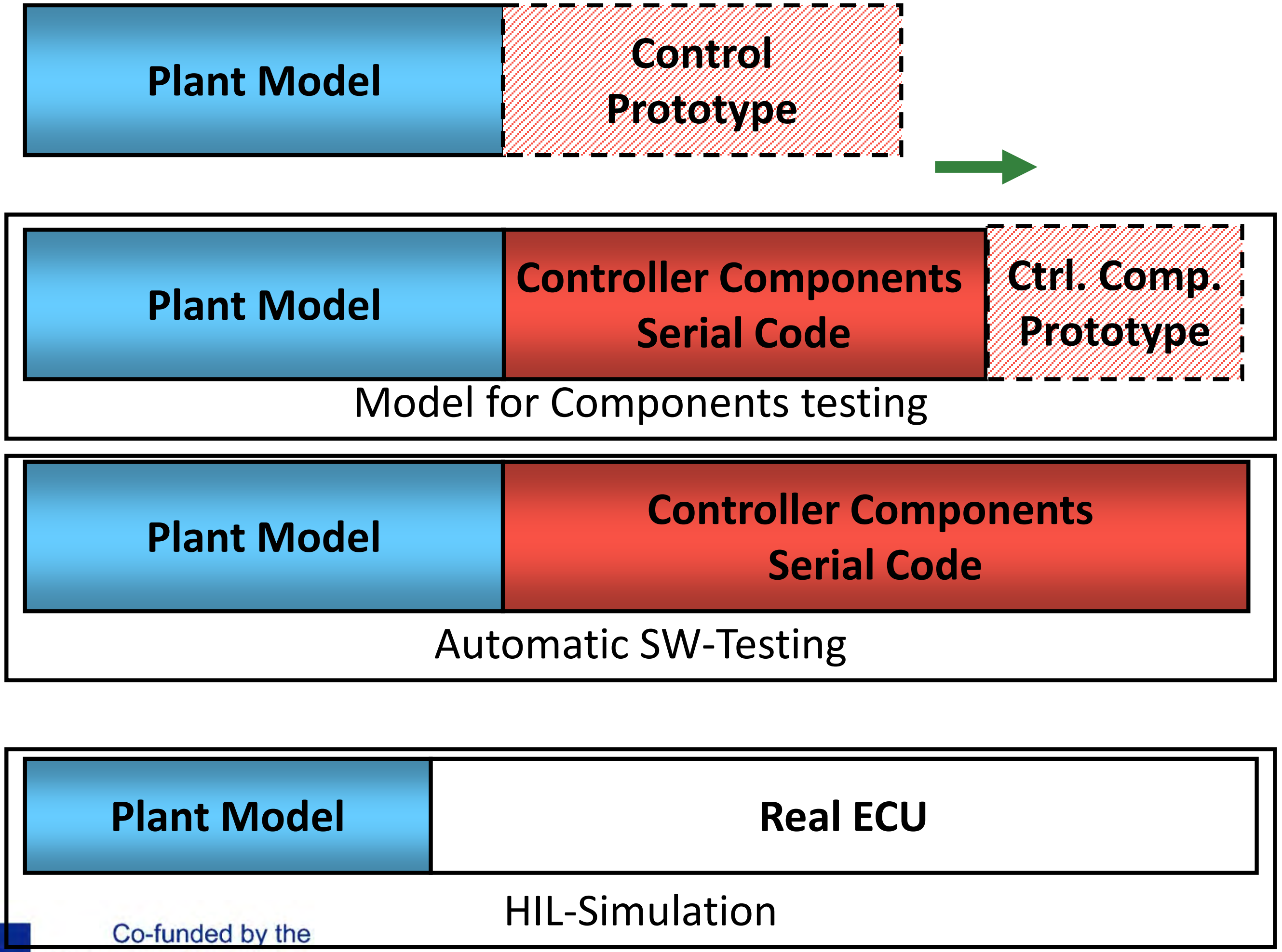
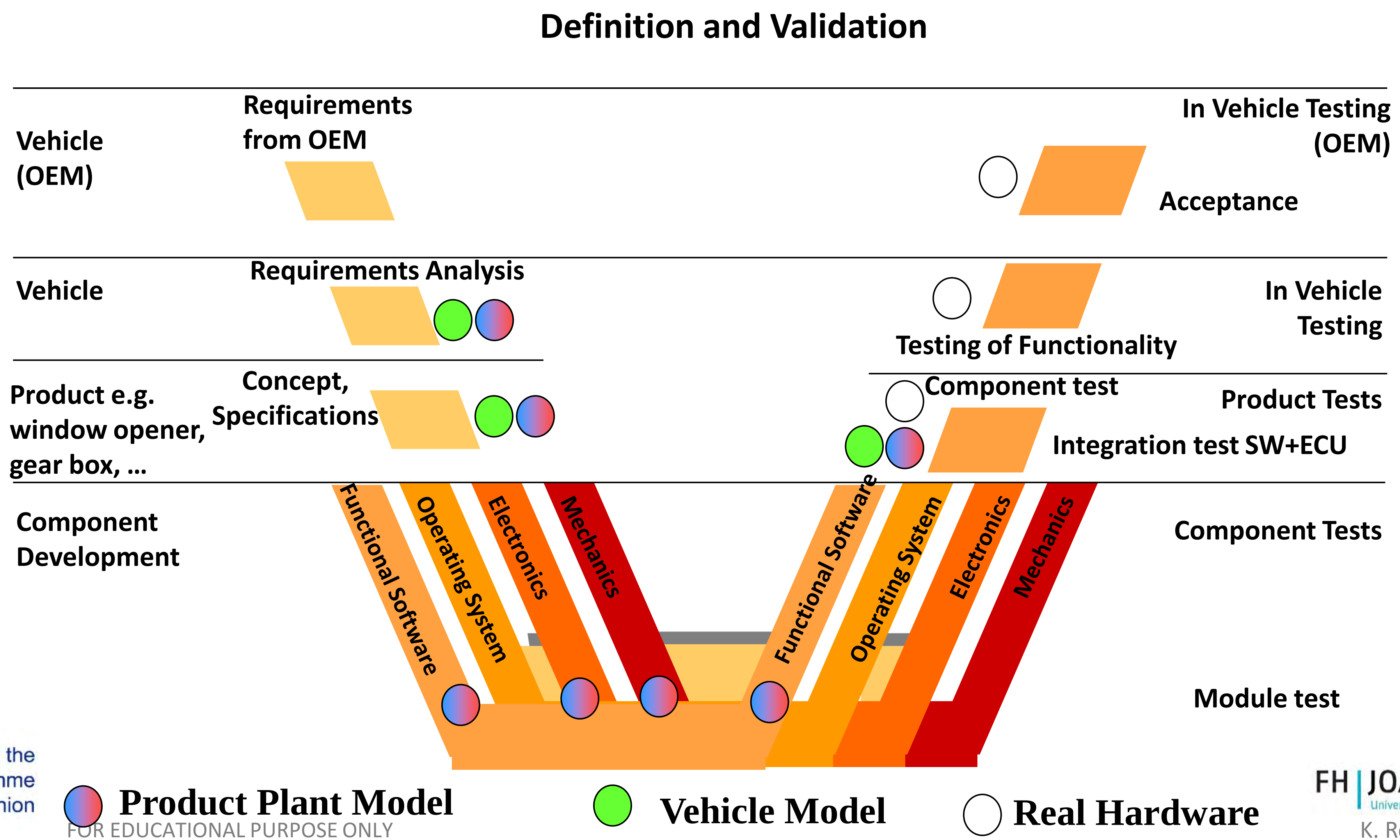
Model Based Design Process



- **Model based**: a simulation model accompanies the Development
- Model In the Loop for feasibility
  - Plant + Prototype
- Software Modules
  - Plant + parts of Prototype
- Software In the Loop
  - Plant + Serial Software
- Hardware In the Loop
  - Real ECU

Usage of Simulation Models



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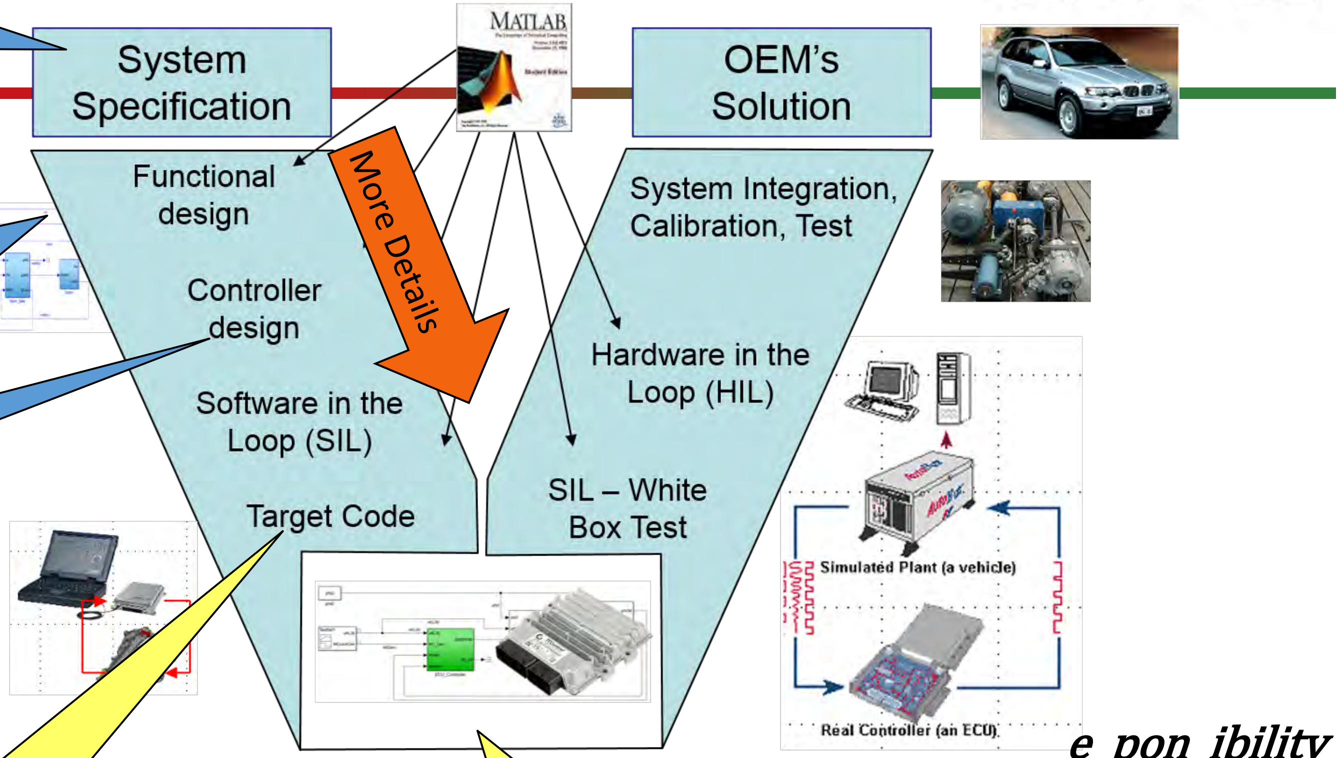
V-Model for Software Development

Feasibility Simulink Model of plant & controller + Documentation

Software Specification
Simple model of Controller, Requirements definition

Model In the Loop
Model of Simulink Software (ideal) against simulated improved plant model.



Software Design
Module split,
→ re-usable, testable

Programming
Simulink Software
→ (automatic) C-Code generation.

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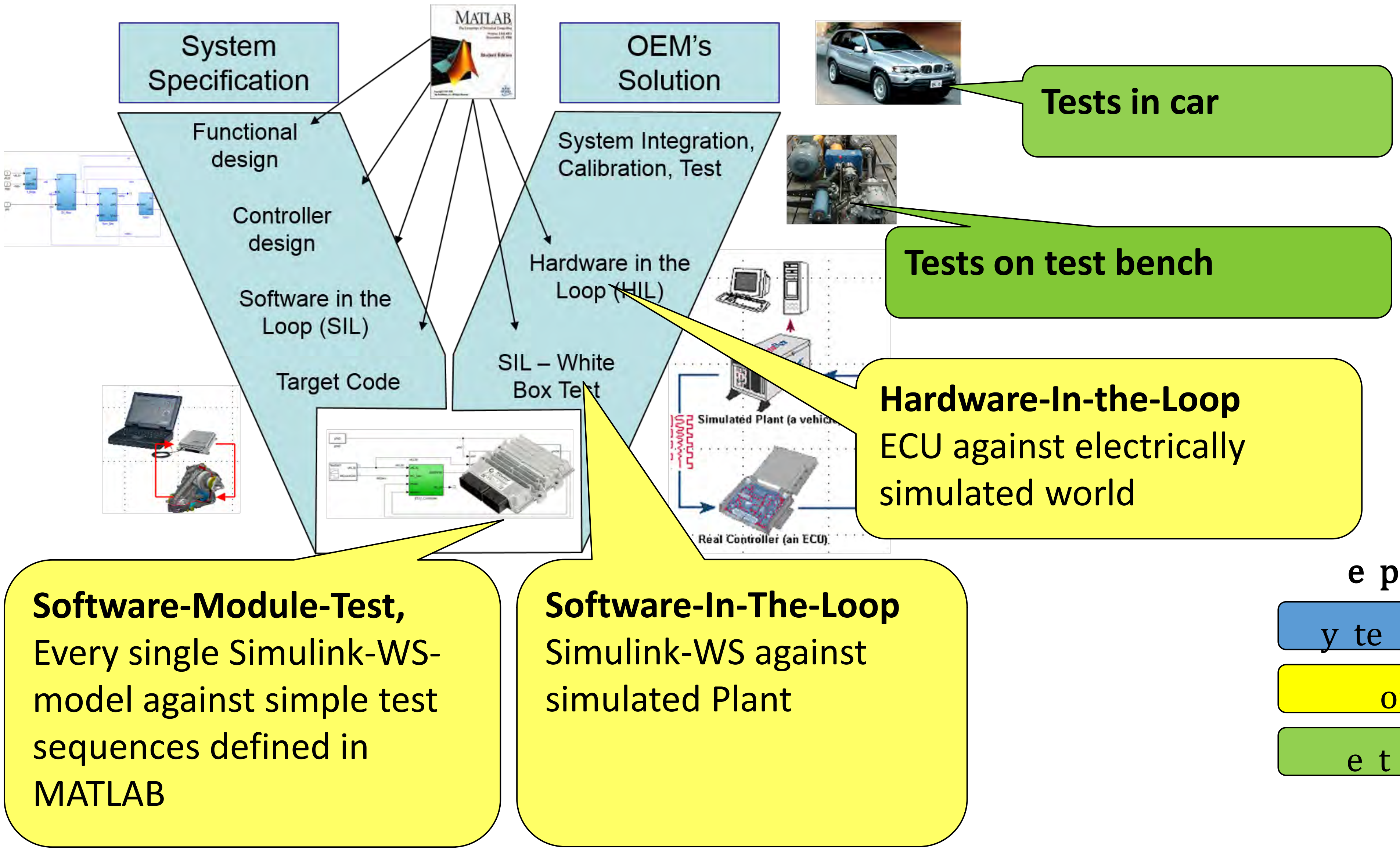
UNITED



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SPICE

- Software Process Improvement and Capability Determination ISO/IEC 15504
- helps fulfilling [1)]
  - Functionality
  - Reliability
  - Usability
  - Efficiency
  - Maintainability
  - Reusability

Goals

- constant development quality
- clear communication between engineers
- avoid to do the same error twice

- uses V-Model

You must fulfil SPICE standard to deliver an European OEM!

1) [ISO 9126, Spillner A., Linz T.: Basiswissen Softwaretest]

Functional Safety, ISO 26262

Avoid ability by operator

Severity to humans

probability probability probability

Increasing development and test effort

Risk matrix ISO/DIS 26262-3		C - Controllability		
S - Severity	E - Exposure	C1	C2	C3
S1	E1	Q[illegible]	QM	QM
	E2	[illegible]	QM	QM
	E3	QM	[illegible]M	ASIL A
	E4	QM	[illegible]	ASIL B
S2	E1	QM	[illegible]	QM
	E2	QM	[illegible]	[illegible]SIL A
	E3	QM	ASIL [illegible]	[illegible]B
	E4	ASIL A	ASIL B	[illegible]IL C
S3	E1	QM	QM	ASIL A
	E2	QM	ASIL A	ASIL B
	E3	ASIL A	ASIL B	ASIL C
	E4	ASIL B	ASIL C	ASIL D

Requirements Management

- Aim
  - describe the functionality unambiguously
  - and testable (=measurable)
- Requirements Management System gives answers to…
  - Which functionality has which development status
  - Which functionalities are OK yet?
  - Which System Requirements can not be fulfilled, if a subsystem /component fails or is changed?

DOORS (***D****ynamic* ***O****bject* ***O****riented* ***R****equirements* ***S****ystem*) is one of the commonly used requirement management systems.

https://en.wikipedia.org/wiki/Rational_DOORS

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Software and Bugs

- Failure .. result/behaviour which is not wanted
  → What do you want? Define Requirements before coding !
- In contrary to mechanics / electrics software has now wear out.
- Failures in software are caused by faults
  →De-Bugging
  find the cause of a failure and fix it

- Aim of Software Development Process is to avoid critical failures totally and reduce others
  - Define requirements clearly
    - Requirements Management
  - structured, clear coding
    - structure easy to read, remarks
    - static testing, coding rules, …
  - testing against requirements
    - find failures
  - Quality Management
    - Avoid doing an error twice

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Software Development

- "How many lines did you code today?"

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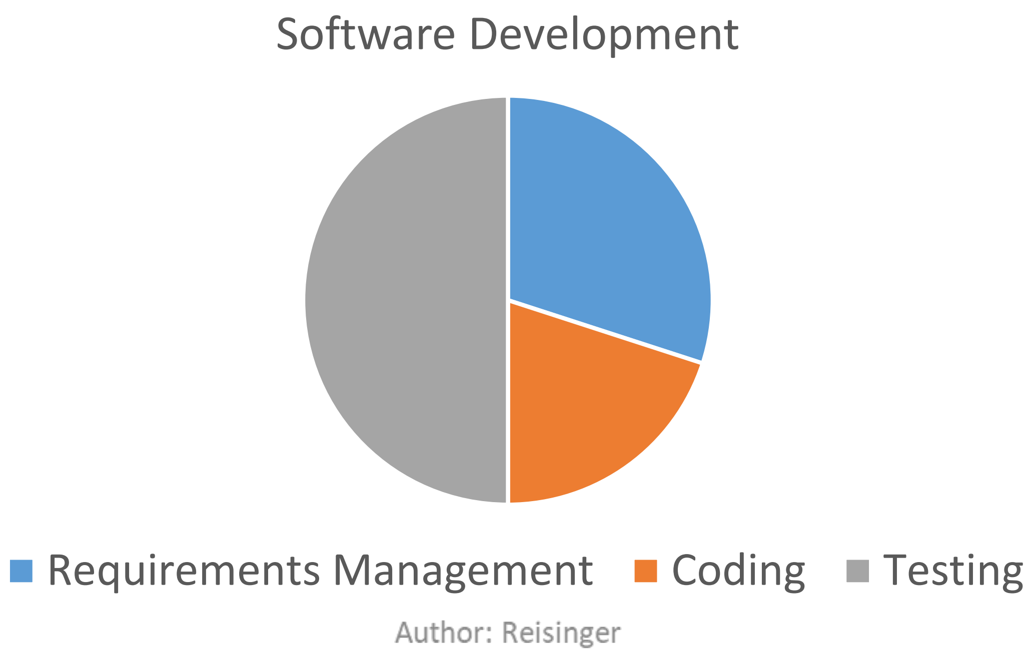
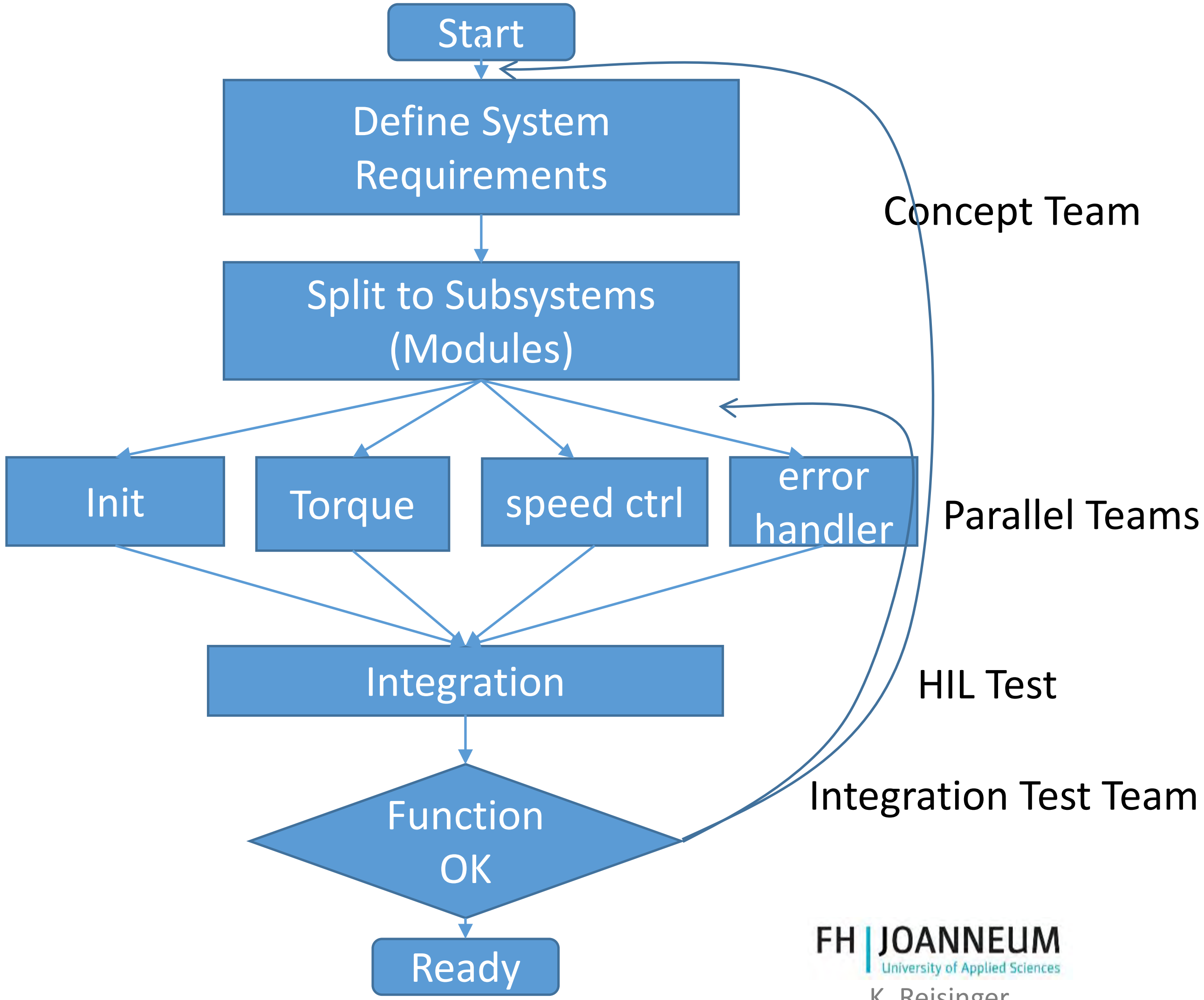
Software Development

- ~~"How many lines did you code today?"~~





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Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Data transfer using Digital Bus Systems

K. Reisinger

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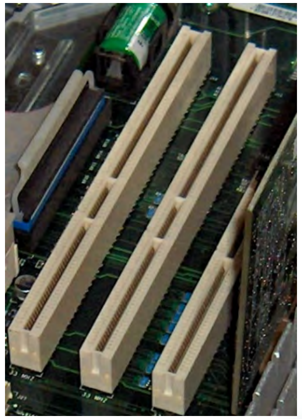
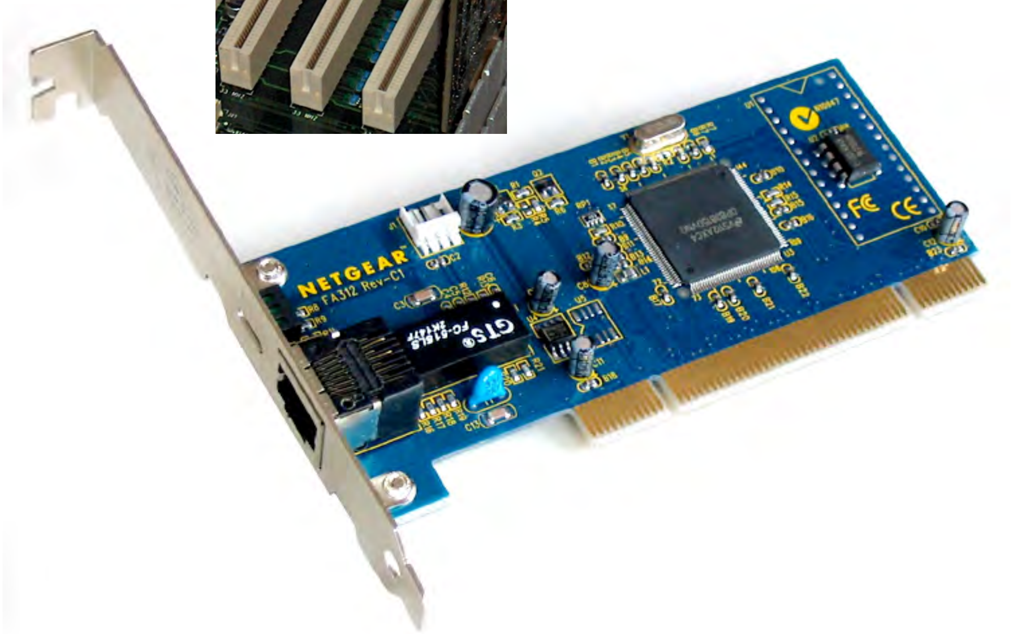
Parallel Bus

- PCI-Bus
  - Peripheral Component Interconnect
- Address data and signal data are transferred in parallel at different electrical lines
  - Up to 124 pins in PC
- Not for wide distances!





[https://de.wikipedia.org/wiki/Peripheral_Component_Interconnect]

Drivetrain bus system of a passenger car

- Used for
  - 1 sensor shared for different ECU‘s
  - Sensor-ECU-connection
  - ECU dashboard connection, …
- Serial bus systems
  - 1 or 2 wires for robust data transfer
- Additional
  - Low speed CAN for interior …
- No Parallel Bus in cars
  - → Serial Data Transfer at 2 lines

Picture e.g.
https://canbuskits.com/images/diag_canbus2.jpg

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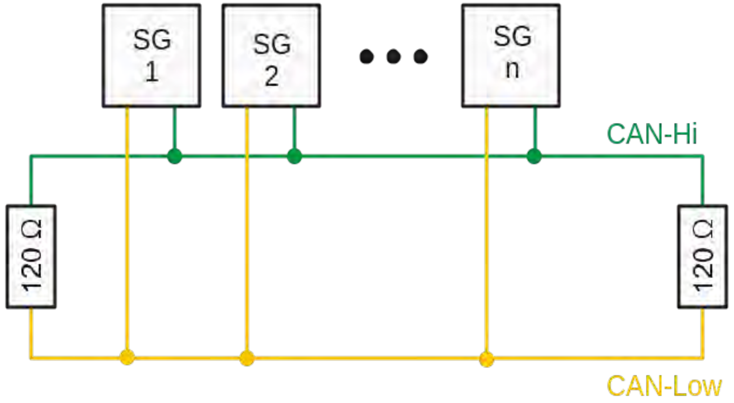
Bus systems 1

- CAN-Bus (Control Area Network)
  - High-Speed-CAN , 250kBit/s, 500kBit/s, 1MBit/s
  - Low-Speed-CAN, <= 125kBit/s
  - Serial, members are not synchronized to each other
  - Non deterministic data transfer (no exactly defined transfer rate)
  - Unshielded twisted pair of 2 wires with termination resistors at both ends.



[Picture https://de.wikipedia.org/wiki/Controller_Area_Network#/media/Datei:CAN-Bus_Elektrische_Zweidrahtleitung.svg]

Bus systems 2

- CAN-FD
  - between 1 MBit and 10 Mbit [1)]
  - CAN + flexible data rate
  - compatible to CAN-members
- FlexRay
  - > 10 MBit [1)]
  - Deterministic data transfer possible
  - Mechanism for safety relevant data
  - Unshielded twisted pair of 2 wires of high quality

1) Ways to transition from classic CAN to the improved CAN FD

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Bus systems 3

- Automotive Ethernet
  - Ethernet, IP-based communication
- MOST-Bus
  - Media Oriented Systems Transport
  - High data rates, low safety
  - Cable or optical fibre
- LIN-Bus
  - simple
  - Communication ECU – Sensor – Actor
  - Single wire (+ supply + GND to sensor makes 3 wires)

More: see https://elearning.vector.com/?lang=en

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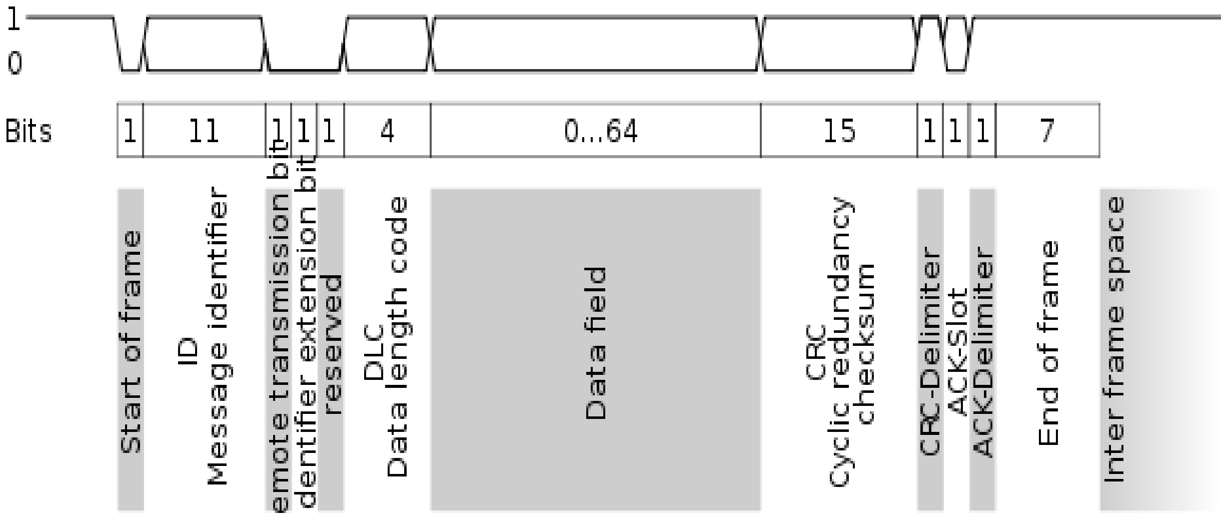
CAN-BUS

- Standardized are
  - Wiring harness, Voltage level,
  - Frames for address and data transfer



[https://de.wikipedia.org/wiki/Controller_Area_Network]

- Company Secret is
  - Which signal is sent? How are the signals coded? Resolution, voltage level of signals …
- If we want to read CAN-Data
  - CAN-Database / Flexray-Database is necessary
  - *.dbc-File, or EXCEL-Sheet.

  - You have to be a development partner of the OEM!

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Example CAN-DB Snow Mobile - Excel

Message	DLC	Signal	Startbit	Length	Order	Value Type	Factor	Offset	Min	Max	Unit	Table	Comment
MCU_to_BMS/ID 200	8	Motor speed	0	16	Intel	Unsigned	1	0	0	65000	rpm		
		Main_relay_ON	16	1	Intel	Unsigned	1	0	0	1	-	0 = Relay OFF 1 = Relay ON	BMS has to respect internal safety mechanisms
		not used	17	23	-	-							
		MCU_Temp	40	8	Intel	Unsigned	1	0	0	255	degC		
		MCU_status	48	8	-	-	-	-	-	-	-	Bit 0: driving Bit 1: charging	charger management done by MCU
		not used	56	8	-	-	-	-	-	-	-		
BMS_to_MCU_1/ID 201	8	Pack_Voltage	0	16	Intel	Unsigned	0,1	0	0	5000	V	total battery pack voltage	
		pack_Current	16	16	Intel	Signed	0,1	0	**-1000**	**1000**	A	total battery pack current < 0: discharge > 0: charge	
		SOC	32	8	-	Unsigned	1	0	0	100	%		from BMS SOC algorithm
		BMS_status_1	40	8	-	Unsigned	-	-	-	-	-	Bit 0: overvoltage warning Bit 1: undervoltage warning Bit 2: overtemperature warning Bit 3: overcurrent warning Bit 4: overcharge warning Bit 5: overdischarge warning Bit 6: repeated overdischarge Bit 7: isolation fault warning	
		BMS_status_2	48	8	-	Unsigned	-	-	-	-	-	Bit 0: single cell overvoltage Bit 1: single cell undervoltage Bit 2: signal error current sensor Bit 3: Finish charging request Bit 4: General hardware failure Bit 5: Communication error Bit 6: balancing active Bit 7: charge complete	
		not used	56	8	-	-	-	-	-	-	-		

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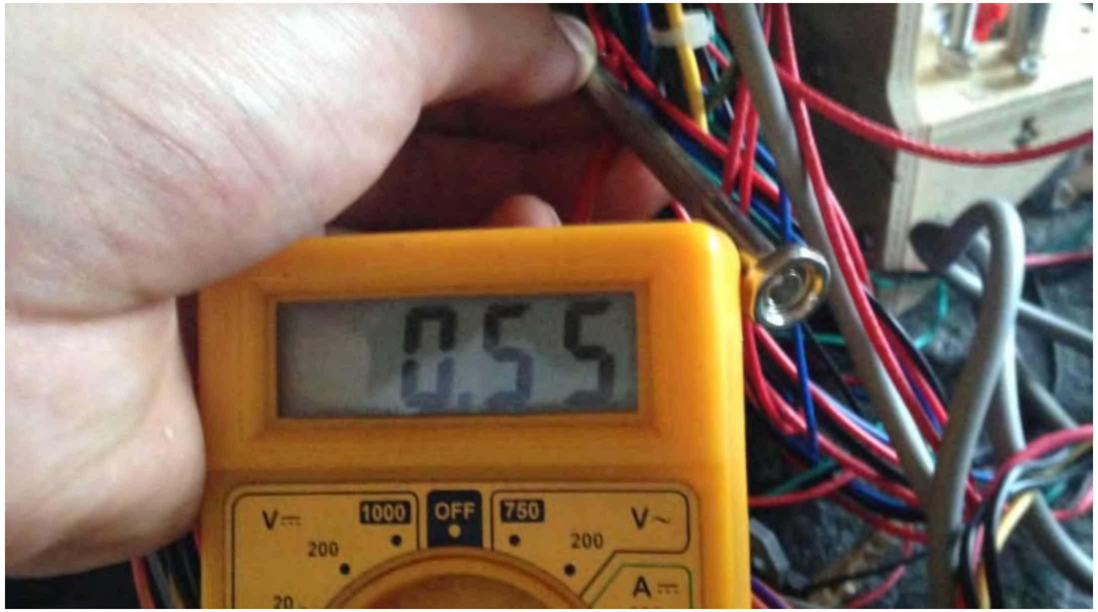
Calibration



= measure and set parameters to specify systems behaviour

- Measurement of signals inside the ECU, prepare a GUI
- Set of parameters inside the ECU in Real-Time, handle parameter sets

Key to develop and optimize systems!

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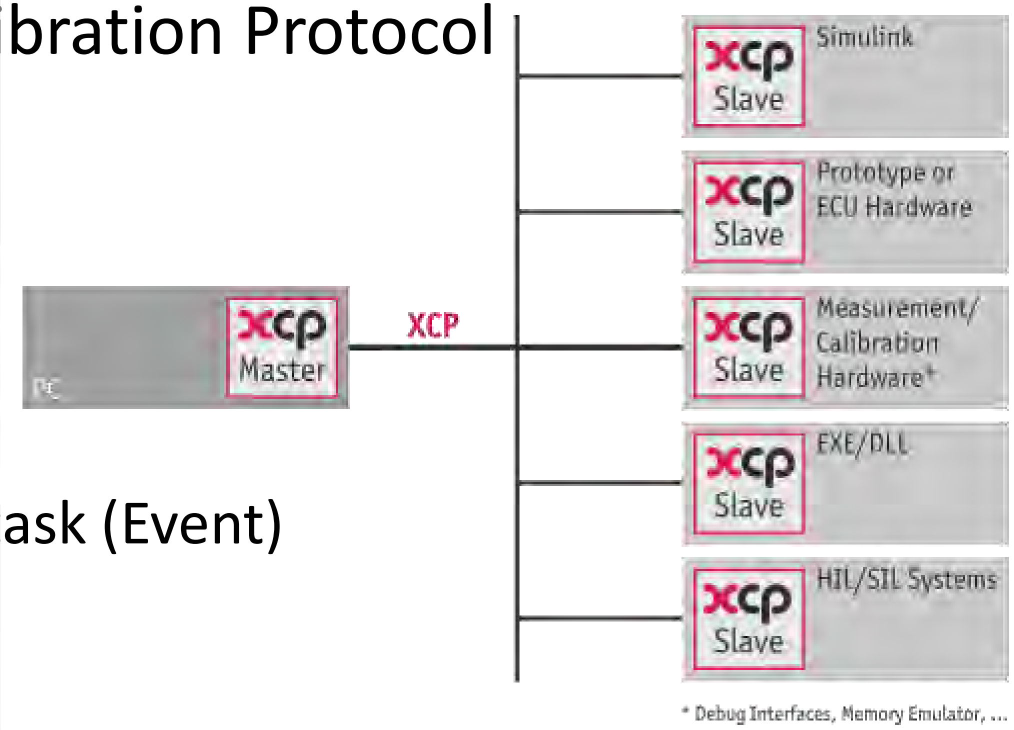
Calibration using CCP/XCP

CCP … CAN Calibration Protocol

XCP … Universal Measurement and Calibration Protocol

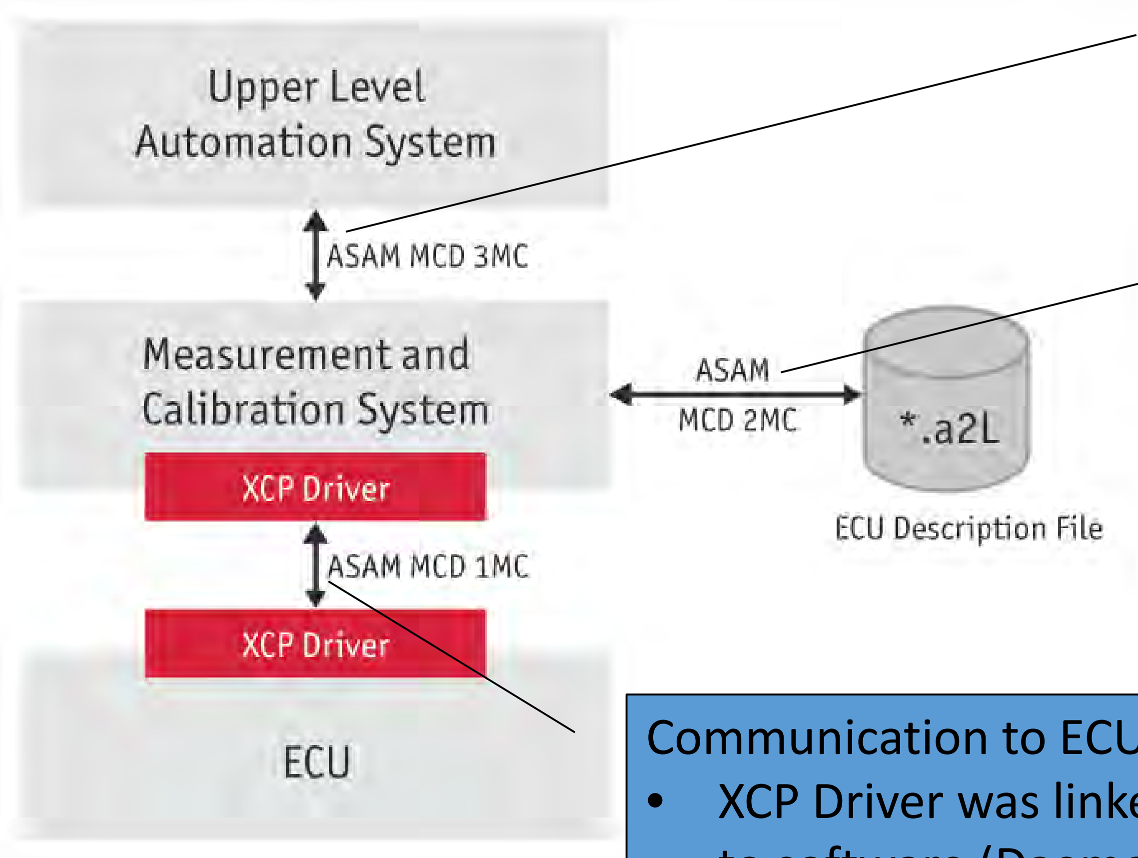
for different transport layers



- Reading and writing data via CAN
    - reading by polling or synchronized to a task (Event)
    - writing parameters to RAM

[Andreas Patzer | Rainer Zaiser: XCP – The Standard Protocol for ECU Development; Vector Informatik GmbH - Stuttgart, Germany (Free download)]

CCP/XCP is Standardized



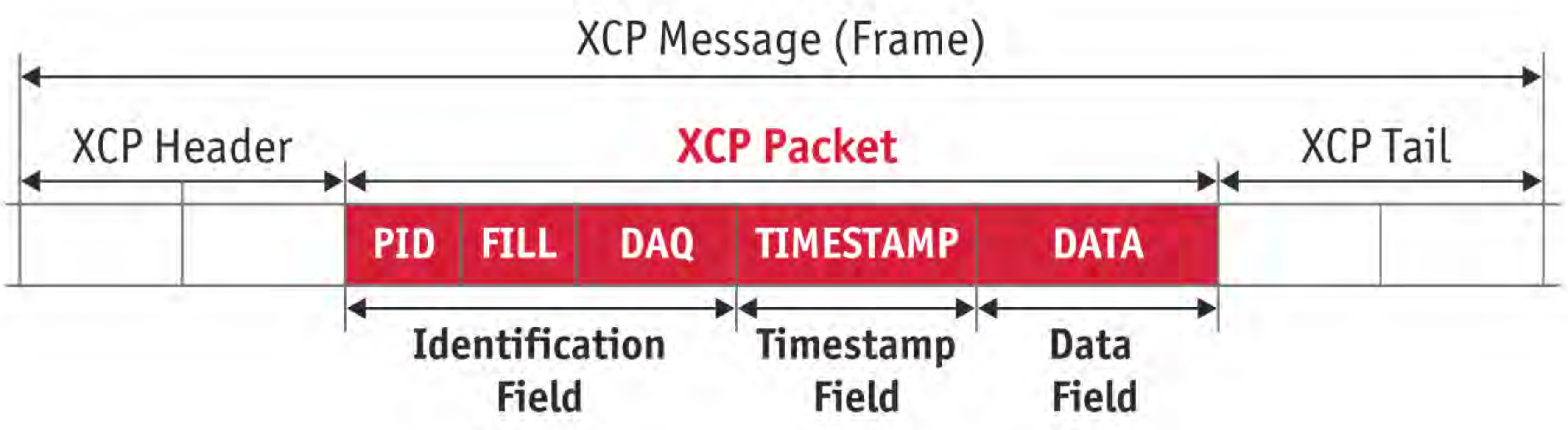
Remote Control of Measurement System (test bench)

CAN Database:
- Name, unit and scaling of variables and Look-Up-Tables
- It's location in RAM

Communication to ECU
- XCP Driver was linked to software (Daemon)

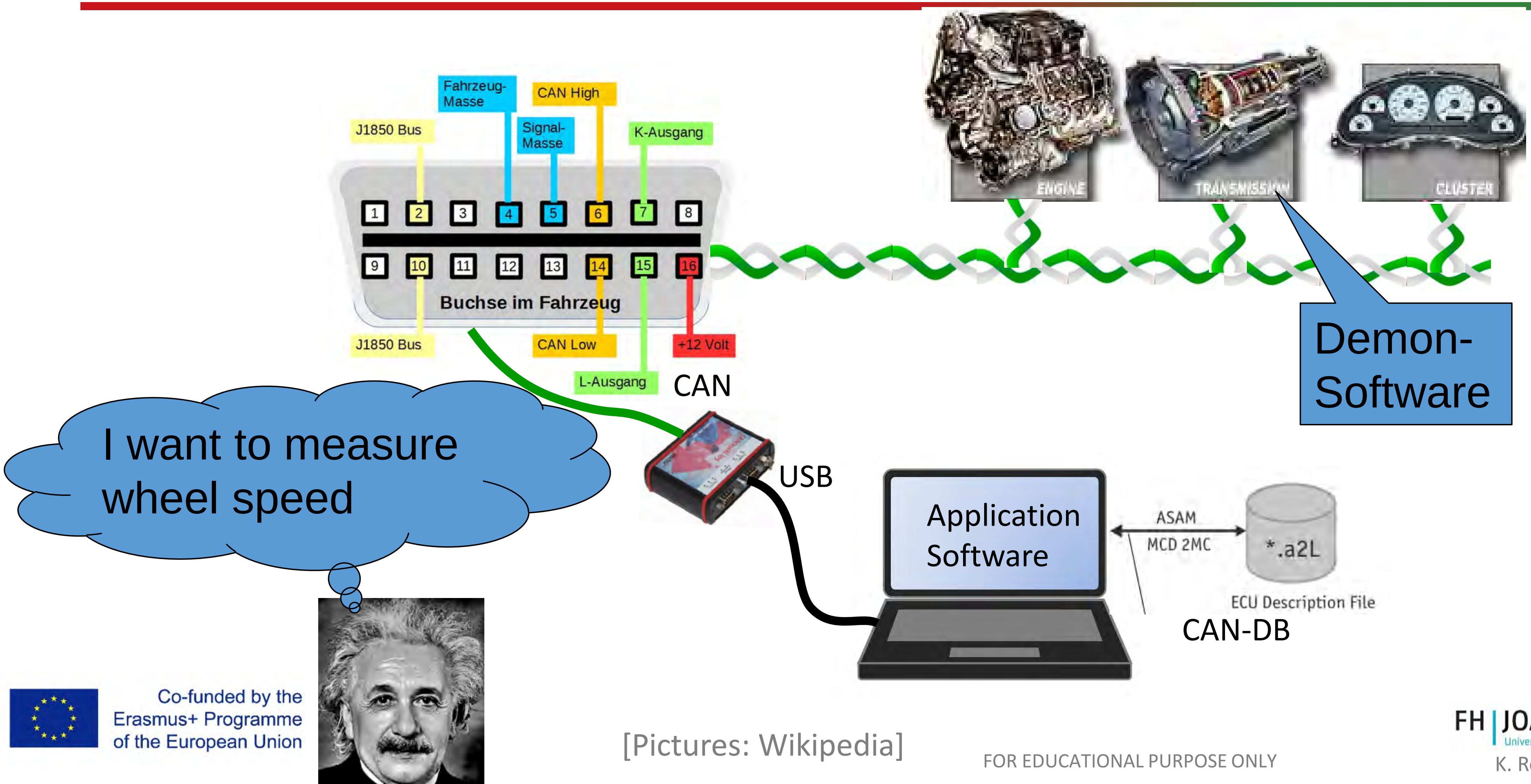
Communication via CAN, FlexRay, …

- connect to existing CAN or Flexray network
- additional messages for send/receive
- XCP message is packed into CAN data frame

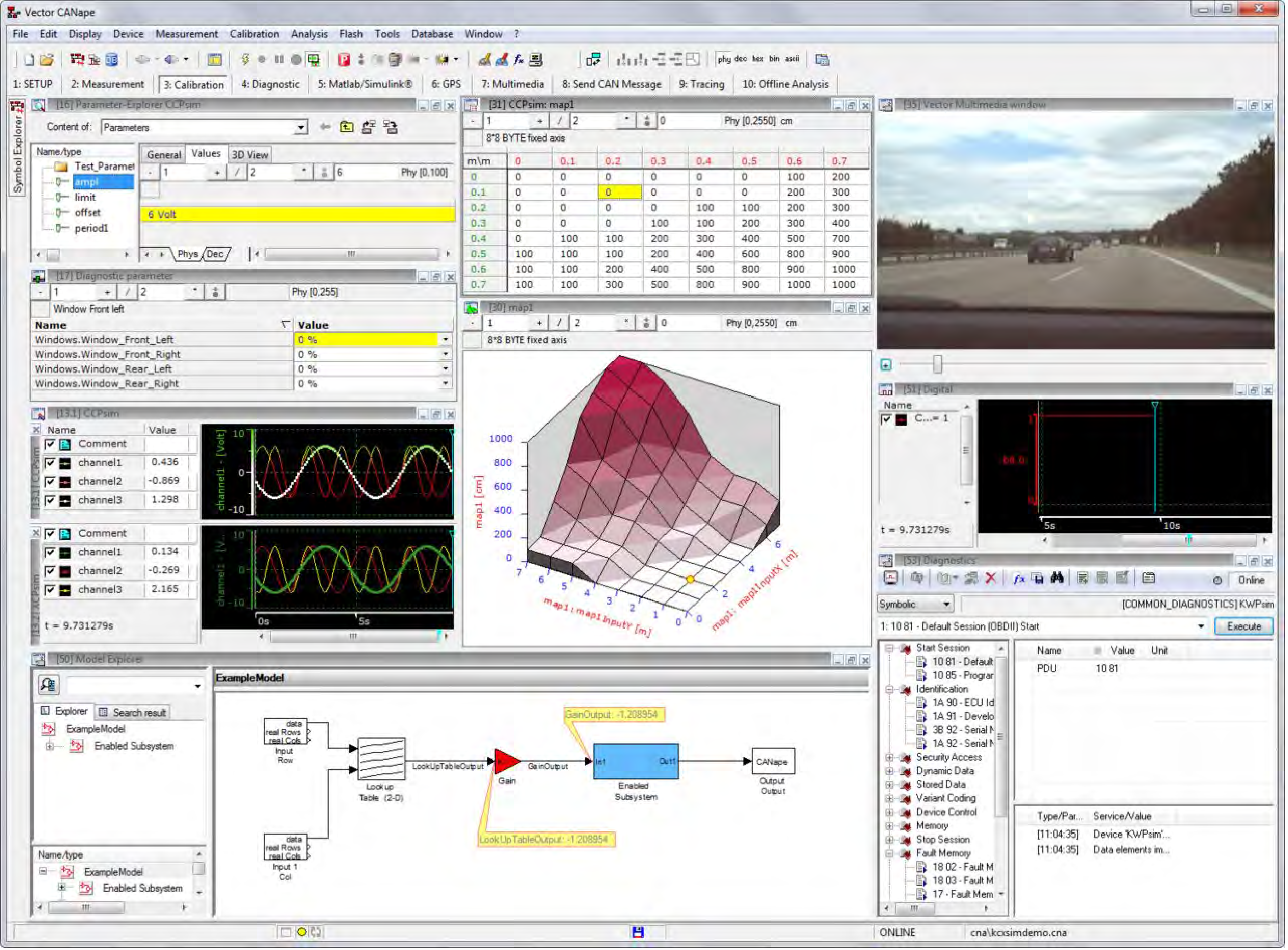


What do we need to calibrate?

UNITED



[Pictures: Wikipedia]



UNITED

CANape GUI to get ECU's view of the words and adjust it.

[https://de.wikipedia.org/wiki/CANape]

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On Board Diagnosis

Avoiding Hazards

- Bring system to a save state
  - diagnose dangerous failures or its causes (faults) permanently and
  - perform action to get safe state within failure tolerance time
  - inform driver about changed car
- Check diagnosis periodically
  - ISO 26262 says: once a start-up

Driven by Law

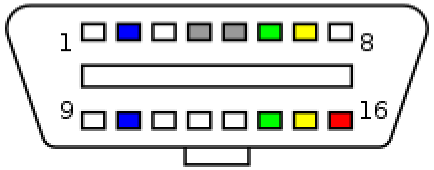
- avoid environmental pollution
  - recognize failure
  - inform driver and reduce car's performance
  - Readable by OBD-II or EOBD standard tools

Serviceability

- help for repair

typ. all wire connections

- recognize faults or failures periodically
- inform driver
- note in EEPROM (Flash)
- Readable by OBD-II or EOBD standard tools



https://en.wikipedia.org/wiki/On-board_diagnostics#OBD-II

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Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Introduction to UAS Mechatronic Laboratory Tutorial

K. Reisinger, T. Lechner

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598710-EPP-1-2018-1-AT-EPPKA2-CBHE-JP

Content of this chapter

- **Introduction to our Mechatronic Lab Tutorials**
  - Mechatronic topics in our curriculum
  - Outline of the laboratory tutorial and it’s guiding example
  - Dvp. Process: V-Model, Model-In-the-Loop (MIL), Software-In-the-Loop (SIL), Hardware-In-the-Loop (HIL)
  - Data acquisition, integer arithmetic's
  - Lessons learned and the lab tutorial in the future
  - XCP/CCP a tool for calibration

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Place in Curriculum

- Bachelor's Program
  - **Engineering Mechanics** (Statics, Kinetics), Mechanical Components
  - Introduction to **Electrical Engineering, Electronic Systems**, Electronic Lab Tutorials, Electrical Machines & Inverters,
  - **Software Development** , c#‘, MatLab/Simulink
  - Control Engineering
- Mechatronic Lab Tutorials
  - Bachelor’s 4th semester

Lessons after this Lab

- Bachelor's Program
  - **Measuring electrical and non-electrical Signals**
- Master‘s Degree Program
  - **Automotive Sensors/Actors**,
  - **Signal Processing, Digital Control Engineering**,
  - Race Car Data Analysis
  - Electric Drive & Propulsion Systems, Energy Management & Storage Systems

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Aim of the Lab - General

- Understanding how mechatronic systems work
  - **work with embedded systems**

    linking mechanics, electrics and software, holistic thinking
  - **Couple mathematical/physical knowledge with software** technology
  - **Understand imperfections and limits**

    A/D-, D/A converter, quantizing effects, cycle time influence
  - **Encoding of signals**

    Data types, fixed point arithmetic

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Our Object to grab the content

goal: control the torque- distribution between front an rear axel of a 4-WD car.

www.heise.de/autos/artikel/Daten-unter-der-Haube-1012221.html?view=bildergalerie

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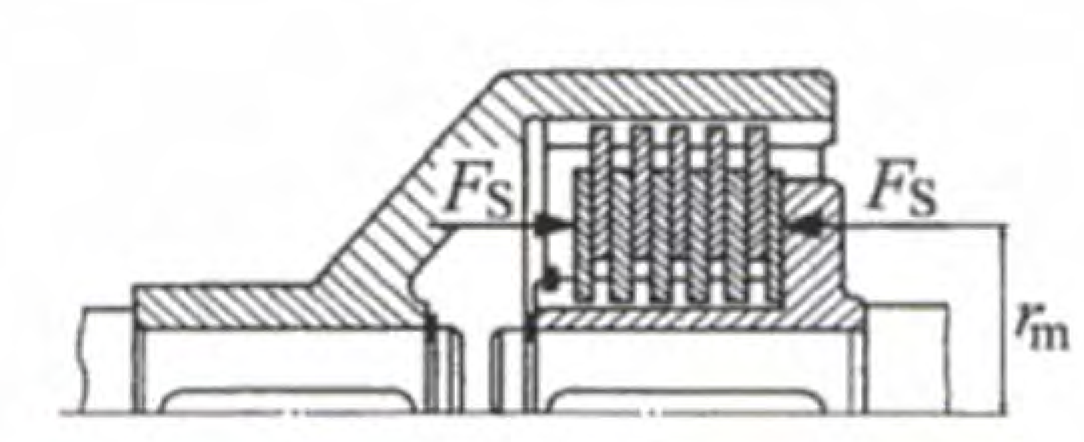
Multi-Plate Clutch

- Clutch Torque M_c ~ Axial Force F_c

$$M_C \cong F_C \cdot \mu \cdot z \cdot r_m$$



Künne B.: Einführung in die Maschinenelemente, Teubner

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Controllable AWD-Clutch
Smart Actuator implementing requested torque

Given: $M_{Req}(t)$ .. desired torque

Press the multi plate clutch with a force producing a friction torque $M_{clutch} = M_{Req} \pm 10\%$ within 150 ms.

feedback: $M_{Clutch}(t)$ .. current friction torque of multi-plate clutch

Actuation concept

An electric motor drives a threat to apply the high axial force for closing the clutch

Control Concept

a) Measuring torque
b) Measuring clutch force
c) Measuring motor torque
d) Estimate motor torque out of current.

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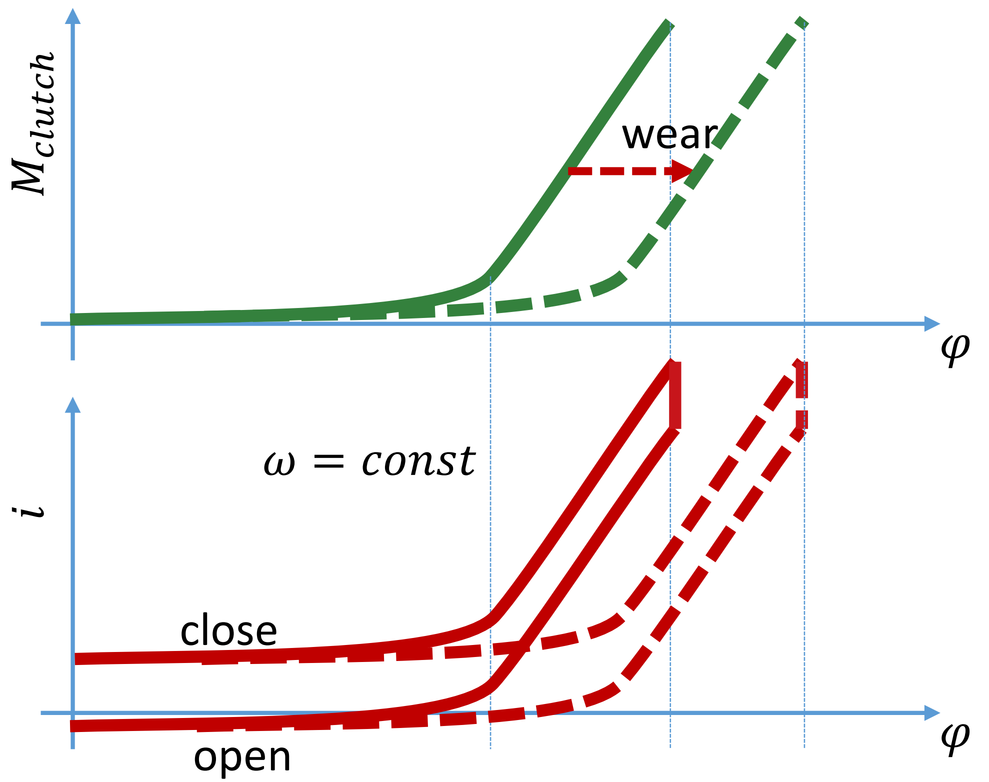
Estimate motor torque out of current.

- $J_{mot} \cdot \frac{d\,\omega}{dt} = k_T \cdot i - M_{shaft} \;\rightarrow\; M_{shaft}$
- Some revs of the motor make 2mm stroke
  → high gear ratio
- $m_{red} = J_{mot} \cdot i_g^2 \gg 1$
  - →very accurate acceleration signal!
  - →not for fast action!
- Solution
  - Table $M(\varphi)$: $M_{Req} \rightarrow \varphi_{Req}$
  - Position Control
  - use $i(\varphi)$ on shutdown to correct wear



φ .. angle of motor, ω .. angular frequency of motor
t .. time, i_g .. ratio, $\frac{mm}{rad}$, J_{mot} .. Inertia, M .. torque, i .. armature current

Lab Tutorial Content

- Introduction Lessons
  - Systems concept
  - Modelling mechanics (Clutch, actuator mechanics incl. worm gear)
  - Control concept
    - State Machine to find initial position
    - Feed forward torque controller using mechanical characteristics
    - Position control algorithm using speed cascade

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Lab Tutorial Content

- Introduction Lessons
  - CAN
    - CAN principles
    - XCP, CCP protocol
  - Development Process: V-Model
- 5 Lab-Sessions in groups of max. 20 students
  - 1 Lab-Session: 5 times 45 minutes

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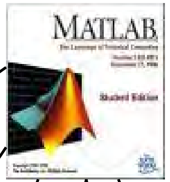
V-Modell

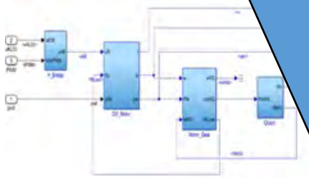
e foc on the ta k of an
y te engineer → rototype
vp.

