TMC4361 DATASHEET

TMC4361 Document Revision 3.10 • 2016-JUL-20

The S-ramp and sixPoint™ ramp motion controller for stepper motors is optimized for high velocities, allowing on-the-fly changes. TMC4361 offers SPI and Step/Dir interfaces, as well as an encoder interface for closed-loop operation.

NOTE:

→ *For new design applications, it is recommended to use the upgraded successor product TMC4361A.*

Figure 1: Sample Image TMC4361 Closed-Loop Drive

**Marking details are explained on page 217.*

Features

- SPI Interfaces for µC with easy-to-use protocol.
- SPI Interfaces for SPI motor stepper drivers.
- Encoder interface for incremental or serial encoders.
- Closed-loop operation for Step and SPI drivers.
- Integrated ChopSync™ and dcStep™ support.
- Internal ramp generator (S-shaped ramps or sixPoint™ ramps supporting on-the-fly changes).
- Controlled PWM output
- Reference switch handling.
- Hardware and virtual stop switches.
- Extensive Support of TMC stepper motor drivers.

Applications

- Textile, sewing machines
- CCTV, security
- Printers, scanners
- ATM, cash recycler
- Office automation
- POS
- Factory automation
- Lab automation
- Pumps and valves
- Heliostat controllers
- CNC machines
- Robotics

Block Diagram: TMC4361 Interfaces & Features

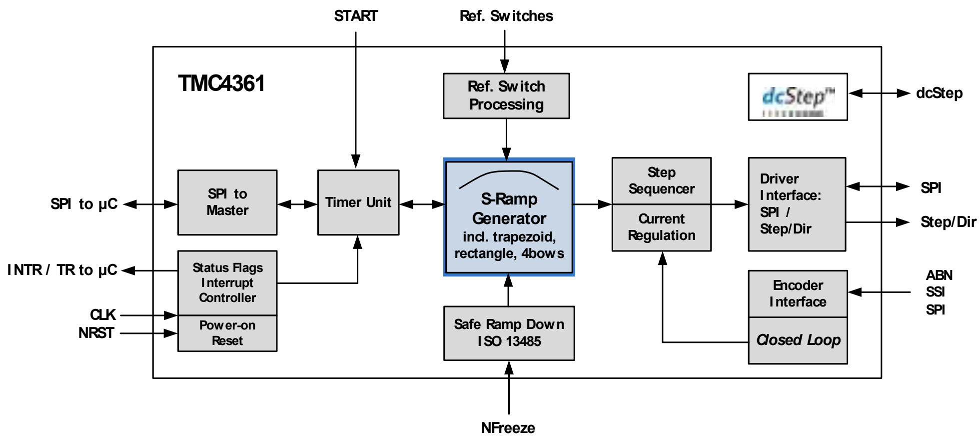


Figure 2: Block Diagram

Read entire documentation; especially the Supplemental Directives in chapter 20 (Page 218).

TRINAMIC MOTION CONTROL

Functional Scope of TMC4361

TMC4361 is a miniaturized high-performance motion controller for stepper motor drivers, particularly designed for fast and jerk-limited motion profile applications with a wide range of ramp profiles. The S-shaped or sixPoint™ velocity profile, closed-loop and open-loop features offer many configuration options to suit the user's specifications, as presented below:

S-Shaped Velocity Profile

S-shaped ramp profiles are jerk-free. Seven ramp segments form the S-shaped ramp that can be optimally adapted to suit the user's requirements. High torque with high velocities can be reached by calibrating the bows of the ramp, as explained in this user manual.

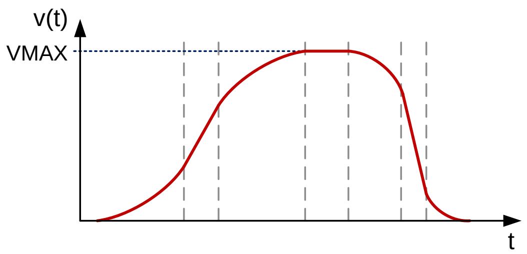


Figure 3: S-shaped Velocity Profile

i More information on ramp configurations and other velocity profiles, e.g. sixPoint™ ramps, are provided in chapter 6 (Page 28).

Closed-loop Operation Feature

A typical hardware setup for closed-loop operation with a TMC262 stepper motor gate driver is shown in the diagram below. In case internal MOSFETs are desired, combine the TMC4361 with the TMC2620, the TMC261 or the TMC2660.

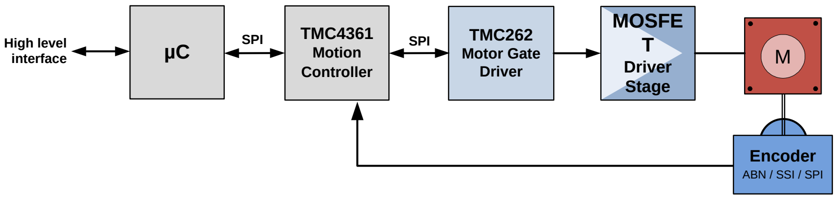


Figure 4: Hardware Set-up for Closed-loop Operation with TMC262

Open-loop Operation with dcStep™ Feature

A typical hardware setup for dcStep operation with a TMC2130 stepper motor driver is shown in the diagram below. This feature is also available for TMC26x stepper motor drivers.

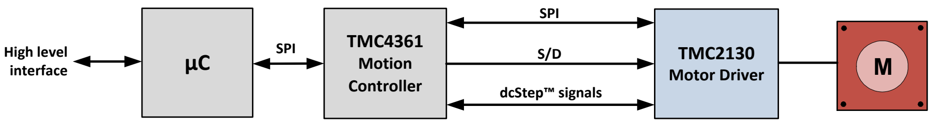


Figure 5: Hardware Set-up for Open-loop Operation with TMC2130

Order Codes

Order code	Description	Size
TMC4361-LA	*Motion controller with closed-loop and dcStep features, QFN40*	*6 x 6 mm²*

Table 1: TMC4361 Order Codes

TABLE OF CONTENTS

Read entire documentation; especially the "Supplemental Directives" on page 218.

Read entire documentation; especially the "Supplemental Directives" on page 218.

Read entire documentation; especially the "Supplemental Directives" on page 218.

Read entire documentation; especially the "Supplemental Directives" on page 218.

MAIN MANUAL

1. Pinning and Design-In Process Information

In this chapter you are provided with a list of all pin names and a functional description of each.

1.1. Pin Assignment: Top View

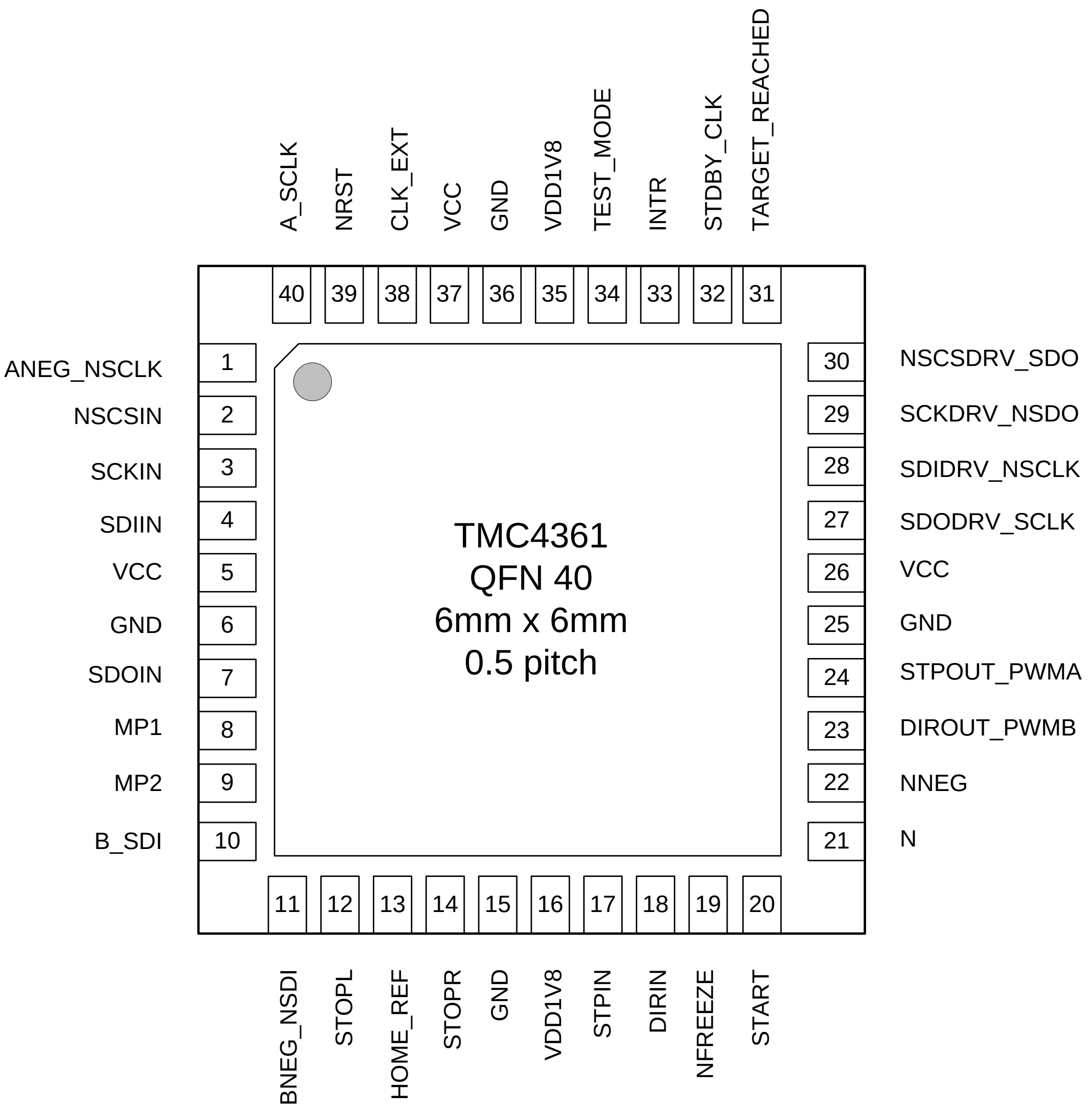


Figure 6: Package Outline: Pin Assignments Top View

Read entire documentation; especially the "Supplemental Directives" on page 218.

1.2. Pin Description

Pin Names and Descriptions			
Pin	**Number**	**Type**	**Function**
Supply Pins			
GND	6, 15, 25, 36	GND	Digital ground pin for IOs and digital circuitry.
VCC	5, 26, 37	VCC	Digital power supply for IOs and digital circuitry (3.3V… 5V).
VDD1V8	16, 35	VDD	Connection of internal generated core voltage of 1.8V.
CLK_EXT	38	I	Clock input to provide a clock with the frequency fCLK for all internal operations.
NRST	39	I (PU)	Low active reset. If not connected, Power-on-Reset and internal pull-up resistor is active.
TEST_MODE	34	I	Test mode input. VCC = 3.3V: Tie to low for normal operation. VCC = 5.0V: Tie to VDD1V8 for normal operation.
NFREEZE	19	I (PU)	Low active safety pin to immediately freeze output operations. If not connected, internal pull-up resistor is active.
Interface Pins for µC			
NSCSIN	2	I	Low active chip selects input of SPI interface to µC.
SCKIN	3	I	Serial clock for SPI interface to µC.
SDIIN	4	I	Serial data input of SPI interface to µC.
SDOIN	7	O	Serial data output of SPI interface to µC (Z if NSCSIN=1).
INTR	33	O	Interrupt output, programmable PD/PU for wired-and/or.
TARGET_REACHED	31	O	Target reached output, programmable PD/PU for wired-and/or.
STDBY_CLK	32	O	StandBy signal or internal CLK output or ChopSync output.
Reference Pins			
STOPL	12	I (PD)	Left stop switch. External signal to stop a ramp. If not connected, internal pull-down resistor is active.
HOME_REF	13	I (PD)	Home reference signal input. External signal for reference search. If not connected, internal pull-down resistor is active.
STOPR	14	I (PD)	Right stop switch. External signal to stop a ramp. If not connected, internal pull-down resistor is active.
STPIN	17	I (PD)	Step input for external step control. If not connected, internal pull-down resistor is active.
DIRIN	18	I (PD)	Direction input for external step control. If not connected, internal pull-down resistor is active.
START	20	IO	Start signal input/output.

•→ *Continued on next page.*

Pin Names and Descriptions			
Pin	**Number**	**Type**	**Function**
S/D Output Pins			
STPOUT PWMA DACA	24	O	Step output. First PWM signal (Sine). First DAC output signal (Sine).
DIROUT PWMB DACB	23	O	Direction output. Second PWM signal (Cosine). Second DAC output signal (Cosine).
Interface Pins for Stepper Motor Drivers			
NSCSDRV PWMB SDO	30	O	Low active chip selects output of SPI interface to motor driver. Second PWM signal (Cosine) to connect with PHB (TMC23x/24x). Serial data output of serial encoder output interface.
SCKDRV MDBN NSDO	29	O	Serial clock output of SPI interface to motor driver. MDBN output signal for MDBN pin of TMC23x/24x. Negated serial data output of serial encoder output interface.
SDODRV PWMA SCLK	27	IO	Serial data output of SPI interface to motor driver. First PWM signal (Sine) to connect with PHA (TMC23x/24x). Clock input of serial encoder output interface.
SDIDRV ERR NSCLK	28	I (PD)	Serial data input of SPI interface to motor driver. Error input signal to ERR pin of TMC23x/24x. Negated clock input of serial encoder output interface. If not connected, internal pull-down resistor is active.
MP1	8	I (PD)	DC_IN as external dcStep input control signal. If not connected, internal pull-down resistor is active.
MP2	9	IO	DCSTEP_ENABLE as dcStep output control signal. SPE_OUT as output signal, connect to SPE pin of TMC23x/24x.
Encoder Interface Pins			
N	21	I (PD)	N signal input of incremental encoder input interface. If not connected, internal pull-down resistor will be active.
NNEG	22	I (PD)	Negated N signal input of incremental encoder input interface. If not connected, internal pull-down resistor will be active.
B SDI	10	I (PD)	B signal input of incremental encoder input interface. Serial data input signal of serial encoder interface (SSI/SPI). If not connected, internal pull-down resistor is active.
BNEG NSDI SDO_ENC	11	IO	Negated B signal input of incremental encoder input interface. Negated serial data input signal of SSI encoder input interface. Serial data output of SPI encoder input interface.
A SCLK	40	IO	A signal input of incremental encoder interface. Serial clock output signal of serial encoder interface (SSI/SPI).
ANEG NSCLK NSCS_ENC	1	IO	Negated A signal input of incremental encoder interface. Negated serial clock output signal of serial encoder interface. Low active chip select output of SPI encoder input interface.

Table 2: Pin Names and Descriptions

Read entire documentation; especially the "Supplemental Directives" on page 218.

1.3. System Overview

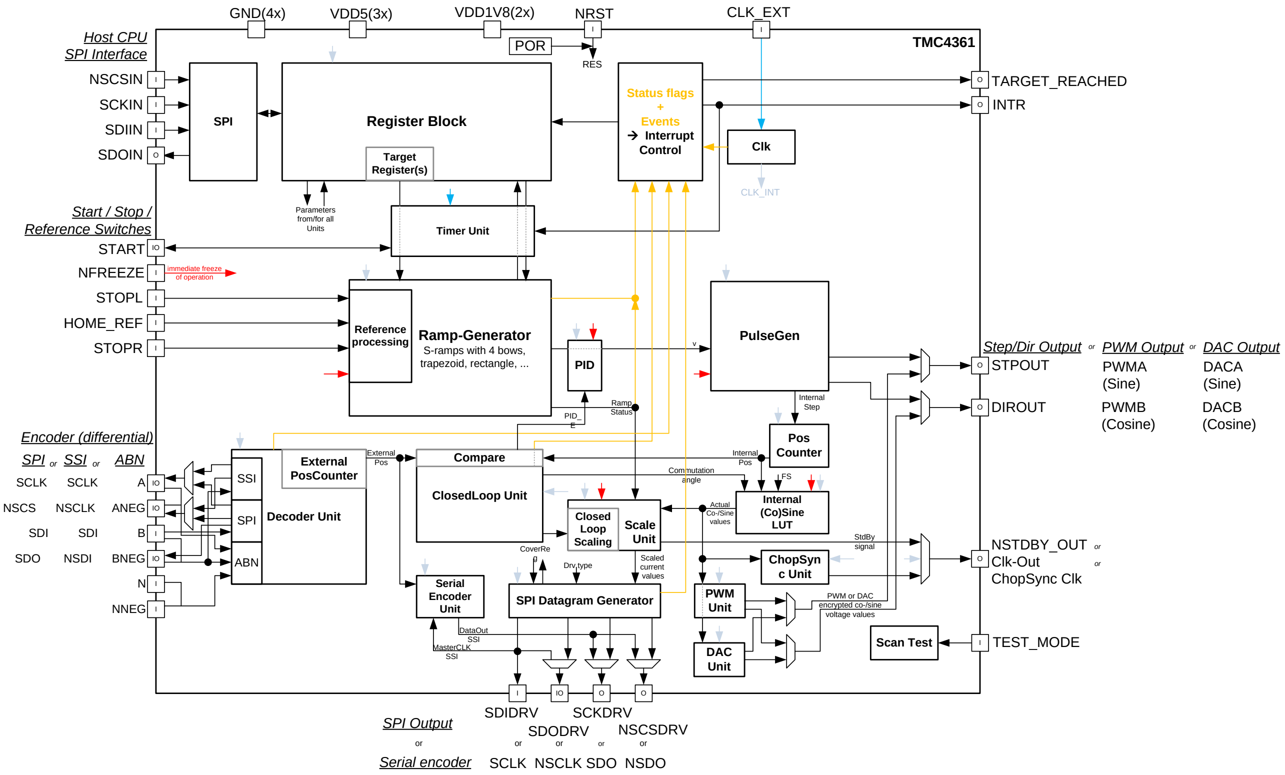


Figure 7: System Overview

Read entire documentation; especially the "Supplemental Directives" on page 218.

2. Application Circuits

In this chapter application circuit examples are provided that show how external components can be connected.

2.1. TMC4361 Standard Connection: VCC=3.3V

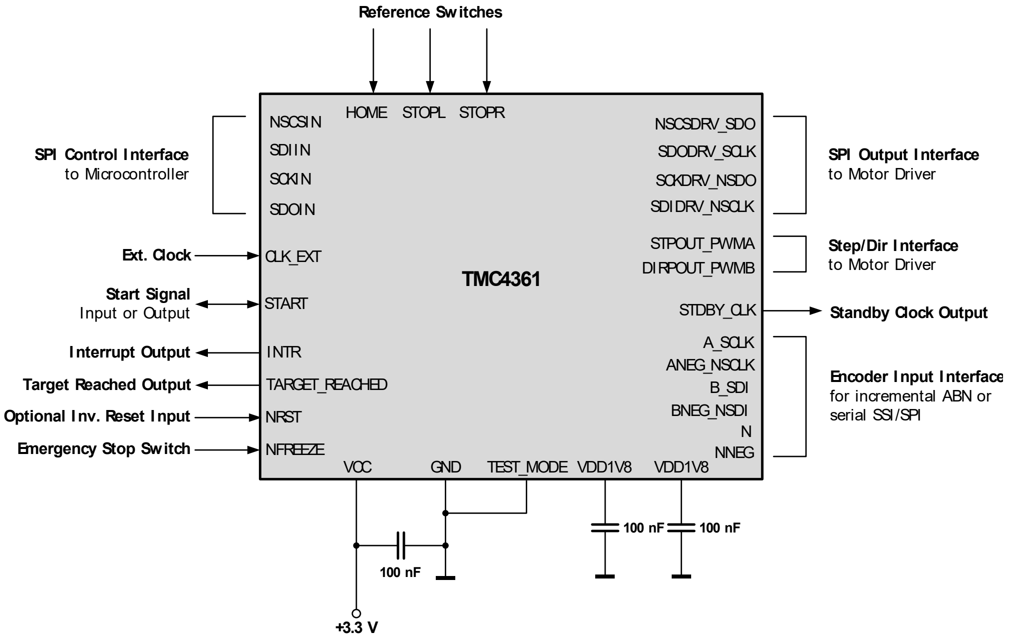


Figure 8: TMC4361 Connection: VCC=3.3V

2.2. TMC4361 with TMC26x Stepper Connection

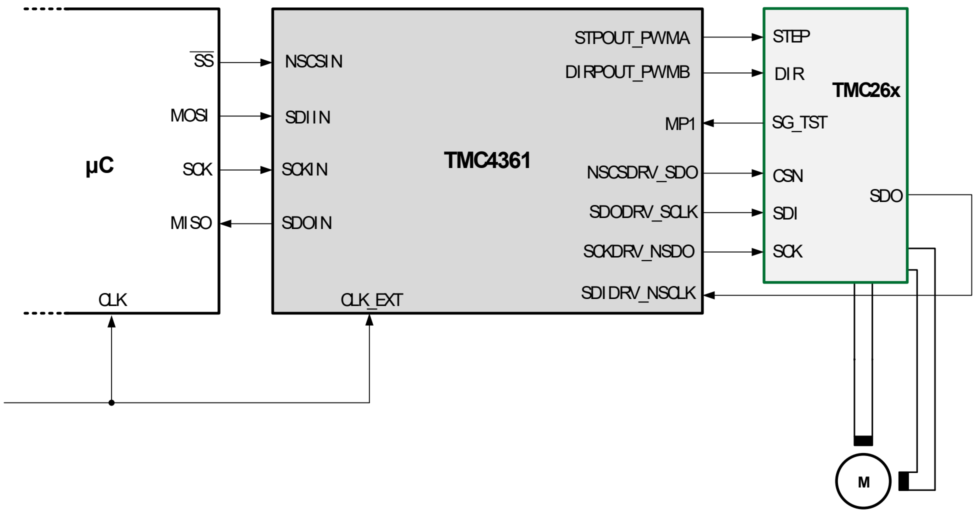


Figure 9: TMC4361 with TMC26x Stepper Driver in SPI Mode or S/D Mode

2.3. TMC4361 with TMC248 Stepper Driver

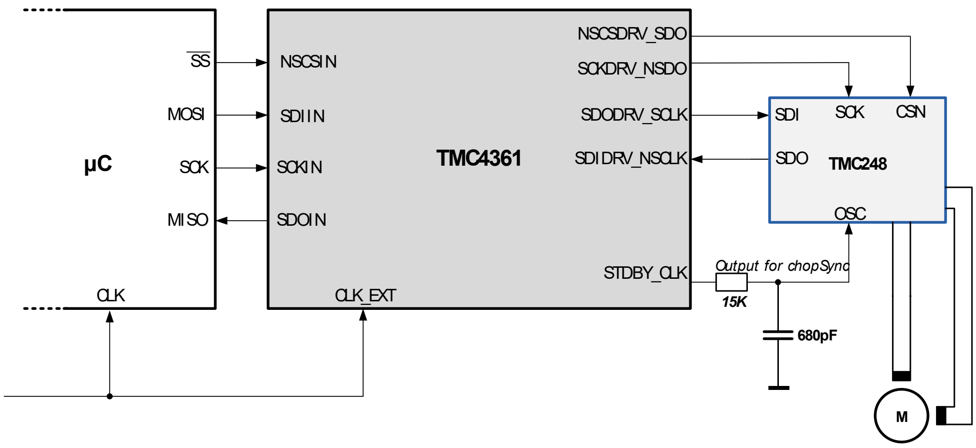


Figure 10: TMC4361 with TMC248 Stepper Driver in SPI Mode

2.4. TMC4361 with TMC2130 Stepper Driver

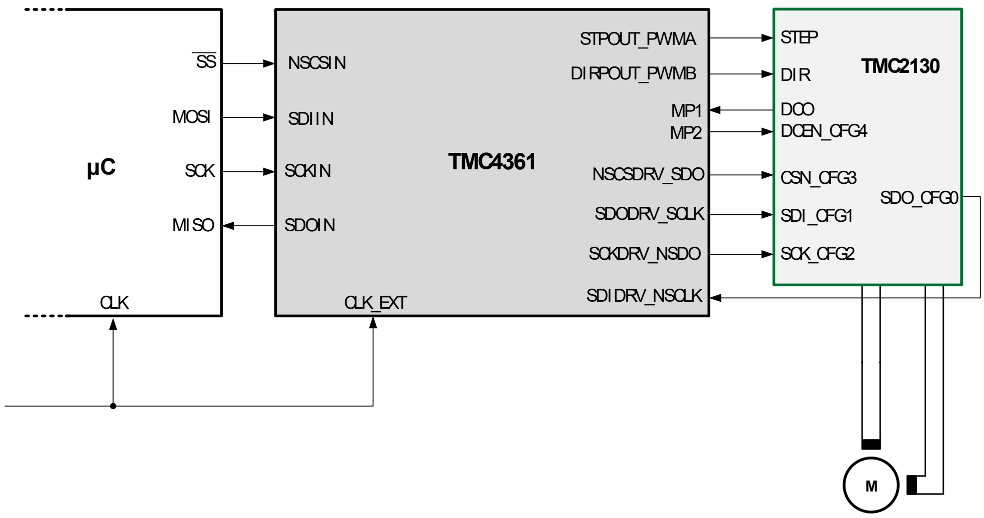


Figure 11: TMC4361 with TMC2130 Stepper Driver in SPI Mode or S/D Mode

3. SPI Interfacing

TMC4361 uses 40-bit SPI datagrams for communication with a microcontroller. The bit-serial interface is 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. In the following chapter information is provided about the SPI control interface, SPI datagram structure and SPI transaction process.

SPI Input Control Interface Pins		
Pin Name	**Type**	**Remarks**
NSCSIN	Input	Chip Select of SPI-μC interface (low active)
SCKIN	Input	Serial clock of SPI-μC interface
SDIIN	Input	Serial data input of SPI-μC interface
SDOIN	Output	Serial data output of SPI-μC interface

Table 3: SPI Input Control Interface Pins

3.1. SPI Datagram Structure

- Microcontrollers that are equipped with hardware SPI are typically able to communicate using integer multiples of 8 bit.
- The NSCSIN line of the TMC4361 has to stay active (low) for the complete duration of the datagram transmission.
- Each datagram that is sent to TMC4361 is composed of an address byte followed by four data bytes. This allows direct 32-bit data word communication with the register set of TMC4361. Each register is accessed via 32 data bits; even if it uses less than 32 data bits.

i Each register is specified by a one-byte address:

For read access the most significant bit of the address byte is 0.
For write access the most significant bit of the address byte is 1.

NOTE:

→ *Some registers are write only registers. Most registers can be read also; and there are also some read only registers.*

<table>
<tr><th colspan="40">TMC4361 SPI Datagram Structure</th></tr>
<tr><th colspan="13">MSB (transmitted first)</th><th colspan="14">40 bits</th><th colspan="13">LSB (transmitted last)</th></tr>
<tr><td colspan="13">39</td><td colspan="14">...</td><td colspan="13">0</td></tr>
<tr><td colspan="8">→ 8-bit address
← 8-bit SPI status</td><td colspan="32">← → 32-bit data</td></tr>
<tr><td colspan="8">39 ... 32</td><td colspan="32">31 ... 0</td></tr>
<tr><td colspan="8">→ to TMC4361:
RW + 7-bit address
← from TMC4361:
8-bit SPI status</td><td colspan="8">8-bit data</td><td colspan="8">8-bit data</td><td colspan="8">8-bit data</td><td colspan="8">8-bit data</td></tr>
<tr><td colspan="8">39 / 38 ... 32</td><td colspan="8">31 ... 24</td><td colspan="8">23 ... 16</td><td colspan="8">15 ... 8</td><td colspan="8">7 ... 0</td></tr>
<tr><td>W</td><td colspan="7">38...32</td><td colspan="4">31...28</td><td colspan="4">27...24</td><td colspan="4">23...20</td><td colspan="4">19...16</td><td colspan="4">15...12</td><td colspan="4">11...8</td><td colspan="4">7...4</td><td colspan="4">3...0</td></tr>
<tr><td>39</td><td>38</td><td>37</td><td>36</td><td>35</td><td>34</td><td>33</td><td>32</td><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td><td>23</td><td>22</td><td>21</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
</table>

Figure 12: TMC4361 SPI Datagram Structure

Read entire documentation; especially the "Supplemental Directives" on page 218.

Read/Write Selection Principles and Process

Read and write selection is controlled by the MSB of the address byte (bit 39 of the SPI datagram). This bit is 0 for read access and 1 for write access. Consequently, the bit named W is a WRITE_notREAD control bit.

The active high write bit is the MSB of the address byte.
Consequently, 0x80 must be added to the address for a write access.

The SPI interface always delivers data back to the master, independent of the Write bit W.

Difference between Read and Write Access	
If …	**Then …**
The previous access was a read access.	The data transferred back is the data read from the address which was transmitted with the previous datagram.
The previous access was a write access	The data read back mirrors the previously received write data.

Figure 13: Difference between Read and Write Access

Conclusion:
Consequently, the difference between a read and a write access is that the read access does not transfer data to the addressed register but it transfers the address only; and its 32 data bits are dummies.

NOTE:

→ *Please note that the following read delivers back data read from the address transmitted in the preceding read cycle. The data is latched immediately after the read request.*

AREAS OF SPECIAL CONCERN

Use of Dummy Write Data

! **A read access request datagram uses dummy write data.**
Read data is transferred back to the master with the subsequent read or write access.

i Reading multiple registers can be done in a pipelined fashion. Data that is delivered is latched immediately after the initiated data transfer.

Read and Write Access Examples

For read access to register *XACTUAL* with the address 0x21, the address byte must be set to 0x21 in the access preceding the read access.
For write access to register *VACTUAL*, the address byte must be set to 0x80 + 0x22 = 0xA2. For read access, the data bit can have any value, e.g., 0.

Read and Write Access Examples		
Action	**Data sent to TMC**	**Data received from TMC**
read *XACTUAL*	→ 0x2100000000	← 0xSS[1)] & unused data
read *XACTUAL*	→ 0x2100000000	← 0xSS & *XACTUAL*
write *VACTUAL*:= 0x00ABCDEF	→ 0xA200ABCDEF	← 0xSS & *XACTUAL*
write *VACTUAL*:= 0x00123456	→ 0xA200123456	← 0xSS00ABCDEF

Table 4: Read and Write Access Examples

[1)] SS is a placeholder for the status bits SPI_STATUS.

Data Alignment

All data is right-aligned. Some registers represent unsigned (positive) values; others represent integer values (signed) as two's complement numbers.
Some registers consist of switches that are represented as bits or bit vectors.

