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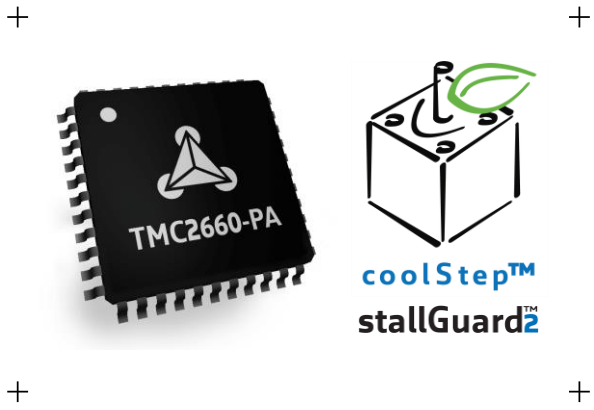
TMC2660 DATASHEET

Universal, cost-effective stepper driver for two-phase bipolar motors with state-of-the-art features. Integrated MOSFETs for up to 4 A motor current per coil. With Step/Dir Interface and SPI.



Applications

Textile, Sewing Machines
Factory Automation
Lab Automation
Liquid Handling
Medical
Office Automation
Printer and Scanner
CCTV, Security
ATM, Cash recycler
POS
Pumps and Valves
Heliostat Controller
CNC Machines

Features and Benefits

Drive Capability up to 4A motor current

Voltage up to 30V DC

Highest Resolution up to 256 microsteps per full step

Compact Size 10x10mm QFP-44 package

Low Power Dissipation, very low RDSON & synchronous rectification

EMI-optimized programmable slope

Protection & Diagnostics overcurrent, short to GND, overtemperature & undervoltage

stallGuard2™ high precision sensorless motor load detection

coolStep™ load dependent current control for energy savings up to 75%

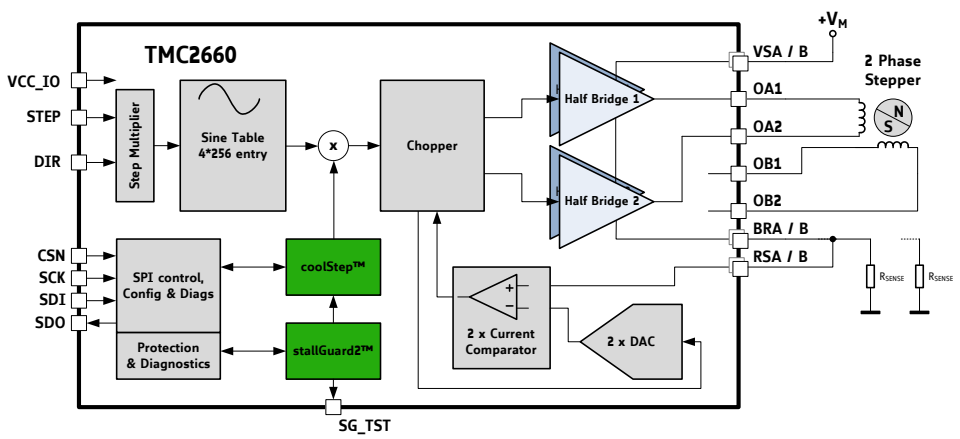
microPlyer™ microstep interpolation for increased smoothness with coarse step inputs.

spreadCycle™ high-precision chopper for best current sine wave form and zero crossing

Description

The TMC2660 driver for two-phase stepper motors offers an industry-leading feature set, including high-resolution microstepping, sensorless mechanical load measurement, load-adaptive power optimization, and low-resonance chopper operation. Standard SPI™ and STEP/DIR interfaces simplify communication. Integrated power MOSFETs handle motor currents up to 2.2A RMS continuously or 2.8A RMS boost current per coil. Integrated protection and diagnostic features support robust and reliable operation. High integration, high energy efficiency and small form factor enable miniaturized designs with low external component count for cost-effective and highly competitive solutions.

Block Diagram



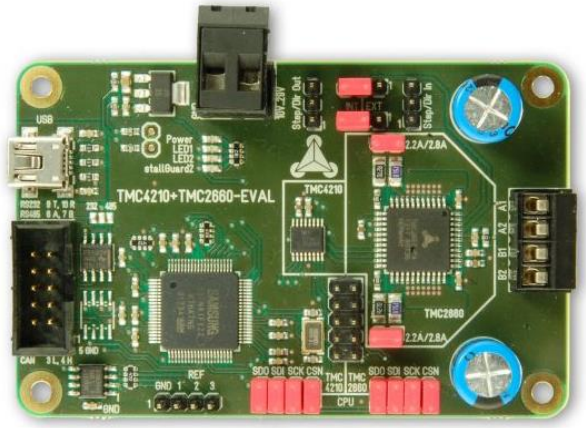
TRINAMIC Motion Control GmbH & Co. KG
Hamburg, Germany

TRINAMIC
MOTION CONTROL

APPLICATION EXAMPLES: SMALL SIZE – BEST PERFORMANCE

The TMC2660 scores with power density, integrated power MOSFETs, and a versatility that covers a wide spectrum of applications and motor sizes, all while keeping costs down. Extensive support at the chips, board, and software levels enables rapid design cycles and fast time-to-market with competitive products. High energy efficiency from TRINAMIC's coolStep technology delivers further cost savings in related systems such as power supplies and cooling.

TMC4210+TMC2660-EVAL EVALUATION-BOARD FOR 1 AXIS



Driver chain with TMC2660

This evaluation board is a development platform for applications based on the TMC2660. The board features USB and CAN interfaces for communication with control software running on a PC. The power MOSFETs of the TMC2660 support drive currents up to 2.8A RMS at 29V.
The control software provides a user-friendly GUI for setting control parameters and visualizing the dynamic response of the motor.
Motor movement can be controlled through the Step/Dir interface using inputs from an external source or signals generated by the onboard microcontroller acting as a step generator.
An external SPI motion controller can be connected if desired.

ORDER CODES

Order code	Description	Size
TMC2660-PA	coolStep™ driver with internal MOSFETs, up to 30V DC, QFP-44 with 12x12 pins	10 x 10 mm²
TMC4210+2660-EVAL	Chipset evaluation board for TMC4210 and TMC2660.	55 x 85 mm²

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1 Principles of Operation

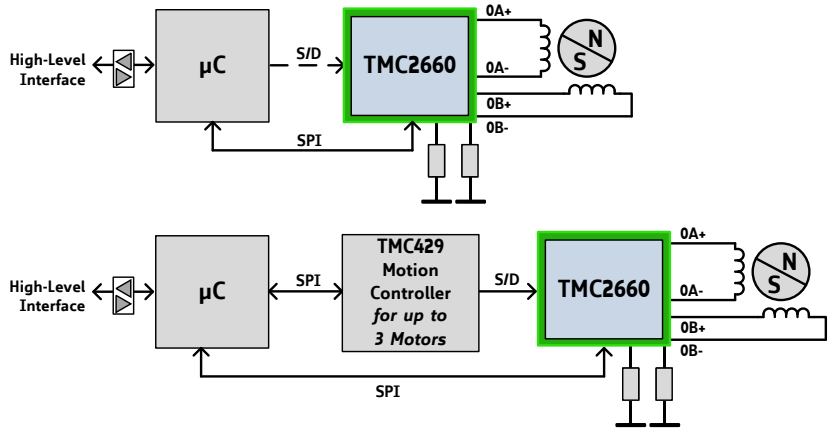

Figure 1.1 Block diagram: applications

The TMC2660 motor driver chip with included MOSFETs is the intelligence and power between a motion controller and the two phase stepper motor as shown in Figure 1.1. Following power-up, an embedded microcontroller initializes the driver by sending commands over an SPI bus to write control parameters and mode bits in the TMC2660. The microcontroller may implement the motion-control function as shown in the upper part of the figure, or it may send commands to a dedicated motion controller chip such as TRINAMIC's TMC429 as shown in the lower part.

The motion controller can control the motor position by sending pulses on the STEP signal while indicating the direction on the DIR signal. The TMC2660 has a microstep counter and sine table to convert these signals into the coil currents which control the position of the motor. If the microcontroller implements the motion-control function, it can write values for the coil currents directly to the TMC2660 over the SPI interface, in which case the STEP/DIR interface may be disabled. This mode of operation requires software to track the motor position and reference a sine table to calculate the coil currents.

