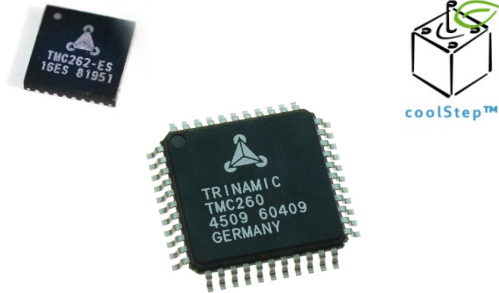




TMC260, TMC261, TMC262

Energy saving high resolution microstep two phase stepper driver with step and direction interface and internal (TMC260, TMC261) or external power stage (TMC262) with diagnostics and protection

TRINAMIC® Motion Control GmbH & Co. KG
Sternstraße 67
D – 20357 Hamburg
GERMANY
www.trinamic.com



1 Features

The TMC262 family is an energy efficient two phase stepper motor driver with high resolution microstepping capability. It integrates the low resonance chopper spreadCycle for quiet and fast motor operation. Its step and direction interface allows simple use. An SPI interface allows for parameterization and diagnostics and can also be used to drive the motor. The TMC262 directly drives four external N/P channel dual MOSFETs for motor currents up to 8A and up to 60V. Protection and diagnostic features further reduce system cost and increase reliability. The TMC260 and TMC261 integrate a power stage for applications up to 40V resp. 60V and 1.7A. Their basic pinning is compatible to the TMC236, allowing a simple upgrade path for existing applications. Its energy efficiency and low power dissipation allow for a miniaturized design with minimum additional infrastructure requirements making it a very cost effective driver.

Highlights

- up to 256 microsteps using the step/direction interface or the SPI interface
- coolStep™: Save up to 75% of energy using automatic load adaptive motor current control
- stallGuard2™: High precision sensorless motor load measurement
- microPlyer: Microstep extrapolator gives 256 microstep smoothness with low frequency step input
- spreadCycle: High precision chopper algorithm
- Dual edge step option allows half step frequency requirement, e.g. for opto-couplers
- Up to 8A Motor current using external N&P channel MOSFET pairs (TMC262)
Up to 1.7A with integrated power MOS transistors (TMC260 and TMC261)
- Synchronous rectification reduces transistor heating
- 9V to 60V operating voltage (TMC261, TMC262), respectively 9V to 40V (TMC260)
- 3.3V or 5V interface
- QFN32 package (TMC262) for extremely small solution with superior thermal performance
- 10mm x 10mm TQFP-44 package (TMC260, TMC261) integrates power bridges
- EMV optimized current controlled gate drivers – up to 40mA gate current (TMC262)
- Overcurrent, short to GND and overtemperature protection and diagnostics integrated

Applications

- Energy efficient industrial and commercial stepper applications
- Precision two phase stepper motor drives
- Medical and optical applications
- Robotics

Motor type

- 2 phase Stepper

2 Table of contents

1	FEATURES.....	1
2	TABLE OF CONTENTS.....	2
3	PRINCIPLE OF OPERATION.....	4
3.1	MOVING THE MOTOR.....	4
3.1.1	<i>Step and direction control.....</i>	4
3.1.2	<i>SPI control.....</i>	4
3.2	CHOPPED MOTOR COIL DRIVER.....	4
3.3	ENERGY EFFICIENT DRIVER WITH LOAD FEEDBACK.....	4
4	PINNING.....	5
4.1	TMC260-PA, TMC261-PA.....	5
4.2	TMC262-LA.....	5
4.3	PACKAGE CODES.....	5
4.4	DIMENSIONAL DRAWINGS.....	6
4.4.1	<i>PQFP44 dimensions.....</i>	6
4.4.2	<i>QFN32 dimensions.....</i>	6
5	BLOCK DIAGRAM.....	8
5.1	PIN DESCRIPTION OF TMC262-LA.....	10
5.2	PIN DESCRIPTION OF TMC260-PA / TMC261-PA.....	11
6	SPI MODE SHIFT REGISTER.....	12
6.1	OVERVIEW (WRITE).....	12
6.2	OVERVIEW (READ).....	12
6.3	DRIVER CONTROL REGISTER BIT ASSIGNMENT.....	13
6.3.1	<i>Driver control register bit assignment in SPI mode.....</i>	13
6.3.2	<i>Driver control register bit assignment in StepDir mode.....</i>	14
6.4	CONFIGURATION REGISTER BIT ASSIGNMENT.....	15
6.5	BIT ASSIGNMENT FOR READ.....	18
6.6	SPI TIMING.....	19
7	STEP AND DIRECTION INTERFACE.....	20
7.1	TIMING.....	20
7.2	INTERNAL MICROSTEP TABLE.....	20
7.3	SWITCHING BETWEEN DIFFERENT MICROSTEP RESOLUTIONS.....	21
7.3.1	<i>Working with half- and fullstep resolution.....</i>	21
7.4	STEP RATE MULTIPLIER AND STAND STILL DETECTION.....	22
8	CURRENT SETTING.....	23
8.1	CONSIDERATIONS ON THE CURRENT SENSE RESISTORS AND LAYOUT.....	23
9	CHOPPER OPERATION OF THE MOTOR COILS.....	25
9.1	SPREADCYCLE CHOPPER.....	25
9.2	CLASSIC CONSTANT OFF TIME CHOPPER.....	27
9.3	RANDOM OFF TIME.....	28
10	MOSFET DRIVER STAGE.....	29
10.1	PRINCIPLE OF OPERATION.....	29
10.2	BREAK-BEFORE-MAKE LOGIC.....	29
10.3	ENN INPUT.....	29
10.4	SLOPE CONTROL IN TMC262.....	30
11	DIAGNOSTICS AND PROTECTION.....	31

11.1	SHORT TO GND DETECTION	31
11.2	OPEN LOAD DETECTION	31
11.3	TEMPERATURE MEASUREMENT.....	32
11.4	UNDERVOLTAGE DETECTION.....	32
12	STALLGUARD₂TM SENSORLESS LOAD MEASUREMENT	33
12.1	TUNING THE STALLGUARD ₂ TM THRESHOLD SGT	33
12.1.1	<i>Variable velocity operation</i>	33
12.1.2	<i>Small motors with high torque ripple and resonance</i>	34
12.1.3	<i>Temperature dependence of motor coil resistance</i>	34
12.1.4	<i>Accuracy and reproducibility of stallGuard₂TM measurement</i>	34
12.2	STALLGUARD ₂ TM MEASUREMENT FREQUENCY AND FILTERING	34
13	COOLSTEPTM SMART ENERGY OPERATION.....	36
13.1	COOLSTEP TM SMART ENERGY CURRENT REGULATOR.....	36
13.1.1	<i>Adaptation to the load situation</i>	36
13.1.2	<i>Low velocity and standby operation</i>	36
13.2	USER BENEFITS, SAVE ENERGY, REDUCE POWER AND COOLING INFRASTRUCTURE.....	37
14	CLOCK OSCILLATOR AND CLOCK INPUT	38
14.1	CONSIDERATIONS ON THE FREQUENCY	38
15	ABSOLUTE MAXIMUM RATINGS	39
16	ELECTRICAL CHARACTERISTICS	39
16.1	OPERATIONAL RANGE	39
16.2	DC CHARACTERISTICS AND TIMING CHARACTERISTICS.....	40
16.3	ESD SENSITIVE DEVICE	44
16.4	MOSFET EXAMPLES.....	45
17	USING AN EXTERNAL POWER STAGE FOR HIGHER VOLTAGE AND CURRENT	46
18	GETTING STARTED	47
18.1	INITIALIZATION OF THE DRIVER.....	47
19	TABLE OF FIGURES.....	48
20	REVISION HISTORY	48
20.1	DOCUMENTATION REVISION	48

3 Principle of operation

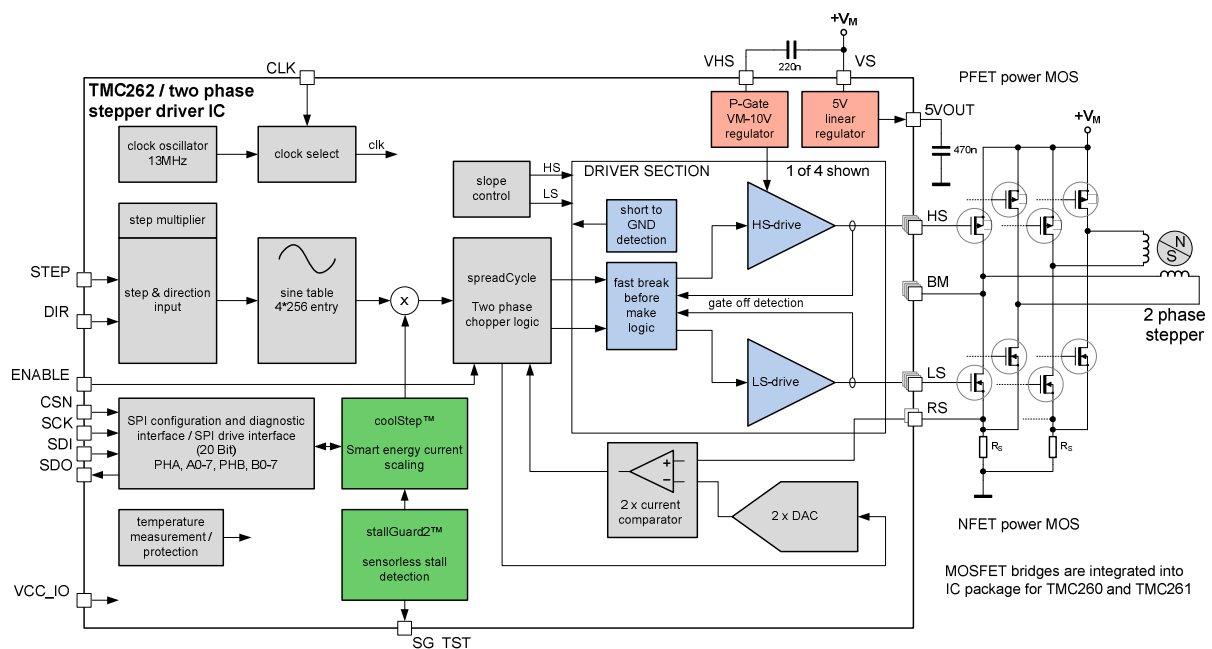


figure 1: basic application block diagram

3.1 Moving the motor

3.1.1 Step and direction control

The TMC262 family is a family of chopped stepper motor drivers with integrated sequencer and SPI interface. They provide two possibilities to control the motor: The motor can be controlled by applying pulses on the step and direction interface, following an initialization phase which uses the SPI interface to parameterize the driver for the application. Control and diagnostic registers give the flexibility to react to changing operation conditions and to modify the behavior of the chip when it receives a step impulse. An internal microstep table supplies sine and cosine values which control the motor current for each step. Each step impulse advances the step pointer in the tables and hence leads to the IC executing the next microstep.

3.1.2 SPI control

A second mode of operation uses the SPI interface, only. Both motor coil currents can be controlled via the SPI interface, while taking advantage of all other control and diagnostic functions. This mode is more flexible, as the microstep waves can be specially adapted to the motor to give the best fit for smoothest operation. It requires slightly more CPU overhead to look up the driver tables and to send out new current values for both coils. The SPI update rate corresponds to the step rate at low velocities. At highest velocities the update rate can be limited to a few 10kHz or some 100kHz, depending on the processor power, or alternatively to an update rate corresponding to a fullstep.

3.2 Chopped motor coil driver

The driver uses a cycle by cycle chopper mode: The motor current becomes regulated by comparing the motor current to a set value for each chopper cycle. This constant off time chopper scheme allows highest dynamic. The spreadCycle chopper scheme automatically integrates a fast decay cycle and guarantees smooth zero crossing performance. In an optional operation mode, fast decay length per cycle can be selected by the user. In this classic constant off time mode, zero crossing can be optimized by setting a programmable current offset.

3.3 Energy efficient driver with load feedback

The TMC262 family integrates a high resolution load measurement stallGuard2™, which allows sensing the mechanical load on the motor. This gives more information on the drive allowing functions like sensorless homing. Its coolStep™ feature uses load measurement information to reduce the motor current to the minimum motor current required in the actual load situation. This saves lots of energy and keeps components cool, making the drive an efficient and precise solution.

4 Pinning

4.1 TMC260-PA, TMC261-PA

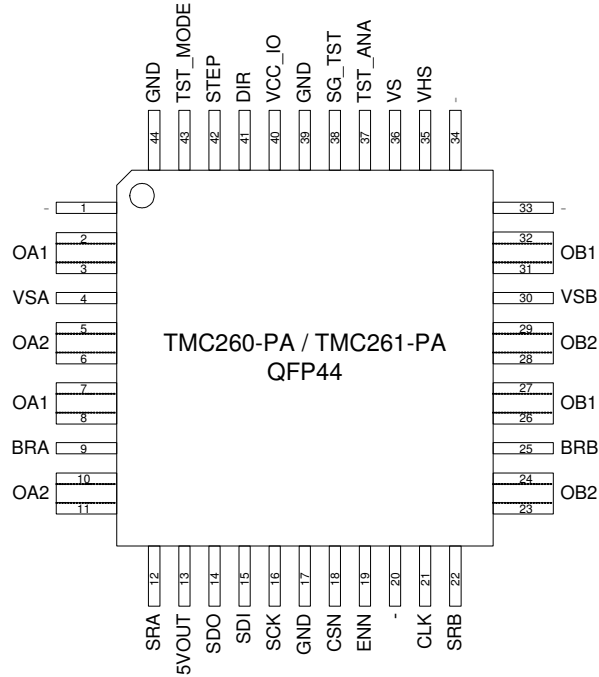


figure 2: TMC260 and TMC261 pinning

4.2 TMC262-LA

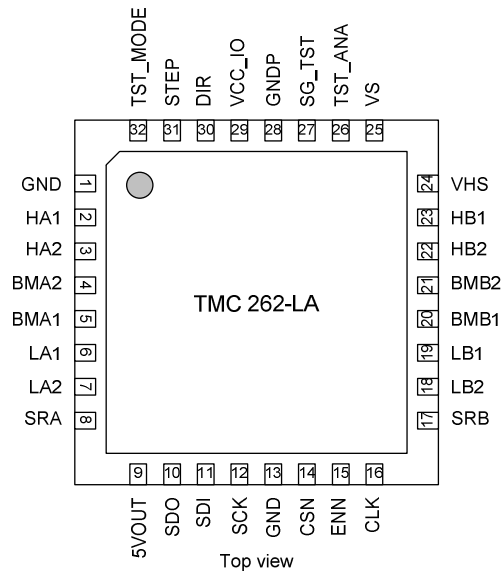


figure 3: TMC262 pinning

4.3 Package codes

Type	Package	Temperature range	Code/markings
TMC260	TQFP44 (RoHS)	-40 °C ... +125 °C	TMC260-PA
TMC261	TQFP44 (RoHS)	-40 °C ... +125 °C	TMC261-PA
TMC262	QFN32 (RoHS)	-40 °C ... +125 °C	TMC262-LA

4.4 Dimensional drawings

For drawings, see next page.

