



Power 'n Motors

Critical aspects in power applications
design, proper component selection
& experimental results

9:00	Introduction
9:15	HV Motors (BLDC) & 3PHs Inverters <ul style="list-style-type: none">• Architectures & components• New Intelligent Power Modules (IPM) from ST<ol style="list-style-type: none">1. Experimental results: Performance Benchmark2. Guidelines to minimize EMI
11:00	Coffee break
11:15	IPM simulation tool
11:45	HV driving with isolation <ul style="list-style-type: none">• Driving an isolated 60kW HB driver: experimental results
12:15	LV Motors (DC & BLDC) <ul style="list-style-type: none">• Architectures & components
12:30	Lunch
13:30	LV Motors (DC & BLDC) <ul style="list-style-type: none">• Choosing right MOSFET for LV Motor Control (1h)<ol style="list-style-type: none">1. Relationship between MOSFET parameters & EMI behavior2. Experimental results: Performances of new F7 Technology
14:30	ST solutions to drive three phases permanent magnet motors <ul style="list-style-type: none">• ST MCU Portfolio for Motor Control• Software & Firmware• Evalboard demonstration
16:00	Conclusions



ST solutions to drive three phases permanent magnet motors

Software & Firmware

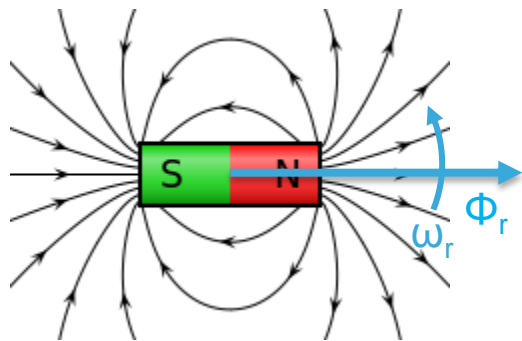
Evaluation boards

What is FOC?

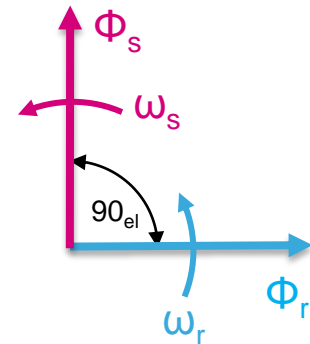
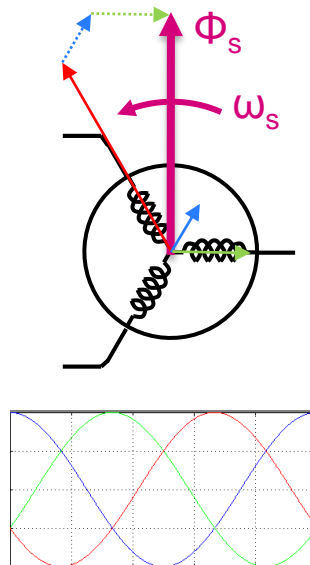
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- FOC is the acronym of **Field Oriented Control**.
- The purpose of the FOC is to maximize the electro-magnetic torque provided by the motor keeping the two magnetic fields (rotor and stator) always at 90 electrical degrees.

Rotor magnetic field



Stator magnetic field



Torque T_e is maximized if the two fields are kept at 90°

Benefits of FOC

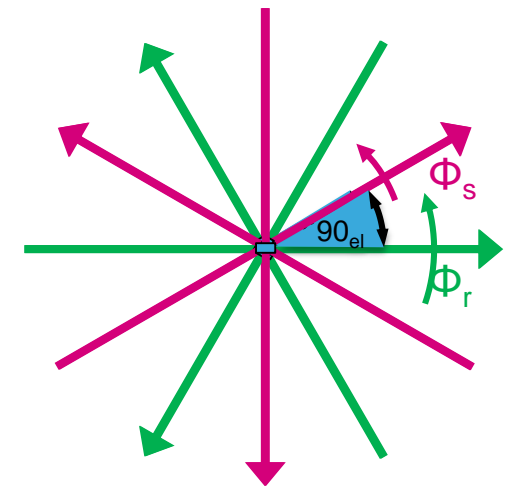
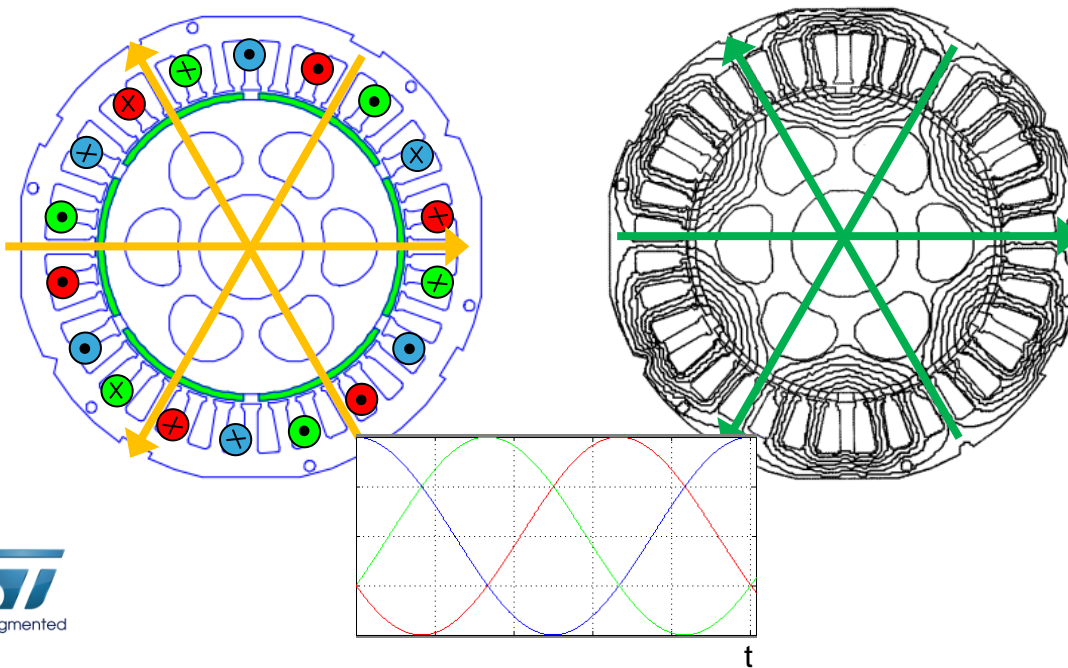
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- Best energy **efficiency** even during **transient operation**.
- **Responsive speed control** to load variations.
- **Decoupled control** of both electromagnetic torque and flux.
- Acoustical **noise reduction** due to sinusoidal waveforms.
- Active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

PMSM FOC Basics

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- Field Oriented Control: stator currents (Field) are controlled in amplitude and phase (Orientation) with respect to rotor flux
 - current sensing is mandatory (3shunt/1shunt/ICS)
 - speed / position sensing is mandatory (encoder/Hall/sensorless algorithm)
 - current controllers needed (PI/D,FF)
 - ❖ not easy... high frequency sinusoidal references + stiff amplitude modulation..
 - ❖ reference frame transformation (Clarke / Park) allows to simplify the problem:



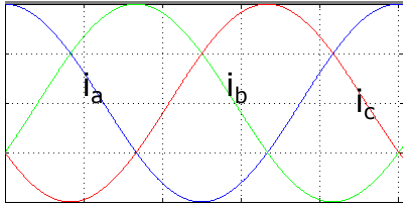
T_e maximized if...