System Specification



OEM's Solution

Lab-Session:
1 & 2



Functional design

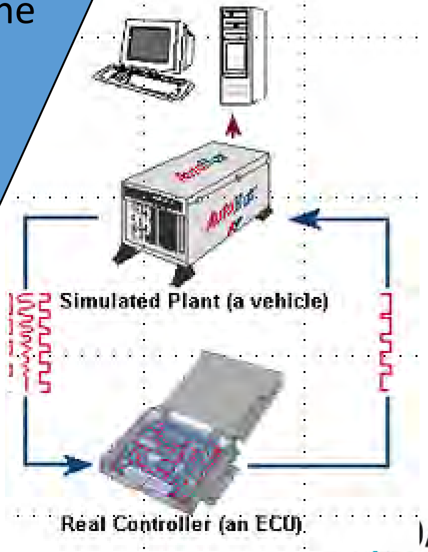
Controller design

System Integration, Calibration, Test

(2), 3 & (4)

Software in the Loop (SIL)

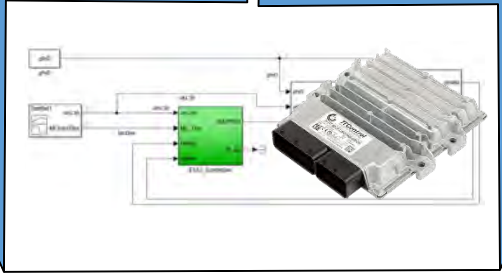
Hardware in the Loop (HIL)



(4) & 5

Target Code

SIL – White Box Test



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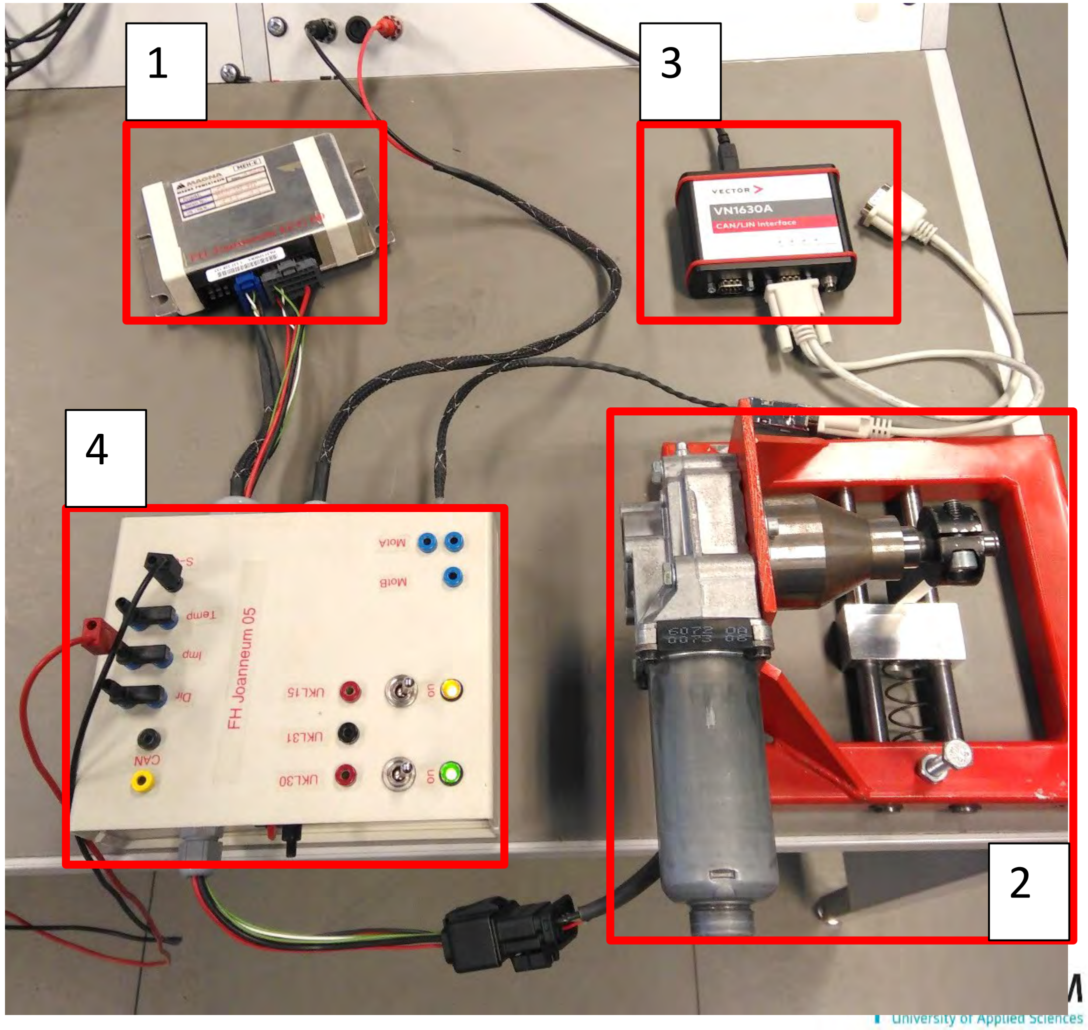
Torque Control – Modell in the Loop Hardware Overview

1 ECU-Controller
2 Environment (plant model)
3 CAN to USB Interface
Vector VN 1630
4 Break Out box



Break Out Box

General requirements

- Replacement for wiring harness, connection between motor, sensors, ECU, External CAN-Interface and power supply.
- Switches for car‘s state
- Connectors to measure and test signal failure.

Special requirements for training

- resistor to limit peak current
- thermal fuse

no burned motor since years ☺

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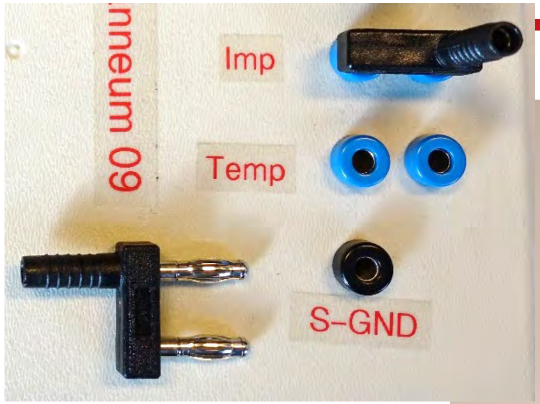
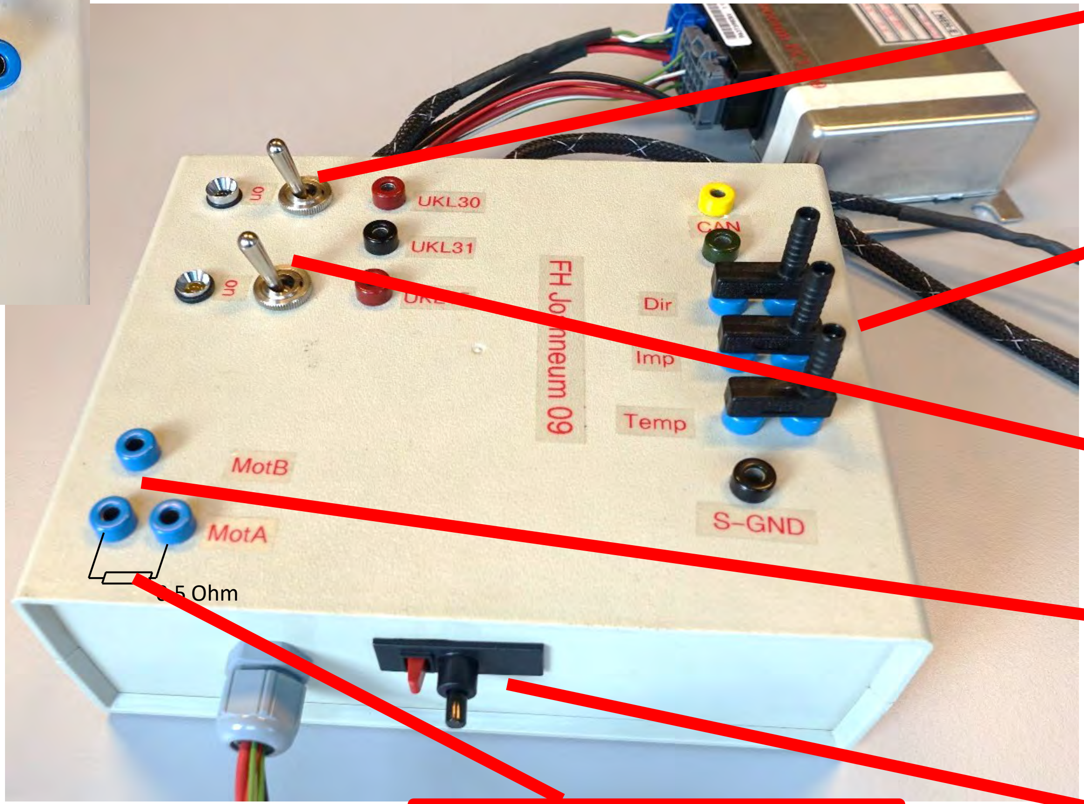
Break Out Box





Power switch and indication

Signal access / manipulation

Ignition On

Terminals for Motor-Voltage

Thermo-Fuse

Resistor to limit peak current

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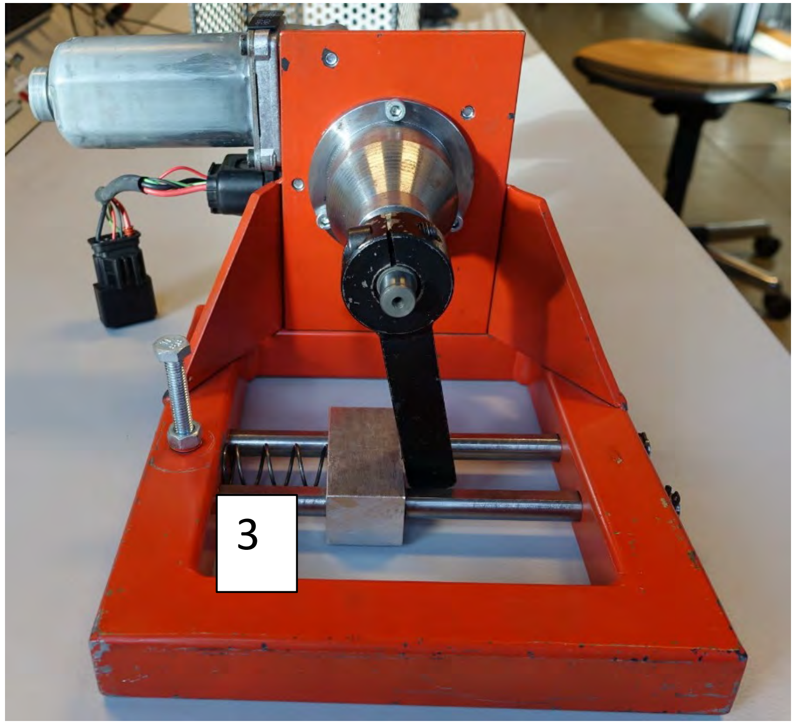
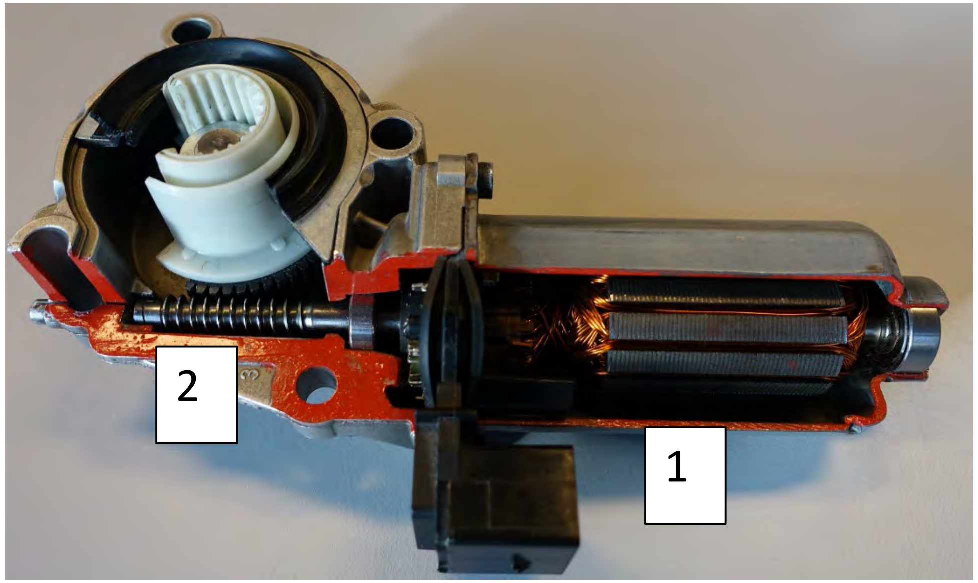
Environment → Plant Model





1 – DC-Motor

2 – Worm Gear → gear ratio is 56

3 – Spring → simulate the feedback from the clutch

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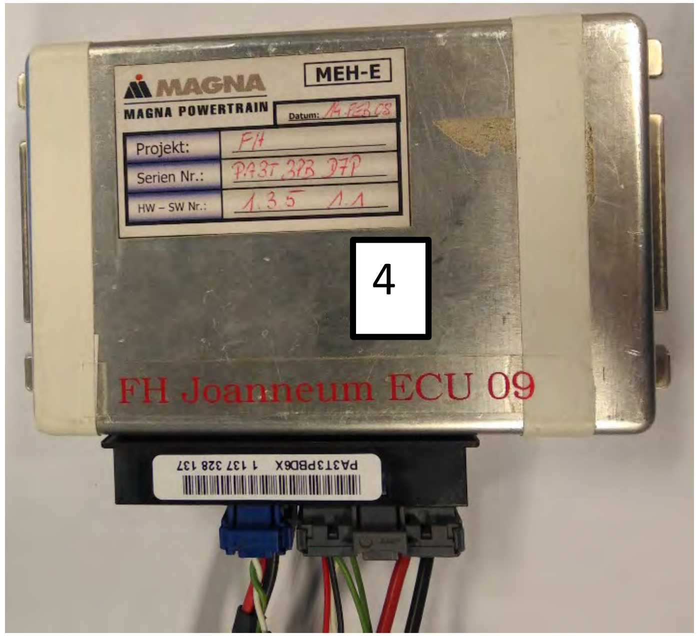
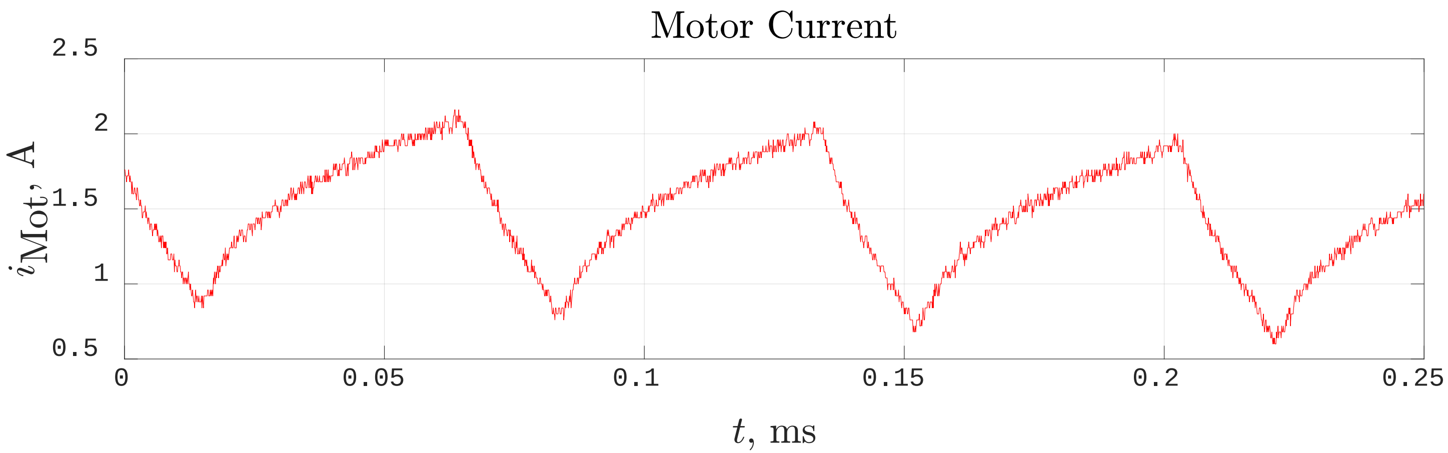
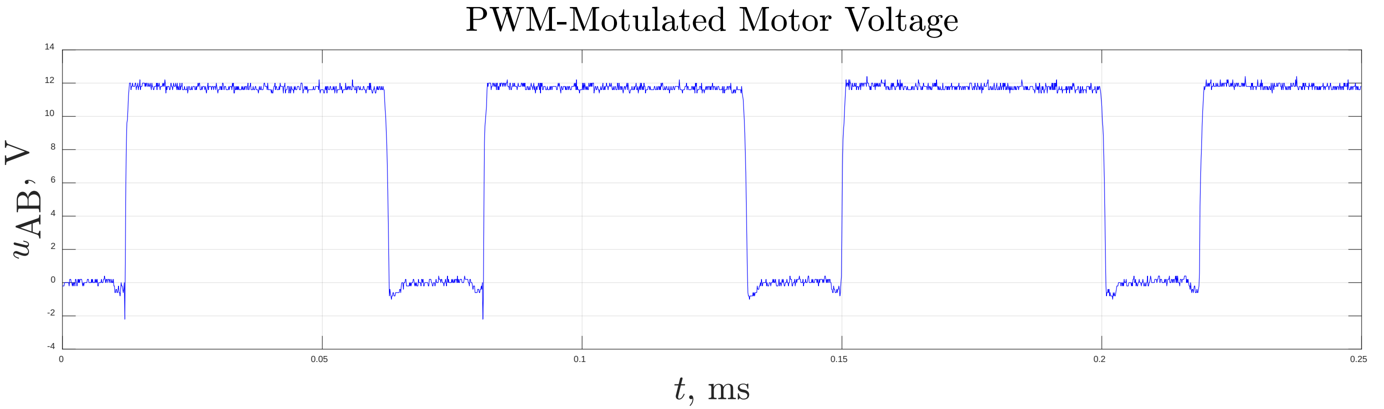
Plant Model, H-Bridge





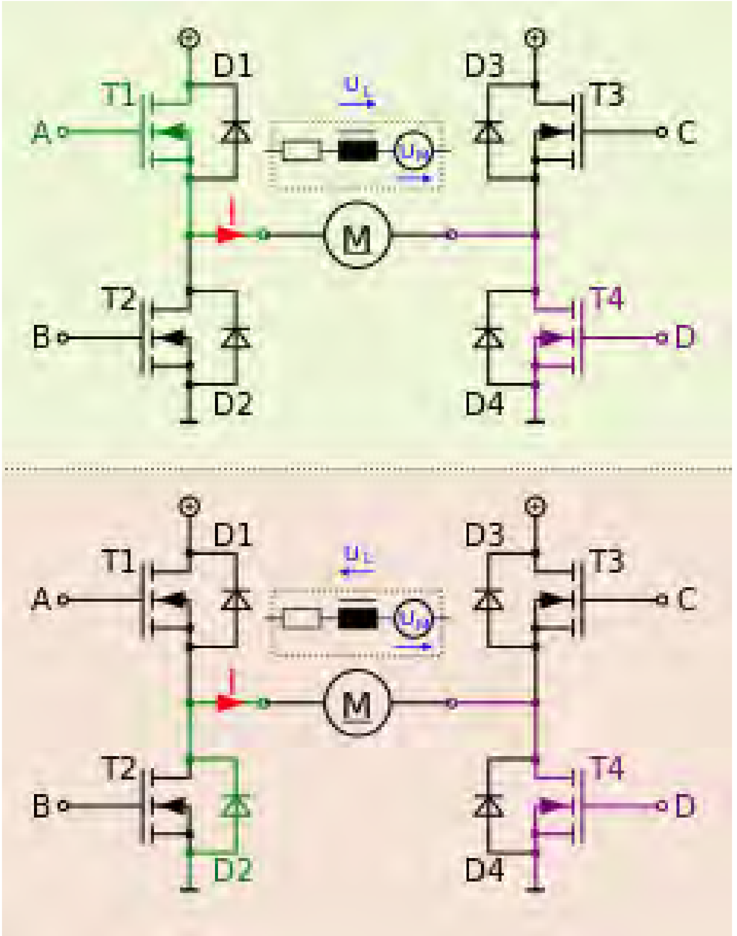


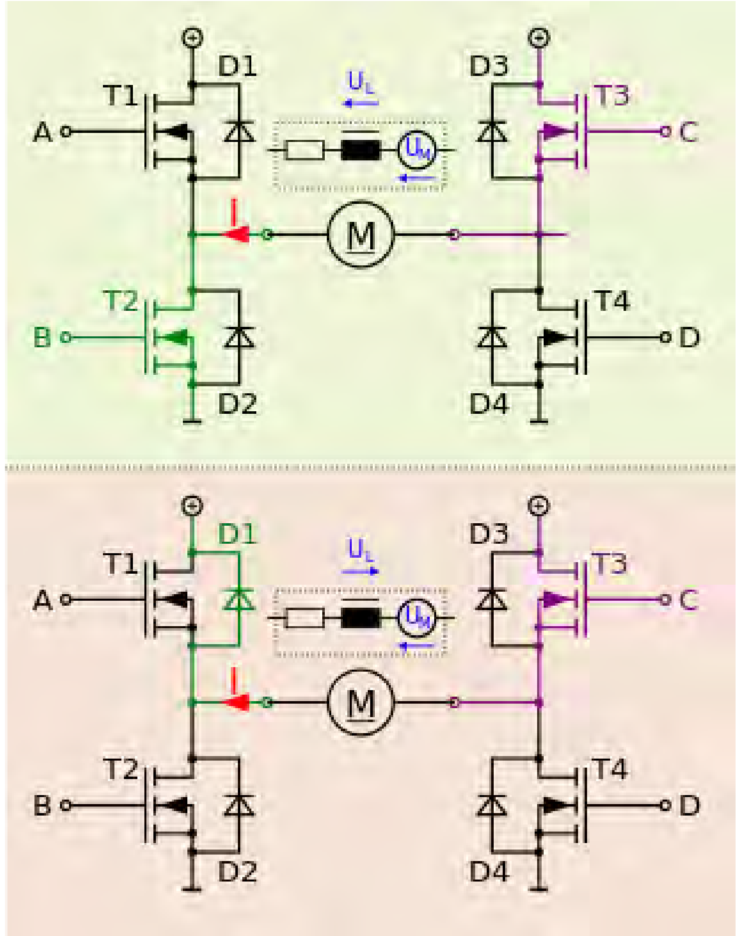
4 – The H-Bridge is integrated at the ECU. The output is a PWM-modulated voltage. The mean-value of the voltage is proportional to the motor speed.

H-Bridge

Quadrant 1 - accelerate forward

Quadrant 3 - accelerate backward





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https://de.wikipedia.org/wiki/Vierquadrantensteller

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Plant Model – Simplifications
As fine as needed!

H-Bridge → Power electronic (included at the ECU)

Input: PWM-Signal from controller. In our model PWM is a numeric value between -1 and +1

Output: PWM-modulated voltage for DC-Motor power supply.

The mean-value influences the motor speed.

Simplification for the model: $u_{\mathrm{AB}} = u_{\mathrm{Kl30}} \cdot \mathrm{PWM}$

u_{AB} DC-Motor input voltage

u_{Kl30} Supply voltage

No resolution of pulsed voltage → short simulation time.

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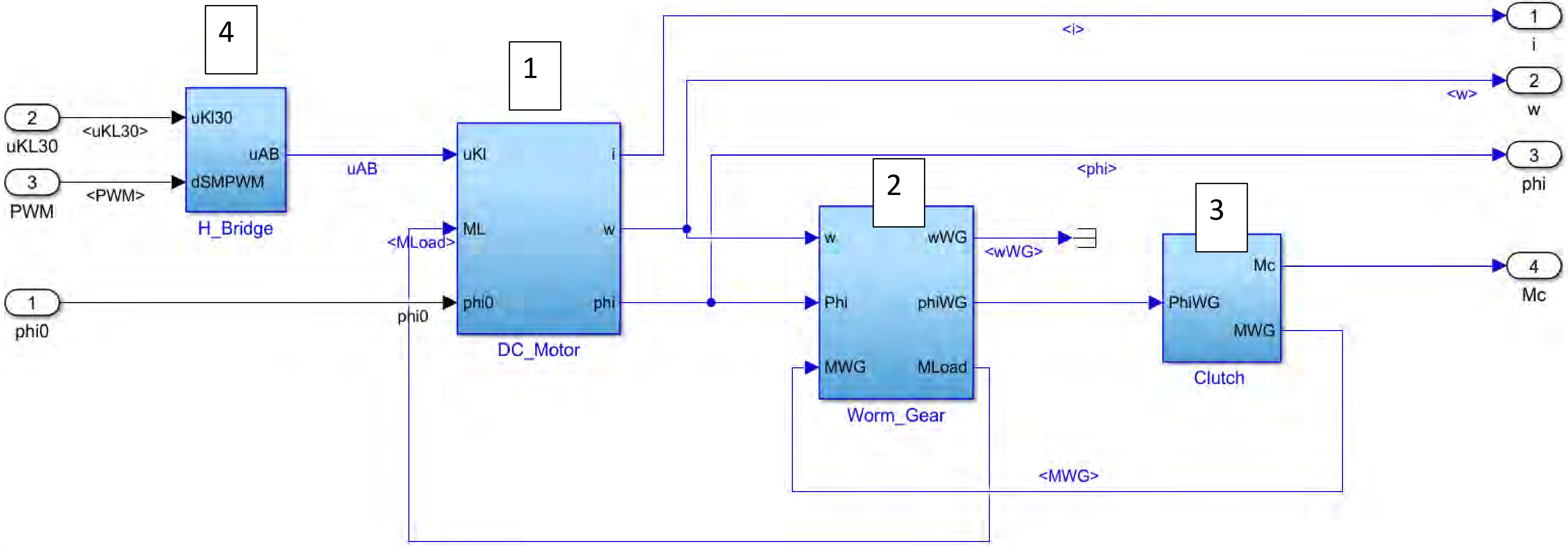
Plant Model



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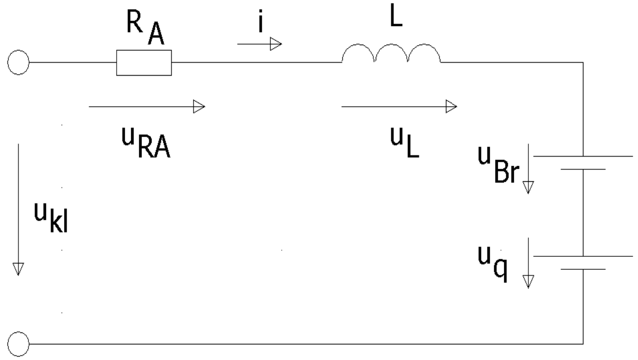
How to model a device with Simulink? Example: Permanent-magnet DC motor

- Describe the motor mathematically
  - 1.) electrical system



irchhoff law: $u_{\mathrm{Kl}} = u_{\mathrm{RA}} + u_{\mathrm{L}} + u_{\mathrm{Br}} + u_{\mathrm{q}}$ 1

oltage rop : $u_{\mathrm{RA}} = i \cdot R_{\mathrm{A}}$ 2

$$u_{\mathrm{L}} = L\frac{\mathrm{d}i}{\mathrm{d}t}$$

$u_{\mathrm{q}} = k_{\mathrm{T}} \cdot \omega$ 4

$u_{\mathrm{Br}} = f(i) \rightarrow$ ook p able

2 , an 4 → 1 $\frac{\mathrm{d}i}{\mathrm{d}t} = \frac{1}{L}(u_{Kl} - i \cdot R_A - u_{Br} - k_T \cdot \omega)$

How to model a device with Simulink? Example: Permanent-magnet DC motor

- Describe the motor mathematically

2.) coupling between electrical and mechanical system

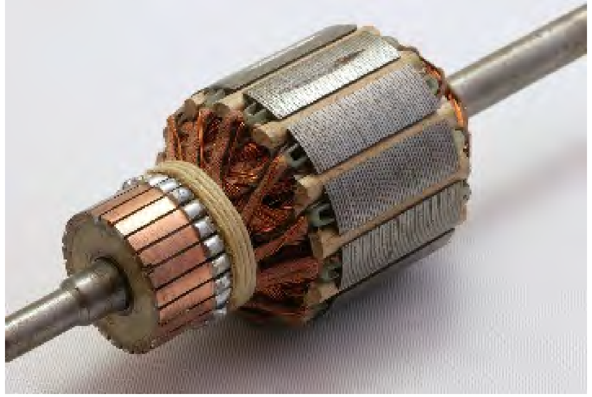
Torque is proportional to the current

$$M_{\mathrm{el}} = k_{\mathrm{T}} \cdot i \quad (6)$$

3.) mechanical system

The rotor is a rotatable mounted inertial mass – principle of angular momentum

$$J \cdot \frac{\mathrm{d}\omega}{\mathrm{d}t} = M_{\mathrm{el}} - M_{\mathrm{load}} - M_{\mathrm{fr}} \cdot \mathrm{sign}(\omega)$$
(7)



https://de.wikipedia.org/wiki/Anker_(Elektrotechnik)

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Scheme of model

Input (voltage)

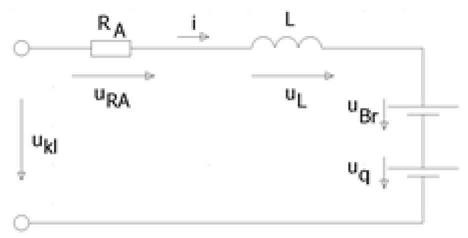
electrical system

Interface between electrical and mechanicl system

mechanical system

Output (angular speed)

U_{kl}



i

$M_{el} = k_T \cdot i$

M_{el}

M_{load}

$$\frac{di}{dt} = \frac{1}{L}(u_{Kl} - i \cdot R_A - u_{Br} - k_T \cdot \omega)$$

$$\frac{d\omega}{dt} = \frac{1}{J}\left(M_{el} - M_{load} - M_{fr} \cdot \mathrm{sign}(\omega)\right)$$

u_q

$u_q = k_T \cdot \omega$

omega

Author: T. Lechner

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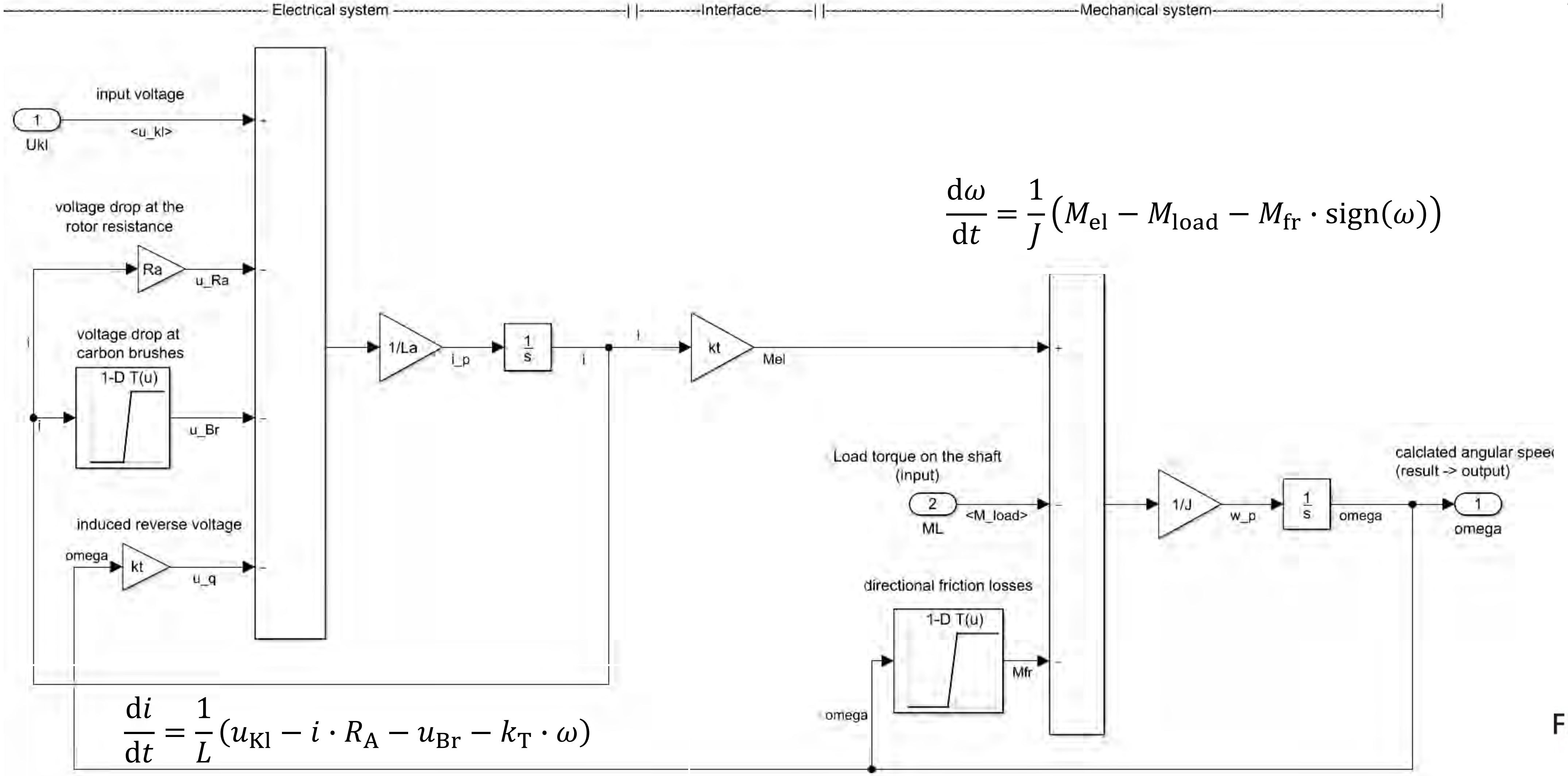
Simulink model

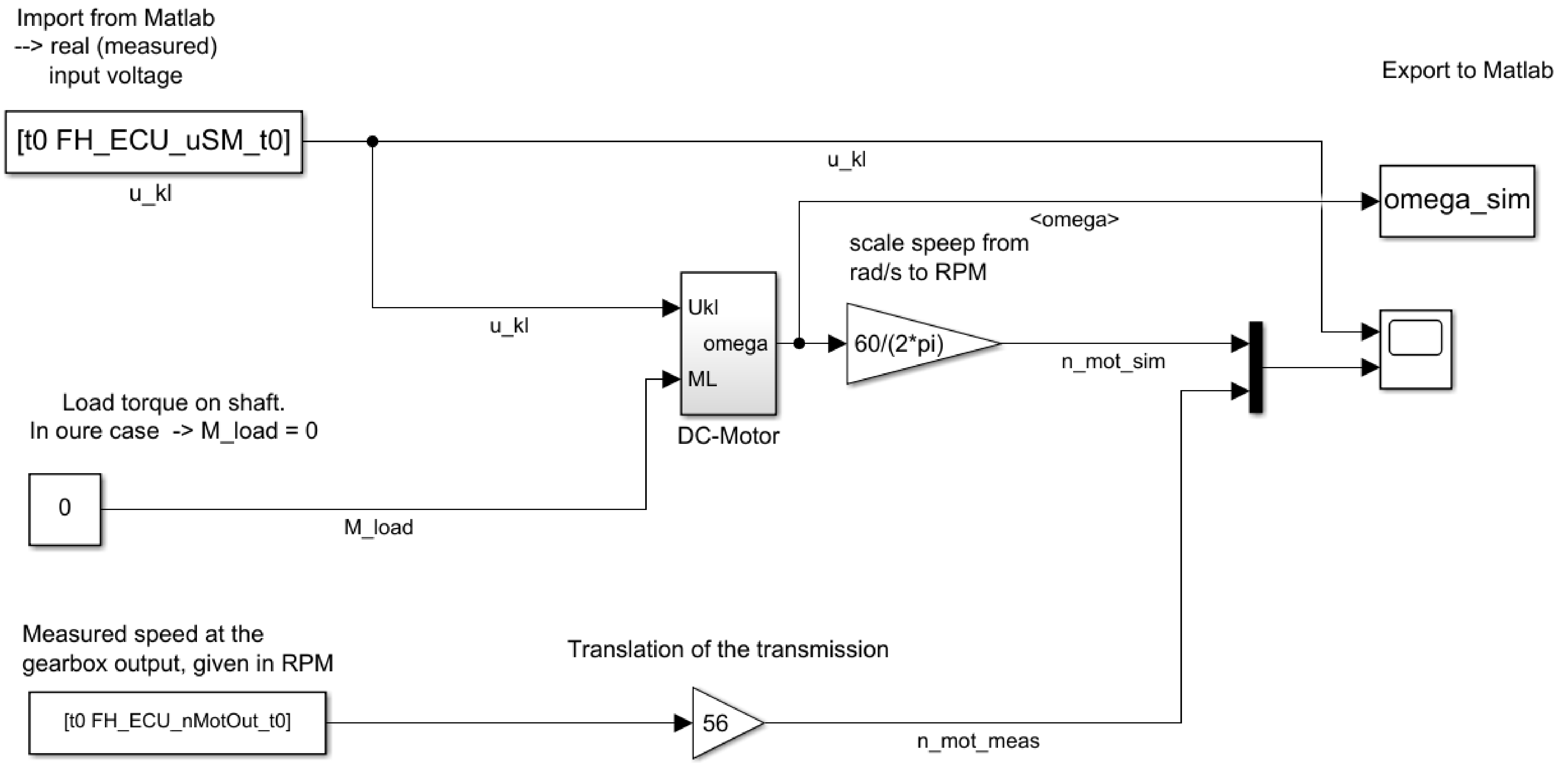
Author: T. Lechner



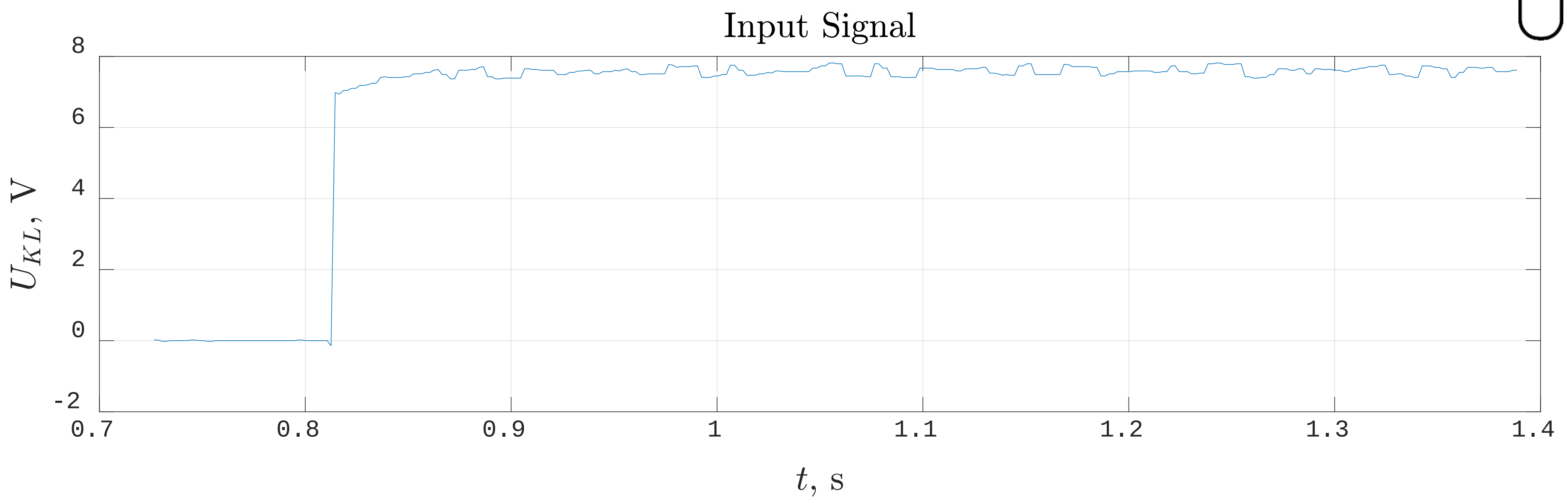
$$\frac{\mathrm{d}\omega}{\mathrm{d}t} = \frac{1}{J}\left(M_{\mathrm{el}} - M_{\mathrm{load}} - M_{\mathrm{fr}} \cdot \mathrm{sign}(\omega)\right)$$

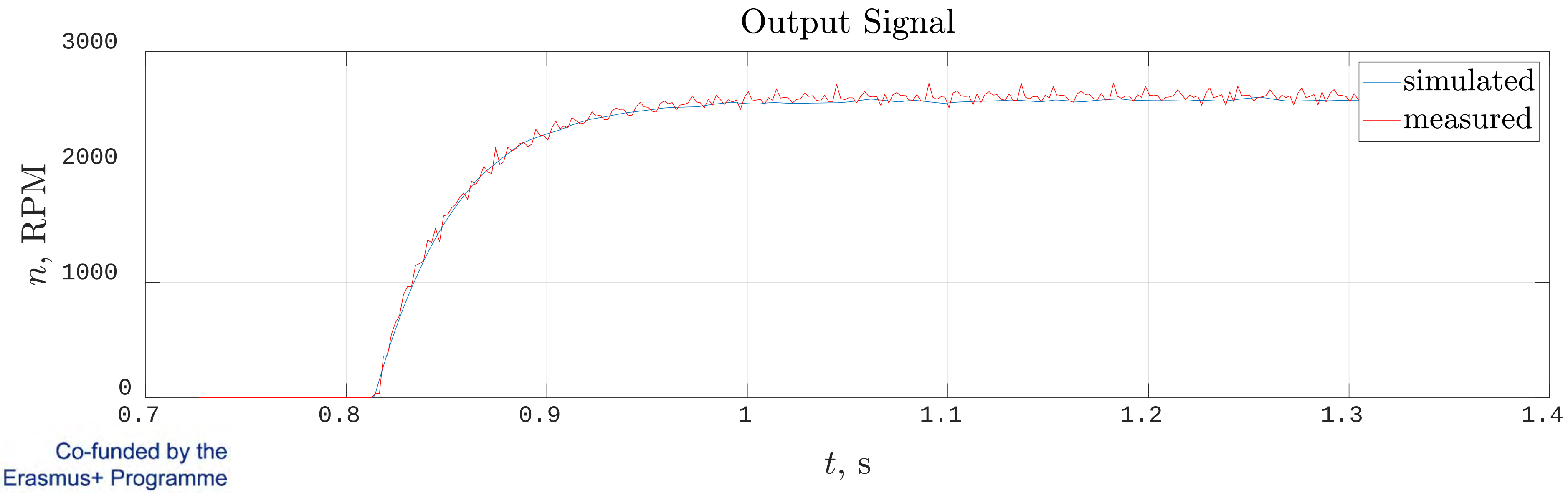
$$\frac{\mathrm{d}i}{\mathrm{d}t} = \frac{1}{L}\left(u_{\mathrm{Kl}} - i \cdot R_{\mathrm{A}} - u_{\mathrm{Br}} - k_{\mathrm{T}} \cdot \omega\right)$$

Find Parameters



Find Parameters





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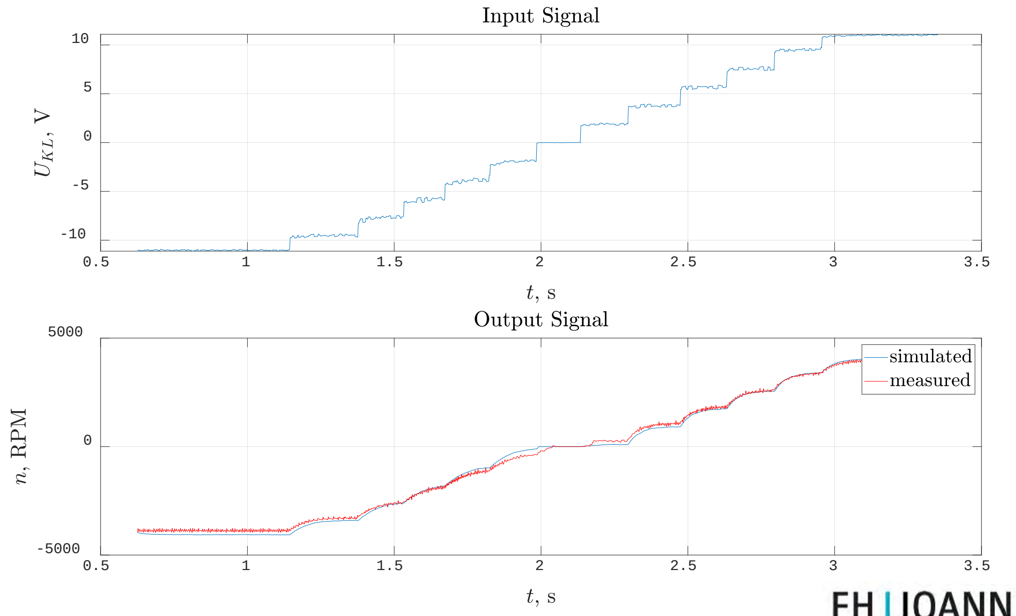
Validate the model

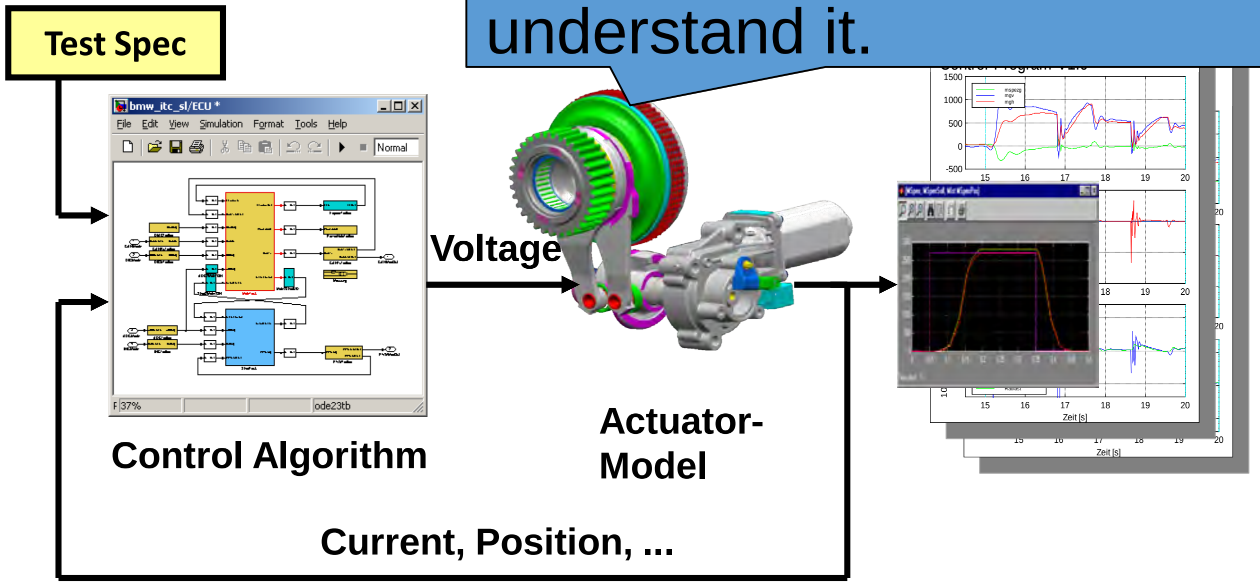
- Parameter validation
  - Use different stimuli than for parameter identification!



Model In The Loop

Task: Put the reality
to a simulation model

Students get Simulink-Plant-Model. They should understand it.



Any plant model can not be destroyed by missuses ☺

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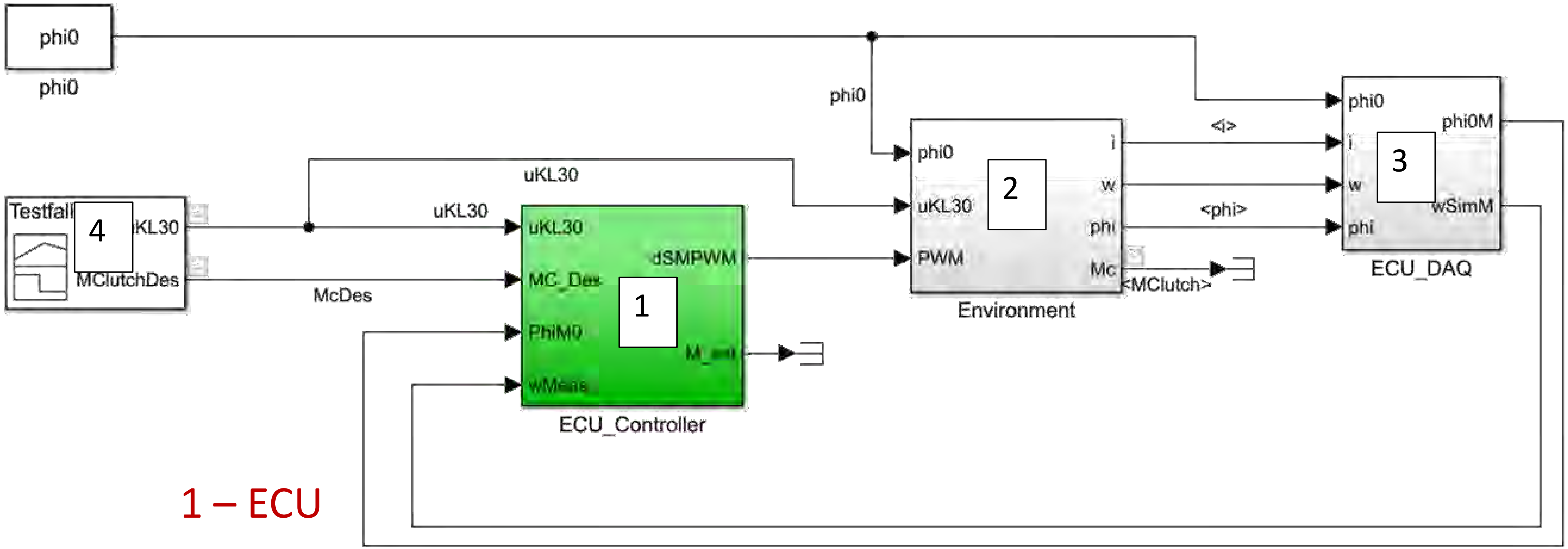
Quelle: Reisinger, Rühringer, Mathis: Modellgestützte Mechatronik-Systementwicklung für Allradanwendungen; TECHME, Sindelfingen Sept. 2007

Modell in the Loop – Top View



1 – ECU

2 – Plant-model (Environment)

3 – Data acquisition

4 – Stimulus (Simulink: `Signal Generator`)

Requirements for Position based Clutch Control Software

- Initializing
  - Search hard-stop
  - Set position to zero
  - Start Clutch Control
- Search hard-stop
  - Move reverse with low speed long enough that hard-stop is found → Speed Controller
- Clutch Control
  - Translate Requested Torque to Requested Position
  - Calculate Current Position (Angle)
  - A Position Controller determines Requested Speed
  - A Speed Controller determines Output Voltage
  - Calculate PWM for motor
  - Translate Current Position to Current Torque

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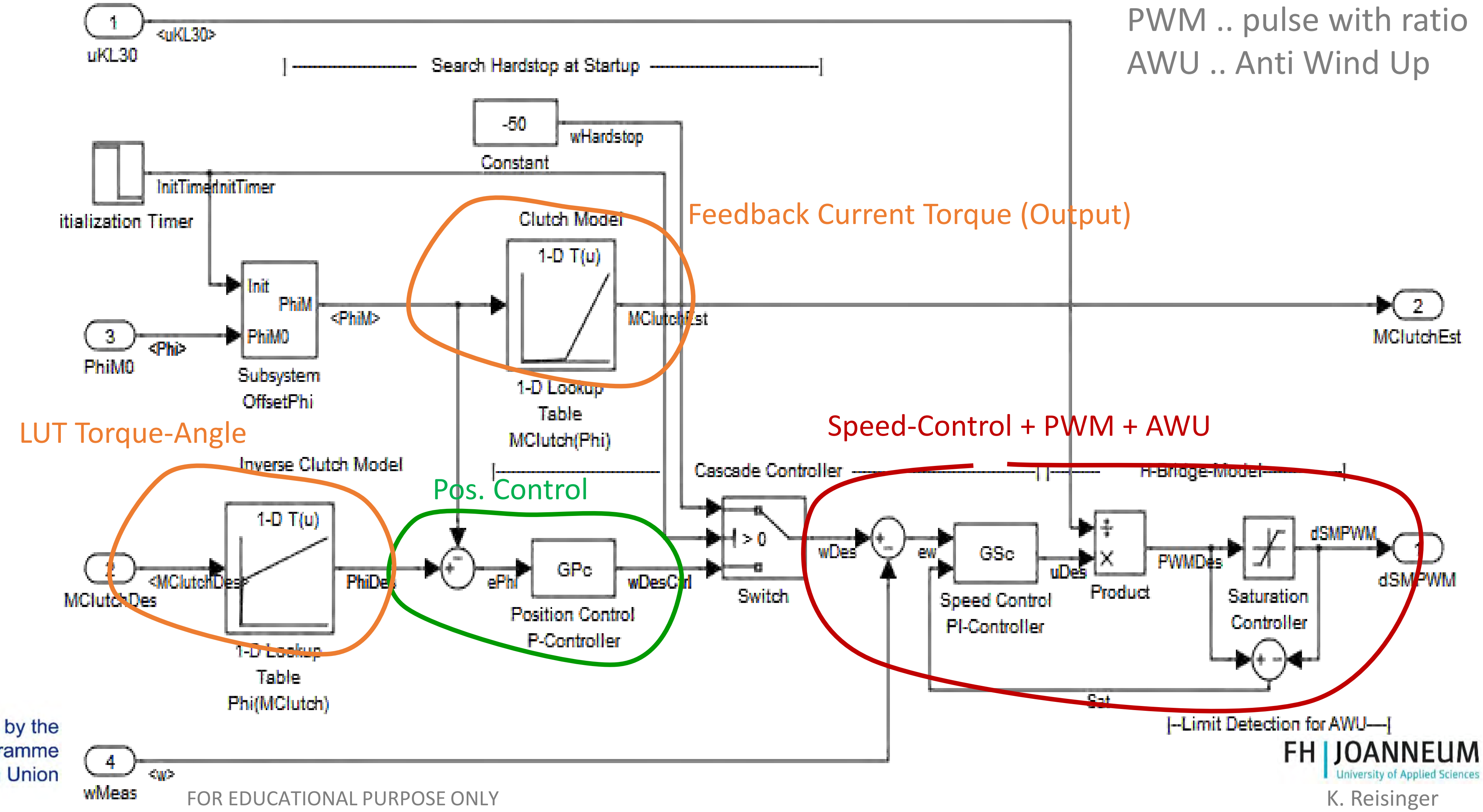
Simple Torque Controller

PWM .. pulse with ratio
AWU .. Anti Wind Up



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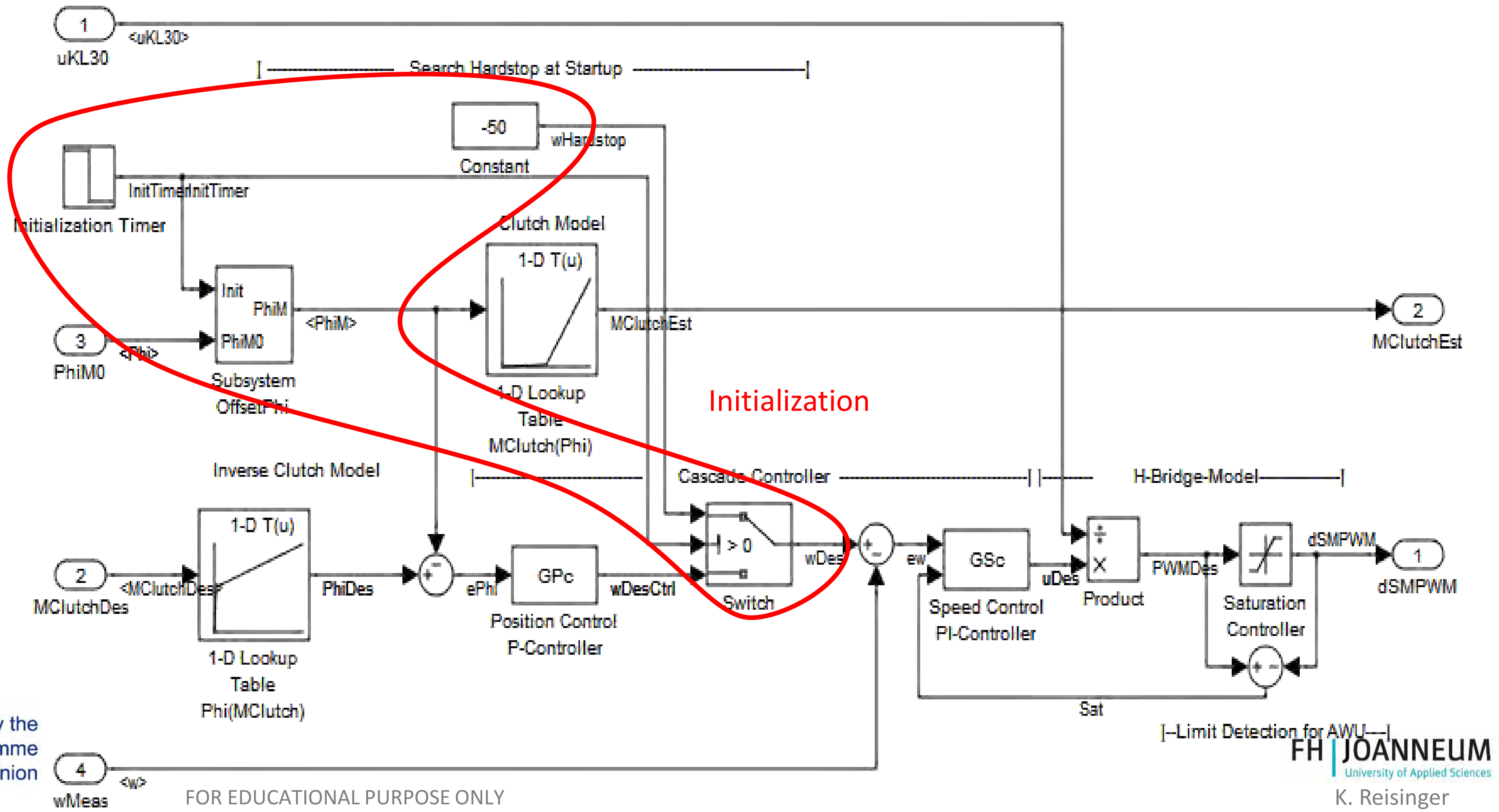
Torque Controller – Init by hard stop



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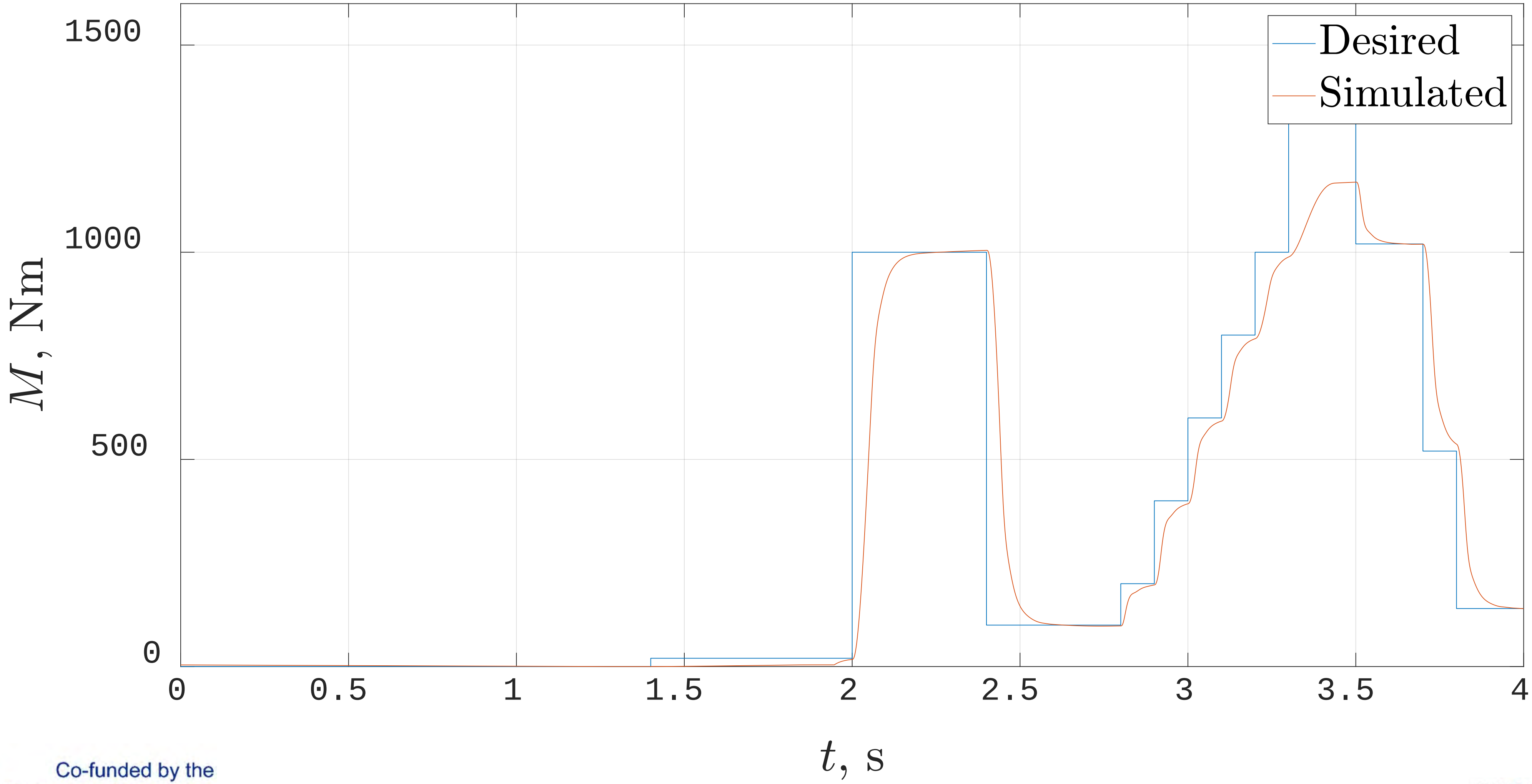
Torque Control-MIL Result



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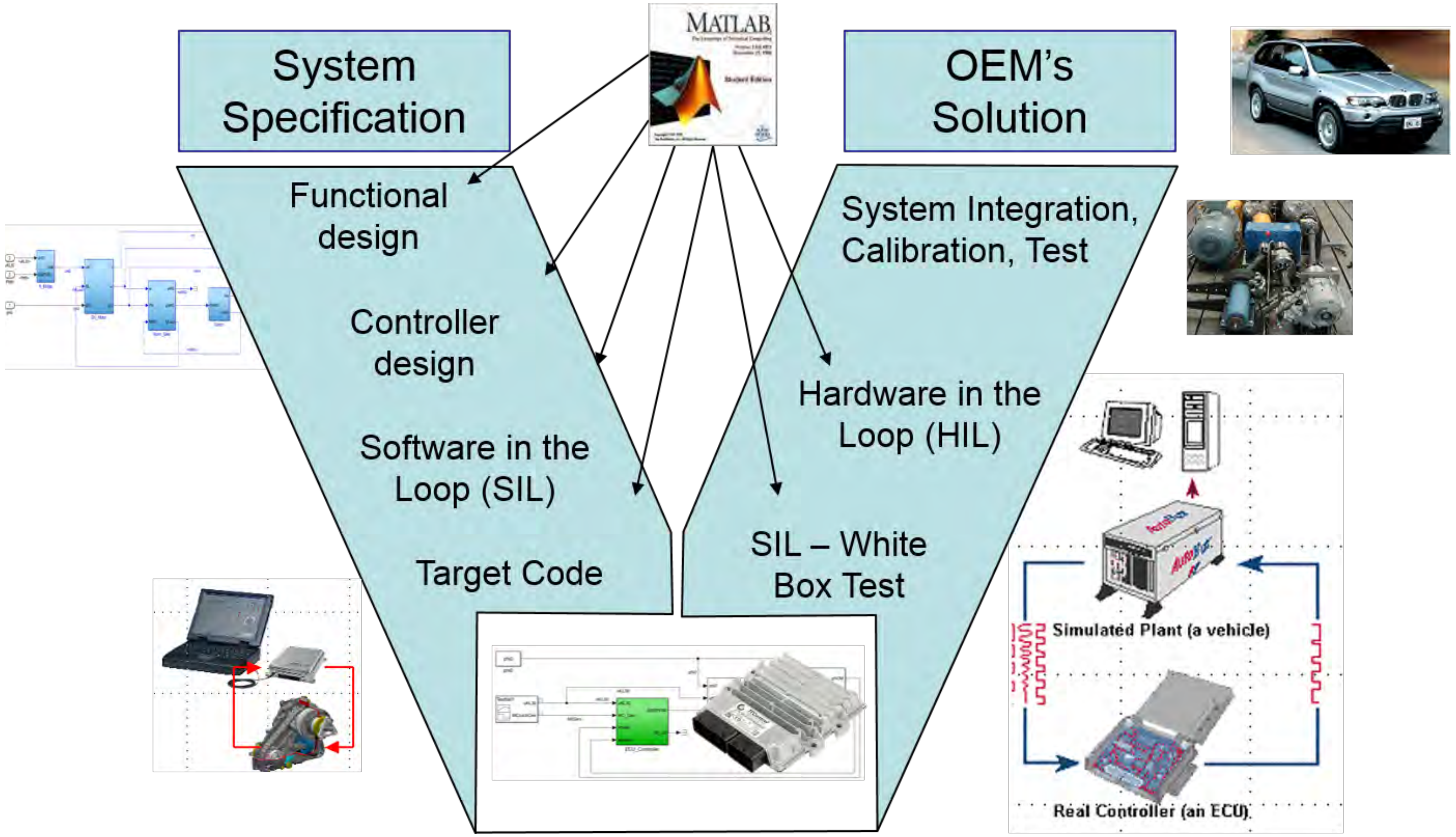
From MIL to SIL

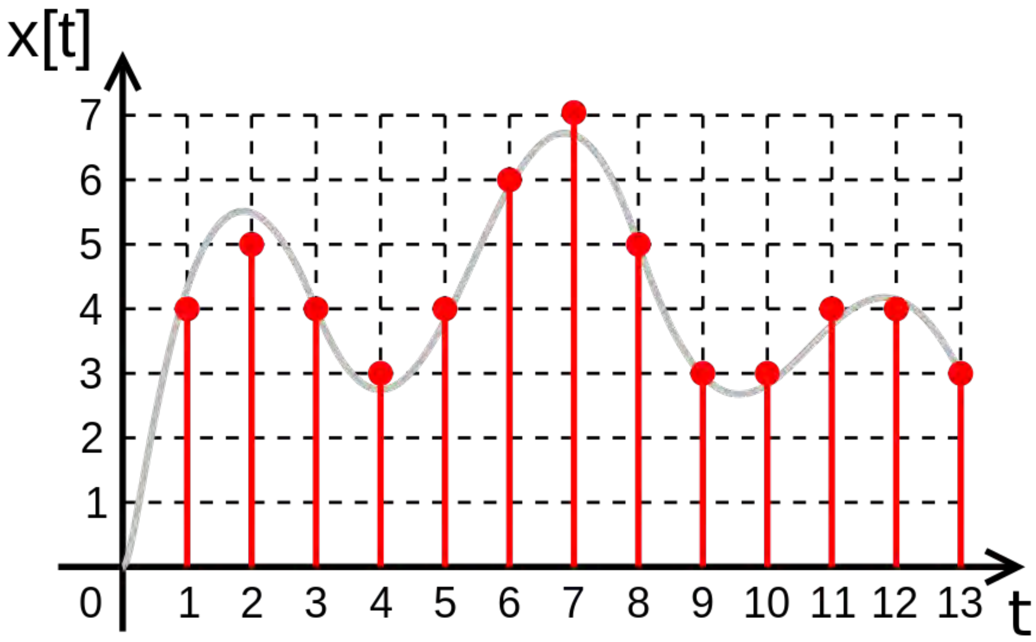
- MIL: „perfect“ environment.
- consider the following technical details:
  - Data Acquisition (DAQ)
    - time discrete
    - quantized
  - Task cycle time in calc.
    - Integrator!
  - Fixed point arithmetic's



Analog-Digital-Conversion (Sampling)

- Discrete Time → Sample Time
- Discrete Amplitude → Quantizing

- Example:
  - 2 Bit ADC → 8 steps from 0 to 7
  - Sample rate 1s

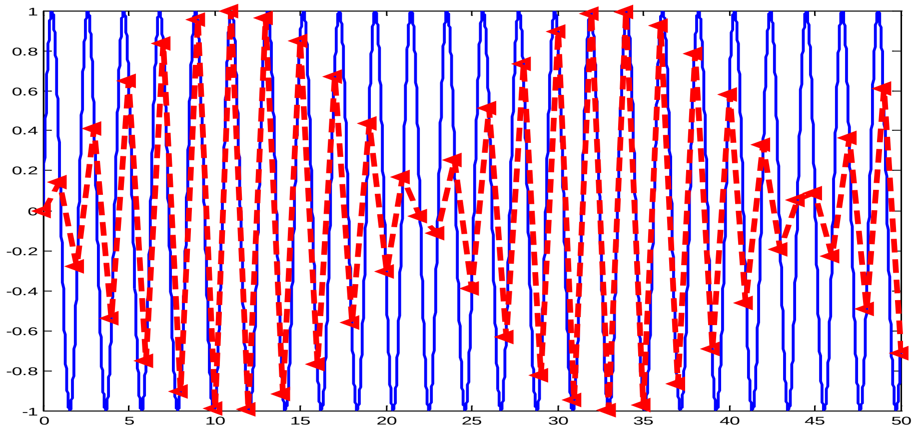


Aliasing

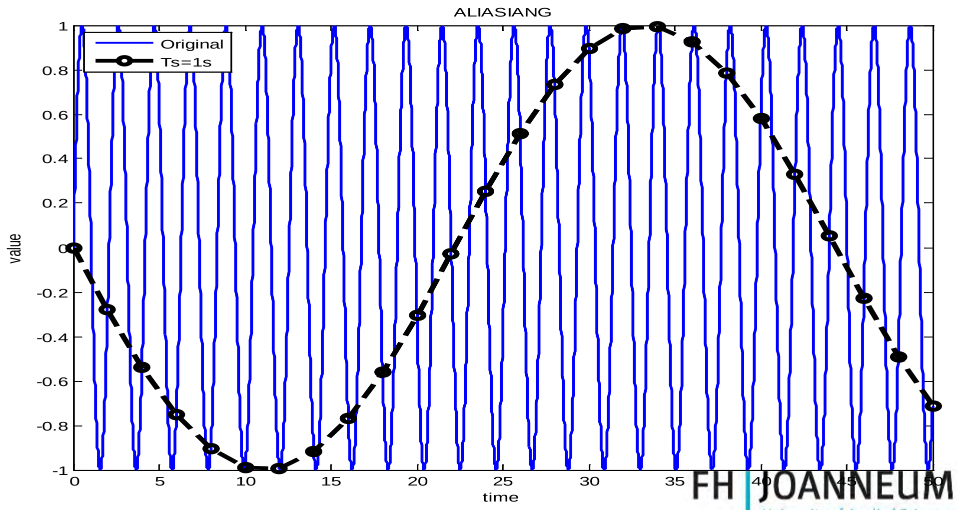
- Nyquist-Shannon-Theorem

$$f_s = \frac{1}{T_s} > 2 \cdot f_{max}$$

- Otherwise aliasing
  - Beat between sampling frequency and signal
  - Non existing frequencies appear.
- Solution
  - Electrical filter before ADC converts the signal!



