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Motor Control Tool Kit for Automotive MCUs

STMicroelectronics

최호승 대리

Agenda

1. What is Motor and FOC
2. Motor Control Ecosystem
3. Motor Control Tool Kit
4. How to install and configure MCTK

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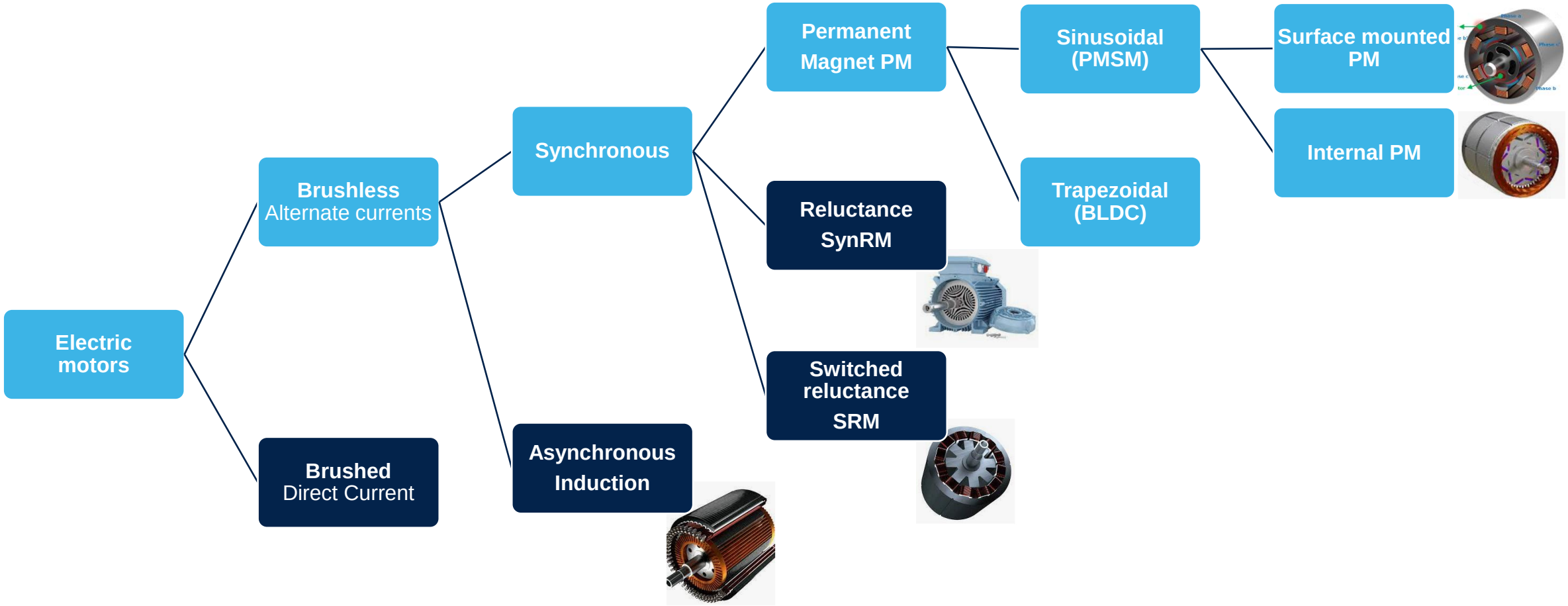
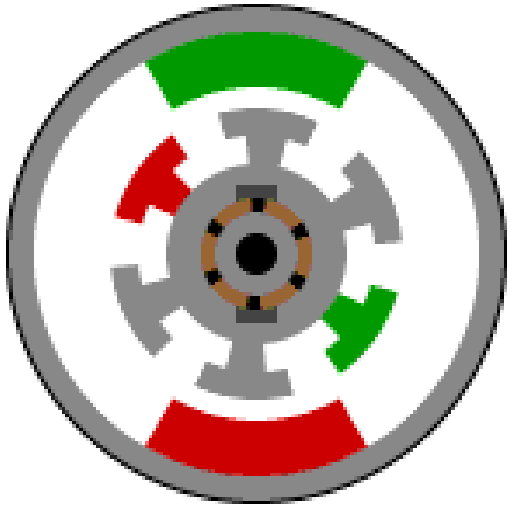
What is Motor and FOC

Electric Motor : Classification



DC (Brushed) Motors

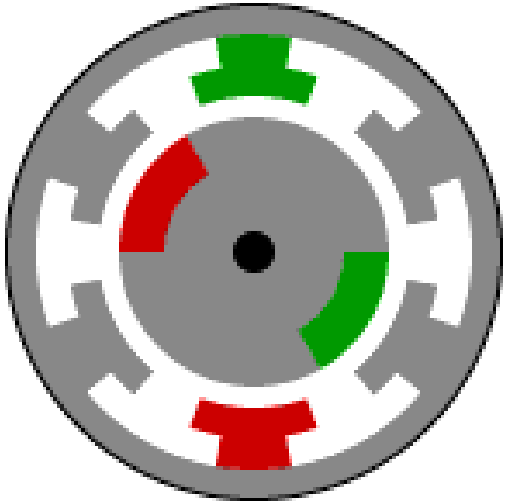


- The stator of a permanent magnet dc motor is composed of two or more permanent magnet pole pieces. The rotor is composed of windings which are connected to a mechanical commutator.

- According to Fleming's left-hand rule, the forces cause a turning effect on the coil, making it rotate. To make the motor rotate in a constant direction, "direct current" commutators make the current reverse in direction every half a cycle (in a two-pole motor) thus causing the motor to continue to rotate in the same direction.

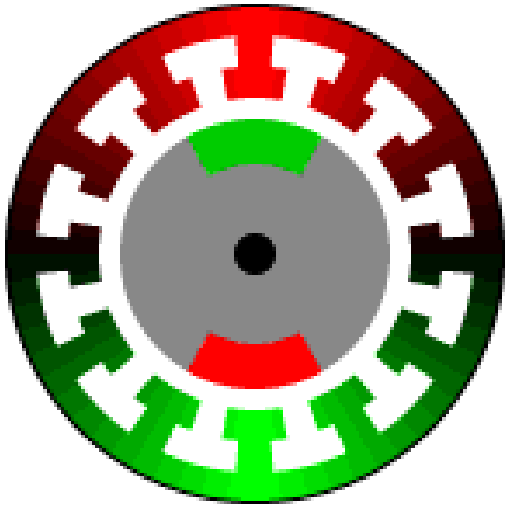
- Notice that the commutator is staggered from the rotor poles. If the connections of a DC motor are reversed the motor will change directions. Though it will not always work as well in both directions.

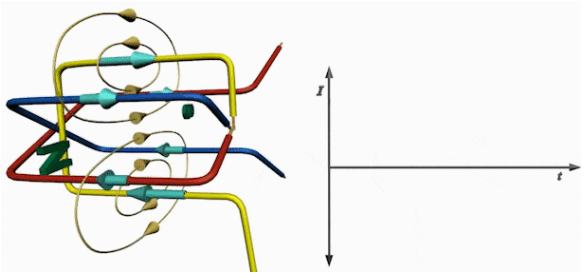
Brushless DC (BLDC) Motor



- A BLDC has a rotor with permanent magnets and a stator with windings. It is essentially a dc motor turned inside out.
- The brushes and commutator have been eliminated and the windings are connected to the control electronics. The control electronics replace the function of the commutator and energize the proper winding.
- As shown in the animation, the winding are energized in a pattern which rotates around the stator. The energized stator winding leads the rotor magnet, and switches just as the rotor aligns with the stator.
- The basic principle of operation is similar to a dc motor.
- Synchronous motors rotate at the same frequency as the revolving magnetic field.

Permanent-Magnet Synchronous Motor (PMSM)





- A PMSM is a synchronous motor that uses permanent magnets rather than windings in the rotor.
- Electronic excitation control with integrated power inverter and rectifier, sensor, and inverter electronics is required for practical operation.
- Form-factors for the PMSMs are either axial flux, radial flux, transverse flux, or flux switching depending on the arrangement of components, with each topology having different tradeoffs among efficiency, size, weight, and operating speed.
- Synchronous motors rotate at the same frequency as the revolving magnetic field.

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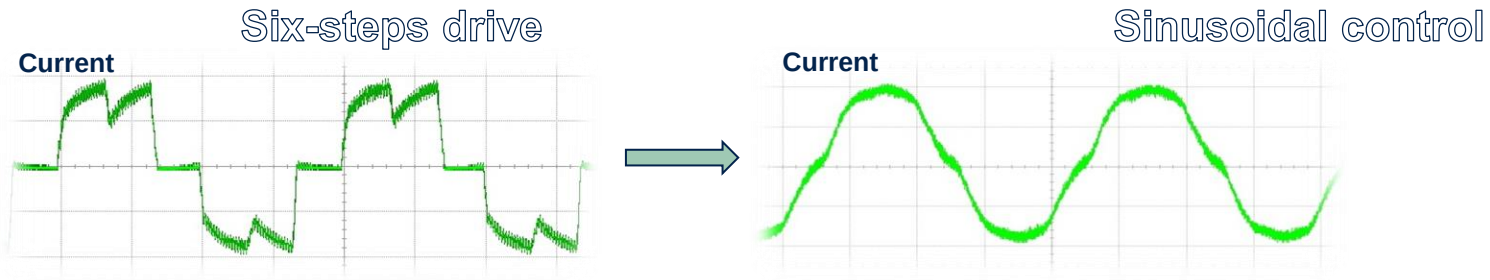
FOC single/dual motor for automotive applications

- **Target applications:**
  - Particularly suitable for **Traction Inverter**, **pumps, HVAC,..**

  - All those applications where:
    - Automotive requirements
    - Accurate and quick regulation of motor speed and/or torque is required
    - CPU load granted to motor control must be low, due to other duties
    - Quietness of sinusoidal current control (vs six steps drive) is valuable
    - Extended speed range is required



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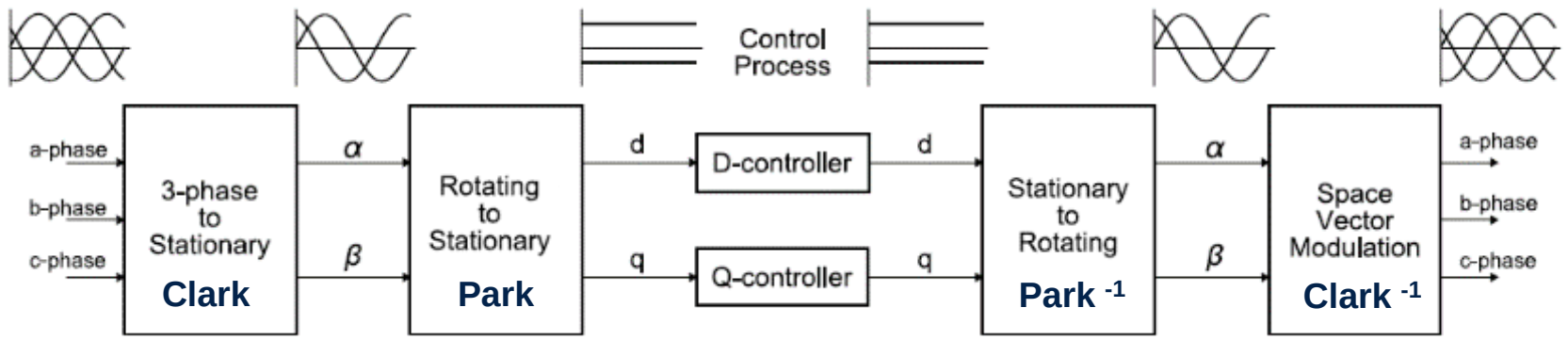
Why FOC?

