UNITED

FH | JOANNEUM
University of Applied Sciences

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

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

The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. 598710-EPP-1-2018-1-AT-EPPKA2-CBHE-JP

FOR EDUCATIONAL PURPOSE ONLY

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

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

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

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

UNITED

FH | JOANNEUM
University of Applied Sciences

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

What is Mechatronics?

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

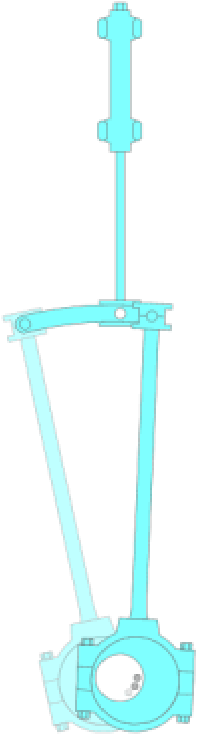
Co-funded by the
Erasmus+ Programme
of the European Union

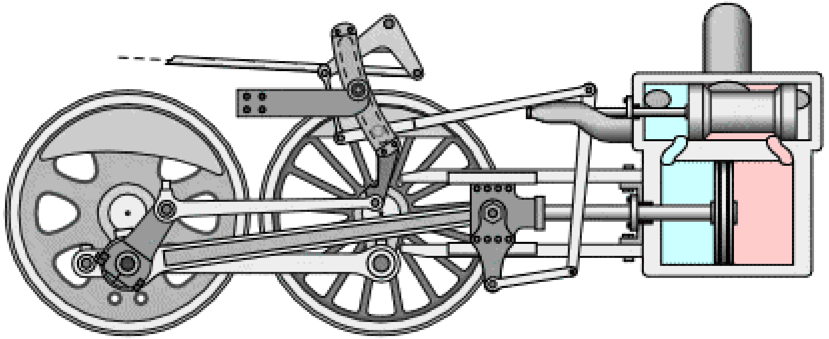
The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. 598710-EPP-1-2018-1-AT-EPPKA2-CBHE-JP

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

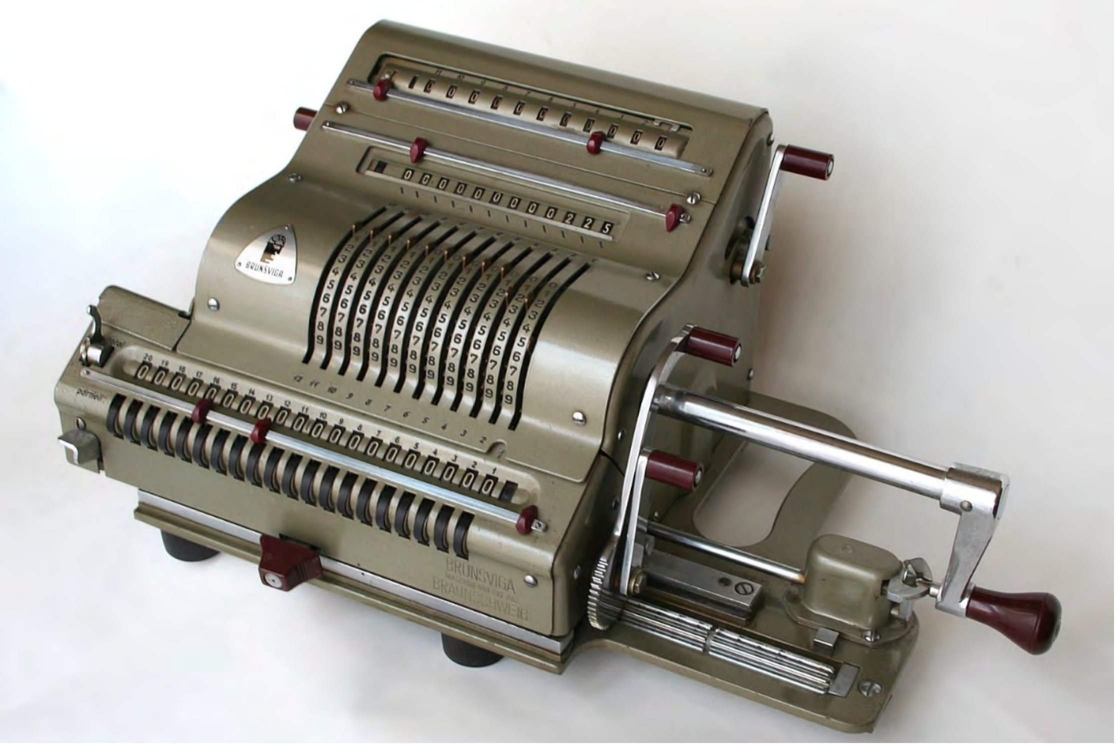




https://www.wikiwand.com/en/Stephenson_valve_gear

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

Limited Intelligence?



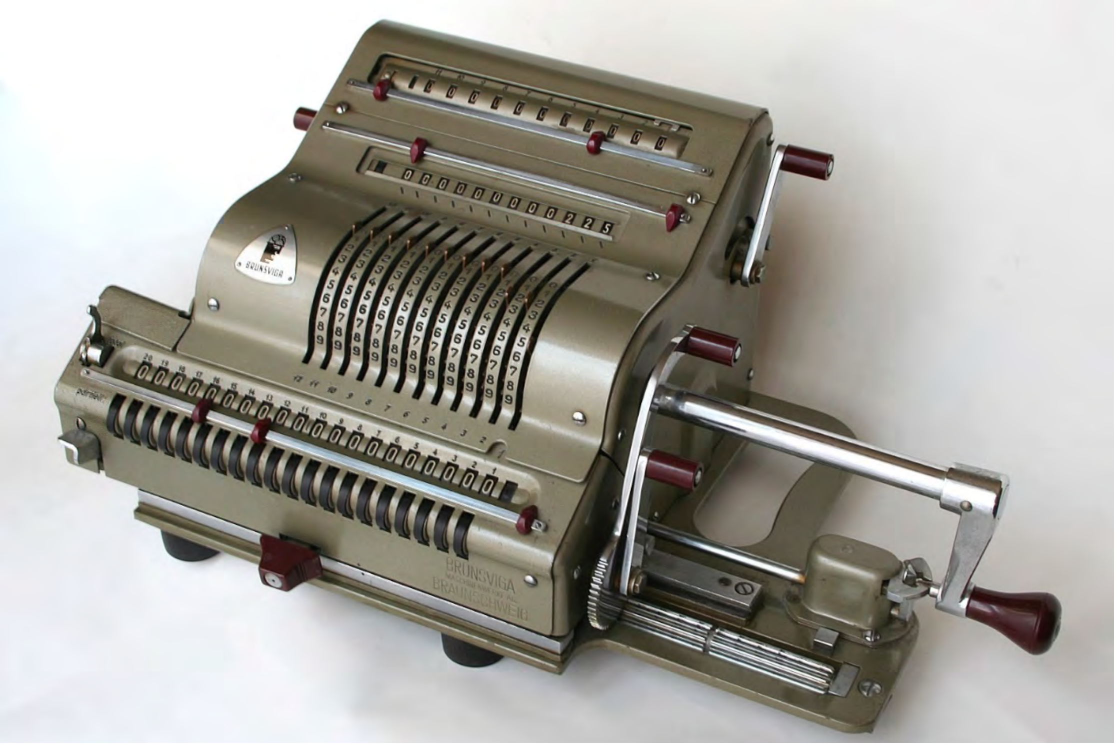
https://de.wikipedia.org/wiki/Vier-Spezies-Maschine

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

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

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

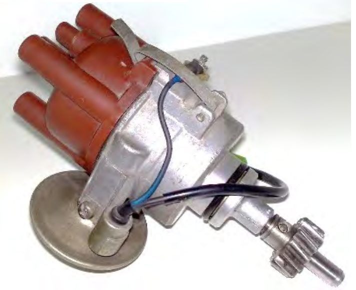
Co-funded by the
Erasmus+ Programme
of the European Union

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]

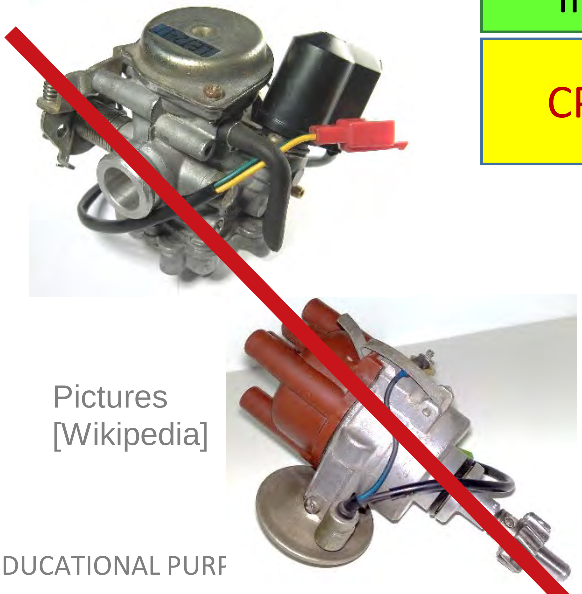
Co-funded by the Erasmus+ Programme of the European Union

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

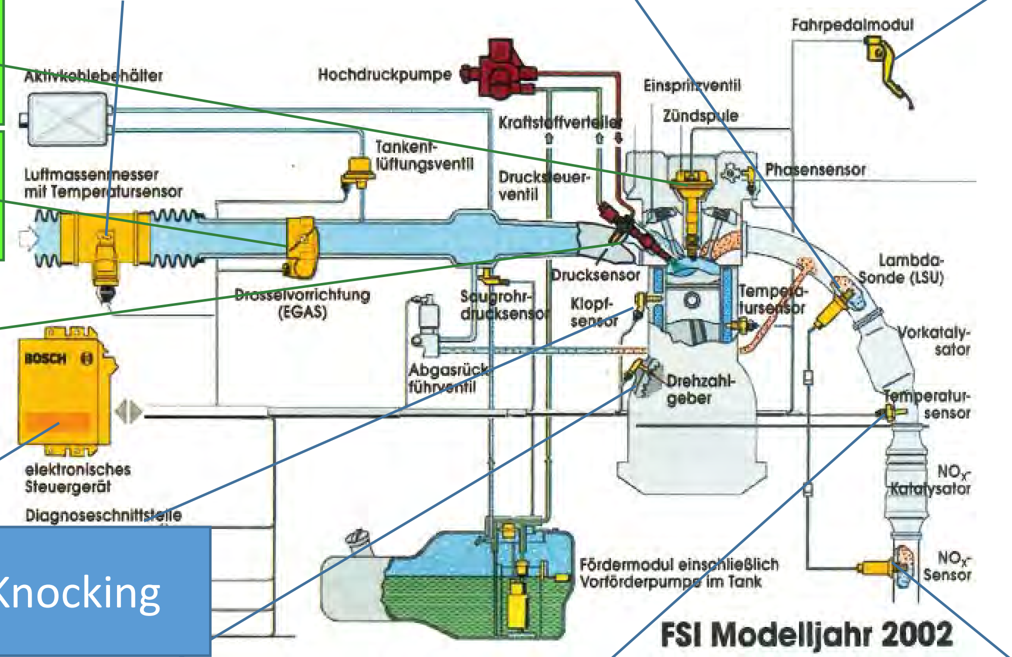
Measure Drivers Request

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

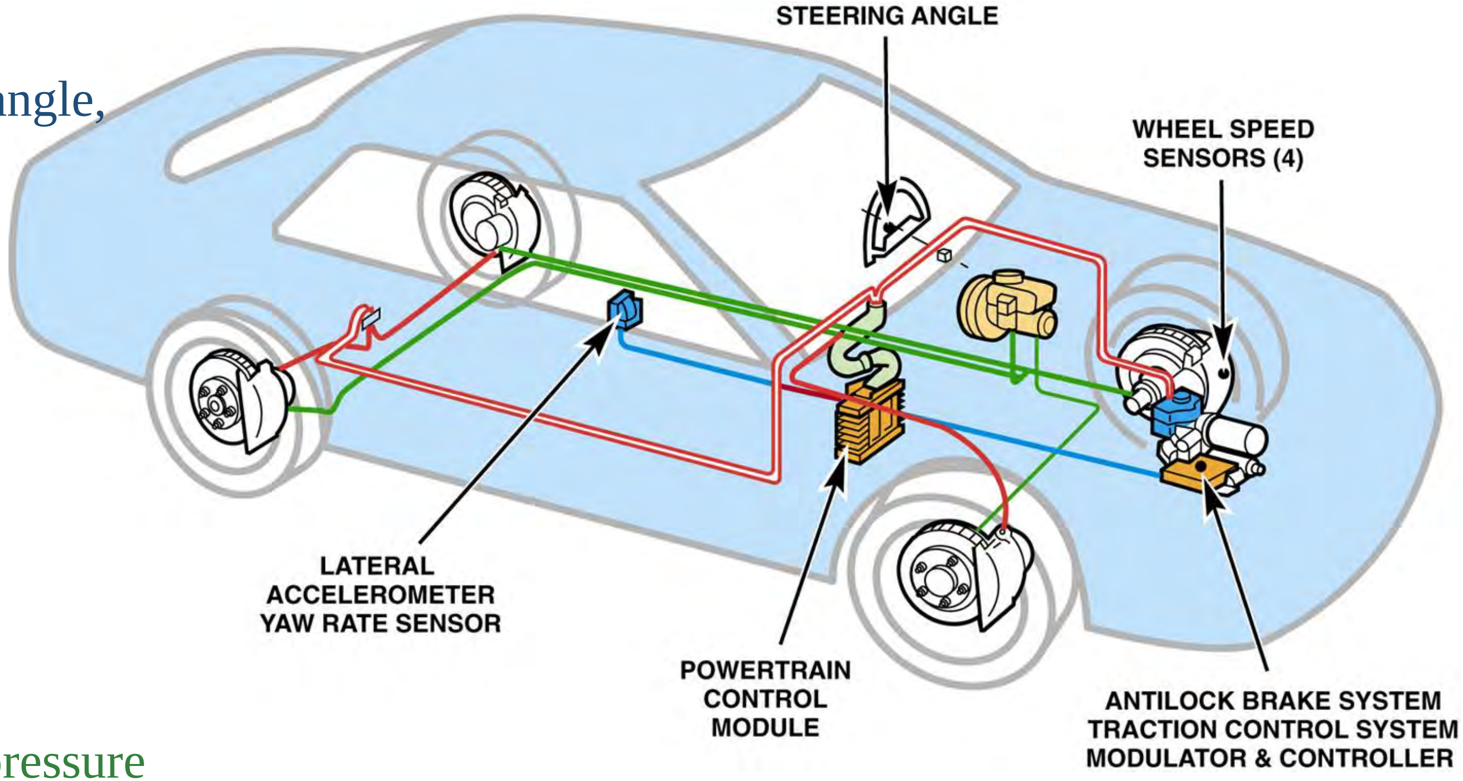
[Base Picture: VW, Bosch, Internet, ZAWM Belgien]

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

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


STEERING ANGLE
WHEEL SPEED SENSORS (4)
LATERAL ACCELEROMETER YAW RATE SENSOR
POWERTRAIN CONTROL MODULE
ANTILOCK BRAKE SYSTEM TRACTION CONTROL SYSTEM MODULATOR & CONTROLLER

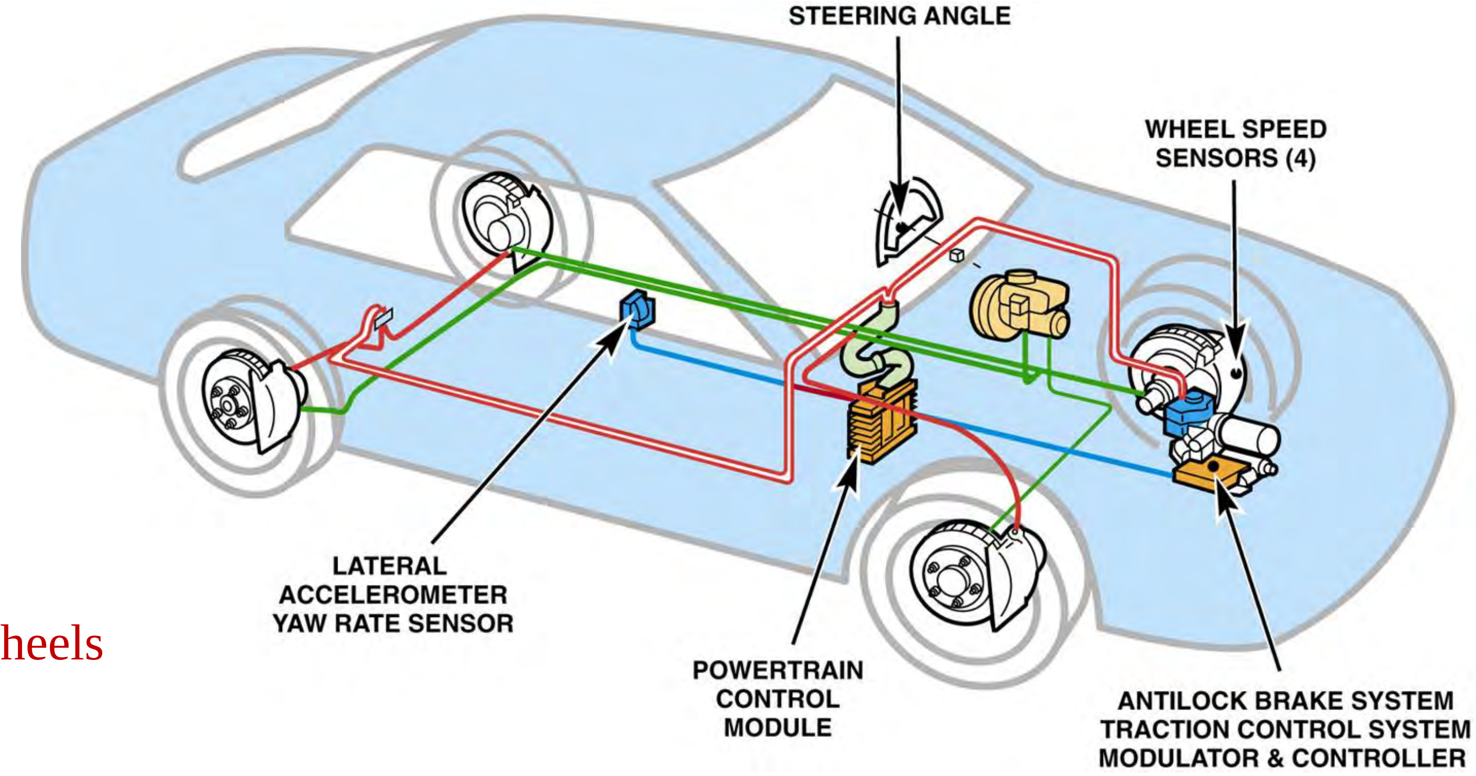
https://www.bwigroup.com/product/antilock-brake-systems/

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

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



STEERING ANGLE
WHEEL SPEED SENSORS (4)
LATERAL ACCELEROMETER YAW RATE SENSOR
POWERTRAIN CONTROL MODULE
ANTILOCK BRAKE SYSTEM TRACTION CONTROL SYSTEM MODULATOR & CONTROLLER

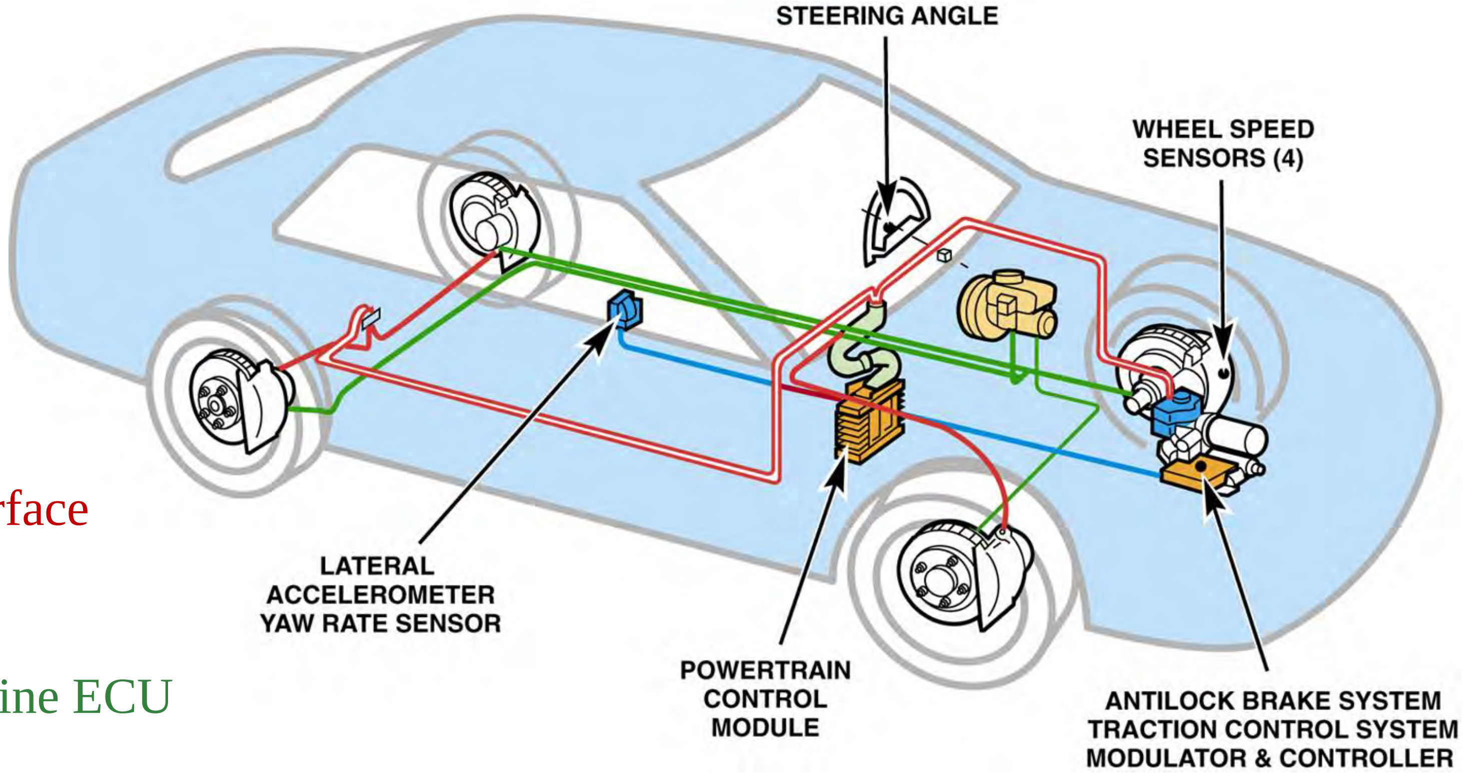
https://www.bwigroup.com/product/antilock-brake-systems/

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

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


STEERING ANGLE
WHEEL SPEED SENSORS (4)
LATERAL ACCELEROMETER YAW RATE SENSOR
POWERTRAIN CONTROL MODULE
ANTILOCK BRAKE SYSTEM TRACTION CONTROL SYSTEM MODULATOR & CONTROLLER

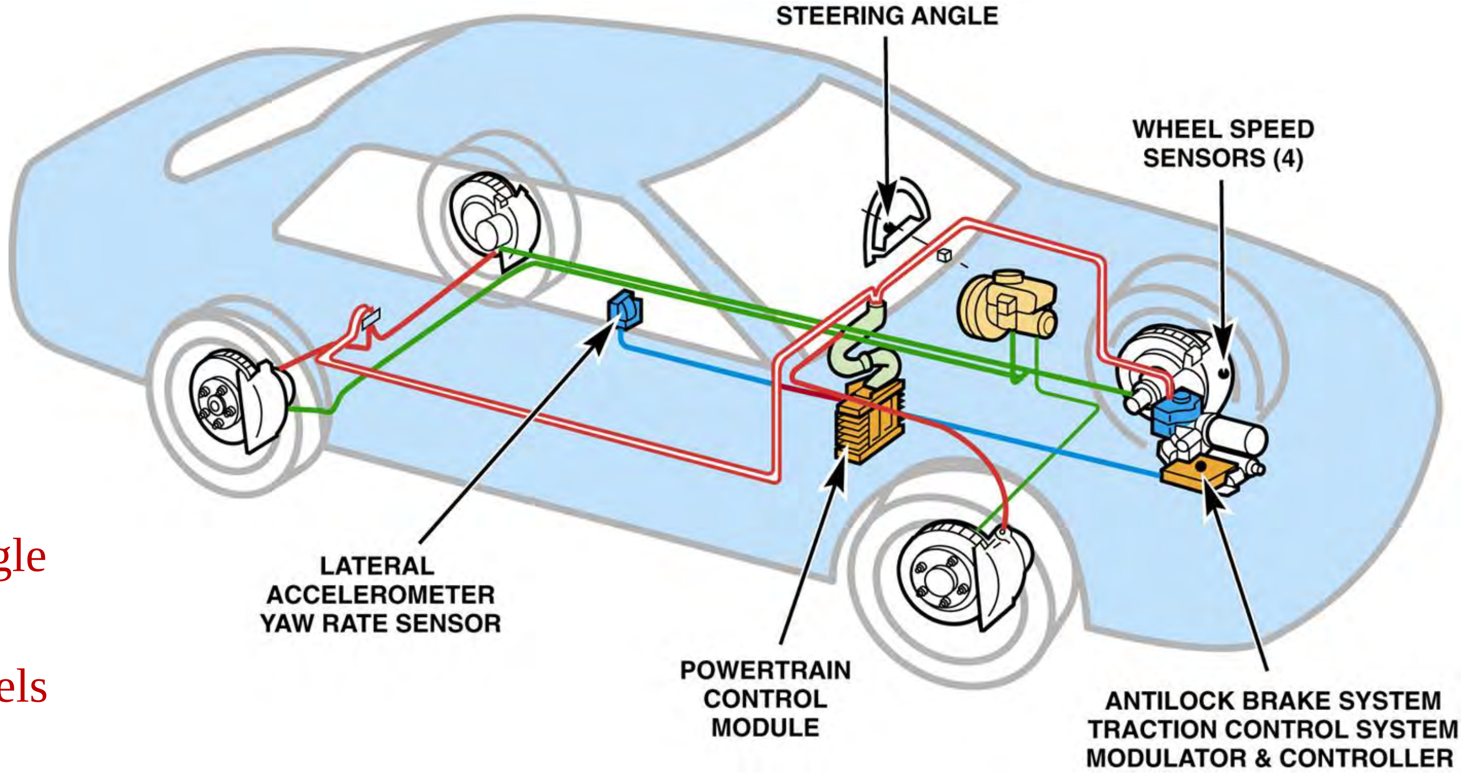
https://www.bwigroup.com/product/antilock-brake-systems/

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

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

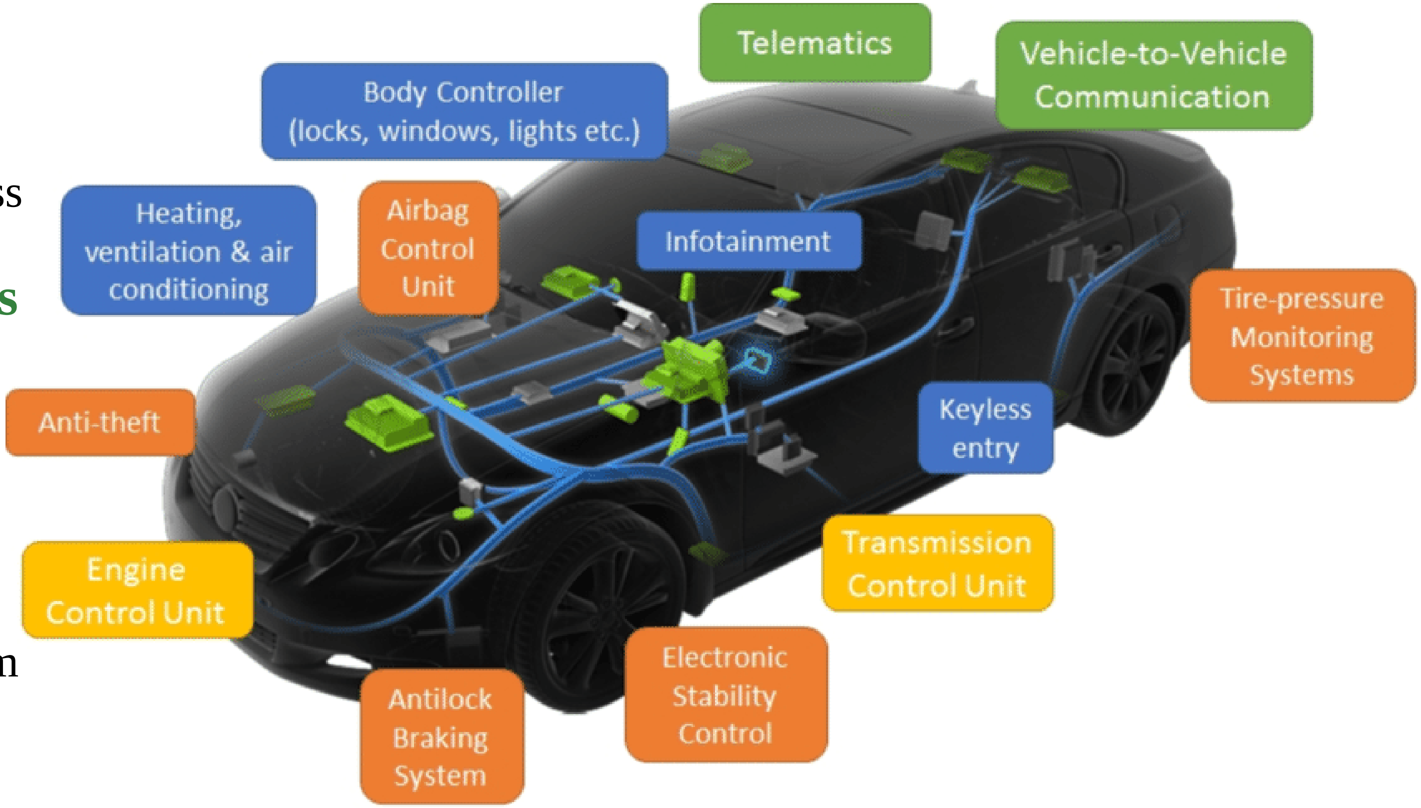

STEERING ANGLE
WHEEL SPEED SENSORS (4)
LATERAL ACCELEROMETER YAW RATE SENSOR
POWERTRAIN CONTROL MODULE
ANTILOCK BRAKE SYSTEM TRACTION CONTROL SYSTEM MODULATOR & CONTROLLER

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

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

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**


Telematics
Vehicle-to-Vehicle Communication
Body Controller (locks, windows, lights etc.)
Heating, ventilation & air conditioning
Airbag Control Unit
Infotainment
Tire-pressure Monitoring Systems
Anti-theft
Keyless entry
Engine Control Unit
Transmission Control Unit
Electronic Stability Control
Antilock Braking System

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

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

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.