$f_s = 2.1\ f$ … no new frequency



$f_s = 1.1\ f$ image frequencies appear

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Integer Mathematics

- µP → 16 Bit
- Datatype → Signed Integer

power supply voltage → Maximum value 20 V

memory map:

n	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
	sign	16384	8192	4096	2048	1024	512	256	128	64	32	16	8	4	2	1	
binary		0	0	0	0	0	0	0	0	0	0	**1**	0	**1**	0	0	
decimal		0	0	0	0	0	0	0	0	0	0	16	0	4	0	0	**20**

10 Bit unused (bits 14–5)

5 Bit used (bits 4–0)

Bit 15 - sign:

Positive → 0

Negative → 1

Integer Mathematics

For a better memory usage → Shift 10 Bits to left (multiplication with 2^{10})

n	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
2^n	sign	16384	8192	4096	2048	1024	512	256	128	64	32	16	8	4	2	1	
binary		0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	
decimal		0	0	0	0	0	0	0	0	0	0	16	0	4	0	0	**20**

$$20 \cdot 2^{10} = 20480$$

n	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
2^n	sign	16384	8192	4096	2048	1024	512	256	128	64	32	16	8	4	2	1	
binary		1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
decimal		16384	0	4096	0	0	0	0	0	0	0	0	0	0	0	0	**20480**

10 free Bits for a higher accuracy

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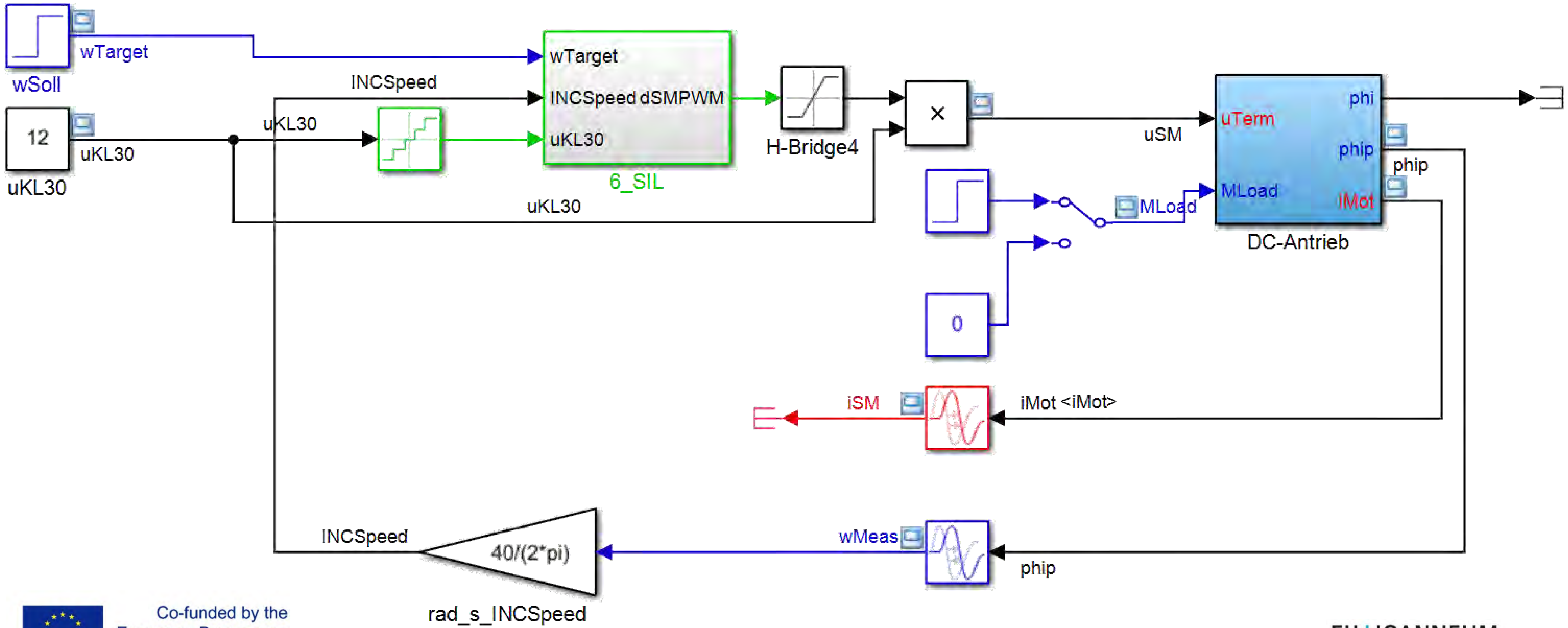
SIL-Model – Top view



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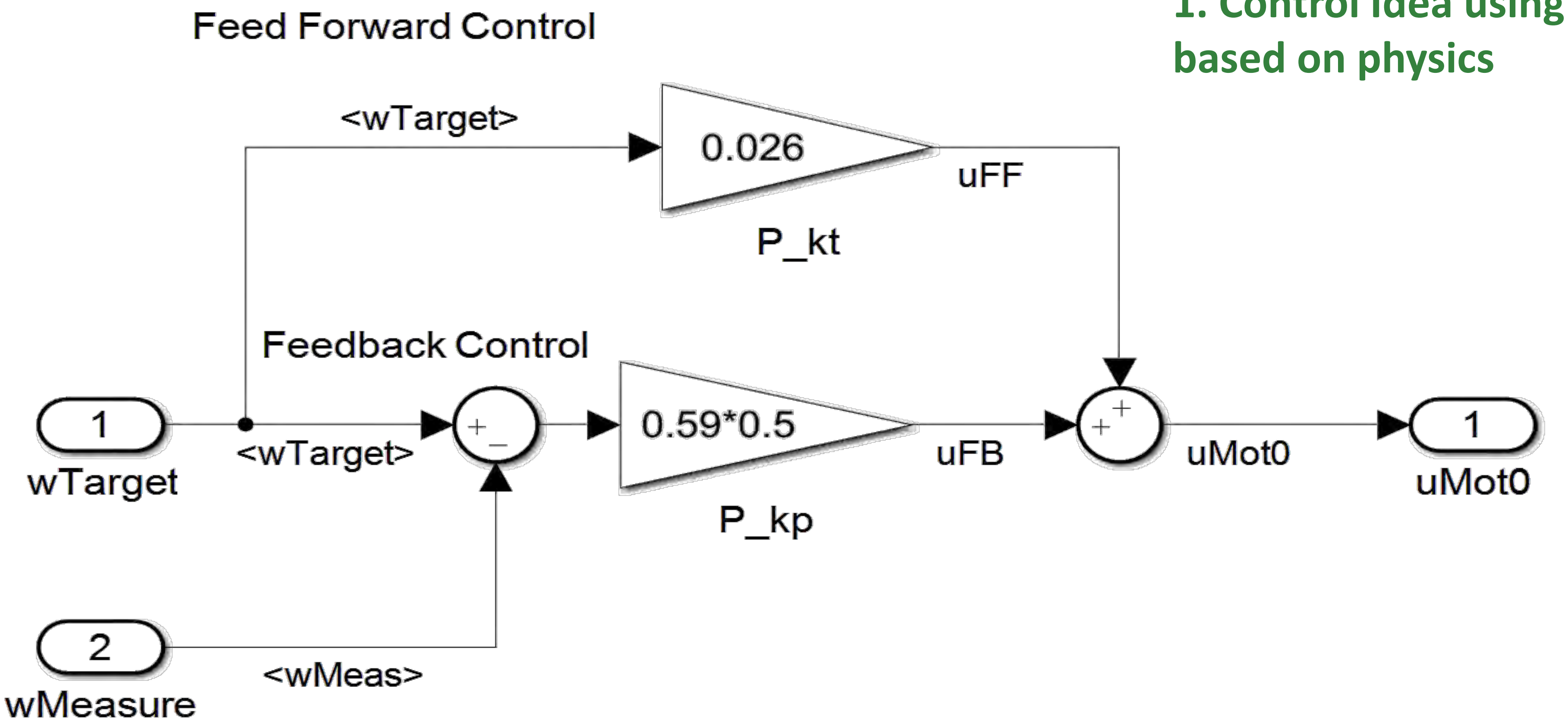
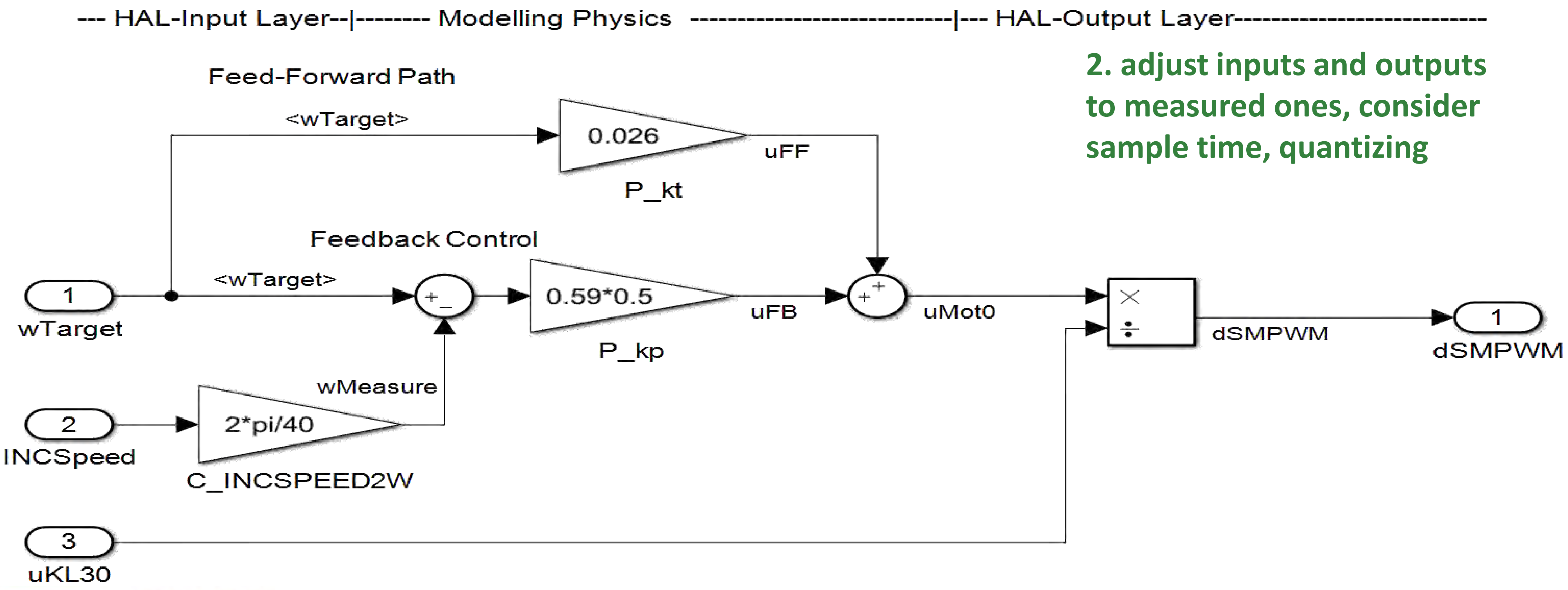
Simple Speed Controller – 1st MIL-Model

1. Control Idea using signals based on physics



Simple Speed Controller – 2nd MIL-Model

2. adjust inputs and outputs to measured ones, consider sample time, quantizing



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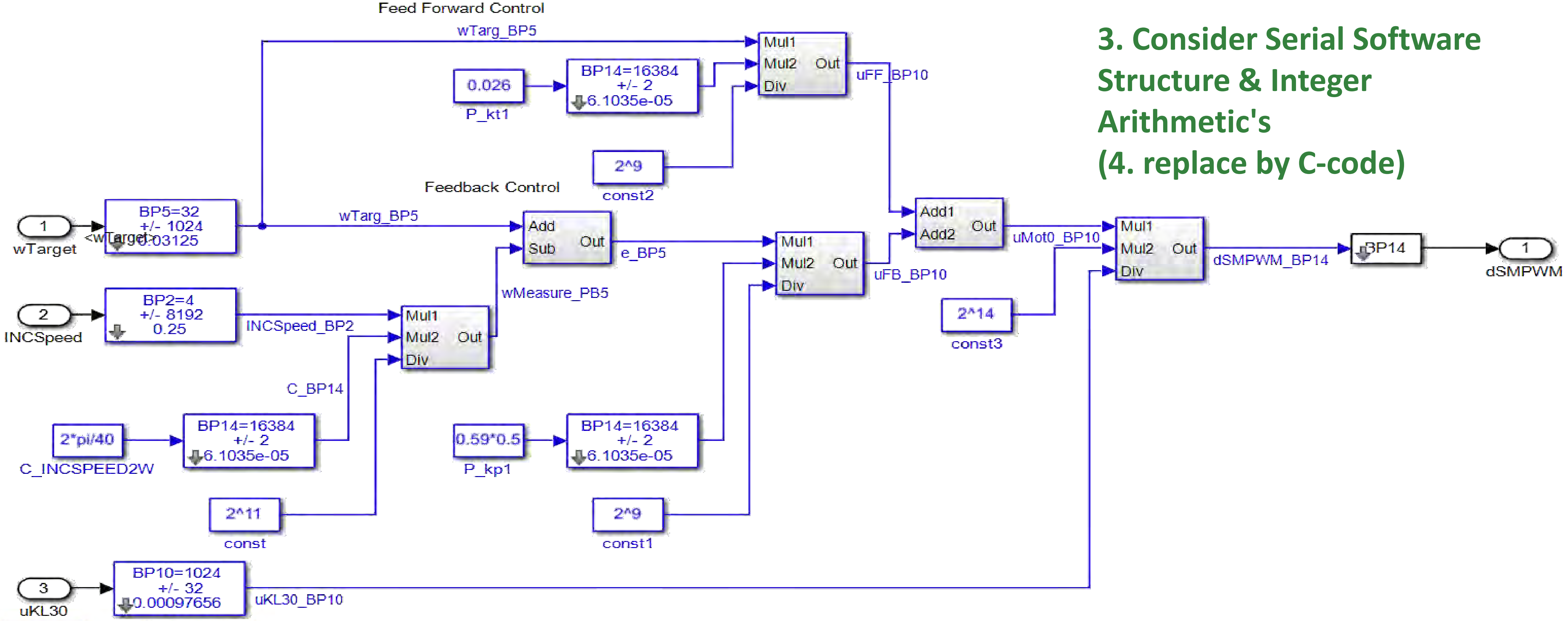
Simple Speed Controller - SIL-Model



3. Consider Serial Software Structure & Integer Arithmetic's
(4. replace by C-code)

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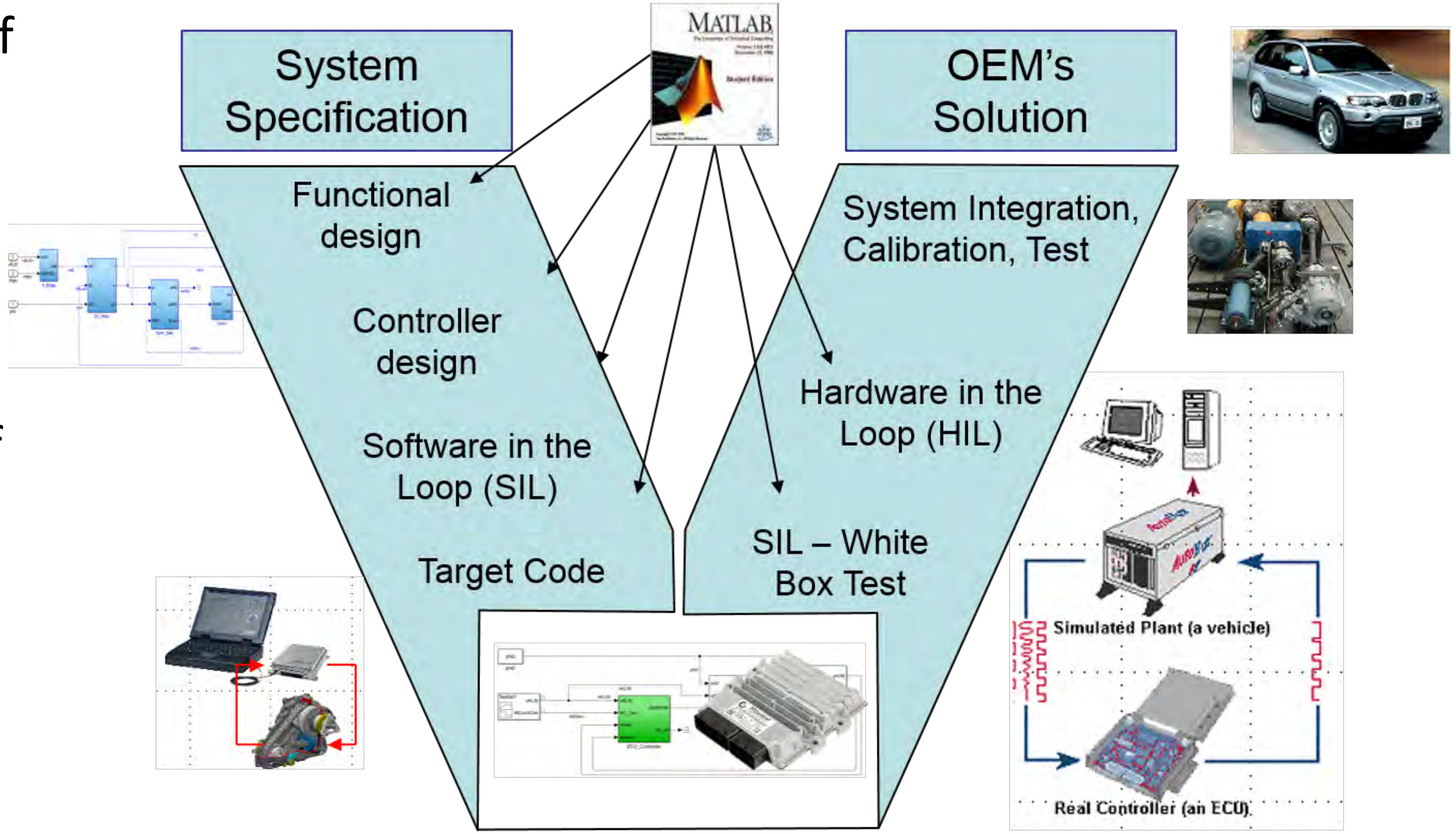
Torque Control - SIL to Target Code

- After a detailed description of the whole system with Simulink, we are ready to generate the target-code.
- Code generation:
  - Programming language C
  - If possible, directly out of Simulink (best practice)
  - Derive the C-Code from the Simulink Model (in case the automatic code generation does not work).



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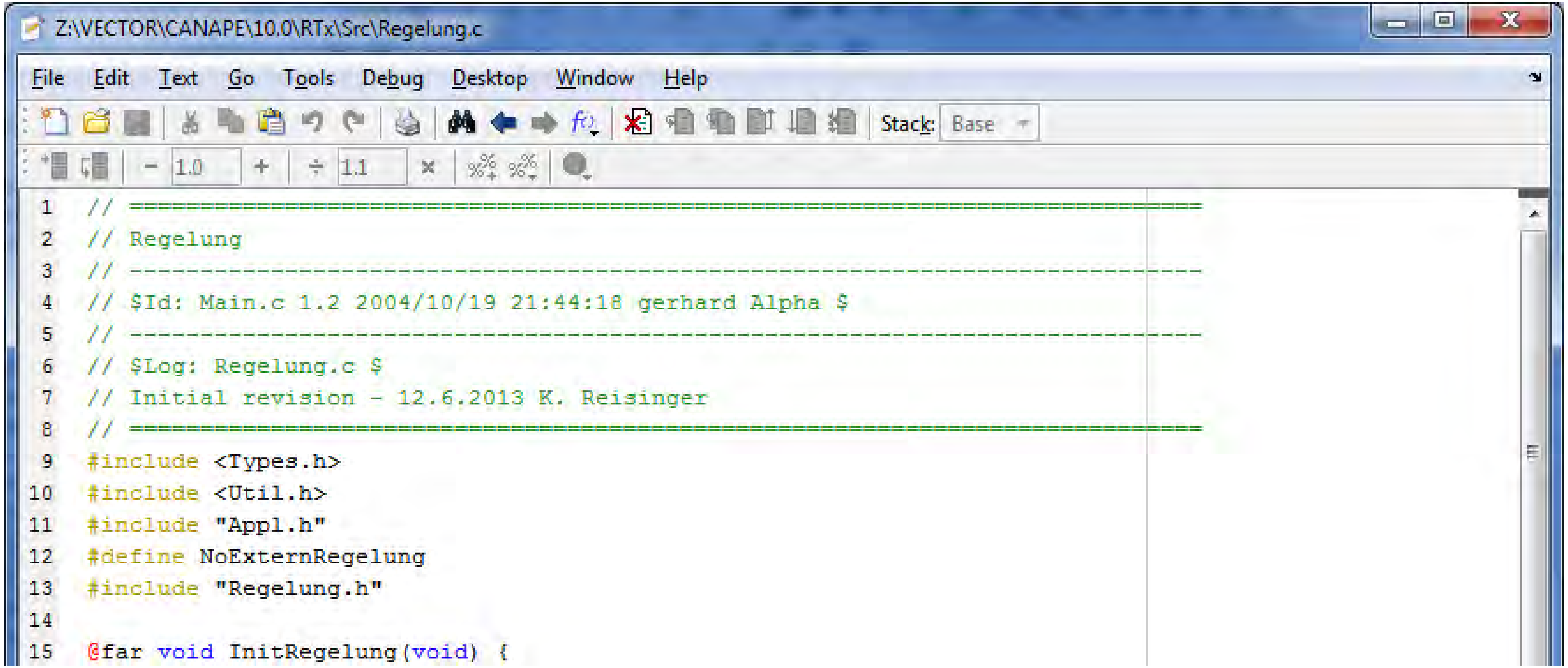
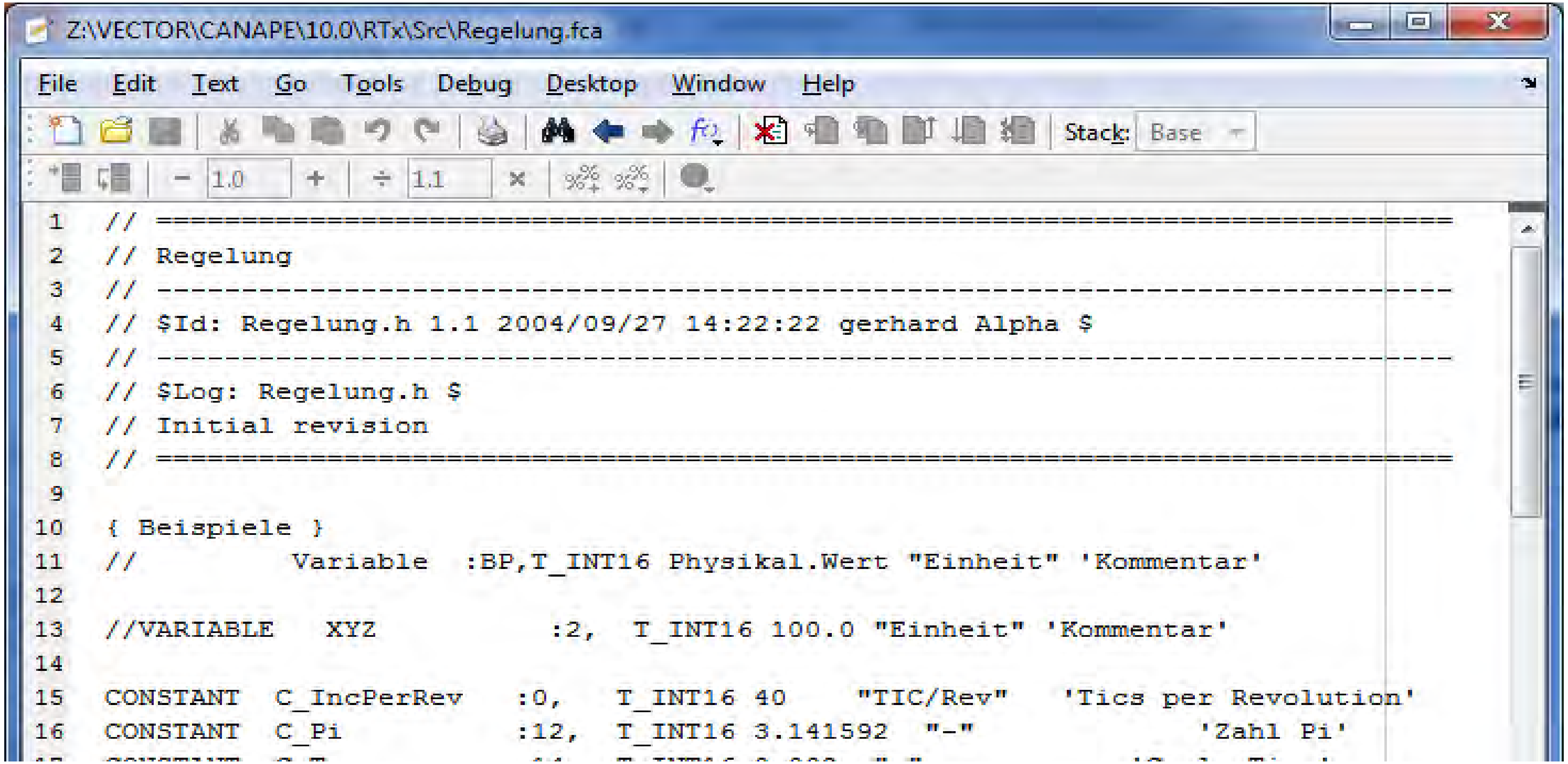
Demo C-Code


Z:\VECTOR\CANAPE\10.0\RTx\Src\Regelung.c
File Edit Text Go Tools Debug Desktop Window Help
Stack: Base
1.0
1.1
// ===
// Regelung
// ---
// $Id: Main.c 1.2 2004/10/19 21:44:18 gerhard Alpha $
// ---
// $Log: Regelung.c $
// Initial revision - 12.6.2013 K. Reisinger
// ===
#include <Types.h>
#include <Util.h>
#include "Appl.h"
#define NoExternRegelung
#include "Regelung.h"
@far void InitRegelung(void) {

Definition of ASAM-2-Data



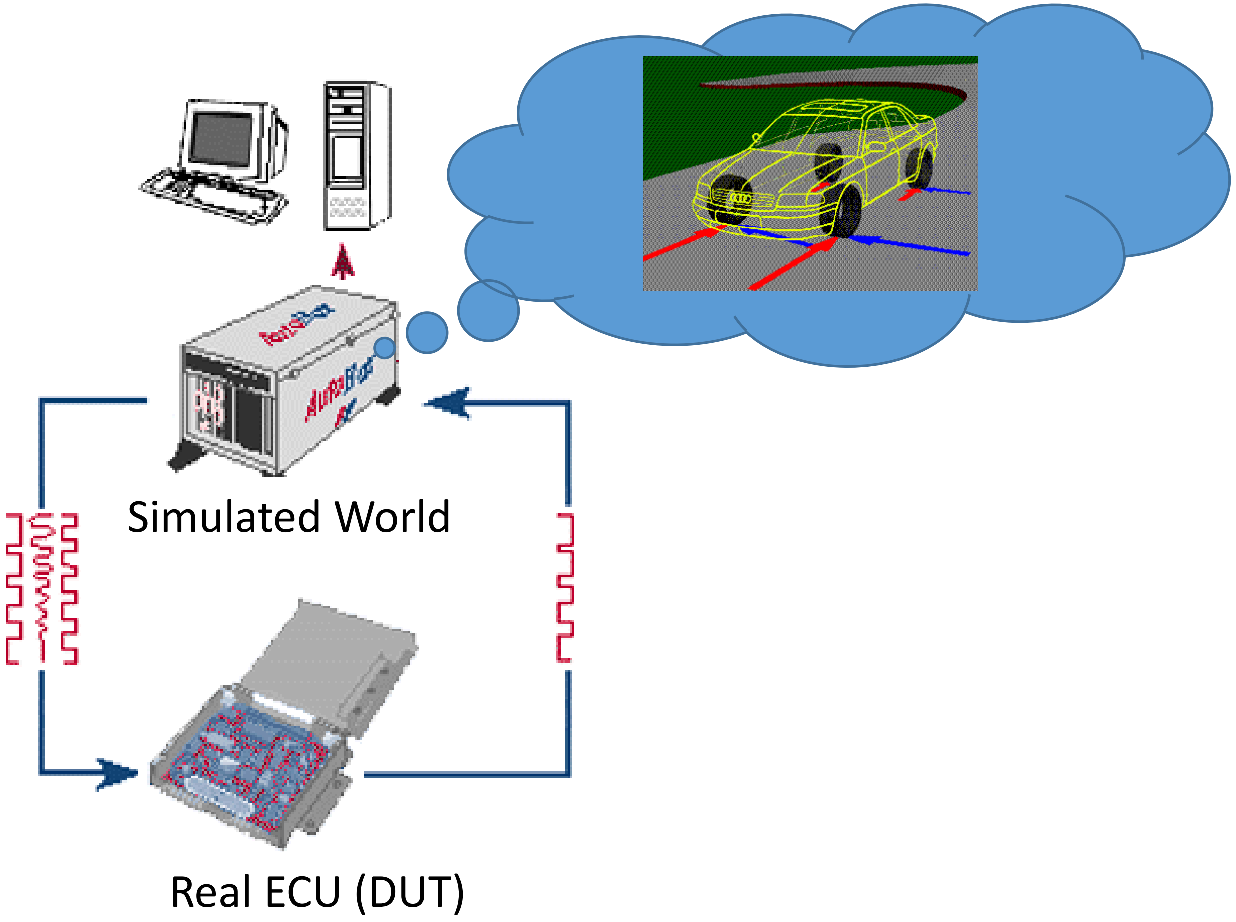

```
// ==========================================================================
// Regelung
// --------------------------------------------------------------------------
// $Id: Regelung.h 1.1 2004/09/27 14:22:22 gerhard Alpha $
// --------------------------------------------------------------------------
// $Log: Regelung.h $
// Initial revision
// ==========================================================================

{ Beispiele }
//          Variable   :BP,T_INT16 Physikal.Wert "Einheit" 'Kommentar'

//VARIABLE   XYZ          :2,  T_INT16 100.0 "Einheit" 'Kommentar'

CONSTANT  C_IncPerRev    :0,    T_INT16 40     "TIC/Rev"   'Tics per Revolution'
CONSTANT  C_Pi           :12,   T_INT16 3.141592  "-"              'Zahl Pi'
```

Software Integration Test - HIL



Hardware In the Loop

Integration Test for ECU
(=Software + Hardware)

- Setup
  - simulation of the world w/o ECU in Real Time
  - generation Bus / electrical signals for ECU
  - measures answers of ECU
  - Testing catalogue for automatic tests
  - automatic test assessment and reporting
- Simulation Model
  - Re-use MIL-Model
  - Low order integrator, (Euler, Heun)
  - 0.5ms – 2 ms sample time
  - No loops!

Quelle: Reisinger, Rühringer, Mathis: Modellgestützte Mechatronik-Systementwicklung für Allradanwendungen; TECHME, Sindelfingen Sept. 2007

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Lessons Learned

- Wide difference in understanding electrics and µP's among the students.
- 2 ECTS is very thought for this content.
- Requirements Management is the most unpopular topic - but necessary.
- Fixed point arithmetic is not that important for the engineer designing the mechatronic system, it's a task of the software developer.

Lessons Learned

- The Simulink-SW-model shall be compiled automatically to be loaded to the ECU – no C-code development for system engineers.
- Stateflow is the real way to model the process automation – but not part of curriculum.
- Simscape is the new way to model the plant – but not part of curriculum.
- Integration of mechatronic systems into test benches shall be added.

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Our next steps 1

Simulink-Coded Rapid Prototype System

- No integer arithmetic's for functional developer
- Auto-Coding
- Download by plug-n-play

https://www.ttcontrol.com

→Starting next Semester

→next Chapter

Our next steps 2

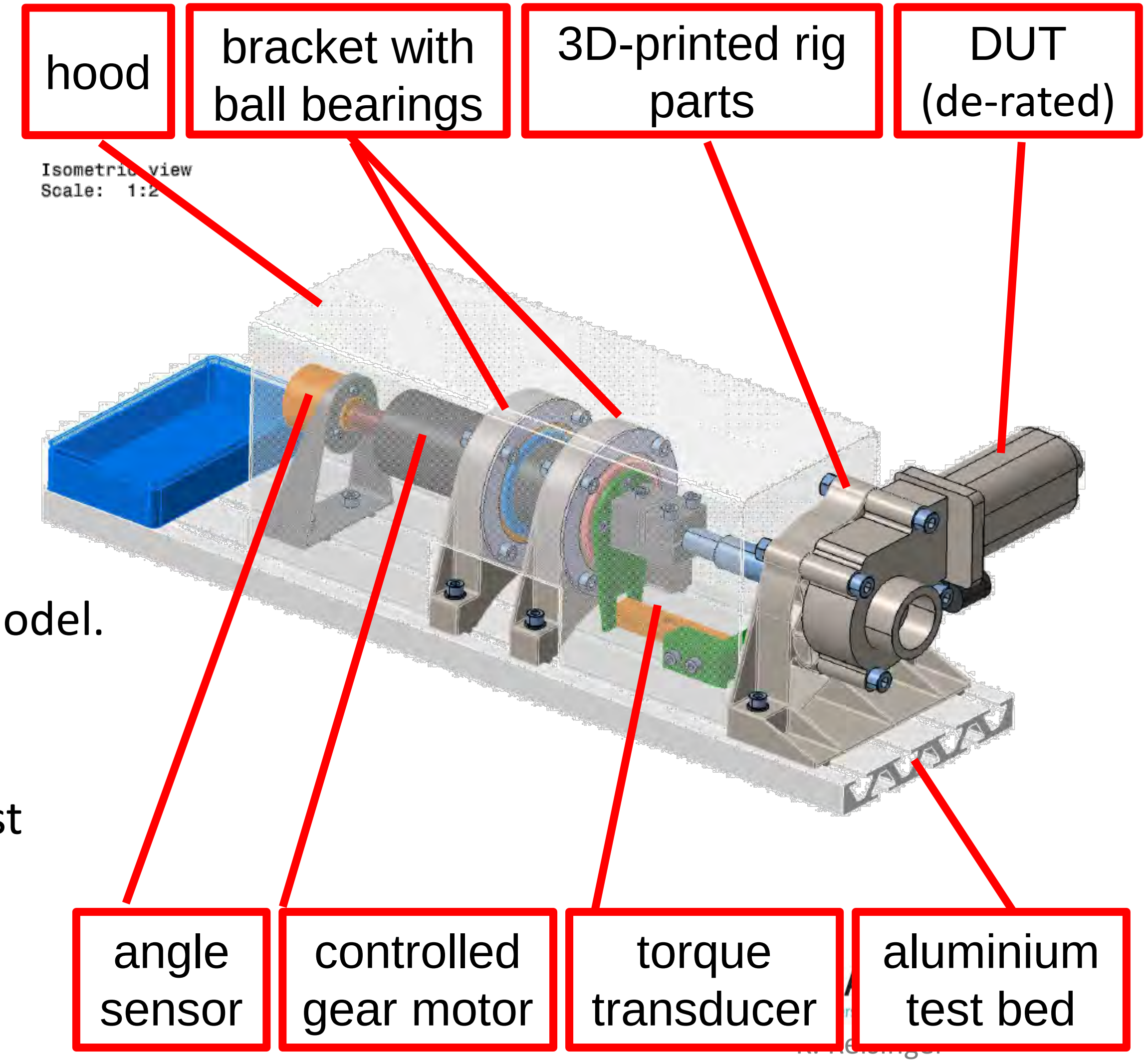
Low-Cost Mini-HIL

Integration of controlled systems into test benches

- 2 groups of 2 students:
  1. developing control software for current task = Device Under Test (DUT).
  2. Application of a HIL test bench and test automation.

- HIL test bench – low performance, full functionality
  - Controlled DC-motor
  - ECU with Simulink-Interface to develop the plant model.
  - Shows all signals to drive a modern test bench.

- CANoe (vector)
  - Test bench automation defines how to drive the test and acquires the resultant signals.



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FH JOANNEUM
University of Applied Sciences

Engineering Knowledge Transfer Units to Increase
Student´s Employability and Regional Development

Setting up a Mechatronic System

T. Lechner

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598710-EPP-1-2018-1-AT-EPPKA2-CBHE-JP

Choosing the ECU

- Interfaces
  - Speed Controller
    - Motor Speed (Input)
    - DC-Motor terminal voltage (Output)
  - Position Controller
    - Rotor position (Input)
    - Motor speed and **direction** (Output → desired value for speed controller)
  - DC-Motor load torque
  - Estimated via DC-Motor current

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Choosing the ECU

- Interfaces
  - Communication between ECU and environment
    - CAN-Interface
  - ECU application
    - Can Calibration Protocol (CCP)

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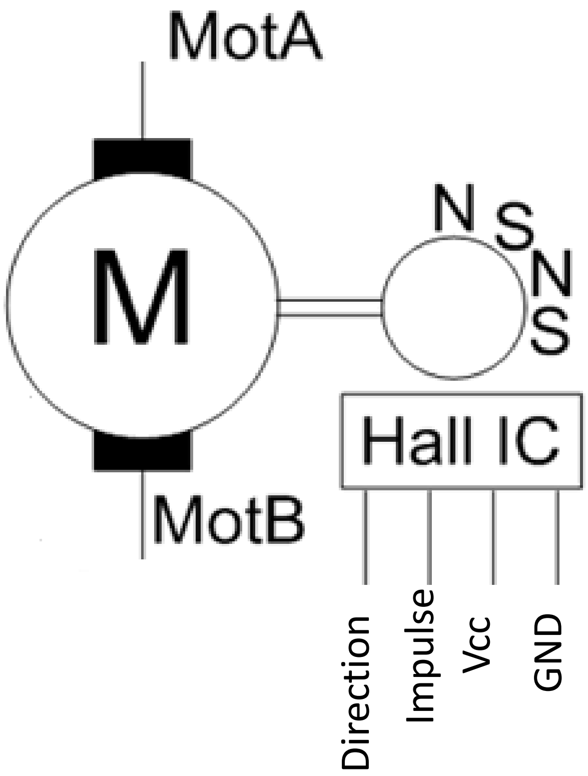
Choosing the ECU

Speed Measurement

- DC-Motor → 10 Magnets
  - Hall-Sensor measures
  - Rotor position (Input)
  - Motor speed and **direction** (Output → desired value for speed controller)
- DC-Motor load torque
  - Estimated via DC-Motor current



Picture: K. Reisinger

Speed Measurement → Timer

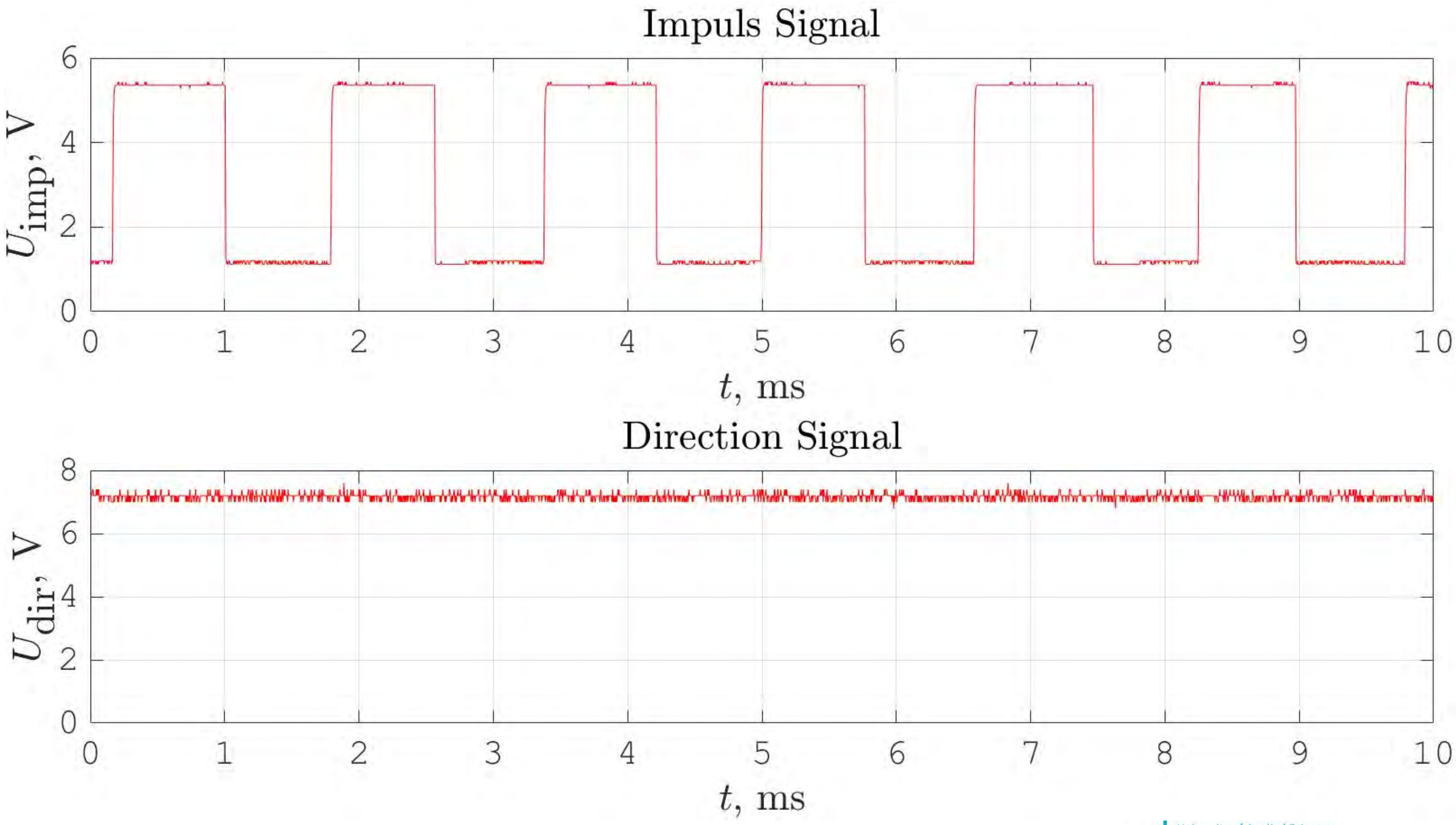
Speed measurement with timer input:

$$f = \frac{1}{\tau}$$

f … Frequency in Hz
τ … Period time in s
f → Measurement value

$$n = \frac{f}{N} \cdot 60$$

n … engine speed in RPM
N … Number of increments per revolution. In our case, N=20.



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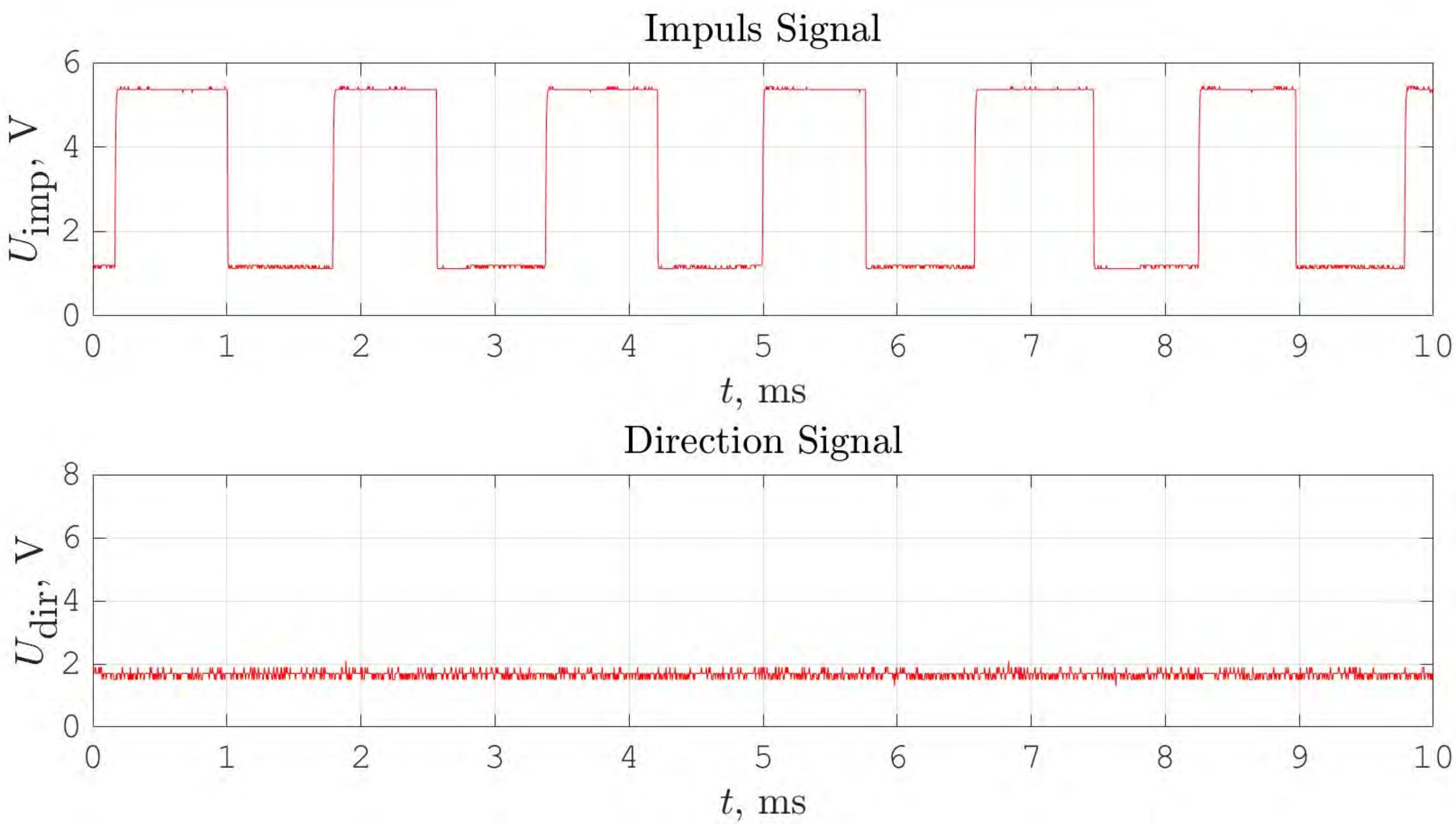
Position using Direction → Counter

Direction measurement with a digital input:

$U_{\mathrm{dir}} \cong 1.9\ \mathrm{V} \rightarrow$ logical 0

$U_{\mathrm{dir}} \cong 5.5\ \mathrm{V} \rightarrow$ logical 1

Direction of rotation:
1 → clockwise
0 → counter clock-wise



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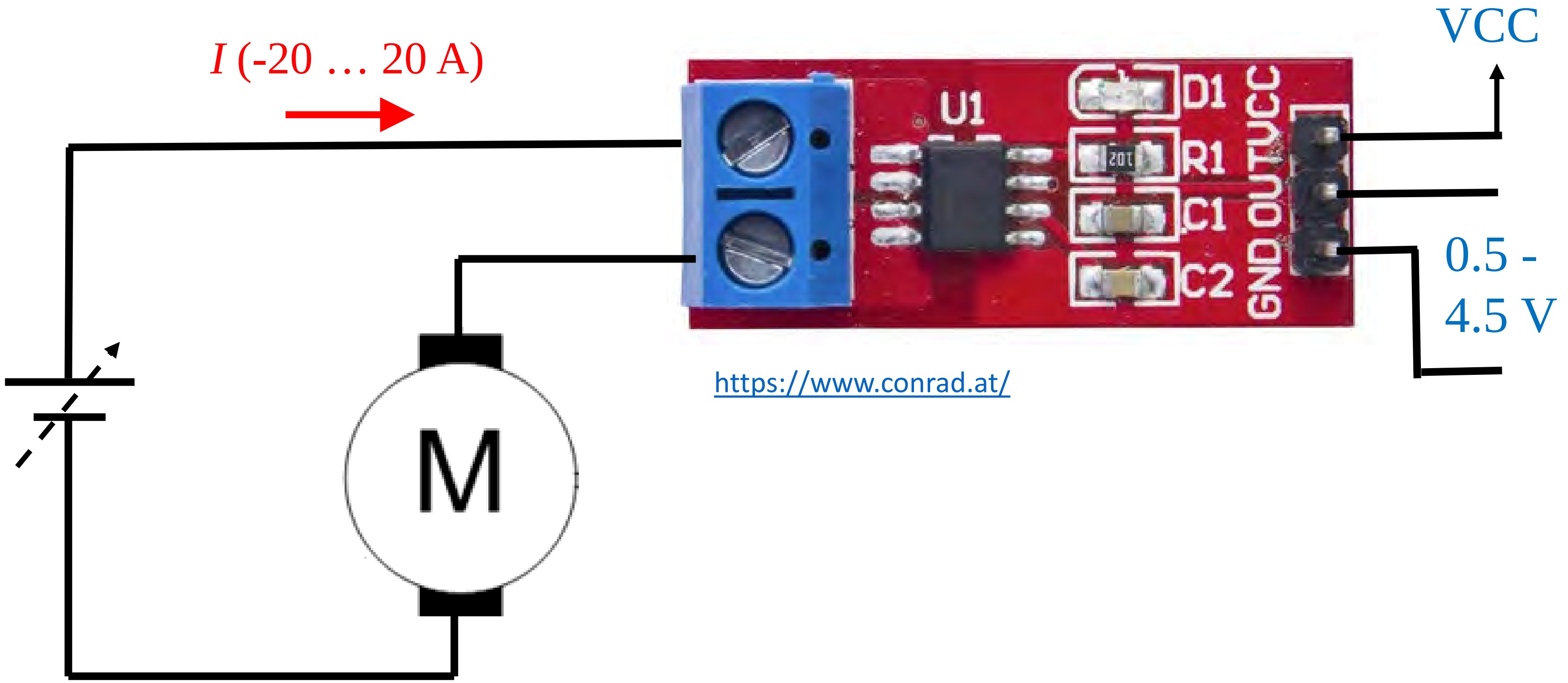
Electrical Current Measurement

Current Measurement with a Hall-Sensor:

Supply Voltage (VCC) → 5 V

-20 A → 0.5 V
0 A → 2.5 V
20 A → 4.5 V

For DAQ → Analog Input



https://www.conrad.at/

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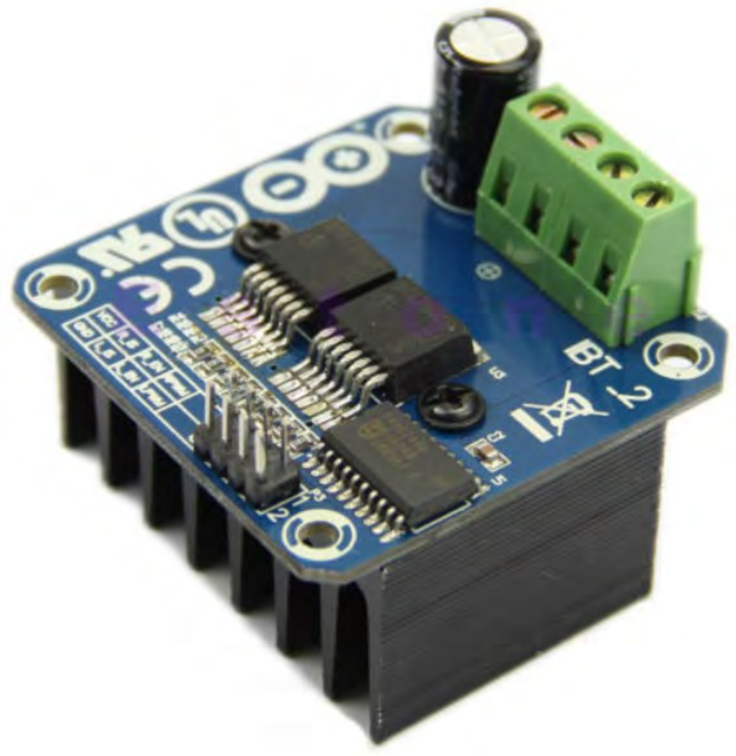
DC-Motor connection

otor ter inal voltage

- he voltage t be variable to change the otor pee
- he voltage t change the polarity to change the irection
- a i ini otor c rrent i 12

PWM modulated Voltage

H-Bridge



http://www.hessmer.org/blog/2013/12/28/ibt-2-h-bridge-with-arduino

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e ire erfor ance

- Minimum cycle time: 2 ms
  - This is an empirical value, estimated according to the expertise we have with a similar application. The cycle time influences the controller performance.
- Automatic software-generation out of Simulink
  - State of the art method. (language C is not longer part of our curriculum)
- Calibration via XCP or CCP
  - State of the art method for development, parameter setting, debugging …
- Calculation with Floating Point Variables (single, double, …)
  - Knowledge about Integer-Arithmetic is not so important for an system engineer.

r hoice

→ HY-TTC 510 from TT-Tech

<u>Key Benefits:</u>

- 32 bit dual-core CPU with 180MHz
- Floating-point unit
- 12 Bit ADC
- PWM-Outputs
- Digital in an Outputs
- CAN, CCP ….

https://www.ttcontrol.com

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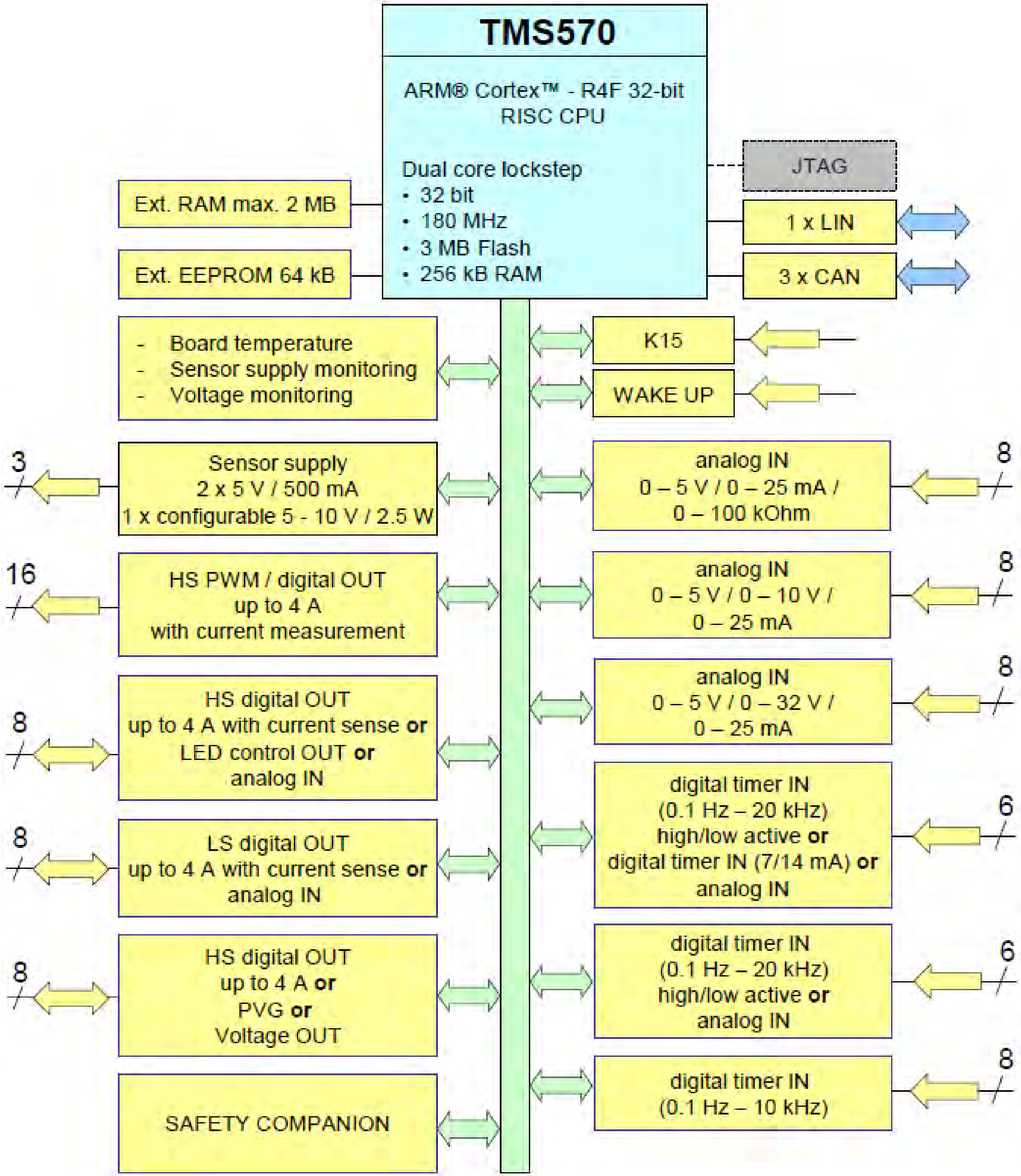

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ECU – Target-performance comparison

	Quantity	Range	Possible with HY TTC 510?
CAN	~2	500 kBaud	- Yes (3 CAN-Interfaces available)
Sensor Supply	1	5 V	- Yes (2 x 5 V supply on board)
Sensor Supply	1	10 V	- Yes (1 x programmable between 5 V an 10 V)
Voltage out 5 V	1	0 - 5 V	- Yes
PWM out	2	15 kHz 0 – 100 % 0 – 5 V	- No (maximum 1 kHz) - Yes - Yes/No → Voltage level must be adapted (voltage divider) - No, too less amperage → work around

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ECU – Target-performance comparison

	Quantity	Range	Possible with HY TTC 510?
Timer in	1	2000 Hz	- Yes (maximum 20 kHz)
Digital in	1	1.9 V → logical 0 5.5 V → logical 1	- Yes
Analog in	1	5 V	- Yes
Counter in	1	1.9 V → logical 0 5.5 V → logical 1	- Yes (for Simulink, a Workaround is necessary)

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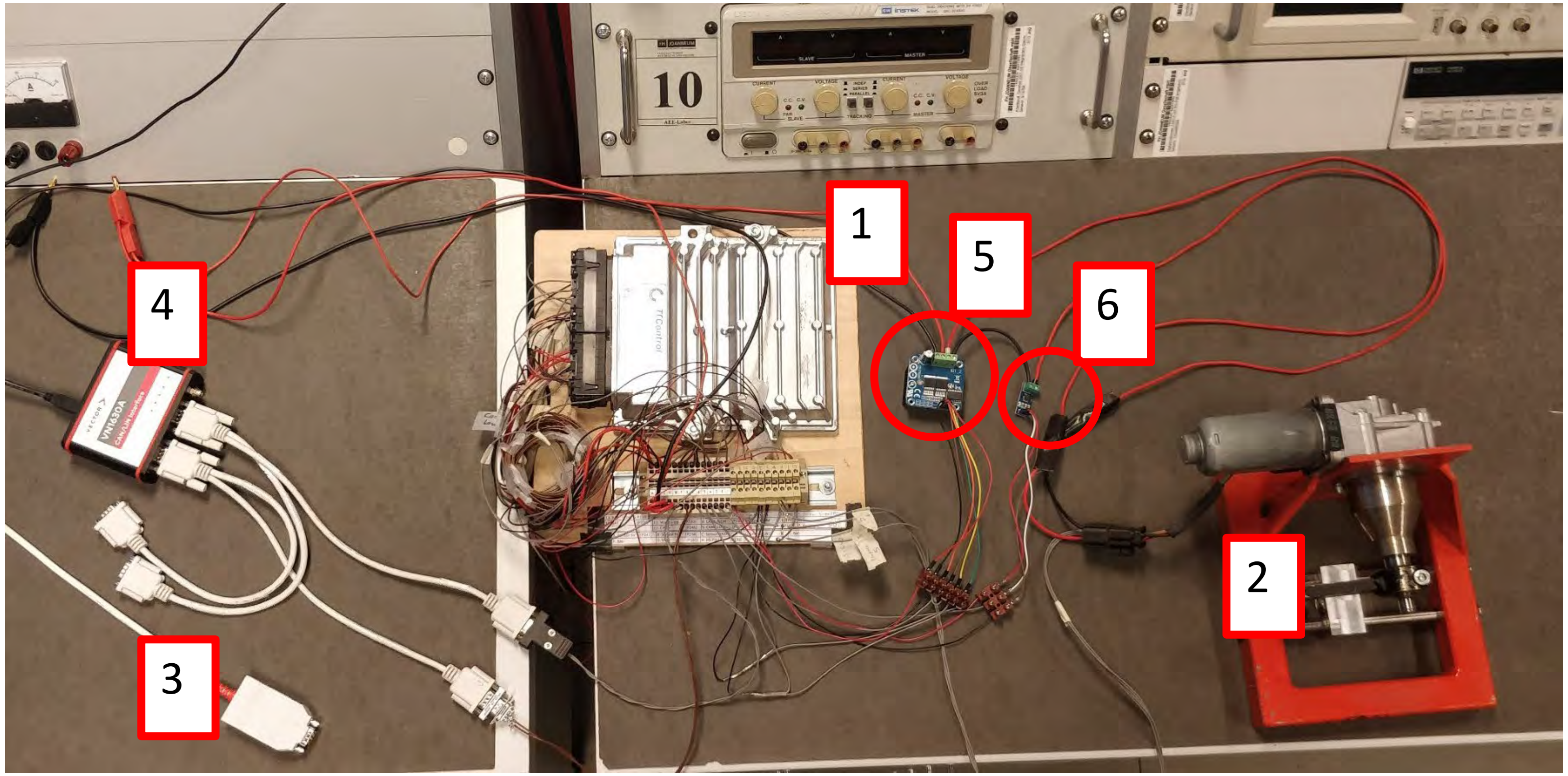
ECU – Target-performance comparison

- Minimum cycle time: 2 ms
  - OK. The cycle time can be adjusted in discreet steps. The minimum value is 1 ms.
- Automatic Software generation out of Simulink
  - OK. A Simulink-Library is included in the scope of delivery. A basic description, for correct solver settings is available.
- Calibration via XCP or CCP
  - OK. CCP is supported in the polling mode.
- Calculation with Floating Points (single, double, …)
  - OK. The µP has a FPU on board.