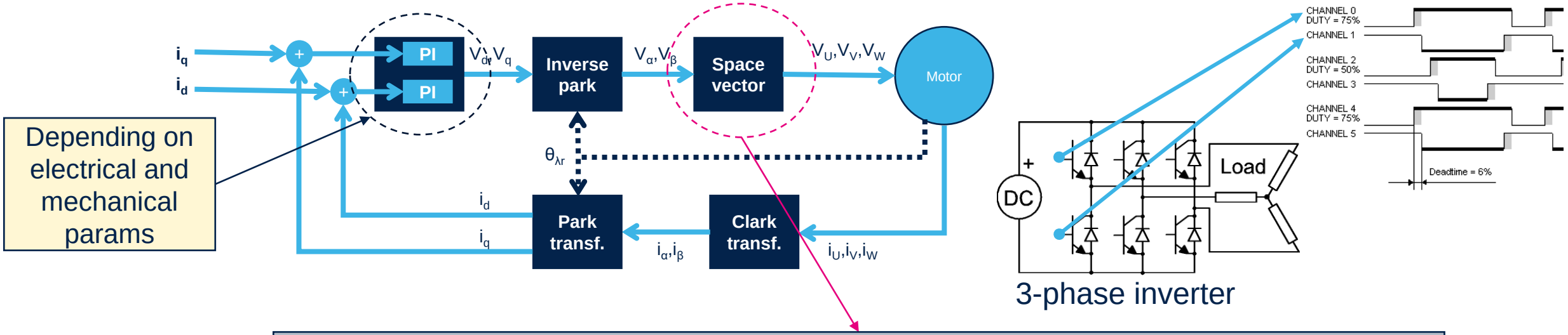
- Best energy **efficiency** even during **transient operation.**
- **Responsive speed control** to load variations.
- **Decoupled control** of both electromagnetic torque and flux.
- Acoustical **noise reduction** due to sinusoidal waveforms.
- Active **electrical brake** and **energy reversal.**



Independent control of flux and torque

Field Oriented Control

- The algorithm requires:
  - Motor phase currents (i_U, i_V, i_W)
  - Rotor position ($\theta_{\lambda r}$)
  - Target quadrature current (i_q) (i.e. motor torque)
  - Target direct current (i_d) is usually forced to zero in order to obtain maximum efficiency



3-phase inverter

The generation of the Vu,Vv,Vw sin waveforms is made by the 3-Phase inverter which performs a DC-AC transformation using the **PWM modulation techniques**

Challenges for FOC Design

Current reading

The algorithm requires the precise measurement of all of the currents at the same time

High performance ADC converter and advanced synchronization techniques are required

Motor position sensing

The position of the motor is needed, and it can be obtained using a variety of methods

The system should be able to manage different sensors (Hall sensors, encoders, etc.) in order to adapt to a wide range of applications
Effective sensorless algorithms requiring complex calculations must be supported

Computational load

The FOC algorithm is based on complex real-time calculations

The system should be based on a capable automotive microcontroller working with optimized firmware libraries

System Integration

The motor is usually driven according to the indications of a system microcontroller

Interfacing is an important part of the final application

Motor Control Ecosystem

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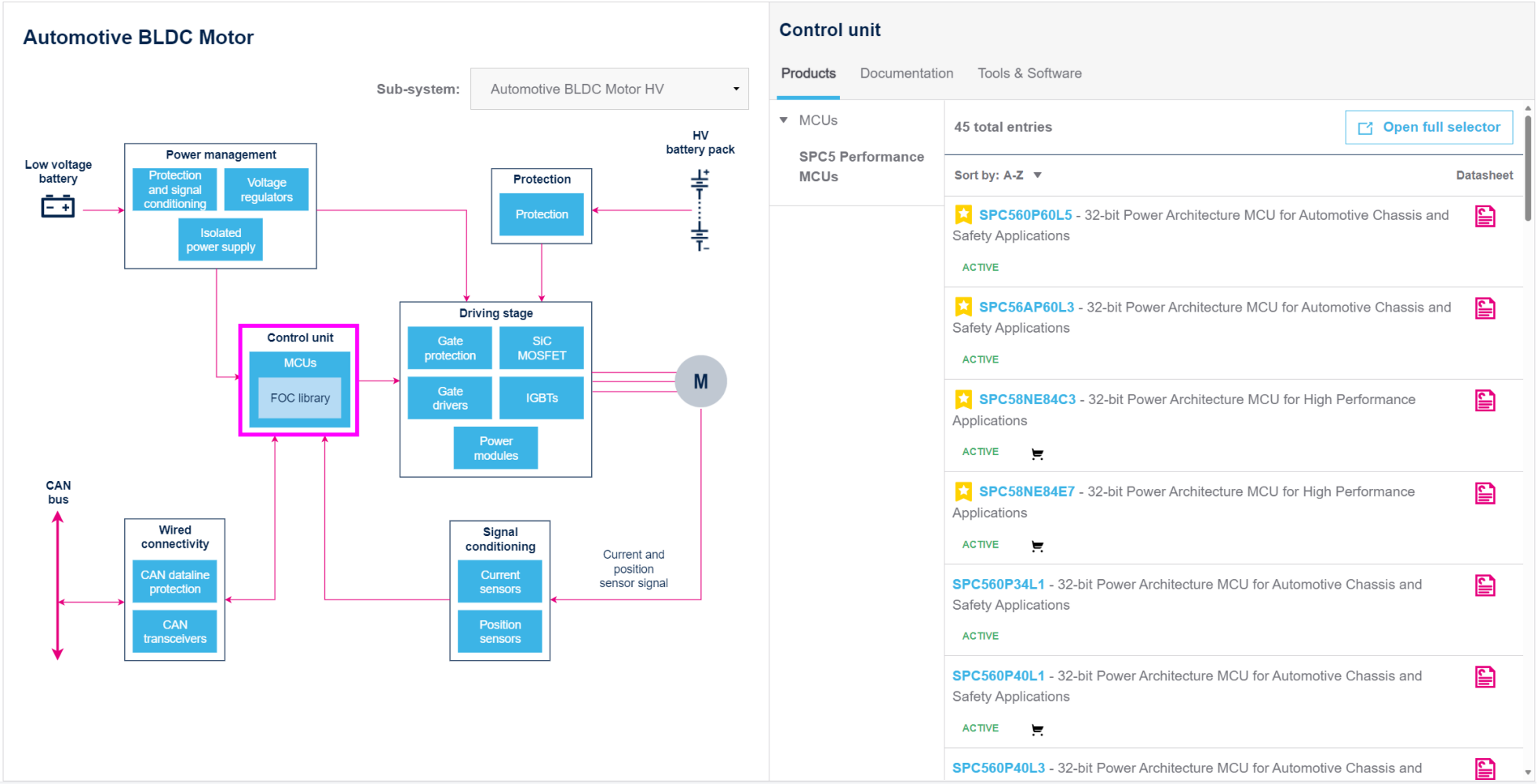
Motor Control Ecosystem



https://www.st.com/en/applications/automotive-motor-control/automotive-bldc-motor.html

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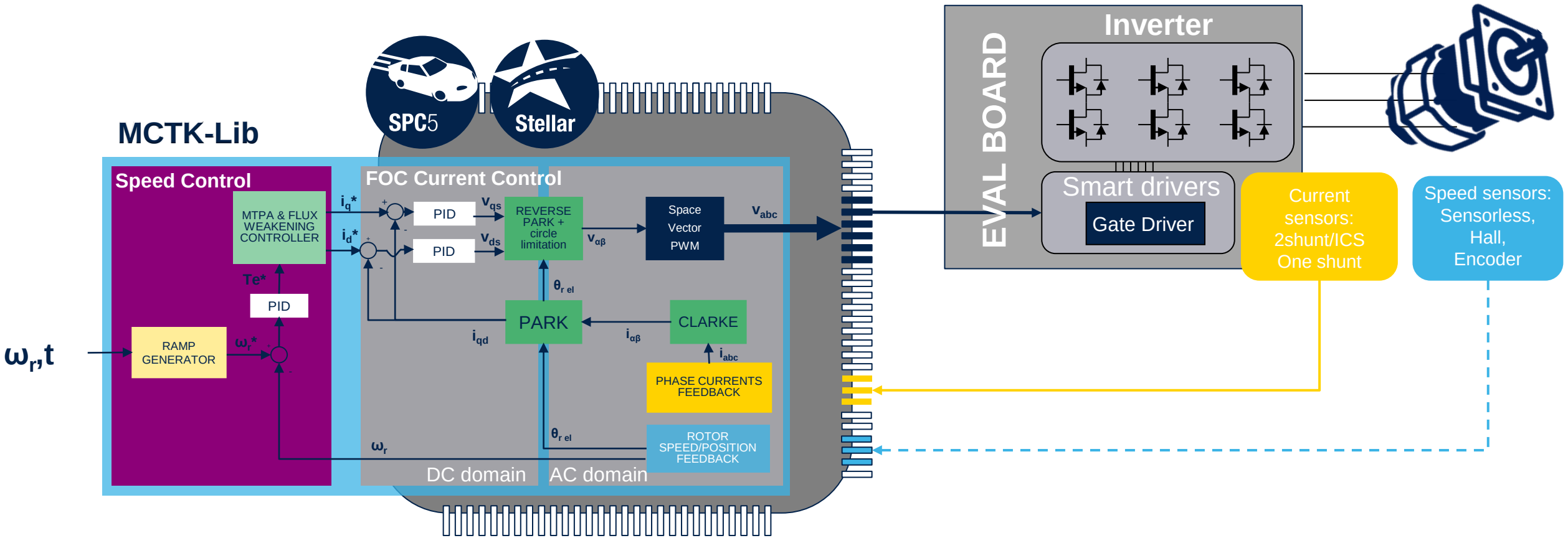
MCTK-Block Diagram



Automotive MCUs support MCTK

6M | 4M | 2M | 1M | 768K | 512K | 384K | 256K | 192K

Pictus - SPC560P

- up to 64 MHz Power Architecture
- e200z0h core
- 512KB Program Flash with ECC
- 4x16KB EEPROM Flash with ECC
- 40KB SRAM with ECC
- 2 x CAN
- 1 x FlexRay
- 2 x LINFlex
- 4 x SPI
- 2 x 10-bit ADC (S&H)

SPC560P50
512KFlash / 40KRam

SPC560P44
384KFlash / 40KRam

SPC560P40
256KFlash / 20KRam

SPC560P34
192KFlash / 20KRam

Leopard - SPC56EL/4L

Dual Core
Safety ASIL level D

SPC564L70 2MFlash / 192KRam	**SPC56EL70** 2MFlash / 192KRam
SPC564L60 1MFlash / 128KRam	**SPC56EL60** 1MFlash / 128KRam
SPC564L54 768kFlash / 96KRam	**SPC56EL54** 768kFlash / 96KRam

- up to 120MHz Power Architecture
- Single (4L) and Dual (EL) e200z4d core
- Lock Step and Decoupled Parallel modes
- 2MB RWW Flash with ECC
- 192KB SRAM with ECC
- EE emulation
- 3 x CAN, 1 x FlexRay, 2 x LINFlex, 3 x SPI
- 2 x 12-bit ADC (S&H)

Bernina SPC58NN

SPC58NN84
6M Flash 448K RAM

SPC58NN80
4M Flash 448K RAM

- 3x z4d core dual issue @200Mhz
- 4x64K+2x16K data flash
- ASIL-D SEooC
- QFP176 / BGA292

Stellar SR5E1

SR5E1E5/7
2M Flash 448K RAM

- 2x ARM Cortex-M7 dual issue @300Mhz
- Up to 2MB flash, 448KB SRAM
- ASIL-D
- eTQFP100 / eTQFP176
- 4 x CAN
- 3 x LINFlex
- 4 x SPI
- 2 x I2C
- 5 x 12-bit ADC

Safety → Safety & Calibration Support

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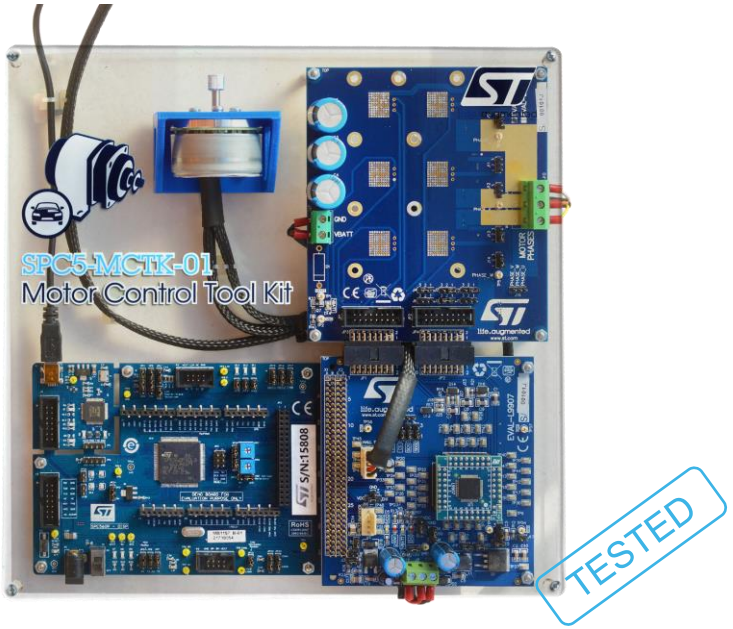
Available HW kit

