ST solutions for efficient and robust motion control

Version 1.0

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Agenda

Presentation

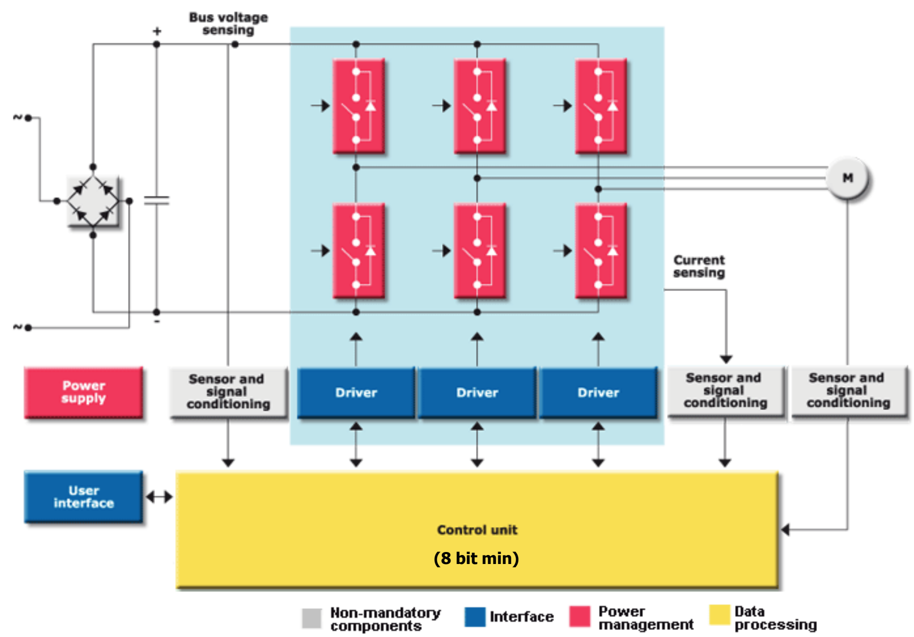
3 phase motors drives introduction

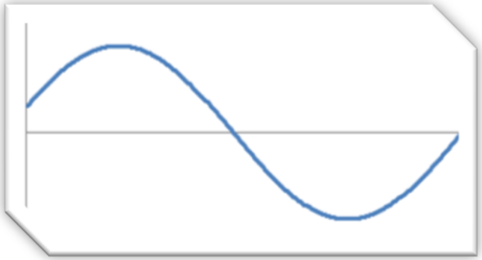
Field Oriented Control with STM32
- Application fit
- Performance
- Development Tools
- Evaluation Boards

ST VDE approved IEC65335 libraries

Scalar drives of 3Φ motors for AC IM

- Work often without any feedback devices (open-loop control)
- **Low cost and easy-to-implement** solution (8-bit MCU)
- On the other side
  - **Developed torque is not controlled directly** (depends on load)
  - **Transient response is not f**ast due to the predefined switching pattern of the inverter
- Adding a speed sensor (tachometer) and slightly increasing control scheme complexity, transients responses can be made faster and torque estimation possible

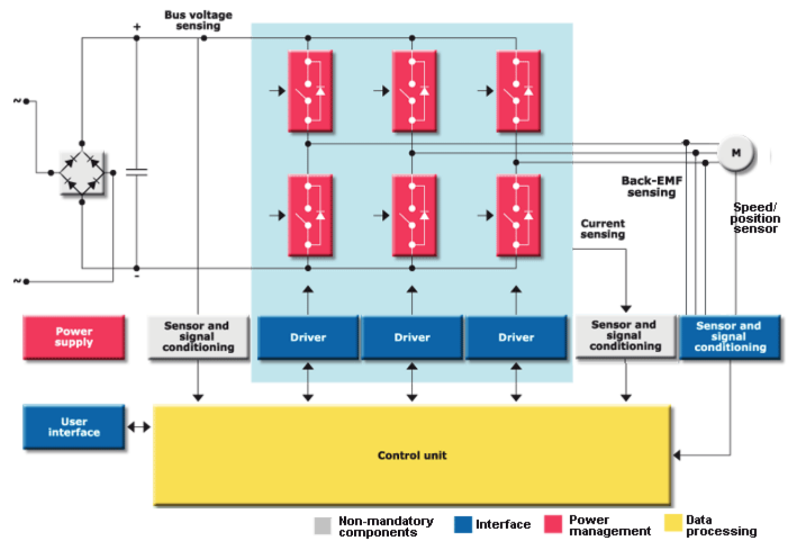


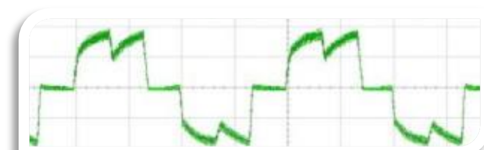


ACIM scalar drive motor phase current

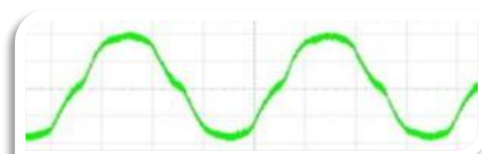
Scalar drives of 3Φ motors for PMSM

- Dislike AC IM, always **requires speed/position info**
  - Hall sensors
  - Drawn from electrical quantities (e.g. phase voltage) feedback (sensor-less)
- Two families of drives available
  - **Six-step**
    - Sensor-less solution is low cost (8 bit MCU): advanced ADC and timer peripherals are mandatory
    - Torque steadiness is not excellent → noisy compared to other methods
  - **Sinusoidal**
    - Sensor-ed can be handled by 8 bit MCUs → low cost MCU
    - Sensor-less solution for sinusoidal would require hard computation (not manageable by 8 bit MCUs) → scalar sensor-less wouldn't be low cost;
    - Torque steadiness is better compared to six step→ more quiet
  - In both cases developed **torque is not accurately controlled**





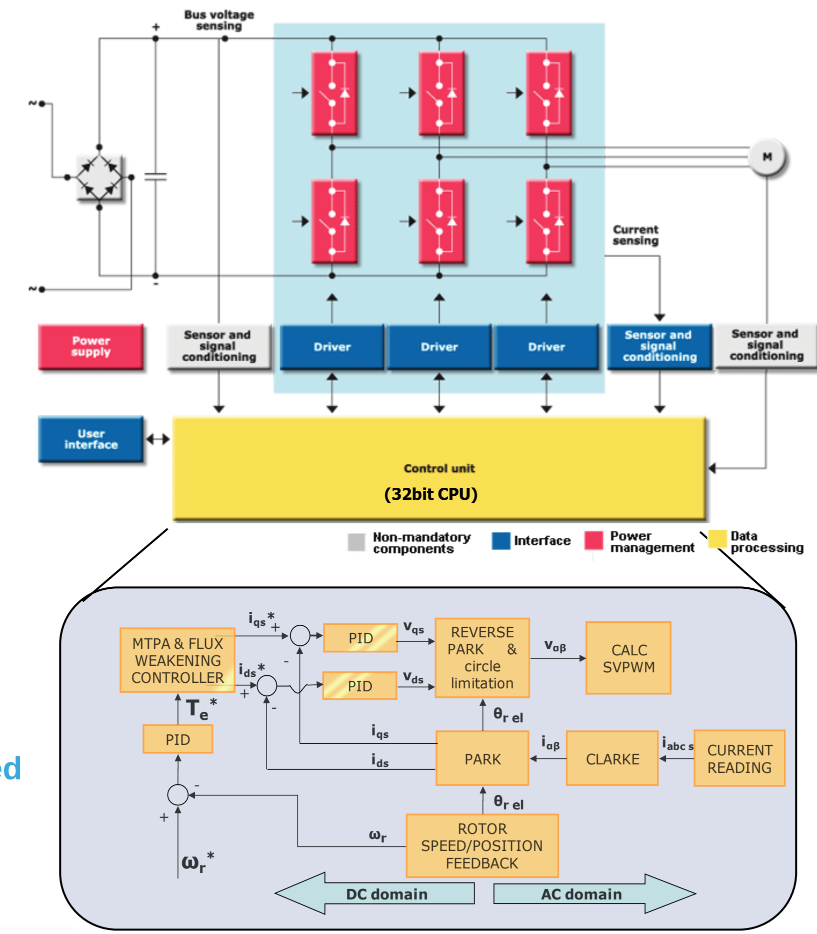
Six step drive - motor phase current

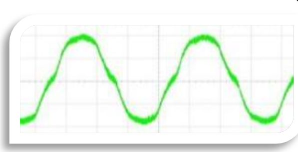


Sinusoidal drive - motor phase current

Field Oriented Control drive (FOC)

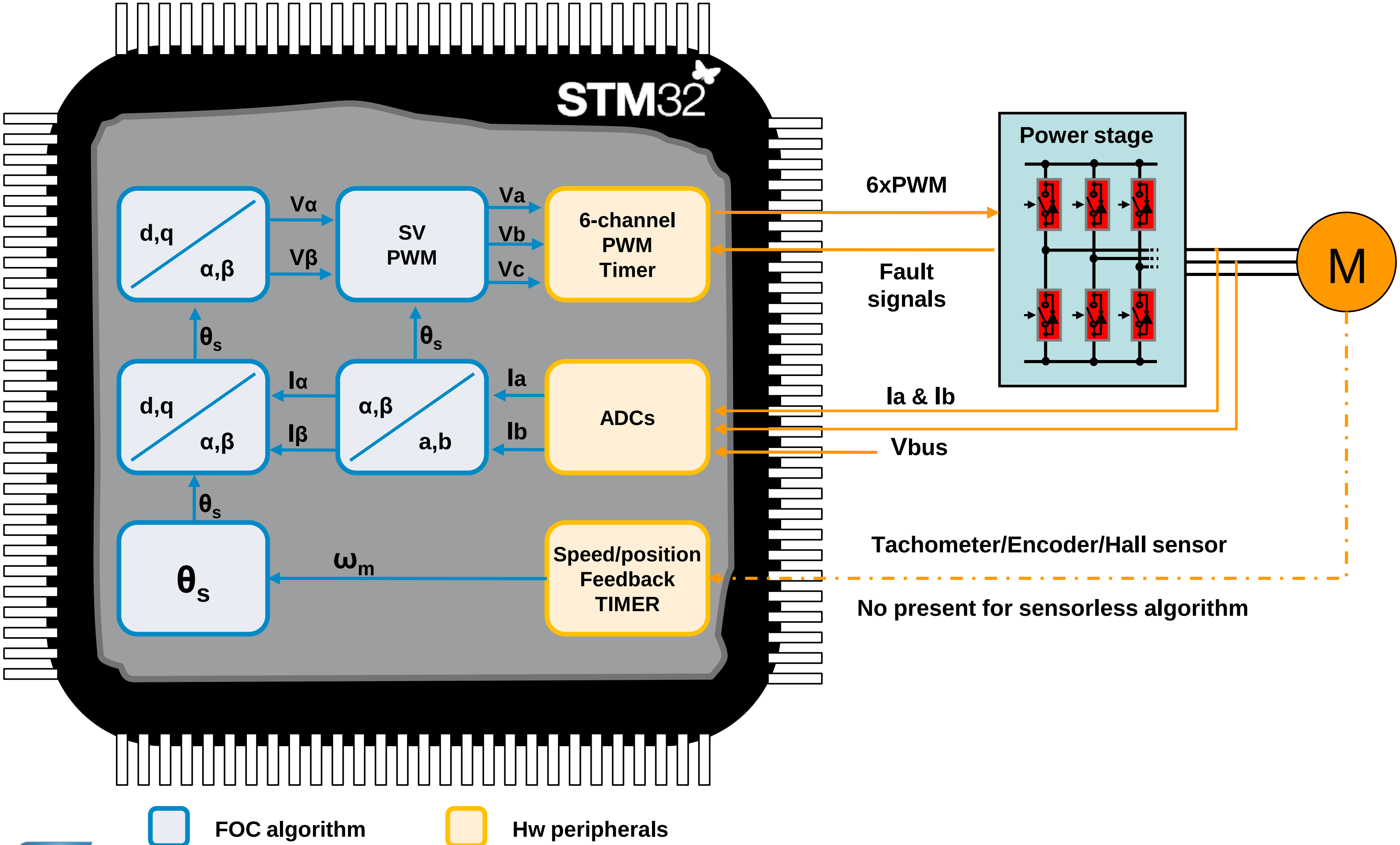
- FOC drive is also called *vector control* drive as the algorithm is based on a vector representation of the stator current, voltage and magnetic flux
- The method always requires rotor speed/position information
  - Measured through real sensors: Hall sensors, quadrature encoder, tachometer, …
  - Computed indirectly from electrical quantities feedback (sensor-less)
- FOC scheme and rotor position estimation algorithm (where needed) must be executed at a rate comparable with PWM frequency
  - Higher computational power required compared to scalar drives → higher cost vs scalar
  - 32bit MCU is optimal
- FOC drive ensures:
  - The torque steadiness typical of a sinusoidal control
  - Excellent performance in terms of **accurate static and dynamic speed** regulation and **rapid response** to sudden changes in load torque
  - **Provide torque control as an alternative to speed control**





Sinusoidal drive - motor phase current

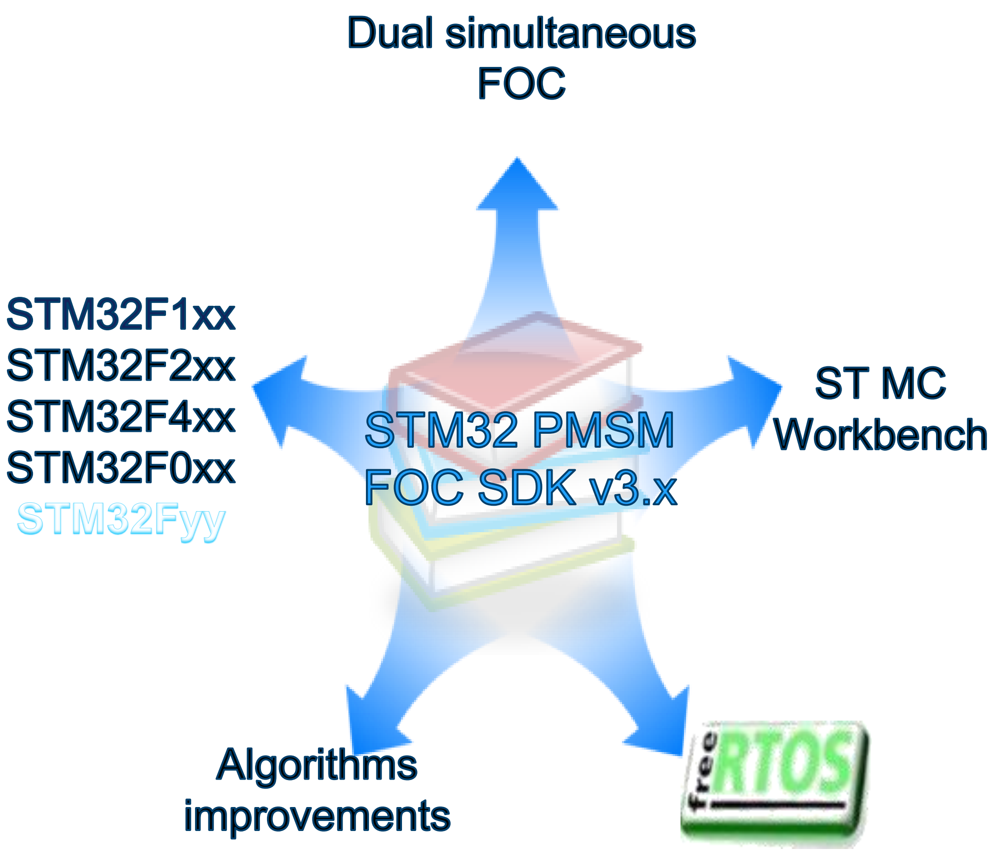
Field Oriented Control with STM32 (3ph brushless):
→ From block diagram to implementation



STM32 PMSM FOC SDK v3.x

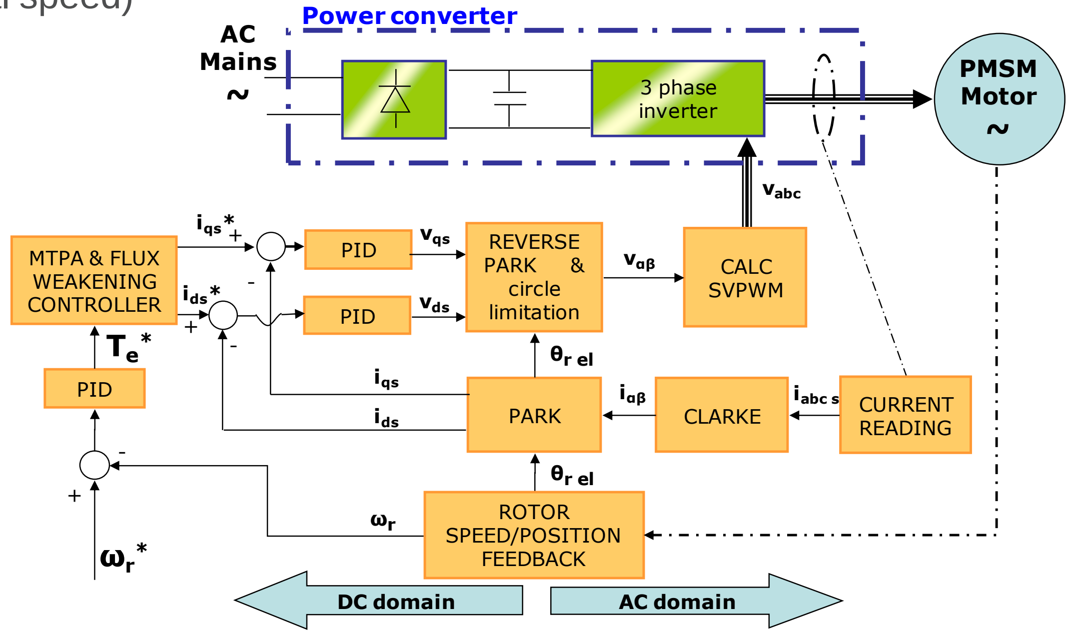
- STM32 PMSM FOC SDK v3.x:
  is a Motor Control Software Development Kit for 3-phase Permanent Magnet Synchronous Motors (PMSM) based on Field Oriented Control (FOC)

- Key features:
  - Single/Dual simultaneous vector control (FOC)
  - Any combination of current reading topologies and/or speed/position sensors is supported
  - Wide range of STM32 microcontrollers families are supported
  - Full customization and real time communication through PC software ST MC Workbench
  - Wide range of motor control algorithms implemented for specific applications
  - Application example based on FreeRTOS
  - Increase code safety through
    - MISRA C rules 2004 compliancy
    - Strict ANSI C compliancy
    - New object oriented FW architecture (better code encapsulation, abstraction and modularity)



FOC block diagram and possible configurations

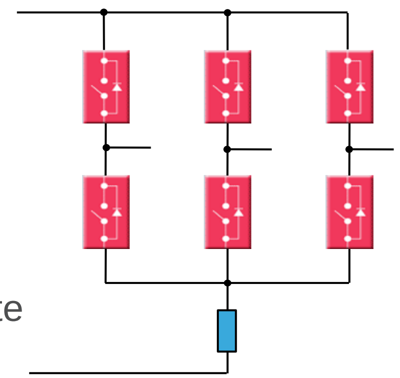
- Speed position feedback is mandatory
- Three speed/position sensors are supported by the STM32 FOC SDK library:
  - Quadrature encoder
    - Expensive sensor, usually only in robotics applications
  - Hall sensors
    - Cheaper sensors, usually for application requiring full torque at zero speed
  - Sensor-less
    - 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)

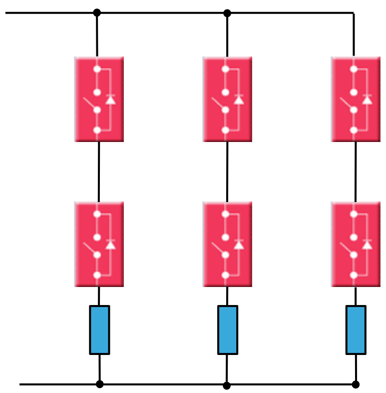


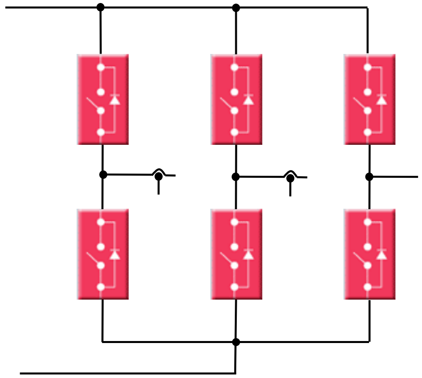
FOC block diagram and possible configurations

