powerSTEP01 system-in-package

ST's motor drivers are moving the future

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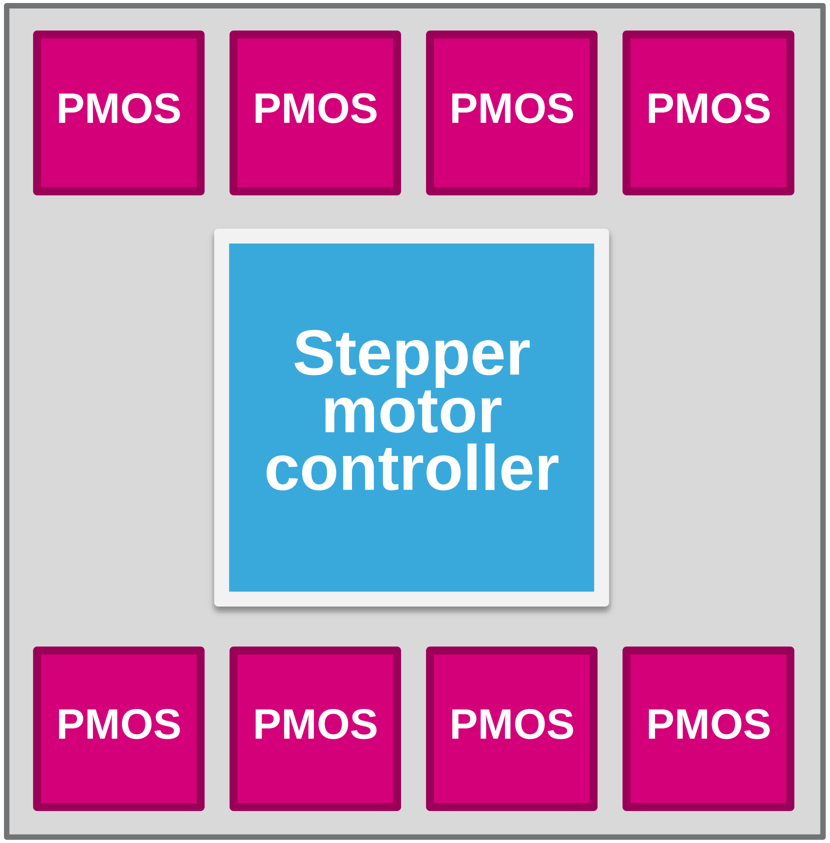
First SiP for stepper motor applications

Stepper motor controller featuring:

- Fully **programmable gate driving**
- Overcurrent protection
- Up to **128 microsteps**
- Current control
  - **Voltage mode driving**
  - **Advanced current control**
- **Sensorless stall detection**
- **Digital Motion Engine**
  - Programmable speed profile
  - High-level commands
- **11 x 14 mm QFN** package

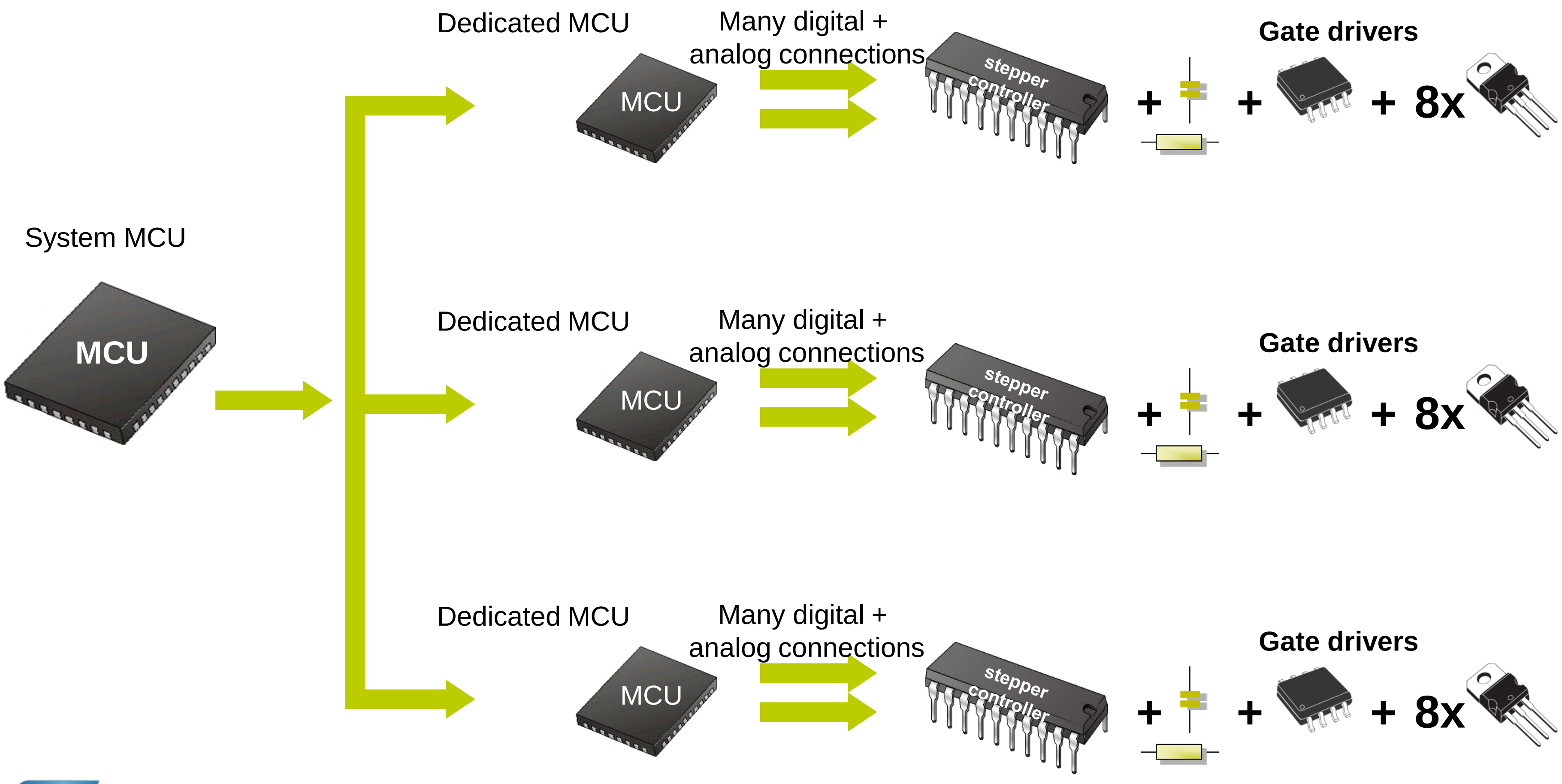
8 x power MOSFETs

- Maximum current 10 A_{RMS}
- **$R_{ds(ON)}$ = 16 mΩ**



Intelligence integration

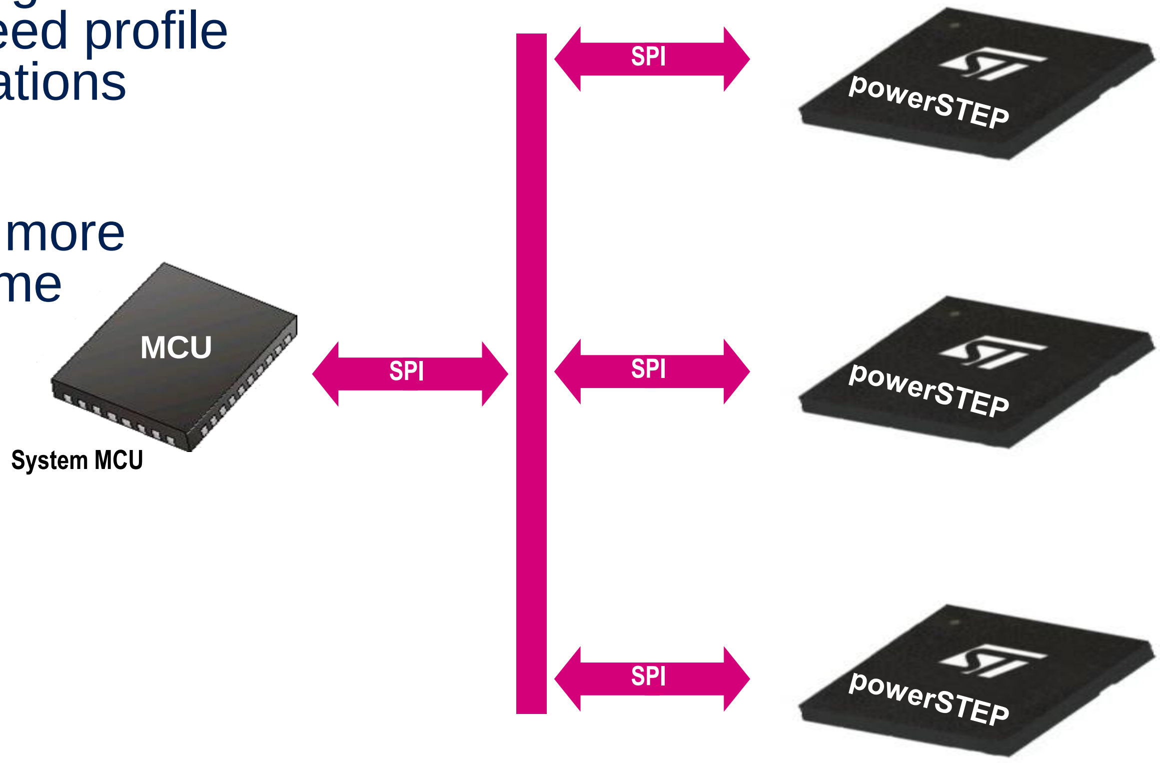
before **powerSTEP01**...



Intelligence integration

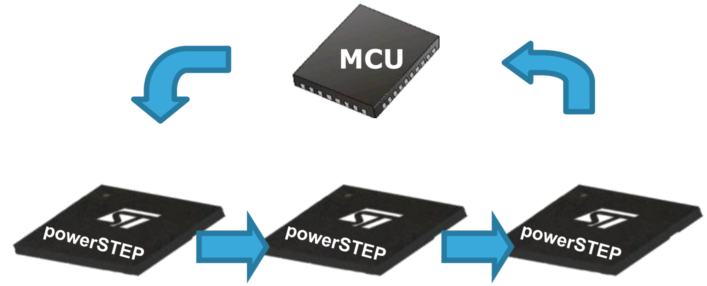
with **powerSTEP01**...

- System is greatly simplified
- Dedicated MCU no longer needed to perform speed profile and positioning calculations
- Less components
- Single MCU can drive more devices at the same time



A full-digital interface to MCU

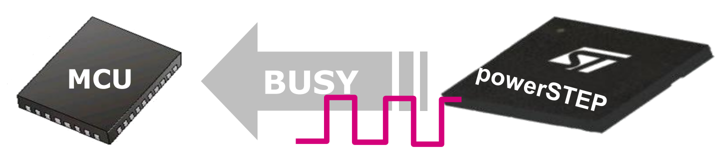
- The fast SPI interface with **daisy-chain** capability allows a single MCU to manage multiple devices



