Joint webinar - March 17, 2022

Model-Based Design with MATLAB and Simulink to accelerate development and deployment of embedded control systems

In collaboration with

POLITECNICO MILANO 1863

Tampere University

MathWorks

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Webinar agenda

3-4.30 PM CET

- Welcome

  By: Antonio Faggio, Texas Instruments

- How to fill the gap from motor control theory to practical implementation using rapid prototyping

  By: Mattia Rossi, Politecnico di Milano & Tampere University

- How to accelerate development of embedded control systems with MATLAB® and Simulink®

  By: John Kluza, Mathworks

- How to realize the rapid prototype board for drive and electric motors

  By: *Angelo Strati*, Wuerth Elektronik

- Closure and Q&A

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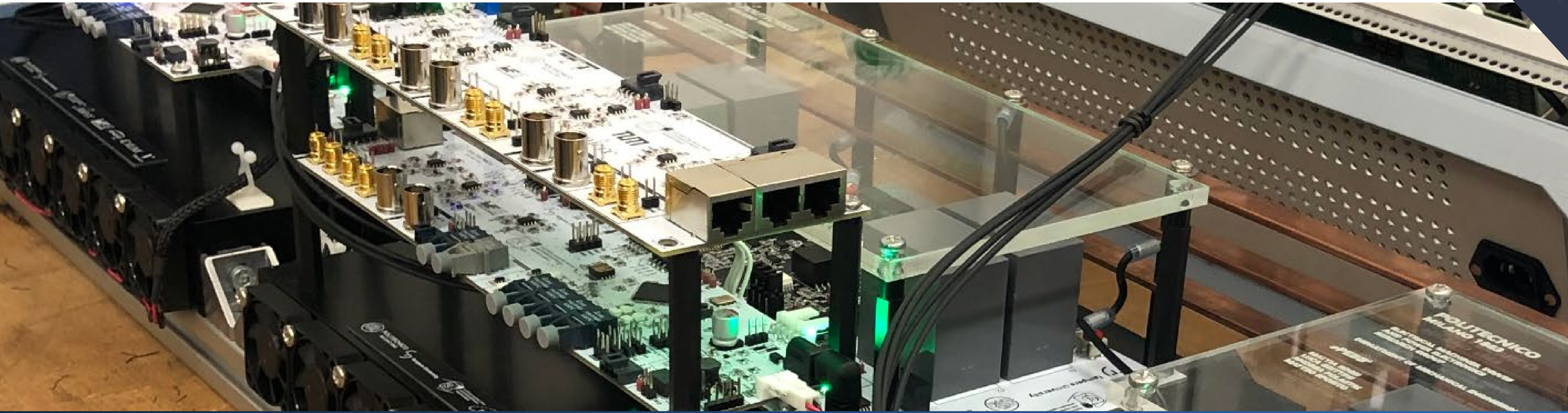
ePEBBs efficient power electronics building blocks

Model-Based Design with MATLAB and Simulink to accelerate development and deployment of embedded control system

Mattia Rossi



Agenda

ON24 Model-Based Design with MATLAB and Simulink
to accelerate development and deployment of embedded control system

- **Texas Instruments**

Antonio Faggio — opening and hosting the event

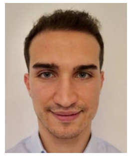
- **Politecnico di Milano / Tampere University / ePEBBˢ Srl**

Mattia Rossi — will summarize how to fill the gap from motor control theory to practical implementation of an embedded closed-loop control scheme for an electrical drive using a rapid prototyping approach with Texas Instruments C2000™ MCU and Brushless DC Drive

- **MathWorks**

John Kluza — will show a Model-Based Design with MATLAB® and Simulink® to accelerate development and deployment of embedded control systems

- **Wuerth Elektronik Italia**



Angelo Strati — will then summarize the realization of the rapid prototype board for drive and electric motors: Implementing both the passive load board and active one; expanding the board with filters and EMC optimization in order to guarantee protection against noise

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Background

(Italy)

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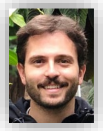

Mattia Rossi
Postdoctoral research fellow
Tampere University
Advanced control for power electronics applications

(Finland)

Tampere University

from 2019

from 2021

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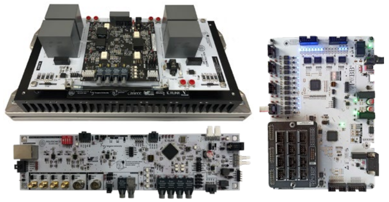
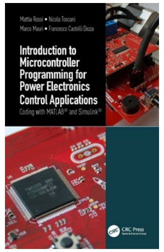
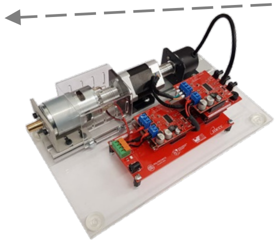


start-up which develops **high-end hardware** and **prototyping** equipment for **power electronic systems**, drives, and smart grid. This is aimed to accelerate the implementation of laboratory-scale power converters and facilitate the derivation of high-quality experimental results and IoT connectivity

Published a **Book** and distribute **MCU-based Hardware Kits**





research initiative

creation of the development TEAM

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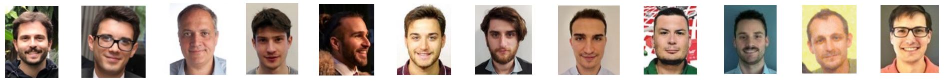
to investigate rapid prototyping approaches in the fields of power management and electrical drives



….and more !!

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Motion Control Systems

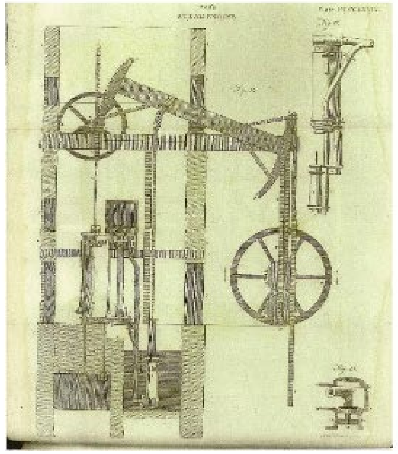
Control of Electrical Drives

How can you move from motor control theory to practice?
Where implement the control logic?

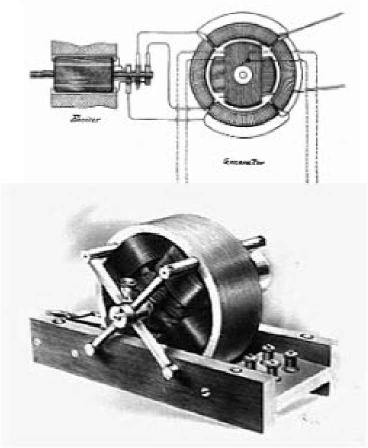
A Practical Example: PMDC Control

Past, Present and Future Motion Control Systems

The path on the development of motion control systems…



James Watt's Steam Engine



Nikola Tesla's & Galileo Ferraris' AC induction machine

Integrated drive system (AC motor + SkiNIGBT power electronics) for today's electric vehicles

Exponential development:

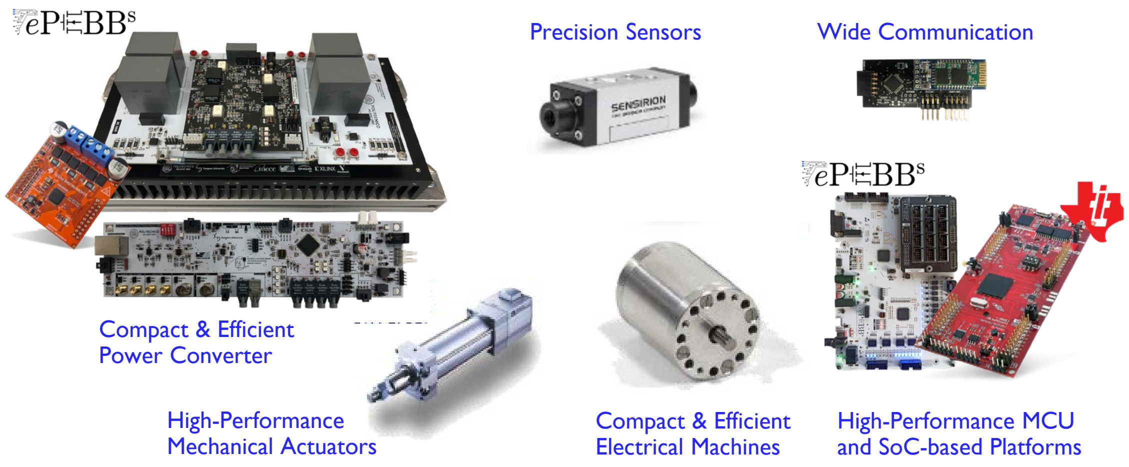
1900	Mechanical
1900	Mechanical + Electrical
1950	Mechanical + Electrical + Electronic → Electronic Motion Control
1975	Mechanical + Electrical + Electronic + Computation
1985	Mechanical + Electrical + Electronic + Computation + Information/Communication
2000	Mechanical + Electrical + Electronic + (Large) Computation + IoT

Source: ETH, Research Vectors in Power Electronics and Motion Control

Past, Present and Future Motion Control Systems

Future innovation in the development of motion control systems:

➤ Key components are today available with high performance



Extremely Wide Application Areas

- Machining
- Handling and Assembly
- Transportation (land, sea, air)
- Gas, Oil and Mining
- Water, Wastewater
- Consumer Electronics
- Computers
- Home Appliances
- Defense
- Medical
- Space Exploration

✓ **1st Option** for gaining a competitive advantage → ***further optimize the «components»*** Component level

e.g. Ultra-High Speed Machines, Ultra-Efficient Converter, ...

✓ **2nd Option** for gaining a competitive advantage → ***target specific system needs*** System level

e.g. System level optimization and Integration (e.g. many servo drives)

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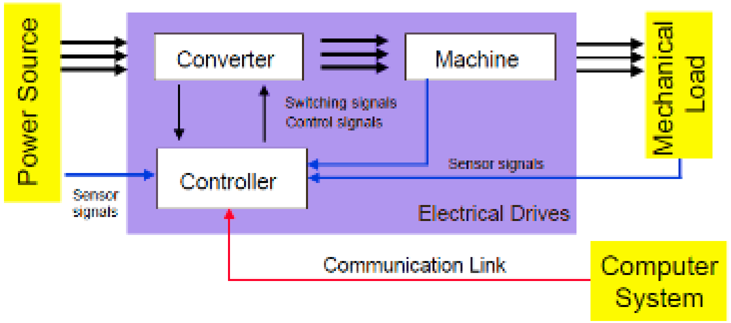
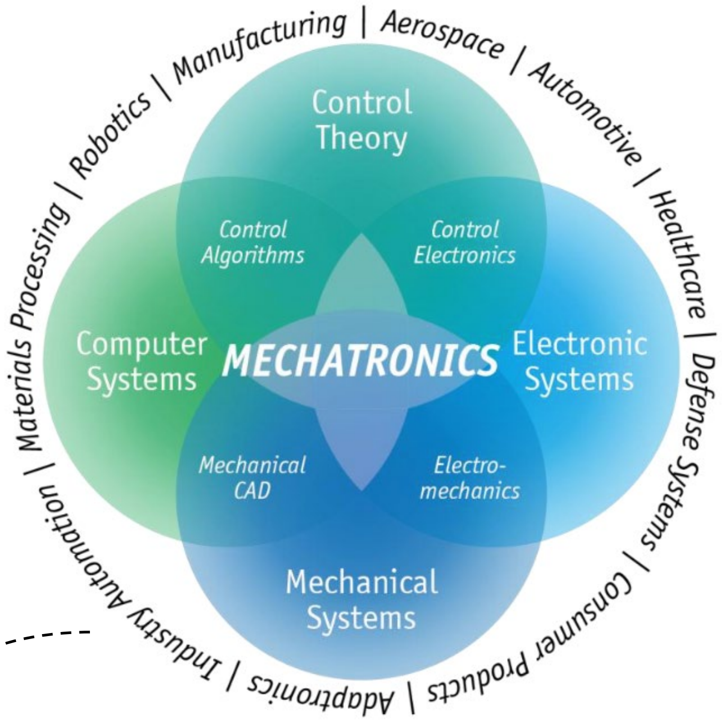
Past, Present and Future Motion Control Systems

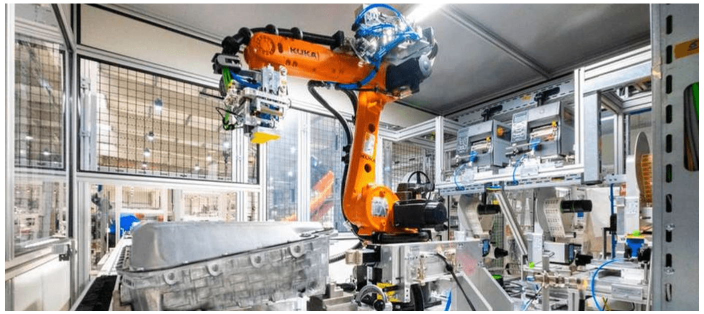
✓ **2nd Option** for gaining a competitive advantage → **target specific system needs**

This is practically achieved by targeting the «System Level»
and have competences to bridge the boundaries between more (>) than 3 key areas





- ➢ This already represent the **TODAY** scenario… ✅
- ➢ Opens Path to Endless Product Innovation



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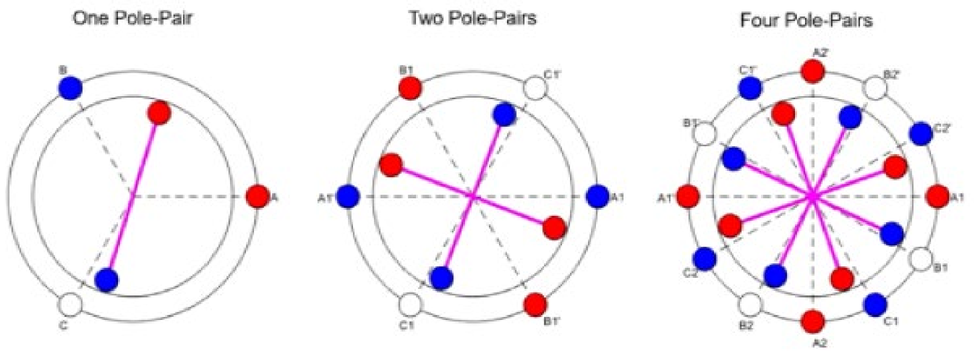
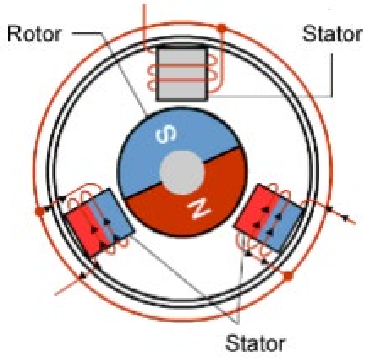
Electrical Machines/Drives

Servo motors/Servo drives in Industrial Automation

Machines ranging from devices like drills and logistics to complex equipment like industrial robots make a wide use of brushed and brushless DC motors (BLDC) and permanent magnet synchronous motor (PMSM)

- ✓ BLDC motors and PMSMs are similarly structured, both have permanent magnets (PM) in the rotor and are defined as synchronous motors
- ✓ There are motors with different PM arrangements where the stator may have different numbers of windings and the rotor multiple pole pairs





Rotor: single pole pair
Stator: three coils spaced at 120°

- ✓ However, the way BLDC motors and PMSMs are controlled is very different due to the difference in the shape of their back EMF (electromotive force)

Six-Step Commutation
(or Trapezoidal Control)

Field-Oriented Control
(FOC)

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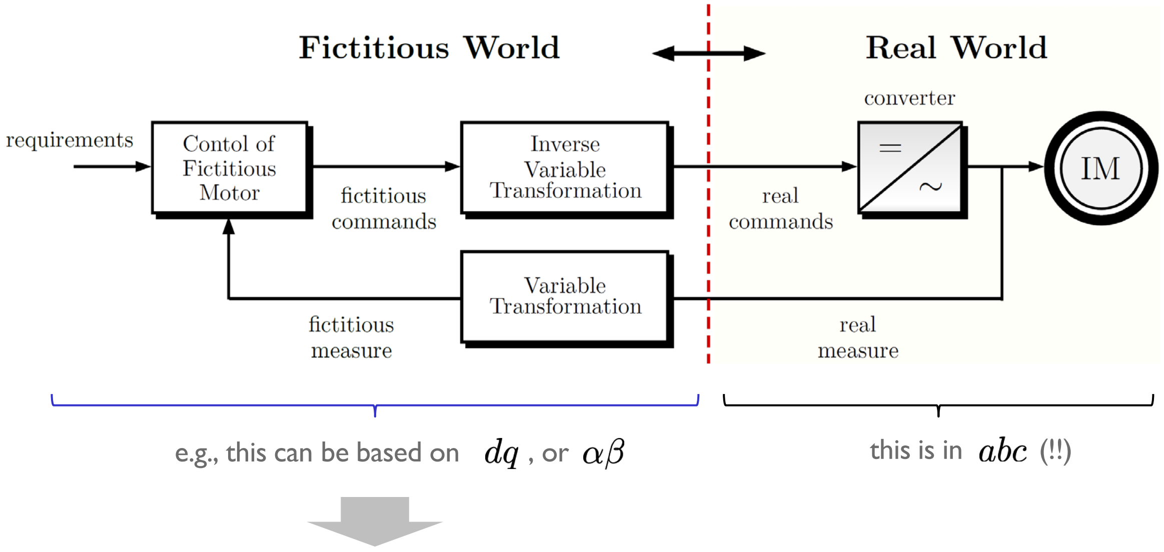
Vector Control Theory for AC Motors

Most of control schemes for AC drives, e.g., PMSMs and induction motors (IMs), are derived from the so-called vector control theory $\longrightarrow$ an example is **field-oriented control (FOC)**

- **Vector control theory** tries to recreate the electromechanical behavior of DC motors on AC motors
- This is achieved by designing a control scheme based on a simpler (fictious) motor model which is derived through appropriate mathematical transformations (and reference frame orientation)



- For instance, by adopting the rotor-FOC **(R-FOC)** for controlling an IM, we obtain two decoupled dynamics for slower transients (i_{sd} related to the rotor flux) and faster transient effects (i_{sd} related to the torque)

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General Approach in Electrical Drives

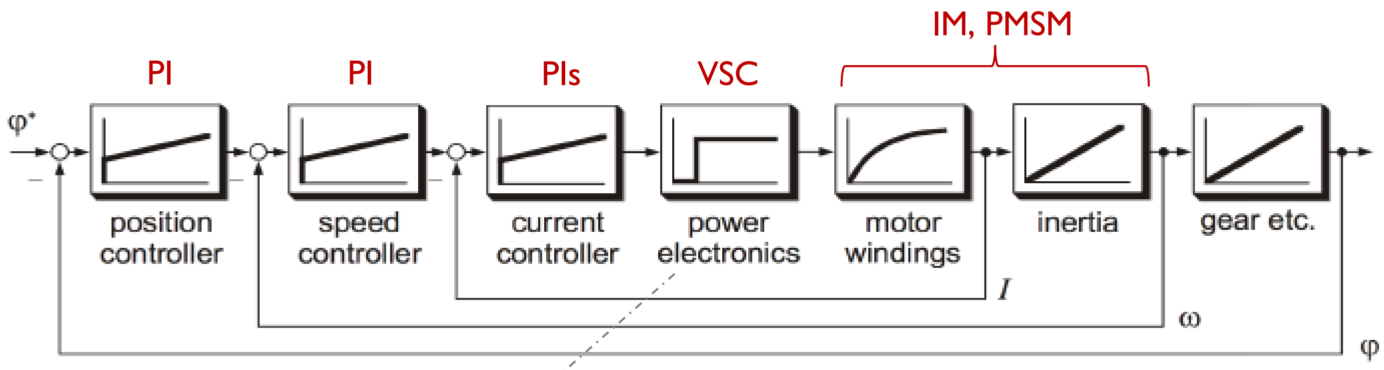
If we consider model-based controllers, the design steps of the closed-loop control schemes are

1) pick a family/class of controllers
2) derive a model accordingly to the controllers family that have been chosen
3) built the closed-loop scheme

Example:

➢ **Standard AC motor control schemes** are based on linear control theory which means to adopt

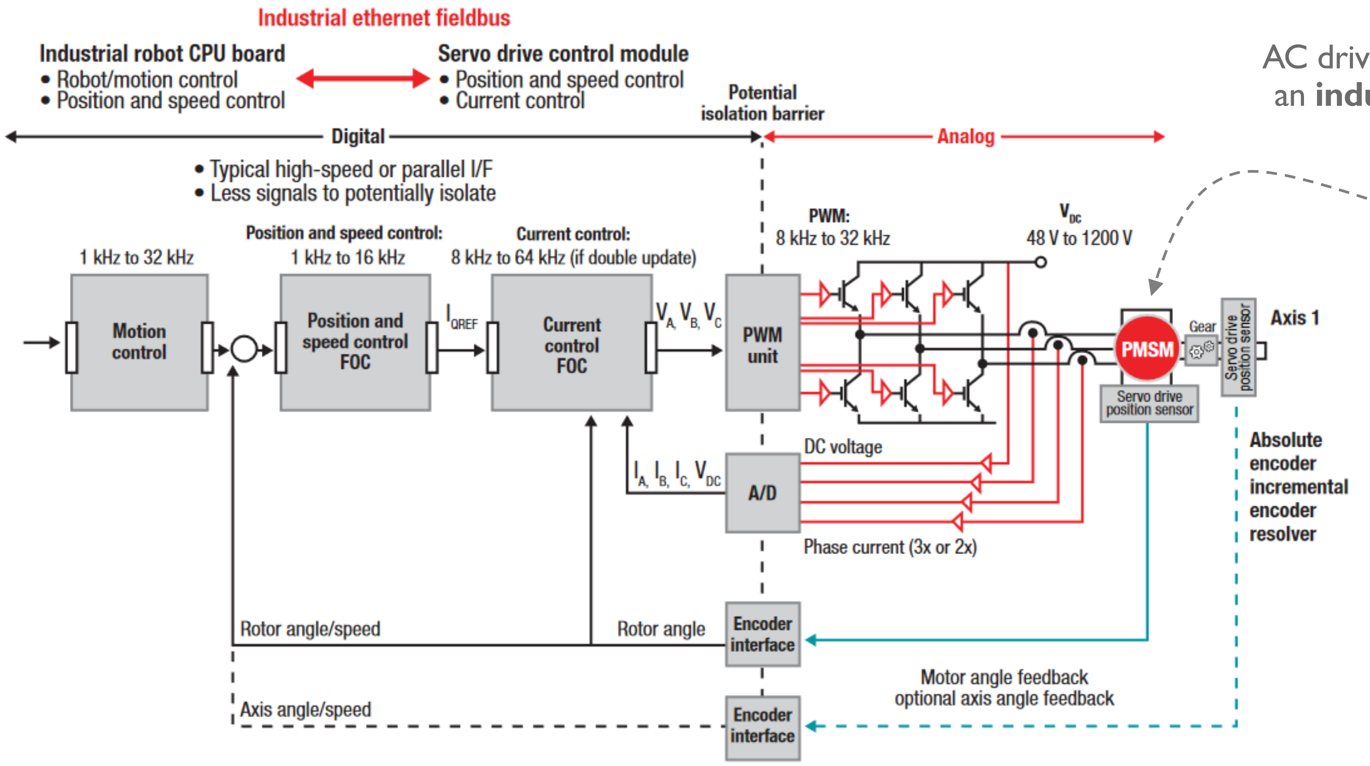
1) PI/PID controllers (linear)
2) derive a motor model in the transformed dq -reference frame (also choosing its alignment) which allows to decouple the control of the AC motor dynamics in multiple SISO loops (instead of making a MIMO controller)
3) built a cascade closed-loop scheme (nested loops architectures)



the power converter is intrinsically subject to a nonlinear behavior due its switching nature f_{sw} ….
which is masked by the modulator principle