- Current feedback is mandatory

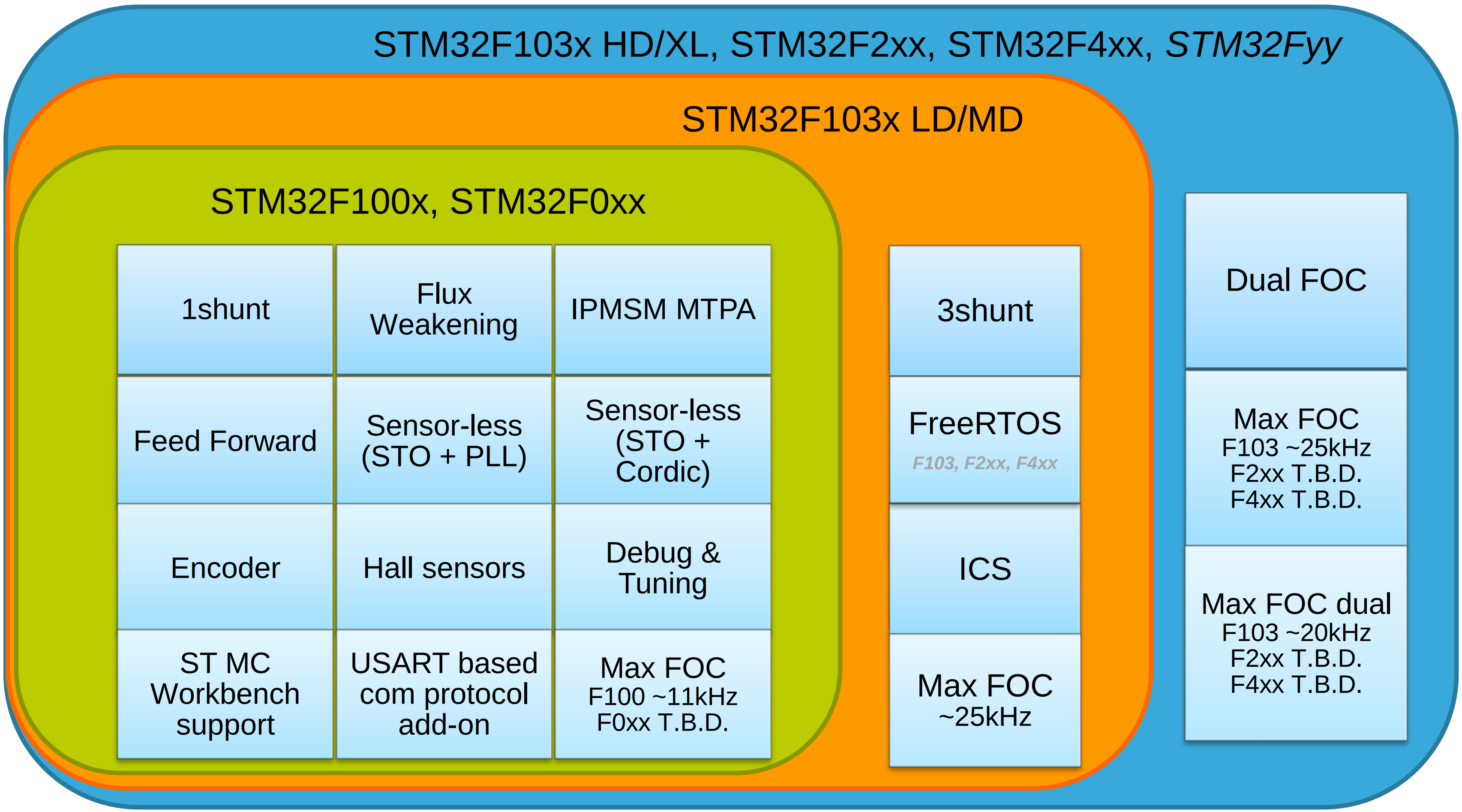
- Three current sensing HW topologies:
  - 1 shunt resistor placed on the DC link
    - ST patented algorithm
    - Only one op-amp /shunt resistor → lowest cost
    - Current reading algorithm may result in not accurate torque regulation
  - 3 shunt resistors placed in the three legs
    - Current reading 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 STM32 FOC SDK library**







Features set, MCU support



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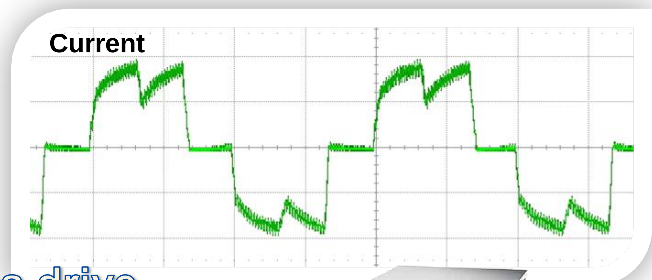
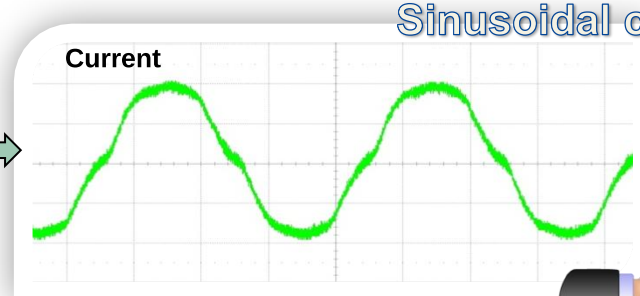
FOC, cost optimized implementation
STM32F100x Value Line

- **Target applications:**
  - All those applications where:
    - Requirements for dynamic performances are moderate
    - Quietness of sinusoidal current control (vs six steps drive) is valuable
    - Extended speed range is required
  - Particularly suitable for **pumps, fans and compressors**



Six-steps drive



Sinusoidal control

DW Spray & drain pumps

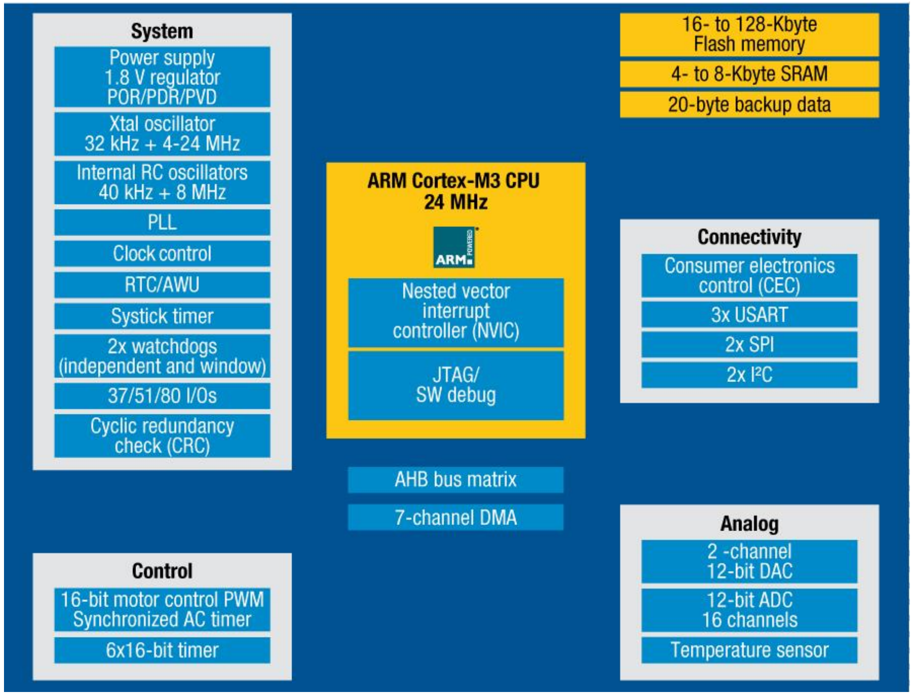
WM Drain pump

Fridge compressor

- More silent
- Lower torque ripple
- Extended speed range easier to be achieved

STM32F100 Value Line Block Diagram

- 32-bit ARM® Cortex™-M3 core
  - Up to 30 DMIPS at 24 MHz max
- 2.0 V to 3.6 V operation
- -40 to +105 °C
- Enhanced control
  - 16-bit 3-phase motor-control timer
  - 6x 16-bit PWM timers
- Advanced analog
  - Fast 12-bit 1.2 µs ADC
  - Dual-channel 12-bit DAC
- System integration
  - Internal 8 MHz RC oscillator
  - Built-in safe reset system



- STM32F100 FOC performance driving example - 3phase PMSM
  - 1shunt/sensorless @20kHz PWM,10kHZ FOC
  - Motor Control **code size is 15.82Kb**
  - Motor Control RAM usage is 2.77Kb
  - FOC Total execution time is 65.22us (ADC ISR + TIM1 Update ISR)
  - FOC introduced **CPU load is 65.2%**
  - **Total CPU load is ~70% (~60% at 8kHz FOC)**

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FOC single and dual motor drive - high performances
STM32F103x, STM32F2x, STM32F4x

- **Target applications:**
  - Wide range from home appliances to robotics, where:
  - Accurate and quick regulation of motor speed and/or torque is required (e.g. in torque load transient or target speed abrupt variations)
  - CPU load granted to motor control must be low due to other duties

Home appliances

Industrial motor drives

Power tools

Games

Escalators and elevators

Fitness, wellness and healthcare

And much much more…

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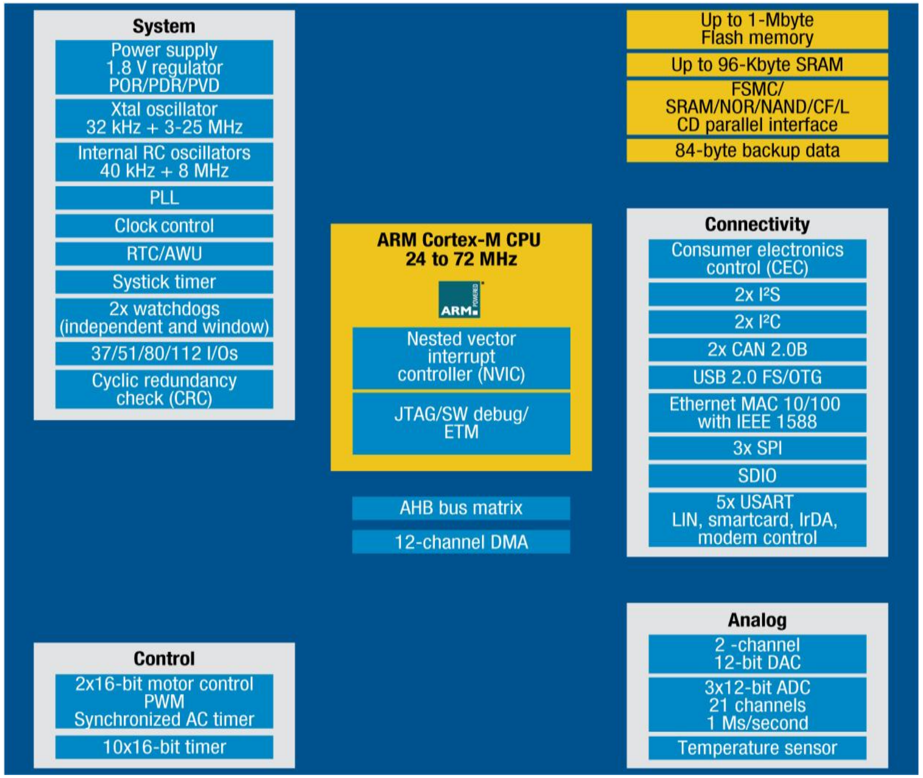
STM32F103 Performance Line Block Diagram

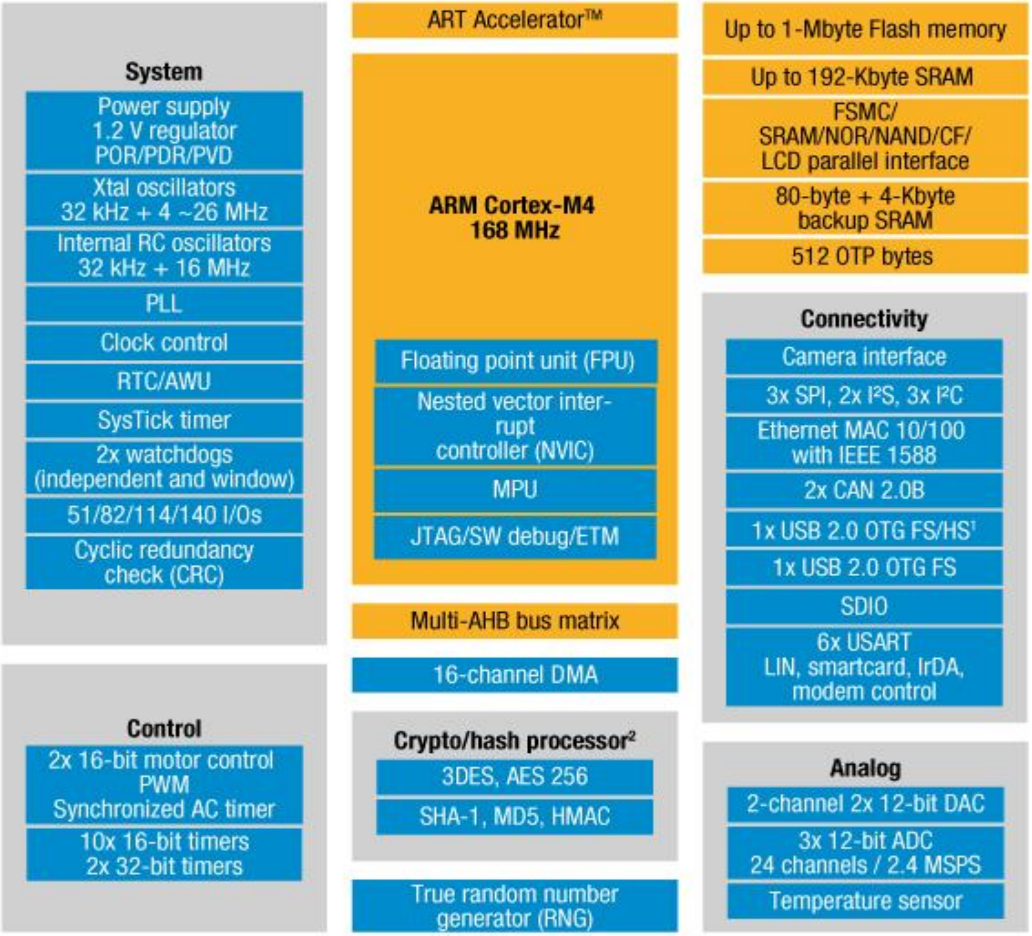
- 32-bit ARM® Cortex™-M3 core
  - Up to DMIPS at 72MHz
- 2V-3.6V Supply
- -40 to +105 °C
- From **16kB to 1MB flash memory**
- Enhanced control
  - **Up to 3x 16-bit Advanced timer**
  - Up to 4x 16-bit PWM timers
- Advanced analog
  - **Up to 3x fast 12-bit 1.2 µs ADC**
- System integration
  - Internal 8 MHz RC oscillator
  - Built-in safe reset system



- STM32F103 FOC performance driving example - 3phase PMSM
  - 1shunt/sensorless @20kHz PWM,16kHZ FOC
  - Motor Control **code size is 16.2Kb**
  - Motor Control RAM usage is 2.5Kb
  - FOC Total execution time is 26.1usec us (ADC ISR + TIM1 Update ISR)
  - FOC introduced **CPU load is 26%**
  - **Total CPU load is ~30%**

STM32F4 block diagram

- 168 MHz Cortex-M4 CPU
  - Floating point unit (FPU)
  - ART Accelerator TM
  - Multi-level AHB bus matrix
- 1-Mbyte Flash, 192-Kbyte SRAM
- 1.7 to 3.6 V supply
- RTC: <1 µA typ, sub second accuracy
- 2x full duplex I²S
- 3x 12-bit ADC 0.41 µs/2.4 MSPS
- 168 MHz timers



Notes:
1. HS requires an external PHY connected to the ULPI interface
2. Crypto/hash processor on STM32F417 and STM32F415

STM32 FOC dual motor drive

Some performances figure examples

- STM32F103 HD, dual FOC
  - Motor 1, 3 shunt/sensorless @16kHz PWM/FOC
  - Motor 2, 3 shunt/sensorless @16kHz PWM, 16kHZ FOC.
  - Motor Control **code size is 22.3Kb** (below 1.5 times single motor case)
  - Motor Control RAM usage is 4.01Kb
  - FOCs introduced **CPU load** (including TIMx Update ISRs) **is 80%**
  - **Total CPU load ~85%**
- STM32F4xx HD, dual FOC
  - Motor 1, 3 shunt/sensorless @16kHz PWM/FOC
  - Motor 2, 3 shunt/sensorless @16kHz PWM, 16kHZ FOC.
  - Motor Control **code size is 22.3Kb** (below 1.5 times single motor case)
  - Motor Control RAM usage is 4.01Kb
  - FOCs introduced **CPU load** (including TIMx Update ISRs) **is 37%**
  - **Total CPU load ~42%**

STM32 – 6 product series

Common core peripherals and architecture:

- Communication peripherals: USART, SPI, I²C
- Multiple general-purpose timers
- Integrated reset and brown-out warning
- Multiple DMA
- 2x watchdogs Real-time clock
- Integrated regulator PLL and clock circuit
- External memory interface (FSMC)
- Dual 12-bit DAC
- Up to 3x 12-bit ADC (up to 0.41 µs)
- Main oscillator and 32 kHz oscillator
- Low-speed and high-speed internal RC oscillators
- -40 to +85 °C and up to 105 °C operating temperature range
- Low voltage 2.0 to 3.6 V or 1.65/1.7 to 3.6 V (depending on series) 5.0 V tolerant I/Os
- Temperature sensor

+

STM32 F4 series - High performance with DSP (STM32F405/415/407/417)

168 MHz Cortex-M4 with DSP and FPU	Up to 192-Kbyte SRAM	Up to 1-Mbyte Flash	2x USB 2.0 OTG FS/HS	3-phase MC timer	2x CAN 2.0B	SDIO 2x I²S audio Camera IF	Ethernet IEEE 1588	Crypto/hash processor and RNG

STM32 F2 series - High performance (STM32F205/215/207/217)

120 MHz Cortex-M3 CPU	Up to 128-Kbyte SRAM	Up to 1-Mbyte Flash	2x USB 2.0 OTG FS/HS	3-phase MC timer	2x CAN 2.0B	SDIO 2x I²S audio Camera IF	Ethernet IEEE 1588	Crypto/hash processor and RNG

STM32 F1 series - 5 product lines (STM32F100/101/102/103/105/107)

Up to 72 MHz Cortex-M3 CPU	Up to 96-Kbyte SRAM	Up to 1-Mbyte Flash	USB 2.0 FS device OTG	3-phase MC timer	Up to 2x CAN 2.0B	Up to 2x I²S audio	Ethernet IEEE 1588

STM32 F0 series - Entry-level (STM32F051)

48 MHz Cortex-M0 CPU	Up to 20-Kbyte SRAM	Up to 128-Kbyte Flash	3-phase MC timer	Comparator	CEC

STM32 L1 series - Ultra-low-power (STM32L151/152/162)

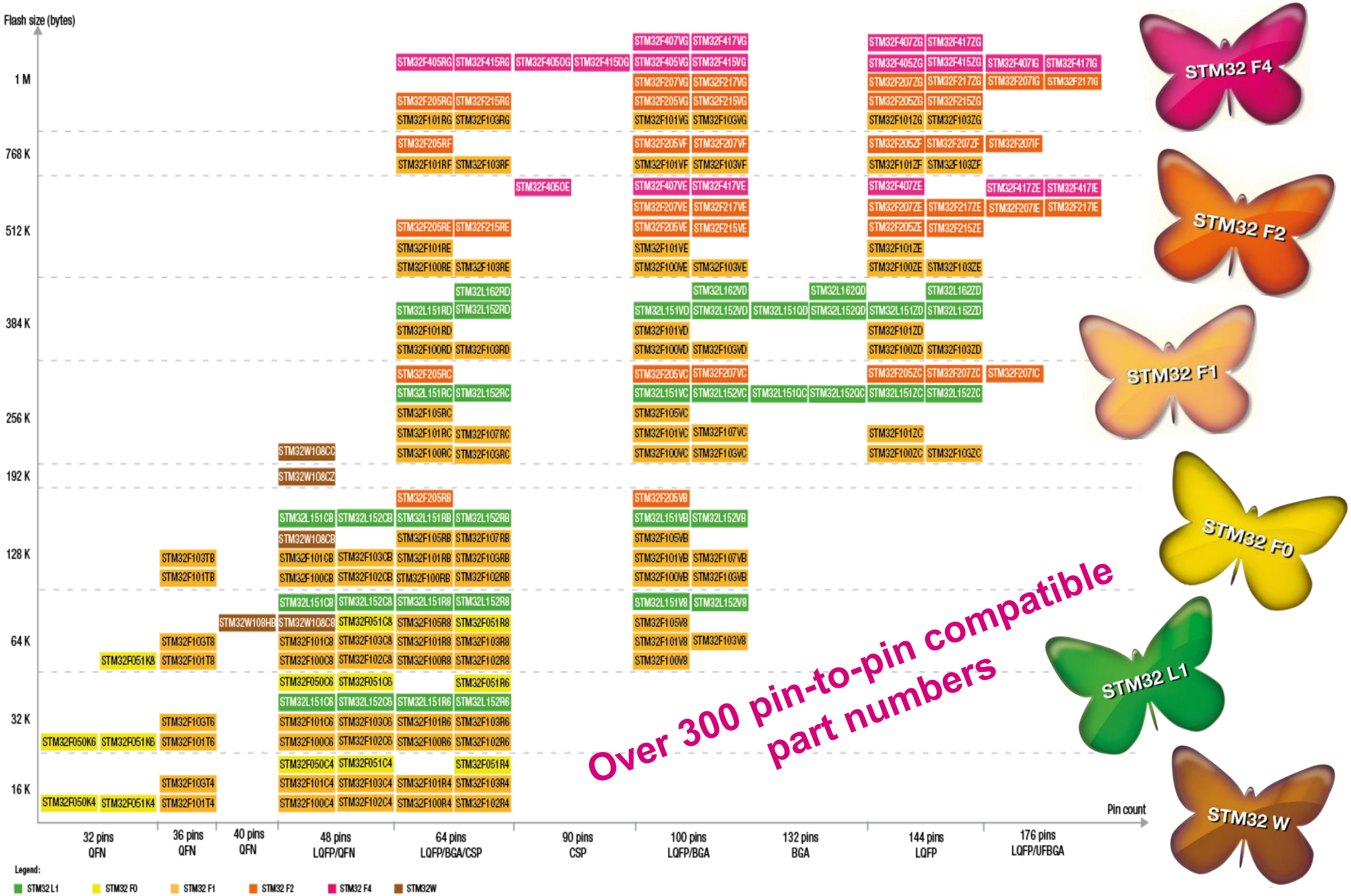
32 MHz Cortex-M3 CPU	Up to 48-Kbyte SRAM	Up to 384-Kbyte Flash	USB FS device	Data EEPROM up to 12 Kbytes	LCD 8x40 4x44	Comparator	BOR MSI VScal	AES 128-bit