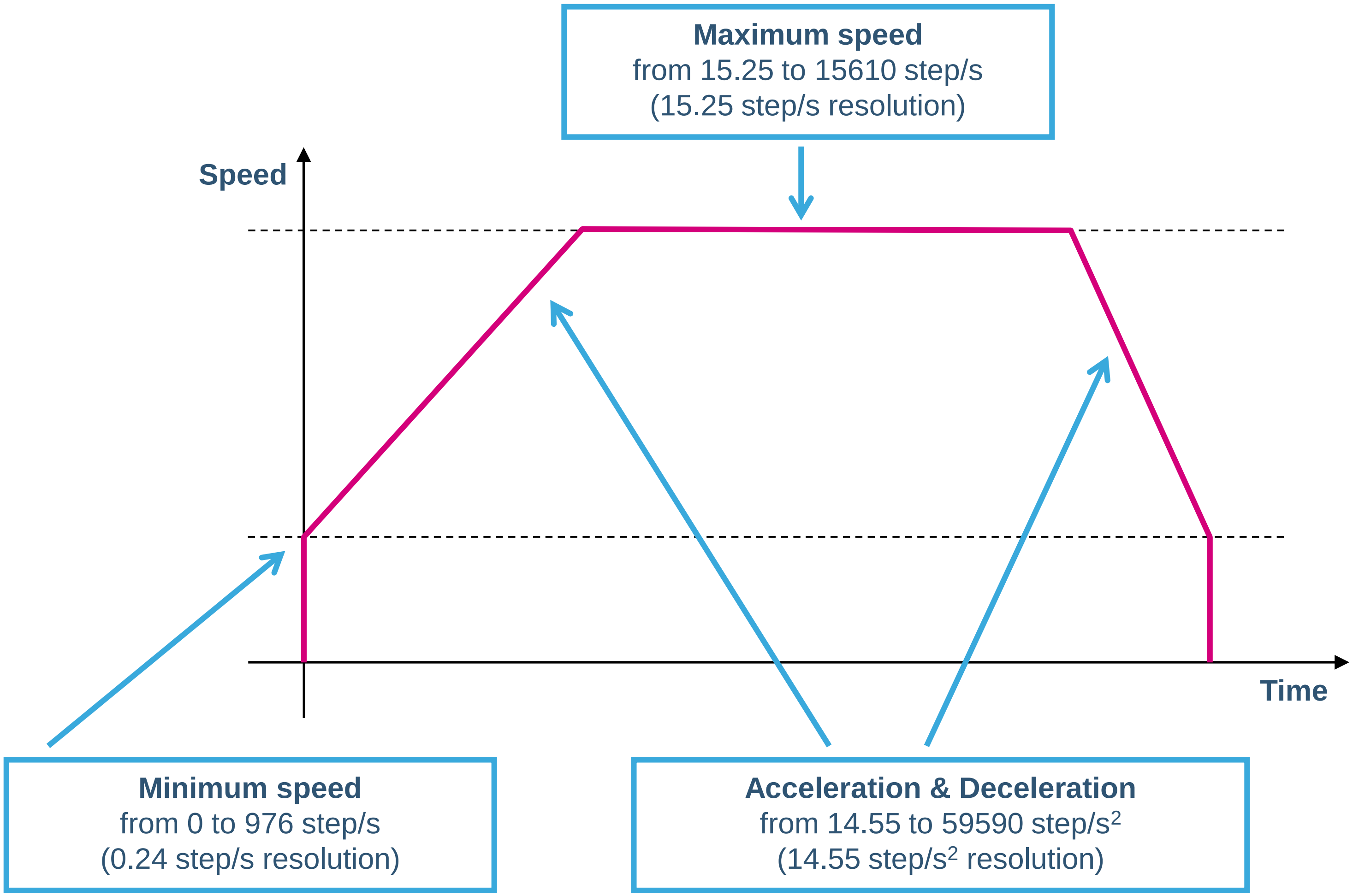
- Programmable alarm **FLAG** open-drain output for interrupt-based FW
  In daisy-chain configuration, **FLAG** pins of different devices can be OR-wired to save host controller GPIOs

- **BUSY** open-drain output allows the MCU to know 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 as **SYNC** signal giving a feedback of the step-clock to the MCU
  (programmable # of microsteps)



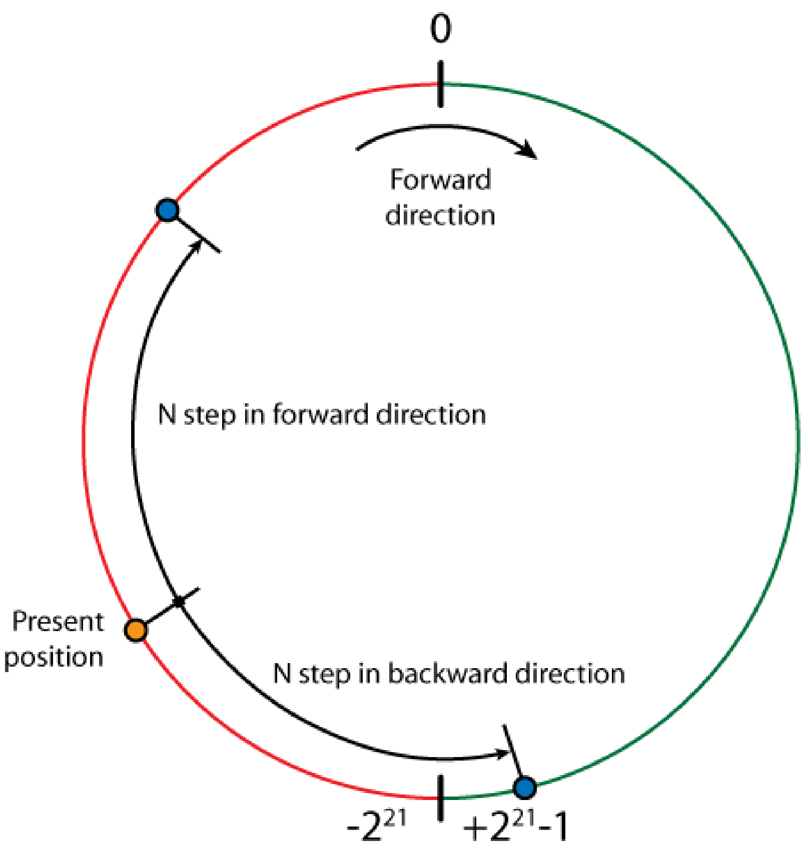
Fully programmable speed profile boundaries



Positioning features: Movement command

Move(N, DIR) command perform a motion of N steps in the selected direction.

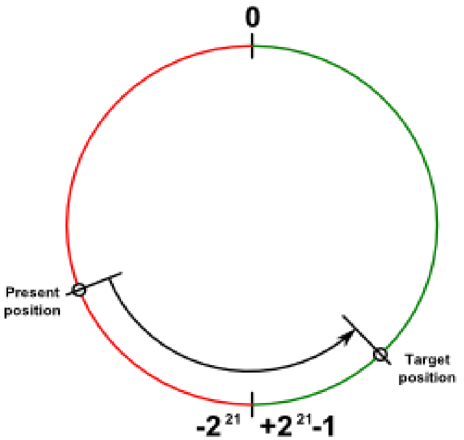
This command can be performed only when the motor is stopped.



Positioning features: Absolute positioning commands

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

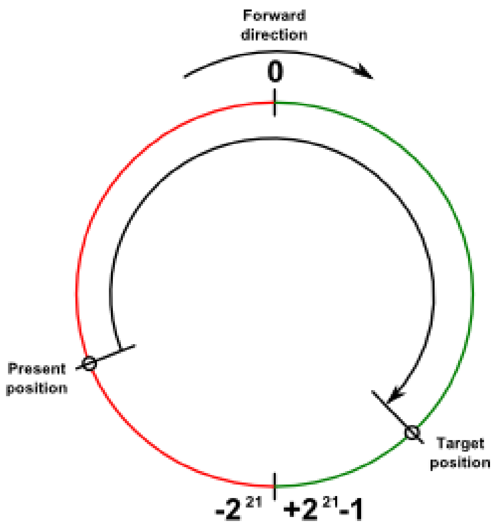
This command can be performed only when motor is stopped or is running at constant speed.



GoTo(Target pos)

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

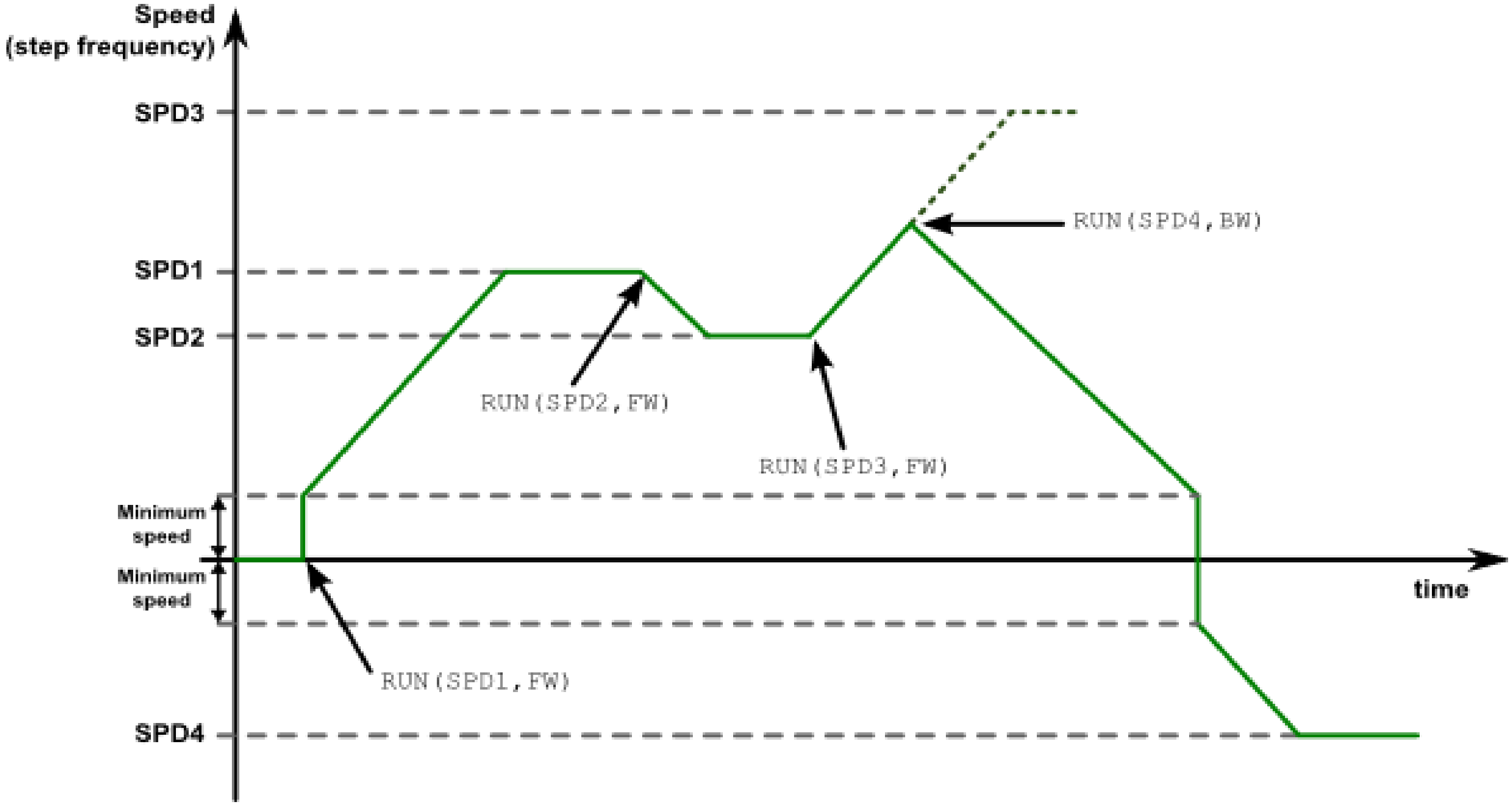
This command can be performed only when the motor is stopped or is running at constant speed.



GoTo_DIR(Target pos,FW)

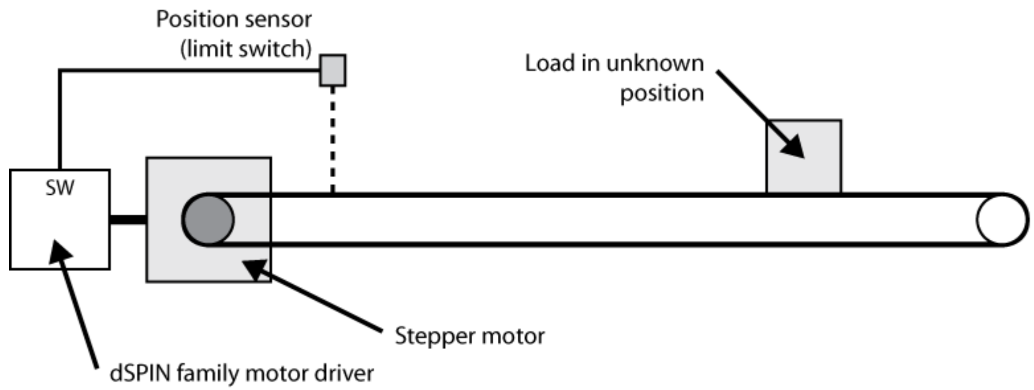
Speed tracking features: Constant speed command

Run(SPD, DIR) command drives the motor to reach the target speed SPD in the selected direction. Target speed and direction can be changed anytime.