PMSM FOC Basics:

reference frame transformations

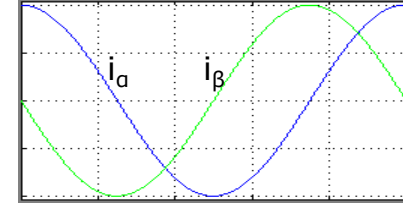
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- Clarke: transforms i_a, i_b, i_c (120°) to i_α, i_β (90°); (consider that $i_a + i_b + i_c = 0$);

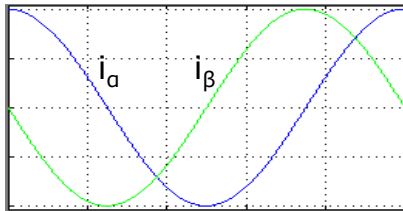


$$i_\alpha = i_{as}$$

$$i_\beta = -\frac{i_{as} + 2i_{bs}}{\sqrt{3}}$$

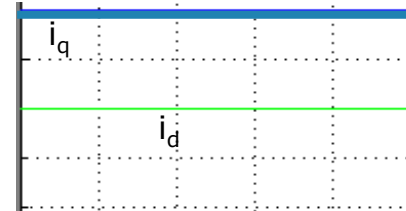


- Park: currents i_α, i_β , transformed on a reference frame rotating with their frequency, become DC currents i_q, i_d (90°)

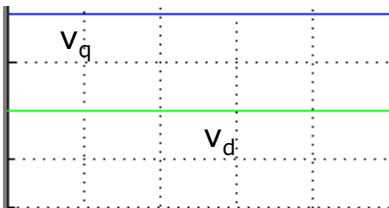


$$i_{qs} = i_\alpha \cos \theta_r - i_\beta \sin \theta_r$$

$$i_{ds} = i_\alpha \sin \theta_r + i_\beta \cos \theta_r$$

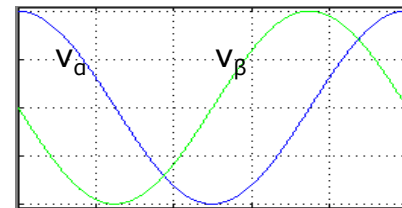


- PI regulators now work efficiently in a 'DC' domain; their DC outputs, voltage reference v_q, v_d are handled by the Reverse Park $\rightarrow v_\alpha, v_\beta$ AC domain



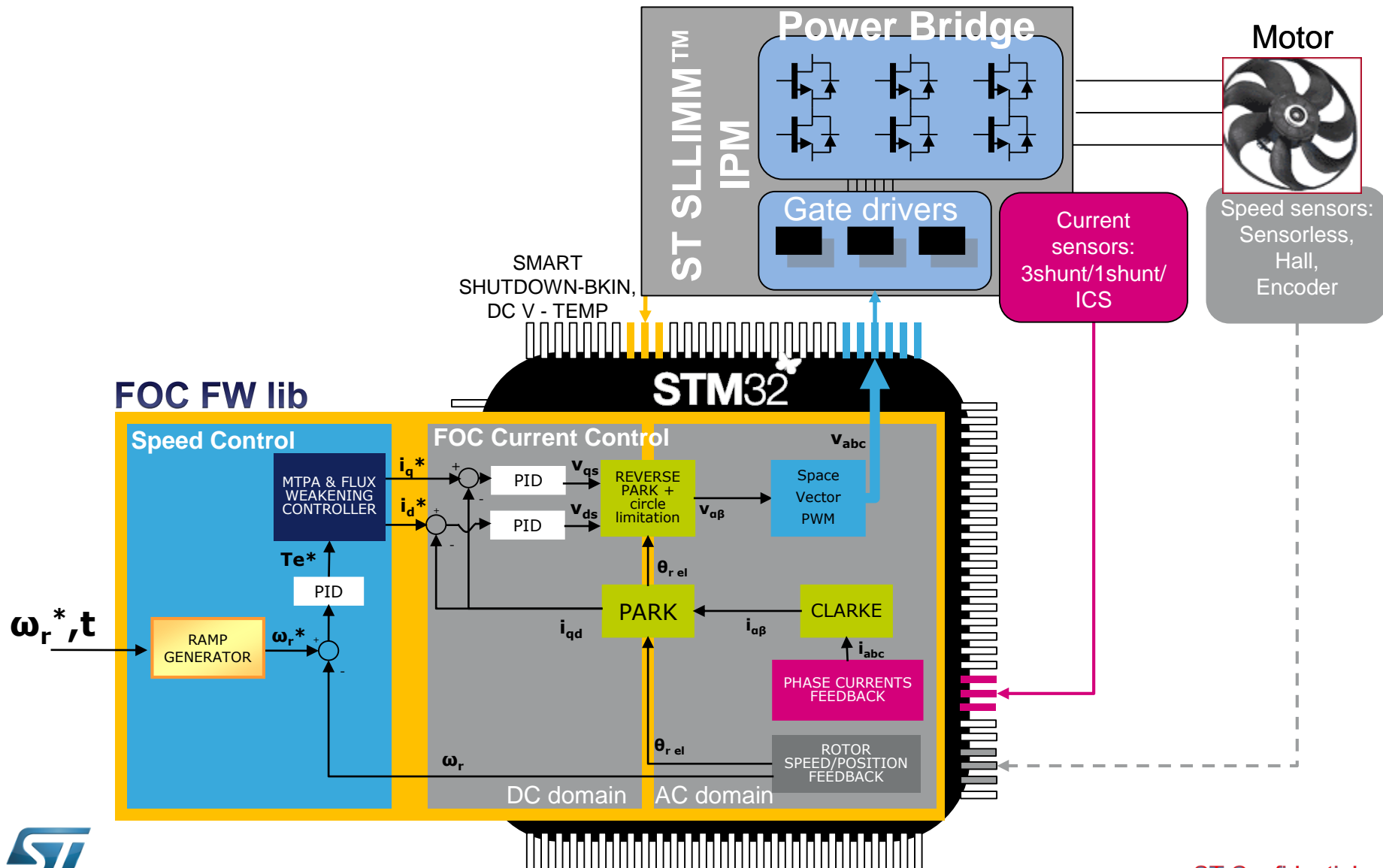
$$v_\alpha = v_{qs} \cos \theta_r + v_{ds} \sin \theta_r$$