SPI Transaction Process

The SPI transaction process is as follows:

- The slave is enabled for SPI transaction by a transition to low level on the chip select input NSCSIN.
- Bit transfer is synchronous to the bus clock SCKIN, with the slave latching the data from SDIIN on the rising edge of SCKIN and driving data to SDOIN following the falling edge.
- The most significant bit is sent first.

i A minimum of 40 SCKIN clock cycles is required for a bus transaction with TMC4361.

AREAS OF SPECIAL CONCERN

System Behavior Specifics

! **Take the following aspects into consideration:**

- **Whenever data is read from or written to the TMC4361,** the first eight bits that are delivered back contain the SPI status *SPI_STATUS* that consists of eight user-selected event bits. The selection of these bits are explained in chapter 5.2. (Page 26).
- **If less than 40 clock cycles are transmitted,** the transfer is not valid; even for read access. However, sending only eight clock cycles can be useful to obtain the SPI status because it sends the status information back first.
- **If more than 40 clocks cycles are transmitted,** the additional bits shifted into SDIIN are shifted out on SDOIN after a 40-clock delay through an internal shift register. This can be used for daisy chaining multiple chips.
- **NSCSIN must be low during the whole bus transaction**. When NSCSIN 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 40 bits are sent, only the last 40 bits received - *before the rising edge of NSCSIN* - are recognized as the command.

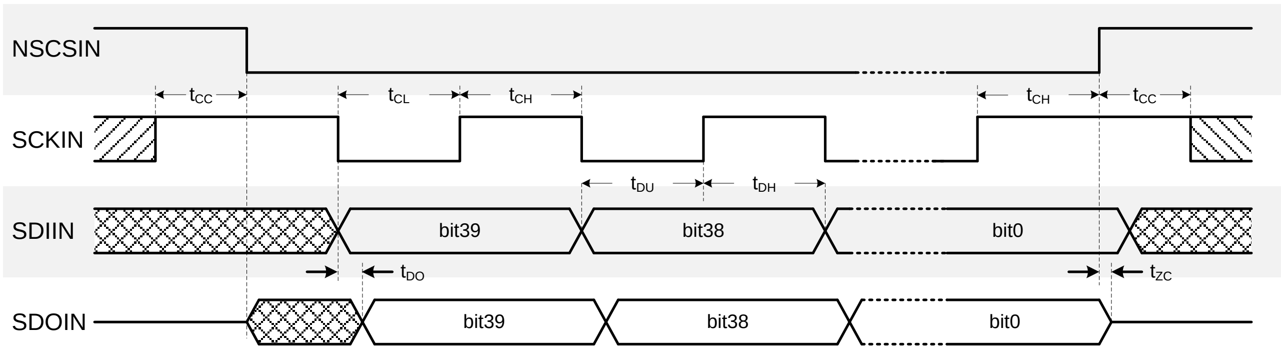


Figure 14: SPI Timing Datagram

3.1.1. SPI Timing Description

The SPI interface is synchronized to the internal system clock, which limits SPI bus clock SCKIN to a quarter of the system clock frequency. The signal processing of SPI inputs is supported with internal Schmitt Trigger, but not with RC elements.

NOTE:

→ *In order to avoid glitches at the inputs of the SPI interface between µC and TMC4361, external RC elements have to be provided.*

Figure 14 shows the timing parameters of an SPI bus transaction, and the table below specifies the parameter values.

SPI Interface Timing						
SPI Interface Timing	**AC Characteristics:**		**External clock period: t_{CLK}**			
Parameter	**Symbol**	**Conditions**	**Min**	**Type**	**Max**	**Unit**
SCKIN valid before or after change of NSCSIN	t_{CC}		10			ns
NSCSIN high time	t_{CSH}	Min. time is for synchronous CLK with SCKIN high one t_{CH} before SCSIN high only.	t_{CLK}	$>2 \cdot t_{CLK}+10$		ns
SCKIN low time	t_{CL}	Min. time is for synchronous CLK only.	t_{CLK}	$>t_{CLK}+10$		ns
SCKIN high time	t_{CH}	Min. time is for synchronous CLK only.	t_{CLK}	$>t_{CLK}+10$		ns
SCKIN frequency using external clock (Example: f_{CLK} = 16 MHz)	f_{SCK}	Assumes synchronous CLK.			f_{CLK} / 4 (4)	MHz
SDIIN setup time before rising edge of SCKIN	t_{DU}		10			ns
SDIIN hold time after rising edge of SCKIN	t_{DH}		10			ns
Data out valid time after falling SCKIN clock edge	t_{DO}	No capacitive load on SDOIN.			$t_{FILT}+5$	ns

Table 5: SPI Interface Timing

i $t_{CLK} = 1 / f_{CLK}$

4. Input Filtering

Input signals can be noisy due to long cables and circuit paths. To prevent jamming, every input pin provides a Schmitt trigger. Additionally, several signals are passed through a digital filter. Particular input pins are separated into four filtering groups. Each group can be programmed individually according to its filter characteristics. In this chapter informed on the digital filtering feature of TMC4361 is provided; and how to separately set up the digital filter for input pins.

Input Filtering Groups		
Pin Names	**Type**	**Remarks**
A_SCLK B_SDI N ANEG_NSCLK BNEG_NSDI NNEG	Inputs	Encoder interface input pins.
STOPL HOME_REF STOPR	Inputs	Reference input pins.
START	Input	START input pin.
SDODRV_SCLK SDIDRV_NSCLK	Inputs	Master clock input interface pins for serial encoder.
STPIN DIRIN	Inputs	Step/Dir interface inputs.

Table 6: Input Filtering Groups (Assigned Pins)

Register Names			
Register Names	**Register Address**		**Remarks**
INPUT_FILT_CONF	0x03	RW	Filter configuration for all four input groups.

Table 7: Input Filtering (Assigned Register)

Input Filter Assignment

Every filtering group can be configured separately with regard to input sample rate and digital filter length.

The following groups exist:

- Encoder interface input pins.
- Reference input pins.
- Start input pin.
- Master clock input pins of encoder output interface.
- Step/Dir input pins.

NOTE:

→ *Differentiated handling for Step/Dir input pins is necessary, as explained on the following pages.*

Input Sample Rate (SR)

Input sample rate = f_{CLK} $1/2^{SR}$ where:

^{SR} (extended with a particular name extension) is in [0… 7].

i This means that the next input value is considered after 2^{SR} clock cycles.

Sample Rate Configuration

Digital Filter Length (*FILT_L*)

Sample Rate Configuration	
SR Value	**Sample Rate**
0	f_{CLK}
1	$f_{CLK}/2$
2	$f_{CLK}/4$
3	$f_{CLK}/8$
4	$f_{CLK}/16$
5	$f_{CLK}/32$
6	$f_{CLK}/64$
7	$f_{CLK}/128$

Table 8: Sample Rate Configuration

i The filter length *FILT_L* can be set within the range [0… 7].

i The filter length *FILT_L* specifies the number of sampled bits that must have the same voltage level to set a new input bit voltage level.

Digital Filter Length Configuration Table

Configuration of Digital Filter Length	
***FILT_L* value**	**Filter Length**
0	No filtering.
1	2 equal bits.
2	3 equal bits.
3	4 equal bits.
4	5 equal bits.
5	6 equal bits.
6	7 equal bits.
7	8 equal bits.

Table 9: Configuration of Digital Filter Length

4.1. Input Filtering Examples

The following three examples depict input pin filtering of three different input filtering groups.

i After passing Schmitt trigger, voltage levels are compared to internal signals, which are processed by the motion controller.

i The sample points are depicted as green dashed lines.

Example 1: Reference Input Pins

In this example every second clock cycle is sampled. Two sampled input bits must be equal to receive a valid input voltage.

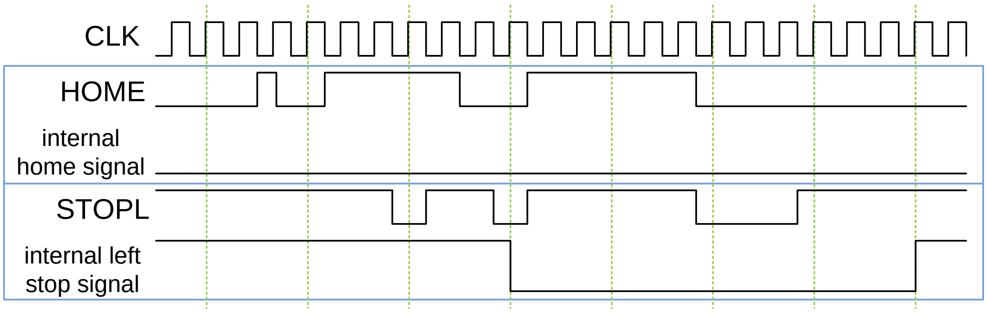


Figure 15: Reference Input Pins: SR_REF = 1, FILT_L_REF = 1

Example 2: START Input Pin

This example shows the START input pattern at every fourth clock cycle:

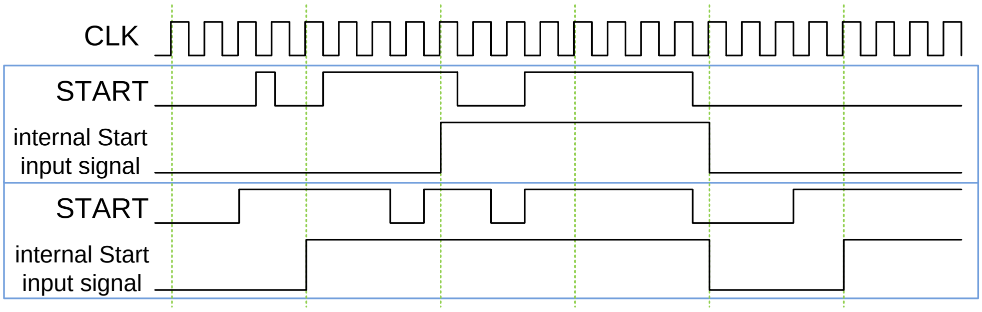


Figure 16: START Input Pin: SR_S = 2, FILT_L_S = 0

Example 3: Encoder Interface Input Pins

This example shows every clock cycle bit. Eight sampled input bits must be equal to receive a valid input voltage.

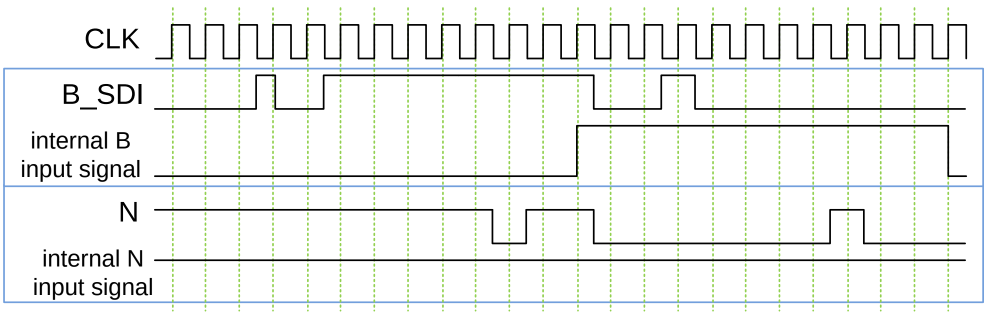


Figure 17: Encoder Interface Input Pins: SR_ENC_IN = 0, FILT_L_ENC_IN = 7

4.2. Configuration of Step/Dir Input Filter

Step/Dir input filtering setup differs slightly from the other groups, because the other four groups already complete the whole *INPUT_FILT_CONF* register 0x03.
This is why it is possible to assign the Step/Dir input group to one of the existing groups by setting the appropriate bit in front of the setup parameters.

i If no group is selected, Step/Dir input filtering is automatically assigned to the encoder input interface filter group.

Step/Dir Pin Filter Assignment

The following example shows the filter settings for Step/Dir interface input pins, which are taken from the reference input pin group.

Step/Dir input pin filter settings are derived from the Reference input filter group:

SR_SDIN = 6, FILT_L_SDIN = 3

NOTE:

→ *Other input filter groups are:*

SR_ENC_IN = 5, FILT_L_ENC_IN = 6
SR_REF = 6, FILT_L_REF = 3
SR_S = 2, FILT_L_S = 4
SR_ENC_OUT = 0
FILT_L_ENC_OUT = 0)

Step/Dir Input Filter Parameter

Bits of register 0x03:	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Input filter group:	■	Serial clock inputs							■	START input						
Filter parameter:		FILT_L_ENC_OUT				SR_ENC_OUT				FILT_L_S				SR_S		
Example:	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0

Bits of register 0x03:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Input filter group:	■	Reference inputs							■	Encoder inputs						
Filter parameter:		FILT_L_REF				SR_ENC_REF				FILT_L_ENC_IN				SR_ENC_IN		
Example:	1	0	1	1	0	1	1	0	0	1	1	0	0	1	0	1

■ = possible selection bits to assign Step/Dir input filter parameter

Figure 18: Step/Dir Input Filter Parameter

5. Status Flags and Events

TMC4361 provides 32 status flags and 32 status events to obtain short information on the internal status or motor driver status. These flags and events can be read out from dedicated registers. In the following chapter, you are informed about the generation of interrupts based on status events. Status events can also be assigned to the first eight SPI status bits, which are sent within each SPI datagram.

Pin Names: Status Events		
Pin Names	**Type**	**Remarks**
INTR	Output	Interrupt output to indicate status events.

Table 10: Pins Names: Status Events

Register Names: Status Flags and Events			
Register Name	**Register Address**		**Remarks**
GENERAL_CONF	0X00	RW	Bits: 15, 29, 30.
STATUS_FLAGS	0X0F	R	32 status flags of TMC4361 and the connected TMC motor driver chip.
EVENTS	0X0E	R+C	32 events triggered by altered TMC4361 status bits.
SPI_STATUS_SELECTION	0X0B	RW	Selection of 8 out of 32 events for SPI status bits.
EVENT_CLEAR_CONF	0X0C	RW	Exceptions for cleared event bits.
INTR_CONF	0X0D	RW	Selection of 32 events for INTR output.

Table 11:Register Names: Status Flags and Events

Read entire documentation; especially the "Supplemental Directives" on page 218.

5.1. Status Event Description

Status events are based on status bits. If the status bits change, related events are triggered from inactive to active level. Resetting events back to inactive must be carried out manually.

Association of Status Bits

Status bits and status events are associated in different ways:

- Status flags reflect the as-is-condition, whereas status events indicate that the dedicated information has changed since the last read request of the *EVENTS* register. Several status events are associated with one status bit.
- Some status events show the status transition of one or more status bits out of a status bit group. The motor driver flags, e.g., trigger only one motor driver event *MOTOR_EV* in case one of the selected motor driver status flags becomes active.
- In case a flag consists of more than one bit, the number of associated events that can be triggered corresponds to the valid combinations. The *VEL_STATE* flag, e.g., has two bit but three associated velocity state events (b'00/b'01/b'10). Such an event is triggered if the associated combination switches from inactive to active.

NOTE:

→ *Some events have no equivalence in the* STATUS_FLAGS *register 0x0F (e.g.,* COVER_DONE *which indicates new data from the motor driver chip).*

Automatic Clearance of EVENTS

The *EVENTS* register 0x0E is automatically cleared after reading the register; subsequent to an SPI datagram request. Events are important for interrupt generation and SPI status monitoring.

NOTE:

→ *It is recommended to clear EVENTS register 0x0E by read request before regular operation.*

AREAS OF SPECIAL CONCERN

How to Avoid Lack of Information

! **Recognition of a status event can fail; in case it is triggered right before or during *EVENTS* register 0x0E becomes cleared.**

In order to prevent events from being cleared, assign *EVENT_CLEAR_CONF* register 0x0C according to the particular event in the EVENTS register:

Action:

➢ Set related *EVENT_CLEAR_CONF* register bit position to 1.

Result:
The related event is not cleared when *EVENTS* register is read out.

In order to clear these events, do the following, if necessary:

Action:

➢ Set related *EVENT_CLEAR_CONF* register 0x0C bit position to 0.
➢ Read out *EVENTS* register 0x0E.
➢ Set related *EVENT_CLEAR_CONF* register bit position to 1.

Result:
The related event is cleared after reading out *EVENTS* register.

5.2. SPI Status Bit Transfer

Up to eight events can be selected for permanent SPI status report. Consequently, these events are always transferred at the most significant transfer bits within each TMC4361 SPI response.

Assign an Event to a Status Bit

In order to select an event for the SPI status bits, assign the *SPI_STATUS_SELECTION* register 0x0B according to the particular event in the EVENTS register:

Action:

➢ Set the related *SPI_STATUS_SELECTION* register bit position to 1.

Result:

The related event is transferred with every SPI datagram response as *SPI_STATUS*.

NOTE:

→ *The bit positions are sorted according to the event bit positions in the EVENTS register 0x0E. In case more than eight events are selected, the first eight bits (starting from index 0 = LSB) are forwarded as SPI_STATUS.*

5.3. Generation of Interrupts

Similar to *EVENT_CLEAR_CONF* register and *SPI_STATUS_SELECTION* register, events can be selected for forwarding via INTR output. The selected events are ORed to one signal which means that INTR output switches active as soon as one of the selected events triggers.

Generate Interrupts

In order to select an event for the INTR output pin, assign the *INTR_CONF* register 0x0D according to the particular event in the EVENTS register:

Action:

➢ Set the related *INTR_CONF* register bit position to 1.

Result:

The related event is forwarded at the INTR output. If more than one event is requested, INTR becomes active as soon as one of the selected events is active.

INTR Output Polarity

Per default, the INTR output is low active.

In order to change the INTR polarity to high active, do the following:

Action:

➢ Set *intr_pol* =1 (*GENERAL_CONF* register 0x00).

Result:

INTR is high active.

Read entire documentation; especially the "Supplemental Directives" on page 218.

5.4. Connection of Multiple INTR Pins

INTR pin can be configured for a shared interrupt signal line of several TMC4361 interrupt signals to the microcontroller.

Connecting several Interrupt Pins

In order to make use of a Wired-Or or Wired-And behavior, the below described actions must be taken:

Action:

- **Step 1:** Set *intr_tr_pu_pd_en* = 1 (*GENERAL_CONF* register 0x00).

OPTION 1: WIRED-OR

Action:

- **Step 2:** Set *intr_as_wired_and* = 0 (*GENERAL_CONF* register 0x00).

Result:
The INTR pin works efficiently as Wired-Or (default configuration).

i In case INTR pin is inactive, the pin drive has a weak inactive polarity output. If one of the connected pins is activated, the whole line is set to active polarity.

OPTION 2: WIRED-AND

Action:

- **Step 2:** Set *intr_as_wired_and* = 1 of the *GENERAL_CONF* register 0x00.

Result:
In case no interrupt is active, the INTR pin has a strong inactive polarity output. During the active state, the pin drive has a weak active polarity output. Consequently, the whole signal line is activated in case all pins are forwarding the active polarity.

Read entire documentation; especially the "Supplemental Directives" on page 218.

6. Ramp Configurations for different Motion Profiles

Step generation is one of the main tasks of a stepper motor motion controller. The internal ramp generator of TMC4361 provides several step generation configurations with different motion profiles. They can be configured in combination with the velocity or positioning mode.

Pin Names: Ramp Generator		
Pin Names	**Type**	**Remarks**
STPOUT_PWMA	Output	Step output signal.
DIROUT_PWMB	Output	Direction output signal.

Table 12: Pin Names: Ramp Generator

Register Names: Ramp Generator			
Register Name	**Register Address**		**Remarks**
GENERAL_CONF	0x00	RW	Ramp generator affecting bits 5:0.
STP_LENGTH_ADD	0x10	RW	Additional step length in clock cycles; 16 bits.
DIR_SETUP_TIME			Additional time in clock cycles when no steps will occur after a direction change; 16 bits.
RAMPMODE	0x20	RW	Requested motion profile and operation mode; 3 bits.
XACTUAL	0x21	RW	Current internal microstep position; signed; 32 bits.
VACTUAL	0x22	R	Current step velocity; 24 bits; signed; no decimals.
AACTUAL	0x23	R	Current step acceleration; 24 bits; signed; no decimals.
VMAX	0x24	RW	Maximum permitted or target velocity; signed; 32 bits= 24+8 (24 bits integer part, 8 bits decimal places).
VSTART	0x25	RW	Velocity at ramp start; unsigned; 31 bits=23+8.
VSTOP	0x26	RW	Velocity at ramp end; unsigned; 31 bits=23+8.
VBREAK	0x27	RW	At this velocity value, the acceleration/deceleration will change during trapezoidal ramps; unsigned; 31 bits=23+8.
AMAX	0x28	RW	Maximum permitted or target acceleration; unsigned; 24 bits=22+2 (22 bits integer part, 2 bits decimal places).
DMAX	0x29	RW	Maximum permitted or target deceleration; unsigned; 24 bits=22+2.
ASTART	0x2A	RW	Acceleration at ramp start or below VBREAK; unsigned; 24 bits=22+2.
DFINAL	0x2B	RW	Deceleration at ramp end or below VBREAK; unsigned; 24 bits=22+2.
BOW1	0x2D	RW	First bow value of a complete velocity ramp; unsigned; 24 bits=24+0 (24 bits integer part, no decimal places).
BOW2	0x2E	RW	Second bow value of a complete velocity ramp; unsigned; 24bits=24+0.
BOW3	0x2F	RW	Third bow value of a complete velocity ramp; unsigned; 24 bits=24+0.
BOW4	0x30	RW	Fourth bow value of a complete velocity ramp; unsigned; 24 bits=24+0.
CLK_FREQ	0x31	RW	External clock frequency f_{CLK}; unsigned; 25 bits.
XTARGET	0x37	RW	Target position; signed; 32 bits.

Table 13: Register Names: Ramp Generator

6.1. Step/Dir Output Configuration

This section focuses on the description of the Step/Dir output configuration.

6.1.1. Step/Dir Output Configuration Steps

Step/Dir output signals can be configured for the driver circuit.

If step signals must be longer than one clock cycle, do as follows:

Action:
- ➢ Set proper *STP_LENGTH_ADD* register 0x10 (bit 15:0).

Result:
The resulting step length is equal to *STP_LENGTH_ADD*+1 clock cycles. This is how the step length is assigned within a range of up to 1-up-to-2^{16} clock cycles.

Action:
- ➢ Set proper *DIR_SETUP_TIME* register 0x10 (bit 31:16).

Result:
The delay period between DIROUT and STPOUT voltage level transitions last *DIR_SETUP_TIME* clock cycles. No steps are sent via STPOUT for *DIR_SETUP_TIME* clock cycles after a level change at DIROUT.

PRINCIPLE:

DIROUT does not change the level:

- During active step pulse signal
- For (*STP_LENGTH_ADD*+1) clock cycles after the step signal returns to inactive level

6.1.2. STPOUT: Changing Polarity

STPOUT characteristics can be set differently, as follows:

Per default, the step output is high active because a rising edge at STPOUT indicates a step.

In order to change the polarity, do as follows:

Action:
- ➢ Set *step_inactive_pol* =1 (bit3 of *GENERAL_CONF* register 0x00).

Result:
Each falling edge indicates a step.

How to prompt Level Change with every Step

In order to prompt a step at every level change, do as follows:

Action:
- ➢ Set *toggle_step* =1 (bit4 of *GENERAL_CONF* register 0x00).

Result:
Every level change indicates a step.

•→ *Continued on next page.*

DIROUT: Changing the Polarity

Per default, voltage level 1 at DIROUT indicates a negative step direction. DIROUT characteristics can be set differently, as shown below.

In order to change polarity, do as follows:

Action:

- Set *pol_dir_out* =0 (bit5 of *GENERAL_CONF* register 0x00).

Result:

A high voltage level at DIROUT indicates a positive step direction.

NOTE:

→ *DIROUT is based on the internal µStep position MSCNT and is therefore based on the internal SinLUT, see* *10.2. , page 90 .*

6.2. Altering the Internal Motion Direction

Per default, a positive internal velocity *VACTUAL* results in a forward motion through internal SinLUT. Consequently, if *VACTUAL* < 0, the SinLUT values are developed backwards.

How to change Motion Direction

In order to alter the default setting of the Internal Motion Direction, do as follows:

Action:

- Set *reverse_motor_dir* =1 (bit28 of *GENERAL_CONF* register 0x00).

Result:

A positive internal velocity for *VACTUAL* results in a backward motion through the internal SinLUT.

6.3. Configuration Details for Operation Modes and Motion Profiles

This section provides information on the two available operation modes (velocity mode and positioning mode), and on the four possible motion profiles (no ramp, trapezoidal ramp including sixPoint™ ramp, and S-shaped ramp). Different combinations are possible. Each one of them has specific advantages. The choice of configuration depends on the user's design specification to best suit his design needs.

Description of Internal Ramp Generator

With proper configuration, the internal ramp generator of the TMC4361 is able to generate various ramps with the related step outputs for STPOUT.

In order to configure the internal ramp generator successfully – i.e. to make it fit as best as possible with your specific use case – information about the scope of each possible combination is provided in the table below and on the following pages.

Ramp Generator Configuration Options			
Operation Mode	**Motion Profile**	**RAMPMODE(2:0)**	**Description**
Velocity Mode	No ramp	b'000	Follows *VMAX* request only.
	Trapezoidal ramp	b'001	Follows *VMAX* request and considers acceleration and deceleration values.
	sixPoint ramp	b'001	Follows *VMAX* request and considers acceleration / deceleration values and start and stop velocity values.
	S-shaped ramp	b'010	Follows *VMAX* request and considers maximum acceleration / deceleration values and adapts these values with 4 different bow values.
Positioning Mode	No Ramp	b'100	Follows *XTARGET* and *VMAX* requests only.
	Trapezoidal ramp	b'101	Follows *XTARGET* request and a maximum velocity *VMAX* request and considers acceleration and deceleration values.
	sixPoint ramp	b'101	Follows *XTARGET* request and a maximum velocity *VMAX* request and considers acceleration / deceleration values and start and stop velocity values.
	S-shaped ramp	b'110	Follows *XTARGET* request and a maximum velocity *VMAX* request and considers maximum acceleration / deceleration values and adapts these values with 4 different bow values.

Table 14: Overview of General and Basic Ramp Configuration Options

6.3.1. Starting Point: Choose Operation Mode

Two operation modes are available: velocity mode and positioning mode.

BEFORE YOU BEGIN **!**

Before setting any parameters:

First select:

- **Operation mode and**
- **Motion profile**

It is not advisable to change operation mode nor motion profile during motion.

Operation Mode: Velocity Mode

The *RAMPMODE* register provides a choice of two operation modes. Either velocity mode or positioning mode can be chosen.

In order to use the velocity mode, do as follows:

Action:

➢ Set *RAMPMODE*(2) =0 (*RAMPMODE* register 0x20).

Result:
Velocity mode is selected. The target velocity *VMAX* is reached with the selected motion profile.

Operation Mode: Positioning Mode

In order to make use of the positioning mode, do as follows:

Action:

➢ Set *RAMPMODE*(2)=1 (*RAMPMODE* register 0x20).

Result:
Positioning mode is selected. *VMAX* is the maximum velocity value of this motion profile that is based on the condition that the ramp stops at target position *XTARGET*.

NOTE:

→ *The sign of* VMAX *is not relevant during positioning. The direction of the steps depends on* XACTUAL, XTARGET, *and the current ramp motion profile status.*

NOTE:

→ *Do NOT exceed* VMAX ≤ f_{CLK} *¼ pulses for positioning mode.*

6.3.2. Motion Profile Configuration

Three basic motion profiles are provided. Each one of them has a different velocity value development during the drive. See table below.

For configuration of the motion profiles, do as follows:

Action:

➢ Use the bits 1 and 0 of the *RAMPMODE* register 0x20.

Result:

As specified in the table below.

You can choose different configuration options from the list below:

- No Ramp motion profile
- Trapezoidal Ramp motion profile (including sixPoint Ramp)
- S-shaped Ramp motion profiles

TMC4361 Motion Profile		
***RAMPMODE* (1:0)**	**Motion Profile**	**Function**
b'00	No Ramp	Follow *VMAX* only (rectangular velocity shape).
b'01	Trapezoidal Ramp	Consideration of acceleration and deceleration values without adaptation of these acceleration values.
	sixPoint Ramp	Consideration of acceleration and deceleration values without adaptation of these acceleration values. **Usage of start and stop velocity values. (see section 6.5. , Page 46)**
b'10	S-shaped Ramp	Use all ramp values (including bow values).

Table 15: Description of TMC4361 Motion Profiles

6.3.3. No Ramp Motion Profile

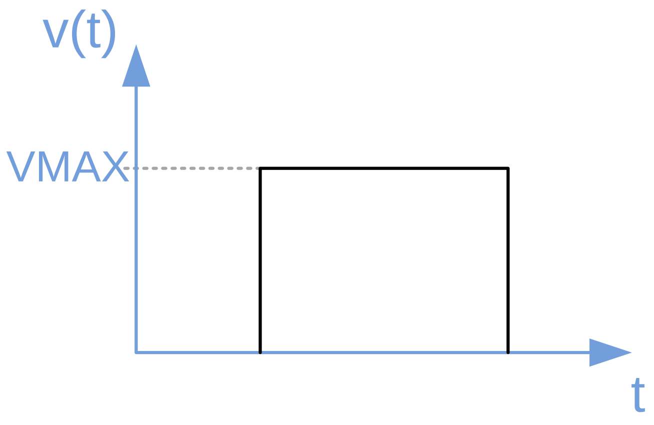


Figure 19: No Ramp Motion Profile

In order to make use of the no ramp motion profile, which is rectangular, do as follows:

Action:

- Set *RAMPMODE*(1:0) =b'00 (register 0x20).
- Set proper *VMAX* register 0x24.

Result:
The internal velocity *VACTUAL* is immediately set to *VMAX*.

Positioning Mode combined with No Ramp Motion Profile

Combining positioning mode with the no ramp motion profile determines that the ramp holds *VMAX* until *XTARGET* is reached. The motion direction depends on *XTARGET*.

In order to make use of the no ramp motion profile in combination with the positioning mode, do as follows:

Action:

- Set *RAMPMODE*(2:0) =b'100.
- Set proper *VMAX* register 0x24.
- Set proper *XTARGET* register 0x37.

Result:
VACTUAL is set instantly to 0 in case the target position is reached.

NOTE:

→ *Do NOT exceed* VMAX ≤ f_{CLK} */ 4 pulses for positioning mode.*

Read entire documentation; especially the "Supplemental Directives" on page 218.

6.3.4. Trapezoidal 4-Point Ramp without Break Point

In order to make use of a trapezoidal 4-point ramp motion profile without break velocity, do as follows:

Action:

- Set *RAMPMODE*(1:0) =b'01 (register 0x20).
- Set *VBREAK* =0 (register 0x27).
- Set proper *AMAX* register 0x28 and *DMAX* register 0x29.
- Set proper *VMAX* register 0x24.