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

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

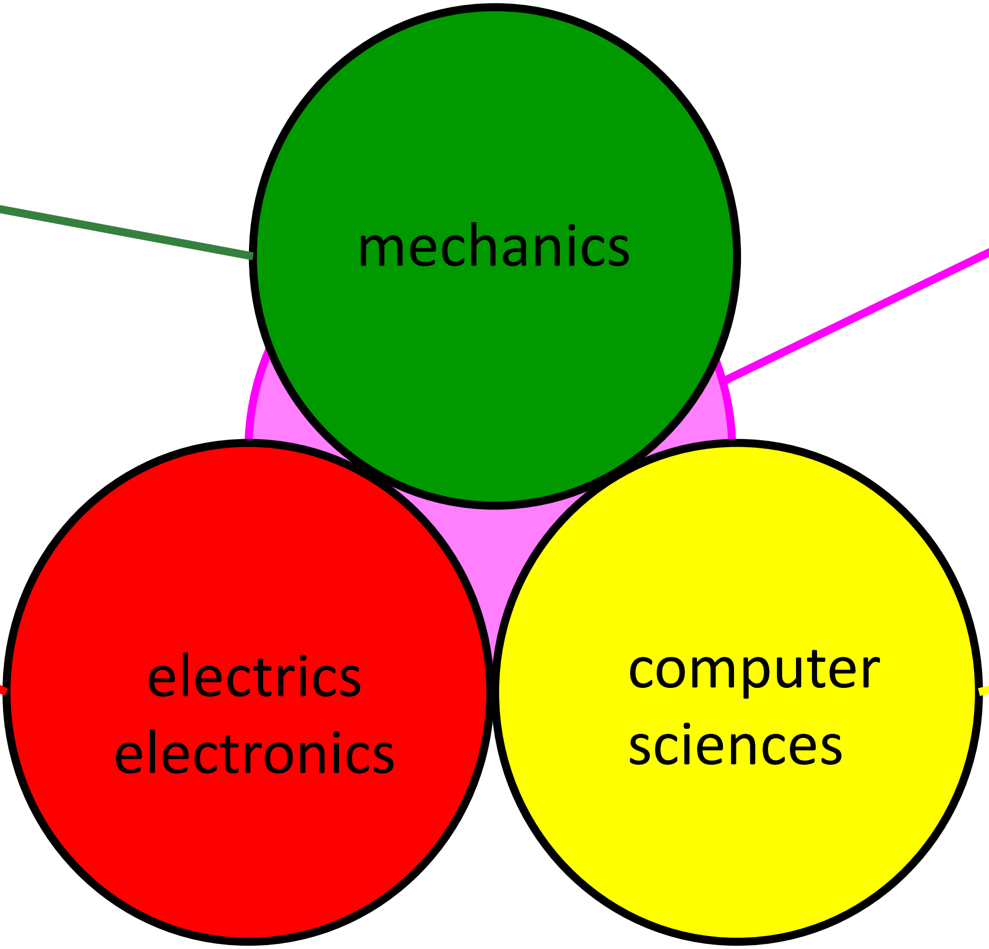
  put energy to the signals to impact the system

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

Mechatronics – The Tasks of the Domains

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



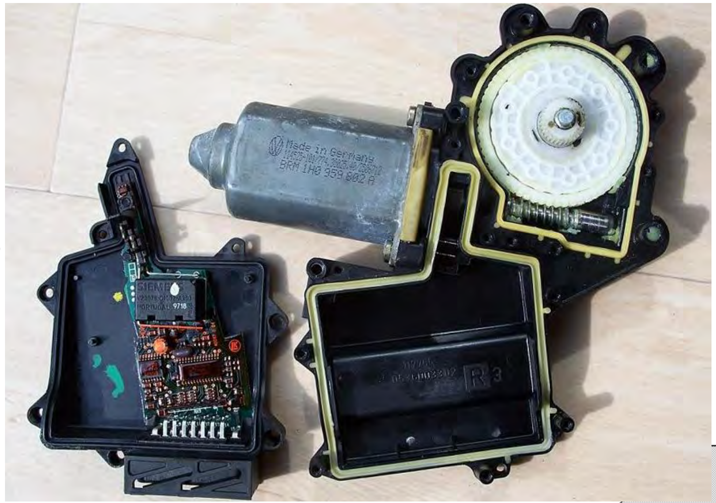
Mechatronics = “Cement” for a holistic product
- systems engineering
- control theory

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

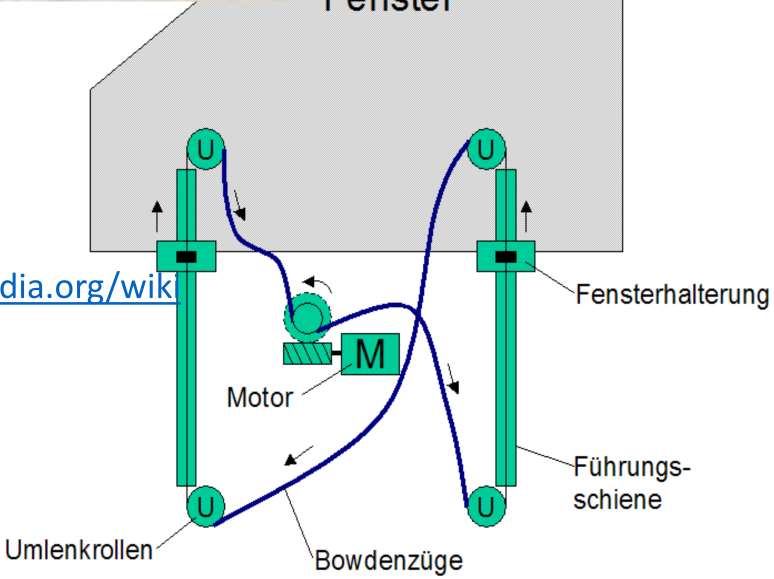
Co-funded by the Erasmus+ Programme of the European Union

FH | JOANNEUM University of Applied Sciences
K. Reisinger

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

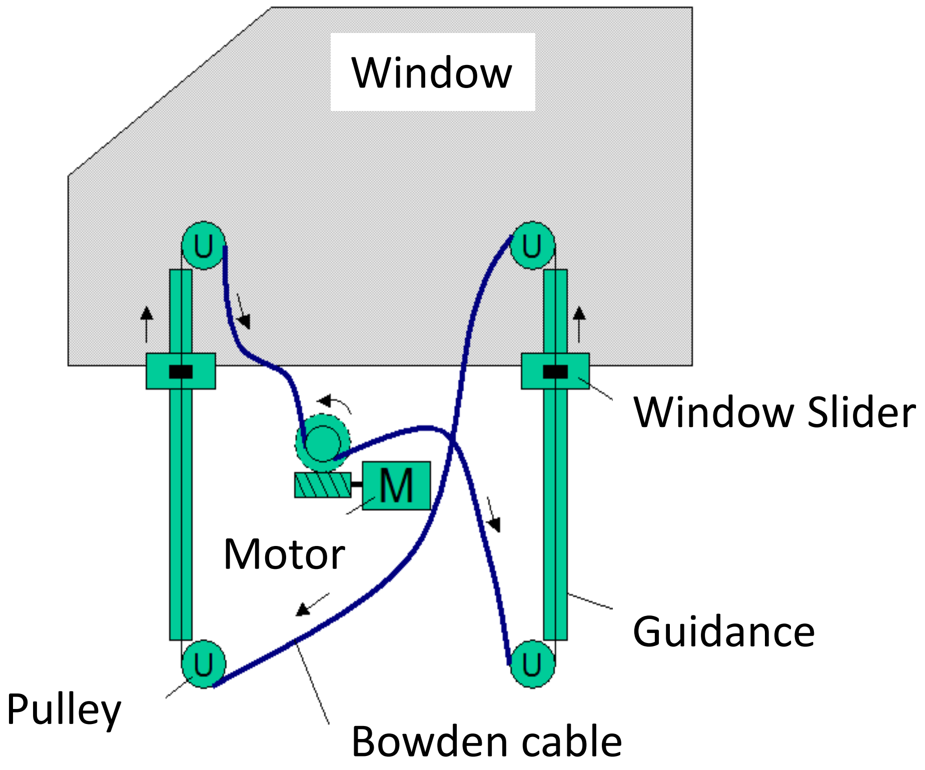
- **clamping hands, heads!**
- the driver takes care
- deactivate when ignition is off (driver is absent)

Solution

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

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

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

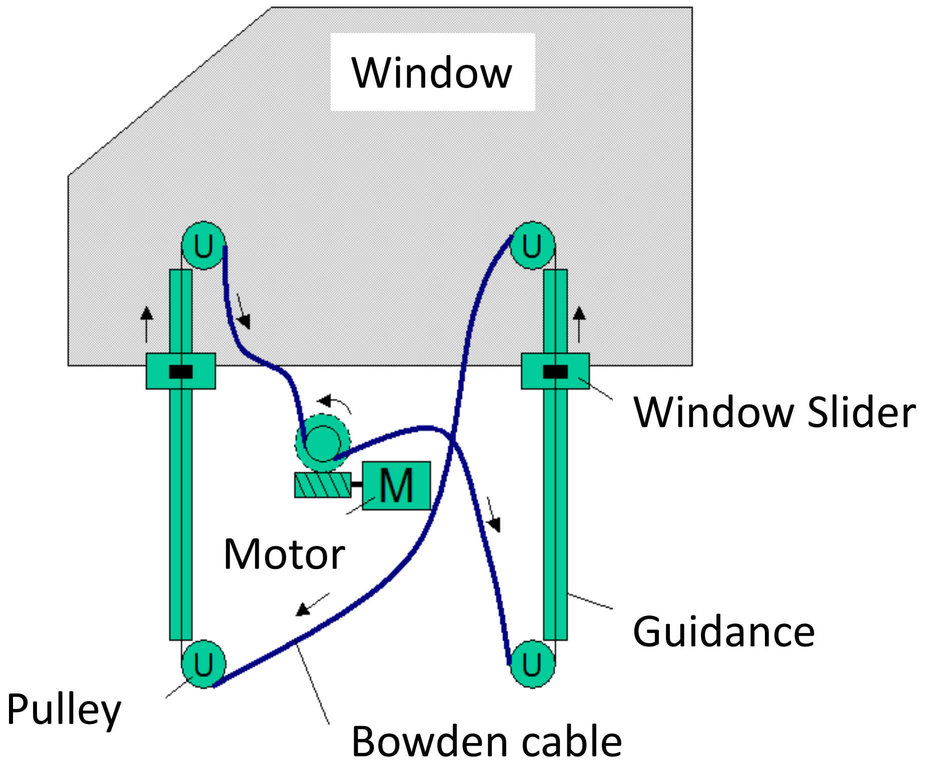
- **clamping hands, heads!**
- the smart system must take care!
- How?

Task break down

- detect clamped objects
- stop closing when detected

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

E.g. Automatic Power Window 2



detect clamped objects

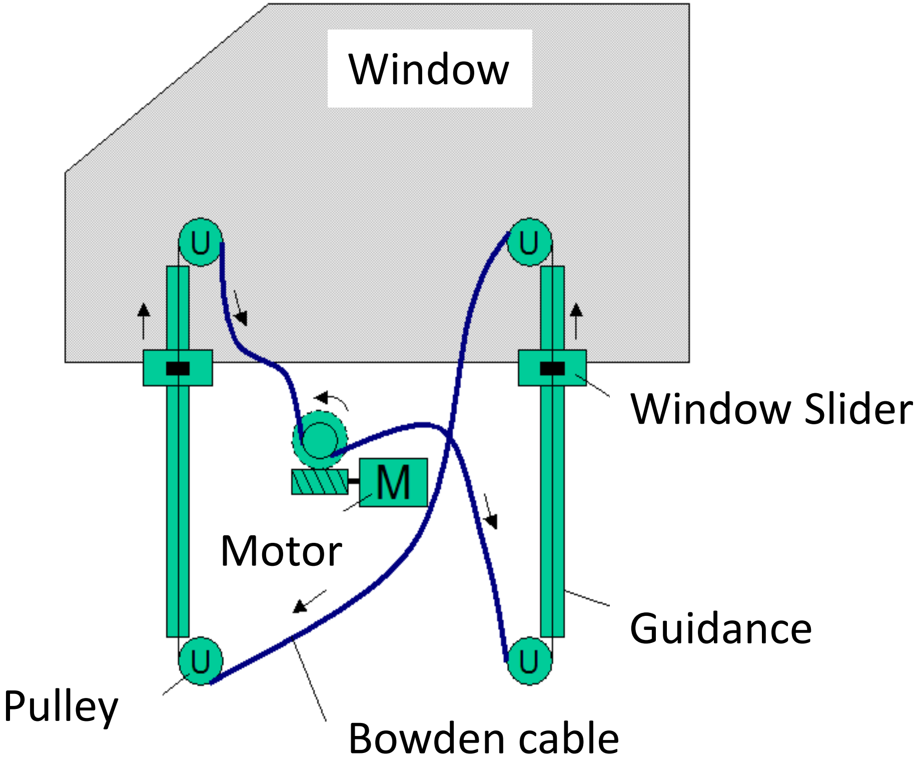
- detect force at the frame
  - air filled sensor hose + pressure sensor
  - How to check periodically?
- measure closing force
  - force sensors at the sliding guidance
  - force sensors in Bowden cable
  - measure support torque of motor
  - torque measurement in Bowden wheel
  - determine motor’s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

stop closing when detected

- open a gap
- switch off the motor

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

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

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

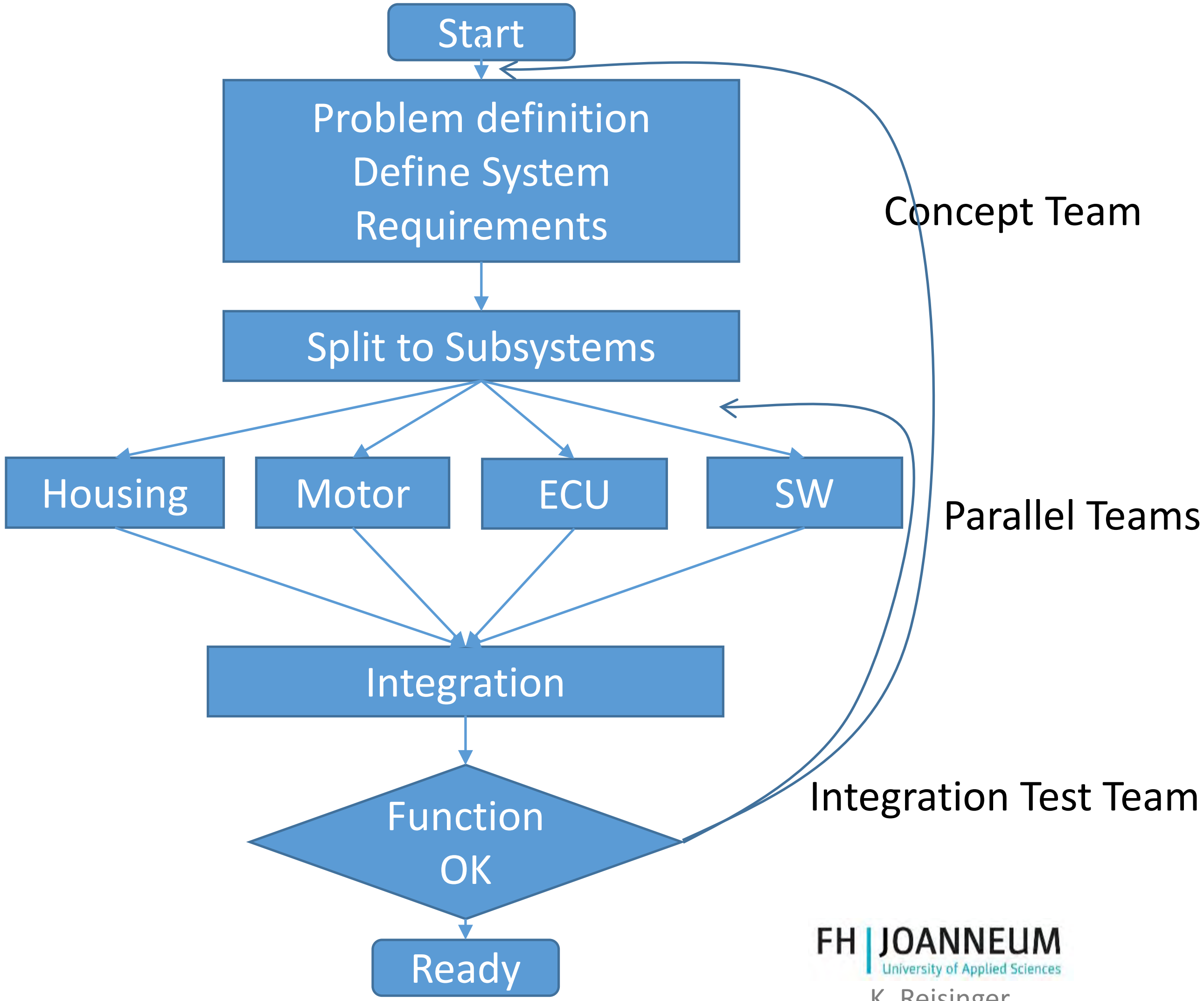
Mechatronic Workflow for new Products

- **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 …

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

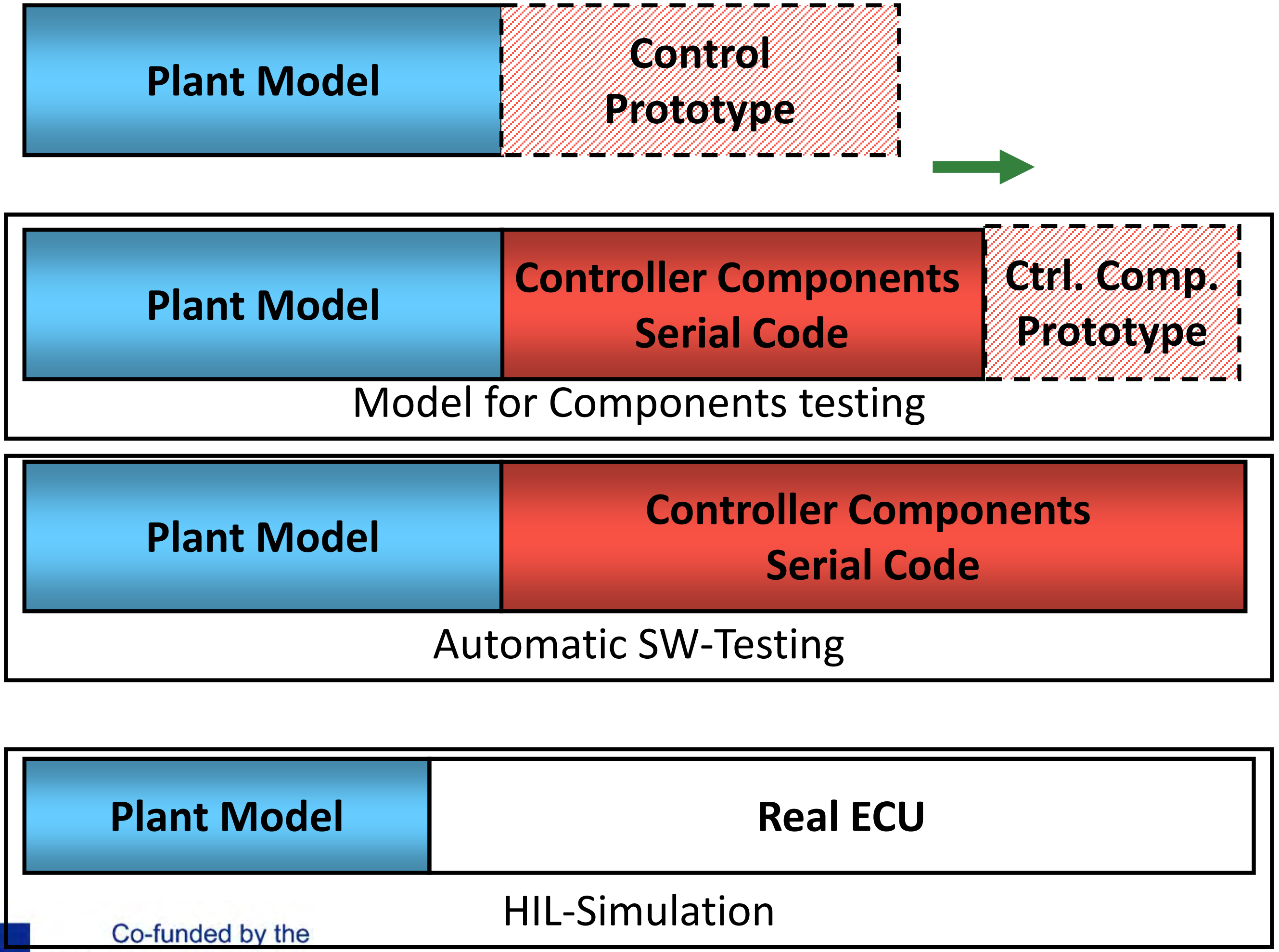
Development of a Mechatronic System

- 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.



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

Model Based Design Process

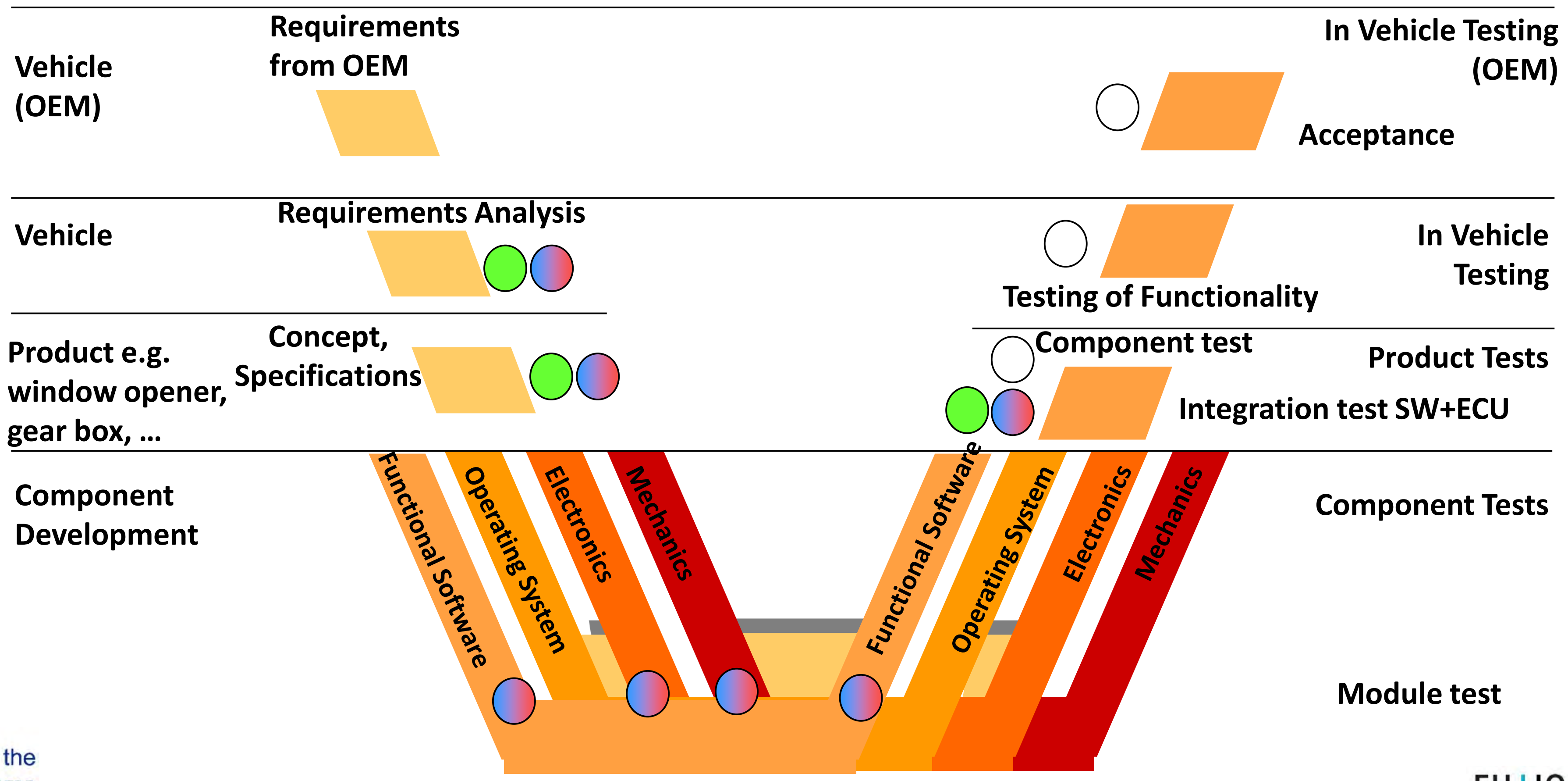


- **Model based**: a simulation model accompanies the Development
- Model In the Loop for feasibility
  - Plant + Prototype
- Software Modules
  - Plant + parts of Prototype
- Software In the Loop
  - Plant + Serial Software
- Hardware In the Loop
  - Real ECU

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

Usage of Simulation Models

Definition and Validation



Vehicle (OEM)

Requirements from OEM

In Vehicle Testing (OEM)

Acceptance

Vehicle

Requirements Analysis

Testing of Functionality

In Vehicle Testing

Product e.g. window opener, gear box, …

Concept, Specifications

Component test

Integration test SW+ECU

Product Tests

Component Development

Functional Software

Operating System

Electronics

Mechanics

Functional Software

Operating System

Electronics

Mechanics

Component Tests

Module test

● Product Plant Model

● Vehicle Model

○ Real Hardware

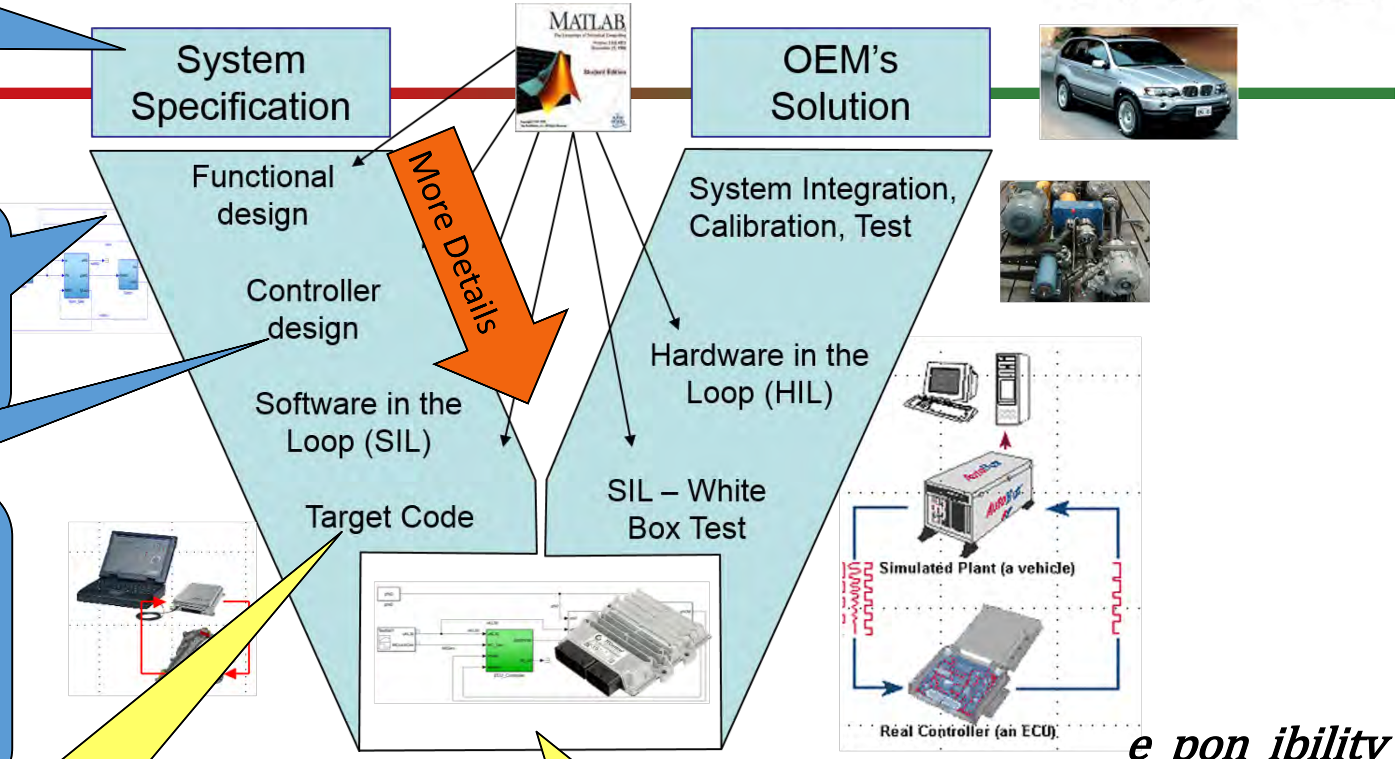
Co-funded by the Erasmus+ Programme of the European Union

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

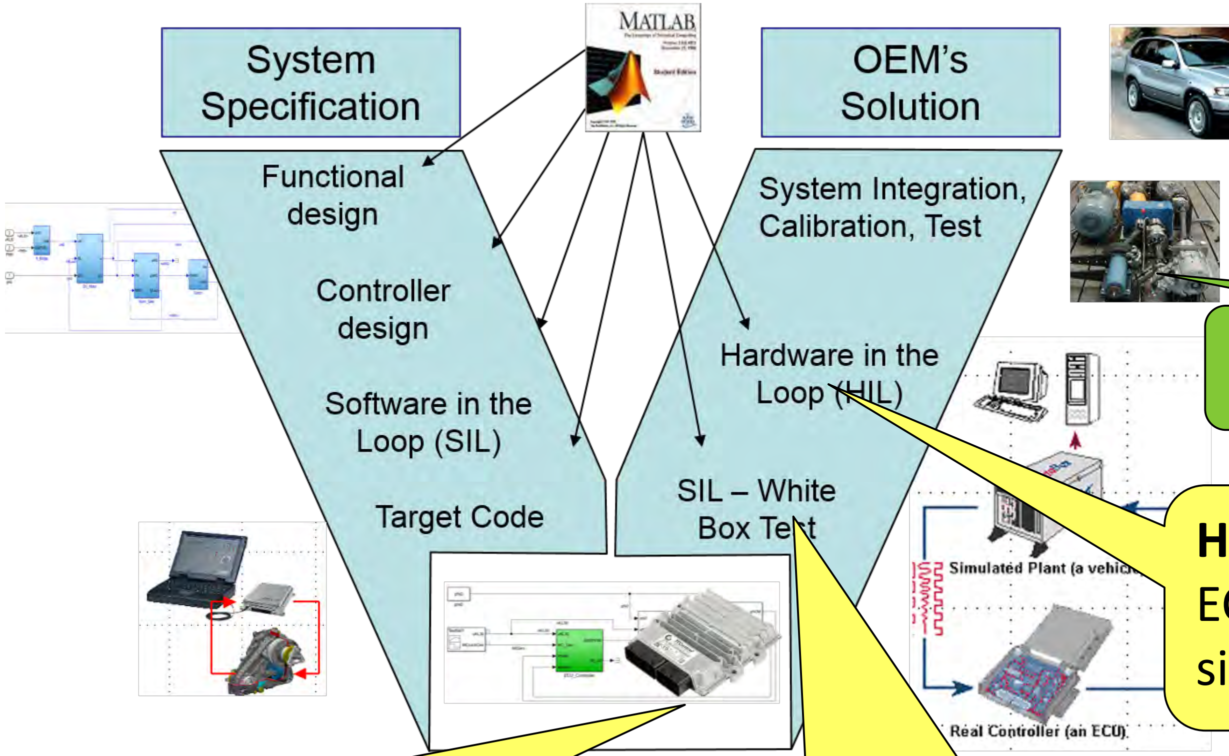
Programming
Simulink Software
→ (automatic) C-Code generation.

e pon ibility

y te ngineer

oftware

e t ngineer



Tests in car

Tests on test bench

Hardware-In-the-Loop
ECU against electrically simulated world

Software-Module-Test,
Every single Simulink-WS-model against simple test sequences defined in MATLAB

Software-In-The-Loop
Simulink-WS against simulated Plant

Responsibility

🟦 System Engineer

🟨 Software

🟩 Test Engineer

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

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

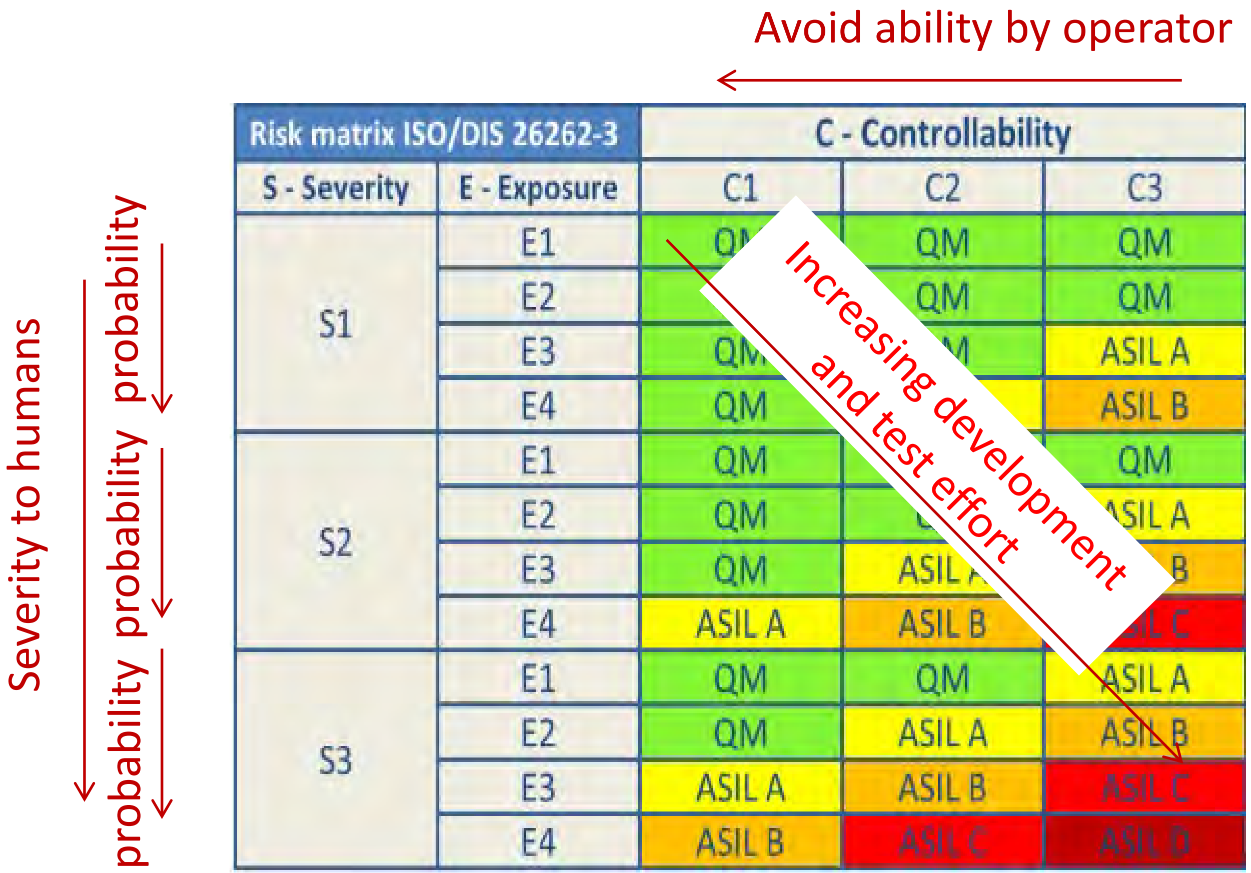
- uses V-Model

You must fulfil SPICE standard to deliver an European OEM!