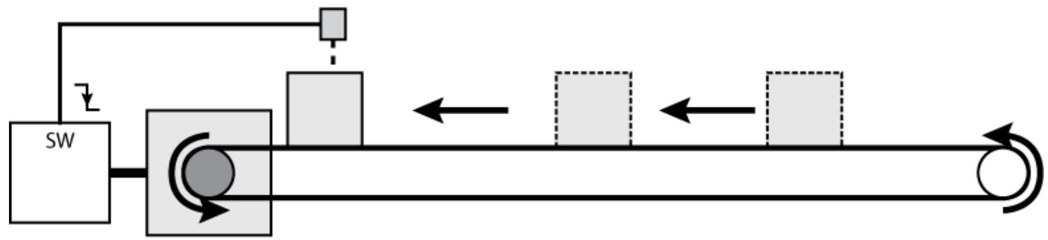


Limit switch management

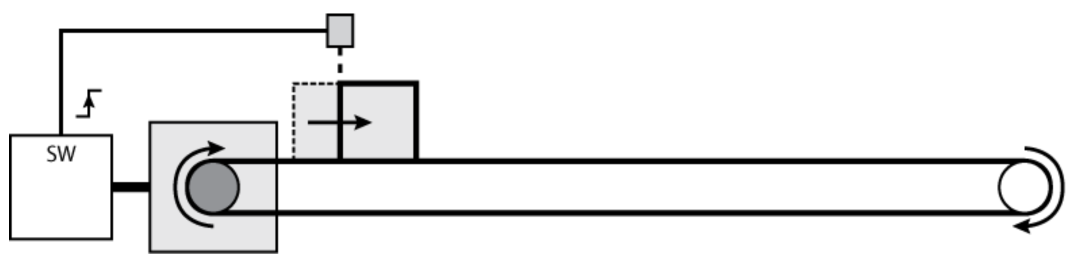
At power up the load could be in an unknown position.
The absolute position counter should be initialized.



The **GoUntil** command moves the mechanical load to the limit switch position.



The **ReleaseSW** command moves the mechanical load on the limit switch triggering threshold.



Undervoltage on the ADC input

The ADC input can also be monitored to detect an undervoltage condition on the motor supply voltage.

If the ADC input falls below the fixed **1.16 V** threshold, an UVLO_ADC event is signaled by the device diagnostic but no automatic actions are performed.

When the ADC is used for the power supply configuration (ADCIN voltage at 1.65 V when nominal voltage is present), the **UVLO** is signaled when the VS voltage is **below 70 % of the nominal value**.

Programmable overcurrent protection

Each MOSFET of the external power stage is protected by an overcurrent protection system.

The overcurrent protection system monitors the voltage drop of the MOS and detects when its value exceeds the programmed threshold which can be set **from 31.25 mV to 1 V**. In this case, the whole power stage is **immediately turned OFF**.

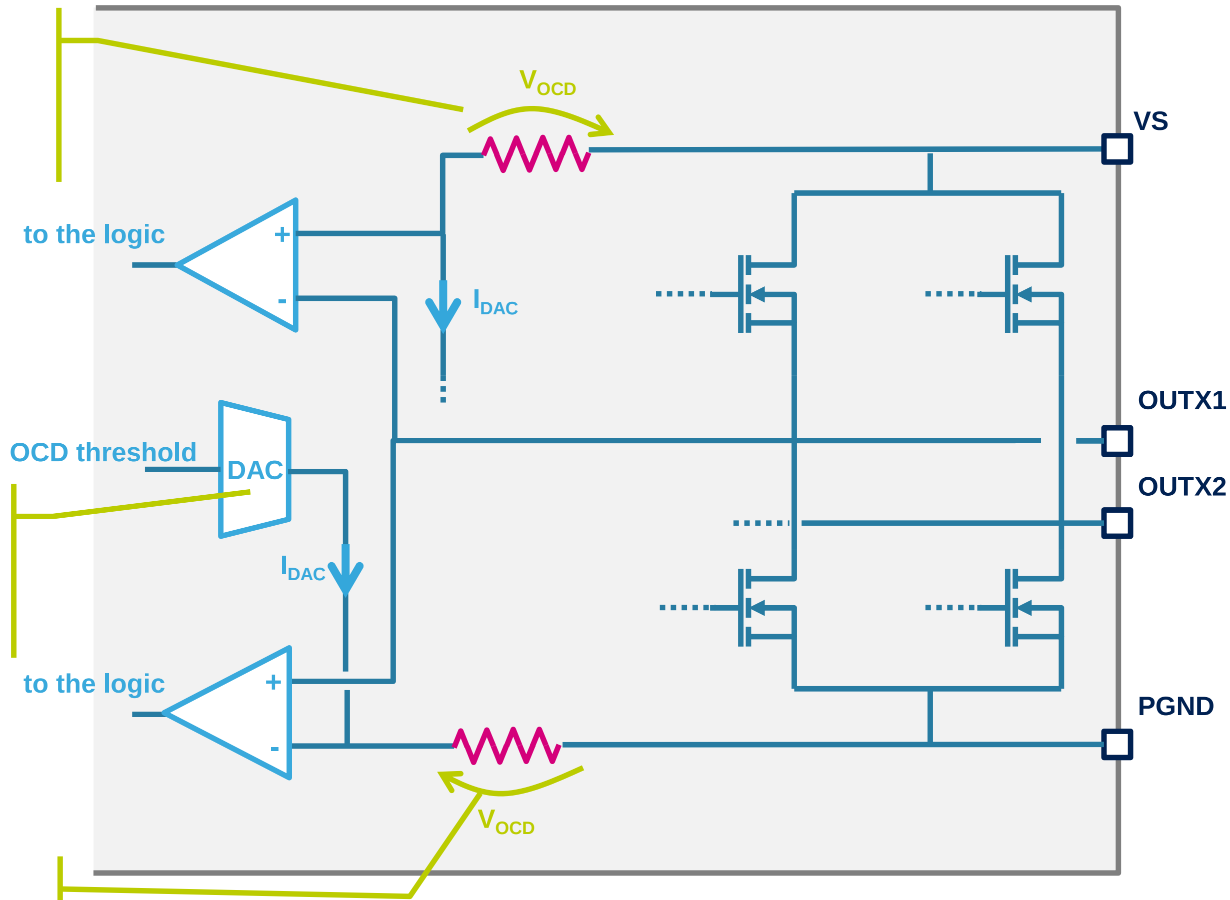
The power stage **cannot be enabled until a GetStatus command releases the failure condition**.

Programmable overcurrent protection

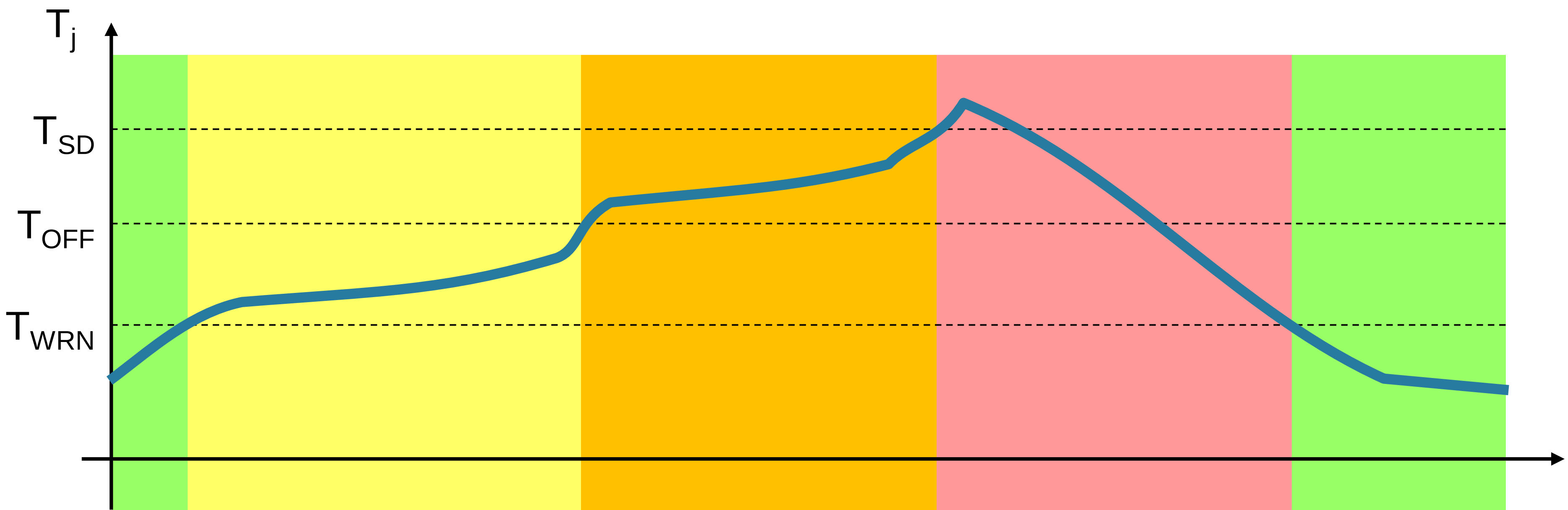
Reference voltage drop for the high-side MOSFETs

OCD DAC generates a reference current which is used to generate the reference voltages

Reference voltage drop for the low-side MOSFETs



Warning temperature and thermal shutdown



Warning region
The device operates normally but it is approaching the thermal shutdown temperature

Power stage shutdown
The power stage is disabled and cannot be turned on in any way.

Device shutdown
The power stage and the linear regulators are disabled.

Safe region
Normal operation is restored

Diagnostic register

The device integrates a diagnostic register collecting the information about the status of the system:

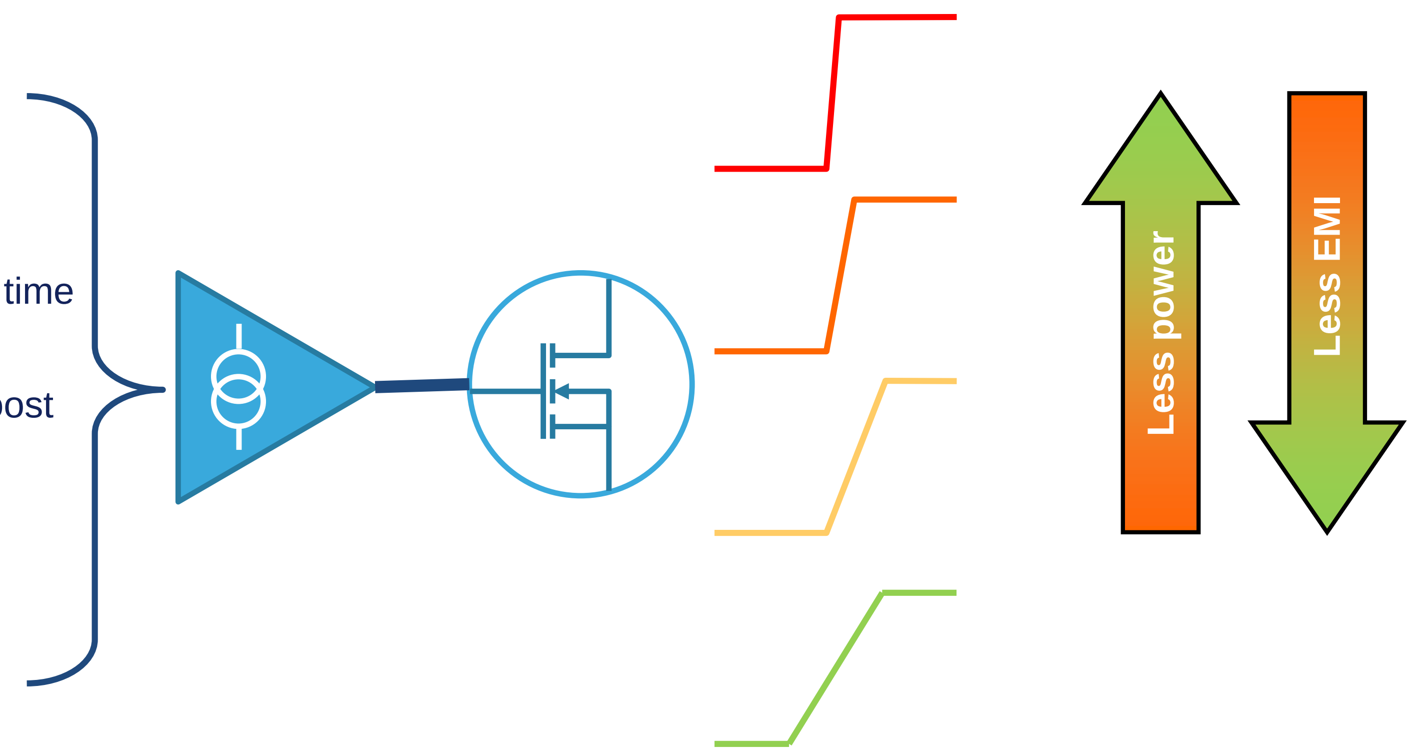
STATUS Register

- Power stage enabled/disabled
- Command under execution (BUSY)
- Motor status (direction, acc., dec., etc.)
- Step-clock mode
- Overcurrent
- Thermal status
- Undervoltage (it indicates the power-up status also)
- Undervoltage on ADC input
- Stall detection
- SW status
- SW input falling edge (limit switch turn-on)
- Incorrect or not performable command received

Programmable gate drivers

Integrated gate drivers are fully programmable, allowing POWERSTEP01 to adjust output slew-rate according to application requirements.