Result:

The internal velocity *VACTUAL* is changed successively to *VMAX* with a linear ramp. Only *AMAX* and *DMAX* define the acceleration/deceleration slopes.

NOTE:

→ *AMAX determines the rising slope from absolute low to absolute high velocities, whereas DMAX determines the falling slope from absolute high to absolute low velocities.*

→ *Acceleration slope and deceleration slopes have only one acceleration and deceleration value each.*

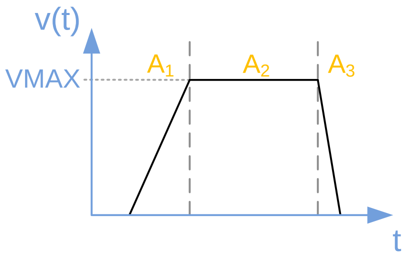


Figure 20: Trapezoidal Ramp without Break Point

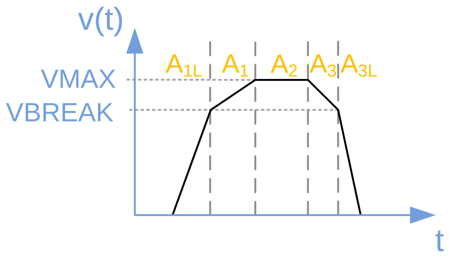


Figure 21: Trapezoidal Ramp with Break Point

6.3.5. Trapezoidal Ramp with Break Point

In order to make use of a trapezoidal ramp motion profile with break velocity, do as follows:

Action:

- Set *RAMPMODE*(1:0)=b'01 (register 0x20).
- Set proper *VBREAK* register 0x27.
- Set proper *AMAX* register 0x28 and *DMAX* register 0x29.
- Set proper *ASTART* register 0x2A and *DFINAL* register 0x2B.
- Set proper *VMAX* register 0x24.

Result:

The internal velocity *VACTUAL* is changed successively to *VMAX* with a linear ramp. In addition to *AMAX* and *DMAX*, *ASTART* and *DFINAL* define the acceleration or deceleration slopes (see Figure above).

NOTES:

→ *AMAX and ASTART determines the rising slope from absolute low to absolute high velocities.*

→ *DMAX and DFINAL determines the falling slope from absolute high to absolute low velocities.*

→ *The acceleration/deceleration factor alters at VBREAK. ASTART and DFINAL are valid below VBREAK, whereas AMAX and DMAX are valid beyond VBREAK.*

6.3.6. Position Mode combined with Trapezoidal Ramps

Motion direction depends on *XTARGET*.

In order to use a 4-point or sixPoint ramps during positioning mode, do as follows:

Action:

- Set *RAMPMODE*(2:0) =b'101 (register 0x20).
- Set Trapezoidal ramp type accordingly, as explained above.
- Set proper *XTARGET* register 0x37.

Result:
The ramp finishes exactly at the target position *XTARGET* by keeping |*VACTUAL*| = *VMAX* as long as possible.

AACTUAL Assignments for Trapezoidal Ramps

***AACTUAL* assignments apply both for 4-point and sixPoint ramps.**

The acceleration/deceleration factor *AACTUAL* register depends on the current ramp phase and the velocity that needs to be reached. The related sign assignment for different ramp phases is given in the following table:

***AACTUAL* ASSIGNMENTS for Trapezoidal Ramps**					
Ramp phase:	A_{1L}	A_1	A_2	A_3	A_{3L}
v>0: AACTUAL=	ASTART	AMAX	*0*	−DMAX	−DFINAL
v<0: AACTUAL=	−ASTART	−AMAX	*0*	DMAX	DFINAL

Table 16: Trapezoidal Ramps: AACTUAL Assignments during Motion

6.3.7. Configuration of S-Shaped Ramps

In order to make use of S-shaped ramps, do as follows:

Action:

- Set *RAMPMODE*(1:0)=b'10 (register 0x20).
- Set proper *BOW1* … *BOW4* registers 0x2C…0x30.
- Set proper *AMAX* register 0x28 and *DMAX* register 0x29.
- Set *ASTART* = 0 (register 0x2A).
- Set *DFINAL* = 0 (register 0x2B).
- Set proper *VMAX* register 0x24.

Result:

The internal velocity *VACTUAL* is changed successively to *VMAX* with S-shaped ramps. The acceleration/deceleration values are altered on the basis of the bow values.

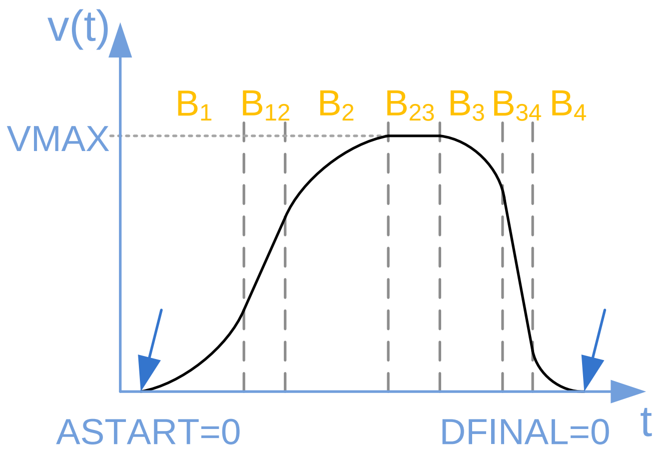


Figure 22: S-shaped Ramp without initial and final Acceleration/Deceleration Values

Definition of Rising Slope for S-shaped Ramps

Rising slope (absolute lower velocities to absolute higher velocities):

- *BOW1* determines the value which increases the absolute acceleration value.
- *BOW2* determines the value which decreases the absolute acceleration value.
- *AMAX* determines the maximum acceleration value.

Definition of Falling Slope for S-shaped Ramps

Falling slope (absolute higher velocities to absolute lower velocities):

- *BOW3* determines the value which increases the absolute deceleration value.
- *BOW4* determines the value which decreases the absolute deceleration value.
- *DMAX* determines the maximum absolute deceleration value.

•→ *Description is continued on next page.*

If the ramp must be stopped during positioning mode with *XTARGET*:

NOTICE

Avoid unintended system behavior during positioning mode!

- You MUST set VMAX to 1. Never to 0.
- After *VACTUAL*=0 (i.e. *VEL_REACHED_F* flag is set) is reached, set *VMAX*=0.

This will ensure smooth operation during positioning mode.

Changing ramp parameters[1] during motion is not advised. Should this be necessary, the following applies:

NOTICE

Avoid unintended system behavior during positioning mode!

Ramp parameter value changes[2] during ramp progress are allowed but can lead to:

- A temporary overshooting of *XTARGET* or mechanical stop positions.
- A temporary overshooting of *VACTUAL* beyond *VMAX* because the bows B1, B2, B3, and B4 are maintained during the ramp progress.

This will ensure smooth operation during positioning mode.

[1] *Exceptions are XTARGET and VMAX. These Parameters can be changed during motion.*

2 Ramp parameter value changes are allowed but need to be conducted with extra care.

6.3.8. Configuration of S-shaped Ramp with *ASTART* and *DFINAL*

In order to configure S-shaped ramps with starting and finishing values for acceleration or deceleration, do as follows:

Action:

- Set *RAMPMODE*(1:0)=b'10 (register 0x20).
- Set S-Shaped ramp as explained above (*BOW1* … *BOW4, AMAX, DMAX)*.
- Set proper *ASTART* register 0x2A.
- Set proper *DFINAL* register 0x2B.
- Set proper *VMAX* register 0x24.

Result:

The internal velocity *VACTUAL* is changed successively to *VMAX* with S-Shaped ramps.

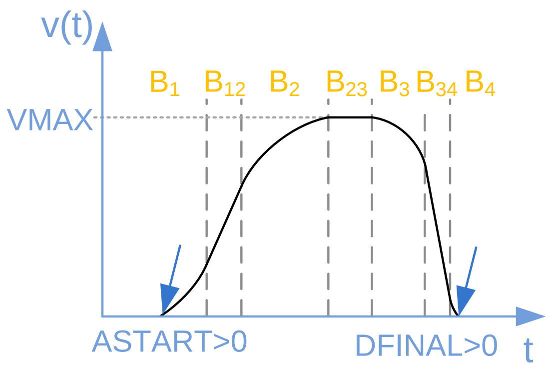


Figure 23: S-shaped Ramp with initial and final Acceleration/Deceleration Values

→ Description is continued on next page.

If S-shaped ramps are selected:

NOTICE

Avoid unintended system behavior!

- Do NOT switch *RAMPMODE*, if *VACTUAL* is not constant.
- Do NOT switch to positioning mode, if *VACTUAL* ≠ 0 and the difference between *XACTUAL* and *XTARGET* is too small for the given falling slope.

This will ensure smooth operation.

NOTE:

→ *There is one exception: If circular motion (see 0) is enabled and current velocity is too high for exact positioning during one revolution, it is possible to change from velocity to positioning mode.*

Definitions for S-shaped Ramps

- The acceleration/deceleration values are altered based on the bow values.
- The start phase and the end phase of an S-shaped ramp is accelerated/decelerated by *ASTART* and *DFINAL*.
- The ramp starts with *ASTART* and stops with *DFINAL*.
- *DFINAL* becomes valid when *AACTUAL* reaches the chosen *DFINAL* value.

i The parameter *DFINAL* is not considered during positioning mode.

***AACTUAL* Assignments for S-shaped Ramps**

AACTUAL assignments and current bow value selection for S-shaped ramps.
The acceleration/deceleration factor depends on the current ramp phase and alters every 64 clock cycles during the bow phases B1, B2, B3, and B4.

Details are provided in the table below:

S-shaped Ramps: Assignments for *AACTUAL* and Internal Bow Value							
Ramp phase:	**B_1**	**B_{12}**	**B_2**	**B_{23}**	**B_3**	**B_{34}**	**B_4**
v>0: *AACTUAL*=	*ASTART→AMAX*	*AMAX*	*AMAX*→0	0	0→−*DMAX*	−*DMAX*	−*DMAX*→−*DFINAL*
BOW_{ACTUAL}=	*BOW1*	0	−*BOW2*	0	−*BOW3*	0	*BOW4*
v<0: *AACTUAL*=	−*ASTART*→−*AMAX*	−*AMAX*	−*AMAX*→0	0	0→*DMAX*	*DMAX*	*DMAX*→*DFINAL*
BOW_{ACTUAL}=	−*BOW1*	0	*BOW2*	0	*BOW3*	0	−*BOW4*

Table 17: Parameter Assignments for S-shaped Ramps

6.3.9. S-shaped Mode and Positioning: Fast Motion

***RAMPMODE*(2:0) =b'110**

- The ramp finishes exactly on target position; keeping |*VACTUAL*| = *VMAX* as long as possible until the ramp falls to reach *XTARGET* exactly.
- It is possible that the phases B12, B23, and B34 are left out due to given values. Therefore, the highest speed performance is possible due to a maximum speed positioning ramp.
- The fastest possible slopes are always performed if the phases B12 and/or B34 are not reached during a rising and/or falling S-shaped slope.
- The ramp maintains the maximum velocity *VMAX* as long as possible in positioning mode until the falling slope finishes the ramp to reach *XTARGET* exactly. The result is the fastest possible positioning ramp in matters of time.

6.4. Start Velocity *VSTART* and Stop Velocity *VSTOP*

S-shaped and trapezoidal velocity ramps can be configured with unsigned start and stop velocity values:
V*START*, or *VSTOP*. Per default, *VSTART* and *VSTOP* are set to 0. The sign is selected automatically, depending on the current ramp status and the target velocity, or target position. This section explains how to set up the respective values correctly.

Starting Ramps with initial Velocity

S-shaped and trapezoidal velocity ramps can be started with an initial velocity value, if you set the *VSTART* value higher than zero (see Figure below).

In order to use trapezoidal ramps with an initial start velocity, do as follows:

Action:
- Set *RAMPMODE*(1:0)=b'01 (register 0x20).
- Set Trapezoidal ramp type accordingly, as explained before.
- Set proper *VSTART* > 0 (register 0x25).
- Set *VSTOP* = 0 (register 0x26).

Result:
The trapezoidal ramp starts with initial velocity.

NOTE:

→ *The initial acceleration value is AMAX if VBREAK < VSTART, otherwise the starting acceleration value is ASTART.*

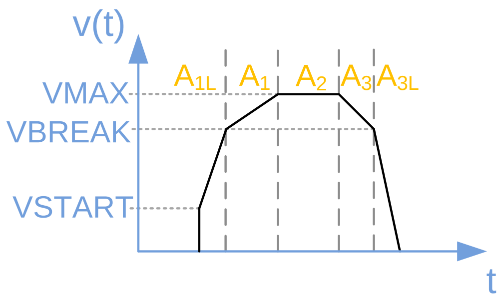


Figure 24: Trapezoidal Ramp with initial Velocity

If trapezoidal ramp with initial velocity *VSTART* is selected:

NOTICE	**Avoid unintended system behavior during positioning mode!** • Use *VSTART* without setting *VSTOP* > *VSTART* only in positioning mode if there is enough distance between the current position *XACTUAL* and the target position *XTARGET*.

This will ensure smooth operation during positioning mode.

•→*Turn page for information on how to configure S-shaped ramps with initial start velocity.*

S-shaped Ramps with initial Start Velocity

In order to use S-shaped ramps with initial start velocity, do as follows:

Action:

- Set *RAMPMODE*(1:0)=b'10 (register 0x20).
- Set S-shaped ramp type accordingly, as explained before.
- Set proper *VSTART* > 0 (register 0x25).
- Set *VSTOP* = 0 (register 0x26).

Result:
The S-shaped ramp starts with initial velocity.

PRINCIPLE:

→ *The initial acceleration value is equal to AMAX. The parameter ASTART is not considered. Consequently, ramp phase B1 is not performed.*

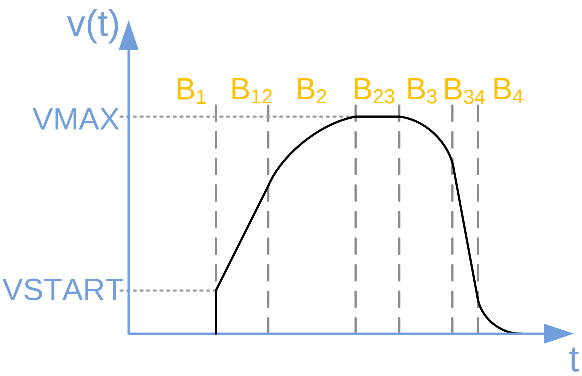


Figure 25: S-shaped Ramp with initial Start Velocity

If S-shaped ramp with initial velocity *VSTART* is selected:

NOTICE

Avoid unintended system behavior during positioning mode!

- Keep in mind that the S-shaped character of the curve is maintained. Because *AMAX* is the start acceleration value, the ramp will always execute phase B2 which could result in positioning overshoots.
- Use *VSTART* only in positioning mode if there is enough distance between the current position *XACTUAL* and the target position *XTARGET*.

This will ensure smooth operation during positioning mode.

•→*Turn page for information on how to configure finishing ramps with stop velocity.*

Finishing Ramps with Stop Velocity

S-shaped and trapezoidal velocity ramps can be finished with a stop velocity value if you set *VSTOP* value higher than zero (see figure below).

In order to configure trapezoidal ramps with stop velocity, do as follows:

Action:
- Set *RAMPMODE*(1:0)=b'01 (register 0x20).
- Set Trapezoidal ramp type accordingly, as explained before.
- Set *VSTART* = 0 (register 0x25).
- Set proper *VSTOP* > 0 (register 0x26).

Result:
The trapezoidal ramp stops with defined velocity.

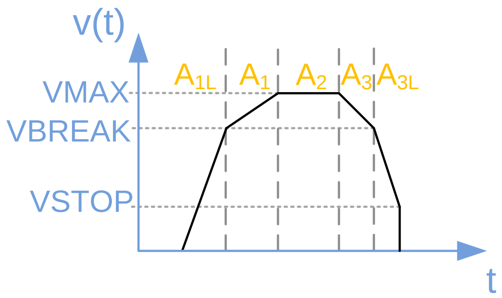


Figure 20: Trapezoidal Ramp with Stop Velocity

If trapezoidal ramps are selected (*VBREAK* > 0):

NOTICE

Avoid unintended system behavior during positioning mode!
- Set *VBREAK* > *VSTOP*.
- Set *VSTART* < *VSTOP*.

This will ensure smooth operation during positioning mode.

•→Turn page for configuration information on S-shaped ramps with stop velocity.

Read entire documentation; especially the "Supplemental Directives" on page 218.

S-shaped Ramps with Stop Velocity

In order to use S-shaped ramps with stop velocity, do as follows:

Action:

- Set *RAMPMODE*(1:0)=b'10 (register 0x20).
- Set S-shaped ramp type accordingly, as explained before.
- Set *VSTART* = 0 (register 0x25).
- Set proper *VSTOP* > 0 (register 0x26).

Result:

The S-shaped ramp finishes with stop velocity.

NOTE:

→ *The final deceleration value is equal to DMAX. The parameter DFINAL is not considered. Consequently, ramp phase B4 is not performed.*

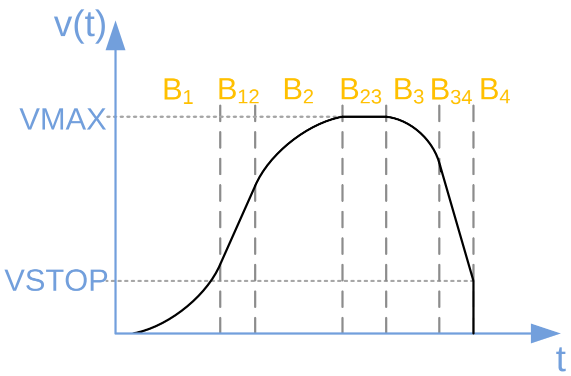


Figure 26: S-shaped Ramp with Stop Velocity

Interaction of *VSTART*, *VSTOP*, *VACTUAL* and *VMAX*:

- *VSTART* and *VSTOP* are only used to start or end a velocity ramp. If the velocity direction alters due to register assignments while a velocity ramp is in progress, the velocity values develop according to the current velocity ramp type without using *VSTART* or *VSTOP*.
- *VSTOP* can be used in positioning mode, if the target position is reached. In velocity mode, *VSTOP* can only be used if *VACTUAL* ≠ 0 and the target velocity *VMAX* is assigned to 0.
- The unsigned values *VSTART* and *VSTOP* are valid for both velocity directions.
- Every register value change is assigned immediately.

•→Turn page for information on how to configure S-shaped ramps with start and stop velocity.

6.4.1. S-shaped Ramps with Start and Stop Velocity

S-shaped ramps can be configured with a combination of *VSTART* and *VSTOP*.
It is possible to include both processes in one S-Shaped ramp to decrease the time between start and stop of the ramp.

In order to use S-Shaped ramps with a combination of start and stop velocity, do as follows:

Action:

- Set *RAMPMODE*(1:0)=b'10.
- Set S-shaped ramp type accordingly, as explained before.
- Set proper *VSTART* > 0 (register 0x25).
- Set proper *VSTOP* > 0 (register 0x26).

Result:
The S-shaped ramp starts with initial velocity and stops with defined velocity.

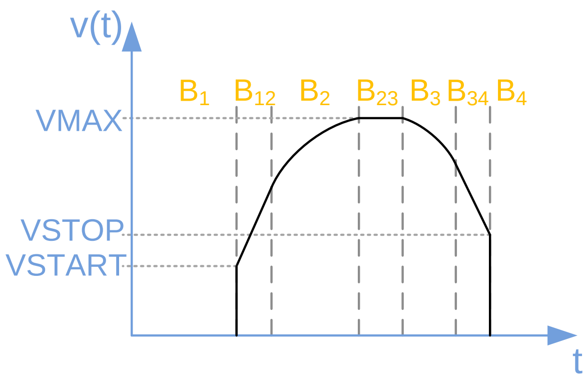


Figure 27: S-shaped Ramp with Start and Stop Velocity

If S-shaped ramp with initial velocity *VSTART* and stop velocity *VSTOP* is selected:

NOTICE

Avoid unintended system behavior during positioning mode!

- Keep in mind that the S-shaped character of the curve is maintained. Because *AMAX* is the start acceleration value, the ramp will always execute phase B2, which could result in positioning overshoots.
- Use *VSTART* in positioning mode, if there is enough distance between the current position *XACTUAL* and the target position *XTARGET*.

This will ensure smooth operation during positioning mode.

•→*Turn page for information on how to use VSTART and ASTART for S-shaped ramps.*

6.4.2. Combined use of *VSTART* and *ASTART for S-shaped Ramps*

For some S-shaped ramp applications it can be useful to start with a defined velocity value (*VSTART* > 0);but not with the maximum acceleration value *AMAX*.

In order to start with a defined velocity value, do as follows:

Action:

- Set *RAMPMODE*(1:0) =b'10 (register 0x20).
- Set S-shaped ramp type accordingly, as explained before.
- Set proper *VSTART* > 0 (register 0x25).
- Set proper *VSTOP* > 0 (register 0x26).
- Set *use_astart_and_vstart* =1 (bit0 of the *GENERAL_CONF* register 0x00).

Result:

The following special ramp types can be generated in this way, as shown below.

i Section B1 is passed through although *VSTART* is used.

Using VSTART *and starting acceleration of 0 for S-shaped ramps* *Using* VSTART *and starting acceleration, which is smaller than* AMAX *for S-shaped ramps*

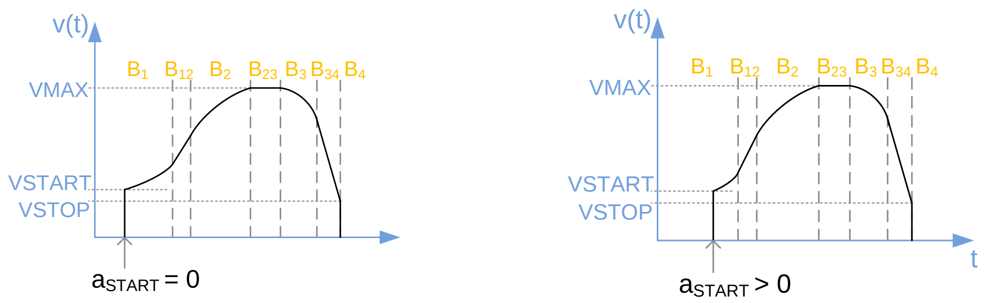


Figure 28: S-shaped Ramps with combined VSTART *and* ASTART *Parameters*

If S-shaped ramp with *VSTART*, *ASTART*, and *VSTOP* is selected:

NOTICE

Avoid unintended system behavior during positioning mode!

- Keep in mind that the S-shaped character of the curve is maintained. Because *ASTART* is the start acceleration value, the ramp will always execute phase B2, which could result in positioning overshoots.
- Use *VSTART* and *ASTART* > 0 without setting *VSTOP* > *VSTART* only in positioning mode, if there is enough distance between the current position *XACTUAL* and the target position *XTARGET*.

This will ensure smooth operation during positioning mode.

6.5. sixPoint Ramps

sixPoint ramps are trapezoidal ramps with initial and stop velocity values that also make use of two acceleration and two deceleration values.

Configuration of sixPoint Ramps

sixPoint ramps are trapezoidal velocity ramps that can be configured with a combination of *VSTART* and *VSTOP.*

In order to use trapezoidal ramps with a combination of start and stop velocity, do as follows:

Action:

- Set *RAMPMODE*(1:0)=b'01 (register 0x20).
- Set a Trapezoidal ramp type appropriately as explained before.
- Set proper *VSTART* > 0 (register 0x25).
- Set proper *VSTOP* > 0 (register 0x26).
- Set proper *VBREAK* > 0 (register 0x27).

Result:
The sixPoint ramp starts with an initial velocity and stops with a defined velocity.

Diagram of sixPoint Ramp

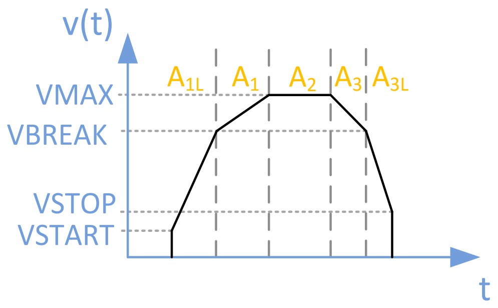


Figure 29: sixPoint Ramp: Trapezoidal Ramp with Start and Stop Velocity

If a sixPoint ramp is used:

NOTICE

Avoid unintended system behavior during positioning mode!

- Set *VBREAK* > *VSTOP*.
- Set *VSTART* < *VSTOP*.

This will ensure smooth operation during positioning mode.

6.6. Internal Ramp Generator Units

This section provides information about the arithmetical units of the ramp parameters.

6.6.1. Clock Frequency

All parameter units are real arithmetical units.
Therefore, it is necessary to set the *CLK_FREQ* register 0x31 to proper [Hz] value, which is defined by the external clock frequency f_{CLK}. Any value between f_{CLK} = 4.2 MHz and 32 MHz can be selected.
Default configuration is 16 MHz.

6.6.2. Velocity Value Units

Velocity values are always defined as pulses per second [pps].
VACTUAL is given as a 32-bit signed value with no decimal places. The unsigned velocity values *VSTART*, *VSTOP*, and *VBREAK* consist of 23 digits and 8 decimal places. *VMAX* is a signed value with 24 digits and 8 decimal places.

The maximum velocity *VMAX* is restricted as follows:

$$VMAX \leq \tfrac{1}{2}\,\text{pulse} \cdot f_{CLK}$$

NOTE:

→ *In case VACTUAL exceeds this limit INCORRECT step pulses at STPOUT output occur.*

6.6.3. Acceleration Value Units

The unsigned values *AMAX*, *DMAX*, *ASTART*, *DFINAL,* and *DSTOP* consist of 22 digits and 2 decimal places.
AACTUAL shows a 32-bit nondecimal signed value. Acceleration and deceleration units are defined per default as pulses per second² [pps²].

If higher acceleration/deceleration values are required for short and steep ramps, do as follows:

Action:
- Set *direct_acc_val_en* =1 (*GENERAL_CONF* register 0x00).

Result:
The parameters are defined as velocity value change per clock cycle with 24-bit unsigned decimal places (MSB $=2^{-14}$). The values are calculated as follows:

$$AMAX\,[pps^2] = AMAX / 2^{37} \cdot f_{CLK}^2$$
$$DMAX\,[pps^2] = DMAX / 2^{37} \cdot f_{CLK}^2$$
$$ASTART\,[pps^2] = ASTART / 2^{37} \cdot f_{CLK}^2$$
$$DFINAL\,[pps^2] = DFINAL / 2^{37} \cdot f_{CLK}^2$$
$$DSTOP\,[pps^2] = DSTOP / 2^{37} \cdot f_{CLK}^2$$

The maximum acceleration or deceleration values, in case *direct_acc_val_en* is activated, are as follows:

AMAX	≤ 65535
DMAX	≤ 65535
ASTART	≤ 65535
DFINAL	≤ 65535
DSTOP	≤ 65535

●→ *Continued on next page.*

6.6.4. Bow Value Units

Bow values BOW1…BOW4:
Bow values are unsigned 24-bit values without decimal places. They are defined per default as pulses per second³ [pps³].

In case higher bow values are required for short and steep ramps, do as follows:

Action:
- Set *direct_bow_val_en* =1 (*GENERAL_CONF* register 0x00)

Result:
The parameters are defined as acceleration value change per clock cycle with 24-bit unsigned decimal places with the MSB defined as 2^{-29}.

The particular bow values *BOW1*, *BOW2*, *BOW3*, *BOW4* are calculated as follows:

$BOWx\ [pps^3] = BOWx / 2^{53} \cdot f_{CLK}^3$

The maximum bow values, in case *direct_acc_val_en* is activated, are as follows:

BOW1…4 $\leq$ 4095

6.6.5. Overview of Minimum and Maximum Values:

Minimum and Maximum Values (Frequency Mode)				
Value Classes	**Velocity**	**Acceleration**	**Bow**	**Clock**
Affected Registers	*VMAX, VSTART, VSTOP, VBREAK*	*AMAX, DMAX, ASTART, DFINAL*	*BOW1, BOW2, BOW3, BOW4*	*CLK_FREQ* (f_{CLK})
Minimum value	3.906 mpps	0.25 mpps²	1 mpps³	4.194 MHz
Maximum value	8.388 Mpps and ½ pulse · f_{CLK}	4.194 Mpps²	16.777 Mpps³	32 MHz

Table 18: Minimum and Maximum Values if Real World Units are selected

Minimum and Maximum Values for Steep Slopes (Direct Mode, example with f_{CLK} =16MHz)		
Value Classes	**Acceleration (*direct_acc_val_en* =1)**	**Bow (*direct_bow_val_en* =1)**
Affected Registers	*AMAX, DMAX, ASTART, DFINAL, DSTOP*	*BOW1, BOW2, BOW3, BOW4*
Value restrictions:	*< 65536*	*< 4096*
Calculation	$a[pps^2] = (\Delta v/clk\_cycle) / 2^{37} \cdot f_{CLK}^2$	$bow[pps^3] = (\Delta a/clk\_cycle) / 2^{53} \cdot f_{CLK}^3$
Minimum value	~1.86 kpps²	~454.75 kpps³
Maximum value	~122.07 Mpps²	~1.86 Gpps³

Table 19: Minimum and Maximum Values for Steep Slopes for f_{CLK} =16MHz

Read entire documentation; especially the “Supplemental Directives” on page 218.

7. External Step Control and Electronic Gearing

Steps can also be generated by external steps that are manipulated internally by an electronic gearing process. In the following chapter, steps generation by external control and electronic gearing is presented.

Pins for External Step Control		
Pin Names	**Type**	**Remarks**
STPIN	Input	Step input signal.
DIRIN	Input	Direction input signal.

Table 20: Pins used for External Step Control

Registers used for external Step Control			
Register Name	**Register Address**		**Remarks**
GENERAL_CONF	0x00	RW	Bits 9:6, 26.
GEAR_RATIO	0x12	RW	Electronic gearing factor; signed; 32 bits=8+24 (8 bits integer part, 24 bits decimal places).

Table 21: Registers used for External Step Control

Enabling External Step Control

In order to synchronize with other motion controllers, TMC4361 offers a step direction input interface at the STPIN and DIRIN input pins.

i Three options are available. In case one of these options is selected, the internal step generator is disabled.

OPTION 1: HIGH ACTIVE EXTERNAL STEPS

Action:

➢ Set *sdin_mode* = b'01 (*GENERAL_CONF* register 0x00).

Result:

As soon as the STPIN input signal switches to high state the control unit recognizes an external step.

OPTION 2: LOW ACTIVE EXTERNAL STEPS

Action:

➢ Set *sdin_mode* = b'10 (*GENERAL_CONF* register 0x00).

Result:

As soon as the STPIN input signal switches to low state the control unit recognizes an external step.