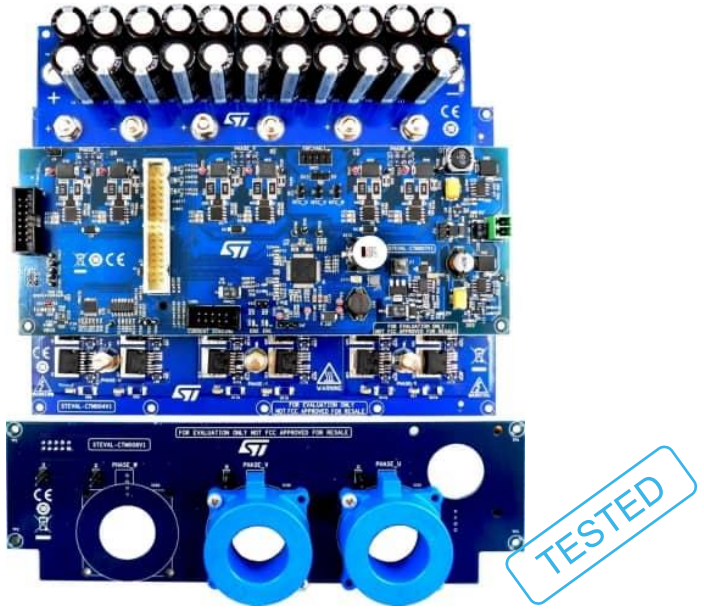
SPC5-MCTK-01 evaluation kit

- SPC560P-DISP: **SPC5 Pictus control board**
- STEVAL-L9907: Driver board with L9907 gate driver and
  Power board with STH315N10F7-2
- Nanotec DF45: BLDC motor

STEVAL-TTM001V1 evaluation kit

- STEVAL-TTM006A: **Stellar E1 control board** (not orderable for now)
- STEVAL- CTM007V1: Driver board with L9907 gate driver
- STEVAL-CTM004V1: Power stage board with STH315N10F7-6 MOSFET
- STEVAL-CTM005V1: Bus link capacitor board
- STEVAL-CTM008V1: Hall current sensing board





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Motor Control Tool Kit

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What is MCTK-LIB

- It is a complete development kit based on automotive grade SR5 E1 line of Stellar electrification MCU and Pictus/Leopard/Bernina Line of SPC5 MCU, to control 3-phase Permanent Magnet Synchronous Motors:
  - Easy to configure and monitor
  - Very flexible and customizable
  - Minimize the customer support effort
  - Reduced FW re-work time when moving from evaluation kits to final customer's production HW
  - FW structure easy to be ported on different SR5E1 line microcontroller
  - Integrated into a Stellar Studio software development environment
  - ready for further customer improvement
- Firmware Library Based on Field Oriented Control (FOC)
  - Sensored and Sensorless support
  - Two shunt / ICS
  - One shunt, three shunt topologies (N/A; will be available in the next release)
  - Bus Voltage, Temperature Sensing and ADC Regular Conversion
  - Flux weakening, MTPA, FeedForward (N/A; will be available in the next release)
  - User Interface (CAN, SERIAL)

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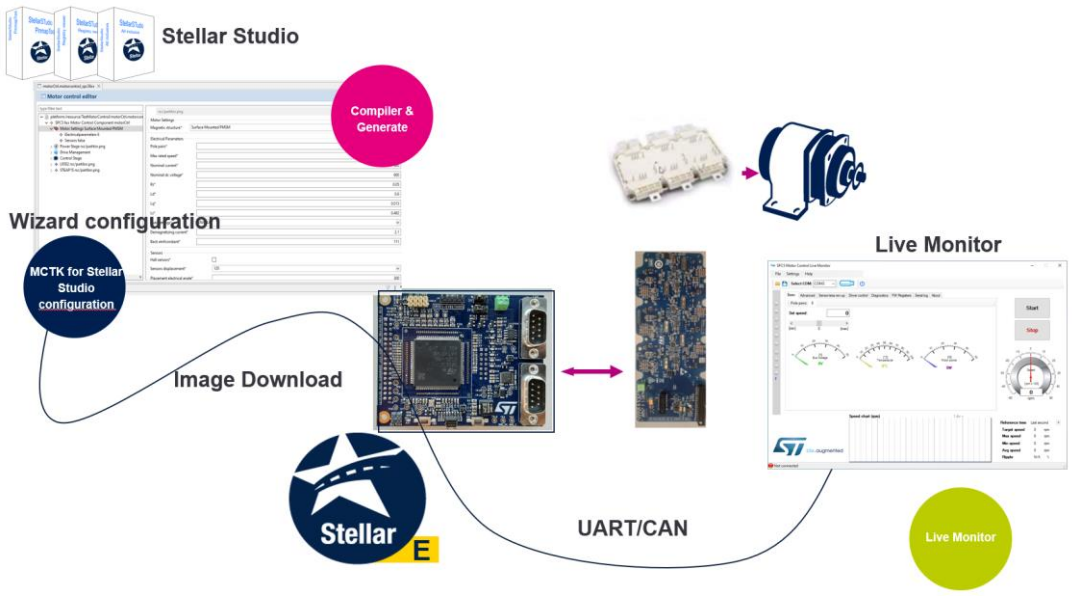
Supported Features



Supported Sensors	• Hall sensors • Encoder • Resolver • Sensor-less
Control Algorithms	• Single Vector FOC algorithm • Torque and Speed control • MTPA, Flux Weakening and Feed Forward technics
Library is deployed as Studio component	• Library Configuration tool available into Motor Control Component • Dedicated Studio components for L9502CD, STGAP4S and L9907
SR5E MCU initialization provided via StellarStudio	• drivers/pin wizard/clock tree/IRQ initialization
Supported Compiler:	• Free GCC • Green Hills (N/A; will be available in the next release) • HighTec (N/A; will be available in the next release)
Current Sensing	• ICS and two shunts current measurements on motor phases or inverter legs • One shunt (N/A; will be available in the next release) • Three shunts (N/A; will be available in the next release)
Configuration/UI	• Stellar Studio motor control component configuration to adapt library to customer motor, topology and application • SR5E motor control live monitor tool to tune on fly library parameters
Power stage configuration	• Stellar Studio L9907 component to Decoupling uC and Power • Stellar Studio L9502 component smart driver support • Stellar Studio STGAP4S component insulated gap driver support • STGAP4S, L9502 and L9907 Fault management configuration

Supported Sensors

- Speed/position sensors supported:
  - Quadrature Encoder
    - Expensive sensor, usually only in robotics applications
  - Hall Sensors
    - Cheaper sensors, usually for application requiring full torque at zero speed
  - Sensor-less
    - State observer + PLL
      - Use electrical quantities (mainly current feedback) to estimate rotor position
      - Used for many applications not requiring full torque at zero speed or very low speed operations (< 3-5% of nominal speed)
    - State Observer + CORDIC

- Current Sensors supported:
  - Two shunt / ICS
  - One shunt topologies

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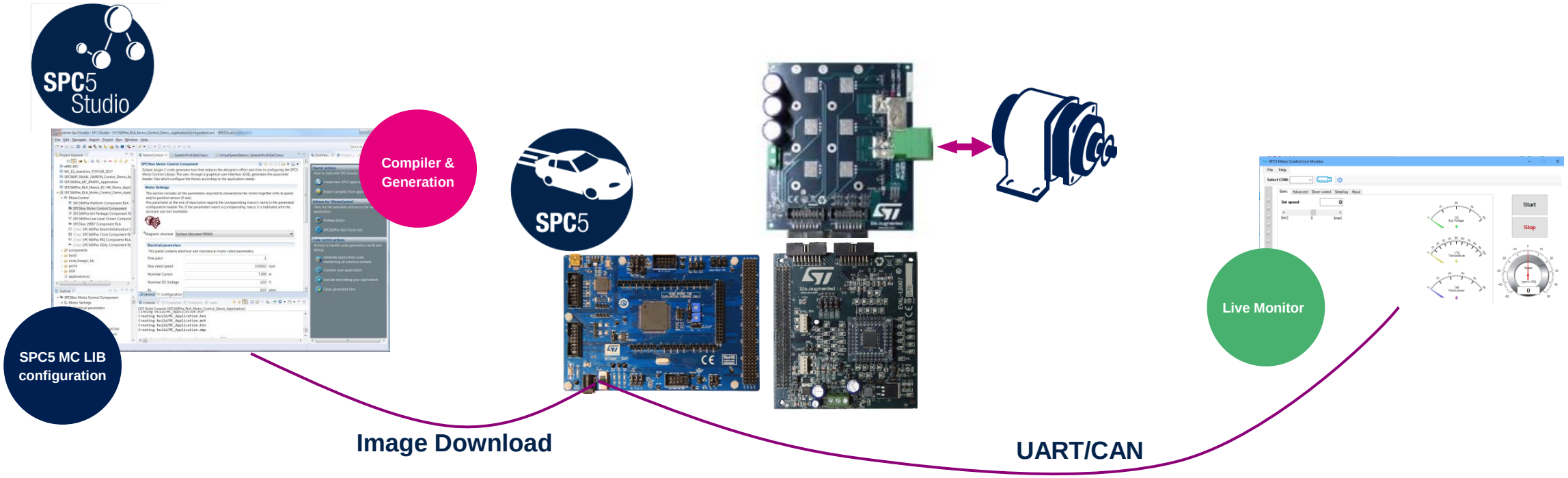
SPC5-MCTK at the glance



- Once the HW and SW are configured, use the SPC5Studio motor control configuration component for a complete and easy customization of the Motor Control library
- Generate, compile and program the binary image on the HW board
- Connect live Monitor via UART, to interact with the motor control library running on MCU, to start, stop, change reference speed, …