System overview

1) ECU HY-TTC 510
2) Device under Test (DUT)
3) PCAN-USB Interface for flashing
4) Vector VN1630 USB to CAN Interface for application (CCP) and measurement
5) H-Bridge
6) Current transducer



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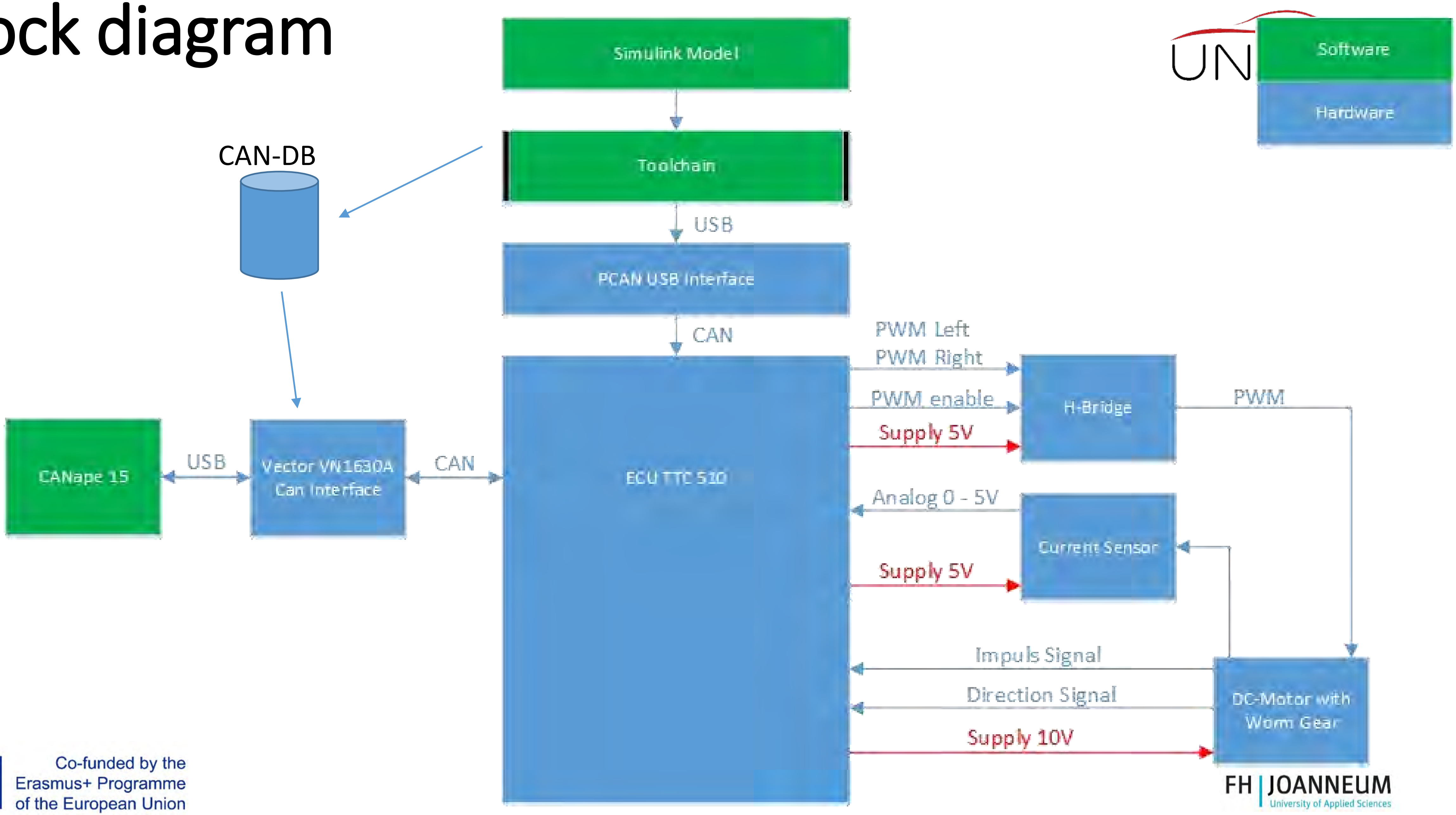
Block diagram



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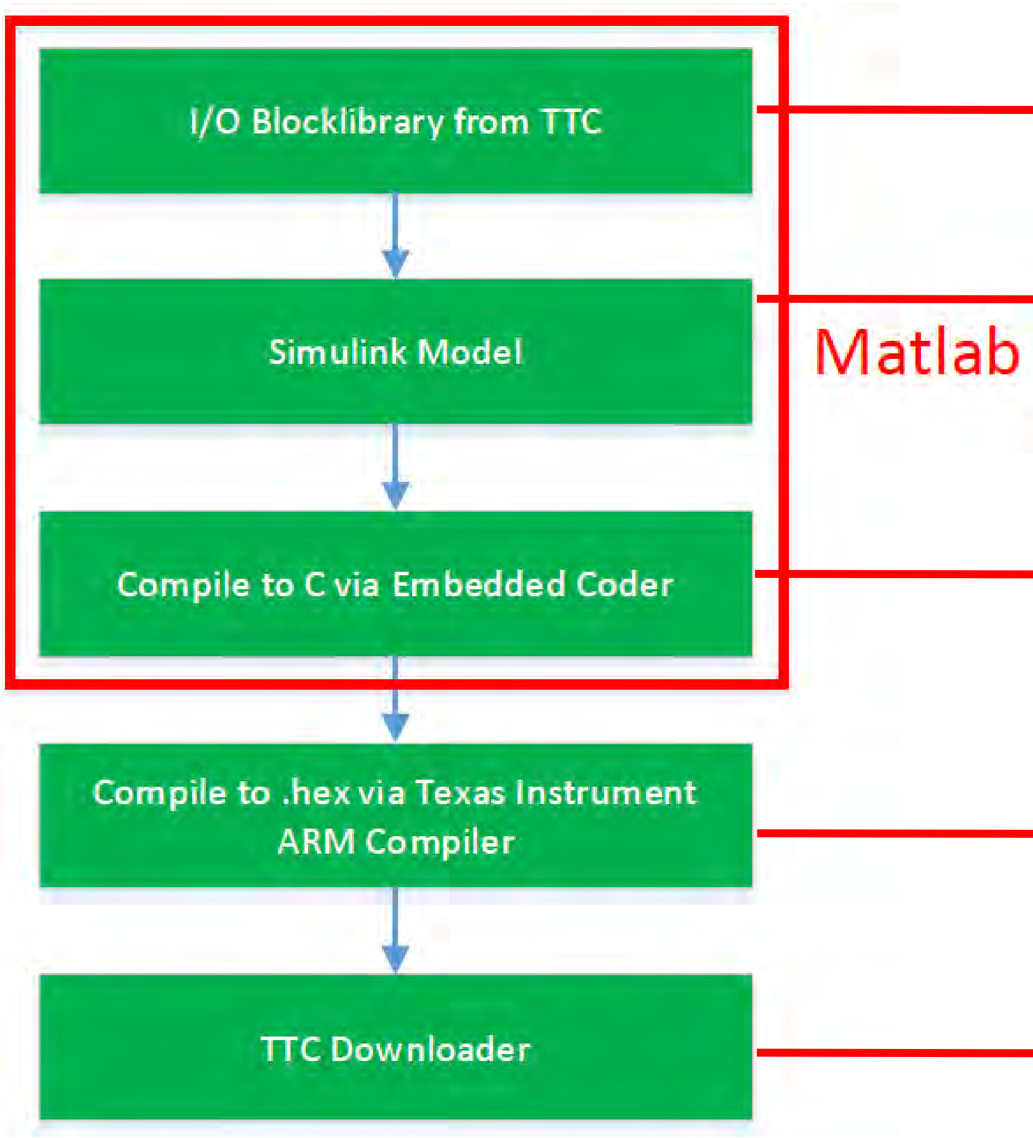
K. Reisinger



or progra ing:
in an o tp t port
ba ic etting cycle ti e, error han ling, ...

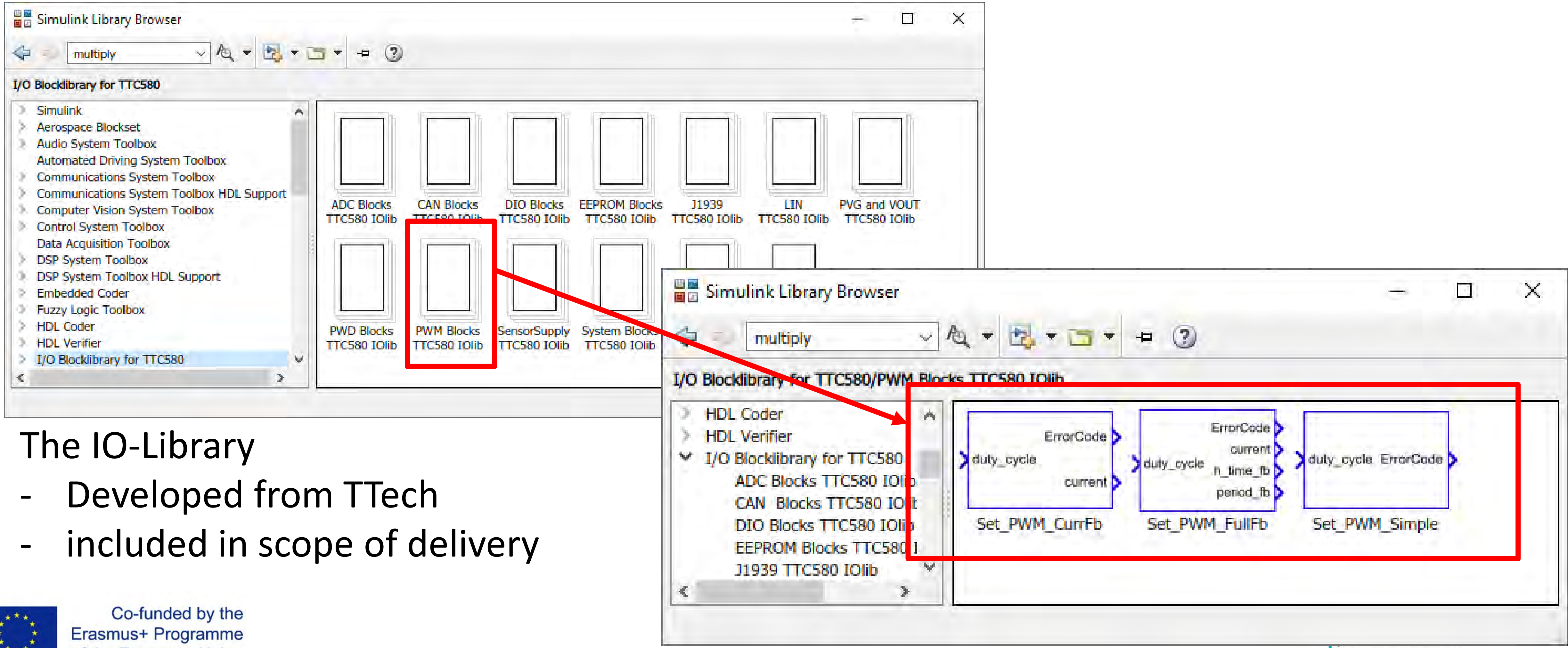
nctional e cription for controller, tate achine...

to atic co e generation o t of the i link o el. .a2l ile generation witho t a re e fro variable .

b ect co e o t of the co e. e lt i a .he ile. inker allocate the a re e for .a2l ile → ile.

ownloa the .he ile to fla h via .

TTC IO-Library



The IO-Library

- Developed from TTech
- included in scope of delivery

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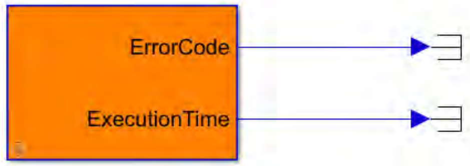
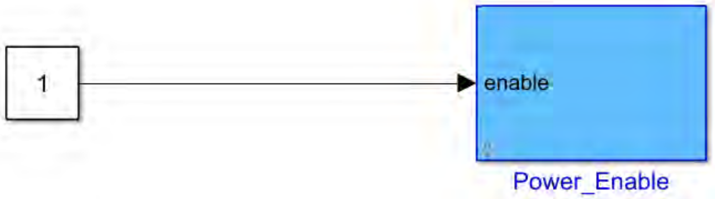
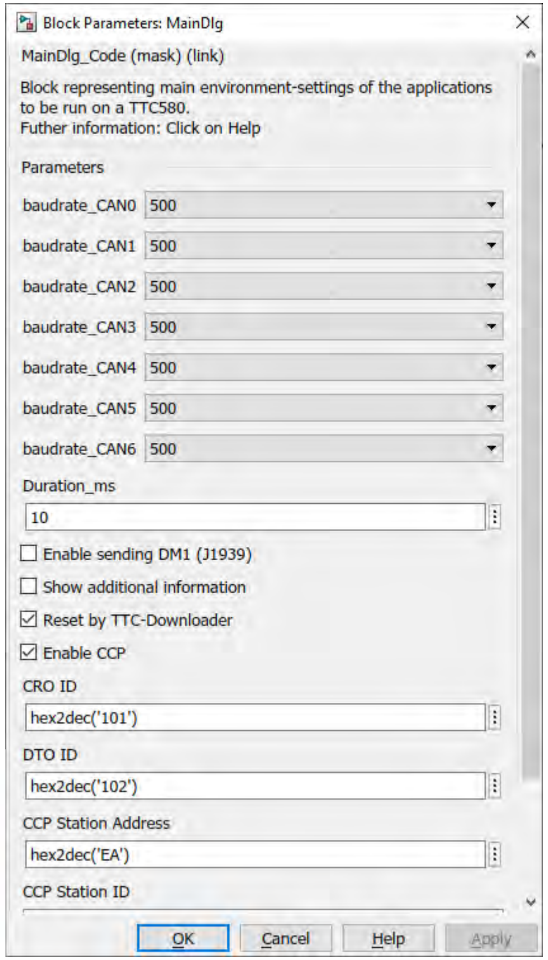
A simple Simulink example

Change PWM ratio as a function of a voltage signal

- Global Settings for the ECU → Block *MainDlg*
- Setup for:
  - CAN Baud rate (max. 1000 kHz)
  - Cycle (Duration) time
  - CCP Addresses
- Power outputs must be enabled
  - Block *Power_Enable*
    - 0 → disable
    - 1 → enable
    - Data type: Boolean



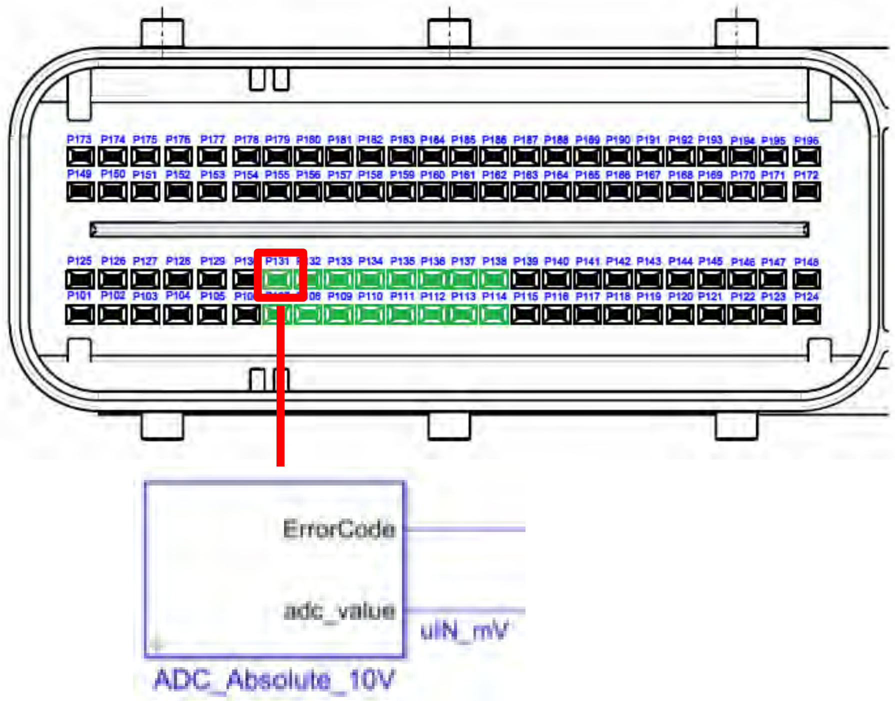




A simple Simulink example

Change PWM ratio as a function of a voltage signal

- Input: Voltage Signal
  - Choosing an Analog-Input port→ Block *`ADC_Absolute_10V`*
  - Choose the input port that fits to the connector pinning:
  - Pin 131 is connected → IO_ADC_09
  - For more info see [1] *4.10*



Pin No.	Function 1	Function 2	SW-define
P107	Analog 0…5 V, 0…10 V Input	Analog 0…25 mA Input	IO_ADC_08
P131	Analog 0…5 V, 0…10 V Input	Analog 0…25 mA Input	IO_ADC_09
P108	Analog 0…5 V, 0…10 V Input	Analog 0…25 mA Input	IO_ADC_10
P132	Analog 0…5 V, 0…10 V Input	Analog 0…25 mA Input	IO_ADC_11
P109	Analog 0…5 V, 0…10 V Input	Analog 0…25 mA Input	IO_ADC_12

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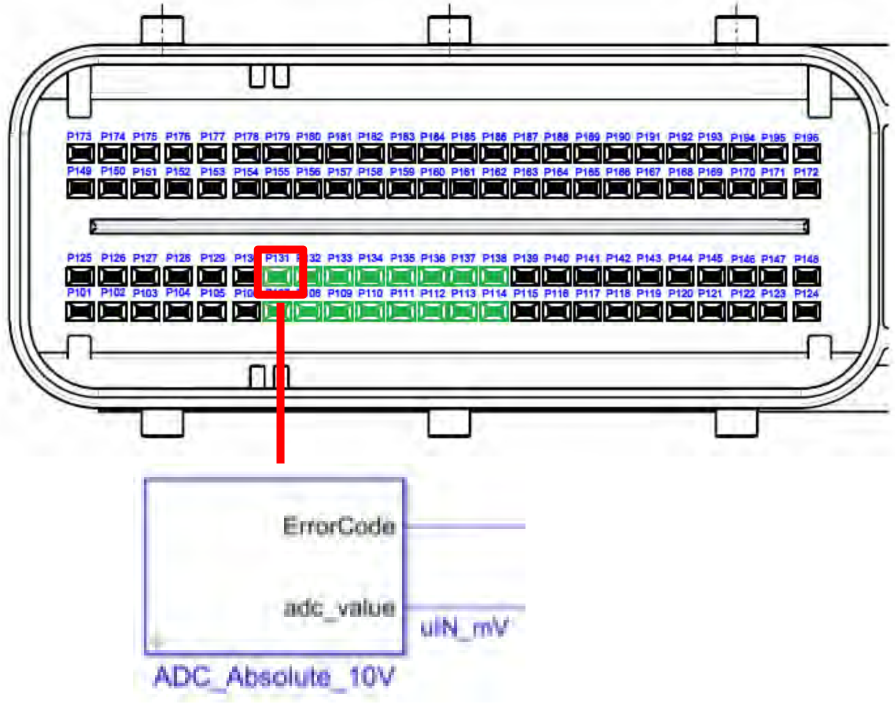
A simple Simulink example

Change PWM ratio as a function of a voltage signal

- Output: PWM-Signal
  - Choosing a PWM output port→ Block *ADC_Absolute_10V*
  - Choose the input port that fits to the connector pinning:

    Pin 177 is connected → IO_PWM_01
  - For more info's see [1] *4.12*



Pin No.	Function 1	Function 2	SW-define
P107	Analog 0…5 V, 0…10 V Input	Analog 0…25 mA Input	IO_ADC_08
P131	Analog 0…5 V, 0…10 V Input	Analog 0…25 mA Input	IO_ADC_09
P108	Analog 0…5 V, 0…10 V Input	Analog 0…25 mA Input	IO_ADC_10
P132	Analog 0…5 V, 0…10 V Input	Analog 0…25 mA Input	IO_ADC_11
P109	Analog 0…5 V, 0…10 V Input	Analog 0…25 mA Input	IO_ADC_12

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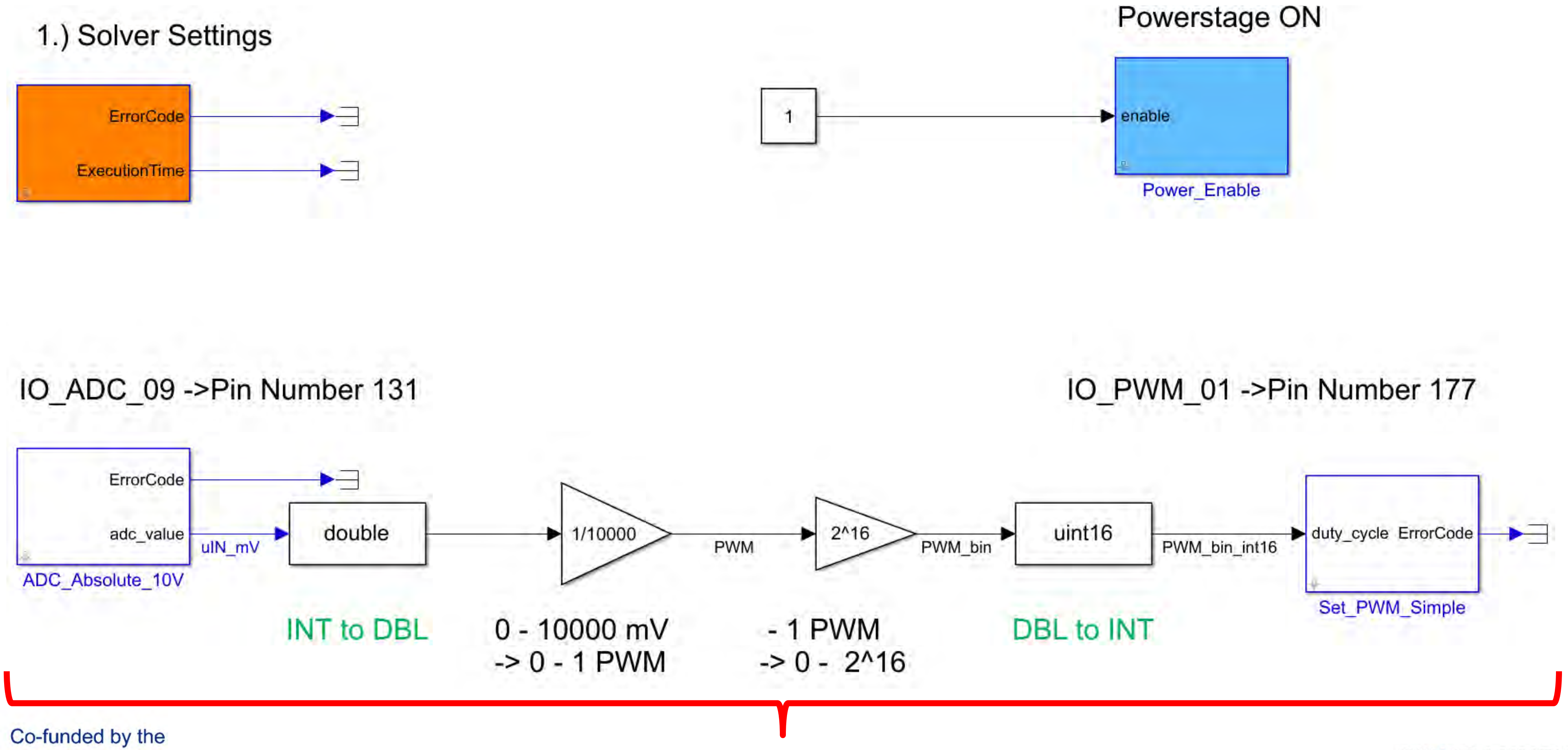
A simple Simulink example

Change PWM ratio as a function of a voltage signal



build → C-Code generation

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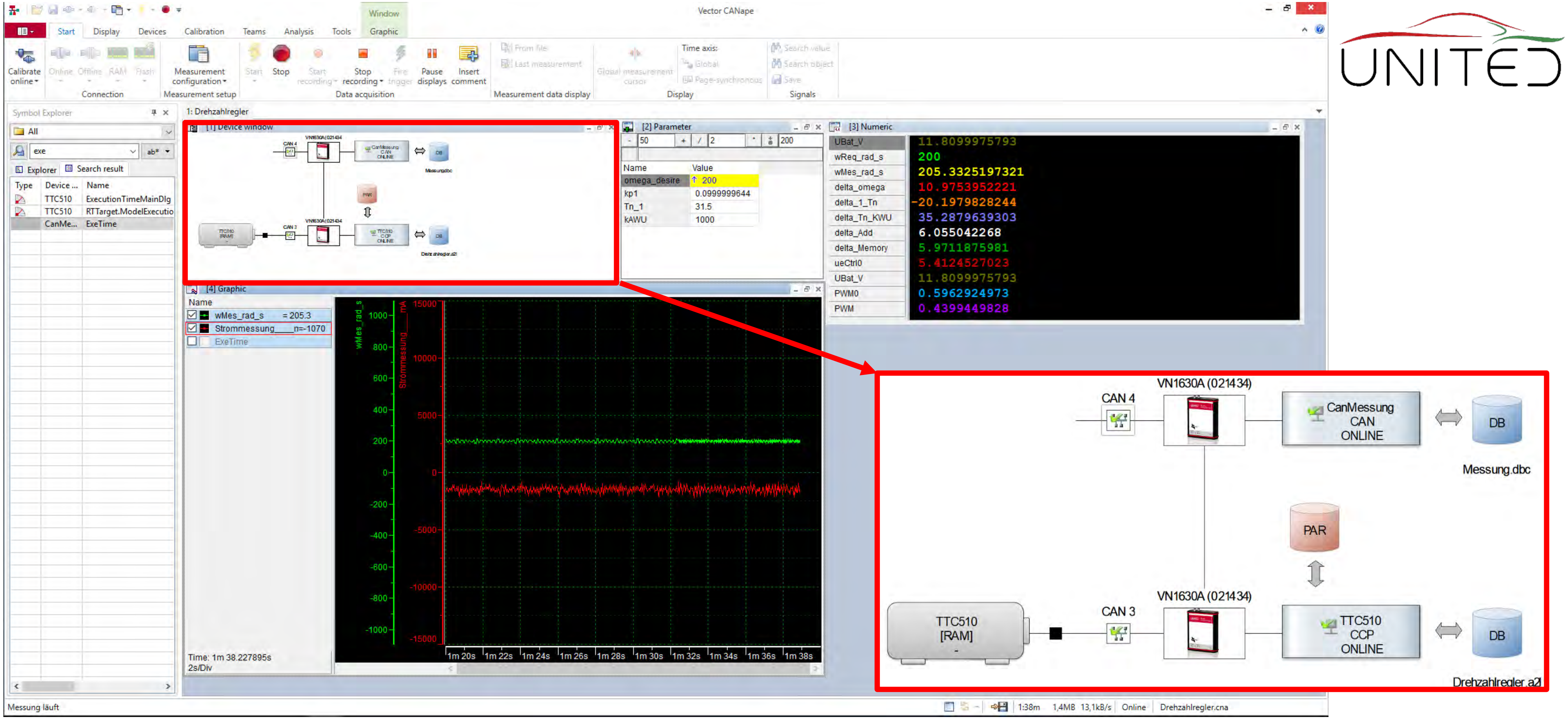

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The Ziegler-Nichols method

Setup for the speed controller (PI)

- Goal: Find optimal values for K_p and T_n
- Set I to zero.
- Increasing K_p to the ultimate gain K_u.
- Adjustment via CCP out of CANape
- PI-controller →

$$K_p = 0.45\, K_u$$

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ECU – adjust the DC motor speed

The TTC510-ECU has no H-Bridge included

- External device must be used
- The ECU controls the H-Bridge with a PWM-Signal
- Maximum PWM-frequency from ECU is 1 kHz → Problem: structure-borne sound

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References

[1] TT Control GmbH: *HY-TTC 500 System Manual Programmable ECU for Sensor-Actuator Management Product Version 01.04;* 28 June 2017

[2] Andreas Patzer | Rainer Zaiser: XCP – The Standard Protocol for ECU Development; Vector Informatik GmbH - Stuttgart, Germany (Free download)

[3] https://www.vector.com/int/en/products/products-a-z/software/canape/

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Hand-On Training Mechatronics

UNITED

Plan a teaching concept for your Courses
Group work for each University, prepare flip charts, ~ 90 min

- What is a proper demo object?
  - safe for students, robust, interesting, cheap, fit to industry nearby
  - must show the mechatronic topics in an easy way
  - the simplified concept must make sense
- Sketch the System
  - Requirements
  - Possible and favorited concepts
- Necessary Hardware

Presentation by a speaker and discussion tomorrow morning.

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UNITED

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Test Facilities of FHJ, it's background and tasks

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K. Reisinger, T. Lechner

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Test Facilities of FHJ, it's background and tasks

T. Lechner

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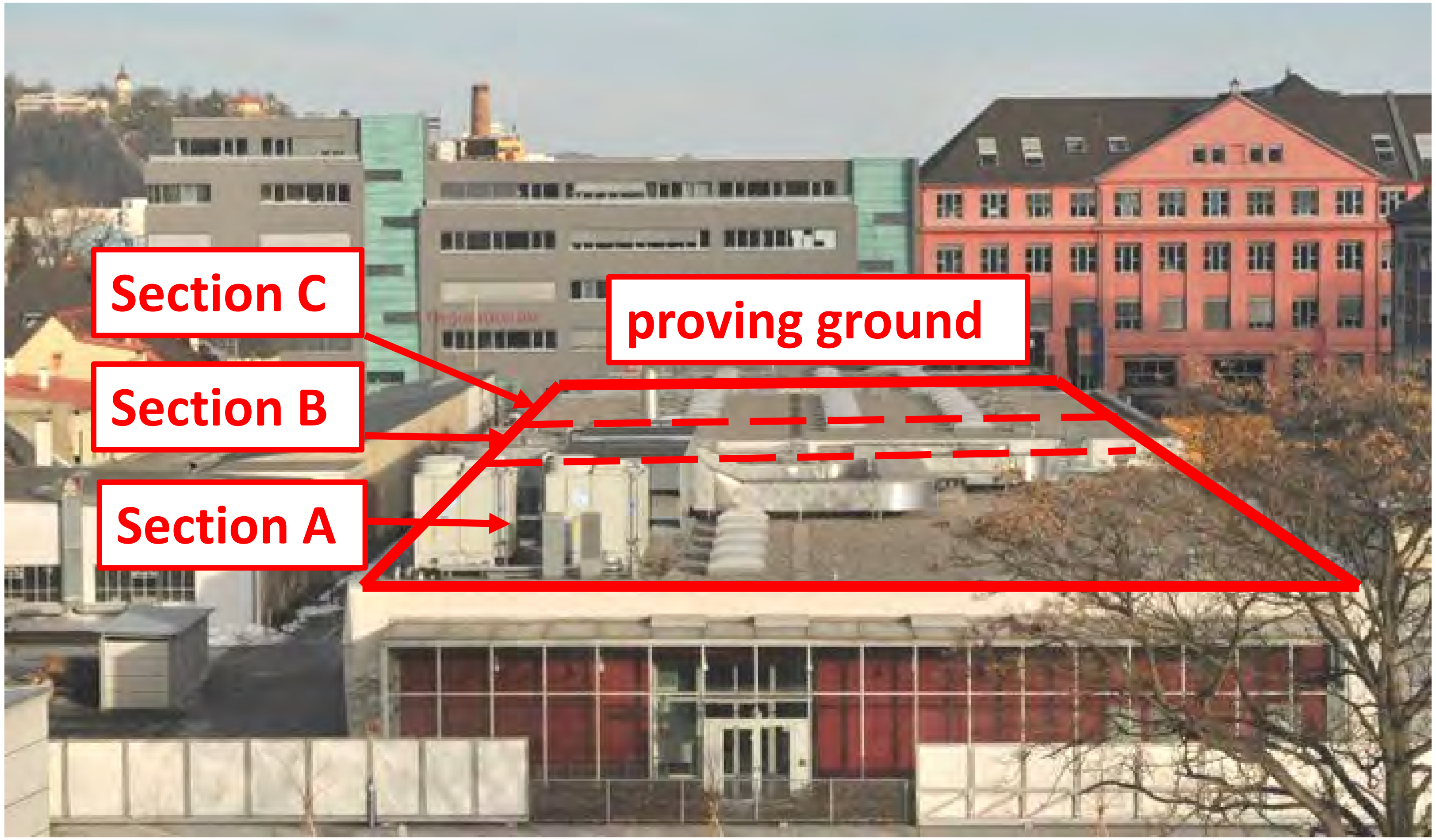
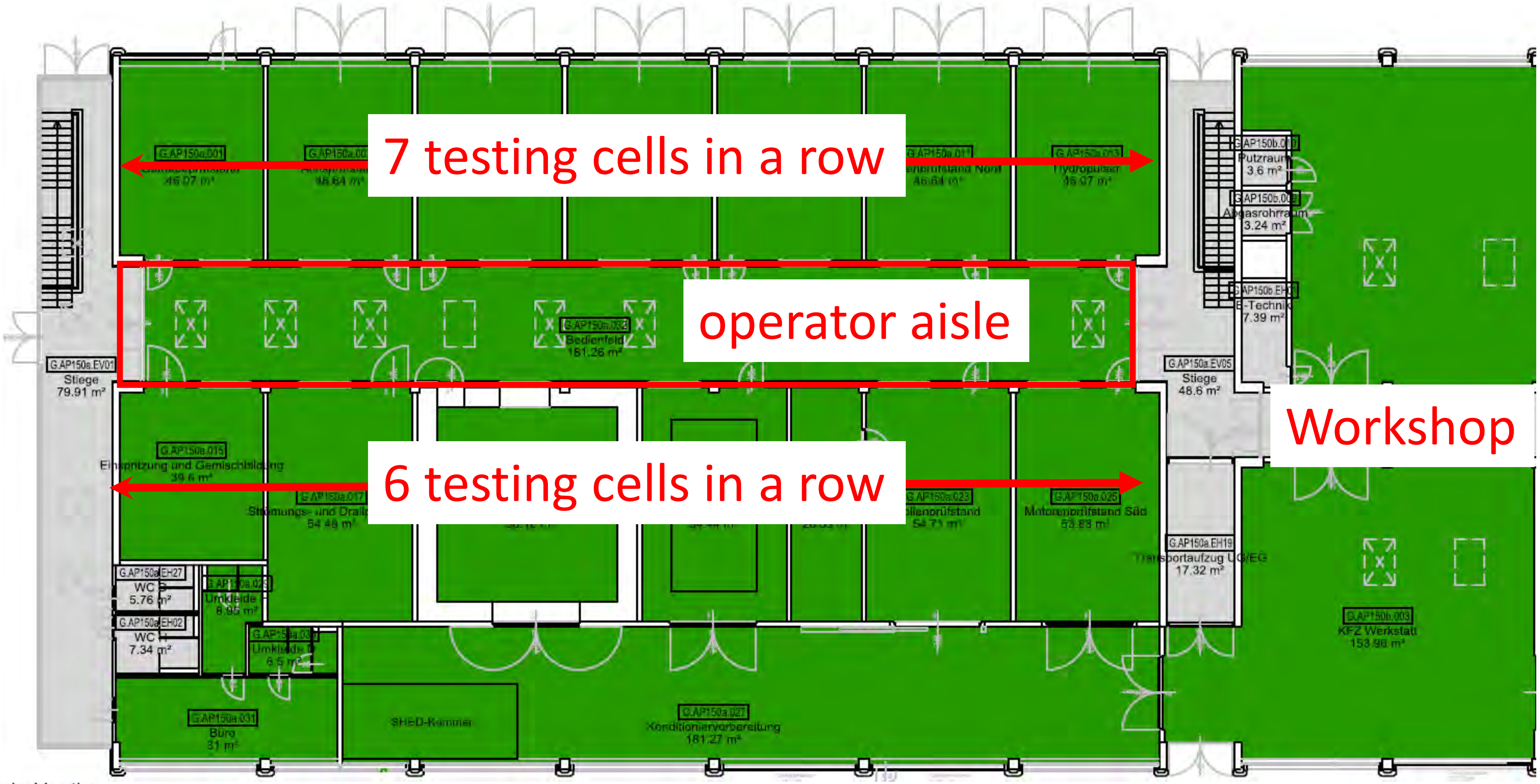
Introduction

- Section C: Laboratories for education
- Section B: Workshops
- Section A: Test bay area



Section A: Floor plan

North



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Operator aisle

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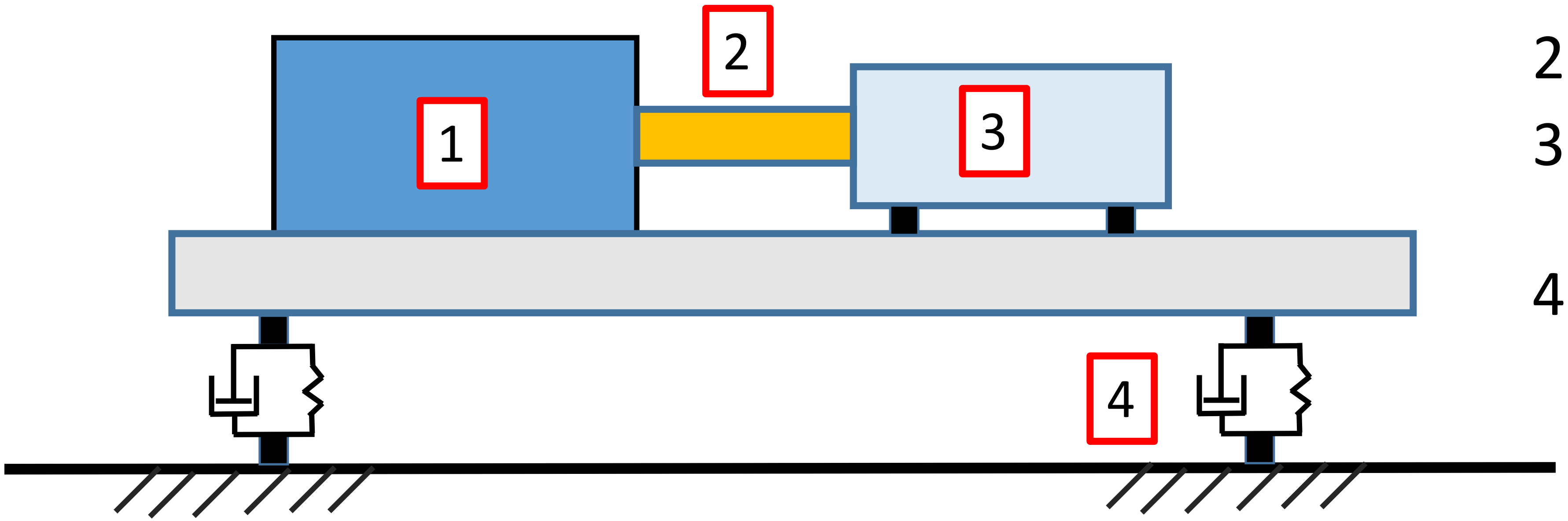
View to test cell

The operator have a view to the test cell through a pane of unbreakable glass.

Engine test rig principle



1 – power absorber

2 – shaft

3 – Unit under Test

4 – Damping system

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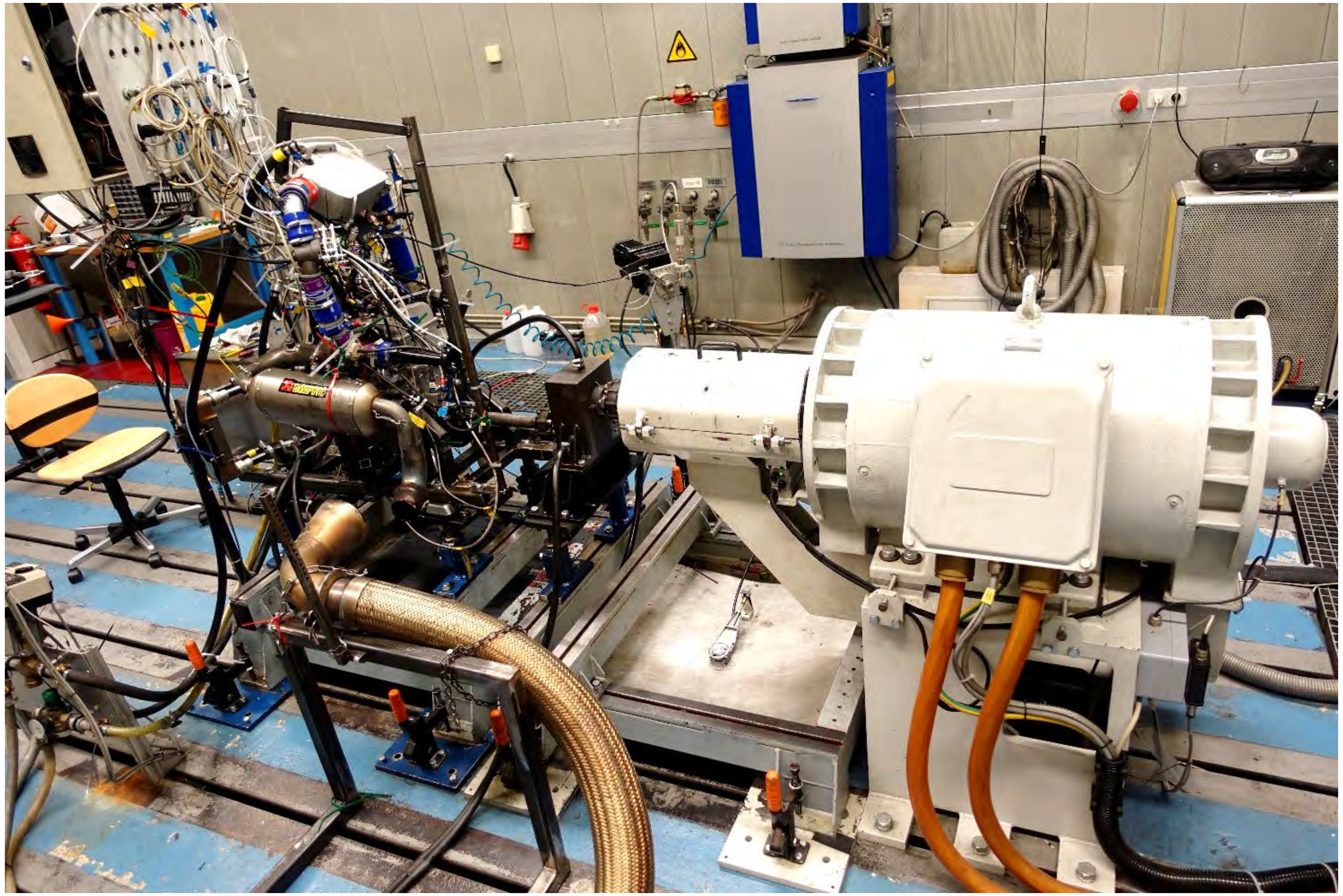
Engine test rig



- Engine test bed south of UAS Graz with AC power absorber (white)

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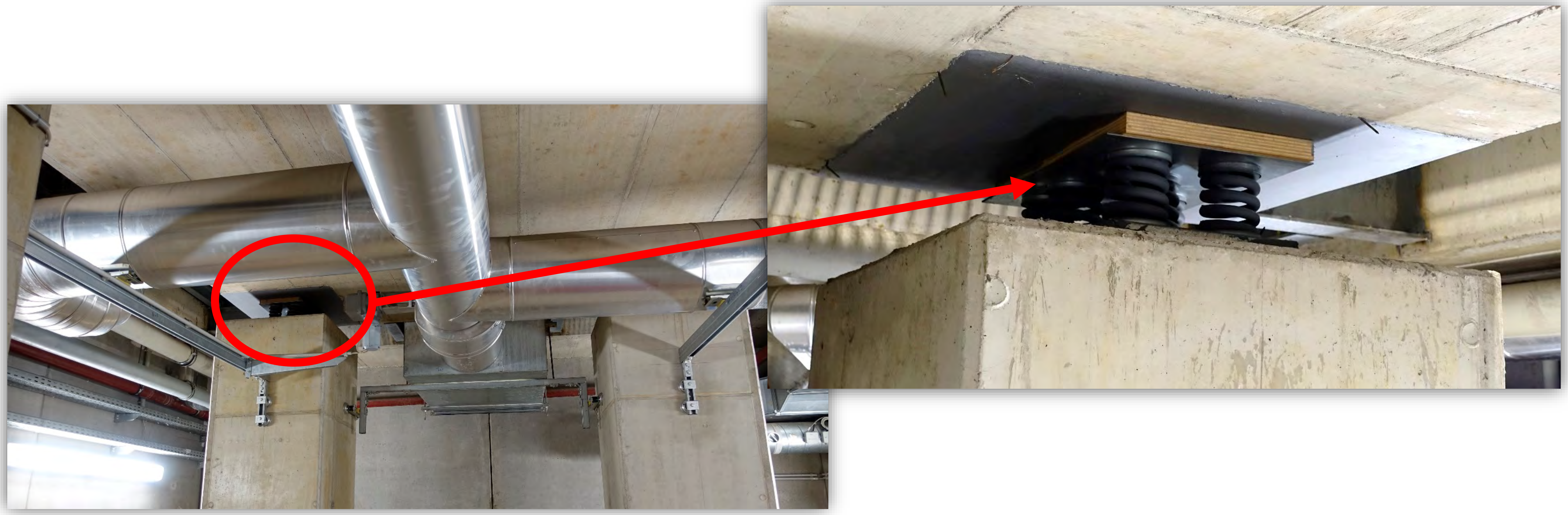
Vibration damping



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Vibration damping

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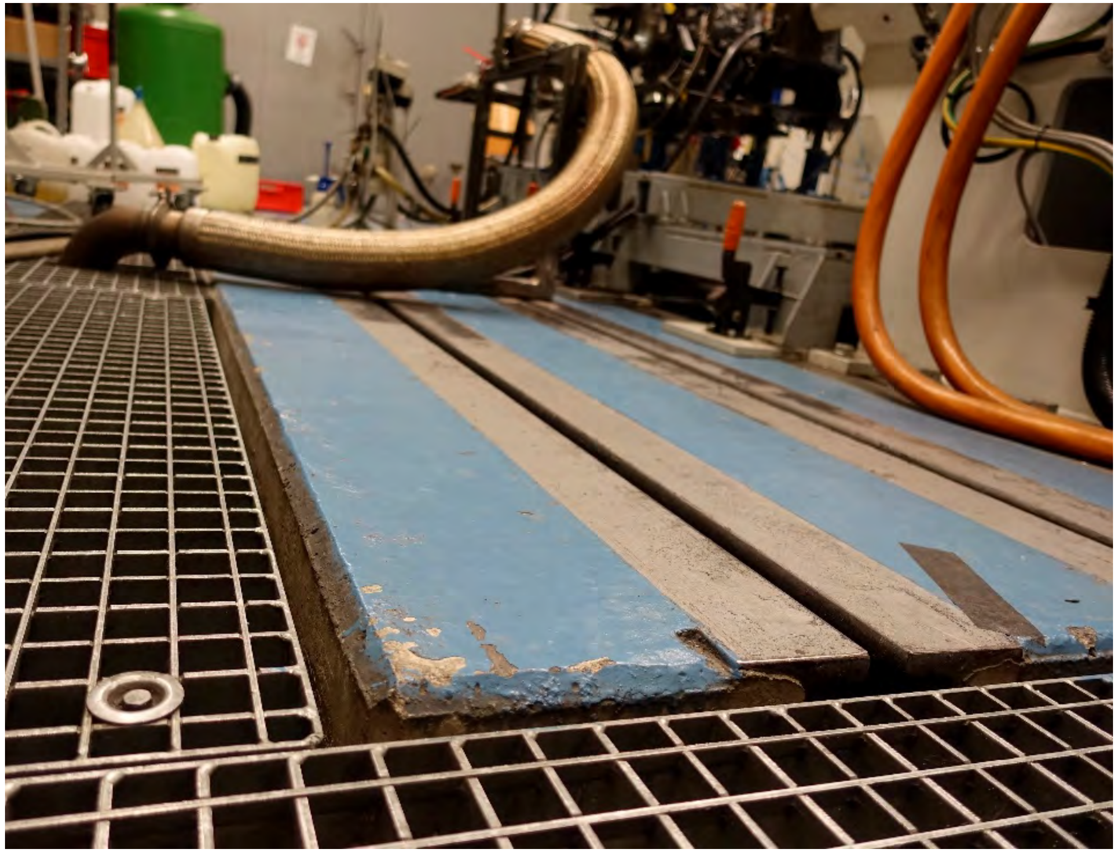
Base plate – T-nuts

UNITED



- Massive Base plate out of concrete
- Track system for T-nuts
  - For easy installation and movement of DUT’s

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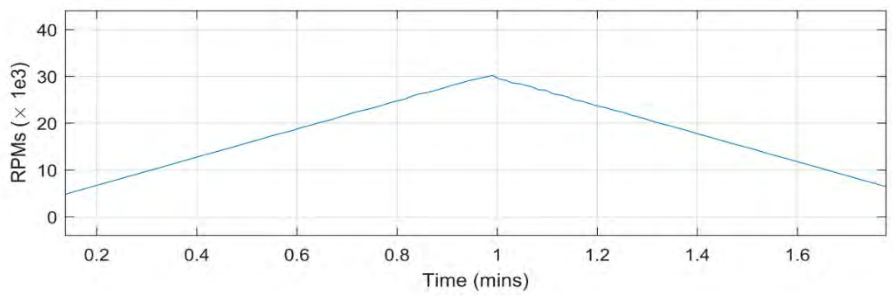
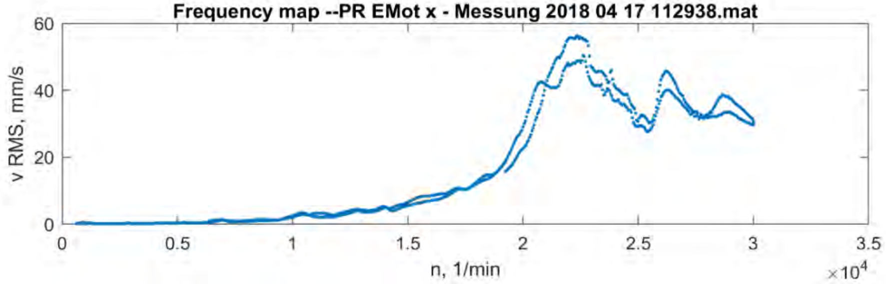
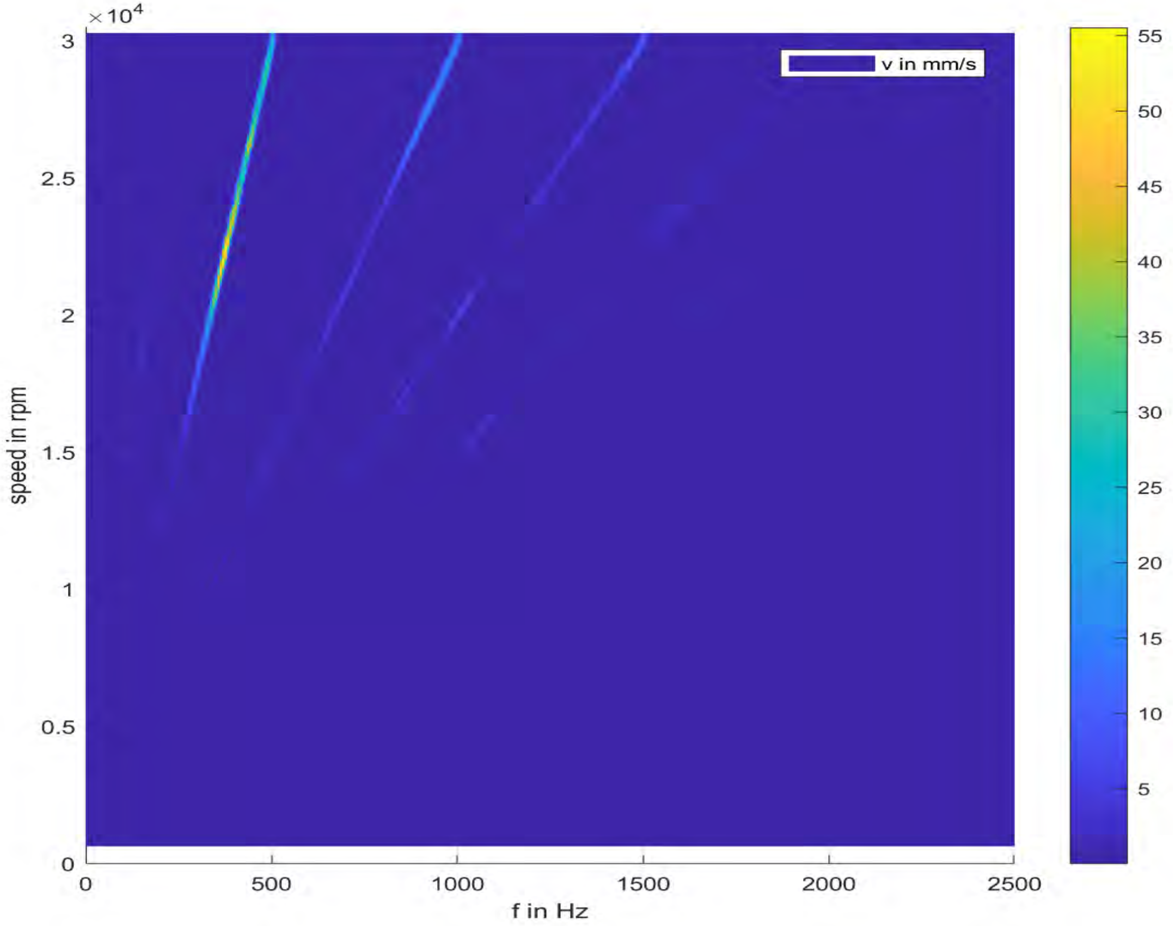
NVH Test at each new Set Up





- Slow speed up excites resonances
- We measure accelerations and integrate to grade the vibration velocity
- A Campel diagram allows to find sources



Campel diagram of a Device under test

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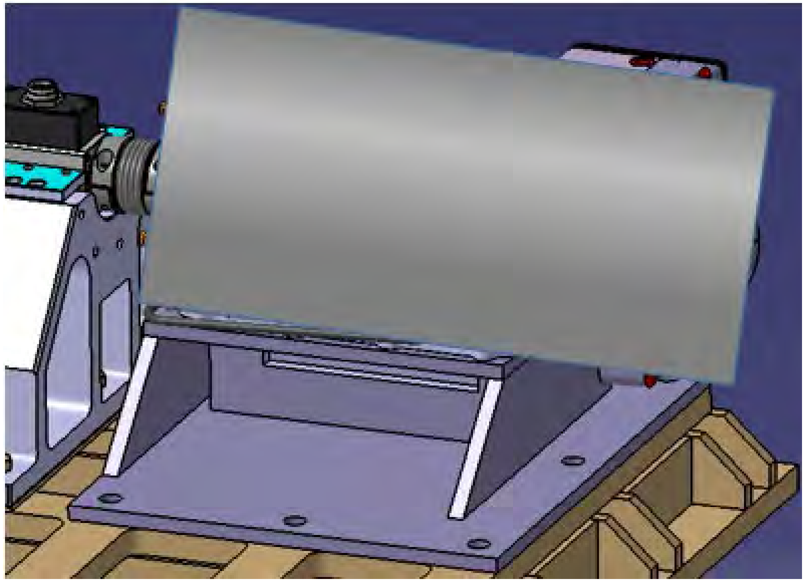
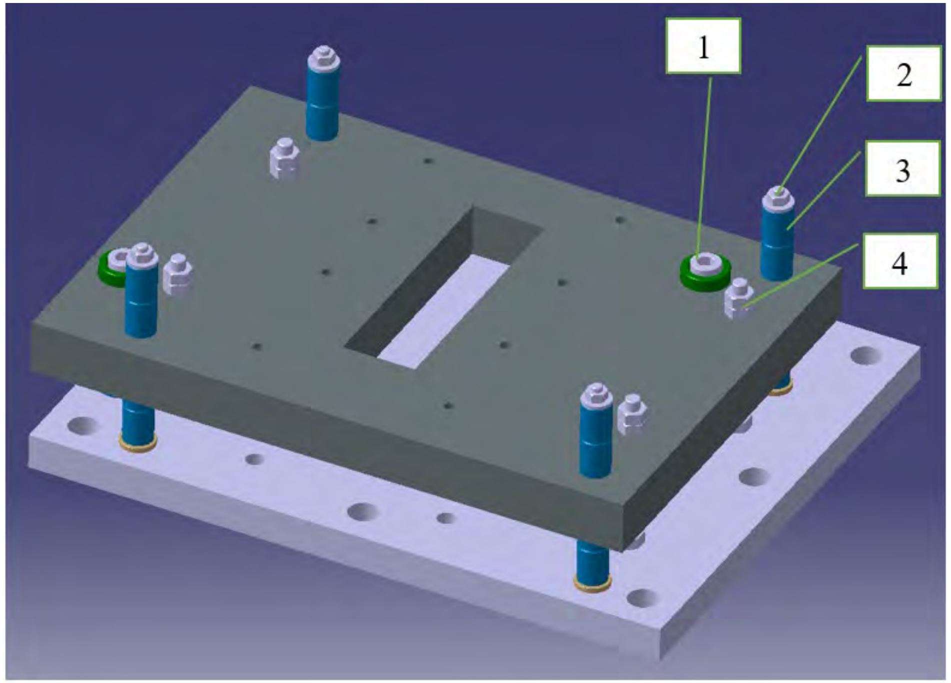
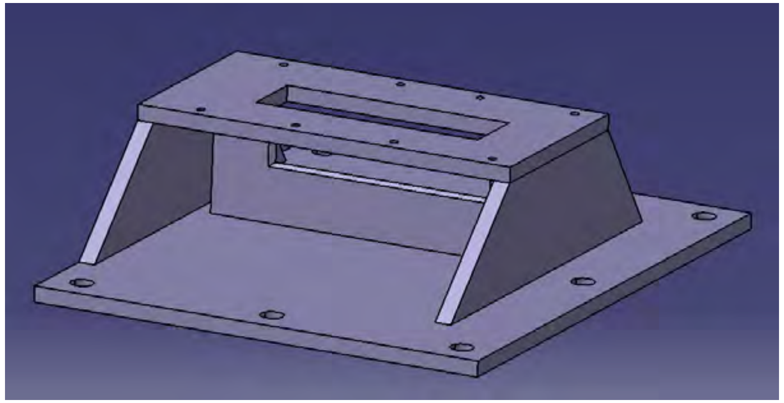
Separated isolation for high speed drives