STM32W series - Wireless (STM32W108)

24 MHz Cortex-M3 CPU	Up to 16-Kbyte SRAM	Up to 256-Kbyte Flash	2.4 GHz IEEE 802.15.4 Transceiver	Lower MAC Digital baseband	AES 128-bit

SILICA
An Avnet Company

STM32 – leading Cortex-M portfolio



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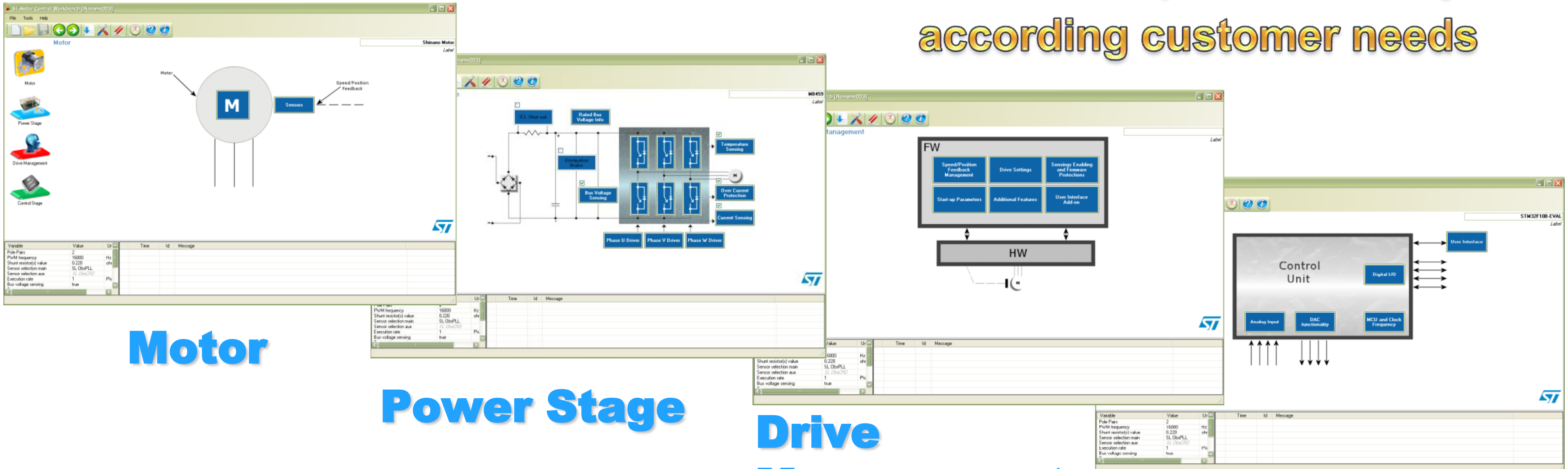
MC Workbench

Quick setup of the library according customer needs



Motor

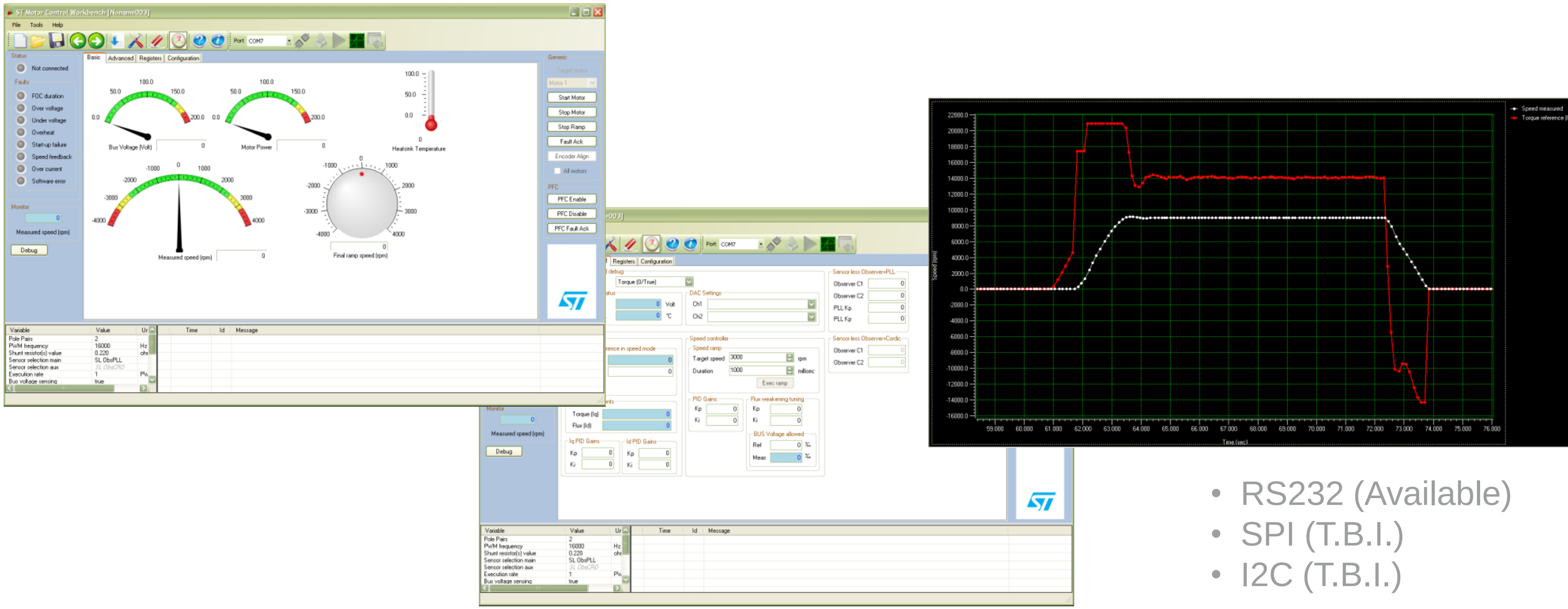
Power Stage

Drive Management

Control Stage

- ST Motor Control Workbench
  - PC software that reduces the design effort and time in the STM32 PMSM FOC firmware library configuration. The user through a graphical user interface (GUI) generate all parameter header files which configures the library according the application needs

Serial communication



- RS232 (Available)
- SPI (T.B.I.)
- I2C (T.B.I.)

- Real time communication
  - Using the ST MC workbench is possible to instantiate a “real time communication” to send start/stop commands or to set a speed ramp
  - Debug or fine tuning motor control variables (like speed PI parameters) can be assessed using the advanced tab
  - Plotting significant motor control variables (virtual oscilloscope) like target or measured motor speed

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STM32 FOC SDK sources and docs

For further info about STM32 PMSM FOC SDK v3.x, please visit:

http://www.st.com/stm32

Downloads:

STM32 PMSM FOC SDK v3.0:

http://www.st.com/internet/com/SOFTWARE_RESOURCES/SW_COMPONENT/FIRMWARE/stm32_pmsm_foc_motorcontrol_fwlib.zip

ST MC Workbenchv1.2.0:

http://www.st.com/internet/com/SOFTWARE_RESOURCES/TOOL/CONFIGURATION_UTILITY/motorcontrol_workbench.zip

TN0516: Overview of the STM32F103xx/STM32F100xx PMSM single/dual FOC SDK V3.0

UM1052**:** STM32F103xx/ STM32F100xx/STM32F2xx/F4xx PMSM single/dual FOC SDK v3.2

UM1053**:** Advanced developers guide for STM32F100x/103x/2x/40x/41x MCUs PMSM single/dual FOC SDK v3.2

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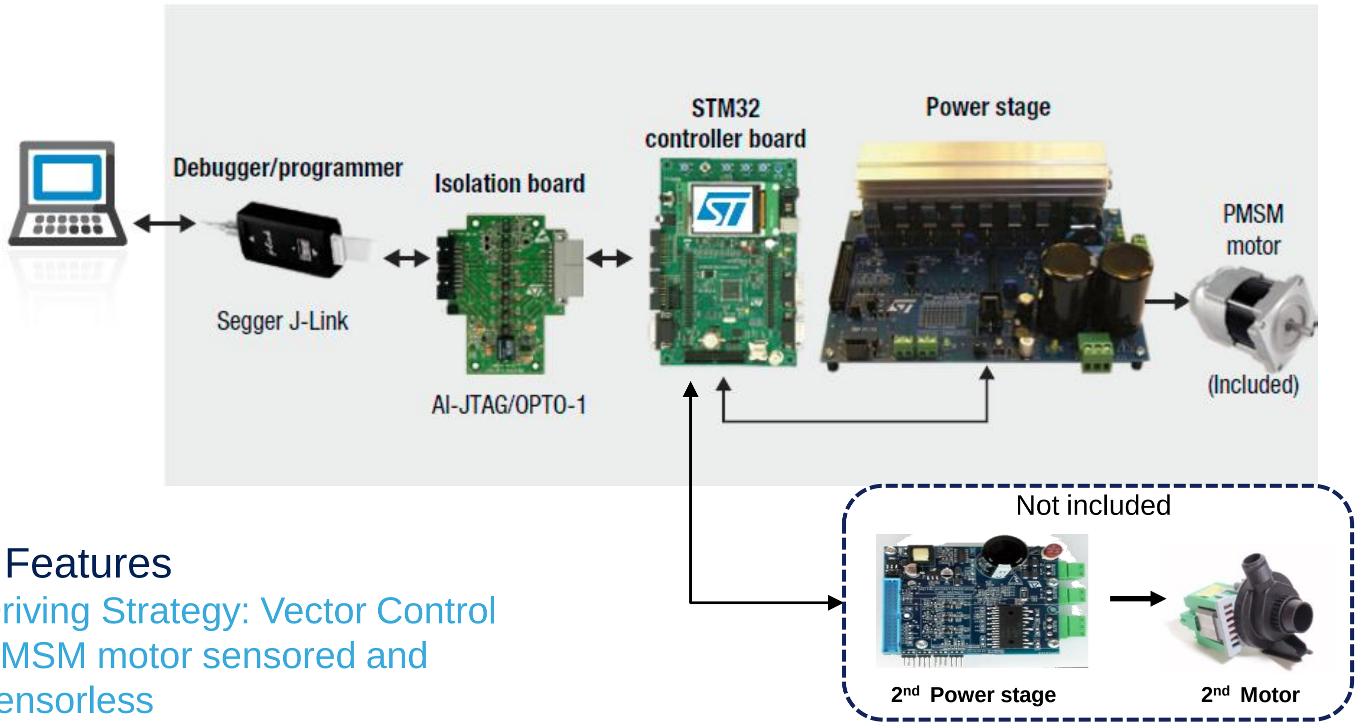
STM32Fxx MC kit



- Main Features
  - Driving Strategy: Vector Control
  - PMSM motor sensored and sensorless
  - Two (34-pin) dedicated motor control connectors
  - Encoder sensor input
  - Hall sensor input
  - Tachometer sensor input
  - Current sensing mode:
    - 3 shunt resistors
    - Single shunt

- Key Component
  - L6390D (Gate Drivers)
  - VIPer16LD (Power Supply down converter)
  - L7815ABV, L78M05CDT, LD1117S33TR (Voltage regulators)
  - STGP10NC60KD (IGBT)
  - TS391ILT, (Comparator)
  - M74HC14TTR (Logic)

Complementing MC starter kits
STM8/32 Evaluation boards

STM8 MC library v1.0

STM32 PMSM FOC SDK v3.2

Scalar Control

STM8/128-EVAL

FOC

STM32F100x

STM32100B-EVAL

STEVAL-IHM033V1

FOC | **Dual FOC**

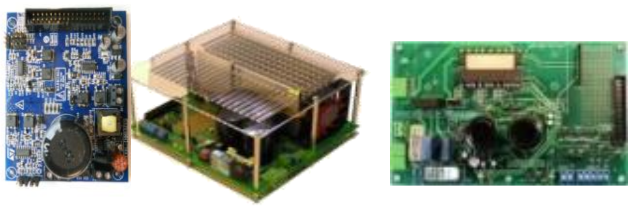
STM32F103, F2xx, F4xx

STM32-EVAL

STEVAL-IHM022V1

MC connector

Power Stages

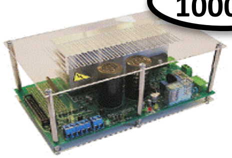


Please visit *http://www.st.com/evalboards* *or contact a* *local ST office*

Thanks configurable tools it is possible to have diverse motor drive solutions

Complementing MC starter kits

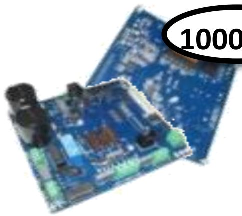
STM8/32 Evaluation boards



1000W

STEVAL-IHM025V1

- 1 x IGBT SLLIMM™ **STGIPL14K60**
- 1 converter based on **Viper16**
- 1 x IGBT **STGP10NC60KD**



1000W

STEVAL-IHM027V1

- 1 x IGBT SLLIMM™ **STGIPS10K60A**
- 1 converter based on **Viper16**
- 1 x IGBT **STGP10NC60KD**

2000W

STEVAL-IHM028V1

- 1 x IGBT SLLIMM™ **STGIPS20K60**
- 1 x PWM SMPS **VIPer26LD**
- 1 x IGBT **STGW35NB60SD**

100W

Coming soon

STEVAL-IHM035V1

- 1 x IGBT SLLIMM™ **STGIPN3H60**
- 1 x PWM SMPS **VIPer16L**

SLLIMM™ (ST IPMs) based

1KW

STEVAL-IHM023V2

- 3 x PWM smart driver **L6390**
- 1 converter based on **Viper16**
- 7 x IGBT power switch **STGP10NC60KD**

STEVAL-IHM021V2

- 3 x PWM smart driver **L6390**
- 1 converter based on **Viper12**
- 6 x MOSFET power switch **STD5N52U**

150W

STEVAL-IHM032V1

- 3 x PWM smart driver: **2xL6392D** and **1x L6391D**
- 1 converter based on **Viper12**
- 6 x IGBT power switch: **STGD3HF60HD**

Gate drivers & Power Transistors based

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Complementing MC starter kits
Low Voltage Power Stages

120W

STEVAL-IHM031V1

Power stage up to 12/24V

- 3 x dual PowerMOSFETs **STS8dnh3l**
- 2 x PWM smart driver **L6387E**
- 1x step down converter **L4976D**

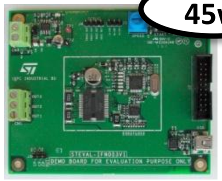
2000W

STEVAL-IEM003V1

Power stage up to 48V

- 3 x PWM smart driver **L6388**
- 6x LV Power MOSFET **STV250N55F3**
- 1x step down converter **L4978D**

Complete 3ph motor drive solutions

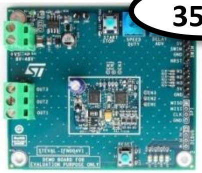


45w

STEVAL-IFN003V1

PMSM FOC Motor Drive

- 1 x 32bit Micro **STM32F103C**
- 1 x Motor Drive Ic **L6230PD**



35W

STEVAL-IFN004V1

BLDC Six-Steps Motor Drive

- 1 x 8bit-Micro **STM8S**
- 1 x Motor Drive Ic **L6230Q**

Low voltage drives

100w

STEVAL-IHM036V1

PMSM FOC Motor Drive

- 1 x 32bit Micro **STM32F100C6**
- 1 x IGBT SLLIMM™ **STGIPN3H60**
- 1 converter based on **Viper16**

1300W

Coming soon

STEVAL-IHM034V1

Dual motor drive + digital PFC

- 1 x 32bit Micro **STM32F103C8T6**
- 1 x IGBT SLLIMM™ **STGIPS20K60**
- 1 converter based on **Viper16L**

40W

Coming soon

STEVAL-IHM038V1

FAN Drive + PFC + IrDA

- 1 x 32bit Micro **STM32F100C6**
- 1 x IGBT SLLIMM™ **STGIPN3H60**
- 1 PFC controller **L6562A**

High voltage drives

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IEC standard - Introduction

- IEC – International Electro-technical Commission
  - WW authority, provides standardization of electric & electronic devices

- IEC60335-1 – safety of household electronics appliances
  - Guarantee the security of the user for domestic appliances
    (and public places like shops, offices, not industry applications)
  - The appliance must remain safe in case of any component failure
    - Safety relies on electronics component?
      >> It must stay safe after two consecutive failures!
    - Safety relies on software?
      >> Class B or Class C required!
  - Definition of procedures, requirements and parts of MCU to be tested

- Certification Bodies
  - WW recognized test houses for software safety inspection (VDE, UL)

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ST Class B software library focus

- IEC60335 - Annex Q defines three safety classes for software
  - Class A: Safety does not rely on SW
  - **Class B: SW prevents unsafe operation**
  - Class C: SW is intended to prevent special hazards (dual MCUs)

- IEC60335 - Annex T – MCU compliance aspects related to
  - **Micro specific HW**
    (fixed by design - dual robust watchdog, dual internal RC oscillators, high impedance I/Os at reset, Flash ECC, SRAM parity)
  - **Micro specific SW**
    (self diagnostic of the core, memories, clocks, execution)
  - **Application specific HW & SW**
    (analog I/O, digital I/O, interrupts, communication, spec. peripherals)

- ST code & end user certification
  - ST pre-certified software is integrated into user code
  - End-application is certified by any certification authority

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Currently published FW packages

Packages certified by VDE at May 2010

- STM8 family
  - STM8S optimized package (Rev 1.0.2)*
  - STM8L10x optimized package (Rev 1.0.2)
  - STM8L15x optimized package (Rev 1.0.2)

  *) covering all members of STM8S family, *package was updated (certification planned in Q3/2012)*

- STM32 family
  - STM32 package (Rev 2.0.0)*

  *) *based on standard peripheral FW library Rev 3.3.0, no support of connectivity and XL devices (certification is planned in Q3/2012 to be based on the FW library Rev 3.5.0 and covering connectivity & XL devices + all new incoming devices)*

  *) *STM32 package is available upon request thru local ST sales offices*

- Available documentation
  - AN3181 for STM8
  - AN3307 for STM32

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Agenda

Presentation

Stepper Motor Control

- Performance
- Evaluation Boards

STm

new stepper motor control

L6472	Dspin current mode
L6474	Easyspin
L6470	Dspin voltage mode

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New Spin...

product	Peculiar features	Operating range	Integrated mosfet	Common features
L6470	**Up to 128 microsteps** **Voltage mode operation** Sensorless Stall Detection	8V – 45V	**3Arms** (7A peak) $R_{DS,ON}$ = **0.28 Ω** Integrated Current Sensing (no ext.shut)	• **Programmable speed profile (*)** • **Programmable positioning (*)** • 8bit 5Mhz **SPI interface** (Daisy Chain compatible) • Integrated 16MHz oscillator • **Integrated 5bit ADC** • **Integrated 3V voltage regulator** • Over Current, Over Temperature and Under Voltage protections • PowerSO (ES) and HTSSOP
L6472	**Up to 16 microsteps** **Current mode** **Advanced** phase current control Accurate internal current sensing			
L6474	**Up to 16 microsteps** **Current mode with adaptive decay**			
L6480	**Up to 128 microsteps** **Voltage mode operation** Sensorless Stall Detection Integrated 15V/7.5V voltage regulator Fully programmable gate driving Embedded miller clamp	7.5V – 85V	NO	

IN DEVELOPPMENT

(*) not available for L6474

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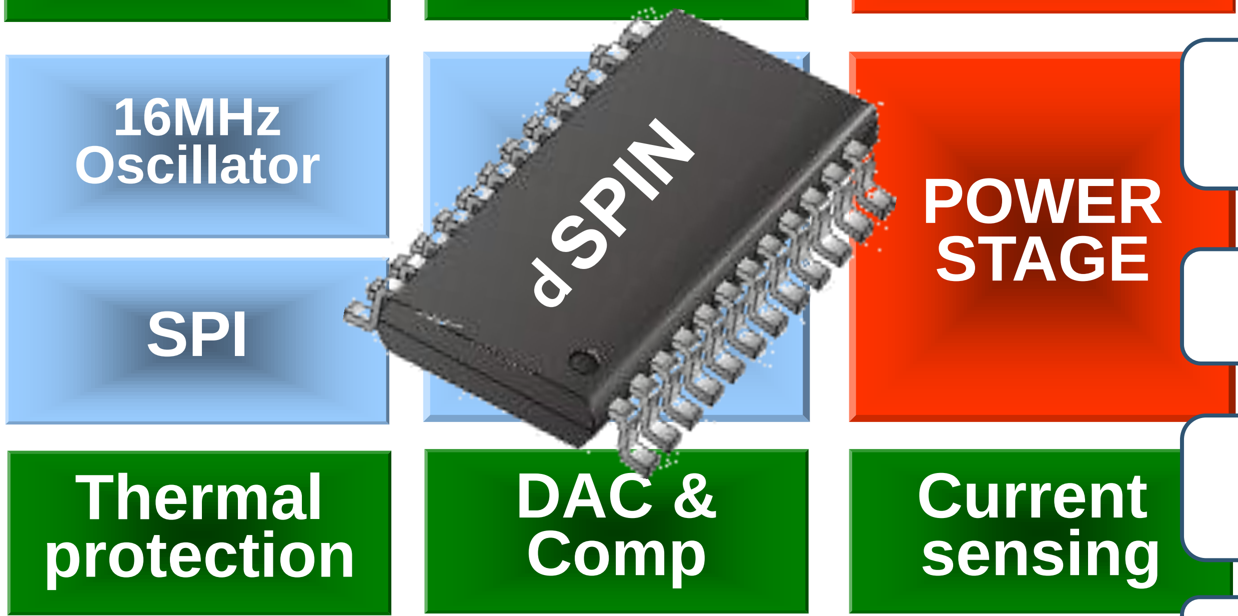
dSPIN

Digital. Accurate. Versatile.