$$v_\beta = -v_{qs} \sin \theta_r + v_{ds} \cos \theta_r$$



PMSM FOC – Block Diagram

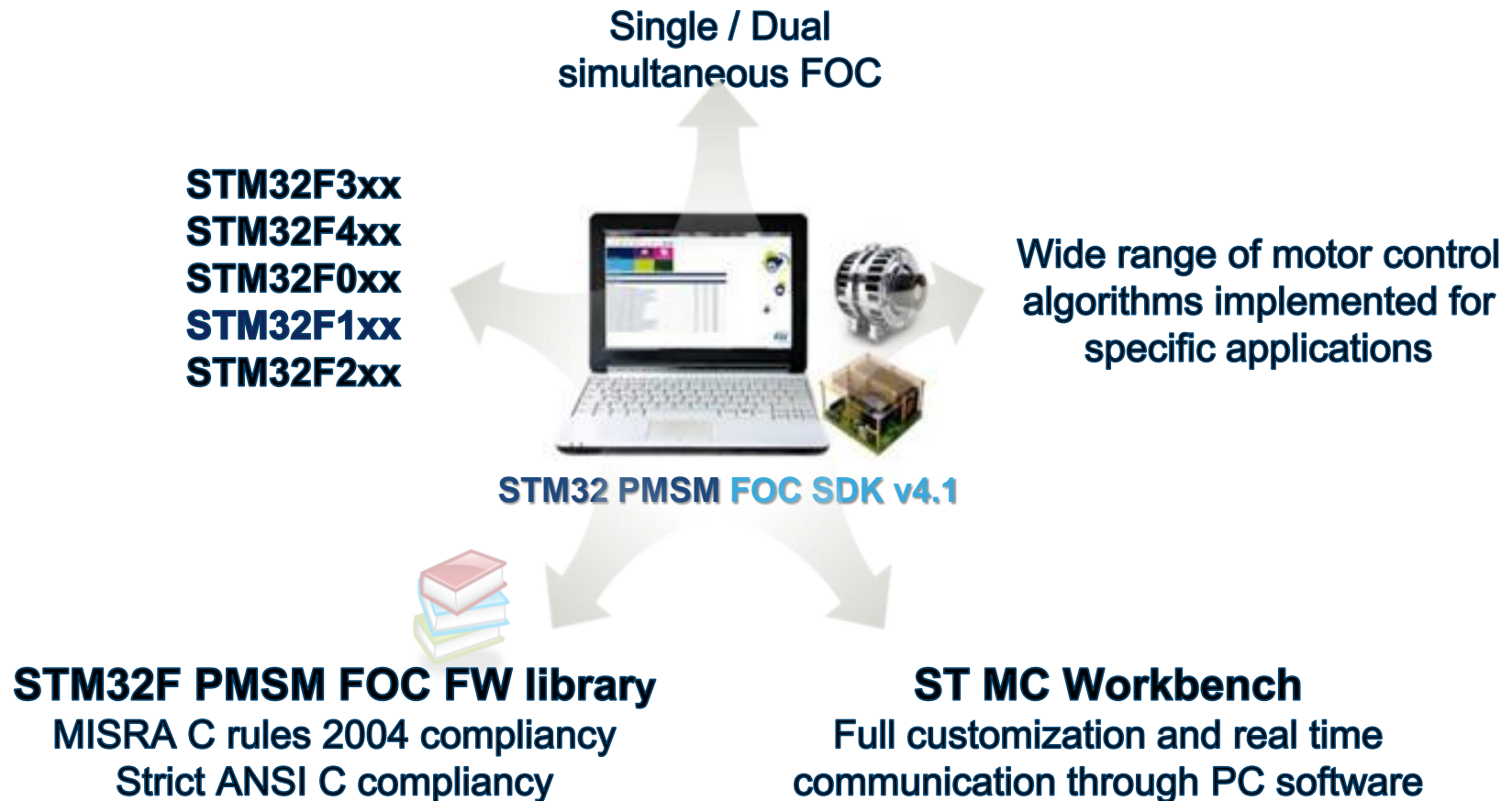
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STM32 PMSM FOC SDK v4.1

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- **STSW-STM32100** - includes the PMSM FOC FW library and ST MC Workbench (GUI), allowing the user to evaluate ST products in applications driving single or dual Field Oriented Control of 3-phase Permanent Magnet motors (**PMSM**), featuring STM32F3xx, STM32F4xx, STM32F0xx, STM32F1xx, STM32F2xx

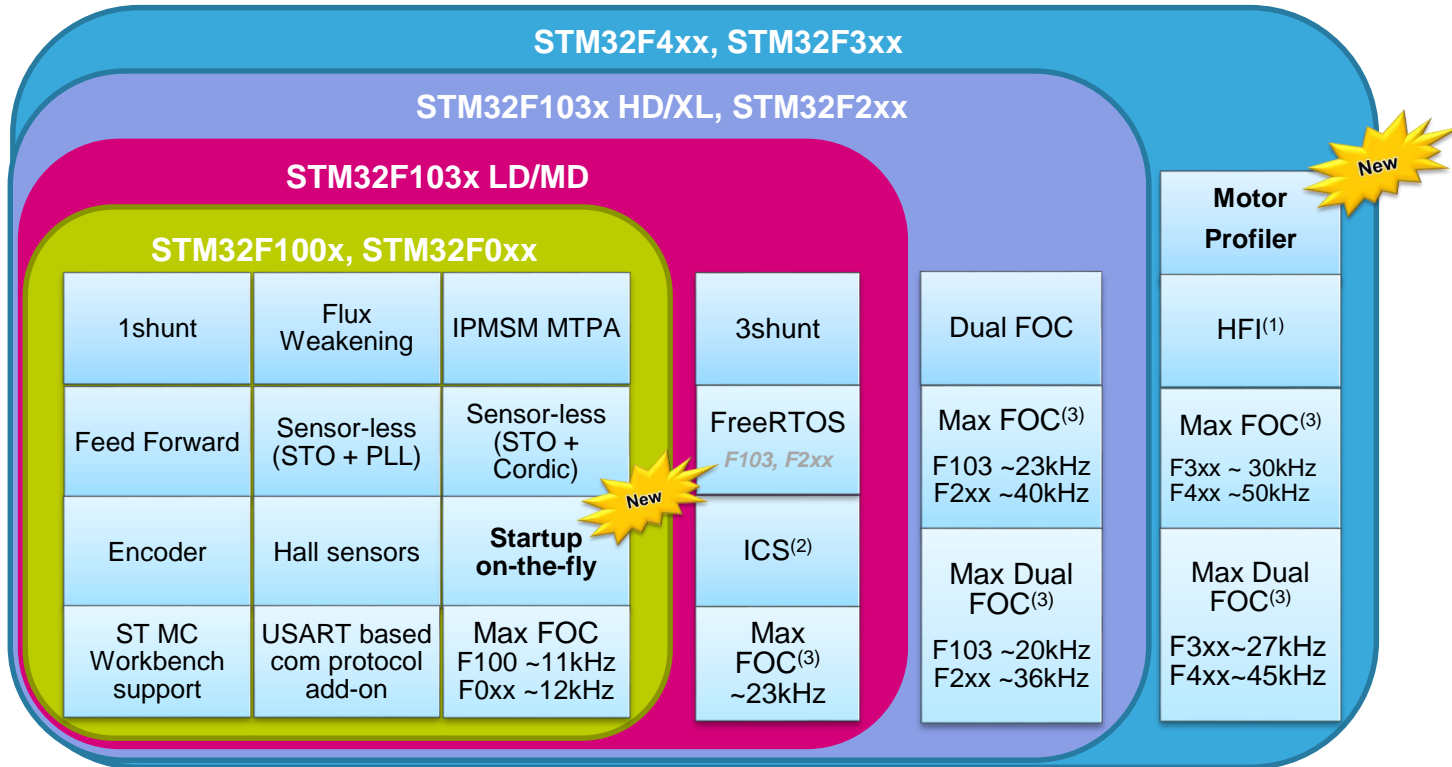


STM32 FOC SDK

Key Features

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MC FW LIB v4.1



Plug-in: Digital PFC

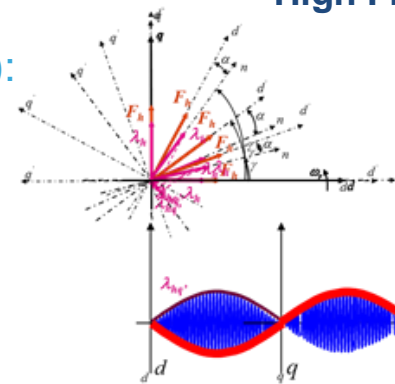
- (1) High Frequency Injection
- (2) Supported only for STM32F103, STM3F2, STM3F4
- (3) Max FOC estimated in sensorless mode