OPTION 3: TOGGLING EXTERNAL STEPS

Action:

➢ Set *sdin_mode* = b'11 (*GENERAL_CONF* register 0x00).

Result:

As soon as the STPIN input signal switches to low or high state the control unit recognizes an external step.

•→ *Continued on next page.*

Selecting the Input Direction Polarity

DIRIN polarity can be assigned. Per default, the negative direction is indicated by DIRIN = 0.

In order to change this polarity:

Action:
- Set *pol_dir_in* = 1 (*GENERAL_CONF* register 0x00).

Result:
A negative input direction is assigned by DIRIN = 1.

7.1. Description of Electronic Gearing

If an external step is not congruent with an internal step, the *GEAR_RATIO* register 0x12 must be set accordingly. This signed parameter consists of eight bit digits and 24 bits decimal places.
With every external step the assigned *GEAR_RATIO* value is added to an internal accumulation register. As soon as an overflow occurs, an internal step is generated and the remainder will be kept for the next external step.
Any absolute gearing value between 2^{-24} and 127 is possible.

NOTE:

→ *Gearing ratios beyond 1 are more reasonable for the SPI output. The internal SinLUTable is used that generates multiple steps one after another without interpolation, if the accumulation register value is above 1. In contrast to a burst of steps at the STPOUT pin, the SPI output will only forward the new position in the inner SinLUT where only some values have been skipped if |GEAR_RATIO|>1.*

→ *A negative gearing factor* GEAR_RATIO < 0 *inverts the interpretation of the input direction which is determined by DIRIN and* pol_dir_in.

7.2. Indirect External Control

It is possible to use the internal ramp generator in combination with the external S/D interface.

In this case, the external step impulses transferred via STPIN and DIRIN cannot influence the internal *XACTUAL* counter directly. Instead, the *XTARGET* register is altered by 1 or −1 with every *GEAR_RATIO* accumulation register overflow.

NOTE:

→ *Whether XTARGET is increased or decreased is determined similarly to the direct electronic gearing control. The accumulation register overflow direction indicates the target alteration. Respectively, the accumulation direction is determined by the GEAR_RATIO sign, by pol_dir_in, and by DIRIN.*

i This feature allows a synchronized motion of different positioning ramps for different TMC4361 chips with differently configured ramps.

In order to select indirect external control, do as follows:

Action:
- Set *sdin_mode* ≠ b'00 according to the required external control option.
- Set *sd_indirect_control* = 1 (*GENERAL_CONF* register 0x00).

Result:
As soon as an external step is generated, *XTARGET* is increased or decreased, according to the accumulation direction.

7.3. Switching from External to Internal Control

In some cases, it is useful to switch from external to internal ramp generation during motion.

TMC4361 supports a smooth transfer from direct external control to an internal ramp. The only parameter you need to know and apply is the current velocity when the switching occurs. In more detail, this means that when the external control is switched off, *VSTART* takes over the definition of the actual velocity value. The ramp direction is then selected automatically. The time step of the last internal step is also taken into account in order to provide a smooth transition from external to internal ramp control.

In order to select automatic switching from external to internal control, do as follows:

PRECONDITION (EXTERNAL DIRECT CONTROL IS ACTIVE):

Action:

- Set *sdin_mode* ≠ b'00 (*GENERAL_CONF* register 0x00).
- Set *sd_indirect_control* = 0 (*GENERAL_CONF* register 0x00).
- Set *ASTART* = 0 (register 0x2A).

PROCEED WITH:

Action:

- Set *automatic_direct_sdin_switch_off* = 1 (*GENERAL_CONF* register 0x00) once before switching to internal control.
- Continually adapt *VSTART* register 0x25 according to the actual velocity of the TMC4361 that must be calculated in the µC.
- If switching must be prompted, set *sdin_mode* = b'00.

Result:

The internal ramp velocity is started with the value of *VSTART*, and the direction is set automatically on the basis of the external steps that have occurred before.

•→Turn page for information on how configure smooth switching for S-shaped ramps.

Smooth Switching for S-shaped Ramps

In order to also support a smooth S-shaped ramp transition - when the external step control is switched off - the starting acceleration value can also be set separately at *ASTART* register 0x2A.

i In contrast to the automatic direction assignment, the sign of *ASTART* must be set manually.

In order to select automatic switching from external to internal control with a starting acceleration value, do as follows:

PRECONDITION (EXTERNAL DIRECT CONTROL IS ACTIVE):

Action:

- Set *sdin_mode* ≠ b'00 (*GENERAL_CONF* register 0x00).
- Set *sd_indirect_control* = 0 (*GENERAL_CONF* register 0x00).

PROCEED WITH:

Action:

- Set *automatic_direct_sdin_switch_off* = 1 once before switching to internal control.
- Continually adapt *VSTART* register 0x25 according to the actual velocity of the TMC4361 – that must be calculated in the µC. Continually adapt *ASTART* according to the actual acceleration (unsigned value) of the TMC4361 – that must be calculated in the µC. Continually set *ASTART*(31) = 0 or 1 according to the current acceleration direction.
- If switching must be prompted, set *sdin_mode* = b'00.

Result:

The internal ramp velocity is started with the value of *VSTART*, and the direction is set automatically on the basis of the external steps that have occurred before. The internal acceleration value is set to:

+*ASTART* if *ASTART*(31) = 0 or

−*ASTART* if *ASTART*(31) = 1.

Read entire documentation; especially the "Supplemental Directives" on page 218.

8. Reference Switches

The reference input signals of the TMC4361 function partly as safety features. The TMC4361 provides a range of reference switch settings that can be configured for many different applications. The TMC4361 offers two hardware switches (STOPL, STOPR) and two additional virtual stop switches (*VIRT_STOP_LEFT*, *VIRT_STOP_RIGHT*). A home reference switch HOME_REF is also available.

Pins used for Reference Switches		
Pin Names	**Type**	**Remarks**
STOPL	Input	Left reference switch.
STOPR	Input	Right reference switch.
HOME_REF	Input	Home switch.
TARGET_REACHED	Output	Reference switch to indicate *XACTUAL=XTARGET.*

Table 22: Pins used for Reference Switches

Dedicated Registers for Reference Switches			
Register Name	**Register Address**		**Remarks**
REFERENCE_CONF	0x01	RW	Configuration of interaction with reference pins.
HOME_SAFETY_MARGIN	0x1E	RW	Region of uncertainty around *X_HOME.*
DSTOP	0x2C	RW	Deceleration value if stop switches STOPL / STOPR or virtual stops are used with soft stop ramps. The deceleration value allows for an automatic linear stop ramp.
POS_COMP	0x32	RW	Free configurable compare position; signed; 32 bits.
VIRT_STOP_LEFT	0x33	RW	Virtual left stop that triggers a stop event at *XACTUAL* ≤ *VIRT_STOP_LEFT*; signed; 32 bits.
VIRT_STOP_RIGHT	0x34	RW	Virtual left stop that triggers a stop event at *XACTUAL* ≥ *VIRT_STOP_RIGHT*; signed; 32 bits.
X_HOME	0x35	RW	Home reference position; signed; 32 bits.
X_LATCH	0x36	RW	Stores *XACTUAL* at different conditions; signed; 32 bits.

Table 23: Dedicated Registers for Reference Switches

8.1. Hardware Switch Support

The TMC4361 offers two hardware switches that can be configured according to your design.

STOPL and STOPR

The hardware provides a left and a right stop in order to stop the drive immediately in case one of them is triggered. Therefore, pin 12 and pin 14 of the motion controller must be used.

NOTE:

→ *Both switches must be enabled before motion occurs.*

In order to enable STOPL correctly, do as follows:

Action:

- Determine the active polarity voltage of STOPL and set *pol_stop_left* (*REFERENCE_CONF* register 0x01) accordingly.
- Set *stop_left_en* =1 (*REFERENCE_CONF* register 0x01).

Result:
The current velocity ramp stops in case the STOPL voltage level matches *pol_stop_left* and *VACTUAL* < 0.

In order to enable STOPR correctly, do as follows:

Action:

- Determine the active polarity voltage of STOPR and set *pol_stop_right* (*REFERENCE_CONF* register 0x01) accordingly.
- Set *stop_right_en* =1 (*REFERENCE_CONF* register 0x01).

Result:
The current velocity ramp stops in case STOPR voltage level matches *pol_stop_right* and *VACTUAL* > 0.

8.1.1. Stop Slope Configuration for Hard or Linear Stop Slopes

The stop slope can be configured for hard or linear stop slopes. Per default, hard stops are selected.

If hard stops are required, do as follows:

OPTION 1: HARD STOP SLOPES

Action:

- Set *soft_stop_en* =0 (*REFERENCE_CONF* register 0x01).

Result:
If one of the stop switches is active and enabled, the velocity ramp is set immediately to *VACTUAL* = 0.

OPTION 2: LINEAR STOP SLOPES

If linear stop ramps are required:

Action:

- Set *soft_stop_en* =1 (*REFERENCE_CONF* register 0x01).

Result:
If one of the stop switches is active and enabled, the velocity ramp is stopped with a linear deceleration slope until *VACTUAL* = 0 is reached. In this case the deceleration factor is determined by *DSTOP*. *VSTOP* is not considered during the stop deceleration slope.

Read entire documentation; especially the "Supplemental Directives" on page 218.

8.1.2. How Active Stops are indicated and reset to Free Motion

When a stop switch becomes active the related status flag is set in the *STATUS* flags register 0x0F. The flag remains active as long as the stop switch remains active.
The particular event is also released in the *EVENTS* register 0x0E, which remains active until the event bit is reset manually. When *VACTUAL* = 0 is reached after the stop event no motion toward this particular direction is possible.

In order to move into the locked direction, the following is required:

PRECONDITION 1:

The particular stop switch is NOT active anymore.

AND/OR

PRECONDITION 2:

The stop switch is disabled (*stop_left/right_en* = 0).

Action:

- Set back the active event by reading out the *EVENTS* register 0x0E.

i There is only one exception to this: If an event is selected for the *EVENT_CLEAR_CONF* register in order to inhibit the regular clearing. See information provided in Chapter 5, Page 24.

Result:
The active stop event is reset to free motion into the locked direction.

8.1.3. How to latch Internal Position on Switch Events

It is possible to select four different events to store the current internal position *XACTUAL* in the register *X_LATCH*.

The table below show which transition of the reference signal leads to the *X_LATCH* transfer. For each transition process the specified reference configurations in the *REFERENCE_CONF* register 0x01 must be set accordingly.

Reference Configuration	***pol_stop_left*=0**	***pol_stop_left*=1**	***pol_stop_right*=0**	***pol_stop_right*=1**
latch_x_on_inactive_l=1	STOPL=0 → 1	STOPL=1 → 0	---	---
latch_x_on_active_l=1	STOPL=1 → 0	STOPL=0 → 1	---	---
latch_x_on_inactive_r=1	---	---	STOPR=0 → 1	STOPR = 1→0
latch_x_on_active_r=1	---	---	STOPR=1 → 0	STOPR = 0→1

Table 24: Reference Configuration and Corresponding Transition of particular Reference Switch

Interchange the Reference Switches without Physical Reconnection

If you need to change the directions of the reference switches, do as follows:

Action:

- Set *invert_stop_direction*=1 (*REFERENCE_CONF* register 0x01).

Result:
STOPL is now the right reference switch and STOPR is now the left reference switch. Consequently, all configuration parameters for STOPL become valid for STOPR and vice versa.

8.2. Virtual Stop Switches

TMC4361 provides additional virtual limits; which trigger stop slopes in case the specific virtual stop switch microstep position is reached. Virtual stop positions are assigned using the *VIRTUAL_STOP_LEFT* register 0x33 and *VIRTUAL_STOP_RIGHT* register 0x34. In this section, configuration details for virtual stop switches are provided for various design-in purposes.

NOTE:

→ *Virtual stop switches must be enabled in the same manner as nonvirtual reference switches. Hitting a virtual limit switch - by receiving the assigned position - triggers the same process as hitting STOPL or STOPR.*

8.2.1. Enabling Virtual Stop Switches

In order to enable left virtual stop correctly, do as follows:

Action:

- Set *VIRTUAL_STOP_LEFT* register 0x33 according to left stop position.
- Set *virtual_left_limit_en* =1 (*REFERENCE_CONF* register 0x01).

Result:
The actual velocity ramp stops in case *XACTUAL* ≤ *VIRT_STOP_LEFT*. The ramp is stopped according to the selected ramp type.

In order to enable right virtual stop correctly, do as follows:

Action:

- Set *VIRTUAL_STOP_RIGHT* register 0x34 according to right stop position.
- Set *virtual_right_limit_en* =1 (*REFERENCE_CONF* register 0x01).

Result:
The actual velocity ramp stops in case *XACTUAL* ≥ *VIRT_STOP_RIGHT*. The ramp is stopped according to the selected ramp type.

8.2.2. Virtual Stop Slope Configuration

The virtual stop slope can also be configured for hard or linear stop slopes.

If virtual hard stops are required, do as follows:

Action:

- Set *virt_stop_mode* = b'01 (*REFERENCE_CONF* register 0x01).

Result:
If one of the virtual stop switches is active and enabled, the velocity ramp will be set immediately to *VACTUAL* = 0.

If virtual linear stop ramps are required, do as follows:

Action:

- Set *virt_stop_mode* = b'10 (*REFERENCE_CONF* register 0x01).

Result:
If one of the virtual stop switches is active and enabled, the velocity ramp is stopped with a linear deceleration slope until *VACTUAL* = 0 is reached. In this case the deceleration factor is determined by *DSTOP*. *VSTOP* is not considered during the stop deceleration slope.

•→ *Continued on next page.*

8.2.3. How Active Virtual Stops are indicated and reset to Free Motion

At the same time when a virtual stop switch becomes active the related status flag is activated in the *STATUS* flags register 0x0F. The flag remains active as long as the stop switch remains active.

The particular event is also released in the *EVENTS* register 0x0E, which remains active until the event is reset manually. When *VACTUAL* = 0 is reached after the stop event no motion in the particular direction is possible.

In order to move into the locked direction, the following is required:

PRECONDITION 1:

The particular stop switch is NOT active anymore because the actual position does not exceed the specified limit.

AND/OR

PRECONDITION 2:

Virtual stop switch is disabled (*virtual_left/right_limit_en* = 0).

Action:

- Set back active event by reading out *EVENTS* register 0x0E.

i There is only one exception to this: If an event is selected for *EVENT_CLEAR_CONF* register in order to inhibit the regular clearing. See information provided in chapter 5, page 24.

Result:

The active virtual stop event bit is reset to free motion into the direction that was locked beforehand.

i *invert_stop_direction* has no influence on *VIRTUAL_STOP_LEFT* and *VIRTUAL_STOP_RIGHT*.

8.3. Home Reference Configuration

In this section home reference switch handling is explained with information about home tracking modes, possible home event configurations and home event monitoring.

Switch Reference Input HOME_REF

For monitoring, the switch reference input HOME_REF is provided.

Perform the following to initiate the homing process:

Action:

- Assign a ramp according to your needs for the homing process.
- Enable the home tracking mode with *start_home_tracking* = 1 (*REFERENCE_CONF* register 0x01).
- Set the correct *home_event* (*REFERENCE_CONF* register 0x01) for the HOME_REF input pin (see *Table* 25, page 59).
- Start the ramp towards the home switch HOME_REF.

Result:

- When the next home event is recognized by TMC4361, *XACTUAL* is latched to *X_HOME*.
- At the same time, the *start_home_tracking* switch is disabled automatically and
- The *XLATCH_DONE* event is released in the events register 0x0E. This event can be used for an interrupt routine for the homing process in order to avoid polling.

i If an incremental encoder is used to monitor the motion, the N channel can be used to fine-tune the homing position (*home_event* = b'0000). After performing the homing process - as explained before - the N channel events can be used to obtain a more precise home position.

i *X_HOME* can be overwritten manually.

•→ *Continued on next page.*

8.3.1. Home Event Selection

Nine different home events are possible.

ℹ Except for the *home_event* = b'0000, which uses the N signal of an incremental ABN encoder, home events are related to the voltage levels of the HOME_REF input pin:

Home Event Selection Table

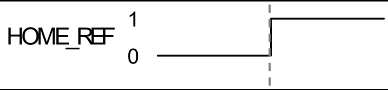
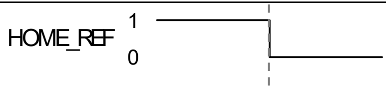
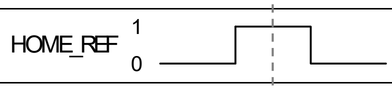
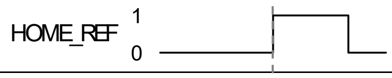
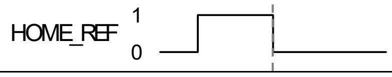
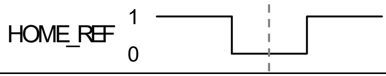
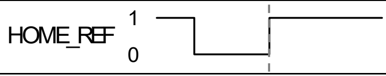
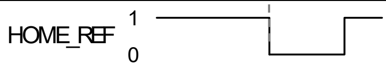
home_event	**Description**		**X_HOME (direction: negative / positive)**
b'0011	*HOME_REF* = 0 indicates negative direction in reference to *X_HOME*		
b'1100	*HOME_REF* = 0 indicates positive direction in reference to *X_HOME*		
b'0110	*HOME_REF* = 1 indicates home position	X_HOME in center	
b'0010		X_HOME on the left side	
b'0100		X_HOME on the right side	
b'1001	*HOME_REF* = 0 indicates home position	X_HOME in center	
b'1011		X_HOME on the right side	
b'1101		X_HOME on the left side	

Table 25: Overview of different home_event Settings

8.3.2. HOME_REF Monitoring

An error flag *HOME_ERROR_F* is permanently evaluated. This error flag indicates whether the current voltage level of the HOME_REF reference input is valid in regard to *X_HOME* and the selected home_event.

Defining a Home Range around HOME_REF

In order to avoid false error flags (*HOME_ERROR_F*) because of mechanical inaccuracies, it is possible to setup an uncertainty home range around *X_HOME*. In this range, the error flag is not evaluated.

If you want to define an uncertainty area around *X_HOME*, do as follows:

Action:
- ➢ Set *HOME_SAFETY_MARGIN* register 0x1E according to the required range in µSteps.

Result:
The homing uncertainties – related to the special application environment – are considered for the ongoing motion. The error flag is NOT evaluated in the following range:

$$X\_HOME - HOME\_SAFETY\_MARGIN \leq XACTUAL \leq X\_HOME + HOME\_SAFETY\_MARGIN$$

•→ *Continued on next page.*

Continued: **Defining a Home Range around HOME_REF**

NOTE:

→ *It is recommended to assign to a higher range value for HOME_SAFETY_MARGIN in which the HOME_REF level is active for the home_events b'0110, b'0010, b'0100, b'1001, b'1011, and b'1101. It avoids false positive HOME_ERROR_Flags.*

→ *After homing with the index channel (home_event = b'0000) for a precise assignment of X_HOME the correct home_event has to be assigned in order to activate the generation of HOME_ERROR_Flags. Note that home_event = b'0000 results in HOME_ERROR_Flag=0 permanently.*

→ *The following examples illustrate the points at which the error flag is release – based on the selected home_event – here for home_event = b'0011 (*), b'1100 (**), b'0110 (***), b'0010 (***), b'0100 (***), b'1001 (****), b'1011 (****), and b'1101 (****).*

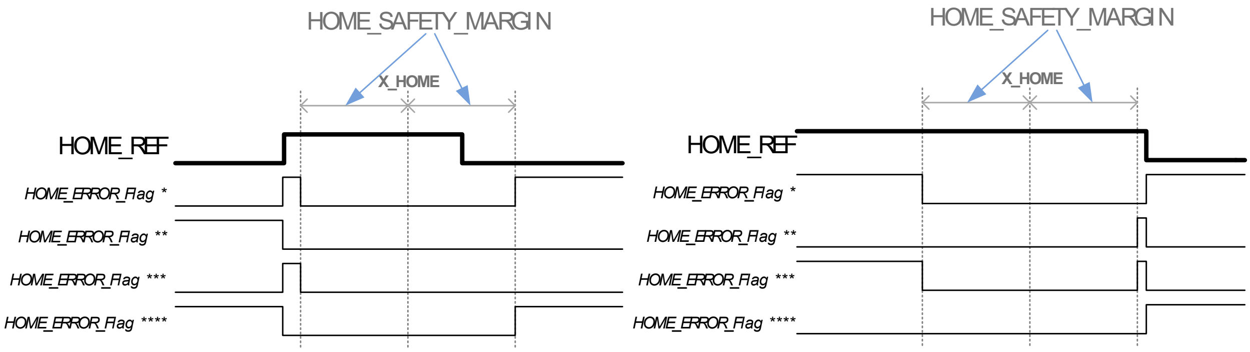


Figure 30: HOME_REF Monitoring and HOME_ERROR_FLAG

8.3.3. Homing with STOPL or STOPR

STOPL and STOPR inputs can also be used as HOME_REF inputs.

OPTION 1: STOPL IS THE HOME SWITCH

Action:

➢ Set *stop_left_is_home* = 1 (*REFERENCE_CONF* register 0x01).

Result:
The stop event at STOPL only occurs when the home range is crossed after STOPL becomes active. The home range is given by *X_HOME* and *HOME_SAFETY_MARGIN*.

OPTION 2: STOPR IS HOME SWITCH

Action:

➢ Set *stop_right_is_home* = 1 (*REFERENCE_CONF* register 0x01).

Result:
The stop event at STOPR only occurs when the home region is crossed after STOPR becomes active. The home region is given by *X_HOME* and *HOME_SAFETY_MARGIN*.

8.4. Target Reached / Position Comparison

In this section, TARGET_REACHED output pin configuration options are explained, as well as different ways how to compare different values internally.

Target Reached Output Pin

TARGET_REACHED output pin forwards the *TARGET_REACHED_F*lag. As soon as *XACTUAL* equals *XTARGET*, TARGET_REACHED is active. Per default, the TARGET_REACHED pin is high active.

To change the TARGET_REACHED output polarity, do the following:

Action:

- Set *invert_pol_target_reached* = 1 (bit16 of the *GENERAL_CONF* register 0x00).

Result:
TARGET_REACHED pin is low active.

8.4.1. Connecting several Target-reached Pins

TARGET_REACHED pins can also be configured for a shared signal line in the same way as several INTR pins can configured for one interrupt signal transfer (see section 5.4. (page 27)).

To use a Wired-Or or Wired-And behavior, the below described order of action must be executed:

Action:

- **Step 1:** Set *intr_tr_pu_pd_en* = 1 (*GENERAL_CONF* register 0x00).

OPTION 1: WIRED-OR

Action:

- **Step 2:** Set *tr_as_wired_and* = 0 (*GENERAL_CONF* register 0x00).

Result:
The TARGET_REACHED pin works efficiently as Wired-Or (default configuration).

i In case TARGET_REACHED pin is inactive, the pin drive has a weak inactive polarity output. During active state, the output is driven strongly. Consequently, if one of the connected pins is activated, the whole line is set to active polarity.

OPTION 2: WIRED-AND

Action:

- **Step 2:** Set *tr_as_wired_and* = 1 (*GENERAL_CONF* register 0x00).

Result:
As long as the target position is not reached, the TARGET_REACHED pin has a strong inactive polarity output. During active state, the pin drive has a weak active polarity output. Consequently, the whole signal line is activated if all connected pins are forwarding the active polarity.

8.4.2. Position Comparison of Internal Values

TMC4361 provides several ways of comparing internal values. The position comparison process is permanently active and associated with one flag and one event.

Basic Comparison Settings

How to compare the internal position with an arbitrary value:

Action:
- Select a comparison value in the *POS_COMP* register 0x32.
- Select *pos_comp_source* = 0 (*REFERENCE_CONF* register 0x01).

Result:
XACTUAL is compared with *POS_COMP*. When *POS_COMP* equals *XACTUAL* the *POS_COMP_REACHED_F*lag becomes set and the *POS_COMP_REACHED* event becomes released.

Select External Position as Comparison Base

How to compare the external position with an arbitrary value:

Action:
- Select a comparison value in the *POS_COMP* register 0x32.
- Select *pos_comp_source* = 1 (*REFERENCE _CONF* register 0x01).

Result:
ENC_POS is compared with *POS_COMP*. When *POS_COMP* equals *ENC_POS* the *POS_COMP_REACHED_F*lag becomes set and the *POS_COMP_REACHED* event becomes released.

NOTE:

→ *Because ENC_POS represents microsteps and not encoder steps, POS_COMP represents also microsteps for the comparison process with external positions.*

→ *In case ENC_POS moves past POS_COMP without assuming the same value as POS_COMP, the POS_COMP_REACHED event is not flagged but is nonetheless listed in the EVENTS register in order to indicate that it has traversed.*

Select Position Compare Flag as TARGET_REACHED Output

A positive comparison result can be forwarded through the INTR pin using the *POS_COMP_REACHED* event as interrupt source.

It is also possible to use the TARGET_REACHED output in order to report the position comparison state (*POS_COMP_REACHED_F*lag) instead of the target reached status.

In order to select the TARGET_REACHED output as *POS_COMP_REACHED_Flag* source, do as follows:

Action:
- Set *pos_comp_output* = b'11 (*REFERENCE _CONF* register 0x01).

Result:
TARGET_REACHED output forwards the *POS_COMP_REACHED_F* status flag.

•→ *Continued on next page.*

Comparison selection grid

In addition to comparing *XACTUAL* / *ENC_POS* with *POS_COMP*, it is also possible to conduct a comparison of one of both parameters with *X_HOME* or *X_LATCH* resp. *ENC_LATCH*. TMC4361 also allows comparison of the revolution counter *REV_CNT* against *POS_COMP*.

SETTINGS ALERT **!**

Only the selected combination generates the *POS_COMP_REACHED*_Flag and the corresponding event.
Therefore, select *modified_pos_compare* in the *REFERENCE_CONF* register 0x01 as outlined in the table below:

Comparison Selection Grid		
modified_pos_compare \ *pos_comp_source*	**'0'**	**'1'**
'00'	*XACTUAL* vs. *POS_COMP*	*ENC_POS* vs. *POS_COMP*
'01'	*XACTUAL* vs. *X_HOME*	*ENC_POS* vs. *X_HOME*
'10'	*XACTUAL* vs. *X_LATCH*	*ENC_POS* vs. *ENC_LATCH*
'11'	*REV_CNT* vs. *POS_COMP*	

Table 26: Comparison Selection Grid to generate POS_COMP_REACHED_Flag

Read entire documentation; especially the "Supplemental Directives" on page 218.

8.5. Repetitive and Circular Motion

TMC4361 also provides options for auto-repetitive or auto-circular motion. In this section configuration options are explained.

8.5.1. Repetitive Motion to XTARGET

Per default, reaching *XTARGET* in positioning mode finishes a positioning ramp.

In order to continuously repeat the specified ramp, do as follows:

PRECONDITION:

- Set *RAMPMODE*(2) = 1 (positioning mode is active).
- Set up a velocity ramp according to your requirements.

Action:

- Set *clr_pos_at_target* =1 (*REFERENCE_CONF* register 0x01).

Result:

After *XTARGET* is reached (*TARGET_REACHED_F*lag is active), *XACTUAL* is set to 0. As long as *XTARGET* is NOT 0, the ramp restarts in order to reach *XTARGET* again. This leads to repetitious positioning ramps from 0 towards *XTARGET*.

NOTE:

→ *It is possible to change XTARGET during repetitive motion. The reset of XACTUAL to 0 is always executed when XACTUAL equals XTARGET.*

8.5.2. Activating Circular Motion

If circular motion profiles are necessary for your application, TMC4361 offers a position limitation range of *XACTUAL* with an automatic overflow processing. As soon as *XACTUAL* reaches one of the two position range limits (positive / negative), the value of *XACTUAL* is set automatically to the value of the opposite range limit.

In order to activate circular motion, do as follows:

PRECONDITION:

If you want to activate circular motion, *XACTUAL* must be located within the defined range.

PROCEED WITH:

Action:

- Set *X_RANGE* ≠ 0 (register 0x36, only writing access!).
- Set *circular_motion* = 1 (*REFERENCE_CONF* register 0x01).

Result:

The positioning range of *XACTUAL* is limited to: −*X_RANGE* ≤ *XACTUAL* < *X_RANGE.*

When *XACTUAL* reaches the most positive position (*X_RANGE* – 1) and the motion proceeds in positive direction; the next *XACTUAL* value is set to −*X_RANGE*. The same applies to proceeding in negative direction; where (*X_RANGE* −1) is the position after −*X_RANGE*.

i During positioning mode, the motion direction will be dependent on the shortest path to the target position *XTARGET*. For example, if *XACTUAL* = 200, *X_RANGE* = 300 and *XTARGET* = −200, the positioning ramp will find its way across the overflow position (299 → −300) (see Figure A) in *Table* 27 (page 67).

8.5.3. Uneven or Noninteger Microsteps per Revolution

Due to definition of the limitation range, one revolution only consists of an even number of microsteps. TMC4361 provides an option to overcome this limitation.

- Some applications demand different requirements because a revolution consists of an uneven or noninteger number of microsteps.
- TMC4361 allows a high adjustment range of microsteps by using:
  CIRCULAR_DEC register 0x7C.

  This value represents one digit and 31 decimal places as extension for the number of microsteps per one revolution.
- A revolution is completed at overflow position. With every completed revolution the *CIRCULAR_DEC* value is added to an internal accumulation register. In case this register has an overflow, *XACTUAL* remains at its overflow position for one step.
- On average, this leads to the following microsteps per revolution:
  Microsteps/rev = (2 · *X_RANGE*) + *CIRCULAR_DEC* / 2^{31}.

Example 1: Uneven Number of Microsteps per Revolution

One revolution consists of 601 microsteps.
A definition of *X_RANGE* = 300 will only provide:

600 microsteps per revolution (−300 ≤ *XACTUAL* ≤ 299).

Whereas *X_RANGE* = 301 will result in:

602 microsteps per revolution (−301 ≤ *XACTUAL* ≤ 300).

By setting:

CIRCULAR_DEC = 0x80000000 (= 2^{31} / 2^{31} = 1).

An overflow is generated at the decimals accumulation register with every revolution. Therefore, *XACTUAL* prolongs the step at the overflow position for one step every time position overflow is overstepped. This results in a microstep count of 601 per revolution.

Example 2: Noninteger Number of Microsteps per Revolution

One revolution consists of 600.5 microsteps.

By setting:

CIRCULAR_DEC = 0x40000000 (= 2^{30} / 2^{31} = 0.5).

Every second revolution an overflow is produced at the decimals' accumulation register. This leads to a microstep count of 600 every second revolution and 601 for the other half of the revolutions. On average, this leads to 600.5 microsteps per revolution.