Attention: Drawings not to scale.

4.4.1 PQFP44 dimensions

Parameter	Ref	Min	Nom	Max
size over pins (X&Y)	A		12	
body size (X&Y)	C		10	
pin length	D		1	
total thickness	E			1.6
lead frame thickness	F	0.09		0.2
stand off	G	0.05	0.10	0.15
pin width	H	0.30		0.45
flat lead length	I	0.45		0.75
pitch	K		0.8	
coplanarity	ccc			0.08

All dimensions are in mm.

4.4.2 QFN32 dimensions

Parameter	Ref	Min	Nom	Max
total thickness	A	0.80	0.85	0.90
stand off	A1	0.00	0.035	0.05
mold thickness	A2	-	0.65	0.67
lead frame thickness	A3		0.203	
lead width	b	0.2	0.25	0.3
body size X	D		5.0	
body size Y	E		5.0	
lead pitch	e		0.5	
exposed die pad size X	J	3.2	3.3	3.4
exposed die pad size Y	K	3.2	3.3	3.4
lead length	L	0.35	0.4	0.45
package edge tolerance	aaa			0.1
mold flatness	bbb			0.1
coplanarity	ccc			0.08
lead offset	ddd			0.1
exposed pad offset	eee			0.1

All dimensions are in mm.

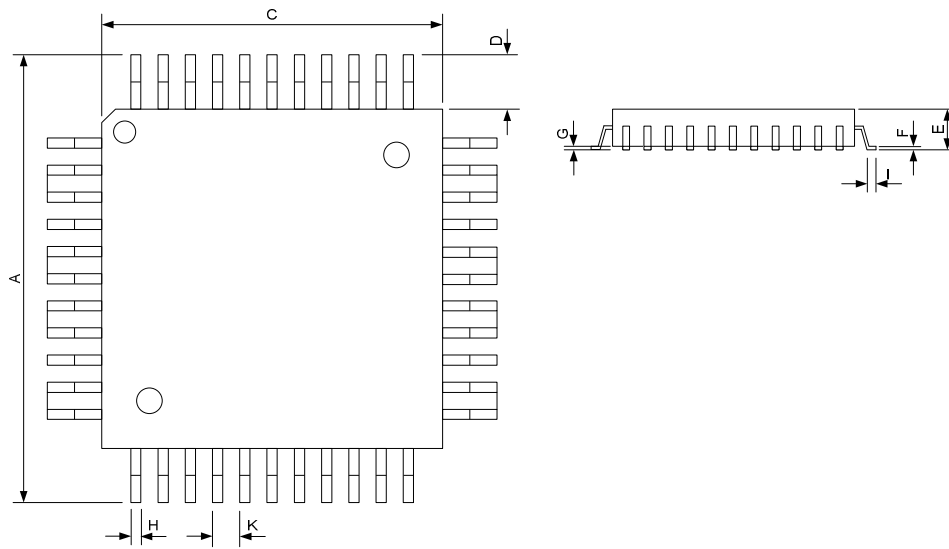


figure 4: PQFP44 dimensions

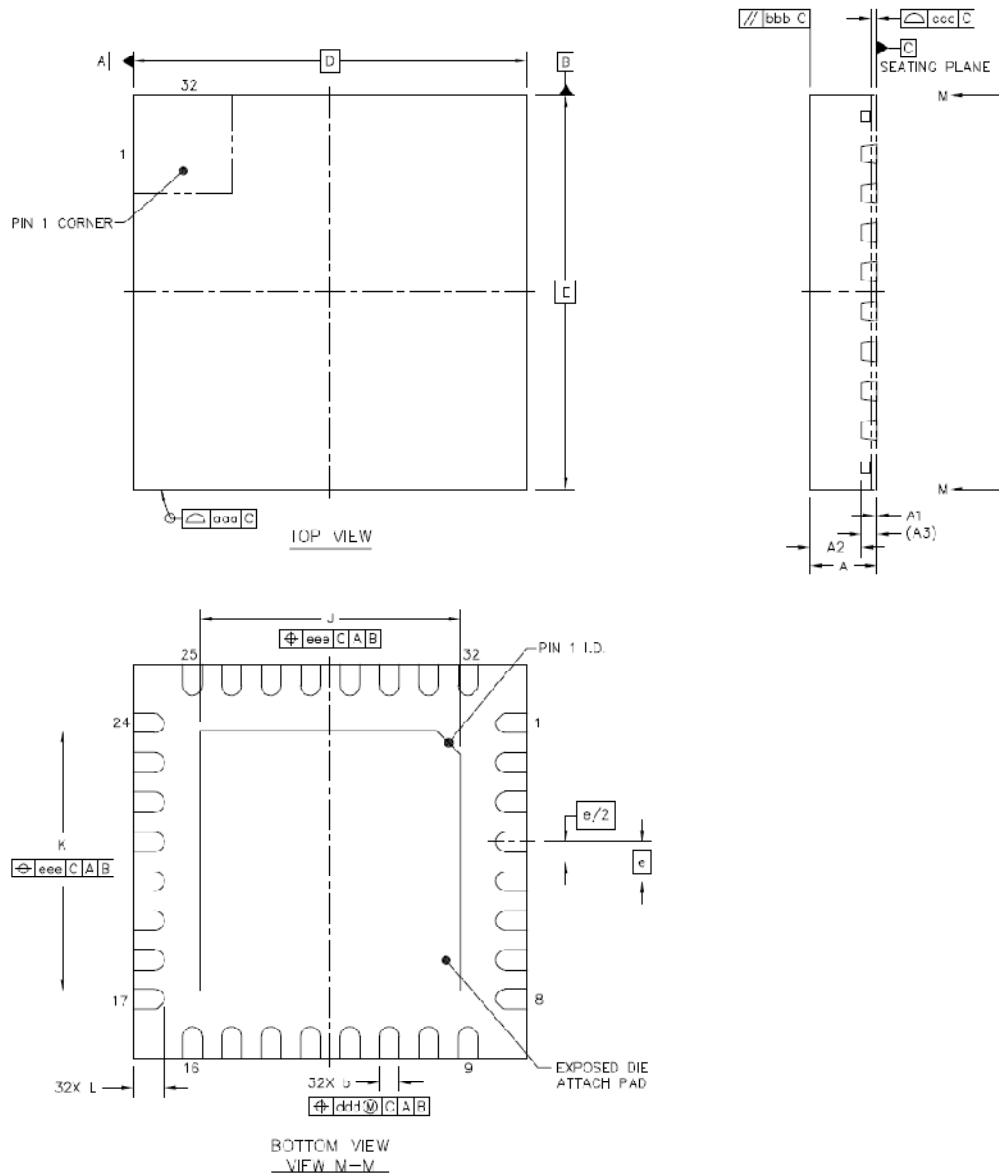


figure 5: QFN32 5x5 dimensions

5 Block diagram

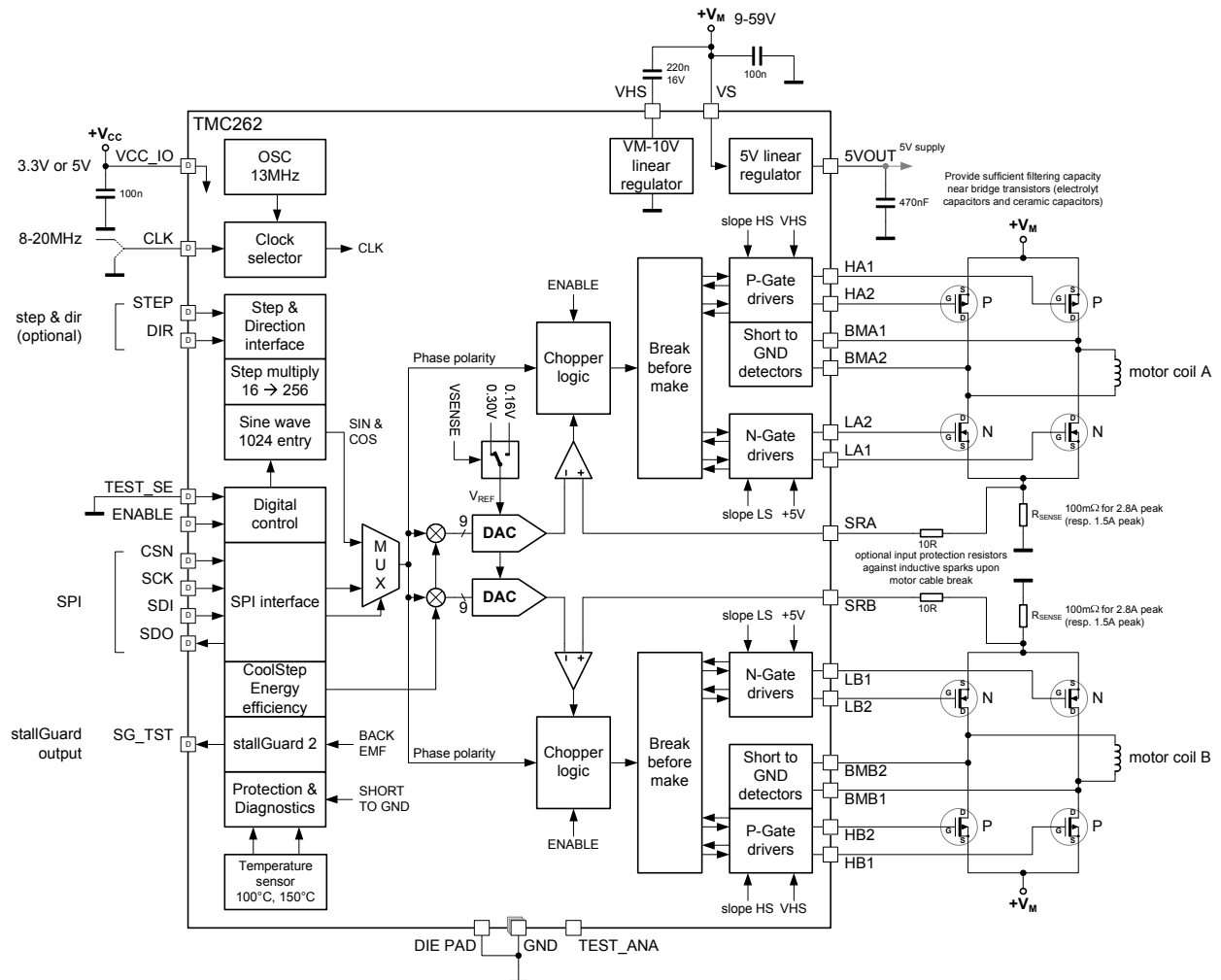


figure 6: TMC262 block and application diagram

The application diagram shows the basic building blocks of the IC and the connections to the power bridge transistors, as well as the power supply. The connection of the digital interface lines to the microcontroller and / or a motion controller is specific to the system architecture and the microcontroller type. Do not leave any input floating over extended periods of time, as there are no pull up or pull down resistors integrated. The choice of power MOSFETs for the TMC262 depends on the desired motor current and supply voltage. Please refer chapter 16.4. For even higher motor current capability, external MOSFET drivers can be added using full N channel bridges.

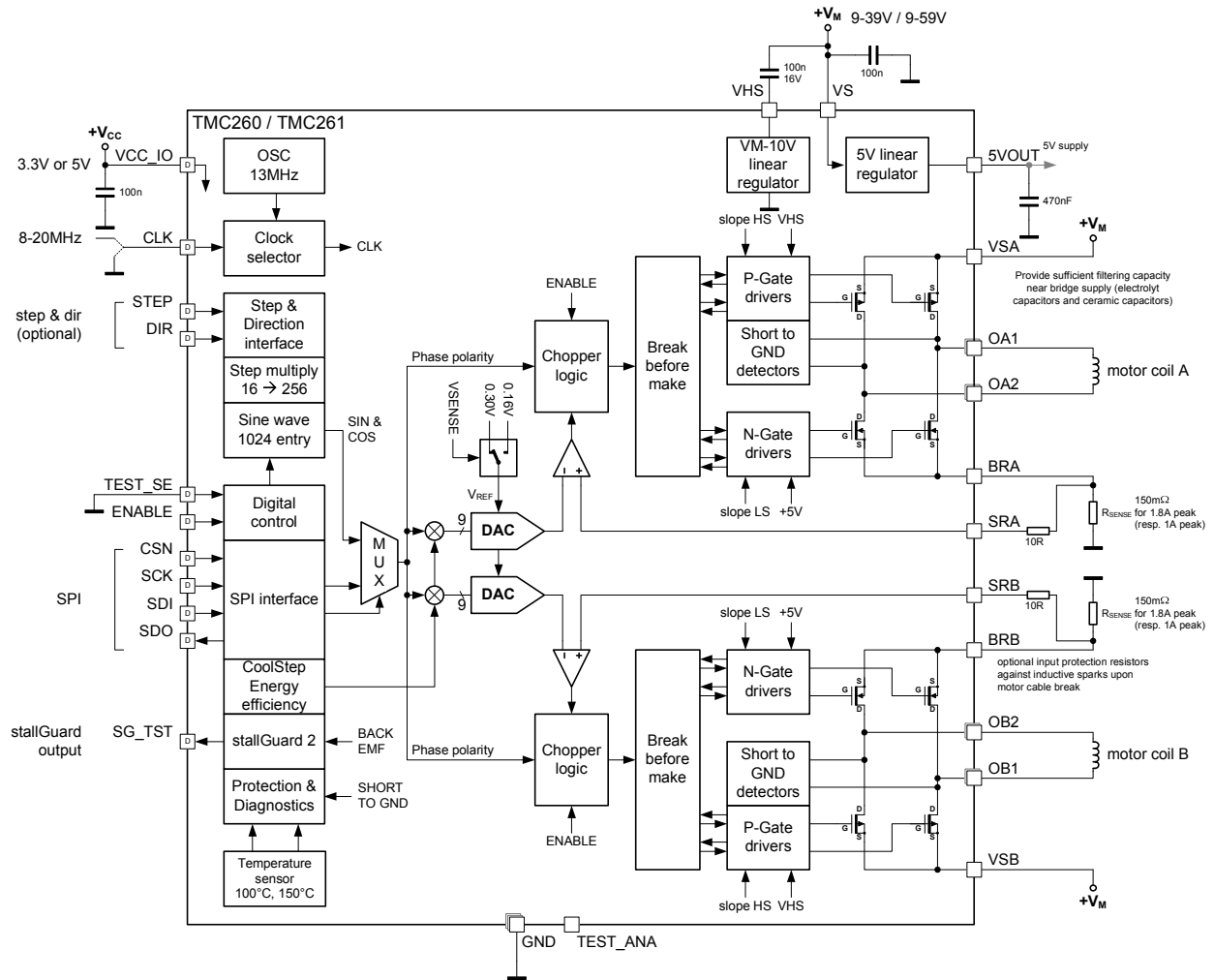


figure 7: TMC260 and TMC261 block and application diagram

The TMC260 and TMC261 integrate 40V resp. 60V MOSFETs capable of driving 1.2A RMS motors continuously. They are identical to the TMC262 in all other respects.