Features

- 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
 - High frequency injection (ST patent pending):
 - for anisotropic motors (IPMSM, $L_d < L_q$)
 - allows precise rotor angle detection; it enables advantages of FOC in torque/speed/position control mode at very low and zero speed
 - STM32F3 and STM32F4 only
 - 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)



High Frequency Injection

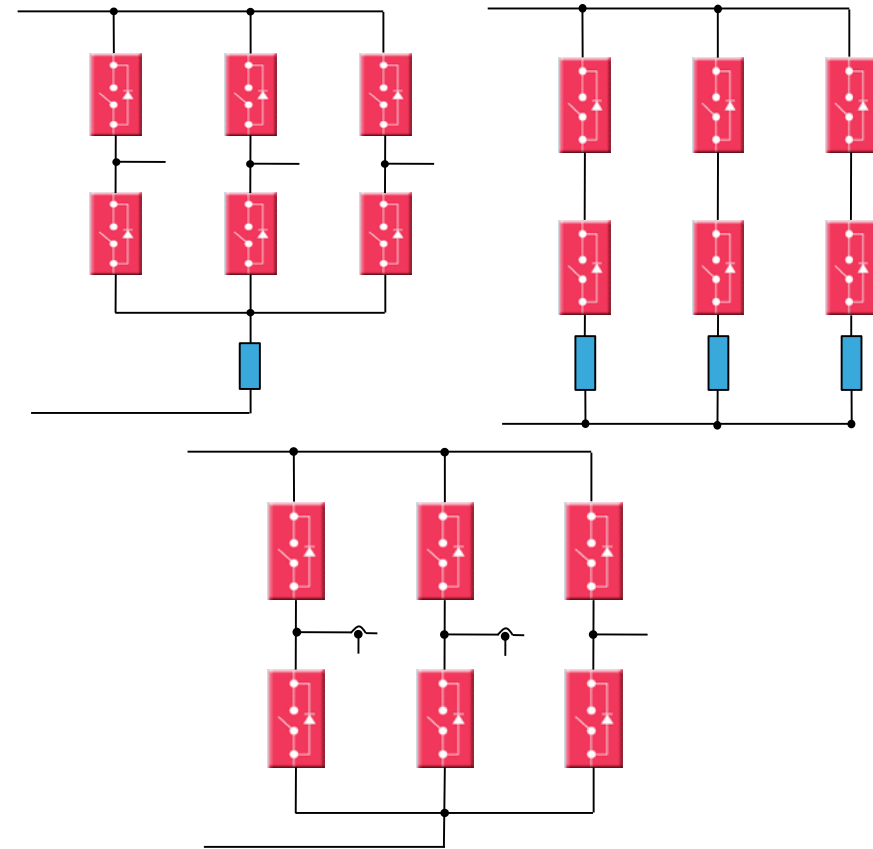


Minimum points of the envelope of λ_{hg} show d/q axes \rightarrow angle detection !

Features

- **Current sensing topologies:**

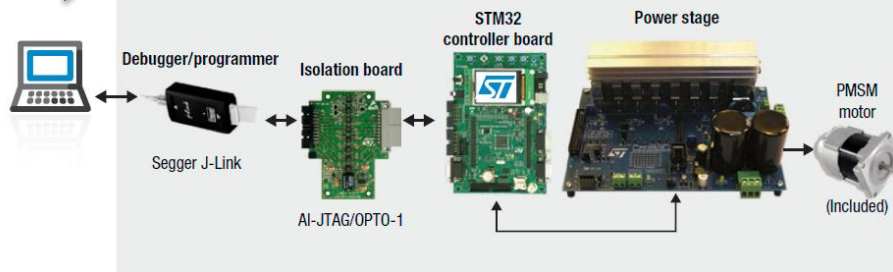
- **1 shunt resistor placed on the DC link**
 - ST patented algorithm
 - Only one op-amp /shunt resistor is needed → lowest cost
 - Current reading algorithm may result in not accurate torque regulation
- **3 shunt resistors placed in the three legs**
 - Current reading accuracy: high
 - Best compromise cost / performances
- **2 Isolated Current Sensors (ICS)**
 - Not dissipative current sensing topology → mandatory when current exceed some tens Ampere
 - Expensive
- **Any possible configuration (2 motors x 3 current sensing x 3 speed sensors type) is supported by FW library**



MC boards offer on ST.com

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MC Kit



Kit: from isolated debug probe to motor

Inverters

Complete 3ph Inverter solutions
Control and power stage in single board

<p>45W</p> <p>STEVAL-IFN003V1</p> <p>PMSM FOC Motor Drive</p> <ul style="list-style-type: none"> 1 x Motor Driver IC L6230PD 1 x 32bit Micro STM32F103C8 	<p>1300W</p> <p>STEVAL-IHM034V2</p> <p>Dual motor drive + digital PFC</p> <ul style="list-style-type: none"> 1 x 32bit Micro STM32F103C8T6 1 x IGBT SLLIMM™ STGIP520C60 1 converter based on Viper16L
<p>35W</p> <p>STEVAL-IFN004V1</p> <p>BLDC Six-Steps Motor Drive</p> <ul style="list-style-type: none"> 1 x Motor Driver IC L6230Q 1 x 8bit-Micro STM8S 	<p>100W</p> <p>STEVAL-IHM036V1</p> <p>PMSM FOC Motor Drive</p> <ul style="list-style-type: none"> 1 x 32bit Micro STM32F100C6 1 x IGBT SLLIMM™ STGIPN3H60 1 converter based on Viper16
<p>10W X2</p> <p>STEVAL-IHM042V1</p> <p>PMSM FOC Motor Drive</p> <ul style="list-style-type: none"> 2 x Motor Driver IC L6230PD 1 x 32bit Micro STM32F303C8T6 1 x DC-DC converter ST1S14PHR 	<p>40W</p> <p>STEVAL-IHM038V1</p> <p>FAN Drive + PFC + IrDA</p> <ul style="list-style-type: none"> 1 x 32bit Micro STM32F100 1 x IGBT SLLIMM™ STGIPN3H60 1 PFC controller L6562A

Low voltage drives High voltage drives



Please visit [System evaluation board](http://www.st.com/evalboards) or contact a [local ST office](http://www.st.com/evalboards)

Power board

Complementing MC starter kits
Evaluation boards for 3-ph motors

Full set of control board featuring all ST MCUs with MC Connector

STM8 MC library v1.0		STM32 PMSM FOC SDK v4.0			
Solar Control Six step for BLDC V/F for ACM		FOC		Dual FOC	
STM8S100-CHVL	STM32F100x	STM32F103	STM32F30x	STM32F4	
MC Connector					
Power Stages					

Full set of Power Stage with MC Connector

Please visit <http://www.st.com/evalboards> or contact a [local ST office](http://www.st.com/evalboards)

