Using the Powerstep01 Stepper Motor Driver in Voltage and Current Mode

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STSPIN STSPIN™ Family

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Technology Tour 2019

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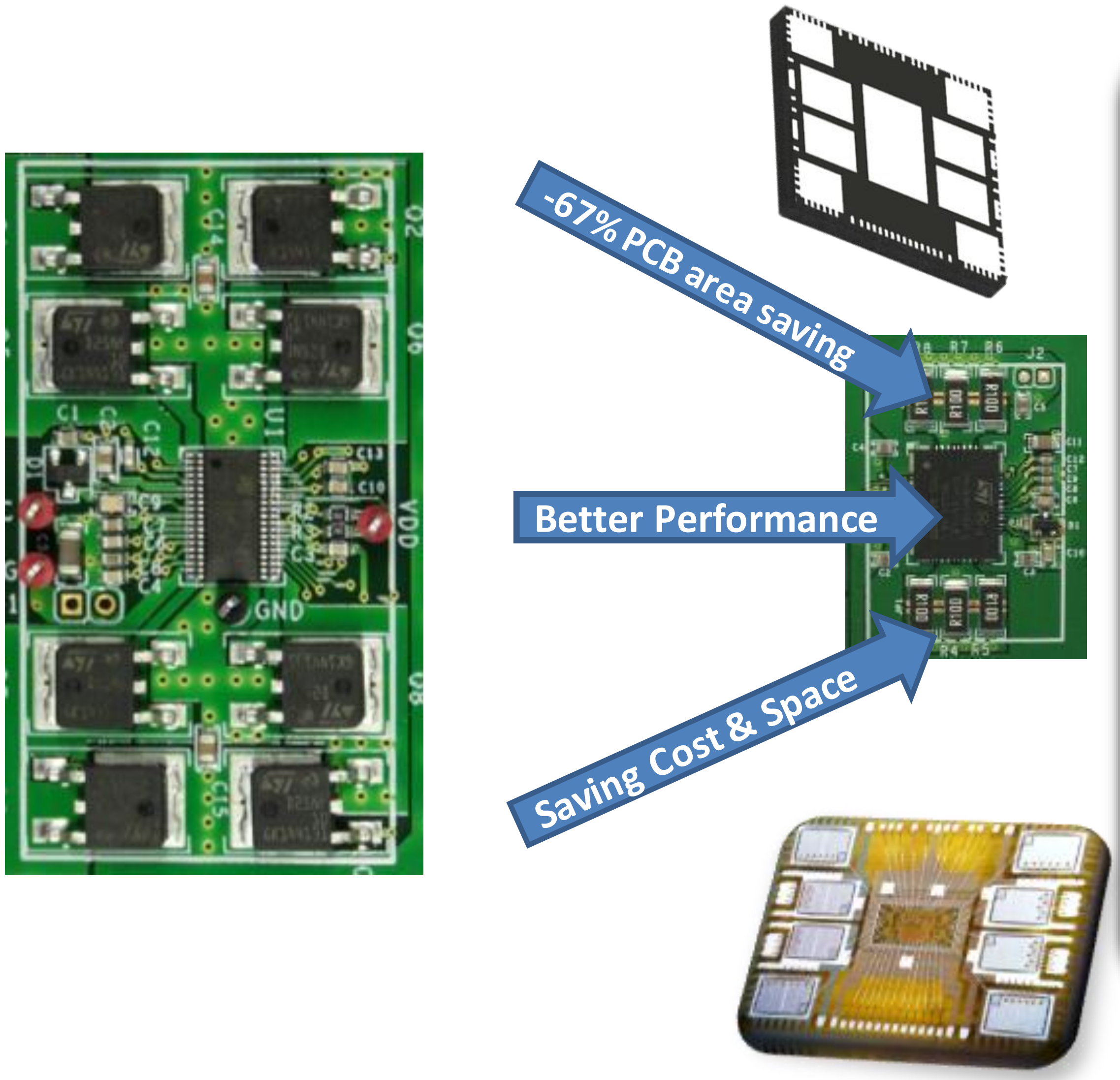
Agenda

- Introduction (15min)
  - Powerstep01: quick overview
  - ST portfolio for stepper motor drivers and controllers

- Current mode control (20 min)
  - PROs & CONs
  - Full-step vs Micro-stepping
  - Digital Motion Engine
  - Introduction to the STSPIN Family Evaluation Tool (GUI and Wizard)

- Voltage mode control (40 min)
  - PROs & CONs
  - Voltage mode setup
  - Stall detection
  - Resonance vs High speed

Powerstep01



Main Features

- System-in-Package integrating advanced stepper controller & 8 Pwr MOSFETs
- Supply Voltage: 8V – 85V
- **Dual full-bridge power stage**
  - **$10A_{rms}$ & $R_{DS(ON)}$ = 16mΩ**
- **Up to 128 µsteps**
- **Programmable between:**
  - Voltage mode control
  - Predictive current control with adaptive decay
- **SPI Interface**
- **Digital Motion Engine embedded**
  - High-level motion commands
  - Programmable Speed Profile & positioning
- **Digital diagnostics embedded (SPI)**
- **Advanced QFN package 14mm x 11mm x 1mm**
- Optional easy driving; clock & dir
- Over Current, 2 Over Temperatures UVLO & OVLO protections
- Programmable non-dissipative current control
- Sensorless stall detection
- Adjustable output slew-rate
- Integrated voltage regulators

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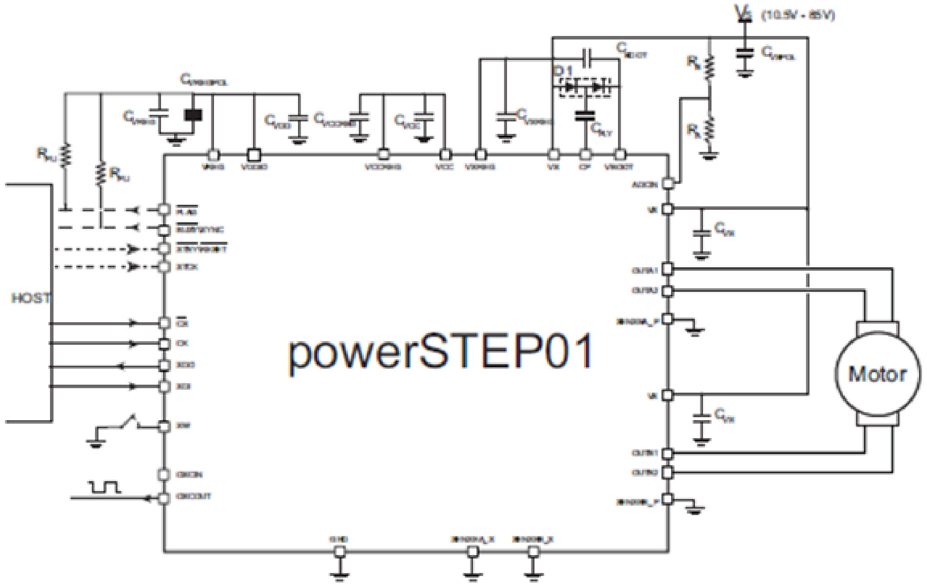
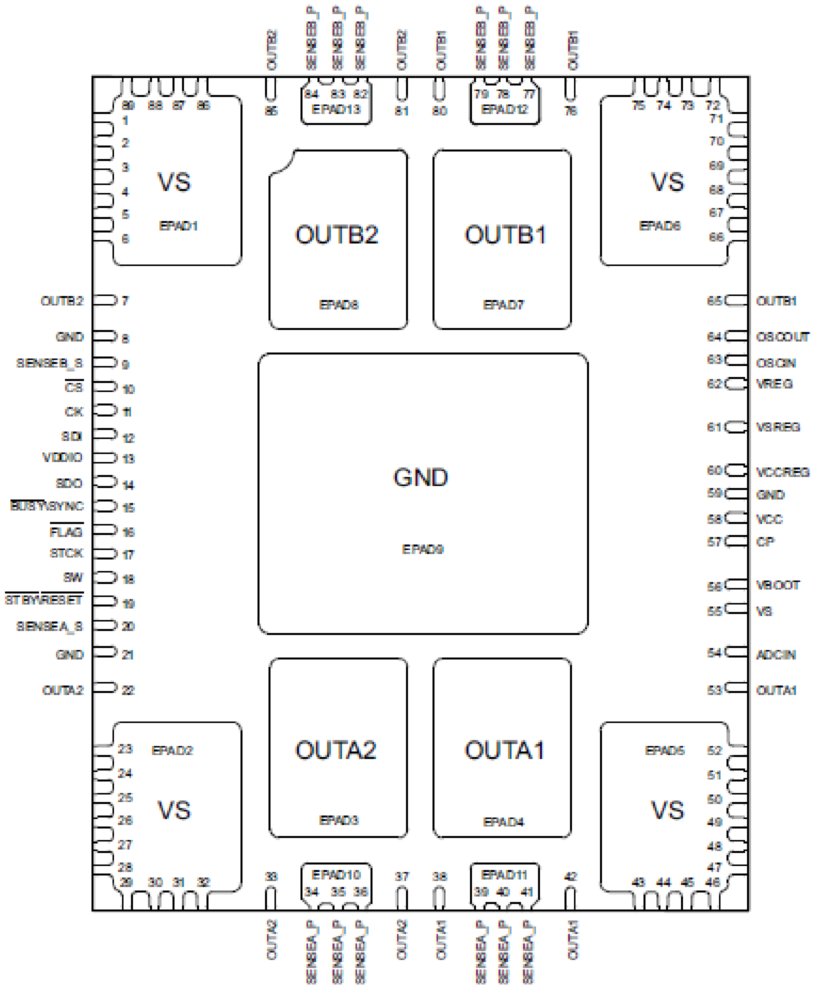
Powerstep01- System in Package