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

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

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	QM	QM	QM
	E2	[illegible]	QM	QM
	E3	QM	QM	ASIL A
	E4	QM	[illegible]	ASIL B
S2	E1	QM	[illegible]	QM
	E2	QM	QM	ASIL A
	E3	QM	ASIL A	ASIL B
	E4	ASIL A	ASIL B	ASIL 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

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

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

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

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

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

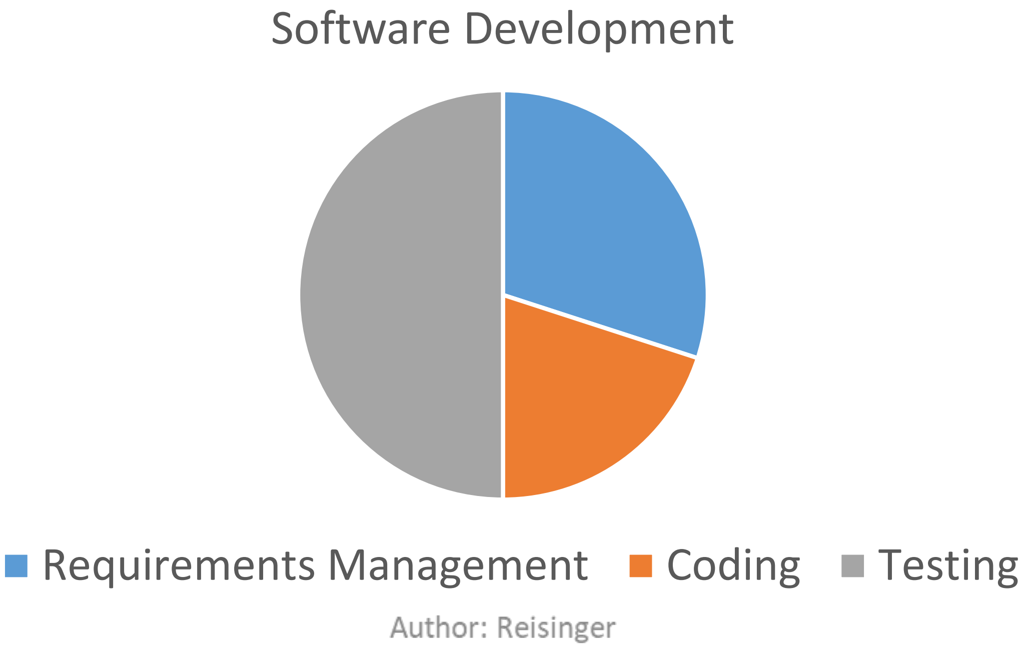
Software Development

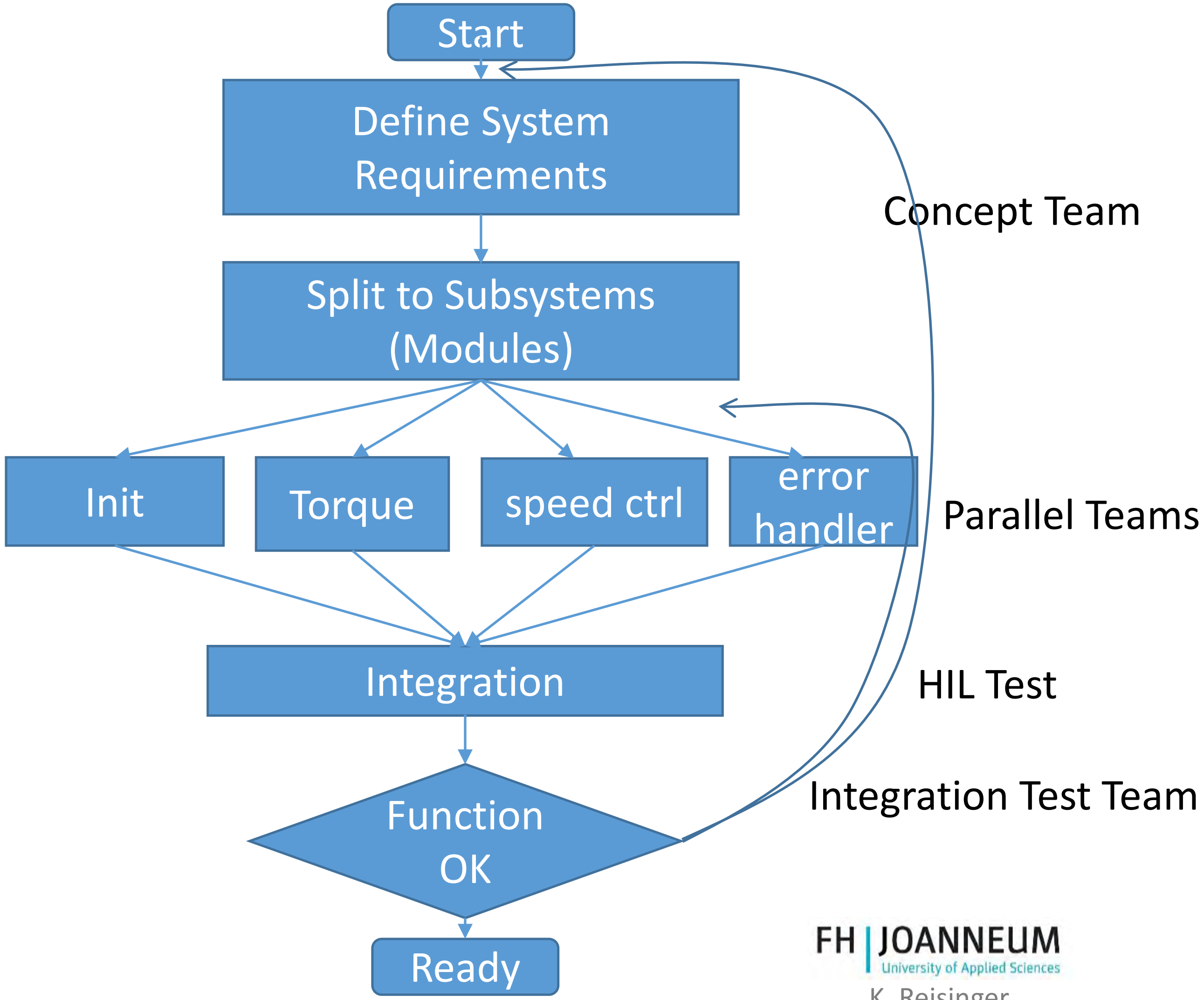
- “How many lines did you code today?”

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

Software Development

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





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

UNITED

FH | JOANNEUM
University of Applied Sciences

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

Data transfer using Digital Bus Systems

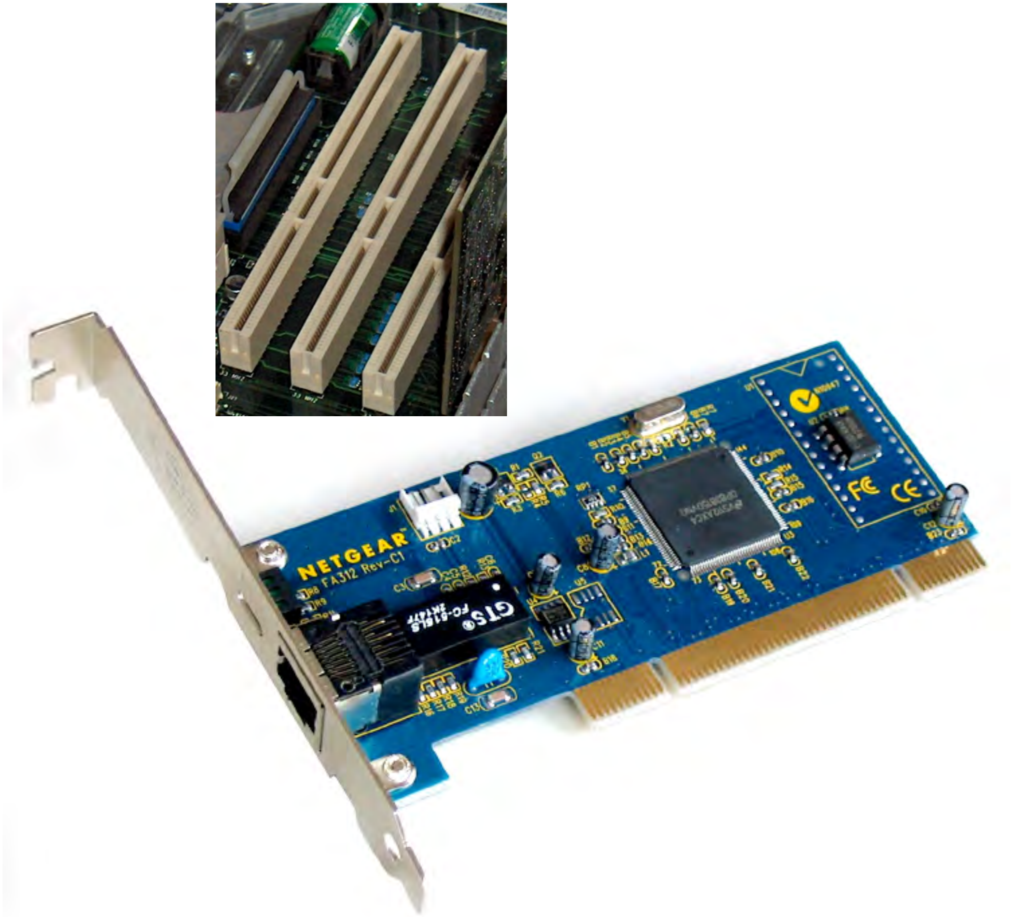
K. Reisinger

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

The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. 598710-EPP-1-2018-1-AT-EPPKA2-CBHE-JP

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]

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

Drivetrain bus system of a passenger car

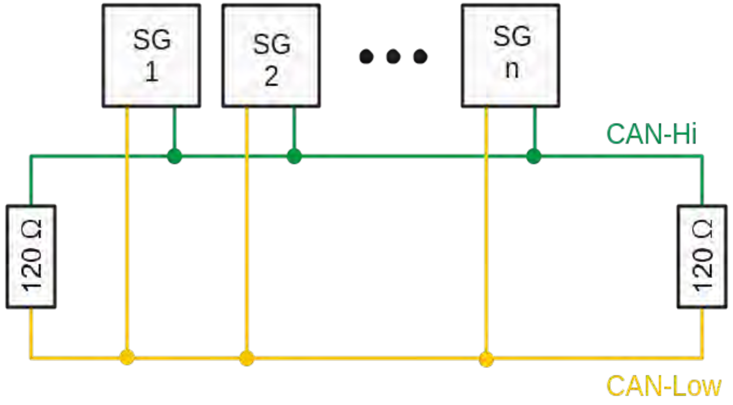
- Used for
  - 1 sensor shared for different ECU‘s
  - Sensor-ECU-connection
  - ECU dashboard connection, …
- Serial bus systems
  - 1 or 2 wires for robust data transfer
- Additional
  - Low speed CAN for interior …
- No Parallel Bus in cars
  - → Serial Data Transfer at 2 lines

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

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

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]

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

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

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

Bus systems 3

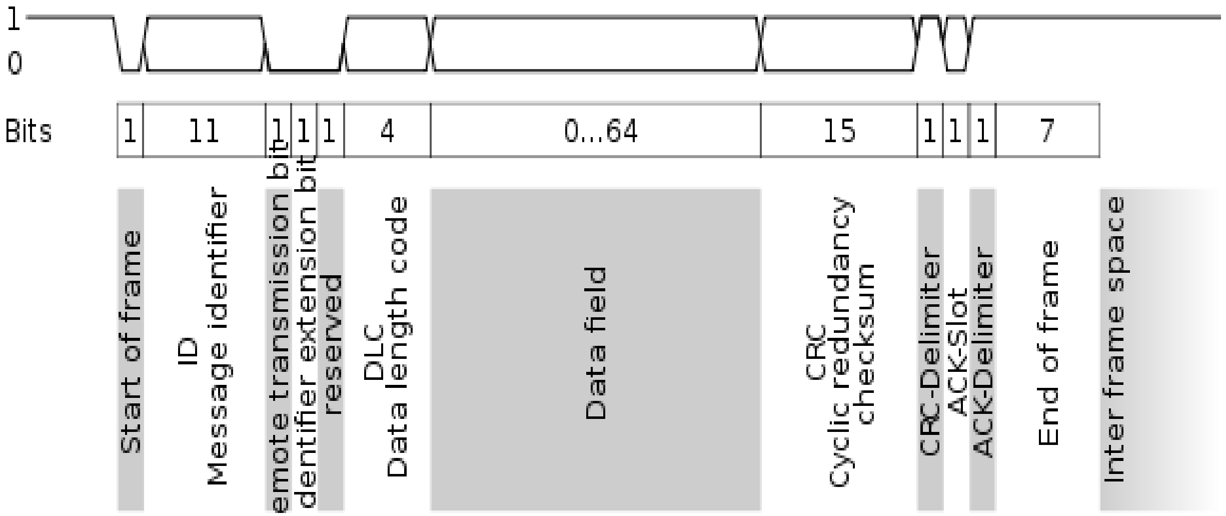
- Automotive Ethernet
  - Ethernet, IP-based communication
- MOST-Bus
  - Media Oriented Systems Transport
  - High data rates, low safety
  - Cable or optical fibre
- LIN-Bus
  - simple
  - Communication ECU – Sensor – Actor
  - Single wire (+ supply + GND to sensor makes 3 wires)

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

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

CAN-BUS

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



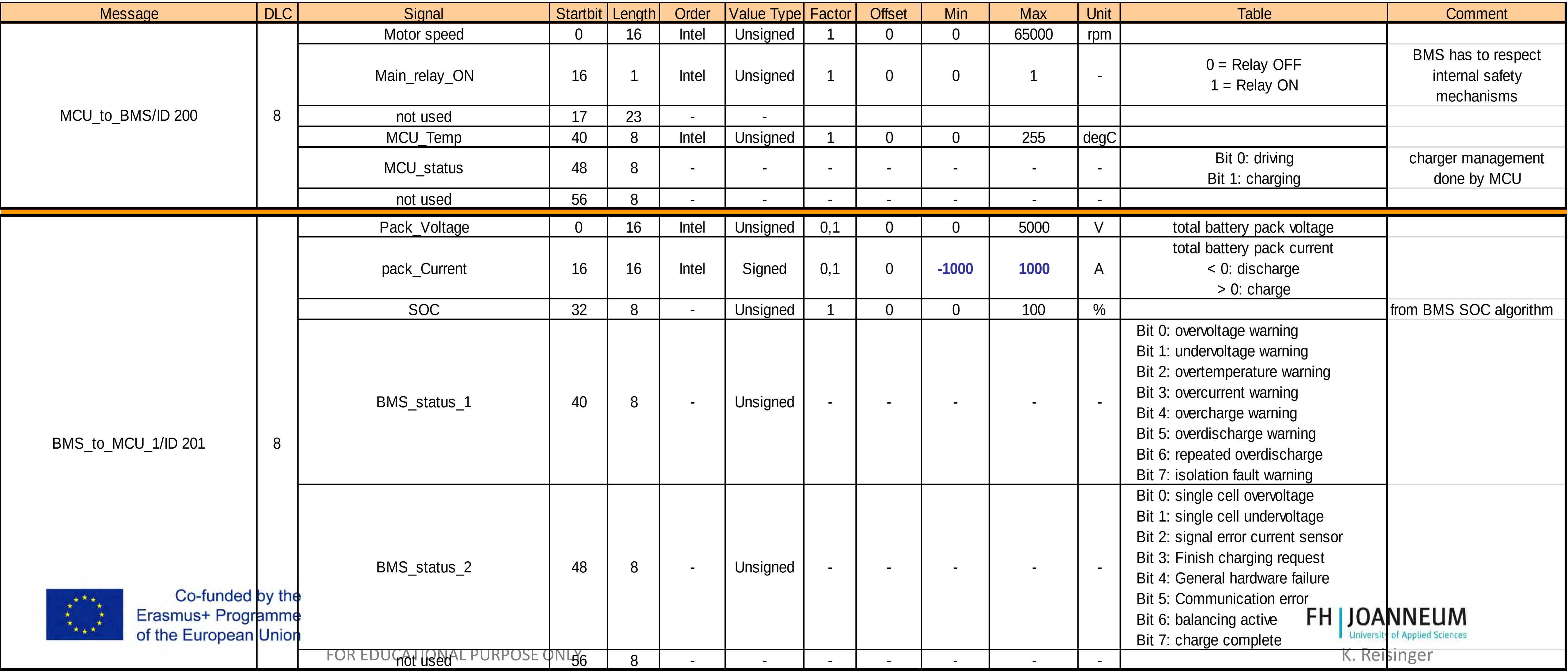
[https://de.wikipedia.org/wiki/Controller_Area_Network]

- 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!

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

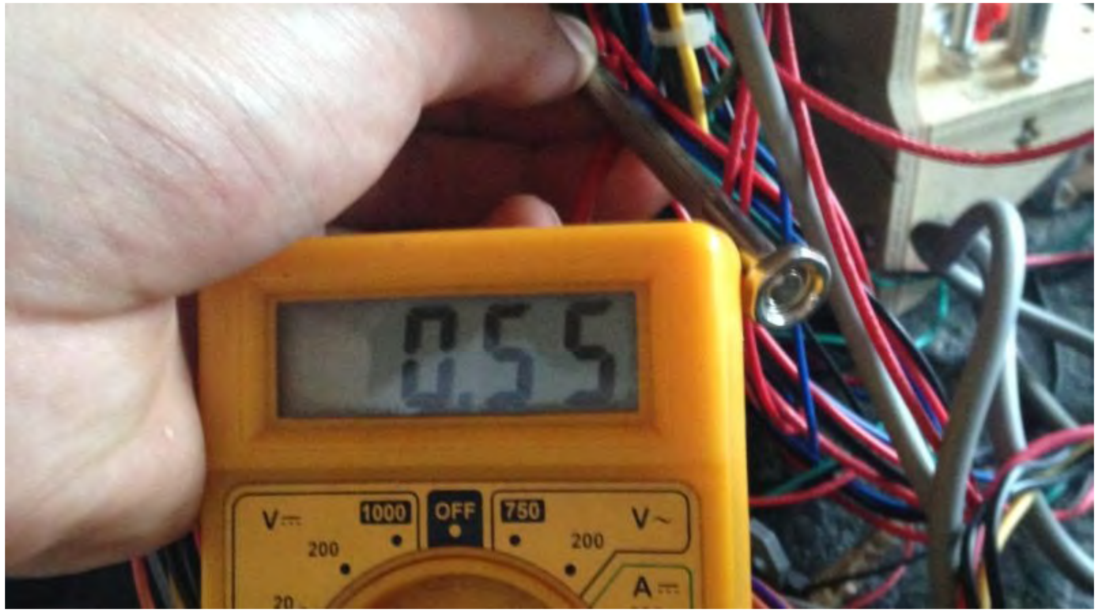
Example CAN-DB Snow Mobile - Excel



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	-	-	-	-	-	-	-		

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

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!

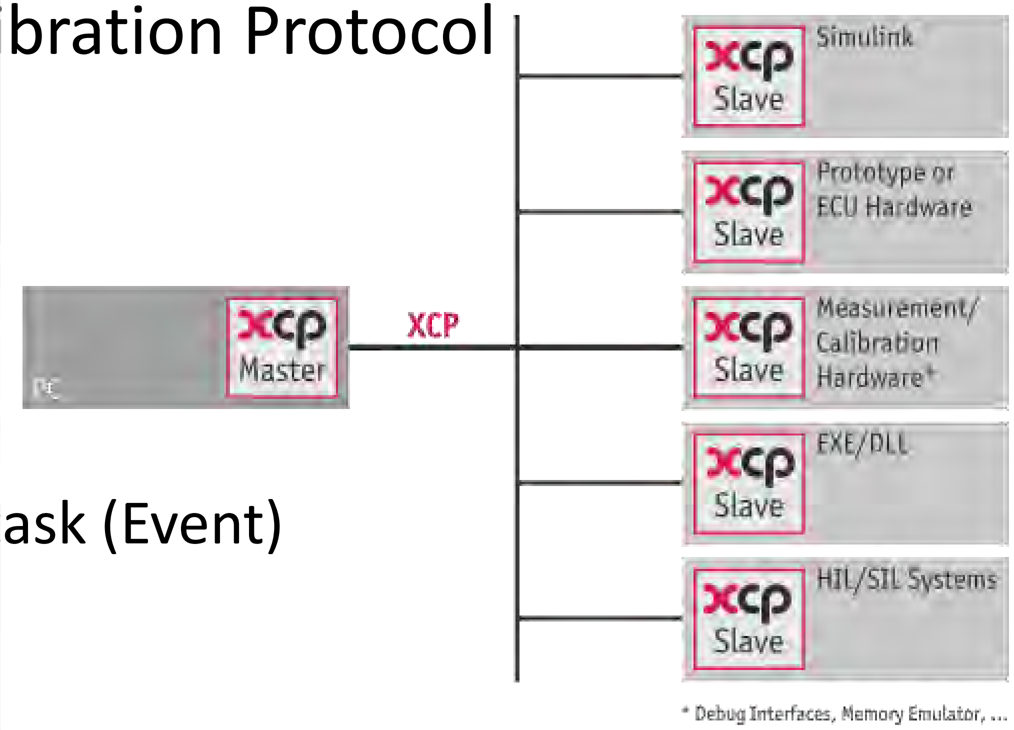
Co-funded by the Erasmus+ Programme of the European Union

Calibration using CCP/XCP

CCP … CAN Calibration Protocol

XCP … Universal Measurement and Calibration Protocol

for different transport layers

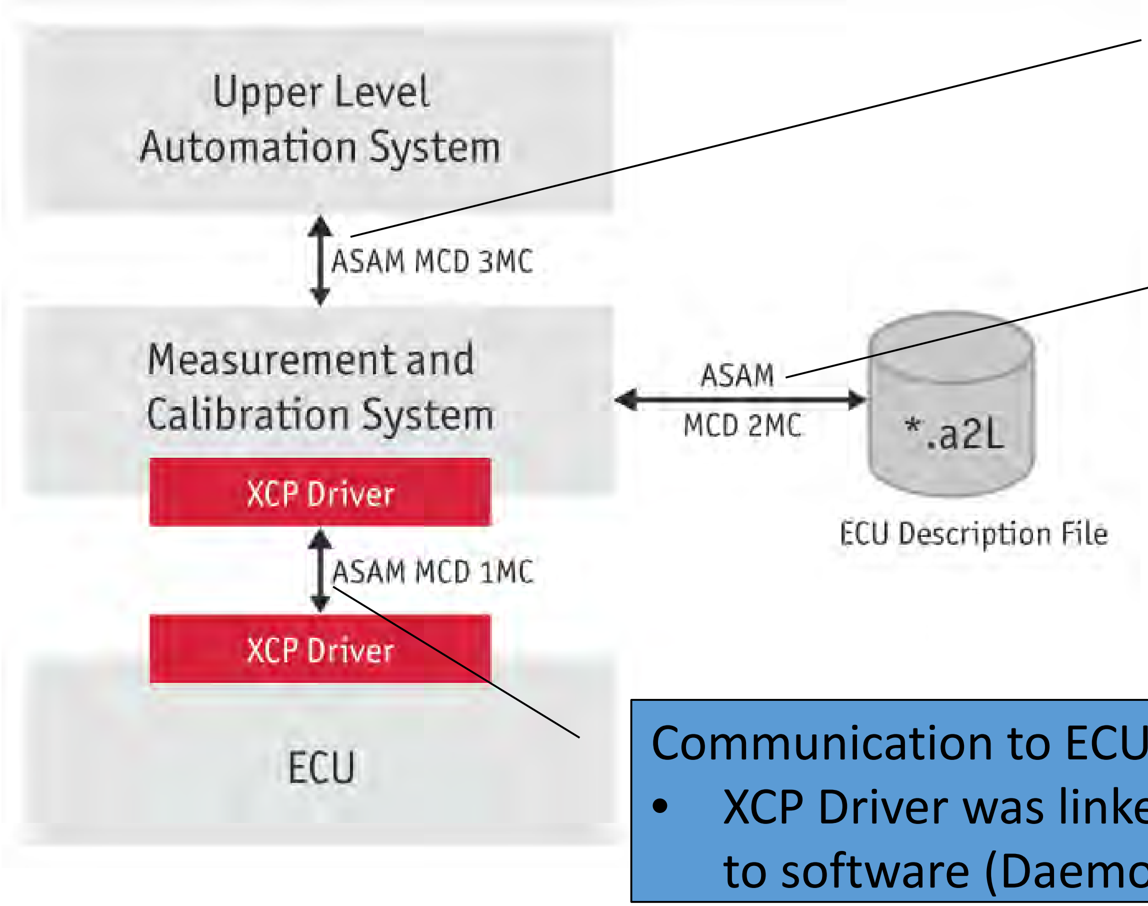

PC
XCP Master
XCP
XCP Slave
Simulink
XCP Slave
Prototype or ECU Hardware
XCP Slave
Measurement/ Calibration Hardware*
XCP Slave
EXE/DLL
XCP Slave
HIL/SIL Systems
* Debug Interfaces, Memory Emulator, ...

- 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)]

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

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

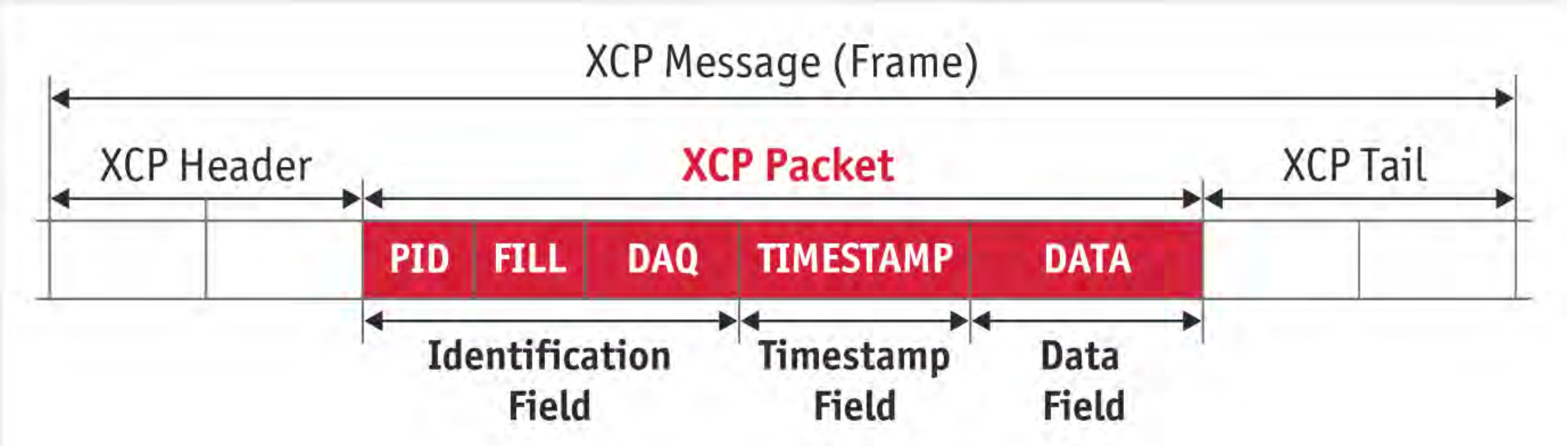
Communication to ECU
- XCP Driver was linked to software (Daemon)

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

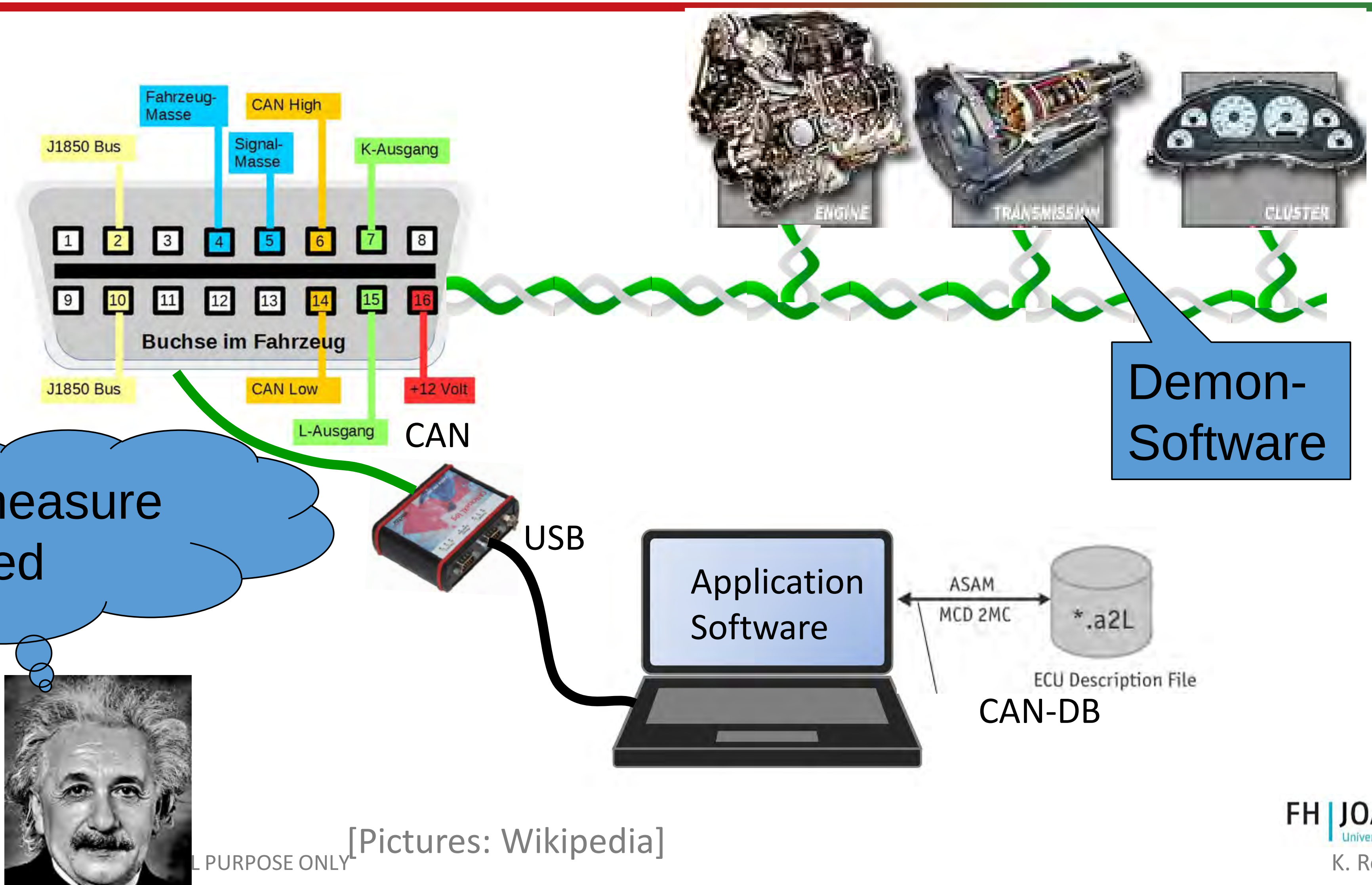
Co-funded by the Erasmus+ Programme of the European Union

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?



Demon-
Software

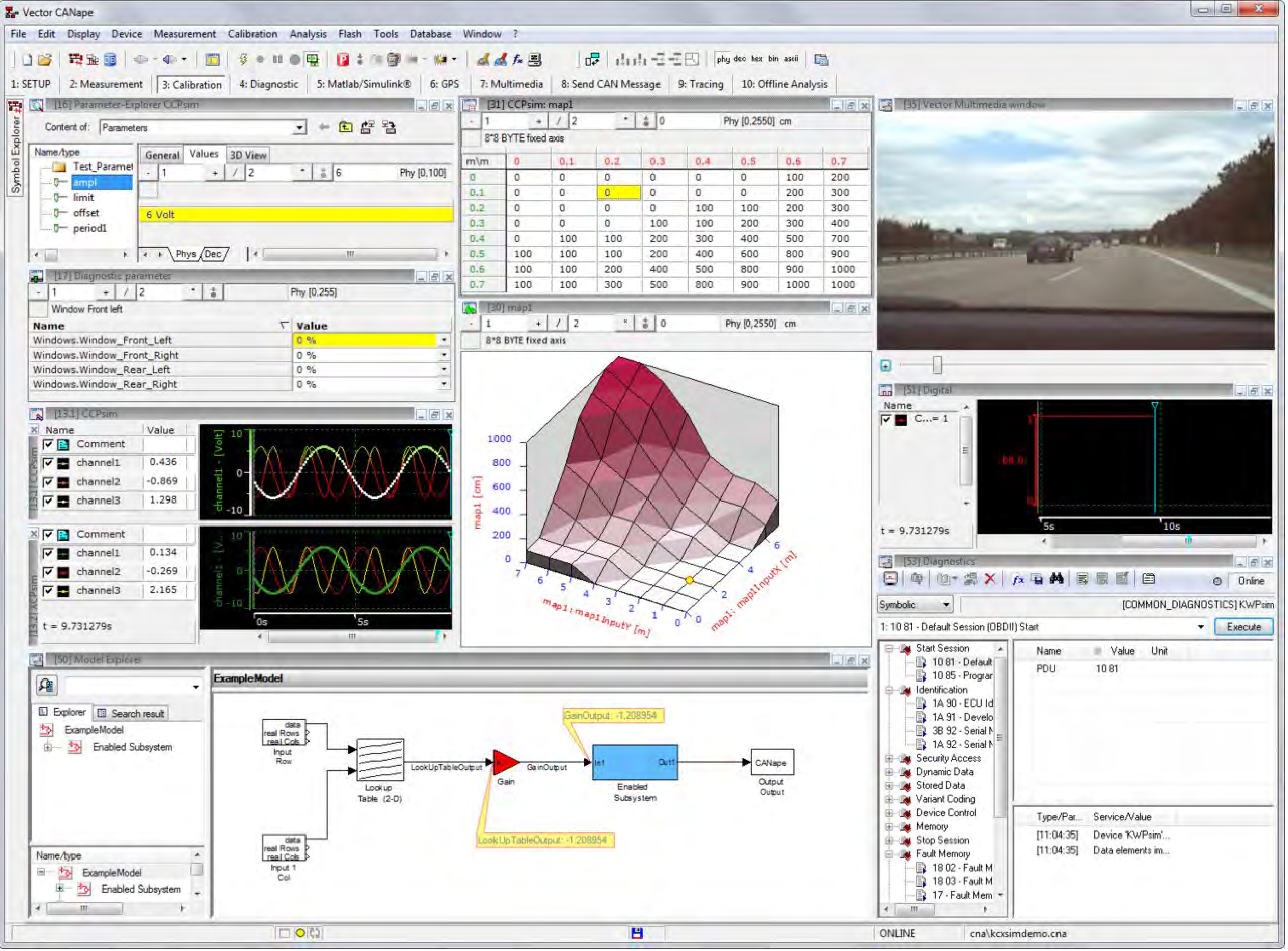
I want to measure wheel speed

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

L PURPOSE ONLY

[Pictures: Wikipedia]

K. Reisinger



m\m	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
0	0	0	0	0	0	0	100	200
0.1	0	0	0	0	0	0	200	300
0.2	0	0	0	0	100	100	200	300
0.3	0	0	0	100	100	200	300	400
0.4	0	100	100	200	300	400	500	700
0.5	100	100	100	200	400	600	800	900
0.6	100	100	200	400	500	800	900	1000
0.7	100	100	300	500	800	900	1000	1000

Name	Value
Windows.Window_Front_Left	0 %
Windows.Window_Front_Right	0 %
Windows.Window_Rear_Left	0 %
Windows.Window_Rear_Right	0 %

Name	Value
Comment	
channel1	0.436
channel2	-0.869
channel3	1.298

Name	Value
Comment	
channel1	0.134
channel2	-0.269
channel3	2.165

GainOutput: -1.208954

LookUpTableOutput: -1.208954

1: 10 81 - Default Session (OBDII) Start

Name	Value	Unit
PDU	10 81	

Type/Par...	Service/Value
[11:04:35]	Device 'KWPsim'...
[11:04:35]	Data elements im...