Industrial Automation

➢ If we consider a FOC for a PMSM, in practice the previous control scheme becomes:



AC drive included into an **industrial robot**

Control Logic

Power Stage

TI C2000 MCUs LaunchPad

TI BoosterPacks

PMSM

Texas Instruments

ePEBBs efficient power electronics building blocks

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Brief Review: Embedded System/Platform

An **embedded system** is a control platform based on programmable logic (e.g. MCU) where the algorithm comprise dedicated functions, typically not changeable after the implementation…

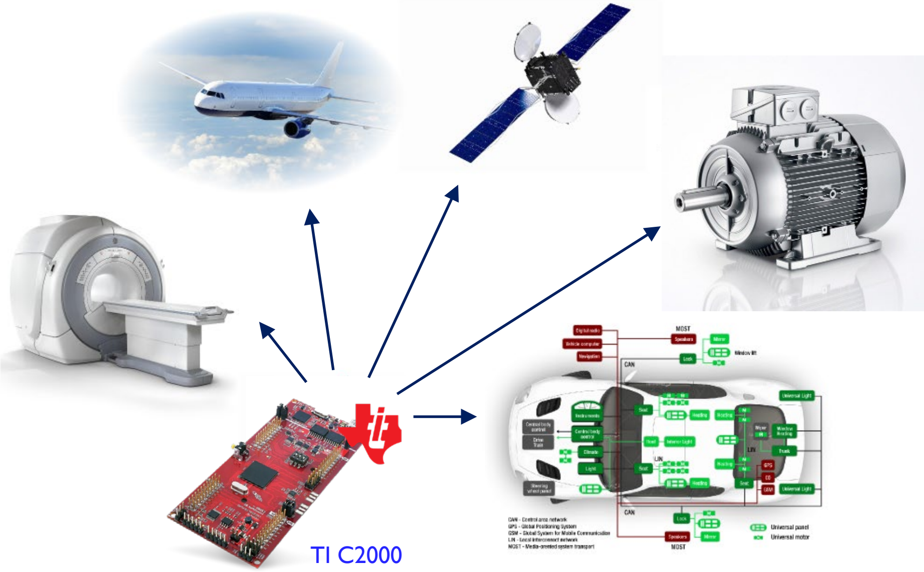
- designed for specific tasks (not general purpose)
- optimization of the number of components, size, costs and footprints
- real-time execution…
- no Operative System (may be light/custom OS)

✓ …so the heart of an embedded system coudl be a microcontroller (MCU)

for us

embedded system → **MCU board**

many vendors



TI C2000
MCUs
LaunchPad

efficient power electronics building blocks

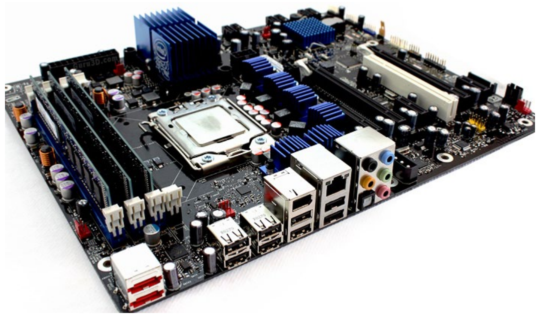
Brief Review: Microprocessor vs Microcontroller

Keep in mind:

Microprocessor
(e.g. PCs)

- high-computational power
- Several communication peripheral
- versatile
  general purpose usage
  (games, documents,…)

motheboard w/ intel i7

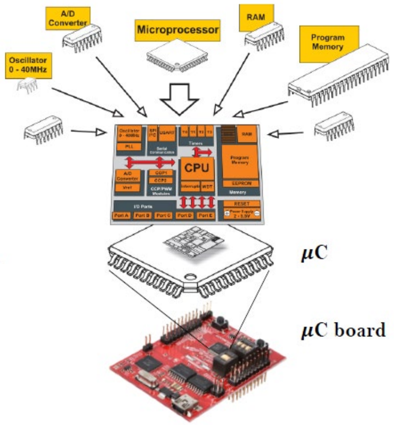


(embedded system)

Microcontroller
(e.g. for motor control)

- «low» computational power PS
- several peripheral (related to the application target and not only communication)
- targeting usage:
  optimizing perfomances and cost cause referred to a specifc application and market laws/scenarios

peripheral:
ADCs, PWM, Timer, GPIOs, SPI, CAN, I2C, QEP



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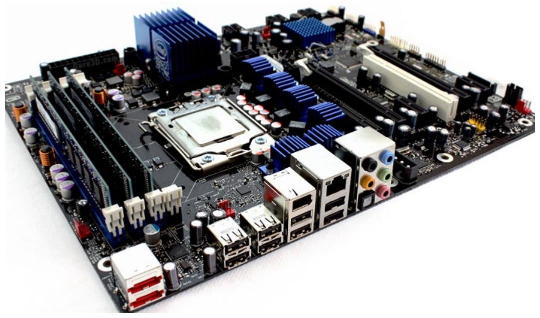

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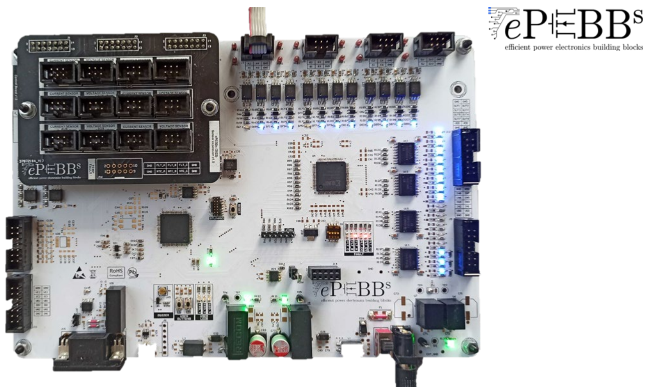
more industrial example



ePEBBs
efficient power electronics building blocks

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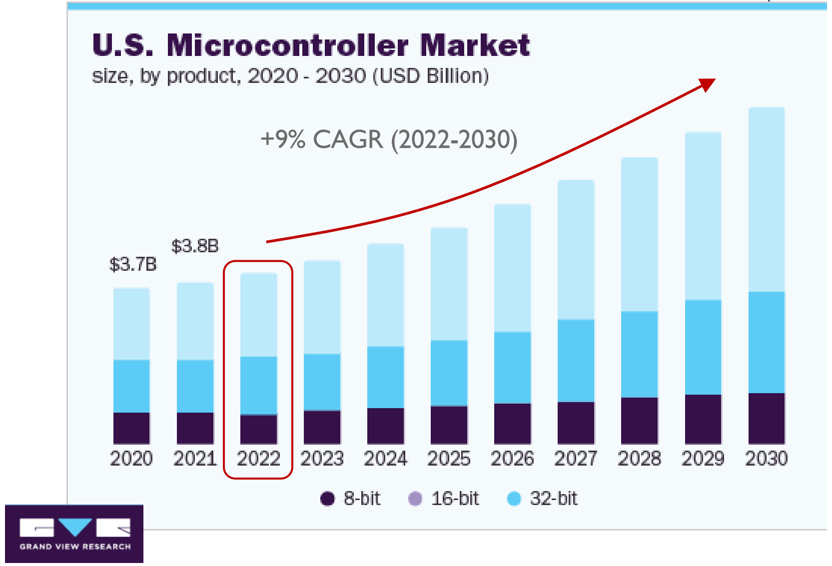
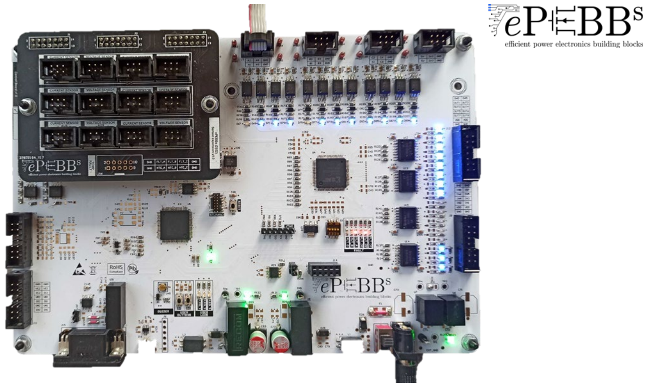


more industrial example



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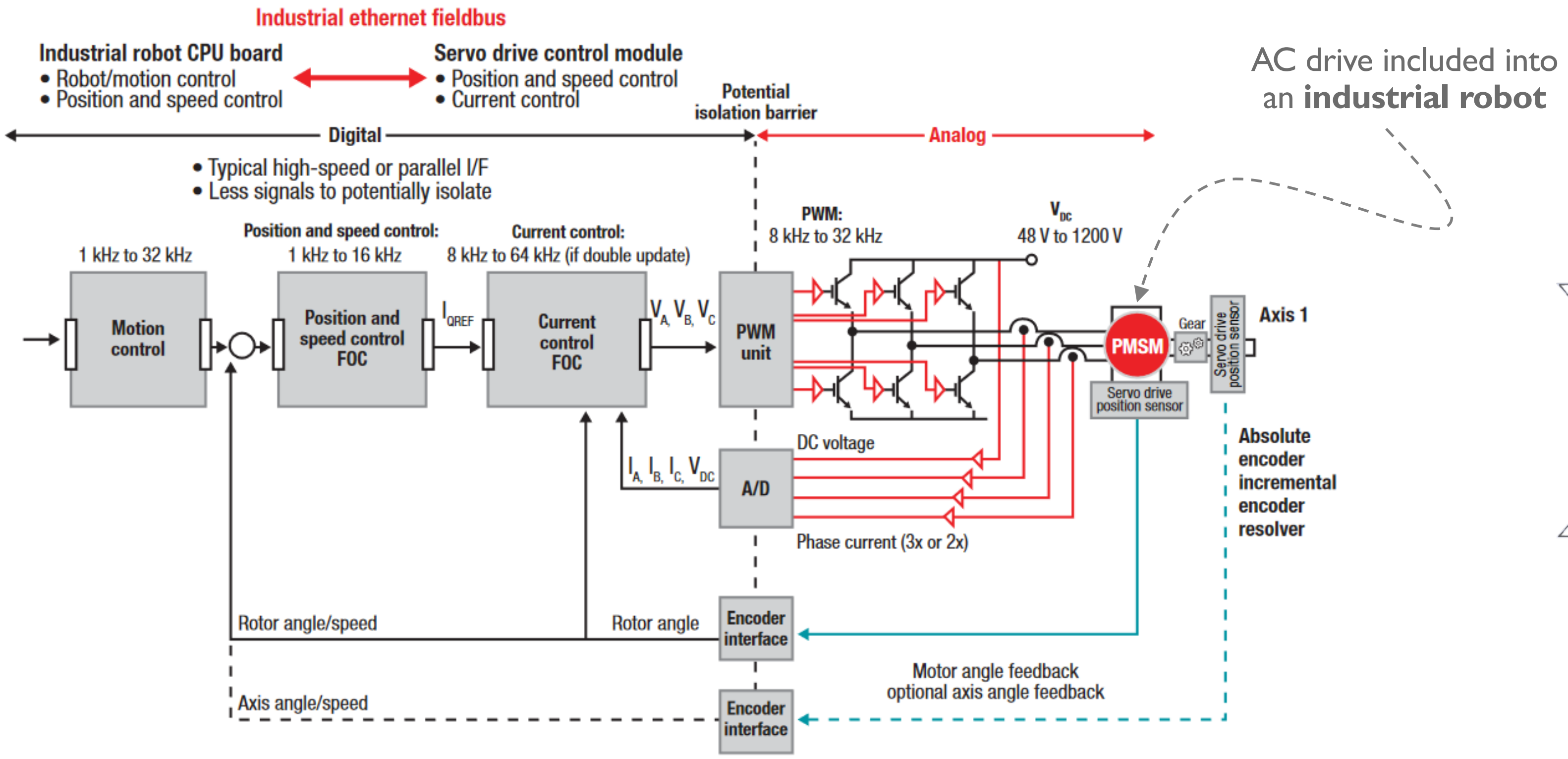
Industrial Automation (pt.2)

➤ If we consider a FOC for a PMSM, in practice the previous control scheme becomes:



Control Logic

Power Stage

TI C2000 MCUs LaunchPad

TI BoosterPacks

PMSM

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Industrial Automation (pt.2)

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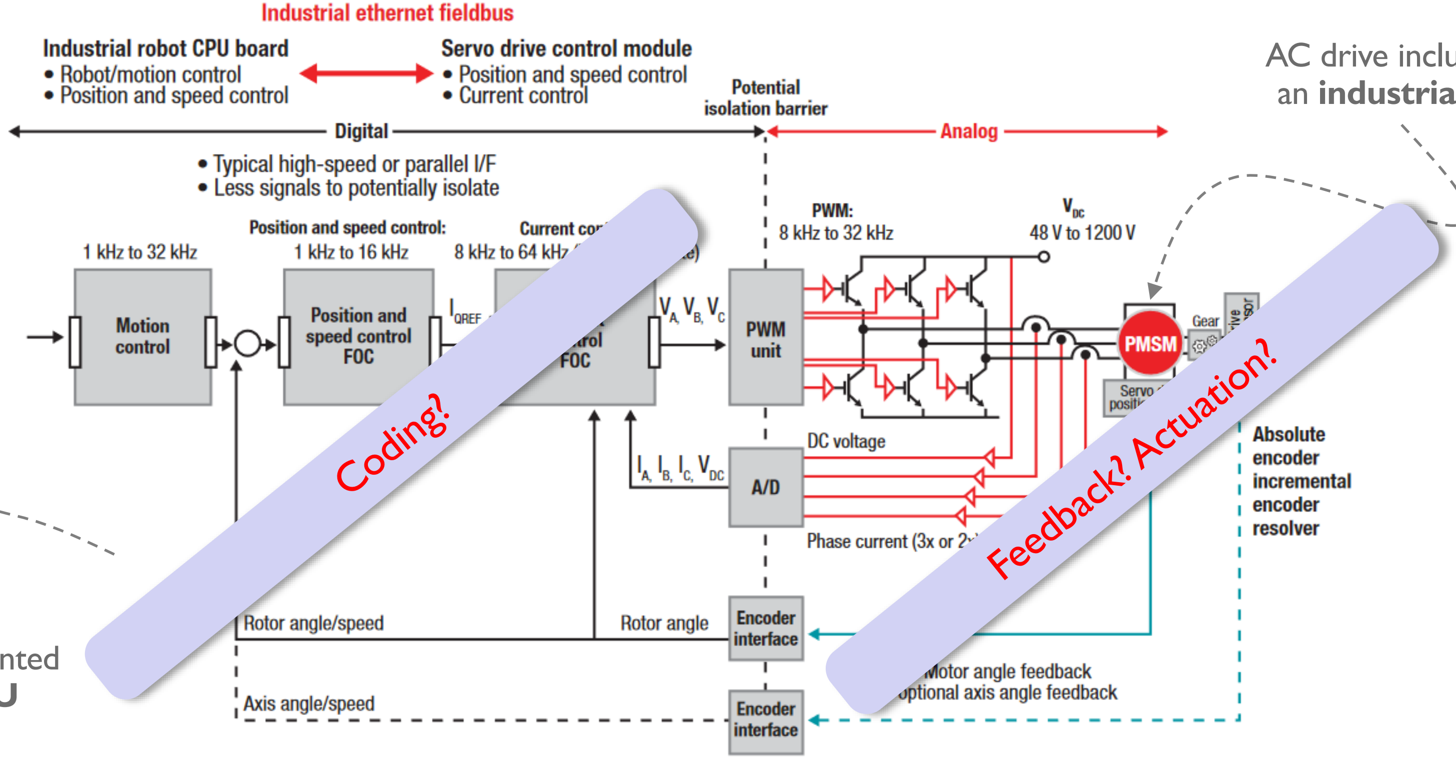
AC drive included into an **industrial robot**



this implemented on a **MCU**

✅ Control Logic

Power Stage

TI C2000 MCUs LaunchPad

TI BoosterPacks

PMSM

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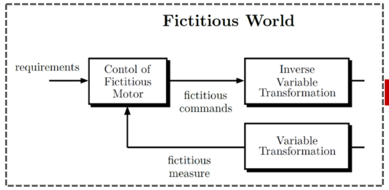
Moving from Theory to Practice

➢ Keep considering a FOC for a PMSM, there are several steps to move from theory to practice:

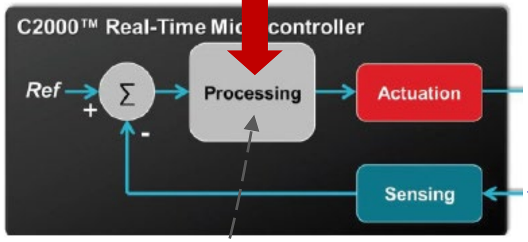


e.g. FOC, DTC

theory

the full cascade closed-loop scheme included here

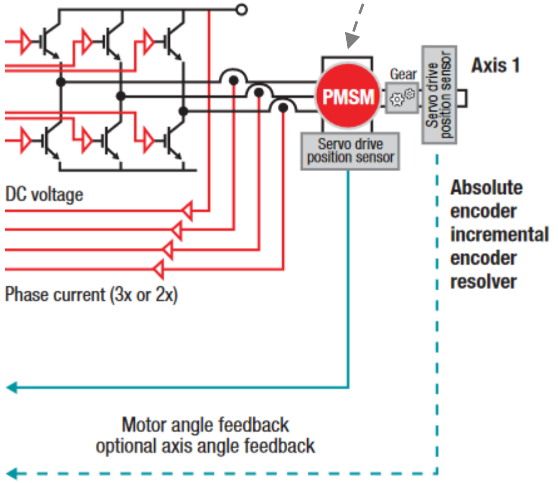
practice



MCU

- ✓ Clarke/Park
- ✓ PI controllers
- ✓ estimators
- ✓ look-up tables
- ✓ in/out scaling

AC drive included into an **industrial robot**



✅ Control Logic

Power Stage

TI C2000 MCUs LaunchPad

TI BoosterPacks

PMSM

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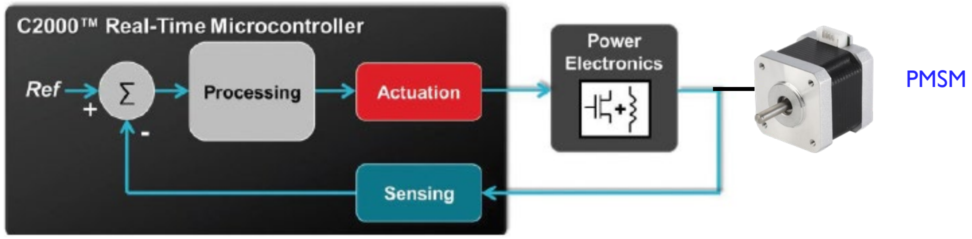
Approaching Motor Control with TI C2000 MCUs

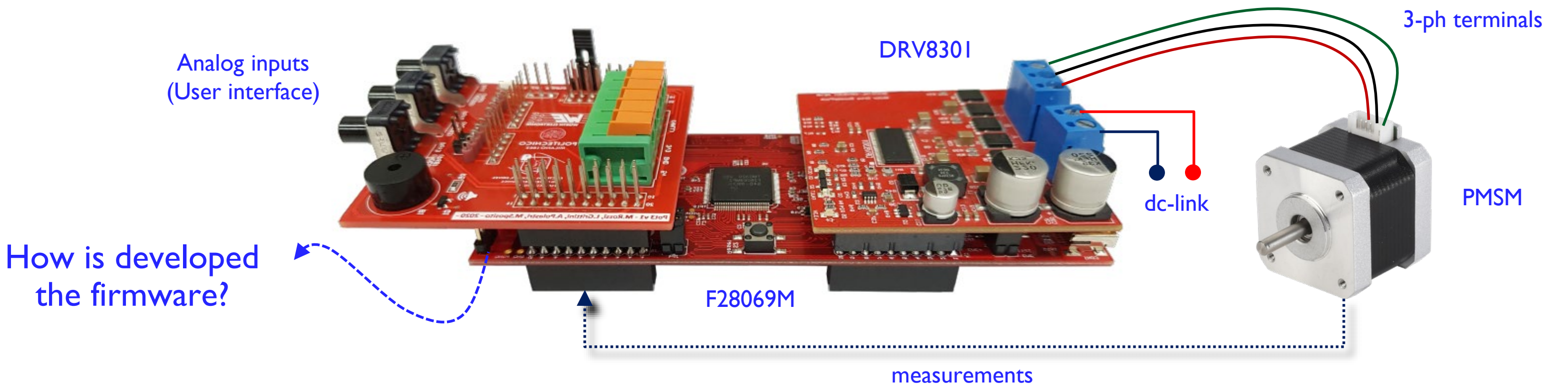
- This can be considered a "practical" scheme for control of electrical drives

  - ✓ The control loop(s) must be translated in «routines» suitable for the MCU
  - ✓ drive system feedback(s) are processed by precise «routines»



Example:

- how a test bench able to implement the control of a PMSM looks like in practice….