L6472: the new **State of the Art** in **µstepping Drivers**



- Programmable speed profile
- Innovative Current mode driving
- Microstepping
- Comprehensive command set
- Protections

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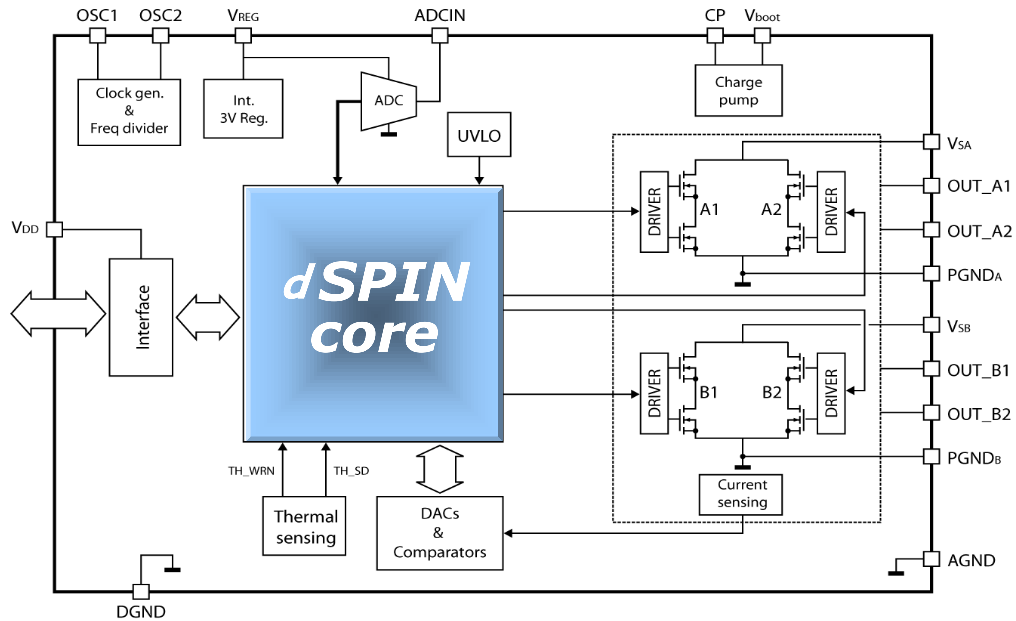
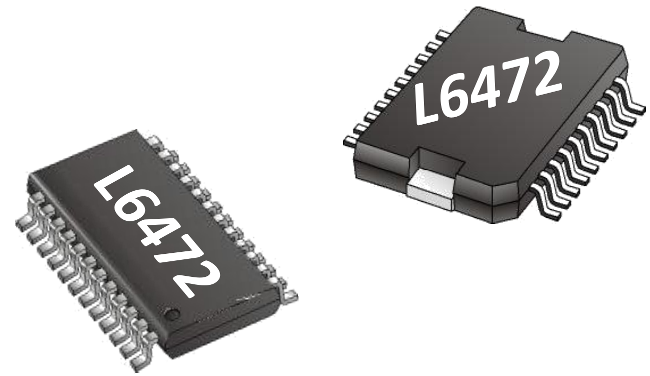
dSPIN

L6472 Monolithic Digital µstepping current mode Driver

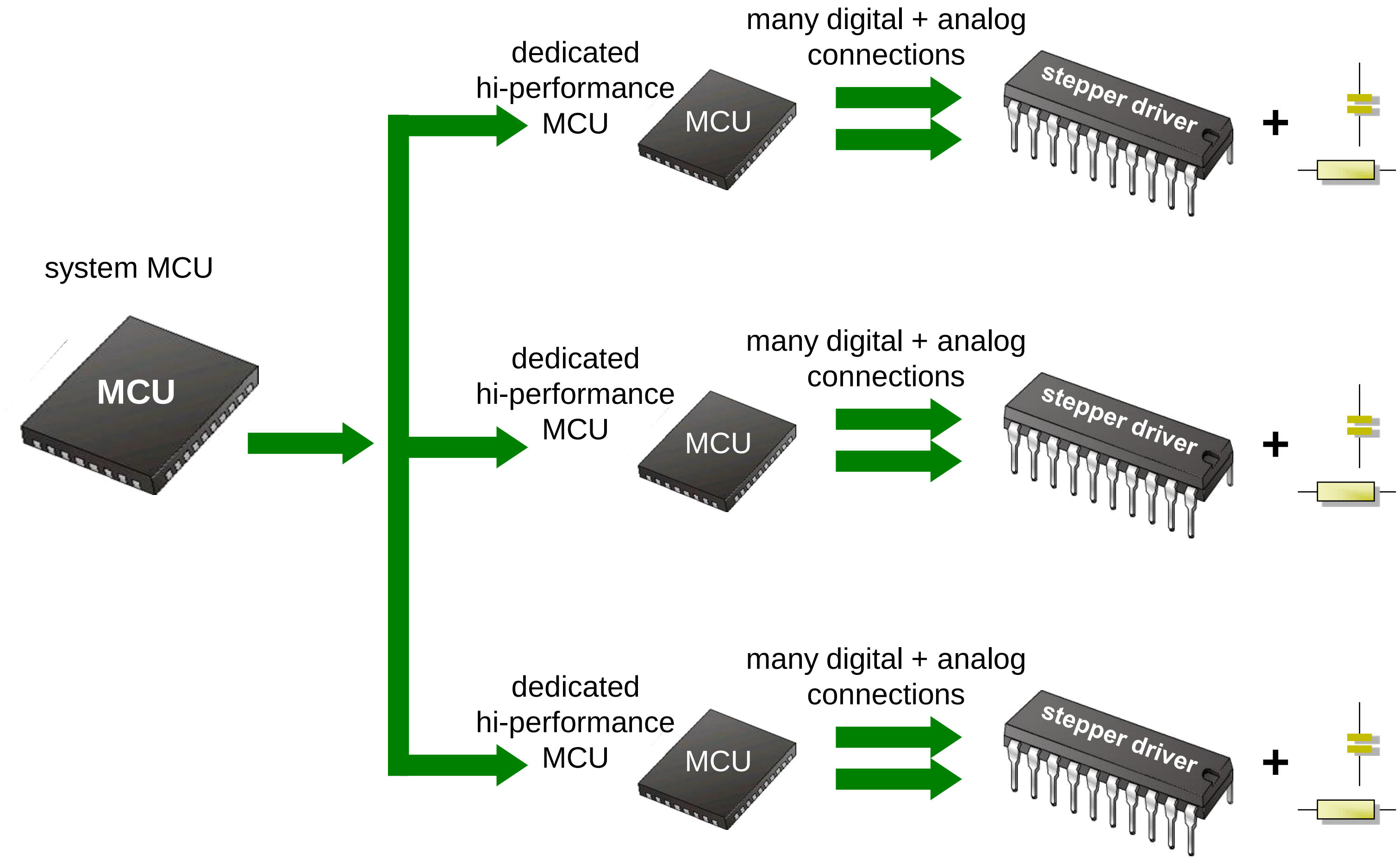
- Supply voltage 8V – 45V
- 3Arms (7A peak)
- $R_{DS,ON}$ = 0.28 Ω
- **Integrated current sensing** (no external shunt)
- Up to 16 microsteps
- **Innovative current control**
  - **Avr phase current control**
  - **Adaptative decay**
- **Programmable speed profile**
- **Programmable positioning**
- 8bit 5Mhz **SPI interface** (Daisy Chain compatible)
- Integrated 16MHz oscillator
- **Integrated 5bit ADC**
- **Integrated 3V voltage regulator**
- Over Current,
- Over Temperature
- Under Voltage protections
- PowerSO and HTSSOP





Intelligence integration

before **dSPIN**...



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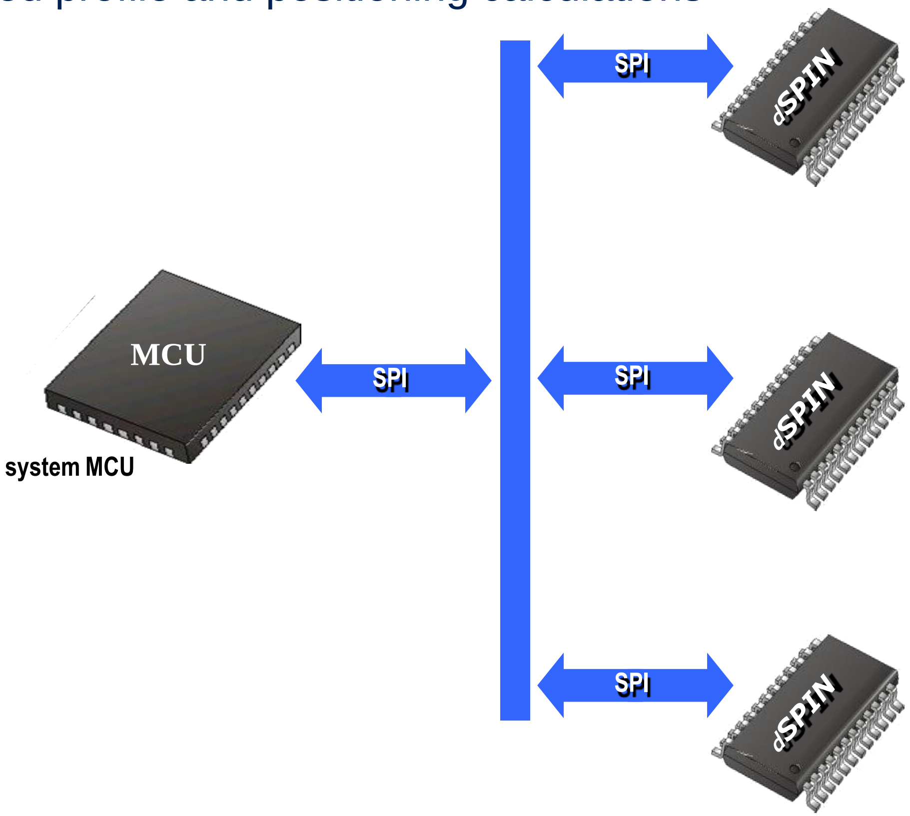
Intelligence integration

with **dSPIN**...

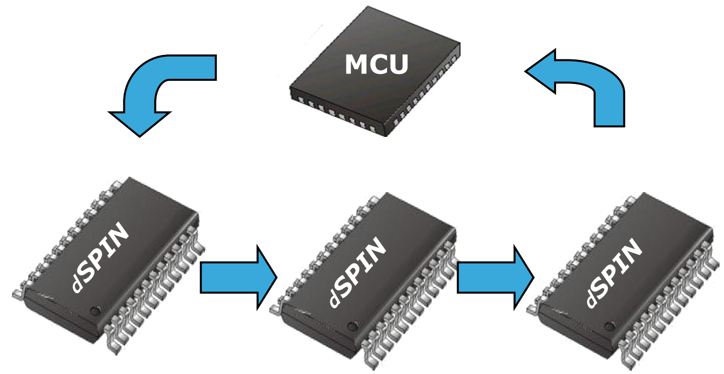
- System is heavily simplified
- No more dedicated MCU to perform speed profile and positioning calculations
- A lot less passive components

and… ***far better performances!***



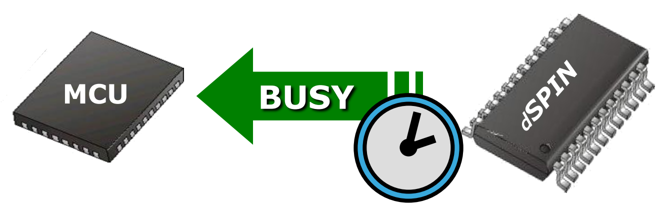
A complete digital interface to MCU

- The fast SPI interface with **daisy-chain** capability allows a single MCU to manage multiple devices



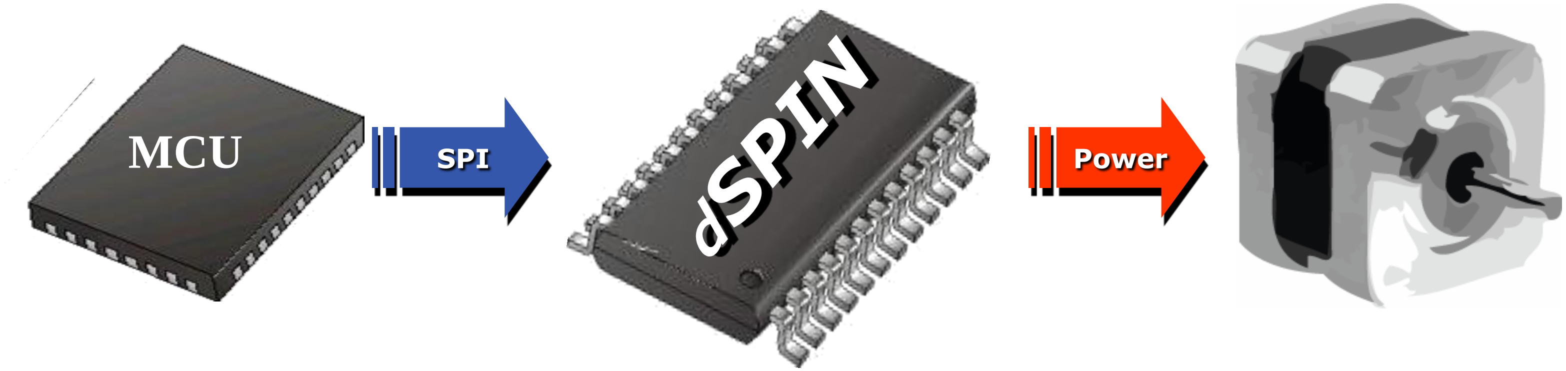
- Programmable alarm **FLAG** open drain output for interrupt-based FW
  In daisy-chain configuration, **FLAG** pins of different devices can be or-wired to save host controller GPIOs

- **BUSY** open drain output allows the MCU to known when the last command has been performed
  In daisy-chain configuration, **BUSY** pins of different devices can be or-wired to save host controller GPIOs



- BUSY Can be used to feedback the μstep clock to the μC (programmable # of µsteps

Positioning and speed profiles: Leave them to *dSPIN*!

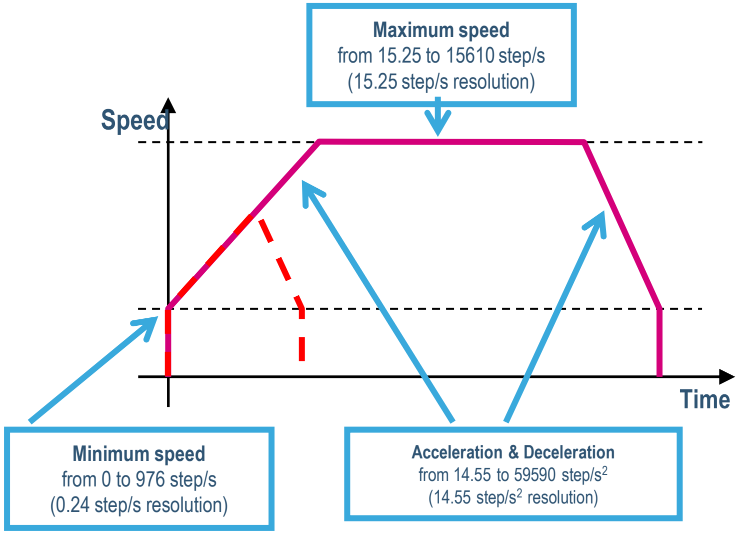


MCU sends **dSPIN** high level commands…

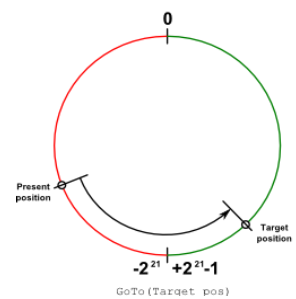
Free-run → run at constant speed
Positioning → reach the desired position

… and **dSPIN** does the tricky job!

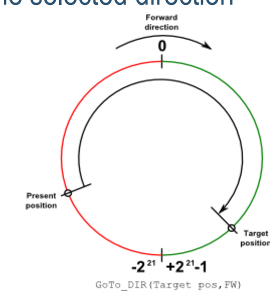
dSPIN
L6472 : Many Commands

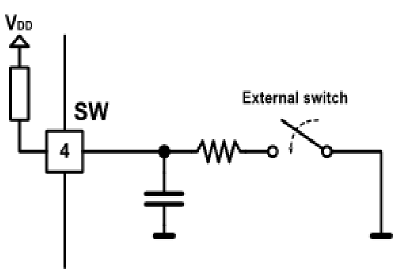


GoTo(Target) command: reach the target position using shortest path



GoTo_DIR(Target, DIR) command: reach the target position moving the motor in the selected direction



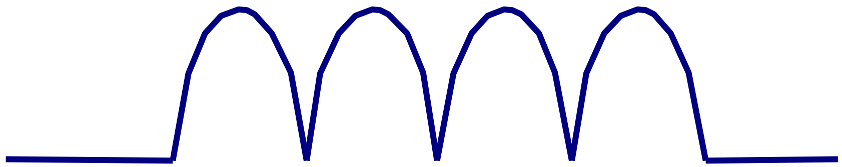


GoUntil command moves the motor with a selected constant speed and stops the motor when the switch is closed; at that time one of the following actions can be taken:

And : GoHome, GoMark, Run, Move, SoftStop, HardStop, SoftHiz, ReleaseSW…..

dSPIN
What is a decay?

Coil with inductance L



Inductors store the kinetic energy of moving electrons in the form of a magnetic field.