Control board

Complementing MC starter kits
Main Power Stages for 3-Ph motors

<p>1000W</p> <p>STEVAL-IHM025V1 High voltage</p> <ul style="list-style-type: none"> 1 x IGBT SLLIMM™ STGIP114K60 1 converter based on Viper16 1 x IGBT STGP10NC60KD 	<p>15W</p> <p>STEVAL-IHM023V2-3 High voltage</p> <ul style="list-style-type: none"> 3 x PWM smart driver L6390 1 converter based on Viper16 7 x IGBT power switch STGP10NC60KD
<p>2000W</p> <p>STEVAL-IHM028V2 High voltage</p> <ul style="list-style-type: none"> 1 x IGBT SLLIMM™ STGIP520C60 1 x PWM SMPS VIPer26LD 1 x IGBT STGW35NB60SD 	<p>150W</p> <p>STEVAL-IHM021V2 High voltage</p> <ul style="list-style-type: none"> 3 x PWM smart driver L6390 1 converter based on Viper12 6 x MOSFET power switch STD5N52U
<p>100W</p> <p>STEVAL-IHM035V2 High voltage</p> <ul style="list-style-type: none"> 1 x IGBT SLLIMM™ STGIPN3H60 1 x PWM SMPS VIPer16L 	<p>150W</p> <p>STEVAL-IHM032V1 High voltage</p> <ul style="list-style-type: none"> 3 x PWM smart driver 2xL6392D and 1x L6391D 1 converter based on Viper12 6 x IGBT power switch STGD3HF60HD
<p>100W</p> <p>STEVAL-IHM045V1 High voltage</p> <ul style="list-style-type: none"> 1 x IGBT SLLIMM™ STGIPN3H60A 1 x PWM SMPS VIPer06LS Op Amp. And Comp. TSV994 and TS374 	<p>120W</p> <p>STEVAL-IHM031V1 Low voltage</p> <ul style="list-style-type: none"> Power stage up to 12/24V 3 x dual PowerMOSFETs STS8dnh3I 2 x PWM smart driver L6387E 1x step down converter L4976D

SLLIMM™ (ST IPMs) based

Gate drivers & Power Transistors based



Please visit [System evaluation boards](http://www.st.com/evalboards) or contact a [local ST office](http://www.st.com/evalboards)



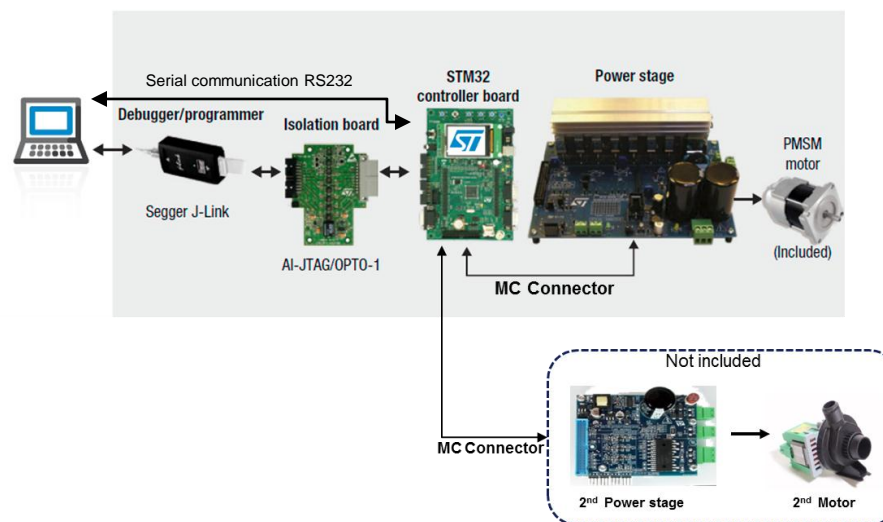
Part Number	Description	ST Link onboard	Type
STM32100B-MCKIT	Motor control starter kit for STM32F100 (128KB Flash) Value Line MCUs	Yes	Single drive
STM3210B-MCKIT	Motor control starter kit for STM32 (128KB flash) Performance and Access Line microcontrollers	No	Single drive

The motor control kit connections represented below can also be applied when combining STM32 control boards and evaluation power boards.

Motor control kits

[STM32100B-MCKIT](#)

[STM3210B-MCKIT](#)



Part Number	Description	ST Link onboard	Type
<u>STEVAL-IHM034V2</u>	Dual motor control and PFC demonstration board featuring the STM32F103 and STGIPS20C60	No	Single/Dual drive
<u>STEVAL-IHM036V1</u>	Low power motor control board featuring the SLLIMM™ STGIPN3H60 and MCU STM32F100C6T6B	No	Single drive
<u>STEVAL-IHM038V1</u>	BLDC ceiling fan controller based on STM32 and SLLIMM-nano	No	Single drive
<u>STEVAL-IHM040V1</u>	BLDC/PMSM driver demonstration board based on STM32 and the SLLIMM nano™	No	Single drive
<u>STEVAL-IHM042V1</u>	Compact, low-voltage dual motor control board based on the STM32F303 and L6230	Yes	Single/Dual drive
<u>STEVAL-IHM043V1</u>	6-Step BLDC sensorless driver board based on the STM32F051 and L6234	No	Single drive
<u>STEVAL-IFN003V1</u>	DC PMSM FOC motor drive	No	Single drive

STEVAL-IHM034V2



STEVAL-IHM036V1



STEVAL-IHM038V1



STEVAL-IHM040V1



STEVAL-IHM042V1



STEVAL-IHM043V1



STEVAL-IFN003V1



Control board

STM32 evaluation boards with MC connector

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Part Number	Description	ST Link onboard ⁽¹⁾	Type
STM3210E-EVAL	Evaluation board for STM32 F1 series - with STM32F103 MCU	No	Single drive
STM3220G-EVAL	Evaluation board for STM32 F2 series - with STM32F207IG MCU	Yes	Single drive
STM32303C-EVAL	Evaluation board for STM32F303xx microcontrollers	Yes	Single/Dual drive
STM3240G-EVAL	Evaluation board for STM32F407 line - with STM32F407IG MCU	Yes	Single drive
STEVAL-IHM022V1	High density dual motor control demonstration board based on the STM32F103ZE microcontroller	No	Single/Dual drive
STEVAL-IHM039V1	Dual motor drive control stage based on the STM32F415ZG microcontroller	No	Single/Dual drive

STM3220G-EVAL



STM3240G-EVAL



STM3210E-EVAL



STEVAL-IHM022V1



STM32303C-EVAL



STEVAL-IHM039V1



(1) Only necessary for high-voltage applications or if not included with the evaluation board:

In-circuit debugger/programmer..



- [ST-LINK/V2](#)
- [ST-LINK/V2-ISOL \(2500 VRMS high isolation voltage\)](#)

Power board

ST evaluation power boards with MC connector

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Part Number	Description
STEVAL-IHM021V2	100 W, 3-phase inverter based on L6390 and UltraFASTmesh™ MOSFET for speed FOC of 3-phase PMSM motor drive
STEVAL-IHM023V3	1 kW 3-phase motor control evaluation board featuring L6390 drivers and new IGBT STGP10H60DF
STEVAL-IHM025V1	1 kW 3-phase motor control demonstration board featuring the IGBT SLLIMM™ STGIPL14K60
STEVAL-IHM028V2	2 kW 3-phase motor control demonstration board featuring the IGBT intelligent power module STGIPS20C60
STEVAL-IHM032V1	150 W inverter featuring the L639x and STGD3HF60HD for 1-shunt based sinusoidal vector control and trapezoidal scalar control
STEVAL-IHM035V2	3-phase high voltage inverter power board for FOC and scalar motor control based on the STGIPN3H60 (SLLIMM™-nano)
STEVAL-IHM045V1	3-phase high voltage inverter power board for FOC based on the STGIPN3H60A (SLLIMM™-nano)

