



Chipsmall Limited consists of a professional team with an average of over 10 year of expertise in the distribution of electronic components. Based in Hongkong, we have already established firm and mutual-benefit business relationships with customers from,Europe,America and south Asia,supplying obsolete and hard-to-find components to meet their specific needs.

With the principle of “Quality Parts,Customers Priority,Honest Operation,and Considerate Service”,our business mainly focus on the distribution of electronic components. Line cards we deal with include Microchip,ALPS,ROHM,Xilinx,Pulse,ON,Everlight and Freescale. Main products comprise IC,Modules,Potentiometer,IC Socket,Relay,Connector.Our parts cover such applications as commercial,industrial, and automotives areas.

We are looking forward to setting up business relationship with you and hope to provide you with the best service and solution. Let us make a better world for our industry!



Contact us

Tel: +86-755-8981 8866 Fax: +86-755-8427 6832

Email & Skype: info@chipsmall.com Web: www.chipsmall.com

Address: A1208, Overseas Decoration Building, #122 Zhenhua RD., Futian, Shenzhen, China



TMC248 DATASHEET

Low-cost stepper driver for two-phase bipolar motors with low noise PWM chopper and stallGuard™. External MOSFETs fit different motor sizes. With SPI, classic analog interface, protection & diagnostics.

+



+

stallGuard™

+

+

APPLICATIONS

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

FEATURES AND BENEFITS

High Current up to 7 A motor current using 4 external dual-MOS transistors.

Voltage Range 7 V... 36 V DC

3.3 V or 5 V DC for digital part

SPI & External Analogue / Digital Signals

Microstep Resolution up to 64 microsteps per full step

Low Power Dissipation via low RDS-ON power stage

Protection: overvoltage, overtemperature & short circuit

Diagnostics: overcurrent, open load, overtemperature, temperature prewarning, and undervoltage

stallGuard™ sensorless stall detection and load measurement

Mixed Decay for smooth motor operation

Slope Control for reduced electromagnetic emissions

Current Control for cool motor and driver

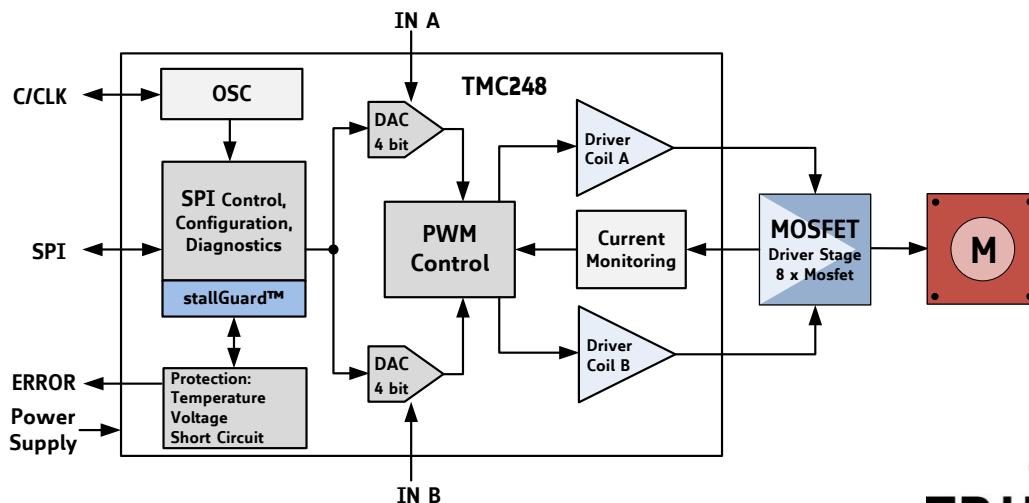
Standby and Shutdown Mode

Smallest Size 5x5mm QFN28 package

DESCRIPTION

The TMC248 driver for two-phase stepper motors offers a competitive feature set, including 64x micro-stepping, sensorless mechanical load measurement with stall detection, and smart current control. Standard SPI™ and communication via external analog / digital signals are available. The TMC248 drives eight external Low-RDS-ON high efficiency MOSFETs for motor currents up to 7A and up to 36V. Integrated protection and diagnostic features support robust and reliable operation. High integration and small form factor enable miniaturized designs with low external component count for cost-effective and highly competitive solutions.

BLOCK DIAGRAM



APPLICATION EXAMPLES: HIGH POWER – SMALL SIZE

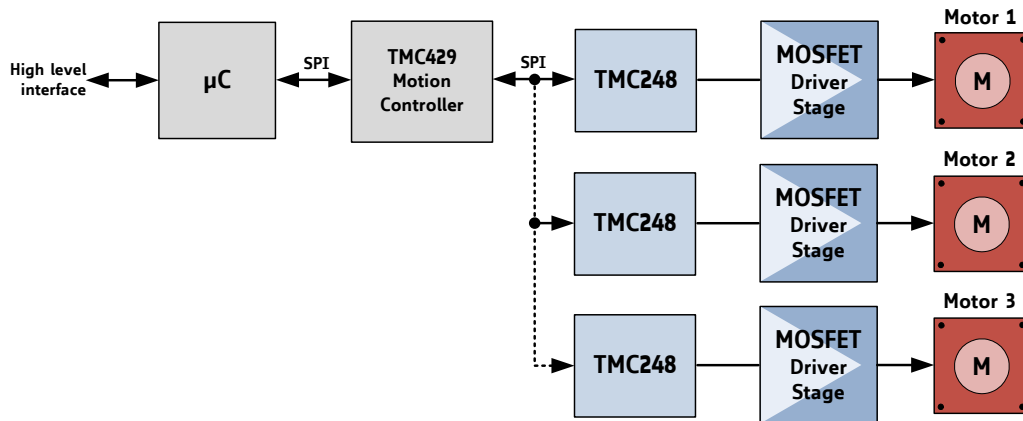
The TMC248 scores with its high power density and a versatility that covers a wide spectrum of applications and motor sizes, all while keeping costs down.

APPLICATION EXAMPLES

COMPACT DESIGN FOR UP TO 3 MOTORS USING SPI INTERFACE

OFFLOAD THE MOTION CONTROL FUNCTION TO TRINAMIC'S TMC429. GET A COMPETITIVE DESIGN FOR MULTIPLE MOTORS!

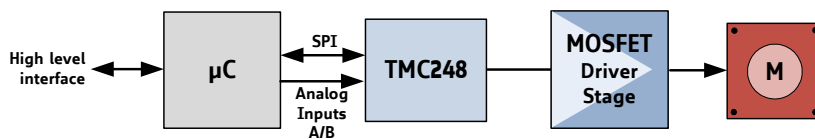
By offloading the motion-control function to the TMC429, up to three motors can be operated reliably with very little demand for service from the microcontroller.



MINIATURIZED DESIGN WITH SIMPLE DIGITAL DRIVER CONTROL

BENEFIT FROM A LARGE CURRENT CONTROL RANGE VIA ANALOG INPUTS!

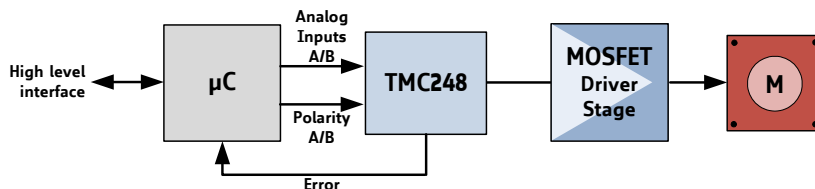
The TMC248 is controlled via SPI bus. The microcontroller initializes the chip and writes control parameters, mode bits, and values for coil currents in the driver chip. Analog A/B inputs allow for a large current control range.



MINIATURIZED DESIGN FOR STANDALONE MODE

REPLACE BIPOLAR DRIVER BY A MODERN CMOS DRIVER. USE NEW HARDWARE AND KEEP YOUR SOFTWARE INVEST!

The TMC248 is controlled by analog current control signals and digital phase signals. Especially for lower speeds inimitable smoothness will be achieved with TRINAMIC's low noise chopper.



TMC429+24x-EVAL

EVALUATION & DEVELOPMENT PLATFORM

This evaluation board is a development platform for applications based on the TMC248. The board features USB interface for communication with control software running on a PC. External power MOSFETs support drive currents up to 3.5A at 24 V. The control software provides a user-friendly GUI for setting control parameters and visualizing the dynamic response of the motor.

ORDER CODES

Order code	Description	Size
TMC248-LA	7 A stepper driver for external MOSFETs, QFN28	5 x 5 mm ²
TMC429+24x-EVAL V2.0	Chipset evaluation board for TMC429, TMC246, TMC248, TMC249.	10 x 16 cm ²