Example 3: Noninteger and uneven Number of Microsteps per Revolution

One revolution consists of 601.25 microsteps.

By setting:

CIRCULAR_DEC = 0xA0000000 (= (2^{31} + 2^{29}) / 2^{31} = 1.25).

With every revolution an overflow is produced at the decimals' accumulation register. Furthermore, at every fourth revolution an additional overflow occurs, which leads to another prolonged step. This leads to a microstep count of 601 for three of four revolutions and 602 for every fourth revolution. On average, this results in 601.25 microsteps per revolution.

8.5.4. Release of the Revolution Counter

By overstepping the position overflow, the internal *REV_CNT* register is increased by one revolution as soon as *XACTUAL* oversteps from (*X_RANGE* –1) to −*X_RANGE* or is decreased by one revolution as soon as *XACTUAL* oversteps in the opposite direction.

The information about the number of revolutions can be obtained by reading out register 0x36, which by default is the *X_LATCH* register (read only).

In order to gain information on the number of revolutions:

Action:

- Set *circular_cnt_as_xlatch* = 1 (*GENERAL_CONF* register 0x00).

Result:

Register 0x36 cease to display the *X_LATCH* value. Instead, the revolution counter *REV_CNT* can be read out at this register address.

NOTE:

→ *As soon as circular motion is inactive (*circular_motion = *0),* REV_CNT *is reset to 0.*

8.6. Blocking Zones

8.6.1. Activating Blocking Zones during Circular Motion

During circular motion, virtual stops can be used to set blocking zones. Positions inside these blocking zones are NOT dedicated for motion.

In order to activate the blocking zone, do as follows:

PRECONDITION:

Circular motion is activated (*circular_motion* = 0) and properly assigned (*X_RANGE* ≠ 0).

PROCEED WITH:

Action:

- Set *VIRTUAL_STOP_LEFT* register 0x33 as left limit for the blocking zone.
- Set *VIRTUAL_STOP_RIGHT* register 0x34 as right limit for the blocking zone.
- Enable both virtual limits as explained in section 8.2.1 (page 56).

Result:

The blocking zone reaches from *VIRTUAL_STOP_LEFT* to *VIRTUAL_STOP_RIGHT*. During positioning, the path from *XACTUAL* to *XTARGET* does not lead through the blocking zone; which can result in a longer path compared to the direct path through the blocking zone (see Figure B1 in *Table* 27 (page 67).

However, the selected virtual stop deceleration ramp is initiated as soon as one of the limits is reached. This can result from the velocity mode or if the target *XTARGET* is located in the blocking zone.

•→ *Continued on next page!*

Blocking Zone Definition

The following positions are located within the blocking zone:

XACTUAL ≤ VIRT_STOP_LEFT

AND / OR

XACTUAL ≥ VIRT_STOP_RIGHT

NOTE:

→ *In case* VIRTUAL_STOP_LEFT < VIRTUAL_STOP_RIGHT, *one of these conditions must be met in order to be located inside the blocking zone.*

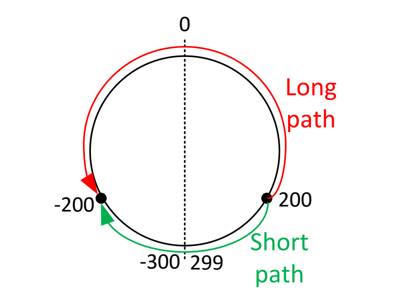
→ *In case* VIRTUAL_STOP_LEFT > VIRTUAL_STOP_RIGHT, *both conditions must be met in order to be located inside the blocking zone.*

8.6.2. Circular Motion with and without Blocking Zone

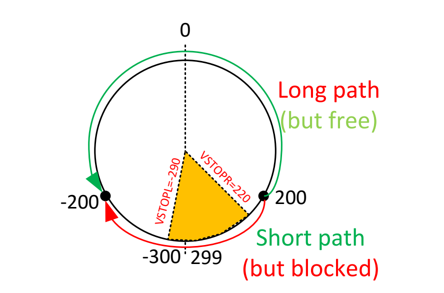
The table below shows circular motion (*X_RANGE* = 300). The green arrow depicts the path which is chosen for positioning.
The shortest path selection is shown in Figure A and the consideration of blocking zones are shown in Figures B1 and B2.

Circular Motion with (B1, B2) and Without (A) Blocking Zone

A



B1



B2

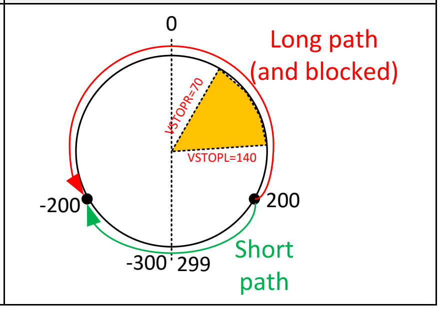


Table 27: Circular motion (X_RANGE = 300)

Moving out of the Blocking Zone

When *XACTUAL* is located inside the blocking zone, it is possible to move out without redefining the blocking zone.

In order to get out of the blocking zone, do the following:

Action:

- Activate positioning mode: *RAMPMODE*(2) = 1.
- Configure velocity ramp according to your needs.
- Clear virtual stop events by reading out *EVENTS* register 0x0E.
- Set regular target position *XTARGET* outside of the blocking zone.

Result:

TMC4361 initiates a ramp with the shortest way to the target *XTARGET*.

i In order to match an incremental encoder in the same manner, select *circular_enc_en* =1 (*REFERENCE_CONF* register 0x01).

9. Ramp Timing and Synchronization

TMC4361 provides various options to initiate a new ramp. By default, every external register change is assigned immediately to the internal registers via an SPI input. With a proper start configuration, ramp sequences can be programmed without any intervention in between.

Synchronization Opportunities

Three levels of ramp start complexity are available. Predefined ramp starts are available, which are independent of SPI data transfer that are explained in the subsequent section 9.1. (page 69).

Two optional features can be configured that can either be used individually or combined, which are as follows:

Shadow Register Set

A complete shadow motion register set can be loaded into the actual motion registers in order to start the next ramp with an altered motion profile.

Target Position Pipeline

Different target positions can be predefined, which are then activated successively. This pipeline can be configured as cyclic; and/or it can also be utilized to sequence different parameters.

Masterless synchronization

Also, another start state "busy" can be assigned in order to synchronize several motion controllers for one single start event without a master.

Dedicated Ramp Timing Pins		
Pin Names	**Type**	**Remarks**
START	Input and Output	External start input to get a start signal or external start output to indicate an internal start event.

Table 28: Dedicated Ramp Timing Pins

Dedicated Ramp Timing Registers			
Register Name	**Register Address**		**Remarks**
START_CONF	0x02	RW	The configuration register of the synchronization unit.
START_OUT_ADD	0x11	RW	Additional active output length of external start signal.
START_DELAY	0x13	RW	Delay time between start triggers and start signal.
X_PIPE0… 7	0x38…0x3F	RW	Target positions pipeline and/or parameter pipeline.

Table 29: Dedicated Ramp Timing Registers

9.1. Basic Synchronization Settings

Usually, a ramp can be initiated internally or externally. Note that a start trigger is not the start signal itself but the transition slope to the active start state. After a defined delay, the internal start signal is generated.

9.1.1. Start Signal Trigger Selection

For ramp start configuration, consider the following steps:

Action:

- ➢ Choose internal or external start trigger(s).
- ➢ Set the triggers according to the table below.
- i All triggers can be used separately or in combination.

Start Trigger Configuration Table	
***trigger_events* = *START_CONF*(8:5)**	**Result**
b’0000	No start signal will be generated or processed further.
b’xxx0	Set *trigger_events*(0) = 0 for internal start triggers only. The internally generated start signal is forwarded to the **START pin** that is assigned as **output**.
b’xxx1	Set *trigger_events*(0) = 1 for an external start trigger. The **START pin** is assigned as **input**. For START input take filter settings into consideration. See chapter 4, page 20.
b’xx1x	TARGET_REACHED event is assigned as start signal trigger for the ramp timer.
b’x1xx	VELOCITY_REACHED event is assigned as start signal trigger for the ramp timer.
b’1xxx	POSCOMP_REACHED event is assigned as start signal trigger for the ramp timer.

Table 30: Start Trigger Configuration

9.1.2. User-specified Impact Configuration of Timing Procedure

Per default, every SPI datagram is processed immediately. By selecting one of the following enable switches, the assignment of SPI requests to registers *XTARGET*, *VMAX*, *RAMP_MODE,* and *GEAR_RATIO* is uncoupled from the SPI transfer. The value assignment is only processed after an internally generated start signal.

In order to influence the impact of the start signal on internal parameter assignments, do the following:

Action:

- ➢ Choose between the following options as shown in the table below.

Start Enable Switch Configuration Table *(All switches can be used separately or in combination.)*	
start_en* =START_CONF*(4:0)	**Result**
b’xxxx1	*XTARGET* is altered only after an internally generated start signal.
b’xxx1x	*VMAX* is altered only after an internally generated start signal.
b’xx1xx	*RAMPMODE* is altered only after an internally generated start signal.
b’x1xxx	*GEAR_RATIO* is altered only after an internally generated start signal.
b’1xxxx	Shadow register is assigned as active ramp parameters after an internally generated start signal. This is explained in more detail in section 9.2. (page 74).

Table 31: Start Enable Switch Configuration

9.1.3. Delay Definition between Trigger and internally generated Start Signal

Per default, the trigger is closely followed by the internal start signal.

In order to delay the generation of the internal start signal, do the following:

Action:
- Set *START_DELAY* register 0x13 according to your specification.

Result:
When a start trigger is recognized, the internal start signal is generated after *START_DELAY* clock cycles.

Prioritizing External Input

Per default, an external trigger is also delayed for the internal start signal generation.

In order to immediately prompt an external start, trigger to an internally generated start signal (regardless of a defined delay), do the following:

Action:
- Set *immediate_start_in* = 1 (*START_CONF* register 0x02).

Result:
When an external start trigger is recognized, the internal start signal is generated immediately, even if the internal start triggers have already initiated a timing process with an active delay.

START Pin Polarity

The START pin can be used either as input or as output pin. However, the active voltage level polarity of the START pin can be selected with one configuration switch in the *START_CONF* register 0x02.

Per default, the voltage level transition from high to low triggers a start signal (START is an input), or START output indicates an active START event by switching from high to low level.

In order to invert active START polarity, do as follows:

Action:
- Set *pol_start_signal* = 1 (*START_CONF* register 0x02).

Result:
The START pin is high active. The voltage level transition from low to high triggers a start signal (START is an input), or START output indicates an active START event by switching from low to high level.

9.1.4. Active START Pin Output Configuration

Per default, the active output voltage level of the START pin lasts one clock cycle.

In order to extend this time span, do the following:

Condition:
- START pin is assigned as output: *trigger_events*(0) = 1.

Action:
- Set *START_OUT_ADD* register 0x11 according to your specification.

Result:
The active voltage level lasts (*START_OUT_ADD* + 1) clock cycles.

Read entire documentation; especially the "Supplemental Directives" on page 218.

9.1.5. Ramp Timing Examples

The following three examples depict SPI datagrams, internal and external signal levels, corresponding velocity ramps, and additional explanations. SPI data is transferred internally at the end of each datagram.

Ramp Timing Example 1

In this example, the velocity value change is executed immediately.

Process Description

- The new *XTARGET* value is assigned after TARGET_REACHED has been set and *START_DELAY* has elapsed.
- A new ramp does not start at the end of the second ramp because no new *XTARGET* value is assigned.
- START is an output.
- Internal start signal forwards with a step length of (*START_OUT_ADD* + 1) clock cycles.

This is how external devices can be synchronized:

Parameter Settings Timing Example 1	
Parameter	**Setting**
RAMPMODE	b'101
start_en	b'00001
trigger_events	b'0010
START_DELAY	>0
START_OUT_ADD	>0
pol_start_signal	1

Table 32: Parameter Settings Timing Example 1

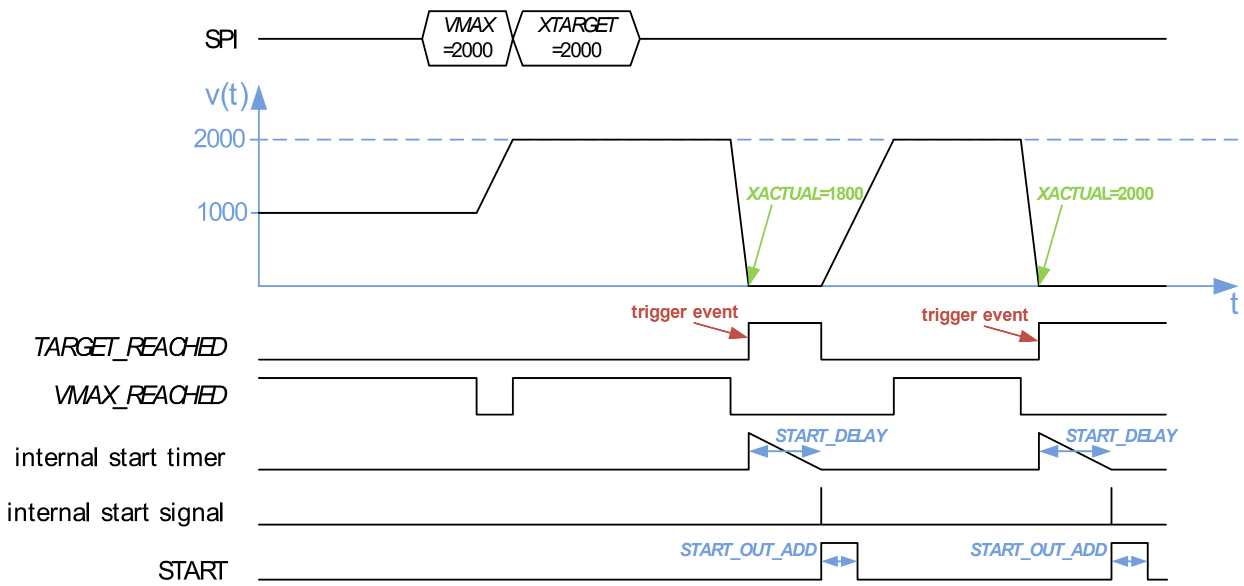


Figure 31: Ramp Timing Example 1

Read entire documentation; especially the "Supplemental Directives" on page 218.

Ramp Timing Example 2

In this example, the velocity value and the ramp mode value change is executed after the first start signal.

Process Description

- The new ramp mode becomes positioning mode with S-shaped ramps.
- The ramp then stops at target position *XTARGET* because of the ramp mode change.
- A further *XTARGET* change starts the ramp again.
- The ramp is initiated as soon as the start delay is completed, which was triggered by the first *TARGET_REACHED* event.
- The active START output signal lasts only one clock cycle.

Parameter Settings Timing Example 2	
Parameter	**Setting**
RAMPMODE	b'001 → b'110
start_en	b'00111
trigger_events	b'0110
START_DELAY	>0
START_OUT_ADD	0
pol_start_signal	0

Table 33: Parameter Settings Timing Example 2

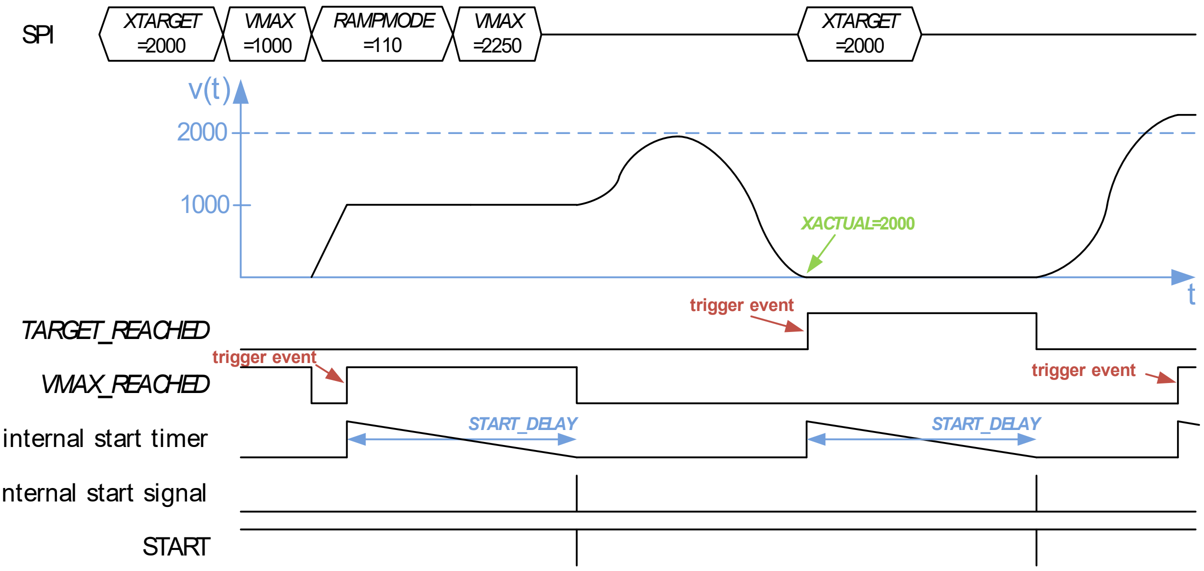


Figure 32: Ramp Timing Example 2

Ramp Timing Example 3

In this example external start signal triggers are prioritized by making use of *START_DELAY* > 0 and simultaneously setting *immediate_start_in* to 1.

Process Description

- When *XACTUAL* equals *POSCOMP* the start timer is activated and the external start signal in between is ignored.
- The second start event is triggered by an external start signal. The *POSCOMP_REACHED* event is ignored.

  The third start timer process is disrupted by the external START signal, which is forced to be executed immediately due to the setting of: *immediate_start_in* = 1.

Parameter Settings Timing Example 3	
Parameter	**Setting**
RAMPMODE	b'000
start_en	b'00010
trigger_events	b'1001
immediate_start_in	0 → 1
START_DELAY	>0
pol_start_signal	1

Table 34: Parameter Settings Timing Example 3

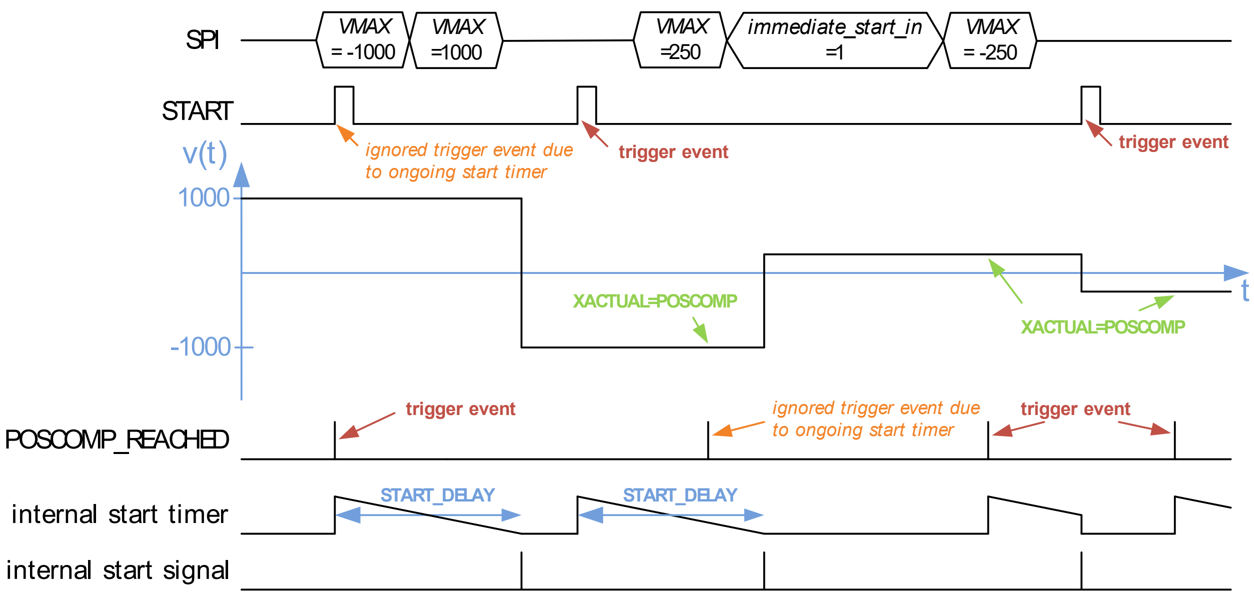


Figure 33: Ramp Timing Example 3

Read entire documentation; especially the "Supplemental Directives" on page 218.

9.2. Shadow Register Settings

Some applications require a complete new ramp parameter set for a specific ramp situation / point in time. TMC4361 provides up to 14 shadow registers, which are loaded into the corresponding ramp parameter registers after an internal start signal is generated.

Enabling Shadow Registers

In order to enable shadow registers, do as follows:

Action

- Set *start_en*(4) = 1 and select one or more *trigger_events* (*START_CONF* register 0x02), see section 9.1.2 (page 69).

Result:
With every successive internal start signal the shadow registers are loaded into the corresponding active ramp register.

Enabling Cyclic Shadow Registers

It is also possible to write back the current motion profile into the shadow motion registers to swap ramp motion profiles continually.

In order to enable cyclic shadow registers, do as follows:

Action

- Set *start_en*(4) = 1 and select one or more *trigger_events* (*START_CONF* register 0x02) , see section 9.1.2 (page 69).
- Set *cyclic_shadow_regs* = 1 (*START_CONF* register 0x02).

Result:
With every successive internal start signal the shadow registers are loaded into the corresponding active ramp register, whereas the active motion profile is loaded into the shadow registers.

•→ *Continued on next page.*

9.2.1. Shadow Register Configuration Options

Four different optional shadow register assignments are available to match the shadow register set according to your selected ramp type. The available options are described on the next pages.

i Please note that the only difference between the configuration of shadow option 3 and 4 is that *VSTART* is exchanged by *VSTOP* for the transfer of the shadow registers.

Option 1: Shadow Default Configuration

If the whole ramp register is needed to set in a single level stack, do as follows:

Action:

- Set *shadow_option* = b'00 (*START_CONF* register 0x02).
- Set *start_en*(4) = 1 and select one or more *trigger_events* (*START_CONF* register 0x02)

Action:

- **Default configuration:** Set *cyclic_shadow_regs* = 0 (*START_CONF* register 0x02)
- **Optional configuration:** Set *cyclic_shadow_regs* = 1 (*START_CONF* register 0x02)

Result:
Every relevant motion parameter is altered at the next internal start signal by the corresponding shadow register parameter. In case cyclic shadow registers are used, the shadow register set is altered by the current motion profile set.

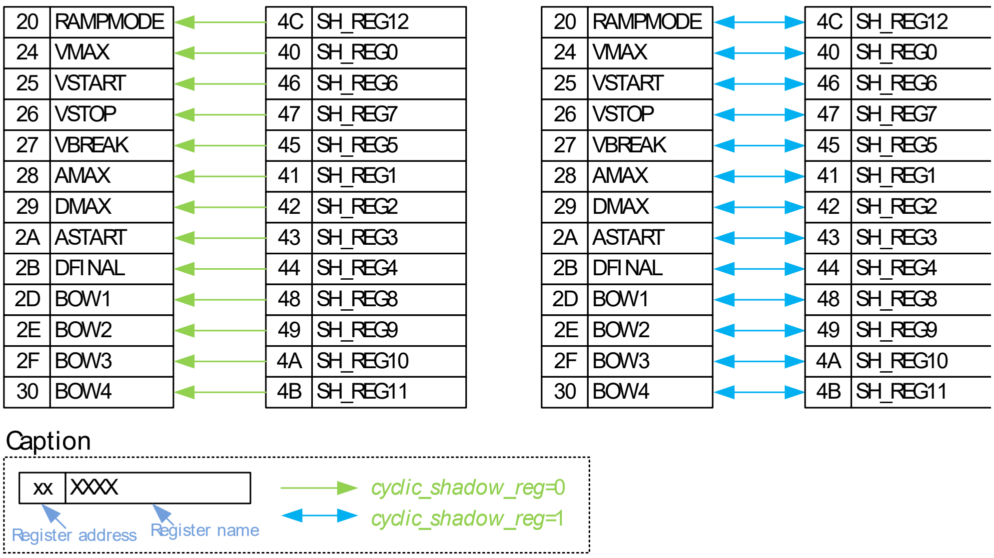


Figure 34: Single-level Shadow Register Option to replace complete Ramp Motion Profile.

i Green arrows show default settings

i Blue arrows show optional settings.

•→ *Continued on next page.*

Option 2: Double-stage Shadow Register Set for S-shaped Ramps

In case S-shaped ramps are configured, a double-stage shadow register set can be used. Seven relevant motion parameters for S-shaped ramps are affected when the shadow registers become active.

In order to use a double-stage shadow register pipeline for S-shaped ramps, do as follows:

Action:

- Set *shadow_option* = b'01 (*START_CONF* register 0x02).
- Set *start_en*(4) = 1 and select one or more *trigger_events* (*START_CONF* register 0x02).

Action:

- **Default configuration:** Set *cyclic_shadow_regs* = 0 (*START_CONF* register 0x02).
- **Optional configuration:** Set *cyclic_shadow_regs* =1 (*START_CONF* register 0x02)

Result:

Seven motion parameters (*VMAX*, *AMAX*, *DMAX*, *BOW1…4*) are altered at the next internal start signal by the corresponding shadow register parameters (*SH_REG0…6*). Simultaneously, these shadow registers are exchanged with the parameters of the second shadow stage (*SH_REG7…13*).
In case cyclic shadow registers are used, the second shadow register set (*SH_REG7…13*) is altered by the current motion profile set, e.g. 0x28 (*AMAX*) is written back to 0x48 (*SH_REG8*).
The other ramp registers remain unaltered.

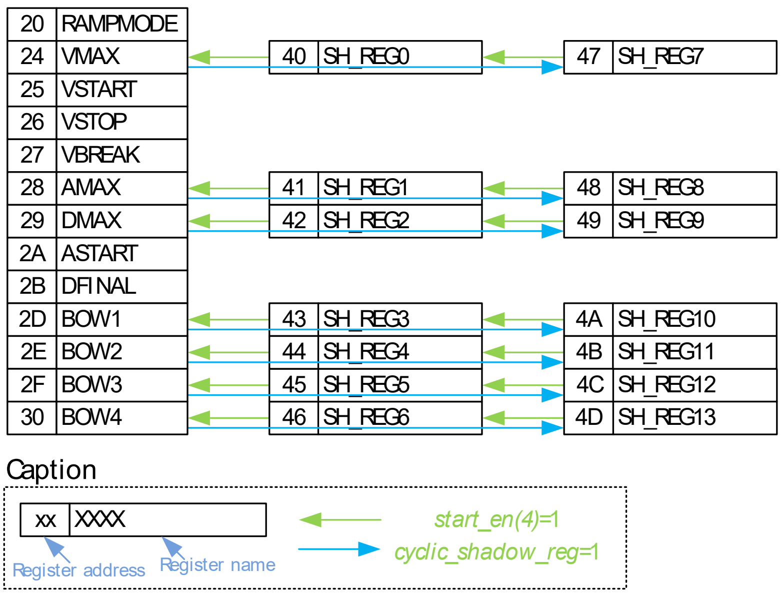


Figure 35: Double-stage Shadow Register Option 1, suitable for S-shaped Ramps.

i Green arrows show default settings

i Blue arrows show optional settings.

•→ *Description is continued on next page.*

Shadow Option3 Double-stage Shadow Register Set for Trapezoidal Ramps (*VSTART*)

In case trapezoidal ramps are configured, a double-stage shadow register set can be used. Seven relevant motion parameters for trapezoidal ramps are affected when the shadow registers become active.

In order to use a double-stage shadow register pipeline for trapezoidal ramps, do as follows:

Action:
- Set *shadow_option* = b'10 (*START_CONF* register 0x02).
- Set *start_en*(4) = 1 and select one or more *trigger_events* (*START_CONF* register 0x02)

Action:
- **Default configuration:** Set *cyclic_shadow_regs* = 0 (*START_CONF* register 0x02).
- **Optional configuration:** Set *cyclic_shadow_regs* = 1 (*START_CONF* register 0x02).

Result:
Seven motion parameters (*VMAX*, *AMAX*, *DMAX, ASTART, DFINAL, VBREAK*, and *VSTART*) are altered at the next internal start signal by the corresponding shadow register parameters (*SH_REG0…6*). Simultaneously, these shadow registers are exchanged with the parameters of the second shadow stage (*SH_REG7…13*).
If cyclic shadow registers are used, the second shadow register set (*SH_REG7…13*) is altered by the current motion profile set, e.g. 0x27 (*VBREAK*) is written back to 0x4C (*SH_REG12*). The other ramp registers remain unaltered.

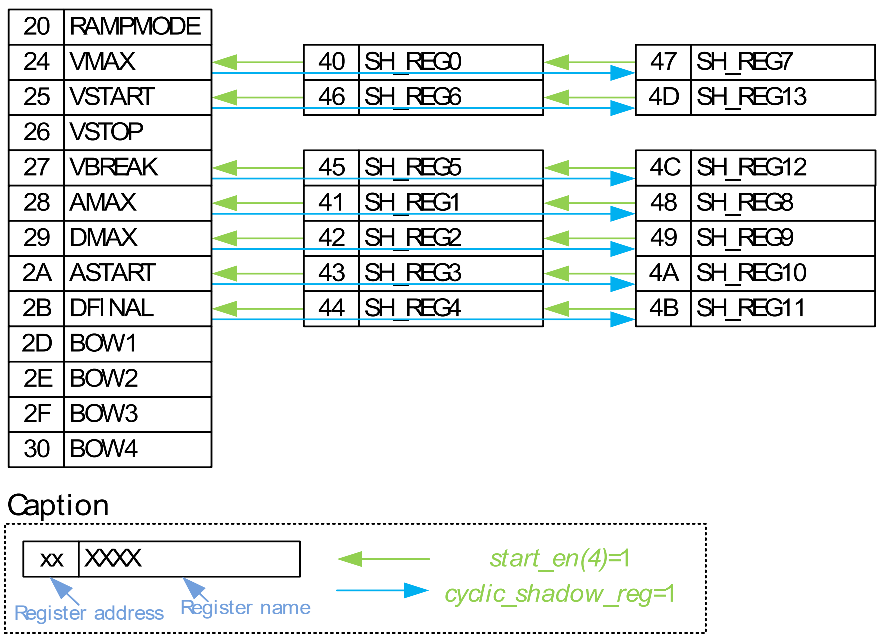


Figure 36: Double-stage Shadow Register Option 2, suitable for Trapezoidal Ramps.

i Green arrows show default settings.

i Blue arrows show optional settings.

•→ *Description is continued on next page.*

Shadow Option4: Double-stage Shadow Register Set for Trapezoidal Ramps (*VSTOP*)

In case trapezoidal ramps are configured, a double-stage shadow register set can be used. Seven relevant motion parameters for trapezoidal ramps are affected when the shadow registers become active.