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

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

K. Reisinger

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

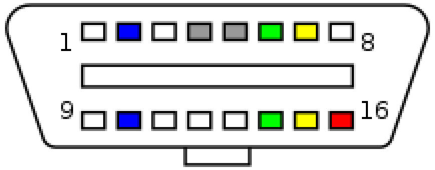
- avoid environmental pollution
  - recognize failure
  - inform driver and reduce car’s performance
  - Readable by OBD-II or EOBD standard tools

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

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

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

UNITED

FH | JOANNEUM
University of Applied Sciences

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

Introduction to UAS Mechatronic Laboratory Tutorial

K. Reisinger, T. Lechner

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

The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. 598710-EPP-1-2018-1-AT-EPPKA2-CBHE-JP

FOR EDUCATIONAL PURPOSE ONLY

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

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

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

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

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**

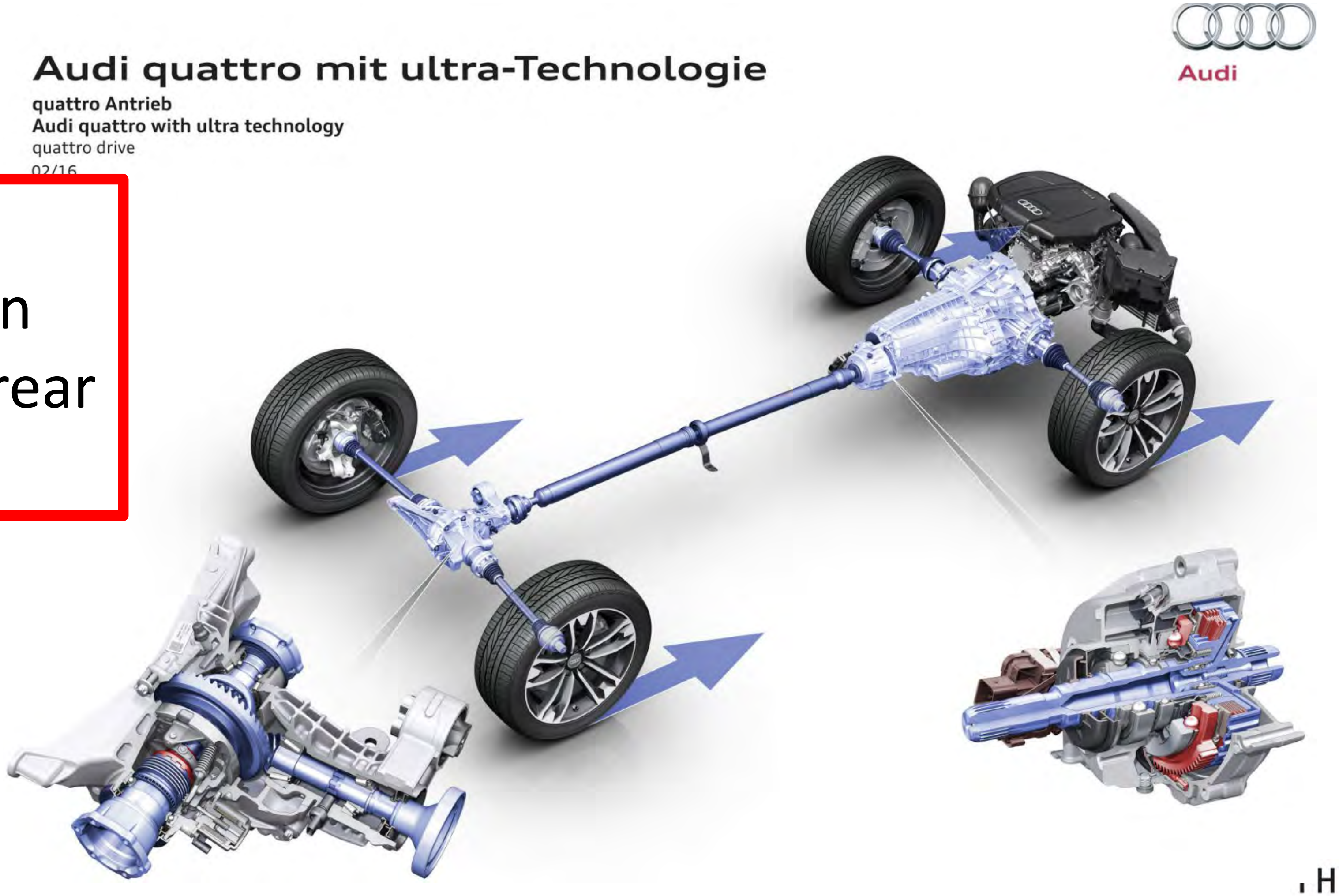
    A/D-, D/A converter, quantizing effects, cycle time influence
  - **Encoding of signals**

    Data types, fixed point arithmetic

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

Our Object to grab the content

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



Audi quattro mit ultra-Technologie

quattro Antrieb
Audi quattro with ultra technology
quattro drive
02/16

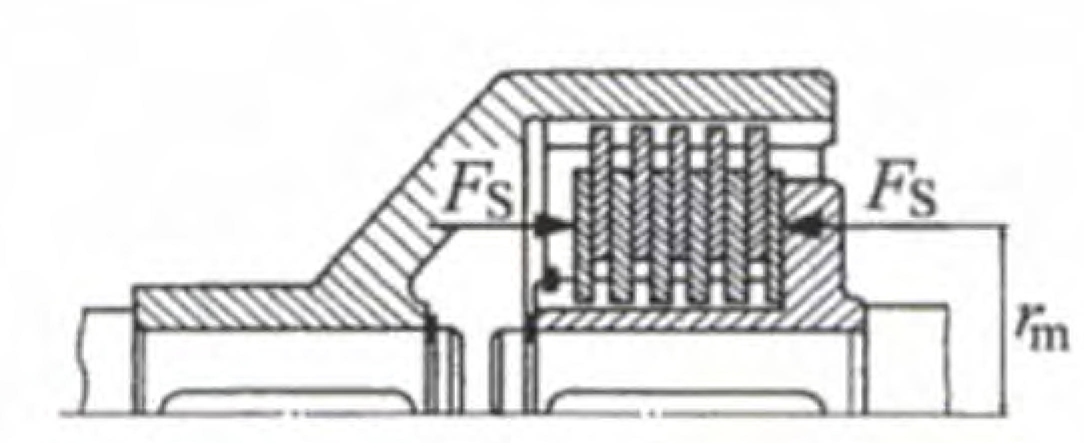
https://www.heise.de/autos/artikel/Daten-unter-der-Haube-1012221.html?view=bildergalerie

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

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

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

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 $\boldsymbol{M_{clutch} = M_{Req} \pm 10\%}$ 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

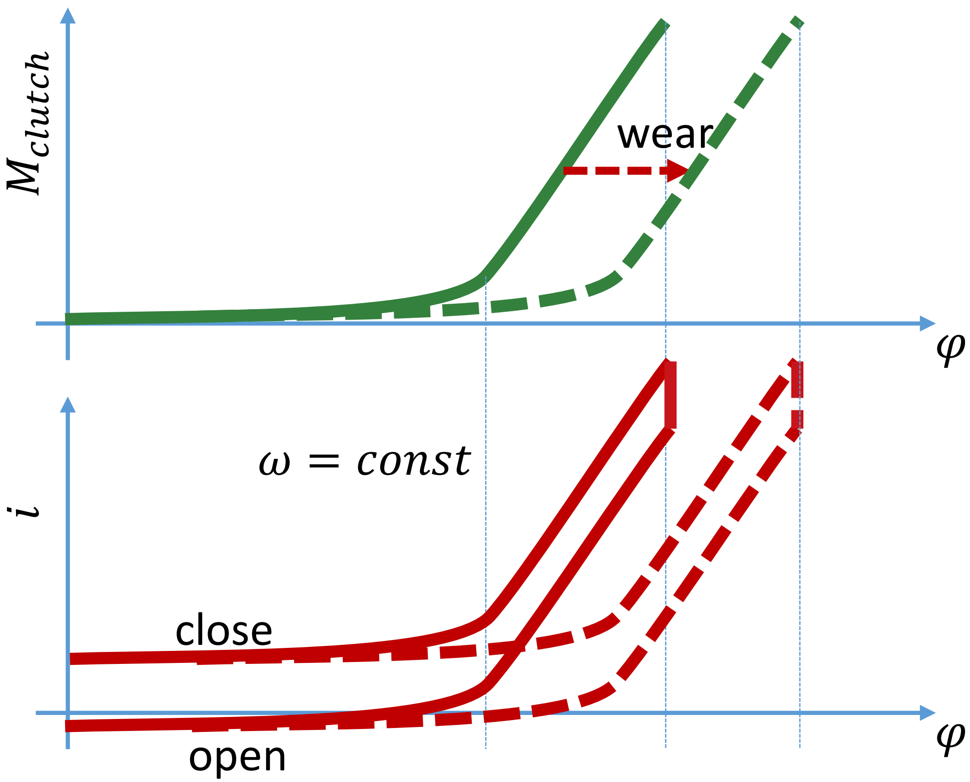
c) Measuring motor torque

d) Estimate motor torque out of current.

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

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

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

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

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

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

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

V-Modell

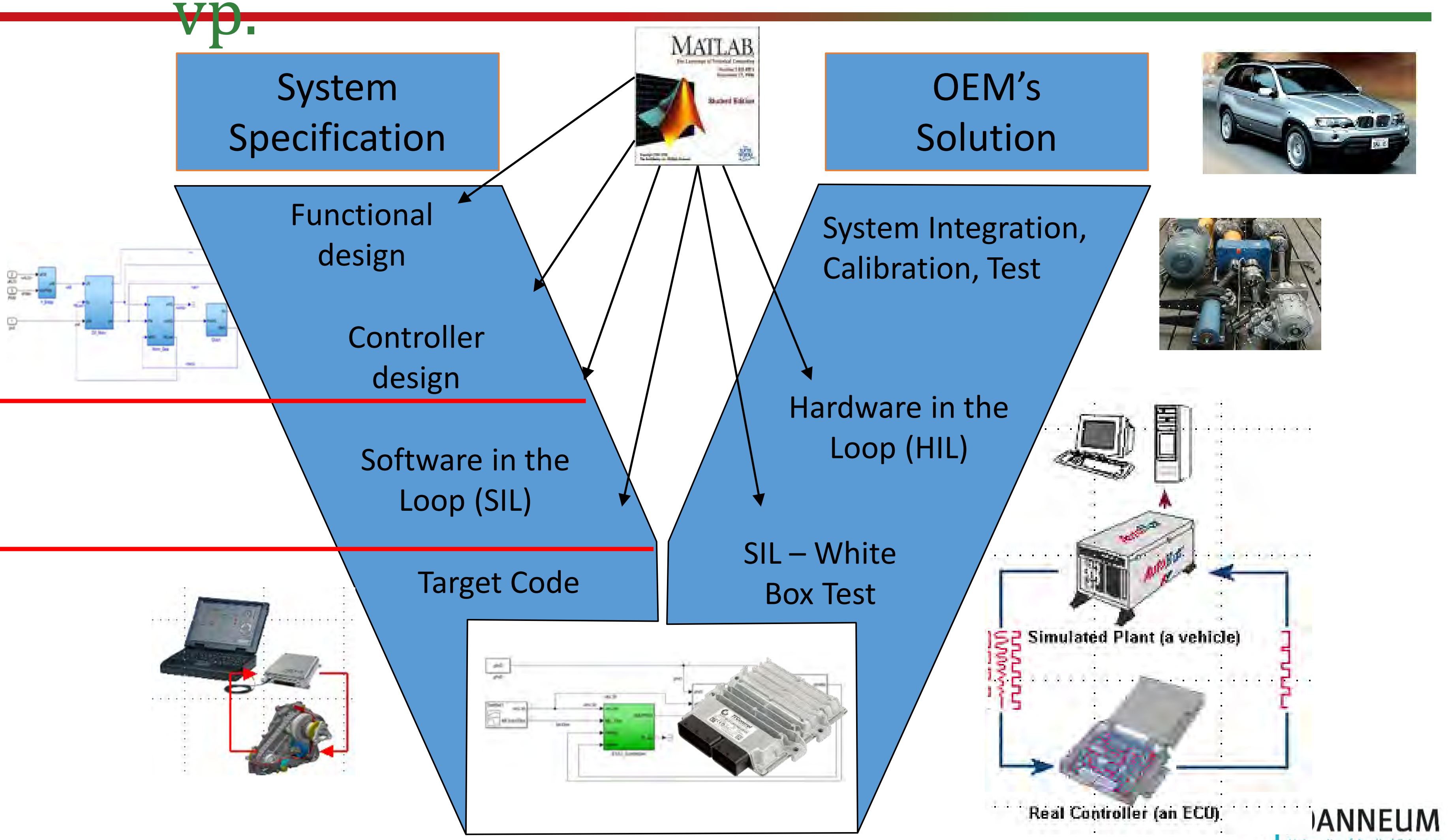
e foc on the ta k of an y te engineer → rototype vp.

Lab-Session:

1 & 2

(2), 3 & (4)

(4) & 5



System Specification

OEM's Solution

Functional design

Controller design

Software in the Loop (SIL)

Target Code

System Integration, Calibration, Test

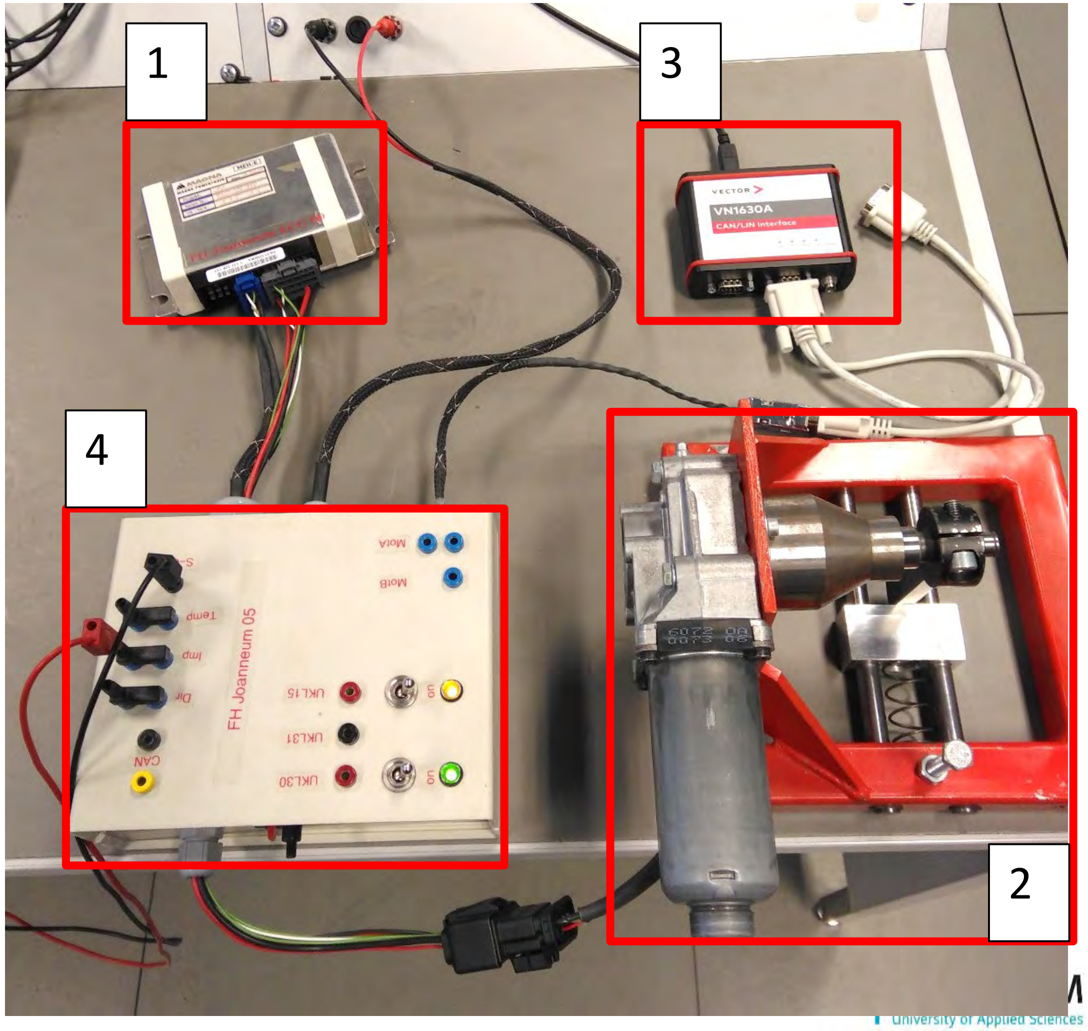
Hardware in the Loop (HIL)

SIL – White Box Test

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

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



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

Break Out Box

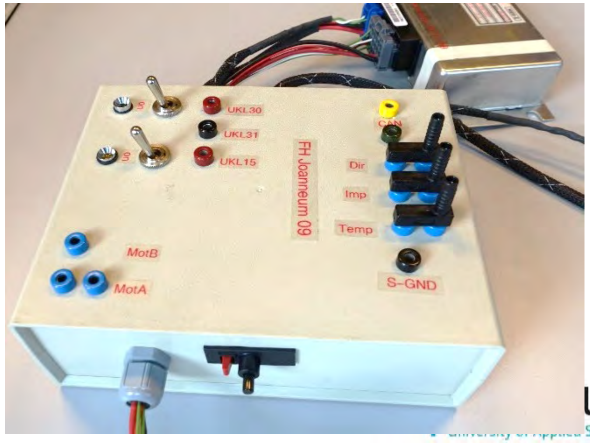
General requirements

- 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

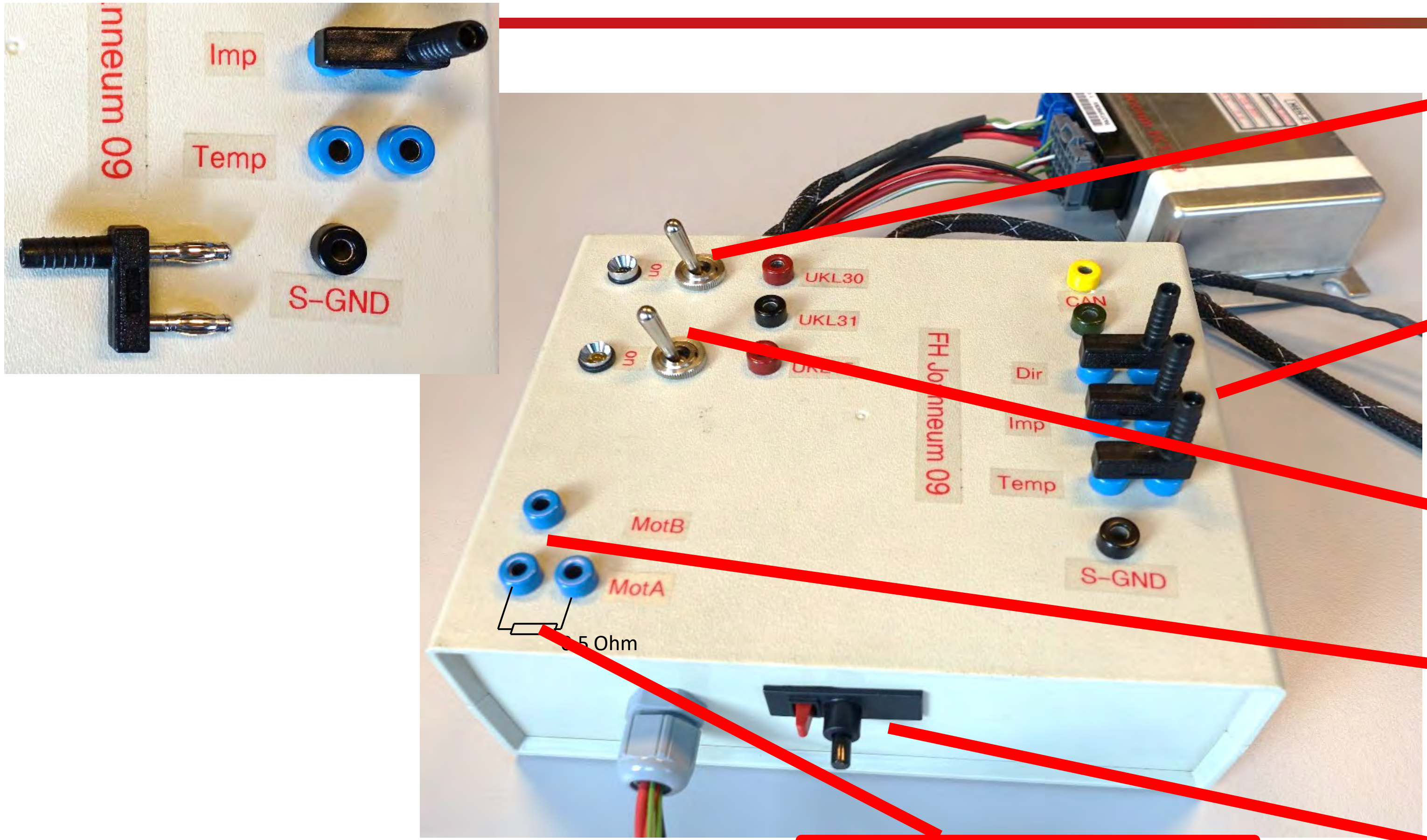
- resistor to limit peak current
- thermal fuse

no burned motor since years ☺



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

Break Out Box



Power switch and indication

Signal access / manipulation

Ignition On

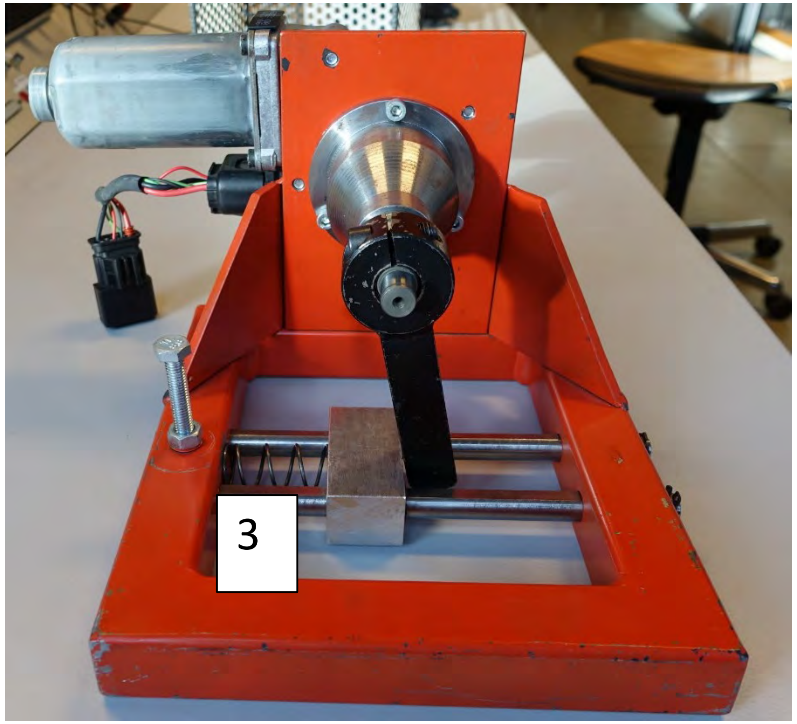
Terminals for Motor-Voltage

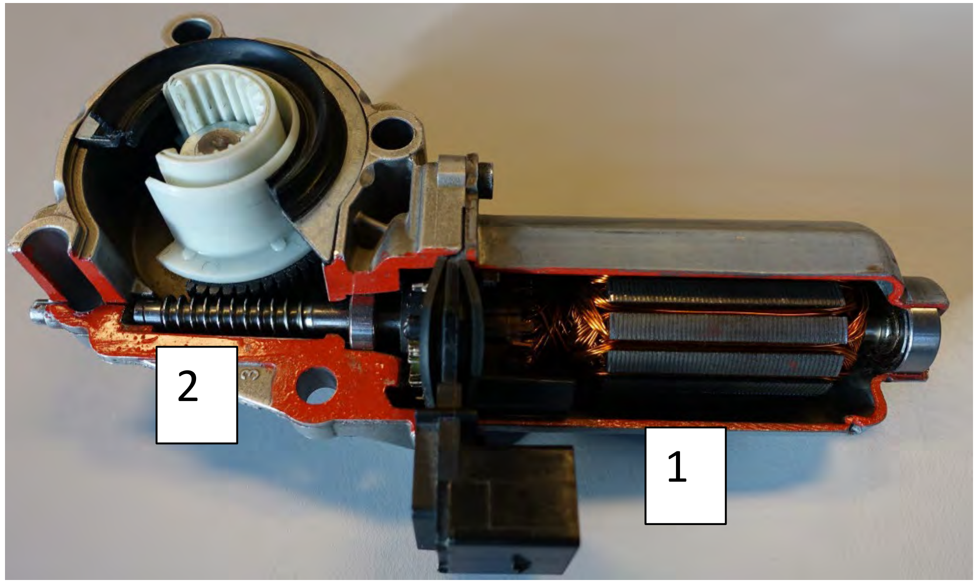
Thermo-Fuse

Resistor to limit peak current

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

Environment → Plant Model





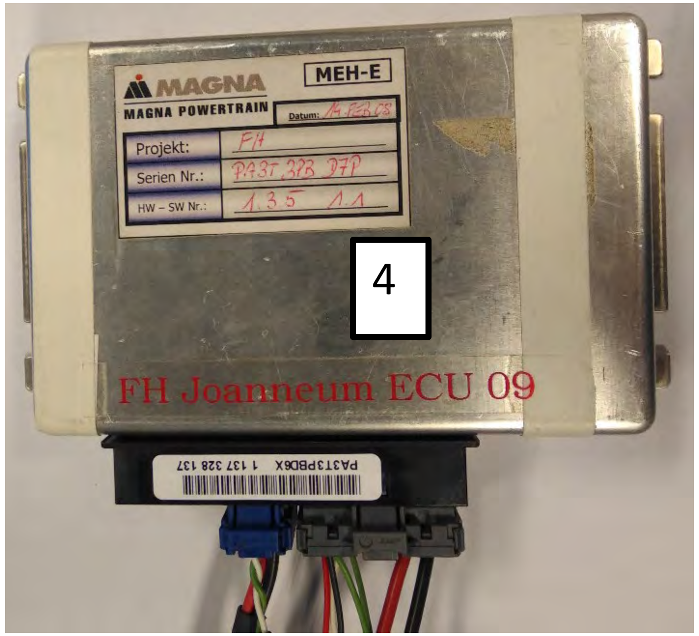
1 – DC-Motor

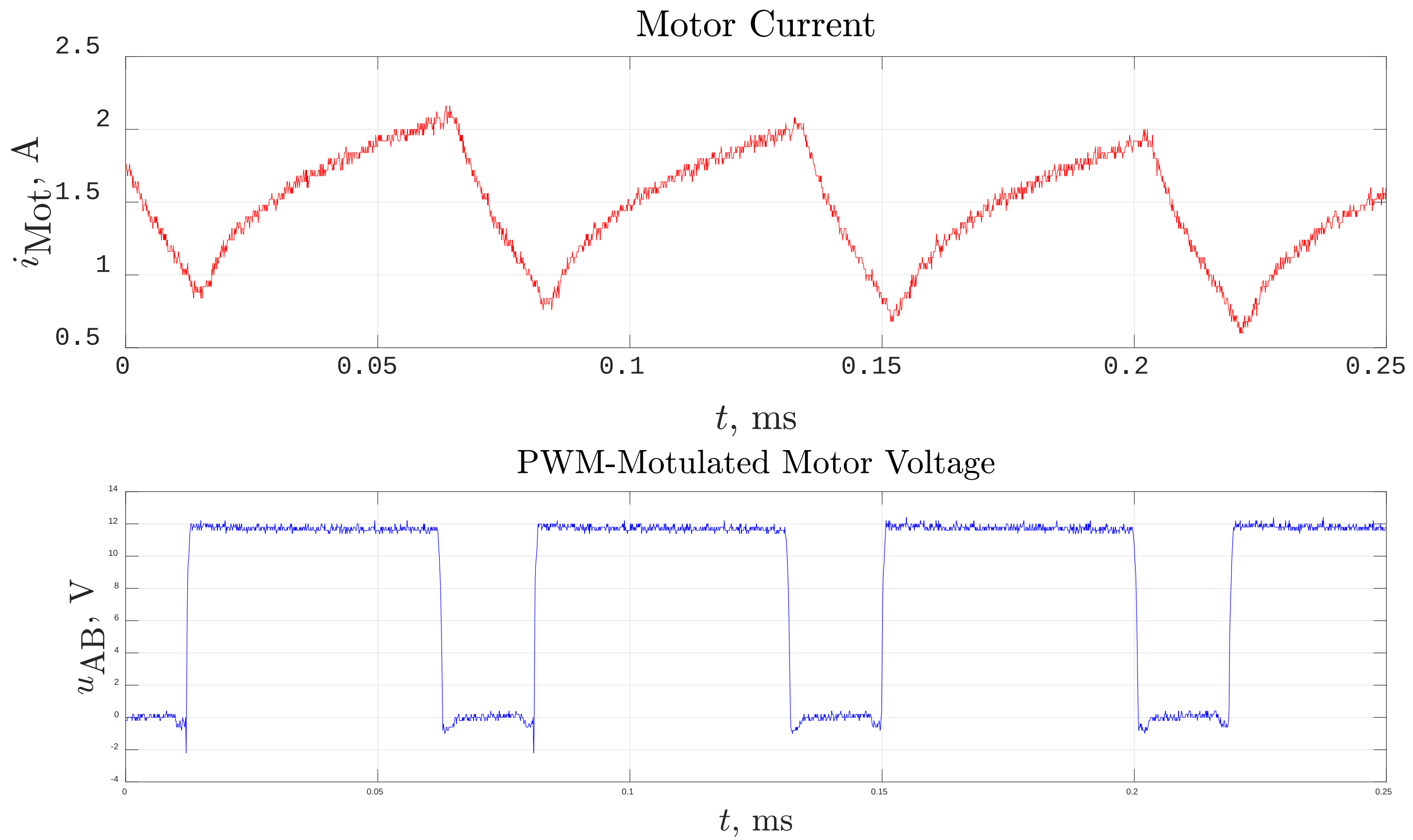
2 – Worm Gear → gear ratio is 56

3 – Spring → simulate the feedback from the clutch

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

Plant Model, H-Bridge





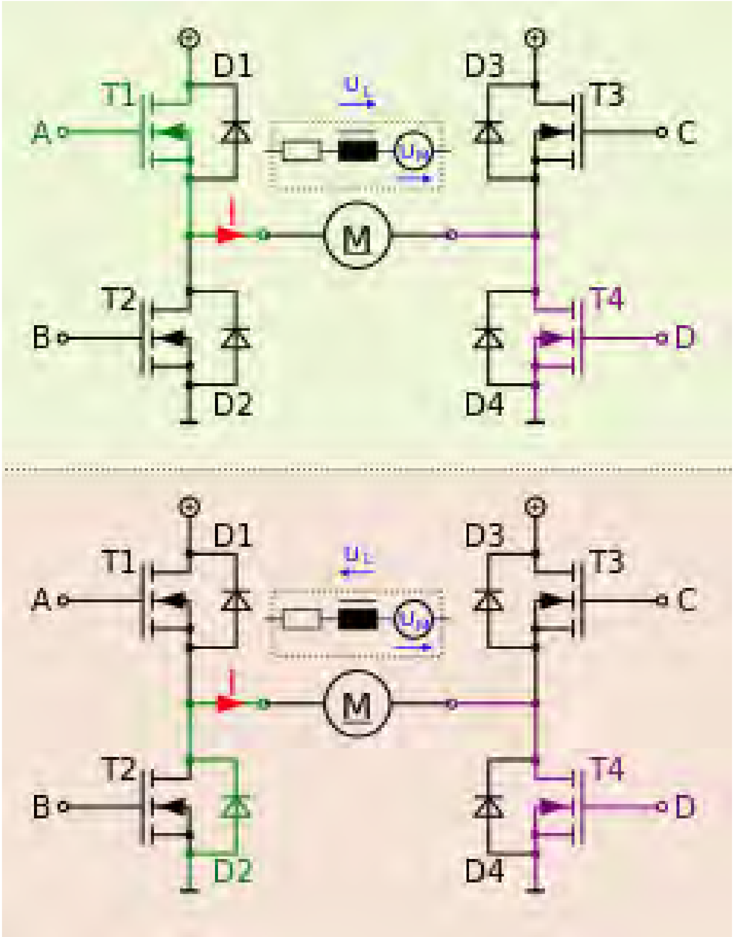
4 – The H-Bridge is integrated at the ECU. The output is a PWM-modulated voltage. The mean-value of the voltage is proportional to the motor speed.