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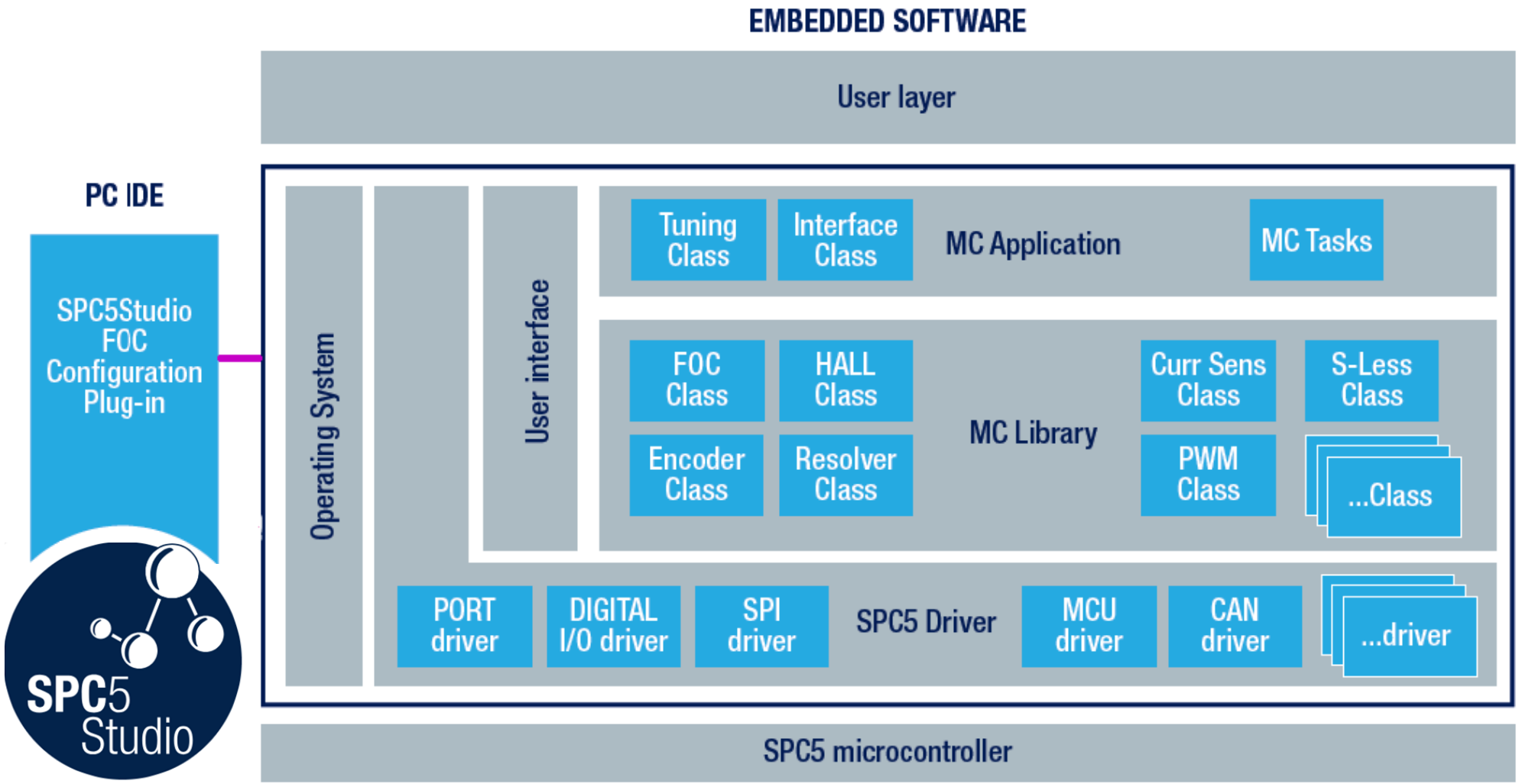
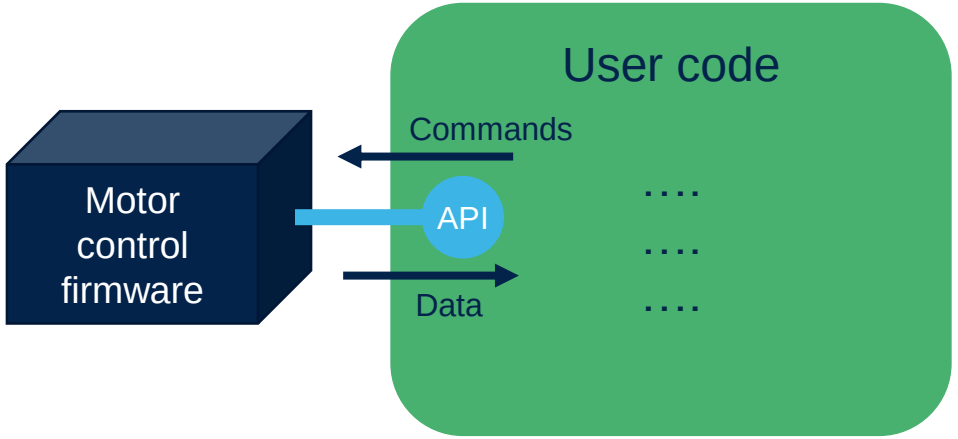
Motor control firmware architecture



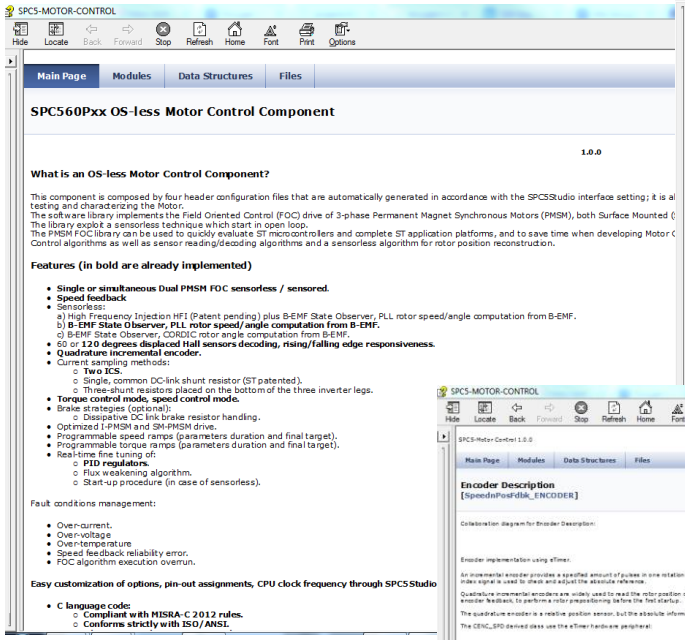
Motor Control API

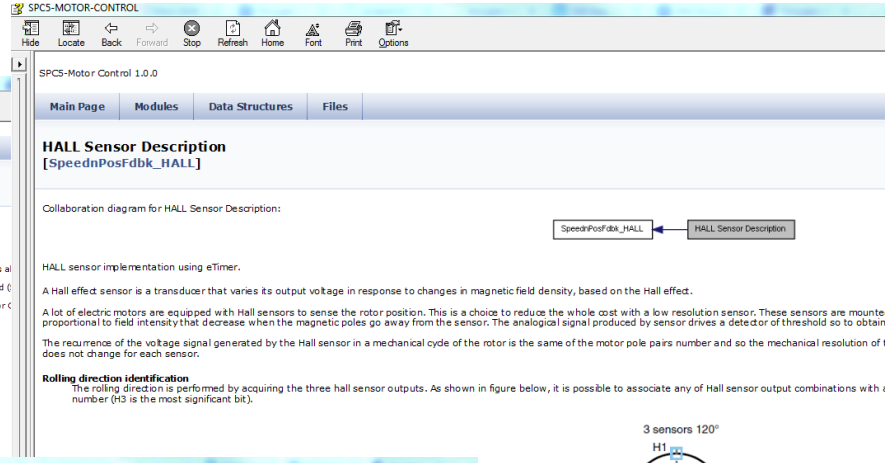
- **What is an API?**
  - An Application Programming Interface (API) specifies how software components should interact with each other.
  - It provide a consistent, programmatic method for accessing a resource.
  - It is a structured way of exposing functionalities.
  - Unlike an user interface the API is a macchine to macchine interface. It allows developers to access the functionality of the software through well-defined data structures.

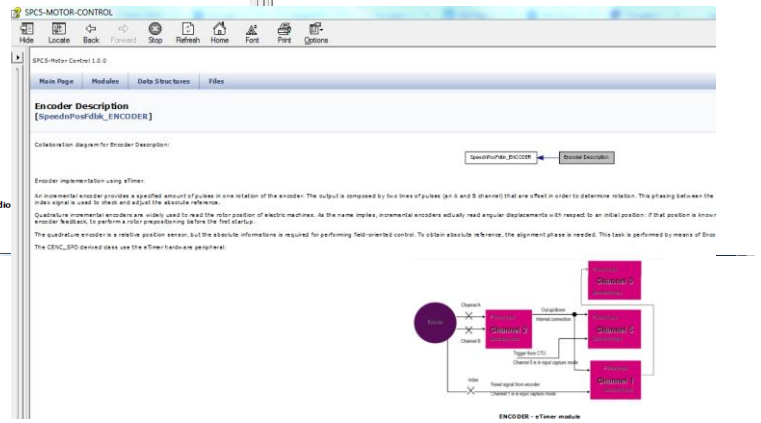


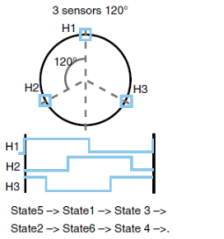
Motor Control API guide document

- The complete and detailed list of SW functions can be found in the
  - Compressed User Manual chm into the document folder of the SPC5Studio Motor Control Component
  - User Manual PDF version (SPC5_MotorControlToolKit_UserManual.pdf)









Three Hall sensors, output-state correspondence

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Refer to the UM2338 document, “Motor Control Toolkit for SPC56ELxx and SPC560Pxx platforms”

How to install and configure MCTK

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How to Install MCTK

- Download SPC5Studio from:
  - https://www.st.com/en/development-tools/spc5-studio.html

- Download StellarStudio from:
  - https://www.st.com/en/development-tools/stellarstudio.htm

- Download MCTK from (MCTK_RTM_3.0.0) web version:
  - https://www.st.com/en/embedded-software/spc5-mctk-lib.html
  - For newer version use the remote update site (MCTK_RTM_3.5.4)

- Download the STLINK Debugger from:
  - https://www.st.com/en/development-tools/stellarlink.html
    - To enable “Execute and Debug” button in SPC5Studio, please refer to below document.
      - SPC5Studio-6.0/openocd/docs/How to use OpenOCD and StellarLink in SPC5Studio.pdf

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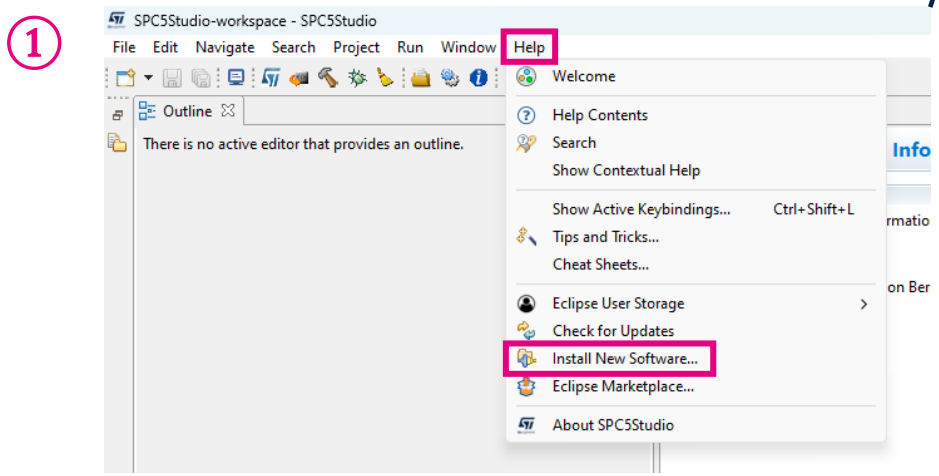
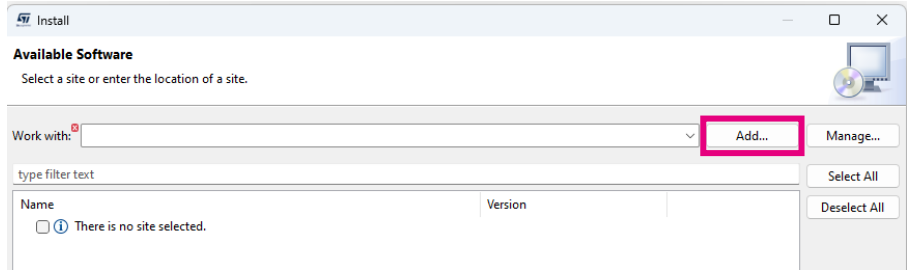
How to Install MCTK : SPC5Studio

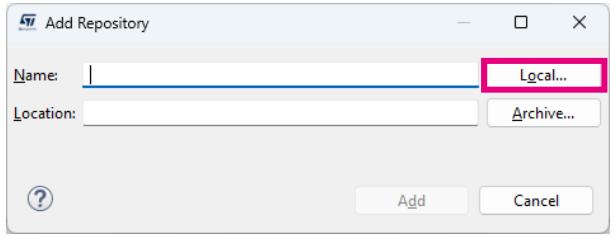
Install MCTK plugin

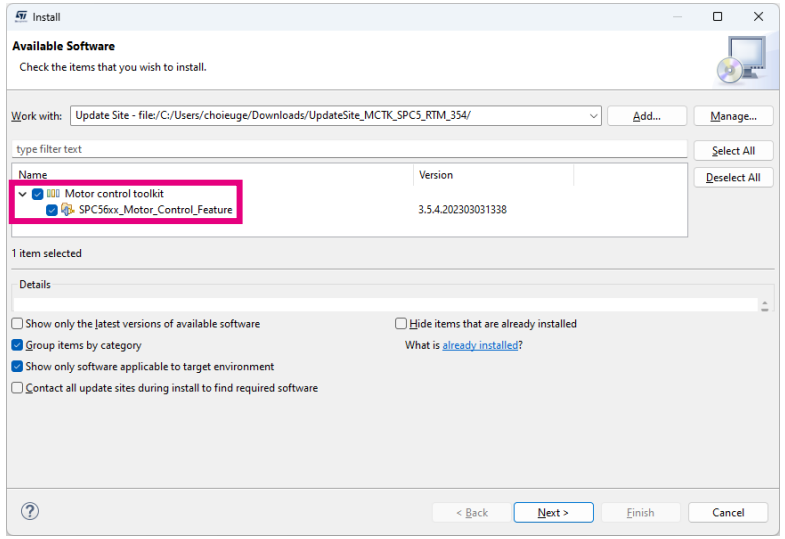
Update Site Procedure

1. Select “Install New Software…” from Help Menu
2. Work with …Add
3. Select your “Local” directory where the update site has been unzipped
4. Accept the license agreement
5. Enjoy the MCTK Library