1 .. Horizontal hard stop
2,3 .. Rubber spring, preloaded, adjustable
4 .. vertical hard stop

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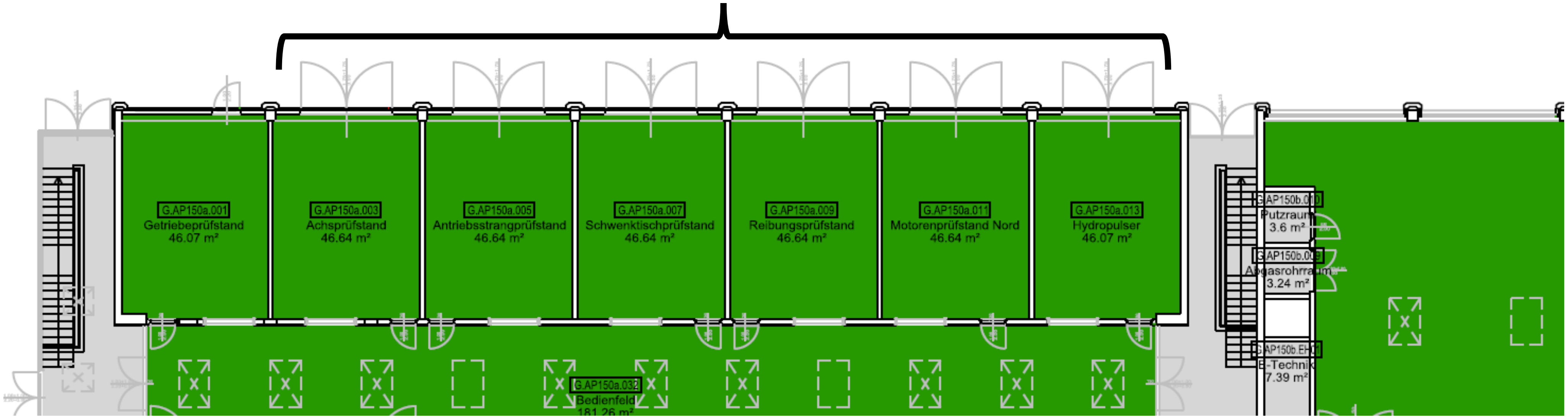
Testing cells entrance

- Doors for suppliers
- 1 door per testing cell



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Doors for suppliers

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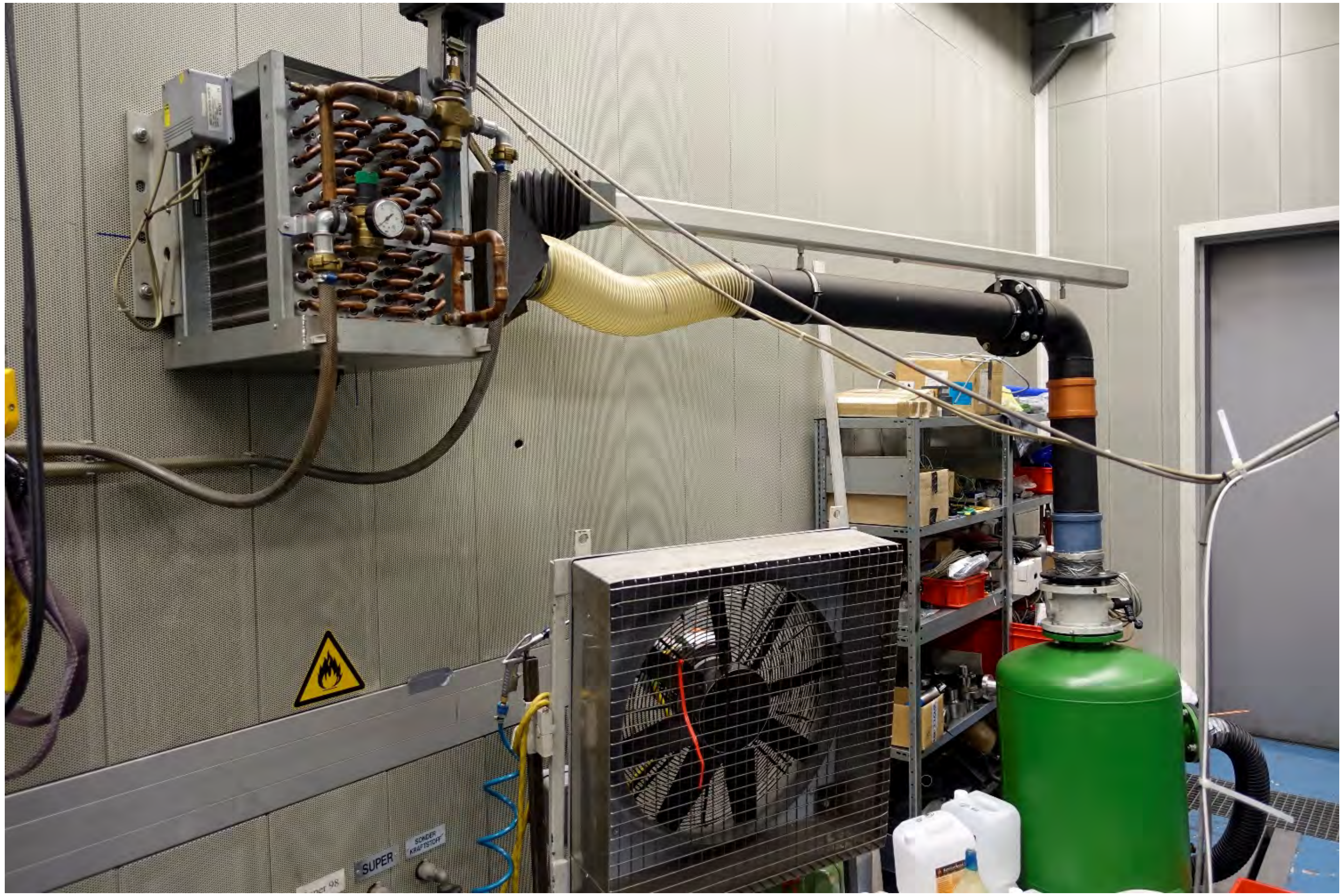
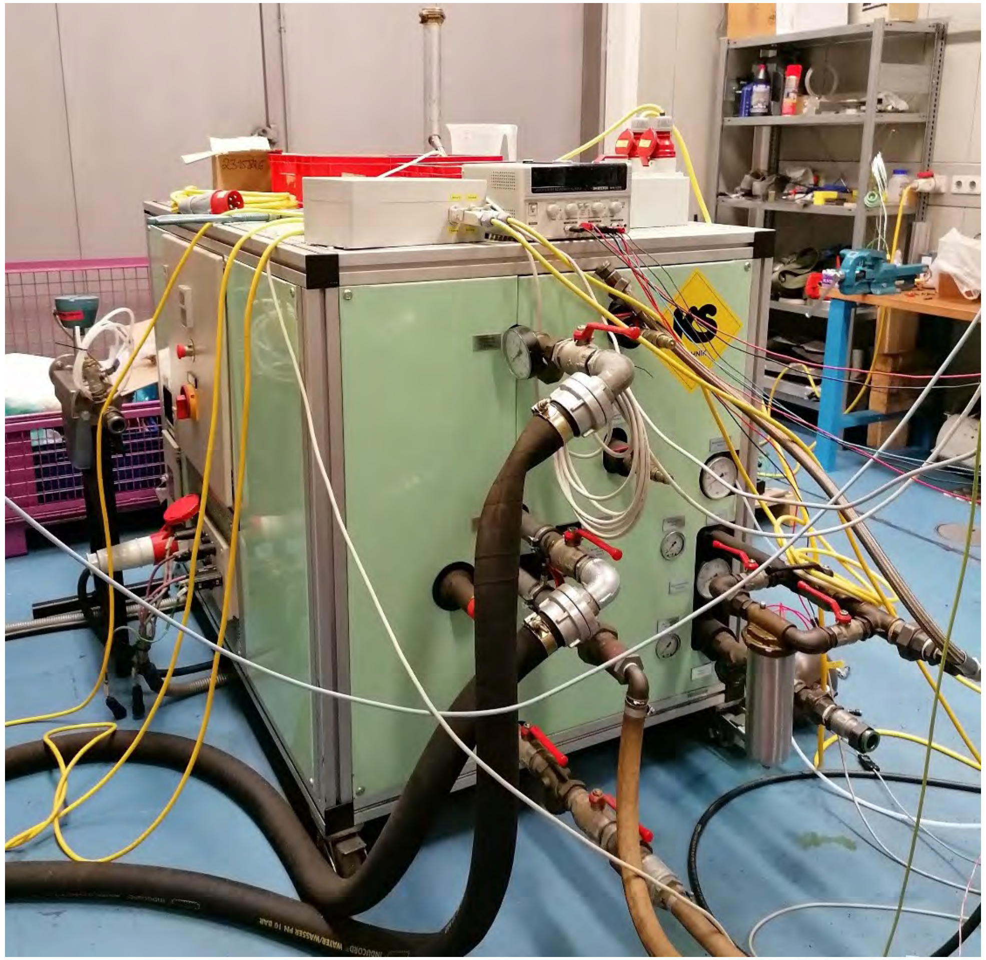
Facility equipment

- Air Supply for ICE
  - Water cooled air conditioner
  - Green: absorber to avoid inlet gas vibration
  - Mass flow meter



Facility equipment

- Cooling liquid and oil conditioning unit for ICE



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Facility equipment

- Fuel storage

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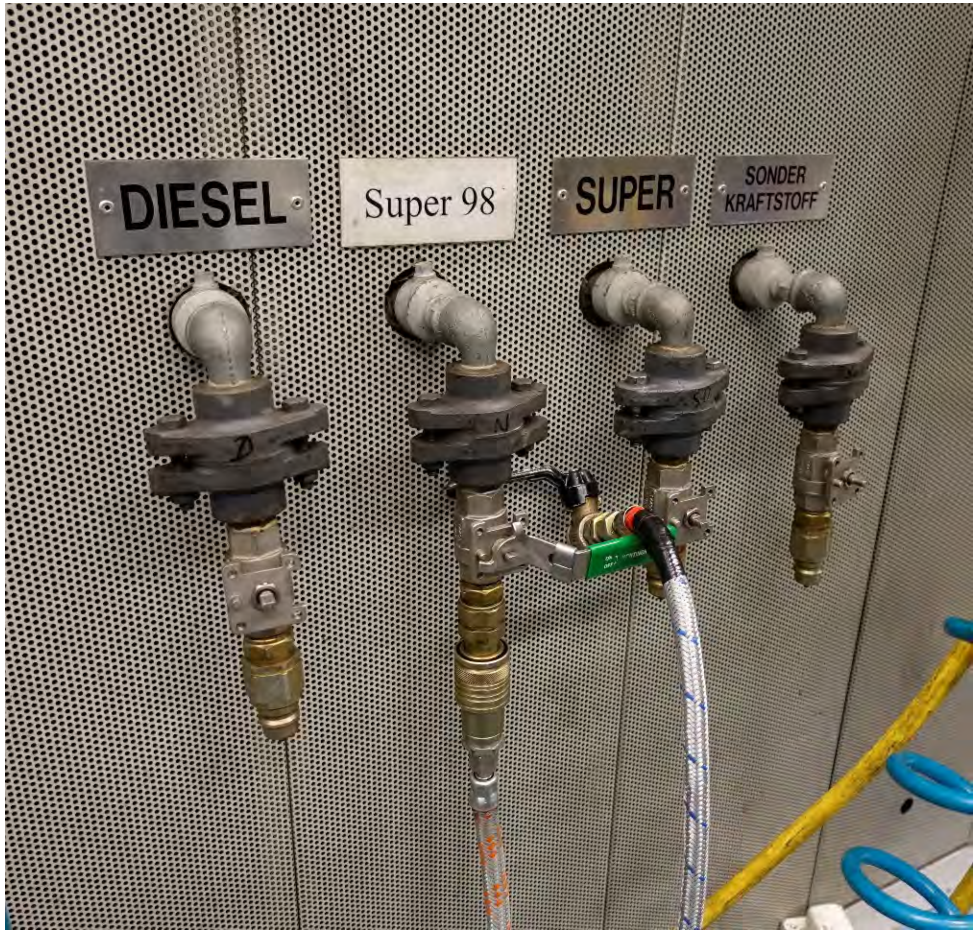
Facility equipment

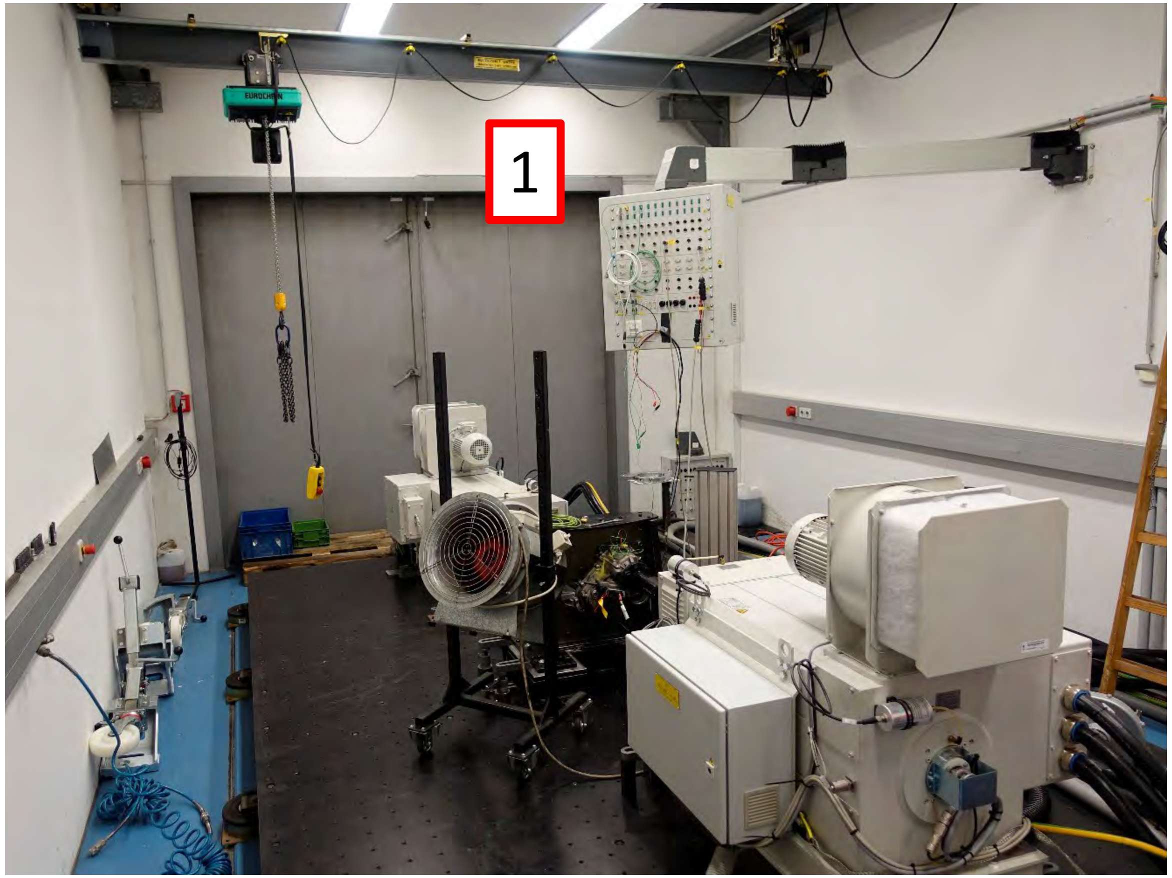
- Fuel supply



Facility equipment

- Gas storage and supply
  - Calibration gases
  - Zero gas
    - Synthetic air for FID
    - Nitrogen for IRD and CLD
  - Span gas
    - FID: Propane in synthetic air
    - IRD: CO and CO2 in nitrogen
    - CLD: NO in nitrogen

Measuring System



- Sensor Box (1)
  - Easy to connect sensors to the **d**ata **acq**uisition system (DAQ)
  - Temperature Sensors
    - Pt100 and Thermocouple
  - Pressure Sensors
  - Analogue input and output channels
  - Digital input and output channels
  - …

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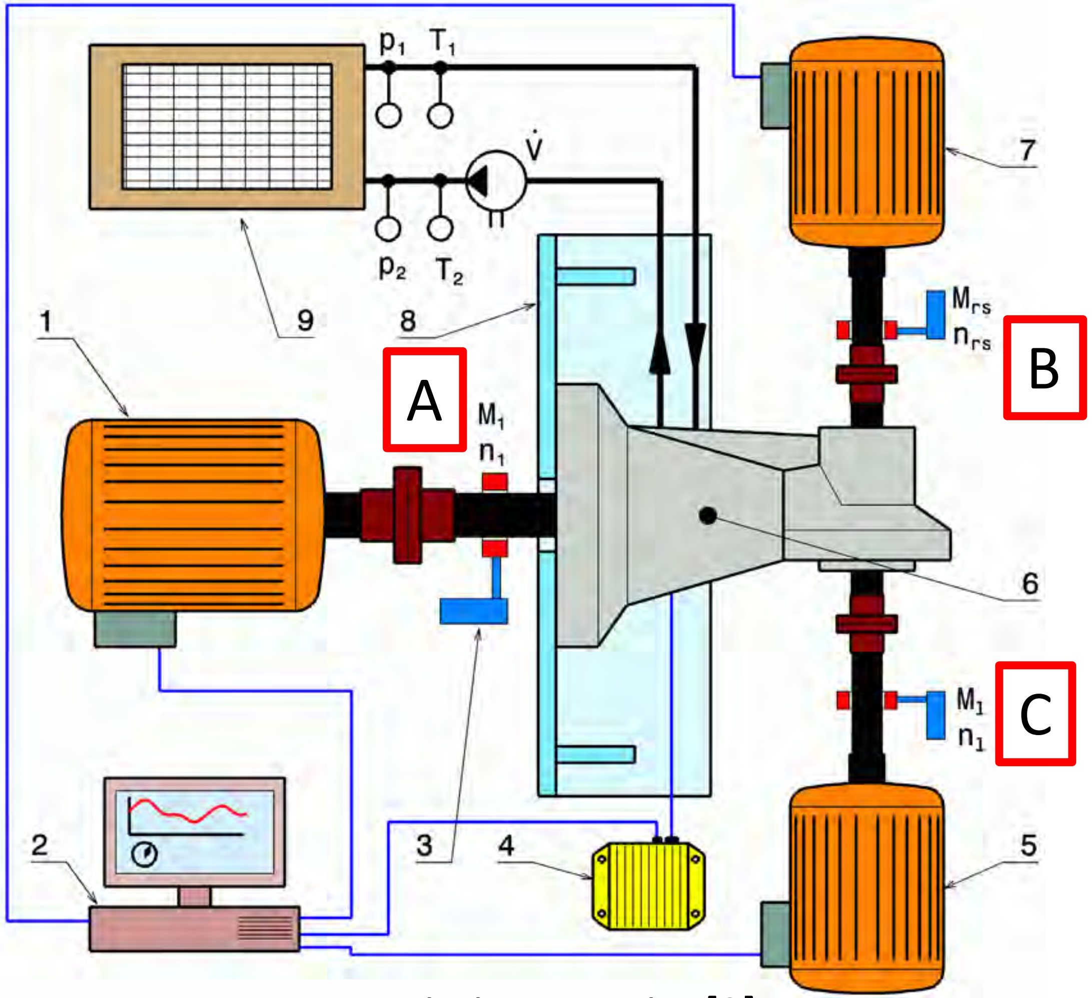
Mechanical power measurement

- Mechanical power:

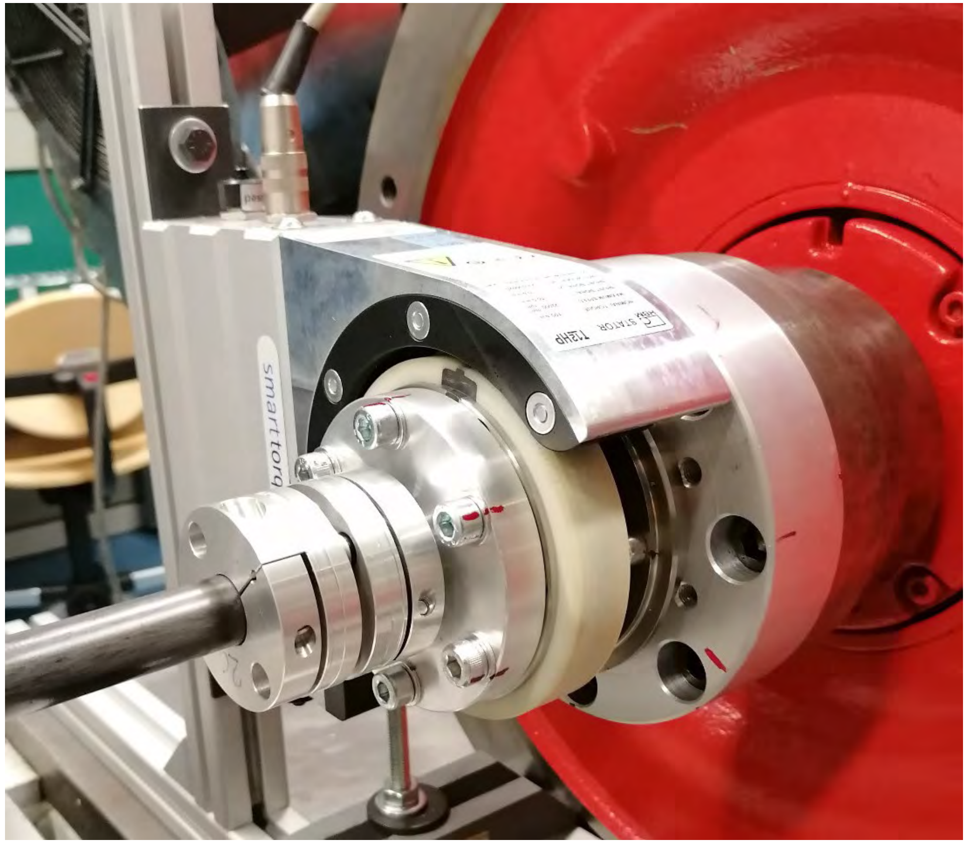
$$P_{\text{mech}} = T \cdot \omega$$
$$\omega = 2 \cdot \pi \cdot n$$

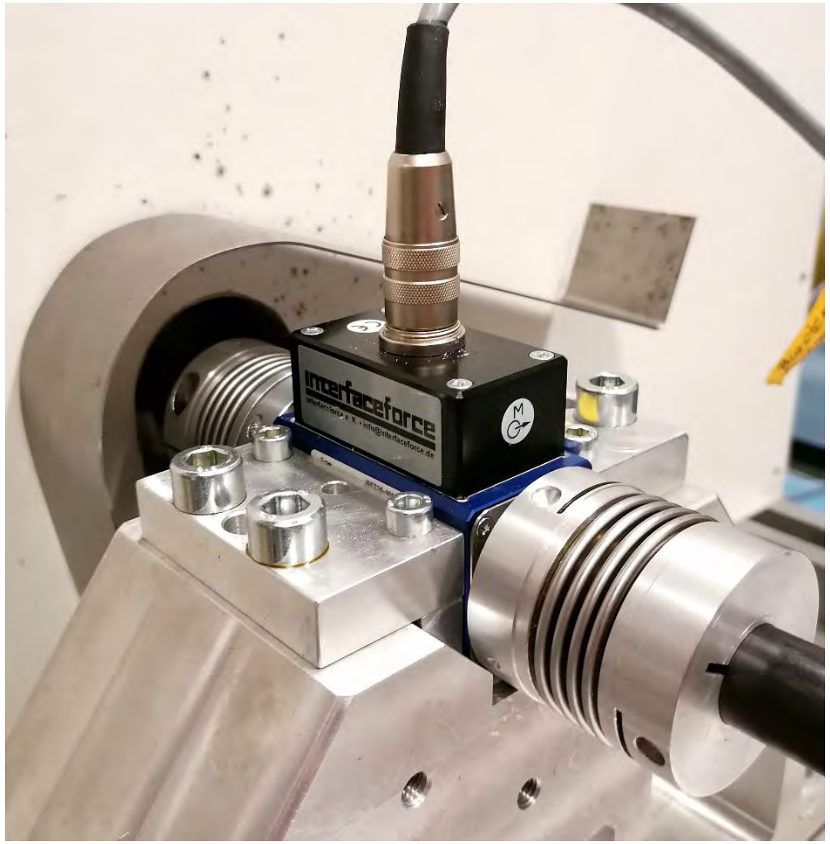
- Torque *T* and speed *n* must be measured to calculate P_{mech}
- To determine the efficiency of the Device under Test (DUT → 6), the power at A (input) as well as B and C (output) must be measured with high accuracy.



Transmission test rig: [2]

Sensors for torque and speed





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Quality Management, [1]

- Accreditation regarding to the standard ISO EN IEC 17025
- Scope of accreditation:
  - EGV 715/2007*ECR
  - 715/2007*CEReg 715/2007
  - EPA 40 CFR Part 86
  - 3 UN GTR No. 19


Bundesministerium
Digitalisierung und
Wirtschaftsstandort

Die Nationale Akkreditierungsstelle / *The National Accreditation Body:*

AKKREDITIERUNG AUSTRIA

bestätigt die Akkreditierung der Rechtsperson / *confirms the accreditation of*

FH JOANNEUM Gesellschaft mbH

Alte Poststraße 149, A-8020 Graz

Identifikationsnummer / *ID-number:* **0222**
als / *as* **Prüfstelle / *Testing Laboratory***
gemäß / *according to* **EN ISO/IEC 17025:2017**
Datum der Erstakkreditierung / *Initial date of accreditation:* **17.02.2004**

Standort/Organisationseinheit / *site/unit:*
Institut Fahrzeugtechnik / Automotive Engineering, Alte Poststraße 149, A-8020 Graz

Informationen zum Akkreditierungsumfang und zu Akkreditierung Austria / *Information about the accreditation scope and Akkreditierung Austria* http://www.bmdw.gv.at/akkreditierung

Die Akkreditierung wurde mittels Bescheid erteilt und damit bestätigt, dass die Konformitätsbewertungsstelle die angeführten Anforderungen erfüllt. Diese Bestätigung darf nur unverändert weiterverbreitet werden. / *The accreditation was granted by a decree which confirms, that the Conformity Assessment Body fulfills the given requirements. This confirmation of accreditation may not be reproduced other than in full.*

Dipl.-Ing. Dr. Norman Brunner
Wien, am 11. Dezember 2019

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References

[1] https://www.fh-joanneum.at/labor/prueffeld-fuer-fahrzeuge/

[2] Michael Trzesniowski: *Rennwagentechnik: Datenanalyse, Abstimmung und Entwicklung*. Springer Vieweg, 2017

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Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Layouts for Drivetrain Testing

K. Reisinger

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Aim of testing

Functional Testing

e.g. calibration of automated gear shift operation; dynamic of a shift operation

- simulation of special subsystem states in car (engine speed, vehicle speed)
- development of functional software
- measuring systems behaviour

Characteristics

- same behaviour as in the car
- high flexibility to test different states

Fatigue Testing; Measuring Characteristics

e.g. durability of a gearbox; efficiency map of a drive

- simulation of defined subsystem states (engine speed, engine torque)
- loads for durability
- measuring systems properties

Characteristics

- defined load states, often steady state
- high automation to get high repeatability

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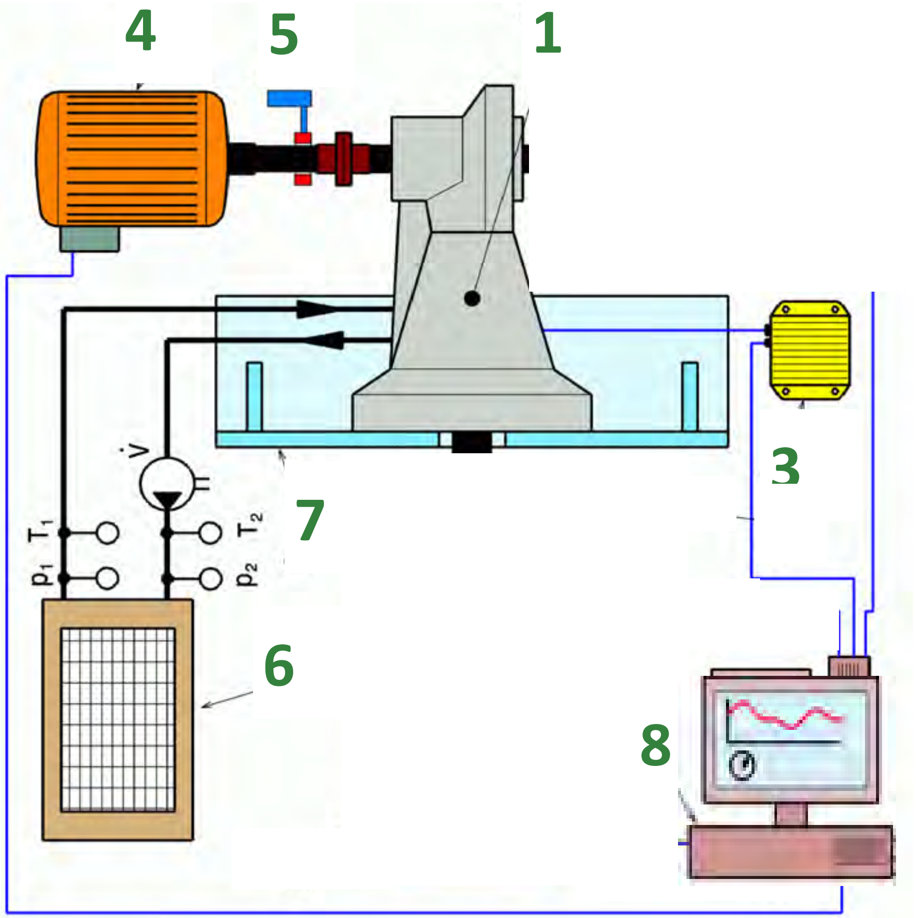
1-M Layout – for Spin Losses



- **Spin Loss Test**
- **Strip Down Test**

1+2 Device under test (DUT)

1 Gear Box
2 ECU of Gearbox (opt.)

3 … open

4 machine (speed control)

5 torque + speed measurement

6 conditioning unit for oil and/or cooling liquid

7 rig

8 rig control system

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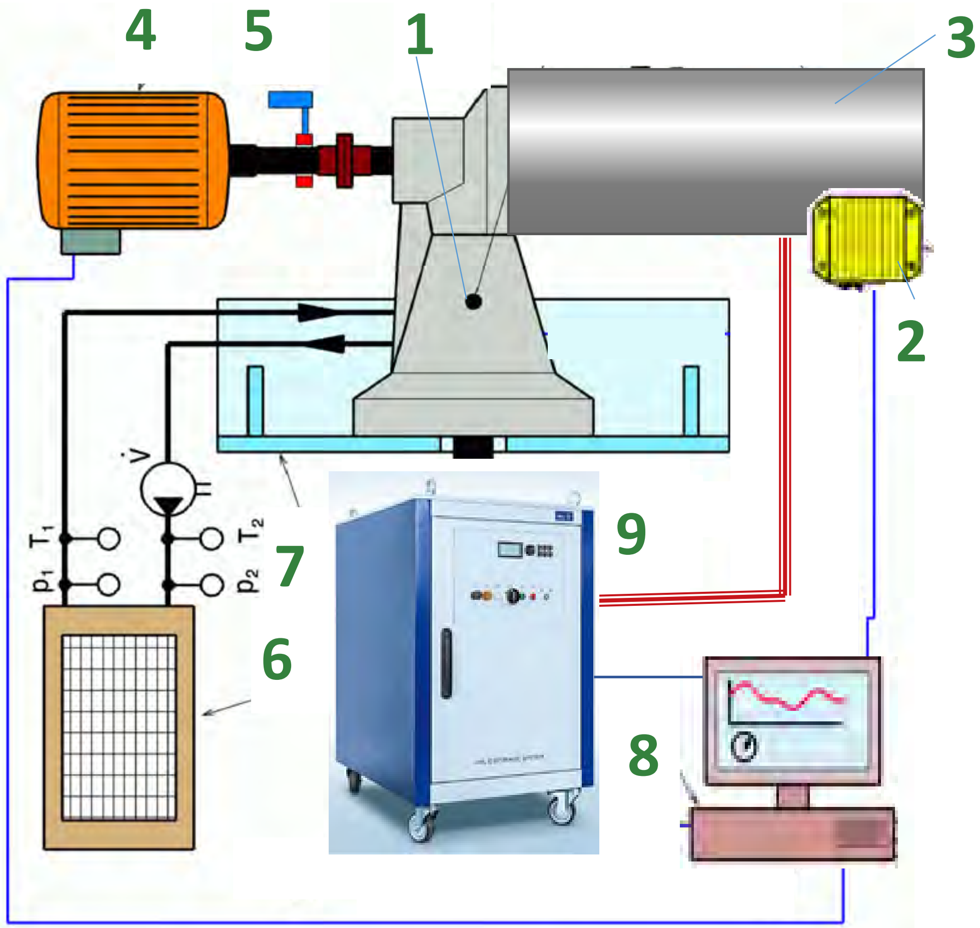
1-M Layout – for Drives



- **E-Drives, with/without gear box**
- **ICE with/without gear box**

1 gearbox or mounting rig

2 ECU

3 inverter + motor or ICE (accel. pedal control)

4 electrical machine (AC, 4-quadrant speed control)

5 torque + speed measurement

6 conditioning unit for oil and/or cooling liquid

7 rig

8 rig control system

9 battery emulator or fuel + exhaust gas connection

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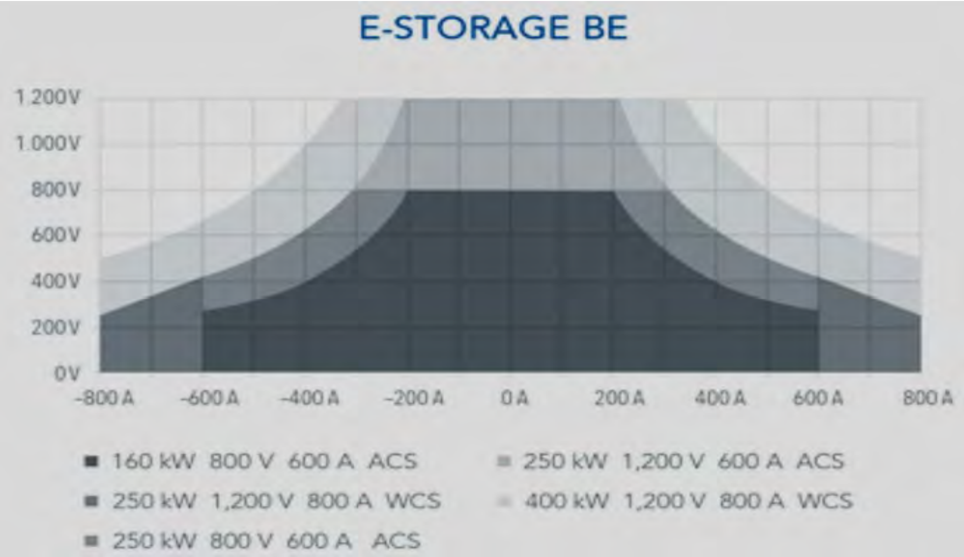
Battery Emulator

- Hazard of fire using pre-serial-production batteries in rooms.
- Different Systems for HV and LV needed (common GND at LV)
- Testing at a defined SOC, SOH and battery temperature

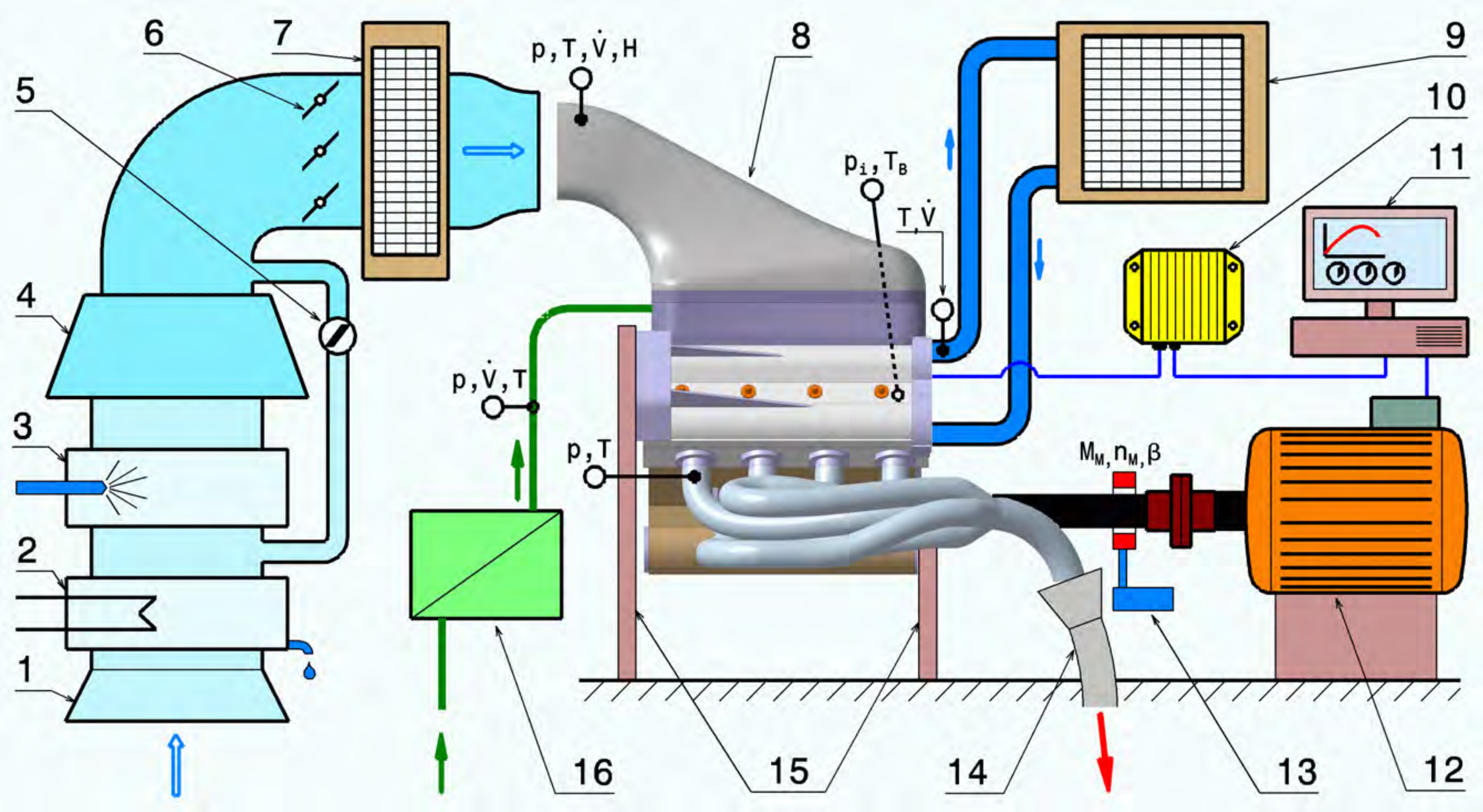


AVL E-Storage Systems 2019

[Dr. K. Reisinger [2020]

Left: Power Distribution Unit ("plug")
Right AVL E-Storage HD 400 kW, 1200 V, 800 A in cellar of FHJ

ICE Engine Test Rig



1..7 air conditioning

8 engine

9 cooling water conditioning

10 ICE-ECU

11 rig control system

12 el. machine

13 torque + speed measurement

14 Exhaust gas analyser

15 rig

16 fuel conditioning

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[Trzesniowski: Rennwagentechnik: Datenanalyse, Abstimmung und Entwicklung. Springer Vieweg, 2017]

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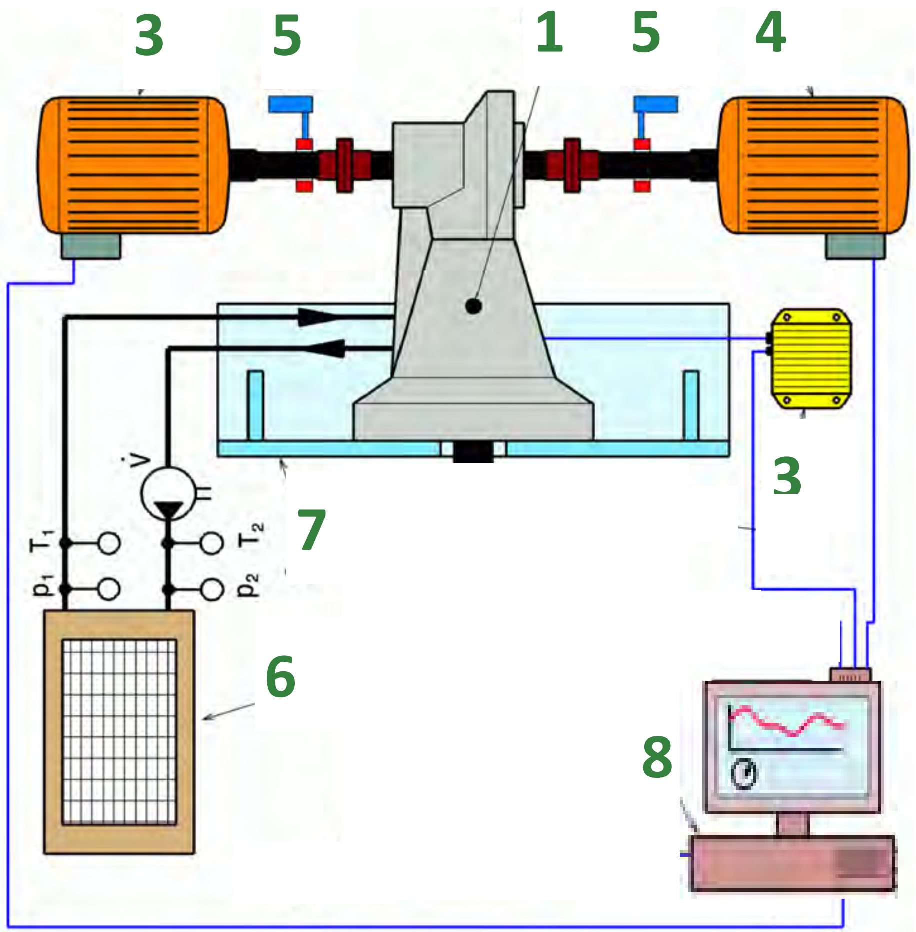
2-M Layout – for Gear Boxes



- **automated/manual transmission gearbox**
- **single speed gearbox (for E-Drive)**
- **Efficiency**

1 unit under test (UUT) = Gear Box

2 ECU of Gearbox (opt.)

3 el. machine (torque control)

4 machine (speed control)

5 torque + speed measurement

6 conditioning unit for oil and/or cooling liquid

7 rig

8 rig control system

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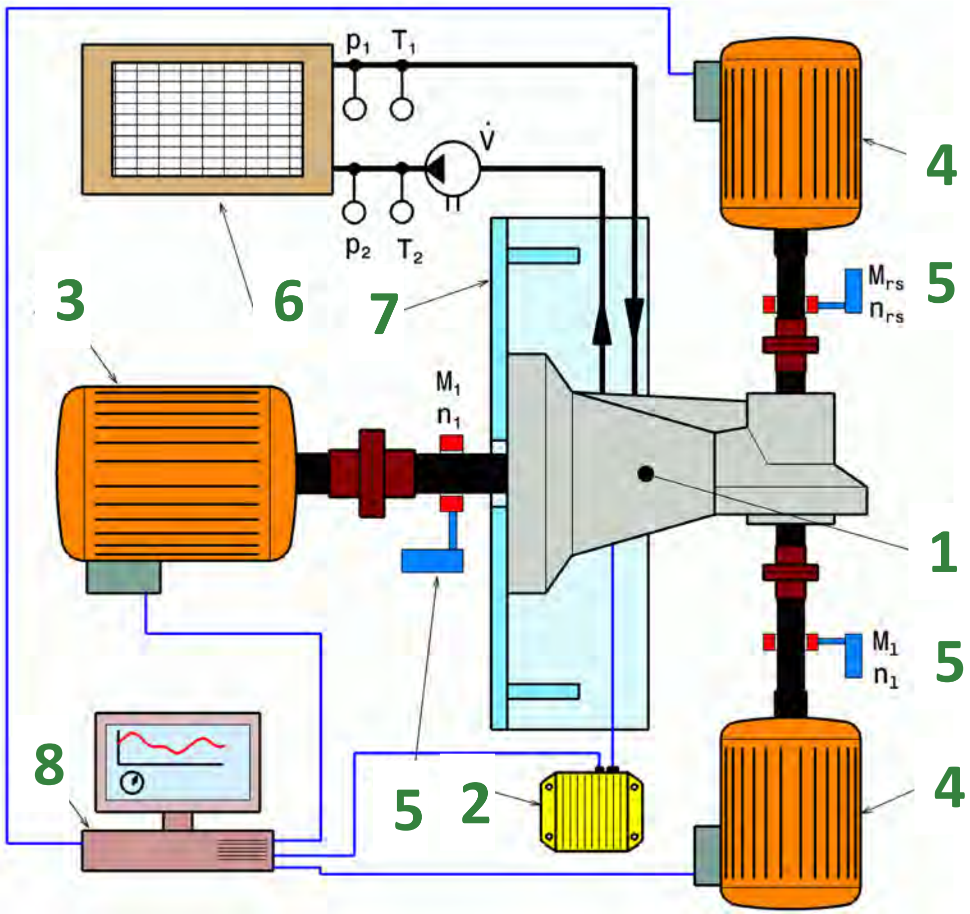
3-M Layout – for Axle Drive Gearboxes



- **Axle drive gearbox**
- **AWD centre differential gearbox**

1 unit under test (UUT)

2 ECU of UUT (opt)

3 el. machine (e.g. torque-control)

4 2x el. machine (e.g. speed control)

5 torque + speed measurement

6 conditioning unit for oil and/or cooling liquid

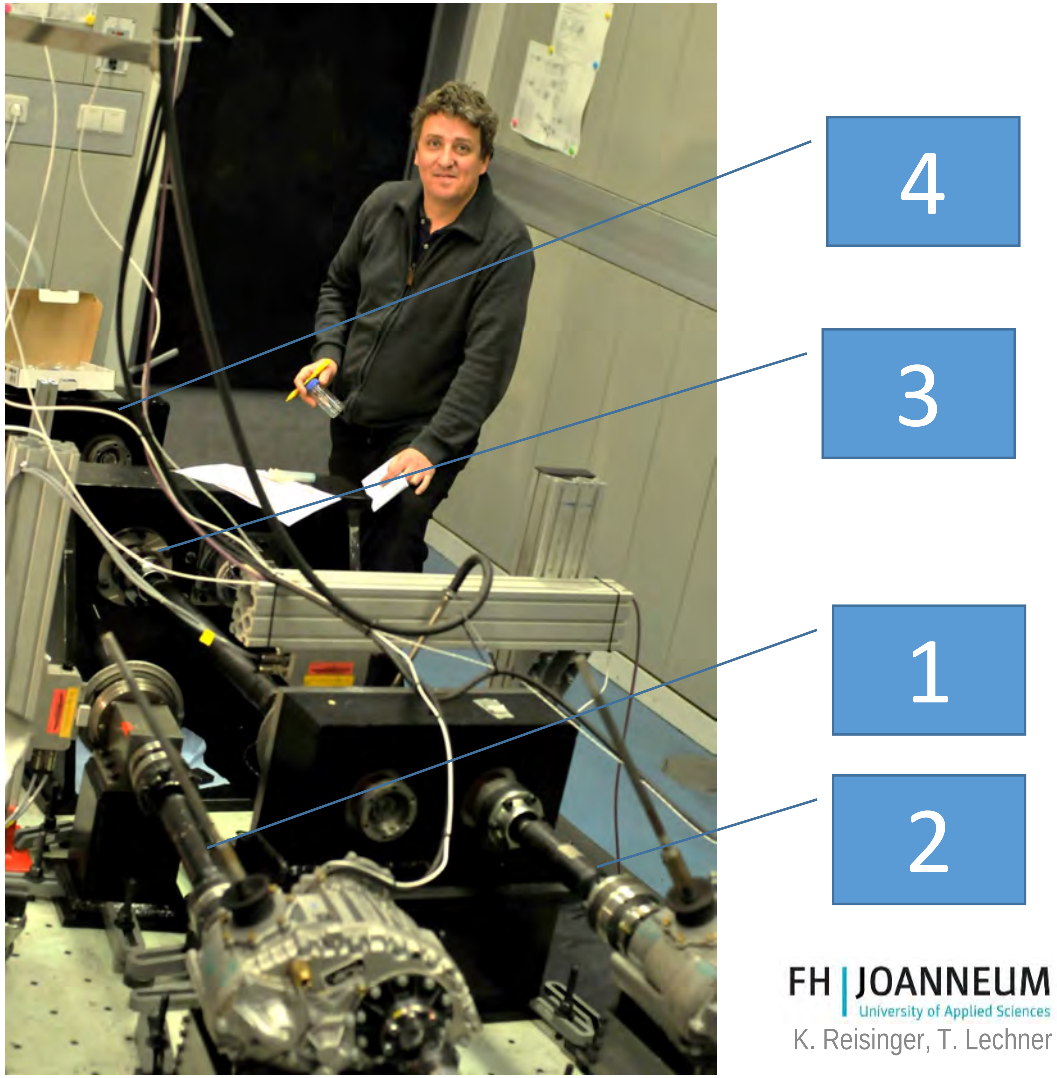
7 rig

8 rig control system

[Trzesniowski: Rennwagentechnik: Datenanalyse, Abstimmung und Entwicklung, Springer Vieweg, 2017]

3-M Transmission Test Rig

- Arrangement for Centre Differential Gearbox
  1 .. Input shaft
  2 .. front output shaft
  3 .. DUT
  4 .. rear output shaft



Picture: [Trzesniowski]

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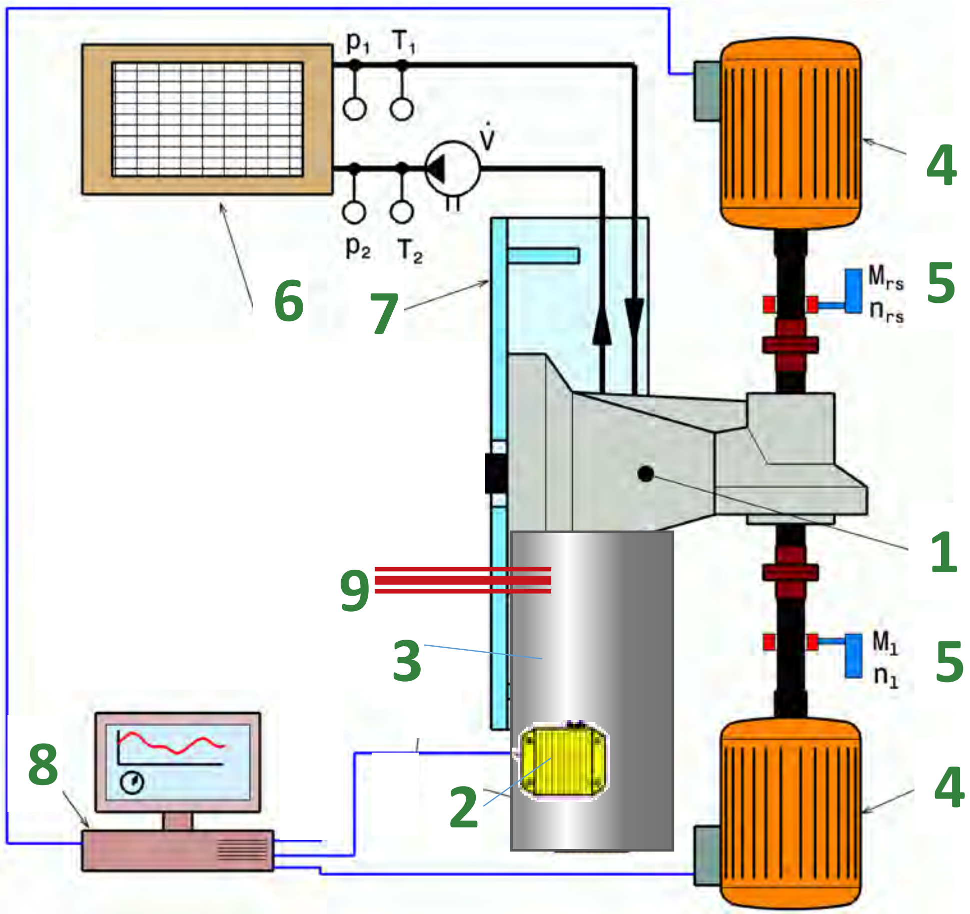
2-M Layout – for Axle Drives



- **Axle drive units, E-Drive/HEV-drive/ICE**

1 gearbox

2 ECU

3 inverter, motor (accel. pedal control)

4 2x el. machine (e.g. speed control)

5 torque + speed measurement

6 conditioning unit for oil and/or cooling liquid

7 rig

8 rig control system

9 battery emulator or fuel + exhaust gas connection

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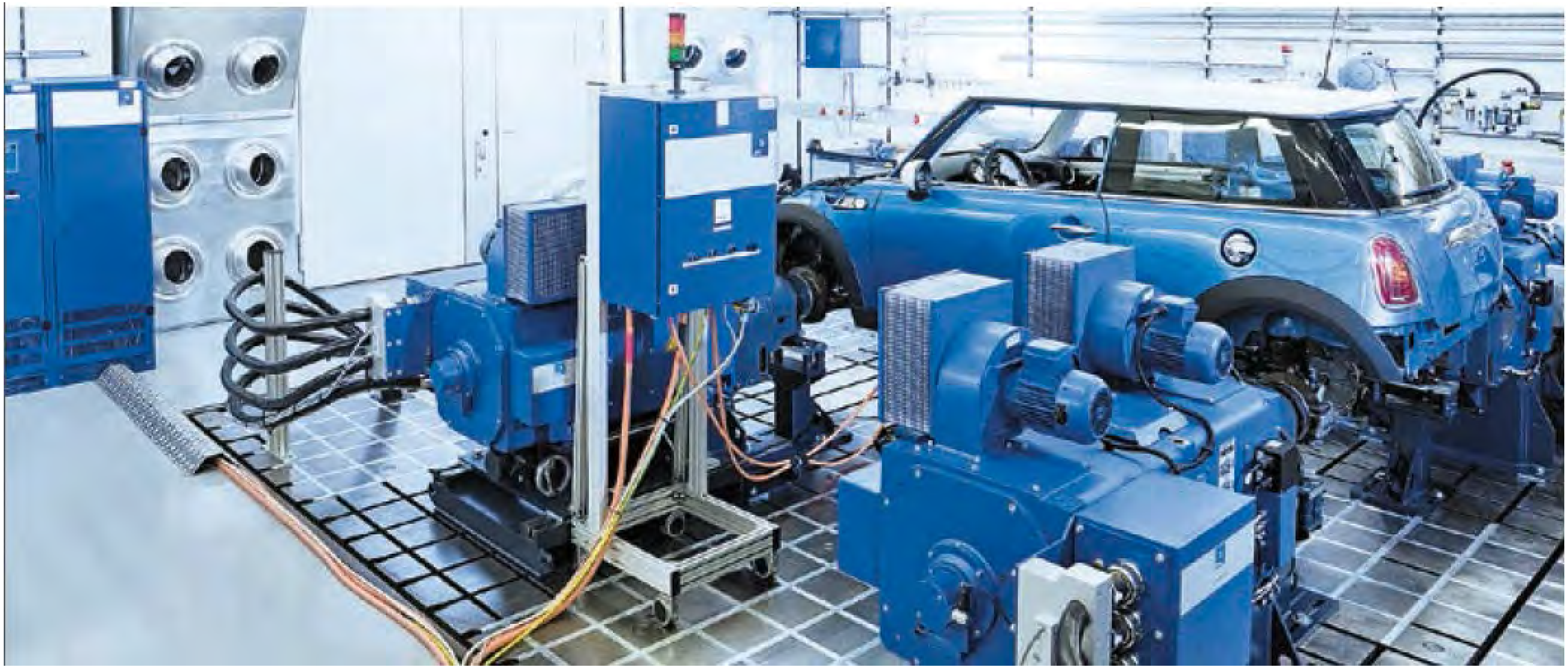
Vehicle Drivetrain Test
Advantage: Simple Interface



see also https://www.avl.com/racing
[https://www.avl.com/de/-/vehicle-in-the-loop-test-system]

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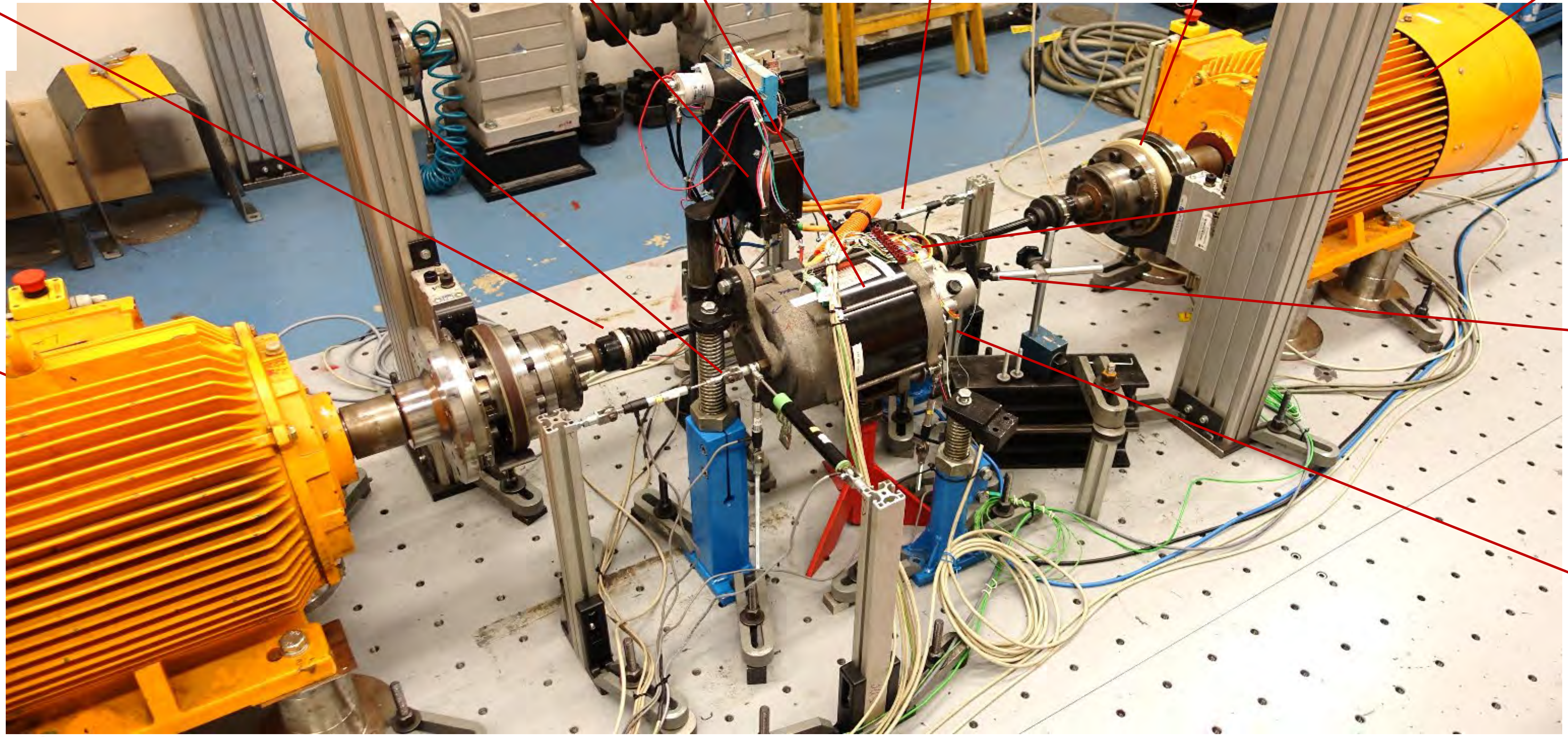
e.g. Rear Drive Module at test bench

Objective: 6 DOF Unit motion due to torque



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Reisinger K. et al.: Endbericht Innovationsscheck Plus 2017, FH Joanneum , Mar. 2019. (*Final report of cooperation project*)

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Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Spin- and Power Losses

K. Reisinger

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Efficiency Description

Simple Approach

$$P_{out} = \eta \cdot P_{in}$$

- **No load, no loss.**
- We have “Spin Losses” also when transferring no power. They are small compared to max. power.
- **Efficiency approach is sufficient at high power**, when non-load-dependent losses are small, compared to load-dependent ones.

P .. power at subsystems’ interface,
$\eta = \frac{P_{out}}{P_{in}}$ .. efficiency,
M .. transferred torque,
n … speed, T.. temperature

Problem

- WLTC has a lot of low power phases. Small constant losses become important.
- They are in the focus of current drivetrain development.