5.1 Pin description of TMC262-LA

Pin	Number	Type	Function
GND	1, 13		Digital and analog low power GND
HxA HBx	2, 3 22, 23	O (VS)	High side P-channel driver output. Becomes driven to VHS to switch on MOSFET.
BMAx BMBx	4, 5 20, 21	I (VS)	Sensing input for bridge outputs. Used for short to GND protection. May be tied to VS if unused.
LxA LBx	6, 7 18, 19	O 5V	Low side MOSFET driver output. Becomes driven to 5VOUT to switch on MOSFET.
SRA SRB	8 17	AI	Sense resistor input of chopper driver.
5VOUT	9		Output of internal 5V linear regulator. This voltage is used to supply the low side drivers and internal analog circuitry. An external capacitor to GND close to the pin is required. Place the capacitor near to pin 9 and pin 13. 470nF ceramic are sufficient for most applications, an additional tantalum capacitor (10µF or more) improves performance with high gate charge MOSFETs.
SDO	10	DO VIO	Data output of SPI interface (Tristate)
SDI	11	DI VIO	Data input of SPI interface (Scan test input in test mode)
SCK	12	DI VIO	Serial clock input of SPI interface (Scan test shift enable input in test mode)
CSN	14	DI VIO	Chip select input of SPI interface
ENN	15	DI VIO	Enable not input for drivers. Switches off all MOSFETs.
CLK	16	DI VIO	Clock input for all internal operations. Tie low to use internal oscillator. A high signal disables the internal oscillator until power down.
VHS	24		High side supply voltage (motor supply voltage - 10V)
VS	25		Motor supply voltage
TST_ANA	26	AO VIO	Analog mode test output. Leave open for normal operation.
SG_TST	27	DO VIO	stallGuard2™ output. Signals motor stall (high active).
GNDP	28		Power GND for MOSFET drivers. Connect directly to GND
VCC_IO	29		Input / output supply voltage VIO for all digital pins. Tie to digital logic supply voltage. Allows operation in 3.3V and 5V systems.
DIR	30	DI VIO	Direction input. Is sampled upon detection of a step to determine stepping direction. An internal glitch filter for 60ns is provided.
STEP	31	DI VIO	Step input. An internal glitch filter for 60ns is provided.
TST_MODE	32	DI VIO	Test mode input. Puts IC into test mode. Tie to GND for normal operation.
exposed die pad	-	GND	Connect the exposed die pad to a GND plane. It is used for cooling of the IC and may either be left open or be connected to GND.

5.2 Pin description of TMC260-PA / TMC261-PA

Pin	Number	Type	Function
OA1	2, 3 7, 8	O (VS)	Bridge A1 output. Interconnect all 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 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 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 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 sensing input of chopper driver.
5VOUT	13		Output of internal 5V linear regulator. This voltage is used to supply the low side drivers and internal analog circuitry. An external capacitor to GND close to the pin is required. Place the capacitor near to pin 13 and pin 17. 470nF ceramic are sufficient.
SDO	14	DO VIO	Data output of SPI interface (Tristate)
SDI	15	DI VIO	Data input of SPI interface (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 of SPI interface
ENN	19	DI VIO	Enable not input for drivers. Switches off all MOSFETs.
CLK	21	DI VIO	Clock input for all internal operations. Tie low to use internal oscillator. A high signal disables the internal oscillator until power down.
VHS	35		High side supply voltage (motor supply voltage - 10V)
VS	36		Motor supply voltage
TST_ANA	37	AO VIO	Analog mode test output. Leave open for normal operation.
SG_TST	38	DO VIO	stallGuard2™ output. Signals motor stall (high active).
VCC_IO	40		Input / output supply voltage VIO for all digital pins. Tie to digital logic supply voltage. Allows operation in 3.3V and 5V systems.
DIR	41	DI VIO	Direction input. Is sampled upon detection of a step to determine stepping direction. An internal glitch filter for 60ns is provided.
STEP	42	DI VIO	Step input. An internal glitch filter for 60ns is provided.
TST_MODE	43	DI VIO	Test mode input. Puts IC into test mode. Tie to GND for normal operation.

*) The OA and OB dual pin outputs directly are connected electrically and thermally to the drain of the MOSFETs of the driver output stage. A symmetrical, thermally optimized layout is required to ensure proper heat dissipation of all MOSFETs into the PCB. Use thick traces and enough vias for the motor driver outputs.

6 SPI mode shift register

The TMC26x requires a configuration via SPI prior to operation. Its SPI interface also allows for reading back status flags. The SPI interface can operate up to the half clock frequency. The MSB (bit 19) is transmitted first. See chapter 6 for details.

6.1 Overview (write)

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

6.2 Overview (read)

Bit	<i>RDSEL</i> =00	<i>RDSEL</i> =01	<i>RDSEL</i> =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	MSTEP4	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		

6.3 Driver control register bit assignment

The driver control register is used to operate the device in SPI mode. In StepDir mode, it selects specific step and direction interface specific parameters. They need to be initialized once upon power up, and whenever basic parameters are required to be changed. Only write access is possible.

The meaning of register 0 depends on the mode selection between SPI mode and StepDir mode as selected by SDOFF (configuration register 11, bit 7).

6.3.1 Driver control register bit assignment in SPI mode

DRVCTRL		write 0xxx, SDOFF=1	
Bit	Name	Function	Comment
19	CFR	select configuration register	0: Operation mode dependent settings (see SDOFF)
18	-	reserved	set to 0
17	PHA	Polarity A	
16	CA7	Current A MSB	0 to max. 248 if hysteresis or offset are used up to their full extent. The resulting value is not allowed to overflow 255.
15	CA6		
14	CA5		
13	CA4		
12	CA3		
11	CA2		
10	CA1		
9	CA0	Current A LSB	
8	PHB	Polarity B	
7	CB7	Current B MSB	0 to max. 248 if hysteresis or offset are used up to their full extent. The resulting value is not allowed to overflow 255.
6	CB6		
5	CB5		
4	CB4		
3	CB3		
2	CB2		
1	CB1		
0	CB0	Current B LSB	

6.3.2 Driver control register bit assignment in StepDir mode

DRVCTRL		write 0xxx, SDOFF=0	
Bit	Name	Function	Comment
19	CFR	select configuration register	0: Operation mode dependent settings (see SDOFF)
18	-	reserved	set to 0
17	-	reserved	set to 0
16	-	reserved	set to 0
15	-	reserved	set to 0
14	-	reserved	set to 0
13	-	reserved	set to 0
12	-	reserved	set to 0
11	-	reserved	set to 0
10	-	reserved	set to 0
9	INTPOL	enable step interpolation	1: Enable step impulse multiplication by 16. Only in resolution 16x microsteps, the microstepping becomes extrapolated to 256 microsteps. Interpolation is possible starting below step distance of max. 2 ²⁰ clock periods.
8	DEDGE	enable double edge step pulses	1: Enable step impulse at each step edge to reduce step frequency requirement.
7	-	reserved	set to 0
6	-	reserved	set to 0
5	-	reserved	set to 0
4	-	reserved	set to 0
3	MRES3	micro step resolution for step/direction mode	0000 ... 1000: 256, 128, 64, 32, 16, 8, 4, 2, FULLSTEP Please take into account, that the microstep position when switching to a lower resolution determines the sequence of patterns.
2	MRES2		
1	MRES1		
0	MRES0		

6.4 Configuration register bit assignment

The configuration registers select the mode of operation and set all motor and application dependent parameters. They need to be initialized once upon power up, and whenever basic parameters are required to be changed. Only write access is possible.

CHOPCONF		write 100x: Chopper Configuration		
Bit	Name	Function	Comment	
19	CFR	select configuration register	1: Configuration register	
18	CFRSEL1	select configuration register	00: Chopper configuration register	
17	CFRSEL0			
16	TBL1	blank time select	00 ... 11: Set comparator blank time to 16, 24, 36 or 54 clocks	
15	TBL0			
14	CHM	chopper mode	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	0	Chopper off time is fixed as set by bits t_{OFF}
			1	Random mode, t_{OFF} is random modulated by $dN_{CLK} = -12 \dots +3$ clocks.
12	HDEC1	hysteresis decrement interval or fast decay mode	CHM=0	Hysteresis decrement period setting: 00 ... 11: 16, 32, 48, 64 clocks
11	HDEC0		CHM=1	FDMODE setting: HDEC1=1 disables current comparator usage for termination of the fast decay cycle HDEC0: MSB of fast decay time setting
10	HEND3	hysteresis low value or sine wave offset	0000 ... 1111: Hysteresis is -3, -2, -1, 0, 1, ..., 12 (1/512 of this setting adds to current setting) With CHM=1 this is the sine wave offset.	
9	HEND2			
8	HEND1			
7	HEND0			
6	HSTRT2	hysteresis start value or fast decay time setting	CHM=0	DAC hysteresis setting: 000 ... 111: add 1, 2, ..., 8 to hysteresis low value HEND (1/512 of this setting adds to current setting) <i>Attention:</i> <i>Effective HEND+HSTRT must be ≤ 15</i>
5	HSTRT1		CHM=1	Fast decay time setting (MSB: HDEC0): 0000 ... 1111: Fast decay time setting with $N_{CLK} = 32 * HSTRT$ (000: slow decay only)
4	HSTRT0			
3	TOFF3	off time and driver enable	Off time setting for constant t_{OFF} chopper $N_{CLK} = 12 + 32 * t_{OFF}$ (Minimum is 64 clocks) 0000: Driver disable, all bridges off 0001: not allowed 0010 ... 1111: 2 ... 15	
2	TOFF2			
1	TOFF1			
0	TOFF0			

SMARTEN		write 1010: Smart Energy control coolStep™	
Bit	Name	Function	Comment
19	CFR	select configuration register	1: configuration register
18	CFRSEL1	select configuration register	01: Smart energy current control configuration register
17	CFRSEL0		
16	-	reserved	set to 0
15	SEIMIN	minimum current for smart current control	0: 1/2 of current setting (CS) 1: 1/4 of current setting (CS)
14	SEDN1	current down step speed	00: for each 32 stallGuard values decrease by one 01: for each 8 stallGuard values decrease by one 10: for each 2 stallGuard values decrease by one 11: for each stallGuard value decrease by one
13	SEDN0		
12	-	reserved	set to 0
11	SEMAX3	stallGuard hysteresis value for smart current control	If the stallGuard result is equal to or above (SEMIN+SEMAX+1)*32, the motor current becomes decreased to save energy. 0000 ... 1111: 0 ... 15
10	SEMAX2		
9	SEMAX1		
8	SEMAX0		
7	-	reserved	set to 0
6	SEUP1	current up step width	Current steps per measured stallGuard value 00 ... 11: 1, 2, 4, 8
5	SEUP0		
4	-	reserved	set to 0
3	SEMIN3	minimum stallGuard value for smart current control and smart current enable	If the stallGuard result falls below SEMIN*32, the motor current becomes increased to reduce motor load angle. 0000: smart current control off 0001 ... 1111: 1 ... 15
2	SEMIN2		
1	SEMIN1		
0	SEMIN0		

SGCSCONF		write 110x: Load measurement stallGuard2™ and Current Setting	
Bit	Name	Function	Comment
19	CFR	select configuration register	1: Configuration register
18	CFRSEL1	select configuration register	10: stallGuard and current configuration register
17	CFRSEL0		
16	SFILT	stallGuard filter enable	0 Standard mode, high time resolution for stallGuard 1 Filtered mode, stallGuard signal updated for each four fullsteps only to compensate for motor pole tolerances
15	-	reserved	set to 0
14	SGT6	stallGuard threshold value	This signed value controls stallGuard level for stall output and sets the optimum measurement range for readout. A lower value gives a higher sensitivity. Zero is the starting value working with most motors. -64 to +63: A higher value makes stallGuard less sensitive and requires more torque to indicate a stall.
13	SGT5		
12	SGT4		
11	SGT3		
10	SGT2		
9	SGT1		
8	SGT0		
7	-	reserved	set to 0
6	-	reserved	set to 0
5	-	reserved	set to 0
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
3	CS3		
2	CS2		
1	CS1		
0	CS0		

DRVCONF		write 111x: Driver Configuration	
Bit	Name	Function	Comment
19	CFR	select configuration register	1: Configuration register
18	CFRSEL1	select configuration register	11: Driver configuration register
17	CFRSEL0		
16	TST	reserved TEST mode	Set to 0. When 1, SG_TST outputs digital test values, and TEST_ANA outputs analog test values. Selection is done by SGT1 and SGT0 (00 ... 11): For TEST_ANA: anatest_2vth, anatest_dac_out, anatest_vdd_half. For SG_TST: comp_A, comp_B, CLK, on_state_xy
15	SLPH1	Slope control high side	00: min, 01: min + tc, 10: med + tc, 11: max In temperature compensated mode (tc), the driver strength is increased if the overtemperature prewarning temperature is reached. This compensates for temperature dependence of high side slope control.
14	SLPH0		
13	SLPL1	Slope control low side	00, 01: min, 10: med, 11: max
12	SLPL0		
11	-	reserved	set to 0
10	DISS2G	short to GND protection disable	0: Short to GND protection is on 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 Direction input off	0: Enable step and direction mode (StepDir) 1: Enable SPI mode
6	VSENSE	sense resistor voltage based current scaling	0: Full scale sense resistor voltage is 305mV 1: Full scale sense resistor voltage is 165mV (refers to a current setting of 31 and DAC value 255)
5	RDSEL1	Select value for read out (RD bits)	00 Microstep position read back
4	RDSEL0		01 stallGuard level read back
			10 stallGuard and smart current level read back
			11 Reserved, do not use
3	-	reserved	set to 0
2	-	reserved	set to 0
1	-	reserved	set to 0
0	-	reserved	set to 0

6.5 Bit assignment for read

Information can be read back from the driver on each access. Different information may be required, depending on the application. This is selected by the bits RDSEL in the register DRVCONF.