The TI C2000 LaunchPad MCUs are low cost, easy-to-use development boards with rapid prototpying capabilities

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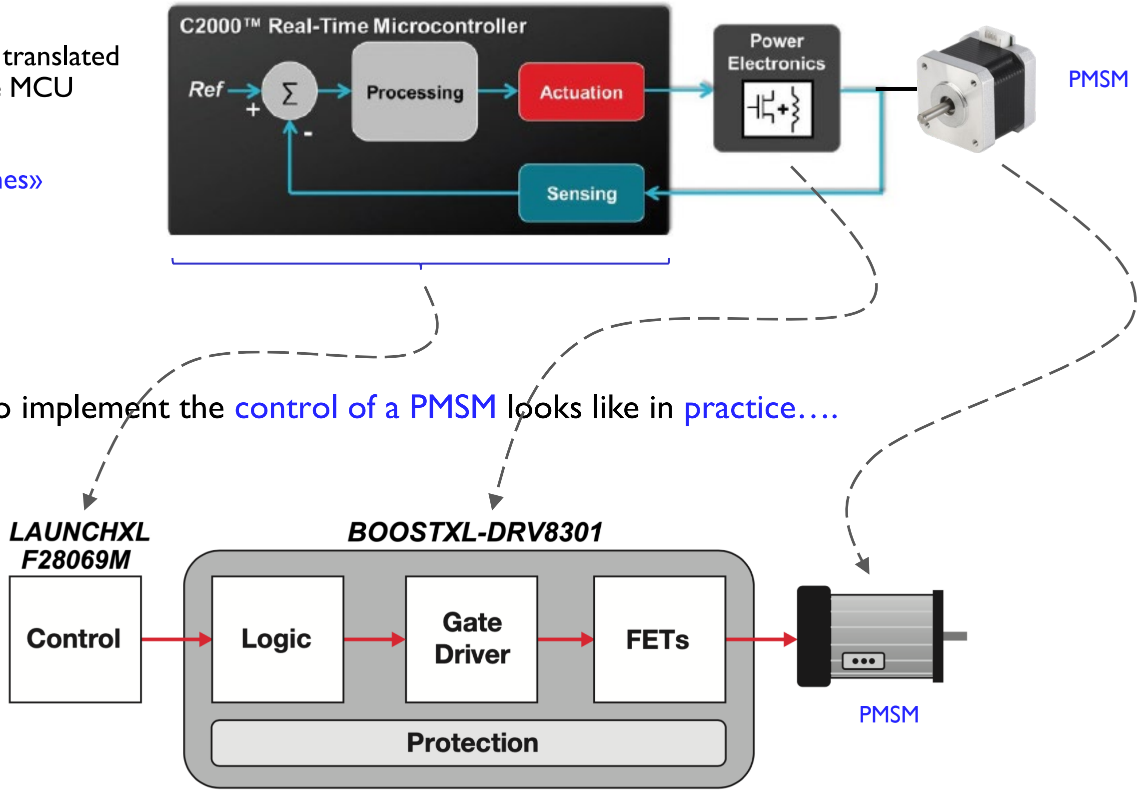

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The TI C2000 LaunchPad MCUs are low cost, easy-to-use development boards with rapid prototpying capabilities

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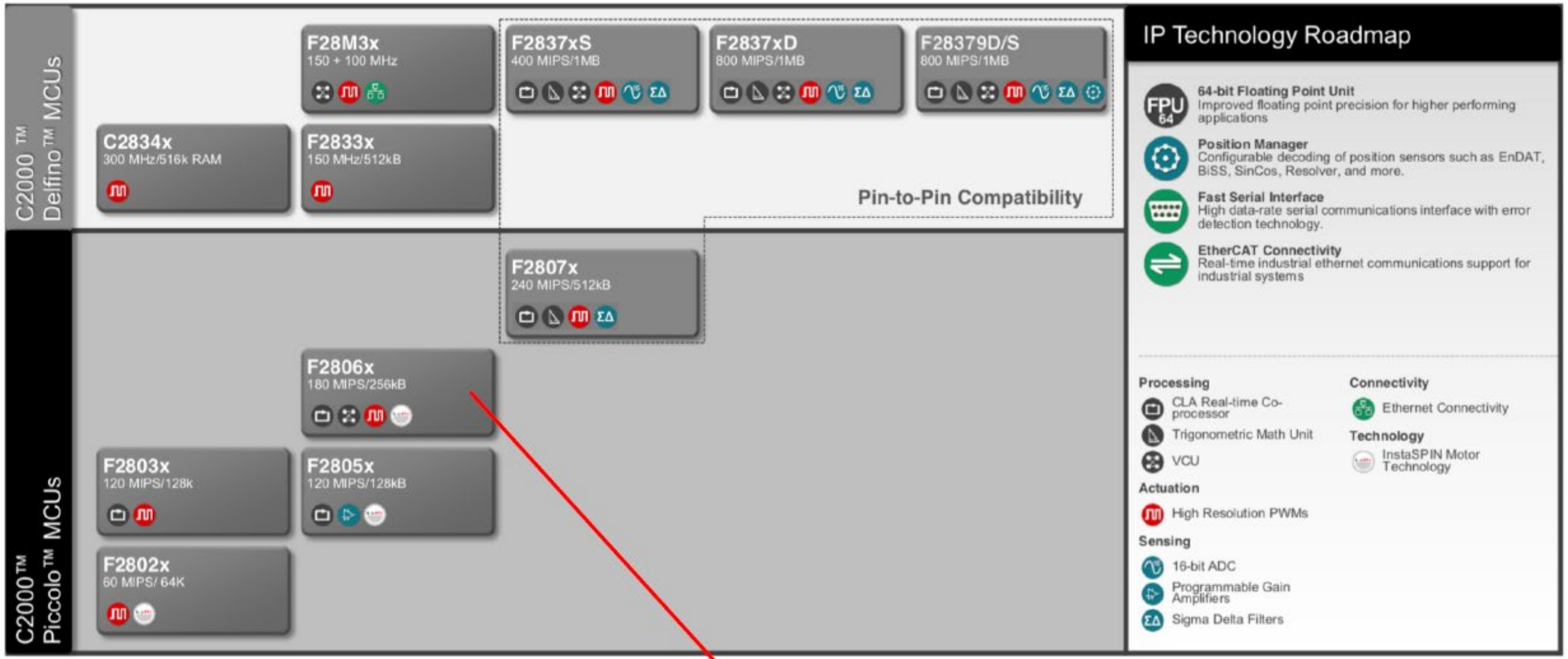
TI C2000 MCU LaunchPad Family

C2000 family is entirely supported on MATLAB/Simulink



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MATLAB & SIMULINK

F28069M

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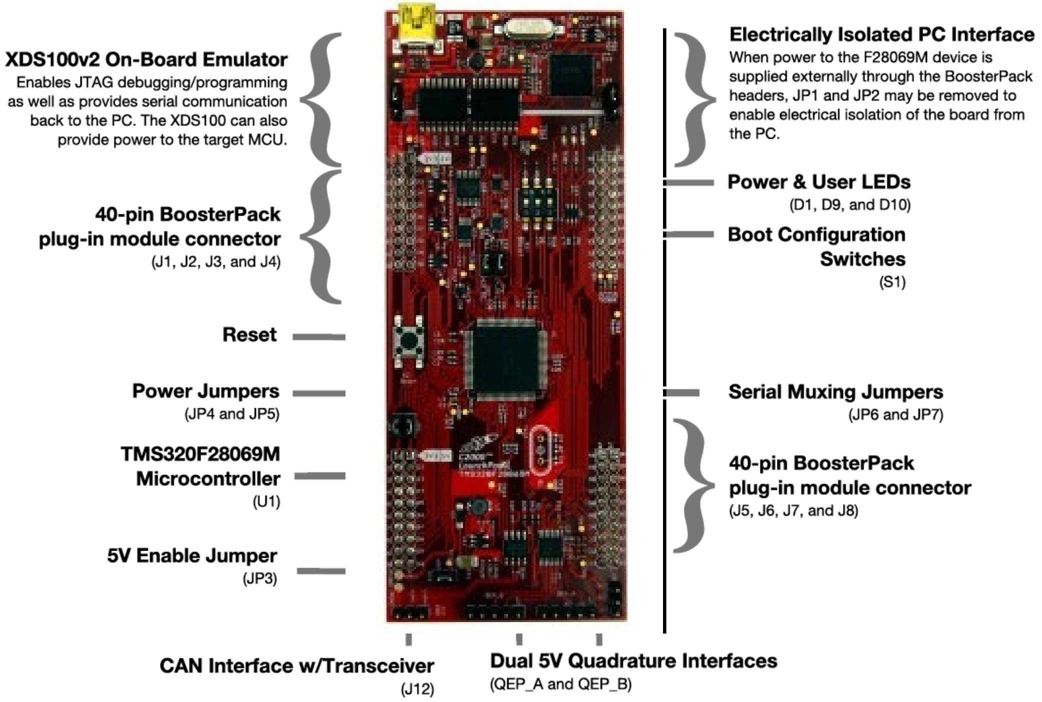
TI LaunchPad: F28069M

C2000 Piccolo: F28069M

- the DSP core and high-performance peripherals make these devices rock in real-time control applications…
- built-in electrically isolated JTAG emulator
- 12bit x 16 channels ADCs
- built in eQEP for (encoder reading)

Feature	LAUNCHXL-F28069M
MCU	TMS320F28069MPZT
Speed	90 MHz
Flash	256 kB
RAM	96 kB
EEPROM	N/A
Timers	3× 32-bit
Serial communication	2 SPI, I²C, 2 UARTs, CAN
ADC channels	12-bit, 16 channels
BoosterPack pins	2× 40
Energia support	No
Extra features	High-resolution PWM



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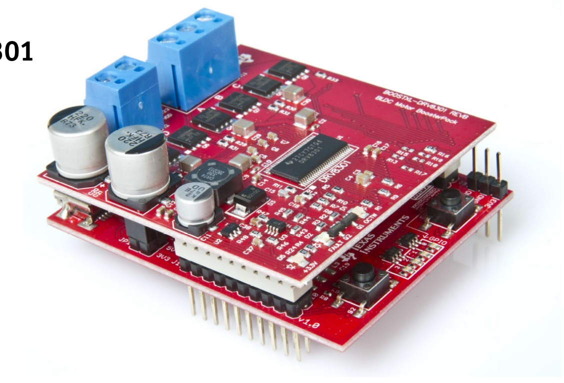
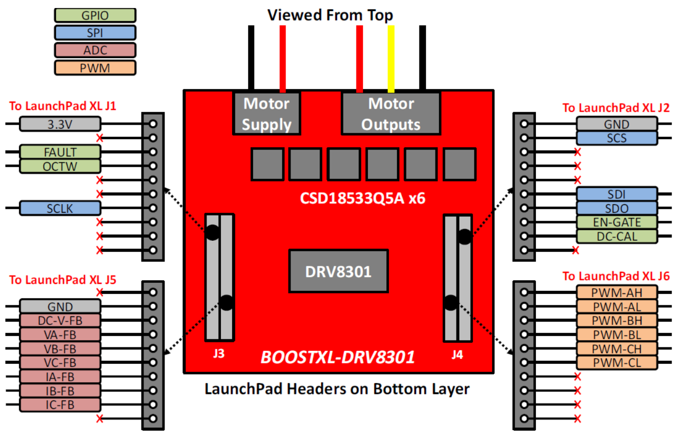
TI BoosterPack DRV8301

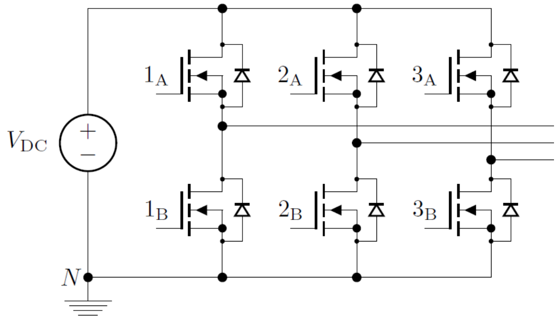
The TI BoosterPack DRV8301 is a complete 3-phase inverter for low voltage motor drive stage:

DRV8301





3-phase 2 level MOSFET-based converter



Features:

- Supports 6 to 24V and up to 10A RMS (14A peak)
- N-Channel NexFET Power MOSFETs (< 6.5 mΩ)
- Low-side current shunt sense on each phase
- DC bus voltage sense (resistive-divider)

particularly useful for lab/teaching experiments

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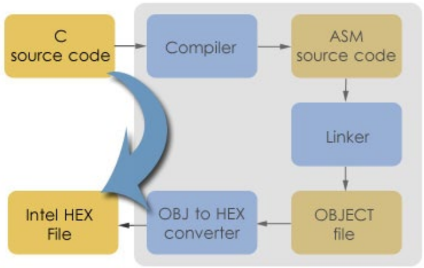
How to Program MCUs: main approaches

- **MCUs "should" be programmed via machine code to execute routines defined by the user**
- peripherals must be correctly set up…..this is time expensive (and quite often an obstacle for rookies)

Today, there are different alternatives and tools which can simplify the implementation

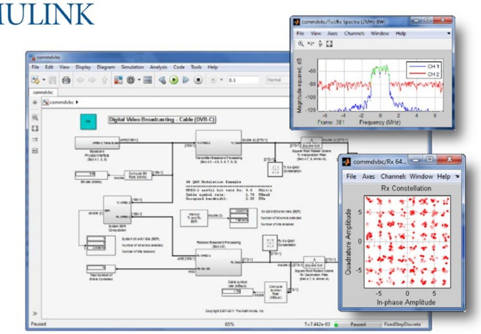
Let's consider two of them:



- ❑ **C/C++ programming**

  use an IDE (e.g. Code Composer Studio) to write C-code (compile, link, download, link, debug)

MATLAB & SIMULINK



- ❑ **Automatic Code Generation/Rapid Prototyping**

  use an interface (e.g. MATLAB/Simulink) to create high-level code (translate, compile, link, download, link, debug)

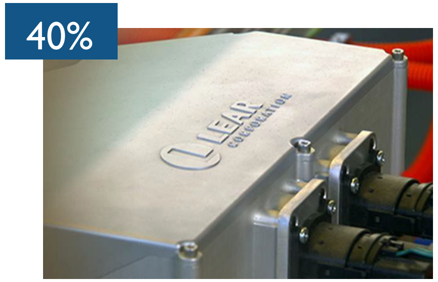
MATLAB & SIMULINK +

Model-based design

ePEBBS
efficient power electronics building blocks

Why Focusing on Rapid Prototyping Approach

- Production Code Generation → user stories



Automotive ECU

Propulsion Control Systems

Flight Control Systems

development time savings for early-stage control testing

Transport ventilator

HDVC Power Systems

Teaching Activities

MathWorks

ePEBBs
efficient power electronics building blocks

MathWorks Rapid Prototyping Approach

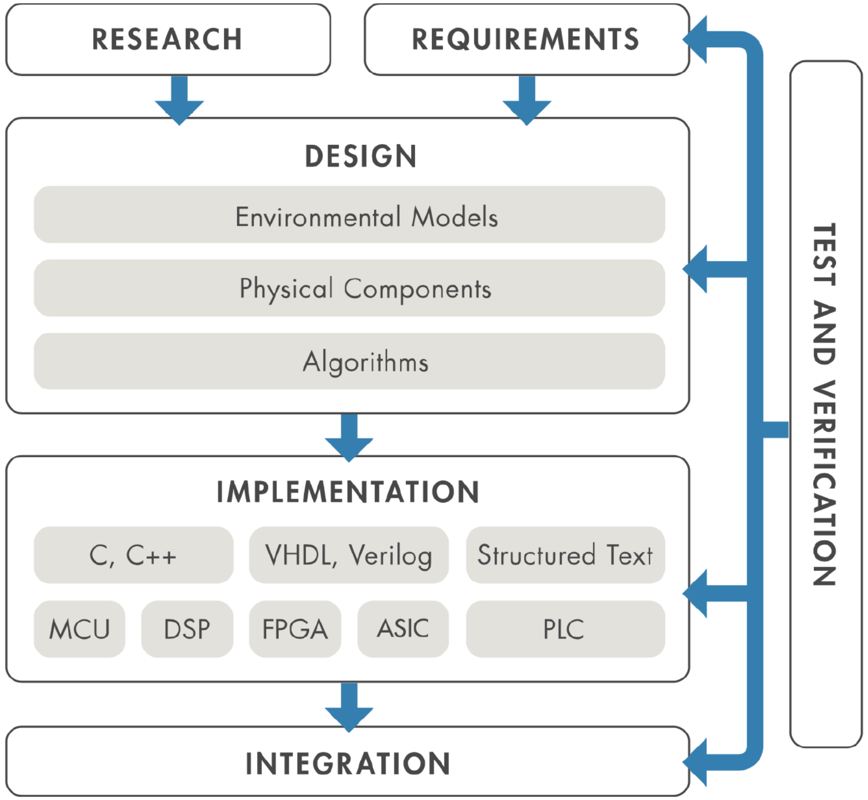
➢ **Workflow** (guidelines) to design a firmware with Simulink rapid prototyping:

MATLAB & SIMULINK

✓ a MATLAB/Simulink model/scheme of the system to be controlled is derived (similarly to what is used for simulations)

✓ according to the target platform (e.g. MCU, FPGA, GPU) the MATLAB/Simulink scheme is automatically translated into one of the following language

✓ the code can be deployed into the target platform (e.g. C in MCU)

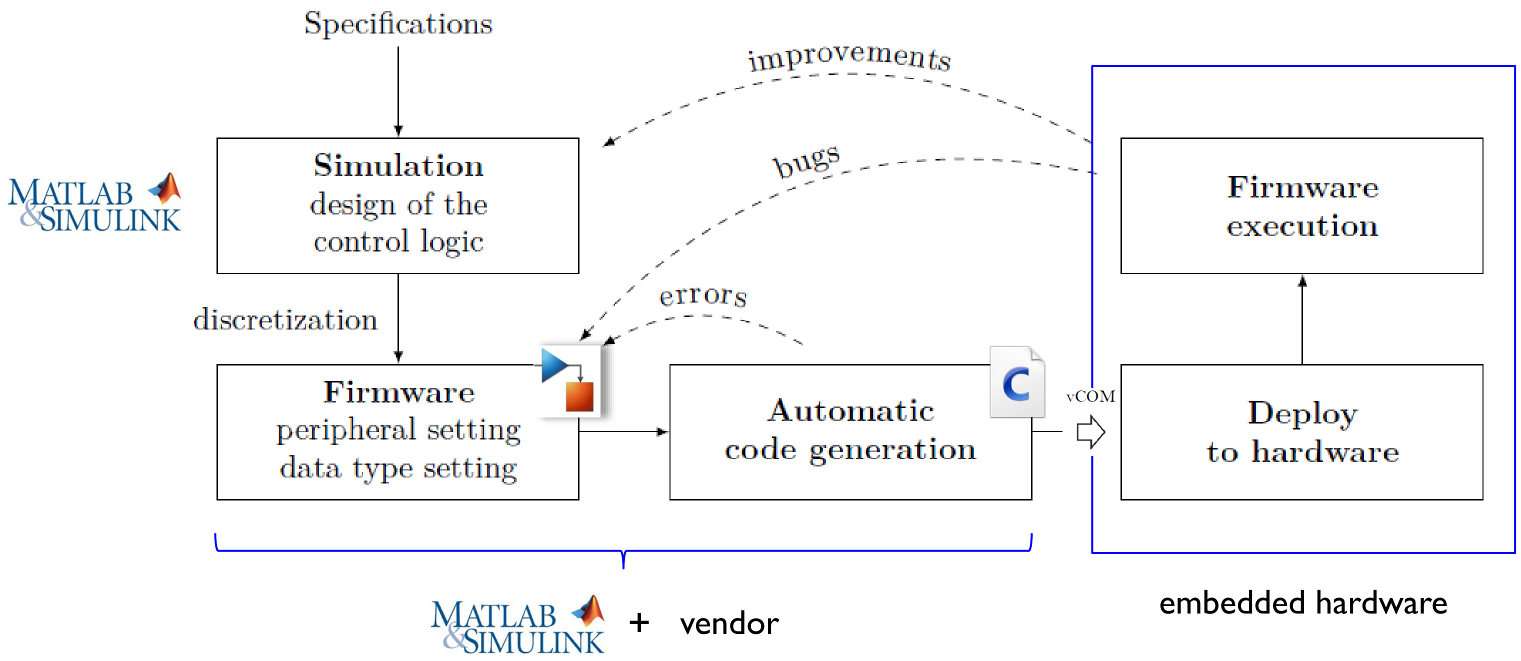


MathWorks Rapid Prototyping Approach

➢ **Workflow** (guidelines) to design a firmware with Simulink rapid prototyping:

(more in details)

Start: motor type, speed/torque profile,
power rating, voltage/current limits

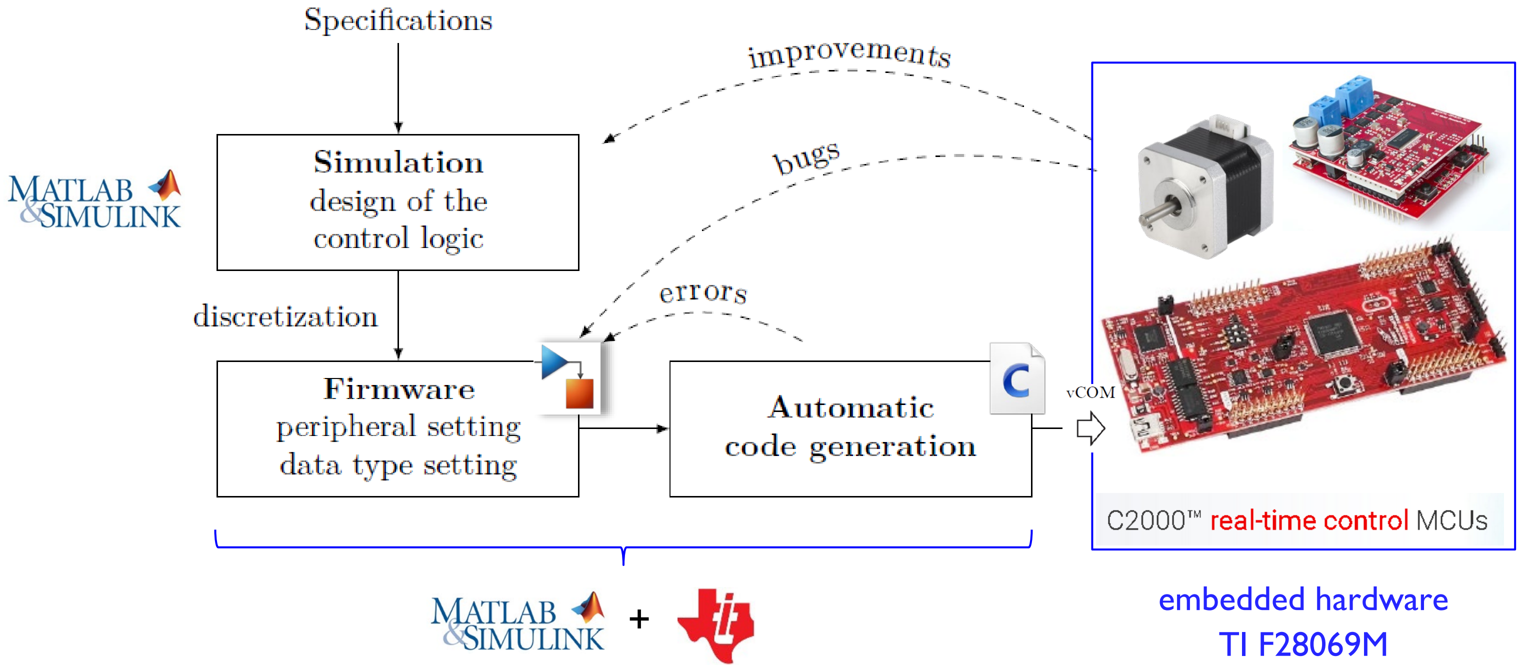


MathWorks Rapid Prototyping Approach for TI C2000

➢ **Workflow** (guidelines) to design a firmware with Simulink rapid prototyping:

(more in details)

Start: motor type, speed/torque profile,
power rating, voltage/current limits



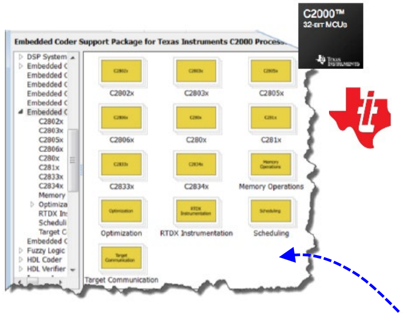
Texas Instruments

embedded hardware
TI F28069M

ePEBBs
efficient power electronics building blocks

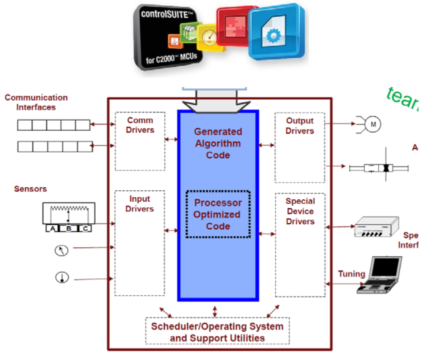
MathWorks Rapid Prototyping Approach for TI C2000