PowerSTEP01 Product Details

- System in Package - SiP
- 14mm x 11mm x 1mm
- Exposed PADs
- Thermally efficient
- Compact and simplified layout





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Evaluation Board - EVLPOWERSTEP01

- Evaluation board
- Application note
- Evaluation software with graphical user interface for motor driver ICs (STSPIN)
- IBU Motor Control & IPS universal interface

EVLPOWERSTEP01

System-in-package integrating microstepping controller and 10 A power MOSFETs demonstration board

Data brief

Features

- Voltage range from 10.5 V to 85 V
- 10 $A_{r.m.s.}$ maximum output current
- Up to 1/128 microstep
- Programmable speed profile and advanced commands
- Adjustable output slew rate
- SPI with daisy chain feature
- FLAG and BUSY LED indicators
- Flexible supply voltage management
- Suitable to be used in combination with STEVAL-PCC009V2

Description

The EVLPOWERSTEP01 demonstration board is a microstepping motor driver delivering up to 10 $A_{r.m.s.}$. In combination with the STEVAL-PCC009V2 communication board and the evaluation software, the board allows the user to investigate all the features of the powerSTEP01. In particular, the board can be used to check the performance and to regulate the parameters in order to fit the application requirements.

The EVLPOWERSTEP01 supports the daisy chain configuration making it suitable for the evaluation of the powerSTEP01 in multi motor applications.

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STSPIN Family vs Motors

Motors

Stepper

Non dissipative over curr.prot

52V / 8V

Dual H-bridge with controller
Integrated Stepper sequence generator

2.8Arms Rdson=0.3Ω	1.4Arms Rdson=0.7Ω
• L6208Q	• L6228Q
• L6208	• L6228

10V / 1.8V

All Compact QFN3x3mm
STBYconsumption<150nA

STSPIN220

up to 256usteps (MODE1-2)
Clock & direction control
STCK DIR (1 BIP. MOTOR)

1.3Arms
Rdson=0.4Ω

45V / 8V — 85V / 8V

SPI µStepper driver — **Monolithic & SiP for wide applications range**

dspin(1) dme ndc
• **L6470** (VM)
• **L6472** (pac)

3Arms
Rdson=0.28Ω

easyspin(3)
• **L6474**

3Arms
Rdson=0.28Ω

Dual full bridge

cspin (2) dme ndc
• **L6480** (VM)
• **L6482** (pac)

SiP (5) pac dme ndc
powerSTEP01
VQFPN 11x14mm
10Arms Rdson= 16mΩ

Brushed DC

Dual H-bridge

2.8Arms Rdson=0.3Ω	1.4Arms Rdson=0.7Ω
• L6205	• L6225
• L6206	• L6226
• L6207 (PWM)	• L6227(PWM)
• L6206Q (5)	• L6226Q
• L6207Q (PWM)	• L6227Q (PWM)

STSPIN240/50

Dual full Bridges(2BLDC)
direct input control PWMX PHX

1.3Arms
Rdson=0.4Ω

Three Phase (BLDC)

Triple half-bridge

1.4Arms Rdson=0.7Ω	2.8Arms Rdson=0.3Ω
• L6229	• L6234
• L6230	• L6235
• L6229Q	• L6235Q
• L6230Q	

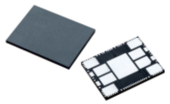
STSPIN230

Triple half bridge direct input control INXH INXL

1.3Arms
Rdson=0.4Ω

1. Motion engine+SPI+Power stage integrated
2. Motion engine+SPI+ dual full bridge gate driver for 8 Mosfet
3. Adaptive decay control, easy step clock and direction through direct pins and SPI
4. "Q" QFN package
5. SiP, digital controller + 8 power discrete MOSFETs+SPI 128usteps, VQFPN package ,sensorless stall detection

Pac=Predictive current control with adaptive decay
Dme= digital motion engine, generate motion profiles through commands sent over SPI= uses CS,CK,SDI,SDO
Ndc=non dissipative c sensing
VM = Voltage mode, 128microsteps



Current mode control

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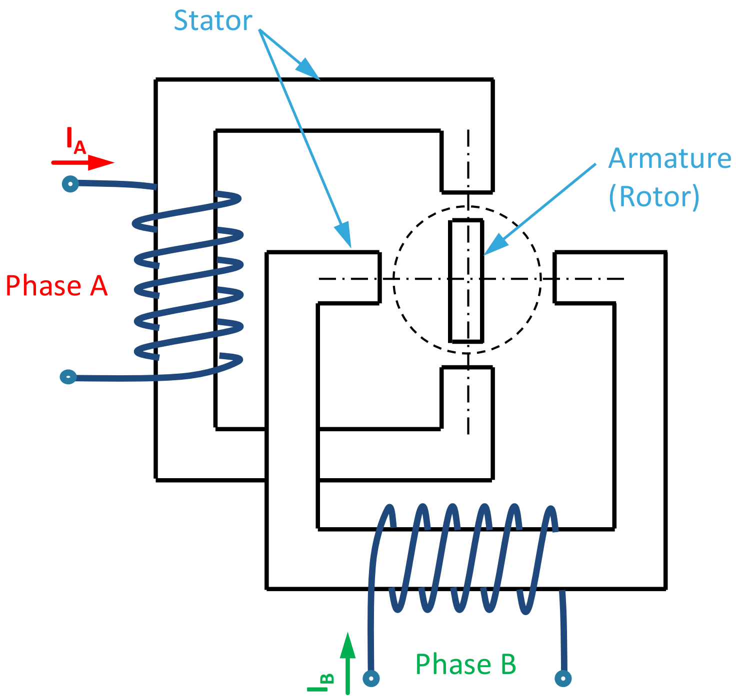
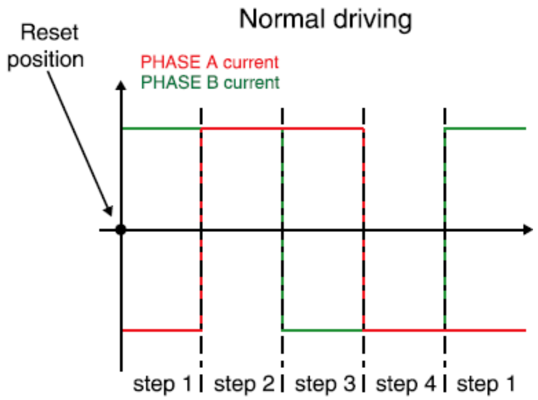
Two-Phase Bipolar Stepper Motors Structure & Benefits

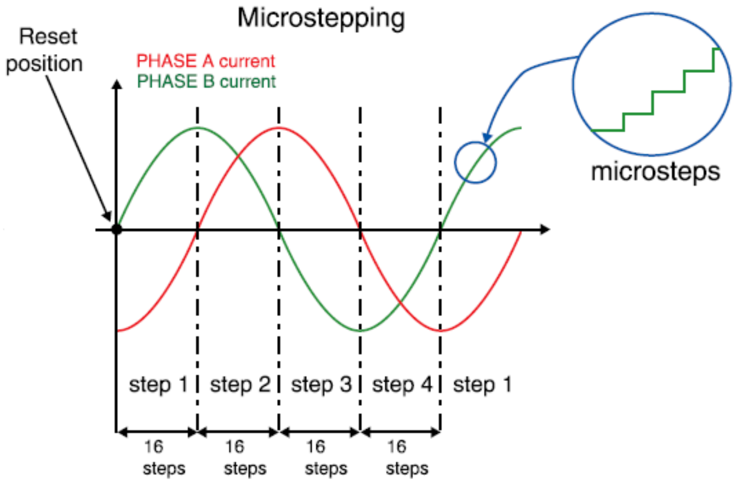
- By driving its phases with phase-shifted currents, bipolar stepper motors allow precise angular positioning and provide non-zero torque even when stopped and thus keep target position fixed.
- Moving from rectangular phase current waveforms to sine-waves the **microstepping** is achieved allowing even more precise positioning.