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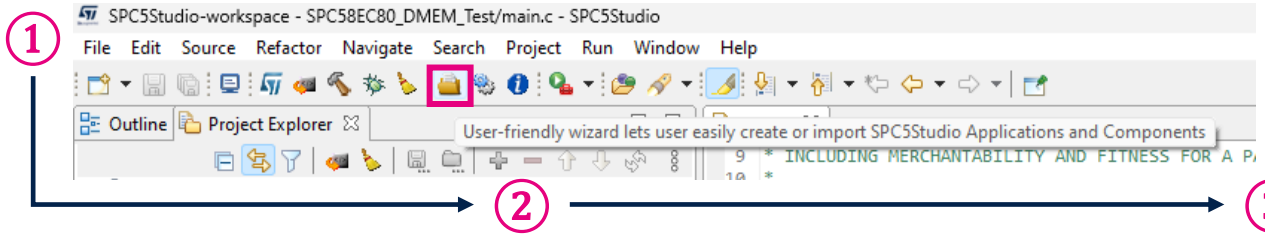
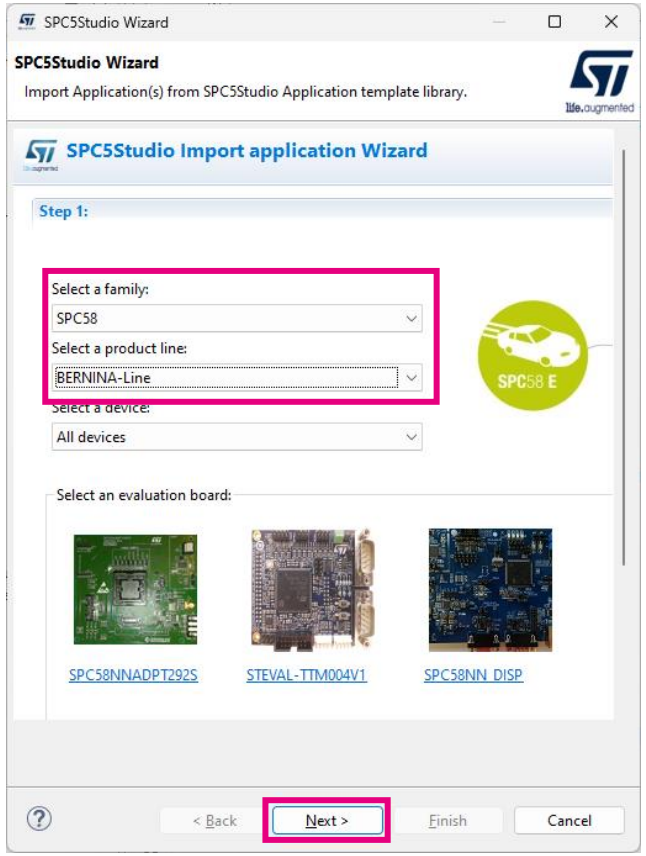
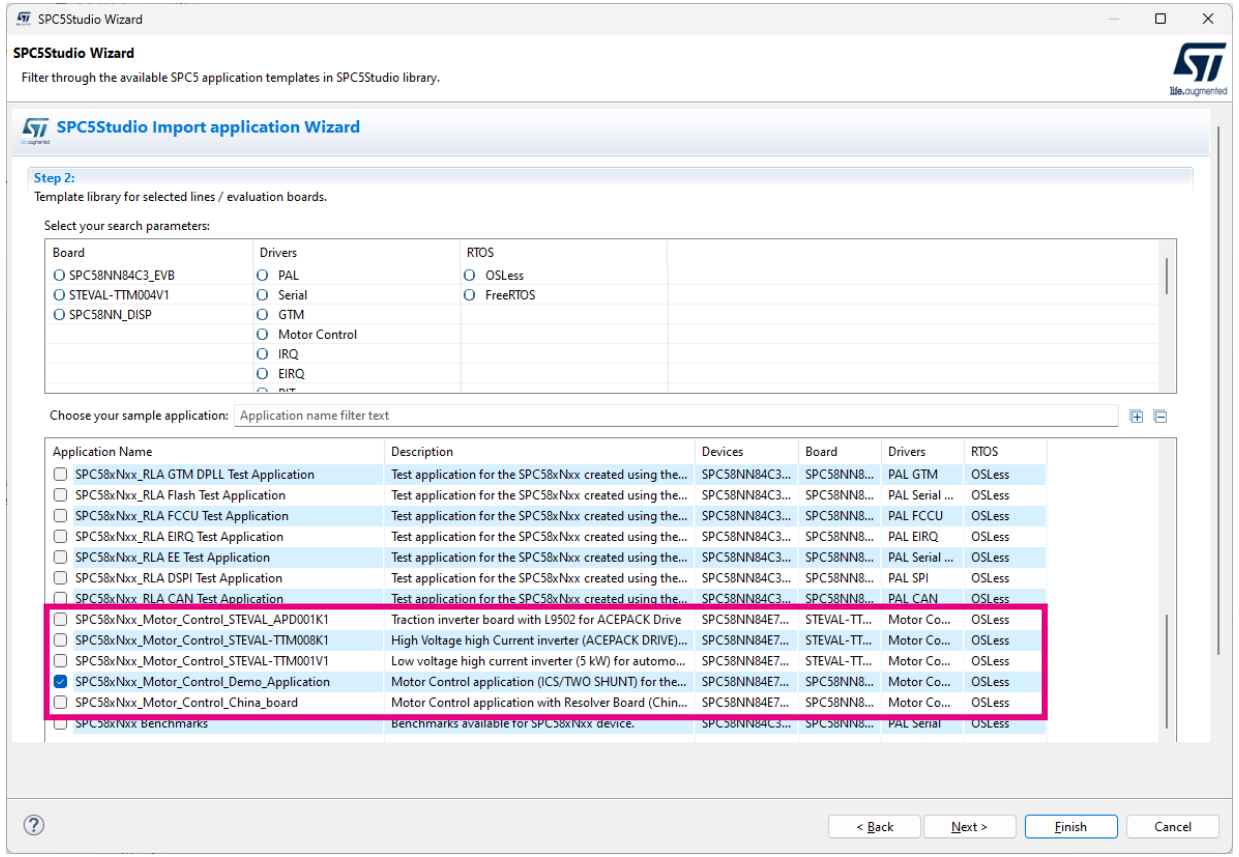
How to Install MCTK : SPC5Studio

Import Sample Application







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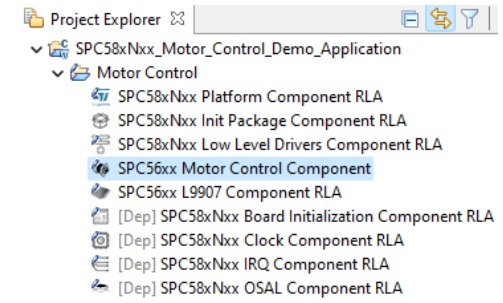
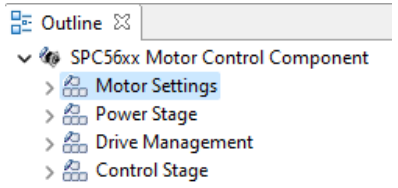
How to configure MCTK

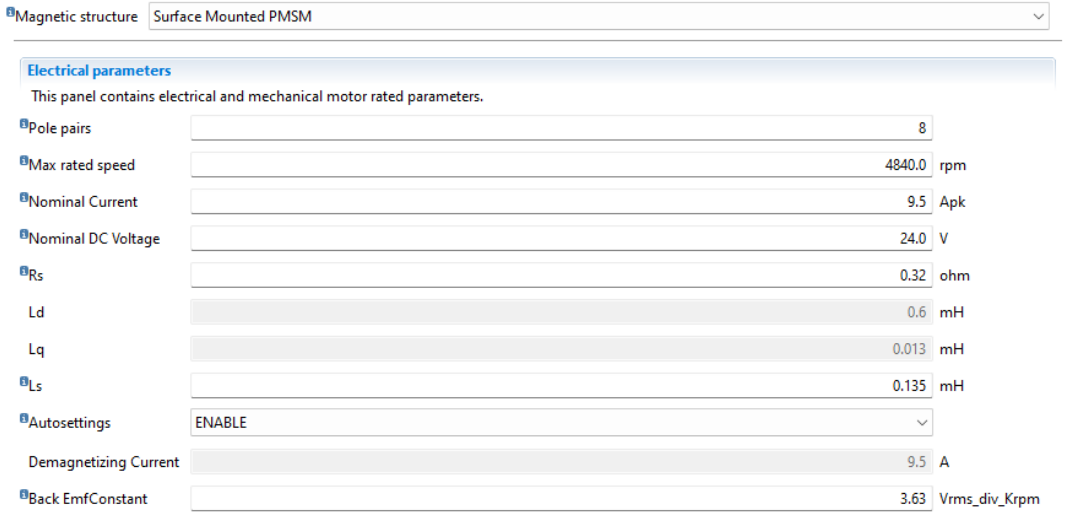
Motor Parameter Configuration

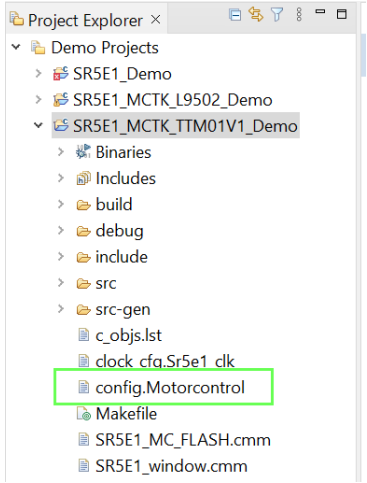
Demo Application is preconfigured to run.

Configuration can be customized to fit customer application.