To optimize power consumption and heat dissipation, software may also adjust coolStep and stallGuard2 parameters in real-time, for example to implement different tradeoffs between speed and power consumption in different modes of operation.

The motion control function is a hard real-time task which may be a burden to implement reliably alongside other tasks on the embedded microcontroller. By offloading the motion-control function to the TMC429, up to three motors can be operated reliably with very little demand for service from the microcontroller. Software only needs to send target positions, and the TMC429 generates precisely timed step pulses. Software retains full control over both the TMC2660 and TMC429 through the SPI bus.

1.1 Key Concepts

The TMC2660 motor driver implements several advanced features which are exclusive to TRINAMIC products. These features contribute toward greater precision, greater energy efficiency, higher reliability, smoother motion, and cooler operation in many stepper motor applications.

stallGuard2™	High-precision load measurement using the back EMF on the coils
coolStep™	Load-adaptive current control which reduces energy consumption by as much as 75%
spreadCycle™	High-precision chopper algorithm available as an alternative to the traditional constant off-time algorithm
microPlyer™	Microstep interpolator for obtaining increased smoothness of microstepping over a STEP/DIR interface

In addition to these performance enhancements, TRINAMIC motor drivers also offer safeguards to detect and protect against shorted outputs, open-circuit output, overtemperature, and undervoltage conditions for enhancing safety and recovery from equipment malfunctions.

1.2 Control Interfaces

There are two control interfaces from the motion controller to the motor driver: the SPI serial interface and the STEP/DIR interface. The SPI interface is used to write control information to the chip and read back status information. This interface must be used to initialize parameters and modes necessary to enable driving the motor. This interface may also be used for directly setting the currents flowing through the motor coils, as an alternative to stepping the motor using the STEP and DIR signals, so the motor can be controlled through the SPI interface alone.

The STEP/DIR interface is a traditional motor control interface available for adapting existing designs to use TRINAMIC motor drivers. Using only the SPI interface requires slightly more CPU overhead to look up the sine tables and send out new current values for the coils.

1.2.1 SPI Interface

The SPI interface is a bit-serial interface synchronous to a bus clock. For every bit sent from the bus master to the bus slave, another bit is sent simultaneously from the slave to the master. Communication between an SPI master and the TMC2660 slave always consists of sending one 20-bit command word and receiving one 20-bit status word.

The SPI command rate typically corresponds to the microstep rate at low velocities. At high velocities, the rate may be limited by CPU bandwidth to 10-100 thousand commands per second, so the application may need to change to fullstep resolution.

1.2.2 STEP/DIR Interface

The STEP/DIR interface is enabled by default. Active edges on the STEP input can be rising edges or both rising and falling edges, as controlled by another mode bit (DEDGE). Using both edges cuts the toggle rate of the STEP signal in half, which is useful for communication over slow interfaces such as optically isolated interfaces.

On each active edge, the state sampled from the DIR input determines whether to step forward or back. Each step can be a fullstep or a microstep, in which there are 2, 4, 8, 16, 32, 64, 128, or 256 microsteps per fullstep. During microstepping, a step impulse with a low state on DIR increases the microstep counter and a high decreases the counter by an amount controlled by the microstep resolution. An internal table translates the counter value into the sine and cosine values which control the motor current for microstepping.

1.3 Mechanical Load Sensing

The TMC2660 provides stallGuard2 high-resolution load measurement for determining the mechanical load on the motor by measuring the back EMF. In addition to detecting when a motor stalls, this feature can be used for homing to a mechanical stop without a limit switch or proximity detector. The coolStep power-saving mechanism uses stallGuard2 to reduce the motor current to the minimum motor current required to meet the actual load placed on the motor.

1.4 Current Control

Current into the motor coils is controlled using a cycle-by-cycle chopper mode. Two chopper modes are available: a traditional constant off-time mode and the new spreadCycle mode. spreadCycle mode offers smoother operation and greater power efficiency over a wide range of speed and load.

2 Pin Assignments

2.1 Package Outline

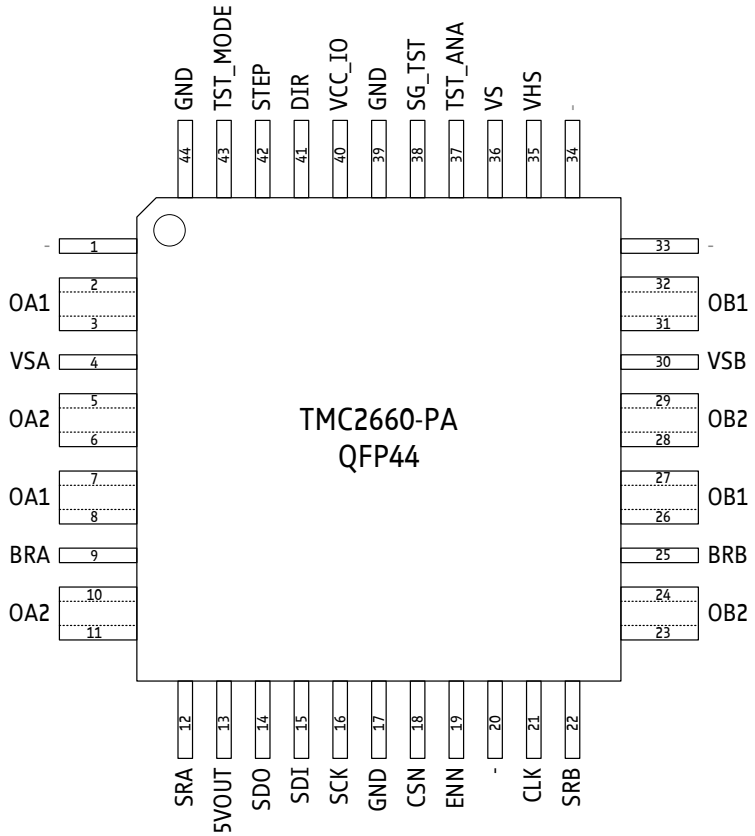

Figure 2.1 TMC2660 pin assignment

2.2 Signal Descriptions

Pin	Number	Type	Function
OA1	2, 3 7, 8	O (VS)	Bridge A1 output. Interconnect all of these pins using thick traces capable to carry the motor current and distribute heat into the PCB.
OA2	5, 6 10, 11	O (VS)	Bridge A2 output. Interconnect all of these pins using thick traces capable to carry the motor current and distribute heat into the PCB.
OB1	26, 27 31, 32	O (VS)	Bridge B1 output. Interconnect all of these pins using thick traces capable to carry the motor current and distribute heat into the PCB.
OB2	23, 24 28, 29	O (VS)	Bridge B2 output. Interconnect all of these pins using thick traces capable to carry the motor current and distribute heat into the PCB.
VSA VSB	4 30		Bridge A/B positive power supply. Connect to VS and provide sufficient filtering capacity for chopper current ripple.
BRA BRB	9 25	AI	Bridge A/B negative power supply via sense resistor in bridge foot point.
SRA SRB	12 22	AI	Sense resistor inputs for chopper current regulation.
5VOUT	13		Output of the on-chip 5V linear regulator. This voltage is used to supply the low-side MOSFETs and internal analog circuitry. An external capacitor to GND close to the pin is required. Place the capacitor near pins 13 and 17. A 470nF ceramic capacitor is sufficient.
SDO	14	DO VIO	SPI serial data output.

Pin	Number	Type	Function
SDI	15	DI VIO	SPI serial data input. (Scan test input in test mode.)
SCK	16	DI VIO	Serial clock input of SPI interface. (Scan test shift enable input in test mode.)
GND	17, 39, 44		Digital and analog low power GND.
CSN	18	DI VIO	Chip select input for the SPI interface. (Active low.)
ENN	19	DI VIO	Power MOSFET enable input. All MOSFETs are switched off when disabled. (Active low.)
CLK	21	DI VIO	System clock input for all internal operations. Tie low to use the on-chip oscillator. A high signal disables the on-chip oscillator until power down.
VHS	35		High-side supply voltage (motor supply voltage - 10V)
VS	36		Motor supply voltage
TST_ANA	37	AO VIO	Reserved. Do not connect.
SG_TST	38	DO VIO	stallGuard2 output. Signals a motor stall. (Active high.)
VCC_IO	40		Input/output supply voltage VIO for all digital pins. Tie to digital logic supply voltage. Operation is allowed in 3.3V and 5V systems.
DIR	41	DI VIO	Direction input. Sampled on an active edge of the STEP input to determine stepping direction. Sampling a low increases the microstep counter, while sampling a high decreases the counter. A 60-ns internal glitch filter rejects short pulses on this input.
STEP	42	DI VIO	Step input. Active edges can be rising or both rising and falling, as controlled by the DEDGE mode bit. A 60-ns internal glitch filter rejects short pulses on this input.
TST_MODE	43	DI VIO	Test mode input. Puts IC into test mode. Tie to GND for normal operation.
n.c.	1, 33		No internal connection - can be tied to any net, e.g., in order to improve power routing to pins VSA and VSB.