KEY BENEFITS

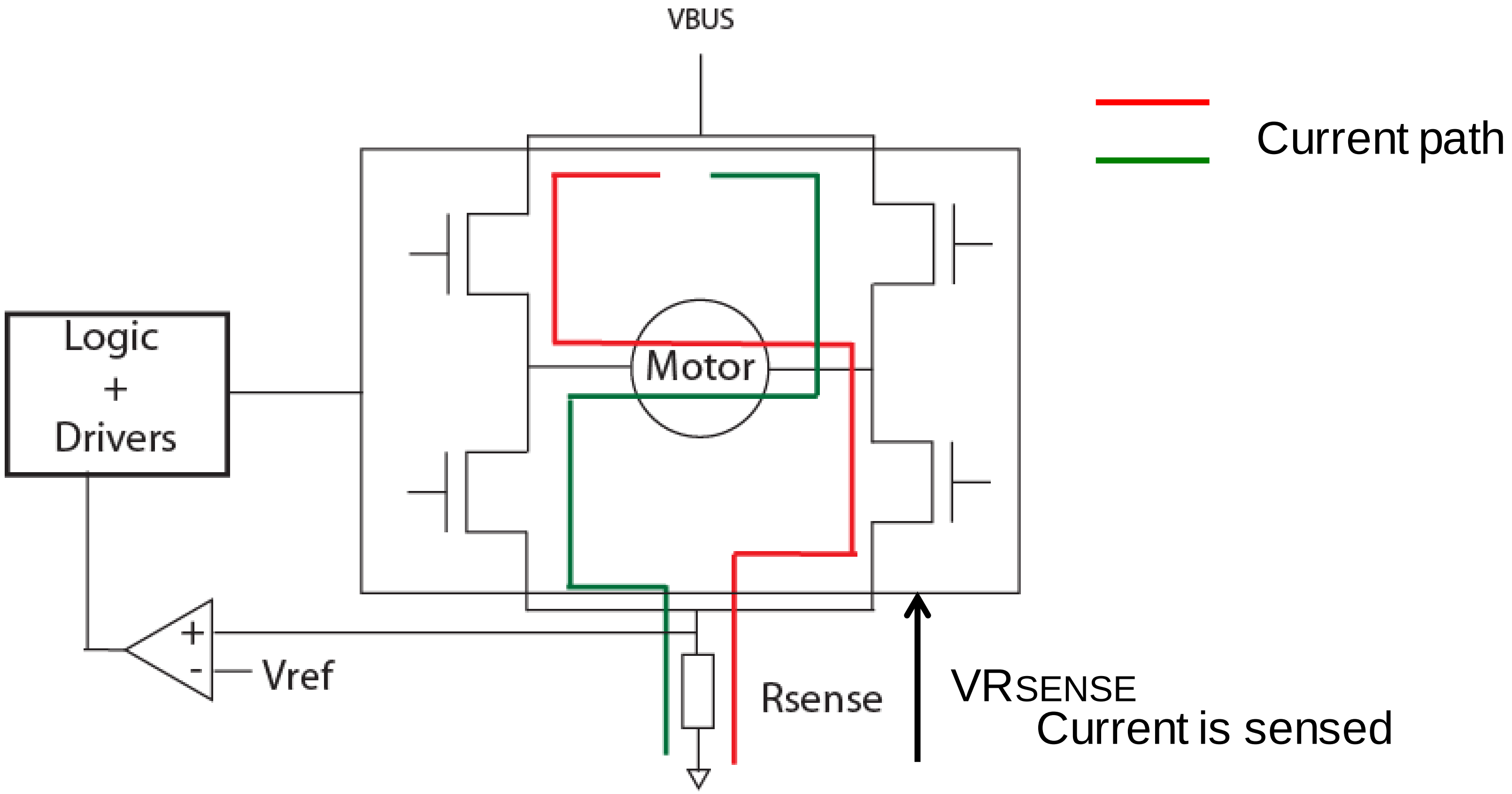
- Precise angular positioning
- Non-zero torque even when stopped
- Positioning applications with high demands on motion precision & smoothness







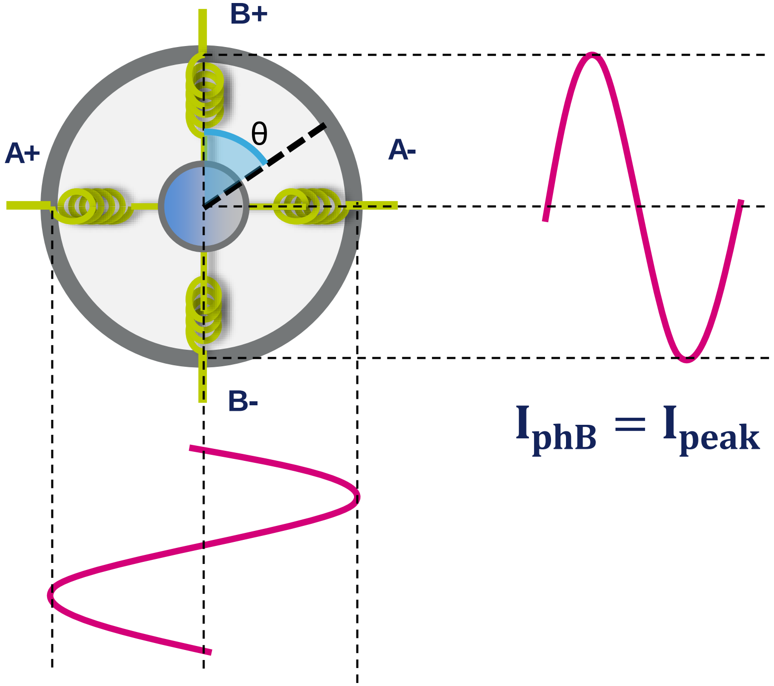
Standard Current Control



Current flows in the H-Bridge and then the resistance RSENSE. VRSENSE is compared to a voltage. If too low, the system will increase the current.

Microstepping in Stepper Motors

Driving the motor phases with sinusoidal currents with a phase relation of 90° (sine and cosine), it is possible to align the stator magnetic field in any possible direction.