STEVAL-IHM021V2



STEVAL-IHM023V3



STEVAL-IHM025V1



STEVAL-IHM032V1



STEVAL-IHM035V2



STEVAL-IHM045V1



STEVAL-IHM028V2

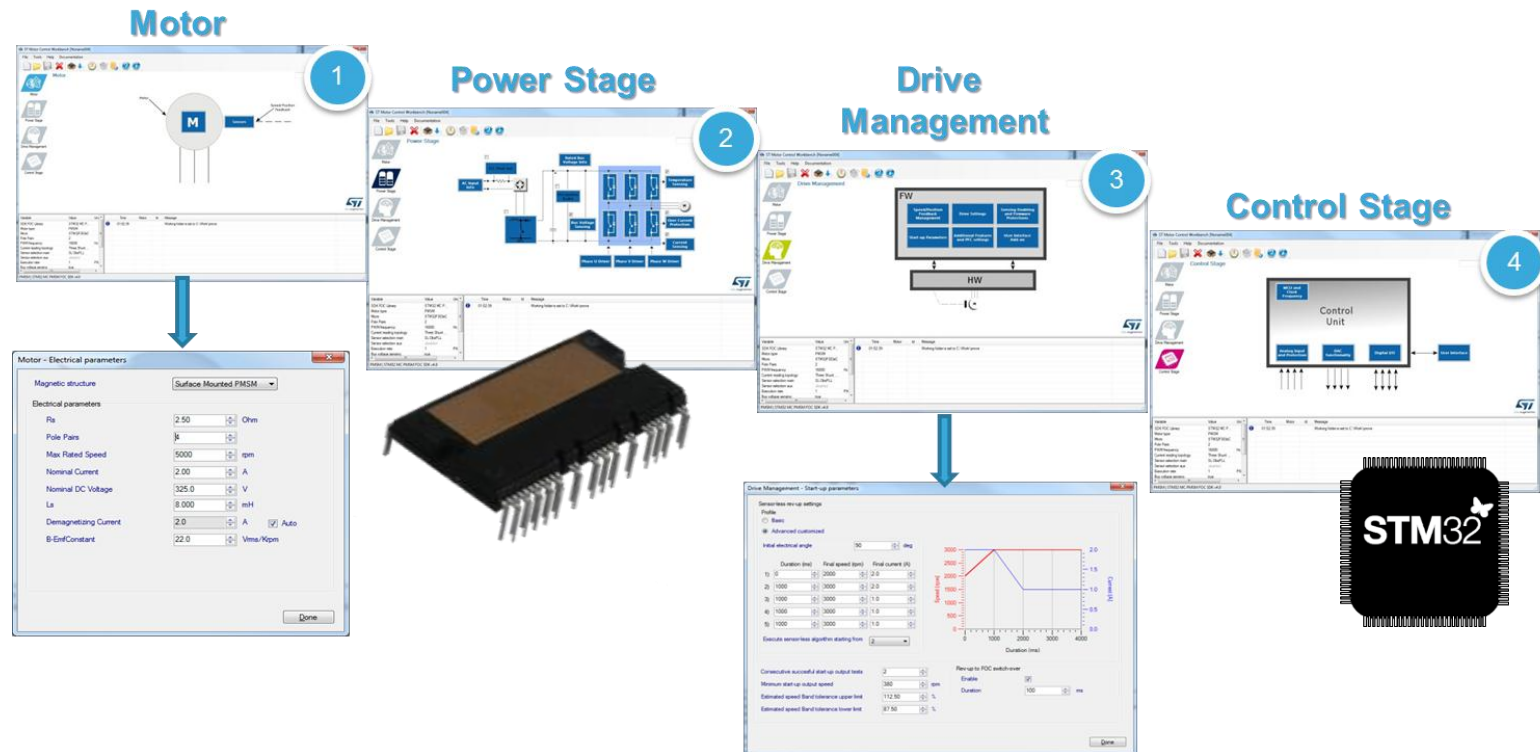


ST PMSM FOC library

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Features

- Wide range of ST products supported (STM32, SLLIMM IPM, L639x, IGBT/Power Mosfet) using PC tool configurator: ST MC Workbench



New project creation (1/2)

Starting from the Hardware

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ST Motor Control Workbench

File Tools Help Documentation

New Project Load Project Help About

New Project

Application type 1
Generic

System 2
☒ Single Motor ☐ Dual Motors

Select Power and Control Boards 3

☐ Inverter ☐ MC Kit ☒ Power & Control

Control
STM320518-EVAL

Power
STEVAl-IHM028V2 MP

Motor 4
M1 Generic Low voltage <= 50V

Motor Control Library
4.1.0

MCU Supported
STM32F4xx
STM32F3xx
STM32F2xx
STM32F103x
STM32F100x
STM32F0x

☐ Use old Library

OK Cancel

Choose:

1. Applications

Application type

Generic
Generic
Pumps
Compressor
Air conditioning
Dish washer
Fans

2. single or dual motor

3. board approach

4. motor

New project creation (2/2)

Hardware for Motor Profiler

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New Project


Application type
Generic

System
☒ Single Motor ☐ Dual Motors

Select Power and Control Boards

☐ Inverter ☐ MC Kit ☒ Power & Control

Control
STM32303C-EVAL **MP**  Evaluation board for STM32F303xx microcontrollers - MOTOR PROFILER supported


Power
STEVAL-IHM028V2 **MP**  2 kW 3-phase motor control evaluation board featuring the STGIPS20C60 IGBT intelligent power module - MOTOR PROFILER supported

Motor
M1 Generic Low voltage <= 50V

Motor Control Library
4.1.0

MCU Supported
STM32F4xx
STM32F3xx
STM32F2xx
STM32F103x
STM32F100x
STM32F0x

☐ Use old Library

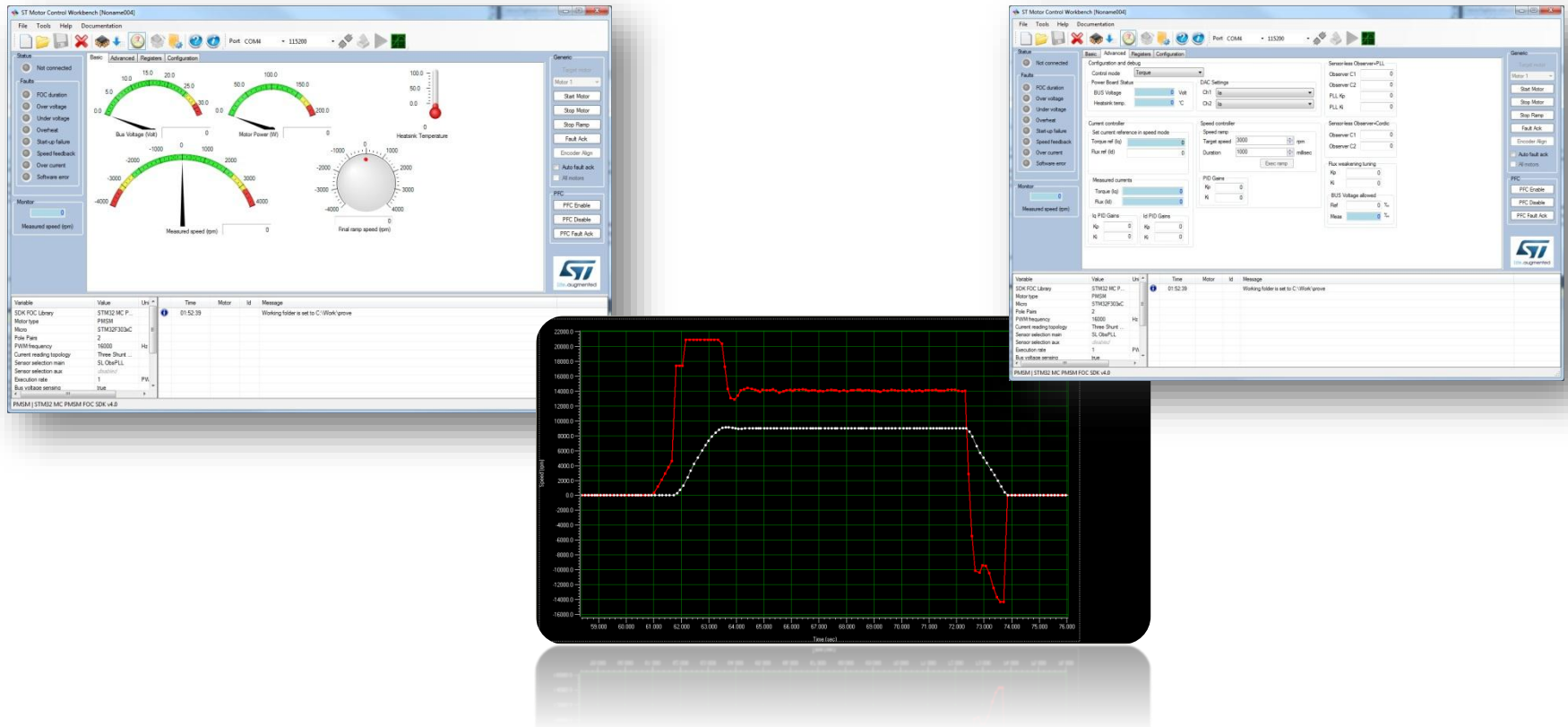
 The project supports the Motor Profiler feature