TABLE OF CONTENTS

1	KEY CONCEPTS	4	9.3	OVERVOLTAGE PROTECTION AND ENN PIN BEHAVIOR	26
1.1	ADVANCED FEATURES	5	10	MICROSTEP RESOLUTION	27
1.2	CONTROL INTERFACES	5	11	MOSFET EXAMPLES	28
2	PIN ASSIGNMENTS	6	12	LAYOUT CONSIDERATIONS	30
2.1	PACKAGE OUTLINE	6	12.1	GROUNDING	30
2.2	SIGNAL DESCRIPTIONS	6	12.2	FILTERING CAPACITORS	30
3	STALLGUARD - STALL DETECTION AND REFERENCE SEARCH	7	12.3	PULL-UP RESISTORS ON UNUSED INPUTS	31
3.1	STALLGUARD MEASUREMENT	7	12.4	POWER SUPPLY SEQUENCING CONSIDERATIONS	31
3.2	IMPLEMENTING SENSORLESS STALL DETECTION	9	12.5	LAYOUT EXAMPLE	32
4	SPI INTERFACE	10	13	ABSOLUTE MAXIMUM RATINGS	33
4.1	BUS SIGNALS	10	14	ELECTRICAL CHARACTERISTICS	34
4.2	MOTOR COIL CURRENT SETTING VIA SPI	11	14.1	OPERATIONAL RANGE	34
4.3	BASE CURRENT CONTROL MODE VIA INA / INB IN SPI MODE	11	14.2	DC SPECIFICATIONS	34
4.4	CONTROLLING POWER DOWN VIA THE SPI INTERFACE	13	14.3	AC SPECIFICATIONS	36
4.5	OPEN LOAD DETECTION	13	14.4	THERMAL PROTECTION	36
4.6	STANDBY AND SHUTDOWN MODE	13	15	PACKAGE MECHANICAL DATA	37
4.7	POWER SAVING	13	15.1	DIMENSIONAL DRAWINGS	37
4.8	BUS TIMING	14	15.2	PACKAGE CODE	37
4.9	USING THE SPI INTERFACE WITH ONE OR MULTIPLE DEVICES	14	16	DISCLAIMER	38
4.10	SPI FILTER	14	17	ESD SENSITIVE DEVICE	38
5	CLASSICAL NON-SPI CONTROL MODE (STANDALONE MODE)	15	18	TABLE OF FIGURES	39
5.1	PIN FUNCTIONS IN STANDALONE MODE	15	19	REVISION HISTORY	40
5.2	INPUT SIGNALS FOR MICROSTEP CONTROL IN STANDALONE MODE	15	20	REFERENCES	40
6	CURRENT SETTING	16			
6.1	SENSE RESISTOR FOR CURRENT SETTING	16			
6.2	RESISTOR R_{SH} FOR HIGH SIDE OVERCURRENT DETECTION	16			
7	CHOPPER OPERATION	18			
7.1	MIXED DECAY MODE	18			
7.2	CHOPPER FREQUENCY	19			
7.3	VOLTAGE PWM MODE FOR LOW NOISE CHOPPER	20			
7.4	ADAPTING THE SINE WAVE FOR SMOOTH MOTOR OPERATION	22			
7.5	BLANK TIME	23			
8	SLOPE CONTROL	24			
9	PROTECTION FUNCTIONS	25			
9.1	OVERCURRENT PROTECTION AND DIAGNOSTIC	25			
9.2	OVER TEMPERATURE PROTECTION AND DIAGNOSTIC	25			

1 Key Concepts

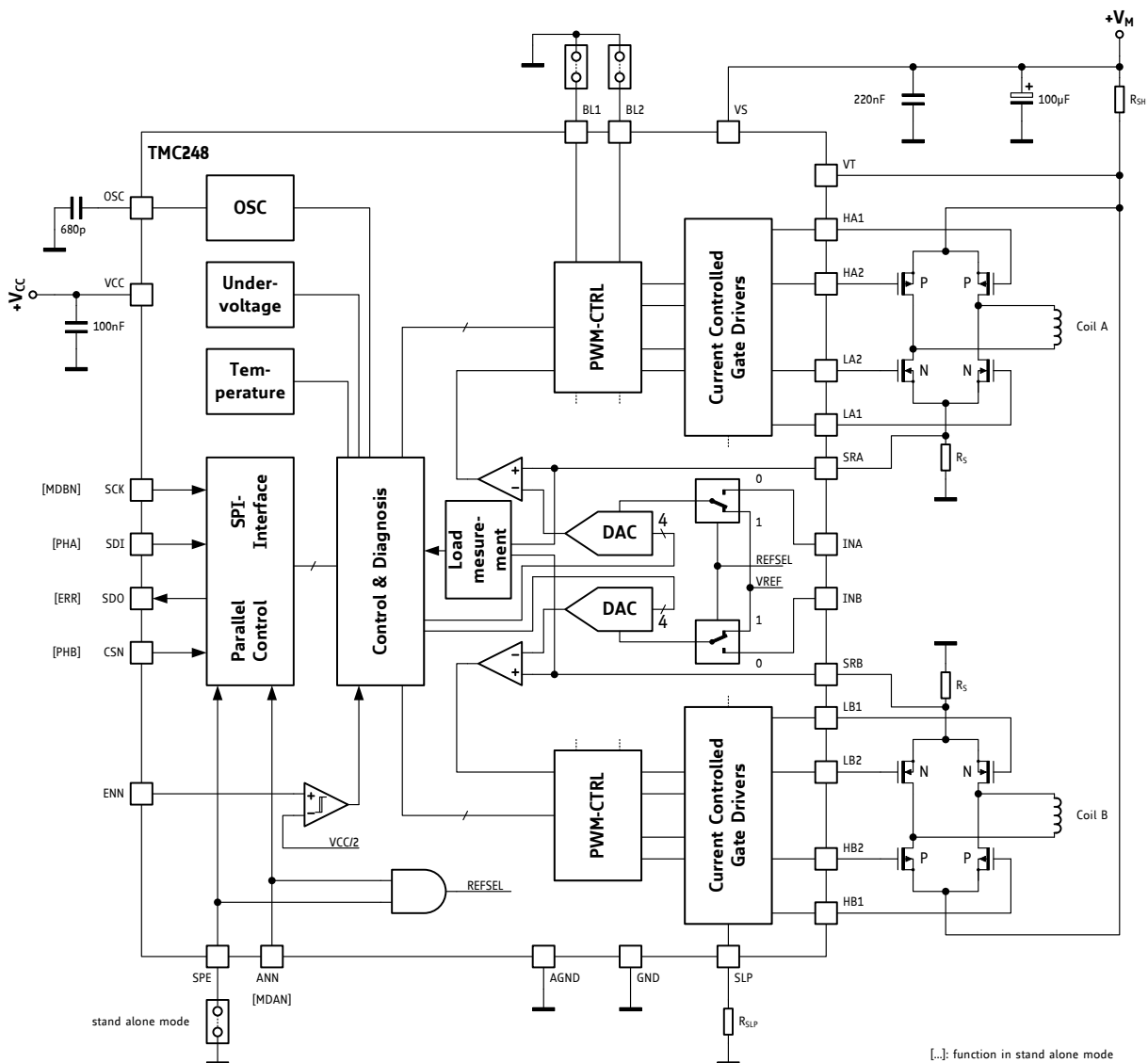


Figure 1.1 TMC248 block diagram

The TMC248 is a dual full bridge driver IC for bipolar stepper motor control applications. The chip is realized in a HVCMOS technology and directly drives eight external Low-RDS-ON high efficiency MOSFETs. A 4A driver can be realized in the size of a stamp.

The TMC248 motor driver implements advanced features which are characteristic to TRINAMIC products. These features contribute toward precision, energy efficiency, reliability, smooth motion, and cooler operation in stepper motor applications.

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

1.1 Advanced Features

<i>stallGuard™</i>	The TMC248 offers sensorless load measurement and stall detection. Its ability to predict an overload makes the TMC248 an optimum choice for drives, where a high reliability is desired. Further, the integrated stallGuard™ feature makes the TMC248 a good choice for applications, where a reference point is needed, but where a switch is not desired.
<i>Current Control</i>	Current control serves a cool driver and motor. Internal DACs allow microstepping as well as smart current control. Its low power dissipation makes the TMC248 an optimum choice for drives, where a high reliability is desired.
<i>Microstepping via SPI</i>	Easy to use digital control of microstepping. After choosing the desired microstep resolution the microcontroller sends digital values for each microstep current via SPI. DACs and comparators convert these digital values to analog signals for coil currents. This way, every microstep is initialized and controlled by the microcontroller. The TMC248 serves for the execution.
<i>Mixed Decay</i>	Mixed decay can be used for smoother operation.
<i>Low Noise Chopper</i>	The TMC248 allows implementing a low noise voltage PWM chopper by two microcontroller PWM outputs using its simple standalone mode. This way, a motor can be moved very smoothly at high microstep resolution without any noise.
<i>Slope Control</i>	Slope control reduces electromagnetic emissions.
<i>Oscillator and Clock Selector</i>	Oscillator and clock selector provide the system clock from the on-chip oscillator or an external source.

1.2 Control Interfaces

There are two control interfaces from the motion controller to the motor driver: the SPI serial interface and the classical analog interface.

1.2.1 SPI 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. The motor can be controlled through the SPI interface alone.

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 TMC248 slave always consists of sending one 12-bit command word and receiving one 12-bit status word.

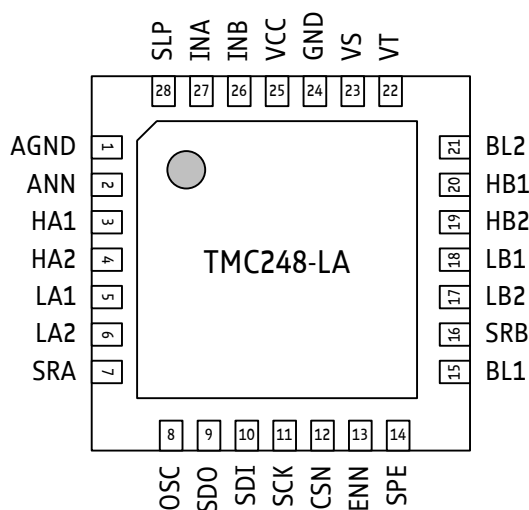
The SPI command rate typically corresponds to the microstep rate at low velocities. At high velocities, the rate may be limited by CPU bandwidth to 10,000 to 100,000 commands per second, so the application may need to change to fullstep resolution.

1.2.2 Classical Non-SPI Control Mode (Standalone Mode)

The driver can be controlled by analog current control signals and digital phase signals.

2 Pin Assignments

2.1 Package Outline



Note:

The exposed die attach pad should be connected to a GND plane or can be left open.