- Gate sink/source current
- Controlled current time (charging time)
- Turn-off current boost time
- Dead time
- Blanking time



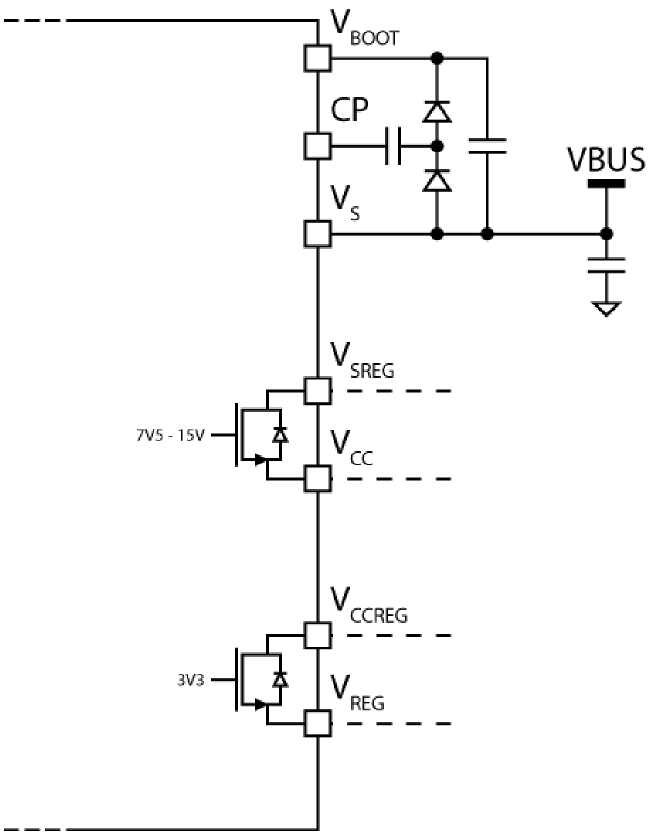
Suggested gate driving configurations

Slew-rate (VS = 48V)	I_{gate}	t_{CC}	t_{DT}	t_{blank}	t_{boost}
790 V/µs	64 mA	500 ns	125 ns	375 ns	0 ns
980 V/µs	96 mA	375 ns	125 ns	500 ns	0 ns
520 V/µs	32 mA	875 ns	125 ns	250 ns	0 ns
400 V/µs	24 mA	1000 ns	125 ns	250 ns	0 ns
220 V/µs	16 mA	1600 ns	125 ns	250 ns	0 ns
114 V/µs	8 mA	3125 ns	125 ns	250 ns	0 ns

Integrated voltage regulators

Supply management:

- Integrated voltage regulators allows device to be self-supplied through high-voltage bus.
- Input and output pins of both voltage regulators are accessible.
  Several supply scenarios are supported.
- **Regulators cannot be used to supply external devices.**



Two driving modes… more flexibility

Voltage mode

- System applies a sinusoidal voltage to the motor and phase. Phase current is not directly controlled.
  It is an **open-loop** approach.
- Extreme smoothness at all speeds
- Precise positioning

Current mode

- System tries to impose phase current applying a switching voltage.
  It is a **closed-loop** approach
- Robust to variation of the motor and application characteristics
- Robust to resonances

Voltage mode driving

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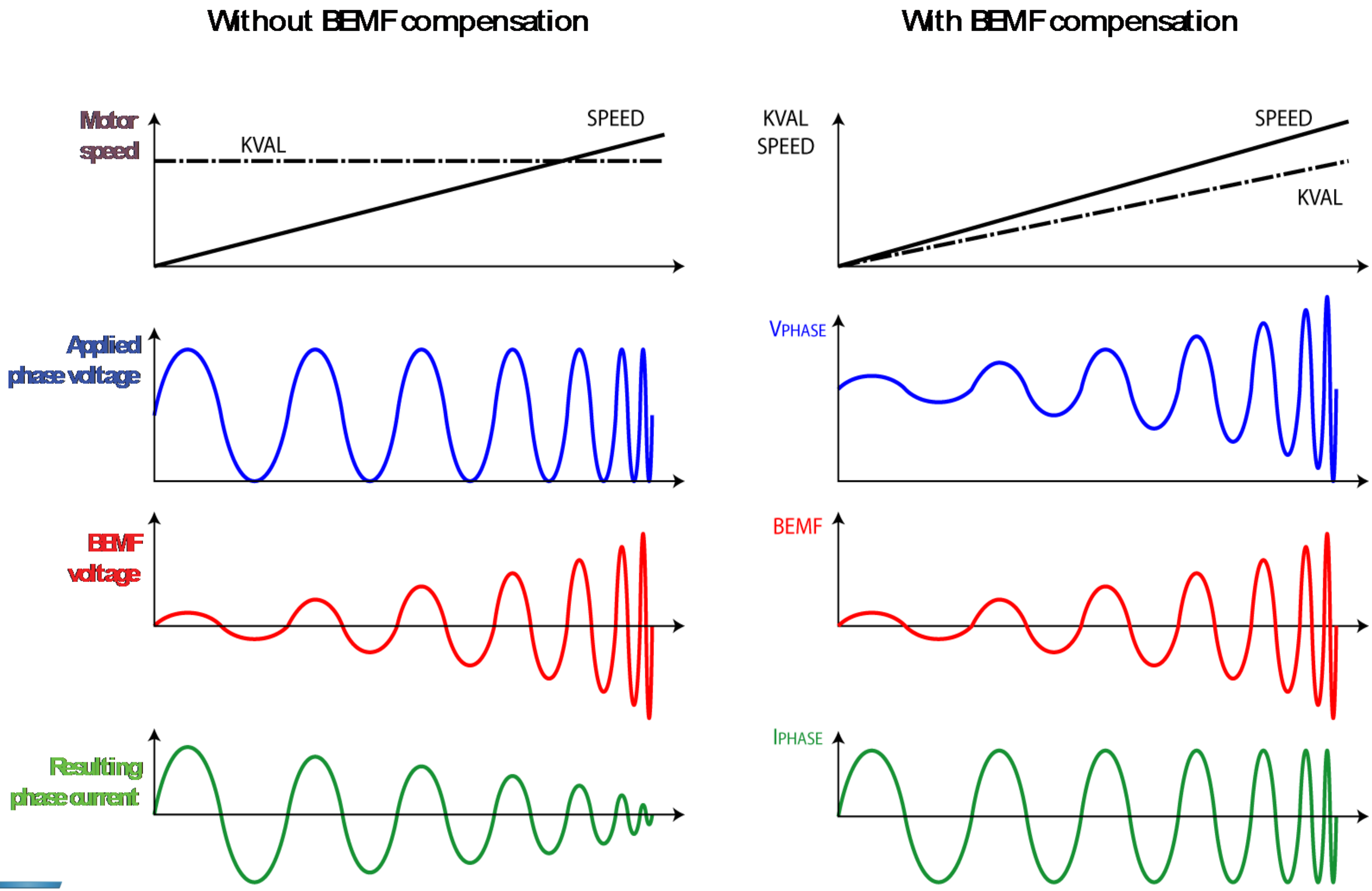
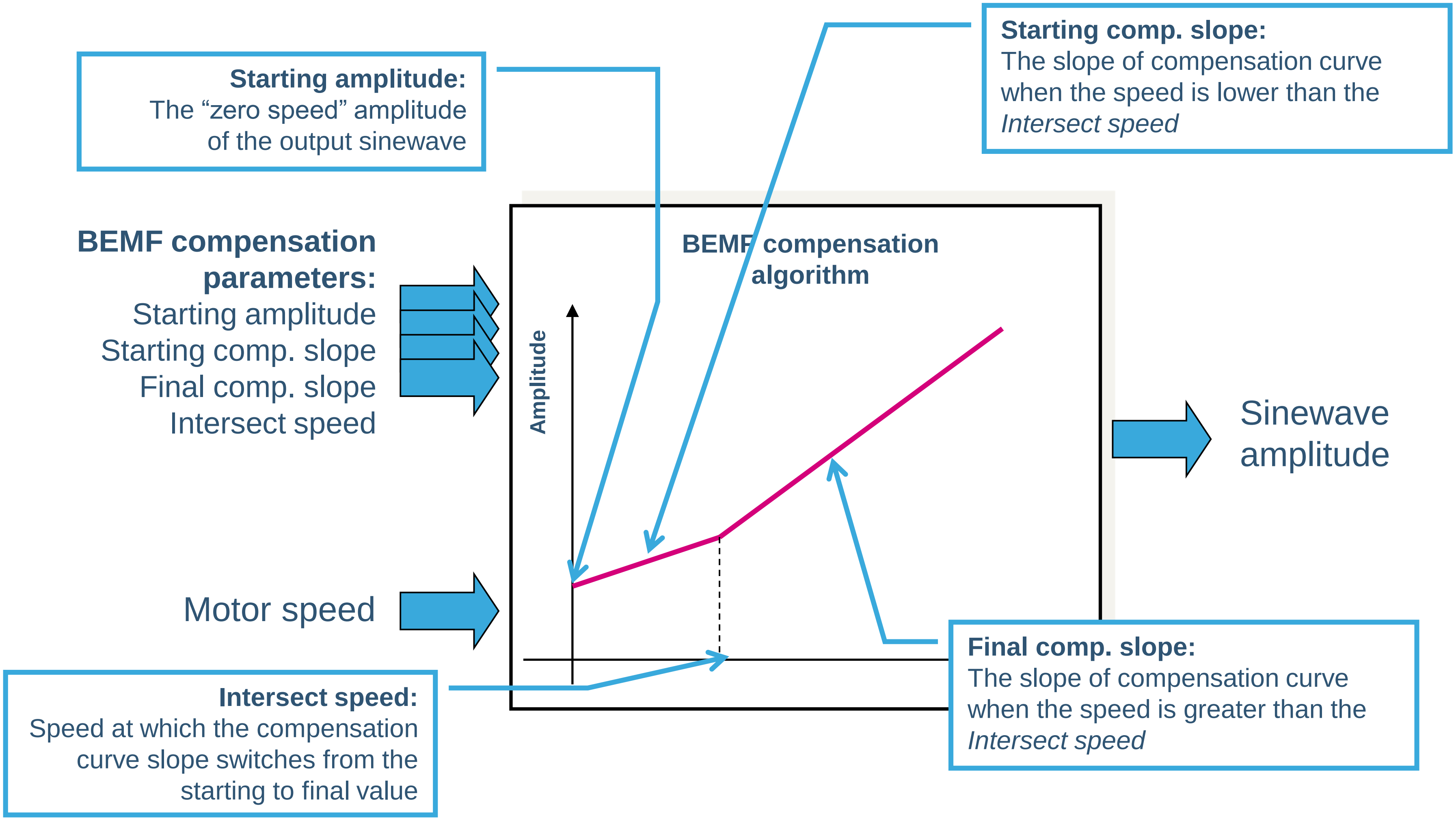
BEMF compensation