3 Internal Architecture

Figure 3.1 shows the internal architecture of TMC2660.

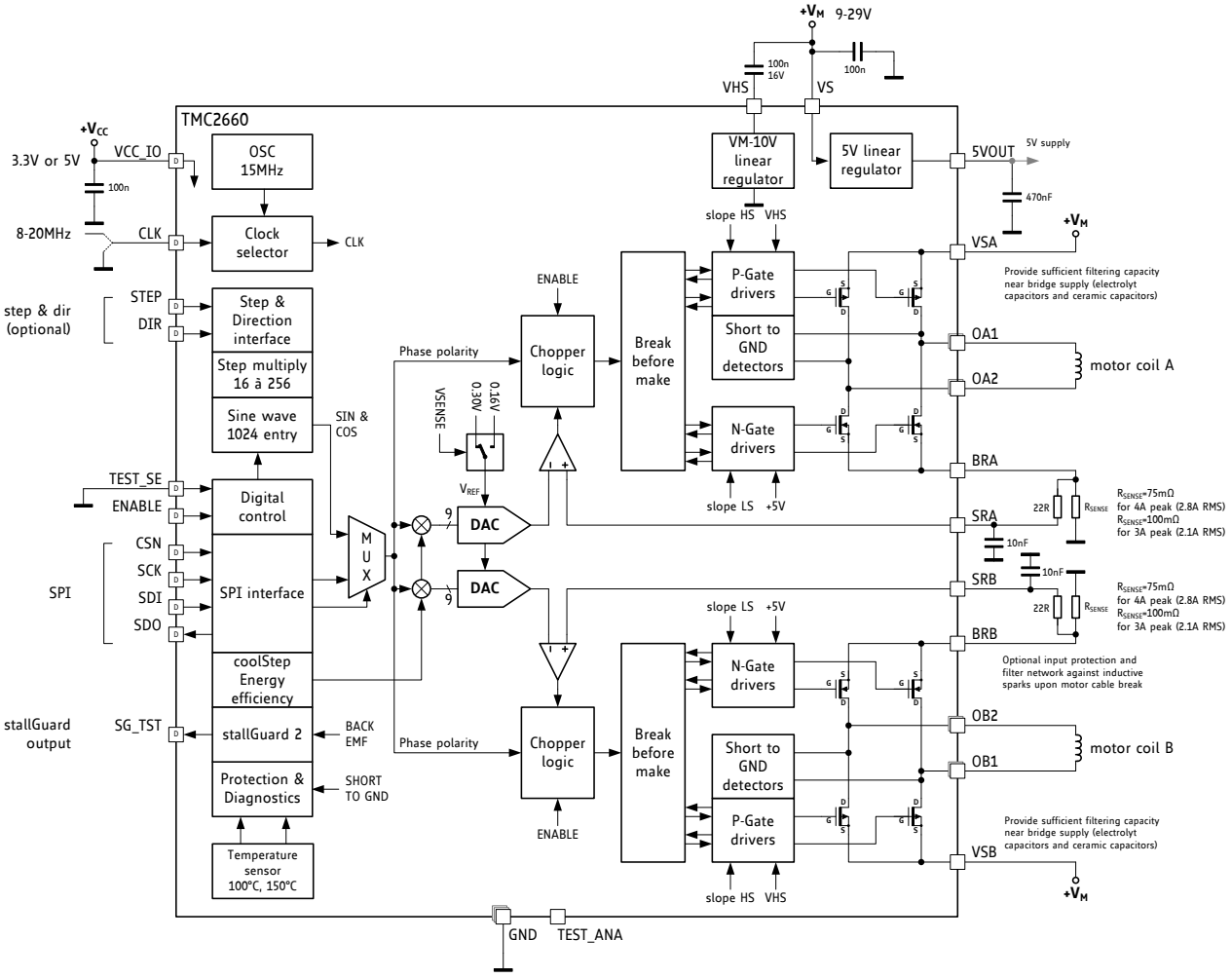

Figure 3.1 TMC2660 block diagram

PROMINENT FEATURES INCLUDE:

Oscillator and clock selector	provide the system clock from the on-chip oscillator or an external source.
Step and direction interface	uses a microstep counter and sine table to generate target currents for the coils.
SPI interface	receives commands that directly set the coil current values.
Multiplexer	selects either the output of the sine table or the SPI interface for controlling the current into the motor coils.
Multipliers	scale down the currents to both coils when the currents are greater than those required by the load on the motor or as set by the CS current scale parameter.
DACs and comparators	convert the digital current values to analog signals that are compared with the voltages on the sense resistors. Comparator outputs terminate chopper drive phases when target currents are reached.
Break-before-make and gate drivers	ensure non-overlapping pulses, boost pulse voltage, and control pulse slope to the gates of the power MOSFETs.
On-chip voltage regulators	provide high-side voltage for P-channel MOSFET gate drivers and supply voltage for on-chip analog and digital circuits.

4 stallGuard2 Load Measurement

stallGuard2 provides an accurate measurement of the load on the motor. It can be used for stall detection as well as other uses at loads below those which stall the motor, such as coolStep load-adaptive current reduction. (stallGuard2 is a more precise evolution of the earlier stallGuard technology.)

The stallGuard2 measurement value changes linearly over a wide range of load, velocity, and current settings, as shown in Figure 4.1. At maximum motor load, the value goes to zero or near to zero. This corresponds to a load angle of 90° between the magnetic field of the coils and magnets in the rotor. This also is the most energy-efficient point of operation for the motor.

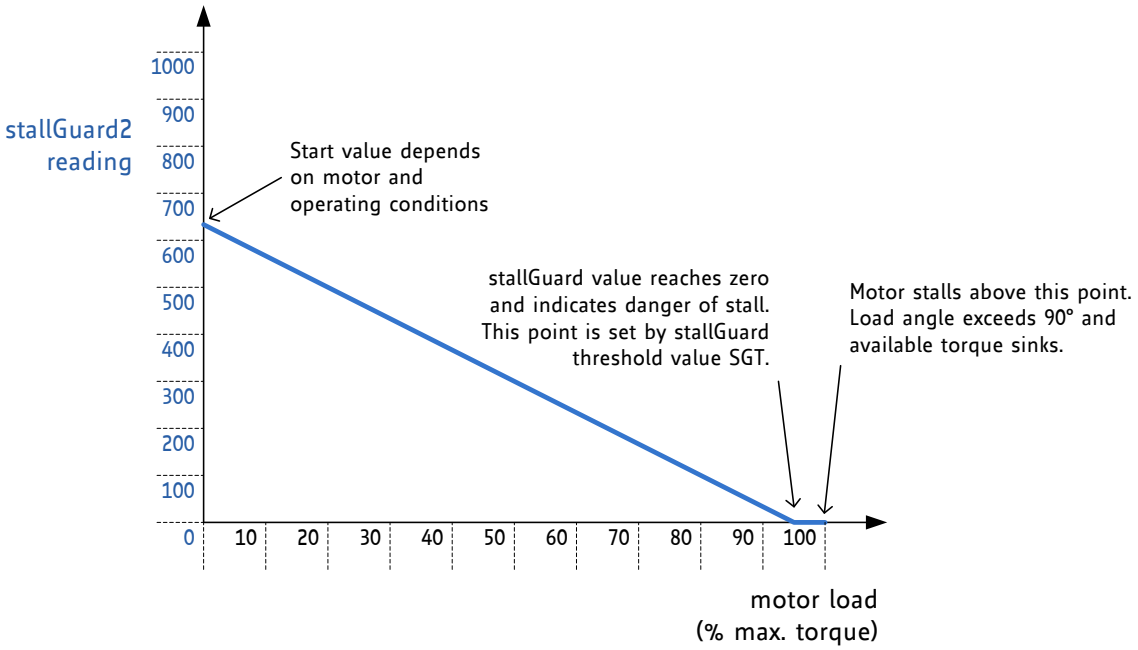

Figure 4.1 stallGuard2 load measurement SG as a function of load

Two parameters control stallGuard2 and one status value is returned.