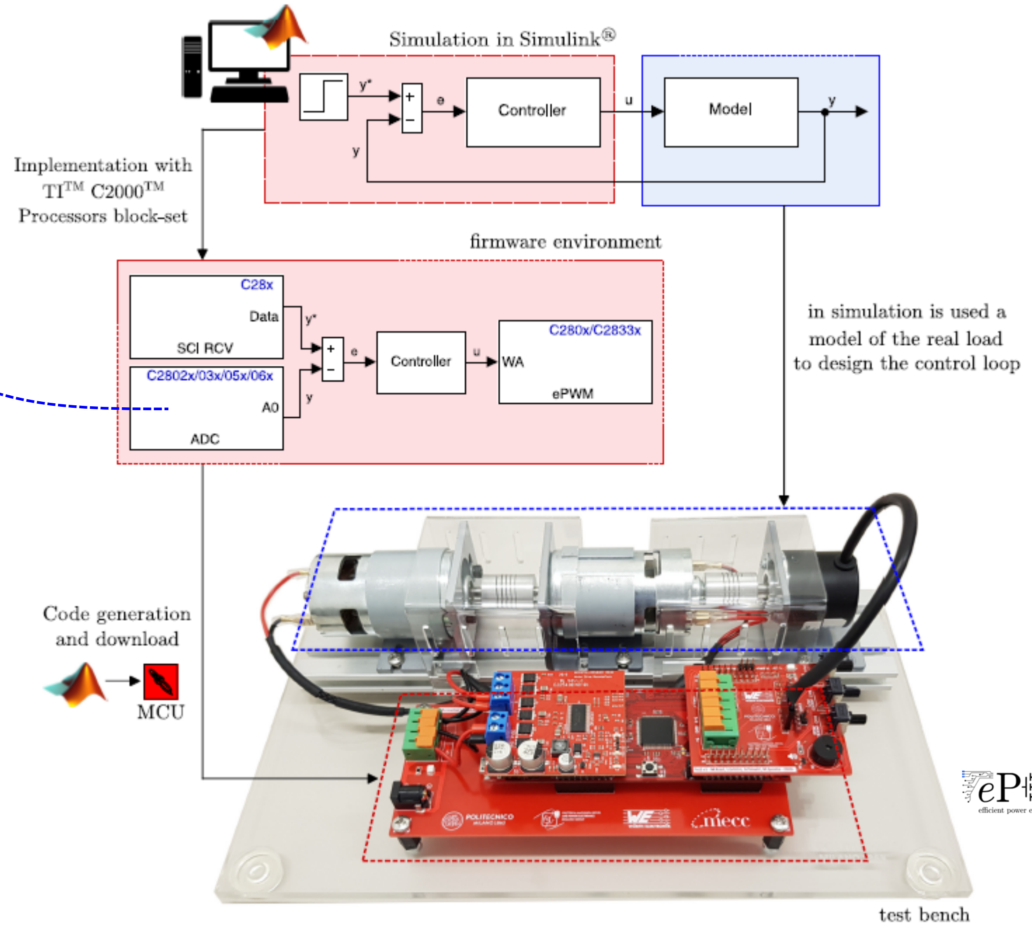
➢ **Workflow** (guidelines) to design a firmware with Simulink rapid prototyping:



we refer to a blockset library
but not all MCUs are supported (!)

all pheripherals should be « known »
and charaterized in Simulink blocks





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MathWorks Rapid Prototyping Approach for TI C2000

This specific workflow requires the usage of different software/packages:

Install

- Code Composer Studio Vx (where x is related to the MATLAB release) - (IDE)
- ControlSUITE Vx - (repository containg the board know how, e.g. peripheral settings/registers/examples)

Given that, Simulink will use

- Embedded Coder for TI C2000 Processors (Add Ons)

  Which is a sort of toolbox that:

  - load the blockset library for the supported board
  - make available a toolchain which work in background with Code Composer Studio Vx to compile the resulting block scheme and generate C code from 8bit to multi-core MCUs

  Additional features:

  - Code optimization (processor-specifc)
  - Code verification (PIL…)
  - Code profiling (tasks, routine…)
  - Code optimization (functions, files…)
  - Embedded targets (boards, scheduler…)

It generates (ANSI/ISO C) by default

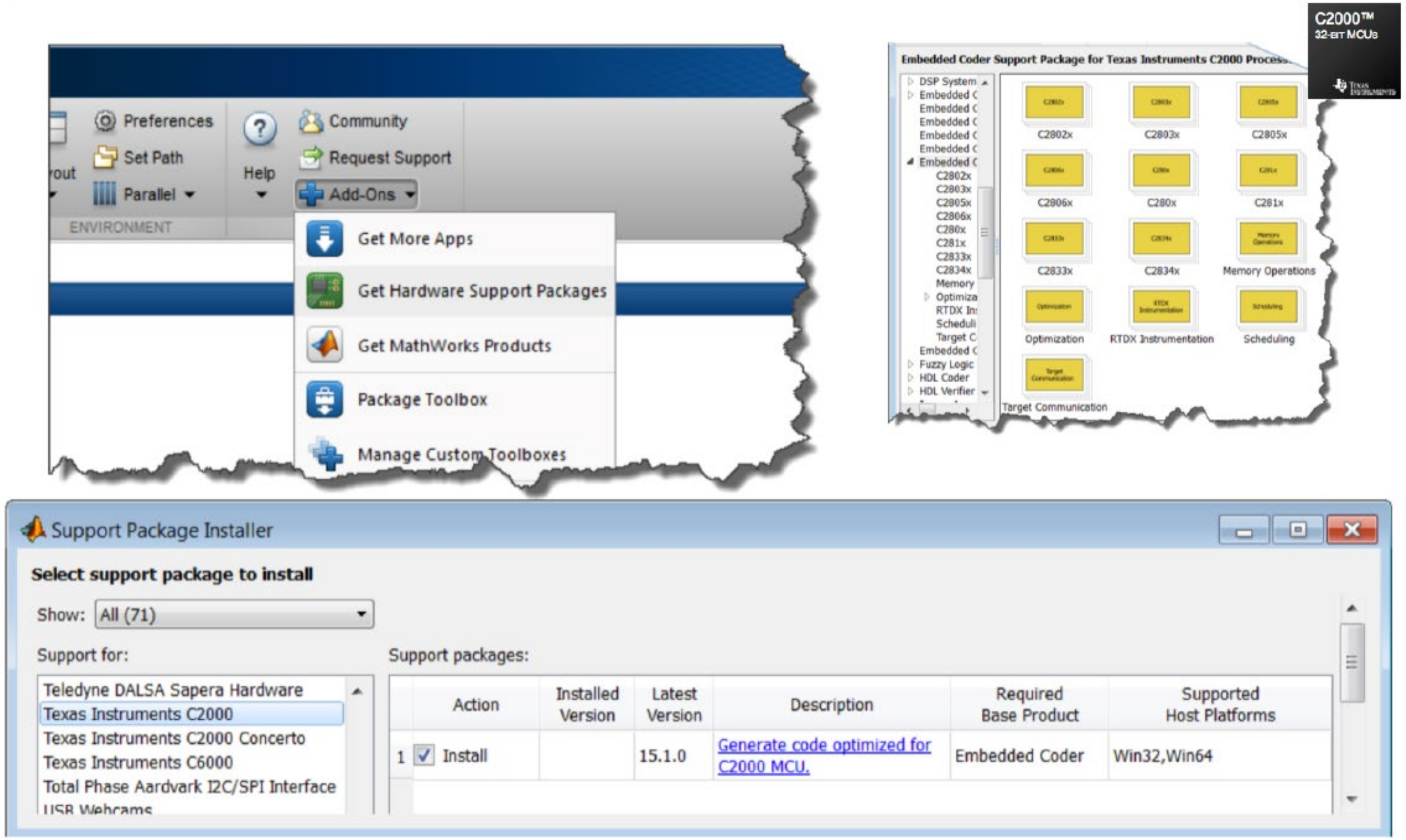
what you see

what happens beyond

efficient power electronics building blocks

MathWorks Rapid Prototyping Approach for TI C2000

How it looks like:

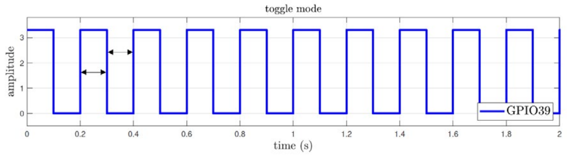


MathWorks

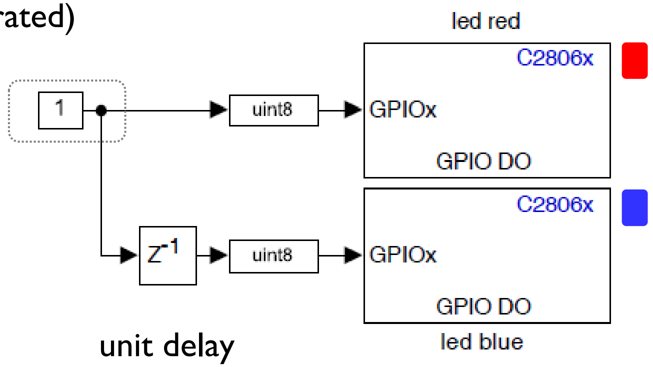
✓ refer to MathWorks/TI website for further details: https://it.mathworks.com/hardware-support/ti-c2000-embedded-coder.html
https://www.ti.com/tool/MATHW-3P-SLEC

MathWorks Rapid Prototyping Approach for TI C2000

➢ An **easy example** to understand the automatic code generation from Simulink is a **led blinking implementation**

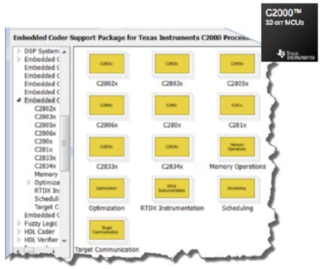


periodic pulse train
(internally generated)

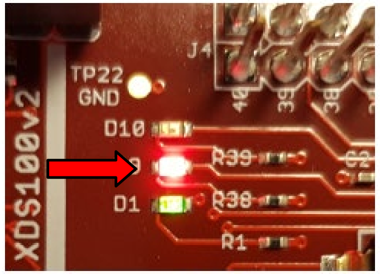


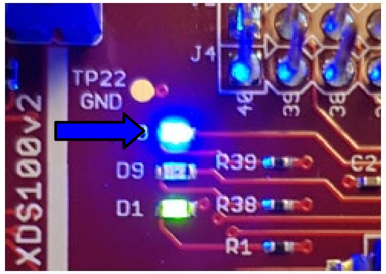
unit delay

on-board LEDs

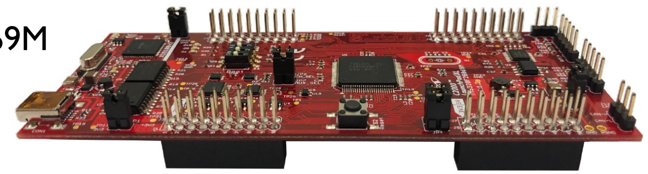


in practice





F28069M



`GPIO_TogglePin` routines are automatically generated in C and included into a `while(1)`

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MCU-based Hardware Kits

- ✓ Given the main benefits related to development time savings and reduce obstacle for rookies….
- ✓ …in 2019 the following partners

the TEAM

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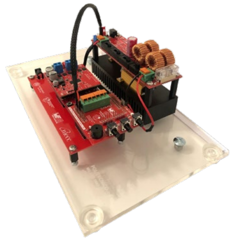
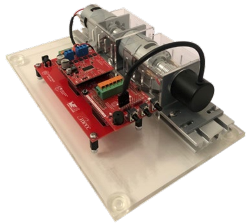
….and more !!

- ✓ started to collaborate on the development of MCU-based hardware kits suitable to effectively investigate and teach rapid prototyping approaches in the fields:



Power Management:
e.g. DC-DC converters

Motor Control:
e.g. PMDC, BLDC, PMSM



- ➢ different ready-to use test benches for the study of power electronics and motor control applications have been developed and are available today…
- ➢ (the programming approach can be either via MATLAB/Simulink or C code)

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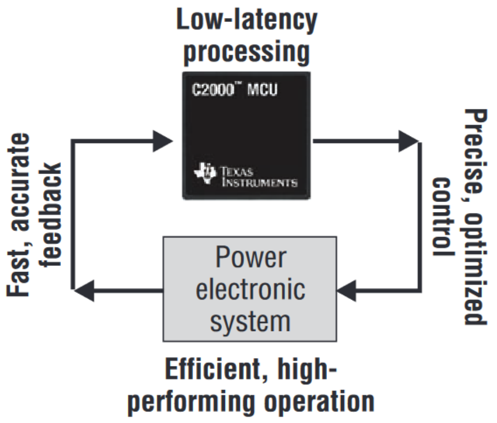
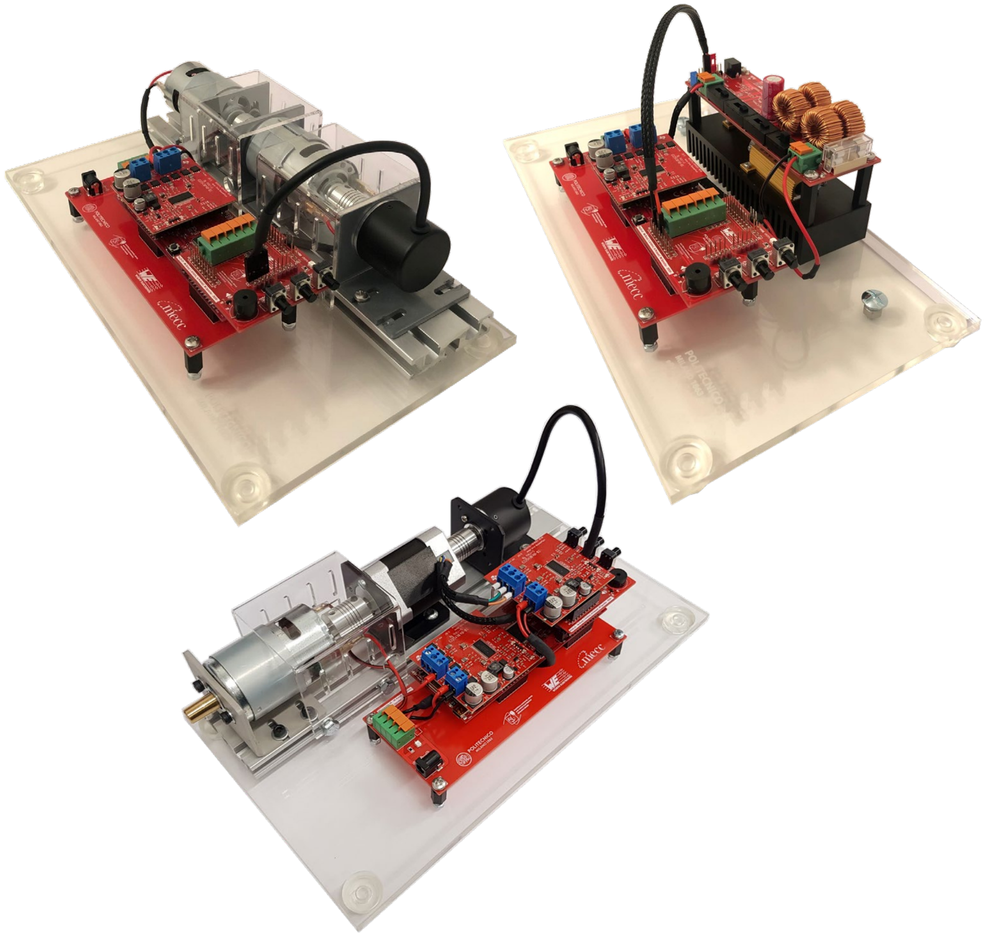
MCU-based Hardware Kits

- ✓ Many MCU-based hardware kits are available…. it depends what has to be tested (!)
- ✓ Full support to TI C2000 Piccolo and Delfino families

- ✓ All kits follows this main idea:





i.e., create a ready-to-use ecosystem in which the user focuses on

- design and implement a control scheme
- practical understanding the effects of parameters changing

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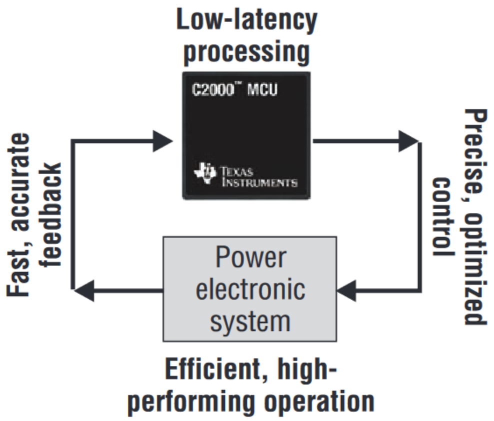

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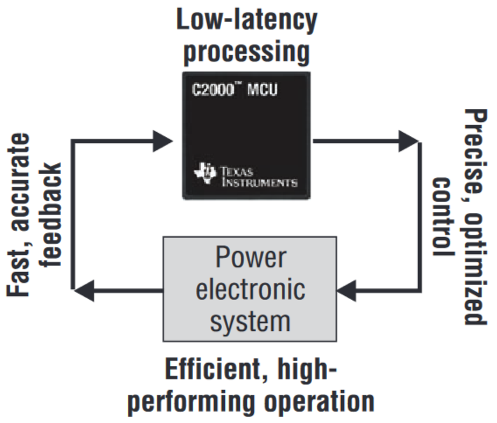

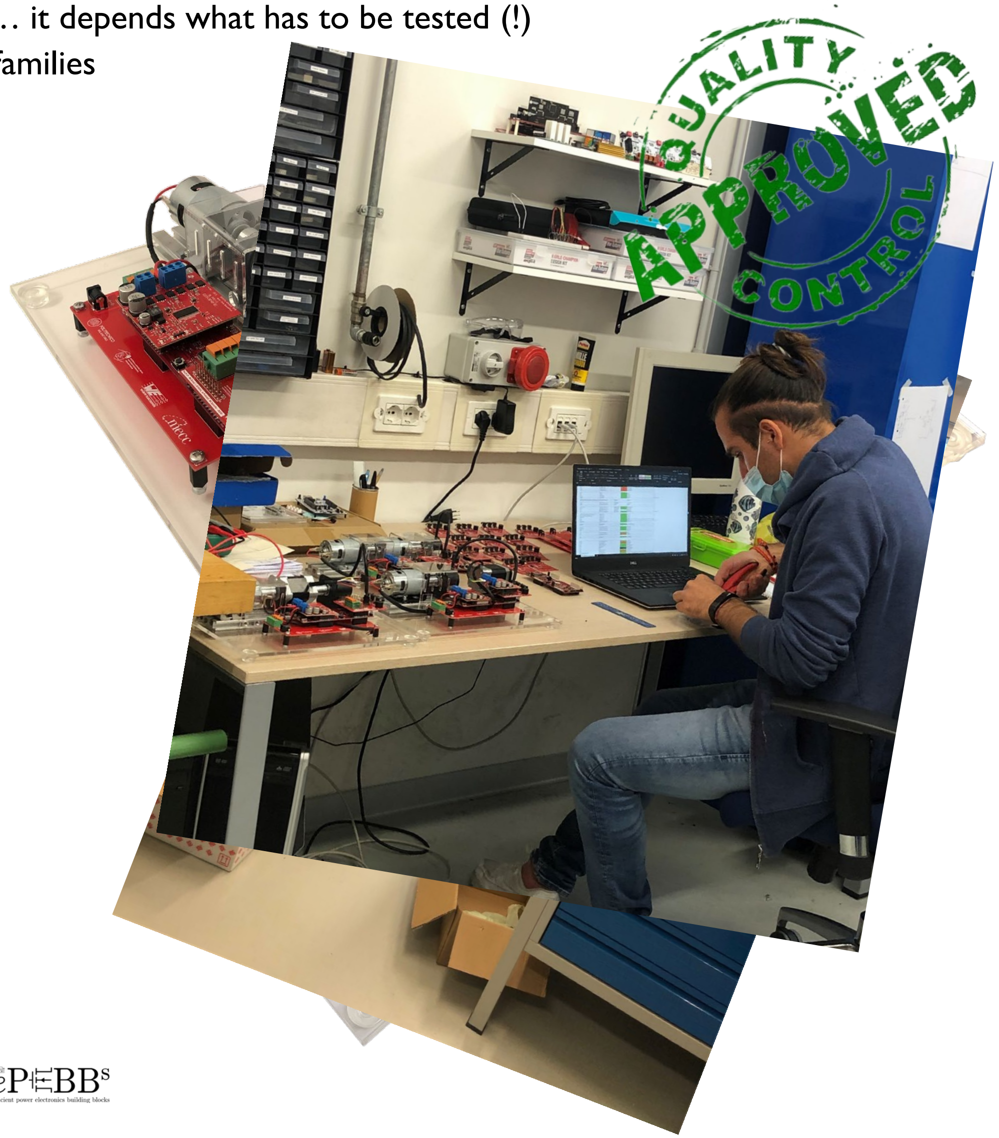

i.e., create a ready-to-use ecosystem in which the user focuses on

- design and implement a control scheme
- practical understanding the effects of parameters changing

MCU-based Hardware Kits

- The collaboration also led to the publish of the **book** :

Introduction to Microcontroller Programming for Power Electronics Control Applications: Coding with MATLAB® and Simulink® (1st ed.)

CRC Press, 2021
https://doi.org/10.1201/9781003196938

M. Rossi, N. Toscani, M. Mauri, and F. Castelli-Dezza

This book covers all the related *embedded implementation aspects on MCUs* and a detailed description of many *different exercises* that can be done with the given hardware kits

This is particularly indicated as starting point for who is interested on the basics of MCU programming

Available at:

- ✓ https://www.amazon.it/Introduction-Microcontroller-Programming-Electronics-Applications/dp/0367709856
- ✓ https://www.routledge.com/Introduction-to-Microcontroller-Programming-for-Power-Electronics-Control/Rossi-Toscani-Mauri-Dezza/p/book/9780367709853

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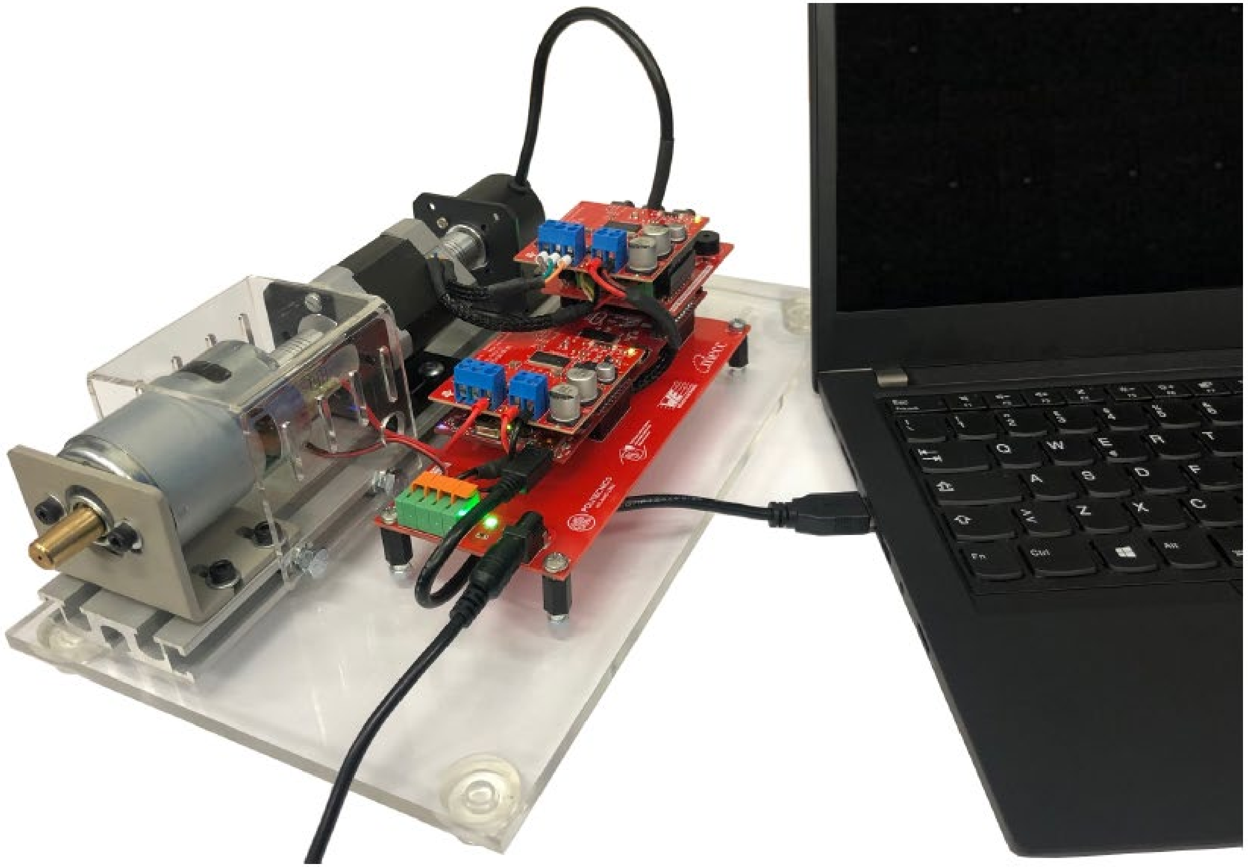
Approaching Motor Control (Implementation)

➢ Now let's use one of the kits to clarify how to move from motor control theory to practice…



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Motion Control Systems

Control of Electrical Drives

How can you move from motor control theory to practice?
Where implement the control logic?