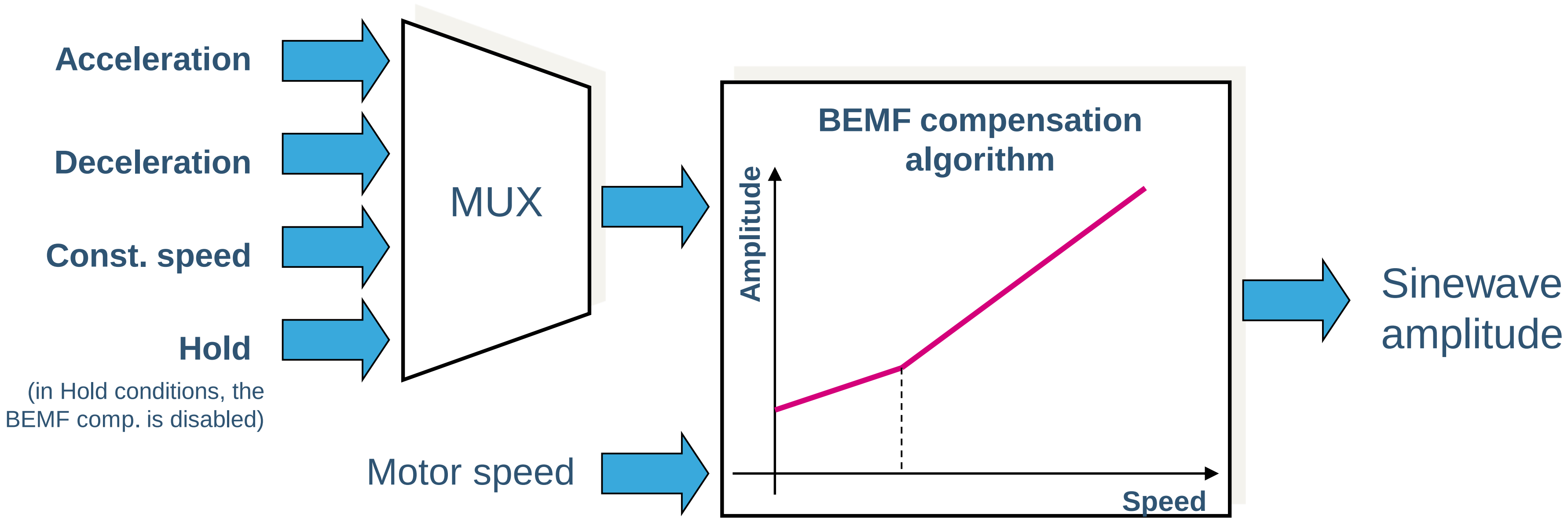
BEMF compensation



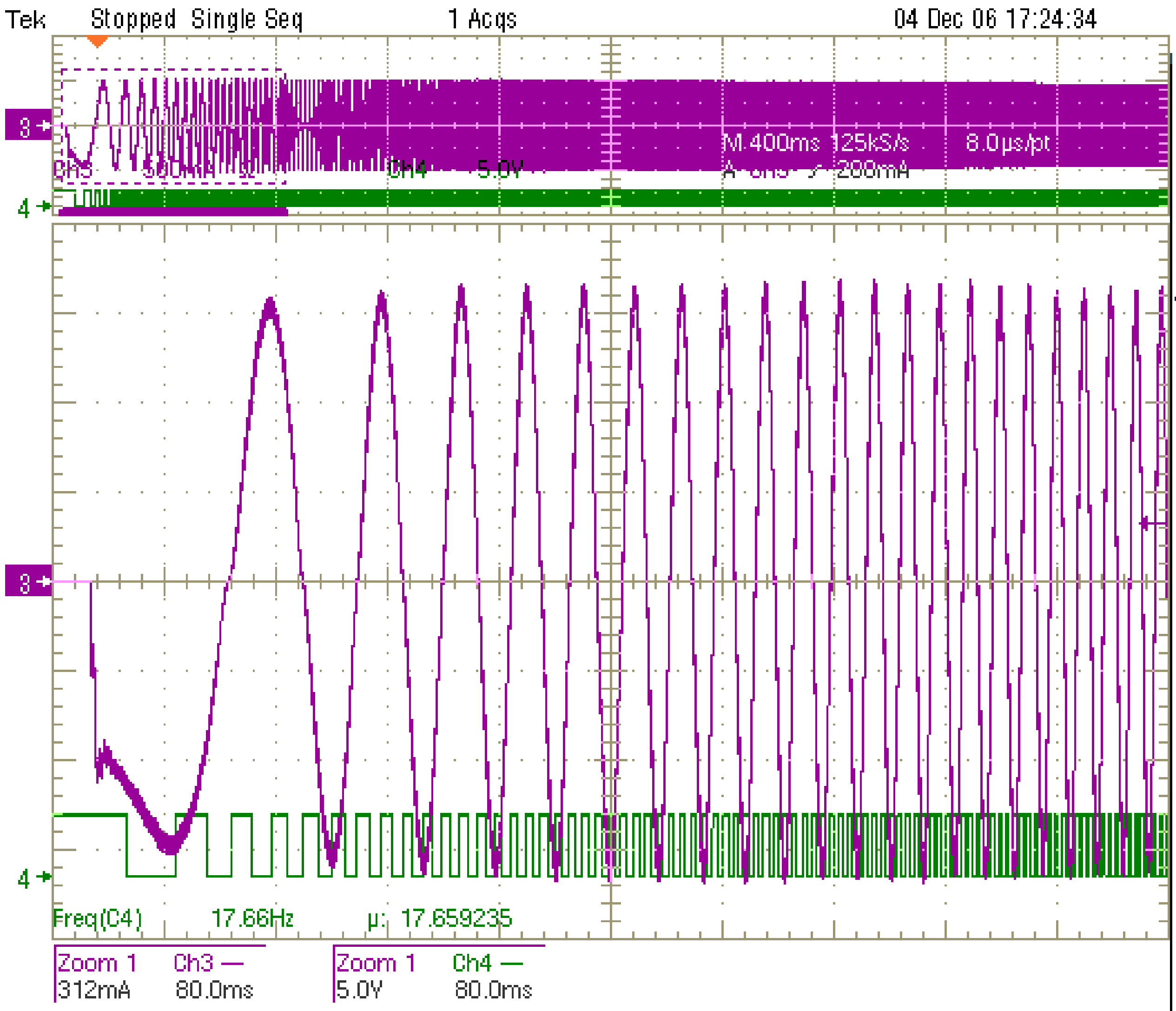
BEMF compensation

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

Device logic switches from different compensation parameters sets according to motor status

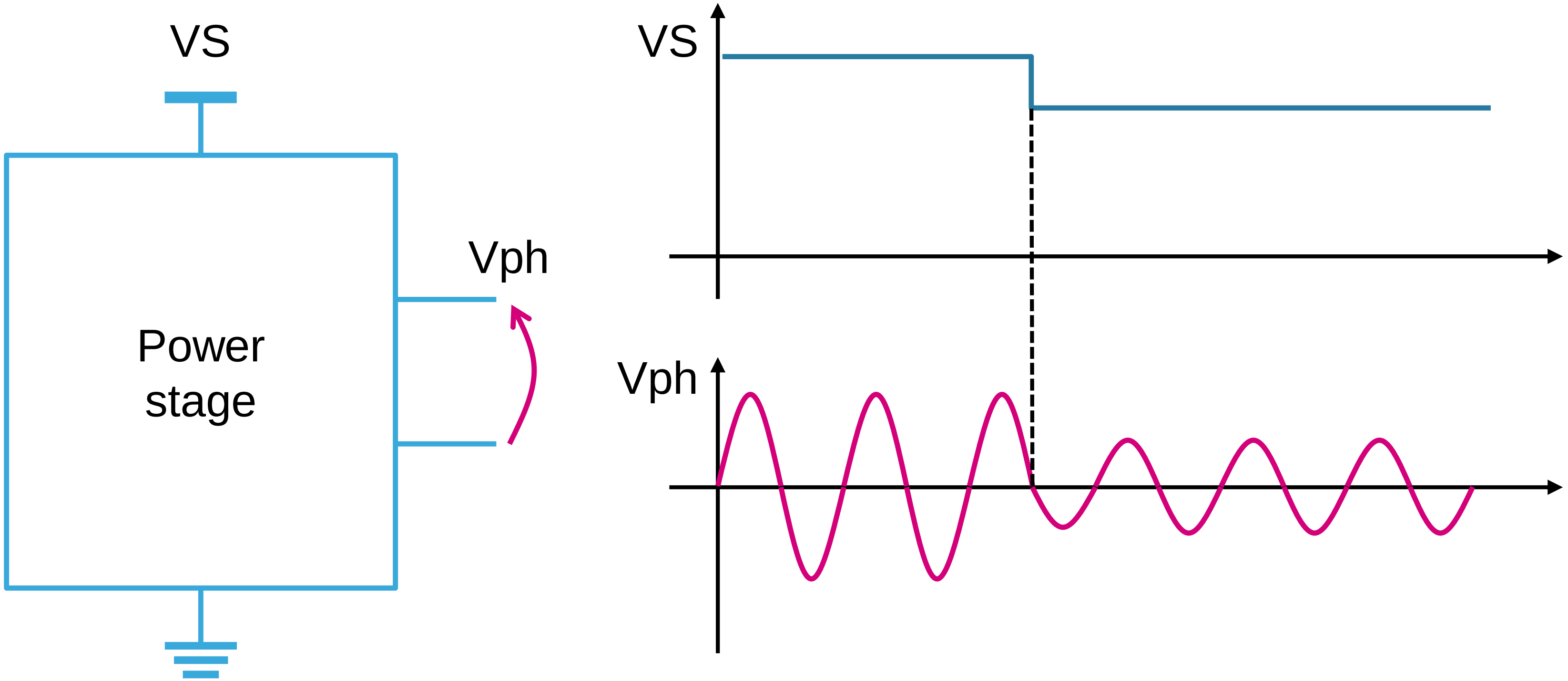


BEMF compensation

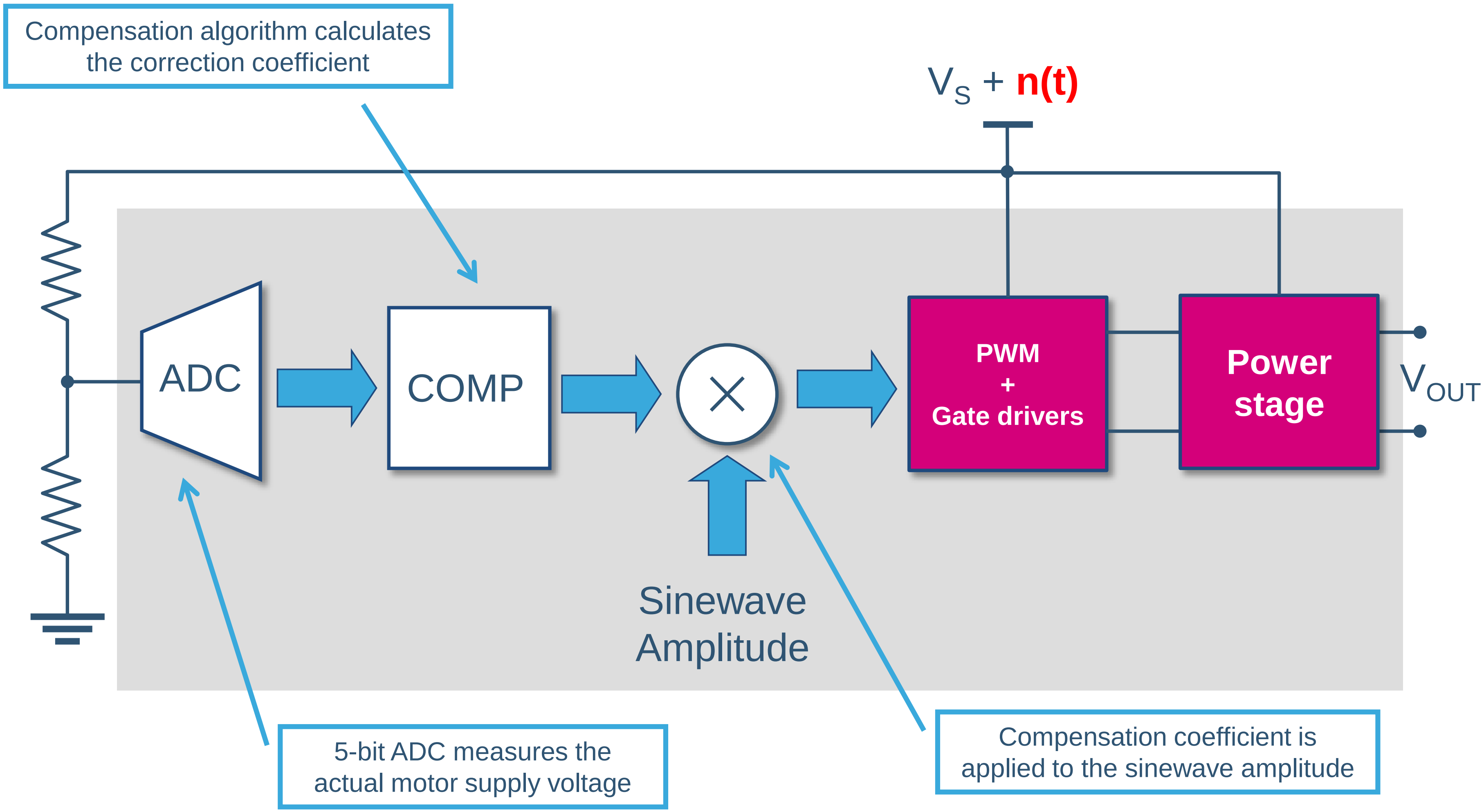


Supply voltage compensation

The voltage sinewaves are generated through a PWM modulation.
As a consequence, the actual phase voltage depends on the supply voltage of the power stage.