Parameter	Description	Setting	Comment
SGT	7-bit signed integer that sets the stallGuard2 threshold level for asserting the SG_TST output and sets the optimum measurement range for readout. Negative values increase sensitivity, and positive values reduce sensitivity so more torque is required to indicate a stall. Zero is a good starting value. Operating at values below -10 is not recommended.	0	indifferent value
		+1... +63	less sensitivity
		-1... -64	higher sensitivity
SFILT	Mode bit which enables the stallGuard2 filter for more precision. If set, reduces the measurement frequency to one measurement per four fullsteps. If cleared, no filtering is performed. Filtering compensates for mechanical asymmetries in the construction of the motor, but at the expense of response time. Unfiltered operation is recommended for rapid stall detection. Filtered operation is recommended for more precise load measurement.	0	standard mode
		1	filtered mode

Status word	Description	Range	Comment
SG	10-bit unsigned integer stallGuard2 measurement value. A higher value indicates lower mechanical load. A lower value indicates a higher load and therefore a higher load angle. For stall detection, adjust SGT to return an SG value of 0 or slightly higher upon maximum motor load before stall.	0... 1023	0: highest load low value: high load high value: less load

4.1 Tuning the stallGuard2 Threshold

Due to the dependency of the stallGuard2 value SG from motor-specific characteristics and application-specific demands on load and velocity the easiest way to tune the stallGuard2 threshold *SGT* for a specific motor type and operating conditions is interactive tuning in the actual application.

The procedure is:

1. Operate the motor at a reasonable velocity for your application and monitor SG.
2. Apply slowly increasing mechanical load to the motor. If the motor stalls before SG reaches zero, decrease SGT. If SG reaches zero before the motor stalls, increase SGT. A good SGT starting value is zero. SGT is signed, so it can have negative or positive values.
3. The optimum setting is reached when SG is between 0 and 400 at increasing load shortly before the motor stalls, and SG increases by 100 or more without load. SGT in most cases can be tuned together with the motion velocity in a way that SG goes to zero when the motor stalls and the stall output SG_TST is asserted. This indicates that a step has been lost.

The system clock frequency affects SG. An external crystal-stabilized clock should be used for applications that demand the highest precision. The power supply voltage also affects SG, so tighter regulation results in more accurate values. SG measurement has a high resolution, and there are a few ways to enhance its accuracy, as described in the following sections.

4.1.1 Variable Velocity Operation

Across a range of velocities, on-the-fly adjustment of the stallGuard2 threshold SGT improves the accuracy of the load measurement SG. This also improves the power reduction provided by coolStep, which is driven by SG. Linear interpolation between two SGT values optimized at different velocities is a simple algorithm for obtaining most of the benefits of on-the-fly SGT adjustment, as shown in Figure 4.2. An optimal SGT curve in black and a two-point interpolated SGT curve in red are shown.

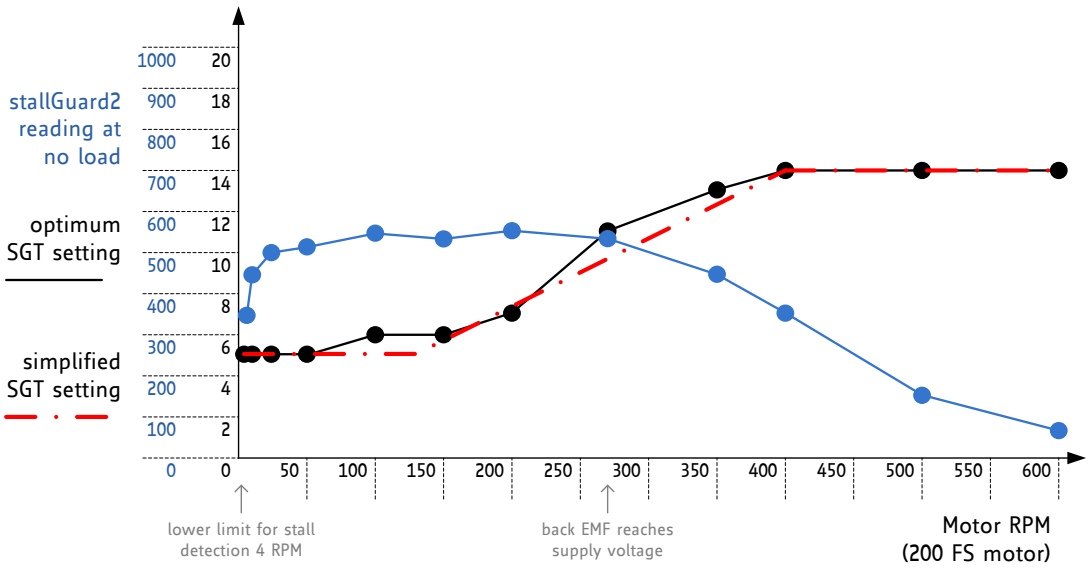

Figure 4.2 Linear interpolation for optimizing SGT with changes in velocity.

4.1.2 Small Motors with High Torque Ripple and Resonance

Motors with a high detent torque show an increased variation of the stallGuard2 measurement value SG with varying motor currents, especially at low currents. For these motors, the current dependency might need correction in a similar manner to velocity correction for obtaining the highest accuracy.

4.1.3 Temperature Dependence of Motor Coil Resistance

Motors working over a wide temperature range may require temperature correction, because motor coil resistance increases with rising temperature. This can be corrected as a linear reduction of SG at increasing temperature, as motor efficiency is reduced.

4.1.4 Accuracy and Reproducibility of stallGuard2 Measurement

In a production environment, it may be desirable to use a fixed SGT value within an application for one motor type. Most of the unit-to-unit variation in stallGuard2 measurements results from manufacturing tolerances in motor construction. The measurement error of stallGuard2 – provided that all other parameters remain stable – can be as low as:

$$stallGuard\ measurement\ error = \pm max(1, |SGT|)$$

4.2 stallGuard2 Measurement Frequency and Filtering

The stallGuard2 measurement value SG is updated with each full step of the motor. This is enough to safely detect a stall, because a stall always means the loss of four full steps. In a practical application, especially when using coolStep, a more precise measurement might be more important than an update for each fullstep because the mechanical load never changes instantaneously from one step to the next. For these applications, the SFILT bit enables a filtering function over four load measurements. The filter should always be enabled when high-precision measurement is required. It compensates for variations in motor construction, for example due to misalignment of the phase A to phase B magnets. The filter should only be disabled when rapid response to increasing load is required, such as for stall detection at high velocity.

4.3 Detecting a Motor Stall

To safely detect a motor stall, a stall threshold must be determined using a specific SGT setting. Therefore, you need to determine the maximum load the motor can drive without stalling and to monitor the SG value at this load, for example some value within the range 0 to 400. The stall threshold should be a value safely within the operating limits, to allow for parameter stray. So, your microcontroller software should set a stall threshold which is slightly higher than the minimum value seen before an actual motor stall occurs. The response at an SGT setting at or near 0 gives some idea on the quality of the signal: Check the SG value without load and with maximum load. These values should show a difference of at least 100 or a few 100, which shall be large compared to the offset. If you set the SGT value so that a reading of 0 occurs at maximum motor load, an active high stall output signal will be available at SG_TST output.

4.4 Limits of stallGuard2 Operation

stallGuard2 does not operate reliably at extreme motor velocities: Very low motor velocities (for many motors, less than one revolution per second) generate a low back EMF and make the measurement unstable and dependent on environment conditions (temperature, etc.). Other conditions will also lead to extreme settings of SGT and poor response of the measurement value SG to the motor load.

Very high motor velocities, in which the full sinusoidal current is not driven into the motor coils also lead to poor response. These velocities are typically characterized by the motor back EMF reaching the supply voltage.

5 coolStep Current Control

coolStep allows substantial energy savings, especially for motors which see varying loads or operate at a high duty cycle. Because a stepper motor application needs to work with a torque reserve of 30% to 50%, even a constant-load application allows significant energy savings because coolStep automatically enables torque reserve when required. Reducing power consumption keeps the system cooler, increases motor life, and allows reducing cost in the power supply and cooling components.

Reducing motor current by half results in reducing power by a factor of four.