DRVSTATUS		read status information – Partially selected by RDSEL in DRVCONF	
Bit	Name	Function	Comment
19	RD9	microstep position in internal sine table for phase A or stallGuard bits 9 to 0 or stallGuard bits 9 to 5 and current control scale	RDSEL=00 Actual microstep position in sine table for phase A in step/direction operation (MSTEP) (MSTEP9=PHA)
18	RD8		
17	RD7		
16	RD6		
15	RD5		
14	RD4		
13	RD3		
12	RD2		
11	RD1		
10	RD0		
9	0	reserved	-
8	0	reserved	-
7	STST	stand still step indicator	1: Indicates, that no step impulse occurred on the step input during the last 2 ²⁰ clock cycles.
6	OLB	open load indicator	Flag becomes set, if no chopper event has happened during the last period with constant coil polarity. Only a current above 1/16 of maximum setting can reset this flag!
5	OLA		
4	S2GB	short to GND detection bits on high side transistors	1: Short condition is detected, driver is currently shut down (clear short condition by disabling driver) In a short circuit condition, the chopper cycle becomes terminated. The short counter is increased by each short circuit. It becomes decreased by one for each phase polarity change. The driver becomes shut down when the counter reaches 3, until the short condition becomes reset by disabling and re-enabling the driver.
3	S2GA		
2	OTPW	overtemperature pre-warning	1: Warning threshold is exceeded
1	OT	overtemperature	1: Driver is shut down due to overtemperature
0	SG	stallGuard status	1: stallGuard threshold is reached, SG output high

6.6 SPI timing

The SPI interface uses the system clock to synchronize all input and output signals. This limits the SPI clock frequency to at maximum half of the system clock frequency. For an asynchronous system using the internal clock, some 10 percent of safety margin should be used, assuming the minimum internal and maximum SPI master clock frequency, in order to ensure a reliable data transmission.

All SPI inputs as well as the ENN input are internally filtered to avoid triggering on short time glitches.

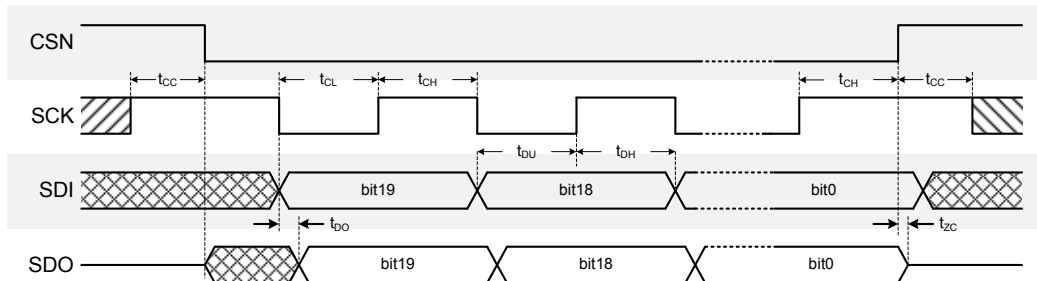


figure 8: SPI timing

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

7 Step and direction interface

The step and direction interface allows easy movement of the motor and is a simple real time interface for a motion controller. Its pulse rate multiplier allows smooth motor operation even with reduced pulse bandwidth.

7.1 Timing

The step and direction interface pins are sampled synchronously with the clock signal. An internal analog filter removes disturbances caused by glitches on the signals, e.g. caused by long PCB traces. Despite this, the signals should be filtered and / or differentially transmitted, if the step source is far from the TMC26x and especially if the step signals are interconnected via cables.

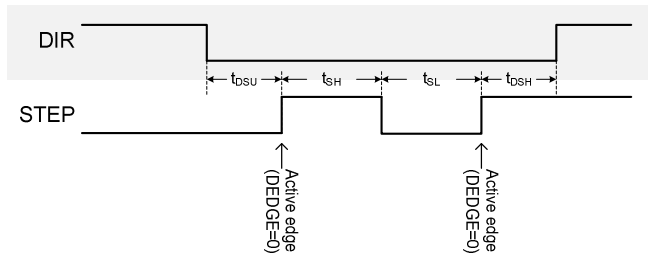


figure 9: STEP and DIR timing

STEP and DIR interface timing		AC-Characteristics				
		clock period is t_{CLK}				
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
step frequency (at maximum microstep resolution)	f_{STEP}	DEGDE=0			$\frac{1}{2} f_{CLK}$	
		DEDGE=1			$\frac{1}{4} f_{CLK}$	
fullstep frequency	f_{FS}				$f_{CLK}/512$	
STEP input low time	t_{SL}		$\max(t_{FILTS}, t_{CLK}+20)$			ns
STEP input high time	t_{SH}		$\max(t_{FILTS}, t_{CLK}+20)$			ns
DIR to STEP setup time	t_{DSU}		20			ns
DIR after STEP hold time	t_{DSH}		20			ns
STEP and DIR spike filtering time	t_{FILTS}	rising and falling edge	36	60	85	ns
STEP and DIR sampling relative to rising CLK input	$t_{SDCLKHI}$	before rising edge of CLK input		t_{FILTS}		ns

7.2 Internal microstep table

The internal microstep table uses 1024 sine wave entries to generate the wave. Its amplitude is +/-248 rather than +/-255, leaving enough headroom for a positive offset correction or hysteresis setting within an 8 bit amplitude range. The step width depends on the microstep resolution setting. Due to the symmetry of the sine wave, only a quarter of the table needs to be stored. The cosine wave uses a phase shift of 90°. Despite many entries in the last quarter of the table being equal, the electrical angle continuously changes, because either sine wave or cosine wave is in an area, where the current vector changes monotonously from position to position.

Entry	0-31	32-63	64-95	96-127	128-159	160-191	192-223	224-255
0	1	49	96	138	176	207	229	243
1	2	51	97	140	177	207	230	244
2	4	52	98	141	178	208	231	244
3	5	54	100	142	179	209	231	244
4	7	55	101	143	180	210	232	244
5	8	57	103	145	181	211	232	245
6	10	58	104	146	182	212	233	245
7	11	60	105	147	183	212	233	245
8	13	61	107	148	184	213	234	245
9	14	62	108	150	185	214	234	246
10	16	64	109	151	186	215	235	246
11	17	65	111	152	187	215	235	246
12	19	67	112	153	188	216	236	246
13	21	68	114	154	189	217	236	246
14	22	70	115	156	190	218	237	247
15	24	71	116	157	191	218	237	247
16	25	73	118	158	192	219	238	247
17	27	74	119	159	193	220	238	247
18	28	76	120	160	194	220	238	247
19	30	77	122	161	195	221	239	247
20	31	79	123	163	196	222	239	247
21	33	80	124	164	197	223	240	247
22	34	81	126	165	198	223	240	248
23	36	83	127	166	199	224	240	248
24	37	84	128	167	200	225	241	248
25	39	86	129	168	201	225	241	248
26	40	87	131	169	201	226	241	248
27	42	89	132	170	202	226	242	248
28	43	90	133	172	203	227	242	248
29	45	91	135	173	204	228	242	248
30	46	93	136	174	205	228	243	248
31	48	94	137	175	206	229	243	248

figure 10: internal microstep table showing the first quarter of the sine wave

7.3 Switching between different microstep resolutions

In principle, the microstep resolution can be changed at any time. The microstep resolution determines the increment respectively the decrement, the TMC26x uses for advancing in the microstep table. At maximum resolution, it advances one step for each step pulse. At half resolution, it advances two steps and so on. This way, a change of resolution is possible transparently at each time.

7.3.1 Working with half- and fullstep resolution

Fullstepping is desirable in some applications, where maximum torque at maximum velocity with a given motor is desired. Especially at low microstep resolutions like full- or halfstepping, the absolute current values and thus the absolute positions in the table are important for best motor performance. Thus, a software which uses resolution switching in order to get maximum torque and velocity from the drive, should switch the resolution at or near certain positions, as shown in the following table.

Step position	MSTEP value	current coil A	current coil B
half step 0	0	0%	100%
full step 0	128	70.7%	70.7%
half step 1	256	100%	0%
full step 1	384	70.7%	-70.7%
half step 2	512	0%	-100%
full step 2	640	-70.7%	-70.7%
half step 3	768	-100%	0%
full step 3	896	-70.7%	70.7%

figure 11: optimum position sequence for half- and full stepping

7.4 Step rate multiplier and stand still detection

The step rate multiplier can be enabled by setting the INTPOL bit. It supports a 16 microstep setting and Step/Dir mode, only. In this setting, each step impulse at the input causes the execution of 16 times 1/256 microsteps. The step rate for the 16 microsteps is determined by measuring the time interval of the previous step pulses and dividing it into 16 equal parts. This way, a smooth motor movement like in 256 microstep resolution is achieved. The maximum time between two microsteps corresponds to 2^{20} i.e. roughly one million clock cycles, in order to reach evenly distributed 1/256 steps. At 16MHz clock frequency, this results in a minimum step input frequency of 16Hz for step rate multiplier operation, i.e. one fullstep per second. A lower step rate causes the stand still flag to be set, and execution of microsteps with a frequency of $1/(2^{16})$ clock frequency.

Attention: The step rate multiplier will only give good results with a stable microstep frequency. Do not use the DEDGE option, if the step input does not have a 50% duty cycle.

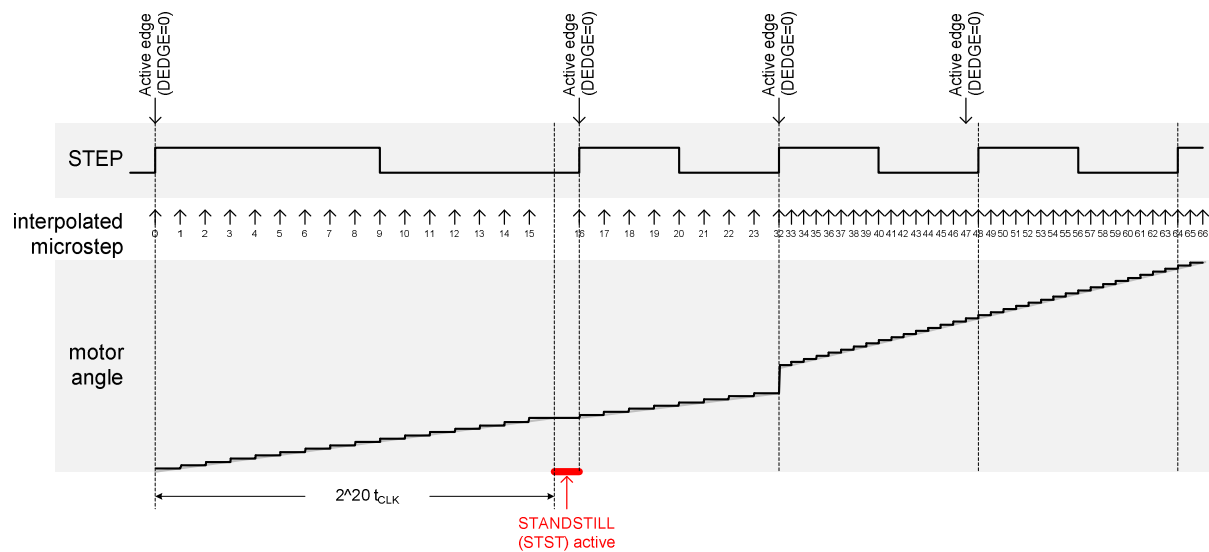


figure 12: operation of the step multiplier in different situations

8 Current setting

The internal 5V supply voltage is used as a reference. To adapt the motor current, and to allow for different values of sense resistors, the voltage divider for full scale can be chosen as $V_{FS(HI)}=1/16$ VDD or $V_{FS(LO)}=1/30$ of VDD. With this, the peak sense resistor voltage at a digital DAC control level of 255 is roughly 0.16V or 0.3V.

Using the internal sine wave table, which has the amplitude of 248, the RMS motor current thus can be calculated by:

$$I_{RMS} = \frac{248}{256} * \frac{CS + 1}{32} * \frac{V_{FS}}{R_{SENSE}} * \frac{1}{\sqrt{2}}$$

The momentary motor current is calculated by:

$$I_{MOT} = \frac{CURRENT_{A/B}}{256} * \frac{CS + 1}{32} * \frac{V_{FS}}{R_{SENSE}}$$

CS is the current scale setting as set by the CS bits and smart current scaler.

V_{FS} is the full scale voltage as determined by VSENSE control bit (please refer electrical characteristics).

$CURRENT_{A/B}$ is the value set by the current setting in SPI mode, or, the actual value from the internal sine wave table in Step/Dir mode.

Parameter	Description	Range	Comment
CS	<i>Current scale.</i> 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: 0 ... 31: 1/32, 2/32, ... 32/32
VSENSE	Allows control of the sense resistor <i>voltage range</i> or adaptation of one electronic module to different maximum motor currents.	0 / 1	0: 305mV 1: 165mV

8.1 Considerations on the current sense resistors and layout

Sense resistors should be carefully selected. The full motor current flows through each sense resistor. They also see the switching spikes from the MOSFET bridges. A low inductance type resistor is required to prevent spikes causing ringing on the current measurement leading to instable measurement results. A low inductivity, low resistance layout is essential. Also, any common GND path of the two sense resistors needs to be prevented, because this would lead to coupling between both current sense signals. A massive GND plane is best. Especially for high current drivers or long motor cables, a spike damping with parallel capacitors can make sense (see figure 13). As the TMC26x is susceptible to negative over voltages on the sense resistor inputs, an additional input protection resistor helps preventing damage in case of motor cable break or increased ringing on the motor lines in case of long motor cables.

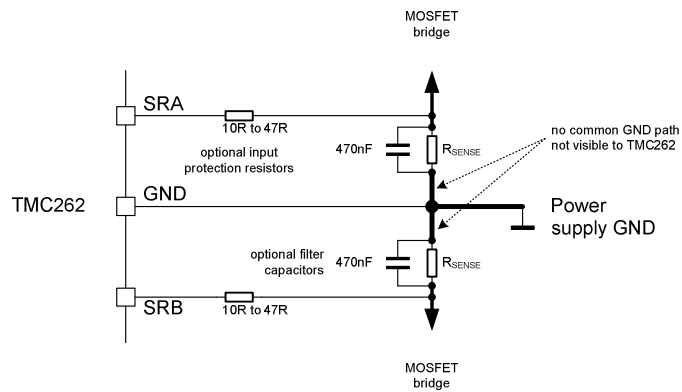


figure 13: sense resistor grounding and optional parts

The sense resistor needs to be able to conduct the peak motor coil current in motor stand still situations, unless standby power is reduced. Under normal conditions, the sense resistor sees a bit less than the coil RMS current, because no current flows through the sense resistor during the slow decay states.

Peak sense resistor power dissipation:

$$P_{RSMAX} = \frac{\left(V_{SENSE} * \frac{CS + 1}{32} \right)^2}{R_{SENSE}}$$

For high current applications, power dissipation is halved by using the low V_{SENSE} setting and using an adapted resistance value. Please be aware, that in this case any voltage drop in PCB traces has a larger influence on the result. A compact power stage layout with massive ground plane is best to avoid parasitic effects.