A Practical Example: PMDC Control

Cascade Speed Control of a DC Drive System

Case study

- DC motors are used to move an Italian tramway vehicle "ATM Carelli 1928 " (let consider one motor only)
- the tramway should accelerate from 0 to 60km/h in 25s
- the tramway mass is 10T and you should consider 200 people as trainload, each with a standard weight of 80kg
- the friction force is proportional to the speed and at rated speed (60km/h or 314rad/s) is 1/3 of traction force

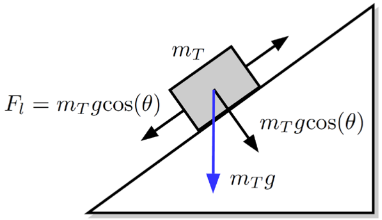
ATM
AZIENDA TRASPORTI MILANESI S.p.A.

- Line voltage : $600\,V$
- Motor rated speed : $314 rad/s$
- Efficiency: 0.9
- Armature circuit time constant :$10ms$

Goal

- **design a cascade speed control for the DC traction system**
- the speed profile is given
- the resistive/load torque is function of the urban geography

track	slope %	speed
$0-1km$	0	$35km/h$
$1-3km$	0	$60km/h$
$3-4km$	5%	$60km/h$
$4-6km$	0	$75km/h$
$6-8km$	0	$60km/h$
$8-9km$	−5%	$60km/h$
$9-10km$	0	$35km/h$

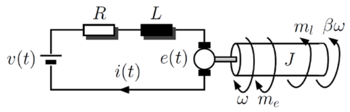


Cascade Speed Control of a DC Drive System

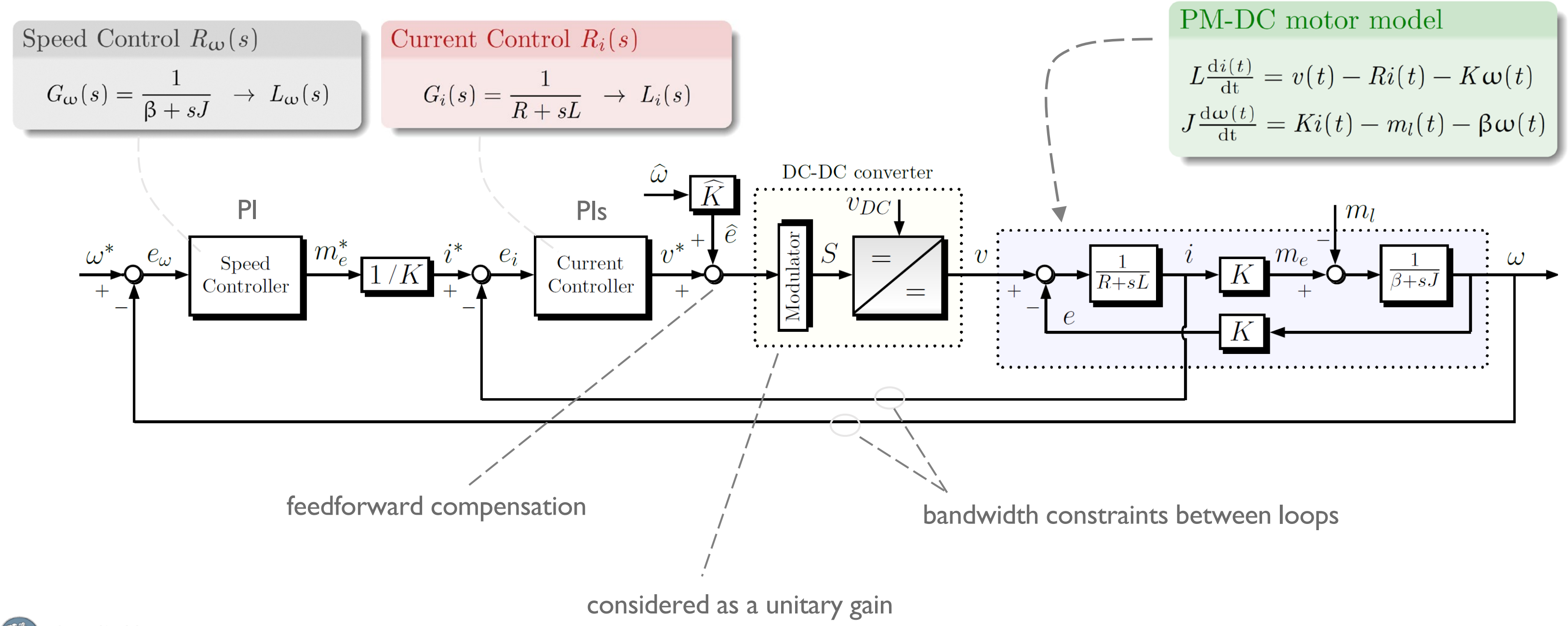
✓ **Simulation point of view**

derive a control scheme based on a cascaded architecture (nested loops):

- use linear control theory $\rightarrow$ use linear controller $\rightarrow$ e.g. PI controllers (its designer choice)
- use pole/zero cancellation $\rightarrow$ use explicit formula to derive $k_p,\ k_i$ formulas
- start design from speed loop $\rightarrow$ keep bandwidth constraints between loops
- use look-up tables or MATLAB Fcn to translate position into speed and torque profiles



A possible control scheme looks like this:



Cascade Speed Control of a DC Drive System

download available
linked to book

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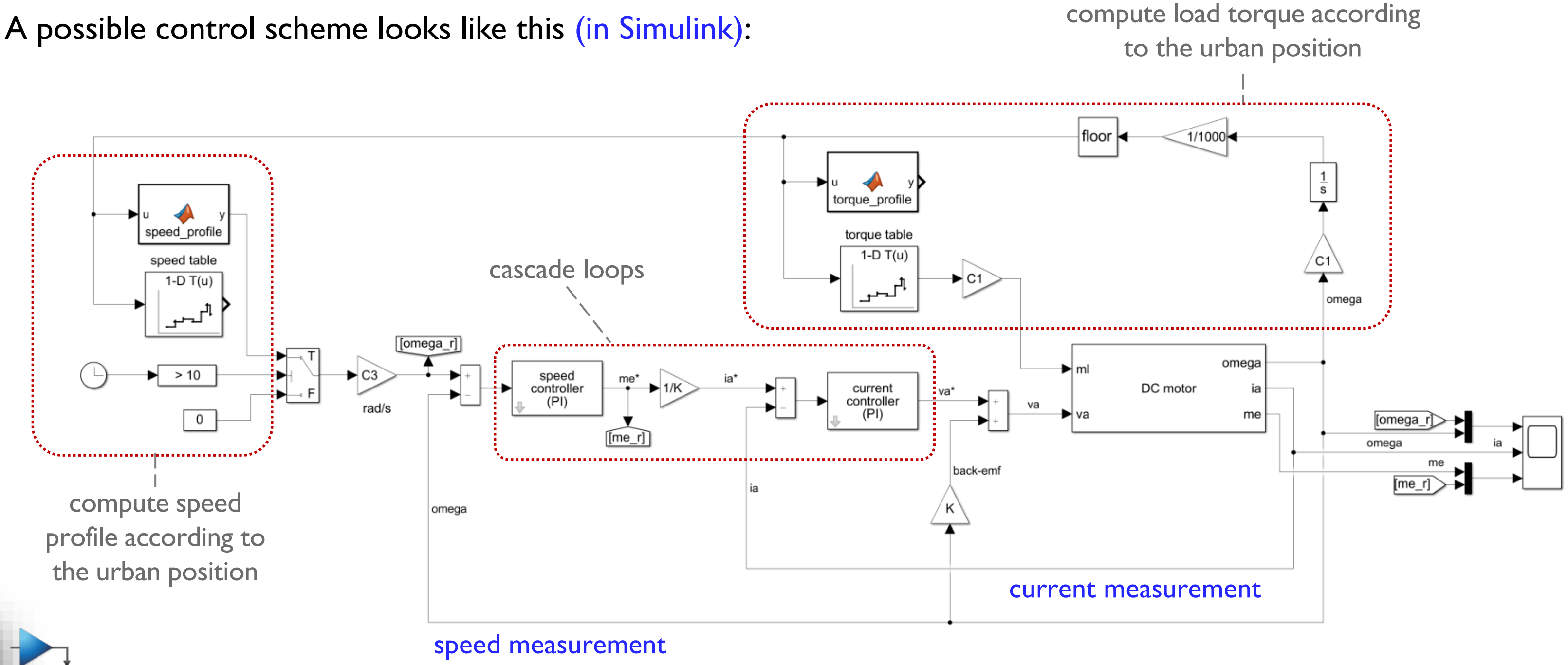
A possible control scheme looks like this (in Simulink):



New Script

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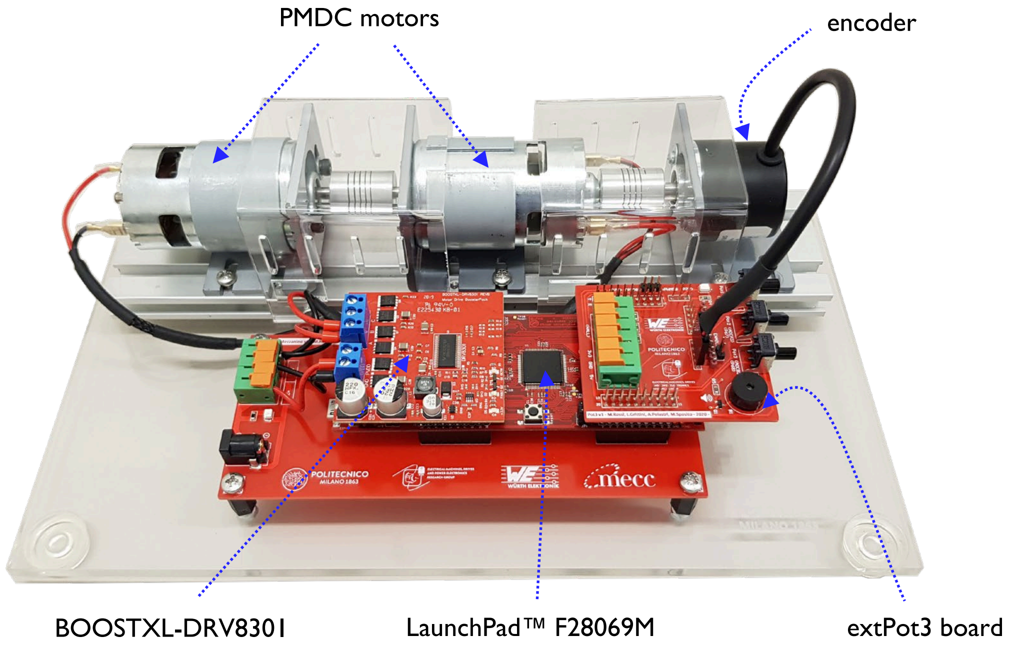
Cascade Speed Control of a DC Drive System

✓ Implementation point of view

How can we easily implement and test such case study in practice?
→ adopt rapid prototyping in a small-case setup !!

Let us consider to use the following **B2B-PMDC kit**



- **back-to-back configuration**
- one LaunchPad™ F28069M board
- one or two Boosterpack TI™ BOOSTXL-DRV8301 converter boards
- one extPot3 board
- a mezzanine board to hold the MCU and manage the external power supply
- two equal PMDC motors
- encoder LPD3806-600BM-G5-24C

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Cascade Speed Control of a DC Drive System

✓ Implementation point of view

a back-to-back configuration is suitable to emulate the tramway case study

track	slope %	speed
$0-1km$	0	$35km/h$
$1-3km$	0	$60km/h$
$3-4km$	5%	$60km/h$
$4-6km$	0	$75km/h$
$6-8km$	0	$60km/h$
$8-9km$	-5%	$60km/h$
$9-10km$	0	$35km/h$

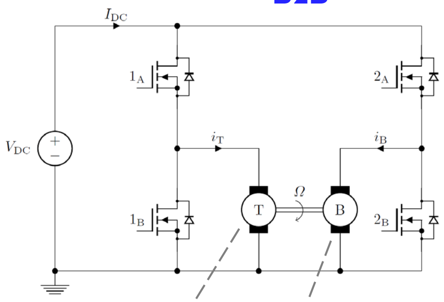
emulate the slope effects

use it to apply a dynamic braking (torque control loop)

control it with a cascade speed control

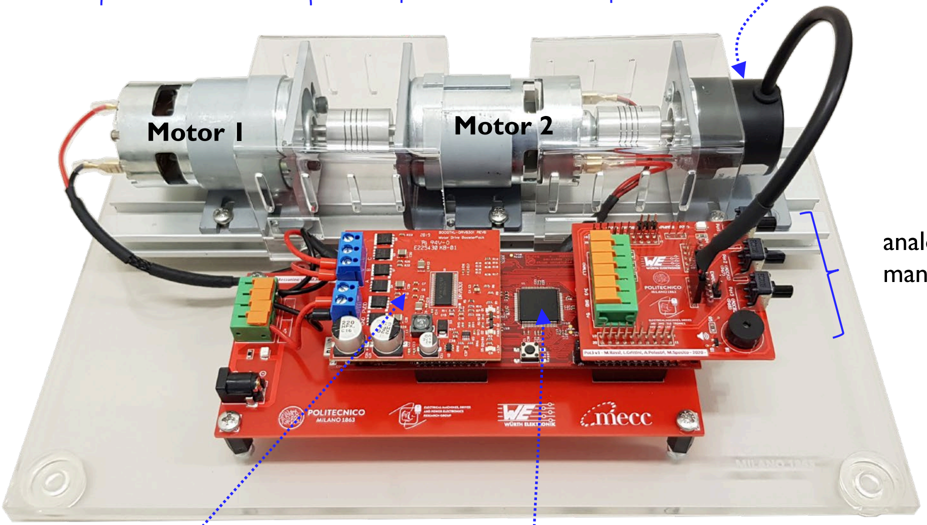
speed measurement (but it can be encoderless)

B2B



Motor 1 (half-bridge)

Motor 2 (half-bridge)



analog inputs that can be used to manually change speed reference or load torque (or debug)

BOOSTXL-DRV8301 (shunt current measurements)

LaunchPad™ F28069M

only one MCU to actively control both DC motors

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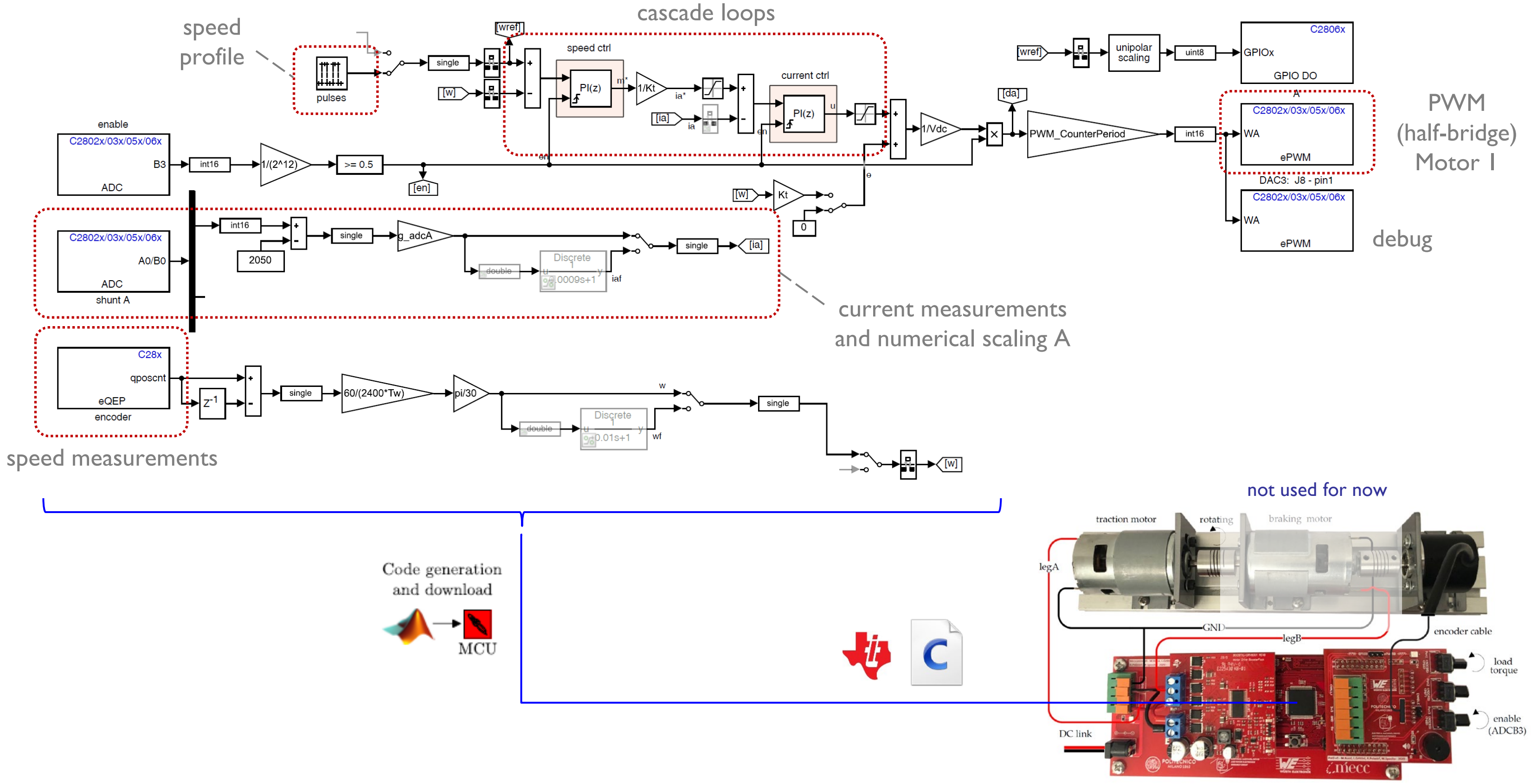
Cascade Speed Control of a DC Drive System

download available
linked to book

✓ Implementation point of view

How a potential firmware for the B2B-PMDC kit look like: **Motor I**



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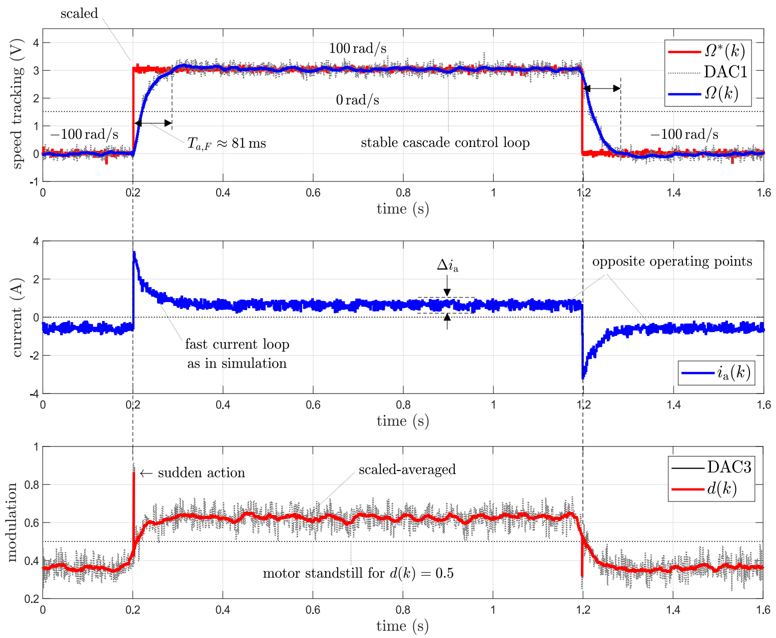
Cascade Speed Control of a DC Drive System

✓ **Implementation point of view** → cascade speed control (half-bridge)

How a potential [firmware] for the B2B-PMDC kit look like: **Motor 1**

- first consider a step-wise speed reference to test if the implemented logic works fine



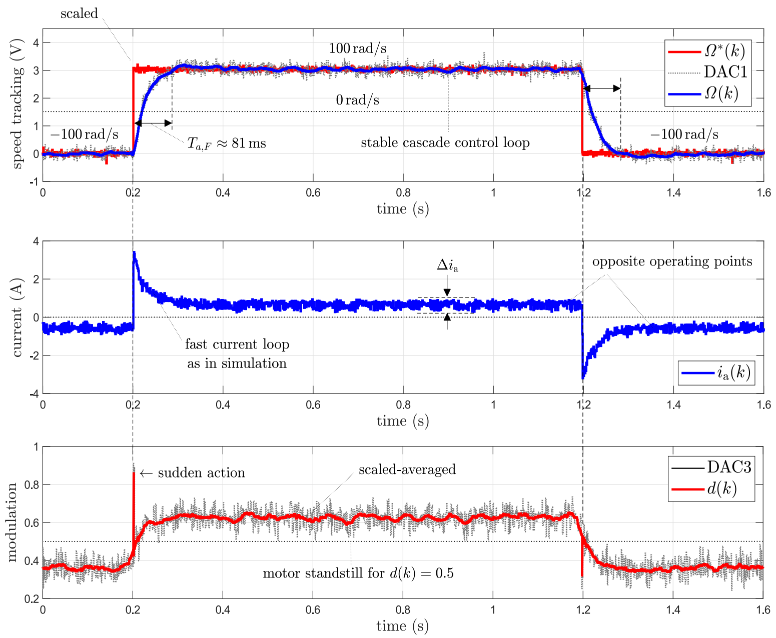
- pay attention to current/voltage saturations
- include anti wind-up and integral reset

Cascade Speed Control of a DC Drive System

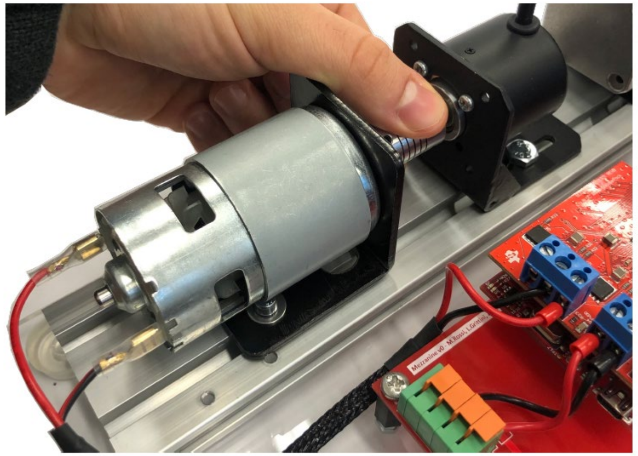
✓ **Implementation point of view** → cascade speed control (half-bridge)

How a potential firmware for the B2B-PMDC kit look like: **Motor I**

➤ first consider a step-wise speed reference to test if the implemented logic works fine



what happens to current/voltage if we apply a load torque at steady state?