Top view

Figure 2.1 TMC248 pin assignments

2.2 Signal Descriptions

Pin	Number	Function
AGND	1	Analog ground (reference for SRA, SRB, OSC, SLP, INA, INB, SLP)
INA	27	Analog current control phase A
INB	26	Analog current control phase B
GND	24	Digital and power GND
OSC	8	Oscillator capacitor or external clock input for chopper
HA1	3	Outputs for high side P-channel transistors.
HA2	4	
HB1	20	
HB2	19	
LA1	5	Outputs for low side N-channel transistors
LA2	6	
LB1	18	
LB2	17	
SRA	7	Bridge A / B current sense resistor input
SRB	16	
SDO	9	Data output of SPI interface (tri-state)
SDI	10	Data input of SPI interface
SCK	11	Serial clock input of SPI interface
CSN	12	Chip select input of SPI interface
SPE	14	Enable SPI mode (high active). Tie to GND for non-SPI applications
SLP	28	Slope control resistor. Tie to GND for fastest slope
ENN	13	Device enable (low active) and overvoltage shutdown input
ANN	2	Enable analog current control via INA and INB (low active)
BL1	15	Digital blank time select
BL2	21	
VS	23	Motor supply voltage
VCC	25	3.0... 5.5V supply voltage for analog and logic circuits
VT	22	Short to GND detection comparator – connect to VS if not used

3 stallGuard - Stall Detection and Reference Search

stallGuard provides a sensorless measurement of the load on the motor. The load detection is based on the motors back EMF of the coils. Thus, the stallGuard feature allows a digital read out of the mechanical load on the motor via the serial interface.

stallGuard is important for:

- finding a reference point
- stall detection
- predicting an overload and assuring high reliability

stallGuard is typically used for the noiseless reference search with a mechanical reference position. The quality of the result depends on three constraints from the stepper motor and its application:

- efficiency of a stepper motor in terms of mechanical power vs. power dissipation
- difference in mechanical load between free running and stall on barrier
- velocity of the stepper motor

3.1 stallGuard Measurement

The stallGuard measurement value changes linearly over a wide range of load, velocity, and current settings. *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.

The load detection level depends on several factors:

<i>Motor velocity</i>	A higher velocity leads to a higher readout value.
<i>Motor resonance</i>	Motor resonances cause a high dynamic load on the motor, and thus measurement may give unsatisfactory results.
<i>Motor acceleration</i>	Acceleration phases also produce dynamic load on the motor.
<i>Mixed decay setting</i>	For load measurement mixed decay has to be off for some time before the zero crossing of the coil current. If mixed decay is used, and the mixed decay period is extended towards the zero crossing, the load indicator value decreases.

Attention:

- To get a readout value, drive the motor using sine commutation and mixed decay switched off.
- The load measurement is available as a three bit load indicator during normal motion of the motor.
- A higher mechanical load on the motor results in a lower readout value.
- The value is updated once per fullstep.

STALLGUARD VALUES

Bits	Description	Value Range
LD2 LD1 LD0 (unsigned 3 bit)	0	Highest mechanical load on motor, stall may occur.
	1, 2	High mechanical load on motor.
	3... 7	Less load on motor. A value in this range should be achieved in a suitable velocity range under no-load conditions, in order to get stable stall detection.
	7: 100% stallGuard signal – lowest motor load.	
		0... 7

The stallGuard signal sensitivity curves show the reaction of the TMC248 to the stallGuard signal taken from measuring the motor. A certain stray occurs within the TMC248, but the resulting curve is monotonously. Typically, the curve for a certain device has a certain offset. For high values above 2, the percentage of the stray is relatively low, so that a motor reaching these values allows safe stall detection.

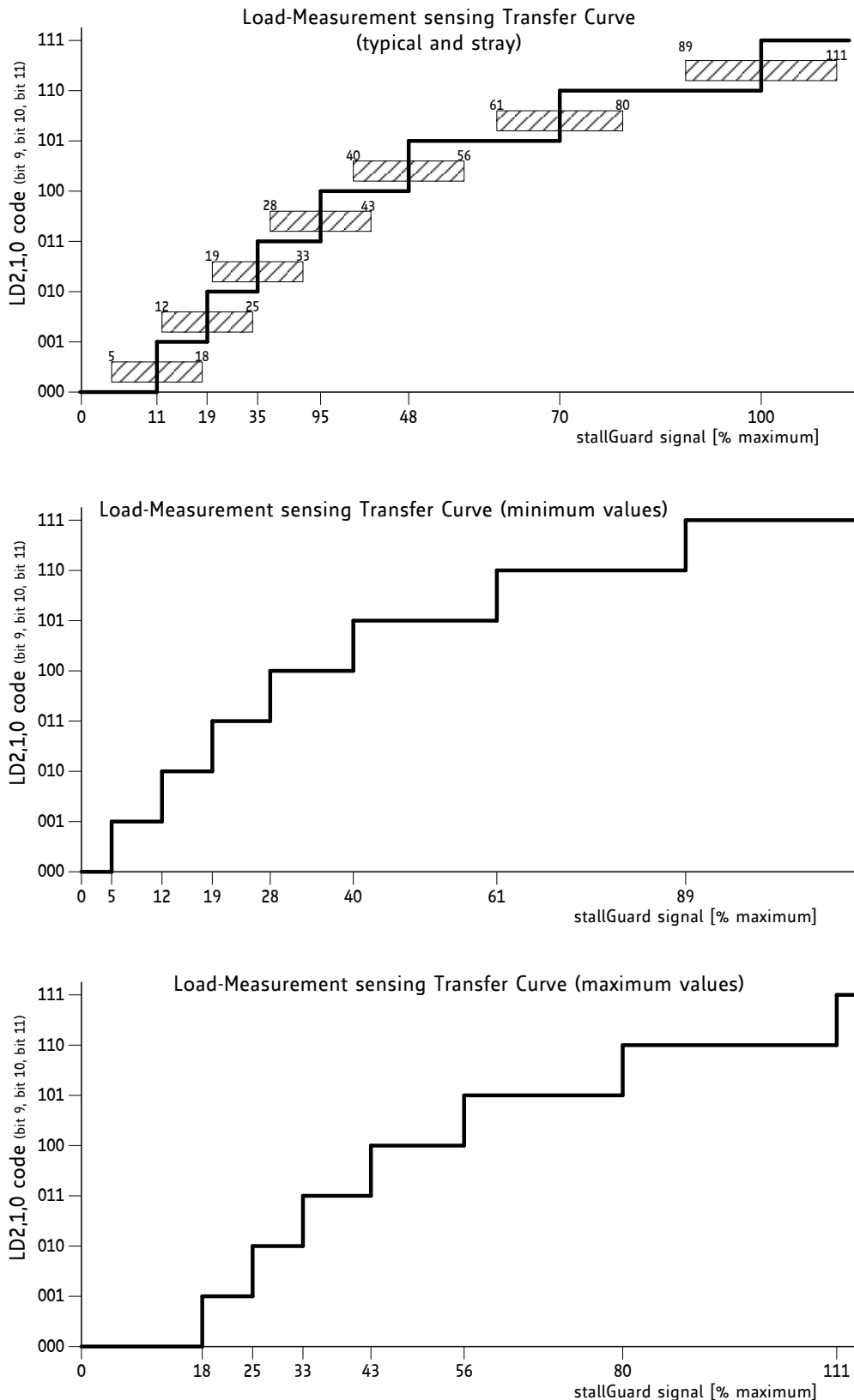


Figure 3.1 stallGuard signal sensitivity curves

3.2 Implementing Sensorless Stall Detection

The sensorless stall detection typically is used, to detect the reference point without the usage of a switch or photo interrupter. Therefore the actuator is driven to a mechanical stop, e.g. one end point in a spindle type actuator. As soon as the stop is hit, the motor stalls. Without stall detection, this would give an audible humming noise and vibrations, which could damage mechanics.

TO GET RELIABLE STALL DETECTION, PROCEED AS FOLLOWS:

1. Choose a motor velocity for reference movement. Use a medium velocity which is far enough from mechanical resonance frequencies. In some applications even the start and/or stop frequency may be used. So, the motor can stop within one fullstep if a stall is detected.
2. Use a sine stepping pattern and switch off mixed decay (at least 1... 3 microsteps before zero crossing of the sine wave current in the related coil).
3. Monitor the load indicator during movement. It should show a stable readout value in the range 3... 7 (L_{MOVE}). If the readout is high (>5), the mixed decay portion may be increased.
4. Choose a threshold value L_{STALL} between 0 and $L_{MOVE} - 1$. Monitor the load indicator during the reference search movement (homing) as the desired velocity is reached.
5. Readout is required at least once per fullstep. If the readout value at one fullstep is below or equal to L_{STALL} , stop the motor.
6. If the motor stops during normal movement without hitting the mechanical stop, decrease L_{STALL} . If the stall condition is not detected at once, when the motor stalls, increase L_{STALL} .

Attention:

- At maximum motor load, the value goes to zero or near to zero.
- Do not read out the value within one chopper period plus 8 microseconds after toggling one of the phase polarities!

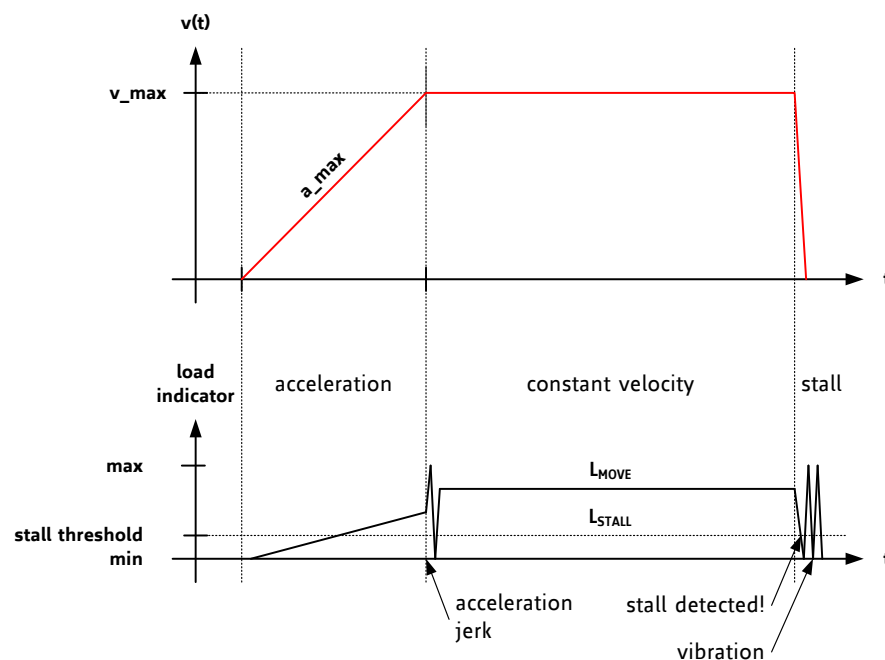


Figure 3.2 Implementing stallGuard

4 SPI Interface

The TMC248 requires setting current absolute values and polarity for each microstep through the SPI interface to drive the motor in SPI mode. The SPI interface also allows reading back status values and bits.