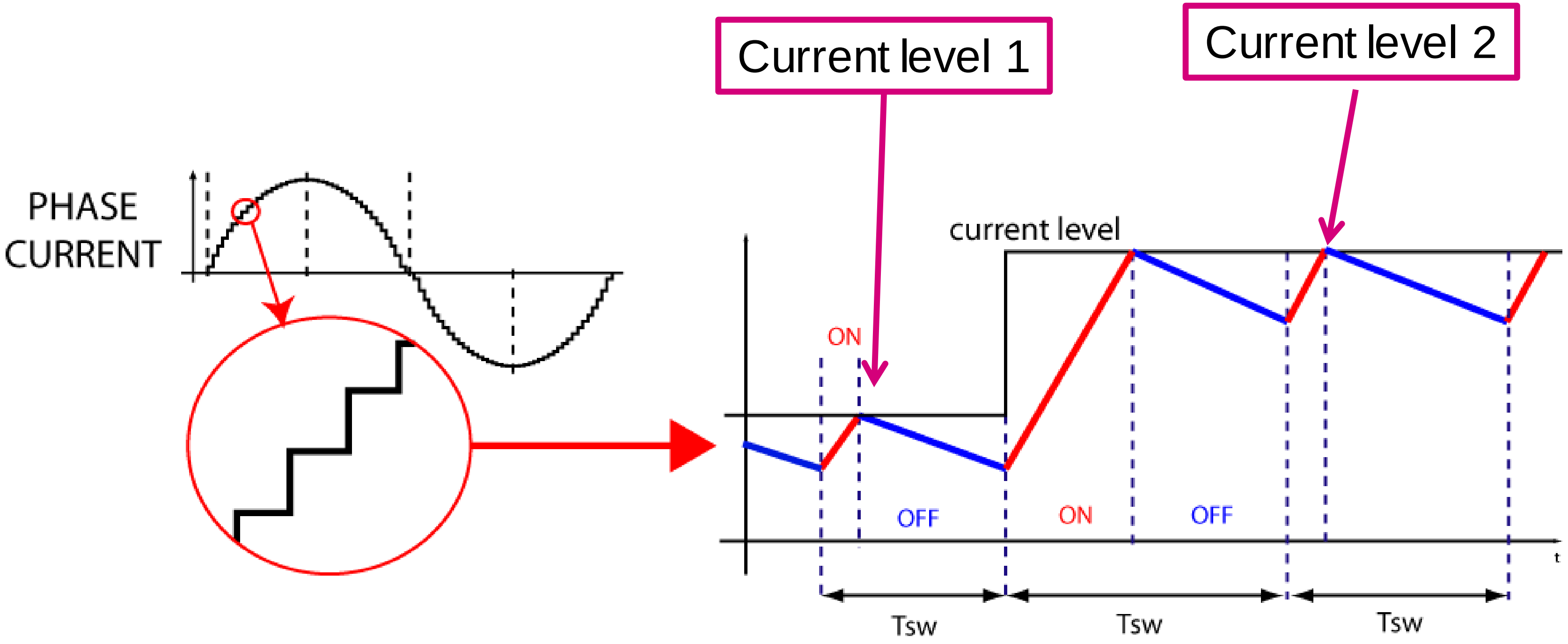


$$I_{phB} = I_{peak} \cdot \cos(\theta)$$

$$I_{phA} = I_{peak} \cdot \sin(\theta)$$

How the Sine Wave Is Generated

The curve is an approximation of a sine wave. The current is increased or decreased by steps

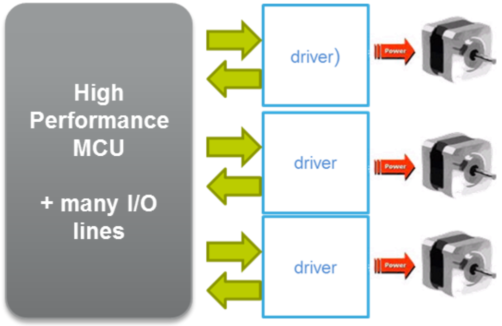


Digital Motion Engine

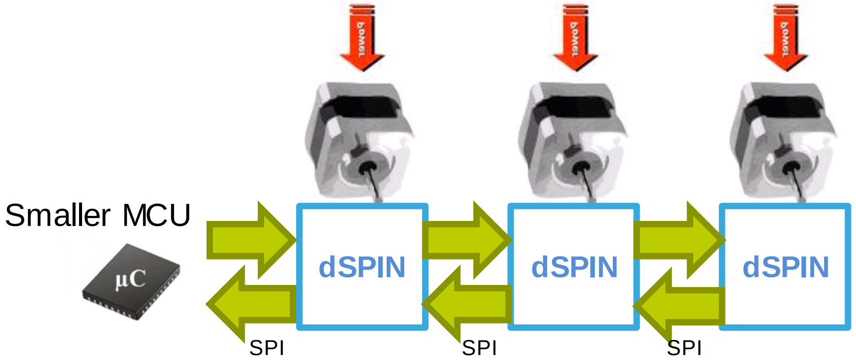
Application benefits

- No need of complex subroutines development, just simple commands via SPI (position, speed profile)
- Lighter architecture, smaller MCU
- Higher precision and smoothness in the motor control, full set of protection

standard APPROACH



ST APPROACH: simpler, cheaper



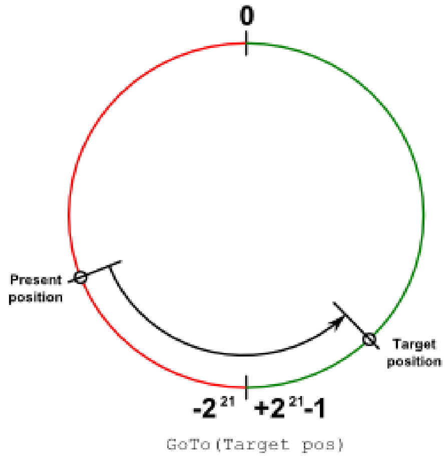
STSPINTM Digital – Highlights

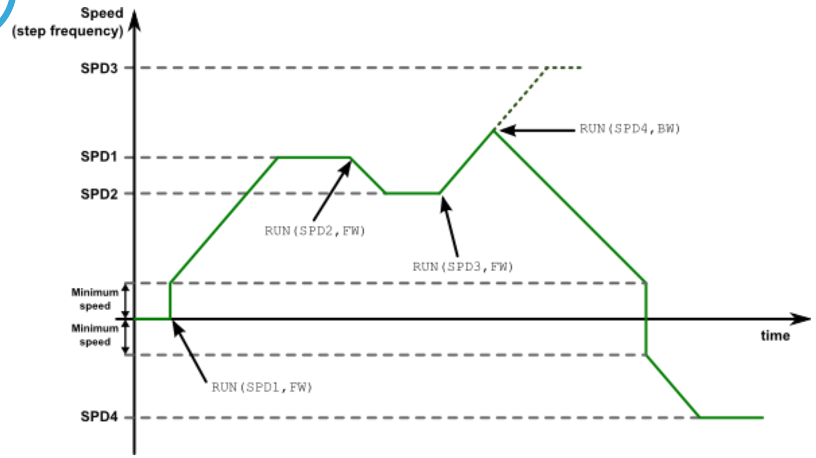
How does the Digital Motion Engine work ?

μC sends to DME high level commands

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

STSPIN$_{digital}$ generates the motion





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STSPIN™ Digital – Highlights

How does the Digital Motion Engine work ?

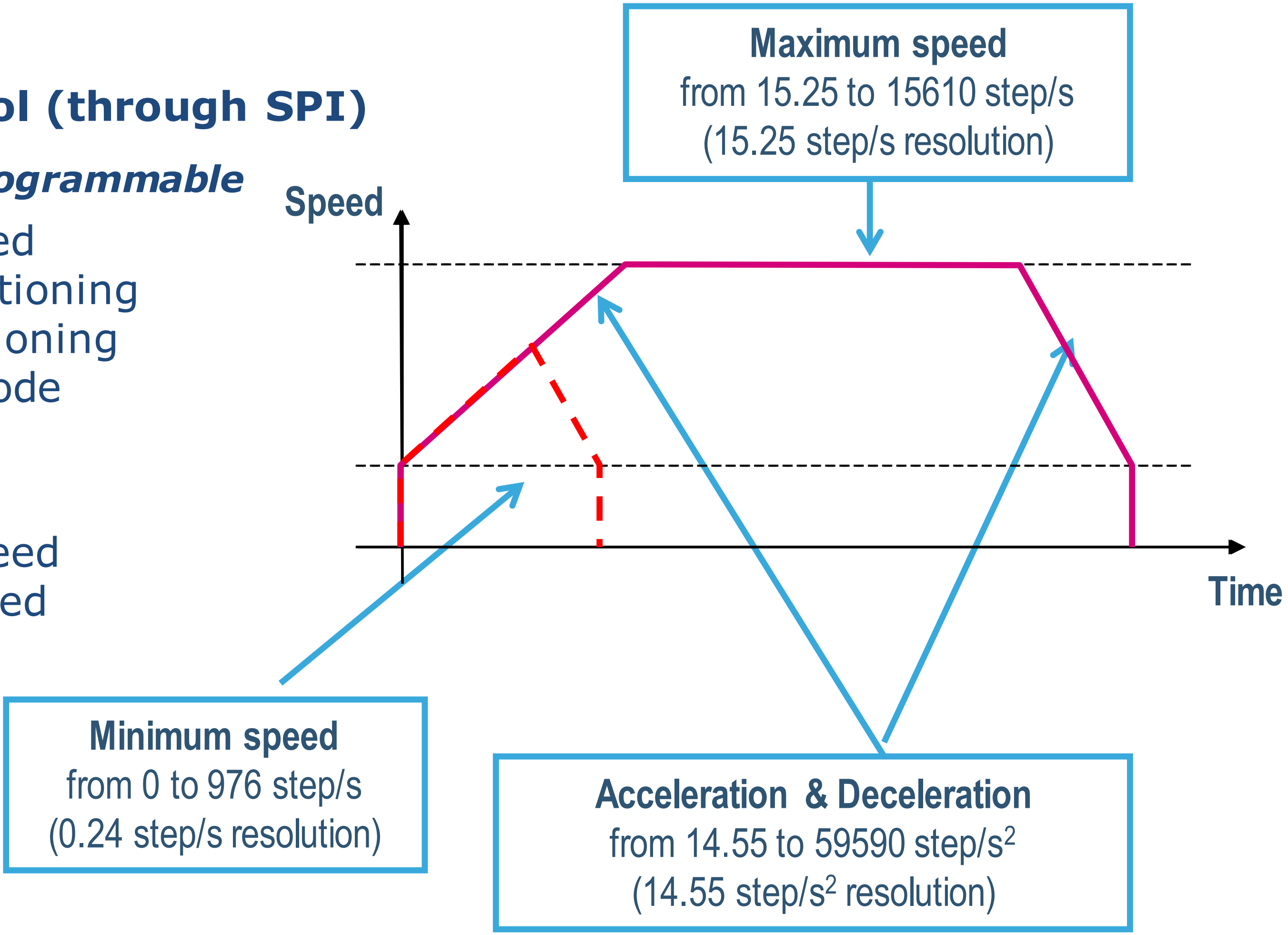
- DME embeds fully programmable speed profile boundaries