9 Chopper operation of the motor coils

Both motor coils are operated using a chopper principle. The chopper for both coils works independently of each other. In figure 14 the different phases of a chopper cycles are shown. In the on-phase, the current is actively driven into the coils by connecting them to the power supply in the direction of the target current. A fast decay phase reverses the polarity of the coil voltage to actively reduce the current. The slow decay phase shorts the coil in order to let the current re-circulate. While in principle the current could be regulated using only on phases and fast decay phases, insertion of the slow decay phase is important to reduce current ripple in the motor and electrical losses. The duration of the slow decay phase sets an upper limit to the chopper frequency. The current comparator can measure coil current, when the current flows through the sense resistor. Whenever the coil becomes switched, spikes at the sense resistors occur due to charging and discharging parasitic capacities. During this time (typically one or two microseconds), the current cannot be measured. It needs to be covered by the blank time setting.

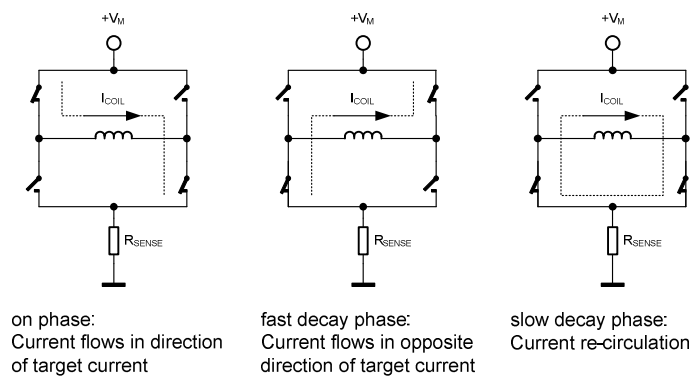


figure 14: chopper phases in motor operation

There are two chopper modes available: A new high performance chopper scheme, and a proven constant off time chopper with a programmable portion of fast decay.

Parameter	Description	Range	Comment
TOFF	The <i>off time</i> setting controls the minimum chopper frequency. For most applications an off time within the range of 5 μ s to 20 μ s will fit. Setting this parameter to zero completely disables all driver transistors and the motor can free-wheel.	0 / 2...15	0: chopper off 2...15: off time setting
TBL	Selects the comparator <i>blank time</i> . This time needs to safely cover the switching event and the duration of the ringing on the sense resistor. For most low current drivers, a setting of 1 or 2 is good. For high current applications with large MOSFETs, a setting of 2 or 3 will be required.	0...3	0: min. setting 3: max. setting
CHM	Selection of the <i>chopper mode</i>	0 / 1	0: spreadCycle 1: classic const. off time

9.1 spreadCycle chopper

The spreadCycle chopper scheme (pat.fil.) is a precise and simple to use chopper principle, which automatically determines the optimum fast decay portion for the motor. Anyhow, a number of settings can be made in order to optimally fit the driver to the motor.

Each chopper cycle is comprised of an on phase, a slow decay phase, a fast decay phase and a second slow decay phase (see figure 15). The slow decay phases limit the maximum chopper frequency and are important for low motor and driver power dissipation. The hysteresis start setting limits the chopper frequency by forcing the driver to introduce a minimum amount of current ripple into the motor coils. The motor inductivity determines the ability to follow a changing motor current. The

duration of the on- and fast decay phase needs to cover at least the blank time, because the current comparator is disabled during this time. This is satisfied by choosing a positive value for the hysteresis as can be estimated by the following calculation:

$$dI_{COILBLANK} = V_M * \frac{t_{BLANK}}{L_{COIL}}$$

$$dI_{COILSD} = R_{COIL} * I_{COIL} * \frac{2 * t_{SD}}{L_{COIL}}$$

where $dI_{COILBLANK}$ is the coil current change during the blank time and dI_{COILSD} is the coil current change during the slow decay time, t_{SD} is the slow decay time, t_{BLANK} is the blank time (as set by TBL), V_M is the motor supply voltage, I_{COIL} is the peak motor coil current at the maximum motor current setting CS, and R_{COIL} and L_{COIL} are motor coil inductivity and motor coil resistance.

With this, a lower limit for the start hysteresis setting can be determined:

$$Hysteresis\ Start \geq (dI_{COILBLANK} + dI_{COILSD}) * \frac{2 * 248}{I_{COIL}} * \frac{CS + 1}{32}$$

Example:

For a 42mm stepper motor with 7.5mH, 4.5Ω phase and 1A RMS current at CS=31, i.e. 1.41A peak current, at 24V with a blank time of 1.5μs:

$$dI_{COILBLANK} = 24V * \frac{2\mu s}{7.5mH} = 6.4mA$$

$$dI_{COILSD} = 4.5\Omega * 1.41A * \frac{2 * 5\mu s}{7.5mH} = 8.5mA$$

With this, the minimum hysteresis start setting is 5.2. A value in the range 6 to 10 can be used.

As experiments show, the setting is quite independent of the motor, as higher current motors typically also have a lower coil resistance. Choosing a default value with enough safety margins normally fits most applications.

The setting can also be determined by experimenting with the motor: A too low setting will result in reduced microstep accuracy, while a too high setting will lead to more chopper noise and motor power dissipation.

The hysteresis principle could in some cases lead to the chopper frequency becoming too low, e.g. when the coil resistance is high when compared to the supply voltage. This is avoided by a second set of parameters: The hysteresis end value and the hysteresis decrement speed (HDEC). This set of additional parameters reduces the hysteresis from the start value to the end value within each chopper cycle. This way, the chopper frequency becomes stabilized at high amplitudes, in case it tends to get too low. This avoids the chopper frequency reaching the audible range.

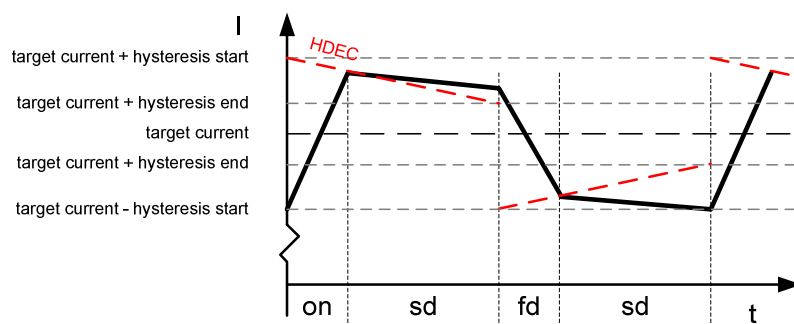


figure 15: spreadCycle (pat.fil.) chopper scheme showing the coil current within a chopper cycle

Parameter	Description	Range	Comment
HSTART	<i>Hysteresis start</i> setting. Please remark, that this value is an offset to the hysteresis end value HEND.	1...8	This setting adds to HEND.
HEND	<i>Hysteresis end</i> setting. Sets the hysteresis end value after a number of decrements. Decrement interval time is controlled by HDEC.	-3...12	-3...-1: negative HEND 0: zero HEND 1...12: positive HEND
HDEC	<i>Hysteresis decrement</i> setting. This setting determines the slope of the hysteresis during on time and during fast decay time.	0...3	0: fast decrement 3: very slow decrement

Example:

In the example above a hysteresis start of 7 has been chosen. The hysteresis end is set to about half of this value, e.g. 3. The resulting configuration register values are as follows:

HEND=6 (sets an effective end value of 3)
HSTART=3 (sets an effective start value of hysteresis end +4)
HDEC=0 (Hysteresis decrement becomes used)

9.2 Classic constant off time chopper

The classic constant off time chopper uses a fixed portion of fast decay following each on phase. While the duration of the on time is determined by the chopper comparator, the fast decay time needs to be set by the user in a way, that the current decay is enough for the driver to be able to follow the falling slope of the sine wave, and on the other hand it should not be too long, in order to minimize motor current ripple and power dissipation. This best can be tuned using an oscilloscope or trying out motor smoothness at different velocities. A good starting value is a fast decay time setting similar to the slow decay time setting.

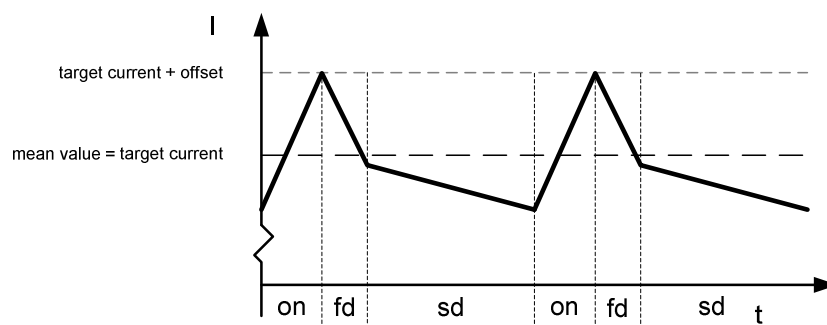


figure 16: classic const. off time chopper with offset showing the coil current within two cycles

After tuning of the fast decay time, the offset should be determined, in order to have a smooth zero transition. This is necessary, because the fast decay phase leads to the absolute value of the motor current being lower than the target current (see figure 17). If the zero offset is too low, the motor stands still for a short moment during current zero crossing, if it is set too high, it makes a larger microstep. Typically, a positive offset setting is required for optimum operation.

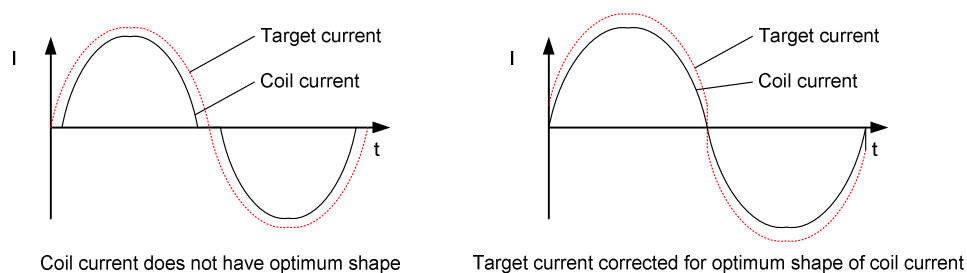


figure 17: zero crossing with classic chopper and correction using sine wave offset

Parameter	Description	Range	Comment
TFD (HSTART & HDEC0)	<i>Fast decay time</i> setting. With CHM=1, these bits control the portion of fast decay for each chopper cycle. They must cover	0...15	0: slow decay only 1...15: duration of fast decay phase
OFFSET (HEND)	<i>Sine wave offset</i> . With CHM=1, these bits control the sine wave offset. A positive offset corrects for zero crossing error.	-3...12	-3...-1: negative offset 0: no offset 1...12: positive offset
NCCFD (HDEC1)	Selects usage of the <i>current comparator</i> for termination of the <i>fast decay</i> cycle. If current comparator is enabled, it terminates the fast decay cycle in case the current reaches a higher negative value than the actual positive value.	0 / 1	0: enable comparator termination of fast decay cycle 1: end by time only

9.3 Random off time

One drawback of the constant off time chopper schemes is that both coil choppers are not synchronized. A beat could occur between the chopper frequencies, especially when they are near to each other. This typically occurs at a few microstep positions within each quarter wave. Factors influencing this are also a bad PCB layout which causes coupling of both sense resistor voltages. A beat between the frequencies can lead to low amplitude mechanical oscillations on the motor as well as to audible chopper noise.

In order to minimize the effect of beat between both chopper frequencies, a random generator can be used to modify the slow decay time setting. It is switched on by the RNDTF bit.

Parameter	Description	Range	Comment
RNDTF	This bit switches on a <i>random off time</i> generator, which slightly modulates the off time t_{OFF} using a random polynomial.	0 / 1	1: random modulation enable

10 MOSFET driver stage

The TMC262 provides a two full bridge driver stage for N&P channel MOSFETs. TMC260 and TMC261 already integrate the power MOSFETs. The gate driver current for the power MOSFETs can be adapted to match the MOSFETs and to influence the slew rate at the coil outputs. Main features of the driver stage:

- 5V gate drive voltage for low side N MOS driver, 8V for high side P MOS driver.
- The drivers protect the bridges actively against cross conduction via an internal Q_{GD} protection that holds MOSFET safely off.
- Automatic brake-before-make logic minimizes dead time and diode conduction time.
- Integrated short to ground protection detects a short of the motor wires and protects the driver.

10.1 Principle of operation

The low side gate driver is supplied by the 5VOUT pin. The low side driver supplies 0V to the MOSFET gate to close the MOSFET, and 5VOUT to open it. The high side gate driver voltage is supplied by the VS and the VHS pin. VHS is more negative than VS and allows opening the VS referenced high side MOSFET. The high side driver supplies VS to the P channel MOSFET gate to close the MOSFET, and VHS to open it. The effective low side gate voltage is roughly 5V; the effective high side gate voltage is roughly 8V.

Parameter	Description	Range	Comment
SLPL	Low side slope control. Controls the MOSFET gate driver current. For TMC262, set a value fitting the external MOSFET gate charge and the desired slope. For TMC260 and TMC261 set to 0 or to 1. Slopes are fast in order to minimize package power dissipation.	0...3	0, 1: min. setting... 3: max. setting
SLPH	High side slope control. Controls the MOSFET gate driver current. For TMC262, set to a value fitting the external MOSFET gate charge and the desired slope. For TMC260 set to 0 or to 1. Slopes are fast in order to minimize package power dissipation. For TMC261 set to 0 or 1 for medium slope; 2 to match fast low side slope.	0...3	0: min. setting... 3: max. setting

10.2 Break-before-make logic

Each half-bridge has to be protected against cross conduction during switching events. When switching off the low-side MOSFET, its gate first needs to be discharged, before the high side MOSFET is allowed to be switched on. The same goes when switching off the high-side MOSFET and switching on the low-side MOSFET. The time for charging and discharging of the MOSFET gates depends on the MOSFET gate charge and the driver current set by SLPL resp. SLPH. The BBM (break-before-make) logic measures the gate voltage and automatically delays switching on of the opposite bridge transistor, until its counterpart is discharged. This way, the bridge will always switch with optimized timing independent of the MOSFETs used and independent of the slope setting.

10.3 ENN input

The motor driver outputs can be completely disabled by hardware, by pulling the ENN input high. This way, the motor can free-wheel. The function however is identical to a software disable, which is achieved by setting the register TOFF to zero. The hardware disable may be used in cases, where the motor is to be hot plugged. For the TMC260, it can be used in overvoltage situations. It can withstand voltages of up to 60V when the driver MOSFETs are disabled.

For normal operation tie ENN low.