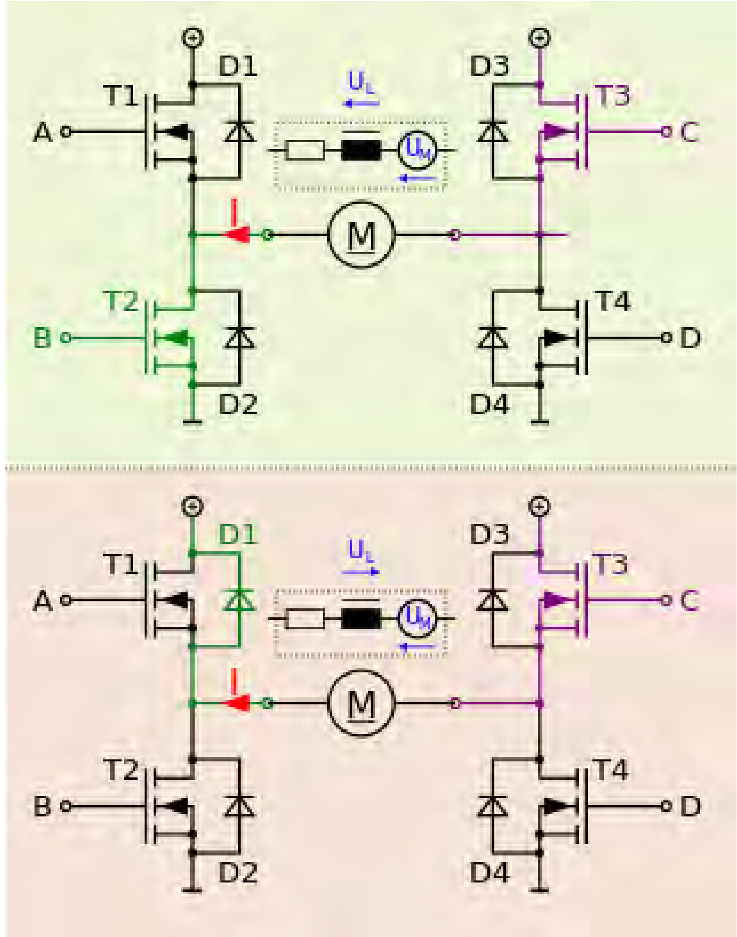
Co-funded by the Erasmus+ Programme of the European Union

H-Bridge

Quadrant 1 - accelerate forward

Quadrant 3 - accelerate backward





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

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

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: $u_{\mathrm{AB}} = u_{\mathrm{Kl30}} \cdot \mathrm{PWM}$

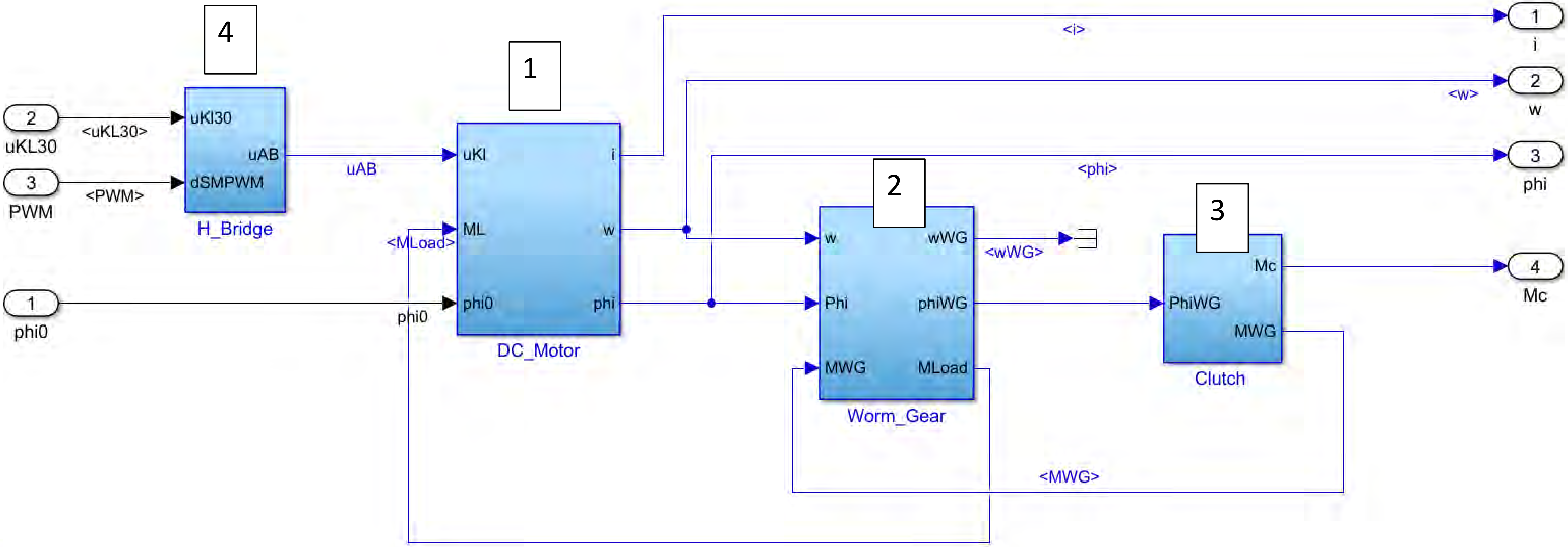
u_{AB} DC-Motor input voltage

u_{Kl30} Supply voltage

No resolution of pulsed voltage → short simulation time.

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

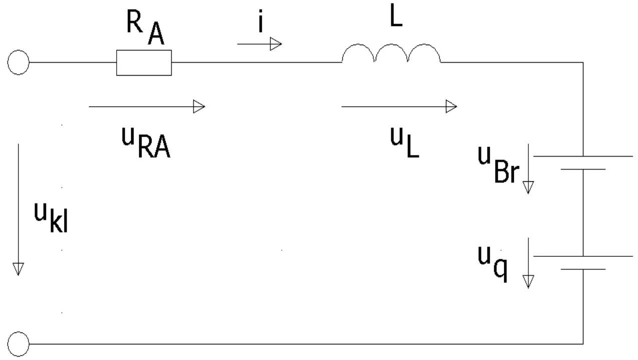
Plant Model



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

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

$u_{\mathrm{Br}} = f(i)$ → 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

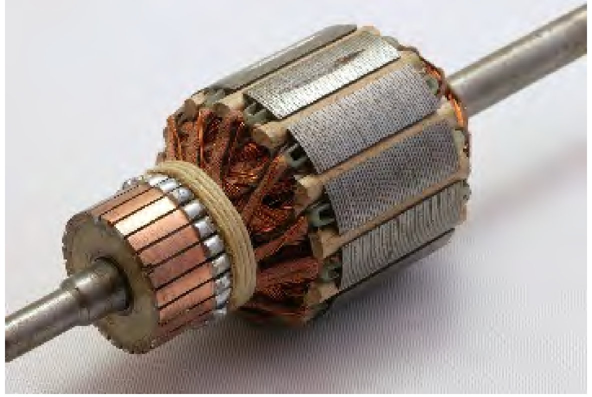
$$M_{\mathrm{el}} = k_{\mathrm{T}} \cdot i \qquad (6)$$

3.) mechanical system

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

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

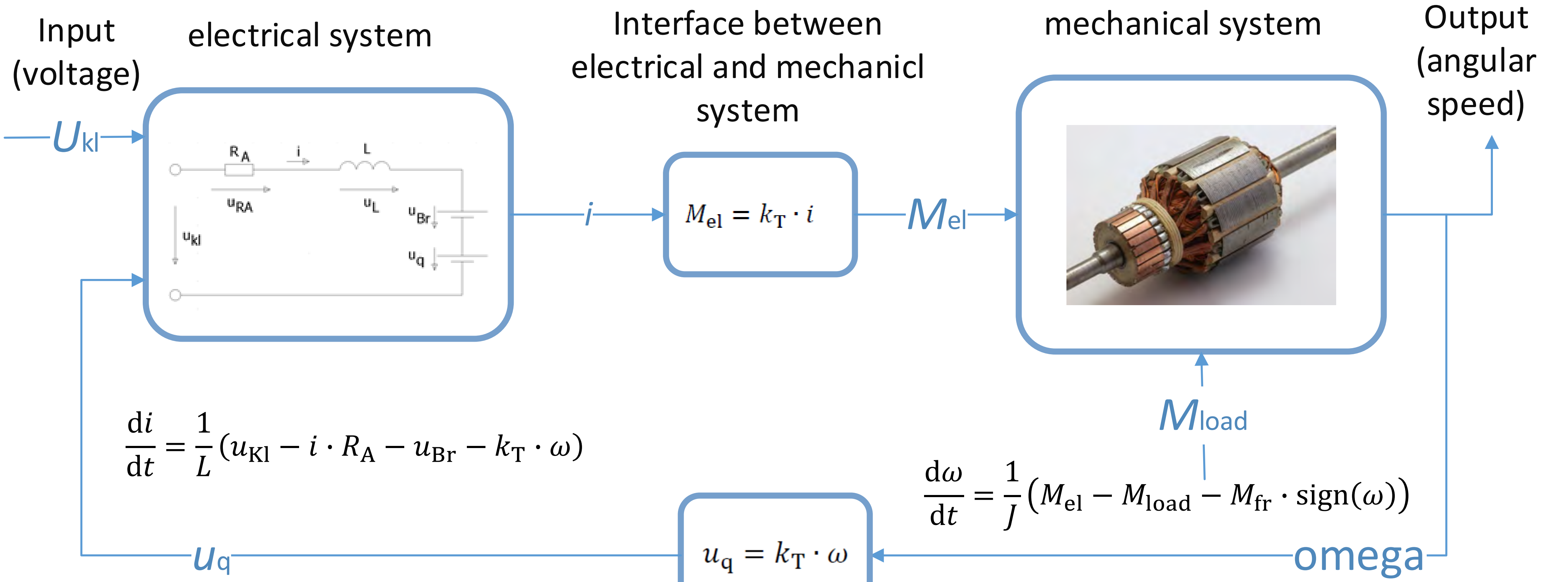
(7)



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

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

Scheme of model



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

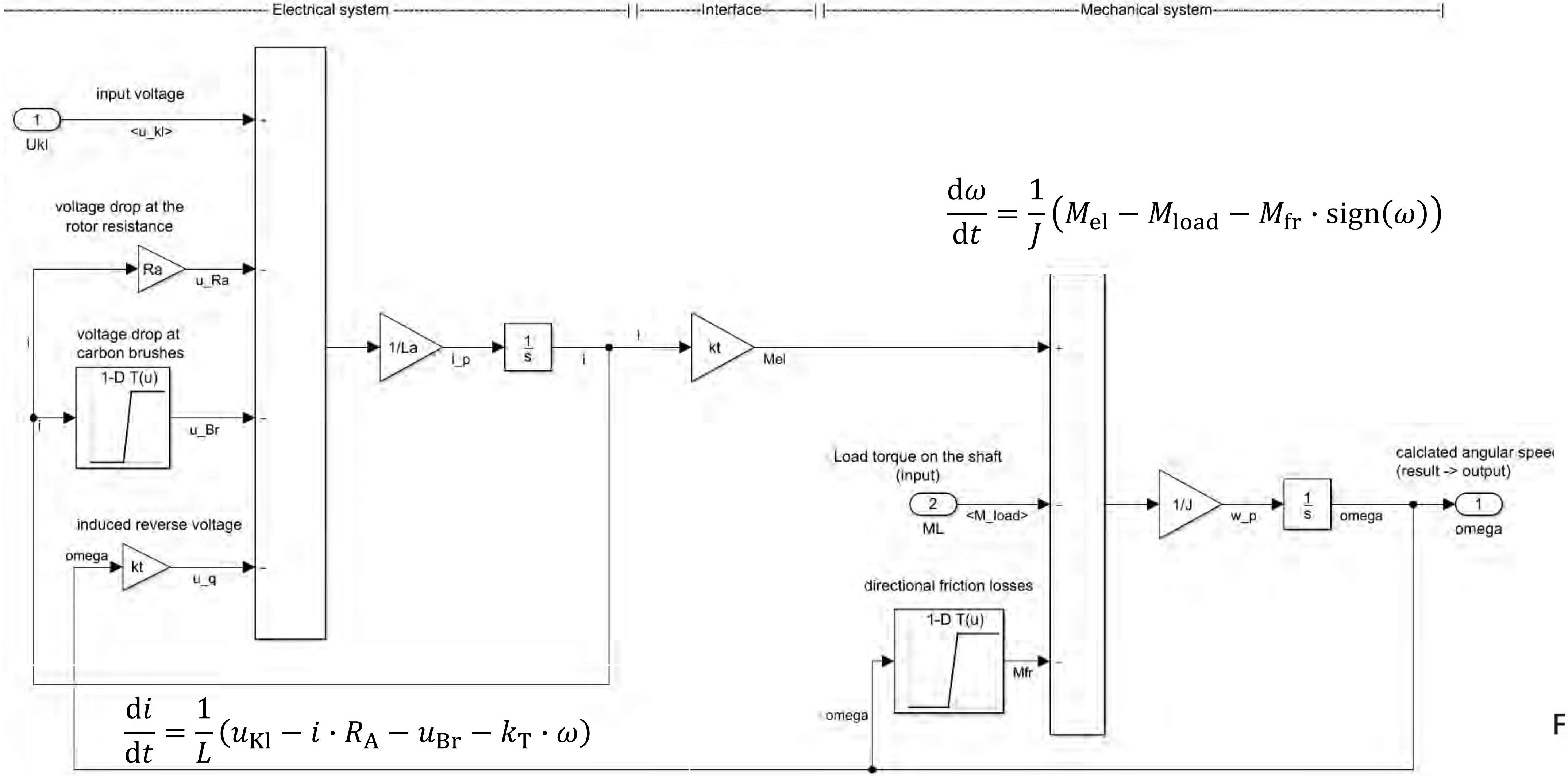
$$\frac{\mathrm{d}\omega}{\mathrm{d}t} = \frac{1}{J}\left(M_{el} - M_{load} - M_{fr} \cdot \mathrm{sign}(\omega)\right)$$

Author: T. Lechner

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

Simulink model

Author: T. Lechner

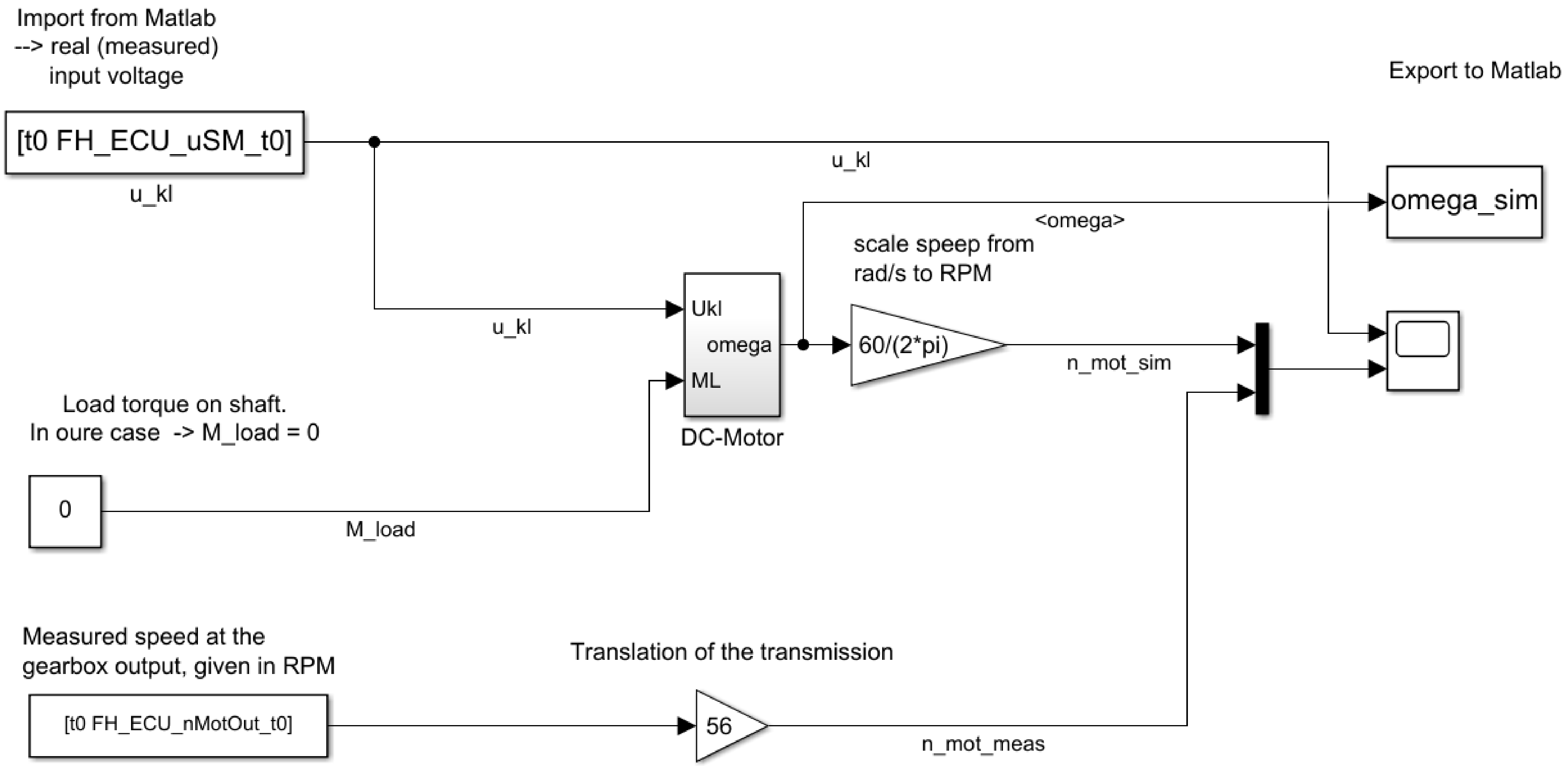


$$\frac{\mathrm{d}\omega}{\mathrm{d}t} = \frac{1}{J}\left(M_{\mathrm{el}} - M_{\mathrm{load}} - M_{\mathrm{fr}} \cdot \mathrm{sign}(\omega)\right)$$

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

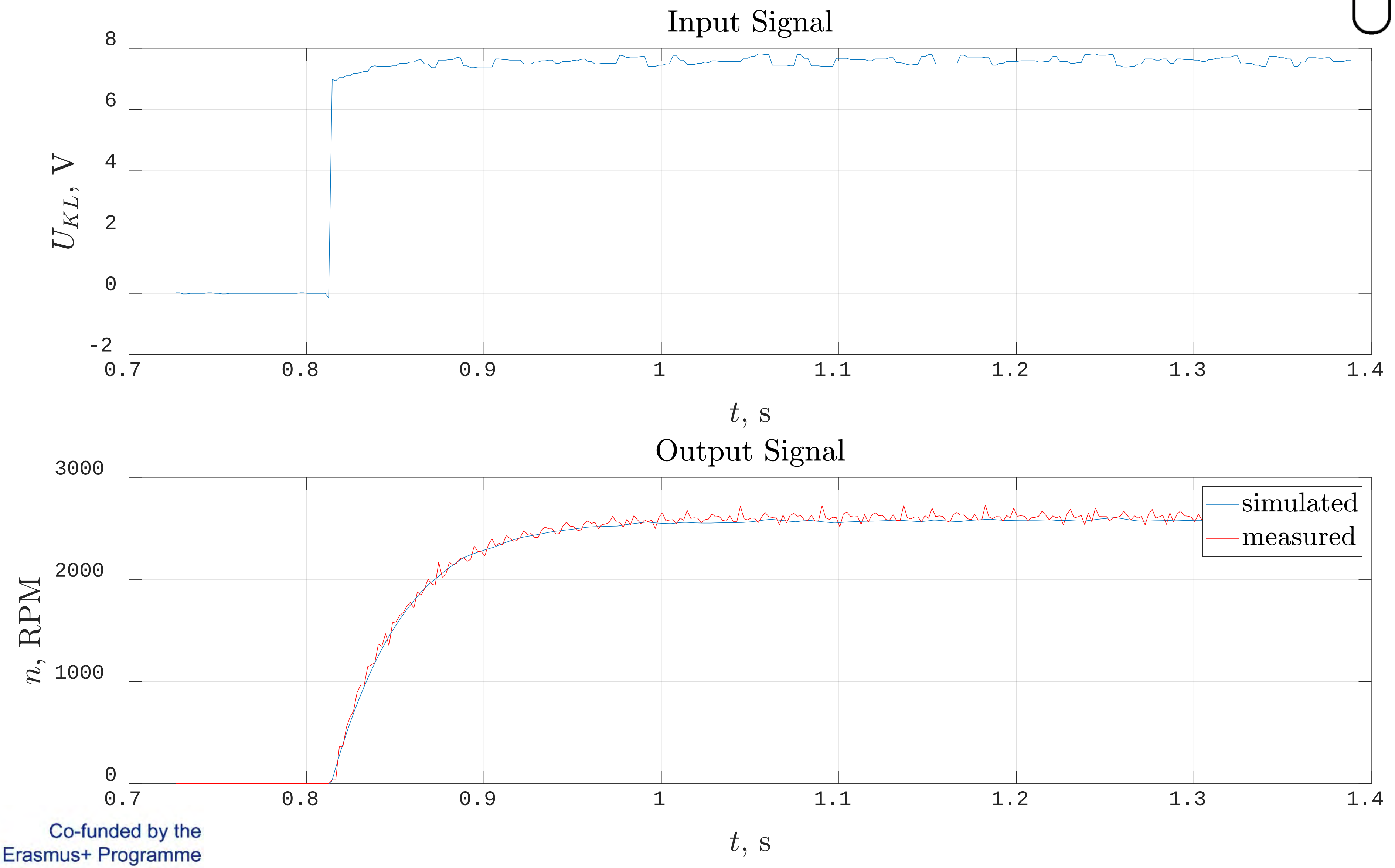
K. Reisinger

Find Parameters



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

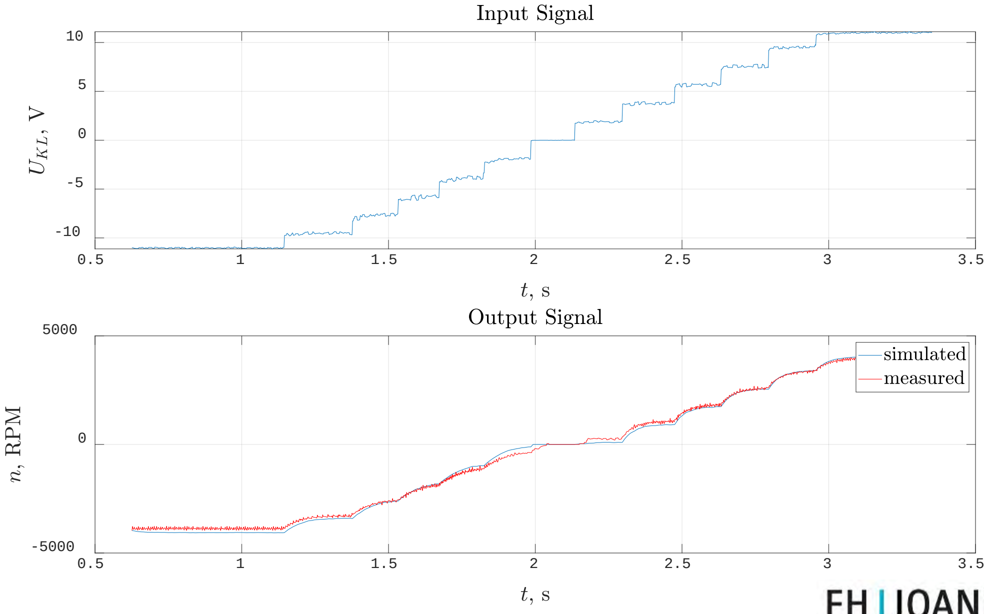
Find Parameters



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

Validate the model

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

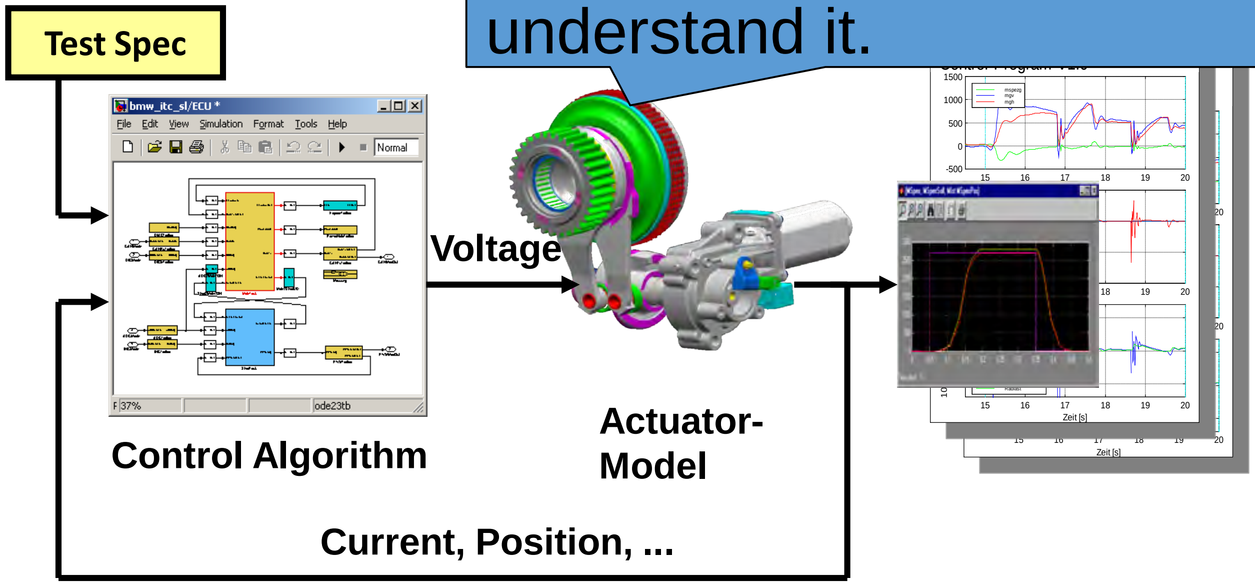


Co-funded by the
Erasmus+ Programme
of the European Union

Model In The Loop

Task: Put the reality to a simulation model

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



Test Spec

Voltage

Control Algorithm

Actuator-Model

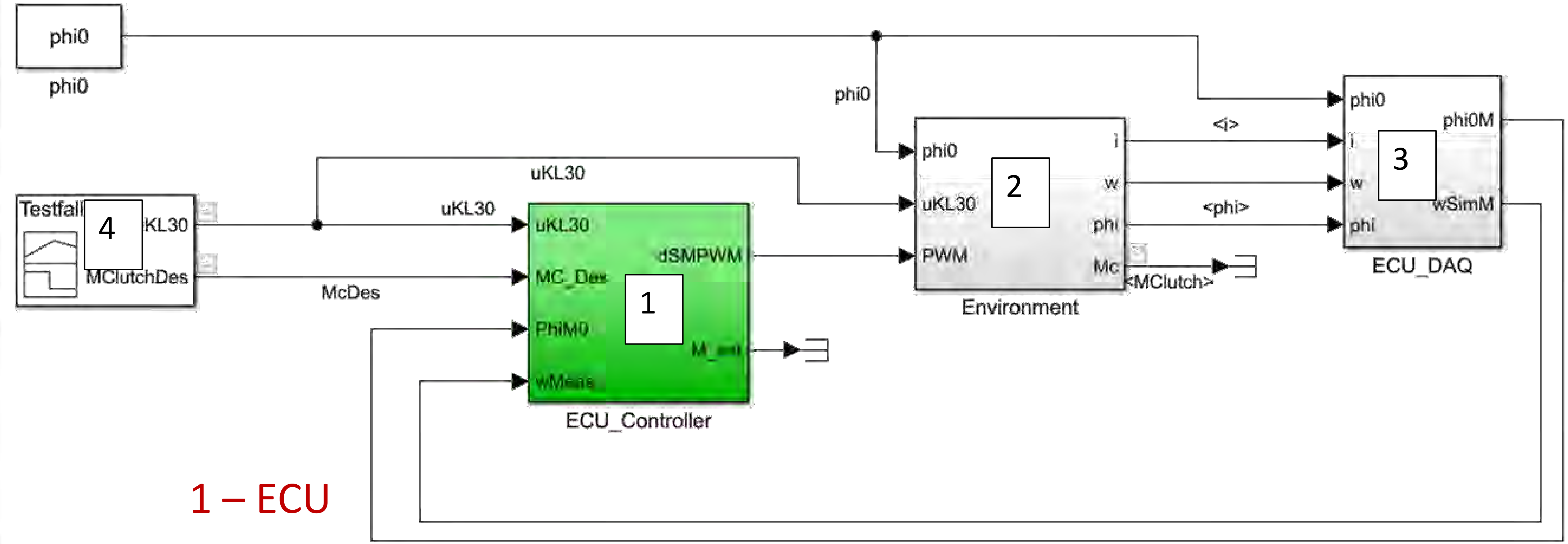
Current, Position, ...

Any plant model can not be destroyed by missuses ☺

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

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

Modell in the Loop – Top View



1 – ECU

2 – Plant-model (Environment)

3 – Data acquisition

4 – Stimulus (Simulink: `Signal Generator`)

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

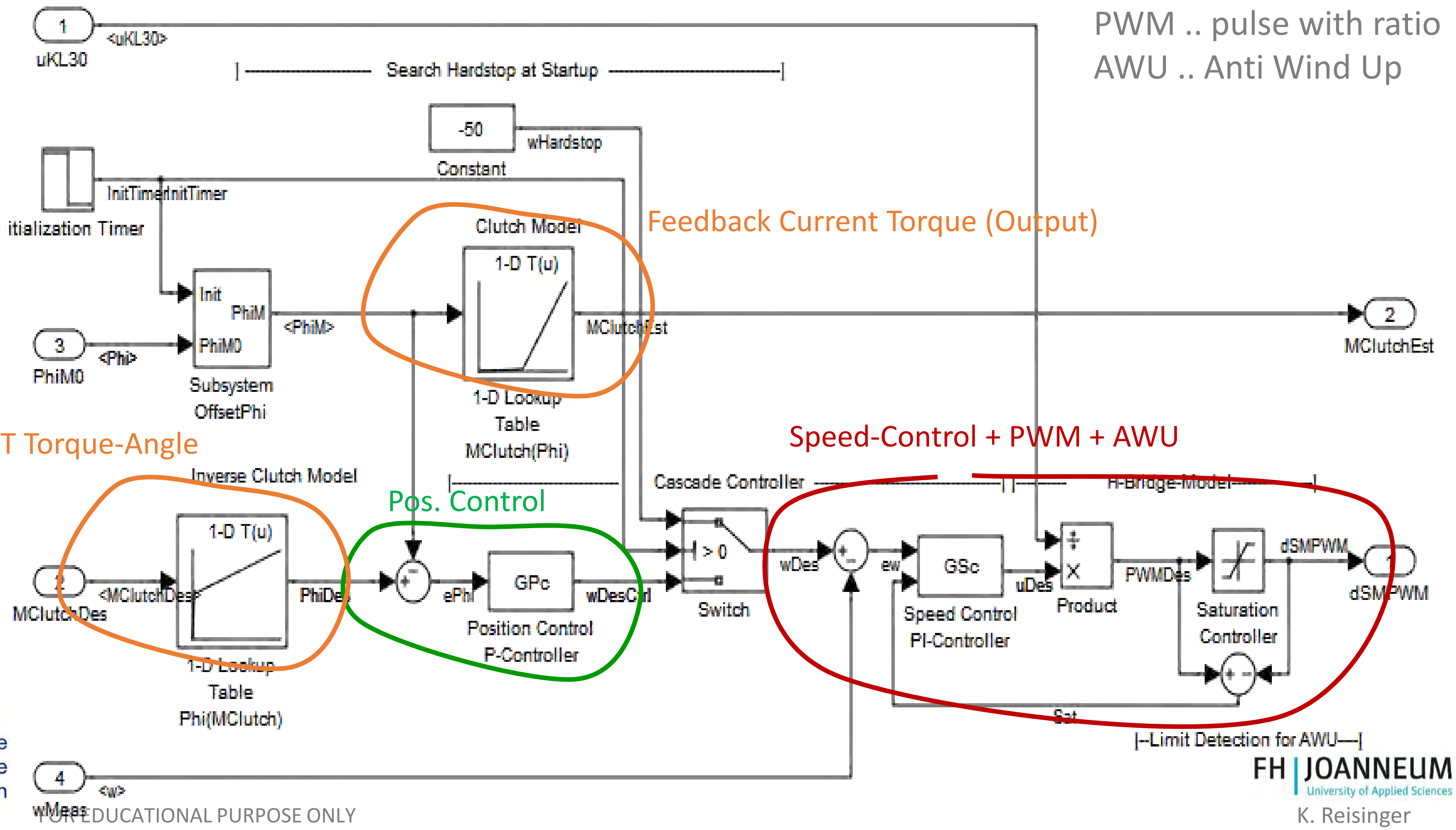
Requirements for Position based Clutch Control Software

- 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

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

Simple Torque Controller

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



Feedback Current Torque (Output)