Exact Solution

$$P_{Loss} = f(M, n, T),$$
$$\mathrm{P_{out}} = \mathrm{P_{in}} - \mathrm{P_{Loss}}$$

Approach: Spin Losses

$$P_{Loss} = \mathrm{f}_1(n, T) + \mathrm{f}_2(M)$$
$$= f_1(n, T) + (1 - \eta) \cdot P_{in}$$

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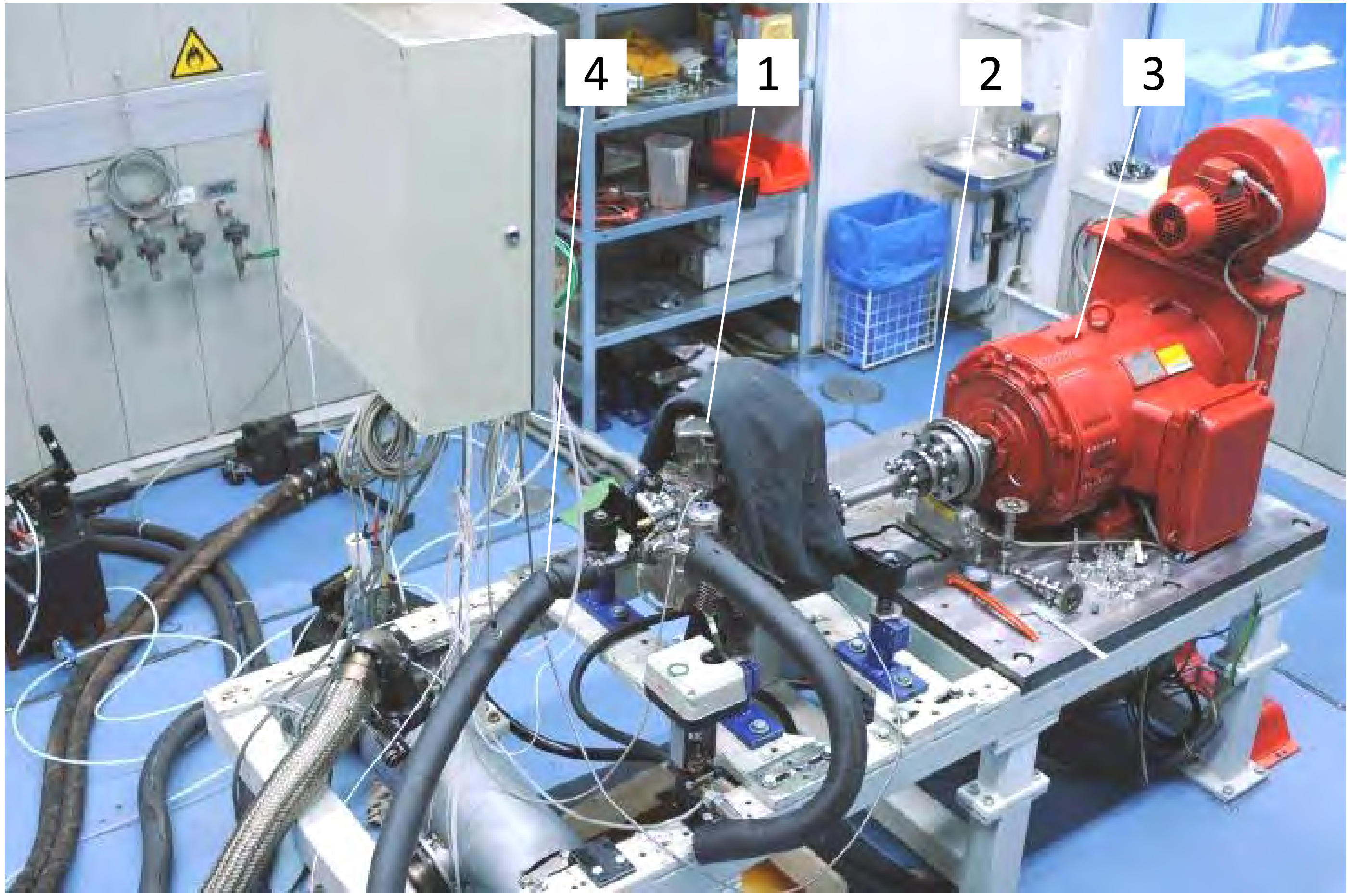
Spin Loss Measurement



1 Device Under Test
Gearbox, non fired ICE

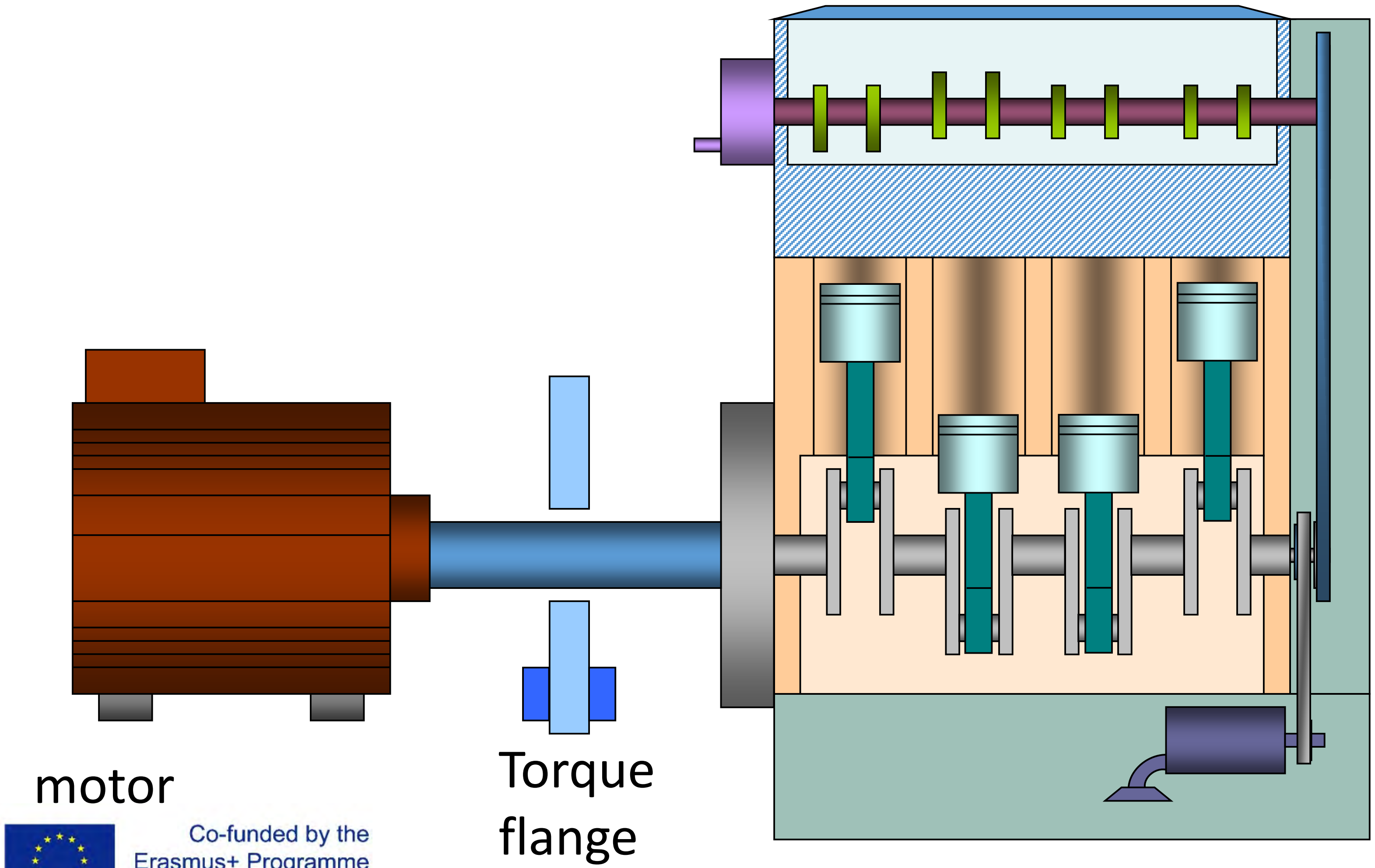
2 sensitive torque measurement device
(2-10 Nm at gearboxes)

3 test bench motor
(speed control)

4 Conditioning of lubricant and /or housing air temperature

[Picture: Trzesniowski]

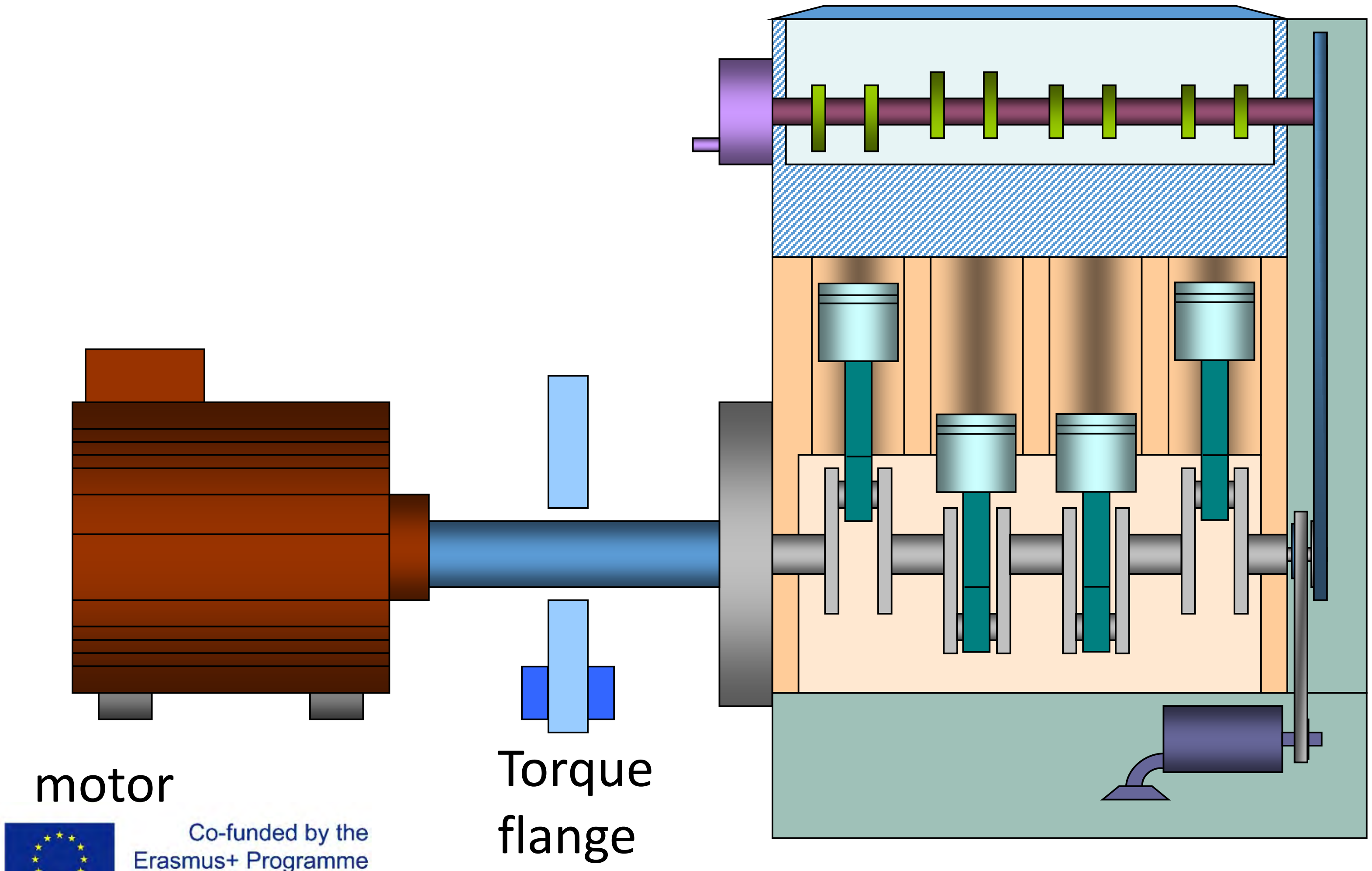
Cause – Effect – Analysis
Strip Down Test



Strip-down method

[M. Trzesniowski]

Cause – Effect – Analysis
Strip Down Test 2



[M. Trzesniowski]

Focus on

- reproducible temperature state
  - Box housing + heater/cooler
  - conditioning of all liquids
- reproducible, accurate torque measurement
  - Offset-Drift
  - smoothing torsional vibrations, avoid Aliasing!
- reproducible assembly influence

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Results of Spin Loss Tests

1. Test matrix

Engine: xyz

Filename \ Part	Crankshaft	Pistons & conrods	Oil pump	Cylinder head / valvetrain	Vacuum pump	Alternator	Power steering pump	A/C pulley	Idler pulley and tensioner	Oil level (l)	Oil temp (°C)	Valve lift (mm)
-000001	●	●	●	●	●					4	~ 90°	9,6
-000002	●	●	●	●	●					3	35	9,6
-000003	●	●	●	●	●					3	90	9,6
-000004	●	●	●	●	●					4	90	9,6
-000005	●	●	●	●	●					2	90	9,6
-000006	●	●	●	●	●					1	90	9,6
-000007	●	●	●	●	●					3	120	9,6
-000008	●	●	●	●	●					3	140	9,6
-000009	●	●	○		○					1	90	
-000010	●	●	○		○					2	90	
-000011	●	●	○		○					3	90	
-000012	●	●	○		○					4	90	
-000013	●	●			○					1	35	

- array of tests
- torque / power loss at each assembly state
- The difference between two assembly states is the component's contribution

But remember:
the losses are maps $P(n, T)$

→ highly automated test procedure is necessary

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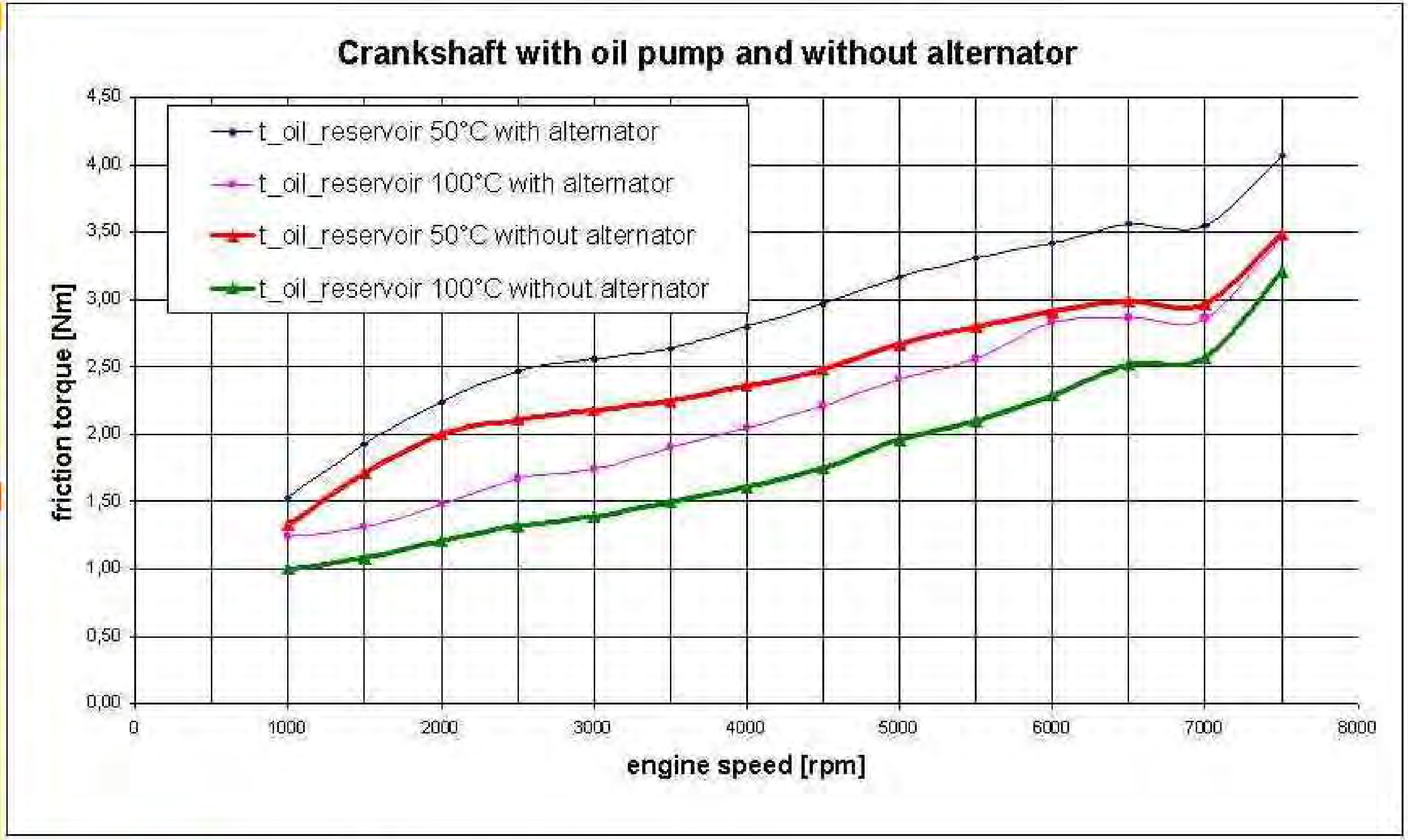
Losses of an ICE at an assembly state

t_oil_reservoir 50°C		
n	Md	Md
1000	1,53	1,33
1500	1,93	1,71
2000	2,24	2,00
2500	2,47	2,11
3000	2,56	2,18
3500	2,64	2,25
4000	2,80	2,36
4500	2,97	2,48
5000	3,17	2,67
5500	3,31	2,80
6000	3,42	2,91
6500	3,56	2,99
7000	3,55	2,97
7500	4,07	3,49

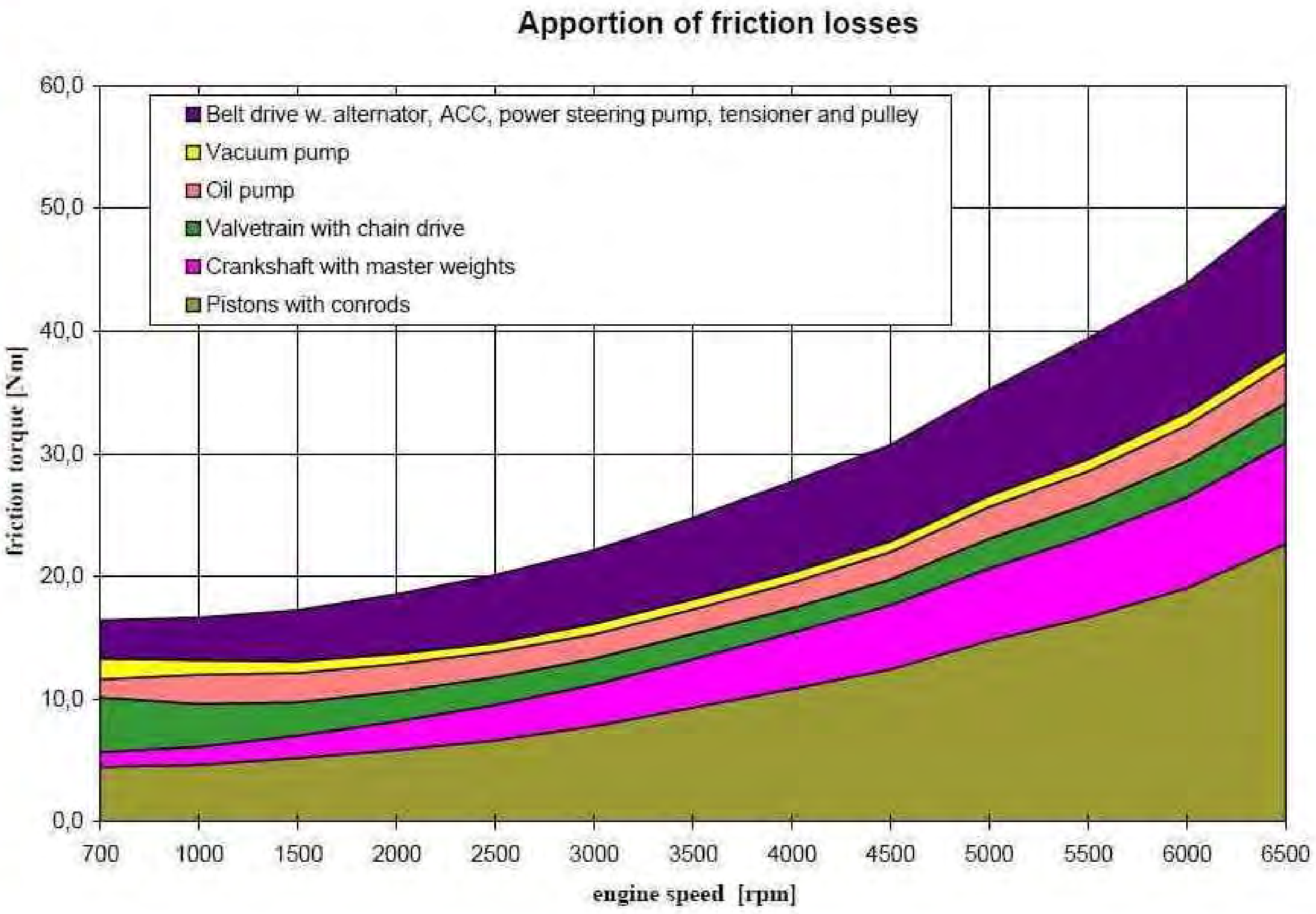
t_oil_reservoir 100°C		
n	Md	Md
1000	1,24	1
1500	1,31	1,08
2000	1,48	1,21
2500	1,67	1,32
3000	1,74	1,39
3500	1,9	1,5
4000	2,05	1,61
4500	2,21	1,75
5000	2,41	1,96
5500	2,56	2,1
6000	2,83	2,29
6500	2,87	2,52
7000	2,86	2,57
7500	3,47	3,21



Md Crankshaft with oil pump and alternator
Md Crankshaft with oil pump and without alternator

Losses of an ICE

n.KW U/min	Md Nm Vacuum pump	Md Nm Pistons with conrods	Md Nm Crankshaft with master weights	Valvetrain with chain drive	Oil pump	Belt drive w. alternator, ACC, power steering pump, tensioner
700	1,7	4,5	1,2	4,5	1,5	3,2
1000	1,2	4,6	1,5	3,5	2,4	3,5
1500	1,0	5,2	1,9	2,7	2,4	4,2
2000	0,9	5,9	2,3	2,4	2,3	4,9
2500	0,8	6,6	2,8	2,3	2,1	5,5
3000	0,8	7,8	3,4	2,2	2,0	6,0
3500	0,8	9,3	3,9	2,1	2,0	6,7
4000	0,8	10,8	4,6	2,0	2,1	7,4
4500	0,8	12,4	5,2	2,1	2,3	7,9
5000	0,9	14,8	5,8	2,4	2,6	8,7
5500	1,0	16,7	6,6	2,6	2,7	9,9
6000	1,1	19,1	7,4	2,9	2,9	10,6
6500	1,1	22,6	8,3	3,2	3,3	11,8



Example: Total friction torque at 90°C and 0.5 l oil level of an 3.0l 6 Cylinder SI motor

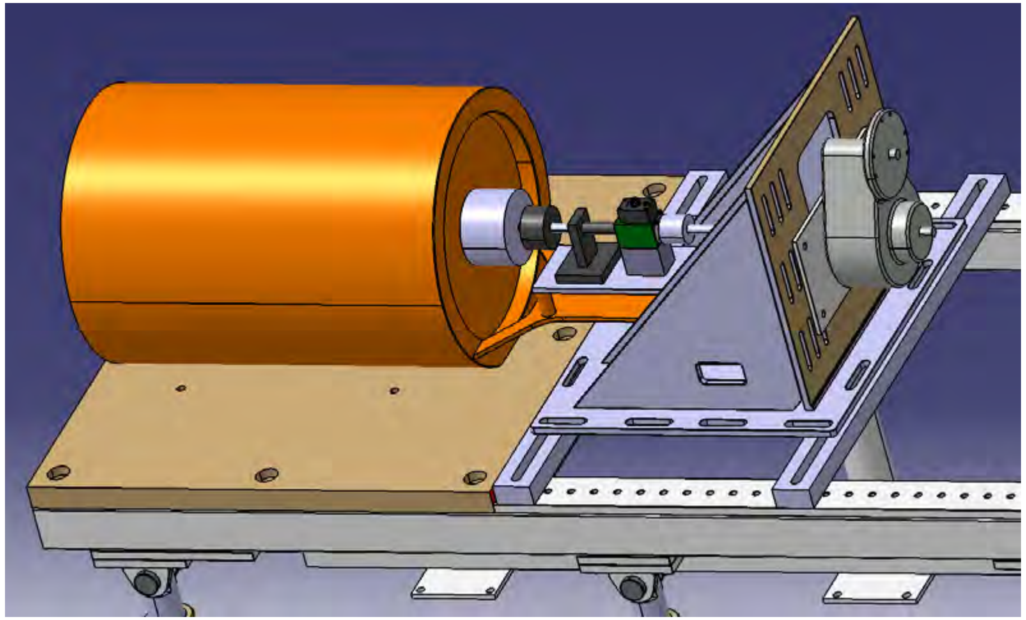
Friction in Gearboxes

Most important at medium speeds

- preloaded bearings
- shaft seals
- churning

At high speeds (> 20.000 RPM) watch also

- bearings and it's lubrication



Test Setup for Gearbox Spin Loss Tests
(Housing for temperature conditioning removed)

[K. Laber, 2018]

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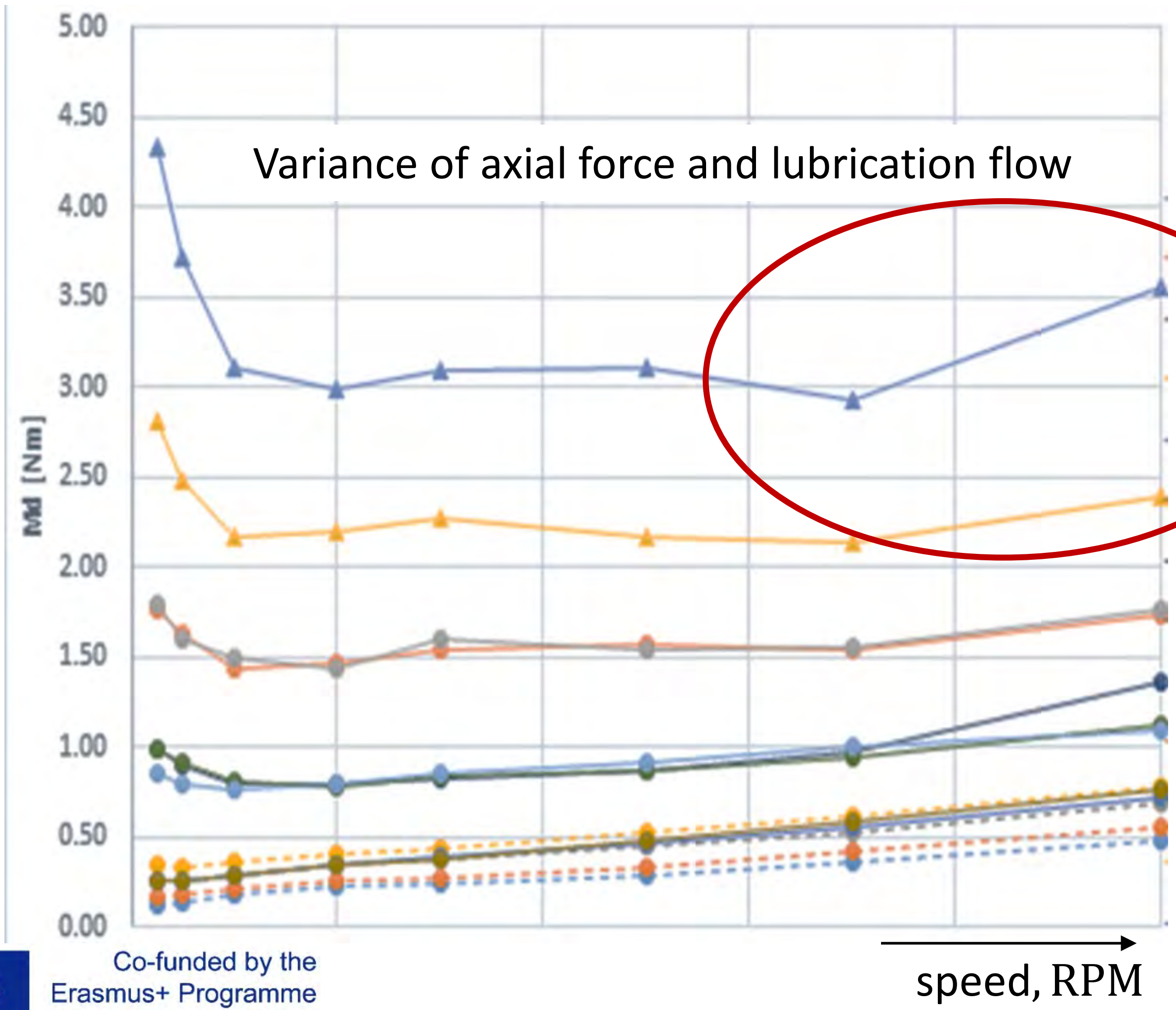
Example:
Losses of 2 Axial Needle Bearings at 80°C



- P_{loss} rises up to kW
- $M_{Loss} = \mathrm{f}(\mathrm{F_{ax}}, \mathrm{n}, \mathrm{T}, \mathrm{Lub.})$

High power input
hard to have (nearly)
steady state temperature

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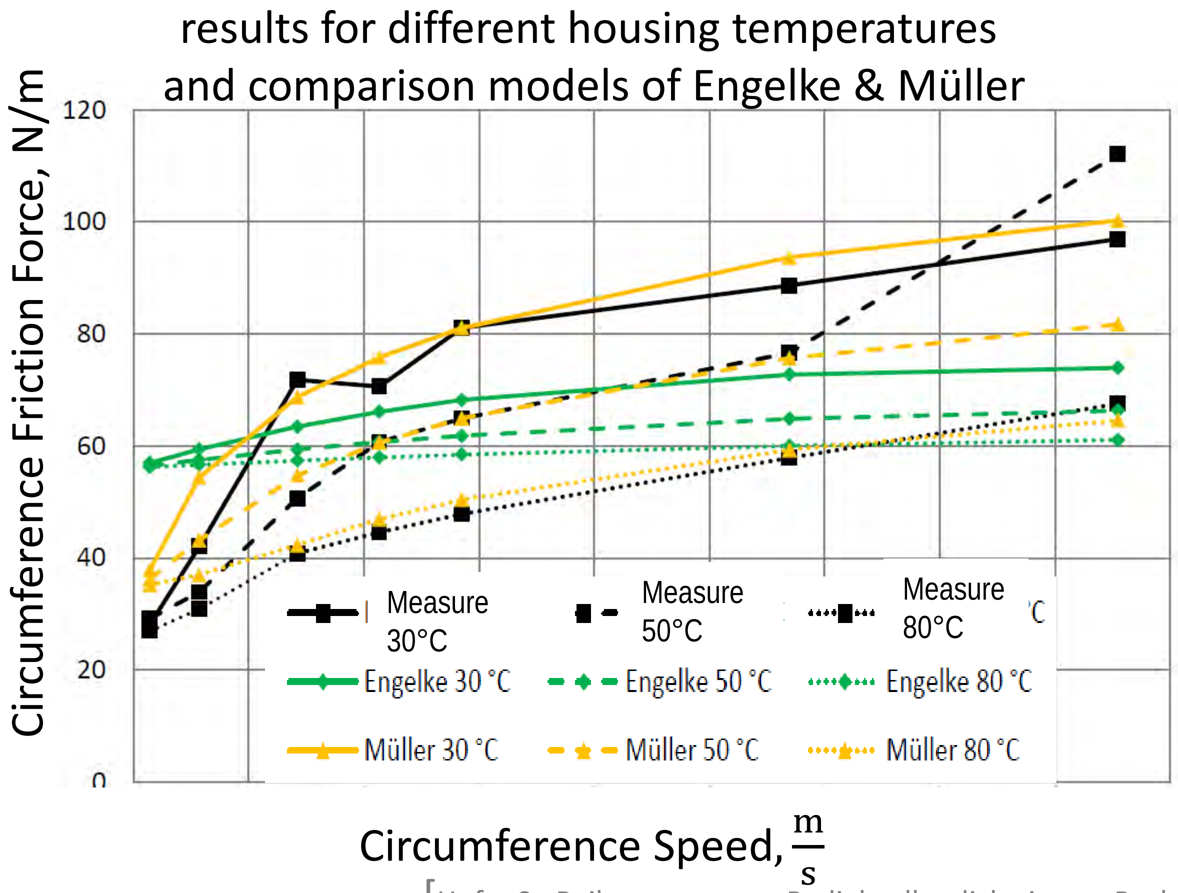
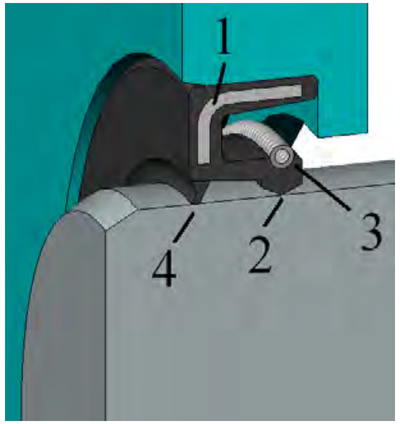
Example
Radial Shaft Seal





1 .. steel brace
2 .. sealing lip
3 .. spring
4 .. dust lip

[https://de.wikipedia.org/wiki/Wellendichtring]

- Losses are important
- Depends on viscosity of lubricant at the sealing lip
  - depends on temperature at sealing lip
  - depends on thermal conduction
  - depends on timing of the test procedure

[Hofer S.: Reibmoment von Radialwellendichtringen, Bachelors Thesis, FHJ 2017]
[ENGELKE, Tobias: Einfluss der Elastomer-Schmierstoff-Kombination auf das Betriebsverhalten von Radialwellendichtringen. Hannover, Gottfried Wilhelm Leibniz Univ., Diss., 2011]
[MÜLLER, Heinz Konrad: Abdichtung bewegter Maschinenteile : Funktion, Gestaltung, Berechnung, Anwendung. Waiblingen : Medienverlag Müller, 1990

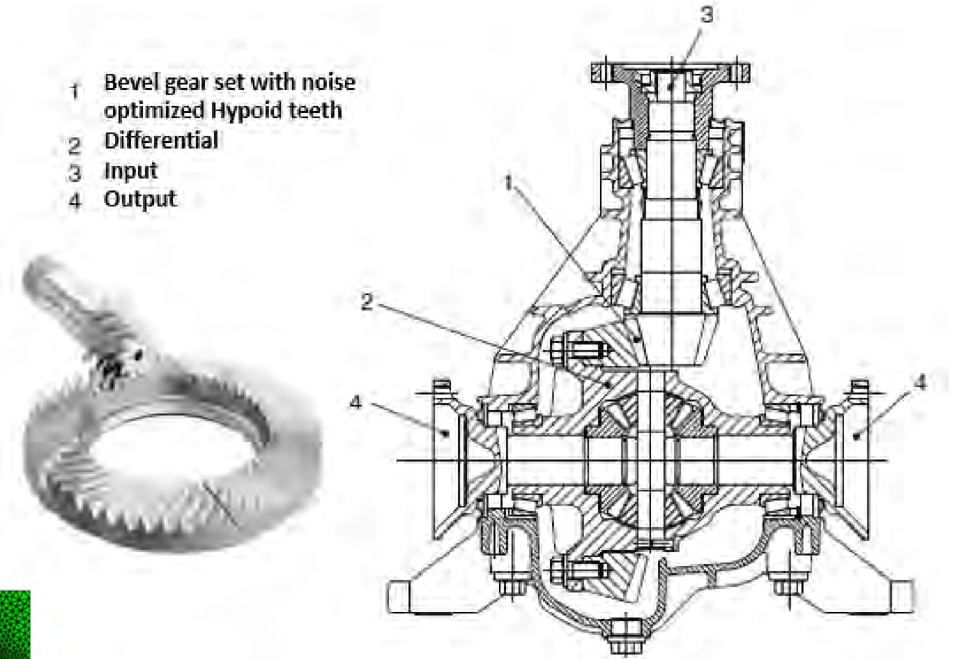
Connection to Student's Projects "Engineering Project" – Gearbox' Efficiency

Objectives

- estimate losses for a driving cycle
- compare to measured values

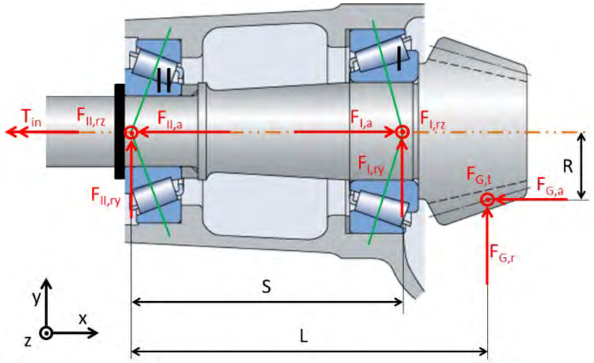
Tasks

- determine loads to components
- estimate losses
- weight them in driving cycle

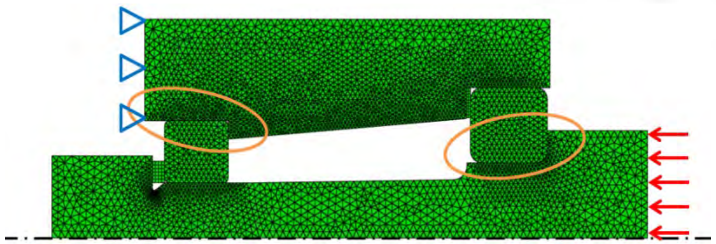


Rear differential gear box

[Platzer P.,Raffelsberger C.,Steinhäusler P.: Engineering Project Thesis, Poster at A3PS Conference, Vienna 2017]

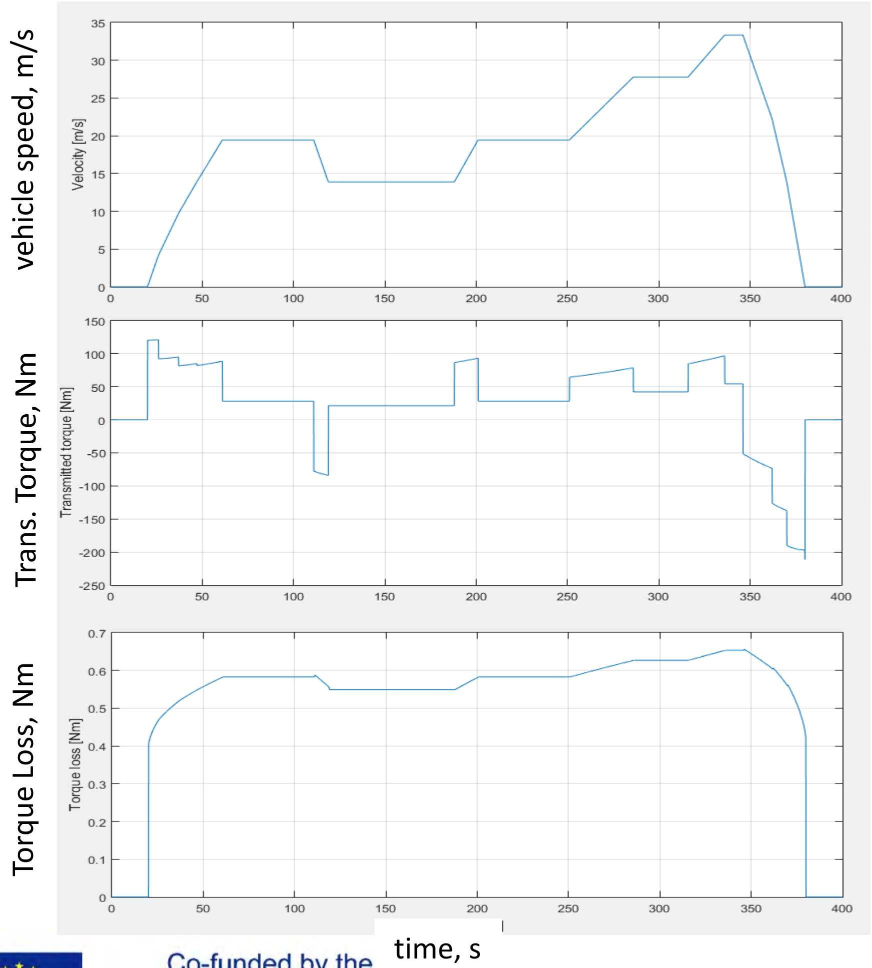


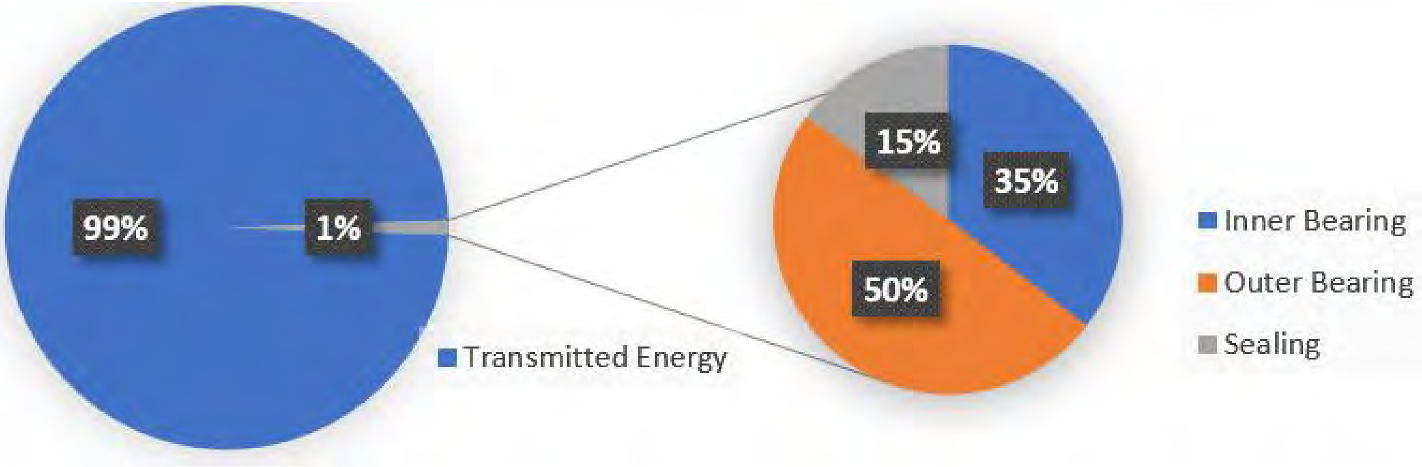
Loads at gears



FEM-Model to determine bearing pre load

Connection to Student's Projects "Engineering Project" – Gearbox' Efficiency





[Platzer P.,Raffelsberger C.,Steinhäusler P.: Engineering Project Thesis, Poster at A3PS Conference, Vienna 2017]

Model in Matlab

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Efficiency

K. Reisinger

Co-funded by the Erasmus+ Programme of the European Union

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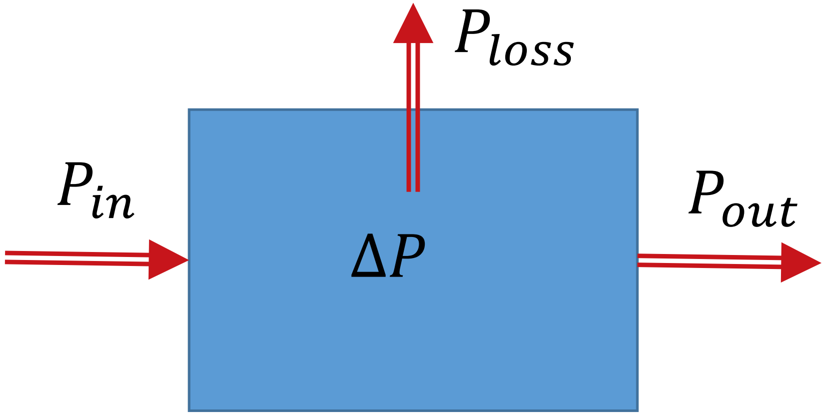
598710-EPP-1-2018-1-AT-EPPKA2-CBHE-JP

Power-Difference Method



P_{in} .. power effort
P_{out}.. power benefit
ΔP .. power stored in E_{kin}, E_{pot}, …
P_{loss} .. losses (typ. thermal)

Power Losses from power effort and power benefit

$$P_{loss} = P_{in} - P_{out} - \Delta P$$

Steady State $\boldsymbol{\Delta P = 0}$

$$P_{loss} = P_{in} - P_{out}$$

E.g. Electric Drive

- Efficiency $\eta = \frac{P_{out}}{P_{in}}, \eta \cong 96\%$ in nominal speed and torque
  $$P_{in} = 1\,000\text{ W}, P_{out} = 960\text{ W}$$
- Accuracy 0.5% at 2 kW, $\pm 1\%$ at 1 kW
- Measured
  $$P_{in} = \begin{pmatrix}1\,010\\990\end{pmatrix}\text{ W}, P_{out} = \begin{pmatrix}970\\950\end{pmatrix}\text{W}$$
  $$P_{loss} = \begin{pmatrix}60\\20\end{pmatrix}\text{W} = 40 \pm 20\text{ W} = 40\text{ W} \pm 50\%$$
  $$\eta = \begin{pmatrix}0.98\\0.94\end{pmatrix}$$

- **Accurate Measurement especially at low power**
- **Consider energy stored in system**

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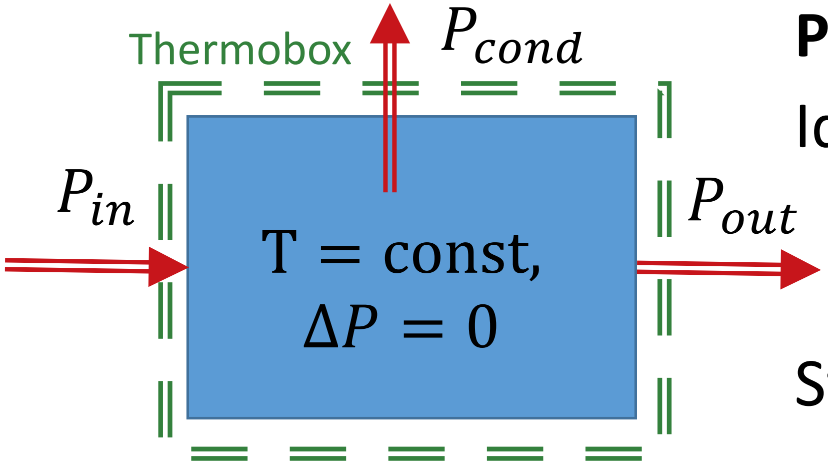
Calorimetric Method



Power Losses using Conditioners Heat Flow

Idea: Losses will be changed to heat

$$P_{cond} = P_{loss} = P_{in} - P_{out} - \Delta P$$

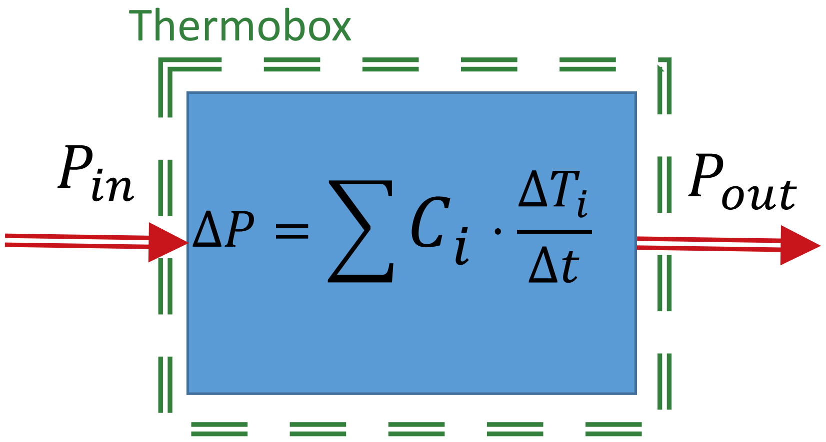
Steady State: $\Delta P = 0$

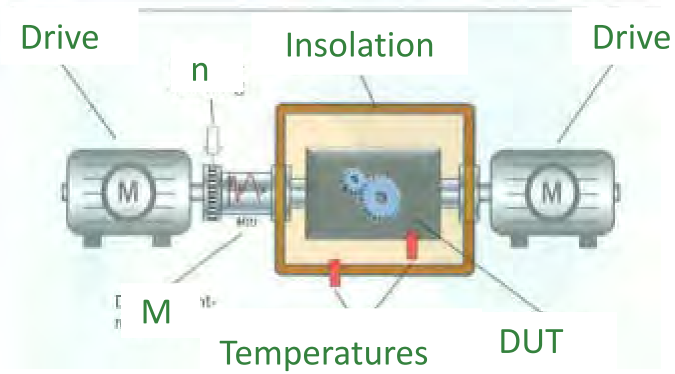
- Conditioning of gear box oil
  - unnatural oil distribution
- Gearbox put in cooling liquid
  - unnatural temperature distribution

Homann/Eckstein, (ika RWTH Aachen):
too high influence of unnatural temperature state.

[Homann J., Eckstein L.: Kalorimetrisches Verfahren zur Wirkungsgradbestimmung von Getrieben, ATZ 11/2014, 116. Jahrgang, P. 68-73]

Short-Time Calorimetric Method





Power Losses using Heat Capacity

Idea: Losses will be changed to warm up

Adiabatic Box:

$$\mathrm{P_{cond}} = 0, P_{in} - P_{out} - \Delta P = 0$$

$$P_{Loss} = \frac{\Delta U}{\Delta T} = \sum C_i \cdot \frac{\Delta T_i}{\Delta t}$$

- Determine heat capacity of each part
- measure temperatures T_i
- Test process
  - heat up to uniformly temperature
  - speed up by accelerating both machines synchronously
  - impress torque
  - measure time and temperature difference of parts with different temperatures

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[Homann J., Eckstein L.: Kalorimetrisches Verfahren zur Wirkungsgradbestimmung von Getrieben, ATZ 11/2014, 116. Jahrgang, P. 68-73]

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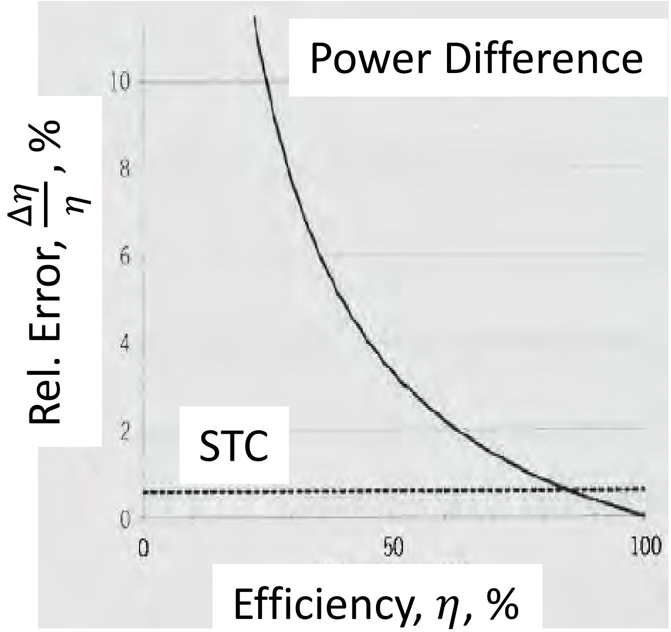
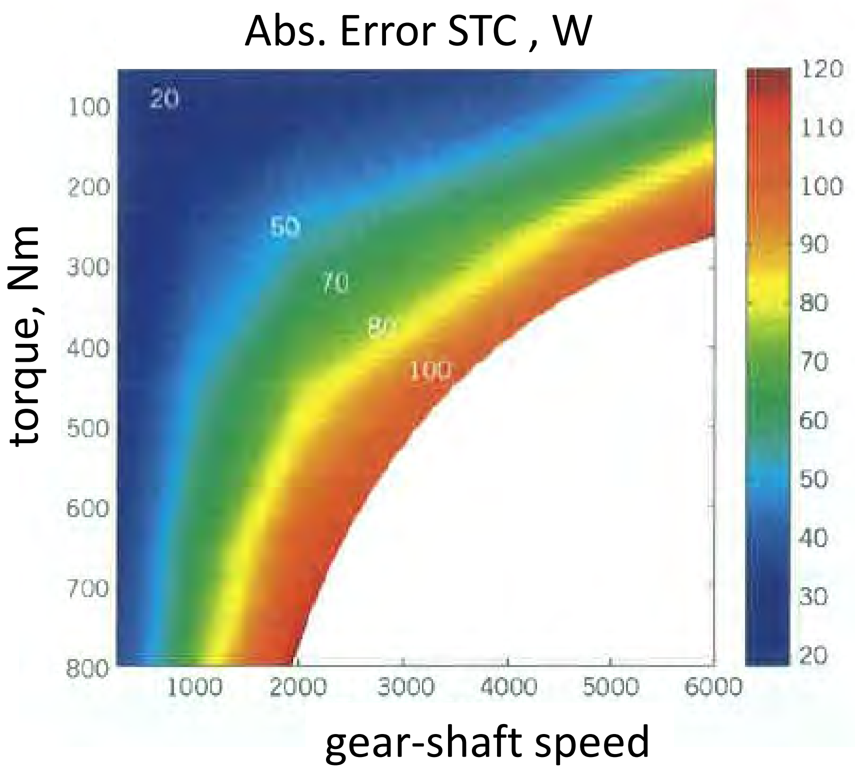
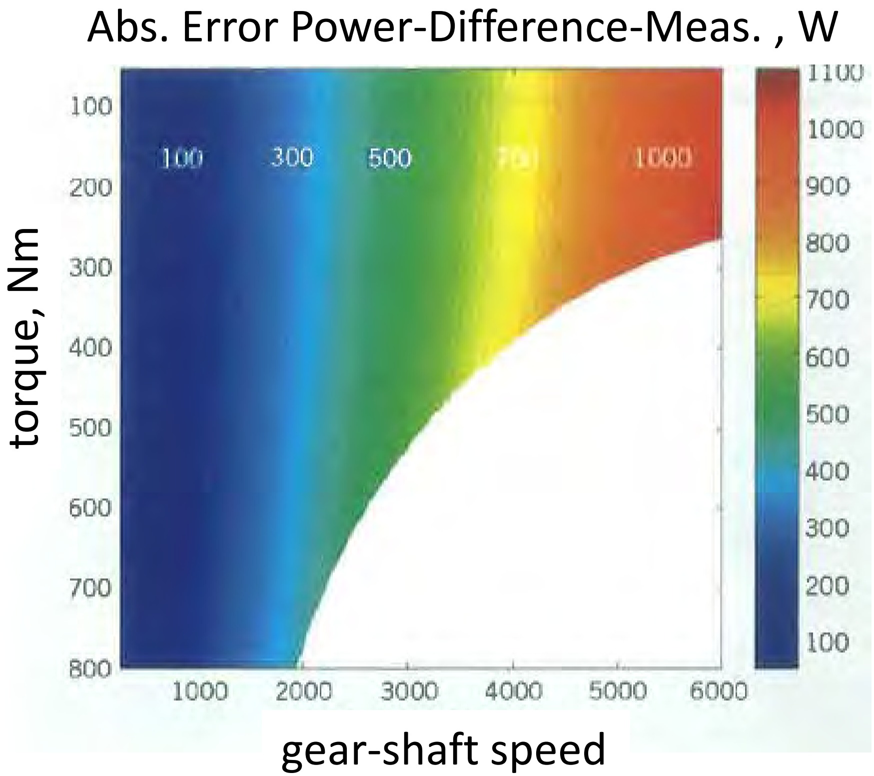
Short-Time Calorimetric Method (STC)







Homann/Eckstein say: good results, especially at low power

[Homann J., Eckstein L.: Kalorimetrisches Verfahren zur Wirkungsgradbestimmung von Getrieben, ATZ 11/2014, 116. Jahrgang, P. 68-73]

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Electrical Power Measurement

T. Lechner

Co-funded by the Erasmus+ Programme of the European Union

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Electric power measurement

- **Motivation**
  - For vehicles with combustion engines, the fuel consumption can be measured with exhaust gas analysers.
  - The fuel consumption is a measure for the used energy.
  - Due to the increasing electrification of powertrains, the electric energy consumption must be ascertained.
  - Therefore, an accurate electric power measurement is needed.
  - For drivetrain development, the efficiency of used components must be measured.

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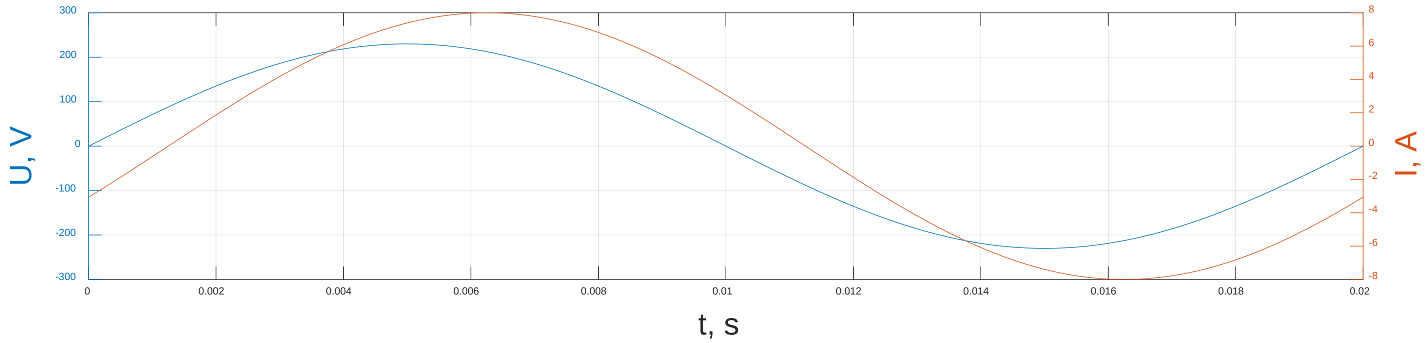
Electric power measurement

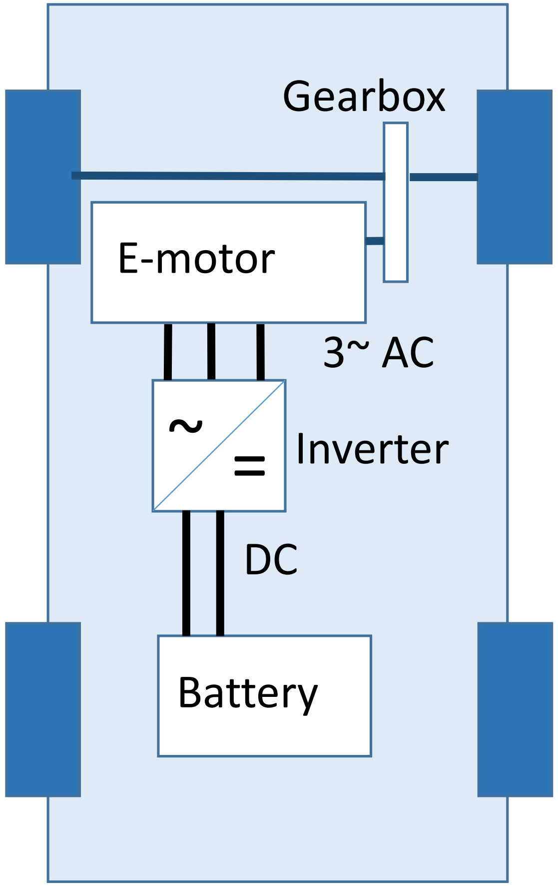
- Introduction
  - Easy to measure in case of:
    - Slow changing direct current or voltage
    - alternating quantities with perfect sinus shape



Active, reactive and apparent power can be easy calculated out of the effective values

Electric power measurement

- For drivetrain development and determining the efficiency of inverters, the power on the DC as well as at the AC side must be measured.
- Inverter:
  - Transfers DC to 3-phase alternating current
  - The goal is to generate 120 degree shifted sinusoidal phase currents.
  - A pulsed voltage generates this with the help of the E-motor's inductance.
  - → Voltages are not sinusoidal, currents are only approximated sinusoidal



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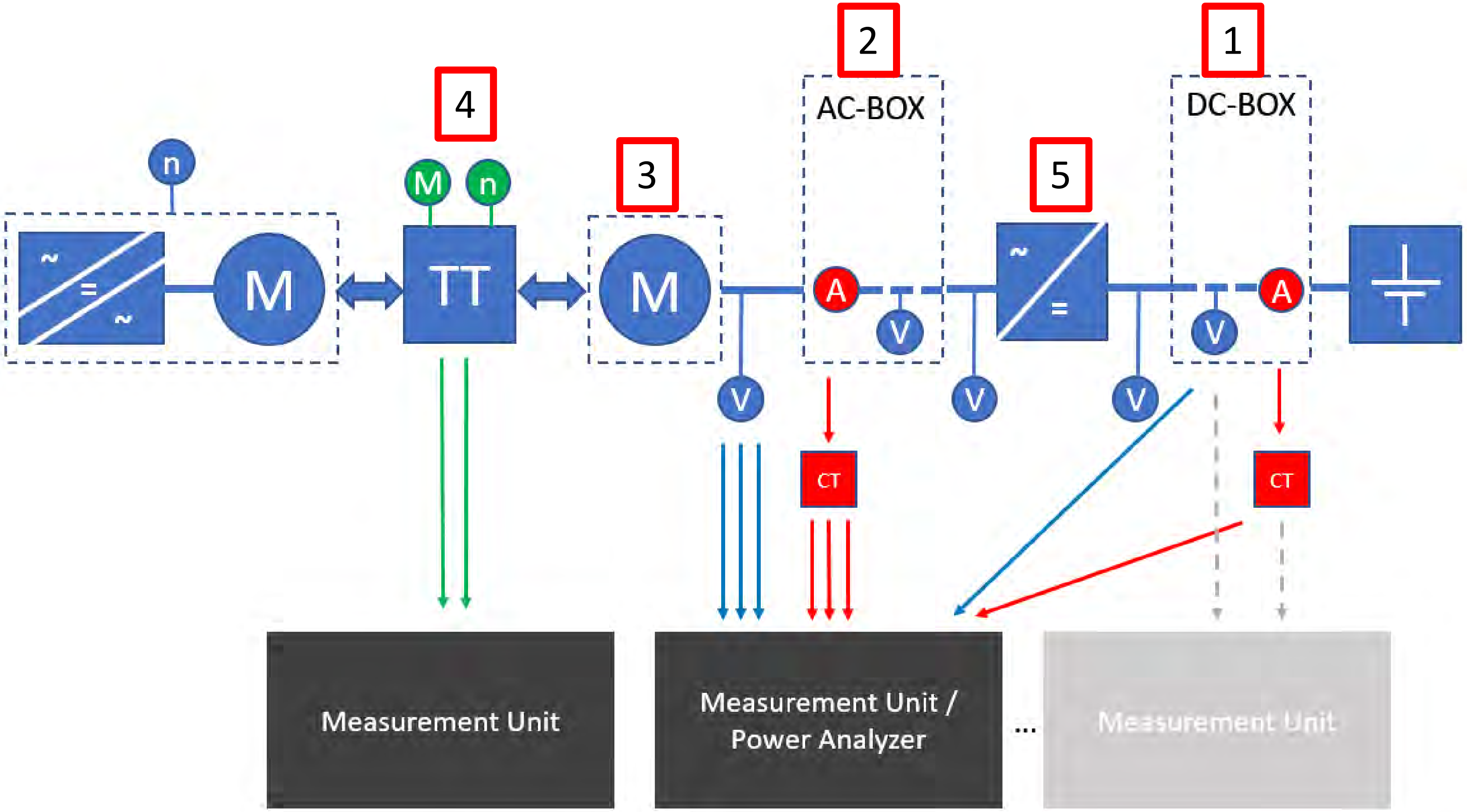
Testing configuration, [1]

1) DC-power
2) AC-power
3) E-motor
4) mechanical power
5) Inverter



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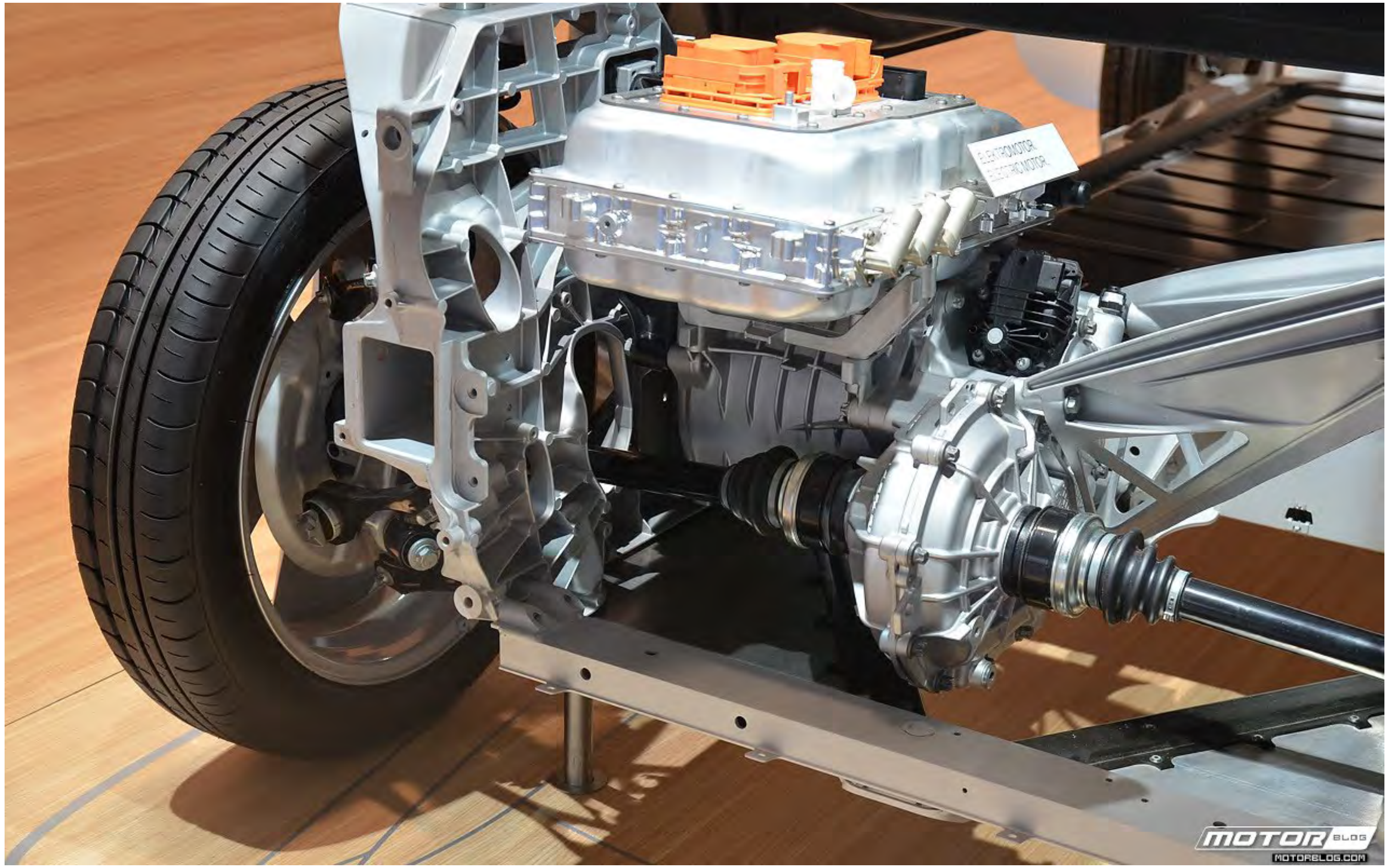
BMW i3 section model, [4]

High encapsulated construction → hard to connect the probes for voltage and current measuring.