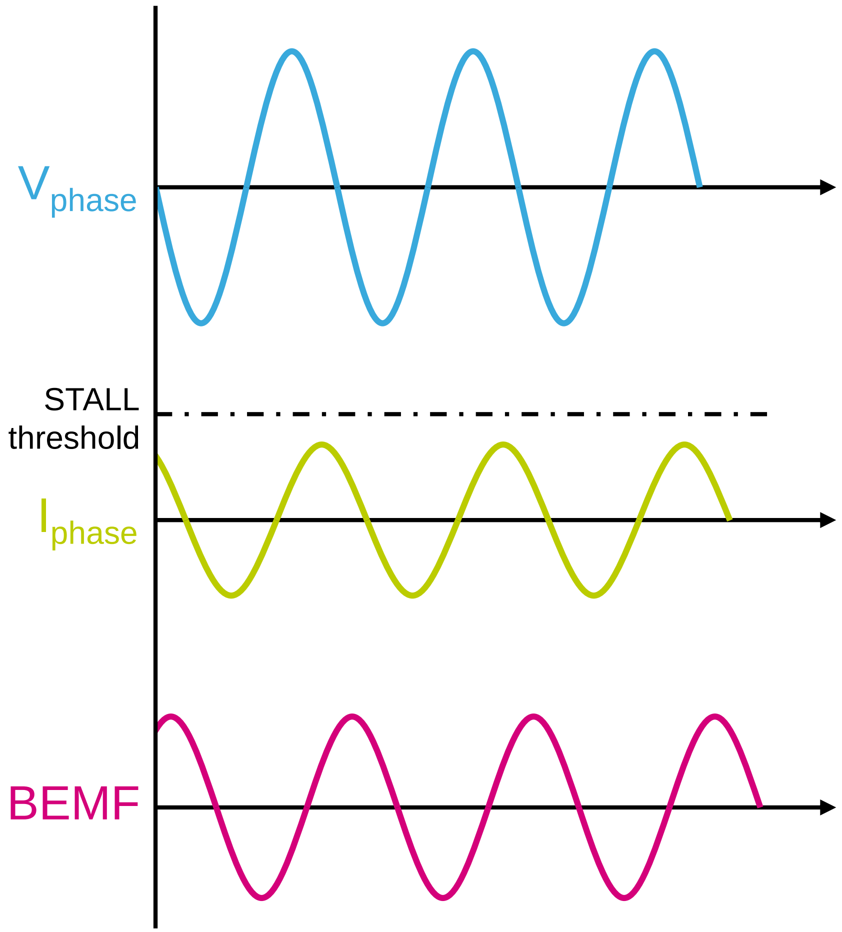


Supply voltage compensation

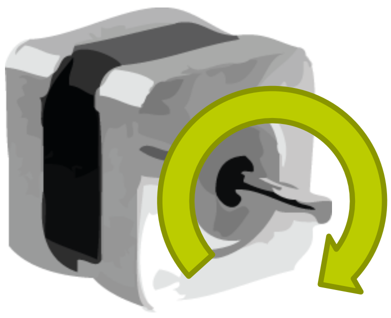


Sensorless stall detection

Using integrated current sensing and the adjustable STALL current threshold (i.e. voltage drop on the external MOSFET), a low cost and easy stall detection can be implemented.



Normal operation



Sensorless stall detection

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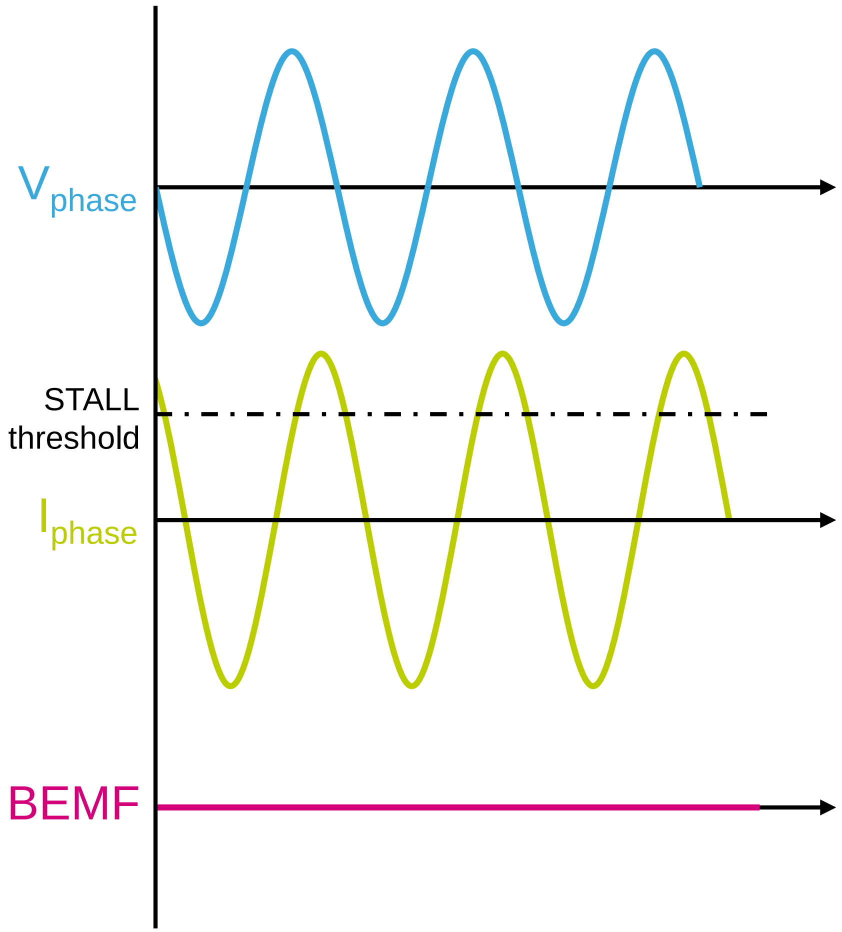
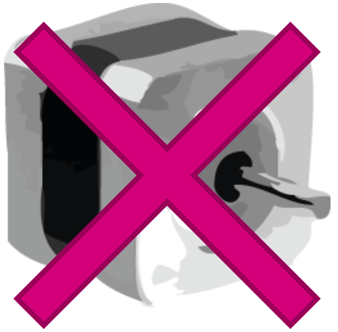
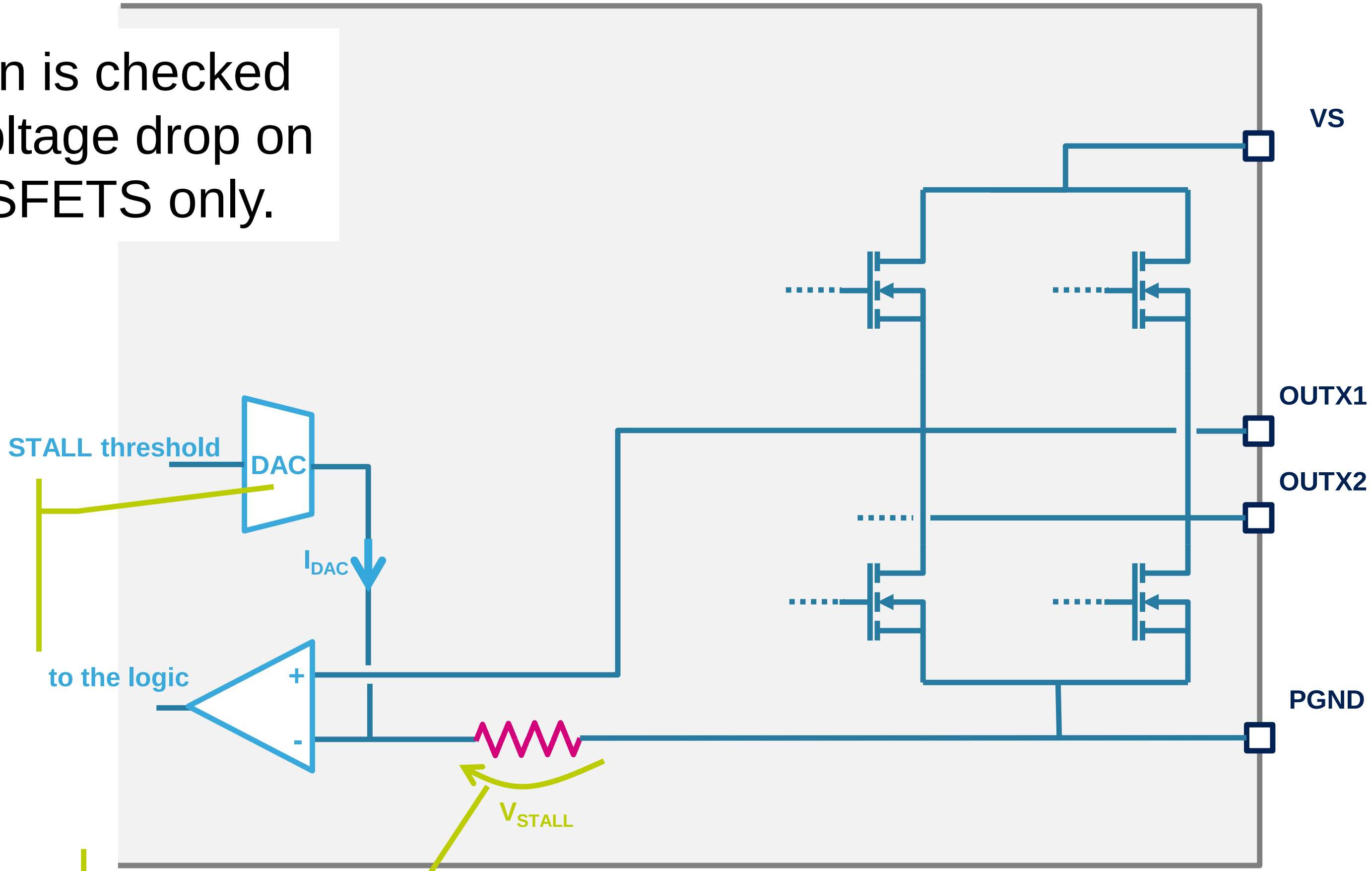


STALL!
BEMF is null and current is suddenly increased



Sensorless stall detection

The stall condition is checked measuring the voltage drop on the low-side MOSFETS only.



STALL DAC generates a reference current which is used to generate the reference voltage

Sensorless stall detection voltage threshold

Sensorless stall detection limitations

Stall detection performances can be reduced in the following conditions:

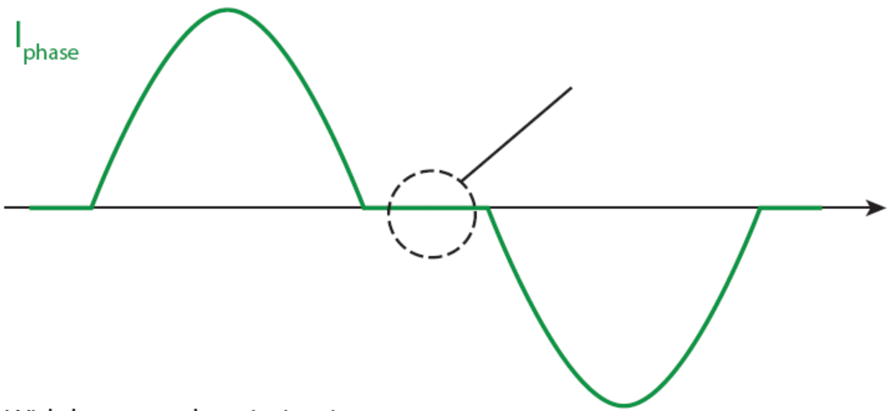
- Low speed
  (negligible BEMF value)
- High speed
  (current can be low because the low-pass filtering effect of the inductor)

Slow speed optimization

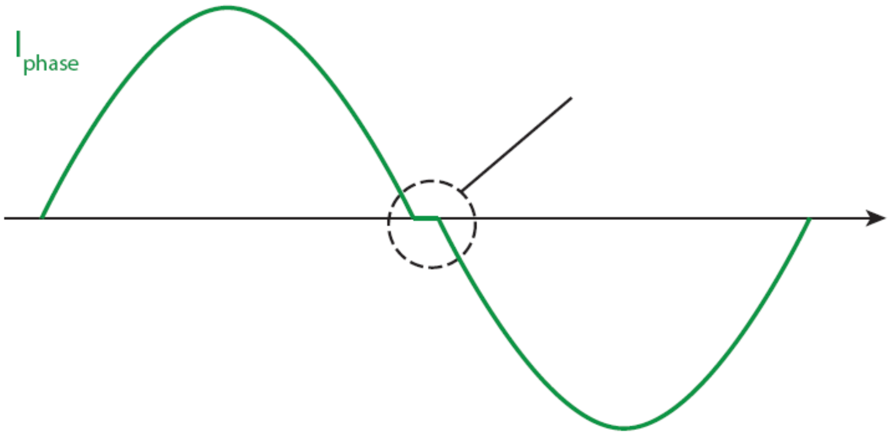
- During low-speed movements, the sinewave current could suffer from zero-crossing distortion.
  As result, **the motor rotation is discontinuous.**

- New low-speed optimization algorithm heavily reduces the distortion.
  Smoothness of the driving is increased.