4.1 Bus Signals

The SPI bus on the TMC248 has five signals:

SCK	bus clock input
SDI	serial data input
SDO	serial data output
CSN	chip select input (active low)
ENN	enable input has to be active (low) in order to use SPI

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 12 SCK clock cycles is required for a bus transaction with the TMC248.

If more than 12 clocks are driven, the additional bits shifted into SDI are shifted out on SDO after a 12-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 12 bits are sent, only the last 12 bits received before the rising edge of CSN are recognized as the command.

The SPI data word sets the current and polarity for both coils. By applying consecutive values, describing a sine and a cosine wave, the motor can be driven in microsteps. Every microstep is initiated by its own telegram. Please refer to the description of the analog mode for details on the waveforms required. The SPI interface timing is described in the timing section.

We recommend the TMC429 to automatically generate the microstepping sequence and motor ramps for up to three motors.

SERIAL DATA WORD TRANSMITTED TO TMC248

MSB TRANSMITTED FIRST

Bit	Name	Function	Remark
11	MDA	Mixed decay enable phase A	1 = mixed decay
10	CA3	Current bridge A.3	MSB
9	CA2	Current bridge A.2	
8	CA1	Current bridge A.1	
7	CA0	Current bridge A.0	LSB
6	PHA	Polarity bridge A	0 = current flow from OA1 to OA2
5	MDB	Mixed decay enable phase B	1 = mixed decay
4	CB3	Current bridge B.3	MSB
3	CB2	Current bridge B.2	
2	CB1	Current bridge B.1	
1	CB0	Current bridge B.0	LSB
0	PHB	Polarity bridge B	0 = current flow from OB1 to OB2

SERIAL DATA WORD TRANSMITTED FROM TMC248

MSB TRANSMITTED FIRST

Bit	Name	Function	Remark
11	LD2	Load indicator bit 2	MSB
10	LD1	Load indicator bit 1	
9	LD0	Load indicator bit 0	LSB
8	1	Always 1	
7	OT	Overtemperature	1 = Chip off due to overtemperature
6	OTPW	Temperature prewarning	1 = Prewarning temperature exceeded
5	UV	Driver undervoltage	1 = Undervoltage on VS
4	OCHS	Overcurrent high side	3 PWM cycles with overcurrent within 63 PWM cycles
3	OLB	Open load bridge B	No PWM switch off for 14 oscillator cycles
2	OLA	Open load bridge A	No PWM switch off for 14 oscillator cycles
1	OCB	Overcurrent bridge B low side	3 PWM cycles with overcurrent within 63 PWM cycles
0	OCA	Overcurrent bridge A low side	3 PWM cycles with overcurrent within 63 PWM cycles

Note:

- The current values correspond to a standard 4 Bit DAC, where 100% = 15/16.
- The content of all registers is cleared to 0 on power-on reset or disable via the ENN pin, bringing the IC to a low power standby mode.
- All SPI inputs have Schmitt-Trigger function.

4.2 Motor Coil Current Setting via SPI

Current Setting CA3..0 / CB3..0	Percentage of Current	TYPICAL TRIP VOLTAGE OF THE CURRENT SENSE COMPARATOR - INTERNAL REFERENCE OR ANALOG INPUT VOLTAGE OF 2V IS USED -
0000	0%	0 V (bridge continuously in slow decay condition)
0001	6.7%	23 mV
0010	13.3%	45 mV
...	...	
1110	93.3%	317 mV
1111	100%	340 mV

4.3 Base Current Control Mode via INA / INB in SPI Mode

In SPI mode the IC can use an external reference voltage for each DAC. This allows the adaptation to different motors.

Note:

- This *Base Current Control Mode* is enabled by tying pin ANN to GND.
- A 2.0 V input voltage V_{IN} gives full scale current of 100%.
- The range for V_{IN} is 0... 3V. Min. 1 V recommended for best microstepping.
- The typical trip voltage of the current sense comparator is determined by the input voltage V_{IN} and the DAC current setting (see table above).

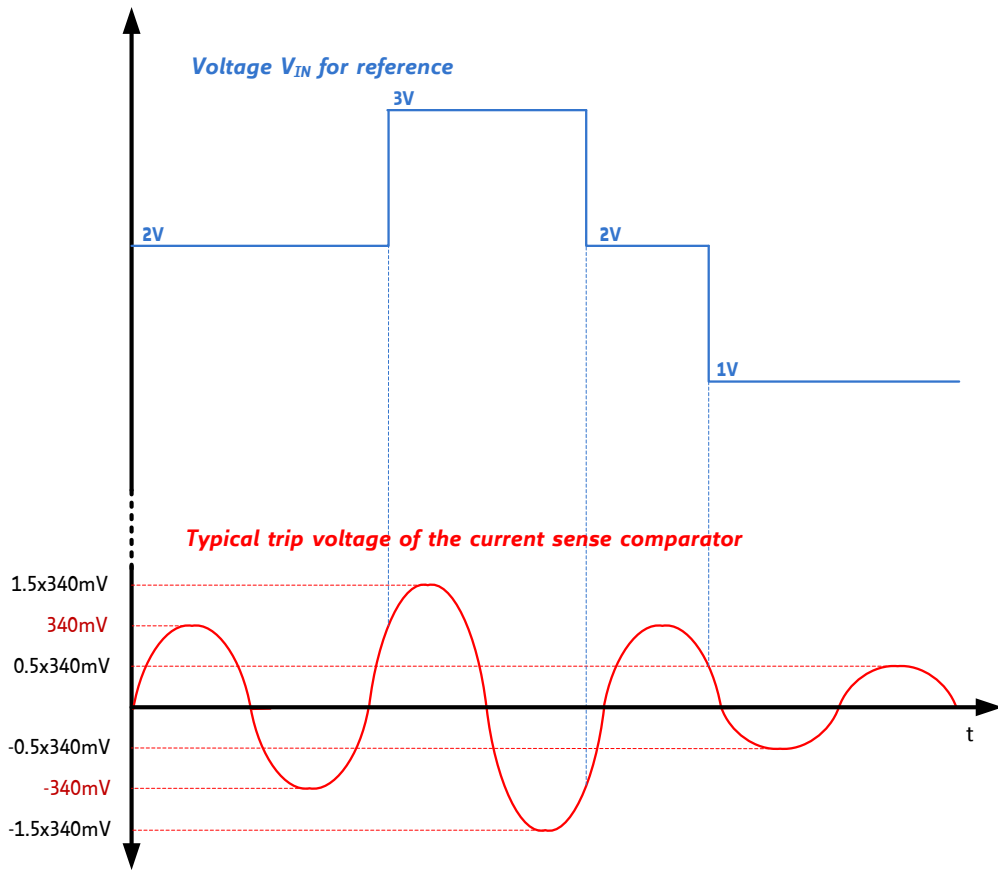


Figure 4.1 Relation between V_{IN} and trip voltage of current sense comparator

IN CASE A VARIABLE INPUT VOLTAGE V_{IN} IS USED THE TYPICAL TRIP VOLTAGE IS CALCULATED:

$$V_{TRIP,A} = 0.17 V_{INA} \times \text{percentage SPI current setting A}$$

$$V_{TRIP,B} = 0.17 V_{INB} \times \text{percentage SPI current setting B}$$

GENERATING INPUT VOLTAGE V_{IN}

A maximum of 3.0V V_{IN} is possible. Multiply the percentage of base current setting and the DAC table to get the overall coil current. It is advised to operate at a high base current setting, to reduce the effects of noise voltages. This feature allows a high resolution setting of the required motor current using an external DAC or PWM-DAC (see schematic for examples).