Full Digital Control (through SPI)

➔ ***Motion profile programmable***

- constant speed
- absolute positioning
- relative positioning
- step-clock mode

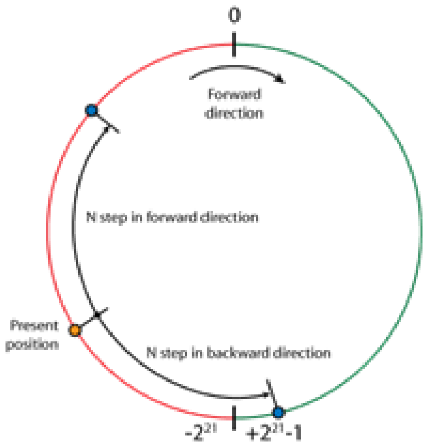
- Acceleration
- Deceleration
- Maximum speed
- Minimum speed

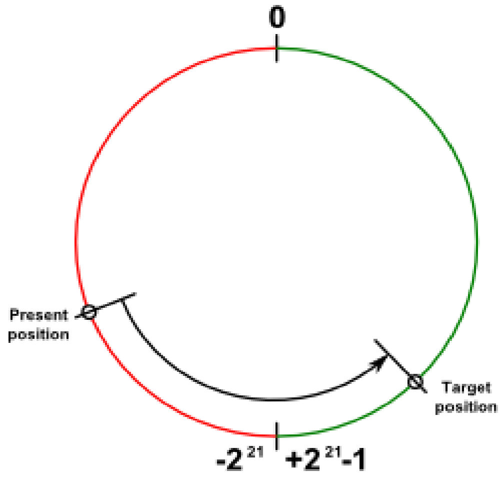


STSPIN^{TM} Digital – Highlights

Digital Motion Engine – Example of high-level commands

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

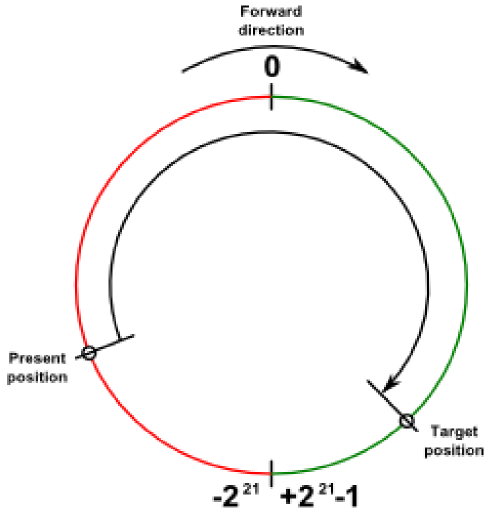




GoTo(Target pos)

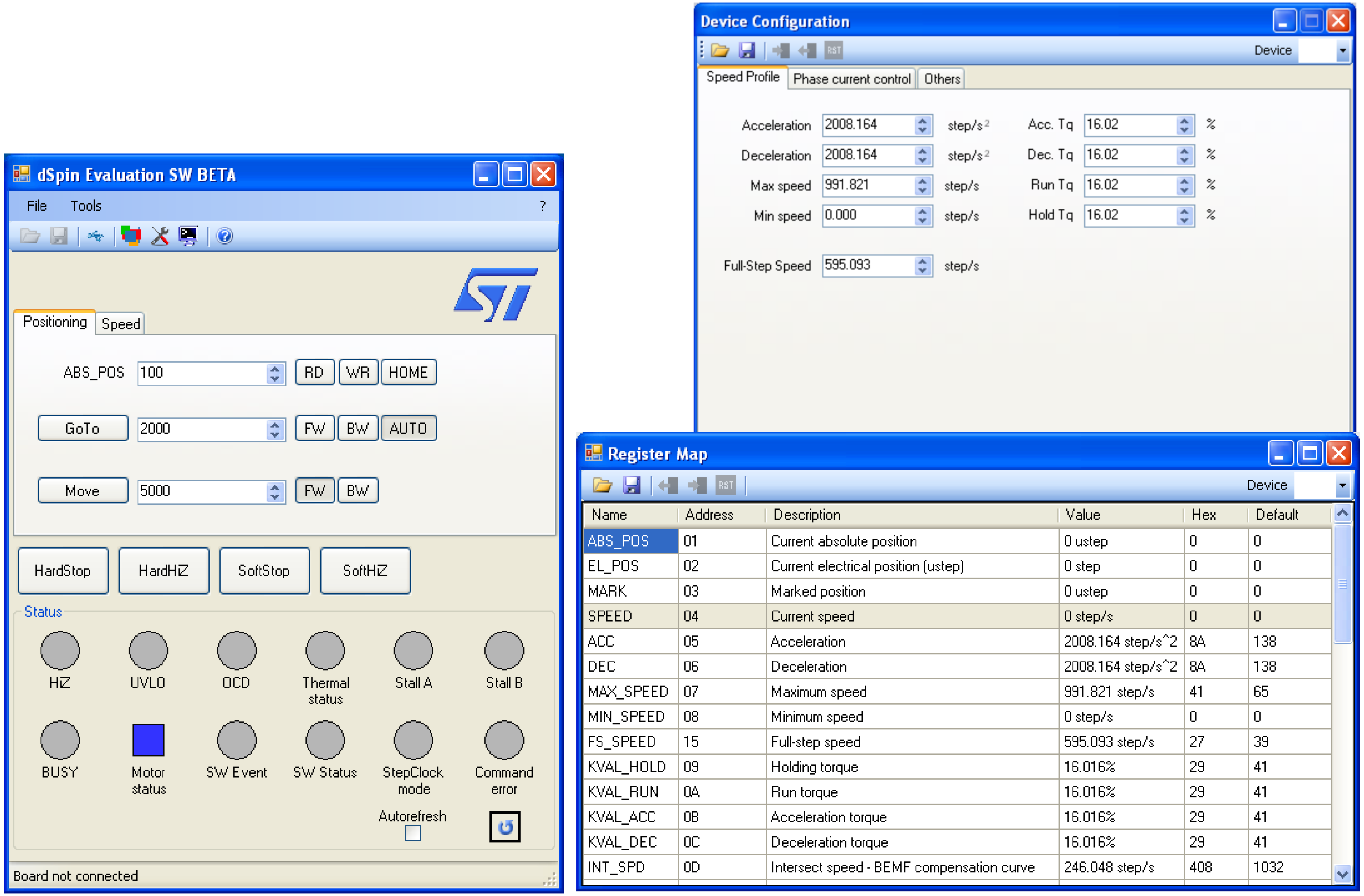
GoTo(Target) command: reach the target position using shortest path
This command can be performed only when motor is stopped or is running at constant speed

GoTo_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)