In order to use a double-stage shadow register pipeline for trapezoidal ramps, do as follows:

Action:
- Set *shadow_option* = b'10 (*START_CONF* register 0x02).
- Set *start_en*(4) = 1 and select one or more *trigger_events* (*START_CONF* register 0x02)

Action:
- **Default configuration:** Set *cyclic_shadow_regs* = 0 (*START_CONF* register 0x02).
- **Optional configuration:** Set *cyclic_shadow_regs* = 1 (*START_CONF* register 0x02)

Result:
Seven motion parameters (*VMAX*, *AMAX*, *DMAX, ASTART, DFINAL, VBREAK*, and *VSTOP*) are altered at the next internal start signal by the corresponding shadow register parameters (*SH_REG0...6*). Simultaneously, these shadow registers are exchanged with the parameters of the second shadow stage (*SH_REG7...13*).
If cyclic shadow registers are used, the second shadow register set (*SH_REG7...13*) is altered by the current motion profile set, e.g. 0x26 (*VSTOP*) is written back to 0x4D (*SH_REG13*). The other ramp registers remain unaltered.

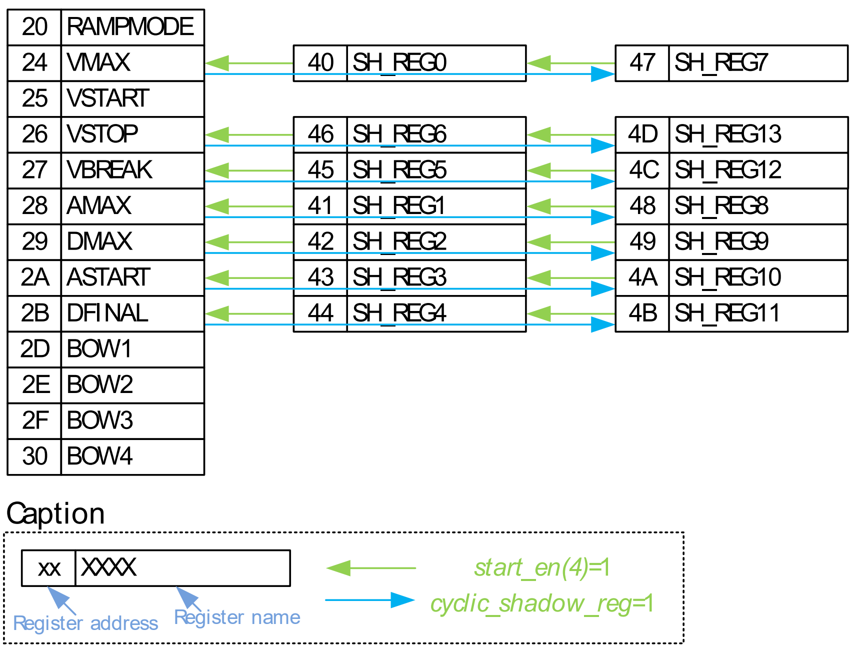


Figure 37: Double-Stage Shadow Register Option 3, suitable for Trapezoidal Ramps

- i Green arrows show default settings.
- i Blue Arrows show optional settings.

•→ *Turn page to see **Areas of Special Concern** pertaining to this section.*

AREAS OF SPECIAL CONCERN

! **The values of ramp parameters, which are not selected by one of the four shadow options stay as originally configured, until the register is changed through an SPI write request.**
Also, the last stage of the shadow register pipeline retains the values until they are overwritten by an SPI write request if no cyclic shadow registers are selected.

9.2.2. Delayed Shadow Transfer

Up to 15 internal start signals can be skipped before the shadow register transfer is executed.

In order to skip a defined number of internal start signals for the shadow transfer, do as follows:

Action:

- Set *shadow_option* according to your specification.
- Set *start_en*(4) = 1 and select one or more *trigger_events* (*START_CONF* register 0x02)
- ***OPTIONAL CONFIGURATION:*** Set *cyclic_shadow_regs* = 1.
- Set *SHADOW_MISS_CNT* ≠ 0 (*START_CONF* register 0x02) according to the number of consecutive internal start signals that you specify to be ignored.

Result:
The shadow register transfer is not executed with every internal start signal. Instead, the specified number of start signals is ignored until the shadow transfer is executed through the (*SHADOW_MISS_CNT*+1)th start signal.

The following figure shows an example of how to make use of *SHADOW_MISS_CNT*, in which the shadow register transfer is illustrated by an internal signal sh_reg_transfer. The signal miss counter *CURRENT_MISS_CNT* can be read out at register address *START_CONF* (23:20):

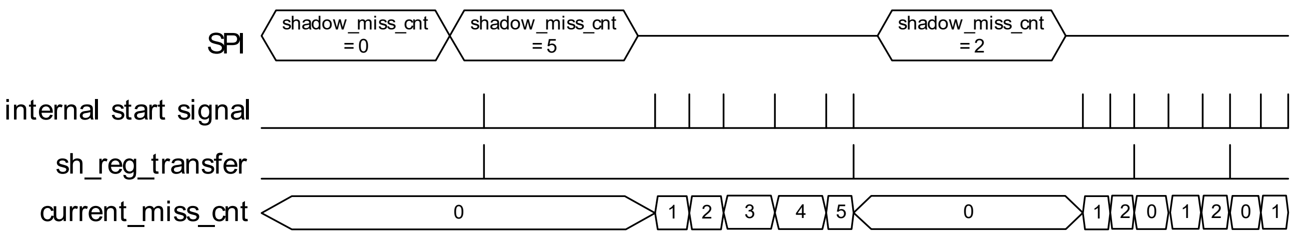


Figure 38: SHADOW_MISS_CNT Parameter for several internal Start Signals

•→ *Description is continued on next page.*

AREAS OF SPECIAL CONCERN

!

Internal calculations to transfer the requested shadow BOW values into internal structures require at most (320 / f_{CLK}) [sec]. before any shadow register transfer is prompted, it is necessary to wait for the completion of all internal calculations for the shadow bow parameters.

In order to make this better understood the following example is provided for a double-stage shadow pipeline for S-shaped ramps:

PRECONDITION:

Shadow register transfer is activated (*start_en*(1) = 1 and one or more *trigger_events* are selected) for S-shaped ramps (*shadow_option* = b'01)

Action

- Set *SH_REG0*, *SH_REG1*, *SH_REG2* (shadow register for *VMAX*, *AMAX*, *DMAX*).
- Set *SH_REG3*, *SH_REG4*, *SH_REG5*, *SH_REG6* (shadow register for *BOW1…4*).
- Ensure that no shadow register transfer occurs during the next 320 / f_{CLK} [s].

Result:
Shadow register transfer can be initiated after this time span.

AREAS OF SPECIAL CONCERN

!

It is strongly recommended that the values of the shadow ramp parameters are only transferred during standstill of the current ramp (*VACTUAL* = 0); especially if the *RAMP_MODE* is changed.

In case the transfer is prompted during motion, *VACTUAL* must be constant for all ramp types. If S-Shaped ramps are selected, please ensure that *VACTUAL* is configured to remain constant for a definite delay $t_{SHADOW\_TRANSFER}$ before you assign any new *VMAX* or *XTARGET* values, because a new internal recalculation process is triggered:

$$t_{SHADOW\_TRANSFER} = x = \frac{\sqrt{\max(BOW3[pps^3], BOW4[pps^3]) \cdot \mathrm{VMAX[pps]}}}{56 \cdot BOW3[pps^3]}$$

If positioning mode is selected, *XTARGET* must be set accordingly in order to maintain a constant *VACTUAL* value.

It is also required that *VMAX* and its shadow counterpart must be equal to avoid alteration of *VACTUAL* during $t_{SHADOW\_TRANSFER}$.

9.3. Pipelining Internal Parameters

TMC4361 provides a target pipeline for sequencing subordinate targets in order to easily arrange a complex target structure.

9.3.1. Configuration and Activation of Target Pipeline

The different target values must be assigned to the *X_PIPE0…7* register. If the target pipeline is enabled, a new assignment cycle is initiated as soon as an internal start signal is generated; moving the values, as described, simultaneously:

PROCESS DESCRIPTION:

- A new *XTARGET* value is assigned that takes over the value of *X_PIPE0.*
- Every *X_PIPE*n register takes over the value of its successor: *X_PIPE*n = *X_PIPE*n+1.

In order to activate the target pipeline, do as follows:

Action:
- ➢ Set *pipeline_en* = b'0001 (*START_CONF* register 0x02).

Result:
The above mentioned process description is executed with every new internal start signal prompting.

Configuration of a cyclic Target Pipeline

It is also possible to reassign the value of *XTARGET* to one (or more) of the pipeline registers *X_PIPE0…7.* Thereby, a cyclic target pipeline is created.

In order to enable a cyclic target pipeline, do as follows:

Action:
- ➢ Set *pipeline_en* = b'0001 (*START_CONF* register 0x02).
- ➢ Set *XPIPE_REWRITE_REG* in relation to the pipeline register where *XTARGET* have to written back (e.g. *XPIPE_REWRITE_REG* = b'00010000).

Result:
The above mentioned process description is executed with every new internal start signal prompting, and *XTARGET* is written back to the selected *X_PIPEx* register (e.g. *XPIPE_REWRITE_REG* = 0x10 → *XTARGET* is written back to *X_PIPE4*).
The processes and actions described on the previous page, are depicted in the following figure. The assignment cycle that is initiated when an internal start signal occurs is depicted.

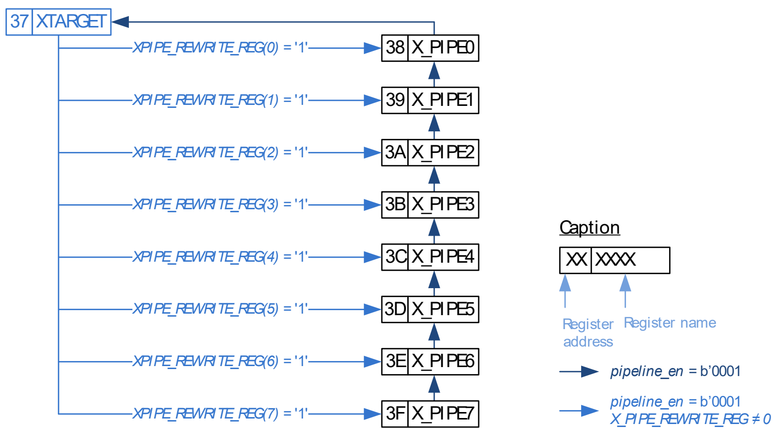


Figure 39: Target Pipeline with Configuration Options

Read entire documentation; especially the "Supplemental Directives" on page 218.

9.3.2. Using the Pipeline for different internal Registers

The TMC4361 pipeline (registers 0x38…0x3F) can be configured so that it splits up into maximal four segments. These segments can be used to feed the following internal parameters:

- *XTARGET* register 0x37
- *POS_COMP* register 0x32
- *GEAR_RATIO* register 0x12
- *GENERAL_CONF* 0x00

Consequently, these definite parameter value changes can be of importance concerning a continuous ramp motion and/or for reduced overhead synchronizing of several motion controllers.

The *POS_COMP* value can be used to initiate a start signal generation during motion. Therefore, it can be useful to pipeline this parameter in order to avoid dependence on SPI transfer speed.
For instance, if the distance between two *POS_COMP* values is very close and the current velocity is high enough that it misses the second value before the SPI transfer is finished, it is advisable to change *POS_COMP* immediately after the start signal.

The same is true for the *GEAR_RATIO* parameter, which defines the step response on incoming step impulses. Some applications require very quick gear factor alteration of the slave controller. Note that when the start signal is prompted directly, an immediate change can be very useful instead of altering the parameter by an SPI transfer.

Likewise, it can (but must not) be essential to change general configuration parameters at a defined point in time. A suitable application is a clearly defined transfer from a direct external control (*sd_in_mode* = b'01) to an internal ramp (*sd_in_mode* = b'00) or vice versa because in this case the master/slave relationship is interchanged.

The following pipeline options are available, which can be adjusted accordingly:

Pipeline Activation Options	
***pipeline_en*(3:0)**	**Description**
b'xxx1	Pipeline for *XTARGET* is enabled.
b'xx1x	Pipeline for *POS_COMP* is enabled.
b'x1xx	Pipeline for *GEAR_RATIO* is enabled.
b'1xxx	Pipeline for *GENERAL_CONF* is enabled.

Table 35: Pipeline Activation Options

Read entire documentation; especially the "Supplemental Directives" on page 218.

9.3.3. Pipeline Mapping Overview

The *pipeline_en* parameter offers an open configuration for 16 different combinations of the pipeline segregation. As a result, the number of pipelines range from 0 to 4. This also has an impact on the pipeline depth. The possible options are as follows: eight stages, four stages, three stages and two stages.

In the "Pipeline Mapping" table below, the arrangement and depth of the pipeline is allocated according to the pipeline setup. The final register destination of pipeline registers are also depicted in order to illustrate from which pipeline registers (*X_PIPE0…7*) the final target registers (*XTARGET*, *POS_COMP*, *GEAR_RATIO*, *GENERAL_CONF*) are fed.

For example, if *POS_COMP* and *GEAR_RATIO* are chosen as parameters that are to be fed by the pipeline, two 4-stage pipelines are created. When an internal start signal is generated, *POS_COMP* assumes the value of *X_PIPE0*, whereas *X_PIPE4* feeds the *GEAR_RATIO* register.

But if *POS_COMP*, *GEAR_RATIO* and *XTARGET* are selected as parameter destinations, two 3-stage pipelines and one double-stage pipeline are created. When an internal start signal is generated, *XTARGET* assumes the value of *X_PIPE0*, *POS_COMP* assumes the value of *X_PIPE3*, whereas *X_PIPE6* feeds the *GEAR_RATIO* register.

Pipeline Mapping Table

More examples are described in detail on the following pages - explaining some of the possible configurations and referencing examples - listed in the table below.

Pipeline Mapping						
Ex.	***pipeline_en* (3:0)**	**Arrangement**	*Final transfer register for…*			
			GENERAL_CONF →pipeline_en(3)	*GEAR_RATIO* →pipeline_en(2)	*POS_COMP* →pipeline_en(1)	*XTARGET* →pipeline_en(0)
-	*b'0000*	*No Pipelining*	-	-	-	-
-	*b'0001*	*One 8-stage pipeline*	-	-	-	X_PIPE0
A	*b'0010*		-	-	X_PIPE0	-
B	*b'0100*		-	X_PIPE0	-	-
-	*b'1000*		X_PIPE0	-	-	-
C	*b'0011*	*Two 4-stage pipelines*	-	-	X_PIPE4	X_PIPE0
-	*b'0101*		-	X_PIPE4	-	X_PIPE0
-	*b'1001*		X_PIPE4	-	-	X_PIPE0
-	*b'0110*		-	X_PIPE4	X_PIPE0	-
-	*b'1010*		X_PIPE4	-	X_PIPE0	-
D	*b'1100*		X_PIPE4	X_PIPE0	-	-
F	*b'0111*	*Two 3-stage pipelines and one double-stage pipeline*	-	X_PIPE6	X_PIPE3	X_PIPE0
-	*b'1011*		X_PIPE6	-	X_PIPE3	X_PIPE0
E	*b'1101*		X_PIPE6	X_PIPE3	-	X_PIPE0
-	*b'1110*		X_PIPE6	X_PIPE3	X_PIPE0	-
G/H	*b'1111*	*Four double-stage pipelines*	X_PIPE6	X_PIPE4	X_PIPE2	X_PIPE0

Table 36: Pipeline Mapping for different Pipeline Configurations

9.3.4. Cyclic Pipelining

For all of the above shown configuration examples, it is possible to write back the current values of the selected registers (*XTARGET*, *POS_COMP*, *GEAR_RATIO* and/or *GENERAL_CONF*) to any of the pipeline registers of their assigned pipeline in order to generate cyclic pipelines.

By selecting proper *XPIPE_REWRITE_REG*, the value that is written back to the pipeline register is selected automatically to fit the selected pipeline mapping.

9.3.5. Pipeline Examples

Below, several pipeline mapping examples with the corresponding configuration are shown.

Examples A+B: Using one Pipeline

Example A: Cyclic pipeline for *POS_COMP,* which has eight pipeline stages.

Example B: Cyclic pipeline for *GEAR_RATIO,* which has six pipeline stages.

A

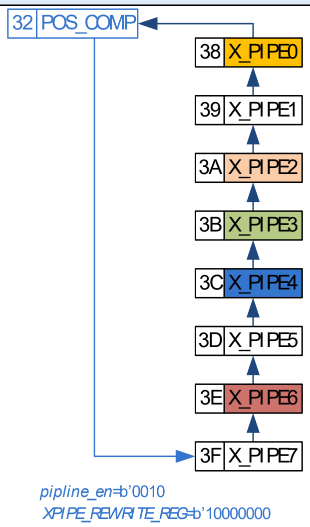


Figure 40: Pipeline Example A

B

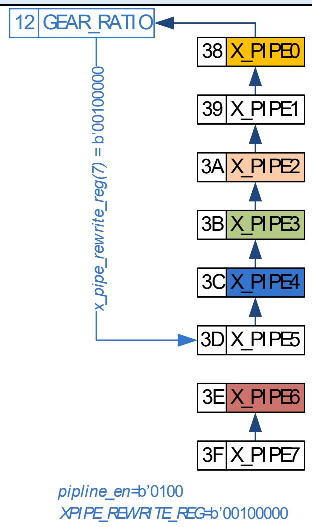


Figure 41: Pipeline Example B

•→ *Description is continued on next page.*

Examples C+D: Using two Pipelines

Example C: Cyclic pipelines for *XTARGET* and *POS_COMP*, which have four pipeline stages each.

Example D: Cyclic pipelines for *GEAR_RATIO*, which has three pipeline stages and *GENERAL_CONF*, which has two pipeline stages.

C

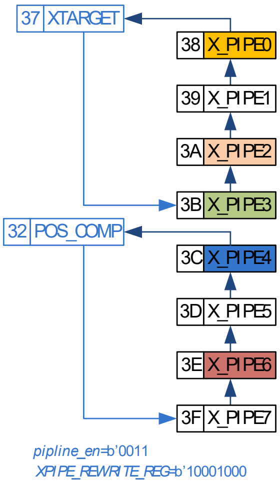


Figure 42: Pipeline Example C

D

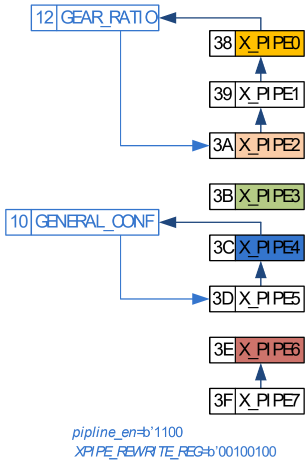


Figure 43: Pipeline Example D

Examples E+F: Using three Pipelines

Example E: Cyclic pipelines for *XTARGET* and *GEAR_RATIO*, which have three pipeline stages each and *GENERAL_CONF*, which has two pipeline stages.

Example F: Two cyclic pipelines for *XTARGET* and *GEAR_RATIO*, which have two pipeline stages each and a noncyclic pipeline for *GEAR_RATIO*, which has three pipeline stages.

E

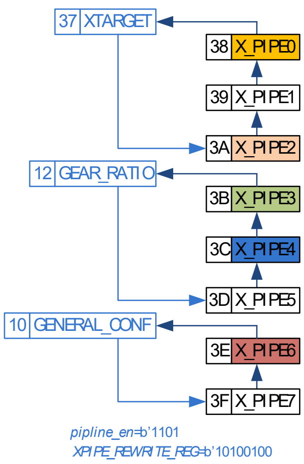


Figure 44: Pipeline Example E

F

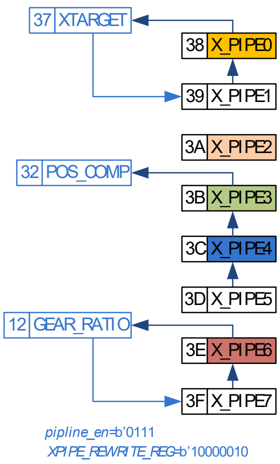


Figure 45: Pipeline Example F

•→ *Continued on next page.*

Examples G+H: Using four Pipelines

Example G: Cyclic pipelines for *XTARGET*, *POS_COMP*, *GEAR_RATIO* and *GENERAL_CONF,* which have two pipeline stages each.

Example H: Four noncyclic pipelines for *XTARGET*, *POS_COMP*, *GEAR_RATIO* and *GENERAL_CONF,* which have two pipeline stages each.

G	H

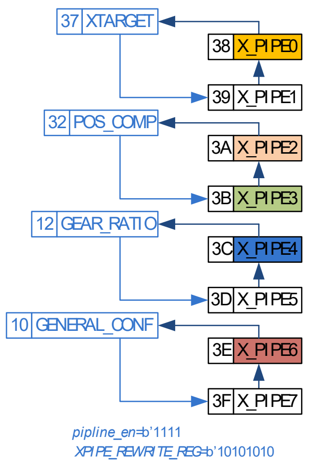


Figure 46: Pipeline Example G

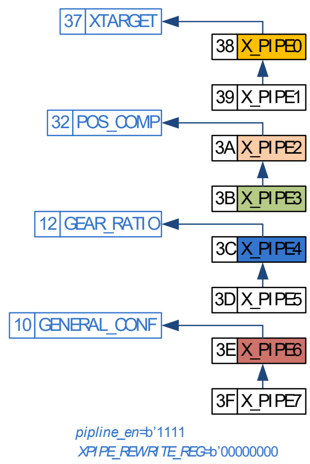


Figure 47: Pipeline Example H

Read entire documentation; especially the "Supplemental Directives" on page 218.

9.4. Masterless Synchronization of Several Motion Controllers via START Pin

START pin can also be assigned as tristate input in order to synchronize several microcontroller masterless.

Activation of the Tristate START Pin

In this case START is assigned as tristate. A busy state is enabled. During this busy state, START is set as output with a strongly driven inactive polarity. If the internal start signal is generated – after the internal start timer is expired –START pin is assigned as input. Additionally, a weak output signal is forwarded at START. During this phase, the active start polarity is emitted.

In case the signal at START input is set to active polarity, e.g. because all members of the signal line are ready, START output remains active (strong driving strength) for *START_OUT_ADD* clock cycles.
Then, busy state is active again until the next start signal occurs.

In order to activate tristate START pin, do as follows:

Action:

➢ Set *busy_en* = 1 (*START_CONF* register 0x02).

Result:
The above mentioned process description is executed.

START Pin Connection

In case START pin is connected with START pins of other TMC4361 devices, it is recommend that a series resistor (e.g. 220 Ω) is connected between the devices to limit the short circuit current flowing that can flow during the configuration phase when different voltage levels at the START pins of the different devices can occur.

NOTE:

→ *Avoid that short circuits last too long.*

10. Serial Data Output

TMC4361 provides an SPI interface for initialization and configuration of the motor driver (in addition to the Step/Dir output) before and during motor motion. It is possible to control TMC stepper drivers during SPI motor drive.

SPI Interface Configuration

The SPI interface is used for the following tasks:

- TMC4361 integrates an adjustable cover register for configuration purposes in order to adjust TMC motor driver chips and third parties chips easily.
- The integrated microstep Sine Wave Lookup Table MSLUT generates two current values that represent sine and cosine values.
- These two current values can be transferred to a TMC motor driver chip at a time, in order to energize the motor coils. This occurs within each SPI datagram. A series of current values is transferred to move the motor. Values of the MSLUT are adjusted using velocity ramp dependent scale values that align the maximum amplitude current values to the requirements of certain velocity slopes.

Pin Names for SPI Motor Drive		
Pin Names	**Type**	**Remarks**
NSCSDRV_SDO	Output	Chip select output to motor driver, low active.
SCKDRV_NSDO	Output	Serial clock output to motor driver.
SDODRV_SCLK	InOut as Output	Serial data output to motor driver.
SDIDRV_NSCLK	Input	Serial data input from motor driver.
STDBY_CLK	Output	Clock output, standby output, or ChopSync clock output.

Table 37: Pin Names for SPI Motor Drive

Register Names for SPI Output Registers			
Register Name	**Register Address**		**Remarks**
GENERAL_CONF	0x00	RW	Affect switches: Bit14:13, bit19, bit20, bit28.
REFERENCE_CONF	0x01	RW	Affect switches: Bit26, bit27, bit30.
SPIOUT_CONF	0x04	RW	Configuration register for SPI output communication.
STEP_CONF	0x0A	RW	Microsteps per fullstep, fullsteps per revolution, and motor status bit event selection.
DAC_ADDR	0x1D	RW	SPI addresses/commands which are put in front of the DAC values: CoilA: DAC_ADDR(15:0), CoilB: DAC_ADDR(31:16)
SPI_SWITCH_VEL	0x1F	RW	Velocity at which automatic cover datagram are sent.
CHOPSYNC_DIV			Chopper clock divider (bit11:0).
FS_VEL	0x60	W	Velocity at which fullstep drive are enabled.
COVER_LOW	0x6C	W	Lower 32 bits of the cover register (µC to motor driver).
COVER_HIGH	0x6D	W	Upper 32 bits of the cover register (µC to motor driver).
COVER_DRV_LOW	0x6E	R	Lower 32 bits of the cover response register (motor driver to µC).
COVER_DRV_HIGH	0x6F	R	Upper 32 bits of the cover response register

Register Names for SPI Output Registers			
Register Name	**Register Address**		**Remarks**
			(motor driver to µC).
CURRENT_CONF	0x05	RW	Current scaling configuration.
SCALE_VALUES	0x06	RW	Current scaling values.
STDBY_DELAY	0x15	RW	Delay time after standby mode is valid.
FREEWHEEL_DELAY	0x16	RW	Delay time after freewheeling is valid.
VDRV_SCALE_LIMIT	0x17	RW	Velocity setting for changing the drive scale value.
UP_SCALE_DELAY	0x18	RW	Increment delay to a higher scaling value; 24 bits.
HOLD_SCALE_DELAY	0x19	RW	Decrement delay to the hold scaling value; 24 bits.
DRV_SCALE_DELAY	0x1A	RW	Decrement delay to the drive scaling value.
BOOST_TIME	0x1B	RW	Delay time after ramp start when boost scaling is valid.
SCALE_PARAM	0x7C	R	Actual current scaling parameter; 8 bits.
CURRENTA *CURRENTB*	0x7A	R	Actual current values of the MSLUT: SIN (coil A) and SIN90_120 (coil B); 9 bits for each.
CURRENTA_SPI *CURRENTB_SPI*	0x7B	R	Actual scaled current values of the MSLUT: SIN (coil A) and SIN90_120 (coil B); 9 bits for each.
MSLUT registers	0x70…78	W	MSLUT values definitions.
MSCNT	0x79	R	Actual microstep position of the MSLUT.
START_SIN *START_SIN90_120* *DAC_OFFSET*	0x7E	RW	Sine start value of the MSLUT (bit 7:0). Cosine start value of the MSLUT (bit 23:16). Offset value for DAC output values (bit 31:24).

Table 38: Dedicated SPI Output Registers

10.1. Getting Started with TMC Motor Drivers

In this chapter information is provided about how to easily start up a connected TMC motor driver.

Setting up *SPIOUT_CONF* correctly

In order to start up a connected TMC motor stepper driver, proper setup of *SPIOUT_CONF* register 0x04 is important. TMC4361 offers presets for current transfer and automatic configuration routines if the correct TMC driver is selected. Status bits of TMC motor drivers are also transmitted to the status register of the motion controller.

TMC4361 provides a programmable lookup table (LUT) for storing the current wave. Per default, the tables are preprogrammed with a sine wave, which is a good starting point for most stepper motors.

Read entire documentation; especially the “Supplemental Directives” on page 218.

10.2. Sine Wave Lookup Tables

TMC4361 provides a programmable lookup table (LUT) for storing the current wave. Reprogramming the table from its predefined values to a motor-specific wave allows improved motor-reliant microstepping, particularly when using low-cost motors.

SETTINGS ALERT **!** **TMC4631-LA provides a default configuration of the internal microstep table MSLUT. In case internal MSLUT is used, proceed with section 10.9. (page 97) in order to configure a well-defined serial data connection to the stepper motor driver. The following explanations that are provided in this section only address engineers who use their own microstep table definition.**

Programming Sine Wave Lookup Tables

The internal microstep wave table maps the microstep wave from 0° to 90° for 256 microsteps. It becomes automatically and symmetrically extended to 360° that consequently comprises 1024 microsteps. As a result, the microstep counter *MSCNT* ranges from 0 to 1023. Only a quarter of the wave is stored because this minimizes required memory and the amount of programmable data.
Therefore, only 256 bits (*ofs*00 to *ofs*255) are required to store the quarter wave. These bits are mapped to eight 32-bit registers *MSLUT*[0] (register 0x70) to *MSLUT*[7] (register 0x77).
When reading out the table the 10-bit microstep counter *MSCNT* addresses the fully extended wave table.

Sine Wave Table Structure

The MSLUT is an incremental table. This means that a certain order and succession is predefined at every next step based on the value before, using up to four flexible programmable segments within the quarter wave. The microstep limits of the four segments are controlled by the position registers X1, X2, and X3.

Within these segments the next value of the MSLUT is calculated by adding the base wave inclination Wx−1 (if *ofs*=0) or its successor Wx (if *ofs*=1). Because four segments are programmable, four base wave inclinations are available as basic increment value: 0, 1, 2, or 3. Thereby, even a negative wave inclination can be realized. This is shown in the next Figure where the values in last quarter segments are decreased or remain constant with every step towards *MSCNT*= 255.

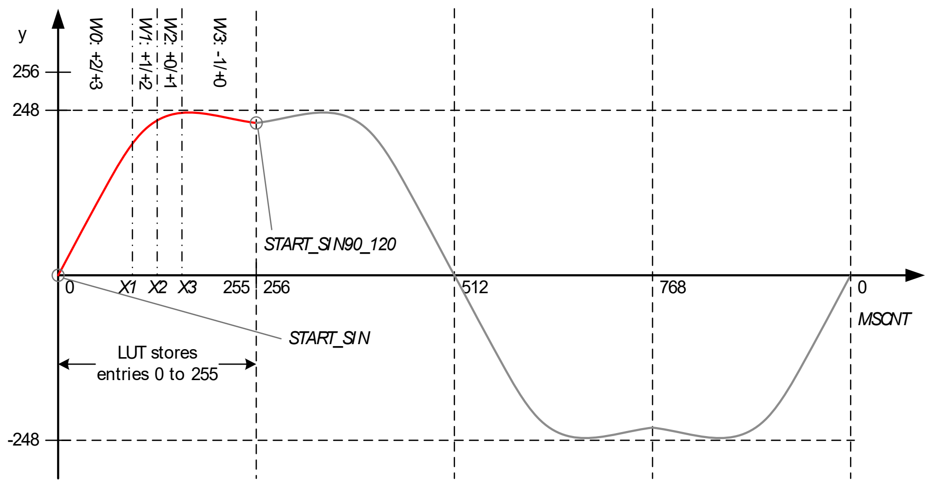


Figure 48: LUT Programming Example

10.2.1. Actual Current Values Output

Actual Current Calculations

When the microstep sequencer advances within the microstep table (MSLUT), it calculates the actual current values for the motor coils with each microstep, and stores them to the register 0x7A, which comprises the values of both waves *CURRENTA* and *CURRENTB*. However, the incremental coding requires an absolute initialization – especially when the microstep table becomes modified. Therefore, *CURRENTA* and *CURRENTB* become re-initialized with the start values whenever *MSCNT* passes zero.