10.4 Slope control in TMC262

The TMC262 driver stage provides a constant current output stage slope control. This allows to adapt driver strength to the drive requirements of the power MOSFETs and to adjust the output slope by providing for a controlled gate charge and discharge. A slower slope causes less electromagnetic emission, but at the same time power dissipation of the power transistors rises. The duration of the complete switching event depends on the total gate charge. The voltage transition of the output takes place during the so called miller plateau (see figure 18). The miller plateau results from the gate to drain capacity of the MOSFET charging / discharging during the switching. From the datasheet of the transistor it can be seen, that the miller plateau typically covers only a part (e.g. one quarter) of the complete charging event. The gate voltage level, where the miller plateau starts, depends on the gate threshold voltage of the transistor and on the actual load current.

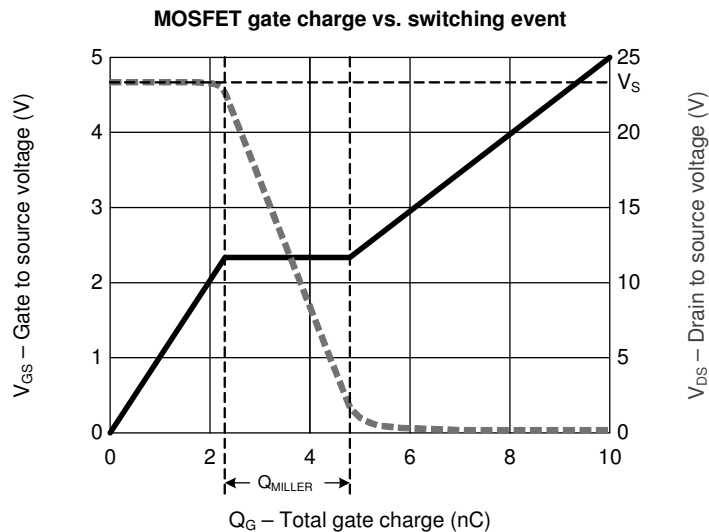


figure 18: MOSFET gate charge as available in device data sheet vs. switching event (dotted line)

The slope time t_{SLOPE} can be calculated as follows:

$$t_{SLOPE} = \frac{Q_{MILLER}}{I_{GATE}}$$

Whereas Q_{MILLER} is the charge the power transistor needs for the switching event, and I_{GATE} is the driver current setting of the TMC262.

Taking into account, that a slow switching event means high power dissipation during switching, and, on the other side a fast switching event can cause EMV problems, the desired slope will be in some ratio to the switching (chopper) frequency of the system. The chopper frequency is typically slightly outside the audible range, i.e. 18 kHz to 40 kHz. The lower limit for the slope is dictated by the reverse recovery time of the MOSFET internal diodes, unless additional Schottky diodes are used in parallel to the MOSFETs source-drain diode. Thus, for most applications a switching time between 100ns and 750ns is chosen.

The required slope time can be calculated as follows:

$$t_{SLOPE} = \frac{Q_{MILLER}}{I_{GATE}}$$

Example:

A circuit using the transistor from the diagram above is operated with a gate current setting of 15mA. The miller charge of the transistor is about 2.5nC.

$$t_{SLOPE} = \frac{2.5nC}{15mA} = 166ns$$

11 Diagnostics and protection

11.1 Short to GND detection

The short to GND detection prevents the high side power MOSFETs to be destroyed by accidentally shorting the motor outputs to ground. It disables the driver, if a short condition persists, only. A temporary event like an ESD event could look like a short, too. This becomes sorted out by the short detection logic. In case of a short being detected, the bridge will be switched off instantaneously. The chopper cycle on the affected coil becomes terminated and the short counter is increased by each short circuit. It becomes decreased by one for each phase polarity change. The driver becomes shut down when the counter reaches 3, until the short condition is reset by disabling the driver and re-enabling it.

Status flag	Description	Range	Comment
S2GA	These bits identify a <i>short to GND condition</i> on phase A resp. phase B persisting for multiple chopper cycles. The flags become cleared when disabling the driver.	0 / 1	1: short condition detected
S2GB			

An overload condition of the high side MOSFET (“short to GND”) is detected by the TMC26x, by monitoring the BM voltage during high side on time. Under normal conditions, the high side power MOSFET reaches the bridge supply voltage minus a small voltage drop during on time. If the bridge is overloaded, the voltage cannot rise to the detection level within a limited time, defined by the internal detection delay setting. Upon detection of an error, the bridge becomes switched off.

The short to GND detection delay needs to be adapted to the slope time, because it must cover the slope.

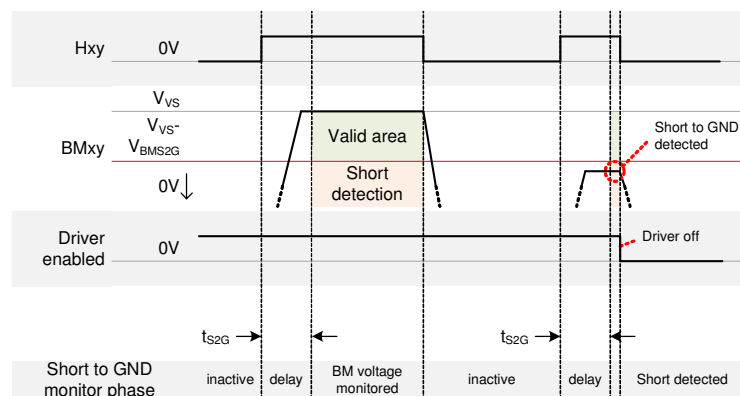


figure 19: timing of the short to GND detector

Parameter	Description	Range	Comment
TS2G	This setting controls the short to GND detection delay time. It needs to cover the switching slope time.	0...3	0: maximum time... 3: minimum time

11.2 Open load detection

The open load detection detects, if a motor coil has an open condition, for example due to a loose contact. When driving in fullstep mode, the open load detection will also detect when the motor current cannot be reached within each step, i.e. due to a too high motor velocity where the back EMF voltage exceeds the supply voltage. The flag just has an informational character and an active open load condition does not in all cases indicate that the motor is not working properly. The flag becomes updated during normal operation of the motor whenever the polarity of the respective phase toggles.

Status flag	Description	Range	Comment
OLA	These bits indicate an <i>open load condition</i> on phase A resp. phase B. The flags become set, if no chopper event has happened during the last period with constant coil polarity. The flag is not updated with too low actual coil current below 1/16 of maximum setting.	0 / 1	1: open load detected
OLB			

11.3 Temperature measurement

The TMC26x integrates a two level temperature sensor (100°C prewarning and 150°C thermal shutdown) for diagnostics and for protection of the driver stage. The temperature detector can detect heat accumulation on the board, i.e. due to missing convection cooling. It cannot detect overheating of the power transistors in all cases, because heat transfer between power transistors and driver chip depends on the PCB layout and environmental conditions. Most critical situations, where the driver MOSFETs could be overheated, are avoided when using the short to GND protection. For many applications, the overtemperature prewarning will indicate an abnormal operation situation and can be used to initiate user warning or power reduction measures. If continuous operation in hot environments is necessary, a more precise processor based temperature measurement should be used to realize application specific overtemperature detection. The thermal shutdown is just an emergency measure and temperature rising to the shutdown level should be prevented by design.

The highside P-channel gate drivers within the TMC26x have a temperature dependency, which can be compensated up to some extent by increasing driver current as soon as the warning temperature threshold is reached. The TMC26x automatically corrects the temperature dependency at two settings, marked as +tc in the SPI register documentation. In these settings, the driver current is increased by one step when the temperature warning threshold is reached.

Status flag	Description	Range	Comment
OTPW	Overtemperature pre-warning. This bit indicates that the pre-warning level is reached. The controller can react to this setting by reducing power dissipation.	0 / 1	1: temperature prewarning level reached
OT	Overtemperature warning. This bit indicates that the overtemperature threshold has been reached and that the driver is switched off due to overtemperature.	0 / 1	1: driver shut down due to overtemperature

11.4 Undervoltage detection

The undervoltage detector monitors both, the internal logic supply voltage and the driver supply voltage. It prevents operation of the chip at voltages, where a proper control of the MOSFET switches cannot be guaranteed due to too low gate drive voltage. Be sure to operate the IC significantly above the undervoltage threshold in order to assure reliable operation.

At undervoltage, the logic control block becomes reset and the driver is disabled. All MOSFETs become switched off. The processor thus also should monitor the supply voltage to detect an undervoltage condition. If the processor does not have an access to the voltage, the TMC26x can directly be monitored via its SPI interface sending out only zero bits and not shifting through information. A reset due to undervoltage or an actual undervoltage condition can be determined for example by monitoring the current setting via its read back function. The current value becomes reset to zero.

12 stallGuard2™ sensorless load measurement

stallGuard2™ delivers a sensorless load measurement of the motor as well as a stall detection signal. The measured value changes linear with the load on the motor in a wide range of load, velocity and current settings. At maximum motor load the stallGuard™ value goes to zero. This corresponds to a load angle of 90° between the magnetic field of the stator and magnets in the rotor. This also is the most energy efficient point of operation for the motor.

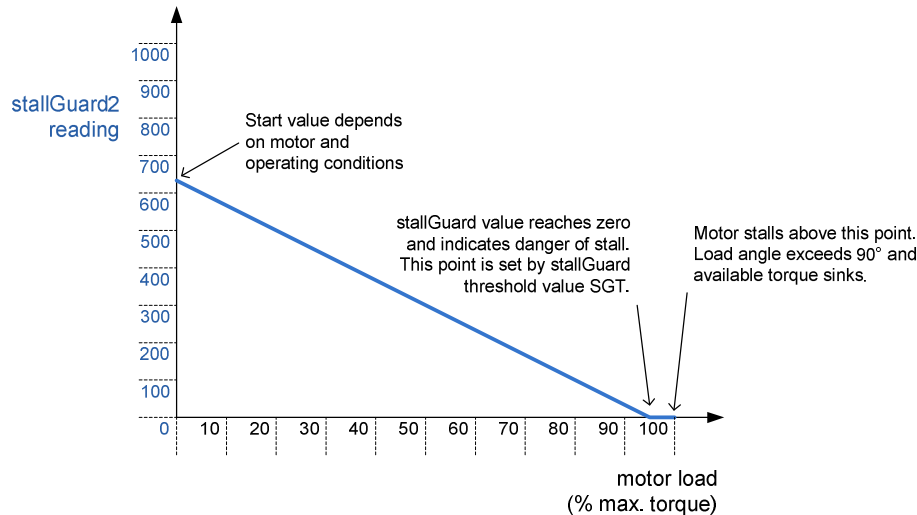


figure 20: principle function of stallGuard2

In order to use stallGuard2™ and coolStep™, the stallGuard2™ sensitivity should first be tuned using the ST setting.

12.1 Tuning the stallGuard2™ threshold SGT

The sensorless motor measurement depends on a number of motor specific parameters and operation parameters. The easiest way to find a parameter set which fits to a specific motor type and operating conditions is interactive tuning:

Operate the motor at a reasonable velocity (taking into account your application) and monitor the stallGuard™ value (SG). Now, apply slowly increasing mechanical load to the motor. If the motor stalls before the stallGuard™ value reaches zero, decrease the stallGuard threshold value (SGT). A good starting value is zero. You can apply negative values and positive values. If the SG value reaches zero far before the motor stalls, increase the SGT value.

The optimum setting is reached, when the stallGuard2™ value reaches zero at increasing load shortly before the motor stalls due to overload. However, this point can be shifted above 100% load, too. In this case, activation of the stall output indicates, that a step has been lost.

Please be aware, that the driver clock frequency influences this setting. You should provide an external stabilized clock for best performance. As the measurement has a high resolution, there are a number of additional possibilities to enhance the absolute precision in order to give a good match to the mechanical load on the motor. The optimum SGT value depends on a number of operating parameters which can be compensated for, as shown in the next chapters.

12.1.1 Variable velocity operation

At varying velocities, a correction of the stallGuard2™ threshold value SGT can improve the exactness of the load measurement and thus of coolStep™, which is based on the load measurement value. A linear interpolation between two SGT values optimized for different velocities provides a higher accuracy when operating with widely varying velocities. Linear interpolation can be used to reduce the required parameter set (see curve for simplified SGT setting in the example in figure 21).

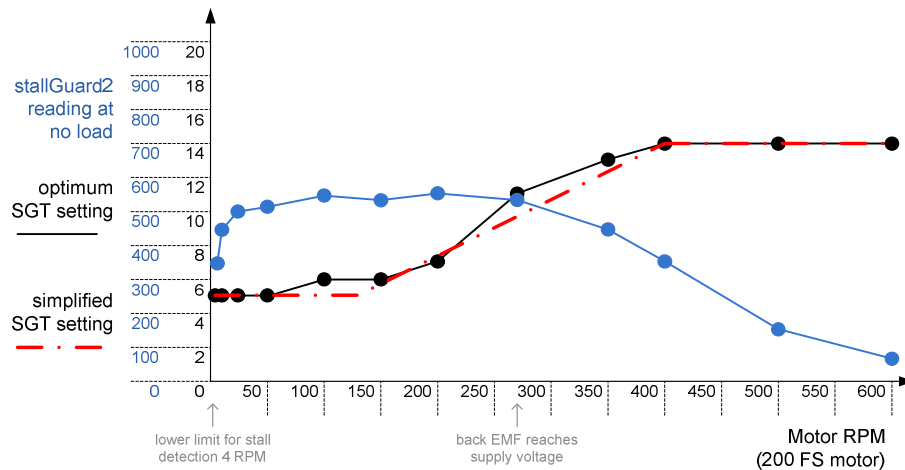


figure 21: optimum SGT setting and stallGuard2 reading with an example motor at 24V

12.1.2 Small motors with high torque ripple and resonance

Motors with a high detent torque also show an increased dependency of the stallGuard2™ reading with varying (lower) motor currents. For these motors, the current dependency might need to be modeled for best result.

12.1.3 Temperature dependence of motor coil resistance

For motors working in a large temperature range, also the motor temperature may be taken into account, because motor coil resistance increases with rising temperature. This will show as a linear reduction of the stallGuard2™ reading at increasing temperature, as the efficiency of the motor sinks.

12.1.4 Accuracy and reproducibility of stallGuard2™ measurement

It might be desired to work with a fixed SGT value within an application for one motor type. Most of the stray in stallGuard2™ reading will result from motor production stray. Other factors which can be compensated for are motor temperature, motor driver supply voltage and TMC26x clock frequency. A stabilized driver supply voltage and an external clock source should be used in these applications. The measurement error of stallGuard2™ – provided that all other parameters remain stable – can be assumed as low as:

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

12.2 stallGuard2™ measurement frequency and filtering

The stallGuard2™ value becomes updated with each full step of the motor. This is enough to safely detect a stall, as stalling of the motor 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, taking into account that mechanical load never changes instantaneously from one step to the next. Therefore, a filtering function is available: The SFILT bit enables filtering of the motor load measurement over a number of 4 measurements. The filter should always be enabled when a precise measurement is desired. It compensates for anisotropies in the construction of the motor, e.g. due to misalignment of the phase A to phase B magnets. Only if very fast response to increasing load is required, the bit should be cleared.