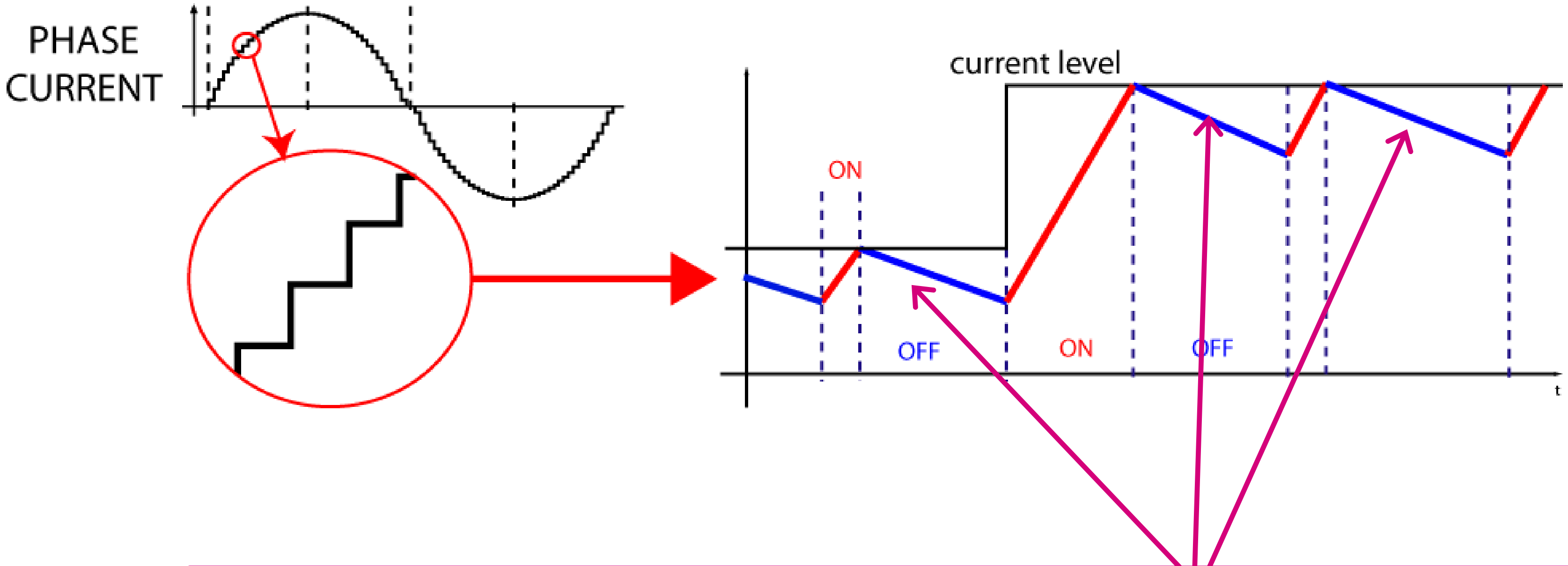
The total energy (or work) done in establishing the final current I2 in the inductor from the starting current I1 is :

$$W = L\int_{I1}^{I2} i\,di = \frac{1}{2} L\,(I2 - I1)^2$$ (assuming i linear)

A decay is a way to remove the energy W from the coil

Why a decay : for stable current

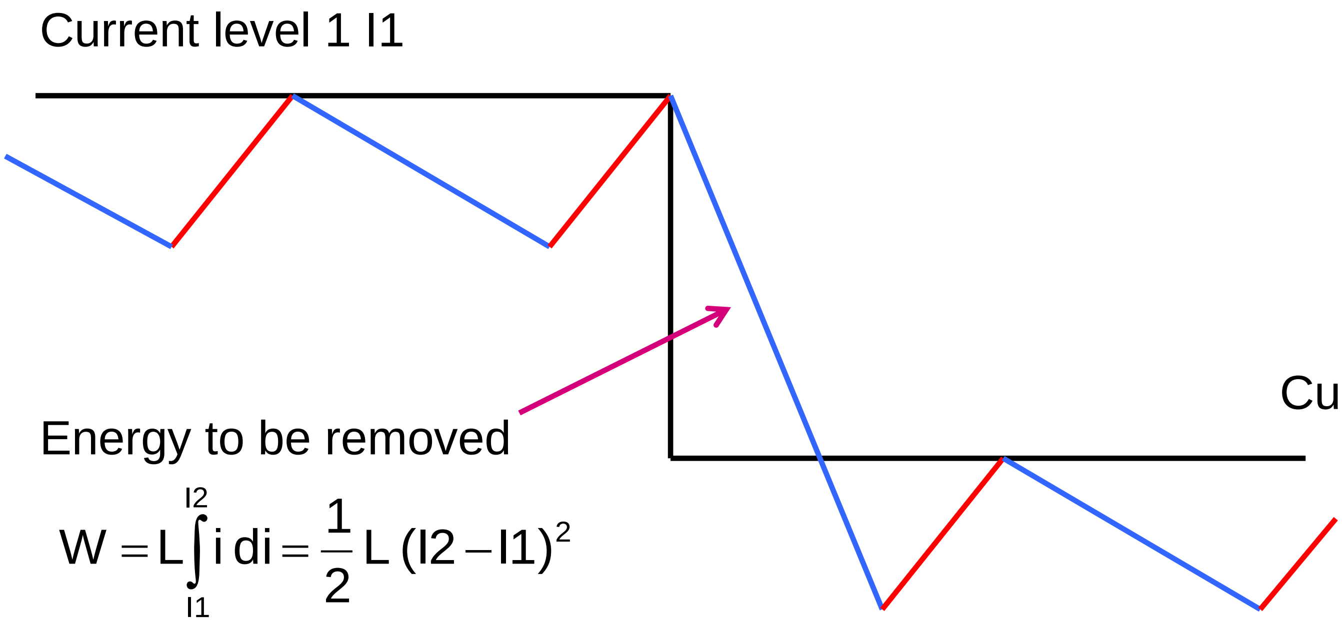
Current is applied with a chopping technique



Energy must be removed in order to keep the current level stable → decay is necessary

dSPIN

Why a decay : Falling steps



$$W = L\int_{I1}^{I2} i\,di = \frac{1}{2}L\,(I2 - I1)^2$$

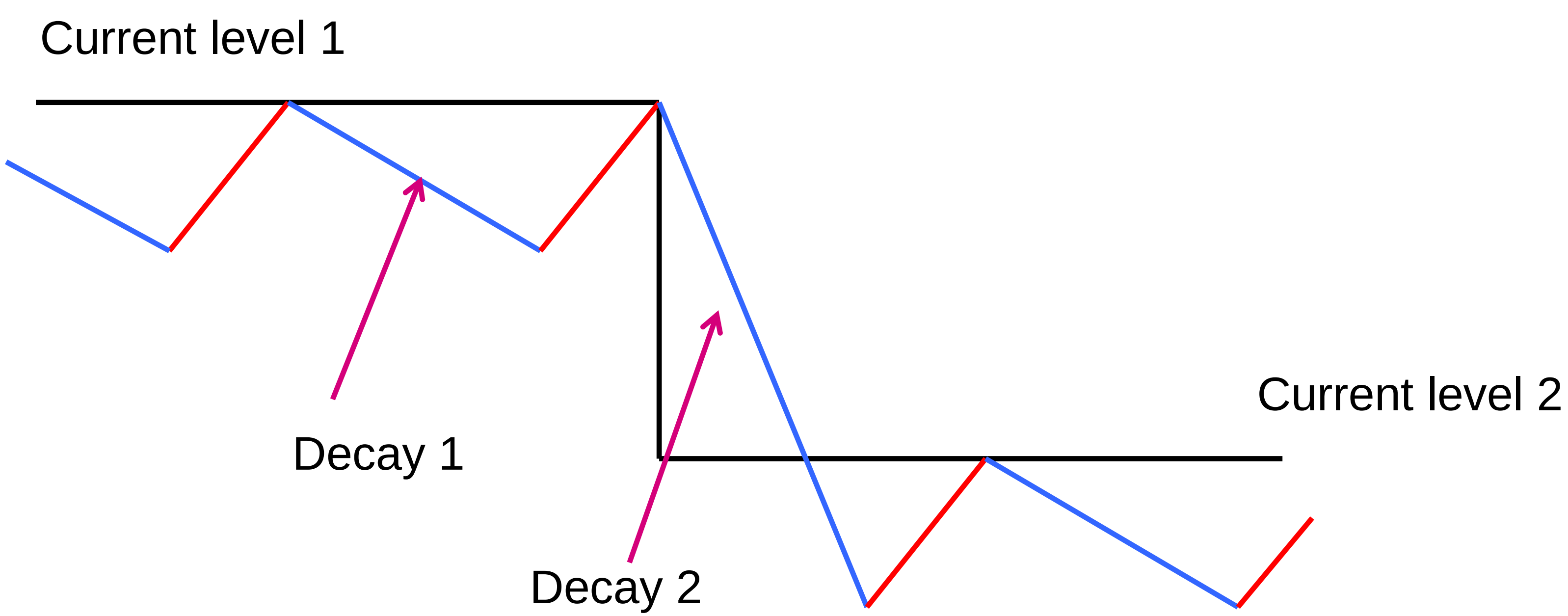
The energy must removed from the inductance when you switch current level1 to a lower current level2 → decay is necessary

dSPIN
Evolved current control

- **Automatic selection of the decay mode**
  Stable current control in microstepping
- **Slow decay and fast decay balancing**
  Reduced current ripple
- **Predictive current control**
  Average current control
- **Automatic OFF time adjustment**
  Fixed switching frequency

dSPIN

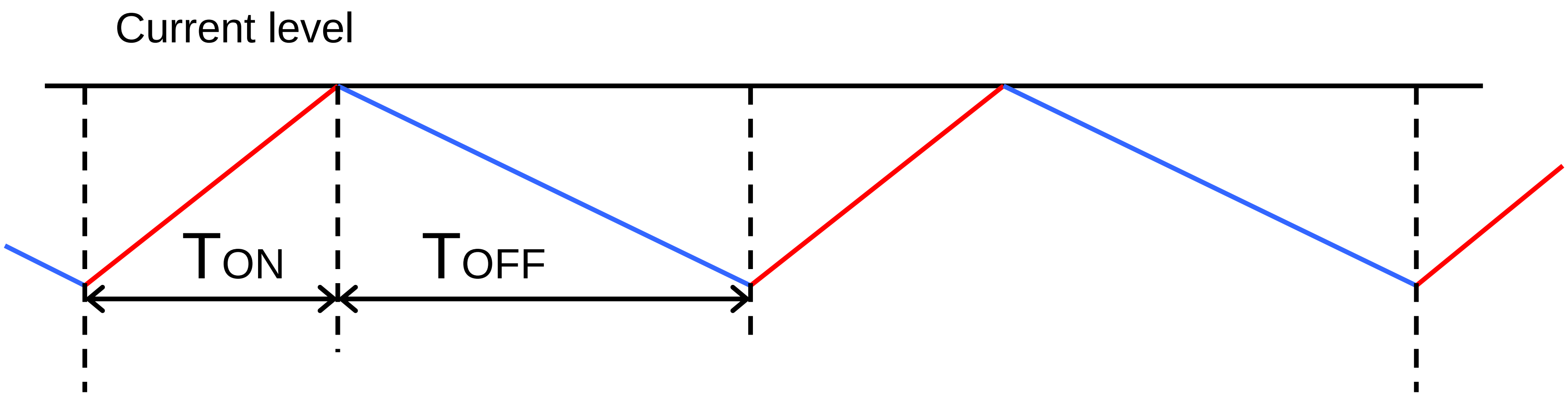
Challenges to perform the right decay



The quantity of energy to removed in decay1 and decay2 are different → must choose the right timing and speed decay

dSPIN

Challenges to perform the right decay



During the OFF state, both slow and fast decay can be performed

L6472 performs

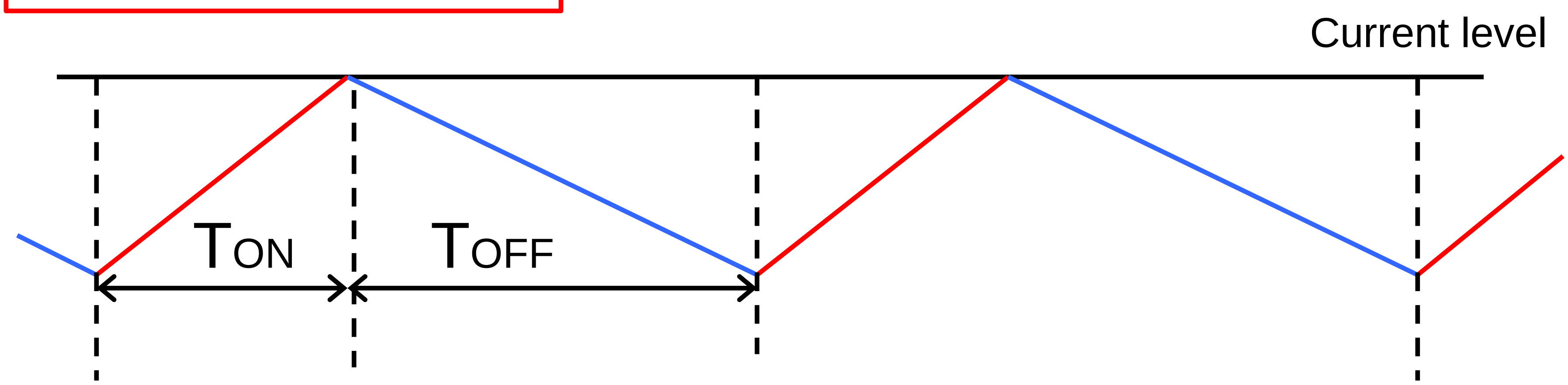
AUTO-ADJUSTED DECAY

dSPIN

Timing PWM to control current

Address [Hex]	Register name	Register function
h0F	**TON_MIN**	**Minimum ON time**
h10	**TOFF_MIN**	**Minimum OFF time**
h18	**CONFIG**	**Bit10-14 : TSW**

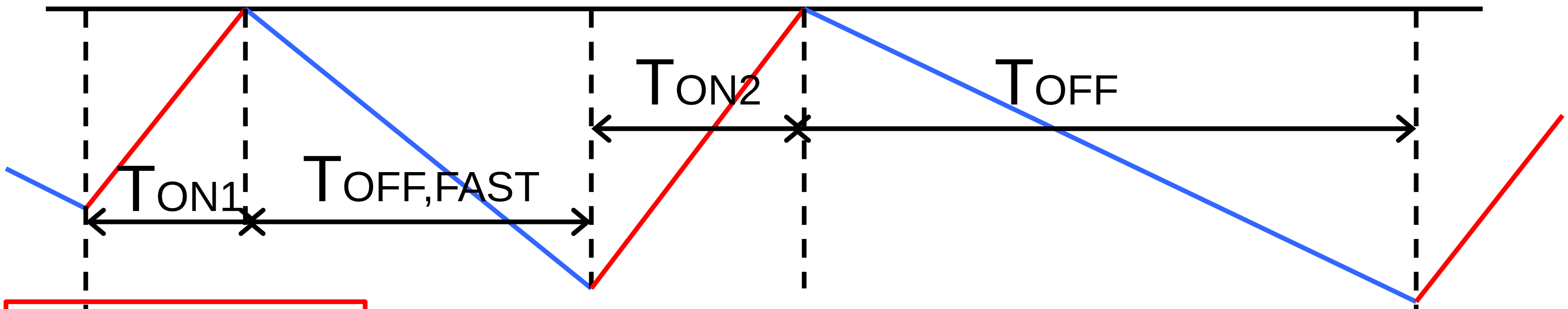
TON Must be > TON_MIN



In stable current, TON and TOFF are constant

Auto-adjusted Decay w/ one Fast Decay

Target Current level



TON1 < TON_MIN

Fast decay for TOFF,FAST = T_FAST/8 in order to remove more energy than a slow decay

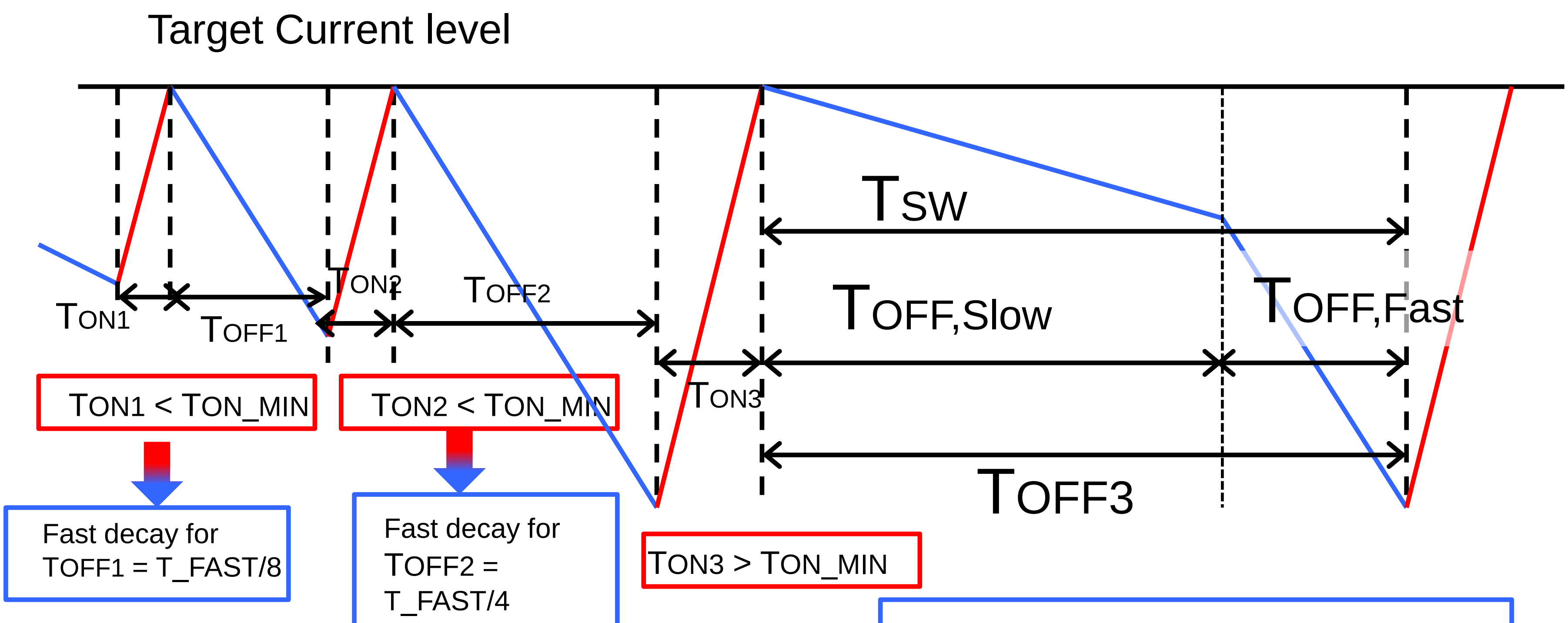
TON2 >TON_MIN

Slow decay for TOFF = TSW(*)

Address [Hex]	Register name	Register function
h0E	**T_FAST**	**Fast decay/fall step time**
h0F	**TON_MIN**	**Minimum ON time**
h18	**CONFIG**	**Bit10-14 : TSW**

(*) No predictive control

Auto-adjusted Decay w/ multiple fast decay



Address [Hex]	Register name	Register function
h0E	**T_FAST**	**Fast decay/fall step time**
h0F	**TON_MIN**	**Minimum ON time**
h18	**CONFIG**	**Bit10-14 : TSW**

Mixed decay :

TOFF3 = TSW (*)

TOFF Fast = TOFF2 = T_FAST/4

TOFF Slow = TOFF3 - TOFF Fast

(*) No predictive control

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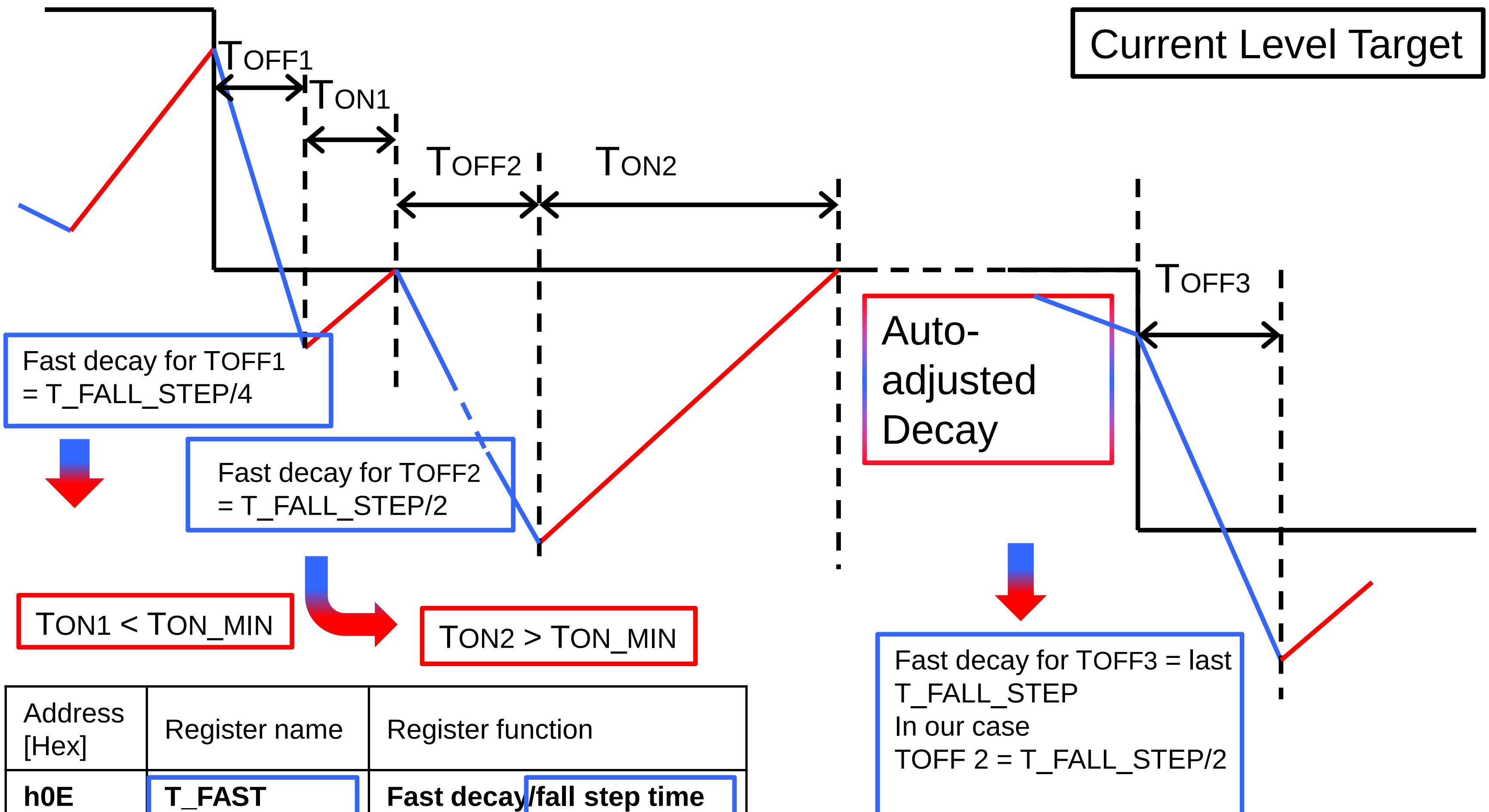
Fast Decay Mode during Falling Step