Energy efficiency - power consumption decreased up to 75%.
Motor generates less heat - improved mechanical precision.
Less cooling infrastructure - for motor and driver.
Cheaper motor - does the job.

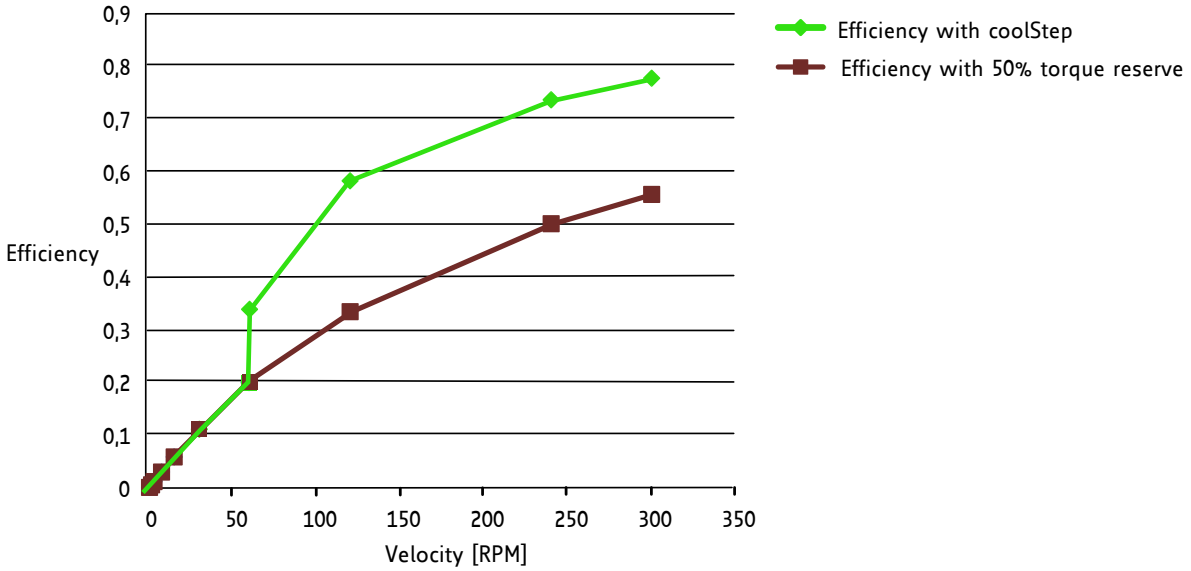

Figure 5.1 Energy efficiency example with coolStep

Figure 5.1 shows the efficiency gain of a 42mm stepper motor when using coolStep compared to standard operation with 50% of torque reserve. coolStep is enabled above 60rpm in the example.

coolStep is controlled by several parameters, but two are critical for understanding how it works:

Parameter	Description	Range	Comment
SEMIN	4-bit unsigned integer that sets a lower threshold. If SG goes below this threshold, coolStep increases the current to both coils. The 4-bit SEMIN value is scaled by 32 to cover the lower half of the range of the 10-bit SG value. (The name of this parameter is derived from smartEnergy, which is an earlier name for coolStep.)	0... 15	lower coolStep threshold: SEMINx32
SEMAX	4-bit unsigned integer that controls an upper threshold. If SG is sampled equal to or above this threshold enough times, coolStep decreases the current to both coils. The upper threshold is (SEMIN + SEMAX + 1) x 32.	0... 15	upper coolStep threshold: (SEMIN+SEMAX+1)x32

Figure 5.2 shows the operating regions of coolStep. The black line represents the SG measurement value, the blue line represents the mechanical load applied to the motor, and the red line represents the current into the motor coils. When the load increases, SG falls below SEMIN, and coolStep

increases the current. When the load decreases and SG rises above (SEMIN + SEMAX + 1) x 32 the current becomes reduced.

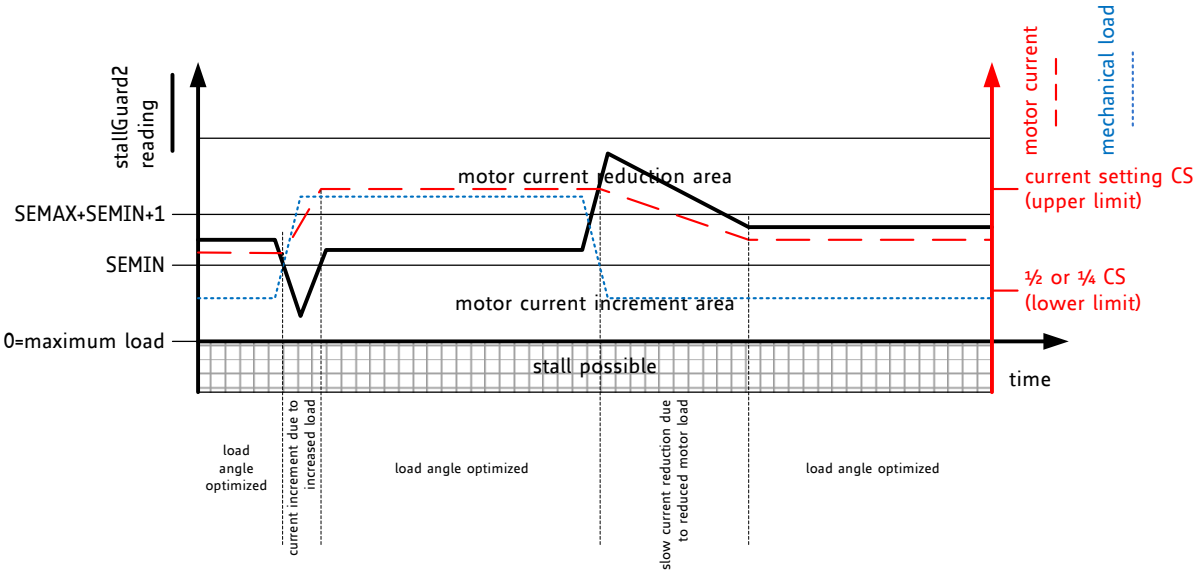

Figure 5.2 coolStep adapts motor current to the load.

Four more parameters control coolStep and one status value is returned:

Parameter	Description	Range	Comment
CS	Current scale. Scales both coil current values as taken from the internal sine wave table or from the SPI interface. For high precision motor operation, work with a current scaling factor in the range 16 to 31, because scaling down the current values reduces the effective microstep resolution by making microsteps coarser. This setting also controls the maximum current value set by coolStep™.	0... 31	scaling factor: 1/32, 2/32, ... 32/32
SEUP	Number of increments of the coil current for each occurrence of an SG measurement below the lower threshold.	0... 3	step width is: 1, 2, 4, 8
SEDN	Number of occurrences of SG measurements above the upper threshold before the coil current is decremented.	0... 3	number of stallGuard measurements per decrement: 32, 8, 2, 1
SEIMIN	Mode bit that controls the lower limit for scaling the coil current. If the bit is set, the limit is ¼ CS. If the bit is clear, the limit is ½ CS.	0	Minimum motor current: 1/2 of CS
		1	1/4 of CS
Status word	**Description**	**Range**	**Comment**
SE	5-bit unsigned integer reporting the actual current scaling value determined by coolStep. This value is biased by 1 and divided by 32, so the range is 1/32 to 32/32. The value will not be greater than the value of CS or lower than either ¼ CS or ½ CS depending on the setting of SEIMIN.	0... 31	Actual motor current scaling factor set by coolStep: 1/32, 2/32, ... 32/32

5.1 Tuning coolStep

Before tuning coolStep, first tune the stallGuard2 threshold level SGT, which affects the range of the load measurement value SG. coolStep uses SG to operate the motor near the optimum load angle of +90°.

The current increment speed is specified in SEUP, and the current decrement speed is specified in SEDN. They can be tuned separately because they are triggered by different events that may need different responses. The encodings for these parameters allow the coil currents to be increased much more quickly than decreased, because crossing the lower threshold is a more serious event that may require a faster response. If the response is too slow, the motor may stall. In contrast, a slow response to crossing the upper threshold does not risk anything more serious than missing an opportunity to save power.

coolStep operates between limits controlled by the current scale parameter CS and the SEIMIN bit.

5.1.1 Response Time

For fast response to increasing motor load, use a high current increment step SEUP. If the motor load changes slowly, a lower current increment step can be used to avoid motor current oscillations. If the filter controlled by SFILT is enabled, the measurement rate and regulation speed are cut by a factor of four.