Without low speed optimizazion



With low speed optimizazion

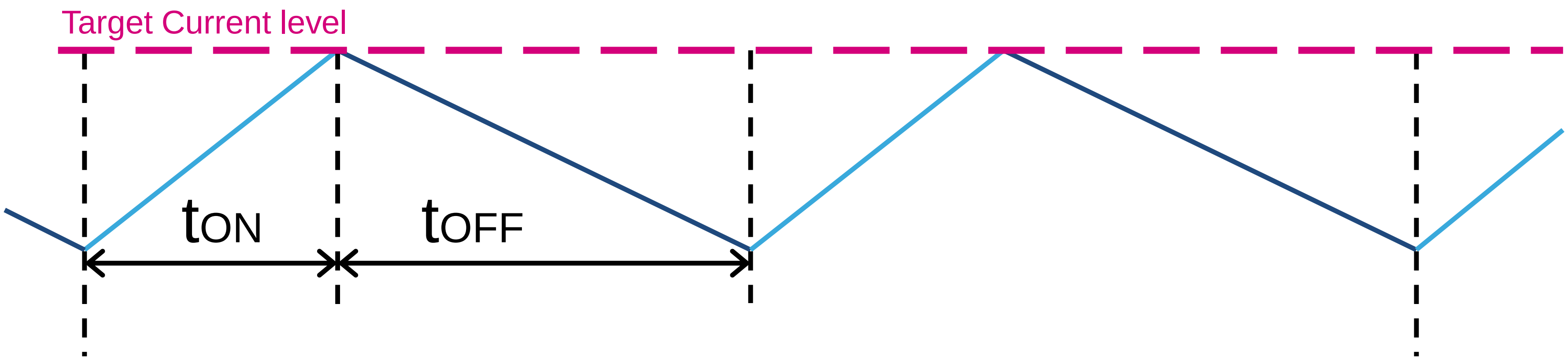


Advanced current control

Advanced 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

Challenges to perform the right decay

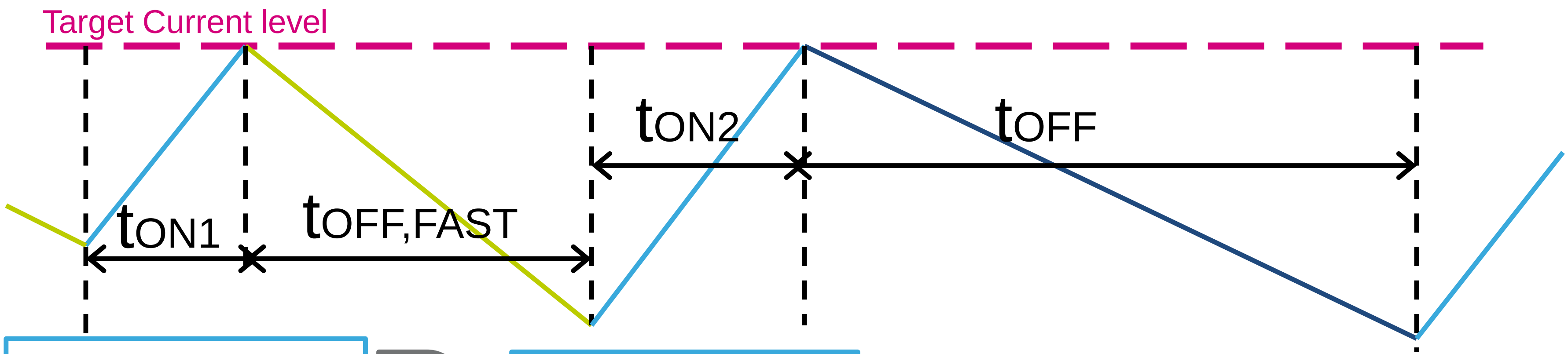


During the OFF state, both slow and fast decay must be used for a better control:

POWERSTEP01 performs an

AUTO-ADJUSTED DECAY

Auto-adjusted decay



tON1 < TON_MIN

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

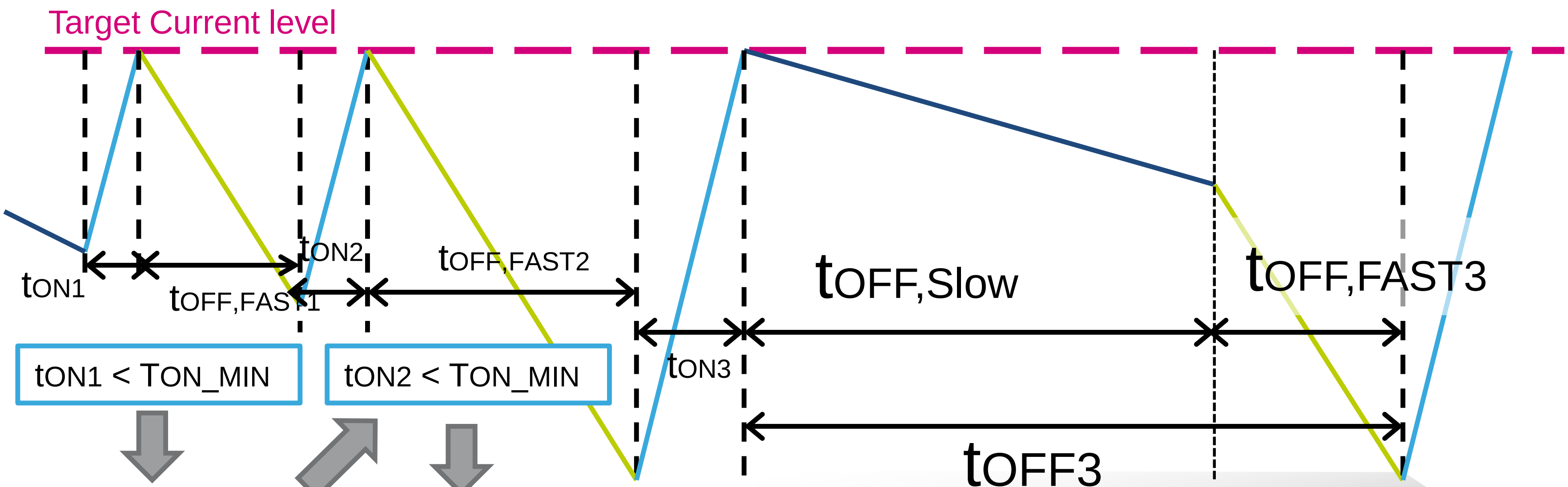
tON2 >TON_MIN

Slow decay for tOFF = TSW(*)

Parameter	Function
TON_MIN	Target minimum ON time
TOFF_FAST	Maximum fast decay duration
TSW	Fixed OFF time(*)

(*) No predictive control

Auto-adjusted decay



tON1 < TON_MIN

Fast decay for
tOFF,FAST1 =
TOFF_FAST/8

tON2 < TON_MIN

Fast decay for
tOFF,FAST2 =
TOFF_FAST/4

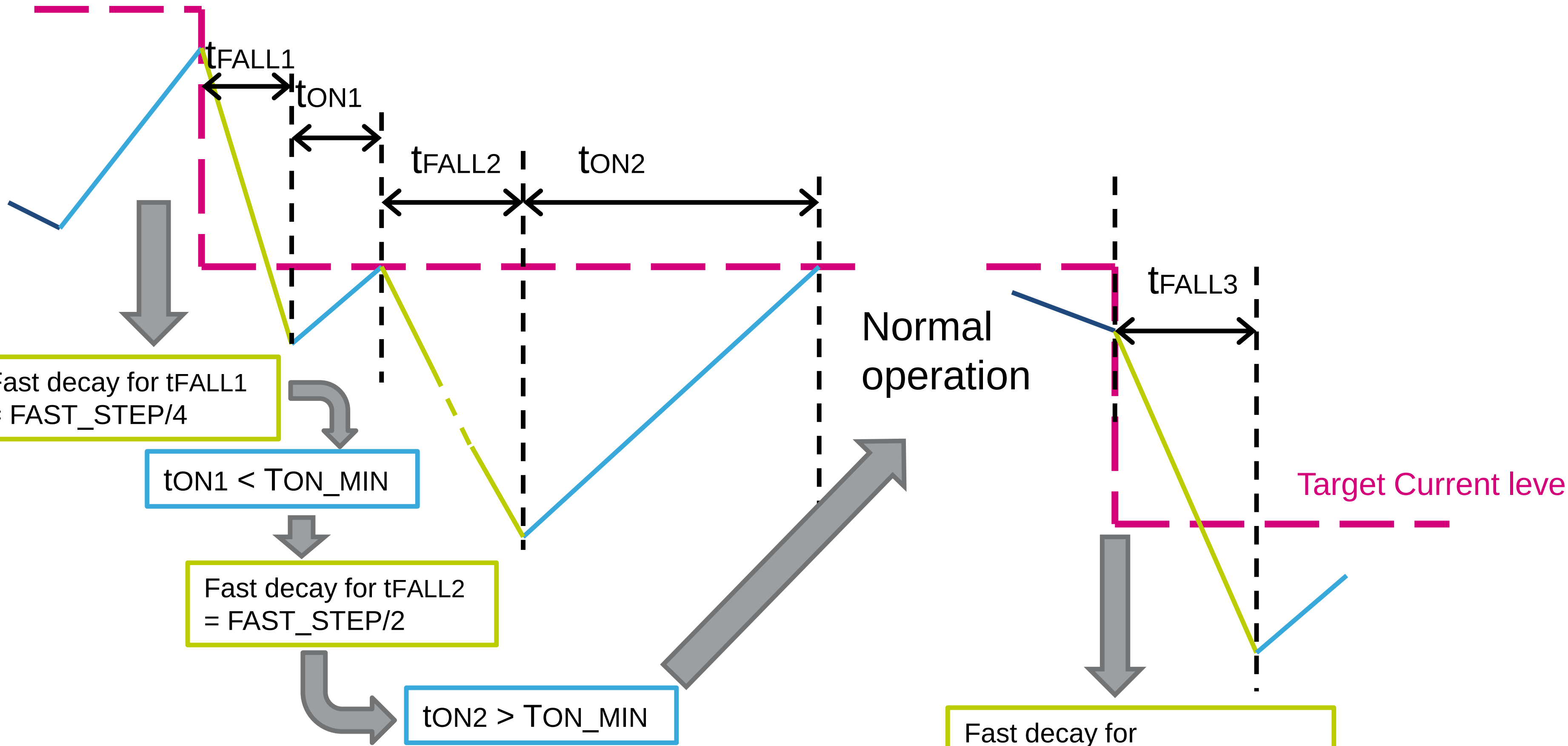
tON3 > TON_MIN

Mixed decay :
tOFF3 = TSW (*)
tOFF,FAST3 = tOFF,FAST2 =
TOFF_FAST/4
tOFF,Slow = tOFF3 – tOFF,FAST3

Parameter	Function
TON_MIN	Target minimum ON time
TOFF_FAST	Maximum fast decay duration
TSW	Fixed OFF time(*)

(*) No predictive control

Falling step control



Parameter	Function
TON_MIN	Target minimum ON time
FAST_STEP	Maximum fast decay duration during falling steps