Characteristics of a 2-Phase Stepper Motor Microstep Table

As mentioned above, the MSLUT can be adapted to the motor requirements. In order to understand the nature of incremental coding of the microstep table, the characteristics of the microstep wave must be understood, as described in the list below:

Characteristics of a 2-phase motor microstep table:

- In principle, it is a reverse characteristic of the motor pole behavior.
- It is a polished wave to provide a smooth motor behavior. There are no jumps within the wave.
- The phase shift between both phases is exactly 90°, because this is the optimum angle of the poles inside the motor.
- The zero transition is at 0°. The curve is symmetrical within each quadrant (like a sine wave).
- The slope of the wave is normally positive, but due to torque variations it can also be (slightly) negative.
- But it must not be strictly monotonic as shown in the figure above.

Considering these facts, it becomes clear that the wave table can be compressed. The incremental coding applied to TMC4361 uses a format that reduces the required information - *per entry of the 8-bit by a 256-entry wave table* - to slightly more than a single bit.

10.2.2. How to Program the Internal MSLUT

Principle of Incremental Encoding

The principle of **incremental encoding** only stores the difference between the actual and the next table entry. In order to attain an absolute start value, the first entry is directly stored in *START_SIN*. Also, for ease-of-use, the first entry of the shifted table for the second motor phase is stored in *START_SIN_90_120*.

Based on these start values, every next table entry is calculated by adding an increment INC to the former value. This increment is the base wave inclination value Wx whenever its corresponding *ofs* bit is 1 or Wx –1 if *ofs* = 0:

INC = Wx + (ofs – 1).

The base wave inclination can be set to four different values (0, 1, 2, 3), because it consists of two bits.

Because the wave inclination does not change dramatically, TMC4361 provides four wave inclination segments with the base wave inclinations (W0, W1, W2, and W3) and the segment borders (0, X1, X2, X3, and 255), as shown in the left quarter of the MSLUT diagram in *Figure* 48, page 90.

Wave Inclination Characteristics		
Wave Inclination Segment	**Base Wave Inclination**	**Segment Ranges**
0	W0	0 … X1
1	W1	X1… X2
2	W2	X2 … X3
3	W3	X3 … 255

Table 39: Wave Inclination Characteristics of Internal MSLUT

10.2.3. Setup of MSLUT Segments

Base Wave Inclination and Border Values

All base wave inclination values (each consists of two bits) as well as the border values (each consists of eight bit) between the segments are adjustable. They are assigned by *MSLUTSEL* register 0x78.

In order to change the base wave inclination values and the segment borders, do as follows:

Action:

- Define the segment borders X1, X2, and X3 and the base wave inclination values W0…W3 according to the requirements
- Set register *MSLUTSEL*(31:24) = X3.
- Set register *MSLUTSEL*(23:16) = X2.
- Set register *MSLUTSEL*(15:8) = X1.
- Set register *MSLUTSEL*(7:6) = W3.
- Set register *MSLUTSEL*(5:4) = W2.
- Set register *MSLUTSEL*(3:2) = W1.
- Set register *MSLUTSEL*(1:0) = W0.

Result:
The segments and the base wave inclination values of the internal MSLUT are changed.

NOTE:

→ *It is not mandatory to define four segments. For instance, if only two segments are required, set X2 and X3 to 255. Then, W0 is valid for segment 0 between MSCNT = 0 and MSCNT = X1, and W1 is valid between MSCNT = X1 and MSCNT = 255 (segment 1).*

In order to change the *ofs* bits, do as follows:

Action:

- Set *MSLUT*[0] register 0x70 = *ofs*31…*ofs*00.
- Set *MSLUT*[1] register 0x71 = *ofs*63…*ofs*32.
- Set *MSLUT*[2] register 0x72 = *ofs*95…*ofs*64.
- Set *MSLUT*[3] register 0x73 = *ofs*127…*ofs*96.
- Set *MSLUT*[4] register 0x74 = *ofs*159…*ofs*128.
- Set *MSLUT*[5] register 0x75 = *ofs*191…*ofs*160.
- Set *MSLUT*[6] register 0x76 = *ofs*223…*ofs*192.
- Set *MSLUT*[7] register 0x77 = *ofs*255…*ofs*224.

Result:
The *ofs* bits of the internal MSLUT are changed.

AREAS OF SPECIAL CONCERN !

Zero Crossing

When modifying the wave:
Special care has to be applied in order to ensure a smooth and symmetrical zero transition whenever the quarter wave becomes expanded to a full wave.

When adjusting the range:
The maximum resulting swing of the wave should be adjusted to a range of −248 to 248, in order to achieve the best possible resolution while at the same time leaving headroom for a hysteresis based chopper to add an offset.

10.2.4. Current Waves Start Values

Starting Current Values of MSLUT Configuration

As both waves are shifted by 90° for two-phase stepper motors, the sine wave starts at 0° when *MSCNT* = 0. By comparison, the cosine wave begins at 90° when *MSCNT* = 256. At this starting points the current values are *CURRENTA* = 0 for the sine wave and *CURRENTB* = 247 for the cosine wave.

In contrast to the starting microstep positions that are fixed, these starting current values can be redefined if the default start values do not fit for the actual MSLUT.

In order to change the starting current values of the MSLUT, do as follows:

Action:

- ➢ Define the start values *START_SIN* and *START_SIN90_120* according to the requirements.
- ➢ Set register 0x7E (7:0) = *START_SIN.*
- ➢ Set register 0x7E (23:16) = *START_SIN90_120.*

Result:
The starting values for both waves are adapted to MSLUT.

10.2.5. Default MSLUT

Base Wave Inclinations

The default sine wave table in TMC drivers uses one segment with a base inclination of 2 and one segment with a base inclination of 1 (see default value of the *MSLUTSEL* register 0x78 = 0xFFFF8056).

The segment border X1 is located at *MSCNT* = 128. The base wave inclinations are

W0 = b'10 (=2) and W1 = b'01 (=1).

As a result, between *MSCNT* = 0 and 128, the increment value INC is either

1 (if *ofs* = 0) or 2 (if *ofs* = 1).

And between *MSCNT* = 128 and 255, the increment value INC is either

0 (if *ofs* = 0) or 1 (if *ofs* = 1).

This reflects the stronger rise in the first segment of the MSLUT in contrast to the second segment. The maximum value is

START_SIN90_120 = 247.

10.2.6. Explanatory Notes for Base Wave Inclinations

Definition of Segments 0,1,2,3

In the following example four segments are defined.

Each segment has a different base wave inclination to illustrate each possible entry:

Segment 0: W0 = 3 which means that the increment value is +2 or +3.
Segment 1: W0 = 2 which means that the increment value is +1 or +2.
Segment 2: W0 = 1 which means that the increment value is 0 or +1.
Segment 3: W0 = 0 which means that the increment value is −1 or 0.

- i In addition to the MSLUT curve (black line), which is defined by the given *ofs* bits, all four segments show upper limits (red line); in case all *ofs* bits in the particular segments are set to 1.
- i The green line shows the lower limit in case all *ofs* bits in the particular segments are set to 0.

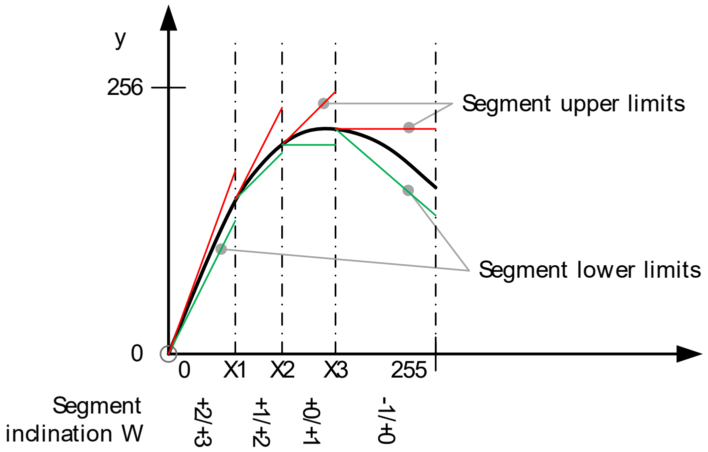


Figure 49: MSLUT Curve with all possible Base Wave Inclinations (highest Inclination first)

Standard Sine Wave Setup Considerations prior to SETUP of MSLUT

In order to set up a standard sine wave table for the MSLUT, the following considerations have to be taken into account:

PRECONSIDERATIONS:

- The microstep table for the standard sine wave begins with eight entries (0 to 7) {0, 1, 3, 4, 6, 7, 9, 10 ...} etc.
- The maximum difference between two values in this section is +2, whereas the minimum difference is +1.
- While advancing according to the table, the very first time the difference between two MSLUT values is lower than +1 is between position 153 and position 154. Both entries are identical.
- The start value is 0 for the sine wave.
- The calculated value for position 256 (i.e. start of cosine wave) is 247.

•→ *Description is continued on next page.*

Standard Sine Wave Setup

In order to set up the standard sine wave table, proceed as follows:

Action:

- Set a starting value *START_SIN* = 0 matching sine wave entry 0.
- Set a base wave inclination range of W0 = b'10 = 2 to skip between +1 / +2, valid from 0 to X1.
- Calculate the differences between every entry: {+1, +2, +1, +2, +1, +2, +1,...}.
- Set the microstep table entries *ofs*XX to 0 for the lower value (+1); 1 for the higher value (+2). Thus, the first seven microstep table entries *ofs*00 to *ofs*06 are: {0, 1, 0, 1, 0, 1, 0 ...}
- The base wave inclination must be lowered at position 153, at very latest. Use the next base wave inclination range 1 with W1 = b'01 = 1 to skip between +0 and +1.
- Set X1 = 153 in order to switch to the next inclination range. From here on, an offset *ofs*XX of 0 means add nothing; 1 means add +1.
- Set *START_SIN90_120* = 247, which is equal to the value at position 256.
- Only two of four wave segments with different base wave inclinations are used. The remaining wave inclination ranges W2 and W3 should be set to the same value as W1; and X2 and X3 can be set to 255. Thereby, only two wave inclination segments are effective.

Result:

A standard sine wave is defined as MSLUT. The following table shows an extract of this curve.

Overview of the Microstep Behavior Example													
Microstep number	0	1	2	3	4	5	6	7	…	153	154	…	255
Desired table entry	0	1	3	4	6	7	9	10	…	200	200	…	247
Difference to next entry	1	2	1	2	1	2	1	…	…	0	…	…	0
Required segment inclination	+2	+2	+2	+2	+2	+2	+2	…	…	+1	…	…	+1
***Ofs* bit entry**	0	1	0	1	0	1	0	…	…	0	…	…	0

Table 40: Overview of the Microstep Behavior Example

10.3. SPI Output Interface Configuration Parameters

TMC4361 provides an SPI output interface. In the next section, the configuration of the interface parameters is explained in detail.

10.3.1. Enabling SPI Output Communication

In order to enable SPI output communication, do as follows:

Action:

- Set *serial_enc_out_enable* = 0 (bit24 of *GENERAL_CONF* register 0x00).

Result:

SPI output is enabled.

i SPI out is the default preconfigured setting.

Pins dedicated to SPI Output Communication

The table below lists the pins that are dedicated to SPI output communication:

SPI Output Communication Pins	
Pin	**Description**
NSCSDRV_SDO	Low active chip select signal.
SCKDRV_NSDOSPI	SPI output clock.
SDODRV_SCLK	MOSI – Output pin to transfer the datagram to the motor driver.
SDIDRV_NSCLK	MISO – Input pin which receives the response from the motor driver. The response is sampled during the data transfer to the motor driver.

Table 41: SPI Output Communication Pins

Read entire documentation; especially the "Supplemental Directives" on page 218.

10.3.2. Setup of SPI Output Timing Configuration

Because TMC4361 represents the master of SPI communication to the motor driver – which is the slave – it is mandatory to set up the timing configuration for the SPI output. TMC4361 provides an SPI clock, which is generated at the SCKDRV_NSDO output pin.

In order to configure the timing of the SPI clock, set up *SPIOUT_CONF* register 0x04 as follows:

Action:

- Set the number of internal clock cycles the serial clock should stay low at *SPI_OUT_LOW_TIME* = *SPIOUT_CONF* (23:20).
- Set the number of internal clock cycles the serial clock should stay high at *SPI_OUT_HIGH_TIME* = *SPIOUT_CONF* (27:24).
- Also, an *SPI_OUT_BLOCK_TIME* = *SPIOUT_CONF*(31:28) can be set for a minimum time period during which no new datagram is sent after the last SPI output datagram.

Result:
SPI output communication scheme is set. During the inactive phase between to SPI datagrams - which is at least *SPI_OUT_BLOCK_TIME* clock cycles long - the SCKDRV_NSDO and NSCSDRV_SDO pins remain at high output voltage level. The timing of the SPI output communication is illustrated in the next *Figure* 50 (page 98).

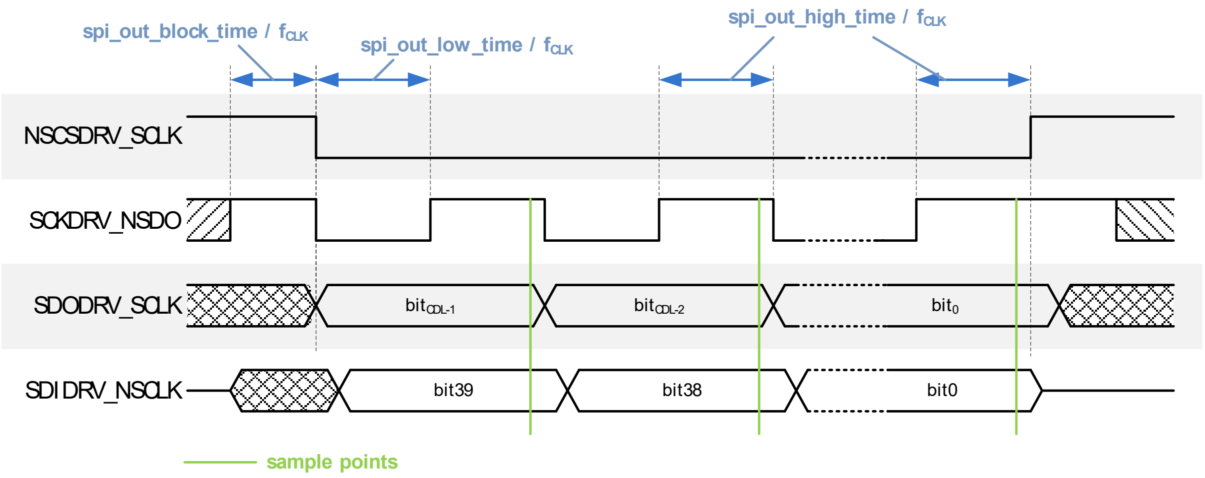


Figure 50: SPI Output Datagram Timing

Minimum and Maximum Time Period

The minimum time period for all three parameters is $2/f_{CLK}$. If an SPI output parameter is set to 0, it is altered to 2 clock cycles internally. A maximum time period of $15/f_{CLK}$ can be set for all three parameters.

Thus, SPI clock frequency f_{SPI_CLK} covers the following range:

$$f_{CLK} / 30 \leq f_{SPI\_CLK} \leq f_{CLK} / 2.$$

10.3.3. Current Diagrams

Basically, SPI output communication serves as automatic current datagram transfer to the connected motor driver. TMC4361 uses the internal microstep lookup table (MSLUT) in order to provide actual current motor driver data.

Process Description

- With every step that is initialized by the ramp generator the *MSCNT* value is increased or decreased, dependent on ramp direction.
- The *MSCNT* register 0x79 (readable value) contains the current microstep position of the sine value.
- Accordingly, the current values *CURRENTA* (0x7A) and *CURRENTB* (0x7B) are altered.
- In case the output configuration of TMC4361 allows for automatic current transfer an updated current value leads to a new datagram transfer.
- Thereby, the motor driver always receives the latest data. The length for current datagrams can be set automatically and TMC4361 converts new values into the selected datagram format, usually divided in amplitude and polarity bit for TMC motor drivers.

10.3.4. Change of Microstep Resolution

By altering the microstep resolution from 256 (*MSTEP_PER_FS* = b'0000) to a lower value, an internal step results in more than one MSLUT step.
For instance, if the microstep resolution is set to 64 (*MSTEP_PER_FS* = b'0010), *MSCNT* is either increased or decreased by 4 per each internal step. Accordingly, the passage through the MSLUT skips three current values per each internal step to match the new microstep resolution.

10.3.5. Cover Datagrams Communication between µC and Driver

In addition to automatic current datagram transfer, the microcontroller can communicate directly with the motor driver through TMC4361 by using cover datagrams. This communication channel can be useful for configuration purposes because no additional SPI communication channel between microcontroller and motor driver is necessary.

Up to 64 bits can be assigned for one cover datagram. This 64-bit SPI cover register is separated into two 32-bit registers - *COVER_HIGH* register 0x6D and *COVER_LOW* register 0x6C. The *COVER_HIGH* register is only required if more than 32 bits must be sent once.

How to Define Cover Datagram Length

How many bits are sent within one cover datagram is defined by the cover datagram length *COVER_DATA_LENGTH* .

In order to define the cover datagram length, do as follows:

Action:

➢ Set the number of cover datagram bits at
COVER_DATA_LENGTH = *SPIOUT_CONF* (19:13).

Result:
The cover datagram length is set to *COVER_DATA_LENGTH* bits. If this parameter is set higher than 64, the cover register data length is still maximum 64 bits.

i For TMC motor drivers it is possible to set *COVER_DATA_LENGTH* = 0. In this case, the cover data length is selected automatically, dependent on the chosen motor driver. More details are provided on the subsequent pages.

Read entire documentation; especially the "Supplemental Directives" on page 218.

10.3.6. Sending Cover Datagrams

The LSB (last significant bit) of the whole cover datagram register is located at *COVER_LOW*(0). As long as *COVER_DATA_LENGTH* < 33, only *COVER_LOW* or parts of this register are required for cover data transfer.

If more than 32 bits are necessary, the complete *COVER_LOW* and (parts of) the *COVER_HIGH* register are required for SPI cover data transfer.

NOTE:

→ *Every SPI communication starts with the most significant bit (MSB).*

OPTION 1: COVER_DATA_LENGTH < 33 BITS

In order to send a cover datagram - that is smaller than 33 bits - do as follows:

Action:
- Set *COVER_LOW* (*COVER_DATA_LENGTH*-1:0) register 0x6C = cover_data.

Result:
After a valid register request to *COVER_LOW*, SPI output is sent out *COVER_DATA_LENGTH* bits of *COVER_LOW* register.

Cover Datagrams with 32 Bits

OPTION 2: COVER_DATA_LENGTH > 32 BITS

In order to send a cover datagram - that consists of more than 32 bits - do as follows:

Action:
- Split cover data into two segments:
- cover_data_low = cover_data(31:0).
- cover_data_high = cover_data >> 32.
- cover_data_high = cover_data(31:0).
- Set *COVER_HIGH*(*COVER_DATA_LENGTH* −32:0) register 0x6D=cover_data_high.
- Set *COVER_LOW* register 0x6C = cover_data_low.

Result:
After a valid register request to *COVER_LOW*, SPI output is sent out *COVER_DATA_LENGTH* bits that comprises register values of *COVER_HIGH* and *COVER_LOW*.

The cover register and the datagram structure are illustrated in the figure below:

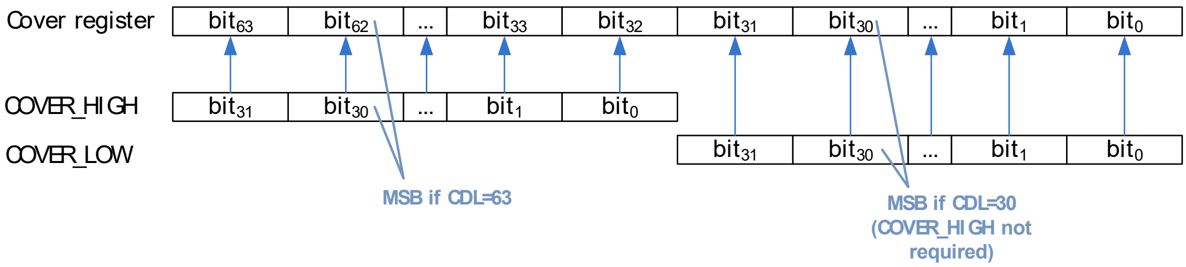


Figure 51: Cover Data Register Composition (CDL – COVER_DATA_LENGTH)

•→ *Continued on next page.*

Receiving Responses to Cover Datagrams

Because the transfer of a cover datagram is usually accompanied by a data transfer from the motor driver, the response is stored in registers; and is thus available for the microcontroller. *COVER_DRV_HIGH* register 0x6F and *COVER_DRV_LOW* register 0x6E form this cover response register that can also comprise up to 64 bits.
Similar to *COVER_LOW* and *COVER_HIGH*, the motor driver response is divided in the registers *COVER_DRV_LOW* and *COVER_DRV_HIGH*. The composition of the response cover register and also the positioning of the MSB follow the same structure.

COVER_DONE Event

At the end of a successful data transmission, the event *COVER_DONE* becomes set. This indicates that the cover register data is sent to the motor driver and that the received response is stored in the *COVER_DRV_HIGH* register 0x6F and *COVER_DRV_LOW* register 0x6E.

10.3.7. Configuring Automatic Generation of Cover Datagrams

In certain setups, it can be useful to automatically send ramp velocity-dependent cover datagrams, e.g. to change chopper settings during motion.

NOTE:

→ *This feature is only available if the cover datagram length does not exceed 32 bits.*

In order to activate ramp velocity-dependent automatic cover data transfer, do as follows:

Action:

- Define the trigger velocity whenever an automatic cover datagram transfer is initiated.
- Set *SPI_SWITCH_VEL* register 0x1D to this absolute velocity [pps].
- Set *COVER_LOW* register 0x6C to the cover_data, which is valid for lower velocity values.
- Set *COVER_HIGH* register 0x6D to the cover_data, which is valid for higher velocity values.
- Set *automatic_cover* = 1 (*REFERENCE_CONF* register 0x01).

Result:

Whenever the absolute internal ramp velocity |*VACTUAL*| passes the *SPI_SWITCH_VEL* value, the particular cover data is sent to the motor driver,
COVER_LOW is sent in case |*VACTUAL*| < *SPI_SWITCH_VEL*,
COVER_HIGH is sent in case |*VACTUAL*| ≥ *SPI_SWITCH_VEL*.

Read entire documentation; especially the "Supplemental Directives" on page 218.

10.4. Overview: TMC Motor Driver Connections

As mentioned before, TMC4361 is able to set the cover register length automatically in case a TMC motor driver is connected. Also, several additional automatic features for the SPI communication are available by selecting TMC motor drivers.

10.4.1. TMC Stepper Motor Driver Settings

Available SPI and Step/Dir™ Communication Schemes for TMC Motors

The SPI and Step/Dir communication schemes are available for the following product lines that are explained in greater detail further below:

- TMC236, TMC239
- TMC246, TMC248, TMC249
- TMC260, TMC261, TMC262, TMC2660
- TMC389
- TMC2130

How to enable SPI Output Settings for TMC Stepper Motor Drivers

In order to enable an operating SPI output setting for a connected TMC stepper motor driver, proceed as follows:

Action:

- Set *SPI_OUT_LOW_TIME, SPI_OUT_HIGH_TIME,* and *SPI_OUT_BLOCK_TIME* according to the TMC motor driver specification, as explained before.
- Set *COVER_DATA_LENGTH* = 0 (bit19:13 of *SPIOUT_CONF* register 0x04).
- Set *spi_output_format = SPI_OUT_CONF* (3:0) according to the connected SPI motor driver as seen below in the table below.

Result:
The communication scheme is now prepared for the connected TMC motor driver with all available features.

TMC Stepper Motor Driver Options				
TMC Motor Driver	***spi_output_format*** =*SPI_OUT_CONF* (3:0)	**Cover Register Datagram Length** *COVER_DATA_LENTGH*=0	**Automatic Current Datagram Transfer**	**Cover Register Datagram Transfer**
SPI output off	b'0000	0	--	--
TMC23x	b'1000	12	✓	✓
TMC24x	b'1001	12	✓	✓
TMC26x/389	b'1010 b'1011	20 20	✓ S/D output	✓
TMC2130	b'1101 b'1100	40 40	✓ S/D output	✓

Table 42: TMC Stepper Motor Driver Options

Read entire documentation; especially the "Supplemental Directives" on page 218.

10.4.2. TMC Motor Driver Response Datagram and Status Bits

When a TMC motor driver receives a current datagram or a cover datagram that is transmitted via SPI output of TMC4361, status data is sent back to the TMC4361 controller immediately. The response is stored in the *COVER_DRV_LOW* 0x6E and *COVER_DRV_HIGH* 0x6F registers, just like all other cover requests.
The type and sequence of the status bits that are sent back are dependent on the selected motor driver. A detailed list for every motor driver is presented in the next sections, in which the motor driver communication specifics for every driver family are explained separately.

The mapping of the available status bits to the TMC4361 *STATUS* register is similar for each and every TMC stepper motor driver. The last eight bits – *STATUS* (31:24) – are equal to the transferred motor status bits. A detailed overview is given in the register chapter 17.14. (page 192).

10.4.3. Events and Interrupts based on Motor Driver Status Bits

TMC4361 also provides one event at ***EVENTS* (30)** that is connected with the motor driver status bits. Here, any of the motor driver status bits can function as the base for this event.

In order to activate a motor driver status bit for the motor event *EVENTS* (30), do as follows:

Action:
- Selected one or more of the motor driver status for the motor event by assigning *MSTATUS_SELECTION* = *STEP_CONF* (23:16) register 0x0A accordingly.

Result:
In case one of the selected motor status bits is activated (Wired-Or), the motor event switch *EVENTS* (30) generates an event.

In order to generate an interrupt for this motor event, configure the INTR output accordingly, as explained in section 5.3. (page 26).

10.4.4. Stall Detection and Stop-on-Stall

stallGuard and stallGuard2 Functionality

TMC stepper motor driver chips with stallGuard and stallGuard2 can detect stall and overload conditions based on the motor's back-EMF without the need of a position sensor. The stall detection status is returned via SPI.

For more information, refer to the AppNote "Parameterization of stallGuard2 & coolStep" that is available online at www.trinamic.com .

Representation of Motor Stall Status

Except for TMC23x and TMC24x, which forward three load detection bits, the motor stall status is represented by one status bit. TMC4361 is able to stop the internal ramp as soon as a stall is recognized. Because stall bit activation can occur unwanted during motion with a low velocity, it is also possible to set up a velocity threshold for the Stop-on-Stall behavior.

Internal Velocity Ramp Stop-on-Stall Activation

In order to activate a Stop-on-Stall for the internal velocity ramp, do as follows:

Action:
- Set *VSTALL_LIMIT* register 0x67 [pps] according to minimum absolute velocity value for a correct stall recognition.
- Set *stop_on_stall* = 1 (bit26 of *REFERENCE_CONF* register 0x01).
- Set *drive_after_stall* = 0 (bit27 of *REFERENCE_CONF* register 0x01).

Result:
The internal ramp velocity is set immediately to 0 whenever a stall is detected and the following is true: |*VACTUAL*| > *VSTALL_LIMIT*.
Then, the *STOP_ON_STALL* event is also generated.

i The status bit stallGuard that is directly mapped from the motor stepper driver, which is listed in *STATUS* (24). This flag is always activated as soon as the motor driver generates the stall guard status bit.

i The *ACTIVE_STALL* status bit = *STATUS* (11) is activated as soon as a stall is detected and |*VACTUAL*| > *VSTALL_LIMIT*.

Internal Velocity Ramp Activation after Stop-on-Stall

In order to activate the internal velocity ramp AFTER a Stop-on-Stall, do as follows:

Action:
- Read out the *EVENTS* register 0x0E to unlock the event *STOP_ON_STALL*.
- Set *drive_after_stall* = 1 (bit27 of *REFERENCE_CONF* register 0x01).

Result:
The internal ramp velocity is no longer blocked by the Stop-on-Stall event.

i In order to activate the Stop-on-Stall behavior again, reset *drive_after_stall* again manually to 0.

10.5. TMC23x, TMC24x Stepper Motor Driver

In this chapter specific information pertaining to the setup of TMC23x and TMC24x is provided.

TMC23x/24x Support

TMC4361 provides the following features in order to support the TMC23x motor stepper driver family well:

- Automatic Mixed Decay chopper mode
- ChopSync
- Automatic switchover between microstep and fullstep operation
- Controlled PWM signal generation and automatic switchover between SPI and PWM mode; see section 13.2. (page 133).

In the following section, the features are explained in greater detail.

i For further information, please refer to the manual of the particular stepper driver motor.

10.5.1. TMC23x Setup

In order to activate the SPI data transfer and SPI feature set for a connected TMC23x stepper motor driver, do as follows:

Action:

- ➢ Set *spi_output_format* = b'1000 (*SPI_OUT_CONF* register 0x04).
- ➢ Set *COVER_DATA_LENGTH* = 0 (*SPI_OUT_CONF* register 0x04).

Result:
TMC23x is selected as connected stepper motor driver.

10.5.2. TMC24x Setup

In order to activate the SPI data transfer and feature set for a connected TMC24x stepper motor driver, do as follows:

Action:

- ➢ Set *spi_output_format* = b'1001 (*SPI_OUT_CONF* register 0x04).
- ➢ Set *COVER_DATA_LENGTH* = 0 (*SPI_OUT_CONF* register 0x04).