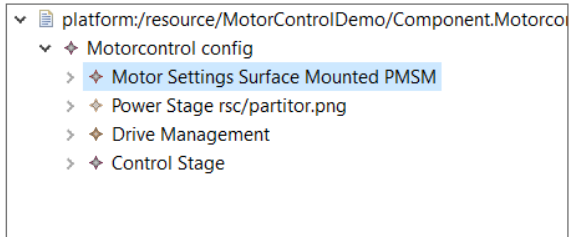


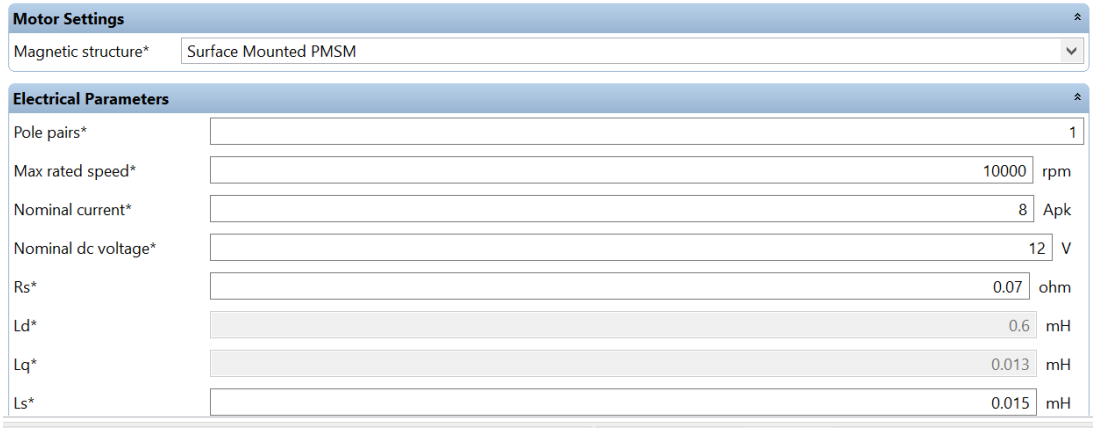




StellarStudio

SPC5Studio

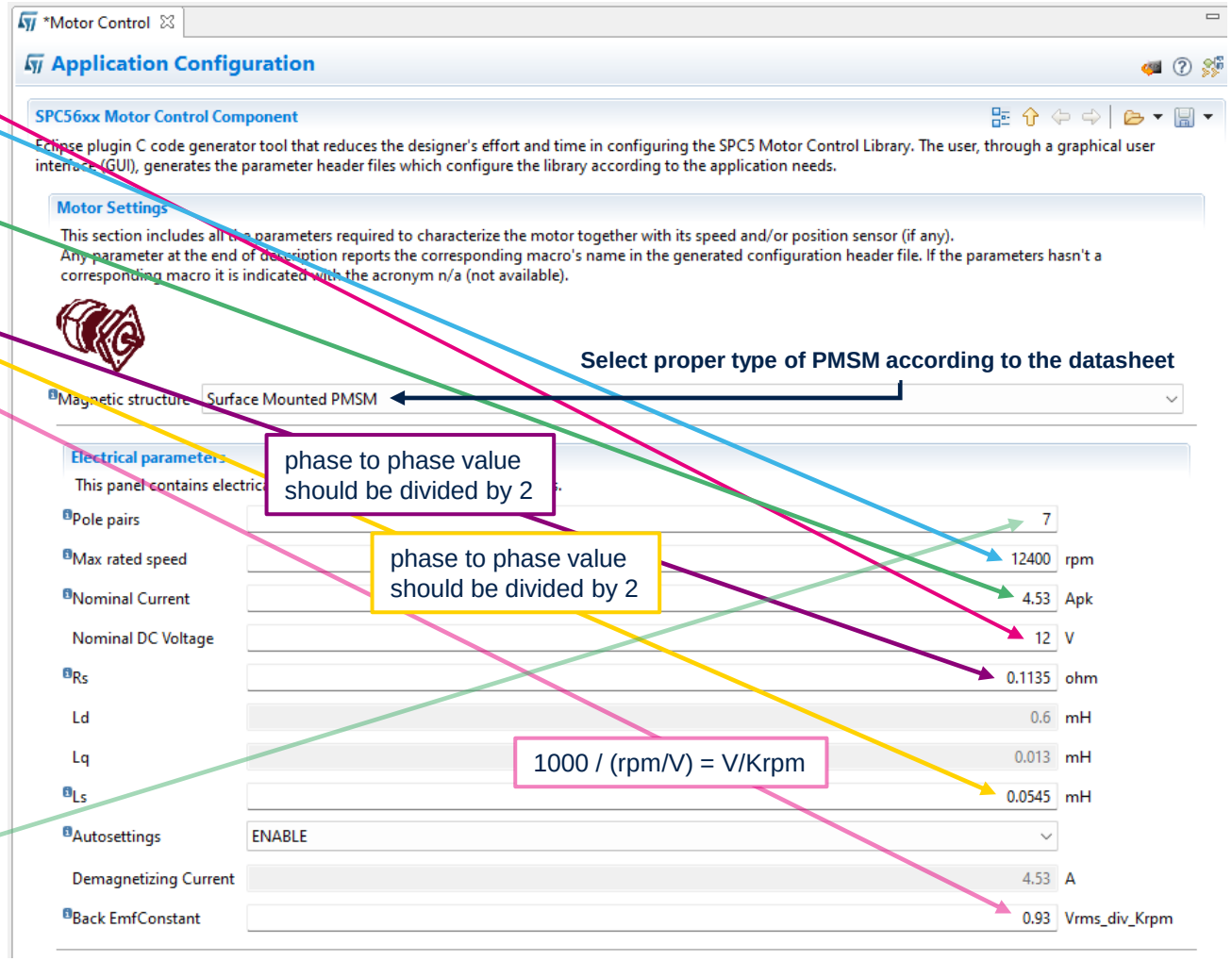




Motor Configuration

Motor Electrical Parameter Configuration

		with Hall sensors	449463
Motor Data			
	Values at nominal voltage		
1	Nominal voltage	V	12
2	No load speed	rpm	12400
3	No load current	mA	522
4	Nominal speed	rpm	9660
5	Nominal torque (max. continuous torque)	mNm	43.3
6	Nominal current (max. continuous current)	A	4.53
7	Stall torque[1]	mNm	473
8	Stall current	A	52.9
9	Max. efficiency	%	81
	Characteristics		
10	Terminal resistance phase to phase	Ω	0.227
11	Terminal inductance phase to phase	mH	0.109
12	Torque constant	mNm/A	8.95
13	Speed constant	rpm/V	1070
14	Speed/torque gradient	rpm/mNm	27.1
15	Mechanical time constant	ms	2.98
16	Rotor inertia	gcm²	10.5
Specifications			
	Thermal data		
17	Thermal resistance housing-ambient		9.66 K/W
18	Thermal resistance winding-housing		2.57 K/W
19	Thermal time constant winding		17.5 s
20	Thermal time constant motor		821 s
21	Ambient temperature		-40...+100°C
22	Max. winding temperature		+155°C
	Mechanical data (preloaded ball bearings)		
23	Max. speed		15 000 rpm
24	Axial play at axial load	< 9.0 N	0 mm
		> 9.0 N	0.15 mm
25	Radial play		preloaded
26	Max. axial load (dynamic)		5 N
27	Max. force for press fits (static)		87 N
	(static, shaft supported)		6500 N
28	Max. radial load, 5 mm from flange		15 N
	Other specifications		
29	Number of pole pairs		7
30	Number of phases		3
31	Weight of motor		170 g



Speed Sensor Configuration

Set Speed Sensor according to your HW

Outline
- SPC56xx Motor Control Component
  - Motor Settings
    - Electrical parameters
    - Sensors

Sensors

This panel contains electrical and mechanical motor related parameters.

Hall sensors	☑	
Sensors displacement	120	deg
Placement electrical angle	300	deg
Quadrature encoder	☐	
Pulses per mechanical revolution	500	
Resolver	☐	
Resolver phase shift	0.0	deg
External Sensor	☐	

Outline
- SPC56xx Motor Control Component
  - Motor Settings
  - Power Stage
  - Drive Management
    - Speed Sensor Selection
      - Main Sensor

Main Sensor

Choose one of the possible Sensors for implementing the FOC algorithm (Speed Sensor or Sensor-less)

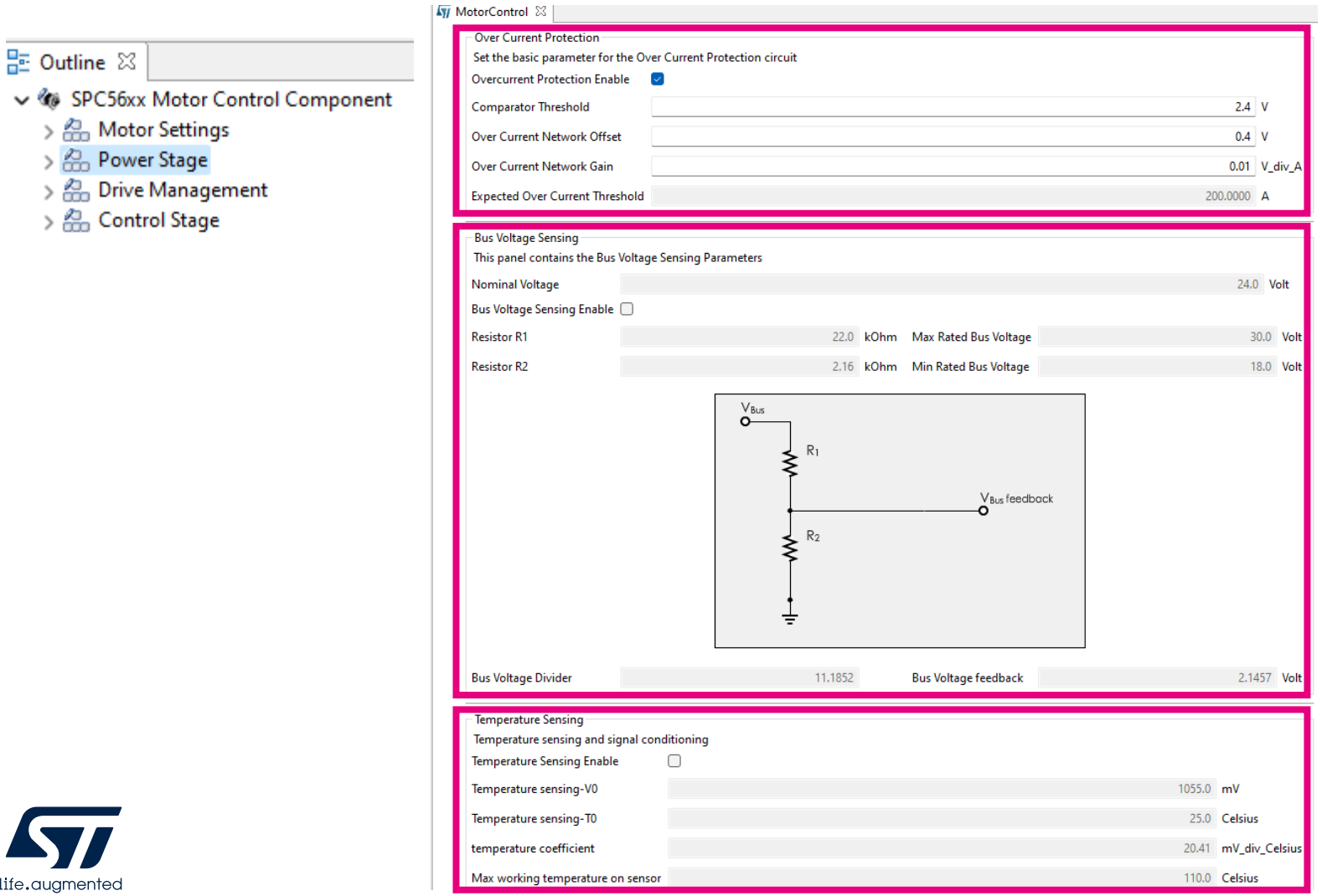
Sensor List

Sensor Selection: Hall Sensors

- Observer +PLL
- Observer +CORDIC
- Observer +HFI
- Quadrature Encoder
- Hall Sensor
- Resolver
- External Sensor

Monitoring Sensor Configuration

Set OVC, OV, OTP Enabled/Disable



- Over Current Protection
- Bus Voltage Sensing
- Temperature Sensing

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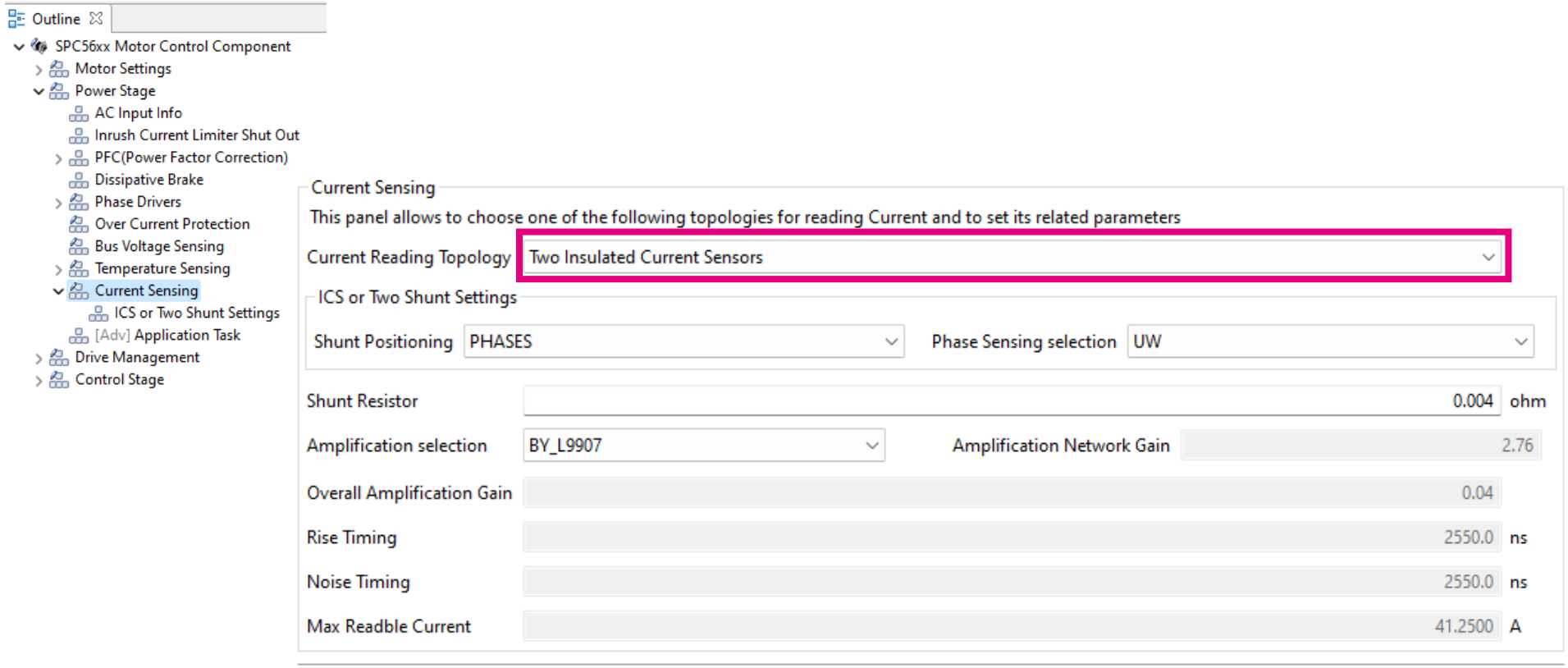
Current Sensing Configuration