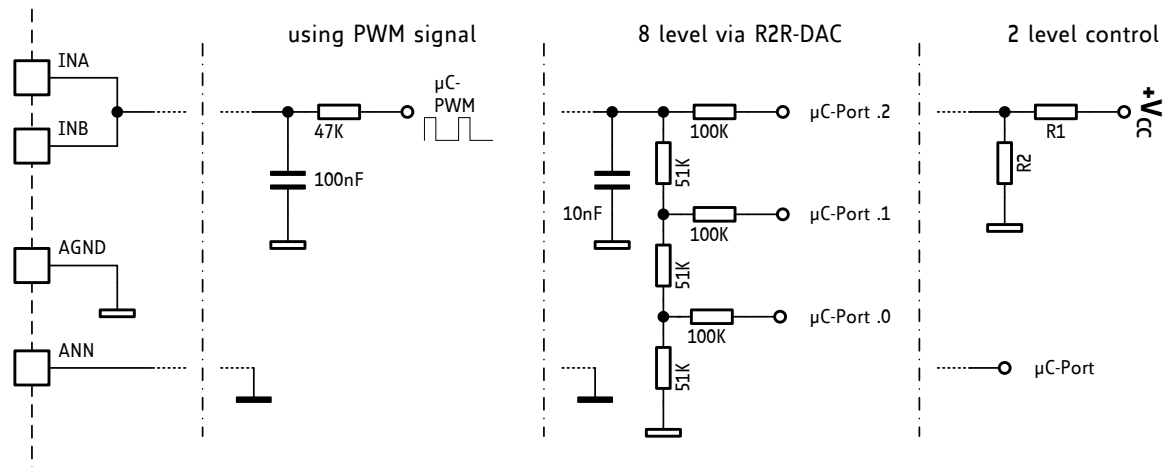
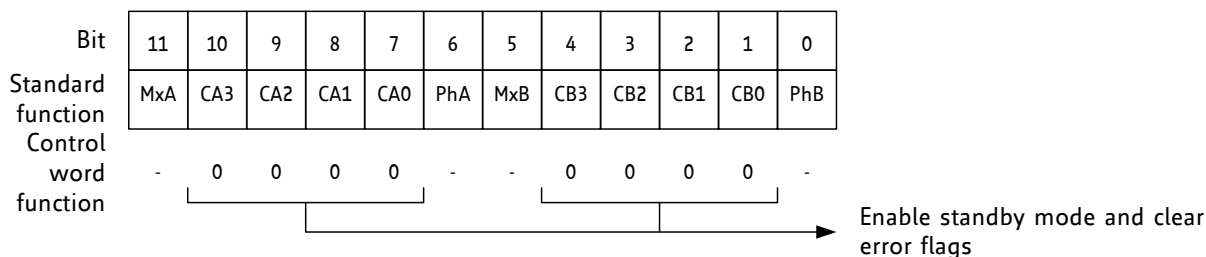


Figure 4.2 External DAC and PWM-DAC

4.4 Controlling Power Down via the SPI Interface



Programming current value 0000 for both coils at a time clears the overcurrent flags and switches the TMC248 into a low current standby mode with coils switched off.

4.5 Open Load Detection

Open load is signaled if there are more than 14 oscillator cycles without PWM switch off. During overcurrent, undervoltage, or overtemperature conditions, the open load flags become active. *Open load detection is not possible while the coil current is set to 0000. In this condition the chopper is off and the open load flag is read as inactive (0).*

The open load flags not only signal an open load condition, but also a torque loss of the motor, especially at high motor velocities. To detect only an interruption of the connection to the motor, it is advised to evaluate the flags during stand still or during low velocities only (e.g. for the first or last steps of a movement).

4.6 Standby and Shutdown Mode

The TMC248 offers two possibilities for reducing power consumption under special conditions: the standby mode and the shutdown mode.

STANDBY MODE

- The circuit can be put into a low power standby mode by the user.
- The circuit automatically goes to standby on Vcc undervoltage conditions.
- The standby mode is available via the interface in SPI-mode and via the ENN pin in non-SPI mode.

Before entering standby mode, the TMC248 switches off all power transistors and holds their gates in a disable condition using high ohmic resistors. In standby mode the oscillator becomes disabled and the oscillator pin is held at a low state.

SHUTDOWN MODE

- The shutdown mode is used for a further reduction of the supply current.
- The shutdown mode can be entered in SPI-mode by pulling the ENN pin high.
- In shutdown mode additionally all internal reference voltages become switched off and the SPI circuit is held in reset.

4.7 Power Saving

The possibility to control the output current can dramatically save energy, reduce heat generation and increase precision by reducing thermal stress on the motor and attached mechanical components. Just reduce motor current during stand still: A slight reduction of the coil currents to 70% of the current of the last step halves power consumption!

In typical applications a 50% current reduction during stand still is reasonable.

4.8 Bus Timing

The SPI interface operates completely asynchronous. It is clocked by SCK and CSN, only. Figure 4.3 shows the timing parameters of an SPI bus transaction, and the table below specifies their values.

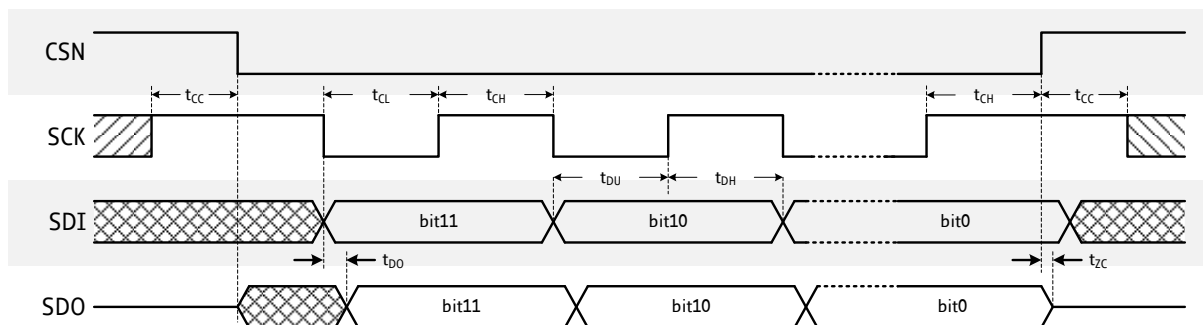


Figure 4.3 SPI Timing

PROPAGATION TIMES

($3.0\text{ V} \leq V_{CC} \leq 5.5\text{ V}$, $-40^{\circ}\text{C} \leq T_j \leq 150^{\circ}\text{C}$; $V_{IH} = 2.8\text{V}$, $V_{IL} = 0.5\text{V}$; $t_r, t_f = 10\text{ns}$; $C_L = 50\text{pF}$, unless otherwise specified)

SPI Interface Timing		AC-Characteristics clock period is t_{CLK}				
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
SCK frequency	f_{SCK}	ENN = 0	DC		8	MHz
SCK stable before and after CSN change	t_1		50			ns
Width of SCK high pulse	t_{CH}		100			ns
Width of SCK low pulse	t_{CL}		100			ns
SDI setup time	t_{DU}		40			ns
SDI hold time	t_{DH}		50			ns
SDO delay time	t_D	$C_L = 50\text{pF}$		40	100	ns
CSN high to SDO high impedance	t_{ZC}	*)	50			ns
ENN to SCK setup time	t_{ES}		30			μs
CSN high to LA / HA / LB / HB output polarity change delay	t_{PD}	**)		3	$t_{OSC} + 4$	μs
Load indicator valid after LA / HA / LB / HB output polarity change	t_{LD}			5	7	μs

*) SDO is tri-stated whenever ENN is inactive (high) or CSN is inactive (high).

***) Whenever the PHA / PHB polarity is changed, the chopper is restarted for that phase. The chopper does not switch on, when the SRA resp. SRB comparator threshold is exceeded upon the start of a chopper period.

4.9 Using the SPI Interface with One or Multiple Devices

The SPI interface allows either cascading of multiple devices, giving a longer shift register, or working with a separate chip select signal for each device, paralleling all other lines. Even when there is only one device attached to a CPU, the CPU can communicate with it using a 16 bit transmission. In this case, the upper 4 bits are dummy bits.

4.10 SPI Filter

To prevent spikes from changing the SPI settings, SPI data words are only accepted, if their length is at least 12 bit.

5 Classical Non-SPI Control Mode (Standalone Mode)

The driver can be controlled by analog current control signals and digital phase signals.

Proceed as follows:

- Tie pin SPE to GND for enabling non-SPI mode. In non-SPI mode the SPI interface is disabled and the SPI input pins have alternate functions.
- The internal DACs are forced to 1111.

5.1 Pin Functions in Standalone Mode

Pin	Standalone mode name	Function in standalone mode
SPE	(GND)	Tie to GND to enable standalone mode
ANN	MDAN	Enable mixed decay for bridge A (low = enable)
SCK	MDBN	Enable mixed decay for bridge B (low = enable)
SDI	PHA	Polarity bridge A (low = current flow from output OA1 to OA2)
CSN	PHB	Polarity bridge B (low = current flow from output OB1 to OB2)
SDO	ERR	Error output (high = overcurrent on any bridge, or over temperature). In this mode, the pin is never tri-stated.
ENN	ENN	Standby mode (high active), high causes a low power mode of the device. Setting this pin high also resets all error conditions.
INA, INB	INA, INB	Current control for bridge A, resp. bridge B. Refer to AGND. The sense resistor trip voltage is 0.34V when the input voltage is 2.0V. Maximum input voltage is 3.0V.

5.2 Input Signals for Microstep Control in Standalone Mode

Attention:

When transferring these waves to SPI operation, note that the mixed decay bits are inverted when compared to standalone mode.

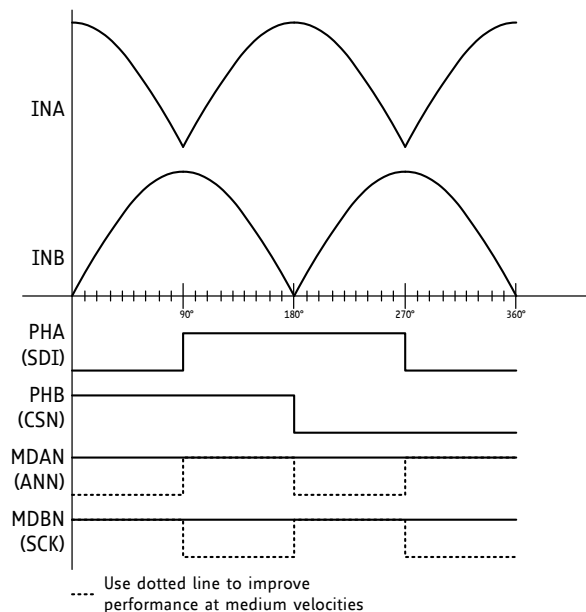


Figure 5.1 Analog control for standalone mode

6 Current Setting

6.1 Sense Resistor for Current Setting

Choose an appropriate sense resistor R_S for setting the desired motor current.