5.1.2 Low Velocity and Standby Operation

Because stallGuard2 is not able to measure the motor load in standstill and at very low RPM, the current at low velocities should be set to an application-specific default value and combined with standstill current reduction settings programmed through the SPI interface.

6 SPI Interface

TMC2660 requires setting configuration parameters and mode bits through the SPI interface before the motor can be driven. The SPI interface also allows reading back status values and bits.

6.1 Bus Signals

The SPI bus on the TMC2660 has four signals:

SCK	bus clock input
SDI	serial data input
SDO	serial data output
CSN	chip select input (active low)

The slave is enabled for an SPI transaction by a low on the chip select input CSN. Bit transfer is synchronous to the bus clock SCK, with the slave latching the data from SDI on the rising edge of SCK and driving data to SDO following the falling edge. The most significant bit is sent first. A minimum of 20 SCK clock cycles is required for a bus transaction with the TMC2660.

If more than 20 clocks are driven, the additional bits shifted into SDI are shifted out on SDO after a 20-clock delay through an internal shift register. This can be used for daisy chaining multiple chips.

CSN must be low during the whole bus transaction. When CSN goes high, the contents of the internal shift register are latched into the internal control register and recognized as a command from the master to the slave. If more than 20 bits are sent, only the last 20 bits received before the rising edge of CSN are recognized as the command.

6.2 Bus Timing

SPI interface is synchronized to the internal system clock, which limits the SPI bus clock SCK to half of the system clock frequency. If the system clock is based on the on-chip oscillator, an additional 10% safety margin must be used to ensure reliable data transmission. All SPI inputs as well as the ENN input are internally filtered to avoid triggering on pulses shorter than 20ns. Figure 6.1 shows the timing parameters of an SPI bus transaction, and the table below specifies their values.

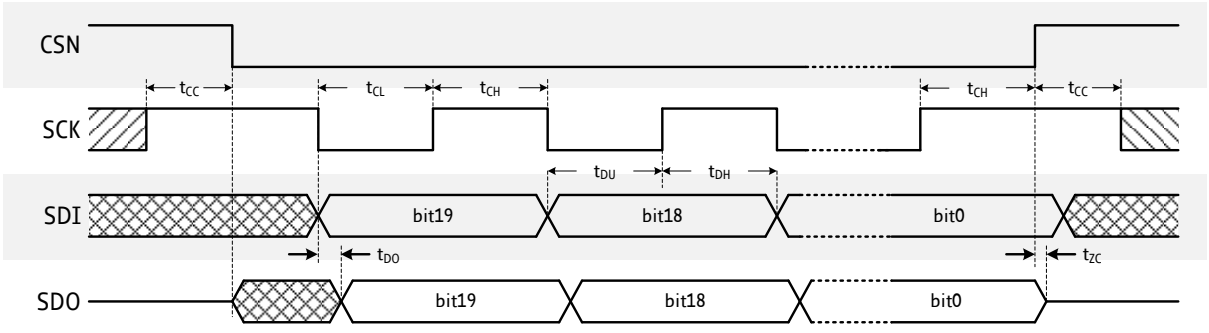

Figure 6.1 SPI Timing

SPI Interface Timing	AC-Characteristics clock period is t_{CLK}					
Parameter	**Symbol**	**Conditions**	**Min**	**Typ**	**Max**	**Unit**
SCK valid before or after change of CSN	t_{CC}		10			ns
CSN high time	t_{CSH}	*)Min time is for synchronous CLK with SCK high one t_{CH} before CSN high only	t_{CLK}	>2t_{CLK} +10		ns
SCK low time	t_{CL}	*)Min time is for synchronous CLK only	t_{CLK}	>t_{CLK}+10		ns
SCK high time	t_{CH}	*)Min time is for synchronous CLK only	t_{CLK}	>t_{CLK}+10		ns
SCK frequency using internal clock	f_{SCK}	Assumes minimum OSC frequency			4	MHz
SCK frequency using external 16MHz clock	f_{SCK}	Assumes synchronous CLK			8	MHz
SDI setup time before rising edge of SCK	t_{DU}		10			ns
SDI hold time after rising edge of SCK	t_{DH}		10			ns
Data out valid time after falling SCK clock edge	t_{DO}	No capacitive load on SDO			t_{FILT}+5	ns
SDI, SCK, and CSN filter delay time	t_{FILT}	Rising and falling edge	12	20	30	ns

6.3 Bus Architecture

SPI slaves can be chained and used with a single chip select line. If slaves are chained, they behave like a long shift register. For example, a chain of two motor drivers requires 40 bits to be sent. The last bits shifted to each register in the chain are loaded into an internal register on the rising edge of the CSN input. For example, 24 or 32 bits can be sent to a single motor driver, but it latches just the last 20 bits received before CSN goes high.

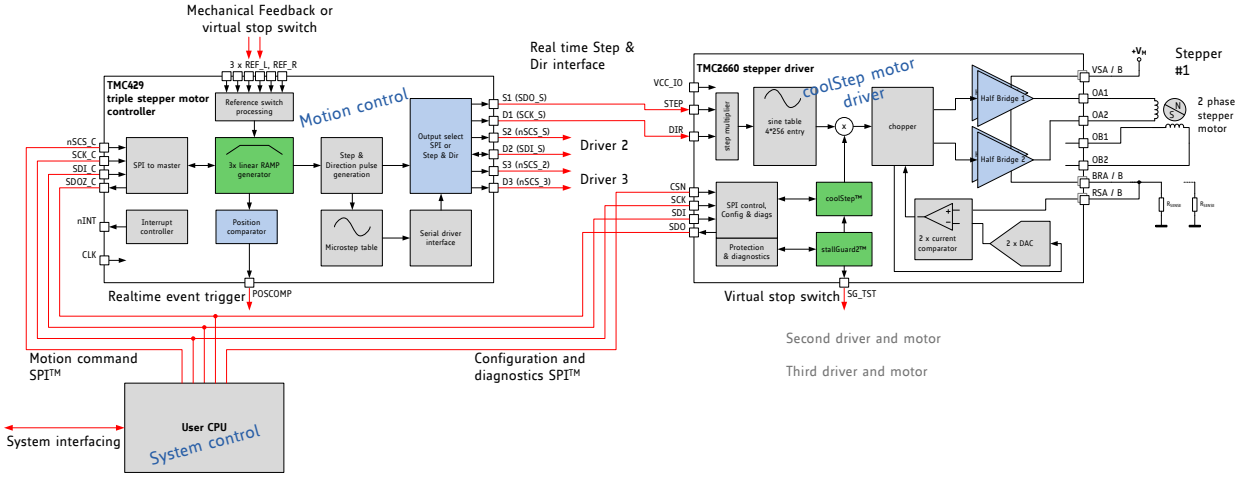

Figure 6.2 Interfaces to a TMC429 motion controller chip and a TMC2660 motor driver

Figure 6.2 shows the interfaces in a typical application. The SPI bus is used by an embedded MCU to initialize the control registers of both a motion controller and one or more motor drivers. STEP/DIR interfaces are used between the motion controller and the motor drivers.

6.4 Register Write Commands

An SPI bus transaction to the TMC2660 is a write command to one of the five write-only registers that hold configuration parameters and mode bits:

Register	Description
Driver Control Register (DRVCTRL)	The DRVCTRL register has different formats for controlling the interface to the motion controller depending on whether or not the STEP/DIR interface is enabled.
Chopper Configuration Register (CHOPCONF)	The CHOPCONF register holds chopper parameters and mode bits.
coolStep Configuration Register (SMARTEN)	The SMARTEN register holds coolStep parameters and a mode bit. (smartEnergy is an earlier name for coolStep.)
stallGuard2 Configuration Register (SGCSCONF)	The SGCSCONF register holds stallGuard2 parameters and a mode bit.
Driver Configuration Register (DRVCONF)	The DRVCONF register holds parameters and mode bits used to control the power MOSFETs and the protection circuitry. It also holds the SDOFF bit which controls the STEP/DIR interface and the RDSEL parameter which controls the contents of the response returned in an SPI transaction

In the following sections, multibit binary values are prefixed with a % sign, for example %0111.

6.4.1 Write Command Overview

The table below shows the formats for the five register write commands. Bits 19, 18, and sometimes 17 select the register being written, as shown in bold. The DRVCTRL register has two formats, as selected by the SDOFF bit. Bits shown as 0 must always be written as 0, and bits shown as 1 must always be written with 1. Detailed descriptions of each parameter and mode bit are given in the following sections.