Address [Hex]	Register name	Register function
h0E	**T_FAST**	**Fast decay/fall step time**
h0F	**TON_MIN**	**Minimum ON time**
h18	**CONFIG**	**Bit10-14 : TSW**

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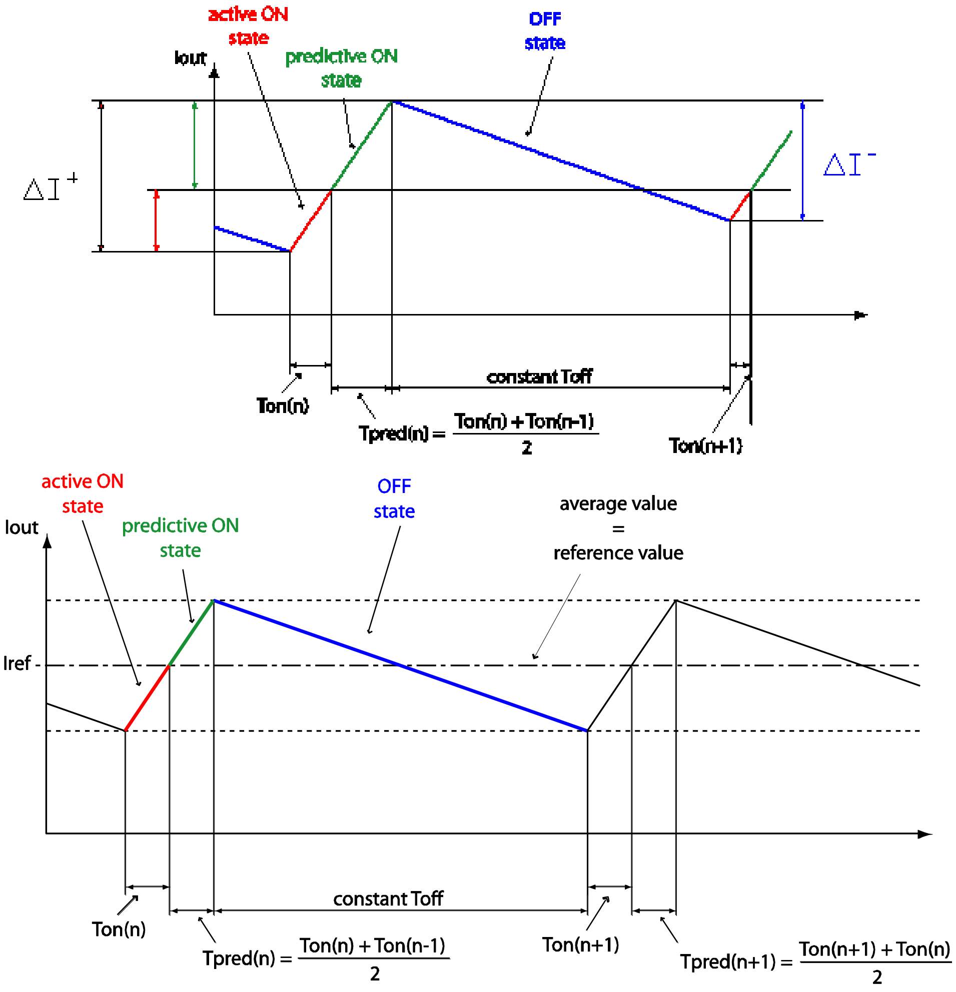
dSPIN
Predictive current control



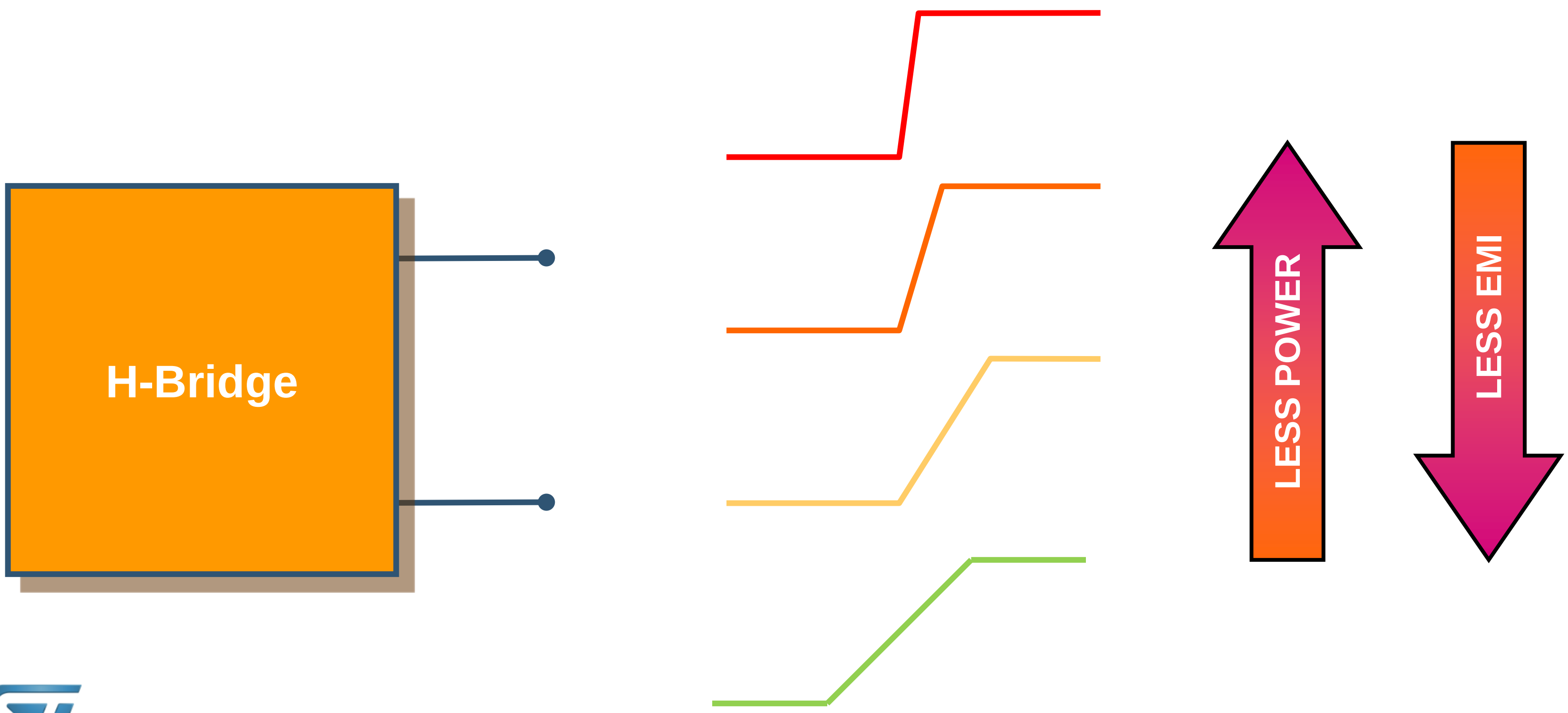
IN STEADY STATE: Ton(n) = Ton(n-1) THEN Ton_pred(n) = Ton(n)

The predictive current algorithm allows to control the average current.

The OFF time is regulated according to the TSW parameter.

dSPIN
Programmable output slew-rate

Four output slew-rate values can be selected via SPI in order to fit the application EMI / Power dissipation tradeoff.



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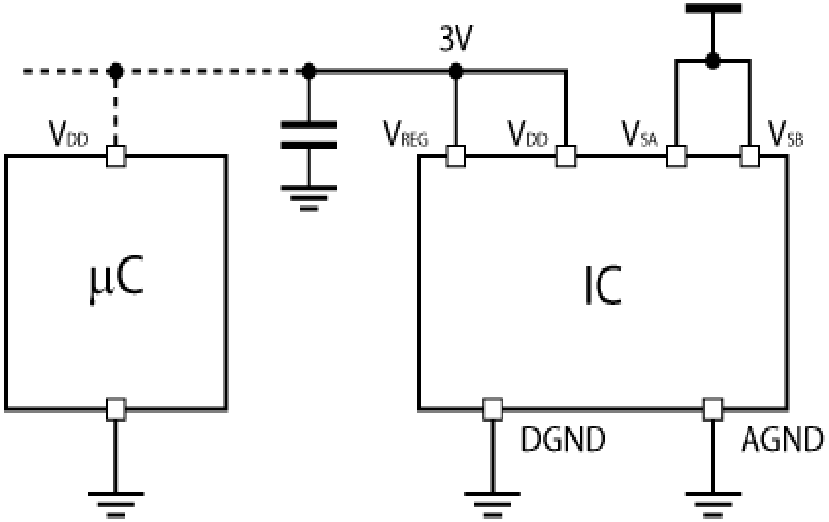
dSPIN

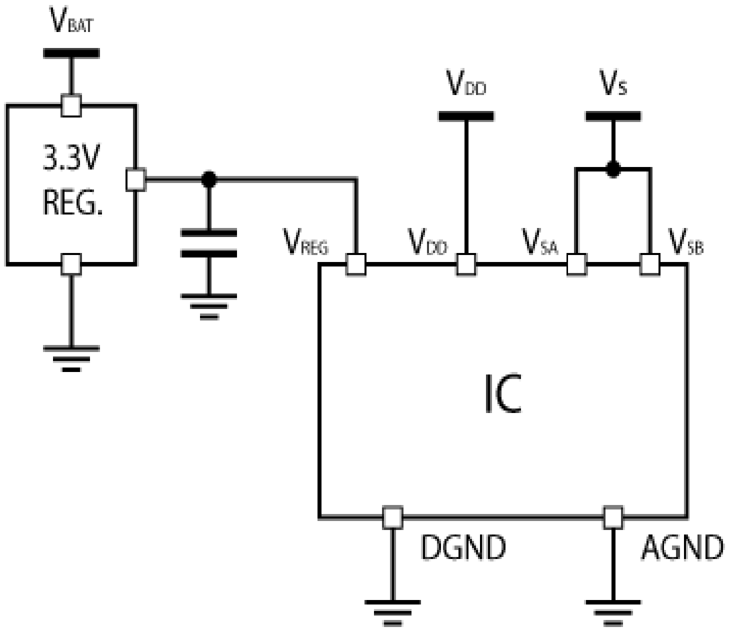
Integrated 3V voltage regulator

Device logic supply management is also flexible!

1. Supply IC logic through the internal 3V regulator
2. Supply IC logic using an external 3V3 supply
3. Supply external components (e.g. a µC) through the internal voltage regulator



Logig supplied by
INTERNAL voltage regulator



Logig supplied by
EXTERNAL voltage regulator

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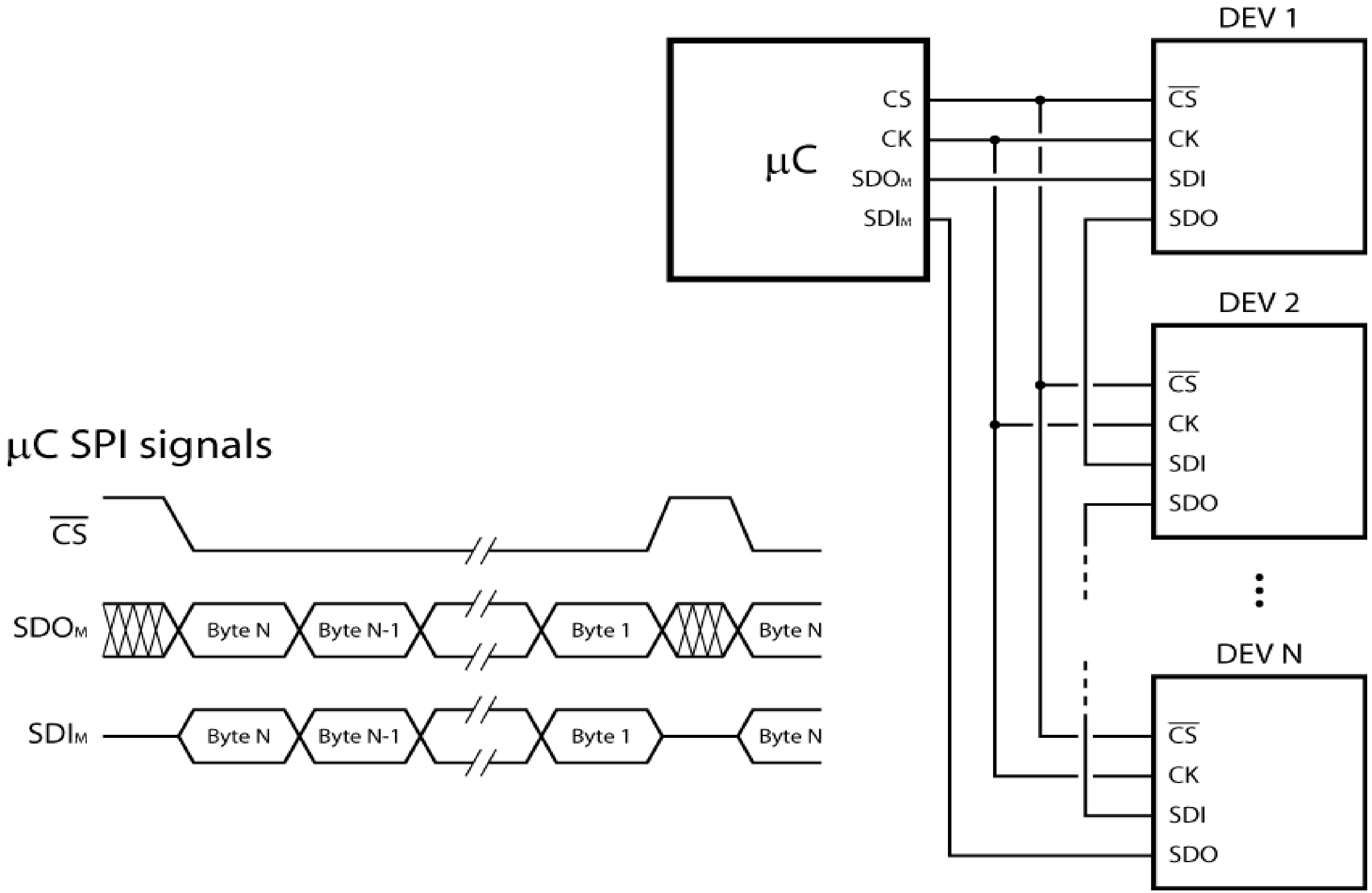
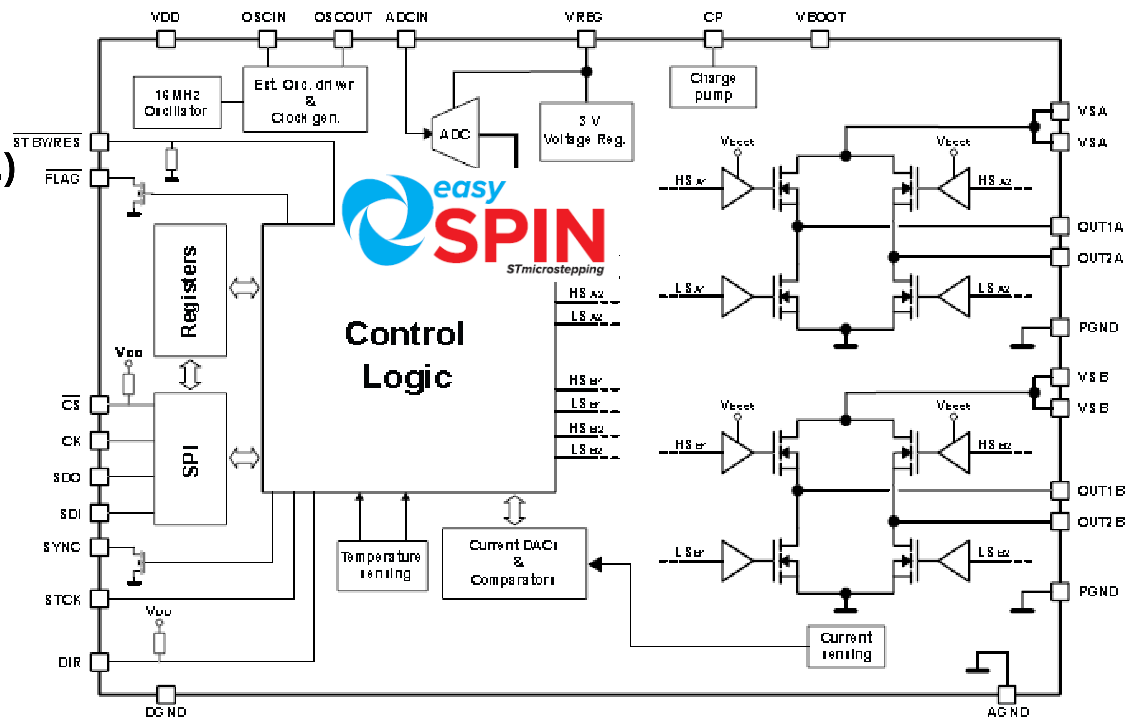
dSPIN
Daisy chaining



*easy*SPIN - L6474

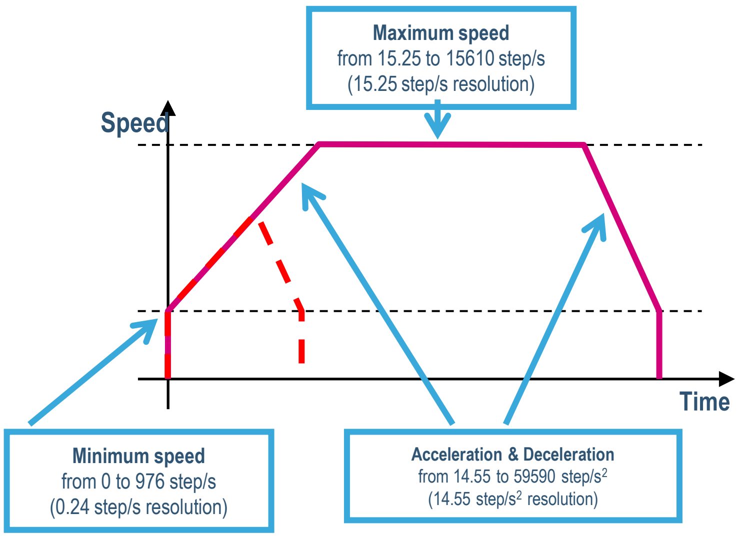
Flexible innovative microstepping motor driver



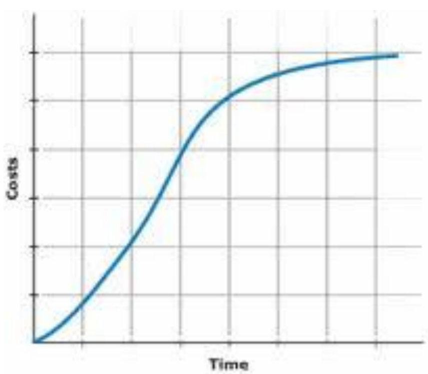
- **Operating voltage: 8 – 45V**
- **7.0 A output peak current (3.0 A r.m.s.)**
- Low RDSon power MOSFETs
- Programmable power MOS slew-rate
- Up to 1/16 microstepping
- **<u>Current control with adaptive decay</u>**
- **SPI interface**
- Low quiescent and standby currents
- Non dissipative current sensing
- **Full set of Protection**
  - Programmable non dissipative over current (on all power MOS)
  - Two levels over temperature protection
  - UVLO

L6474H

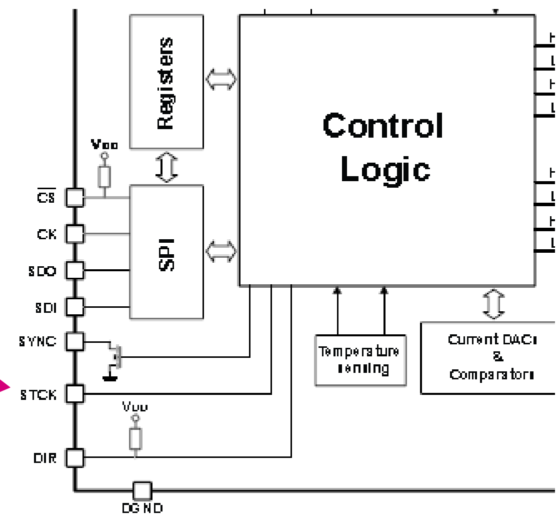
*easy*SPIN - L6474
Speed Profiles using STCK



L6472 : Acceleration and Deceleration are linear



L6474 : Any shape can be performed with the STCK pin*



L6470: dSPIN

ST motor Drivers are moving the future

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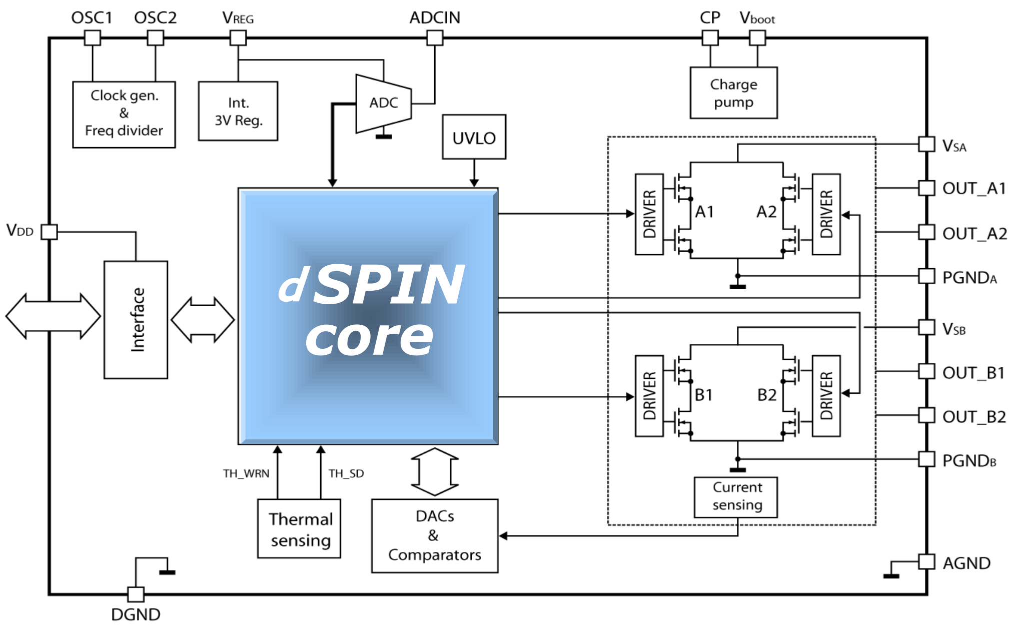
dSPIN

L6470 Monolithic Digital µ stepping voltage mode Driver

- Supply voltage **8V – 45V**
- **3Arms** (7A peak)
- $R_{DS,ON}$ = **0.28 Ω**
- Integrated Current Sensing (no external shunt)
- Up to **128 microsteps**
- Voltage mode operation
- Sensorless **Stall Detection**
- Programmable speed profile
- Programmable positioning
- 8bit 5Mhz **SPI interface** (Daisy Chain compatible)
- Integrated 16MHz oscillator
- Integrated 5bit ADC
- Integrated 3V voltage regulator
- **Over Current, Over Temperature**
- **and Under Voltage protections**
- **HTSSOP** and **POWERSO** packages



Voltage mode vs. Current mode

Current mode principle:

- System tries to impose phase current applying a switching voltage.
  It is a **closed-loop** approach.