Parameter	Description	Range	Comment
SGT	This signed value controls <i>stallGuard2™</i> threshold level for stall output and sets the optimum measurement range for readout. A lower value gives a higher sensitivity. Zero is the starting value working with most motors. A higher value makes stallGuard less sensitive and requires more torque to indicate a stall.	-64 ... +63	0: indifferent value +1...+63: less sensitivity -1...-64: higher sensitivity
SFILT	Enables the <i>stallGuard2™</i> filter for more precision of the measurement. If set, reduces the measurement frequency to one measurement per four fullsteps.	0 / 1	0: standard mode 1: filtered mode
Status word	Description	Range	Comment
SG	This is the <i>stallGuard2™</i> result. A higher reading indicates less mechanical load. A lower reading indicates a higher load and thus a higher load angle. Tune the SGT setting to show a SG reading of 0 at maximum load before motor stall. This is also signaled by the output SG_TST.	0... 1023	0: maximum load >1: less load

13 coolStep™ smart energy operation

In order to use coolStep™, you should first tune the stallGuard2™ sensitivity. coolStep™ uses the stallGuard2™ measurement, to operate the motor near the optimum load angle of +90°. See example figure.

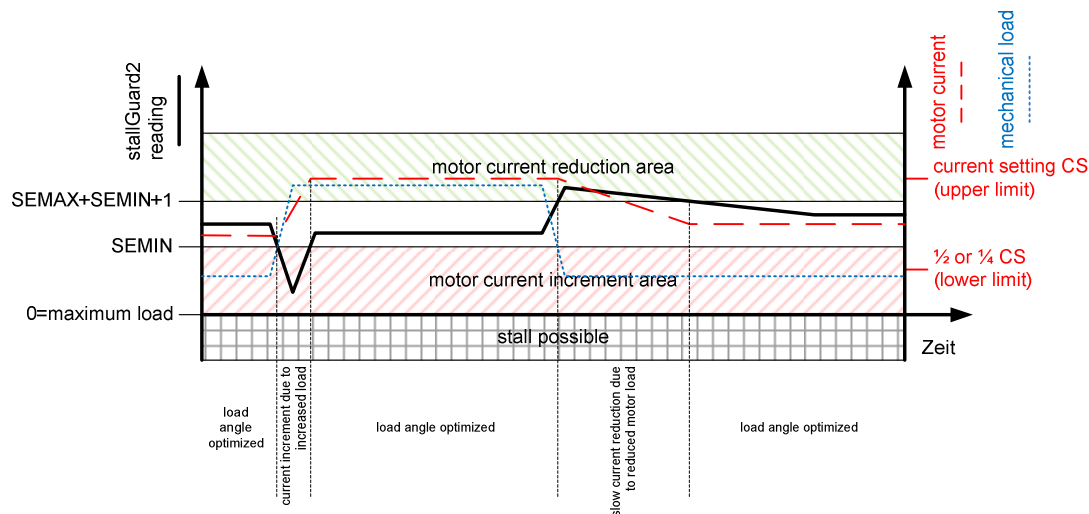


figure 22: motor current control via coolStep adapts motor current to motor load

13.1 coolStep™ smart energy current regulator

The coolStep™ current regulator allows to control the reaction of the driver to increasing or decreasing load. The internal regulator uses two thresholds to determine the minimum and the maximum load angle for optimum motor operation. The current increment speed and the current decrement speed can be adapted to the application. Additionally, the lower current limit can be set in relation to the upper current limit set by the current scale parameter CS.

13.1.1 Adaptation to the load situation

To allow the motor current to quickly respond to increasing motor load, use a high current increment step. If the motor load changes only slowly, a lower current increment step can be used. The current decrement can then be adapted to work as quickly as possible, while avoiding oscillations of the motor. Keep in mind, that enabling the stallGuard2™ filter via SFILT quarters the measurement speed and thus the regulation speed.

13.1.2 Low velocity and standby operation

Since coolStep™ is not able to detect the motor load in standstill and at very low RPM operation, the current at low velocities should be set to an application specific default value and should be combined with a stand still current reduction.

Parameter	Description	Range	Comment
SEMIN	Sets the <i>lower threshold</i> for stallGuard2™ reading. Below this value, the motor current becomes increased. Set SEMIN to zero to disable coolStep™.	0...15	lower stallGuard threshold: SEMIN*32
SEMAX	Sets the <i>distance</i> between the lower and the <i>upper threshold</i> for stallGuard2™ reading. Above the upper threshold the motor current becomes increased.	0...15	upper stallGuard threshold: (SEMIN+SEMAX+1)*32
SEUP	Sets the <i>current increment step</i> . The current becomes incremented for each measured stallGuard2™ value below the lower threshold.	0...3	current increment step size: 0...3: 1, 2, 4, 8
SEDN	Sets the number of stallGuard2™ readings above the upper threshold necessary for each <i>current decrement</i> of the motor current.	0...3	number of stallGuard measurements per decrement: 0...3: 32, 8, 2, 1
SEIMIN	Sets the <i>lower motor current limit</i> for coolStep™ operation by scaling the CS value.	0 / 1	minimum motor current: 0: 1/2 of CS 1: 1/4 of CS
Status word	Description	Range	Comment
SE	This status value provides the <i>actual motor current</i> setting as controlled by coolStep™. The value goes up to the CS value and down to the portion of CS as specified by SEIMIN.	0...31	actual motor current scaling factor: 0 ... 31: 1/32, 2/32, ... 32/32

13.2 User benefits, save energy, reduce power and cooling infrastructure

coolStep™ allows saving a lot of energy, especially for motors which see varying loads and operate at a high duty cycle. Taking into account that a stepper motor application needs to work with a torque reserve of 30% to 50%, even a constant load application allows saving lots of energy, because the driver automatically enables torque reserve when required. The reduction in power dissipation further keeps the system cooler and increases life time and allows savings in the power supply and cooling infrastructure. Keep in mind, that half motor current means a quarter of the power dissipation in the motor coils. This power dissipation makes up for most of the stepper motor losses!



www.coolstep.org

14 Clock oscillator and clock input

The internal clock frequency for all operations is nominal 13MHz. An external clock of 10MHz to 20MHz (16MHz recommended for optimum performance) can be supplied for more exact timing, especially when using coolStep™ and stallGuard2™. Alternatively, the internal clock frequency can be measured, by measuring the delay time after the last step, until the TMC26x raises the STANDSTILL flag. From this measurement, chopper timing parameters can be corrected, as the internal oscillator is relatively stable over a wide range of environment temperatures.

An external clock frequency of up to 20MHz can be supplied. The external clock is enabled with the first positive polarity seen on the CLK input. Tie the CLK input to GND near to the TMC26x if the internal clock oscillator is to be used. Switching off the external clock frequency prevents the driver from operating normally. Be careful to switch off the motor before switching off the clock (e.g. using the enable input), because otherwise the chopper would stop and the motor current level could rise uncontrolled. The short to GND detection stays active even without clock, if enabled.

14.1 Considerations on the frequency

A higher frequency allows faster step rates, faster SPI operation and higher chopper frequencies. On the other hand, it may cause more electromagnetic emission and causes more power dissipation in the TMC26x digital core. Generally a frequency of 8MHz to 16MHz should be sufficient for most applications, unless the motor is to operate very fast. For reduced requirements concerning the motor dynamics, a clock frequency of 4 to 8MHz should be considered.

15 Absolute Maximum Ratings

The maximum ratings may not be exceeded under any circumstances. Operating the circuit at or near more than one maximum rating at a time for extended periods shall be avoided by application design.

Parameter	Symbol	Min	Max	Unit
Supply voltage (TMC261, TMC262)	V_{VS}	-0.5	60	V
Supply voltage (TMC260)		-0.5	40	V
Supply and bridge voltage max. 20000s (TMC262)			65	V
Logic supply voltage	V_{VCC}	-0.5	6.0	V
I/O supply voltage	V_{VIO}	-0.5	6.0	V
Logic input voltage	V_I	-0.5	$V_{VIO}+0.5$	V
Analog input voltage	V_{IA}	-0.5	$V_{CC}+0.5$	V
Voltages on low side driver pins (LSx)	V_{OLS}	-0.7	$V_{CC}+0.7$	V
Voltages on high side driver pins (HSx)	V_{OHS}	$V_{HS} - 0.7$	$V_{VM}+0.7$	V
Voltages on BM pins (BMx)	V_{IBM}	-5	$V_{VM}+5$	V
Relative high side driver voltage ($V_{VM} - V_{HS}$)	V_{HSVM}	-0.5	15	V
Maximum current to / from digital pins and analog low voltage I/Os	I_{IO}		+/-10	mA
Non destructive short time peak current into input / output pins	I_{IO}		500	mA
5V regulator output current	I_{5VOUT}		50	mA
5V regulator peak power dissipation ($V_{VM}-5V$) * I_{5VOUT}	P_{5VOUT}		1	W
Junction temperature	T_J	-50	150	°C
Storage temperature	T_{STG}	-55	150	°C
ESD-Protection (Human body model, HBM), in application	V_{ESDAP}		1	kV
ESD-Protection (Human body model, HBM), device handling	V_{ESDDH}		300	V

16 Electrical Characteristics

16.1 Operational Range

Parameter	Symbol	Min	Max	Unit
Junction temperature	T_J	-40	125	°C
Supply voltage TMC261, TMC262	V_{VS}	9	59	V
Supply voltage TMC260	V_{VS}	9	39	V
I/O supply voltage	V_{VIO}	3.00	5.25	V

16.2 DC Characteristics and Timing Characteristics

DC characteristics contain the spread of values guaranteed within the specified supply voltage range unless otherwise specified. Typical values represent the average value of all parts measured at +25°C. Temperature variation also causes stray to some values. A device with typical values will not leave Min/Max range within the full temperature range.

Power supply current	DC-Characteristics					
	$V_{VS} = 24.0V$					
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Supply current, operating	I_{VS}	$f_{CLK}=16MHz, 40kHz$ chopper, $Q_G=10nC$		12		mA
Supply current, driver disabled	I_{VS}	$f_{CLK}=16MHz$		10		mA
Supply current, driver disabled, dependency on CLK frequency	I_{VS}	f_{CLK} variable		$I_{VS0}+$ 0.32 /MHz		mA
Static supply current	I_{VS0}	$f_{CLK}=0Hz$, digital in- puts at +5V or GND		3.2	4	mA
Part of supply current NOT consumed from 5V supply	I_{VSHV}	driver disabled		1.2		mA
IO supply current	I_{VIO}	no load on outputs, inputs at V_{IO} or GND		0.3		μA

NMOS low side driver	DC-Characteristics					
	$V_{LSX} = 2.5V$, slope setting controlled by SLPL					
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Gate drive current LSx low side switch ON ^{a)}	I_{LSON}	SLPL=00/01		13		mA
Gate drive current LSx low side switch ON ^{a)}	I_{LSON}	SLPL=10		25		mA
Gate drive current LSx low side switch ON ^{a)}	I_{LSON}	SLPL=11	25	37	60	mA
Gate drive current LSx low side switch OFF ^{a)}	I_{LSOFF}	SLPL=00/01		-13		mA
Gate drive current LSx low side switch OFF ^{a)}	I_{LSOFF}	SLPL=10		-25		mA
Gate drive current LSx low side switch OFF ^{a)}	I_{LSOFF}	SLPL=11	-25	-37	-60	mA
Gate Off detector threshold	V_{GOD}	V_{LSX} falling		1		V
Q_{GD} protection resistance after detection of gate off	$R_{LSOFFQGD}$	SLPL=11 $V_{LSX} = 1V$		26		Ω
Driver active output voltage	V_{LSON}			V_{VCC}		V

Notes:

- a) Low side drivers behave similar to a constant current source between 0V and 2.5V (switching on) resp. between 2.5V and 5V (switching off), because switching MOSFETs go into saturation. At 2.5V, the output current is about 85% of peak value. This is the value specified.

PMOS high side driver	DC-Characteristics					
$V_{VS} = 24.0V$, $V_{VS} - V_{HSX} = 2.5V$, slope setting controlled by SLPH						
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Gate drive current HSx high side switch ON ^{b)}	I_{HSON}	SLPH=00/01		-15		mA
Gate drive current HSx high side switch ON ^{b)}	I_{HSON}	SLPH=10		-29		mA
Gate drive current HSx high side switch ON ^{b)}	I_{HSON}	SLPH=11	-28	-43	-70	mA
Gate drive current HSx high side switch OFF ^{c)}	I_{HSOFF}	SLPH=00/01		15		mA
Gate drive current HSx high side switch OFF ^{c)}	I_{HSOFF}	SLPH=10		29		mA
Gate drive current HSx high side switch OFF ^{c)}	I_{HSOFF}	SLPH=11	28	43	70	mA
Gate Off detector threshold	V_{GOD}	V_{HSX} rising		$V_{VS}-1$		V
Q_{GD} protection resistance after detection of gate off	$R_{HSOFFQGD}$	SLPH=11 $V_{HSX} = V_{VS} - 1V$		32		Ω
Driver active output voltage	V_{HSON}	$I_{OUT} = 0mA$	$V_{VHS}-2.8$	$V_{VHS}-2.3$	$V_{VHS}-1.8$	V

Notes:

- b) High side switch on drivers behave similar to a constant current source between V_{VS} and $V_{VS} - 2.5V$. At $V_{VS}-2.5V$, the output current is about 90% of peak value. This is the value specified.
- c) High side switch off drivers behave similar to a constant current source between $V_{VS} - 8V$ and $V_{VS}-2.5V$. At $V_{VS}-2.5V$, the output current is about 65% of peak value. This is the value specified.