Basic information:

- The maximum motor current is reached, when the coil current setting is programmed to 1111.
- This results in a current sense trip voltage of 0.34V if the internal reference or a reference voltage of 2V is used. (Refer to chapter 4.3 for more information about current setting in SPI mode.)
- The current sense resistor of bridge A, B is calculated as:

$$R_{SENSE} = V_{TRIP} / I_{max}$$

R_{SENSE} Current sense resistor of bridge A, B

V_{TRIP} Programmed trip voltage of the current sense comparators

I_{max} Desired maximum coil current

Mode of operation	Maximum motor current
Operation in fullstep mode	The maximum motor current is specified by the manufacturer.
Operation in microstep mode	Multiply the value for fullstep mode by 1.41 for the maximum current I_{max} .

EXAMPLE FOR TYPICAL APPLICATION

$$R_{SENSE} = 0.34V / I_{max}$$

POSSIBLE SENSE RESISTOR SETTINGS

R_S	I_{max}
0.47 Ω	723mA
0.33 Ω	1030mA
0.22 Ω	1545mA
0.15 Ω	2267mA
0.10 Ω	3400mA

6.2 Resistor R_{SH} for High Side Overcurrent Detection

The TMC248 detects an overcurrent to ground, when the voltage between VS (supply voltage) and VT (threshold voltage) exceeds 150mV. The high side overcurrent detection resistor should be chosen in a way that 100mV voltage drop are not exceeded between VS and VT, when both coils draw the maximum current. In a microstep application, this is the case when sine and cosine wave have their highest sum, i.e. at 45 degrees. This corresponds to 1.41 times the maximum current setting for one coil. In a fullstep application this is adequate to the double coil current.

IN A MICROSTEP APPLICATION:

$$R_{SH} = 0.1V / (1.41 \times I_{max})$$

IN A FULLSTEP APPLICATION:

$$R_{SH} = 0.1V / (2 \times I_{max})$$

R_{SH} : High side overcurrent detection resistor

I_{max} : Maximum coil current

If higher resistance values should be used, a voltage divider in the range of 10 Ω to 100 Ω can be used for VT. This might also be desired to limit the peak short to GND current, as described in the following chapter.

A careful PCB layout is required for the sense resistor traces and for the R_{SH} traces.

6.2.1 Making the Circuit Short Circuit Proof

In most applications, a short circuit does not describe only one special condition. It typically involves inductive, resistive and capacitive components. Worst events are unclamped switching events, because huge voltages can build up in inductive components and result in a high energy spark going into the driver, which can destroy the power transistors.

Note:

Never disconnect the motor during operation as this can destroy the power transistors!

An absolute protection against random short circuit conditions is not given, but pre-cautions can be taken to improve robustness of the circuit:

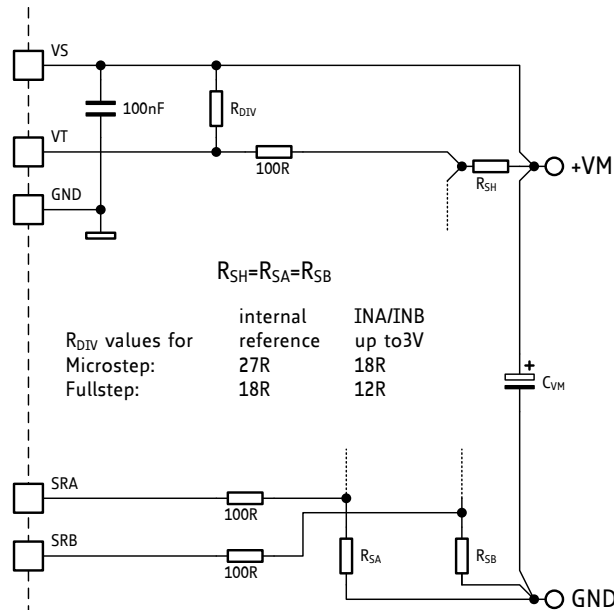
In a short condition, the current can become very high before it is interrupted by the short detection, due to the blanking during switching and internal delays. The high-side transistors allow a high current flowing for the selected blank time. The lower the external inductivity, the faster the current climbs. If inductive components are involved in the short, the same current will shoot through the low-side resistor and cause a high negative voltage spike at the sense resistor. *Both, the high current and the voltage spikes are dangerous for the driver.*

PROCEED AS FOLLOWS, IF SHORT CIRCUITS ARE EXPECTED:

1. Protect SRA/SRB inputs using a series resistance.
2. Increase R_{SH} (high side overcurrent detection resistor) to limit the maximum transistor current. Use the same value as for the sense resistors.
3. Set the blank time as short as possible.

The second point effectively limits the short circuit current, because the upper driver transistor with fixed ON gate voltage of 6V forms a constant current source together with its internal resistance and the high side overcurrent detection resistor R_{SH} .

A positive side effect is that only one type of low resistive resistor is required. The drawback is that power dissipation increases.



Example:

A 0.33 Ohms sense resistor allows for roughly 1 A motor coil current. A high side short detection resistor of 0.33 Ohms limits maximum high side transistor current to typically 4A during a short circuit condition. The schematic shows the modifications to be done.

The effectiveness of the steps described above should be tested in the given application!

Figure 6.1 Schematic with $R_{SH}=R_{SA}=R_{SB}$

7 Chopper Operation

The currents through both motor coils are controlled using a chopper. The TMC248 uses a quiet fixed frequency chopper. Both coils are chopped with a phase shift of 180 degrees. The Chopper cycles through three phases: on, fast decay, and slow decay.

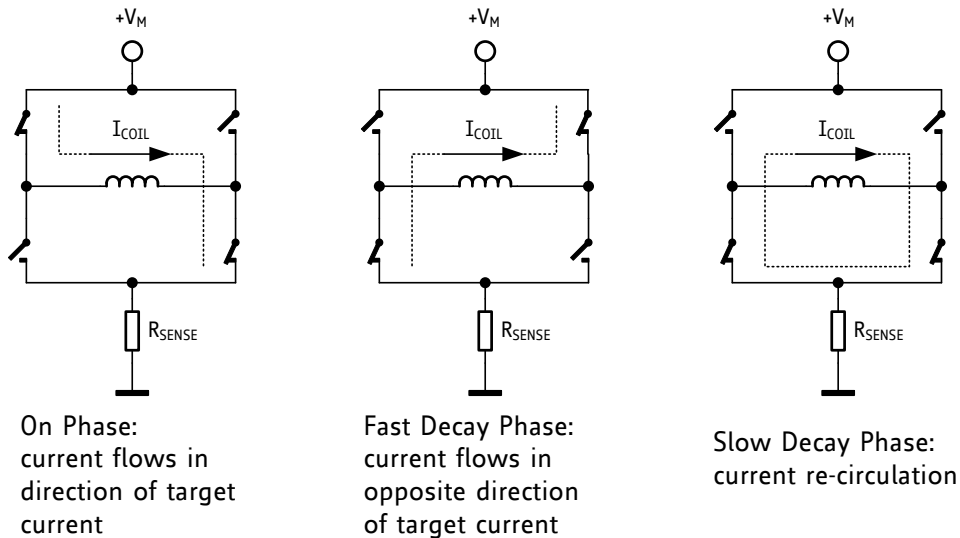


Figure 7.1 Chopper phases

Fast decay switches off both upper transistors, while enabling the lower transistor opposite to the selected polarity. Slow decay always enables both lower side transistors.

When the polarity is changed on one bridge, the PWM cycle on that bridge becomes restarted at once.

7.1 Mixed Decay Mode

The mixed decay option is realized as a self stabilizing system, by shortening the fast decay phase, if the ON phase becomes longer.

It is advised to enable the mixed decay for each phase during the second half of each microstepping half-wave, when the current is meant to decrease. This leads to less motor resonance, especially at medium velocities.

MIXED DECAY IN APPLICATIONS WITH HIGH RESOLUTION OR LOW INDUCTIVITY MOTORS

In applications requiring high resolution, or using low inductivity motors, the mixed decay mode can also be enabled continuously to reduce the minimum motor current which can be achieved.

USING MIXED DECAY CONTINUOUSLY OR WITH HIGH INDUCTIVITY MOTORS AT LOW SUPPLY VOLTAGE

If mixed decay mode is continuously on or high inductivity motors are used at low supply voltage, it is advised to raise the chopper frequency to minimum 36 kHz, because the half chopper frequency could become audible.

With low velocities or during standstill mixed decay should be switched off.