Voltage mode principle:

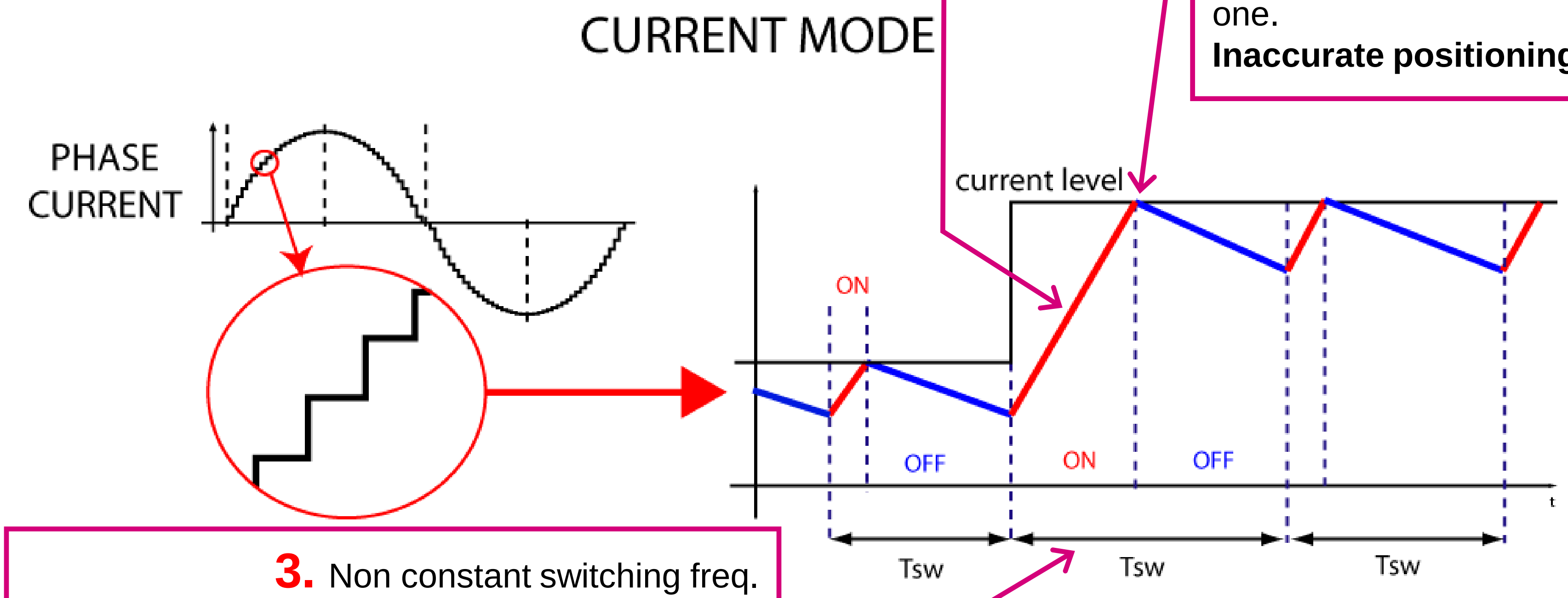
- System applies a sinusoidal voltage to motor and phase. Phase current is not directly controlled.
  It is a **open-loop** approach.

dSPIN

Voltage mode vs. Current mode

1. Abrupt current changes cause strong mechanical vibrations. Current mode tries to follow even non idealities (reference voltage quantization and sampling)
Noisy and jerky motion.

2. Peak current is controlled. Average current value is different from target one.
Inaccurate positioning



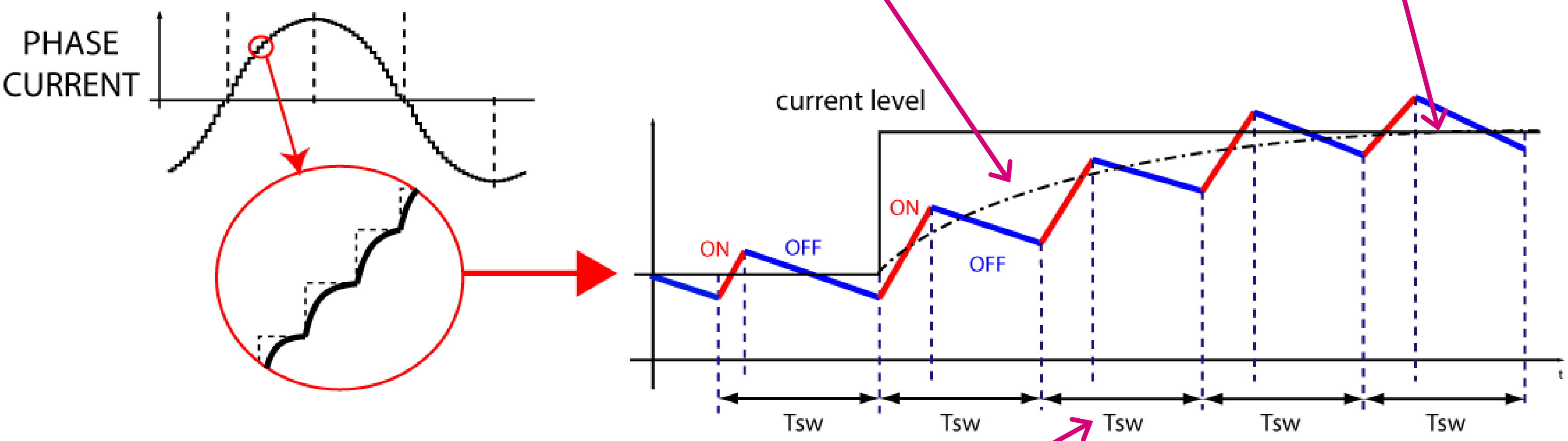
3. Non constant switching freq.
Torque ripple and EMI are difficult to control.

dSPIN
Voltage mode vs. Current mode

Smooth current transient reduces mechanical vibrations.
Motor movement is soft and silent!

Average current is controlled.
Accurate positioning.

VOLTAGE MODE



Constant switching freq.
Torque ripple and EMI are under control.

dSPIN
Voltage mode vs. Current mode

- Current mode systems strain with several tricks (e.g. mixed decay) trying to find a solution to follow adequately the sinusoidal profile of the current
  - Results are generally quite poor, require fine tuning and are trade-off between adequate profile and current ripple

- Voltage mode intrinsically uses the best decay style
  - Current profile is very smooth
  - No compromise on current ripple. No mixed decays
  - No tuning of the decays

    Best decay is always used with each motor

dSPIN
Voltage mode: drawbacks and solutions

- ✘ Back-Electro Motive Force heavily influences voltage to current relation
- ✔ Effective and flexible BEMF compensation system
- ✘ Windings applied voltages are perturbed by supply voltage fluctuations
- ✔ Supply voltage compensation though integrated 5bit ADC
- ✘ Phase resistances vary with temperature
- ✔ Phase resistance compensation register

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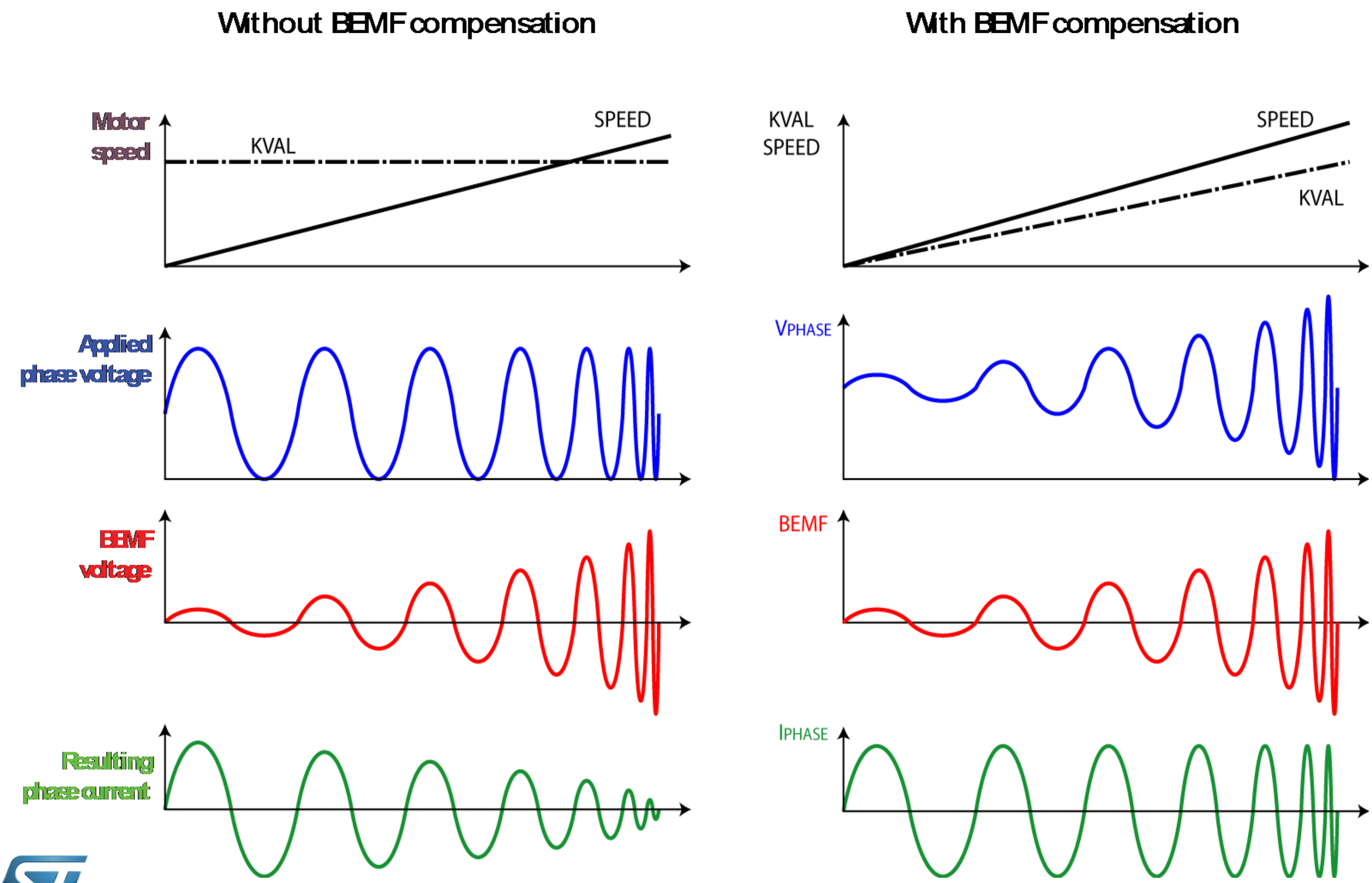
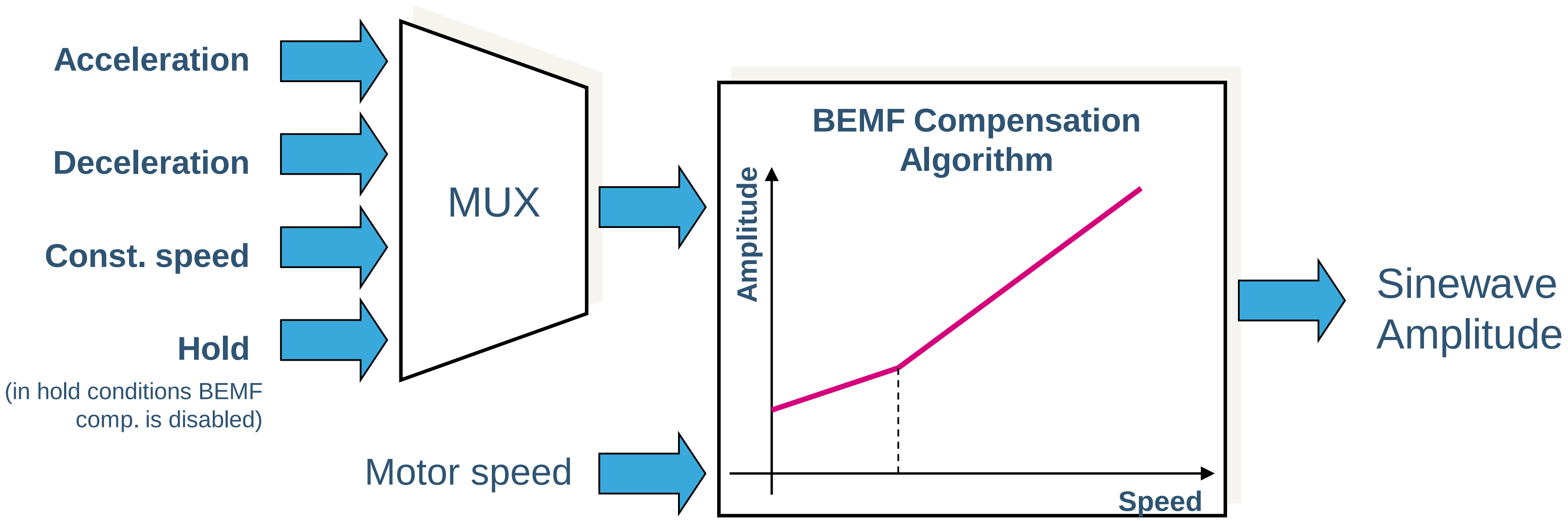
dSPIN
BEMF compensation



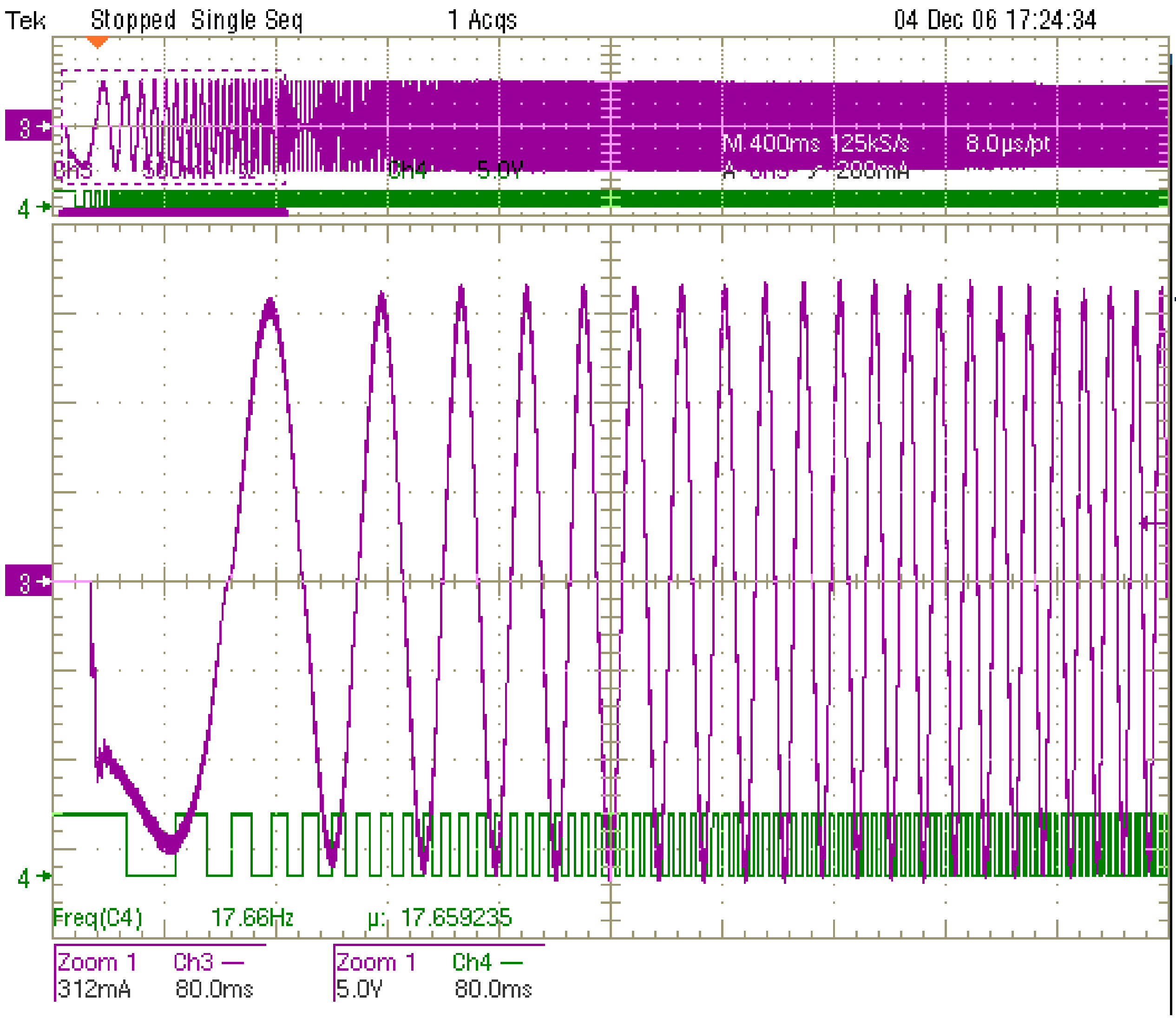
dSPIN
BEMF compensation

According to motor conditions (acc/deceleration, constant speed, hold) a different torque, and then current, could be needed