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How a potential firmware for the B2B-PMDC kit look like: **Motor I**

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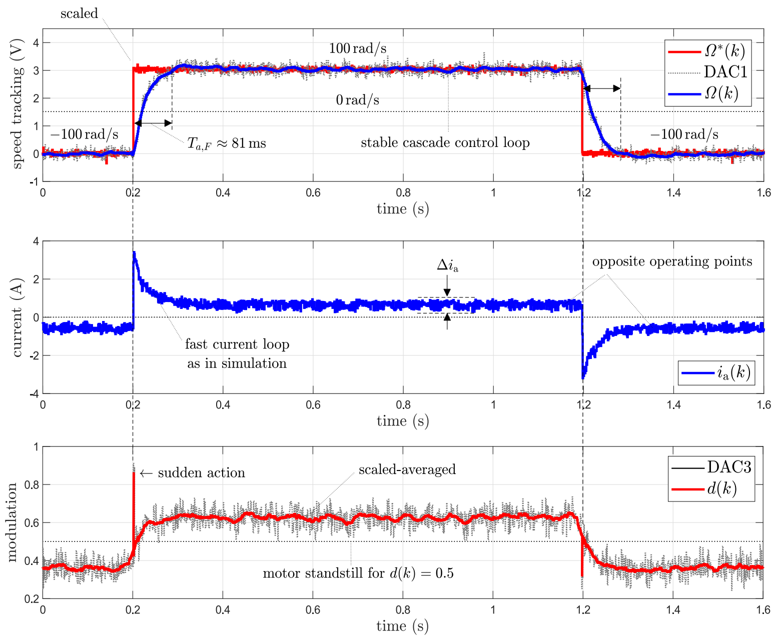

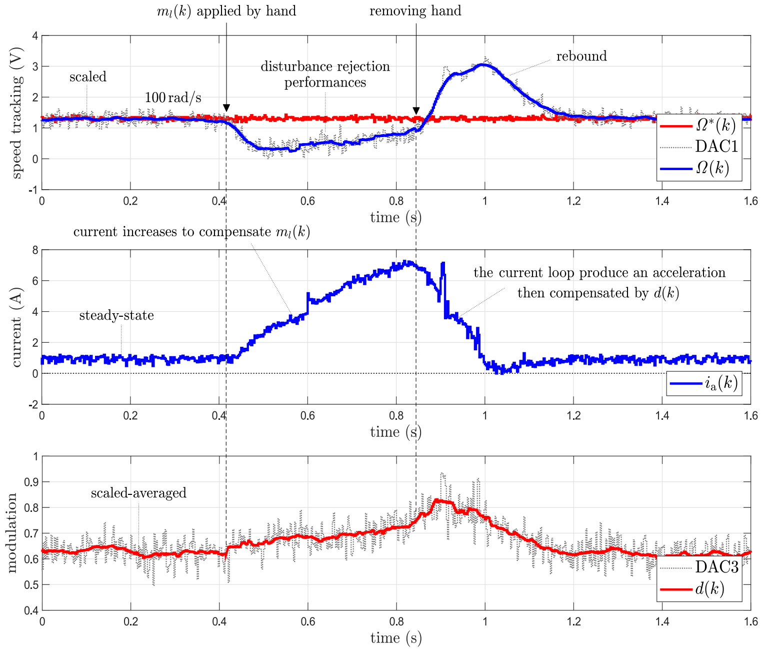

- pay attention to current/voltage saturations
- include anti wind-up and integral reset

✓ **cascade speed control works fine**

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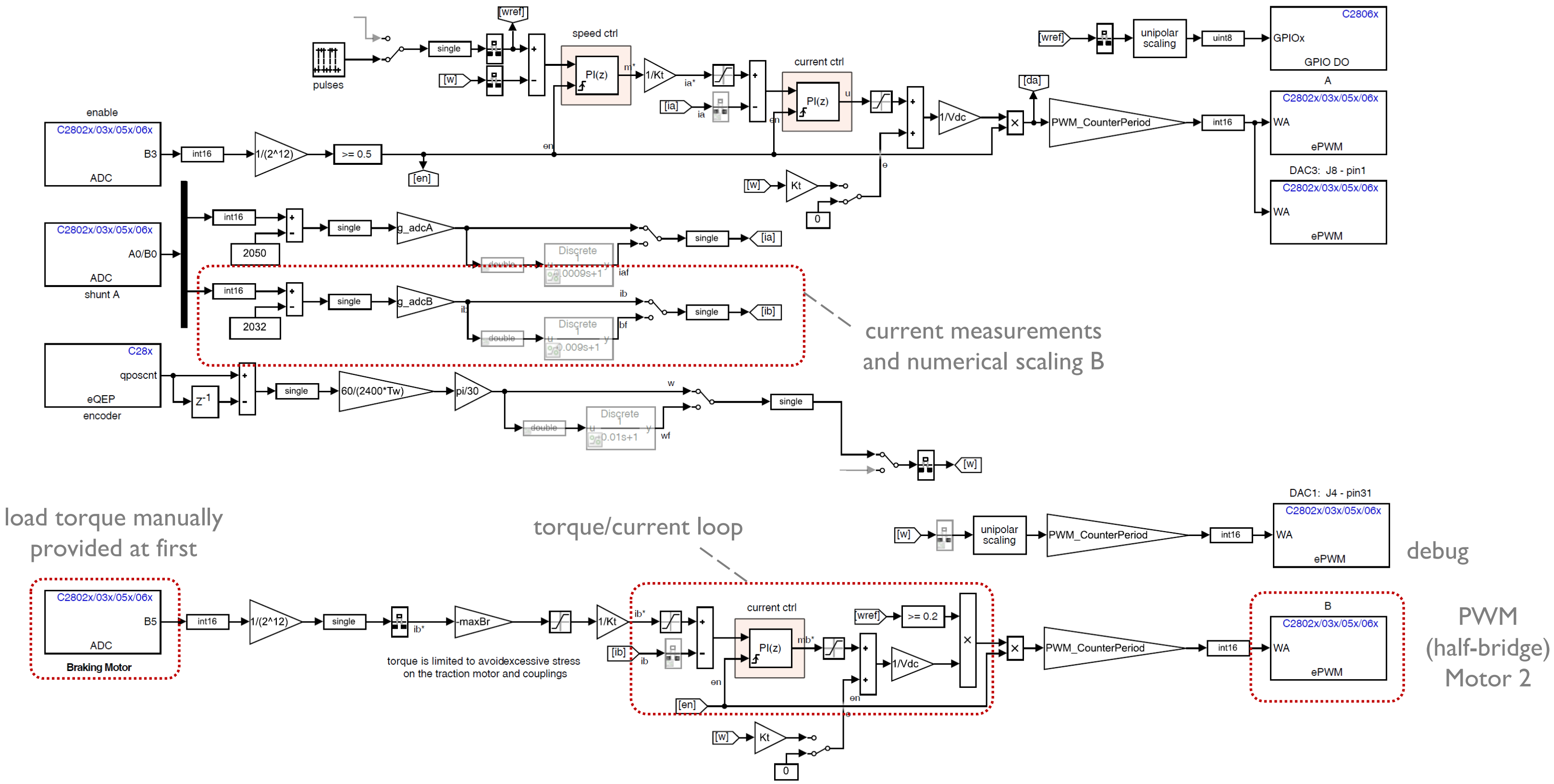
Cascade Speed Control of a DC Drive System

✓ **Implementation point of view** → cascade speed control (half-bridge) + (current) torque control loop (half-bridge)

How a potential firmware for the B2B-PMDC kit look like: **Motor 1 + Motor 2**



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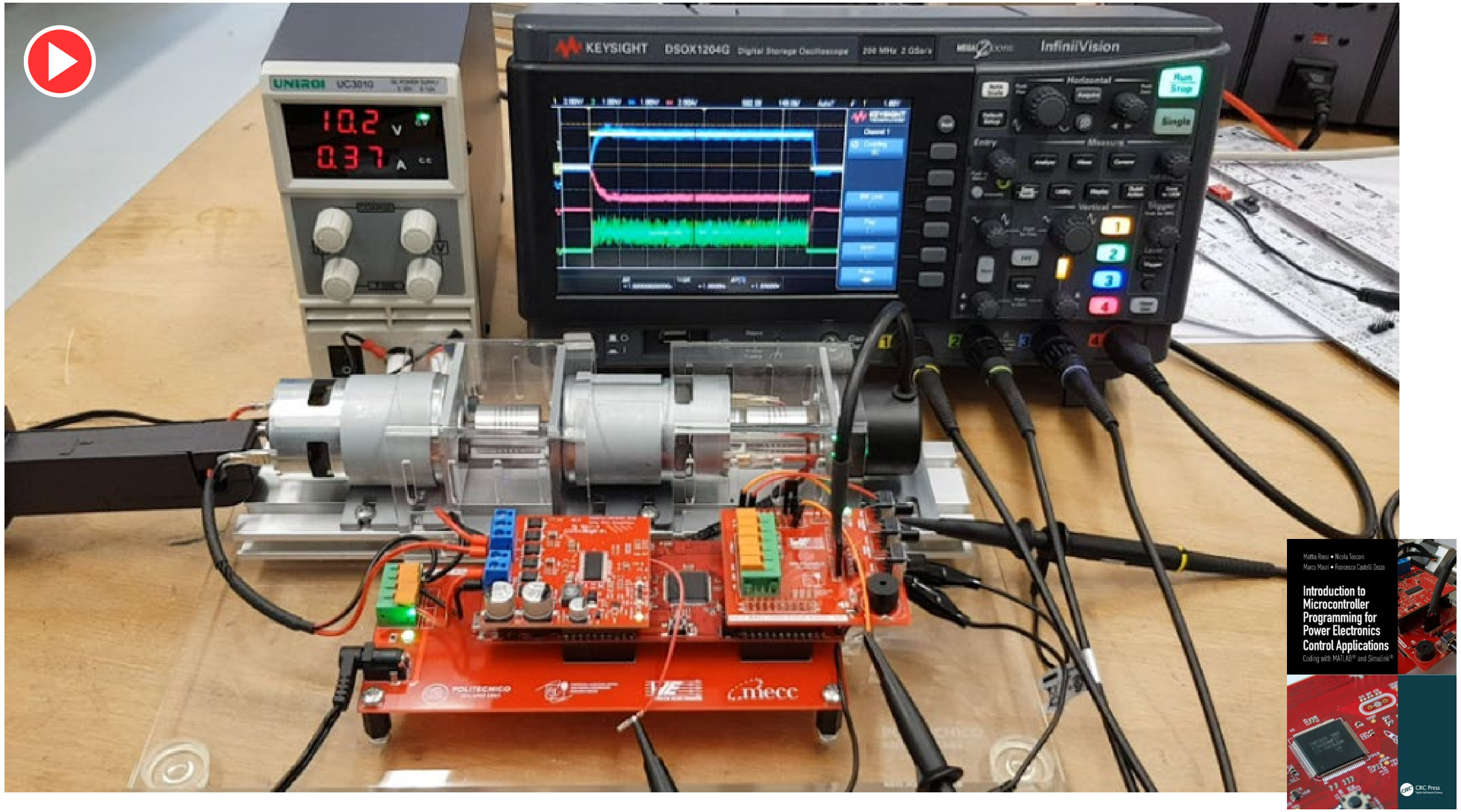
Cascade Speed Control of a DC Drive System

download available
linked to book

✓ **Implementation point of view** → cascade speed control (half-bridge) + (current) torque control loop (half-bridge)

in operation



Conclusions

✓ **Why easily moving from theory to practice is important ?**

✓ target specific mechatronic system needs is practically achieved by targeting the «System Level» and have competences to bridge the boundaries between more (>) than 3 key areas

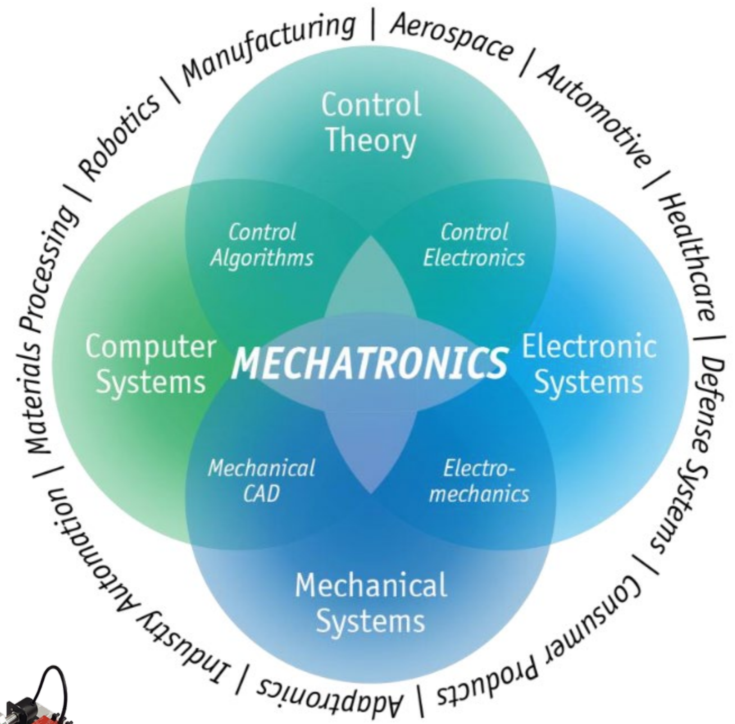
✓ As shown by the examples, rapid prototyping approach is a suitable approach to reduce the development time and quickly test effectiveness of a control approach

- investigate intelligence on the controller in order to face nonlinearities, constraints, delays, model mismatch

- check these things in safe environment getting know how on practical aspects

Quickly complete research analysis circle

MATLAB & SIMULINK



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Further Examples (extra material)

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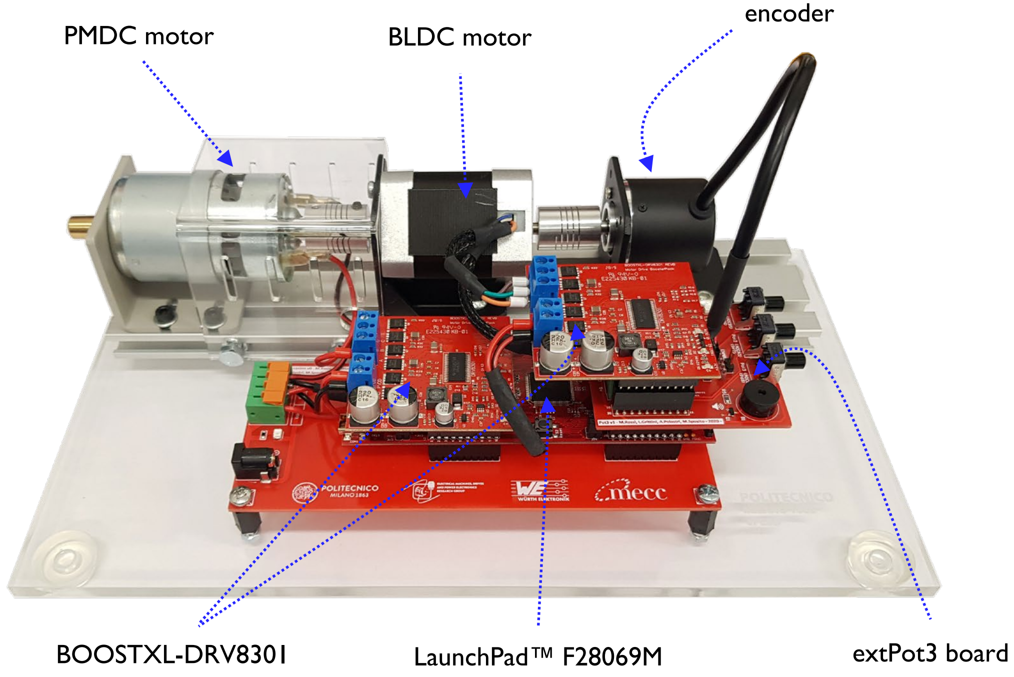
Cascade Speed Control of a AC Motor

➢ Implementation point of view (B2B configuration BLDC + DC motors)

The **B2B-BLDC kit** includes a BLDC/AC motor with Hall sensor which can be used to implement either trapezoidal control or FOC via Simulink workflow

The brushed DC motor may be used to actively braking the BLDC motor in order to

- ✓ exploit the operating region
- ✓ estimate an efficiency map for the motor

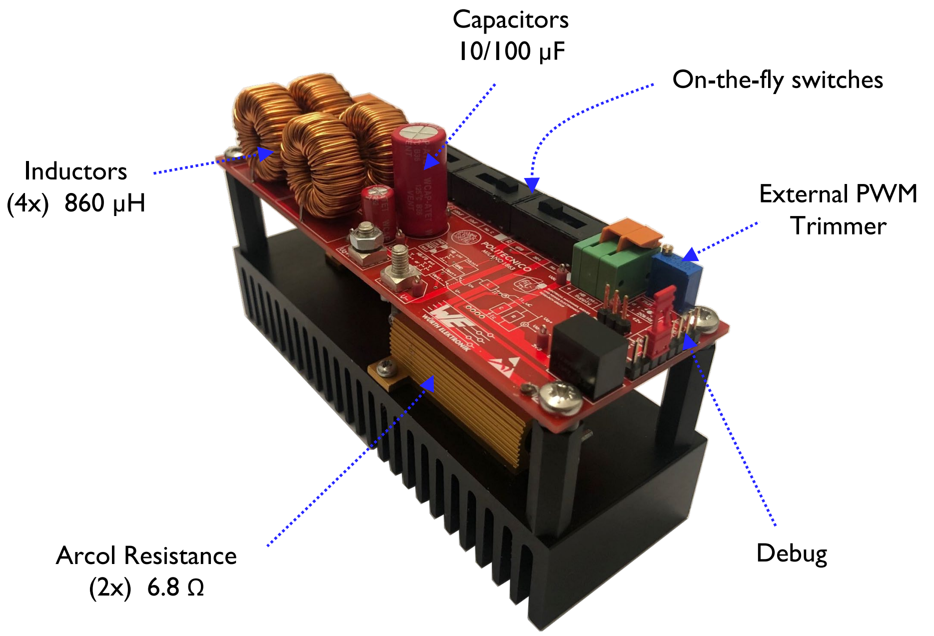


- **back-to-back configuration**
- one LaunchPad™ F28069M board
- one or two Boosterpack TI™ BOOSTXL-DRV8301 converter boards
- one extPot3 board
- a mezzanine board to hold the MCU and manage the external power supply
- one BLDC motor with Hall sensors
- one PMDC motor
- encoder LPD3806-600BM-G5-24C

Voltage/Current Control of a DC-DC converter

➢ Implementation point of view (LC output filter or RL load)

- this **RL(C) load** includes a modular LC filter + R (e.g., output stage for DC-DC converters) suitable to change on-the-fly both the LC filter and load values (on-board sensors)
- it can be also used as RL load in AC mode



- Different resistance, inductance, capacitance values can be set on-the-fly
- Choose between internal or external switching stage
- Choose between internal or external PWM signals generation
- Half-Bridge converter is used
- Over-current and over-voltage protections
- On-board high-accuracy current sensor
- On-board isolated voltage sensing
- both DC or AC operation

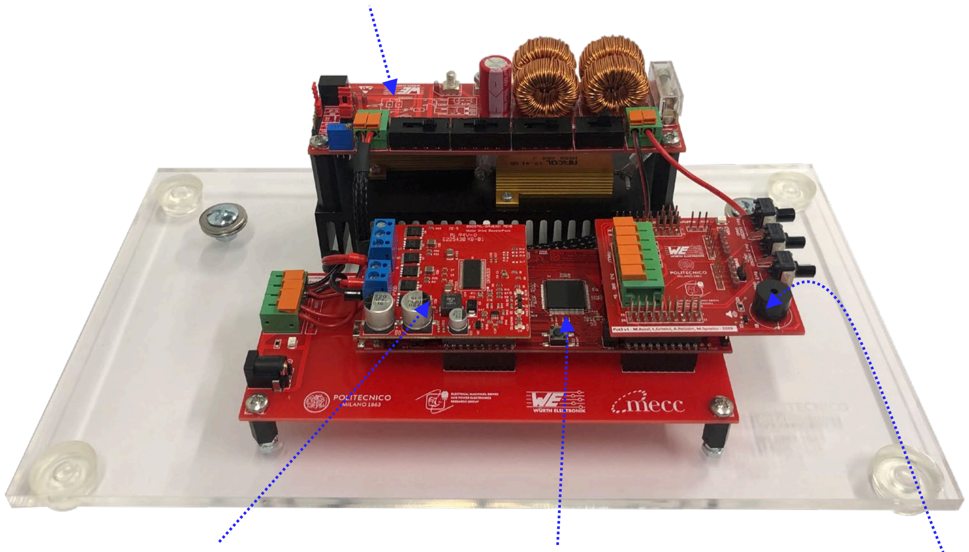
Voltage/Current Control of a DC-DC converter

➢ Implementation point of view

Regarding **power management** applications…

This is an example which integrates the RL(C) load to realize a **step-down DC-DC converter** with variable LC filter and load values to investigate the control design and parameter uncertainty (robustness)

RLC



BOOSTXL-DRV8301

LaunchPad™ F28069M

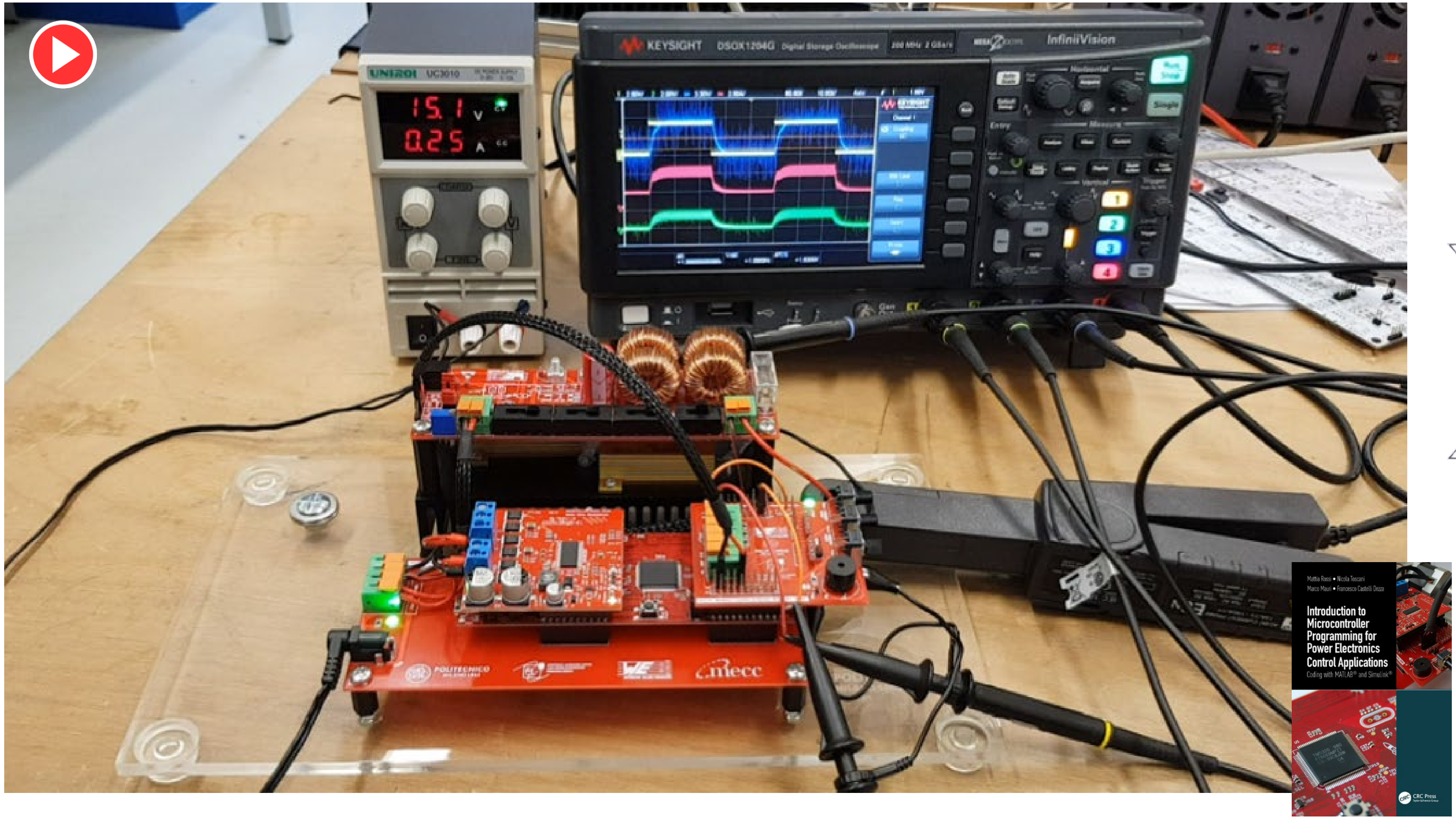
extPot3 board

- Integration of the extRL(C) board, the LaunchPad™ F28069M, the BOOSTXL DRV8301 and the extPot3 boards
- Choice between extPWM (from MCU) and internal PWM (trimmer) generation
- Choice between AC or DC operation
- Choice between several values of resistance, capacitance and inductance
- Comparison between extRL(C) and BOOSTXL-DRV8301 on-board sensors
- Over-voltage and over-current protection