Live Demonstration
SPINFamily Evaluation Tool



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Voltage mode control

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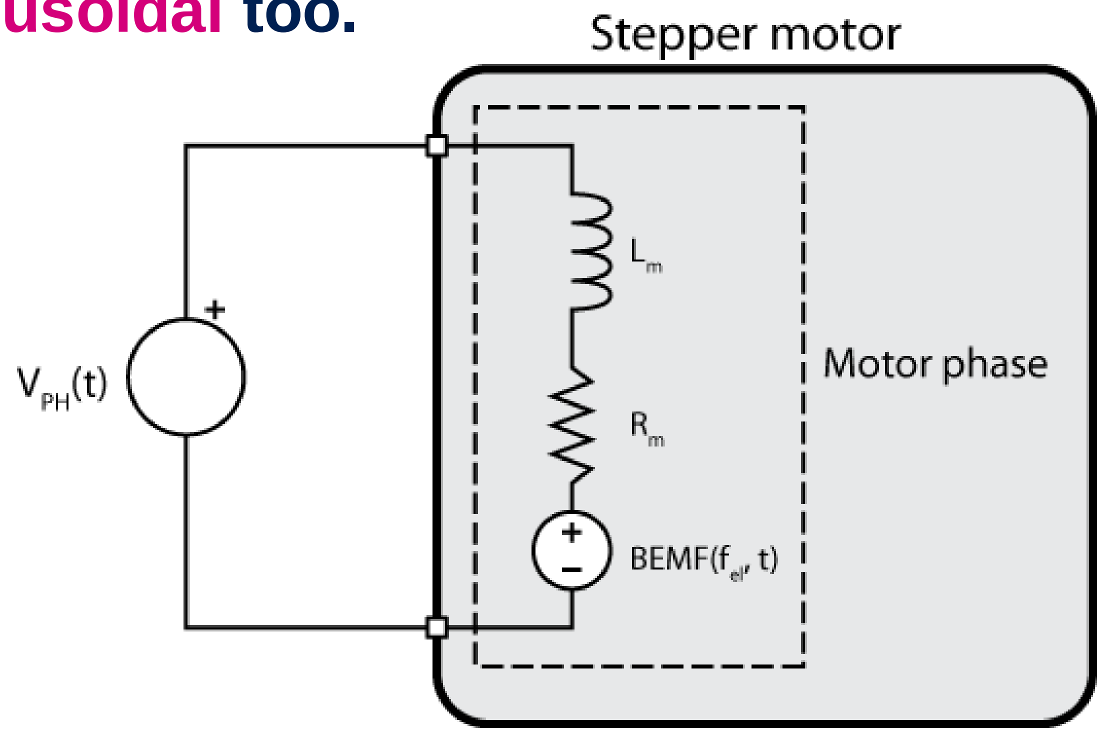
Voltage Mode Basics

Voltage mode is based on the linear model of stepper motors

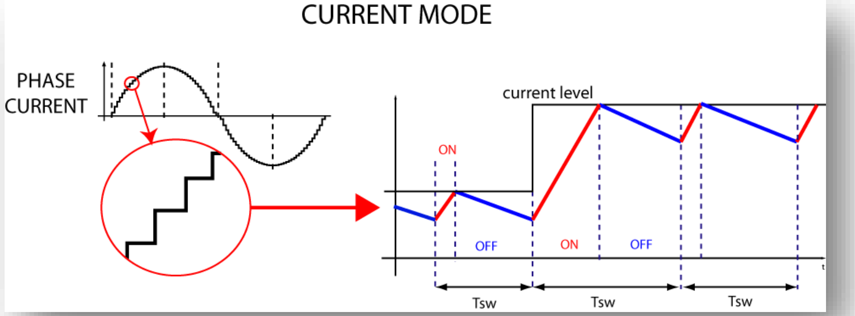
If a voltage sinewave is applied to a stepper motor phase the resulting current is sinusoidal too.



Voltage Mode Control

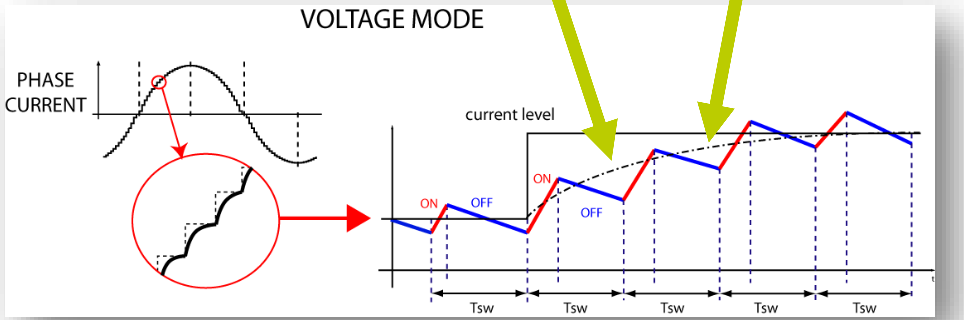
From current to voltage mode

- 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



Average current is controlled.
Accurate positioning

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



Constant switching frequency
Torque ripple and EMI are under control.

Voltage Mode vs. Current Mode

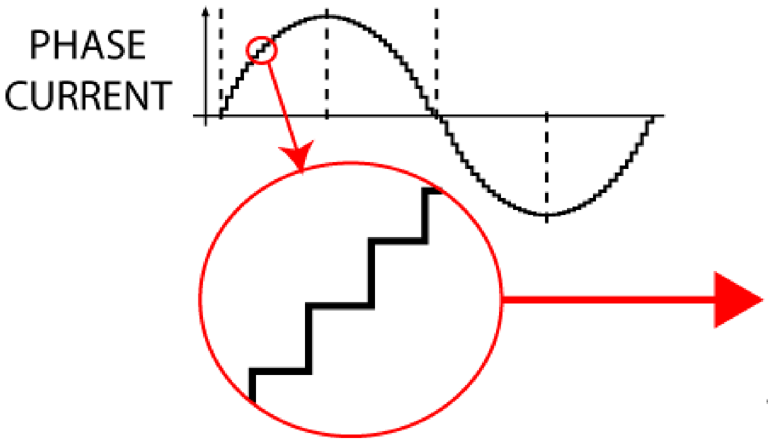
Current mode driving

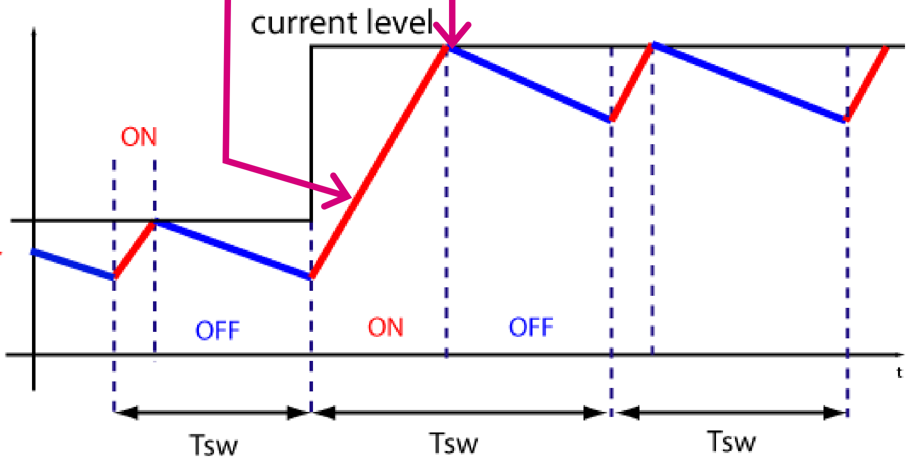
Abrupt current changes cause strong mechanical vibrations.
Current mode tries to follow even non idealities
(reference quantization and sampling)

Noisy and jerky motion.

Peak current is controlled.
Average current value is
different from target one.

Inaccurate positioning





Non constant switching freq.

Torque ripple is difficult to control.

Voltage Mode vs. Current Mode

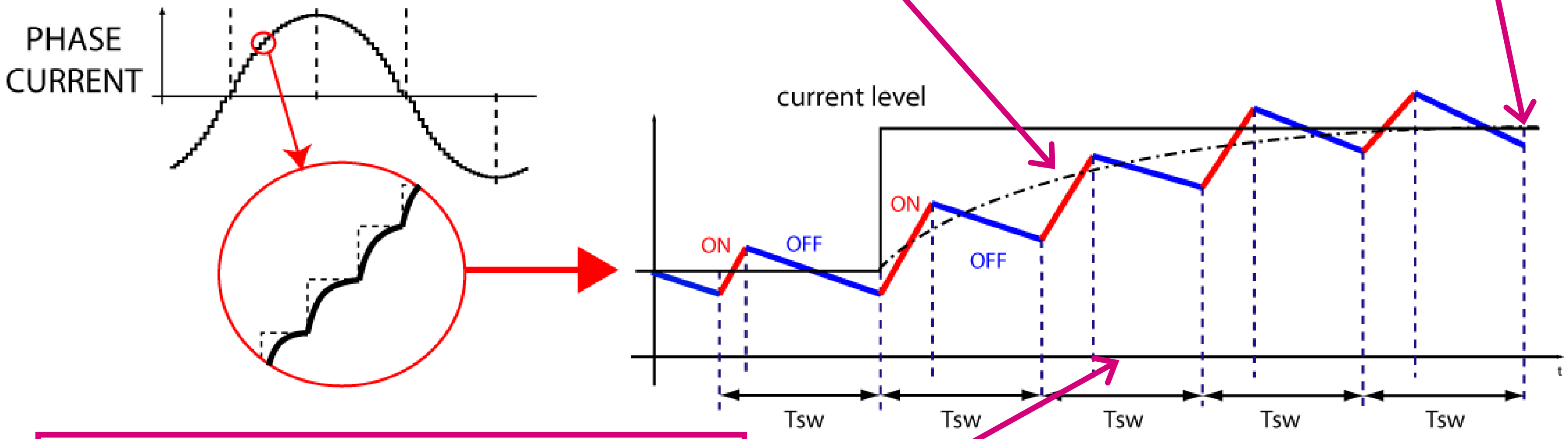
Voltage mode driving

Smooth current transient reduces mechanical vibrations.