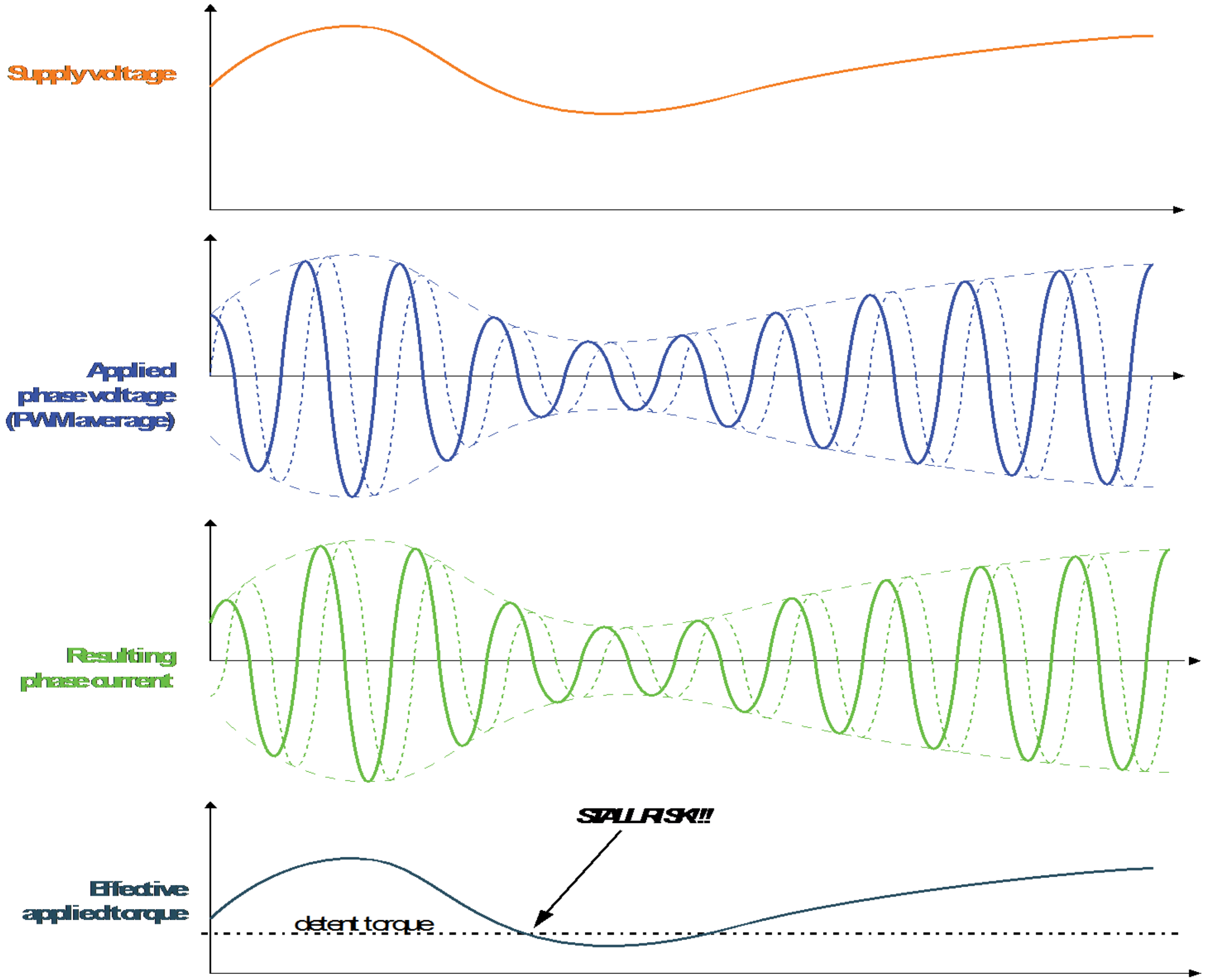
d*SPIN* logic switches from different compensation parameters sets according to motor status



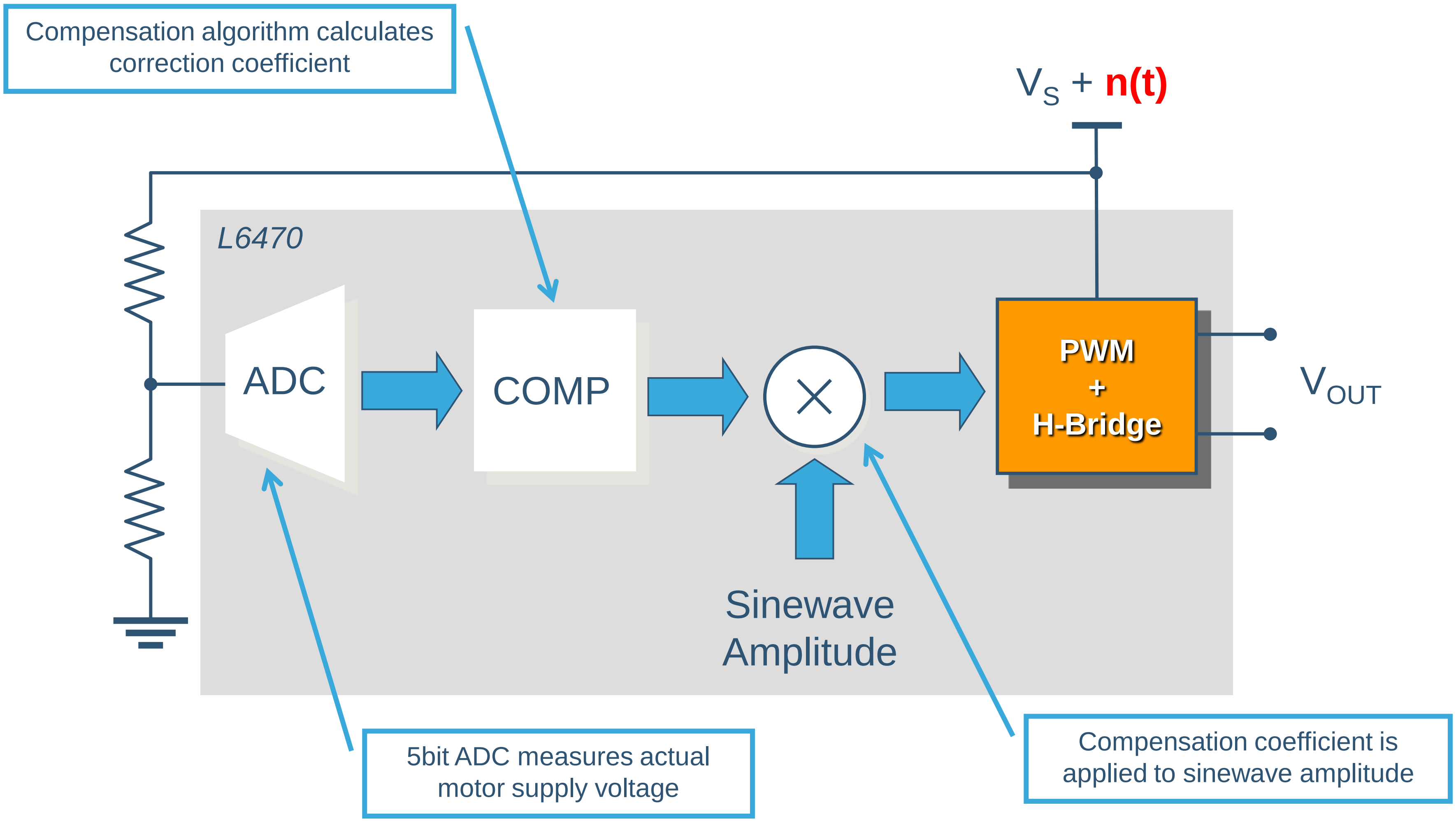
dSPIN
BEMF compensation waveform



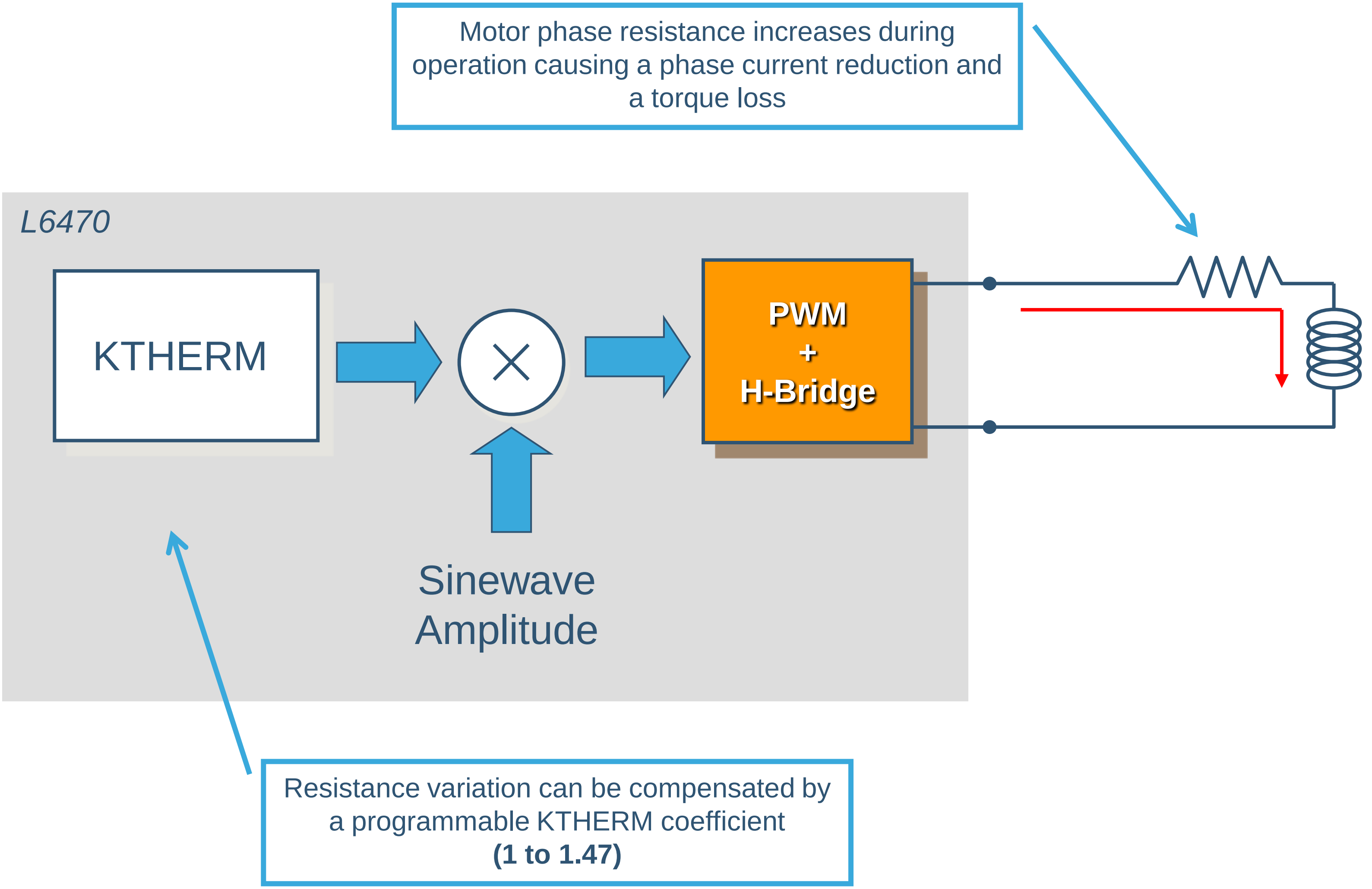
dSPIN
Supply voltage compensation (1)



dSPIN
Supply voltage compensation



dSPIN
Phase resistances variation comp.



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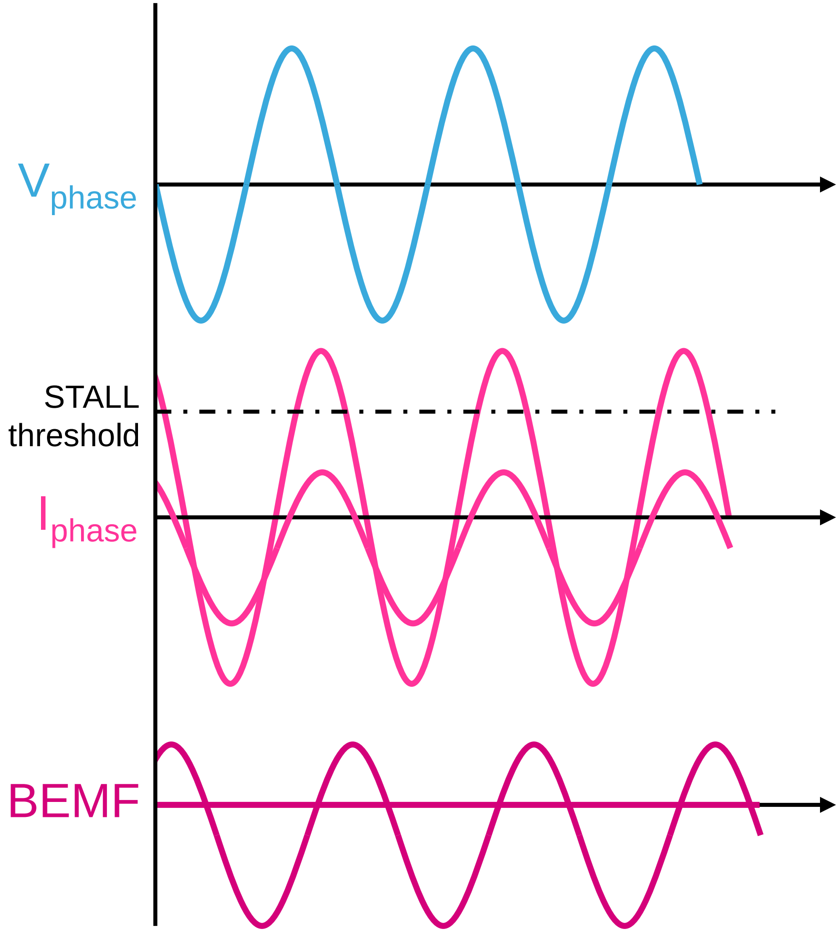
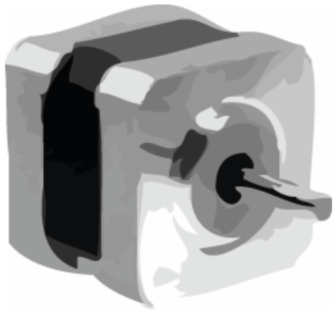
dSPIN

Sensorless stall detection

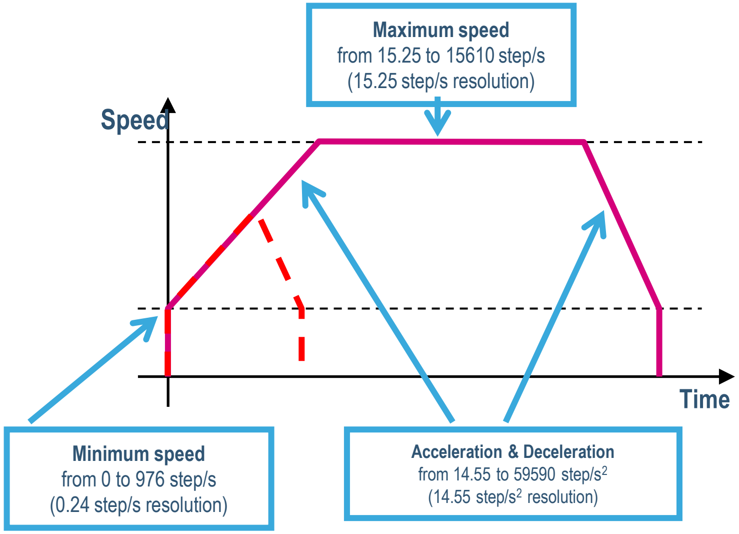
Using integrated current sensing and the adjustable STALL current threshold a cheap and easy stall detection can be implemented



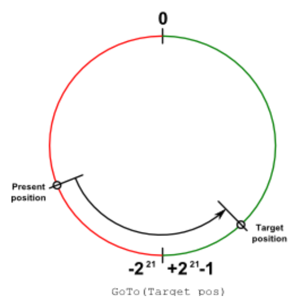
STALL!
BEMF is null and current is suddenly increased
Normal operation



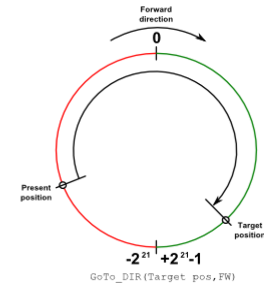
dSPIN
L6470 : Many Commands

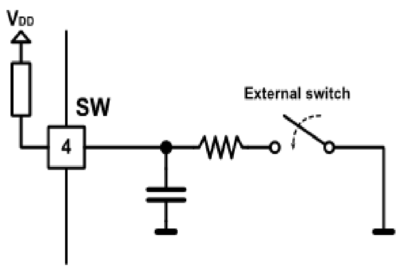


GoTo(Target) command: reach the target position using shortest path



GoTo_DIR(Target, DIR) command: reach the target position moving the motor in the selected direction





GoUntil command moves the motor with a selected constant speed and stops the motor when the switch is closed; at that time one of the following actions can be taken:

And : GoHome, GoMark, Run, Move, SoftStop, HardStop, SoftHiz, ReleaseSW…..

Integrated position registers allows to map up to
32768 full steps (@128 μstep operation)
equivalent to about **164 rotations** (200 step/rotation motor)

dSPIN
Register map

Address [Hex]	Register name	Register function	Len. [bit]	Reset Hex	Reset Value	Remarks(3)
h01	ABS_POS	Current Position			0	R, WS
h02	EL_POS	Electrical Positio			0	R, WS
h03	MARK	Mark Position	22	000000	0	R, WS, WR
h04	SPEED	Current Speed			0 step/tick (0 step/s)	R
h05	ACC	Acceleration			125.5e-12 step/tick^2 (2008 step/s^2)	R, WS
h06	DEC	Deceleration			125.5e-12 step/tick^2 (2008 step/s^2)	R, WS
h07	MAX_SPEED	Maximum Speed			248e-6 step/tick 3 step/s)	R, WS, WR
h08	MIN_SPEED	Minimum Speed			p/tick p/s)	R, WS
h15	FS_SPD	Full Step Speed	10	027	150.7e-6 step/tick .7 step/s)	R, WS, WR
h09(2)	KVAL_HOLD	Holding K_{VAL}			$\cdot V_S$	R, WS, WR
h0A(2)	KVAL_RUN	Constant Speed K_{VAL}	8	29	$0.16 \cdot V_S$	R, WS, WR
h0B(2)	KVAL_ACC	Acceleration Starting K_{VAL}	8	29	$0.16 \cdot V_S$	R, WS, WR
h0C(2)	KVAL_DEC	Deceleration Starting K_{VAL}	8	29	$0.16 \cdot V_S$	R, WS, WR

Absolute position register can be set

Motor electrical position (current microstep) can be set

Speed profile parameters

Torque control parameters

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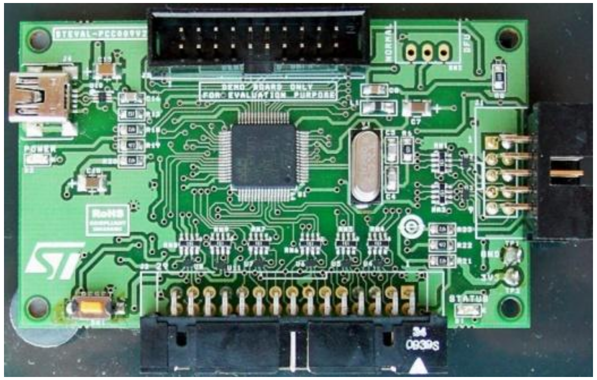
Tools & Documentations

- Sales Codes
  - L6470H -Tray
  - L6470HTR -Tape&Reel
  - ES available on L6470PD
- Product Page http://www.st.com/dspin
  - Data Sheet
  - Application Note (AN3103)
  - d SPIN Evaluation Tool Software
  - Evaluation Board: EVAL6470H
  - Control boards STEVAL-PCC009V2 (and –V1)
  - d SPIN Firmware Library
    - Available on http://www.st.com/dspin



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Tools & Documentations

- Sales Codes
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  - Data Sheet
  - Application Note
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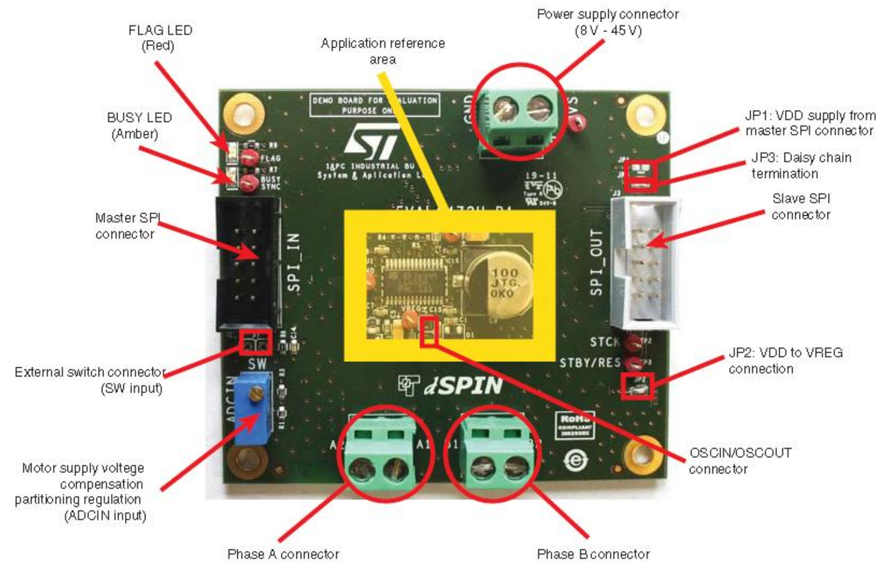

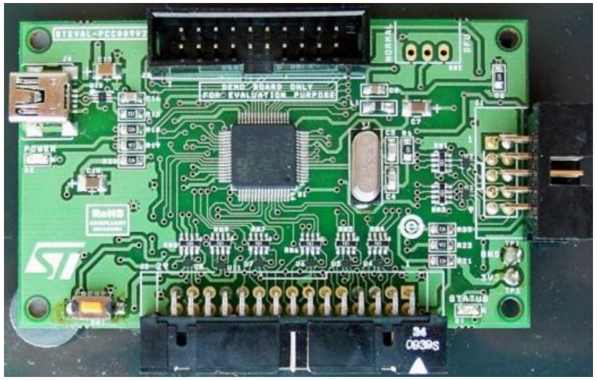

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