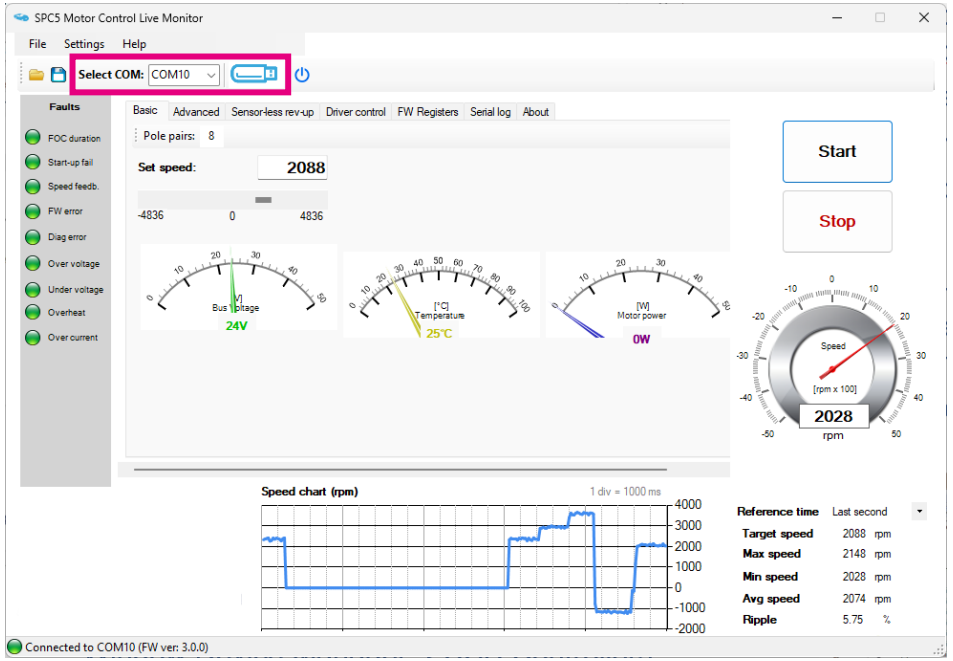
Set current reading topology



- Two Shunt / ICS
- One Shunt

MCTK with GUI

Connect MCTK to PC GUI thru UART communication



- Install and Open MC Live Monitor
- Make sure to have selected SERIAL into Drive Setting
- Select virtual COM* and set baud rate
- Click on Connect Button
- Start the Motor
- Change the reference speed
- Monitor actual speed, voltage and power
- Go the advanced option to change amplification gain or set ramp speed
- Go to register view to check all library parameters

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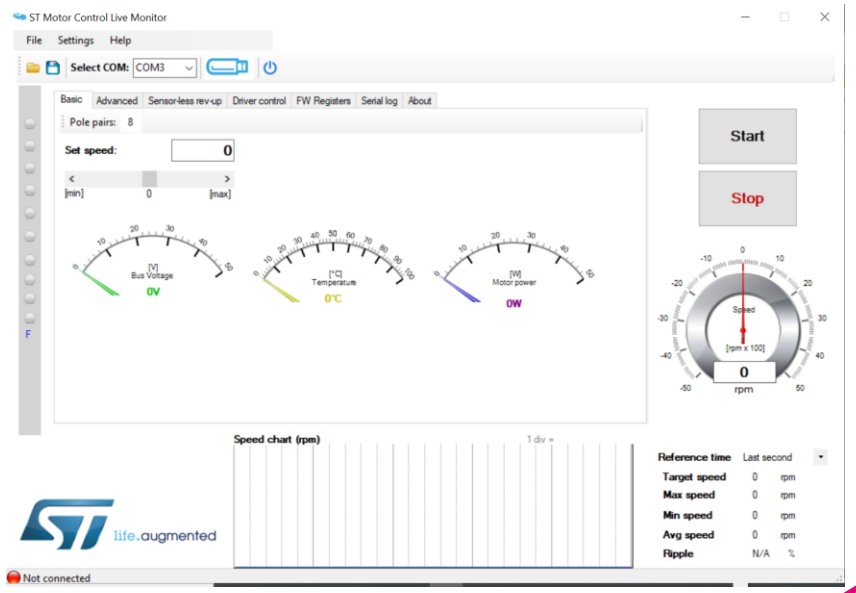
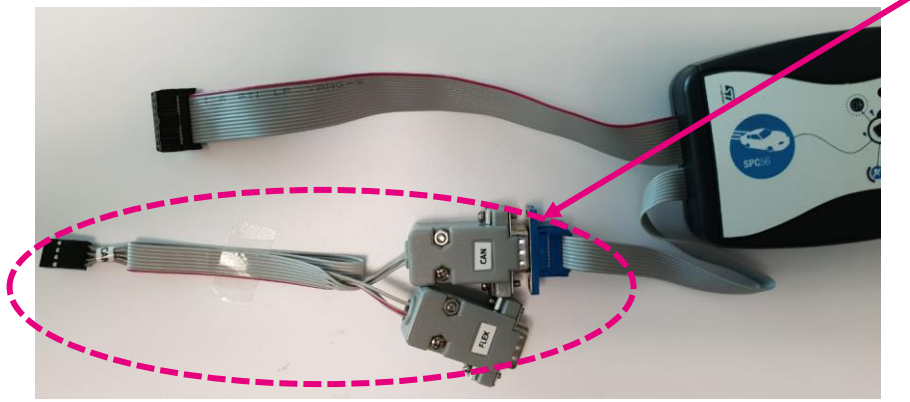
MCTK with GUI

Connect MCTK to PC GUI thru CAN communication





- Download and Flash to SPC5-CONNECT the MCTK-Connect firmware upgrade (ask for binary)
  - Connect SPC5-CONNECT to PC using USB and to EVBE700S on J12 connector using CAN_TO_P3 cable
  - Use Live Monitor normally as in the Serial Virtual COM connection

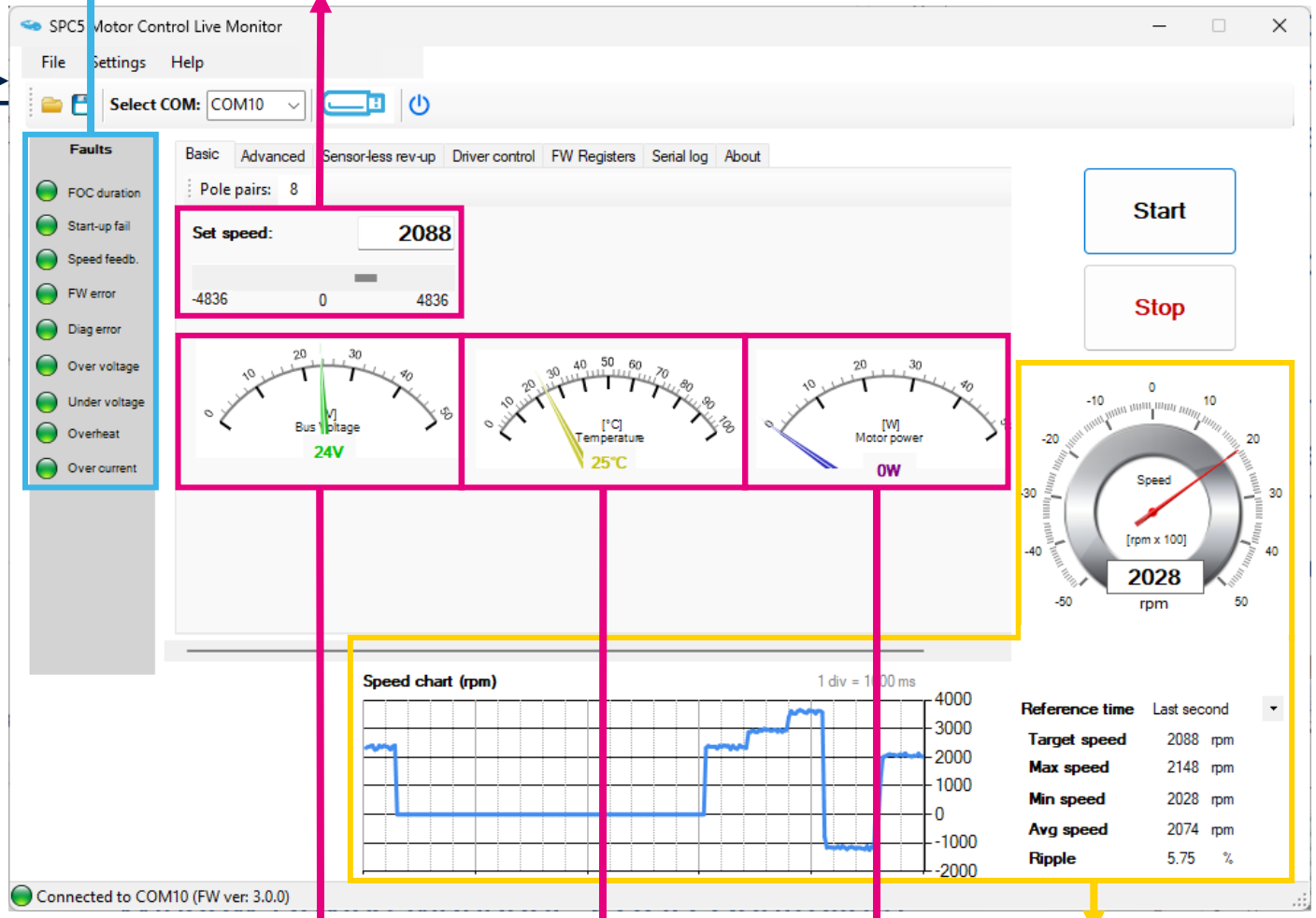
* Make sure to have selected CAN into Drive Setting