Motor movement is soft and silent.

Average current is controlled.

Accurate positioning.



Constant switching freq.

Torque ripple is under control.

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Innovative Voltage Mode control

Voltage Mode Drawbacks	Solutions Implemented on powerstep01
✘ 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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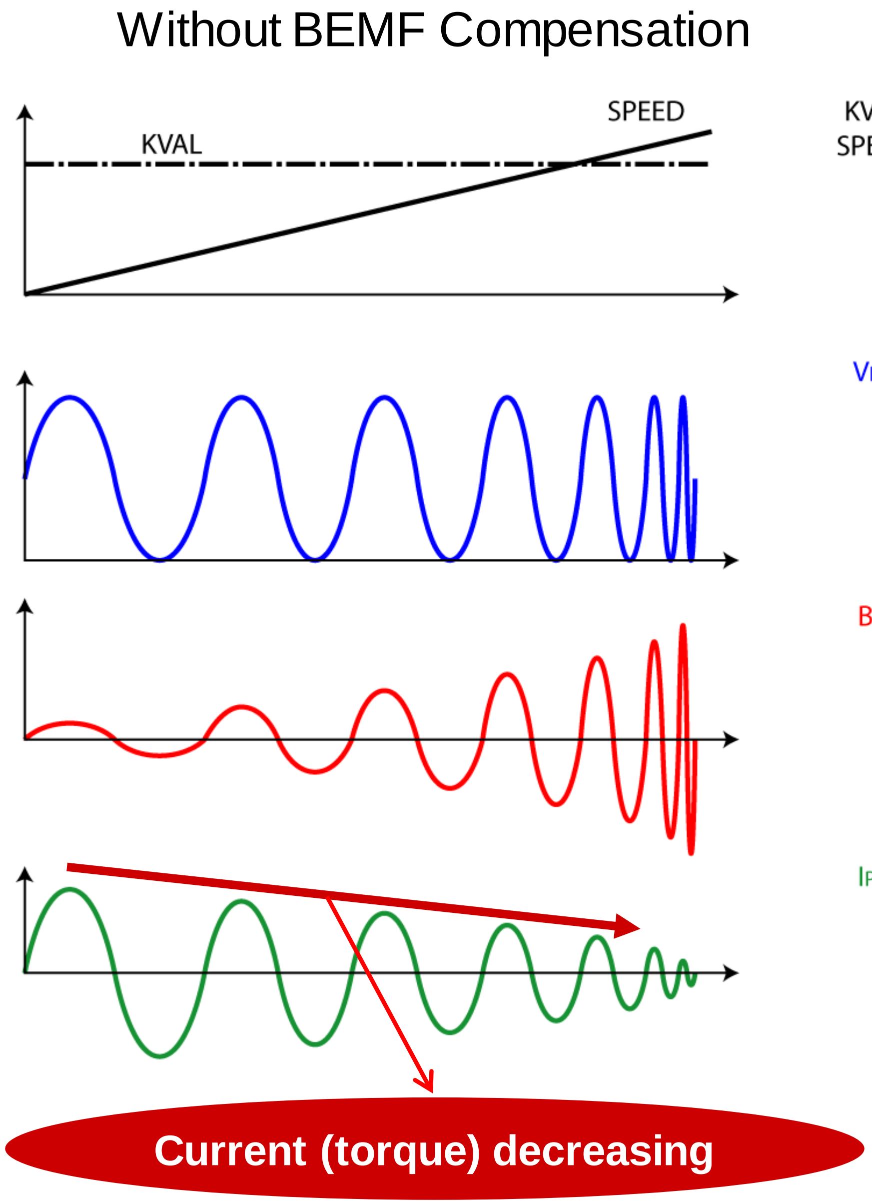
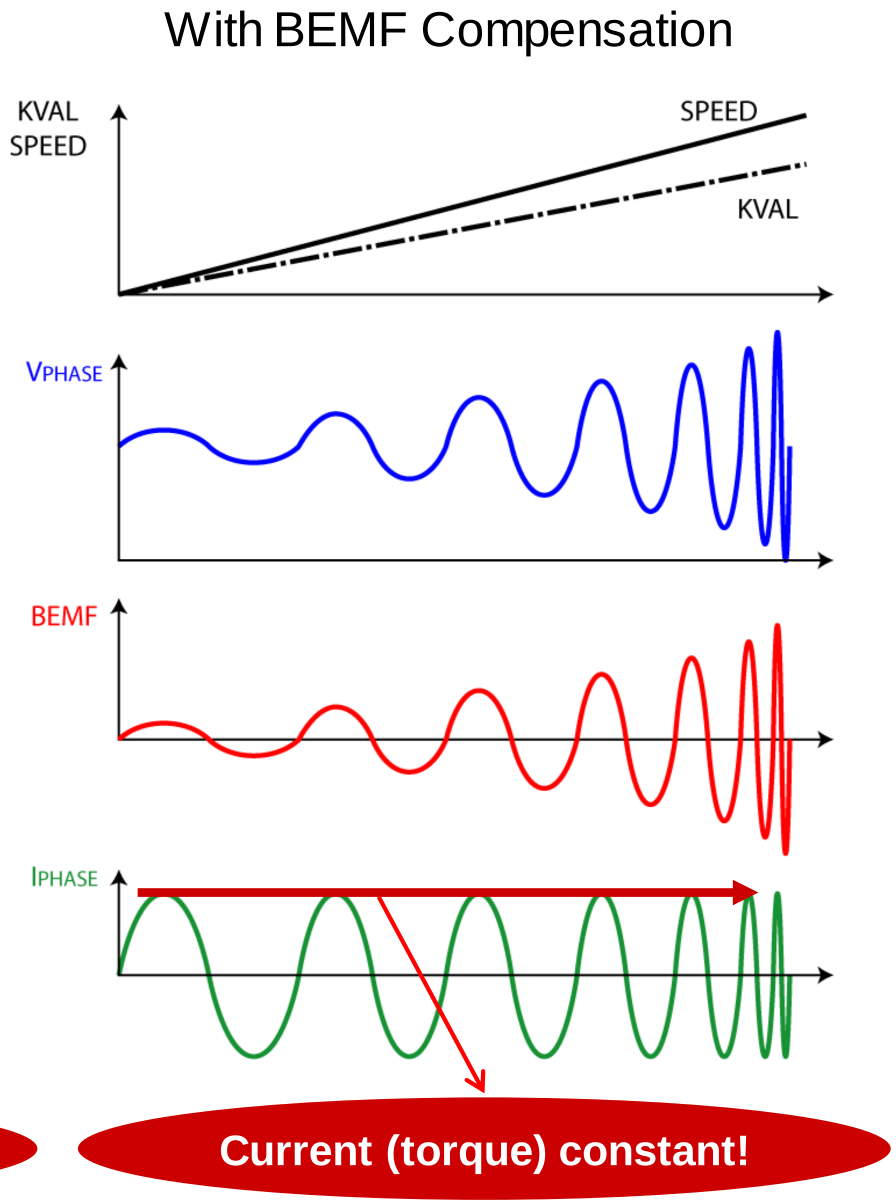
BEMF Compensation