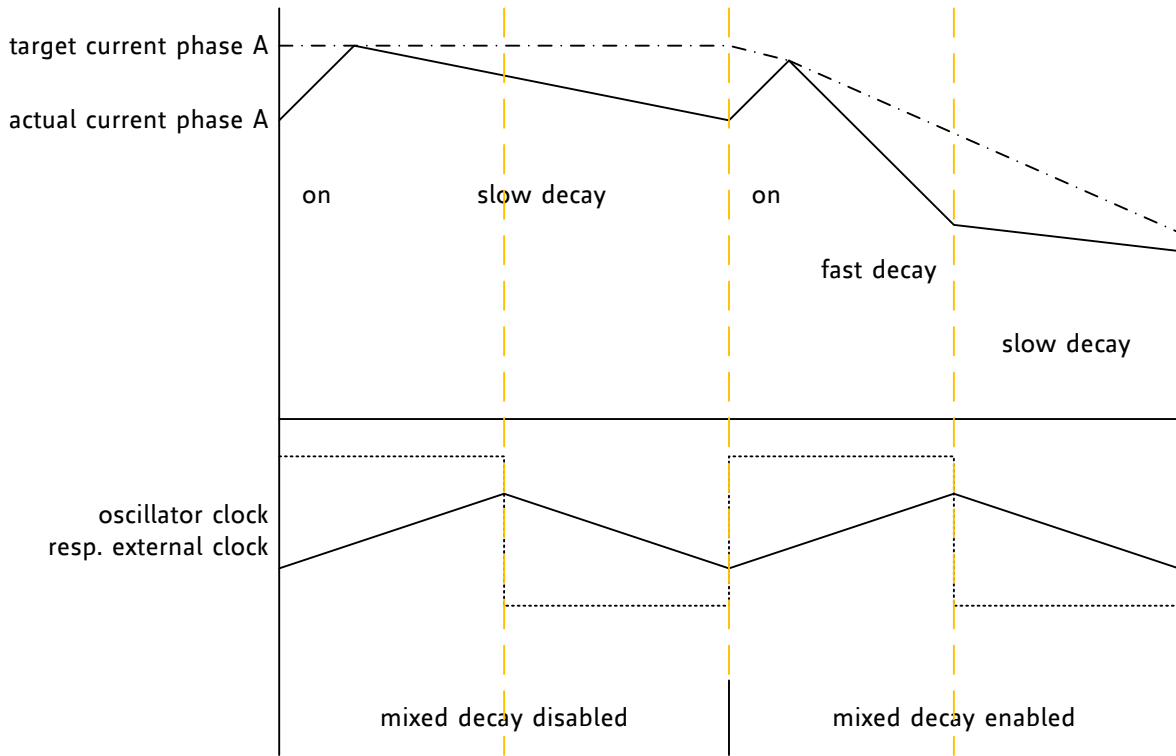


Figure 7.2 Chopper cycle

7.2 Chopper Frequency

The PWM oscillator frequency can be set by an external capacitor. The internal oscillator uses a 28kΩ resistor to charge / discharge the external capacitor to a trip voltage of 2/3 V_{CC} respectively 1/3 V_{CC}. It can be overdriven using an external CMOS level square wave signal. Do not set the frequency higher than 100 kHz and do not leave the OSC terminal open! The two bridges are chopped with a phase shift of 180 degrees at the positive and at the negative edge of the clock signal.

The PWM oscillator frequency is calculated as: $f_{osc} = \frac{1}{40\mu s \times C_{OSC} [nF]}$

f_{osc} : PWM oscillator frequency

C_{OSC} : Oscillator capacitor in nF

OSCILLATOR FREQUENCIES

f_{osc} typ.	C_{OSC}
16.7kHz	1.5nF
20.8kHz	1.2nF
25.0kHz	1.0nF
30.5kHz	820pF
36.8kHz	680pF
44.6kHz	560pF

An unnecessary high frequency leads to high switching losses in the power transistors and in the motor.

For most applications a chopper frequency slightly above audible range is sufficient. When audible noise occurs in an application, especially with mixed decay continuously enabled, the chopper frequency should be **two times** the audible range.

7.3 Voltage PWM Mode for Low Noise Chopper

The TMC248 uses a cycle-by-cycle based chopper system, because it brings the best performance over a wide range of velocities. It regulates the current by terminating each chopper cycle as soon as the target current has been reached. This direct current regulation provides good dampening of motor resonance, low motor power loss and automatic adaptation to the specific motor. On the other hand, chopper stability requires good decoupling between both motor coils and it needs a precise layout of the high current paths. Instabilities caused by magnetic coupling in the motor or by coupling of the coil current regulators due to electric coupling can lead to chopper noise and fine vibrations. Under normal conditions, these will not do any harm. *In applications, where the motor moves very slowly or where precise standstill with low mass on the motor axis is required, a voltage PWM chopper is a good choice.*

The low noise feed forward chopper principle uses a voltage PWM controlled driving rather than current controlled driving. This is possible, because the stepper motor has a certain coil resistance. This resistance converts an externally applied voltage to current. As long as the motor velocity is low, back EMF caused by the motor rotation does not need to be taken into account.

At increasing velocities, the motors back EMF has an increasing influence and influences coil current. This can be compensated by increasing the driver voltage with increasing velocity. Effects like motor temperature dependency of the coil resistance should be taken into account, in case the motor operates in an increased temperature range. The described compensation principle can be realized in a completely feed-forward way, based on the motor data, or by measuring the effective current and adding a regulation loop.

The chopper principle described generates a certain motor voltage by toggling each motor phase with a certain PWM frequency. Therefore the motor full bridges either switch on the motor current in one direction or in the opposite direction.

This way, the duty cycle of toggling the coil polarity produces a certain effective voltage on the coils:

- A 50 percent duty cycle gives a mean current of zero.
- A higher or lower duty cycle gives a positive or negative current.
- A high PWM resolution will bring a high microstep resolution.

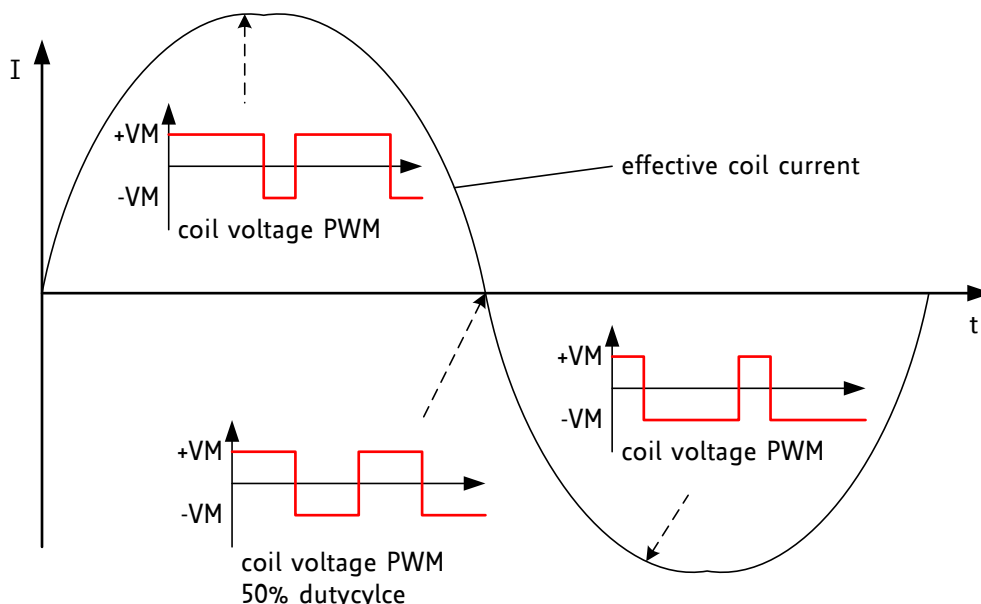


Figure 7.3 Voltage PWM generates motor current

7.3.1 Calculating the PWM for Low Noise Chopper

A microcontroller or an FPGA can be used for generating the two PWMs required to drive the motor. For a 256 microstep resolution a PWM resolution of 9 to 10 bit is required. Assuming a target chopper

frequency of roughly 20 kHz, a base clock frequency of 20 MHz ($=2^{10} \times 20 \text{ kHz}$) is required to yield a 10 bit PWM. A 16 MHz clock frequency will allow realizing a 9 bit PWM with 31 kHz, or a resolution of 800 PWM steps with 20 kHz. This is a feasible value for most standard 8 bit or better microcontrollers.

Basically, one motor coil is driven with a PWM, which duty cycle is modulated using a sine wave. The other coil with a cosine modulated PWM. Assuming, that the system supply voltage would exactly match the motor voltage required for nominal current, the PWM duty cycle will be altered between 100% for maximum positive current and 0% for maximum negative current. As this is not a typical constellation, the PWM modulation required to match the motor needs to be calculated.

The PWM modulation is calculated as:

$$PWMAmpl = I_{COILpeak} \frac{R_{COIL}}{(V_M - V_{BEMF})}$$

PWMAmpl PWM amplitude required to reach the nominal motor current. Half of this amplitude is applied in positive direction (additional to 50% duty cycle), and half of it is applied in negative direction (subtracted from 50% duty cycle)

$I_{COILpeak}$ Nominal peak coil current of the motor, i.e. $I_{COILRMS} * 1.41$

R_{COIL} Resistance of the motor coil

V_M Motor driver supply voltage (may be measured in the application)

V_{BEMF} Velocity dependent back EMF voltage of the motor. It is measured in $V/rad/s$.
At standstill V_{BEMF} is zero and can be ignored for low RPM.

For higher velocities, multiply it by the angular velocity of the motor.

EXAMPLE

A 1A RMS motor with 6.50hm coil resistance is to be operated from a 12V supply at low velocity.

$$1A * 1.41 \frac{6.5\Omega}{(12V - 0V)} = 0.76$$

Therefore, the duty cycle needs to be modulated between $0.5 + 0.76/2 = 88\%$ for the positive sine wave peak and $0.5 - 0.76/2 = 12\%$ for the negative sine wave peak.

7.3.2 Hardware Setup for Low Noise Chopper

The TMC248 provides a standalone mode, which allows direct control of coil polarity using a digital signal. Further, the coil current can be controlled using an analog voltage in the range 0 V... 3 V. As current control is done by PWM duty cycle, the integrated PWM based analog current control of the IC is not used. Therefore, in principle it would be possible to work without sense resistors.

We recommend using the analog current limit as a safety feature. Further it can be used for allowing a fallback to classical fullstepping at higher velocity (in order to also allow faster movements):

During voltage PWM mode the analog current control can be used to limit the motor current in case of an error. Therefore, the current limit must be set at least 20% to 30% higher than the desired maximum motor current for PWM operation (peak current value plus additional ripple). The mixed decay mode must be switched off ($MDAN=MDBN=VCC$), because it would interfere with voltage PWM operation. *Both motor coil limits can be set to the same analog current limiting value: for a safety limit and for a change to fullstepping.*

In fullstepping switching to a lower value may be desired in order to match motor RMS current.

The processor controlled PWM uses the polarity inputs (PHA, PHB) for both coils to control motor PWM.