Register/ Bit	DRVCTRL (*SDOFF*=1)	DRVCTRL (*SDOFF*=0)	CHOPCONF	SMARTEN	SGCSCONF	DRVCONF
19	**0**	**0**	**1**	**1**	**1**	**1**
18	**0**	**0**	**0**	**0**	**1**	**1**
17	PHA	0	**0**	**1**	**0**	**1**
16	CA7	0	TBL1	0	SFILT	TST
15	CA6	0	TBL0	SEIMIN	0	SLPH1
14	CA5	0	CHM	SEDN1	SGT6	SLPH0
13	CA4	0	RNDTF	SEDN0	SGT5	SLPL1
12	CA3	0	HDEC1	0	SGT4	SLPL0
11	CA2	0	HDEC0	SEMAX3	SGT3	0
10	CA1	0	HEND3	SEMAX2	SGT2	DISS2G
9	CA0	INTPOL	HEND2	SEMAX1	SGT1	TS2G1
8	PHB	DEDGE	HEND1	SEMAX0	SGT0	TS2G0
7	CB7	0	HEND0	0	0	*SDOFF*
6	CB6	0	HSTRT2	SEUP1	0	VSENSE
5	CB5	0	HSTRT1	SEUP0	0	*RDSEL1*
4	CB4	0	HSTRT0	0	CS4	*RDSEL0*
3	CB3	MRES3	TOFF3	SEMIN3	CS3	0
2	CB2	MRES2	TOFF2	SEMIN2	CS2	0
1	CB1	MRES1	TOFF1	SEMIN1	CS1	0
0	CB0	MRES0	TOFF0	SEMIN0	CS0	0

6.4.2 Read Response Overview

The table below shows the formats for the read response. The RDSEL parameter in the DRVCONF register selects the format of the read response.

Bit	*RDSEL*=%00	*RDSEL*=%01	*RDSEL*=%10
19	MSTEP9	SG9	SG9
18	MSTEP8	SG8	SG8
17	MSTEP7	SG7	SG7
16	MSTEP6	SG6	SG6
15	MSTEP5	SG5	SG5
14	MSTEP4	SG4	SE4
13	MSTEP3	SG3	SE3
12	MSTEP2	SG2	SE2
11	MSTEP1	SG1	SE1
10	MSTEP0	SG0	SE0
9	-	-	-
8	-	-	-
7	STST		
6	OLB		
5	OLA		
4	S2GB		
3	S2GA		
2	OTPW		
1	OT		
0	SG		

6.5 Driver Control Register (DRVCTRL)

The format of the DRVCTRL register depends on the state of the SDOFF mode bit.

SPI Mode SDOFF bit is set, the STEP/DIR interface is disabled, and DRVCTRL is the interface for specifying the currents through each coil.

STEP/DIR Mode SDOFF bit is clear, the STEP/DIR interface is enabled, and DRVCTRL is a configuration register for the STEP/DIR interface.

6.5.1 DRVCTRL Register in SPI Mode

DRVCTRL		Driver Control in SPI Mode (SDOFF=1)	
Bit	**Name**	**Function**	**Comment**
19	0	Register address bit	
18	0	Register address bit	
17	PHA	Polarity A	Sign of current flow through coil A: 0: Current flows from OA1 pins to OA2 pins. 1: Current flows from OA2 pins to OA1 pins.
16	CA7	Current A MSB	Magnitude of current flow through coil A. The range is 0 to 248, if hysteresis or offset are used up to their full extent. The resulting value after applying hysteresis or offset must not exceed 255.
15	CA6		
14	CA5		
13	CA4		
12	CA3		
11	CA2		
10	CA1		
9	CA0	Current A LSB	

DRVCTRL		Driver Control in SPI Mode (SDOFF=1)	
Bit	**Name**	**Function**	**Comment**
8	PHB	Polarity B	Sign of current flow through coil B: 0: Current flows from OB1 pins to OB2 pins. 1: Current flows from OB2 pins to OB1 pins.
7	CB7	Current B MSB	Magnitude of current flow through coil B. The range is 0 to 248, if hysteresis or offset are used up to their full extent. The resulting value after applying hysteresis or offset must not exceed 255.
6	CB6		
5	CB5		
4	CB4		
3	CB3		
2	CB2		
1	CB1		
0	CB0	Current B LSB	

6.5.2 DRVCTRL Register in STEP/DIR Mode

DRVCTRL		Driver Control in STEP/DIR Mode (SDOFF=0)	
Bit	**Name**	**Function**	**Comment**
19	0	Register address bit	
18	0	Register address bit	
17	0	Reserved	
16	0	Reserved	
15	0	Reserved	
14	0	Reserved	
13	0	Reserved	
12	0	Reserved	
11	0	Reserved	
10	0	Reserved	
9	INTPOL	Enable STEP interpolation	0: Disable STEP pulse interpolation. 1: Enable STEP pulse multiplication by 16.
8	DEDGE	Enable double edge STEP pulses	0: Rising STEP pulse edge is active, falling edge is inactive. 1: Both rising and falling STEP pulse edges are active.
7	0	Reserved	
6	0	Reserved	
5	0	Reserved	
4	0	Reserved	
3	MRES3	Microstep resolution for STEP/DIR mode	Microsteps per 90°: %0000: 256 %0001: 128 %0010: 64 %0011: 32 %0100: 16 %0101: 8 %0110: 4 %0111: 2 (halfstep) %1000: 1 (fullstep)
2	MRES2		
1	MRES1		
0	MRES0		

6.6 Chopper Control Register (CHOPCONF)

CHOPCONF		Chopper Configuration		
Bit	**Name**	**Function**	**Comment**	
19	1	Register address bit		
18	0	Register address bit		
17	0	Register address bit		
16	TBL1	Blanking time	Blanking time interval, in system clock periods: %00: 16 %01: 24 %10: 36 %11: 54	
15	TBL0			
14	CHM	Chopper mode	This mode bit affects the interpretation of the HDEC, HEND, and HSTRT parameters shown below.	
			0	Standard mode (spreadCycle)
			1	Constant t_{OFF} with fast decay time. Fast decay time is also terminated when the negative nominal current is reached. Fast decay is after on time.
13	RNDTF	Random TOFF time	Enable randomizing the slow decay phase duration: 0: Chopper off time is fixed as set by bits t_{OFF} 1: Random mode, t_{OFF} is random modulated by dN_{CLK}= -12 … +3 clocks.	
12	HDEC1	Hysteresis decrement interval or Fast decay mode	CHM=0	Hysteresis decrement period setting, in system clock periods: %00: 16 %01: 32 %10: 48 %11: 64
11	HDEC0		CHM=1	HDEC1=0: current comparator can terminate the fast decay phase before timer expires. HDEC1=1: only the timer terminates the fast decay phase. HDEC0: MSB of fast decay time setting.
10	HEND3	Hysteresis end (low) value or Sine wave offset	CHM=0	%0000 … %1111: Hysteresis is -3, -2, -1, 0, 1, …, 12 (1/512 of this setting adds to current setting) This is the hysteresis value which becomes used for the hysteresis chopper.
9	HEND2			
8	HEND1		CHM=1	%0000 … %1111: Offset is -3, -2, -1, 0, 1, …, 12 This is the sine wave offset and 1/512 of the value becomes added to the absolute value of each sine wave entry.
7	HEND0			
6	HSTRT2	Hysteresis start value or Fast decay time setting	CHM=0	Hysteresis start offset from HEND: %000: 1 %100: 5 %001: 2 %101: 6 %010: 3 %110: 7 %011: 4 %111: 8 *Effective: HEND+HSTRT must be ≤ 15*
5	HSTRT1			
4	HSTRT0		CHM=1	Three least-significant bits of the duration of the fast decay phase. The MSB is HDEC0. Fast decay time is a multiple of system clock periods: N_{CLK}= 32 x (*HDEC0+HSTRT*)

CHOPCONF		Chopper Configuration	
Bit	**Name**	**Function**	**Comment**
3	TOFF3	Off time/MOSFET disable	Duration of slow decay phase. If TOFF is 0, the MOSFETs are shut off. If TOFF is nonzero, slow decay time is a multiple of system clock periods: N_{CLK}= 12 + (32 x TOFF) (Minimum time is 64clocks.) %0000: Driver disable, all bridges off %0001: 1 (use with TBL of minimum 24 clocks) %0010 … %1111: 2 … 15
2	TOFF2		
1	TOFF1		
0	TOFF0		