OK Cancel

Example
HW supporting Motor Profiler

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- Real time tuning capabilities

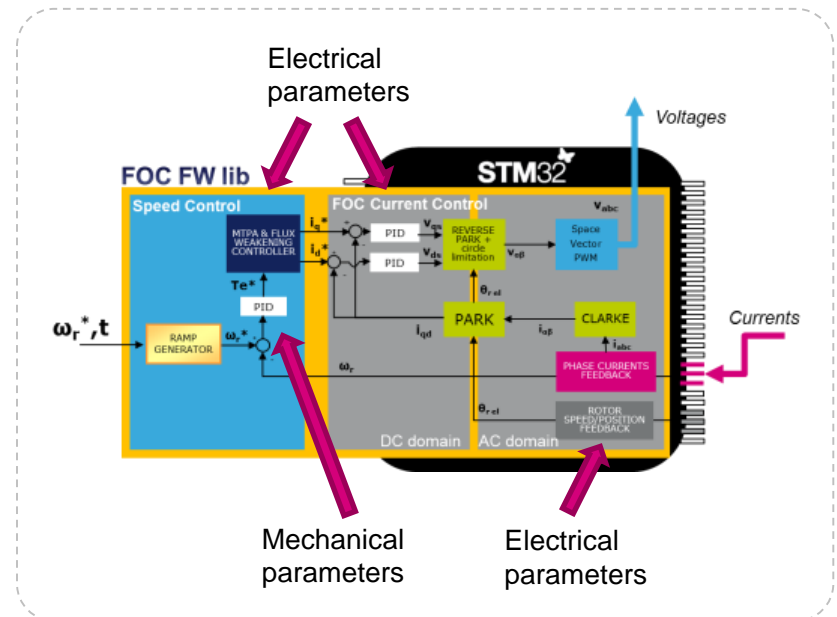


“Motor Profiler” why?

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Why motor electrical parameters are required by FOC?

- Electrical and mechanical parameters are required by the algorithms to define the model of the motor
- It is required to tune the current regulators
- It is required for Sensorless state observer algorithm
- It is required for additional features
- It is required to tune the speed regulators

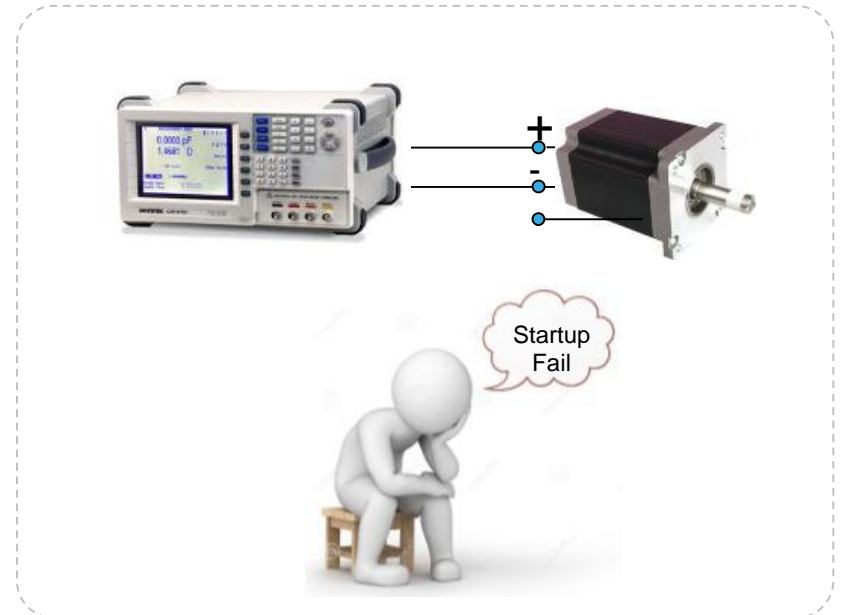


“Motor Profiler” why?

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Sometimes to start the evaluation of motor control solution can be hard

- To measure the motor parameters can requires specific skills and equipment
- Tuning of the regulators can be empirical
- Find the proper acceleration for the startup can't be easy
- Many trials and errors before to run the motor



What can't be measured

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These parameters shall be insert by the user

- Motor poles pairs
- Maximum Application speed
 - Nominal speed of the motor will be computed and used to validate the maximum application speed insert by the user
- Nominal current
- Motor anisotropy Lq/Ld ratio

Motor - Electrical parameters

Magnetic structure: Surface Mounted PMSM

Electrical parameters

Pole Pairs	2	
Max. Application Speed	4000	rpm
Nominal Current	2.10	A
Demagnetizing Current	2.1	A <input checked="" type="checkbox"/> Auto

☒ Motor Profiler

Done

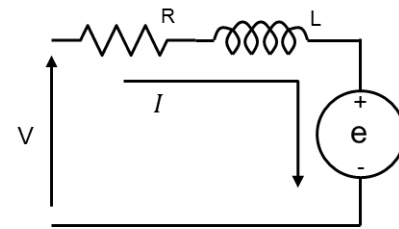
Measure electrical parameters

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Electrical motor parameters measurement

- No additional HW and equipment required
- To perform the measurements is required to apply a voltage and measure the current
- Usual PWM generation is used to supply the voltage
- To compute the real voltage applied it is also measured the DC bus voltage
- Usual motor phase current sensing is used to measure the current

Electrical motor parameters



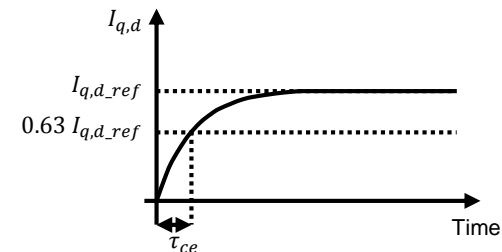
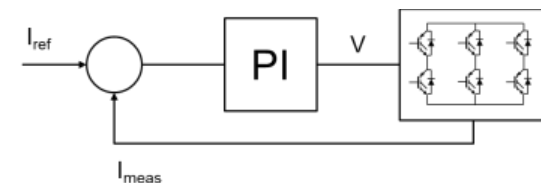
Current regulators tuning

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Automatic tuning of current regulators

- Once the R_s and L_d are known, is possible to tune-up the closed loop current regulators
- K_p and K_i of I_q and I_d current regulator, and related dividers, are computed according a single common parameter ω_{ce} (current regulation closed loop bandwidth)
- ω_{ce} defines the closed loop electrical constant time τ_{ce}