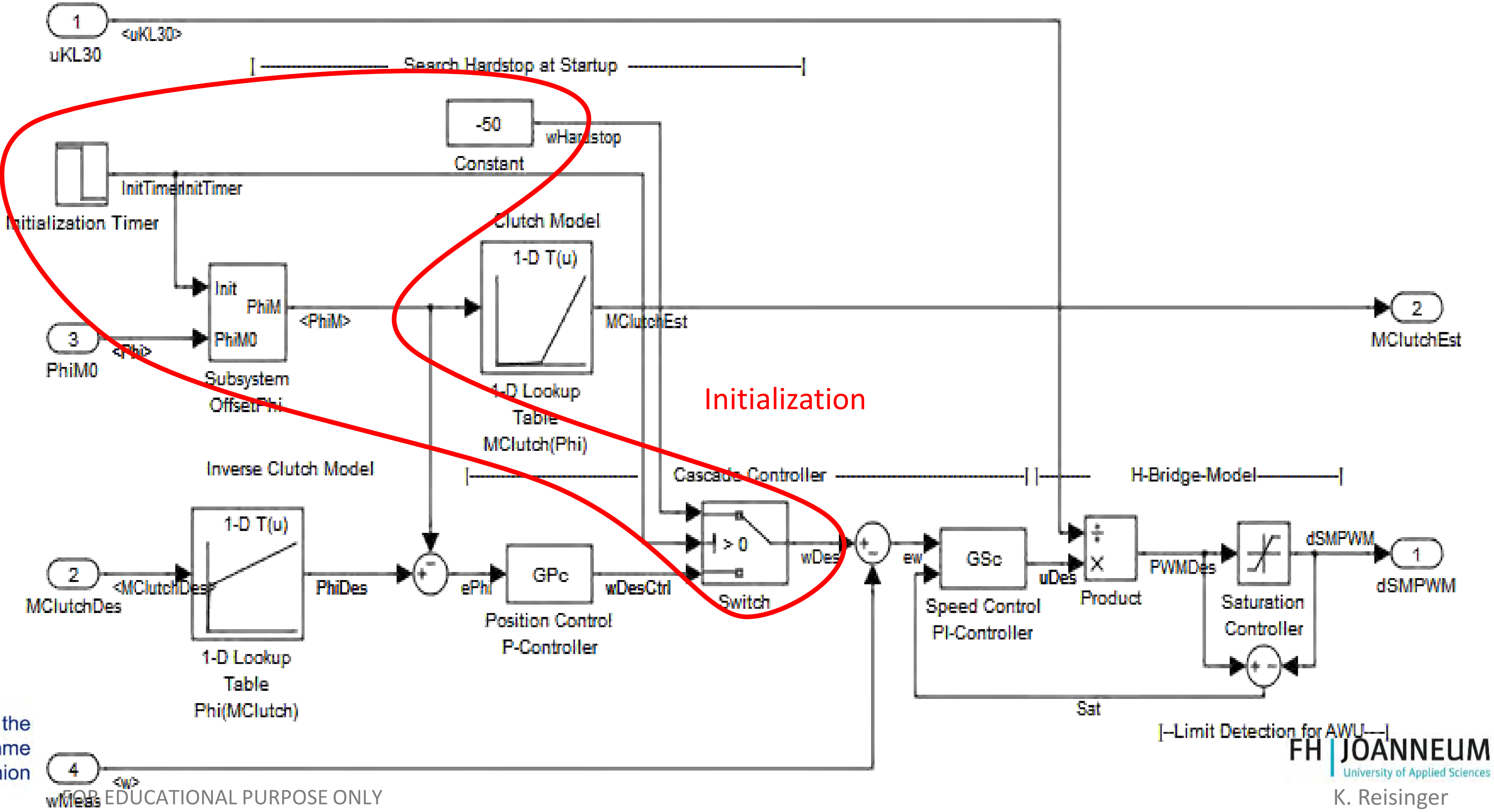
LUT Torque-Angle

Pos. Control

Speed-Control + PWM + AWU

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

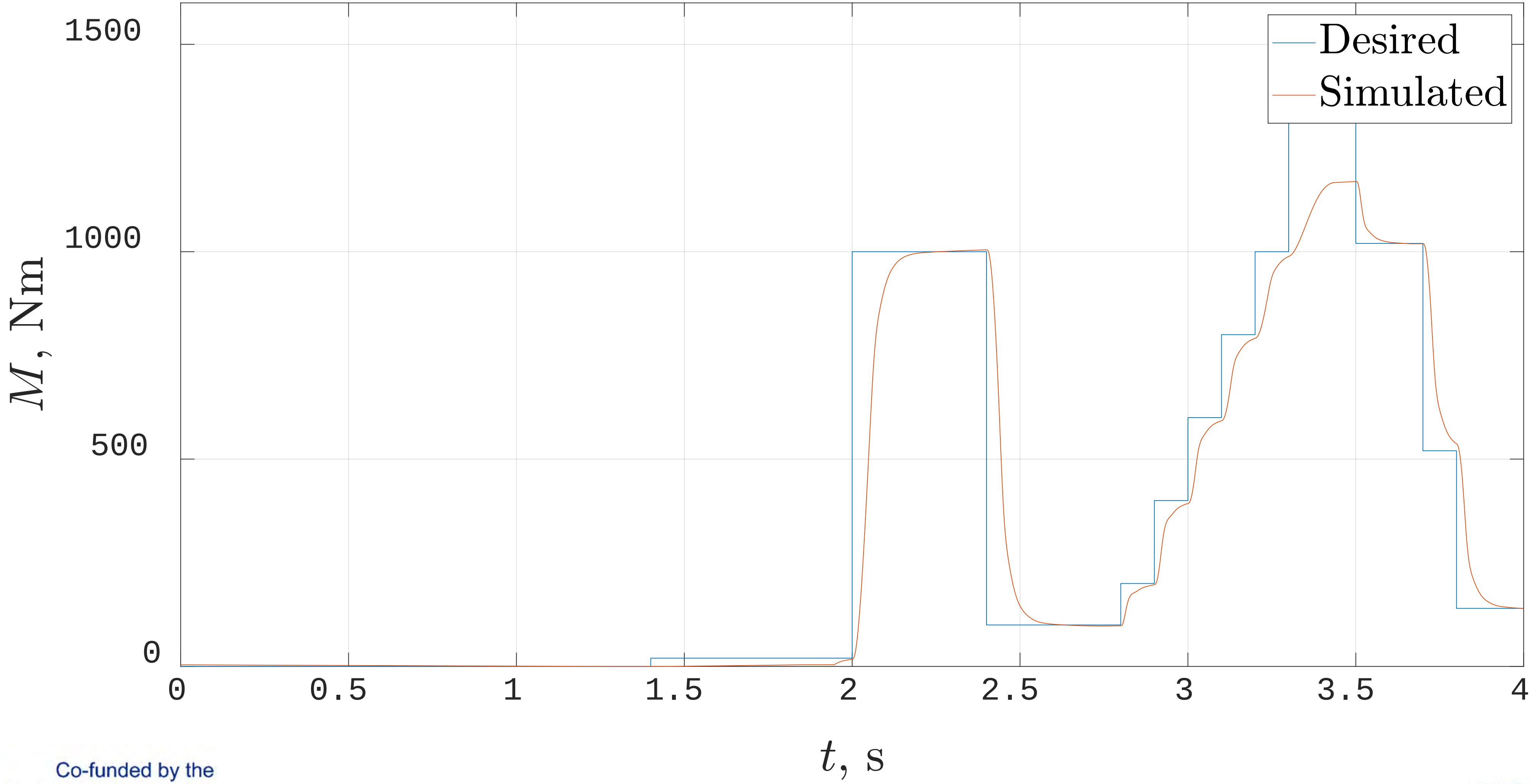
Torque Controller – Init by hard stop



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

FH JOANNEUM University of Applied Sciences

Torque Control-MIL Result

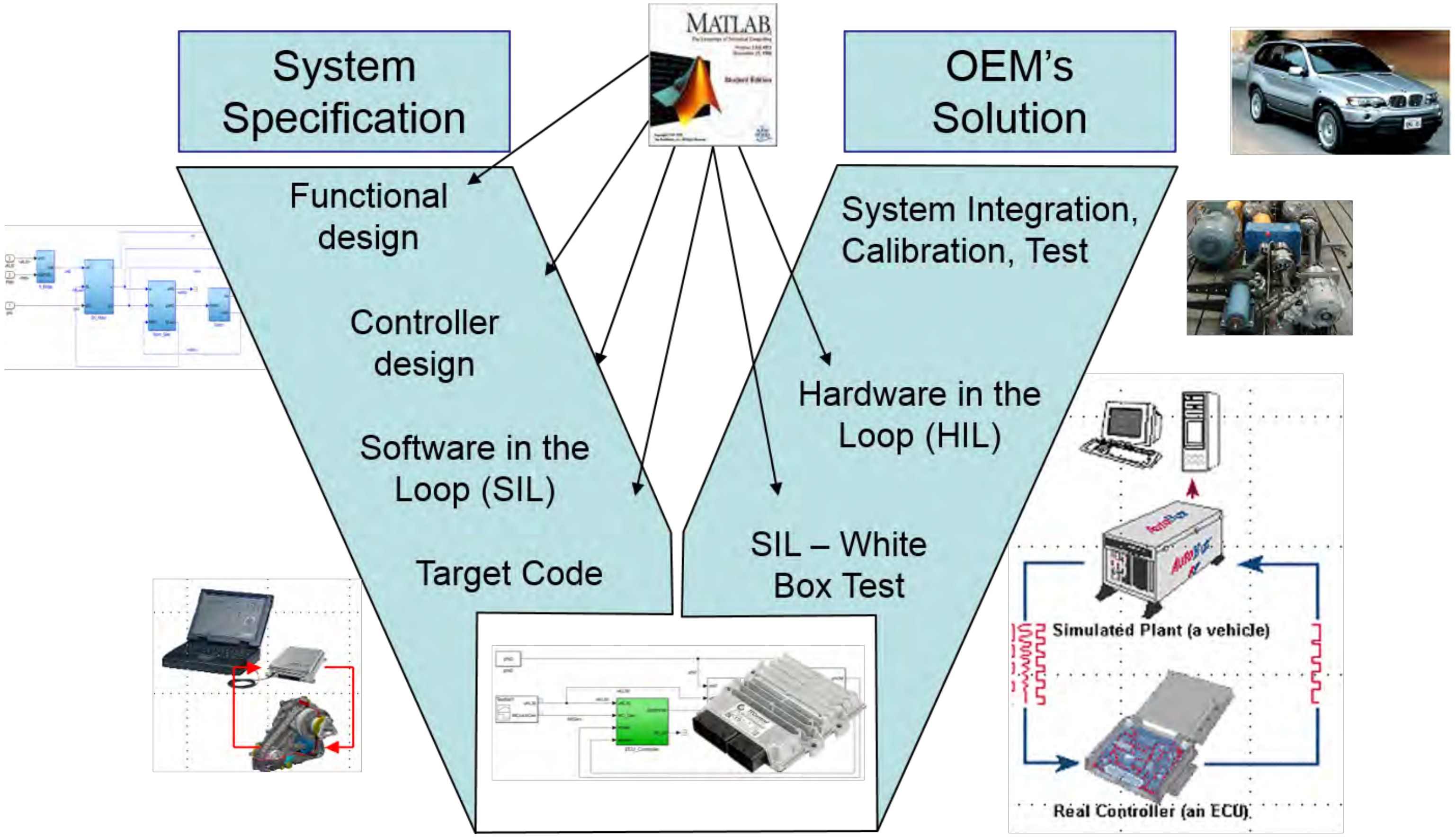


Co-funded by the Erasmus+ Programme of the European Union

FOR EDUCATIONAL PURPOSE ONLY

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



System Specification

Functional design

Controller design

Software in the Loop (SIL)

Target Code

SIL – White Box Test

Hardware in the Loop (HIL)

System Integration, Calibration, Test

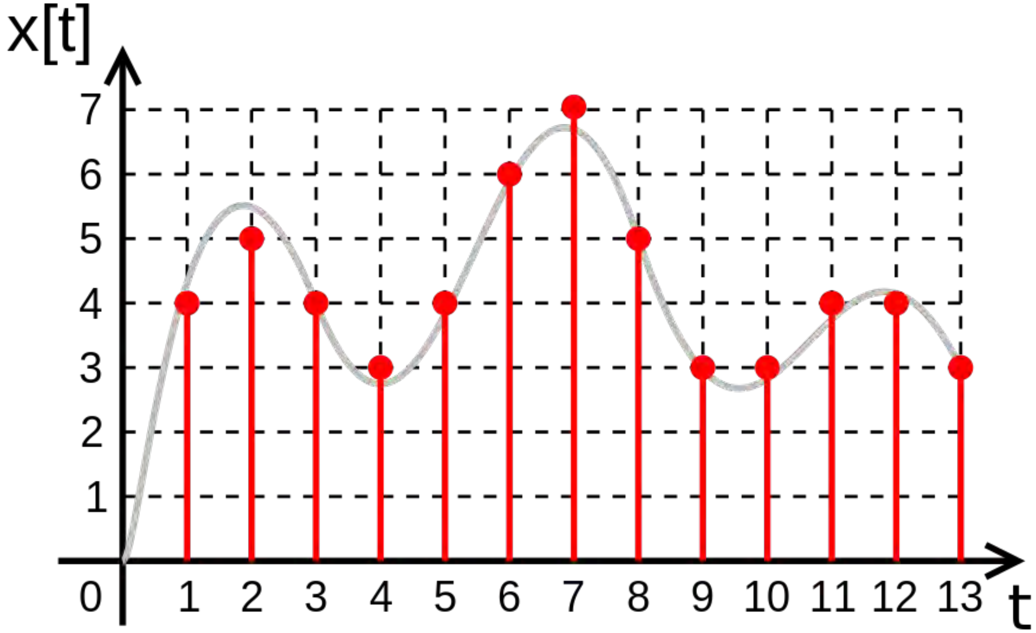
OEM’s Solution

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

Analog-Digital-Conversion (Sampling)

- Discrete Time → Sample Time
- Discrete Amplitude → Quantizing

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



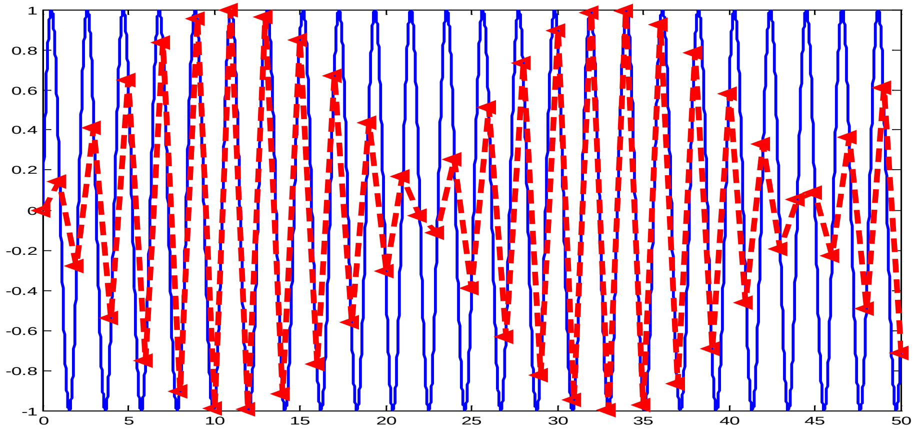
Co-funded by the Erasmus+ Programme of the European Union

Aliasing

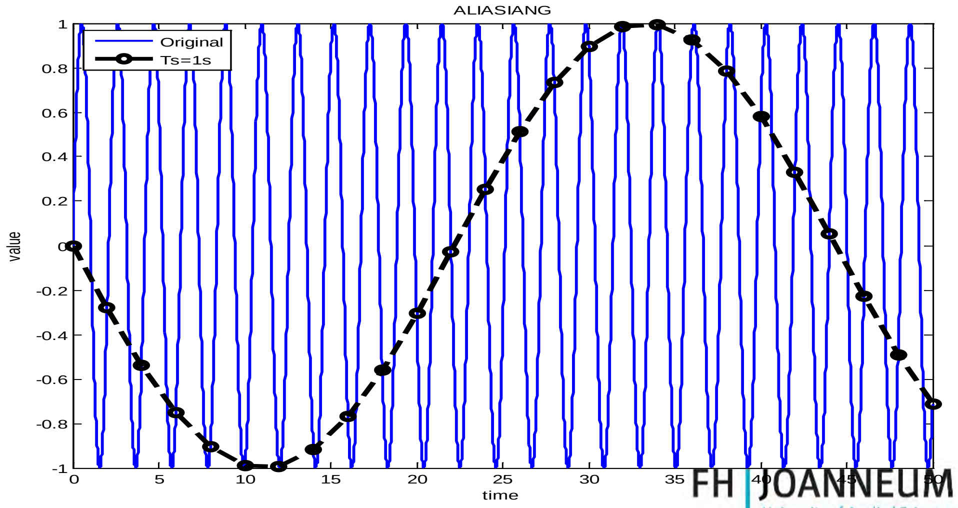
- Nyquist-Shannon-Theorem

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

- 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

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

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

5 Bit used

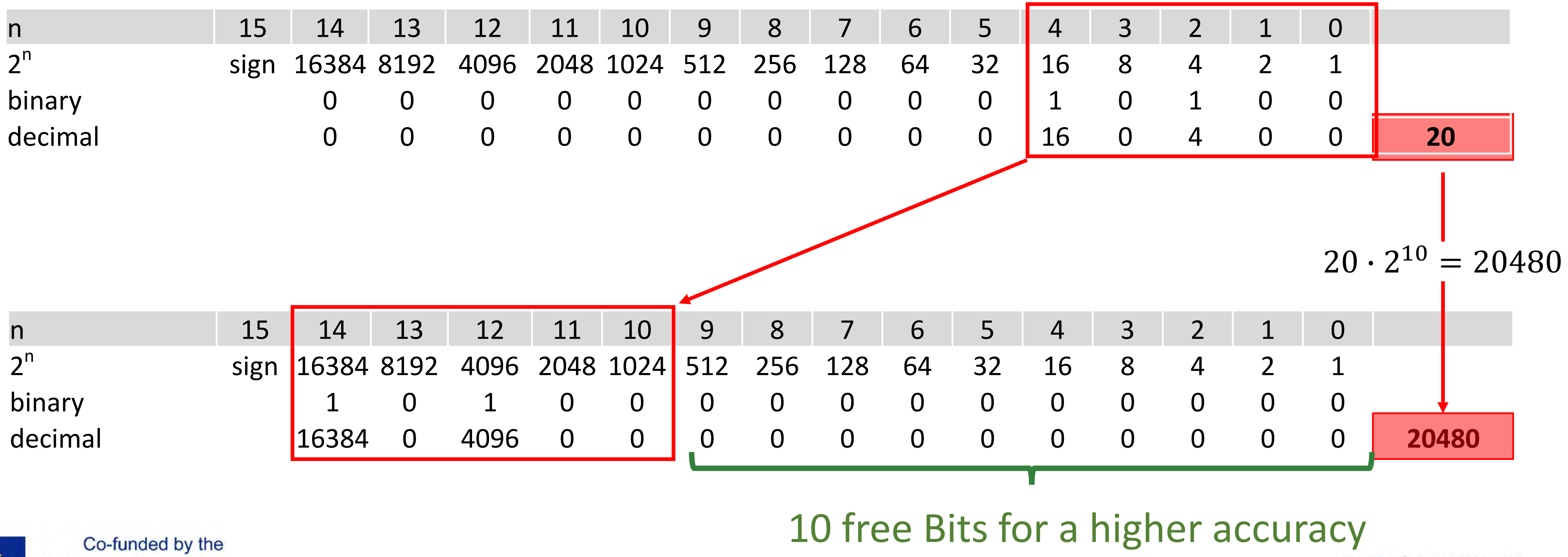
Bit 15 - sign:

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**

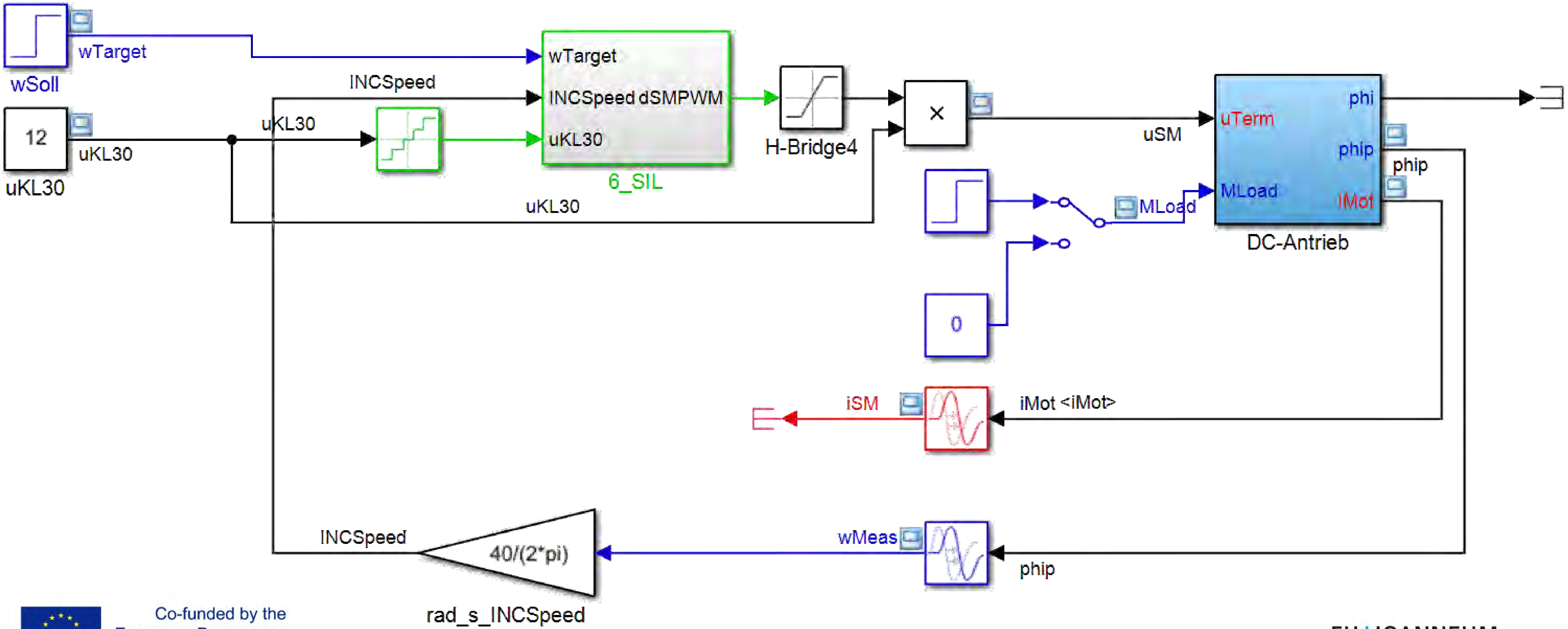
$$20 \cdot 2^{10} = 20480$$

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

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

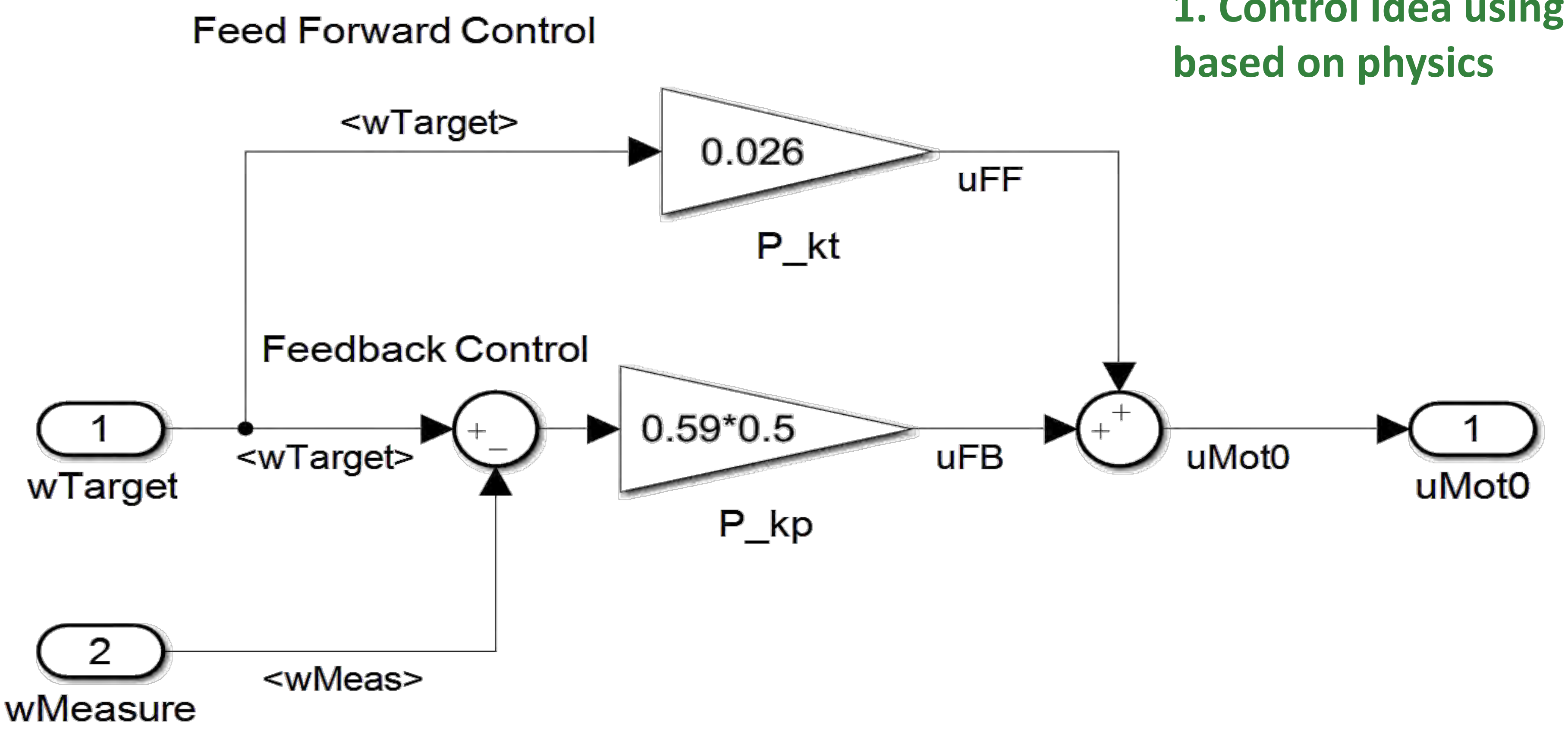
SIL-Model – Top view



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

Simple Speed Controller – 1^{st} MIL-Model

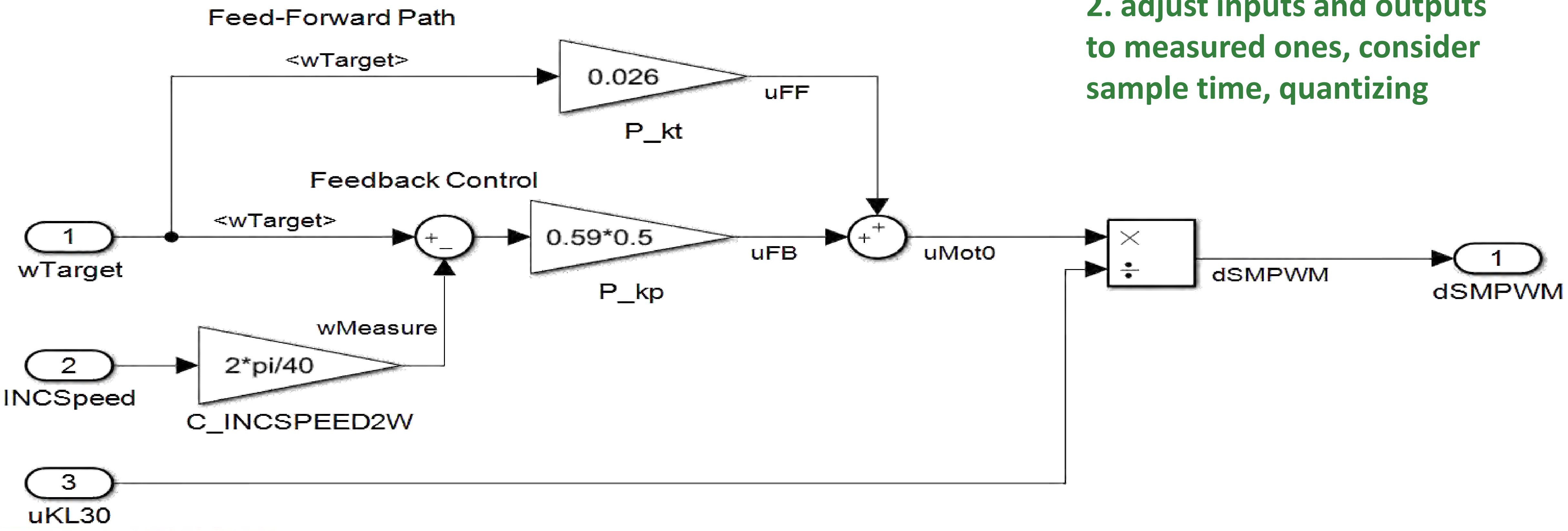
1. Control Idea using signals based on physics



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

Simple Speed Controller – 2nd MIL-Model

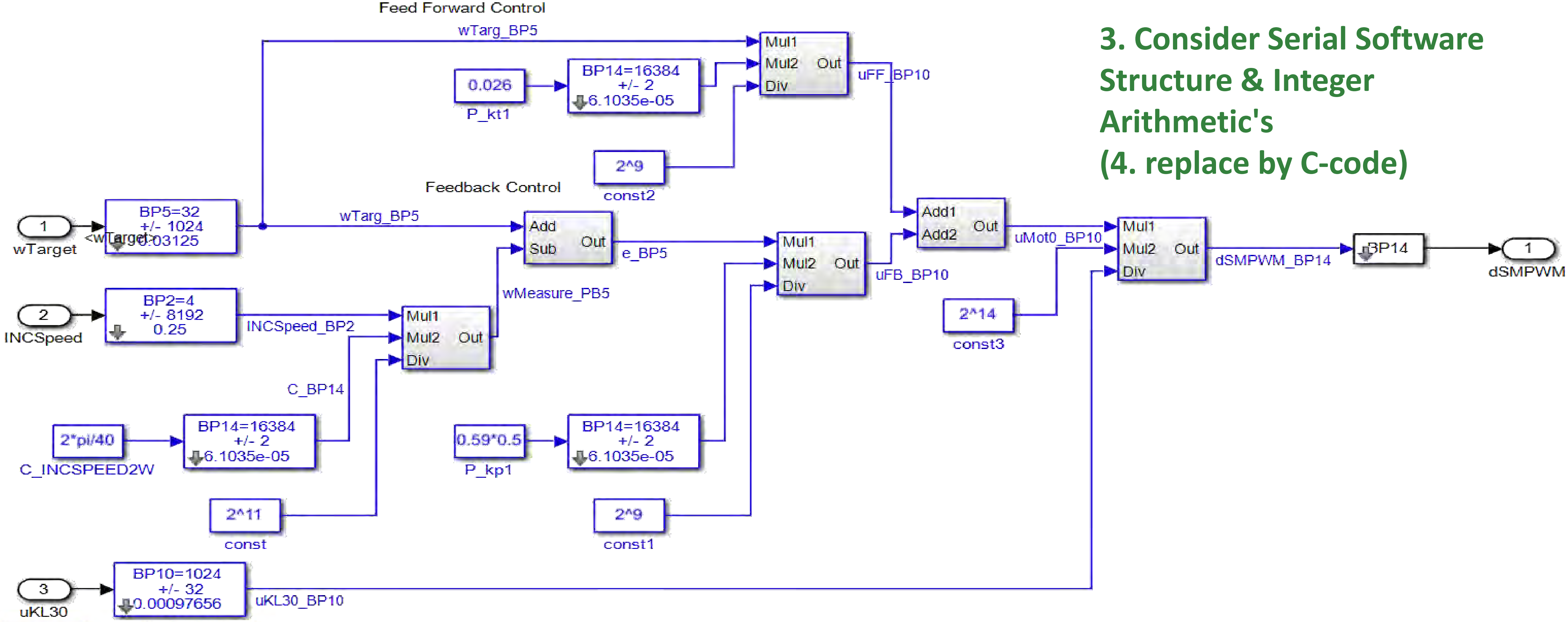
--- HAL-Input Layer--|-------- Modelling Physics ---------------------------|--- HAL-Output Layer-------------------------



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

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

Simple Speed Controller - SIL-Model

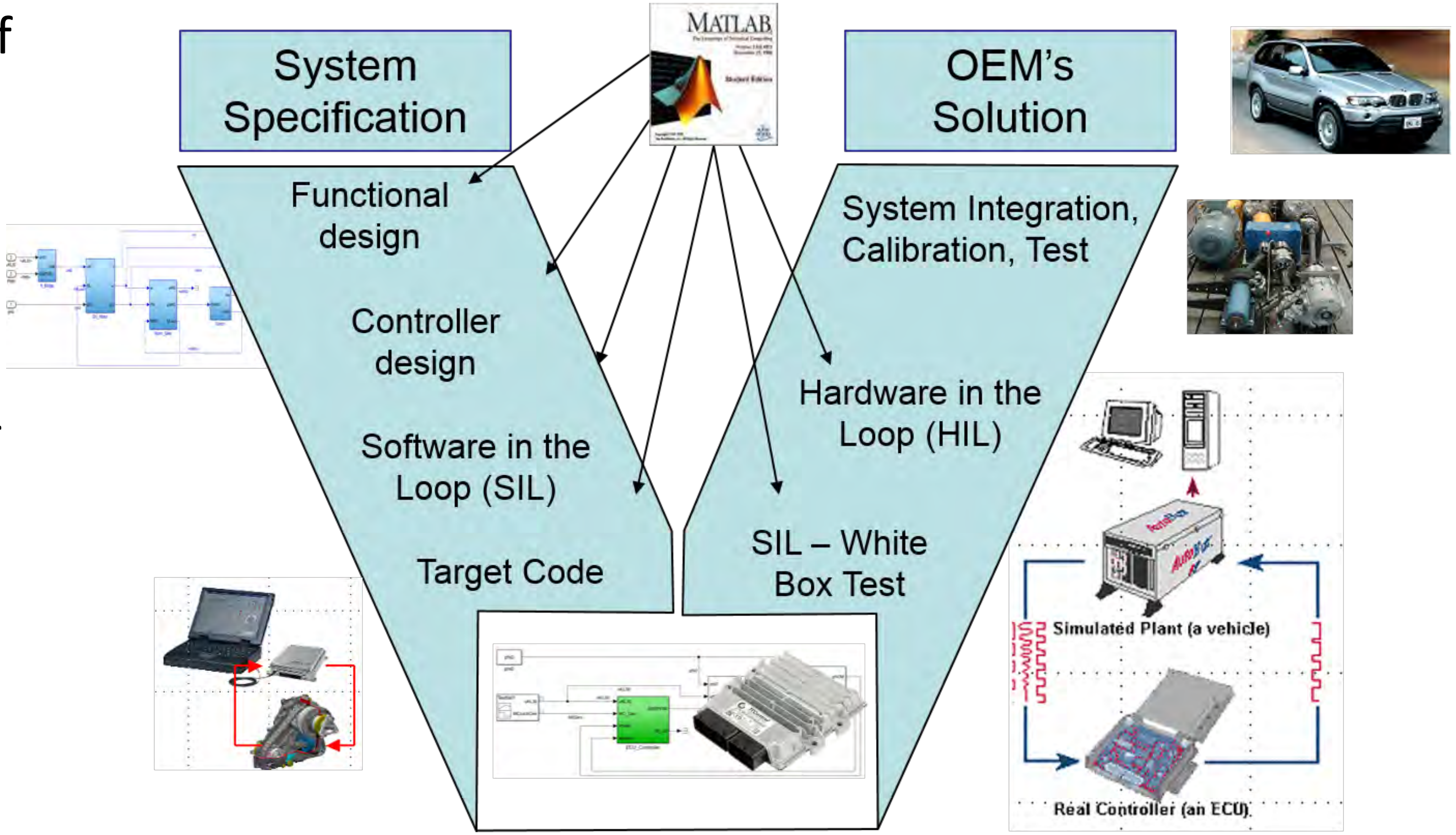


3. Consider Serial Software Structure & Integer Arithmetic's
(4. replace by C-code)

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

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).