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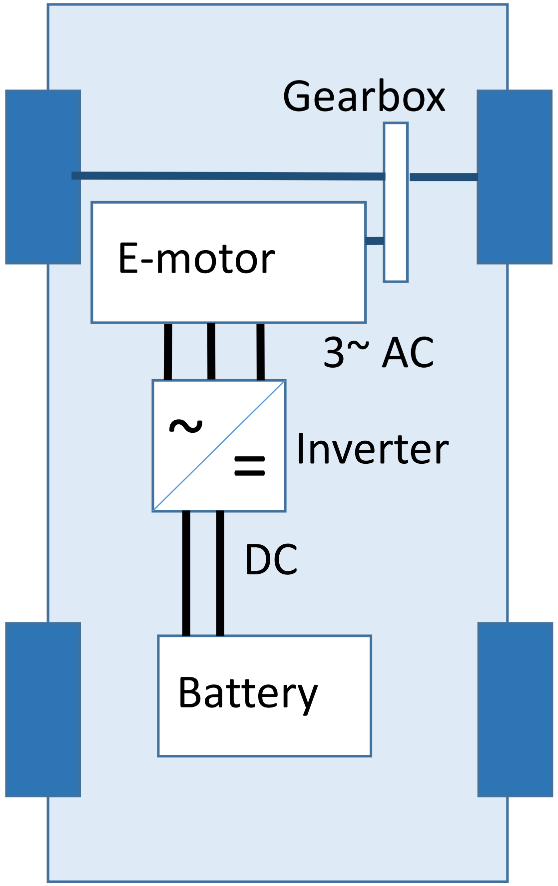
Electric power measurement

- The switching frequency of the frequency converter must be set to a value to reduce or prevent audible noise.
  - Switching frequency > 10 kHz
  - For accurate power measurement: Data acquisition devices with high sample rates are necessary.
- Inverter efficiency is very high
  - For accurate power measurement: currents an voltages must be measured very exactly.



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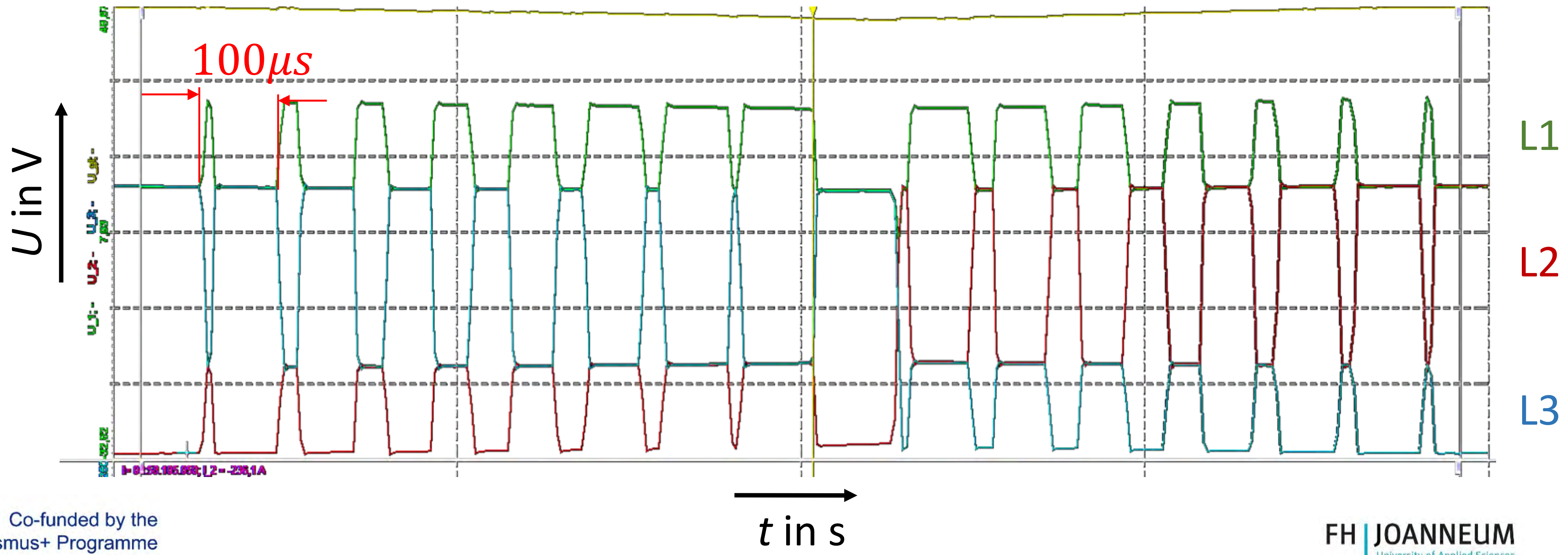
DAQ-System, sample rate

- Which sample frequency f_s is needed?
  - Inverter pulsed voltage:



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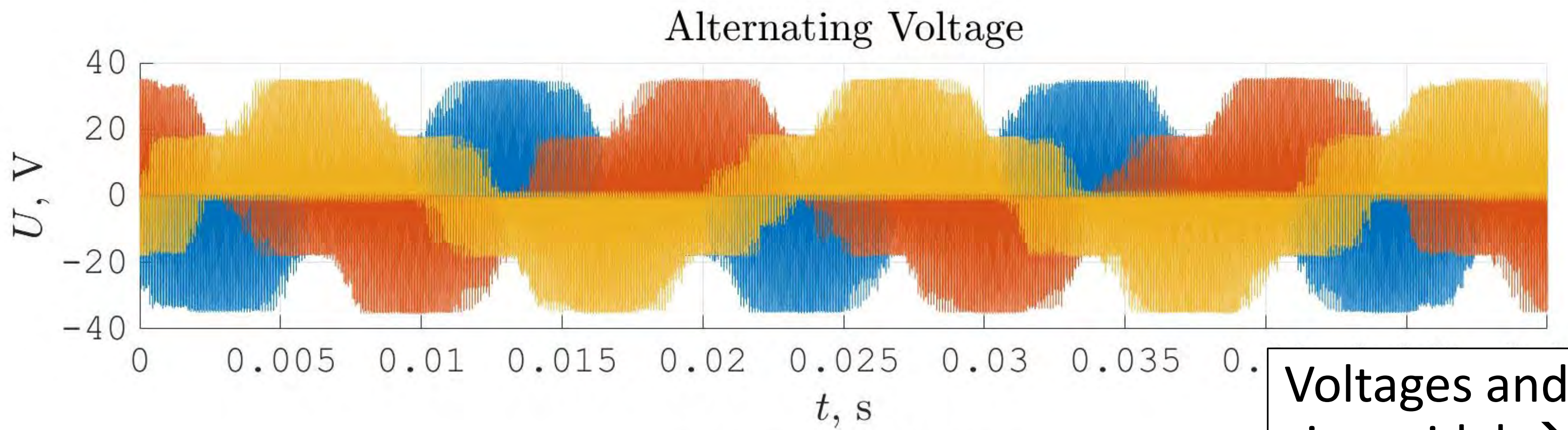
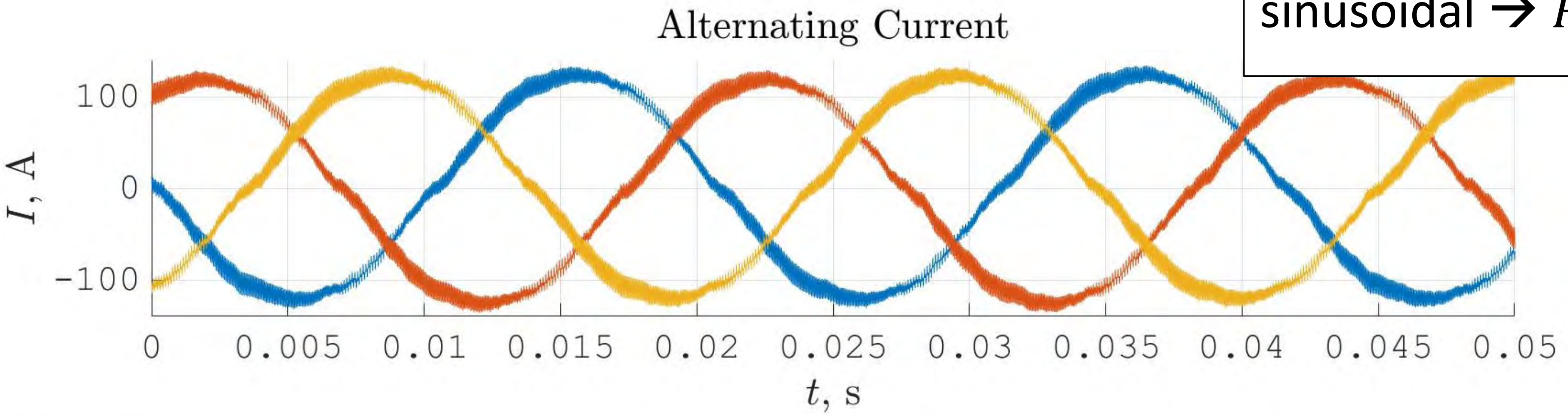
Result of current and voltage measure



Voltages and currents are not sinusoidal → $P \neq U_{\mathrm{eff}} \cdot I_{\mathrm{eff}}$



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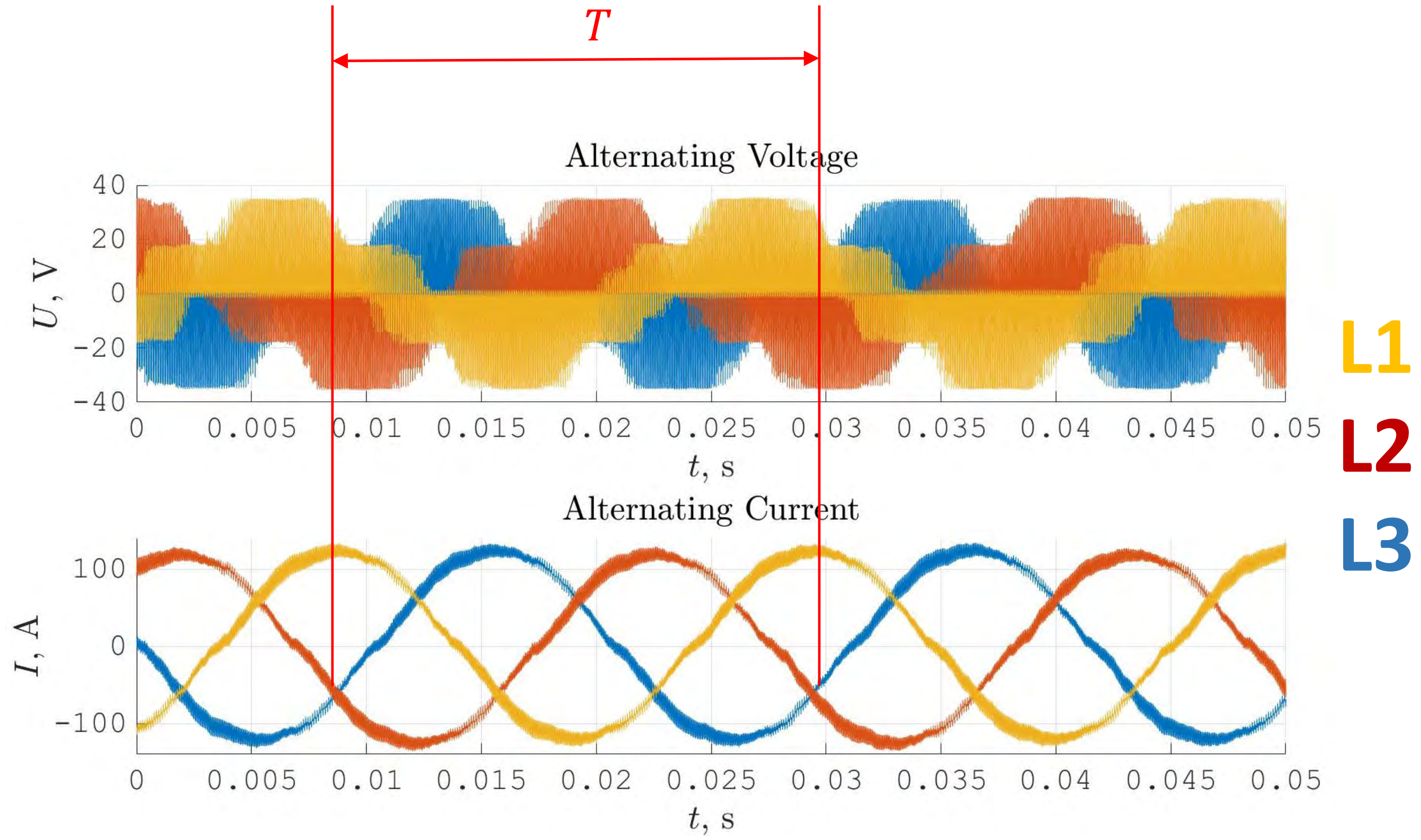
Active power calculation



Current power value

$$p(t) = u(t) \cdot i(t)$$

Active power *P* per phase L_j

$$P_{L_j} = \int_{t_1}^{t_1+n\cdot T} p_j(t)\mathrm{d}t$$

Active power

$$P = P_{L1} + P_{L2} + P_{L3}$$

→ Find the periodicity!

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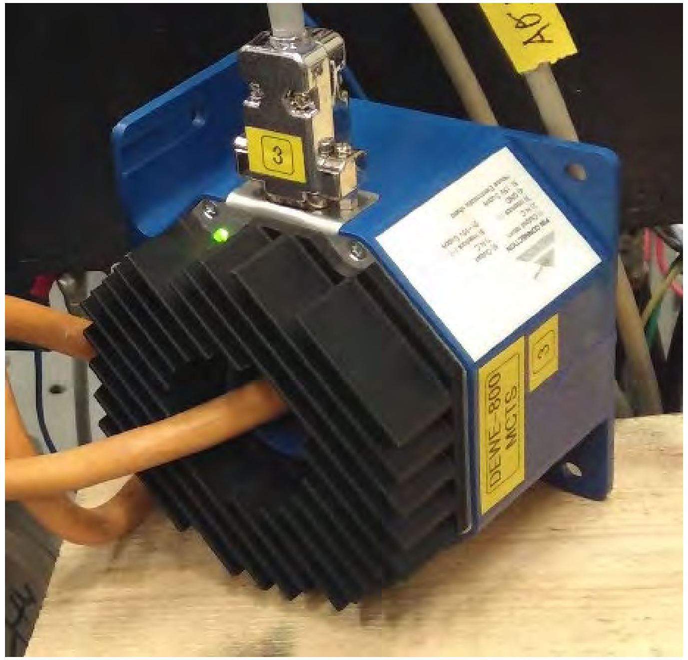
DAQ-System, accuracy

- Typical inverter losses: 3 %
  - Example: 0.1 % accuracy for voltage and current measuring → maximum 0.2 % error for input power P_{in} and output power P_{out}.
  - Power loss $P_{\mathrm{v}} = P_{\mathrm{out}} - P_{\mathrm{in}}$

    P_{v} fluctuates around +/- 0.4% of P_{in}. This are +/- 13% of P_{v}!
- Current measurement:
  - Indirect measured via the magnetic field that covers the electric conductor
  - Sensor: Zero flux transducer, Error out of:

    linearity 0.001%, offset deviation 0.004 %



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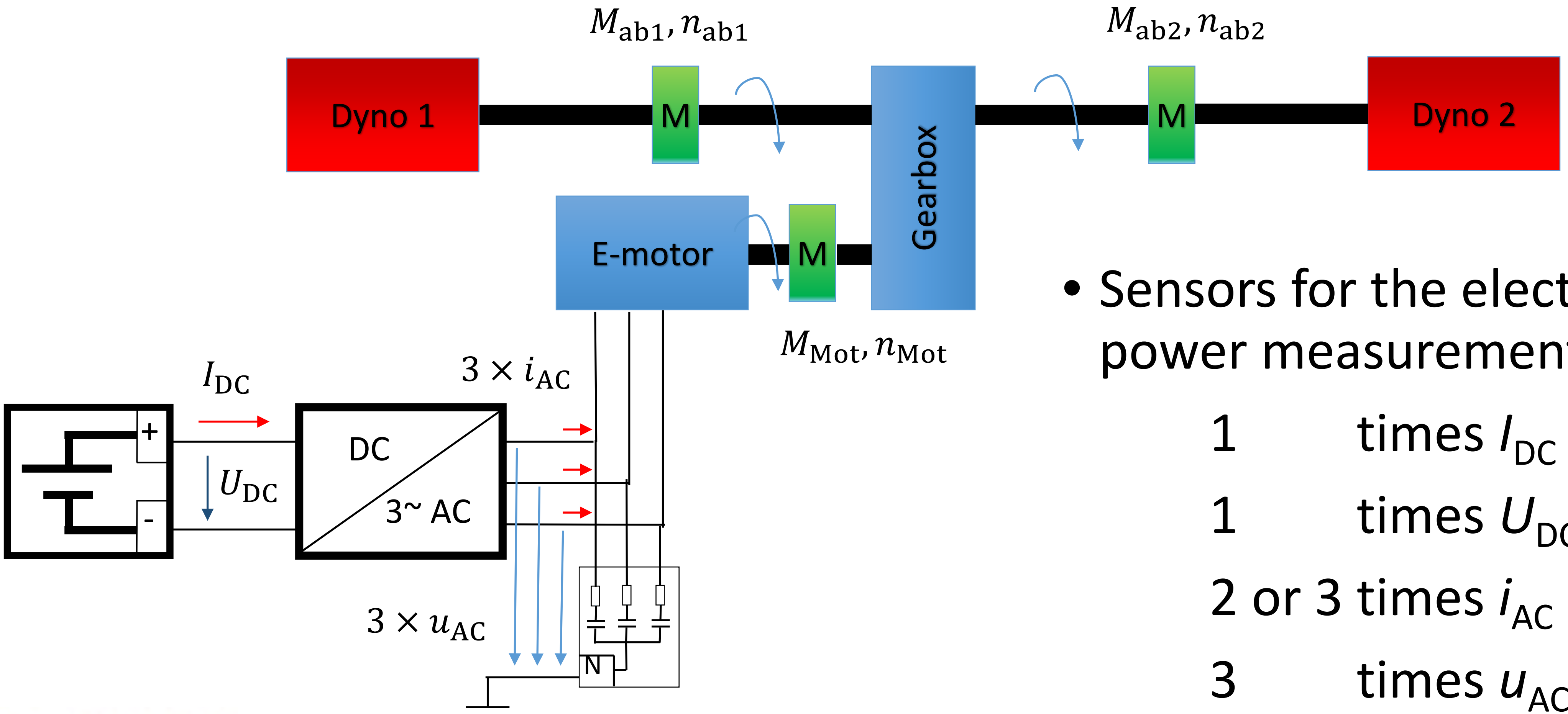
Exemplary test bed setup



- Sensors for the electric power measurement:

  1 times I_{DC}

  1 times U_{DC}

  2 or 3 times i_{AC}

  3 times u_{AC}

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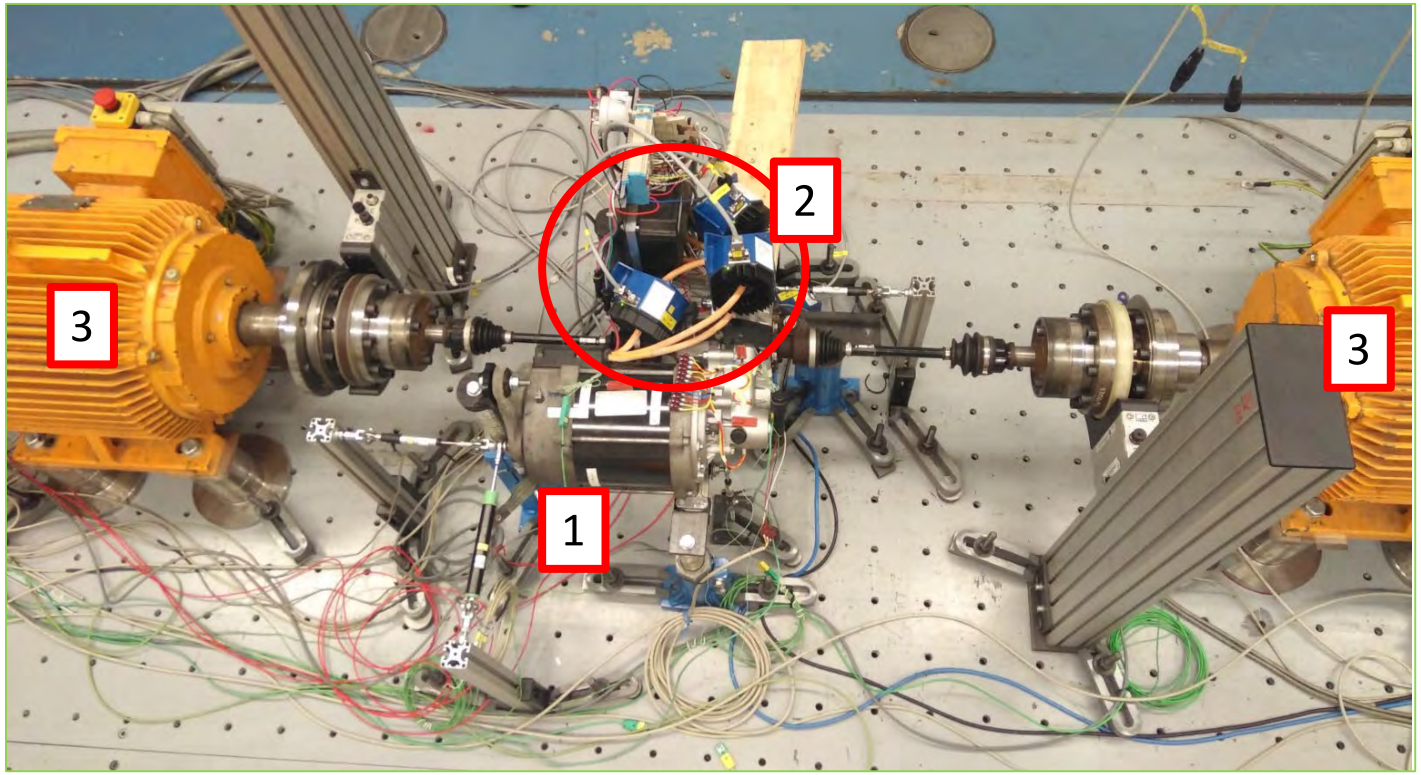
Exemplary setup at a test bed

1 – Device under test (DUT)

2 – Current transducer for AC

3 – Dynamometer 1 and 2



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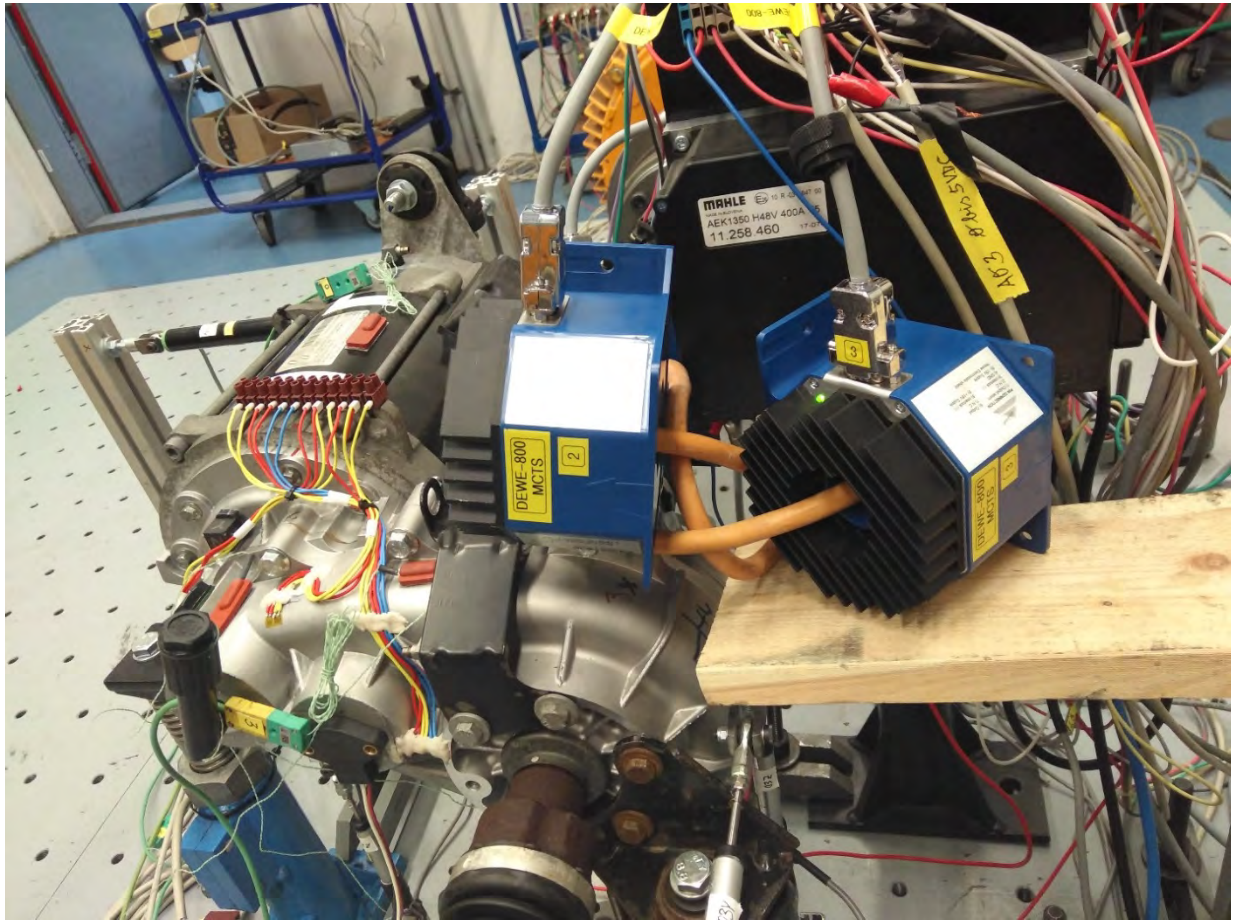
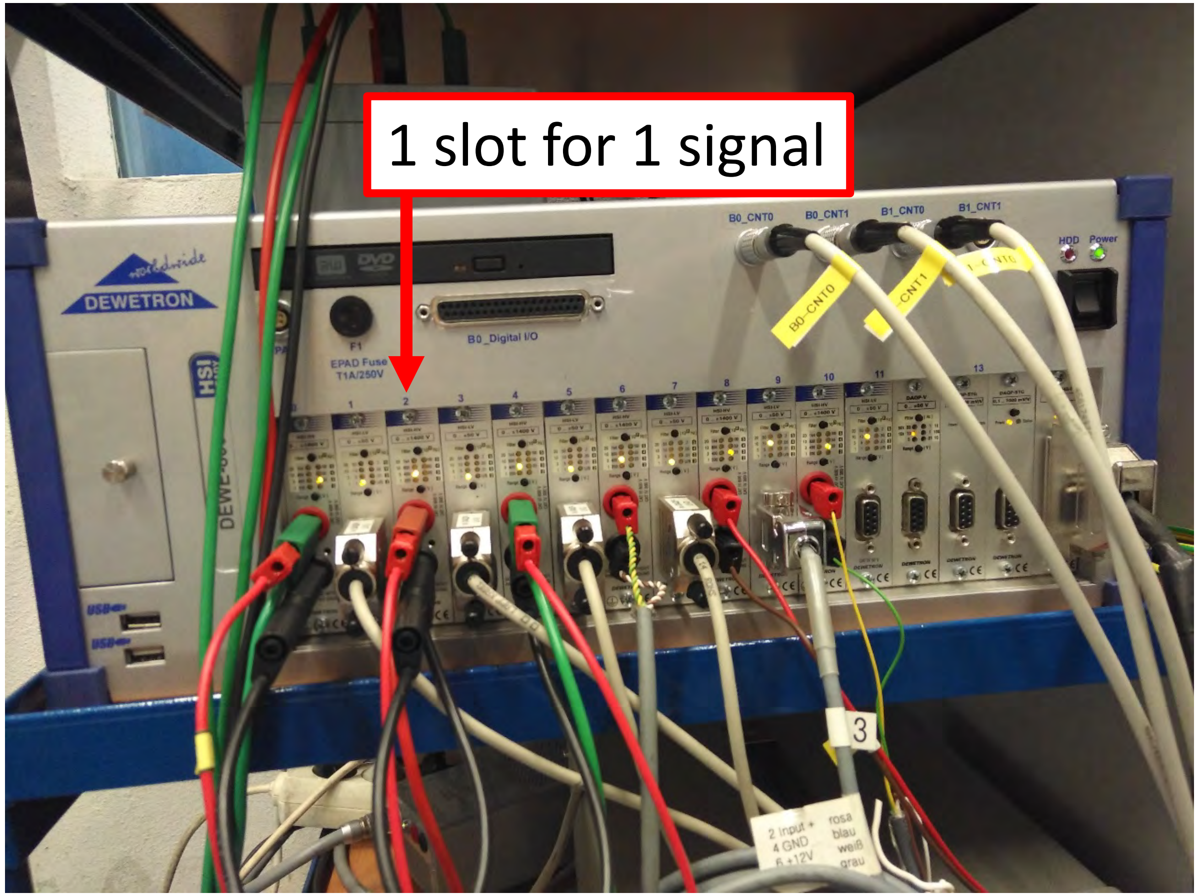
Zero flux transducer, [2]

- Zero-Flux Current Transducers
  - Model: PM-MCTS 1000
  - Input: Current
  - Output: Voltage
  - Range:
    - DC, Peak up to 1000A
    - RMS Sinus up to 700A



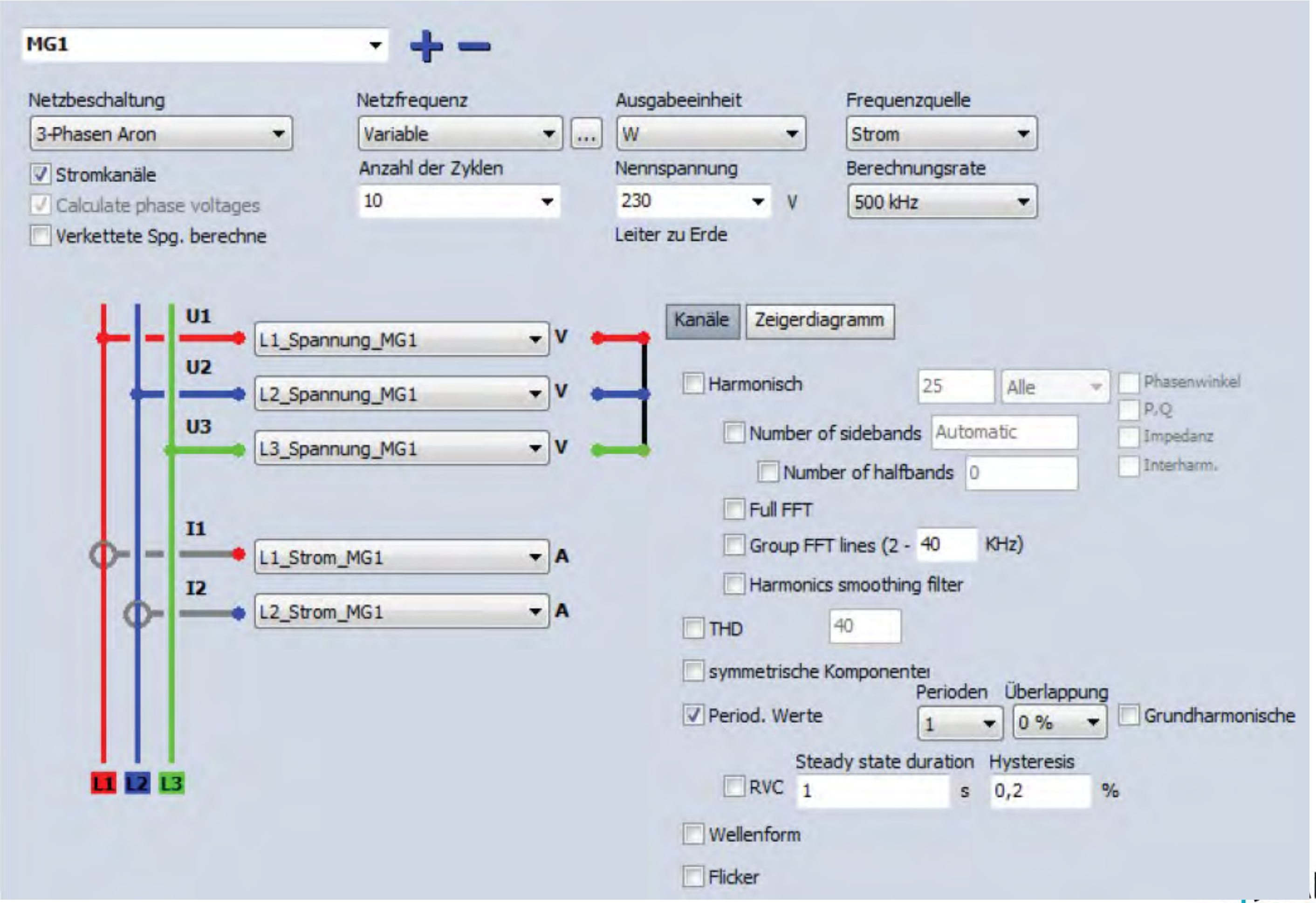
Data acquisition system

- Voltage measurement
  - direct connection possible
  - no differential probe is needed
  - to reduce errors



DAQ-System, Software

- Setup overview



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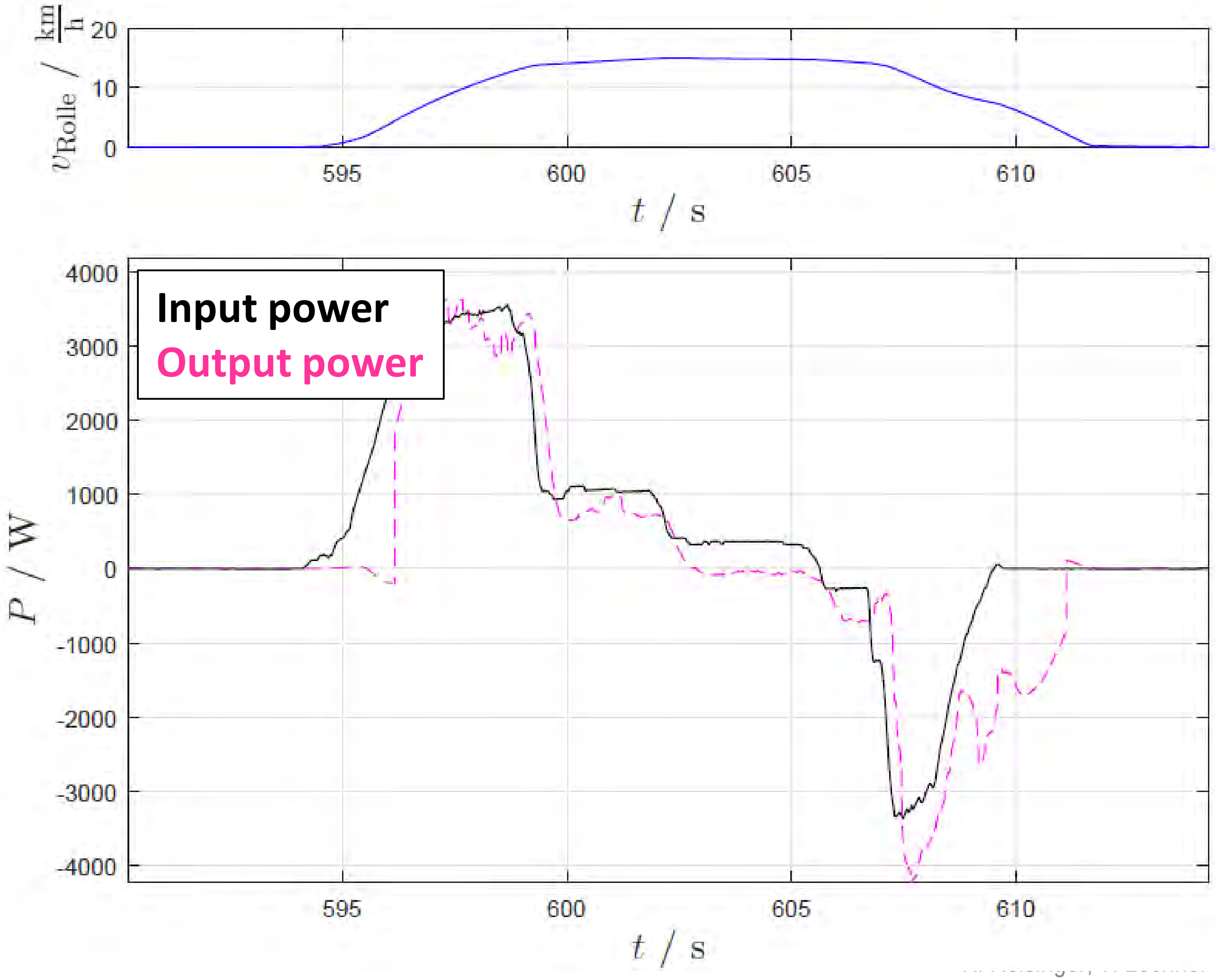
Hybrid Car Results, [3]

- The shown results where measured at a chassis dynamometer
- The input power as well as the mechanical output power where measured depending to vehicle speed.



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References

[1] Wiedner, Christoph: *THE CHALLENGES OF ANALYZING THE EFFICIENCY OF ELECTRICAL POWER TRAINS*. DEWETRON GmbH, 2018

[2] 2020 01 27: https://www.dewetron.com/products/daq-components-daq-sensors/current-transducers/

[3] Patrick Moser: Leistungsflussmessung in einem Hybridfahrzeug (Bachelor Thesis), October 2016

[4] 2020 01 28: https://de.wikipedia.org/wiki/Elektroauto

UNITED

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Challenges when Testing Mechatronic Systems

K.Reisinger

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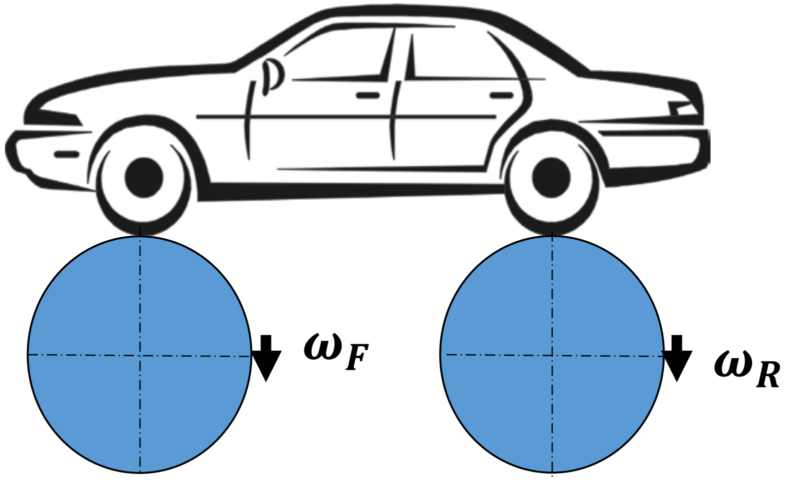
Example: Chassis Dyno



- Front and rear roller are driven separately by an speed controlled AC-Motor.
  - front roller turns $v_F = r_r \cdot \omega_F = v_{Req} \pm 5\%$
  - rear roller makes $v_R = v_{Req} \pm 5\%$
  - Speed difference $\Delta v = \pm 0.1 \cdot v_{Req}$
- What happens in an 2WD car?
  - nearly nothing → OK for testing
- What happens in an locked 4WD car?
  - nearly nothing, speed will be synchronized by car → OK
- What happens in an controlled 4WD car?
  - AWD-ECU recognizes too high slip, sometimes at front, sometimes at rear
  - AWD-Clutch opens/closes periodically
  - self exciting vibration

Controller needs to synchronize front/rear roller

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Requirements for Testing Embedded Systems

- All interfaces must be simulated as accurately as required
- Mechanic interfaces
  - speeds **often speed differences (=wheel slip)** must fit to models in Embedded System under test (DUT)
  - accuracy depends on sensitivity of DUT
- Electric interfaces
  - supply like in the car
  - electrical signals
- Bus-Interface (CAN)
  - control signals as in the car
  - residual bus simulation to be satisfied to run
- ECU internal
  - set to test mode
  - prepare for remote control
  - read signals

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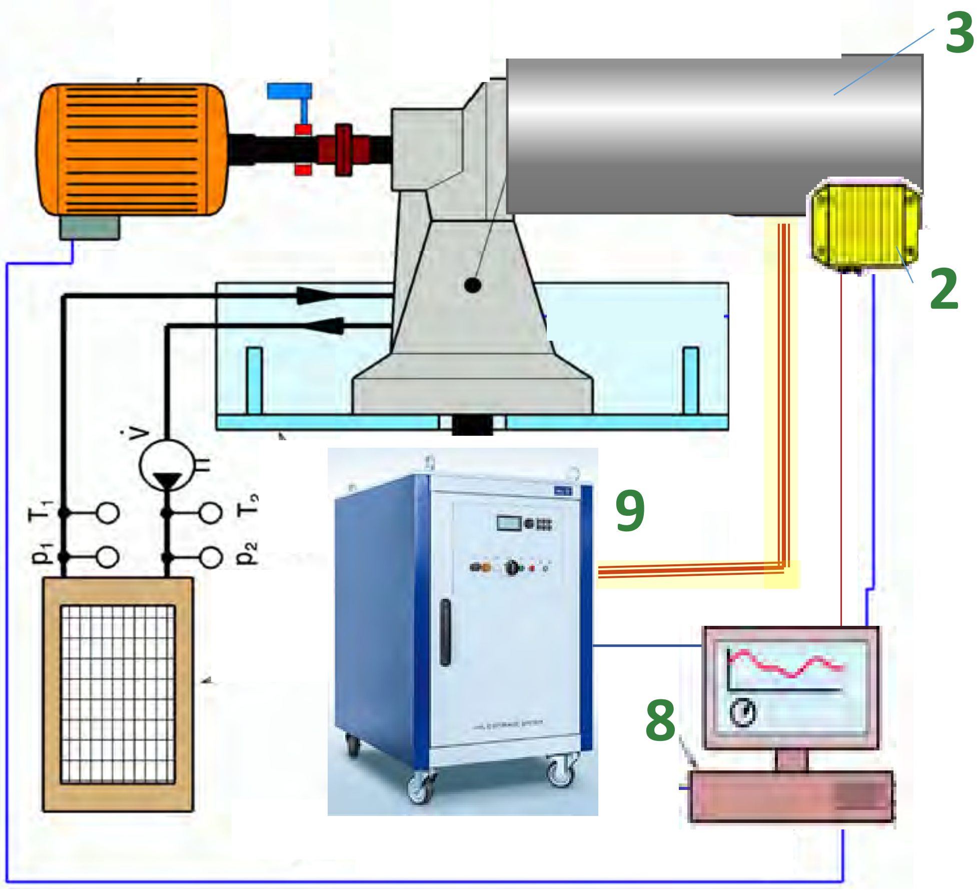
Simulate Electrical Supply at Test Bench

- **Supply battery voltage independent of test duration**
- Tests are compacted, no time to relax like in the car
  - real battery can burn (prototypes)
  - real battery becomes empty
  - real battery becomes hot
- We have to simulate a real battery
  - test bench defines SOC
  - a battery model calculates offered voltage in real time
    - constant (nominal) voltage
    - **behaviour model: R,R+RC, …**
    - electro-chemical model
  - Battery Emulator offers voltage



3 .. DUT, 2 .. DUT's ECU
8 .. test bench control
9 .. battery emulator

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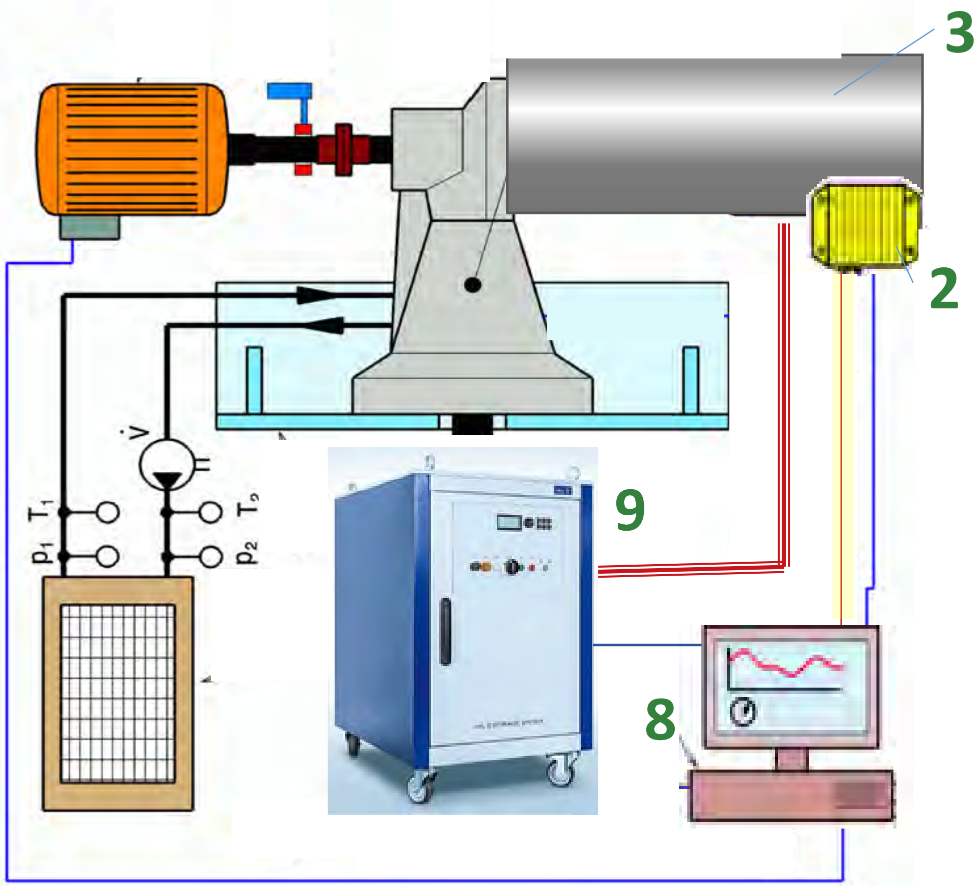
Simulate Electrical Signals at Test Bench

- **Invoke DUT's start-up;**
- **provide sensor signals**
    - e.g. Ignition On (Term15), brake light switch, sensor signals, …
- provide electrical signals
    - test bench relays
    - test bench replay (time dependent tables) + D/A interface
    - real time simulation + D/A interface



3 .. DUT, 2 .. DUT's ECU
8 .. test bench control
9 .. battery emulator

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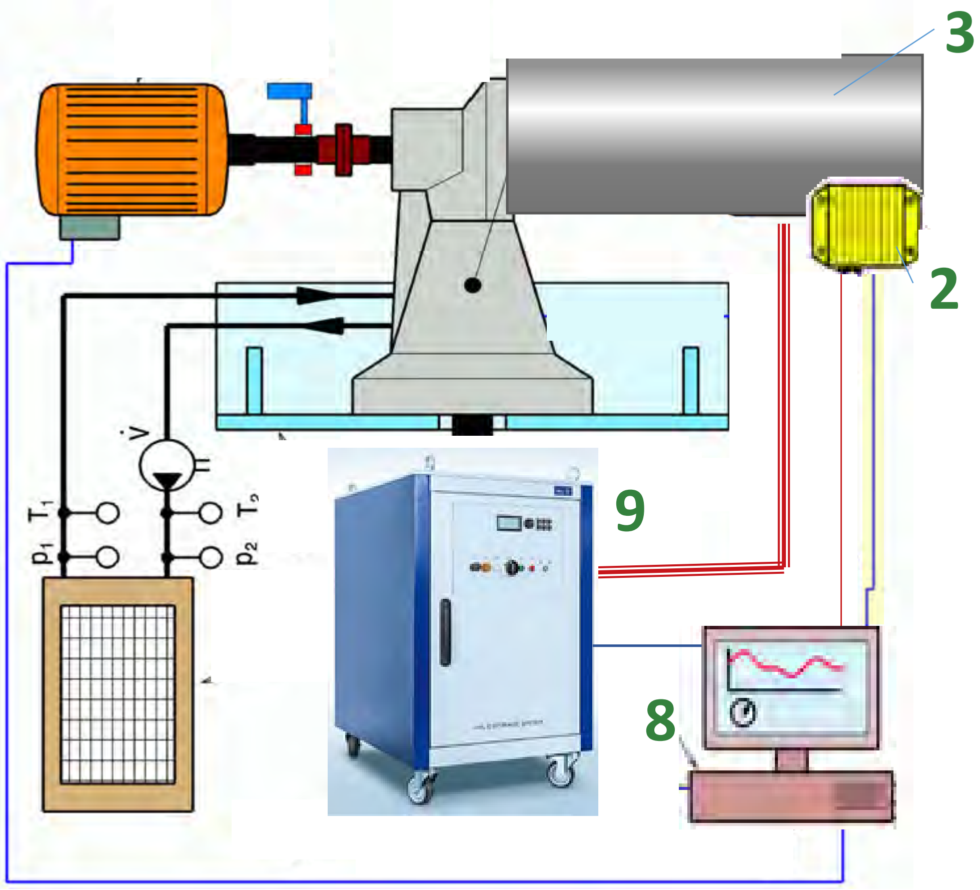
Simulate BUS Signals at the Testbench

- **interface for control**
- **provide correct sensor signals and acknowledgements to run**
  - e.g. anti-theft protection
  - external sensors
- residual bus simulation - replay
  - install neighbour ECU
  - replay recorded bus signals using CANoe
  - test bench replay (time dependent tables)
- control signals as in the car
  - depends on test concept and models running in DUT's ECU
  - test bench replay (time dependent tables)
  - Hardware In the Loop simulation



3 .. DUT, 2 .. DUT's ECU
8 .. test bench control
9 .. battery emulator

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https://en.wikipedia.org/wiki/CANoe
https://www.vector.com/

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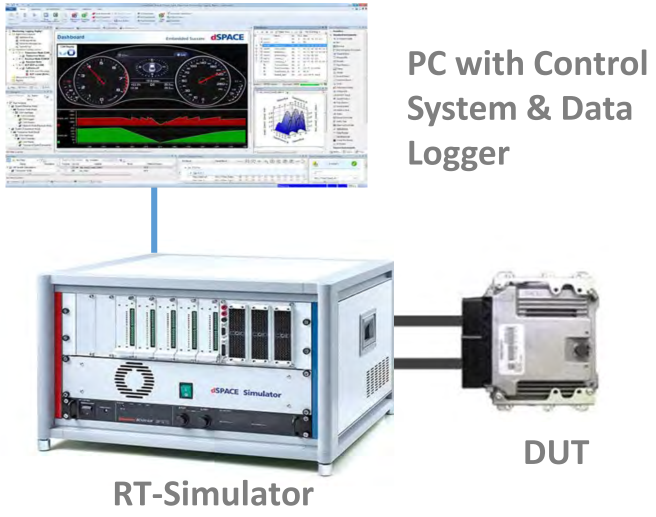
RT-Hardware for test bench

- **Simulates signals like in the car in real-time**
  - **based on requested values from testbench**
  - **based on measured signals from Testbench and DUT**
  - **uses models representing car's parts, which are not present**
  - **Shall be compatible to Matlab/Simulink**

- e.g. Hardware in The Loop
  - Test automation: PC
  - Reality: ECU + Software
  - Measuring: ECU output signals
  - Simulation: All except ECU
  - Output to ECU: ECU input signals



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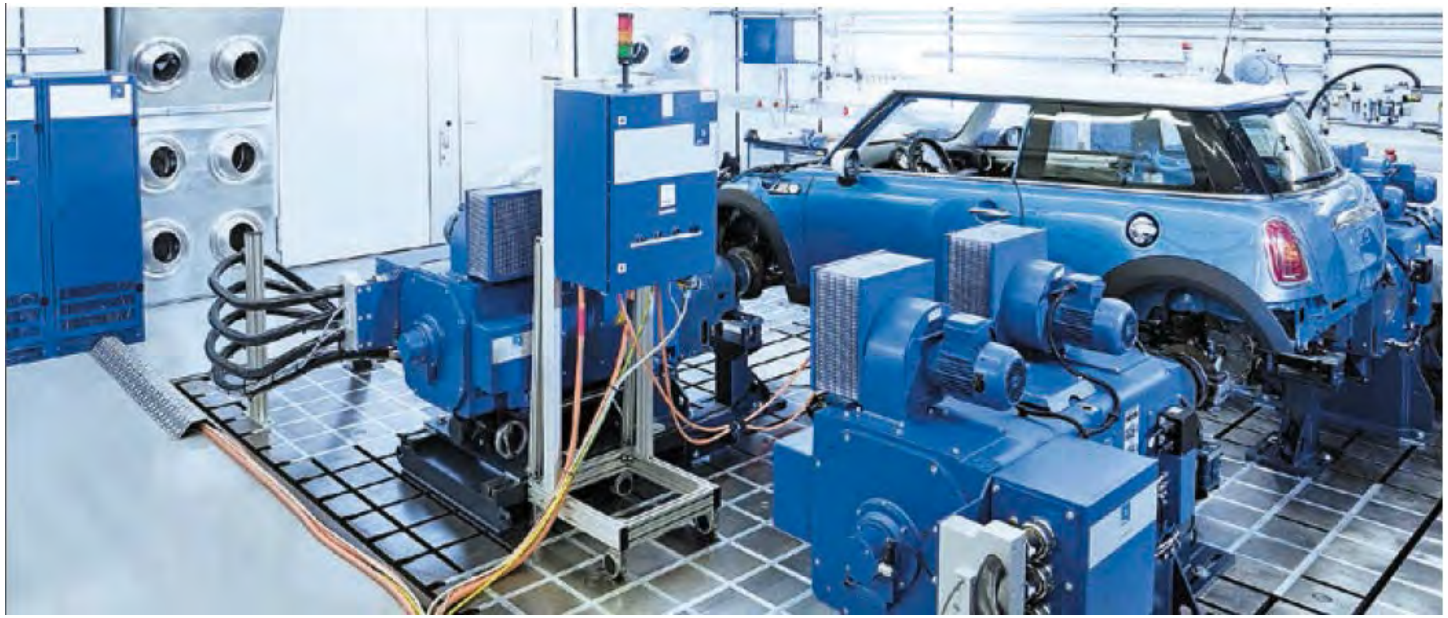
e.g. Vehicle In the Loop

- Test automation: Test bench control
- Reality
  Vehicle, except tyres,
  acceleration, yaw-rate
- Measuring
  wheel torques
- Simulation
  - tyre slip, road, resistances
  - wheels acceleration, speeds
  - body motion
- Output to test bench
  wheel speeds, brake/throttle robot, steering robot
- Bypass signals in Vehicle-CAN
  acceleration, yaw rate (if necessary)



[https://www.avl.com/de/-/vehicle-in-the-loop-test-system

Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

SHED Chamber

J. Brenner, T. Lechner, K. Reisinger

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Introduction

- ALL emissions of vehicles must be measured
  - For exhaust gas emissions → Chassis Dynamometer
- For evaporative emissions on vehicle
  - tank systems and components
  - as well as elastic plastics and rubber parts

  → SHED Chamber
- The goal is it, to measure emitted **h**ydro**c**arbon (HC) emissions.
  - Whole vehicle
  - Parts of vehicles like fuel systems and components for fuel transport.
- Used sensor: gas analyser → FID … flame ionization detector

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SHED Schematic

Sealed Housing for Evaporative emission Determination

1 Computer
controls temperature profile, data acquisition

2 Air bag (4 m^3)
membrane to equalize air pressure

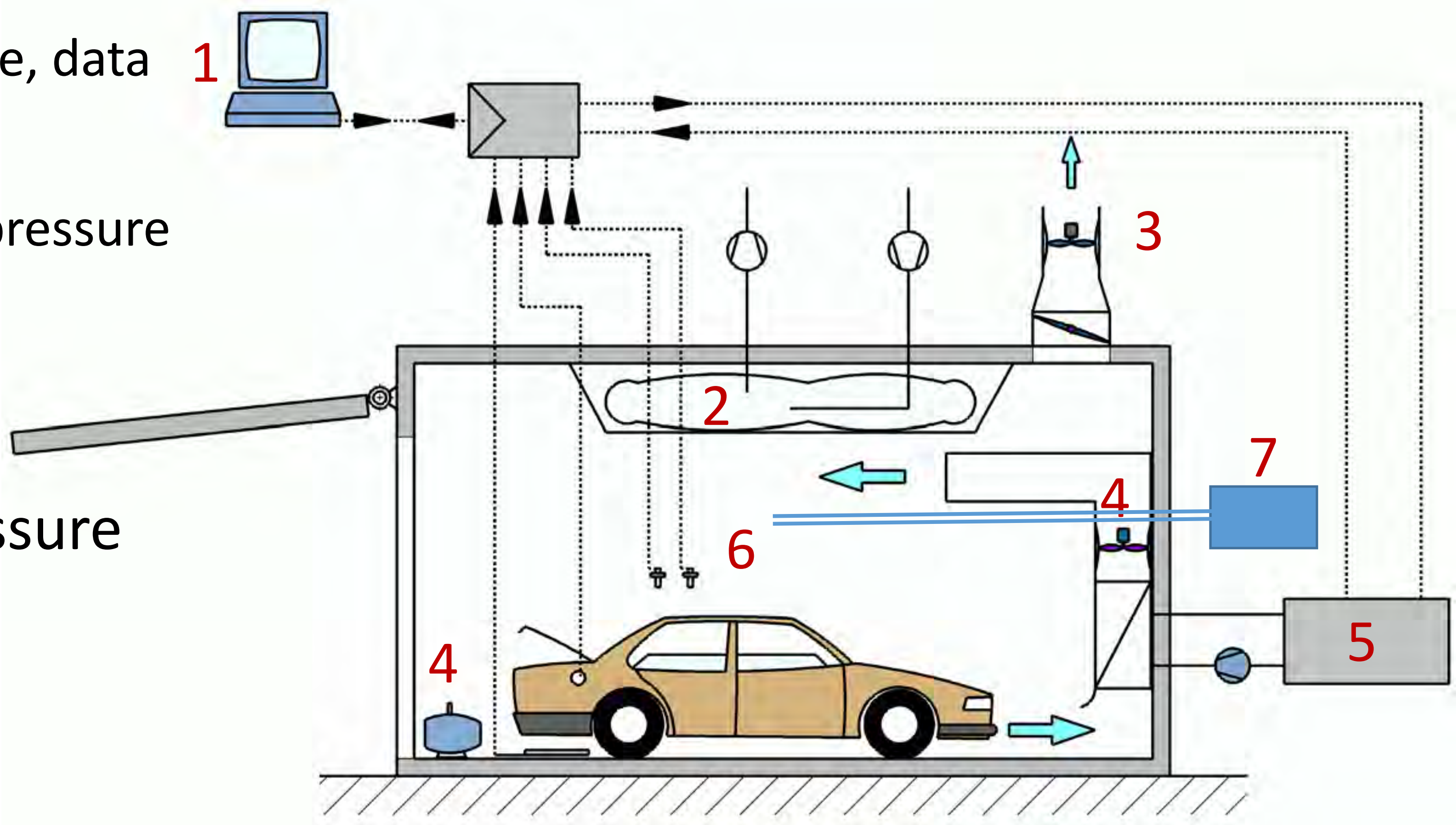
3 Purging fan

4 Mixing fan + Blower
defined air convection

5 Heating system

6 Temperature and pressure sensors

7 FID flame ionisations detector



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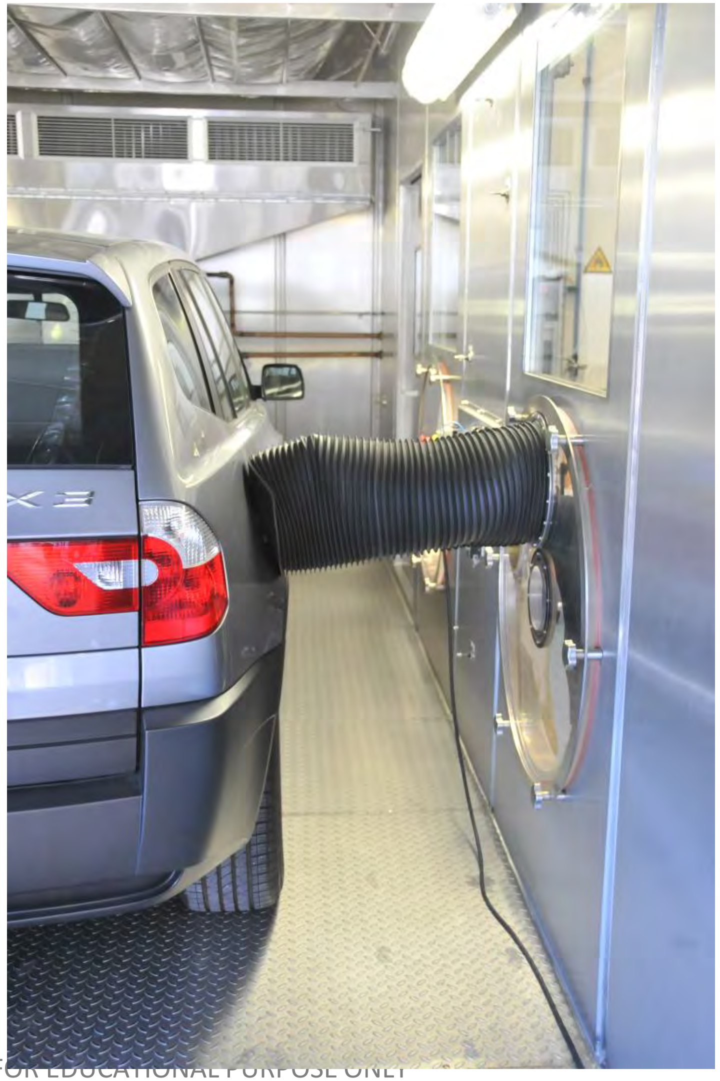
SHED

[Trzesniowski]

On-board Refuelling



[Trzesniowski]

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FHJ SHED Technical Data

- Measuring Chamber
  - Temperature Range: 18°C to 45°C
  - Test chamber volume: 70 m^3
  - Volume compensation by Tedlar-bag
  - For refuelling test: variable ports
- Analysis System
  - FID
  - Measuring ranges: 10, 52, 100 and 250 ppm (C_1)
- Test bed control system
  - Tornado from the manufacturer Kristel, Seibt & Co GmbH

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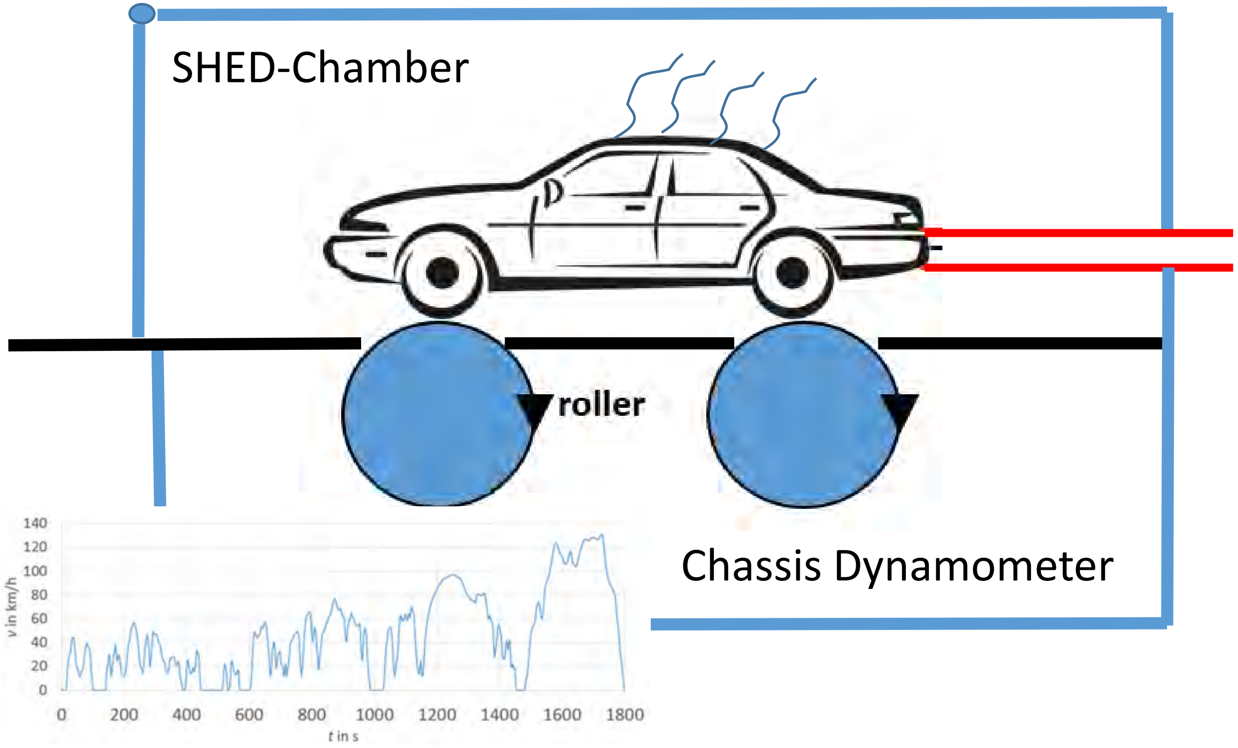
Running Losses



- To measure the evaporation emissions of a driving car
  - Needs a combination out of chassis dynamometer and SHED-chamber.
  - Not covered by the portfolio of FHJ.