Voltage-mode control of a Step-Down DC-DC converter

download available
linked to book

- In operation (varying LC and R parameters)



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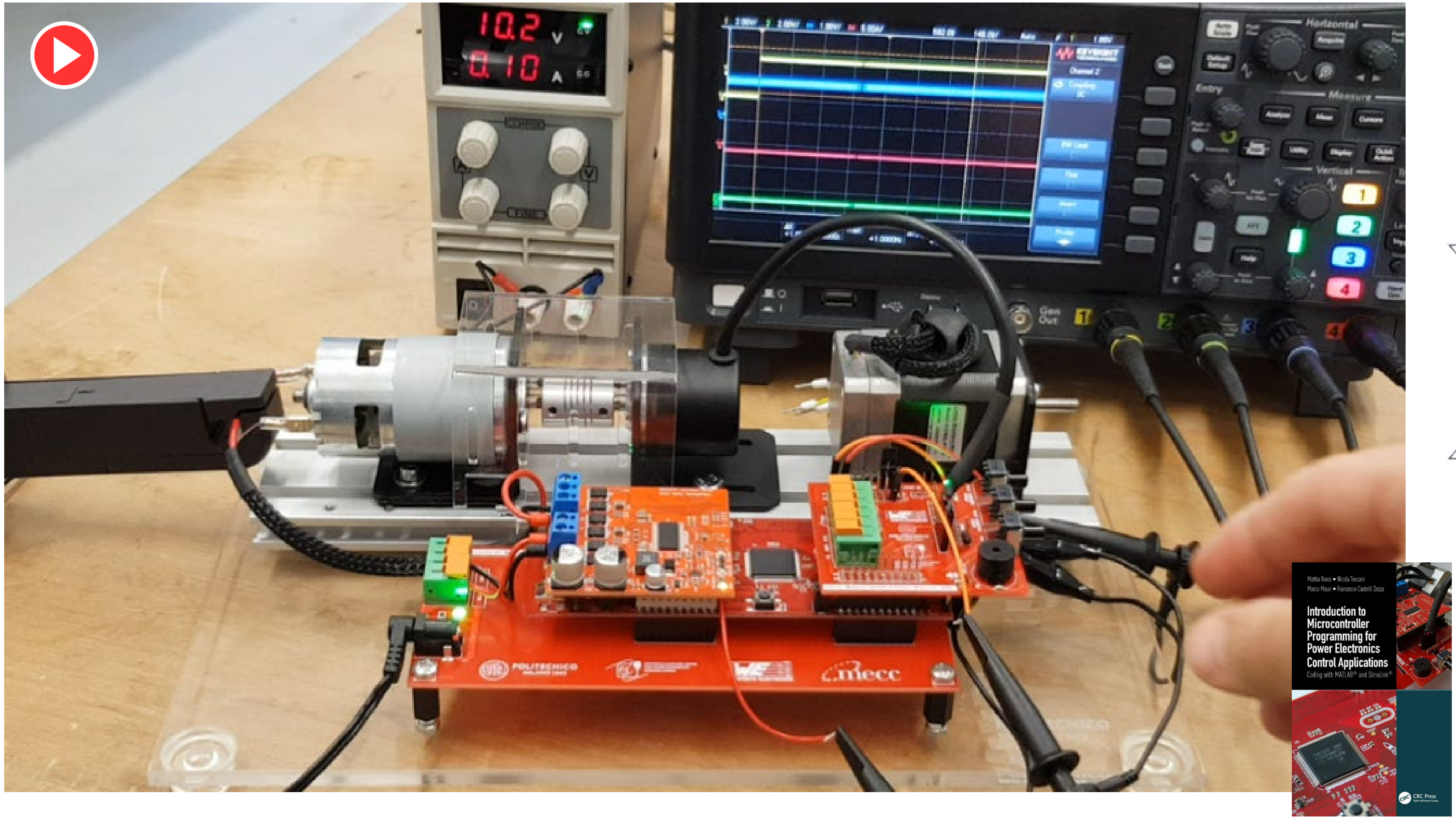
ePEBBs
efficient power electronics building blocks

Cascade Speed Control of a DC Motor

download available
linked to book

- In operation (single motor)



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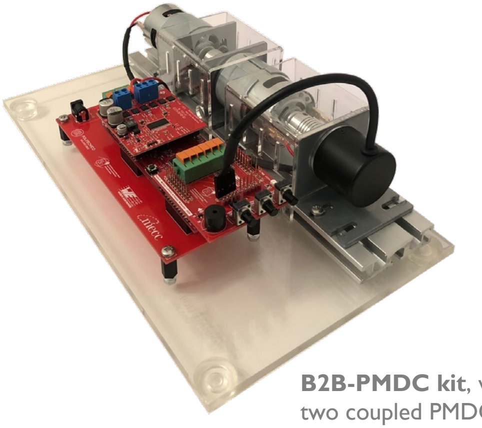
TEXAS INSTRUMENTS
MathWorks
ePEBBs efficient power electronics building blocks

ePEBBs
efficient power electronics building blocks

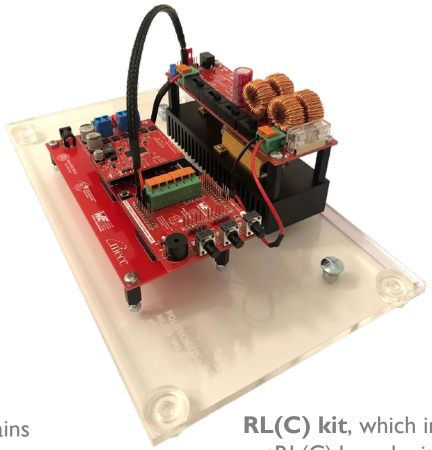
MCU-based Hardware Kits

If you are interested in implement control algorithms using *rapid prototyping* approach for:

- ✓ high-level implementation via MATLAB/Simulink
- ✓ combination of C/C++ code with Simulink environment
- ✓ test it on our customized MCU-based evaluation boards



B2B-PMDC kit, which contains two coupled PMDC motors anchored on an aluminium base plate, encoder sensor and MCU interface for external power supply.



RL(C) kit, which integrates the extRL(C) board with the LaunchPad™ F28069M and the BOOSTXL DRV8301 boards

B2B-BLDC kit, which contains a PMDC motor, and a BLDC motor coupled anchored on an aluminium base plate, encoder sensor and MCU interface for external power supply.

✓ Feel free to contact one of the team member:

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ePEBBs efficient power electronics building blocks

End Credits

Thanks for your attention

Mattia Rossi
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Credits to:

ePEBBs – efficient power electronics building blocks
Nicola Toscani, Matteo Sposito, Andrea Polastri, Luca Grittini, Alessandro Grittini

Texas Instruments
Antonio Faggio, Olivier Monnier, Matt Hein

Würth Elektronik – More than you expect
Angelo Strati, Giuseppe Ballarin, Domenico Santoro

MathWorks
John Kluza, Antonin Ancelle, Antonino Riccobono

Politecnico Milano 1863
Francesco Castelli Dezza, Marco Mauri

Tampere University
Petros Karamanakos

Useful Links

➢ **Please check the following links to find further info:**

- https://it.mathworks.com/hardware-support/ti-c2000-embedded-coder.html
- https://www.ti.com/tool/MATHW-3P-SLEC

- https://www.amazon.it/Introduction-Microcontroller-Programming-Electronics-Applications/dp/0367709856
- https://www.routledge.com/Introduction-to-Microcontroller-Programming-for-Power-Electronics-Control/Rossi-Toscani-Mauri-Dezza/p/book/9780367709853

- https://www.linkedin.com/company/epebbs

…and feel free to ask questions

in collaboration with:

Texas Instruments
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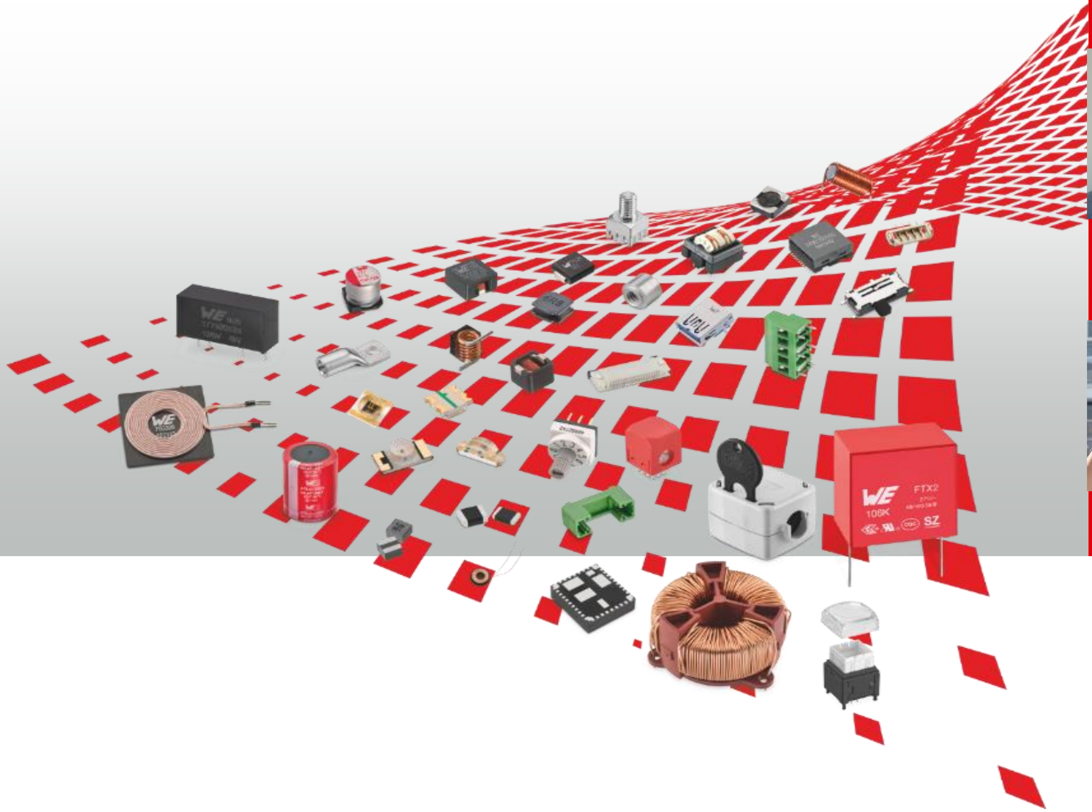
MathWorks
Tampere University

ePEBBs
efficient power electronics building blocks

Industrial Drive: EMC analysis



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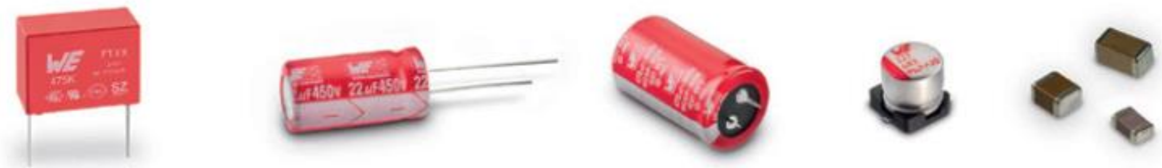
Wurth Elektronik Line Card

Wurth Elektronik Line Card

EMC Components



Capacitors

Power Magnetics

Signal & Communications

Wurth Elektronik Line Card

Wurth Elektronik Line Card

Fuseholders

Switches

Assembly Technique

REDCUBE Terminals

Free Technical Support

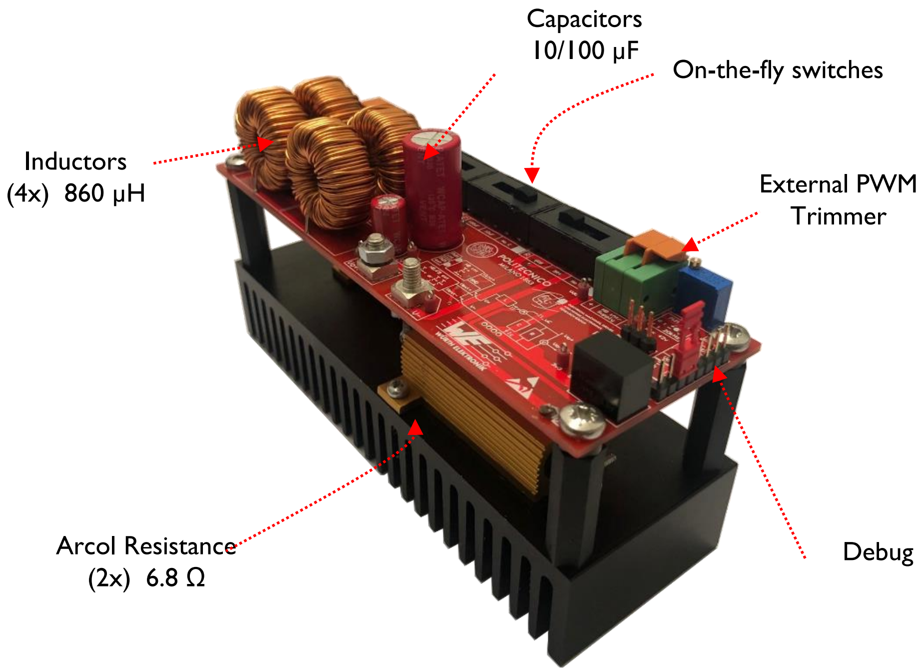
- Possibility to agree on the presence of a FAE during the EMC tests in the laboratory
- Realization of free in-House seminars at your headquarters or in video-conference on different topics (EMC, ESD, DC / DC filtering, selection of inductors ...)
- Support in the selection of components for your application
- Sending of free samples for the prototyping phase and / or the EMC test phase
- Possibility to request on-site presence for project support

ITALIAN TECHNICAL SCHOOL

RLC Board

WÜRTH ELEKTRONIK

- Implementation point of view (LC output filter or RL load)
  - this RL(C) load includes a modular LC filter + R (e.g., output stage for DC-DC converters) suitable to change on-the-fly both the LC filter and load values (on-board sensors)
  - it can be also used as RL load in AC mode



- Different resistance, inductance, capacitance values can be set on-the-fly
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Voltage/Current Control of a DC-DC converter

WÜRTH ELEKTRONIK

- Implementation point of view

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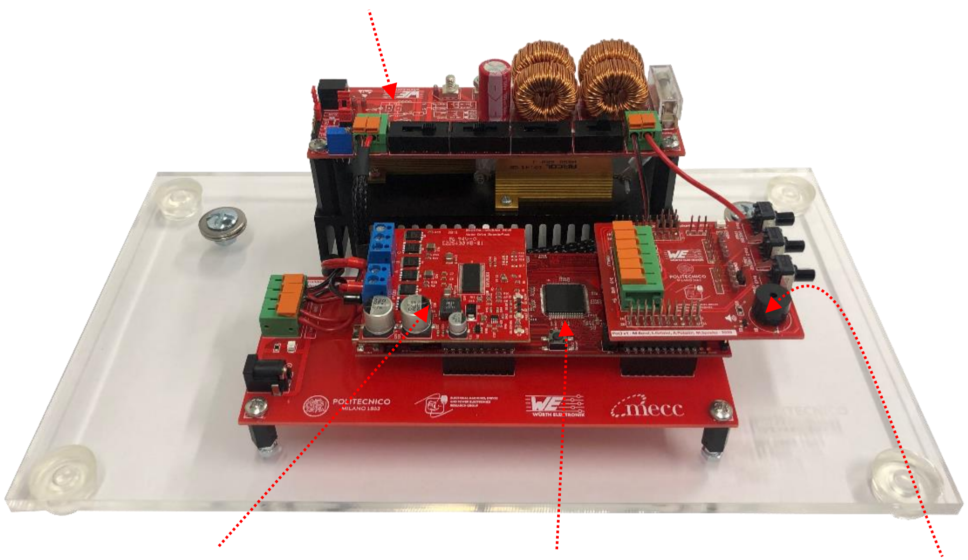

- Integration of the extRL(C) board, the LaunchPad™ F28069M, the BOOSTXL DRV8301 and the extPot3 boards
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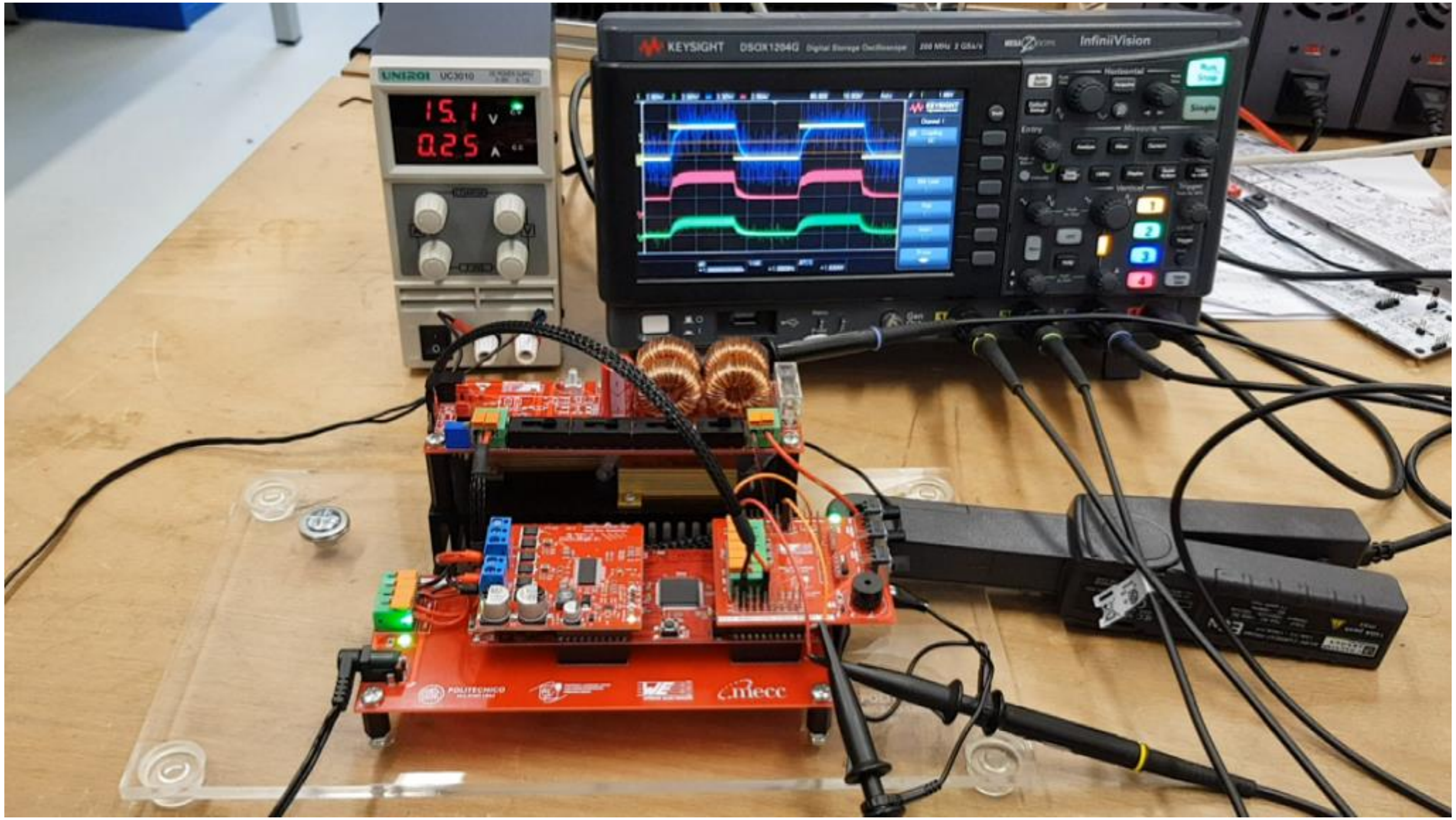
Voltage-mode control of a Step-Down DC-DC converter

WÜRTH ELEKTRONIK

- In operation (varying LC and R parameters)



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Thank You For your Attention

Model-Based Design with TI C2000™ using MATLAB® and Simulink®

March 17, 2022

John Kluza
MathWorks, Partner Manager

VONSCH Speeds the Development of Control Systems for Solar Inverters and Battery Chargers

Challenge

Develop solar inverter and battery charger control systems amid frequently shifting market requirements

Solution

Use Model-Based Design with MATLAB and Simulink to model power electronics and control systems, run simulations, and generate embedded code for a TI microcontroller

Results

- Product development time reduced by one year
- New product R&D accelerated via model reuse
- Number of hardware prototypes reduced

Development and testing of FOTO CONTROL 1f and FOTO CHARGER products.

"Model-Based Design enabled us to quickly adapt to changing legislation and requirements. Before prototype hardware was available, we designed and simulated the entire system in Simulink and generated embedded code for the controller, which was working on the prototype within a day or two after the hardware was available."