6.7 coolStep Control Register (SMARTEN)

SMARTEN		coolStep Configuration	
Bit	**Name**	**Function**	**Comment**
19	1	Register address bit	
18	0	Register address bit	
17	1	Register address bit	
16	0	Reserved	
15	SEIMIN	Minimum coolStep current	0: ½ CS current setting 1: ¼ CS current setting
14	SEDN1	Current decrement speed	Number of times that the stallGuard2 value must be sampled equal to or above the upper threshold for each decrement of the coil current: %00: 32 %01: 8 %10: 2 %11: 1
13	SEDN0		
12	0	Reserved	
11	SEMAX3	Upper coolStep threshold as an offset from the lower threshold	If the stallGuard2 measurement value SG is sampled equal to or above (SEMIN+SEMAX+1) x 32 enough times, then the coil current scaling factor is decremented.
10	SEMAX2		
9	SEMAX1		
8	SEMAX0		
7	0	Reserved	
6	SEUP1	Current increment size	Number of current increment steps for each time that the stallGuard2 value SG is sampled below the lower threshold: %00: 1 %01: 2 %10: 4 %11: 8
5	SEUP0		
4	0	Reserved	
3	SEMIN3	Lower coolStep threshold/coolStep disable	If SEMIN is 0, coolStep is disabled. If SEMIN is nonzero and the stallGuard2 value SG falls below SEMIN x 32, the coolStep current scaling factor is increased.
2	SEMIN2		
1	SEMIN1		
0	SEMIN0		

6.8 stallGuard2 Control Register (SGCSCONF)

SGCSCONF		stallGuard2™ and Current Setting	
Bit	**Name**	**Function**	**Comment**
19	1	Register address bit	
18	1	Register address bit	
17	0	Register address bit	
16	SFILT	stallGuard2 filter enable	0: Standard mode, fastest response time. 1: Filtered mode, updated once for each four fullsteps to compensate for variation in motor construction, highest accuracy.
15	0	Reserved	
14	SGT6	stallGuard2 threshold value	The stallGuard2 threshold value controls the optimum measurement range for readout. A lower value results in a higher sensitivity and requires less torque to indicate a stall. The value is a two's complement signed integer. Values below -10 are not recommended. Range: -64 to +63
13	SGT5		
12	SGT4		
11	SGT3		
10	SGT2		
9	SGT1		
8	SGT0		
7	0	Reserved	
6	0	Reserved	
5	0	Reserved	
4	CS4	Current scale (scales digital currents A and B)	Current scaling for SPI and step/direction operation. %00000 … %11111: 1/32, 2/32, 3/32, … 32/32 This value is biased by 1 and divided by 32, so the range is 1/32 to 32/32. Example: CS=0 is 1/32 current
3	CS3		
2	CS2		
1	CS1		
0	CS0		

6.9 Driver Control Register (DRVCONF)

DRVCONF		Driver Configuration	
Bit	**Name**	**Function**	**Comment**
19	1	Register address bit	
18	1	Register address bit	
17	1	Register address bit	
16	TST	Reserved TEST mode	Must be cleared for normal operation. When set, the SG_TST output exposes digital test values, and the TEST_ANA output exposes analog test values. Test value selection is controlled by SGT1 and SGT0: TEST_ANA: %00: anatest_2vth, %01: anatest_dac_out, %10: anatest_vdd_half. SG_TST: %00: comp_A, %01: comp_B, %10: CLK, %11: on_state_xy
15	SLPH1	Slope control, high side	%00: Minimum %01: Minimum temperature compensation mode. %10: Medium temperature compensation mode. %11: Maximum In temperature compensated mode (tc), the MOSFET gate driver strength is increased if the overtemperature warning temperature is reached. This compensates for temperature dependency of high-side slope control.
14	SLPH0		
13	SLPL1	Slope control, low side	%00: Minimum. %01: Minimum. %10: Medium. %11: Maximum.
12	SLPL0		
11	0	Reserved	
10	DISS2G	Short to GND protection disable	0: Short to GND protection is enabled. 1: Short to GND protection is disabled.
9	TS2G1	Short to GND detection timer	%00: 3.2µs. %01: 1.6µs. %10: 1.2µs. %11: 0.8µs.
8	TS2G0		
7	SDOFF	STEP/DIR interface disable	0: Enable STEP and DIR interface. 1: Disable STEP and DIR interface. SPI interface is used to move motor.
6	VSENSE	Sense resistor voltage-based current scaling	0: Full-scale sense resistor voltage is 305mV. 1: Full-scale sense resistor voltage is 165mV. (Full-scale refers to a current setting of 31 and a DAC value of 255.)
5	RDSEL1	Select value for read out (RD bits)	%00 Microstep position read back
4	RDSEL0		%01 stallGuard2 level read back %10 stallGuard2 and coolStep current level read back %11 Reserved, do not use
3	0	Reserved	
2	0	Reserved	
1	0	Reserved	
0	0	Reserved	

6.10 Read Response

For every write command sent to the motor driver, a 20-bit response is returned to the motion controller. The response has one of three formats, as selected by the RDSEL parameter in the DRVCONF register. The table below shows these formats. Software must not depend on the value of any bit shown as reserved.

DRVSTATUS				**Read Response**	
Bit	**Name**			**Function**	**Comment**
	RDSEL=%00	**%01**	**%10**		
19	MSTEP9	SG9	SG9	Microstep counter for coil A *or* stallGuard2 value SG9:0 *or* stallGuard2 value SG9:5 *and* coolStep value SE4:0	Microstep position in sine table for coil A in STEP/DIR mode. MSTEP9 is the Polarity bit: 0: Current flows from OA1 pins to OA2 pins. 1: Current flows from OA2 pins to OA1 pins.
18	MSTEP8	SG8	SG8		
17	MSTEP7	SG7	SG7		
16	MSTEP6	SG6	SG6		
15	MSTEP5	SG5	SG5		stallGuard2 value SG9:0.
14	MSTEP4	SG4	SE4		
13	MSTEP3	SG3	SE3		
12	MSTEP2	SG2	SE2		stallGuard2 value SG9:5 and the actual coolStep scaling value SE4:0.
11	MSTEP1	SG1	SE1		
10	MSTEP0	SG0	SE0		
9	Reserved				
8	Reserved				
7	STST			Standstill indicator	0: No standstill condition detected. 1: No active edge occurred on the STEP input during the last 2^{20} system clock cycles.
6	OLB			Open load indicator	0: No open load condition detected. 1: No chopper event has happened during the last period with constant coil polarity. Only a current above 1/16 of the maximum setting can clear this bit! *Hint:* This bit is only a status indicator. The chip takes no other action when this bit is set. False indications may occur during fast motion and at standstill. Check this bit only during slow motion.
5	OLA				
4	S2GB			Short to GND detection bits on high-side transistors	0: No short to ground shutdown condition. 1: Short to ground shutdown condition. The short counter is incremented by each short circuit and the chopper cycle is suspended. The counter is decremented for each phase polarity change. The MOSFETs are shut off when the counter reaches 3 and remain shut off until the shutdown condition is cleared by disabling and re-enabling the driver. The shutdown conditions reset by deasserting the ENN input or clearing the TOFF parameter.
3	S2GA				
2	OTPW			Overtemperature warning	0: No overtemperature warning condition. 1: Warning threshold is active.
1	OT			Overtemperature shutdown	0: No overtemperature shutdown condition. 1: Overtemperature shutdown has occurred.
0	SG			stallGuard2 status	0: No motor stall detected. 1: stallGuard2 threshold has been reached, and the SG_TST output is driven high.

6.11 Device Initialization

The following sequence of SPI commands is an example of enabling the driver and initializing the chopper:

```
SPI = $901B4;       // Hysteresis mode
```

or

```
SPI = $94557;       // Constant t_off mode

SPI = $D001F;       // Current setting: $d001F (max. current)

SPI = $E0010;       // low driver strength, stallGuard2 read, SDOFF=0

SPI = $00000;       // 256 microstep setting
```

First test of coolStep current control:

```
SPI = $A8202;       // Enable coolStep with minimum current ¼ CS
```

The configuration parameters should be tuned to the motor and application for optimum performance.