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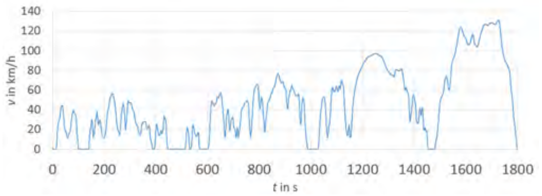
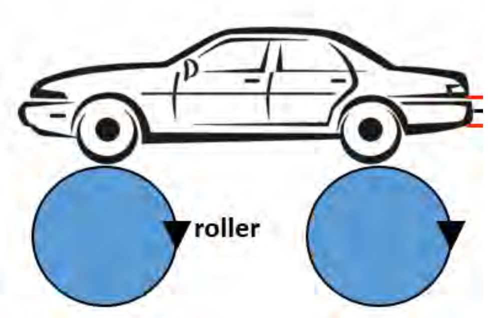
Hot Soak Test





- To measure the THC evaporation emissions of a car after it has driven.
  - Needs a chassis dynamometer and an extra SHED-chamber.
  - Certified fuel is needed.
  - The carbon canister has to be prepared.
  - The SHED-chamber must be air conditioned.
  - The THC-emissions are measured after different time stamps

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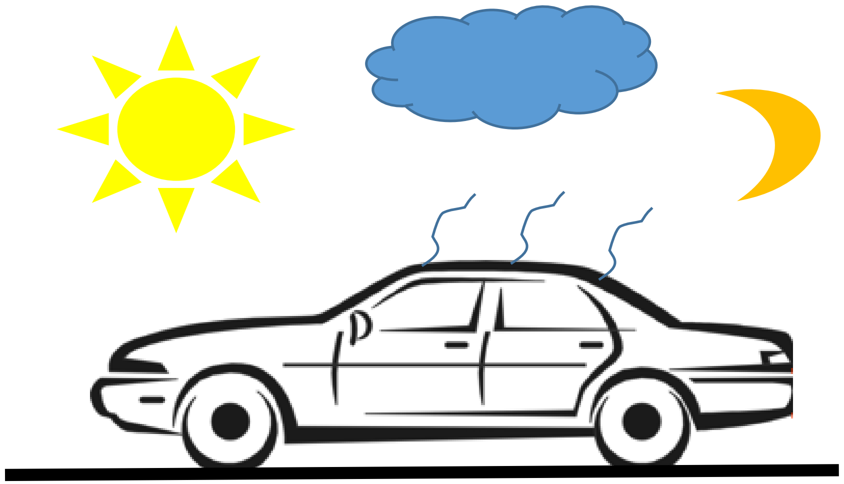
Diurnal Test



- To simulate a typical parking situation
  - To measure the evaporating THC emissions while the vehicle is parked.
  - The temperature is changing during the course of a day.
  - Measurement duration: 24, 48 or 72 hours

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ORVR Test

On-board **R**efuelling **Vapour** **R**ecovery (ORVR)-Test

- Goal is to measure the THC evaporating emissions while fuel-filling a vehicle.
- A system with a fuel-hose as well as fuel conditioning and dispensing is needed.
- Emissions from filler neck or ambient connector for carbon canister are to measure.

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Calibration of SHED System

Calibration of FID

- pure air for zero point calibration
- 4 bottles of calibrated test gas, a mixture of propane and pure air for different measurement ranges.

Propane injection for Shed chamber calibration

Calibration of SHED chamber

- To proof the measurement quality, the measurement system must be calibrated → propane injection test
- 0.5 g -1.0 g propane where injected in the shed-chamber (66 m^3).
- The measurement system must find 98 %.

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Questions…

feel free to contact for

- Mechatronics, Efficiency

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- Testing, Measurement, Calibration:

  DI(FH) Thomas Lechner, thomas.lechner@fh-Joanneum.at

- SHED Chamber:

  Jürgen Brenner, juergen.brenner@fh-Joanneum.at

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Engineering Knowledge Transfer Units to Increase Student´s Employability and Regional Development

Measuring fuel consumption and pollutant emissions - Chassis Dynamometer

T. Lechner

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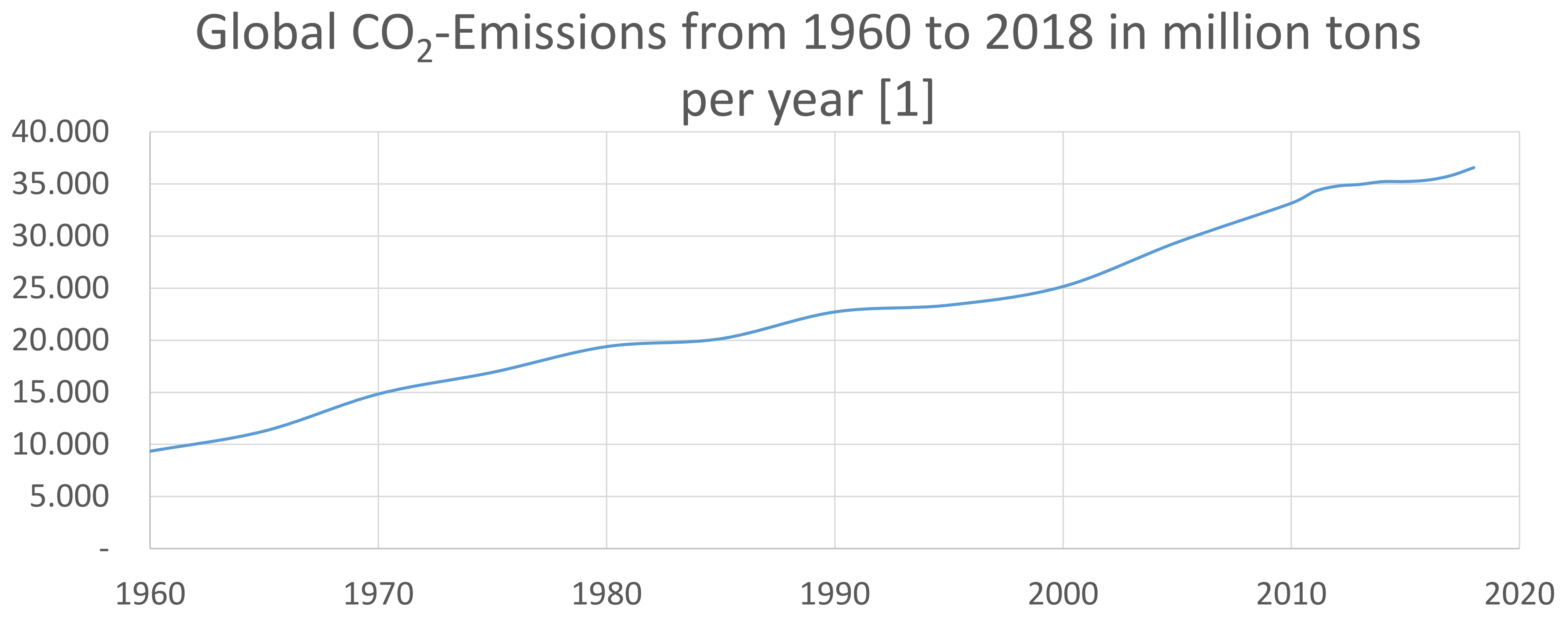
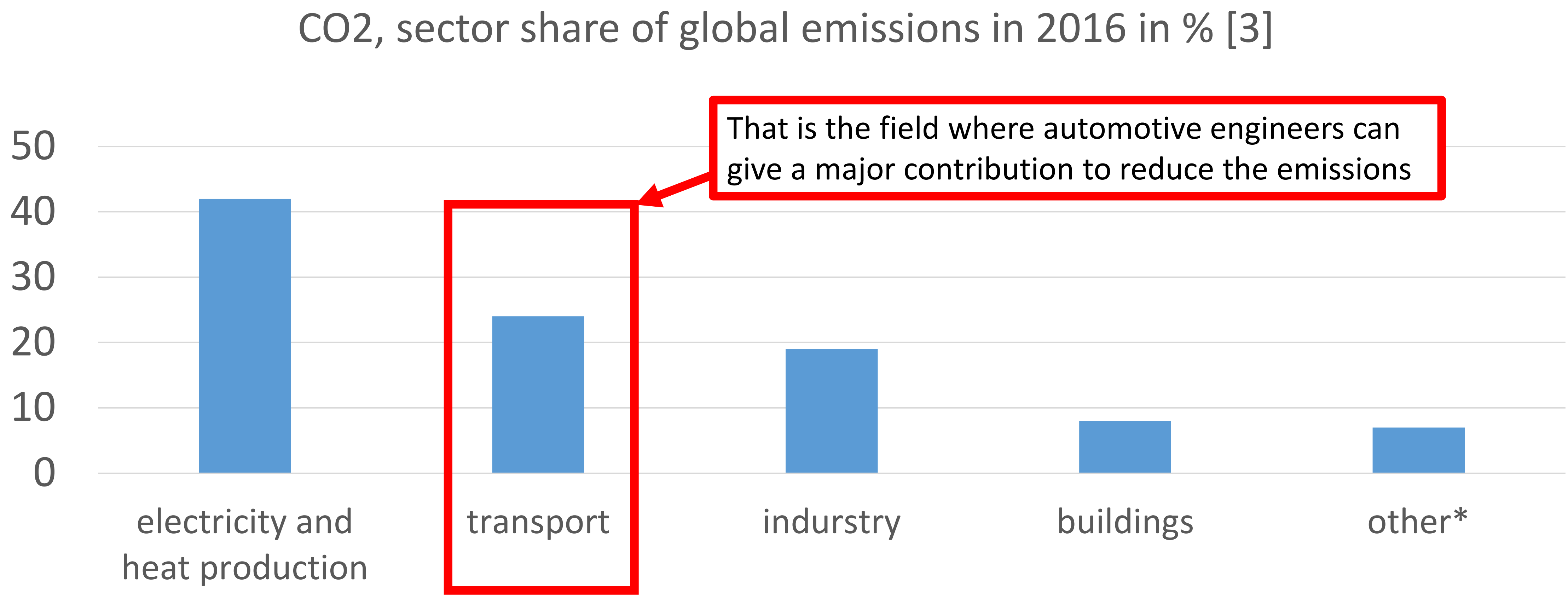
Contents

- Introduction
- Chassis dynamometer
- Drive cycles
- Exhaust gas measurement
  - Gaseous compounds
  - Soot particle

Global CO2-Emissions - Trend



Global CO2-Emissions per Sector



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EU CO2 emission target

- EU contribution for climate protection
  - Since 2015, a **target of 130 grams of CO2 per kilometre** applies for the EU fleet-wide average emission of new passenger cars.
  - From 2021 the EU fleet-wide average emission target for new cars will be **95 g CO_2/km**.
    - Petrol: ~ 4.1 litre/100 km
    - Diesel: ~ 3.6 litre/100 km

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CO2-fleet emission 2018

2018th CO_2-fleet emission of selected OEM's [4]

OEM	CO2 Emission in g/100 km	delta to 95 g/100 km
Mercedes	139.6	44.5
Mazda	135.2	40.2
BMW	128.9	33.9
Kia	120.4	25.4
Peugeot	107.7	12.2
Toyota	99.9	4.9

based on NEDC

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Pollutant

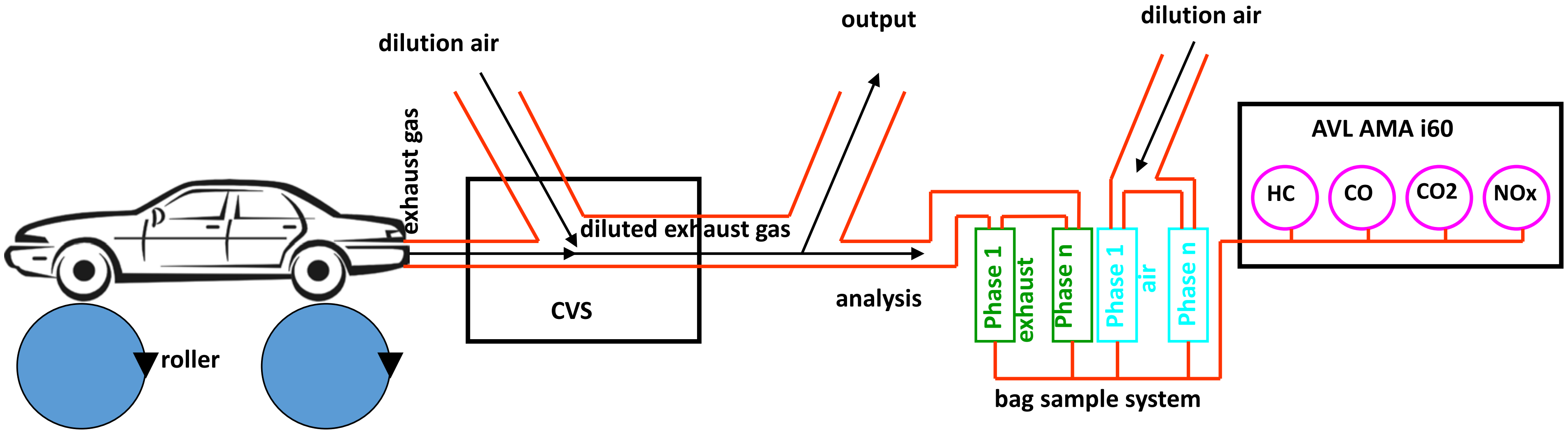
- EURO 6: List of pollutants to measure and legal limits [6]

Measured Value	Diesel	Petrol
CO2, g/km	-	-
CO, g/km	0.5	1
THC, g/km	-	0.1
NMHC, g/km	-	0.068
NO_X, g/km	0.08	0.06
HC+NO_X, g/km	0.17	-
PM, g/km	0.0045	0.0045*
PN, #/km	$6 \cdot 10^{11}$	$6 \cdot 10^{11}$

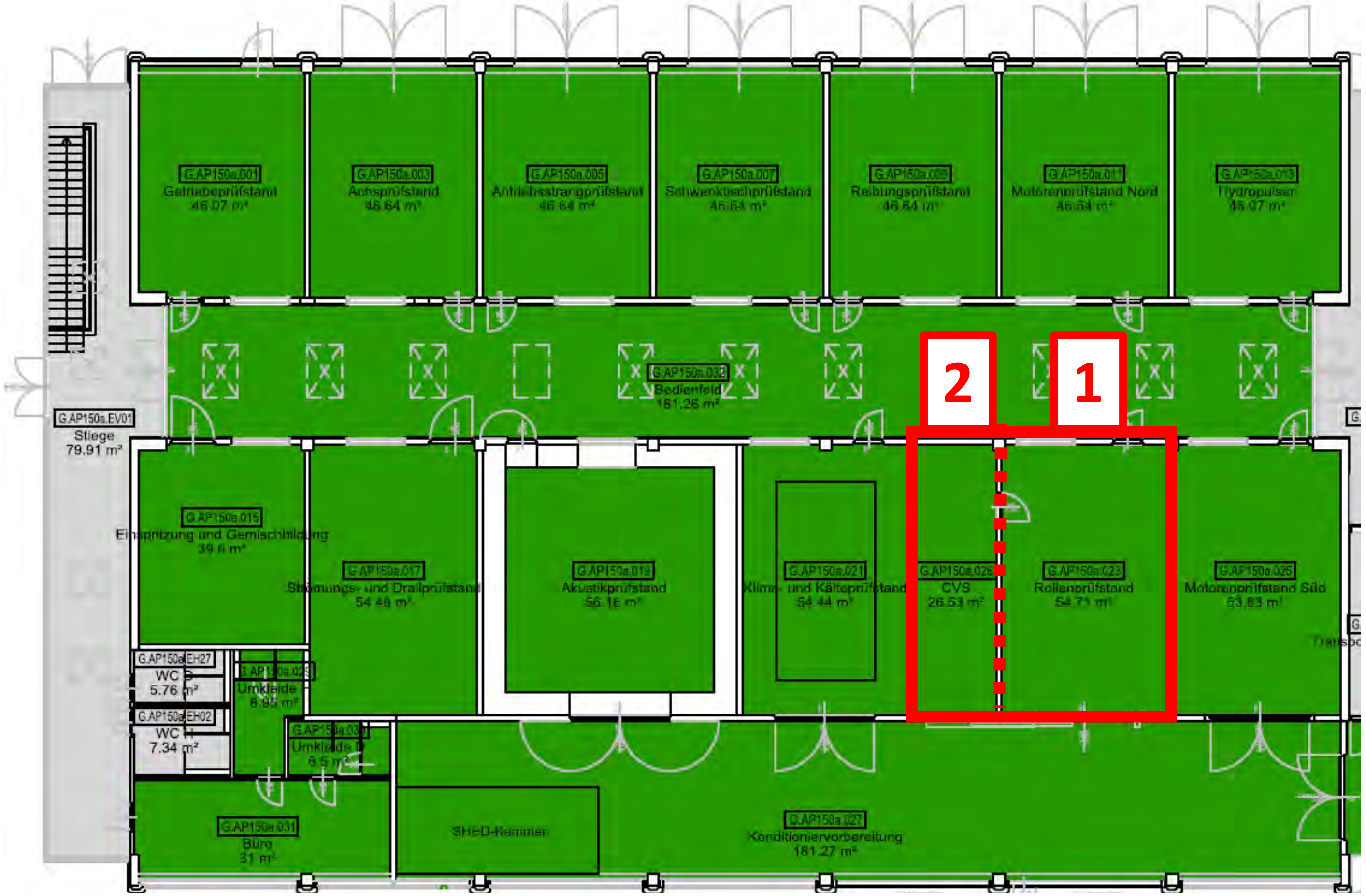
*) for direct injected engines

Measuring Device

- Equipment to measure emission values
  → chassis dynamometer



Floor plane



1 – Chassis dynamometer 54.71 m²

2 – Exhaust gas analysing device, 26.53 m²

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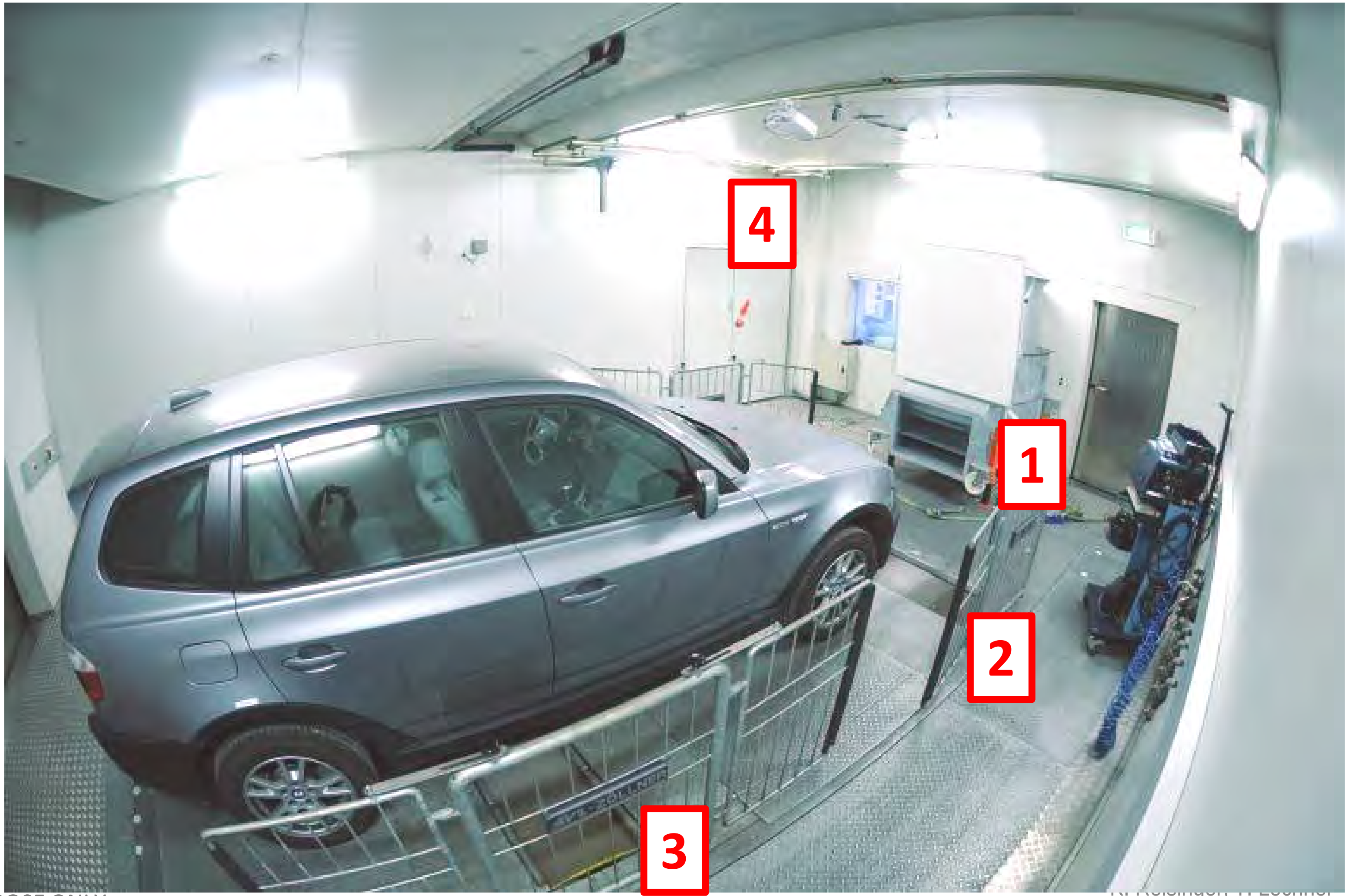
Measuring Device – Overview

1 – wind fan

2 – front axle

3 – rear axle

4 – CVS and Analysers are behind



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CVS - Venturi Nozzle

- The volume of the diluted exhaust gas (V_{mix}) is an important measurement value.
- Measuring device → **C**ritical **F**low **V**enturi (CFV) → commonly used
- Flow rate depends on
  - geometric dimensions
  - absolute temperature and pressure at Venturi inlet

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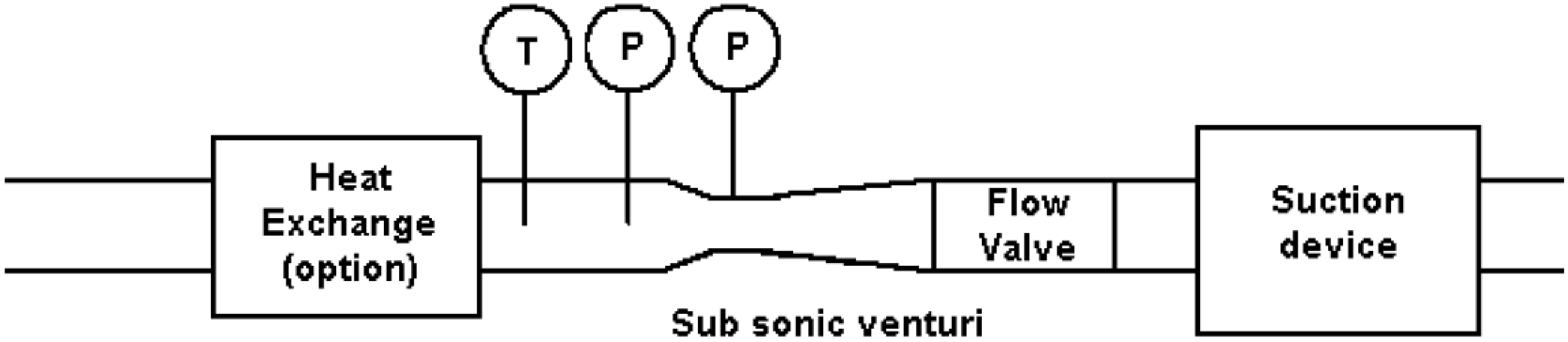
SSV, schematic drawing



The flow rate through the SSV can be set and controlled by speed control of the flow and/or flow valve

[5] Sub-Annex 5, § 3.3.6.3.2

Legal Documents

- Europe: Regulation No. 2017/1151 [5]
- USA: 40 CFR Part 1066 with references to Part 1065
- China Similar to the European law (EURO 5 and EURO6)

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Driving Cycle, basis

- The goal is to measure **realistic and comparable** exhaust gas emissions as well as the fuel consumption.
  - The chassis dynamometer must simulate real driving conditions.
    - Task of the control system
    - Simulate a flat road, not wind influenced
    - Vehicle specific driving resistance values (road load)
  - The driving route must be representative for real life.
    - Regulated drive cycle → vehicle velocity over time
    - Shall be represent the average of all vehicle drives

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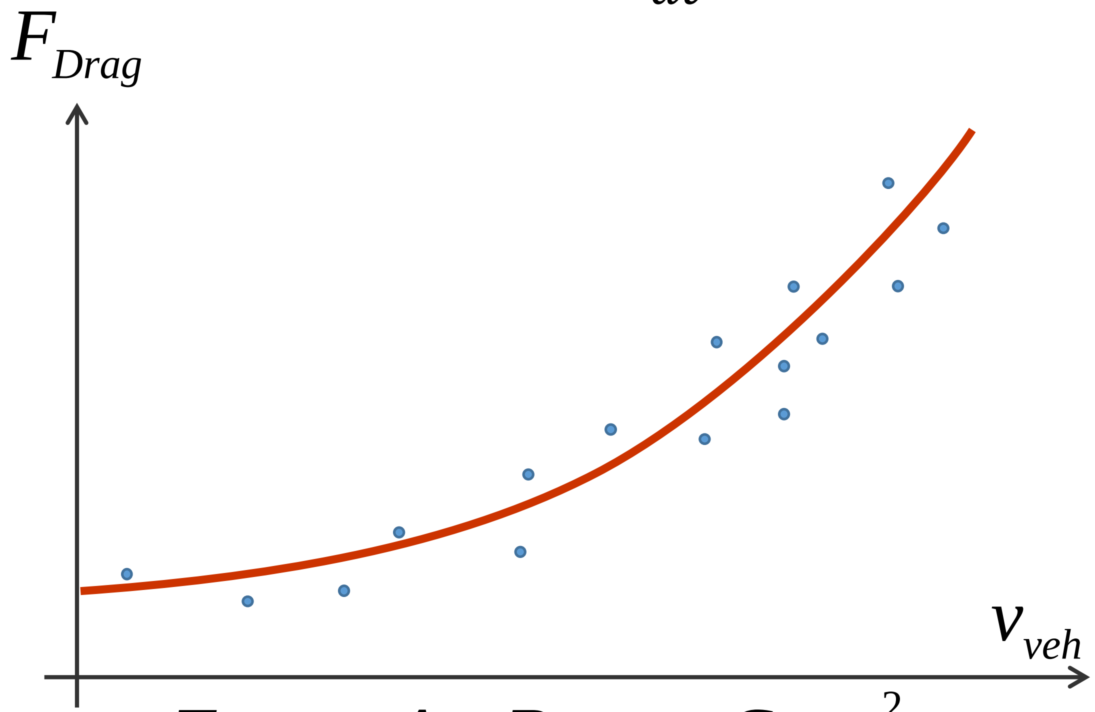
Drag Measurement

- Coast Down Test at horizontal road in neutral gear measures
  - rolling resistance
  - + aerodynamic drag
  - + losses in drive train
- Measure speed over time
- Differentiate in respect to time, calculate drag
- Fit quadratic parabolic equation

$$(m_{veh} + m'_{rot}) \cdot \frac{d\,v}{dt} = F_R + F_{AD}$$



$$F_{Drag} = A + B v_{veh} + C v_{veh}^{2}$$

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Road load equation, [5] Sub-Annex 4

- To simulate realistic driving conditions, the road load must be detected for each vehicle.
- The road load equation:

$$F = f_0 + f_1 \cdot v + f_2 \cdot v^2$$

F	longitudinal force in N
v	velocity in km/h
f_0	constant **r**oad **l**oad **c**oefficient (rlc) → friction, rolling resistance
f_1	first order rlc → linearly depending on the velocity
f_2	second order rlc → mainly influenced by the air drag

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Road Load Coefficient

- The road load coefficient must be measured.
- For that, legally conferment methods are:
  - coast down method (standard method)
    - Accelerate the vehicle to a maximum speed at a test track
    - (WLTP: 130 km/h)
    - Coast down the vehicle
    - Measure the vehicle velocity in accurate time stamps
  - wind tunnel method
    - Combination of a wind tunnel and a (flat belt) chassis dynamometer

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Measuring Procedure Overview

- Vehicle preconditioning
  - To guarantee comparable results, vehicles must be set to a defined initial state.
  - For this, a part of the relevant drive cycle should have driven.
  - After the preconditioning phase, the vehicle shall be kept in a room with stabilized temperature.
- Emission measurement
  - Due to a legally conformant drive cycle.
  - Pollutants and fuel consumption are calculated out of measured values.
  - Documentation of results → test report for customers

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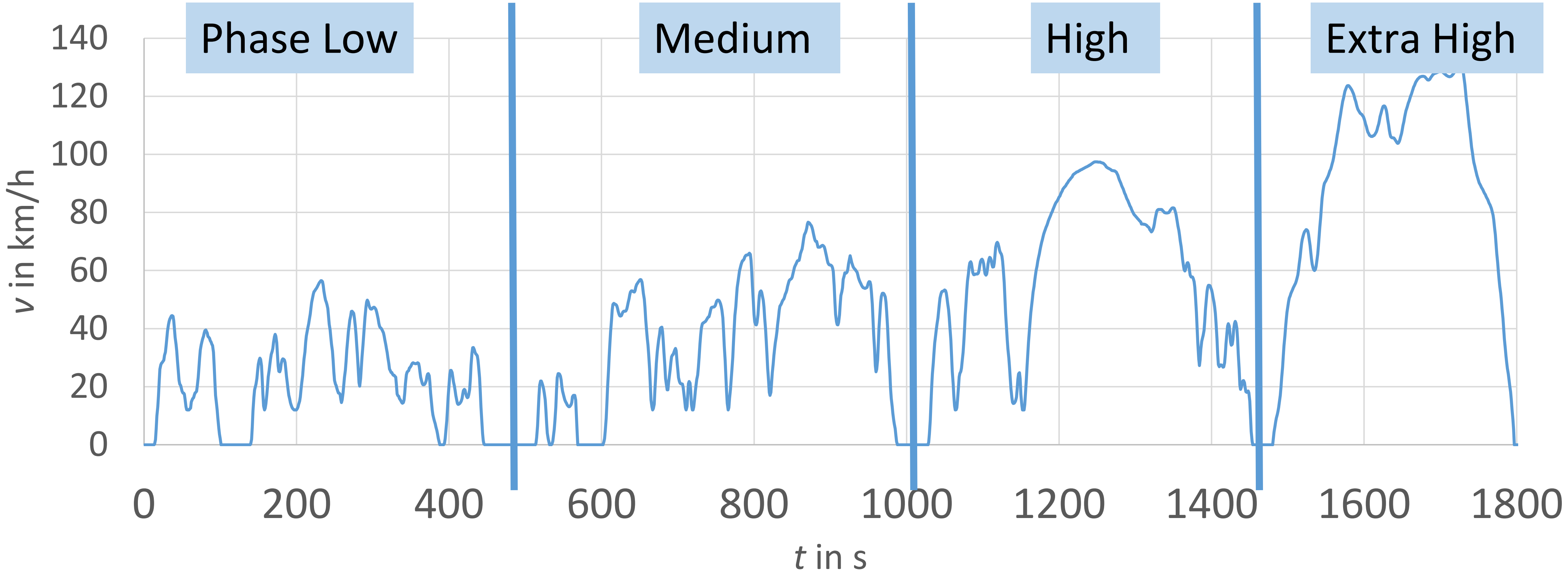
Driving Cycle Europe

WLTC Class 3 – **W**orldwide harmonized **L**ight vehicle **T**est **C**ycle



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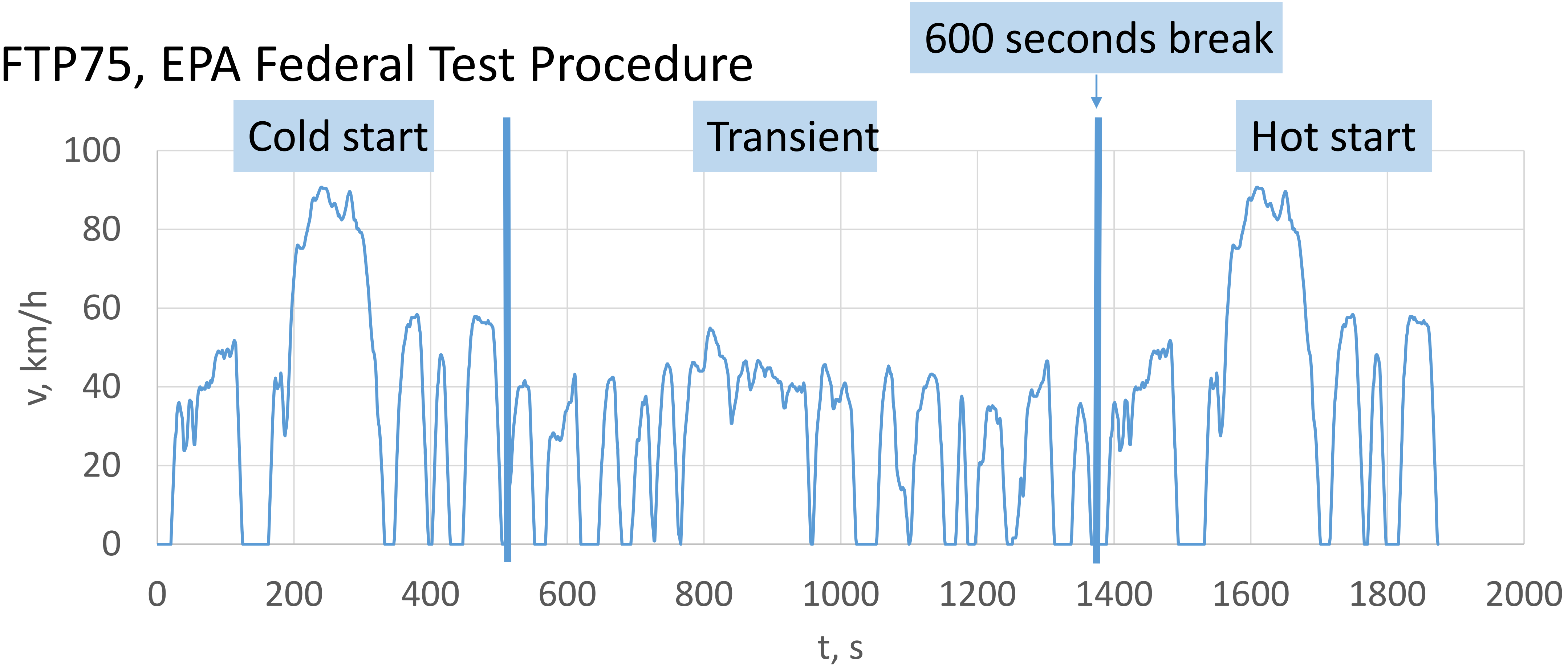
Driving Cycle Europe

- WLTC Class 3
  - Class 3: power to weight ration >34 W/kg
  - 4 Phases → 2x4 bags per phase to sample diluted exhaust gas and dilution air
  - Maximum velocity is 131 km/h
  - Phase 1 and 2: urban
  - Phase 3 (rural) and Phase 4 (motorway): suburban
  - Testing duration is 1800 seconds

Driving Cycle USA

FTP75, EPA Federal Test Procedure



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Measuring Procedure

- A complete exhaust measurement can be segmented in 4 steps.
  1) Preliminary works
  2) Vehicle fixing at the test bed
  3) Vehicle pre-conditioning
  4) Carrying out of the measurement
- The exact procedure is described in detail at the respective laws.
- For a valid measurement, all involved participants must strictly comply with that!
- The next slides shows the measuring procedure in generally.

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Measuring Procedure, Step 1

- Preliminary works
  - Vehicle delivery and takeover
  - Control the vehicle regarding to the measurement capability
  - Refuelling the vehicle with certified fuel
    - Exact chemical compositions a needed for the calculation.
  - Mount adapters to the exhaust pipe
    - To connect the vehicle with the exhaust fan.

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Measuring Procedure, Step 2

- Fix the vehicle at the test bed
  - The vehicle must be adjusted very accurate to prevent influences by cross forces.
  - Control the tyre pressure.
  - Connect the exhaust adapter to the CVS-system.
  - Load batteries.

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Measuring Procedure, Step 2

Rear and front axes are of the vehicle are exactly loaded at the roller apex.

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Measuring Procedure, Step 2

The car is fixed with belts or alternative with bars.

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Measuring Procedure, Step 3

- Pre conditioning phase
  - System warm up
    - Example: 1 WLTC without emission measurement
  - Road Load adaption to guarantee, that the control systems simulates a “true environment”
    - To check the road load coefficient:

      1) coast down at the test bed

      2) compare test bed results with measured driving resistance
  - Pre run to set the system to defined output state.
    - Example: 1 WLTC without emission measurement
  - Vehicle conditioning
    - Example WLTC: from 6 to 36 hours, ambient temperature → 23 °C +/- 3 °C

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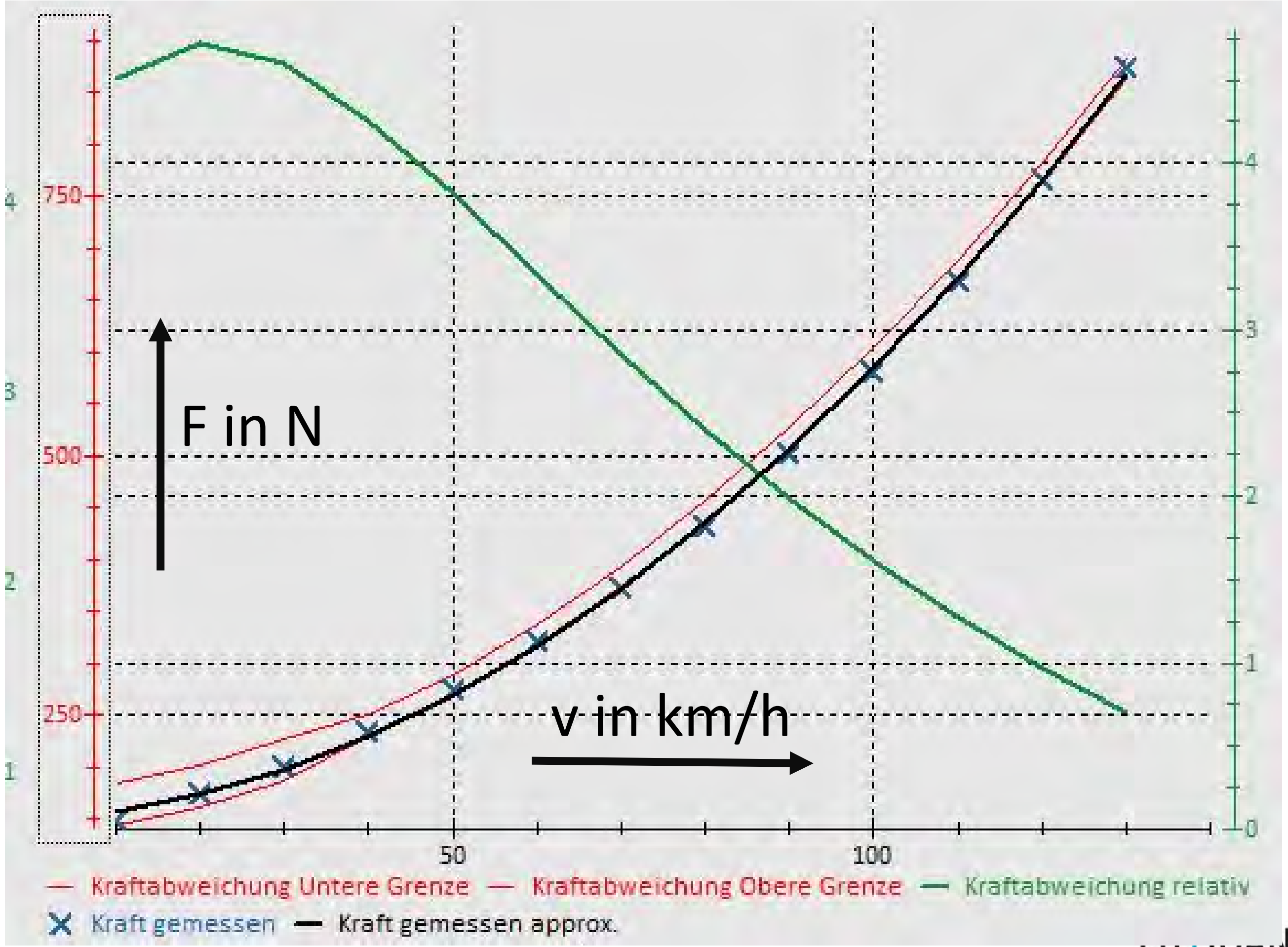
Step 3, Coast down comparison

- black: velocity depending force, measured at the test bed.
- red: desired value tolerance lines
- green: deviation between desired and measured value in %



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Step 4, ready to measure

- Calibration and, if necessary, adjustment of the measurement system
  - Gas analyser → with calibration gases
- **Measuring the vehicle**
  - Cycle for WLTP is WLTC
  - During the test, some gaseous pollutants are measured with an sampling frequency of 1 Hz.
  - A sample taken out of the diluted exhaust gas will be stored in special bags.
  - After the test (WLTC finished), the measurement system has to be calibrated once again.
  - The sample taken will be analysed, after the test has finished.

Step 4, measurement

drivers view

bag sampling system

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Measure gas concentration

- For gaseous compounds (C_i in ppm) → gas analyser

$$M_\mathrm{i} = \frac{V_\mathrm{mix} \cdot Q_\mathrm{i} \cdot k_\mathrm{H} \cdot \boldsymbol{C_i} \cdot 10^{-6}}{d}$$

- THC, CH_4 — Heated Flame Ionisation Detection (FID)
- CO and CO_2 — Infrared Detector (IRD)
- NO and NO_x — Chemiluminescence Detector (CLD)

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Measure soot particles

- Particle mass in g/km
  - A sample taken out of the diluted exhaust emission is passed through a special filter plate.
  - The weight of the filter plate must be measured before and after the test.
  - The weight difference between the loaded and the unloaded filter allows a conclusion to the emitted particle mass.
  - **Problem:** The weight difference is only in the range of few micrograms.
  - A accurate scale is needed. The ambient climate in the sample chamber must be constant.

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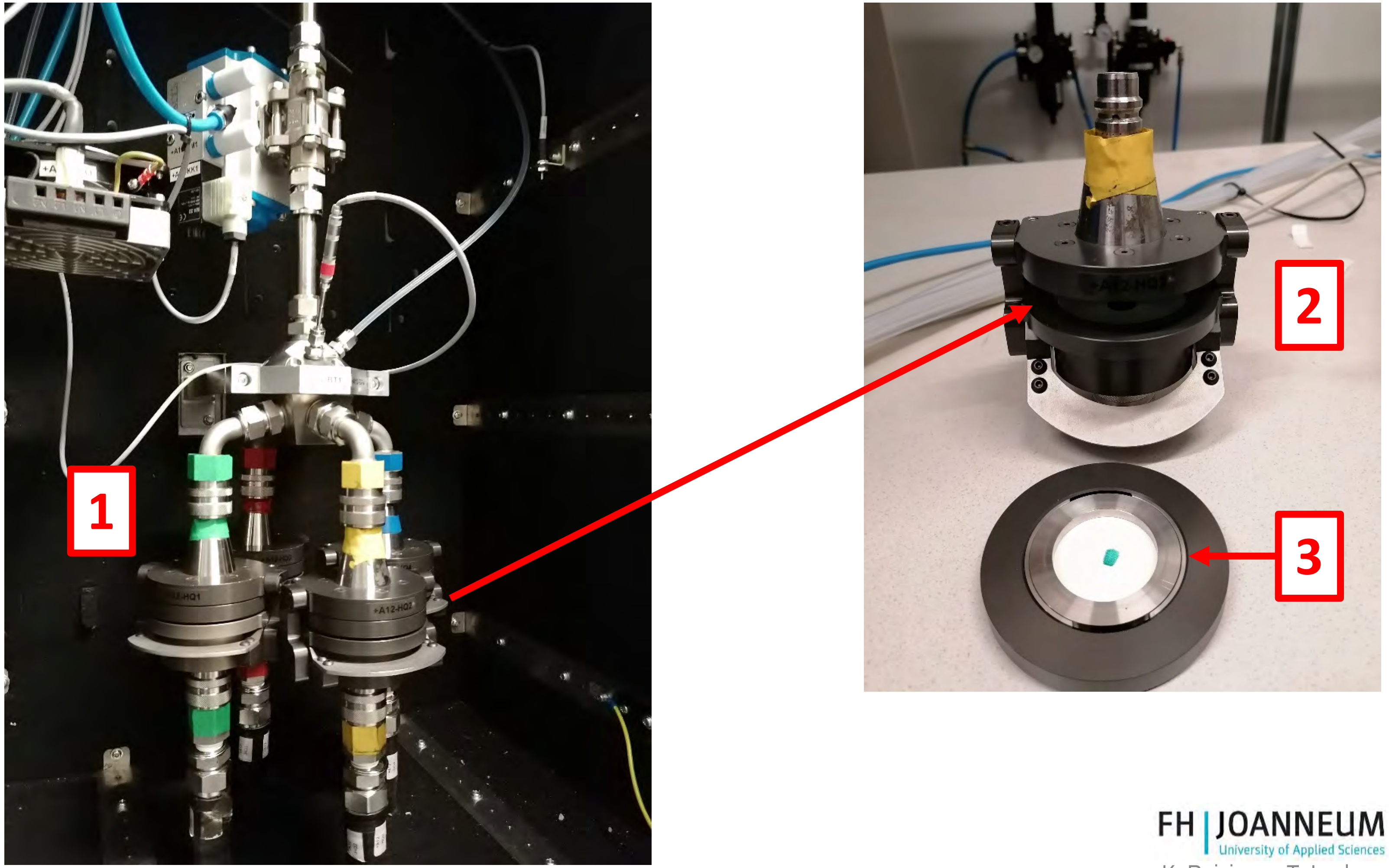
Measuring Device, PSS

1) In PSS installed filter holder
2) Dismounted and opened filter holder
3) Filter plate



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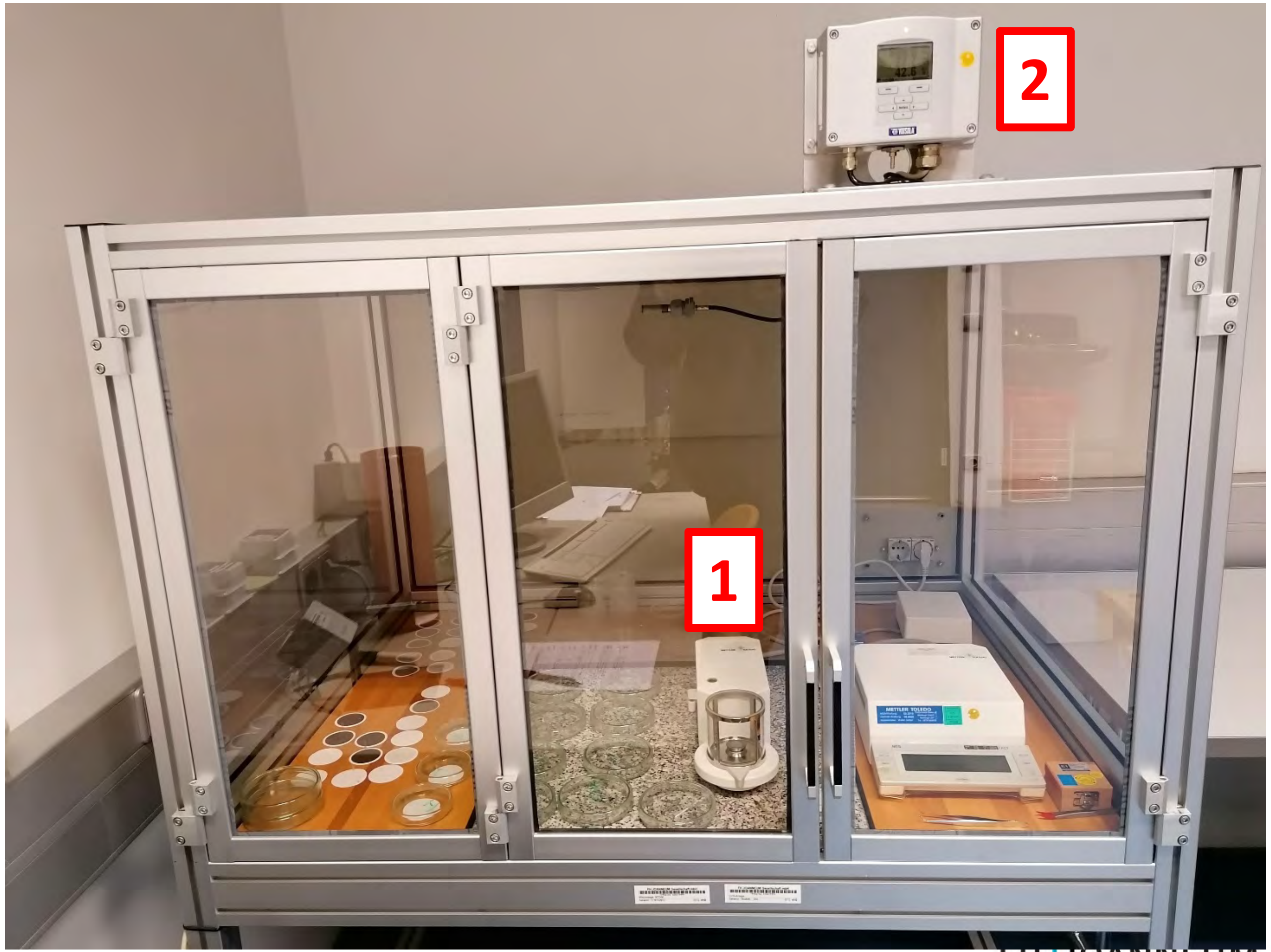
Sample Chamber

UNITED

1) Micro scale
2) Ambient temperature, humidity and pressure



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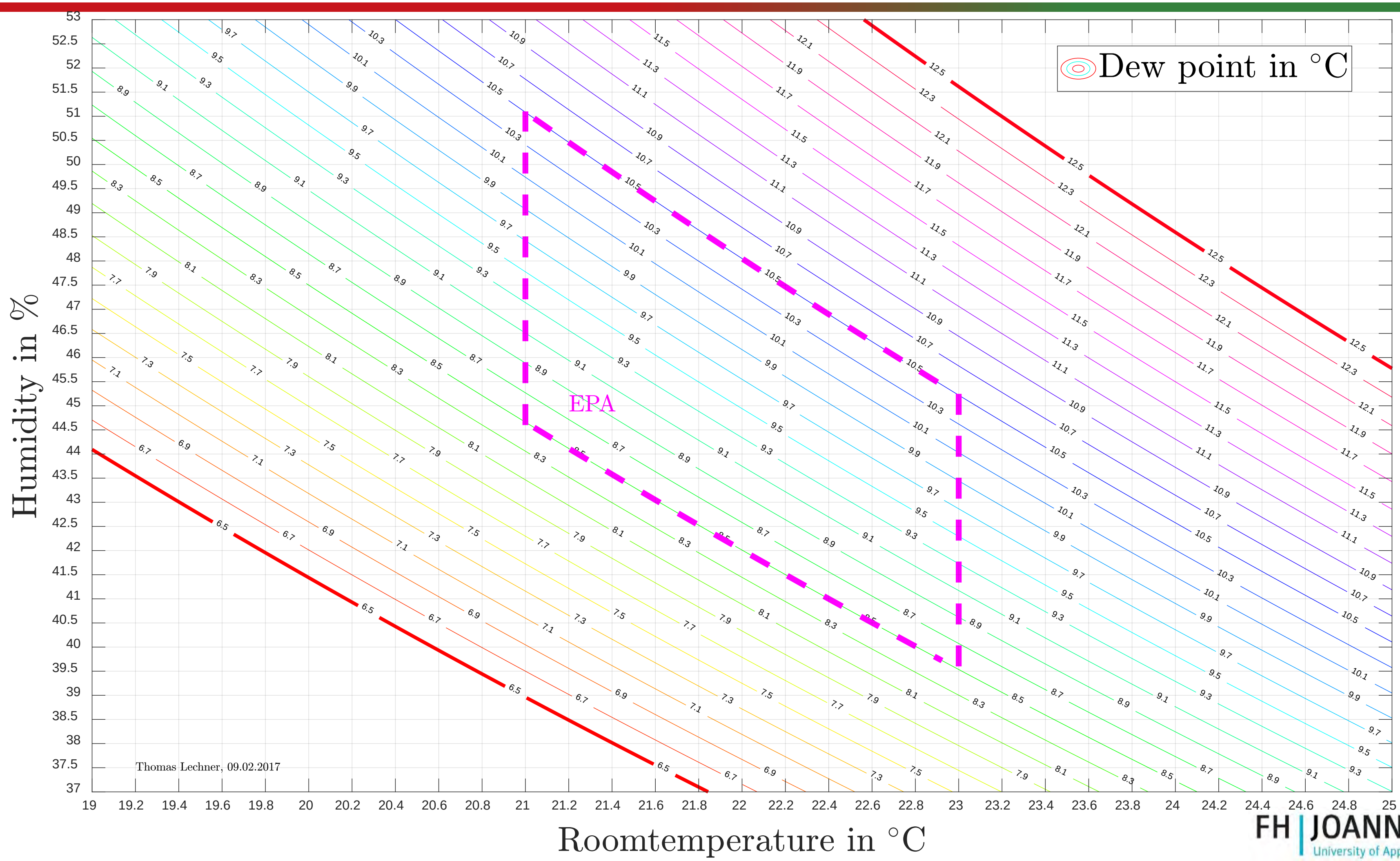
Loaded Filter Plates

Different loaded filter plates

Sample Chamber, Tolerance range



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Measure soot particles

- Particle number in #/km
  - Measuring device: Particle counter

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Fuel consumption

- The calculation is based on the carbon balance.
- The fuel consumption is influenced by
  - Mass emissions of HC, CO and CO_2
    - The highest measured concentration in the exhaust gas comes from CO_2
  - Fuel density and consistence
    - Certified fuel is necessary.

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[5] Commission Regulation (EU) No. 2017/1151: *Type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6)*, June 1, 2017

[6] https://www.delphi.com/newsroom/press-release/delphi-technologies-launches-26th-worldwide-emissions-standards-book

Hands-On Training Test Facility

Plan a concept for your University

Group Work for each University, prepare flip charts

- Which tests could be needed from industry?
  - Functional Testing?
  - Durability Testing?
  - Complexity?
- How can students be involved in these industry projects?
- How do the tests fit to curricula?
- Can results be introduced to lectures?
- Necessary Hardware

Presentation by a speaker and discussion after coffee brake.

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Hands-On Training

Present the tools you planned to buy and the trainings done with it

Group Work for each University, prepare flip charts

- Concept of training?
  - Technical content
  - Who shall be trained? – expected knowledge of trainees.
  - Topics to be trained
- Necessary Hardware

Presentation by a speaker and discussion

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