System Specification

OEM's Solution

Functional design

Controller design

Software in the Loop (SIL)

Target Code

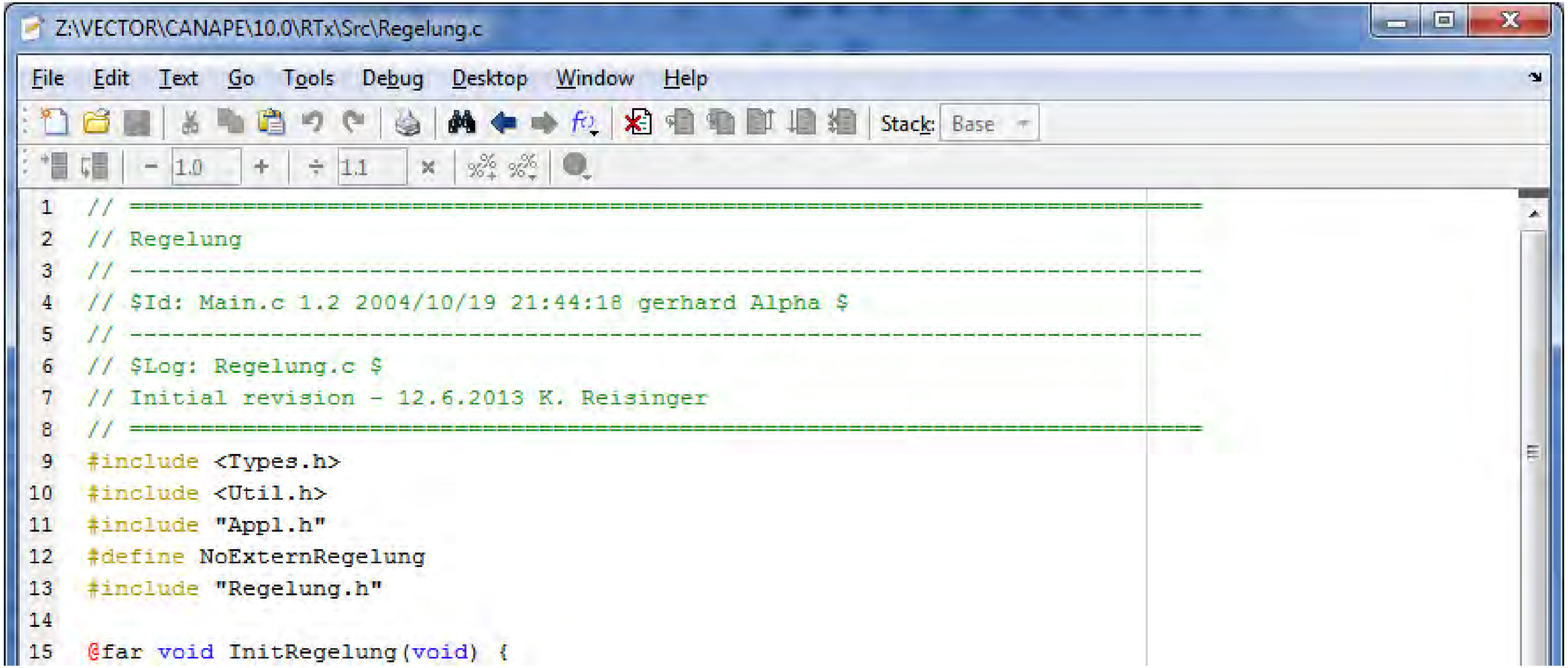
System Integration, Calibration, Test

Hardware in the Loop (HIL)

SIL – White Box Test

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

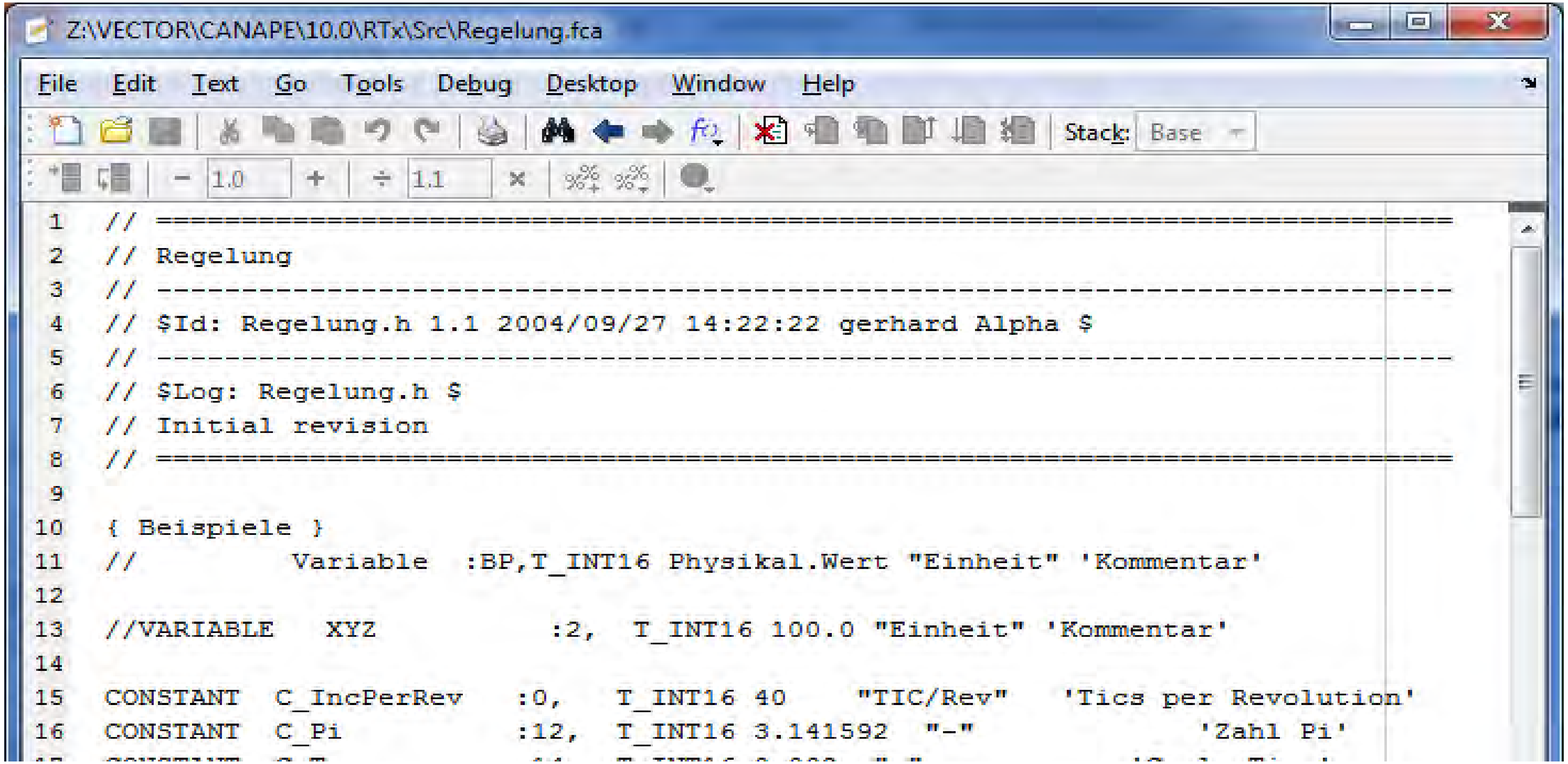
Demo C-Code



```c
// ============================================================================
// 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) {
```

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

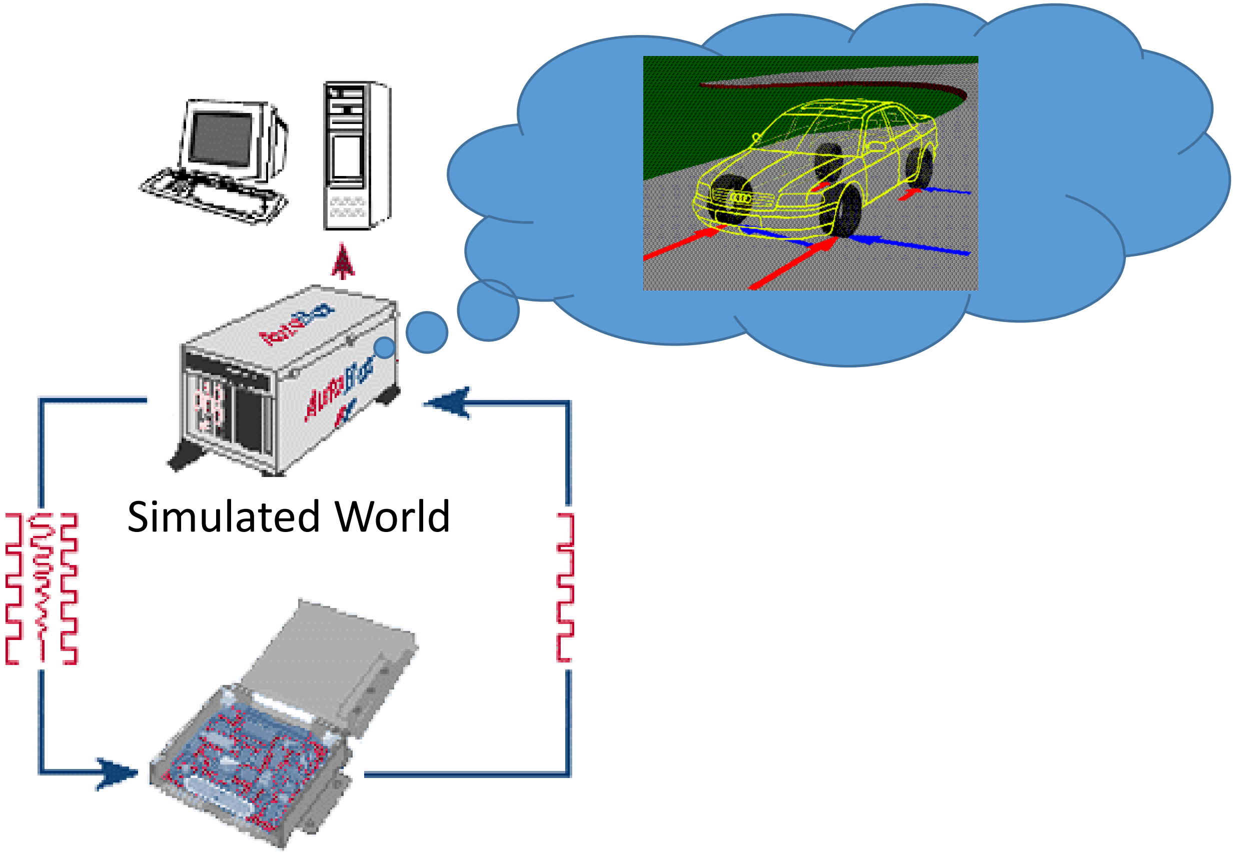
Definition of ASAM-2-Data



```
// ==============================================================================
// 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'
```

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

Software Integration Test - HIL



Simulated World

Real ECU (DUT)

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!

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

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

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.

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

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.

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

Our next steps 1

Simulink-Coded Rapid Prototype System

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

→Starting next Semester

→next Chapter

https://www.ttcontrol.com

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

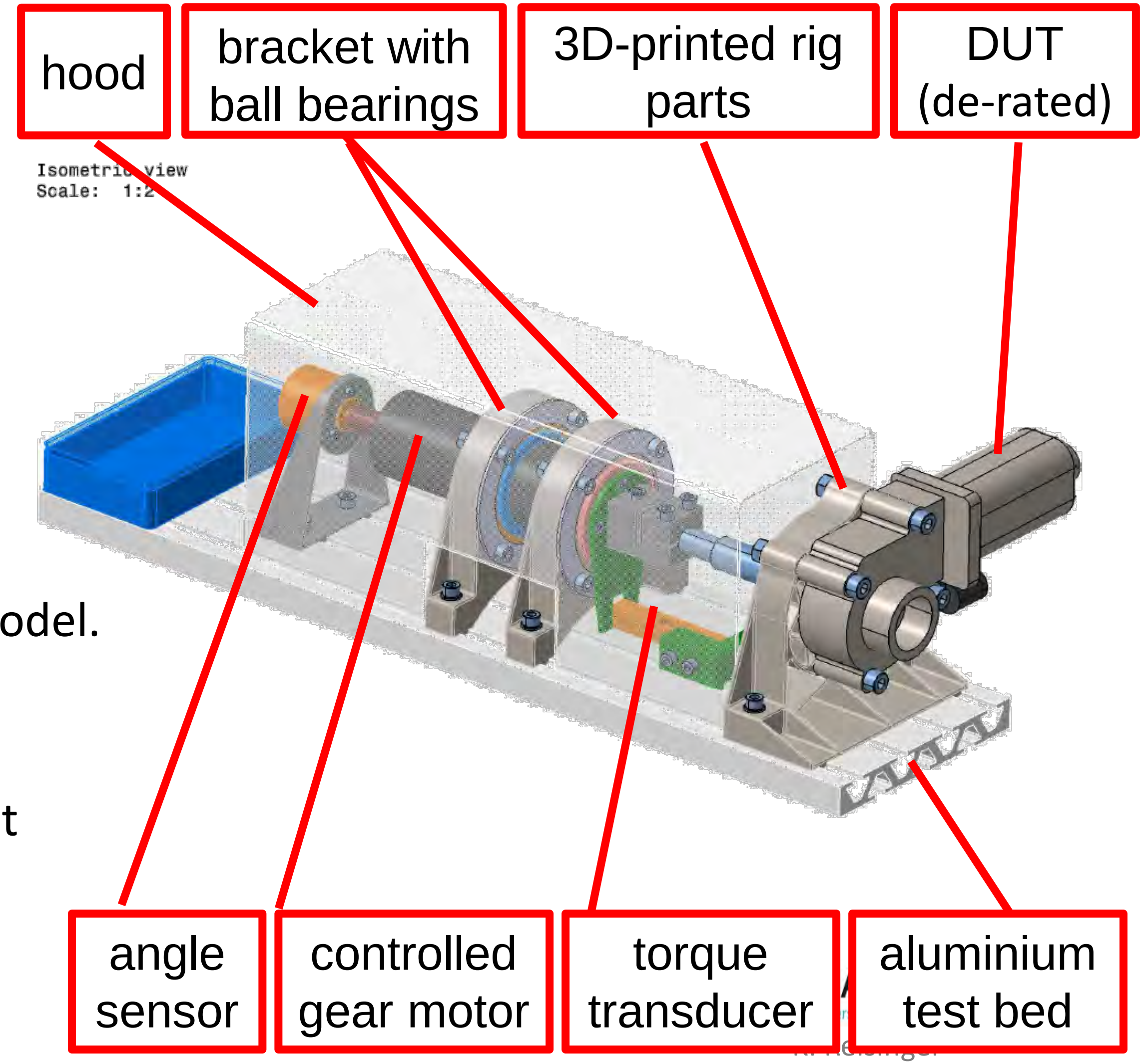
Our next steps 2

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.



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

UNITED

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

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

The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. 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

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

Choosing the ECU

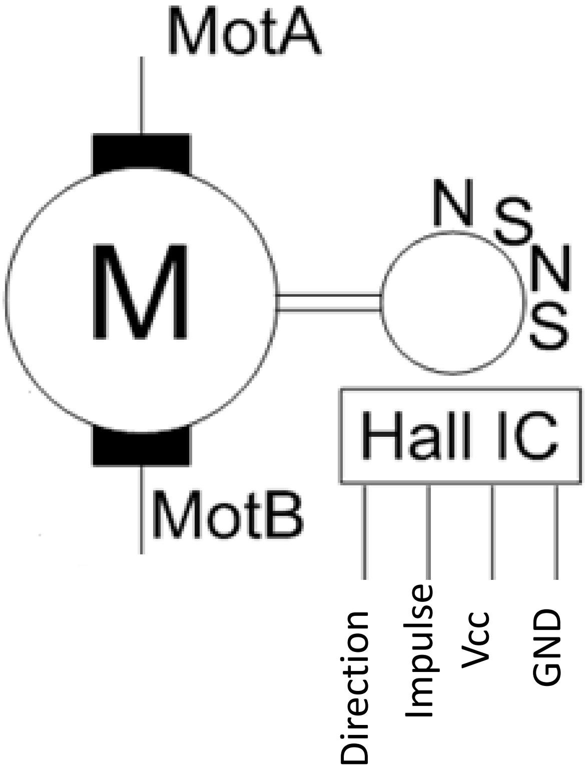
- Interfaces
  - Communication between ECU and environment
    - CAN-Interface
  - ECU application
    - Can Calibration Protocol (CCP)

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

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

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

Speed Measurement → Timer

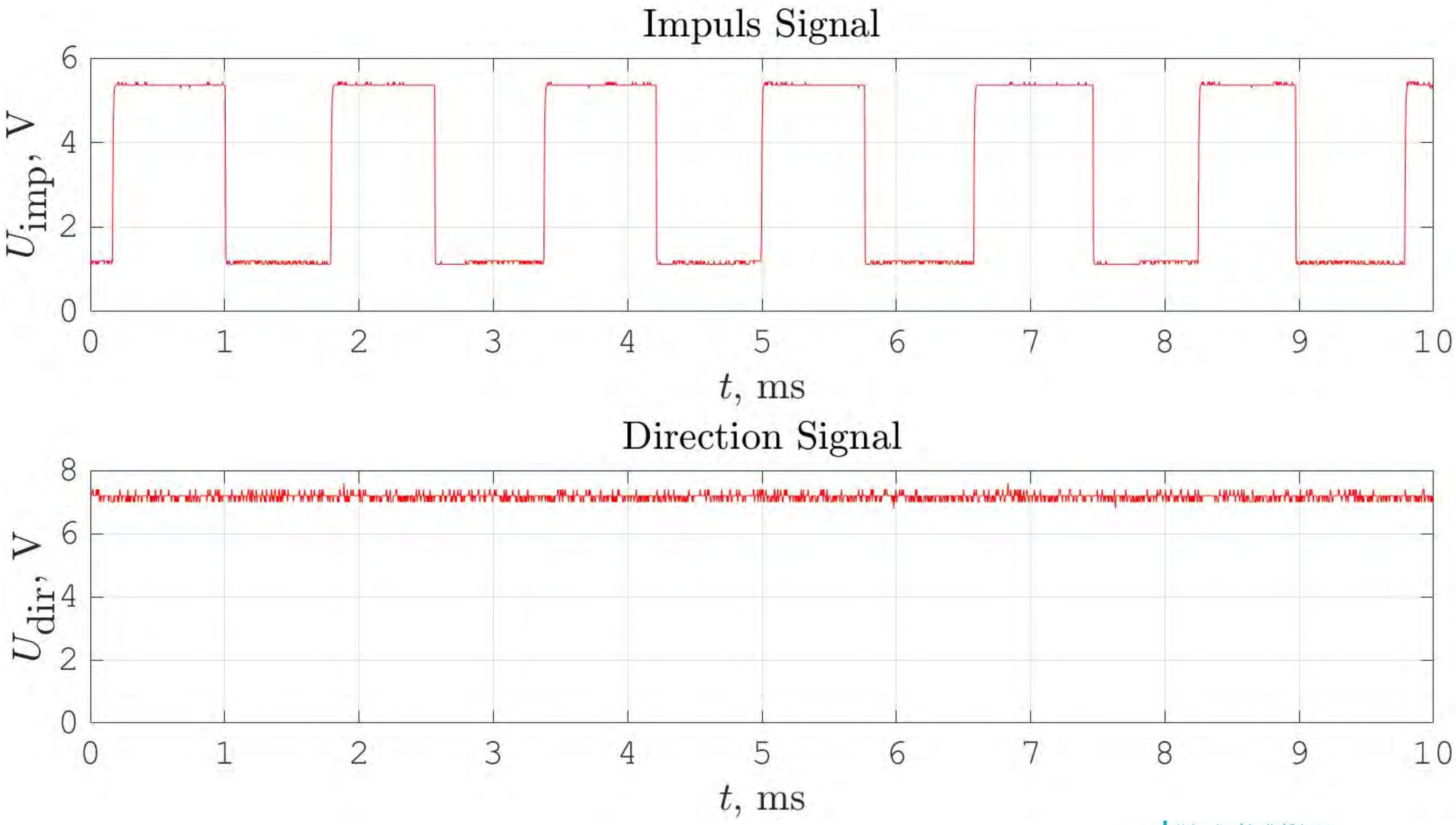
Speed measurement with timer input:

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

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.



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

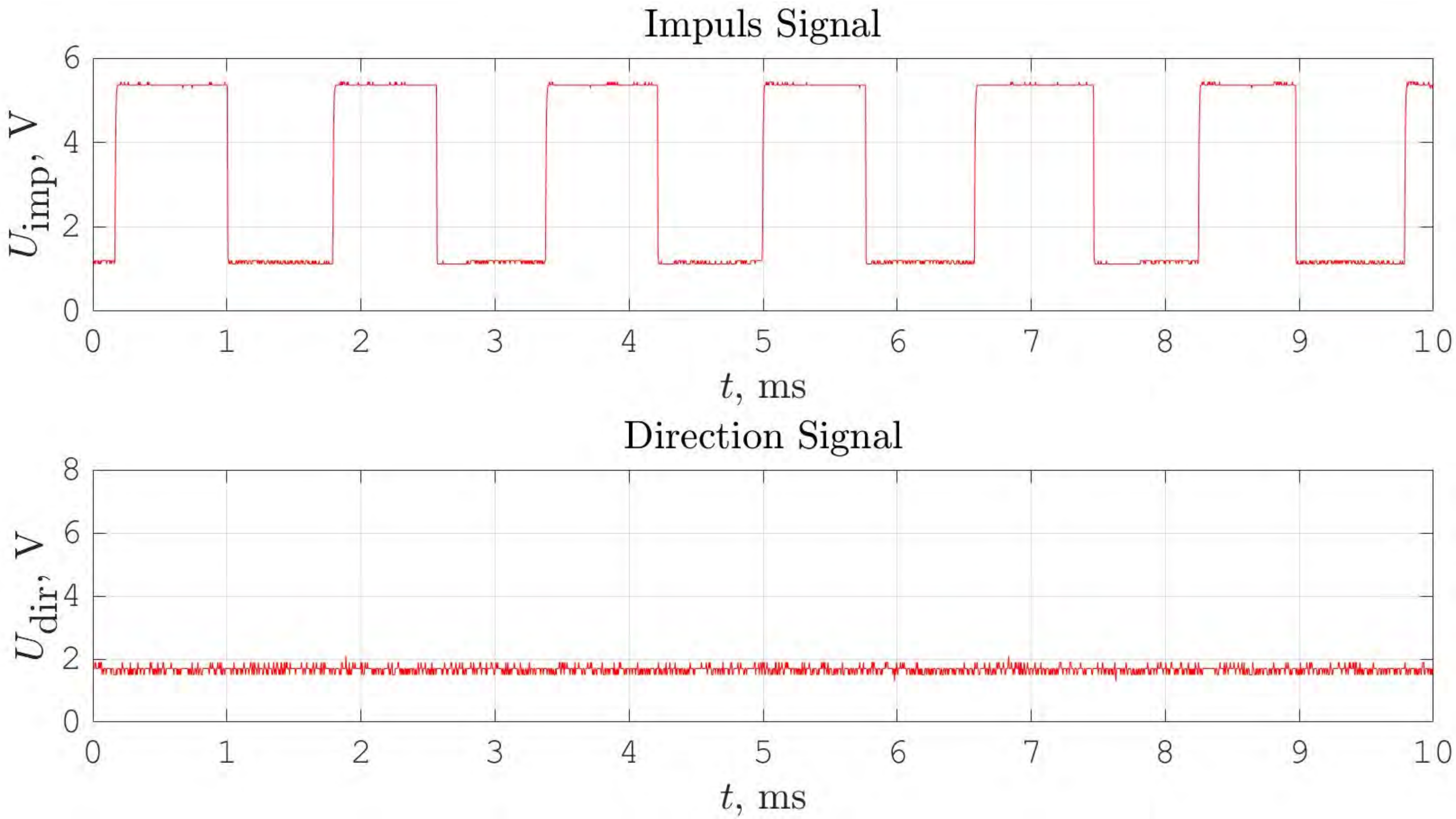
Position using Direction → Counter

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



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

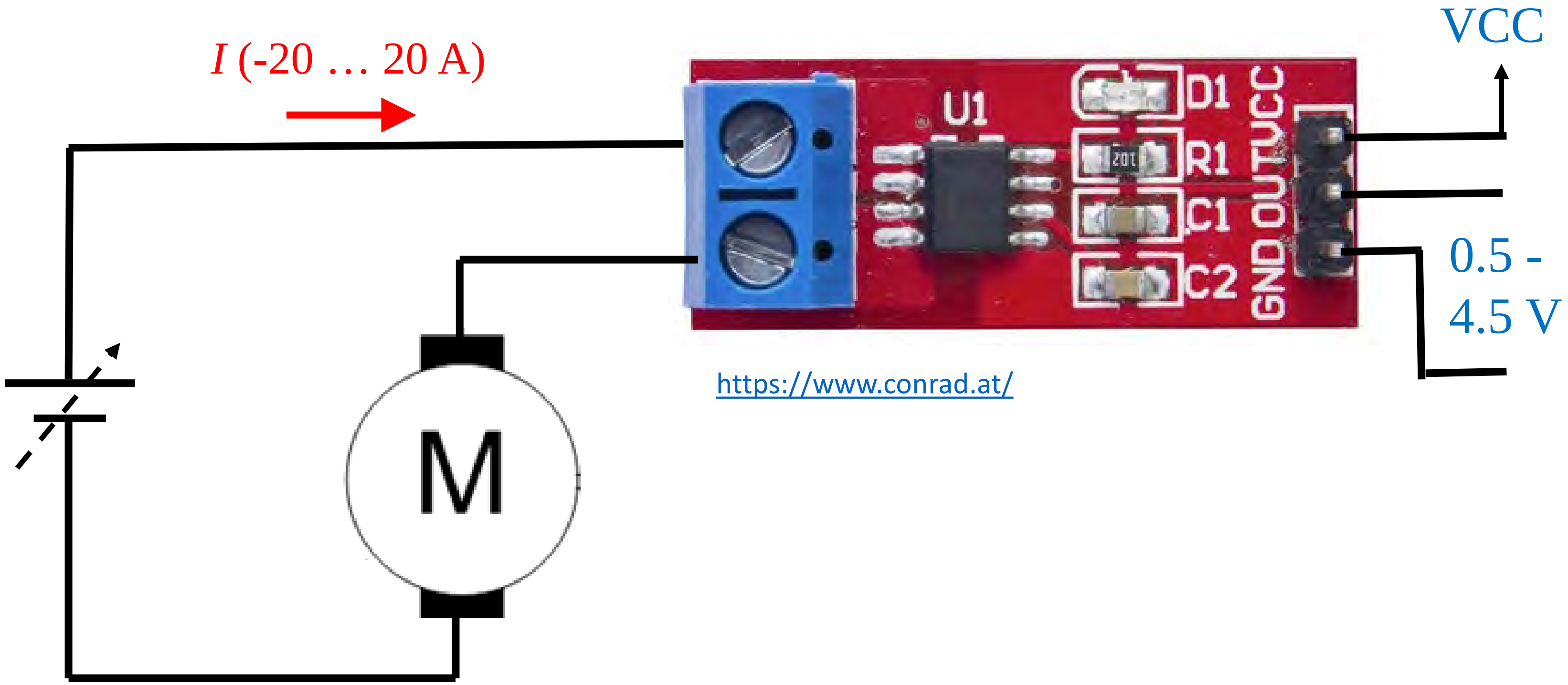
Electrical Current Measurement

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/

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

FOR EDUCATIONAL PURPOSE ONLY

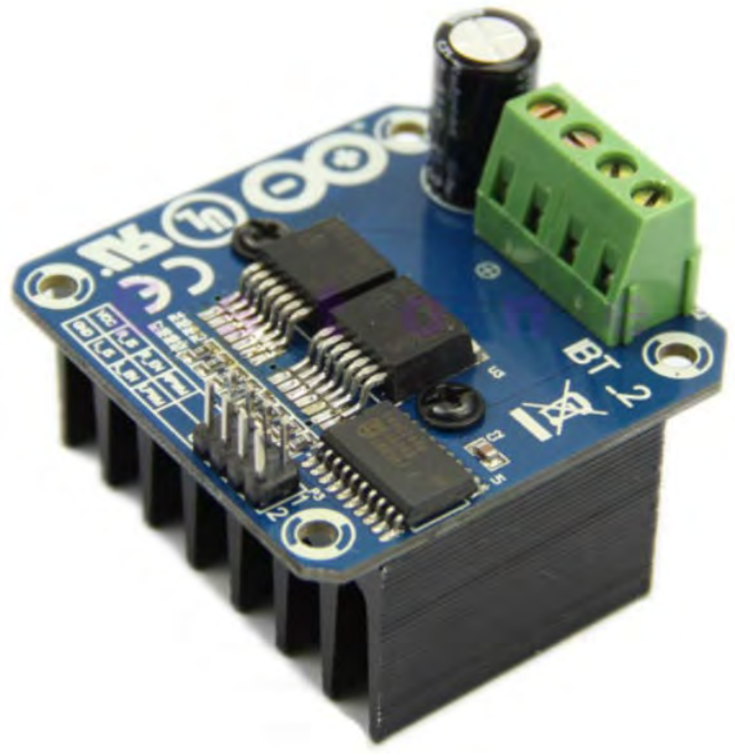
DC-Motor connection

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

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

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.