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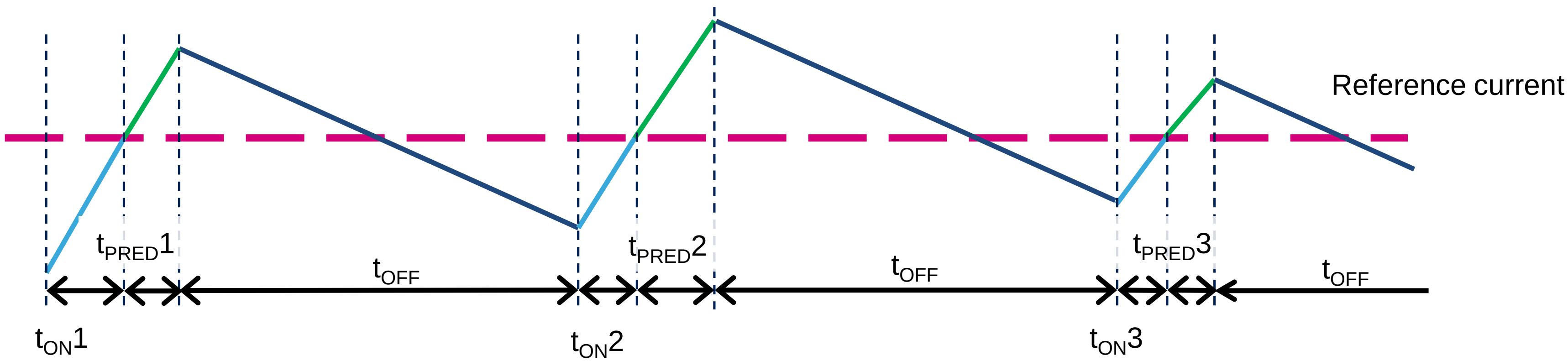
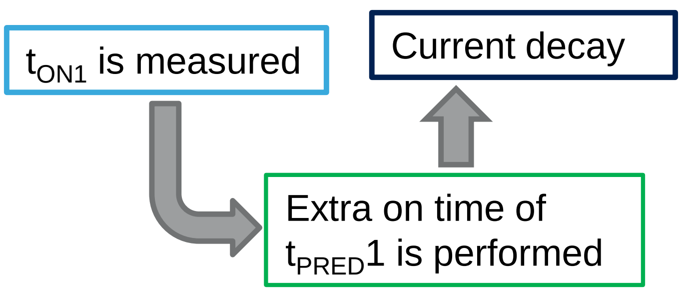
Predictive current control: average current



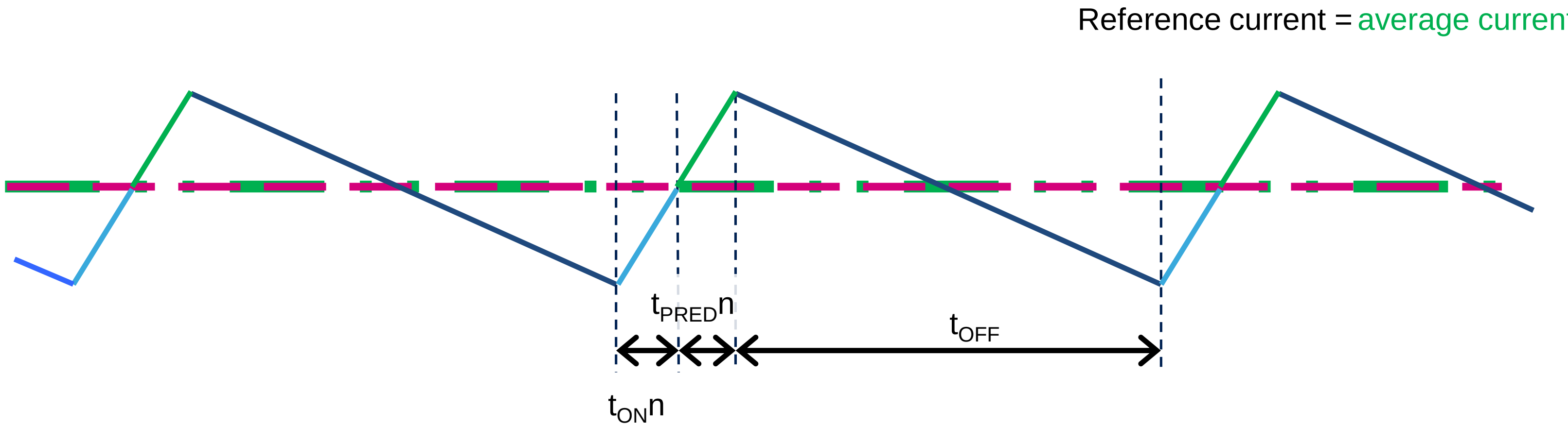


The extra on time is calculated cycle-by-cycle using the following formula:

$$t_{PRED}n = (t_{ON}n\text{-}1 + t_{ON}n)/2$$

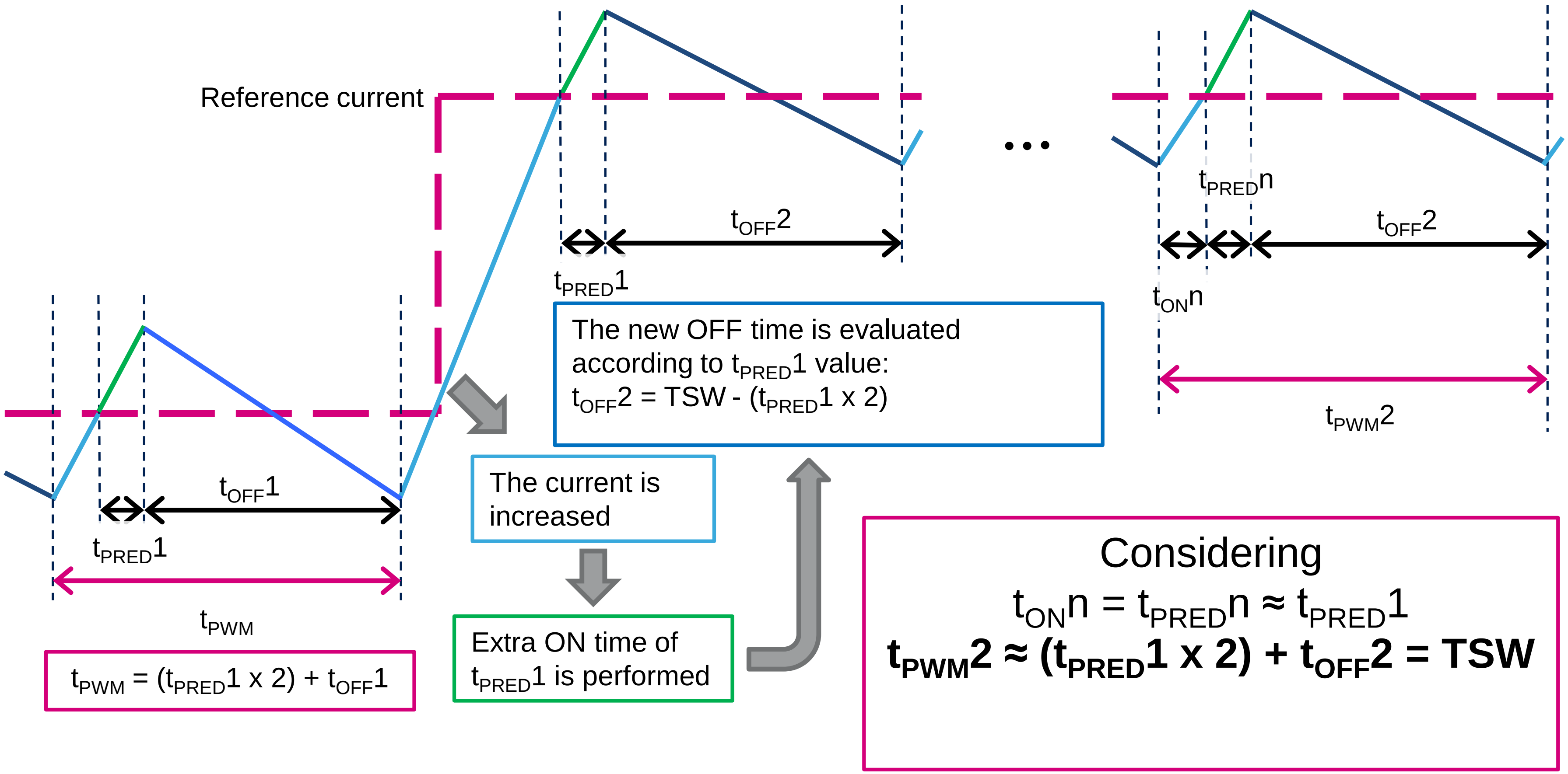
Note: The TON_MIN limit of the current control is checked on t_{ON} time only.
If t_{ON} < TON_MIN, no extra on time is performed and the decay adjustment sequence is performed.

Predictive current control: average current



When the system reaches the stability → $t_{PRED}n = t_{ON}n$
In this case, the average current is equal to the reference: the system implements a control of the average value of the current.

Predictive current control: switching freq.

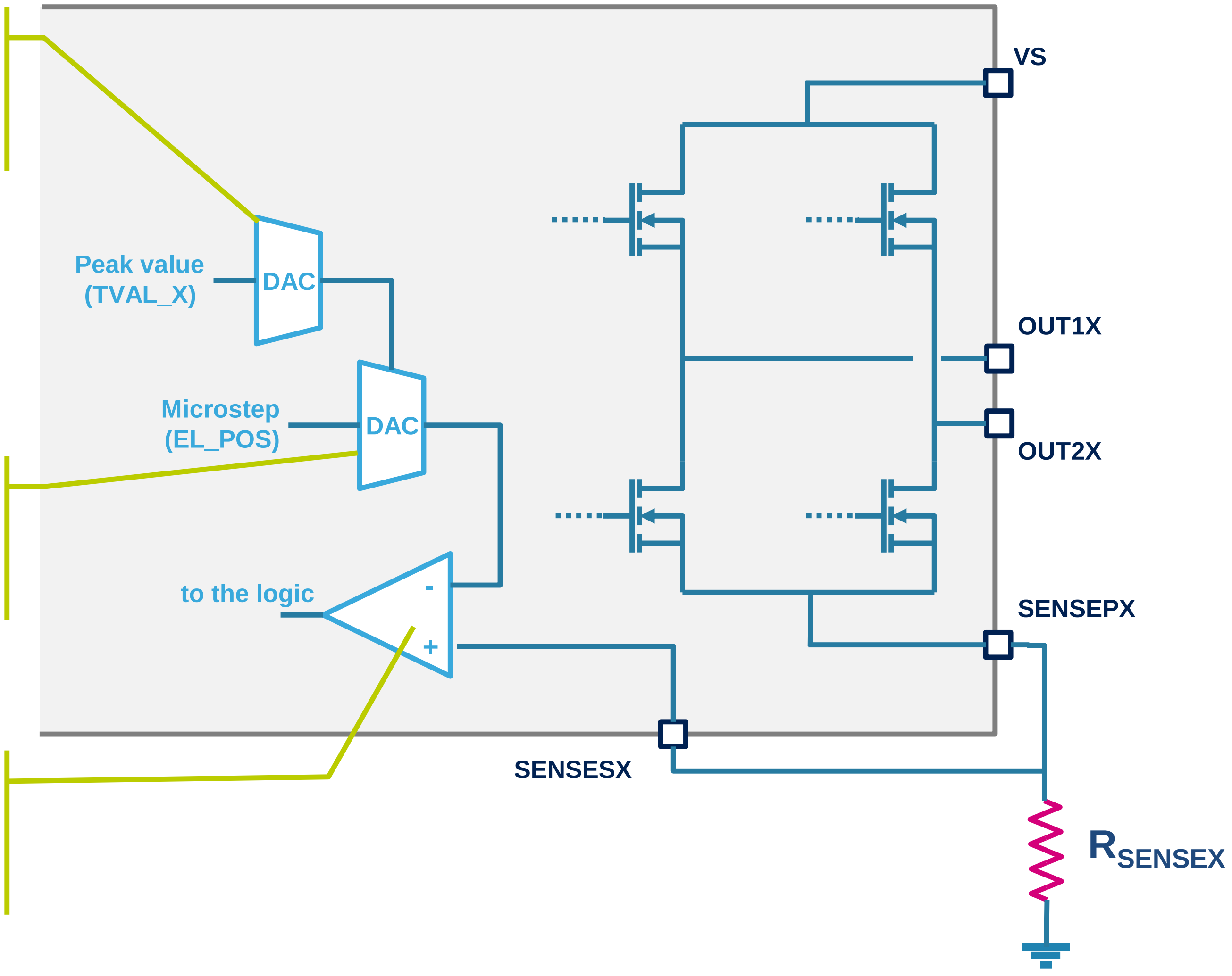


Current sensing

The peak DAC defines the amplitude of the microstepping sinewave (TVAL_X registers)

The microstep DAC returns a fraction of the peak according to the EL_POS register

The reference is compared to the voltage on the SENSE pin



Competitive advantages

- High level of integration
- Voltage mode driving and advanced current control
- Protected power stage
- Advanced diagnostics
- Extended power range
- Suitable for multi-motor applications