MCTK with GUI

Fault diagnosis information

Live speed control

UART/CAN Communication



Temperature monitoring

Speed monitoring

Voltage monitoring

Motor power monitoring

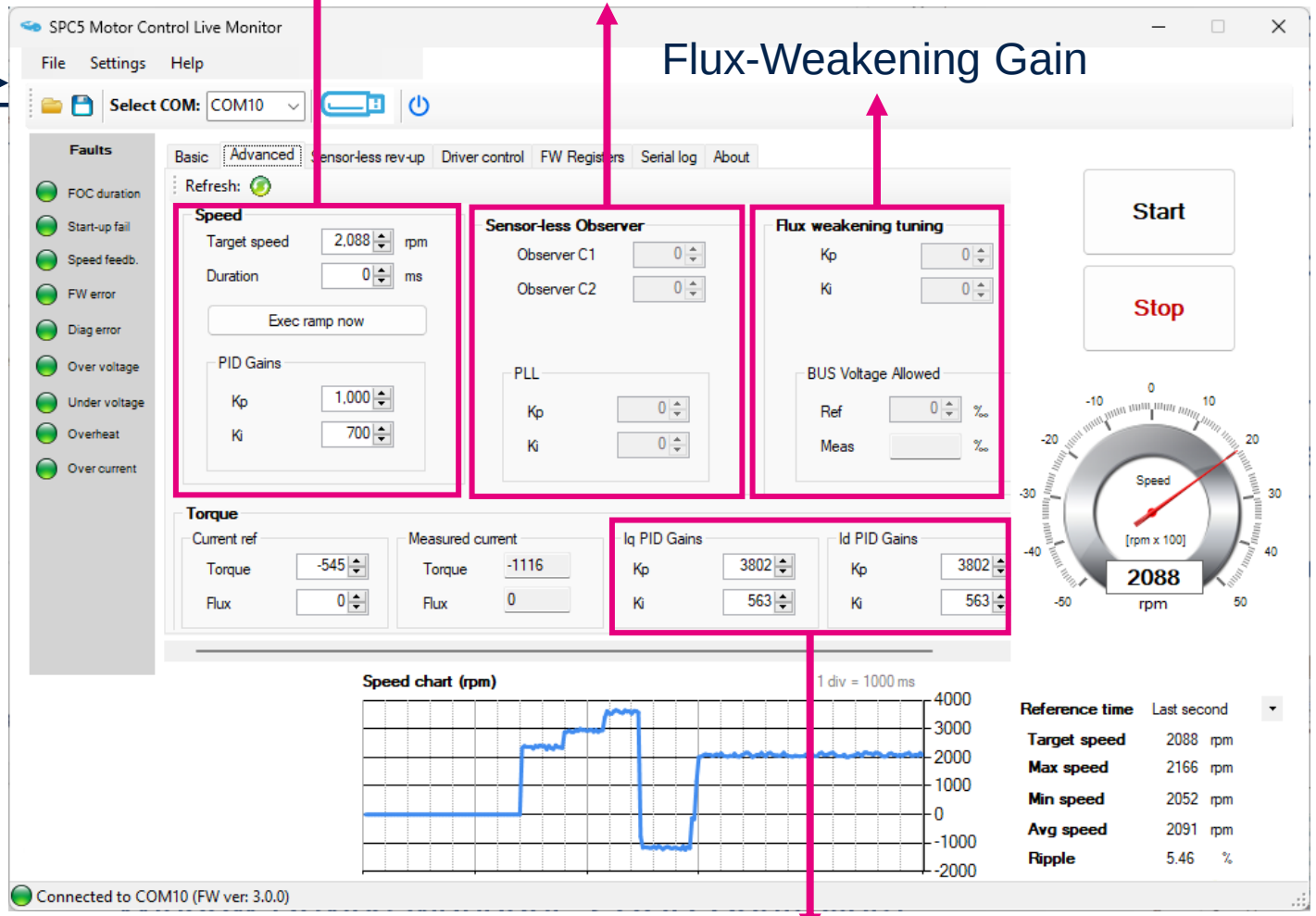
MCTK with GUI

PID Gain

Observer Gain

UART/CAN Communication

Flux-Weakening Gain

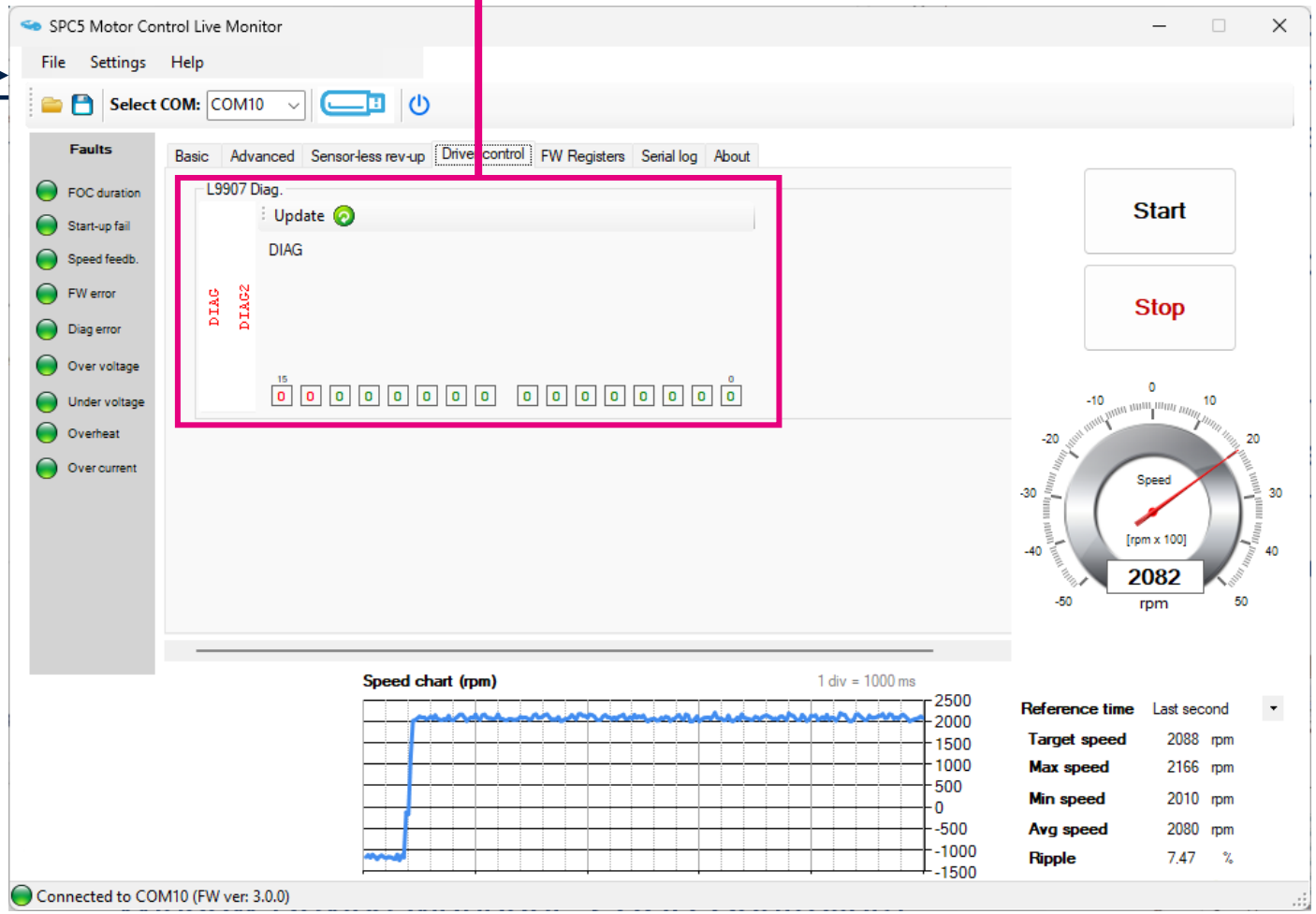


FOC PID Gain

MCTK with GUI

Gate Driver Fault Diagnosis

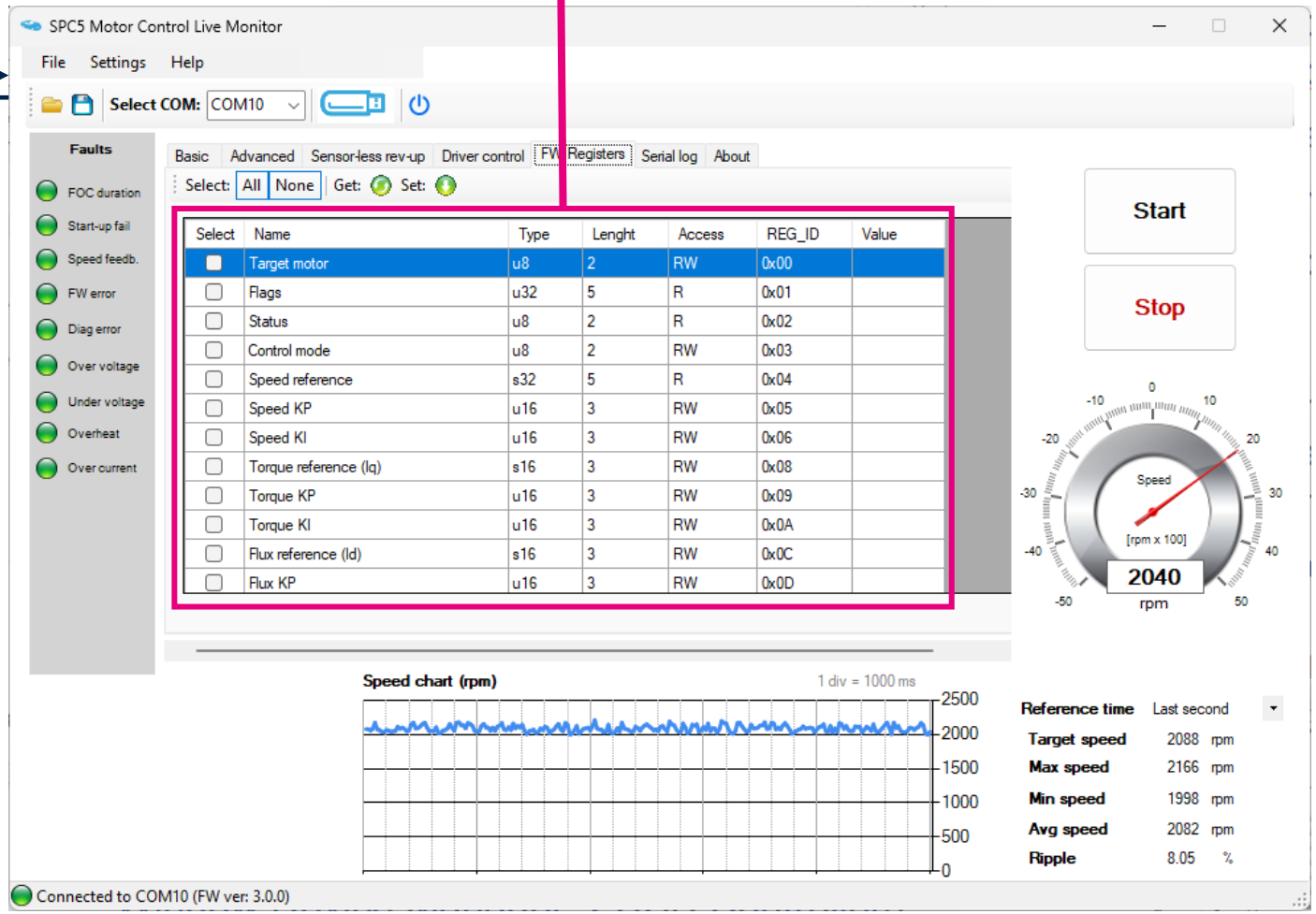
UART/CAN Communication



MCTK with GUI

MCTK Parameters

UART/CAN Communication

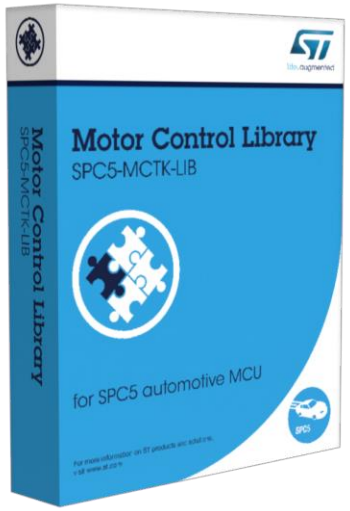


Select	Name	Type	Lenght	Access	REG_ID	Value
	Target motor	u8	2	RW	0x00	
	Flags	u32	5	R	0x01	
	Status	u8	2	R	0x02	
	Control mode	u8	2	RW	0x03	
	Speed reference	s32	5	R	0x04	
	Speed KP	u16	3	RW	0x05	
	Speed KI	u16	3	RW	0x06	
	Torque reference (Iq)	s16	3	RW	0x08	
	Torque KP	u16	3	RW	0x09	
	Torque KI	u16	3	RW	0x0A	
	Flux reference (Id)	s16	3	RW	0x0C	
	Flux KP	u16	3	RW	0x0D	

What you'll find on st.com page

- Software:
  - Motor Control Live Monitor
    - Executable installation file
  - Motor Control Binary Image
    - the same/update provided built in with kit
  - Web Motor Control Update Site for SPC5Studio
      - It installs the SPC5Studio Web Motor Control component
      - This provides configuration plugin with binary of the library
      - That's allow customer to configure the library and change the motor
  - Demo Application for SPC5Studio/StellarStudio
      - Based on the SPC5Studio/StellarStudio Web Motor Control component for both ICS and one shunt configuration

- Documentation:
  - Data brief
  - Quick Start Guide
  - Video Tutorial
  - User Manual (inside the Studio plugin)
  - General Presentation



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