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

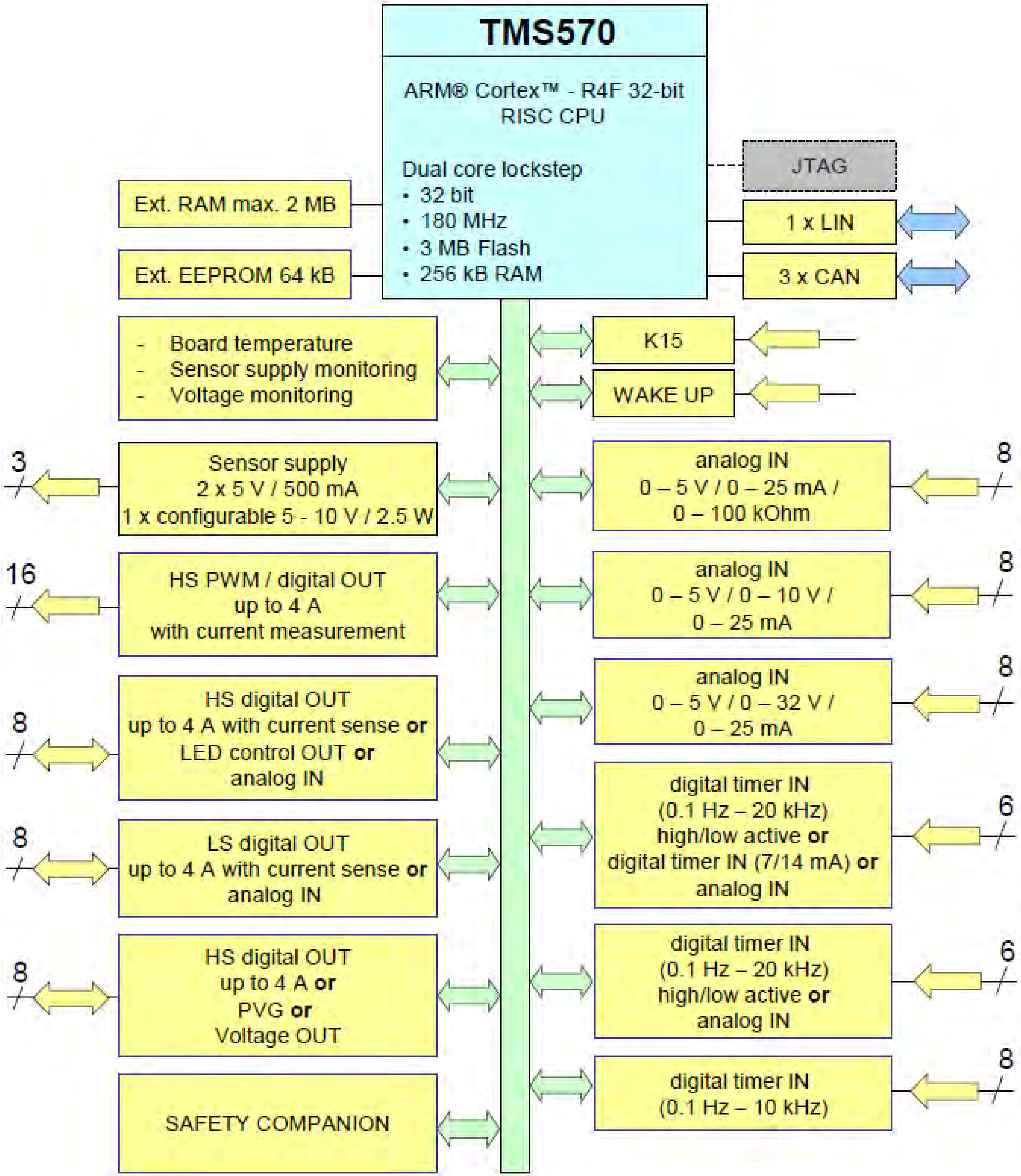
r hoice

→ HY-TTC 510 from TT-Tech

Key Benefits:

- 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



TMS570

ARM® Cortex™ - R4F 32-bit RISC CPU

Dual core lockstep
- 32 bit
- 180 MHz
- 3 MB Flash
- 256 kB RAM

Ext. RAM max. 2 MB

Ext. EEPROM 64 kB

JTAG

1 x LIN

3 x CAN

- Board temperature
- Sensor supply monitoring
- Voltage monitoring

K15

WAKE UP

3 — Sensor supply 2 x 5 V / 500 mA 1 x configurable 5 - 10 V / 2.5 W

16 — HS PWM / digital OUT up to 4 A with current measurement

8 — HS digital OUT up to 4 A with current sense **or** LED control OUT **or** analog IN

8 — LS digital OUT up to 4 A with current sense **or** analog IN

8 — HS digital OUT up to 4 A **or** PVG **or** Voltage OUT

SAFETY COMPANION

analog IN 0 – 5 V / 0 – 25 mA / 0 – 100 kOhm — 8

analog IN 0 – 5 V / 0 – 10 V / 0 – 25 mA — 8

analog IN 0 – 5 V / 0 – 32 V / 0 – 25 mA — 8

digital timer IN (0.1 Hz – 20 kHz) high/low active **or** digital timer IN (7/14 mA) **or** analog IN — 6

digital timer IN (0.1 Hz – 20 kHz) high/low active **or** analog IN — 6

digital timer IN (0.1 Hz – 10 kHz) — 8

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

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

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

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)

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

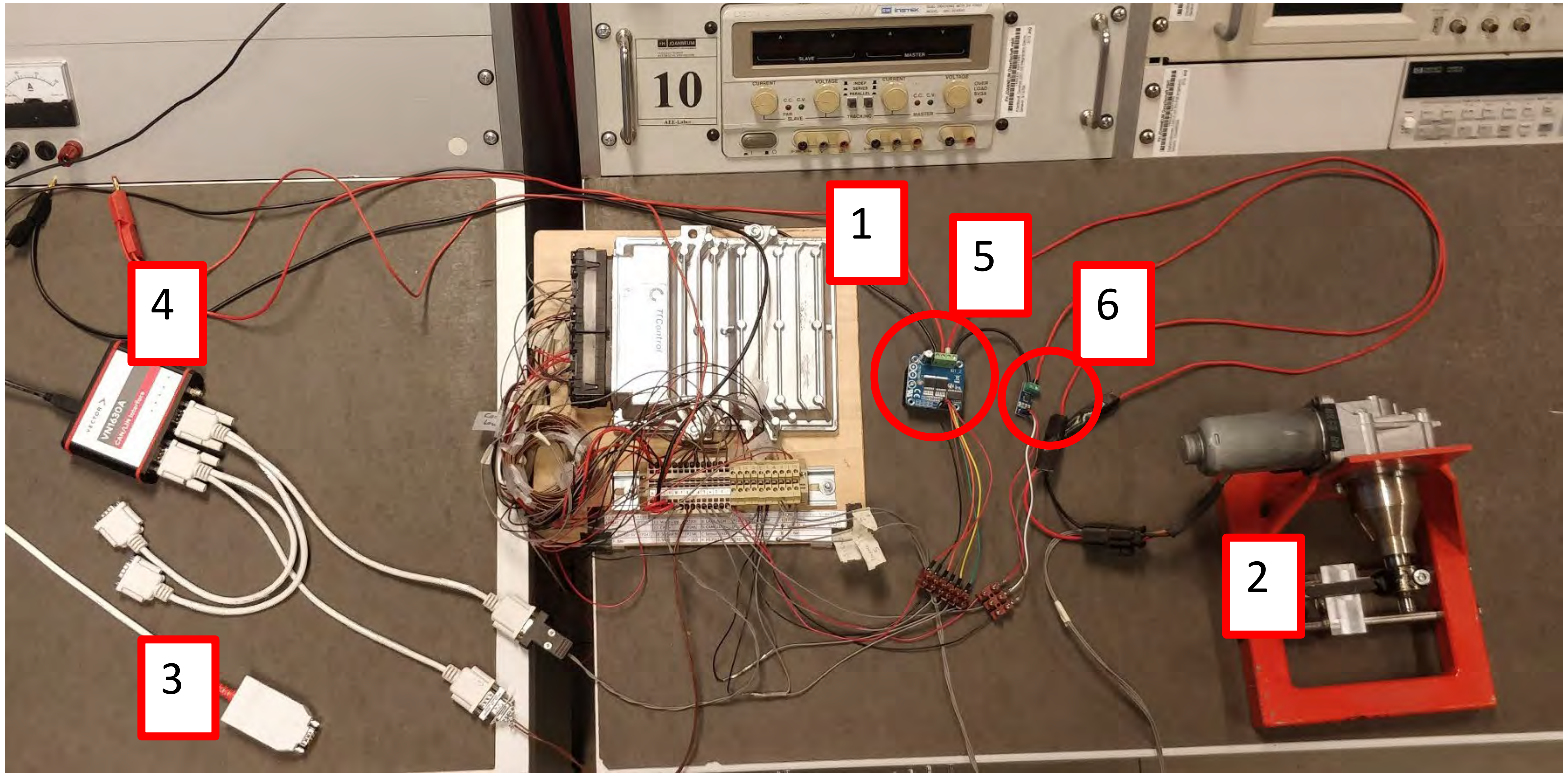
ECU – Target-performance comparison

- 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.

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

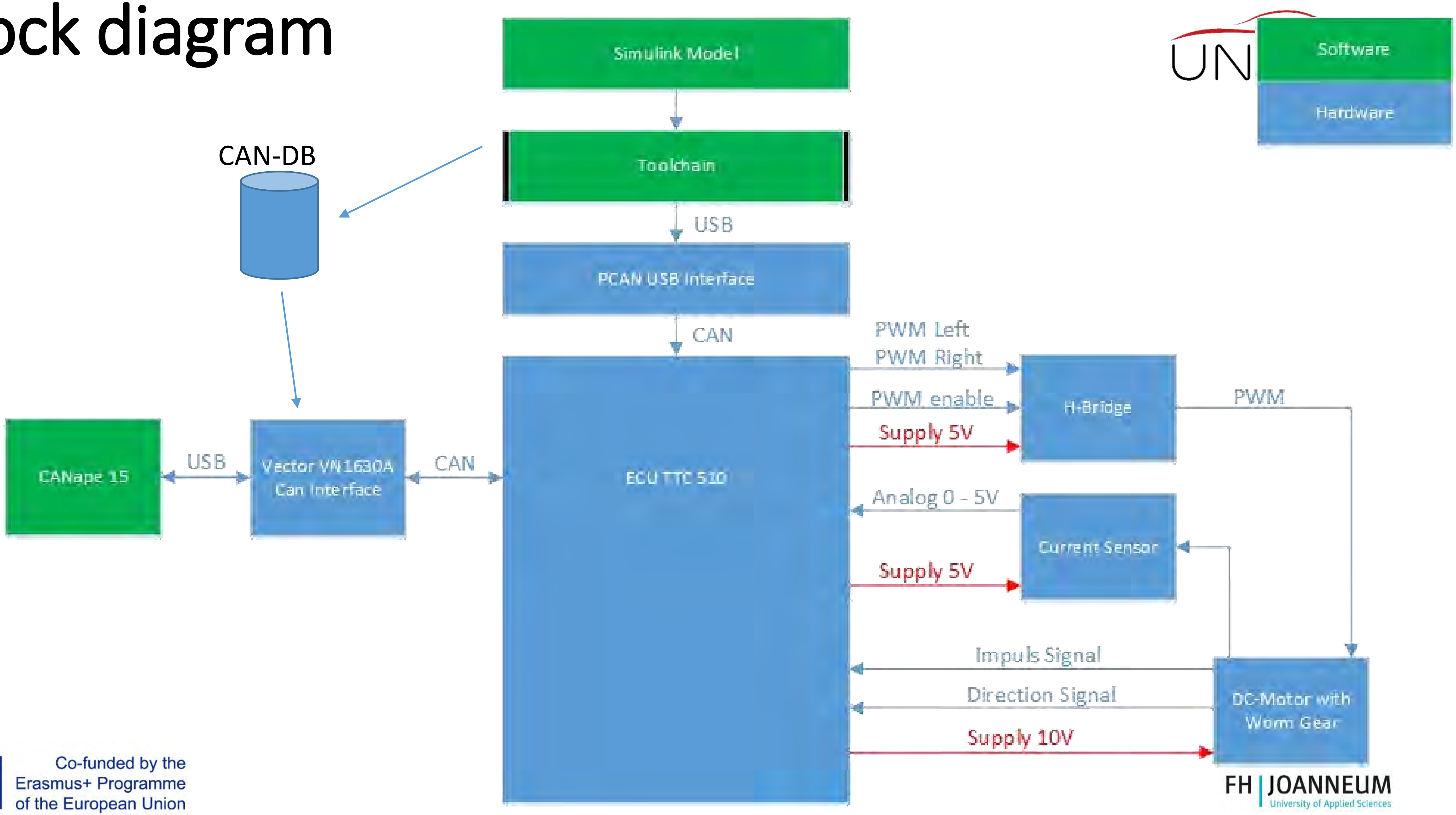
System overview

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



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

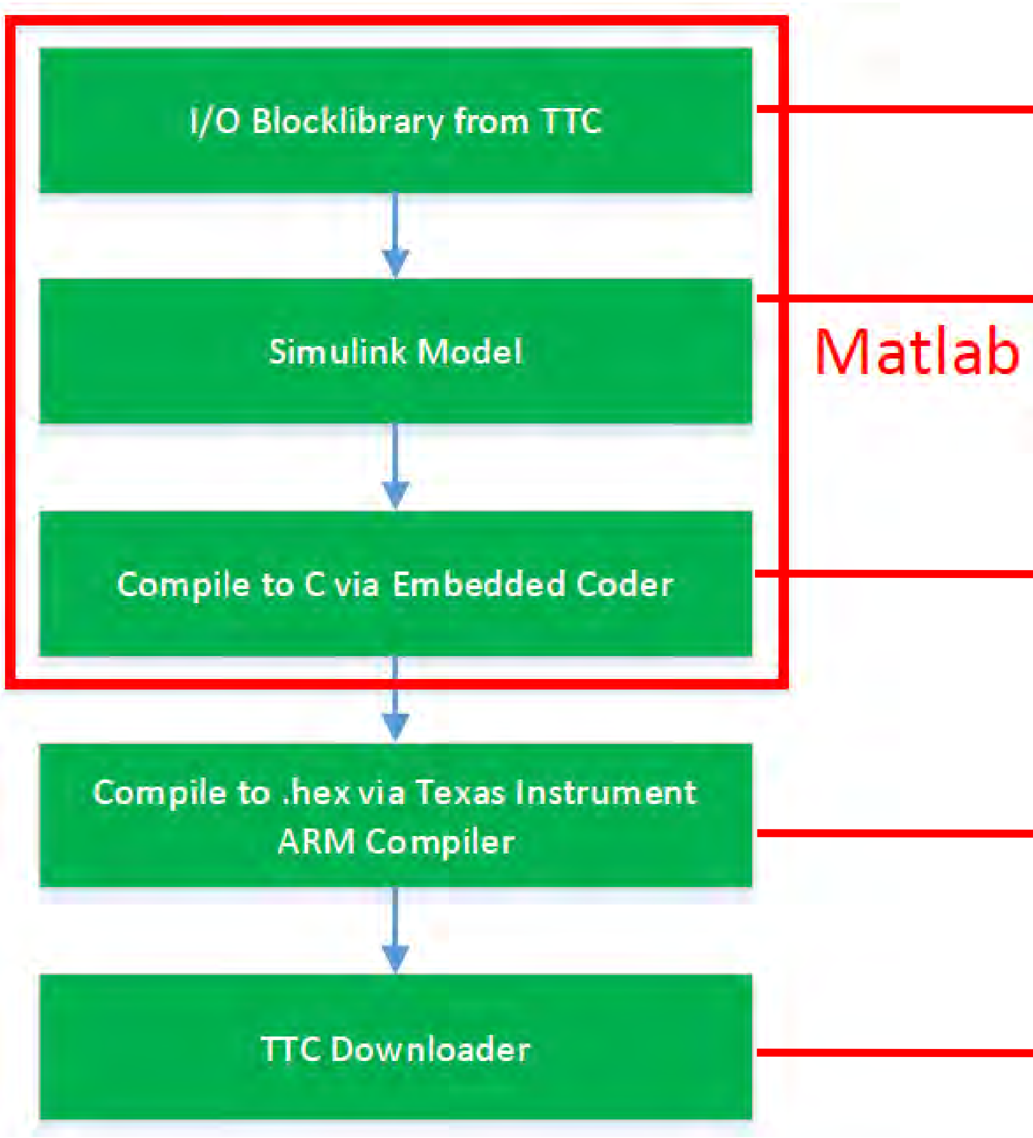
Block diagram



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

FOR EDUCATIONAL PURPOSE ONLY

K. Reisinger


I/O Blocklibrary from TTC
Simulink Model
Compile to C via Embedded Coder
Matlab
Compile to .hex via Texas Instrument ARM Compiler
TTC Downloader

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...

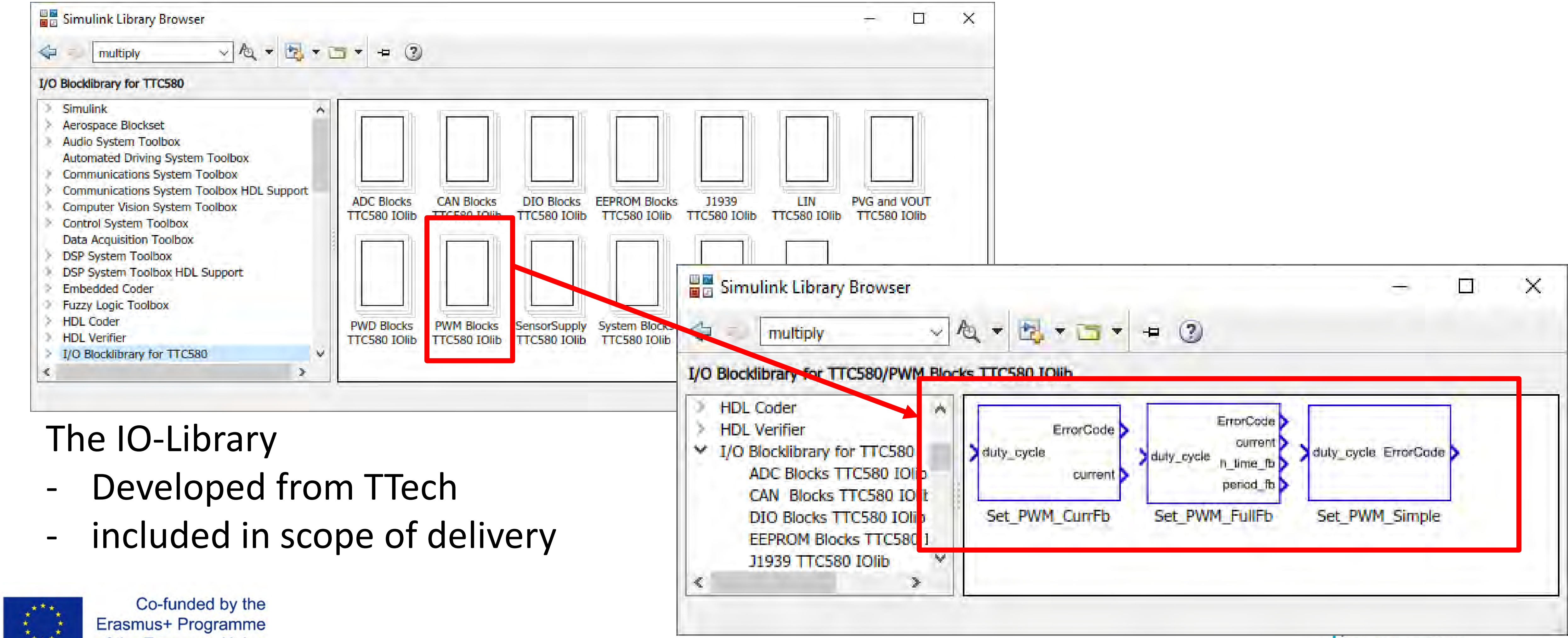
to atic co e generation o t of the i link o el. .a2l ile generation witho t a re e fro variable .

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 .

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

TTC IO-Library



The IO-Library

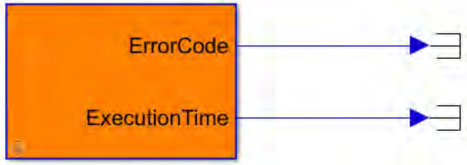
- Developed from TTech
- included in scope of delivery

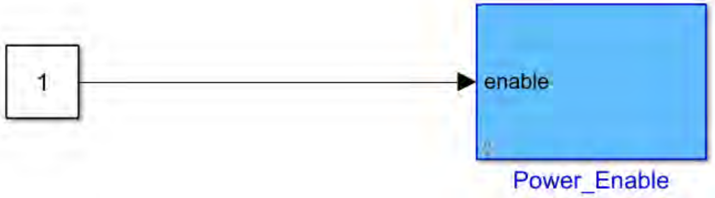
Co-funded by the
Erasmus+ Programme
of the European Union

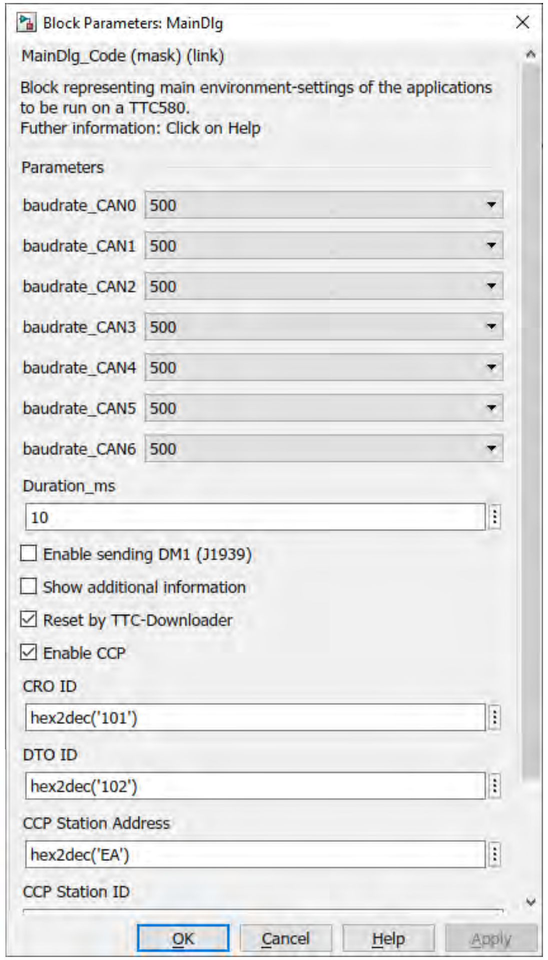
A simple Simulink example

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







Block Parameters: MainDlg

MainDlg_Code (mask) (link)

Block representing main environment-settings of the applications to be run on a TTC580.
Futher information: Click on Help

Parameters

baudrate_CAN0	500
baudrate_CAN1	500
baudrate_CAN2	500
baudrate_CAN3	500
baudrate_CAN4	500
baudrate_CAN5	500
baudrate_CAN6	500

Duration_ms
10

☐ Enable sending DM1 (J1939)
☐ Show additional information
☑ Reset by TTC-Downloader
☑ Enable CCP

CRO ID
hex2dec('101')

DTO ID
hex2dec('102')

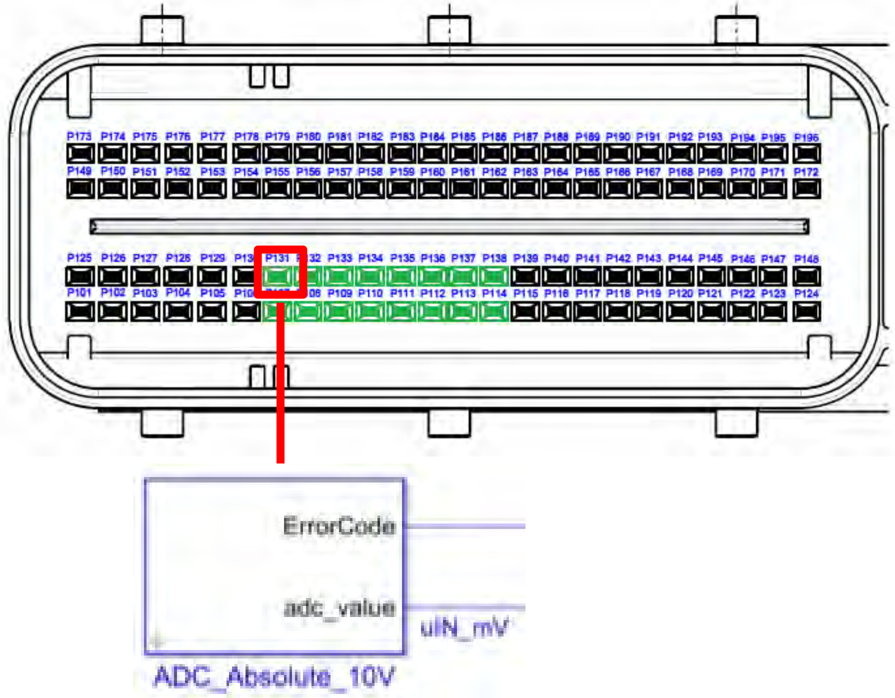
CCP Station Address
hex2dec('EA')

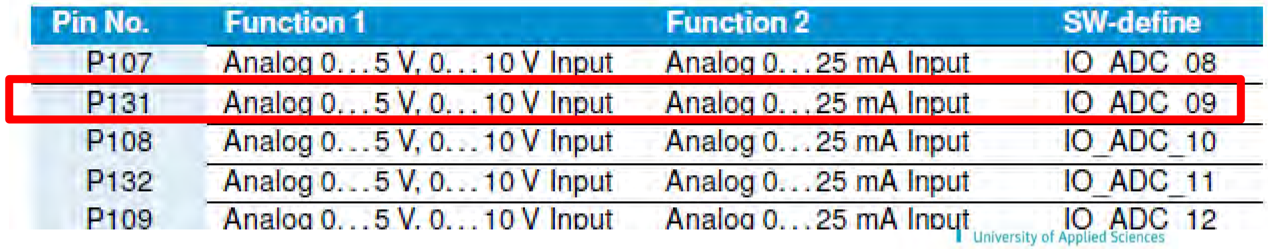
CCP Station ID

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*


P173 P174 P175 P176 P177 P178 P179 P180 P181 P182 P183 P184 P185 P186 P187 P188 P189 P190 P191 P192 P193 P194 P195 P196
P149 P150 P151 P152 P153 P154 P155 P156 P157 P158 P159 P160 P161 P162 P163 P164 P165 P166 P167 P168 P169 P170 P171 P172
P125 P126 P127 P128 P129 P13 P131 32 P133 P134 P135 P136 P137 P138 P139 P140 P141 P142 P143 P144 P145 P146 P147 P148
P101 P102 P103 P104 P105 P10 08 P109 P110 P111 P112 P113 P114 P115 P116 P117 P118 P119 P120 P121 P122 P123 P124
ErrorCode
adc_value
uIN_mV
ADC_Absolute_10V



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

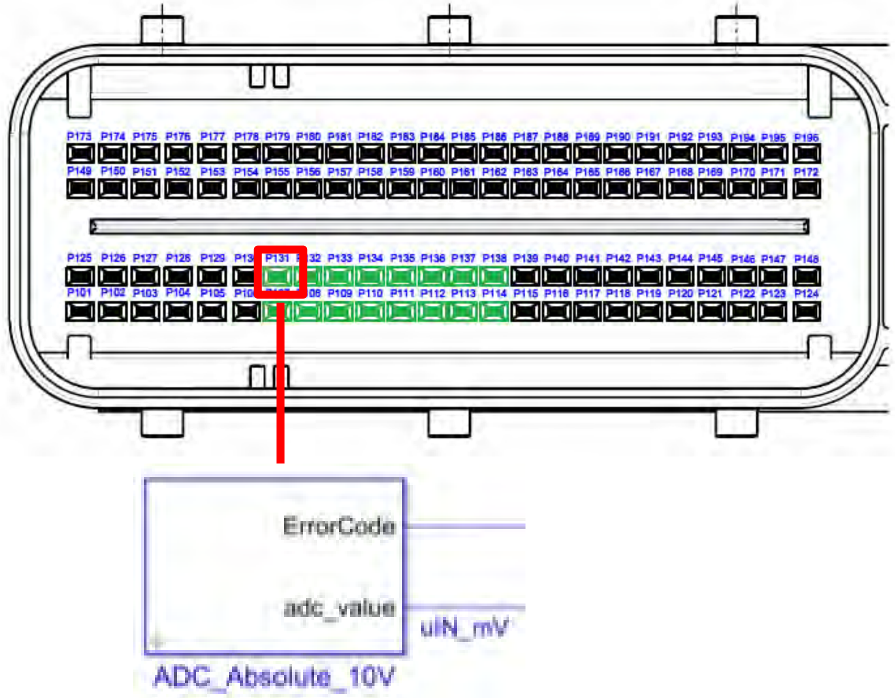
Co-funded by the
Erasmus+ Programme
of the European Union

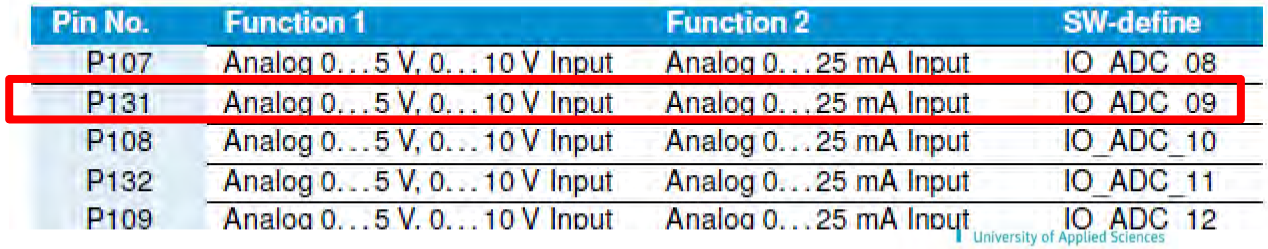
A simple Simulink example

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*



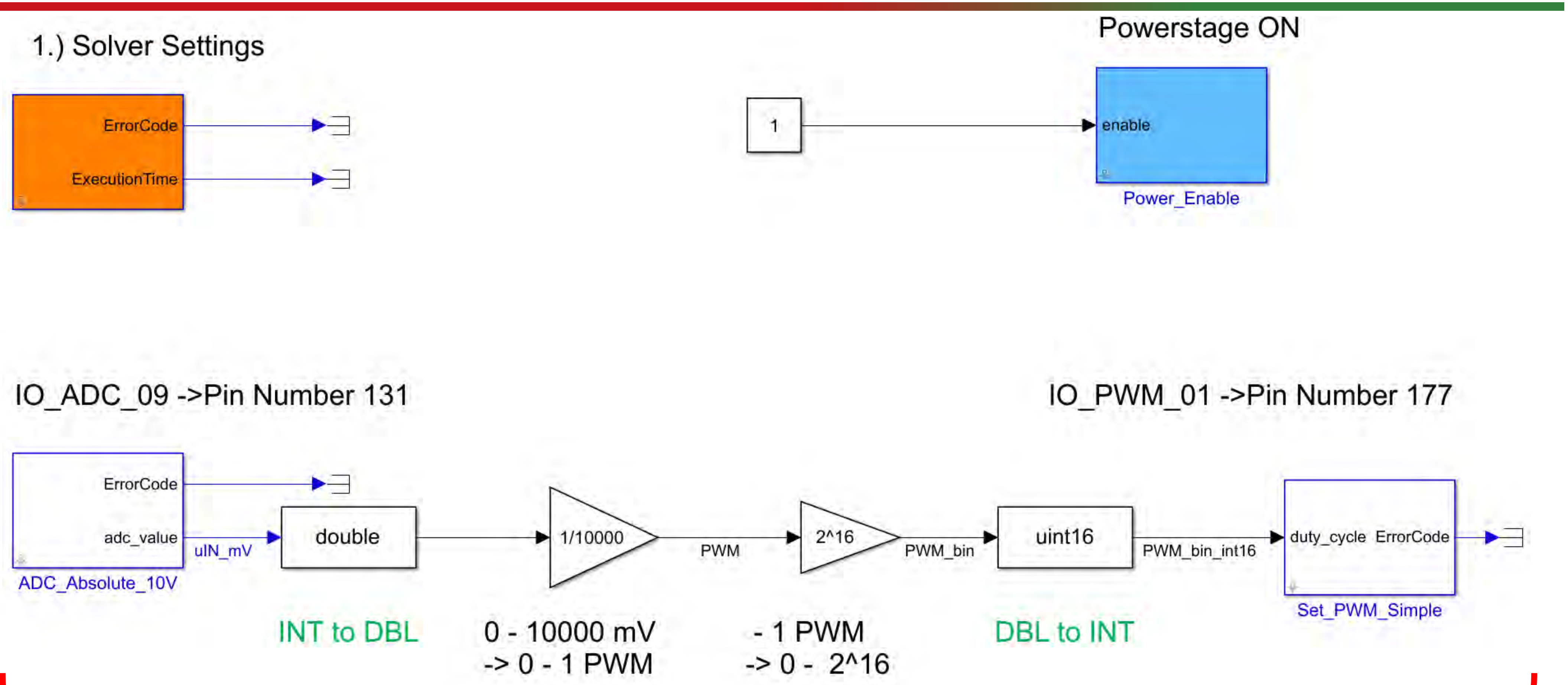


Pin No.	Function 1	Function 2	SW-define
P107	Analog 0. . . 5 V, 0. . . 10 V Input	Analog 0. . . 25 mA Input	IO_ADC_08
P131	Analog 0. . . 5 V, 0. . . 10 V Input	Analog 0. . . 25 mA Input	IO_ADC_09
P108	Analog 0. . . 5 V, 0. . . 10 V Input	Analog 0. . . 25 mA Input	IO_ADC_10
P132	Analog 0. . . 5 V, 0.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

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

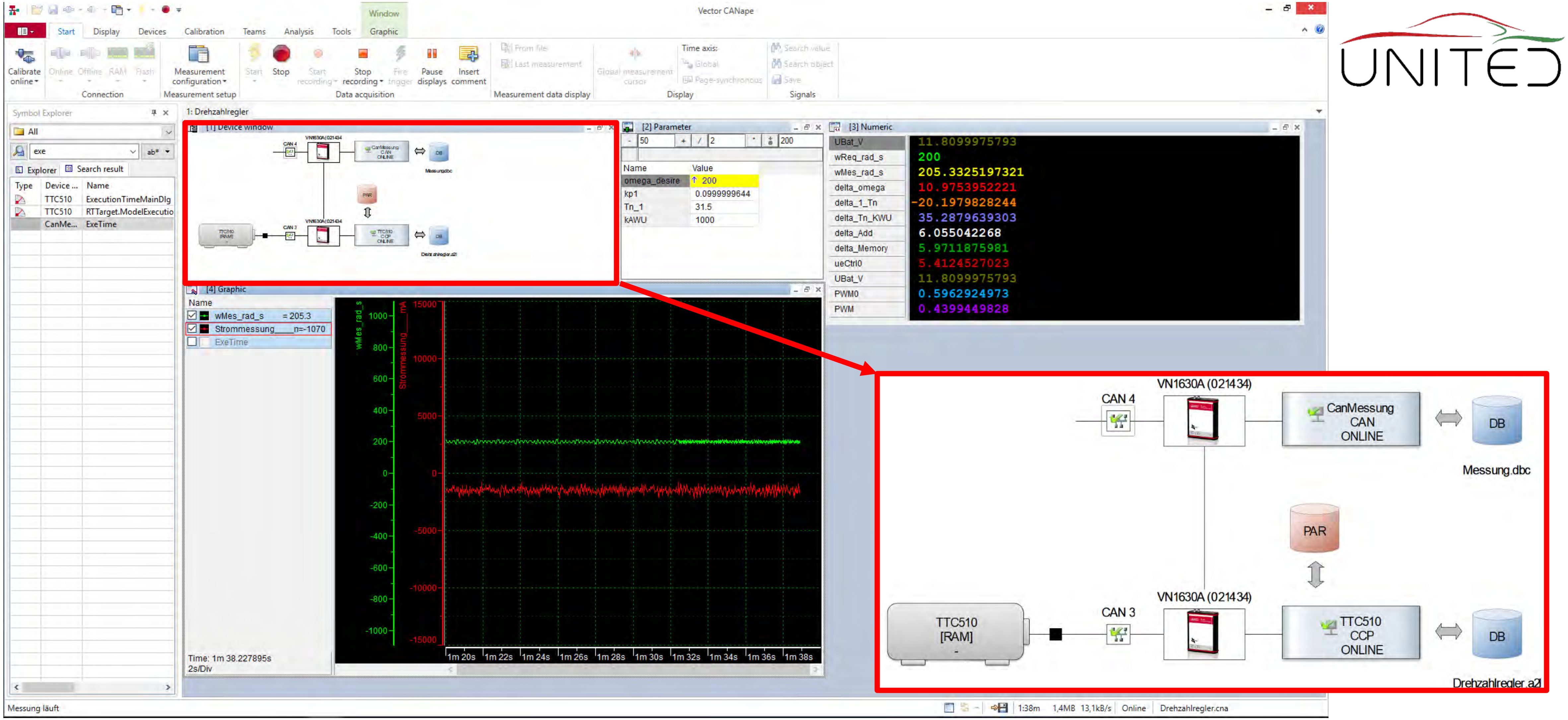
A simple Simulink example

Change PWM ratio as a function of a voltage signal



build → C-Code generation

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



Type	Device ...	Name
	TTC510	ExecutionTimeMainDlg
	TTC510	RTTarget.ModelExecutio
	CanMe...	ExeTime

Name	Value
omega_desire	↑ 200
kp1	0.0999999644
Tn_1	31.5
kAWU	1000

UBat_V	11.8099975793
wReq_rad_s	200
wMes_rad_s	205.3325197321
delta_omega	10.9753952221
delta_1_Tn	-20.1979828244
delta_Tn_KWU	35.2879639303
delta_Add	6.055042268
delta_Memory	5.9711875981
ueCtrl0	5.4124527023
UBat_V	11.8099975793
PWM0	0.5962924973
PWM	0.4399449828

Name	
☑ 🟩 wMes_rad_s	= 205.3
☑ 🟥 Strommessung___	n=-1070
□ ExeTime	

Time: 1m 38.227895s
2s/Div

Messung läuft

1:38m 1,4MB 13,1kB/s Online Drehzahlregler.cna

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

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 →

$$K_p = 0.45\ K_u$$

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

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

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

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/

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

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

Hand-On Training Mechatronics

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.

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