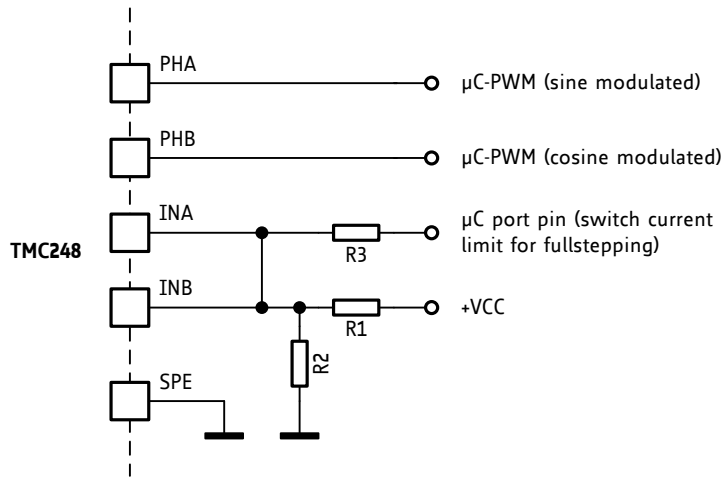


Figure 7.4 Controlling the driver with two PWMs in standalone mode

7.4 Adapting the Sine Wave for Smooth Motor Operation

The optimization of the sine wave is possible for the mixed decay mode and for the voltage PWM mode. After reaching the target current in each chopper cycle, both, the slow decay and the fast decay cycle reduce the current by some amount. Especially the fast decay cycle has a larger impact. Thus, the medium coil current always is a bit lower than the target current. This leads to a flat line in the current shape flowing through the motor. It can be corrected, by applying an offset to the sine shape. In mixed decay operation via SPI, an offset of 1 does the job for most motors.

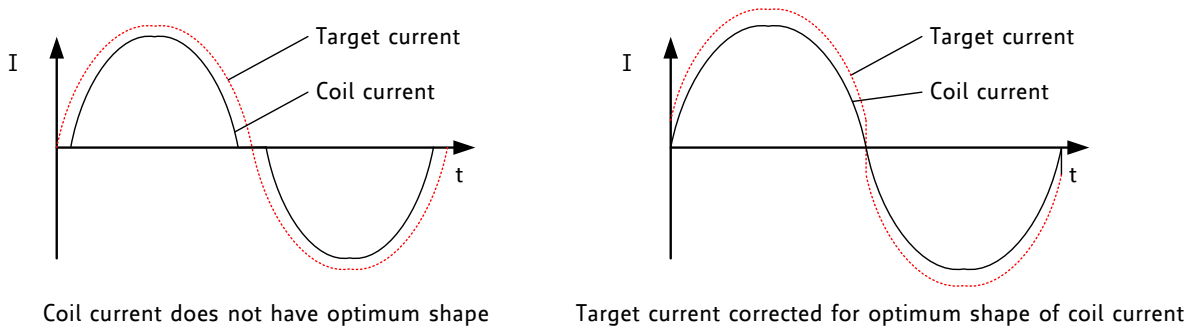


Figure 7.5 Adapting sine wave for smooth motor operation

7.5 Blank Time

The TMC248 uses a digital blanking pulse for the current chopper comparators. This prevents current spikes, which can occur during switching action due to capacitive loading, from terminating the chopper cycle.

The lowest possible blanking time gives the best results for microstepping. A long blank time leads to a long minimum turn-on time, thus giving an increased lower limit for the current.

Please remark, that the blank time should cover both, switch-off time of the lower side transistors and turn-on time of the upper side transistors plus some time for the current to settle. Thus the complete switching duration should never exceed 1.5 μ s. With slow external power stages it will become necessary to add additional RC-filtering for the sense resistor inputs.

The TMC248 allows adapting the blank time to the load conditions and to the selected slope in four steps:

BLANK TIME SETTINGS

BL2	BL1	Typical blank time	Remarks
GND	GND	0.6 μ s	Very short. Will require good filtering on SRA and SRB.
GND	VCC	0.9 μ s	Works well in good low inductivity layouts.
VCC	GND	1.2 μ s	Default for most applications.
VCC	VCC	1.5 μ s	May be used with slow bridges or high sense resistor trace inductivity.

8 Slope Control

The output-voltage slope of the full bridge is controlled by a constant current gate charge / discharge of the MOSFETs. The charge / discharge current for the MOSFETs can be controlled by an external resistor: a reference current is generated by internally pulling the SLP-Pin to 1.25V via an integrated 4.7K Ω resistor. This current is used to generate the current for switching on and off the power transistors.

The gate-driver output current can be set in a range of 2... 25 mA by an external resistor:

$$R_{SLP} [\text{k}\Omega] \approx \frac{123}{I_{OUT} [\text{mA}]} - 4.7$$

R_{SLP} : Slope control resistor

I_{OUT} : Controlled output current of the low-side MOSFET driver

The SLP-pin can directly be connected to AGND for the fastest output-voltage slope (respectively maximum output current).

Please note, that there is a tradeoff between reduced electromagnetic emissions (slow slope) and high efficiency because of low dynamic losses (fast slope). Typical slope times range between 100ns and 500ns. Slope times below 100ns are not recommended, because they superimpose additional stress on the power transistors while bringing only very slight improvement in power dissipation.

For applications where electromagnetic emission is very critical, it might be necessary to add additional LC (or capacitor only) filtering on the motor connections. For these applications emission is lower, if only slow decay operation is used.

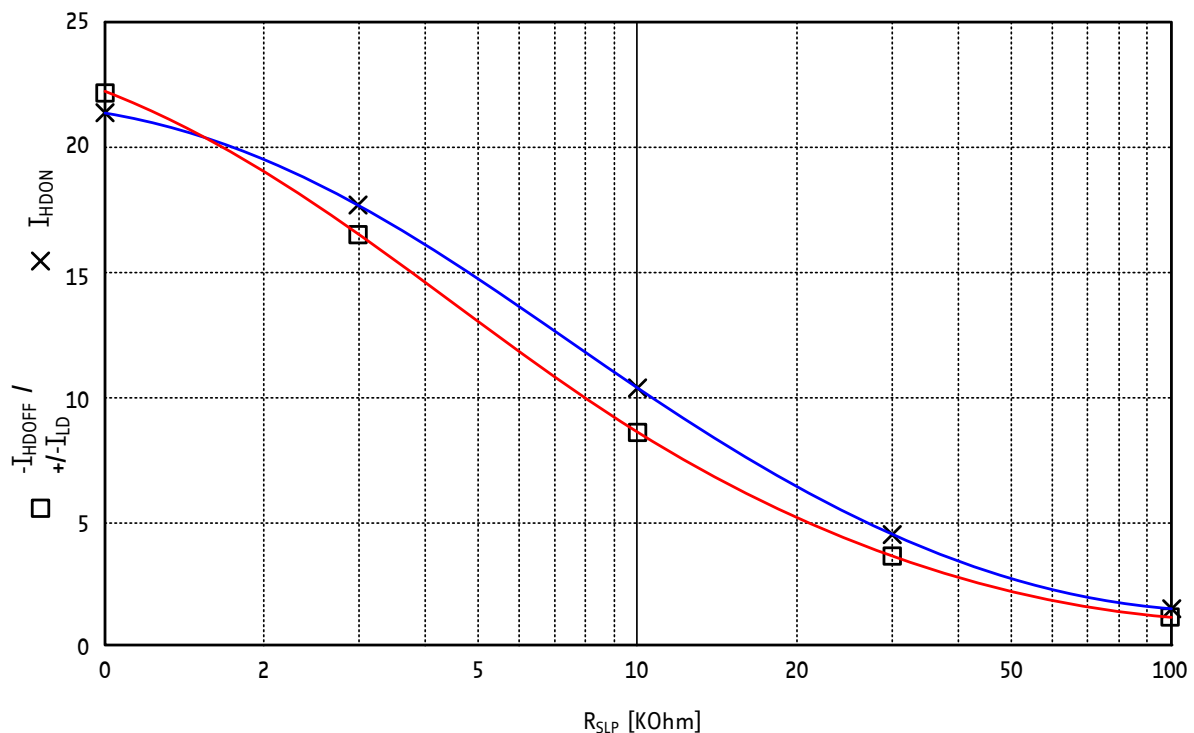


Figure 8.1 R_{SLP} versus I_{DH}

9 Protection Functions

9.1 Overcurrent Protection and Diagnostic

9.1.1 Low Side Overcurrent

The TMC248 uses the current sense resistors on the low side to detect an overcurrent. If a voltage above 0.61 V is detected, the PWM cycle is terminated at once and all transistors of the bridge are switched off for the rest of the PWM cycle. The error counter is increased by one. If the error counter reaches 3, the bridge remains switched off for 63 PWM cycles and the error flag is read as *active*.

CLEARING ERROR FLAG AND COUNTER

The user can clear the error condition in advance by clearing the error flag.

The error counter is cleared, whenever there are more than 63 PWM cycles without overcurrent. There is one error counter for each of the low side bridges, and one for the high side.

Note:

The overcurrent detection is inactive during the blank pulse time for each bridge, to suppress spikes which can occur during switching.

9.1.2 Short to Ground and Overcurrent Detection

The high side comparator detects a short to GND or an overcurrent, whenever the voltage between VS and VT becomes higher than 0.15 V at any time (except for the blank time period which is logically ORed for both bridges). If the voltage between VS and VT becomes higher than 0.15 V all transistors become switched off for the rest of the PWM cycle, because the bridge with the failure is unknown.

In high side overcurrent conditions the user can determine which bridge sees the overcurrent, by selectively switching on only one of the bridges with each polarity (therefore the other bridge should remain programmed to 0000).

CLEARING ERROR FLAGS

The overcurrent flags can be cleared by disabling and re-enabling the chip either via the ENN pin or by sending a telegram with both current control words set to 0000.

9.2 Over Temperature Protection and Diagnostic

The circuit switches off all output power transistors during an over temperature condition. The over temperature flag should be monitored to detect this condition. The circuit resumes operation after cool down below the temperature threshold. However, operation near the over temperature threshold should be avoided, if a high lifetime is desired.