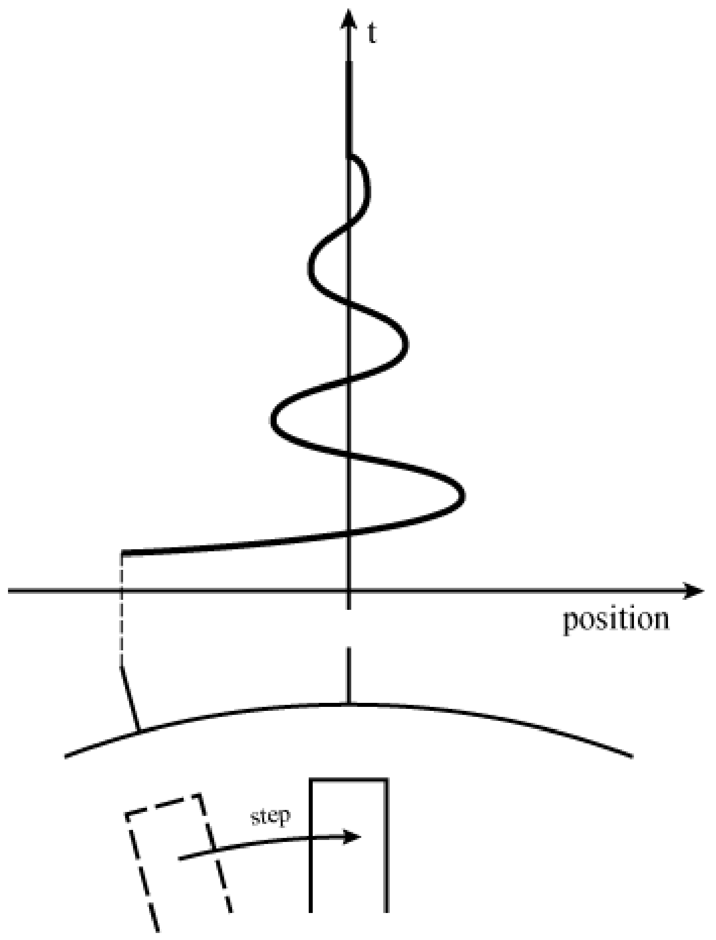




Voltage Mode and Motor Resonances

If the stepper motor motion is not uniform, the mechanics may resonate.

When this occurs, the **BEMF voltage is no longer sinusoidal** and changes in the control algorithm are necessary.



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Voltage Mode and Motor Resonances

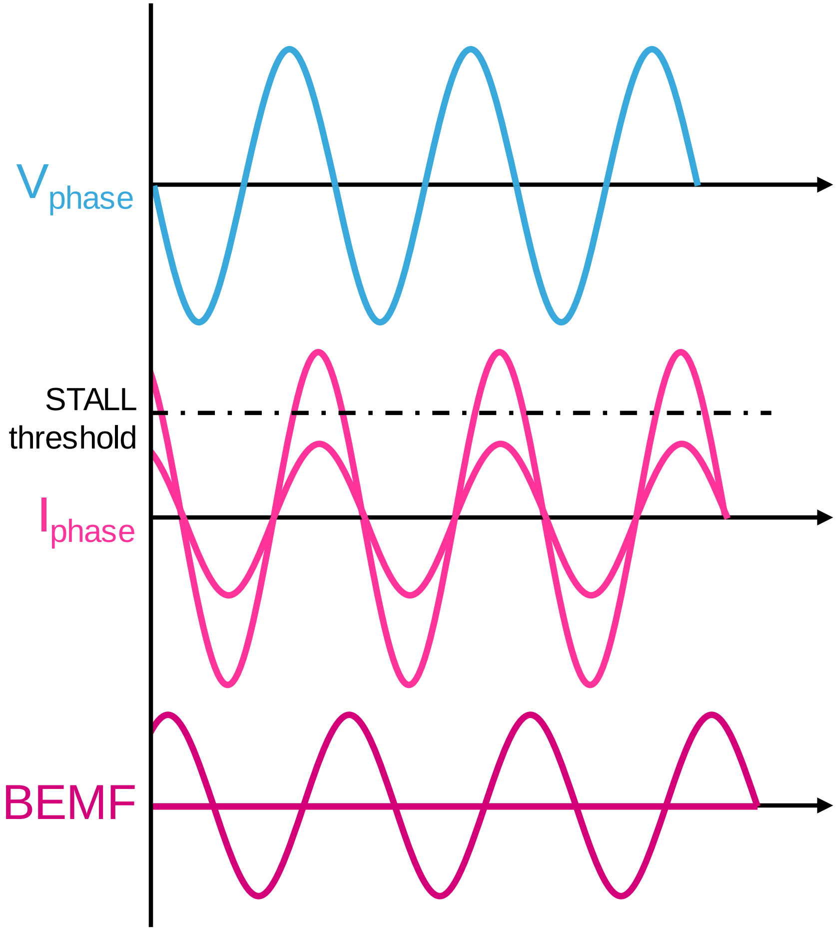
The motor resonances can be avoided using the following strategies:

1. **By applying a mechanical load to the motor**
   The load shifts the resonance of the system.

2. **By increasing the speed of the motor**
   The resonance speed is a limited range. By using the motor inertia and higher acceleration values, the system can move away from the resonance.

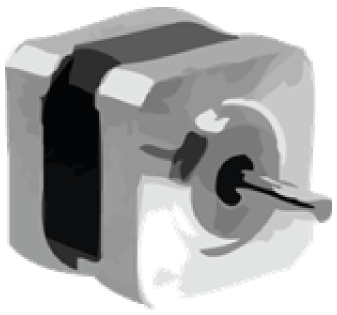
Sensor-less Stall Detection

Using integrated current sensing and the adjustable STALL current threshold, an inexpensive and easy stall detection can be implemented



STALL!
BEMF is null and current is suddenly increased

Normal operation



Thank You

Backup

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Manual tuning procedure for Powerstep01 in voltage mode

Note: this procedure requires the use of an oscilloscope current probe.
From the default settings (which include voltage mode at 128 microsteps per step) set the following configuration registers (using the register map page). Note, you must click the WRITE icon after changing the hex column. Also, before the tuning process can be undertaken, one must determine the desired current magnitude (sinusoidal peak).

1. Set up an oscilloscope with a current probe so that the current in one of the motor coils can be observed.

2. Set FS__SPD(15) to 3FF to disable.
3. Set all 4 KVAL registers (09,0A,0B,0C) to zero
4. Set INT_SPD(0D) to maximum
5. Set ST_SLP(0E) to zero
6. Set FN_SLP_ACC(0F) to zero
7. Set FN_SLP_DEC(10) to zero

8. This is a good point to use the “save current configuration” icon in the upper left of the register map page to save the configuration to a file with a convenient working name.

9. ON the main control screen, pick the SPEED tab and run at 1 full step per second. Note that regardless of the microstepping mode, this speed is always set in full steps per second. This will produce a slow sinusoidal output voltage which rises from zero to peak in one second (4 second total period). However, since we have set all of the KVAL registers to zero, the initial voltage (and thus current) will be zero.

10. Start increasing the hex value of the KVAL_RUN(0A) register until you obtain the desired peak current value. Note that, despite the program warning about not being in hi-z mode, this register can be adjusted on-the-fly.

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Manual tuning procedure for Powerstep01 in voltage mode

11. Once a proper value is determined for KVAL_RUN, set the other three KVAL registers to this same value.
12. This is a good point to stop and do another incremental save of the register values.
13. Now run at 2 steps per second. We will expect to see about the same current magnitude.
14. Now start incrementally increasing the stepping speed until the current magnitude has decreased by about 10 to 20%. Note, the motor must be moving.
15. Now start gradually start increasing the ST_SLP(0E) register value until the current magnitude comes back up to the desired value.
16. Set FN_SLP_ACC(0F) and FN_SLP_DEC(10) to this same value. This would be a good point to stop the motor and save another incremental file with the configuration values so far.
17. Now start again gradually increasing the speed while observing the current magnitude. We are seeking the speed setting where the current just decreases by 5% or so. Note this speed (in full steps per second).

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Manual tuning procedure for Powerstep01 in voltage mode

18. Set INT_SPD(0D) to this value. Note that you will have to keep adjusting the hex value until "steps per second" value displayed in the "value" column is correct.

19. Again, start incrementally increasing the speed until current magnitude has decreased by about 10 to 20%.

20. Now start gradually start increasing the FN_SLP_ACC(0F) register value until the current magnitude comes back up to the desired value.

21. Set FN_SLP_DEC(0F) to the same value.

This should complete the tuning. Operate the motor throughout the expected running speed range and verify that the current magnitude does not vary by more than about 10%. Since it is the ratio of the current in the two motor windings, rather than their absolute values, that determines the positioning angle, and the same settings are applied to both coils, the rotor position is likely to be correct even if we see some variation in actual coil current at various speeds. Indeed, it is not uncommon that the system will not be able to maintain the full desired current magnitude at the highest desired speeds, but the rotor speed and dynamic rotor angle should still be correct. If the magnitude gets too small, or the system develops resonant behavior then we will have established the proctical speed limit for this system, given the available bus voltage.