- Dr. Jakub Vonkomer, VONSCH

[Link to user story]

Production Code Generation – User Story Examples

Running prototype in nine months

GM Global
Hybrid Powertrain

Test case development reduced from days to hours

TRW Germany
Electronic parking brake control system

Design time cut by 60%

Honeywell Aerospace USA
Flight Control Systems

Development accelerated by 50%

Weinmann Medical Germany
Transport ventilator

System implemented in one week

Alstom Grid UK
HVDC Power Systems

Development time reduced 50%

Alstom France
Train Control Systems

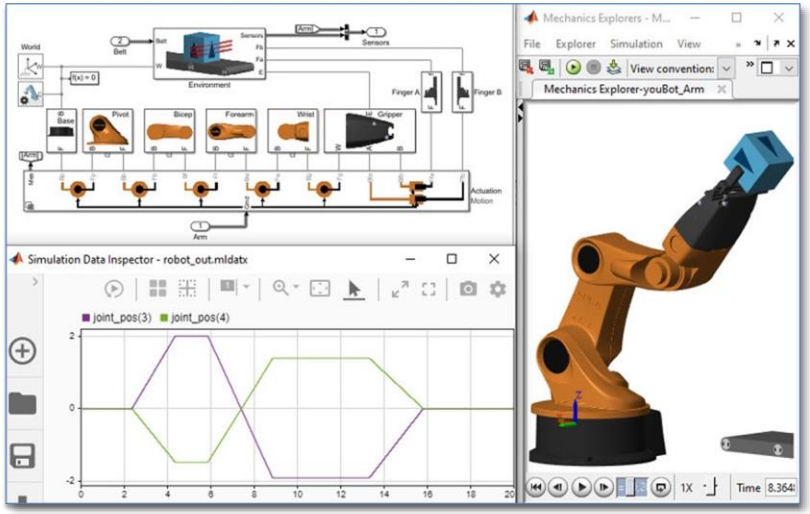
http://www.mathworks.com/company/user_stories/product.html?expand=EC

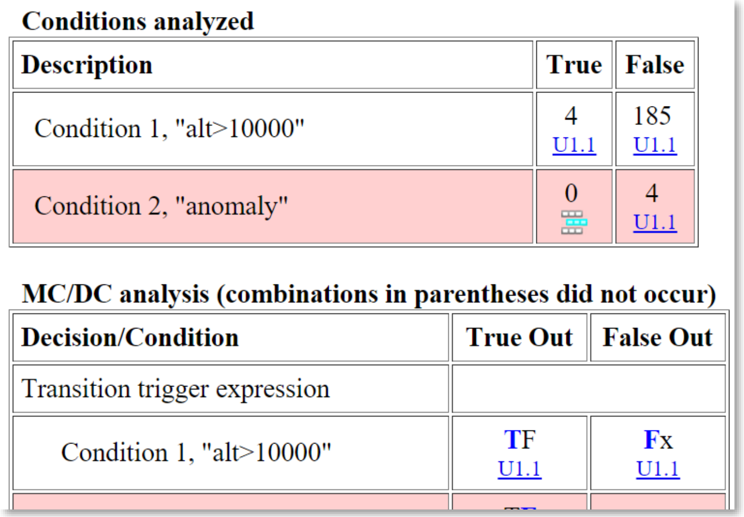
There are three key pieces to Model-Based Design

Modeling & Simulation

Test & Verification

Code Generation



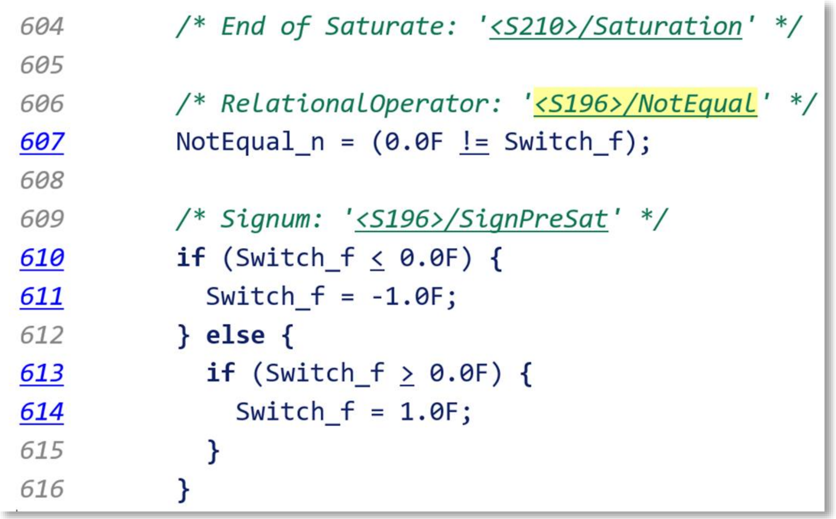


Conditions analyzed

Description	True	False
Condition 1, "alt>10000"	4 U1.1	185 U1.1
Condition 2, "anomaly"	0	4 U1.1

MC/DC analysis (combinations in parentheses did not occur)

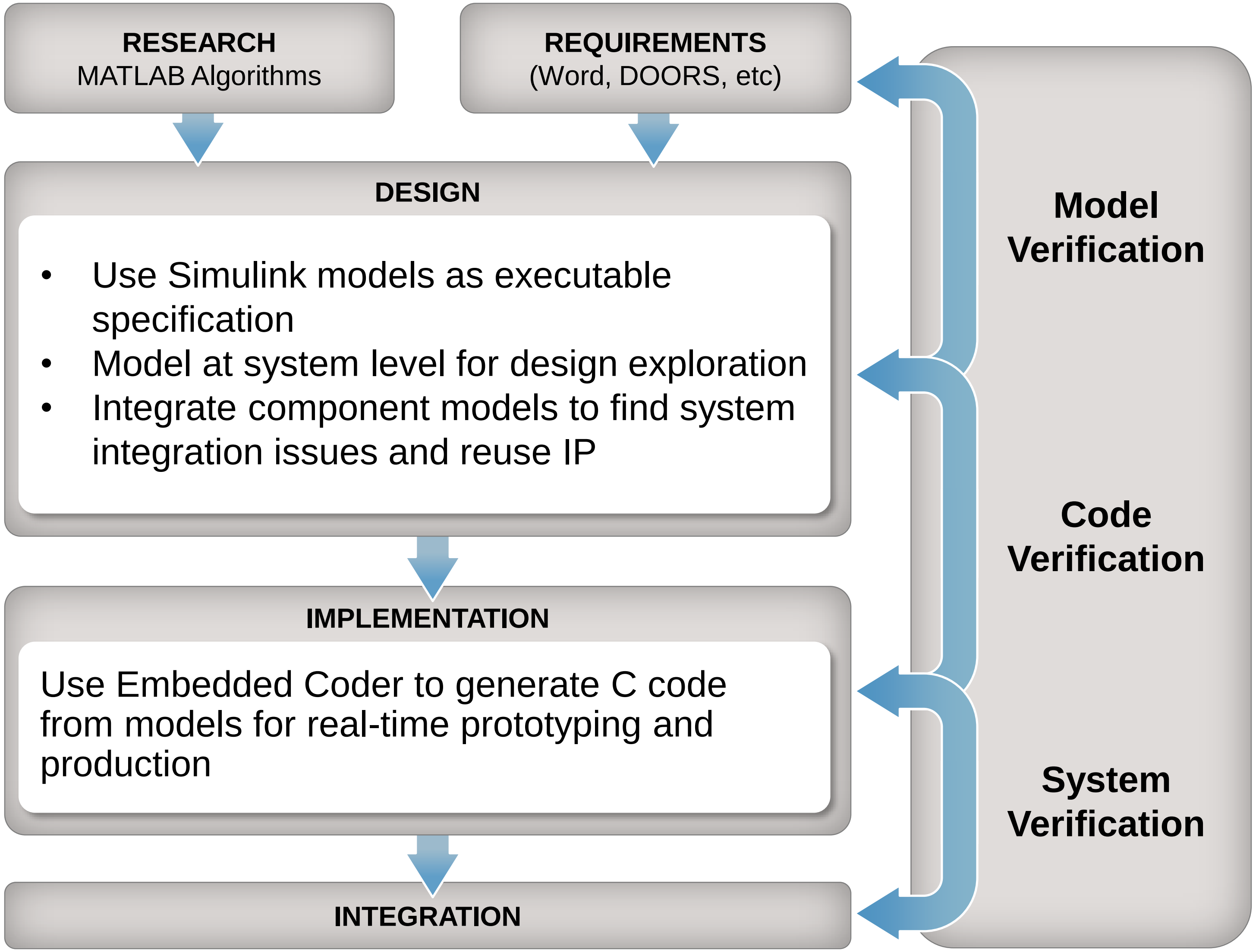
Decision/Condition	True Out	False Out
Transition trigger expression		
Condition 1, "alt>10000"	TF U1.1	Fx U1.1



MATLAB® & SIMULINK®

Simulation and Model-Based Design

Model-Based Design Workflow



- Understand system behavior earlier in the project
- Handle system complexity and design changes
- Reduce iteration cycles
- Generate code automatically for practically any hardware platform
- Verify control algorithms and strategies against virtual systems using desktop and real-time simulations

SIMULINK®

Code Generation

Physical Modeling

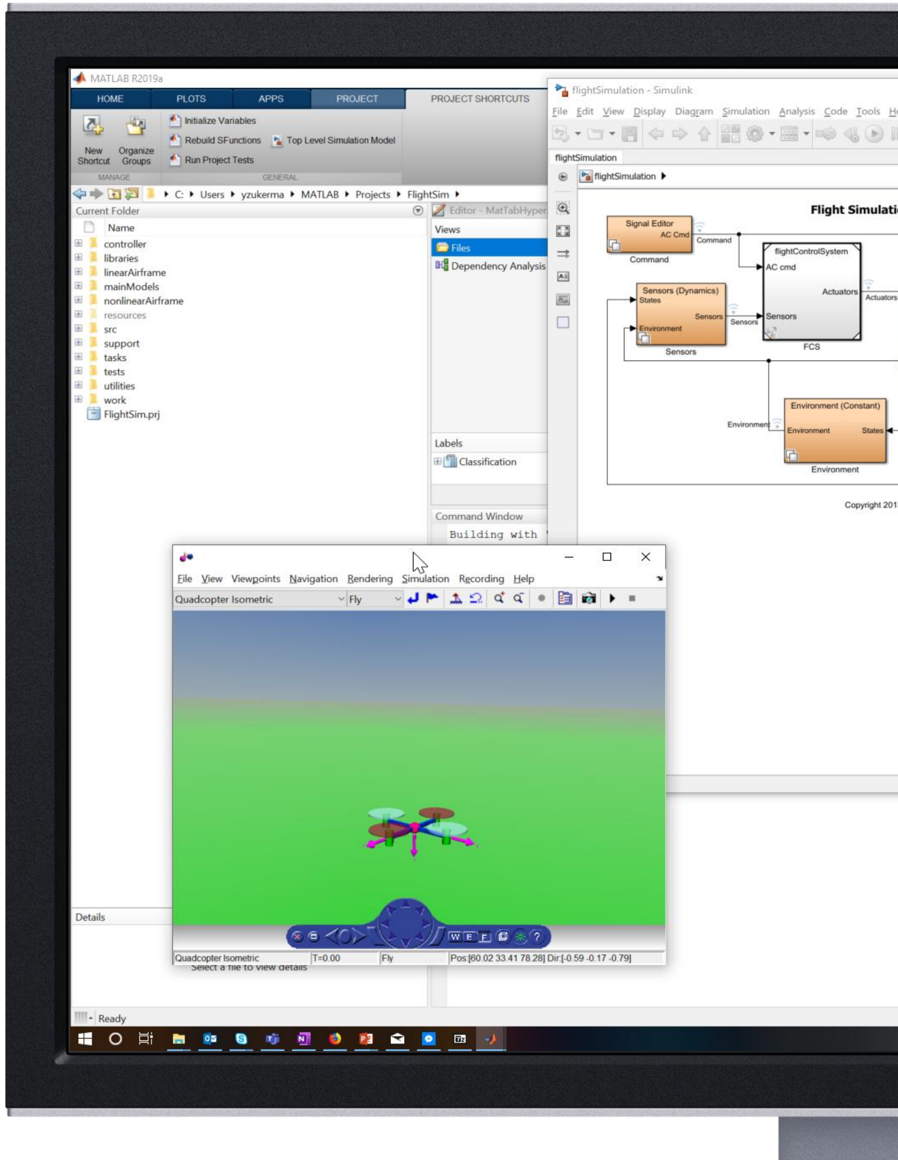
Event-based Modeling

System Engineering

Real-Time Simulation & Testing

Verification, Validation & Test

Industry-Specific Solutions



Generate quality C code from Simulink models

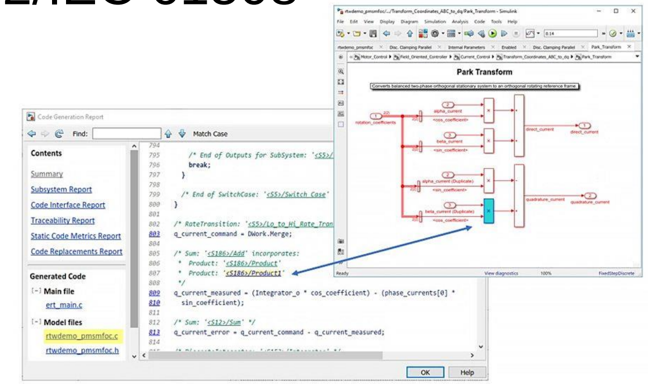
Embedded Coder

- Enables you to:
  - Accelerate project completion
  - Reduce cost by minimizing hardware resource requirements
  - Create innovative products by maximizing algorithm content
  - Achieve safety critical certifications

*The code generated with Embedded Coder required about **16% less RAM** than the handwritten code used on a previous version of the ECU; the code met all project requirements for efficiency and structure. Mario Wünsche, Daimler*

[Daimler Designs Cruise Controller for Mercedes-Benz Trucks]

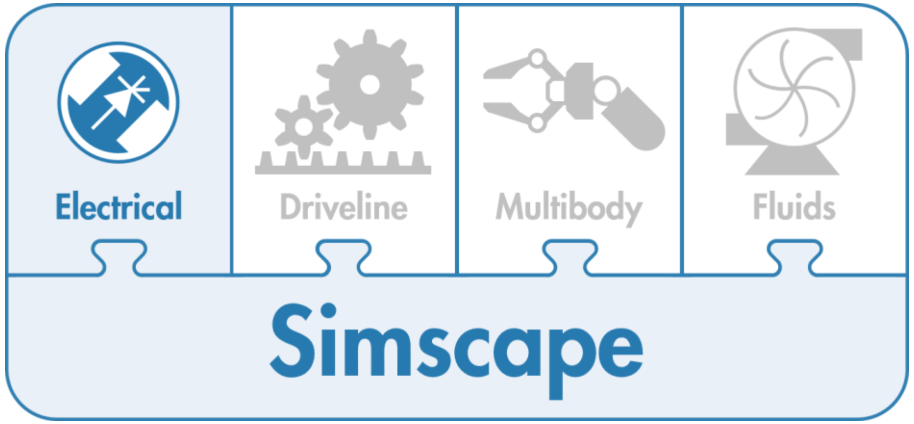
- Offers you these features:
  - Generate readable, compact, and fast C and C++ code from Simulink models
  - Precise control of optimizations and customization to facilitate integration with legacy code
  - Suitable for rapid prototyping and mass production
  - Supports AUTOSAR, MISRA C, ISO 26262/IEC 61508

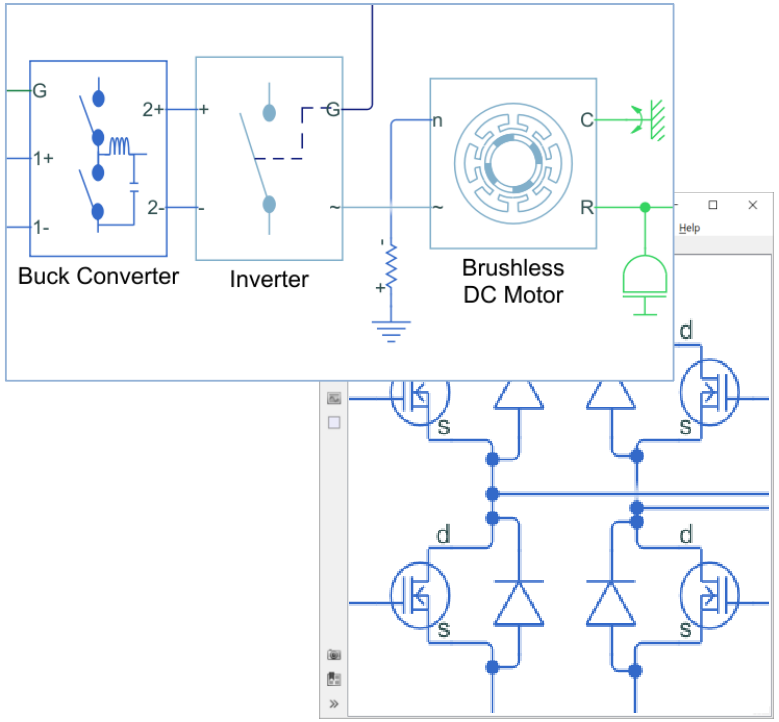


Model electrical systems with schematic circuits in Simulink

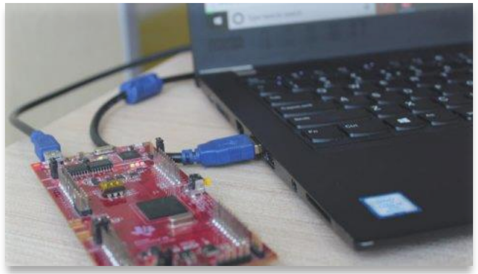
Simscape Electrical

- Enables physical modeling (acausal) of electronic and mechatronic systems
  - Evaluate analog circuit architectures
  - Develop mechatronic systems with electric drives
  - Simulate model or generate C code for HIL
- Libraries of electrical components for
  - Power electronics, sensors, actuators, passives, logic, etc
  - Nonlinearities, operational limits, faults, thermal effects
  - Create custom models using MATLAB-based language
  - Import SPICE netlists
- Simulation modes for ideal switching, discretization, phasor, load flow, and harmonic analysis



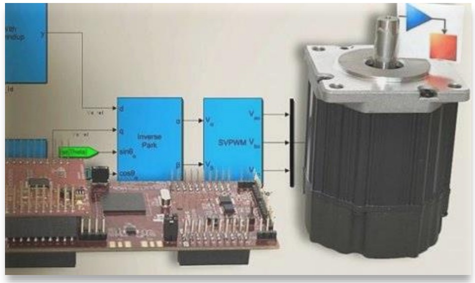


Solutions for TI C2000 MCUs



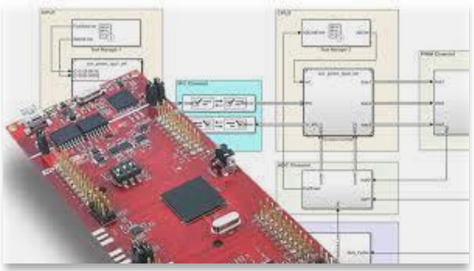
Embedded Coder Support Package for TI C2000

Design, simulate and deploy Simulink models on TI C2000 processors, useful for quick prototyping all the way to production



Motor Control Blockset

Simulate and generate code for control algorithms against motor and inverter models at all levels of fidelity



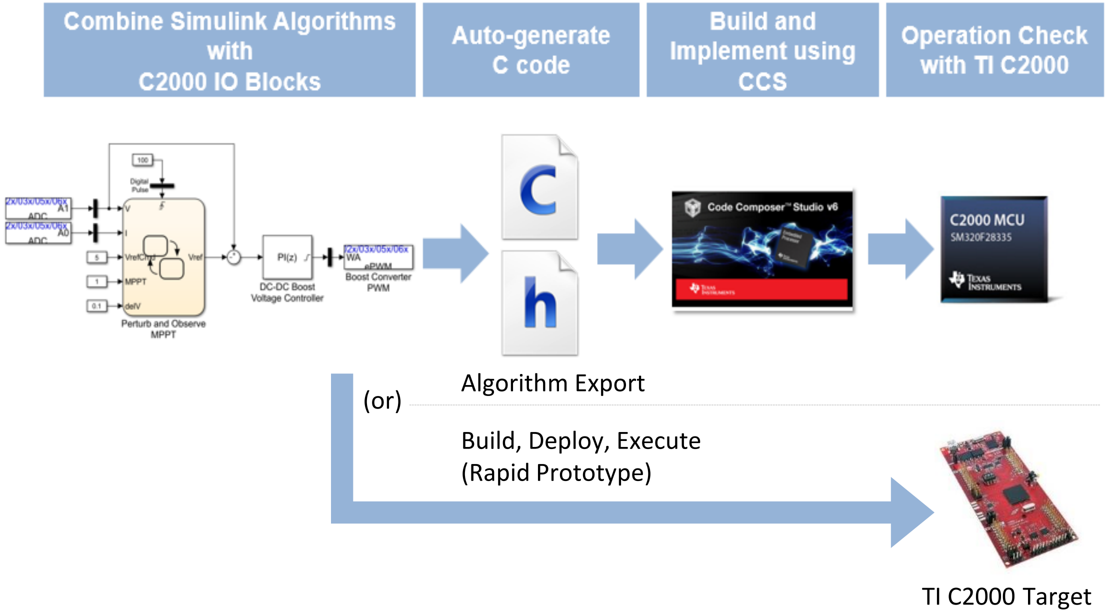
SoC Blockset Support Package for TI C2000

Multicore and peripheral modeling and targeting for TI C2000 multicore MCUs.

Design, simulate and deploy Simulink models on TI C2000 processors

Embedded Coder Support Package for TI C2000

- Capabilities such as
  - Automated build, deploy and execution
  - Processor-in-the-loop (PIL) & execution profiling
  - Real-time tuning and logging using external mode
  - Supports optimizations including IQMath
- Block libraries for
  - Digital I/O, ADC, DAC, Comparator
  - eCAP, ePWM, eQEP
  - eCAN, LIN, I2C, SCI, SPI
  - Watchdog, DMA, CLA, IPC for multi-core processors
- 25+ examples and extensive documentation
  - Examples include Digital DC/DC Buck using Peak Current Mode Control with TI CMPSS, and How to Use TI CLA in Simulink
- Easy install via MATLAB Add-on Explorer

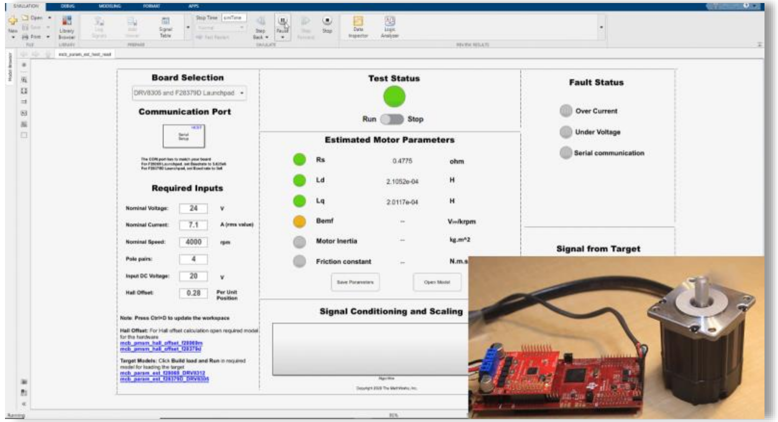


Built as an Add-on to Embedded Coder

- Generate readable, compact, and fast C code from Simulink models
- Precise control of optimizations and customization to facilitate integration with legacy code
- Suitable for rapid prototyping and mass production
- Supports AUTOSAR, MISRA C, ISO 26262/IEC 61508

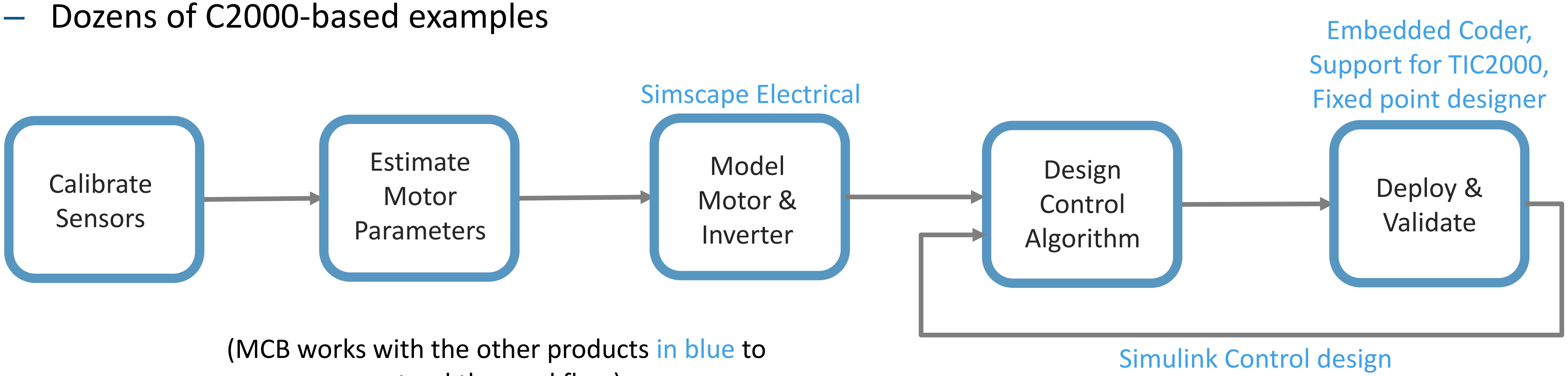
Rapidly design and implement motor control algorithms from Simulink

Motor Control Blockset (MCB)



Speed development of FOC algorithms for PMSM and induction motors, and generate embeddable C code from them.

- Blocks for Park and Clarke transforms, sensorless observers, field weakening, space-vector generator
- Empirical gain calculation & Field oriented control Autotuner Block
- Motor and inverter models included
- Motor parameter estimation tool to refine closed loop simulation
- Integrates with related MathWorks products for advanced applications
- Dozens of C2000-based examples



(MCB works with the other products in blue to extend the workflow)

MathWorks

Accelerating the pace of engineering and science

- Founded in 1984
- Headquartered in Natick, Massachusetts, USA
- 5,000+ employees
- 33 offices in 16 countries
- More than 5 million MATLAB users worldwide
- $1.3 Billion in revenue

MATLAB & SIMULINK

For more information…

- Take a free, self-paced online course at MATLAB Academy
  - matlabacademy.mathworks.com
- Download C2000 support for existing licenses
  - mathworks.com/ti
- Download a free trial
  - mathworks.com
- View webinar on developing PID and more advanced motor controllers and deploying to C2000 hardware
  - Live in Italian on March 30, search “adattativo” on **it.**mathworks.com
  - Also pre-recorded in English, search “adaptive webinar” on **www.**mathworks.com