High side voltage regulator	DC-Characteristics					
$V_{VS} = 24.0V$						
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Output voltage	V_{VHS}	$I_{OUT} = 0mA$ $T_J = 25^\circ C$	9.3	10.0	10.8	V
Output resistance	R_{VHS}	Static load		50		Ω
Deviation of output voltage over the full temperature range	$V_{VHS(DEV)}$	$T_J = \text{full range}$		60	200	mV
DC Output current	I_{VHS}				4	mA
Current limit	I_{VHSMAX}			15		mA
Series regulator transistor output resistance (determines voltage drop at low supply voltages)	R_{VHSLV}			400	1000	Ω

Internal MOSFETs TMC260		DC-Characteristics				
$V_{VS} = V_{VSX} \geq 12.0V, V_{BRX} = 0V$						
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
N channel MOSFET on resistance	R_{ONN}	$T_J = 25^\circ C$		125	190	m Ω
P channel MOSFET on resistance	R_{ONP}	$T_J = 25^\circ C$		190	240	m Ω
N channel MOSFET on resistance	R_{ONN}	$T_J = 150^\circ C$		205		m Ω
P channel MOSFET on resistance	R_{ONP}	$T_J = 150^\circ C$		312		m Ω

Internal MOSFETs TMC261		DC-Characteristics				
$V_{VS} = V_{VSX} \geq 12.0V, V_{BRX} = 0V$						
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
N channel MOSFET on resistance	R_{ONN}	$T_J = 25^\circ C$		100	150	m Ω
P channel MOSFET on resistance	R_{ONP}	$T_J = 25^\circ C$		200	255	m Ω
N channel MOSFET on resistance	R_{ONN}	$T_J = 150^\circ C$		164		m Ω
P channel MOSFET on resistance	R_{ONP}	$T_J = 150^\circ C$		328		m Ω

Linear regulator		DC-Characteristics				
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Output voltage	V_{5VOUT}	$I_{5VOUT} = 10mA$ $T_J = 25^\circ C$	4.75	5.0	5.25	V
Output resistance	R_{5VOUT}	Static load		3		Ω
Deviation of output voltage over the full temperature range	$V_{5VOUT(DEV)}$	$I_{5VOUT} = 10mA$ $T_J = \text{full range}$		30	60	mV
Output current capability (attention, do not exceed maximum ratings with DC current)	I_{5VOUT}	$V_{VS} = 12V$	100			mA
		$V_{VS} = 8V$	60			mA
		$V_{VS} = 6.5V$	20			mA

Clock oscillator and input		Timing-Characteristics				
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Clock oscillator frequency	f_{CLKOSC}	$t_J = -50^\circ C$	8.8	12.4	17.9	MHz
Clock oscillator frequency	f_{CLKOSC}	$t_J = 50^\circ C$	9.4	13.2	18.8	MHz
Clock oscillator frequency	f_{CLKOSC}	$t_J = 150^\circ C$	9.6	13.4	18.9	MHz
External clock frequency (operating)	f_{CLK}		4		20	MHz

Detector levels	DC-Characteristics					
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
V _{VS} undervoltage threshold	V _{UV}		6.5	7.5	8	V
Short to GND detector threshold (V _{VS} - V _{BMx})	V _{BMS2G}		1.0	1.5	2.3	V
Short to GND detector delay (low side gate off detected to short detection)	t _{S2G}	TS2G=00	2.0	3.2	4.5	μs
		TS2G=10		1.6		μs
		TS2G=01		1.2		μs
		TS2G=11		0.8		μs
Overtemperature prewarning	t _{OTPW}		80	100	120	°C
Overtemperature shutdown	t _{OT}	Temperature rising	135	150	170	°C

Sense resistor voltage levels	DC-Characteristics					
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Sense input peak threshold voltage (low sensitivity)	V _{UV}	VSENSE=0 Cx=255; Hyst.=0	285	307	329	mV
sense input peak threshold voltage (high sensitivity)	t _{OTPW}	VSENSE=1 Cx=255; Hyst.=0	153	165	177	mV

Digital logic levels	DC-Characteristics					
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Input voltage low level ^{d)}	V _{INLO}		-0.3		0.8	V
Input voltage high level ^{d)}	V _{INHI}		2.4		V _{VIO} +0.3	V
Output voltage low level	V _{OUTLO}	I _{OUTLO} = 1mA			0.4	V
Output voltage high level	V _{OUTH}	I _{OUTH} = -1mA	0.8V _{VIO}			V
Input leakage current	I _{I LEAK}		-10		10	μA

Notes:

- d) Digital inputs left within or near the transition region substantially increase power supply current by drawing power from the internal 5V regulator. Make sure that digital inputs become driven near to 0V and up to the V_{IO} I/O voltage.

16.3 ESD sensitive device

The TMC26x is an ESD sensitive CMOS device and also MOSFET transistors used in the application schematic are very sensitive to electrostatic discharge. Take special care to use adequate grounding of personnel and machines in manual handling. After soldering the devices to the board, ESD requirements are more relaxed. Failure to do so can result in defect or decreased reliability.



16.4 MOSFET examples

There is a number of N&P channel paired MOSFETs available, which fit the TMC262, as well as single N and P devices. The user choice will depend on the electrical data (voltage, current, R_{DSon}) and on the package and configuration (single / dual). The following table gives a few examples of SMD MOSFET pairs for different motor voltages and currents. The MOSFETs explicitly are modern types with a low total gate charge.

For the actual application, we suggest to calculate static and dynamic power dissipation for a given MOSFET pair. A gate charge below 20nC should be preferred to reach reasonable slopes.

Transistor type	manu- facturer	voltage V_{DS}	max. RMS current (*)	package	R_{DSon} N (5V)	R_{DSon} P (8V)	Q_G N	Q_G P
unit		V	A		m Ω	m Ω	nC	nC
SUD23N06 SUD08P06	Vishay	60	6	DDPAK	35	125	8	10
SI7414 SI7415	Vishay	60	3	PPAK1212	28	60	9	12
SI7530	Vishay	60	3	PPAK-SO8	70	55	6	22
SI4559ADY	Vishay	60	2.2	SO8	55	110	7	12
IRF7343	Vishay	55	1.8	SO8	55	125	13	22
FDD8424H	Fairchild	40	4.2	DDPAK-4L	25	45	9	14
SI4565DY	Vishay	40	3	SO8	35	45	9	13
SI4567DY	Vishay	40	2.5	SO8	60	80	6	10
SI3529DV	Vishay	40	1.5	TSOP-6	110	190	2.5	4
FDS8960C	Fairchild	35	3.3	SO8	20	45	6	9
BSZ050N03 BSZ180P03	Infineon	30	8	S3O8	7	18	13	15
FDS8958A	Fairchild	30	3.2	SO8	25	45	6	9
TMC34NP	Trinamic	30	3	PPAK1212	35	50	5	11
SI4544DY	Vishay	30	3	SO8	40	40	9	15
SI4539ADY	Vishay	30	2.8	SO8	45	50	6	12
SI4532ADY	Vishay	30	2.7	SO8	50	70	4	8
IRF9952	Vishay	30	2	SO8	80	220	4	5.5

(*) Remark: The maximum motor current applicable in a given design depends upon PCB size and layout, since all of these transistors are mainly cooled via the PCB. The data given implies adequate cooling measures taken by the user, especially for higher current designs. The maximum RMS current rating takes into account package power dissipation, on resistances and gate charges.

17 Using an external power stage for higher voltage and current

The TMC262 uses a completely complementary driving scheme for power transistors. This allows attaching an external gate driver, using the low side driver output information, only. Therefore, the external gate driver needs to bring brake-before make capability. You can directly attach gate driver ICs like TMC603 as gate drivers for high current NMOS transistor bridges. The TMC603 also supplies a gate drive voltage regulator and allows 100% duty cycle. Please refer TMC603 datasheet. The example shows a standard low side / high side driver boosting TMC262. The higher gate driving capability allows addressing designs for more than 20A and higher voltages.

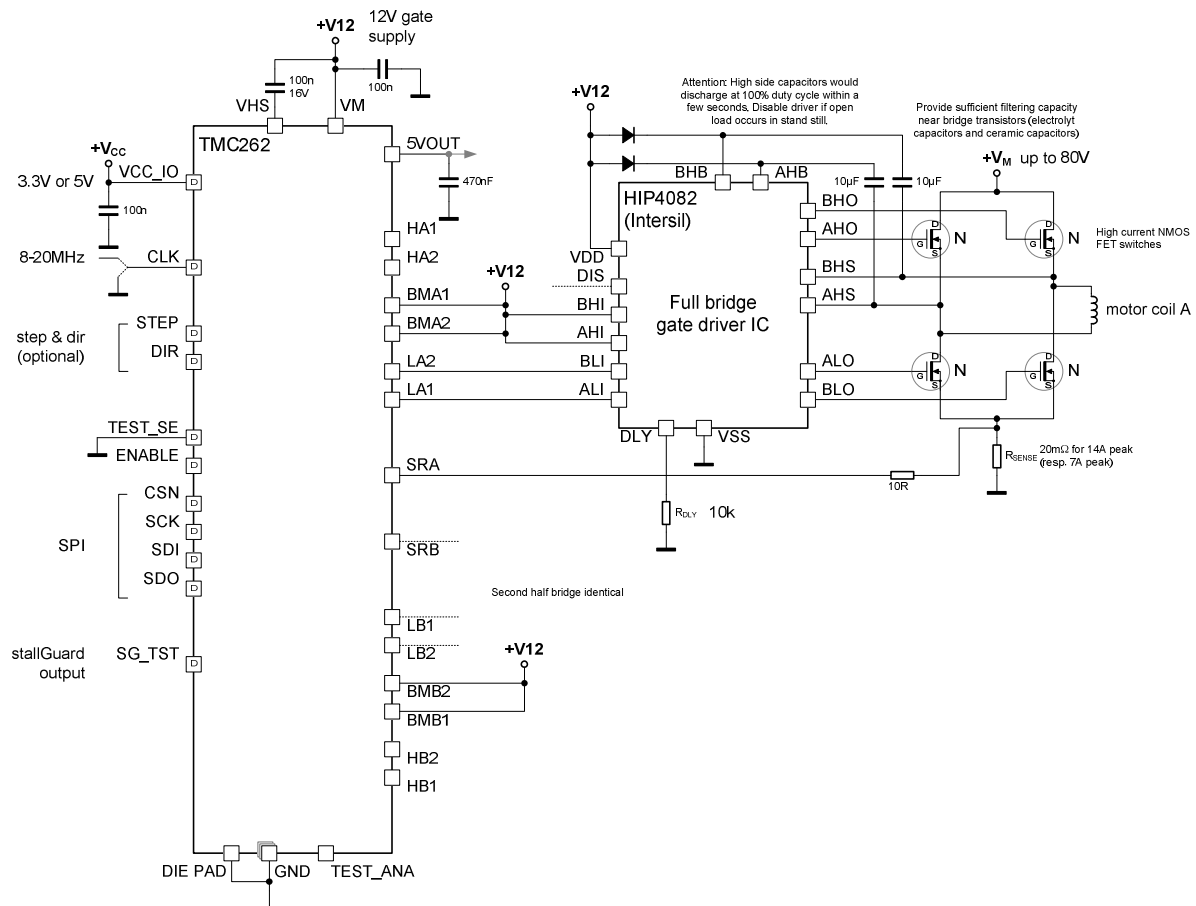


figure 23: high current high voltage power stage using additional gate drivers (example)

Please be aware, that the short to GND protection of the TMC262 cannot be used in this scheme: The driver cannot be fully disabled, because the external gate driver just switches on either high side MOSFET or low side MOSFET. An external short to GND protection could use a series resistor to measure power bridge current and to disable the high side MOSFETs by using the TMC262 enable input ENN. Use a gate driver like TMC603 to provide additional short to GND protection without the need for a high side shunt.

18 Getting started

18.1 Initialization of the driver

Initialization SPI datagram example sequence to enable the driver and initialize the chopper:

```
SPI = $901B4;    // Hysteresis mode
or
SPI = $94557;    // Const. toff mode

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

or
SPI = $EF010;    // high gate driver strength, stallGuard read, SDOFF=0 for TMC262
SPI = $E0010;    // low driver strength, stallGuard read, SDOFF=0 for TMC260/261

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

First test of coolStep™ current control:

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

Please note, that the configuration parameters should be tuned to the motor and application for optimum performance.

19 Table of figures

FIGURE 1: BASIC APPLICATION BLOCK DIAGRAM	4
FIGURE 2: TMC260 AND TMC261 PINNING	5
FIGURE 3: TMC262 PINNING	5
FIGURE 4: PQFP44 DIMENSIONS	7
FIGURE 5: QFN32 5X5 DIMENSIONS	7
FIGURE 6: TMC262 BLOCK AND APPLICATION DIAGRAM	8
FIGURE 7: TMC260 AND TMC261 BLOCK AND APPLICATION DIAGRAM	9
FIGURE 8: SPI TIMING	19
FIGURE 9: STEP AND DIR TIMING	20
FIGURE 10: INTERNAL MICROSTEP TABLE SHOWING THE FIRST QUARTER OF THE SINE WAVE	21
FIGURE 11: OPTIMUM POSITION SEQUENCE FOR HALF- AND FULL STEPPING	21
FIGURE 12: OPERATION OF THE STEP MULTIPLIER IN DIFFERENT SITUATIONS	22
FIGURE 13: SENSE RESISTOR GROUNDING AND OPTIONAL PARTS	24
FIGURE 14: CHOPPER PHASES IN MOTOR OPERATION	25
FIGURE 15: SPREADCYCLE (PAT.FIL.) CHOPPER SCHEME SHOWING THE COIL CURRENT WITHIN A CHOPPER CYCLE	26
FIGURE 16: CLASSIC CONST. OFF TIME CHOPPER WITH OFFSET SHOWING THE COIL CURRENT WITHIN TWO CYCLES.....	27
FIGURE 17: ZERO CROSSING WITH CLASSIC CHOPPER AND CORRECTION USING SINE WAVE OFFSET.....	27
FIGURE 18: MOSFET GATE CHARGE AS AVAILABLE IN DEVICE DATA SHEET VS. SWITCHING EVENT (DOTTED LINE)	30
FIGURE 19: TIMING OF THE SHORT TO GND DETECTOR	31
FIGURE 20: PRINCIPLE FUNCTION OF STALLGUARD2	33
FIGURE 21: OPTIMUM SGT SETTING AND STALLGUARD2 READING WITH AN EXAMPLE MOTOR AT 24V.....	34
FIGURE 22: MOTOR CURRENT CONTROL VIA COOLSTEP ADAPTS MOTOR CURRENT TO MOTOR LOAD.....	36
FIGURE 23: HIGH CURRENT HIGH VOLTAGE POWER STAGE USING ADDITIONAL GATE DRIVERS (EXAMPLE)	46

20 Revision History

20.1 Documentation Revision

Version	Date	Author BD=Bernhard Dwersteg	Description
0.90	2010-APR-14	BD	First release candidate of datasheet covering TMC260, TMC261 and TMC262
0.92	2010-APR-19	BD	Corrected gate driver specs, new MOSFET examples
0.94	2010-APR-22	BD	New headline, photo, details
0.95	2010-MAY-14	BD	Added chapter 10, more technical parameters
0.96	2010-MAY-21	BD	Idea for short to GND protection for ext. drivers
0.97	2010-JUN-25	BD	Step Dir detail, added power supply current
1.00	2010-AUG-09	BD	V2 silicon results, increased chopper thresholds (identical ratio of VCC power supply as in V1 and V1.2 silicon) VSENSE bit description corrected based on actual values
1.01	2010-AUG-10	BD	Removed preliminary note from el. specs, corrected UV threshold, additional values
1.03	2010-AUG-20	BD	Added note on unused inputs and larger 5VOUT capacity
1.04	2010-SEP-29	BD	Details on ENN and Open load detection, corrected VM→VS

Table 1: Documentation Revisions