Current regulators tuning

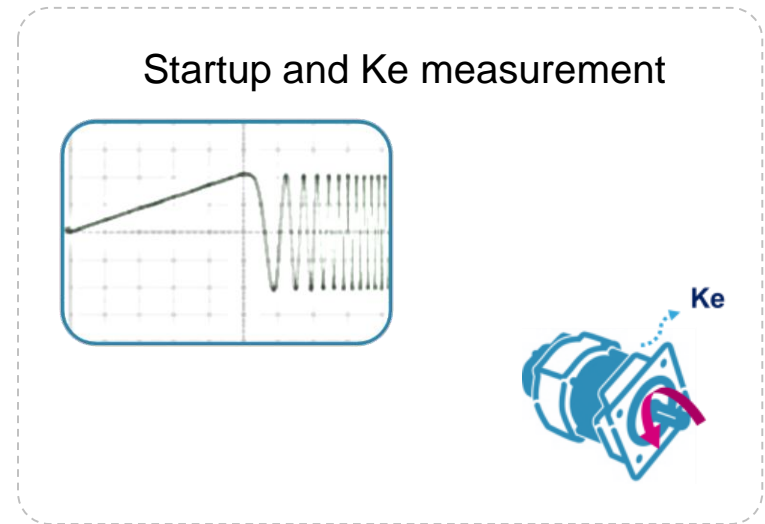


Measure electrical parameters

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Startup and Ke measurement

- To measure the K_e (motor BEMF voltage constant) is necessary that the motor is running
- With tuned current controllers it is possible to apply an open loop acceleration (Startup)
- On the fly measurement of K_e is performed using the motor model



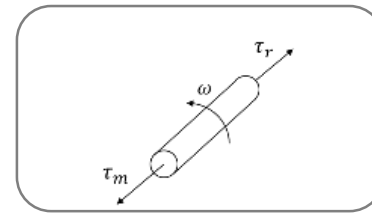
Mechanical motor parameters

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Mechanical motor parameters measurement

- First order (inertial plus frictional) mechanical system model is used to perform the measurement

Mechanical motor parameters



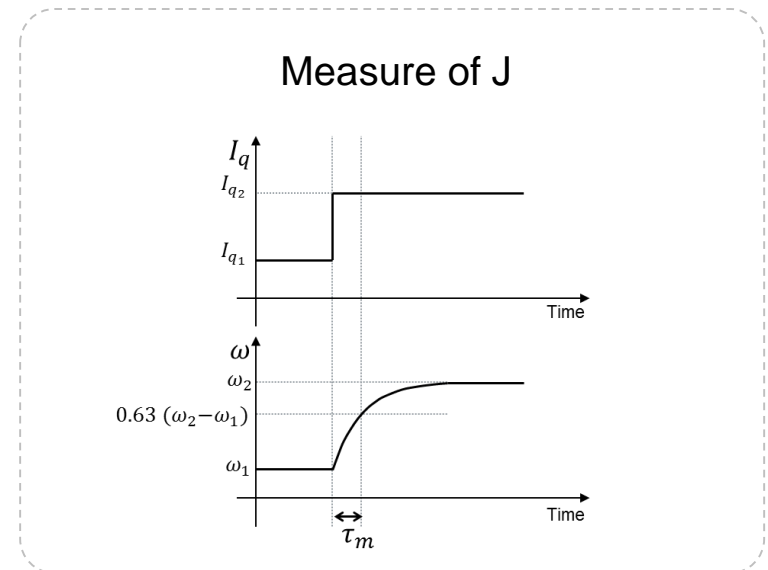
$$I_q - I_{q0} \rightarrow \boxed{\frac{1}{J^*s + F^*}} \rightarrow \omega$$

Mechanical motor parameters

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Measurement of J (moment of inertia)

- The measurement of the moment of inertia is done through the measurement of the mechanical constant time τ_m

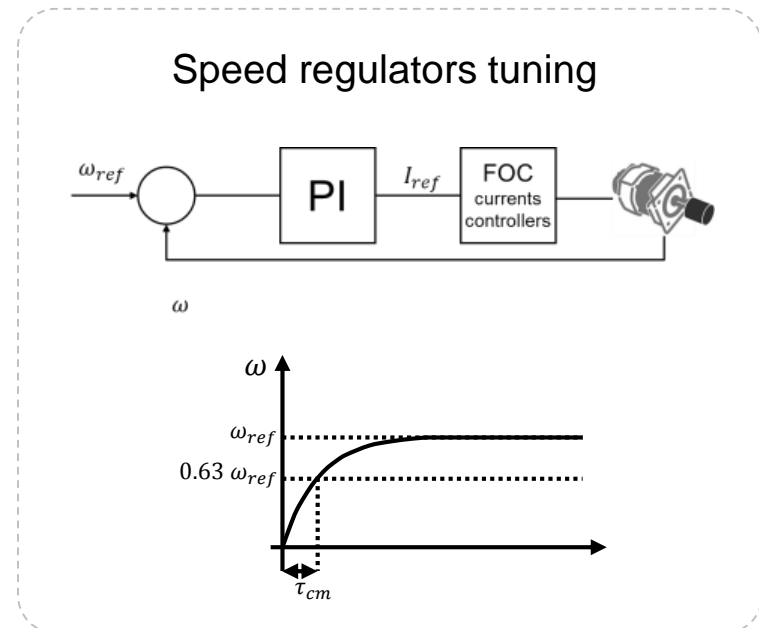


Speed regulators tuning

32

Automatic tuning of speed regulators

- Once the J and F are measured is possible to tune-up the closed loop speed regulators
- Kp and Ki of speed regulator, and related dividers, are computed according a single common parameter ω_{cm} (speed regulation closed loop bandwidth)
- ω_{cm} defines the closed loop mechanical constant time τ_{cm}



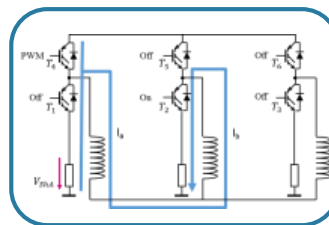
Motor Profiler + One Touch Tuning

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Plug and Spin your Motor in less than 60 seconds

Motor stopped

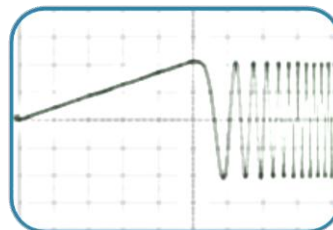
- Rs measurement
- Ls measurement
- Current regulators set-up



10 sec

Open loop

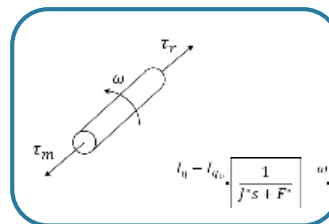
- Ke measurement
- Sensorless state observer set-up
- Switch over



5 sec

Closed loop

- Friction coefficient measurement
- Moment of inertia measurement
- Speed regulator set-up



45 sec



For further info about **STM32 PMSM FOC SDK**, please visit:

<http://www.st.com/stm32>

Part number: STSW-STM32100

Downloads:

STM32 PMSM FOC SDK:

<http://www.st.com/web/catalog/tools/FM147/CL1794/SC961/SS1743/PF257936>

UM1052:

STM32F PMSM single/dual FOC SDK

UM1053:

Advanced developer guide for STM32F PMSM single/dual FOC library

UM1080:

Quick start guide for STM32F PMSM single/dual FOC SDK V4.0

Motor Control FORUM



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