Result:
TMC24x is selected as connected stepper motor driver.

i In addition to the TMC23x features mentioned above, the TMC24x stepper driver family provides three stallGuard bits as load measurement indicator. Therefore, the TMC24x stepper family is supported by the TMC4361 for the following:

– Stall detection and
– Stop-on-Stall behavior

•→ *Turn to next page for more information.*

10.5.3. TMC23x/24x Status Bits

TMC4361 maps the following status bits of TMC23x/24x stepper drivers – which are transferred with each SPI datagram – to the STATUS register 0x0F:

Status Register Mapping for TMC23x/24x		
STATUS bit @TMC4361	**Status flag @TMC23x/24x**	**Description**
STATUS (24)	UV	Undervoltage flag.
STATUS (25)	OT	Over temperature flag.
STATUS (26)	OTPW	Temperature prewarning flag.
STATUS (27)	OCA	Overcurrent flag for bridge A.
STATUS (28)	OCB	Overcurrent flag for bridge B.
STATUS (29)	OLA	Open load flag for bridge A.
STATUS (30)	OLB	Open load flag for bridge B.
STATUS (31)	OCHS	Overcurrent high side flag.

Table 43: Mapping of TMC23x/24x Status Flags

TMC23x/24x Microsteps

TMC4361 only forward new current data (*CURRENTA_SPI* and *CURRENTB_SPI* at register 0x7B) for TMC23x/TMC24x in case the upper five bits of one of the two 9-bit current values changes; because TMC23x and TMC24x current data consist of four bit current values and one polarity bit for each coil.
Consequently, alterations of the internal microstep resolution only apply in case the new microstep resolution is lower than 16 bits.

10.5.4. Automatic Fullstep Switchover for TMC23x/24x

Because SPI current data is transmitted, automatic switchover from microsteps to fullsteps and vice versa is only dependent on the internal ramp velocity.

In order to activate automatic switchover between microstep and fullstep operation, do as follows:

Action:
- Set *FS_VEL* register 0x60 according to the velocity [pps] at which the switchover must happen.
- Set *fs_en* = 1 (bit19 of *GENERAL_CONF* register 0x00).

Result:
Now, current values are switched to fullstep values in case |*VACTUAL*| ≥ *FS_VEL*.
A switchback from fullsteps to µsteps is executed in case |*VACTUAL*| < *FS_VEL*.
The status bit *FS_ACTIVE* is set active as long as fullstep mode is enabled and activated.

•→ *Turn to next page for more information.*

10.5.5. Mixed Decay Configuration for TMC23x/24x

TMC4361 supports the mixed decay feature for the TMC23x/24x chopper in *SPI_OUT_CONF* register 0x04.

In order to configure mixed decay bits for TMC23x/24x, do as follows:

Action:

- Set *mixed_decay* = b'00 if mixed decay must always be deactivated.
- Set *mixed_decay* = b'01 if mixed decay must be activated for each coil during the falling ramp of the sine curve until reaching value 0.
- Set *mixed_decay* = b'10 if mixed decay must always be activated, except during standstill.
- Set *mixed_decay* = b'11 if mixed decay must always be activated.

Result:
The mixed decay bits for TMC23x/24x stepper motor drivers are set according to the configuration and the internal MSLUT values.

i Please refer to the TMC23x/TMC24x datasheets to get more information about the configuration of mixed decay bits.

10.5.6. ChopSync Configuration for TMC23x/24x Stepper Drivers

TMC4361 forwards the internal clock at the output pin STDBY_CLK. This pin can also be used to provide an external clock for the TMC23x/24x stepper motor driver. This external clock generator automatically generates clock cycles that are modified by the chopSync feature if TMC23x/24x is configured as connected motor driver. Using chopSync enhances the motor drive for fast and smooth operation.

In order to enable the chopSync clock via the STDBY_CLK pin, do as follows:

Action:

- Set *CHOPSYNC_DIV* register 0x1F to generate an external clock frequency f_{OSC} according to the following equation: $f_{OSC} = f_{CLK}$ / *CHOP_SYNC_DIV.*
- Set *stdby_clk_pin_assignment* = b'10 (*GENERAL_CONF* register 0x00).

Result:
STDBY_CLK generates an external clock with the selected frequency f_{OSC} that automatically provides the chopSync feature.

i Recommended minimum external frequency f_{OSC}: two times higher than audible range.

Connection of STDBY_CLK output pin of TMC4361 and OSC input pin of TMC23x/24x[1]

NOTICE

Risk of Burns! Avoid overheating and damage of the TMC23x/24x stepper driver and damage of the connected motor!

- You MUST use a low pass filter between STDBY_CLK output of TMC4361 and the OSC input pin of TMC23x/24x.
- You MUST keep the external clock frequency of the TMC23x/24x stepper motor driver below 50 kHz (to prevent overheating).

This will ensure smooth and safe operation.

[1] Per default (i.e. after power on and reset), STDBY_CLK forwards the internal clock that is too high for the TMC23x/24x. See Figure 10, (page 15) that provides a properly connected sample hardware setup.

10.5.7. Using TMC24x stallGuard Characteristics

TMC24x forwards stallGuard values ={LD2&LD1&LD0} instead of one stallGuard2 status bit. These bits represent an unsigned value between 0 and 7. The lower the value is the higher the mechanical load is. TMC4361 can generate a one-bit internal stall signal by analyzing the stallGuard values.

In order to set up the stall load limit for automatic stall recognition, do as follows:

Action:
- Set proper *STALL_LOAD_LIMIT* (bit10:8 of *SPIOUT_CONF* register 0x04).

Result:
Whenever {LD2&LD1&LD0} ≤ *STALL_LOAD_LIMIT* a stall is indicated.

This feature also allows use of the Stop-on-Stall feature – already explained in section 10.4.4, page 104 – because this also applies to other TMC motor stepper drivers.

Additionally, a standby datagram can be sent automatically when a Stop-on-Stall is executed. In order to activate this behavior, do as follows:

Action:
- Set *VSTALL_LIMIT* register 0x67 [pps] according to minimum absolute velocity value for a correct stall recognition.
- Set *stop_on_stall* = 1 (bit26 of *REFERENCE_CONF* register 0x01).
- Set *drive_after_stall* = 0 (bit27 of *REFERENCE_CONF* register 0x01).
- Set *stdby_on_stall_for_24x* = 1 (bit6 of *SPIOUT_CONF* register 0x04).

Result:
Whenever a stall is calculated by comparing *STALL_LOAD_LIMIT* to the response of TMC24x, while at the same time the absolute value of *VACTUAL* exceeds *VSTALL_LIMIT*, the internal ramp velocity is stopped immediately. Additionally, both current values are then set to 0 whereupon a standby mode for the TMC24x stepper motor driver is generated that switches off all power driver outputs and clears the error flags.

i To return from Stop-on-Stall, *drive_after_stall* must be set manually, as stated further in section 10.4.4 (Page 104).

In order to exchange the UV status bit in the *STATUS* register 0x0F with the calculated stallGuard bit, do as follows:

Action:
- Set *stall_flag_instead_of_uv_en* = 1(bit10:8 of *SPIOUT_CONF* register 0x04).

Result:
STATUS (24) shows the calculated stallGuard bit by comparing *STALL_LOAD_LIMIT* with the received response datagram of TMC24x.

10.6. TMC26x Stepper Motor Driver

TMC26x Stepper Motor Driver Support

TMC4361 provides the following features in order to support the TMC26x motor stepper driver family well:

- SPI mode that sets up current values directly.
- S/D mode in which the TMC26x processes S/D outputs of TMC4361.
- Automatic switchover between microstep and fullstep operation for both modes.
- Stall detection and Stop-on-Stall behavior for both modes.
- S/D mode only: Transfer of automatic scaling values from TMC4361 to TMC26x.
- S/D mode only: Transfer of auto-generated polling datagrams sent by TMC4361 for reception of status data and microstep position from TMC26x.

In the following section, the features are explained in greater detail.

i For more information, please refer to the manual of the connected stepper driver motor.

10.6.1. TMC26x Setup (SPI mode)

In order to activate the SPI data transfer mode and feature set for a connected TMC26x stepper motor driver, do as follows:

Action:

- Set *spi_output_format* = b'1010 (*SPI_OUT_CONF* register 0x04).
- Set *COVER_DATA_LENGTH* = 0 (*SPI_OUT_CONF* register 0x04).

Result:

TMC26x in SPI mode is selected as connected stepper motor driver. Cover datagrams and current datagrams are sent via SPI output pins.

10.6.2. TMC26x Setup (S/D mode)

In order to activate the S/D mode and feature set for a connected TMC26x stepper motor driver, do as follows:

Action:

- Connect SPI output pins and S/D outputs to the TMC26x stepper motor driver.
- Set *spi_output_format* = b'1011 (*SPI_OUT_CONF* register 0x04).
- Set *COVER_DATA_LENGTH* = 0 (*SPI_OUT_CONF* register 0x04).
- Set *DIR_SETUP_TIME* and *STP_LENGTH_ADD* (register 0x10) according to the hardware setup.
- Set proper *POLL_BLOCK_MULT* (bit12:7 of SPIOUT_CONF register 0x04).

Result:

TMC26x in S/D mode is selected as connected stepper motor driver. SPI output pins transfer only cover datagram and automatic configuration datagrams because motion is generated by processing the STPOUT/DIROUT output signals of TMC4361. The next polling datagram is sent (*POLL_BLOCK_MULT*+1)**SPI_BLOCK_TIME* clock cycles after the last polling datagram.

i A high microstep frequency requires a short SPI datagram polling time.

•→ *Continued on next page.*

10.6.3. Sending Cover Datagrams to the TMC26x Driver

Based on the TMC26x settings - that were explained above - TMC4361 now sends 20-bit datagrams automatically.

In order to send cover datagrams to TMC26x motor stepper drivers, do as follows:

Action:

- Set *COVER_LOW* (19:0) to the register values that need to be transferred.

Result:

A cover datagram is sent to the connected driver. *COVER_DONE* is set after data transfer. The response of TMC26x is stored in *COVER_DRV_LOW* (19:0).

10.6.4. TMC26x SPI Mode: Automatic Fullstep Switchover

Because SPI current data is transmitted, the automatic switchover from microsteps to fullsteps and vice versa entirely depends on the internal ramp velocity.

In order to activate automatic switchover between microstep and fullstep operation, do as follows:

Action:

- Set *FS_VEL* register 0x60 according to the absolute velocity [pps] at which the switchover should happen.
- Set *fs_en* = 1 (bit19 of *GENERAL_CONF* register 0x00).

Result:

Now, current values are switched to fullstep values, in case |*VACTUAL*| ≥ *FS_VEL*.
A switchback from fullsteps to µsteps is executed in case |*VACTUAL*| < *FS_VEL*.

The status bit *FS_ACTIVE* is set active as long as fullstep mode is enabled and activated.

•→ Continue on the next page for information on fullstep switchover for TMC26x in S/D mode.

10.6.5. TMC26x S/D Mode: Automatic Fullstep Switchover

In S/D mode, switchover from microsteps to fullsteps and vice versa is not only dependent on the internal ramp velocity but also on the microstep position of the TMC26x MSLUT; because switching to a lower resolution must be executed carefully to catch the correct microstep position. Proper setting of read selection bits for TMC26x stepper drivers TMC4361 is required to execute switchover automatically.

In order to activate automatic switchover between microstep and fullstep operation in TMC26x S/D mode, do as follows:

PRECONDITION:

Mandatory TMC26x configuration MUST be executed via cover datagrams:
- Set RDSEL1 = 0 and RDSEL0 = 0 @TMC26x.

Action:
- Set *disable_polling* = 0 (bit6 of *SPI_OUT_CONF* register 0x04).
- Set *FS_VEL* register 0x60 according to the absolute switching velocity [pps].
- Set *fs_en* = 1 (bit19 of *GENERAL_CONF* register 0x00).
- Set *fs_sdout* = 0 (bit20 of *GENERAL_CONF* register 0x00).

Result:
The µstep resolution of TMC26x is set to fullsteps, in case |*VACTUAL*| ≥ *FS_VEL*.
A switchback from fullsteps to µsteps is executed in case |*VACTUAL*| < *FS_VEL*.
FS_ACTIVE is set active as long as fullstep mode is enabled and activated. Presettings of the TMC26x DRVCTRL register – *that is executed beforehand via cover datagrams* – are considered whenever the particular register is overwritten with a newly assigned microstep resolution.

10.6.6. TMC 26x S/D Mode: Change of Current Scaling Parameter

SPI mode-supported TMC26x drivers are automatically scaled by means of current datagrams. In order to automatically scale the current of a connected TMC26x motor stepper driver in S/D mode, TM4361-LA sends auto-generated cover datagrams by altering directly the CS value of the TMC26x SGCSCONF register.
TMC4361 provides features that change the current scaling automatically, which are explained in chapter 11, page 120.

In order to activate automatic current scaling for a connected TMC26x in S/D mode, do as follows:

Action:
- Set *scale_val_transfer_en* = 1 (bit5 of *SPI_OUT_CONF* register 0x04).
- Set the scale value register 0x06 and scale configuration register 0x05 according to your requirements (see chapter 11, page 120).

Result:
If the current scaling is adapted internally, TMC4361 automatically sends cover datagrams to TMC26x that change the CS bit directly.
Presettings of the TMC26x SGCSCONF register – *that are executed beforehand via cover datagrams* – become considered whenever the particular register is overwritten with a newly assigned current scaling value.

NOTE:

→ *Please consider that the CS value consists of 5 bits only. Therefore, the scaling values in register 0x06 must be adapted to 5-bit values as well.*

10.6.7. TMC26x Status Bits

TMC4361 maps the following status bits of TMC26x stepper drivers – which are transferred within each SPI response – to the *STATUS* register 0x0F:

Status Register Mapping for TMC26x		
STATUS Bit @TMC4361	**Status Flag @TMC26x**	**Description**
STATUS(24)	SG	stallGuard2™ status flag
STATUS(25)	OT	Over temperature flag
STATUS(26)	OTPW	Temperature prewarning flag
STATUS(27)	S2GA	Short-to-ground detection flag for high side MOSFET of coil A
STATUS(28)	S2GB	Short-to-ground detection flag for high side MOSFET of coil B
STATUS(29)	OLA	Open load flag for bridge A
STATUS(30)	OLB	Open load flag for bridge B
STATUS(31)	STST	Standstill flag

Table 44: Mapping of TMC26x Status Flags

i If polling is not disabled (*disable_polling* = 0), status data from TMC26x is also available in S/D mode.

10.7. TMC389 Stepper Motor Driver

Configuration for the TMC389 3-Phase Stepper Driver

If a TMC389 is connected to the SPI output and a microstep resolution of 256 is set, a 3-phase stepper output for coil B can be generated. All features of TMC26x stepper motor drivers in SPI mode are also available for TMC389.

In order to activate the SPI data transfer mode and feature set - *for a connected TMC389 3-phase stepper motor driver* - do as follows:

Action:

- Set *spi_output_format* = b'1010 (*SPI_OUT_CONF* register 0x04).
- Set *three_phase_stepper_en* = 1 (*SPI_OUT_CONF* register 0x04).
- Set *COVER_DATA_LENGTH* = 0 (*SPI_OUT_CONF* register 0x04).

Result:

Now, the *CURRENTB* and *CURRENTB_SPI* values are shifted by 120° towards *CURRENTA* and *CURRENTA_SPI* — in contrast to the 90° shift of the 2-phase stepper motors.

10.8. TMC2130 Stepper Motor Driver

TMC2130 Support

TMC4361 provides the following features in order to support the TMC2130 motor stepper driver well:

- SPI mode that sets up current values directly.
- S/D mode in which the TMC2130 processes S/D outputs of TMC4361.
- Automatic switchover between microstep and fullstep operation for both modes.
- Stall detection and Stop-on-Stall behavior for both modes.
- S/D mode only: Transfer of automatic scaling datagrams from TMC4361 to TMC2130.
- S/D mode only: Transfer of auto-generated polling datagrams sent by TMC4361 for reception of status data and microstep position from TMC2130.

In the following section, the features are explained in greater detail.

i For more information, please refer to the manual of the TMC2130 stepper driver motor.

10.8.1. Set-up TMC2130 Support (SPI Mode)

In order to activate the SPI data transfer mode and feature set - *for a connected TMC2130 stepper motor driver* - do as follows:

Action:

- ➢ Set *spi_output_format* = b'1101 (*SPI_OUT_CONF* register 0x04).
- ➢ Set *COVER_DATA_LENGTH* = 0 (*SPI_OUT_CONF* register 0x04).

Result:
TMC2130 in SPI mode is selected as connected stepper motor driver. Cover datagrams and current datagrams are sent via SPI output pins.

10.8.2. Set-up TMC2130 Support (S/D Mode)

In order to activate the S/D mode and feature set - for a connected TMC2130 stepper motor driver - do as follows:

Action:

- ➢ Connect SPI output pins and S/D outputs to the TMC2130 stepper motor driver.
- ➢ Set *spi_output_format* = b'1100 (*SPI_OUT_CONF* register 0x04).
- ➢ Set *COVER_DATA_LENGTH* = 0 (*SPI_OUT_CONF* register 0x04).
- ➢ Set *DIR_SETUP_TIME* and *STP_LENGTH_ADD* (register 0x10) according to the hardware setup.
- ➢ Set proper *POLL_BLOCK_MULT* (bit12:7 of SPIOUT_CONF register 0x04).

Result:
TMC2130 in S/D mode is selected as connected stepper motor driver. SPI output pins transfer only cover datagrams and automatic configuration datagrams because motion is generated by processing the STPOUT/DIROUT output signals of TMC4361. The next polling datagram is sent (*POLL_BLOCK_MULT*+1) · *SPI_BLOCK_TIME* clock cycles after the last polling datagram.

i A high microstep frequency requires a short SPI datagram polling time.

Read entire documentation; especially the "Supplemental Directives" on page 218.

10.8.3. Sending Cover Datagrams to the TMC2130 Driver

Based upon the TMC2130-supported settings explained above, the TMC4361 now sends 40 bit datagrams automatically.

In order to send cover datagrams to TMC2130 motor stepper drivers, do as follows:

Action:
- Set *COVER_HIGH* (7:0) register 0x6D to the address value that need to be transferred.
- Set *COVER_LOW* (31:0) register 0x6C to the data values that need to be transferred.

Result:
A cover datagram is sent to the connected driver. *COVER_DONE* is set after data transfer. The response of TMC2130 is stored in *COVER_DRV_HIGH* (7:0) and *COVER_DRV_LOW* (31:0)

10.8.4. TMC2130 SPI Mode: Automatic Fullstep Switchover

Because SPI current data is transmitted, the automatic switchover from microsteps to fullsteps and vice versa entirely depends on the internal ramp velocity.

In order to activate automatic switchover between microstep and fullstep operation, do as follows:

Action:
- Set *FS_VEL* register 0x60 according to absolute velocity [pps] at which the switchover should happen.
- Set *fs_en* = 1 (bit19 of *GENERAL_CONF* register 0x00).

Result:
Now, current values are switched to fullstep values, in case |*VACTUAL*| ≥ *FS_VEL*.
A switchback from fullsteps to µsteps is executed in case |*VACTUAL*| < *FS_VEL*.
The status bit *FS_ACTIVE* is set active as long as fullstep mode is enabled and activated.

10.8.5. TMC2130 S/D Mode: Automatic Fullstep Switchover

During S/D mode, switchover from microsteps to fullsteps and vice versa is only executed directly by TMC2130. Therefore, a fullstep velocity must only be defined in TMC2130. TMC4361 transfers microsteps whether TMC2130 is operating in fullstep or microstep mode.

Read entire documentation; especially the "Supplemental Directives" on page 218.

10.8.6. TMC 2130 S/D Mode: Changing current Scaling Parameter

TMC4361 provides features that change the current scaling automatically, which is explained in Chapter 11, page 120. Stepper motor drivers that are supported by SPI current datagrams are automatically scaled via current datagrams. To automatically scale the current of a connected TMC2130 motor stepper driver in S/D mode, TM4361-LA sends auto-generated cover datagrams by altering the CS value of the TMC2130 IHOLD_IRUN register.

In order to activate automatic current scaling for TMC2130 in S/D mode:

Action:

- Set *scale_val_transfer_en* = 1 (bit5 of *SPI_OUT_CONF* register 0x04).
- Set scale value register 0x06 and scale configuration register 0x05 according to your requirements (see chapter 11, page 120).

Result:

When current scaling is adapted internally, TMC4361 sends cover datagrams to TMC2130 automatically, which changes the CS bit directly.
Presettings of the IHOLD_IRUN register of the TMC2130 – executed before via cover datagrams – are considered whenever the particular register is overwritten with a newly assigned current scaling value.

i Please consider that the IRUN and IHOLD values consist of 5 bits only. Therefore, scaling values in register 0x06 must also be adapted to 5-bit values.

TMC2130 Status Bits

TMC4361 maps the following status bits of TMC2130 stepper drivers – *which are transferred within each SPI response* – to the *STATUS* register 0x0F:

Status Register Mapping for TMC2130		
STATUS Bit @TMC4361	**Status Flag @TMC2130**	**Description**
STATUS (24)	SG	stallGuard2™ status flag.
STATUS (25)	OT	Over temperature flag.
STATUS (26)	OTPW	Temperature prewarning flag.
STATUS (27)	S2GA	Short-to-ground detection flag for high side MOSFET of coil A.
STATUS (28)	S2GB	Short-to-ground detection flag for high side MOSFET of coil B.
STATUS (29)	OLA	Open load flag for bridge A.
STATUS (30)	OLB	Open load flag for bridge B.
STATUS (31)	STST	Standstill flag.

Table 45: Mapping of TMC2130 Status Flags

i If polling is not disabled (*disable_polling* = 0), status data from TMC2130 is also available in S/D mode.

10.9. Connecting Non-TMC Stepper Motor Driver or SPI-DAC at SPI output interface

TMC4361 also provides configuration data for driver chips of other companies via the cover registers. The following output format settings can be selected:

Non-TMC Data Transfer Options		
Output Formats	***spi_output_format***	**Comment**
SPI output off	b'0000	SPI output driver pins are switched off.
Cover output only	b'1111	Only cover datagrams are sent via the SPI output pins.
Unsigned scaling factor	b'0100	The actual unsigned current scaling value is provided at the SPI output pins.
Signed current data	b'0101	Both actual signed current values are provided in one datagram at the SPI output pins.
DAC scaling factor	b'0110	The actual unsigned current scaling value is provided at the SPI output pins for a defined DAC address.
DAC absolute values	b'0011	Both actual signed current values are provided in two datagrams at the SPI output pins for defined DAC addresses, which are absolute values. Phase bits are generated at the STPOUT/DIROUT interface. Phase bit = 0 signifies positive values.
DAC absolute values	b'0010	Both actual signed current values are provided in two datagrams at the SPI output pins for defined DAC addresses, which are absolute values. Phase bits are generated at the STPOUT/DIROUT interface. Phase bit = 1 signifies positive values.
DAC adapted values	b'0001	Both actual signed current values are provided in two datagrams at the SPI output pins for defined DAC addresses. These values are mapped to positive values: Current value equals minimum value (-255) = 0 Current value equals 0 = 128 Current value equals maximum value (+255) = 255

Table 46: Non-TMC Data Transfer Options

NOTE:

→ *Please note that the COVER_DATA_LENGTH must be set according to the predefined driver chip datagram length.*

Cover Output only **!** **In order to send cover datagrams only, use this option to avoid datagrams that send scaling or current values whenever these internal values are changed.** Please keep in mind that only the SPI protocol is available that is used for TMC motor stepper drivers.

Sending unsigned Scaling Factor

Setting *spi_output_format* = b'0100 leads to a transfer of the 8-bit scaling factor if this value is altered internally: Output data(7:0) = *SCALE_PARAM* (7:0).
The MSB 7 is sent first. If more than 8 bits are configured as *COVER_DATA_LENGTH,* leading zeros are inserted before the MSB.

Sending signed Current Values

Setting *spi_output_format* = b'0101 leads to a transfer of both signed current values that consists of 18 bits and are sent one after the other in one datagram: Output data(17:0) = *CURRENTA_SPI* (8:0) & *CURRENTB_SPI* (8:0).
The MSB (bit17) is sent first. If more than 18 bits are configured as *COVER_DATA_LENGTH*, leading zeros are inserted before the MSB.

Read entire documentation; especially the "Supplemental Directives" on page 218.

10.9.1. Connecting a SPI-DAC

DAC Output Values

Connecting a compatible SPI-DAC to SPI output pins, several possibilities are available for output configuration:

- Output of the internal SPI current values.
- Output of the internal current scaling value.
- Several SPI protocols are available.

10.9.2. DAC Data Transfer

SPI-DACs can convert more than one digital value, but every value is transmitted in one datagram. Because TMC4361 provides two current values, a datagram transfer from TMC4361 to a connected SPI-DAC is split into two datagrams, one for each current value: *CURRENTA_SPI* and *CURRENTB_SPI*.
The transmission is initiated as soon as one of both values is changed internally. The data transfer of the second current value *CURRENTB_SPI* is executed automatically whenever the transmission of *CURRENTA_SPI* is completed.
If only the scaling factor *SCALE_PARAM* needs to be transferred, only one datagram is sent out.

10.9.3. Changing SPI Output Protocol for SPI-DAC

Per default, the SPI protocol follows the TMC style: To initiate a data transfer, the negated chip select signal NSCSDRV_SDO switches from high to low level. After a while, the serial clock SCKDRV_NSDO switches from high to low level. When the transmission is finished, the serial clock switches to high level. Afterwards, the negated chip select signal switches to high level to finish the data transfer.

Adaptations to suit other SPI protocols are also available:

In order to set serial clock to low level - *before the negated chip select switches to low level* - do as follows:

Action:
➢ Set *sck_low_before_csn* = 1 (bit4 of *SPIOUT_CONF* register 0x04).

Result:
SCKDRV_NSDO is tied low before NSCSDRV_SDO switches to low level to initiate data transfer.

Per default, TMC drivers sample master data with the rising edge of the serial master clock. Thus, TMC4361 shifts output data at SDODRV_SCLK with the falling edge of SCKDRV_NSDO.

If the data must be sampled with the falling edge of the master clock at the driver's side, do as follows:

Action:
➢ Set *new_out_bit_at_rise* = 1 (bit5 of *SPIOUT_CONF* register 0x04).

Result:
The output data at SDODRV_SCLK is changed with the rising edge of SCKDRV_NSDO.

Read entire documentation; especially the "Supplemental Directives" on page 218.

10.9.4. DAC Address Values

SPI transmission to a DAC transfers an address or a command prior to the value that must be defined. The length of the prefixed command/address can be assigned by setting *DAC_CMD_LENGTH* according to specification of the SPI-DAC.

In order to set up the DAC communication scheme, do as follows:

Action:

➢ Set *DAC_CMD_LENGTH* (bit11:7 of *SPI_OUT_CONF* register 0x04) according to the length of the address / command, which is placed in front of the values.

➢ Set *DAC_ADDR* register 0x1D according to your requirements:

Address/command of the 1st value: Set DAC_ADDR*(15:0)* = DAC_ADDR_A.
Address/command of the 2nd value: Set DAC_ADDR*(31:16)*= DAC_ADDR_B.

Result:
DAC_ADDR_A is placed in front of the first transferred value that can be the current value of coilA (=*CURRENTA_SPI*) or the scaling factor (=*SCALE_PARAM*), whereas *DAC_ADDR_B* is placed before the second current value *CURRENTB_SPI*.

i *COVER_DATA_LENGTH* comprises the whole datagram length, which is the sum of the address/length *DAC_CMD_LENGTH* and the 8-bit data length.

i If the cover register length comprises more bits than the combination of address/command and value, trailing zeros are added at the end.

i The command bits consist of the least significant bits of *DAC_ADDR_x* if the command length is less than 16 bits long.

10.9.5. DAC Data Values

Several opportunities are available for the DAC data style:

- Current values are converted to absolute values. The phases of the values are generated at the STPOUT (coilA) and DIROUT (coilB) pins. The base line (value equals 0) is located at 0 (see *Table* 47, **Figures B and C**).
- The current values*, which range between −255 and 255,* are mapped to values between 0 and +255: the minimum value of −255 is an output value of 0, whereas the baseline is set to +128. The maximum value remains at +255. In detail, the value is divided by two and 128 is added to the quotient (*Table* 47, page 119, **Fig. A**).

TMC4381 provides an offset to compensate for a shifted DAC baseline.

In order to shift the DAC baseline, do as follows:

Action:

➢ Set *DAC_OFFSET* (bit31:24 of register 0x7E) according to your requirements.

Result:
The digital values are shifted accordingly. *Table* 47 (page 119), **Figure D** shows absolute DAC values. The DAC baseline is shifted by 32 steps, whereas *Table* 47 (page 119), **Figure E** shows mapped DAC values, which are shifted by 64 steps.

i For the three available absolute values options – including the unsigned scale parameter transfer – the offset represents an unsigned number.

i For the mapped values option the offset represents a signed number. To avoid a carry over at the value limits +255 and -256 when using an DAC offset, the MSLUT values must be scaled down for the SPI output values (see Table 47 (page 119), Figures D and E). This can be done by using the current scale feature, as explained in chapter 11, page 120.

i •→ Continued on next page.

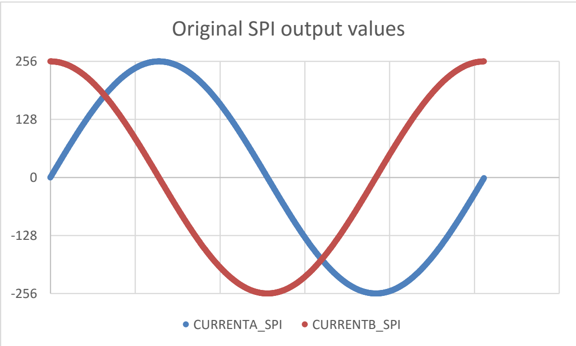
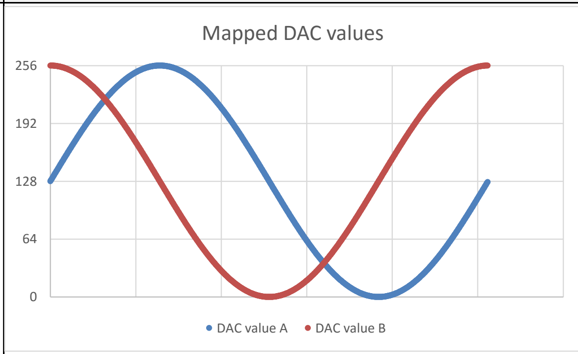
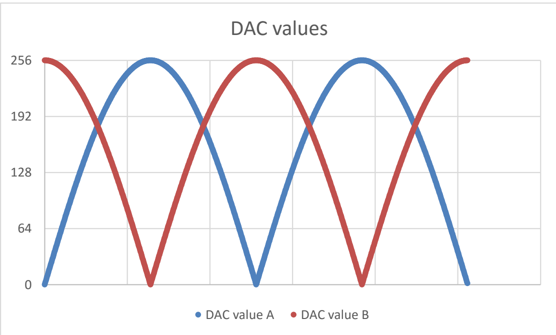
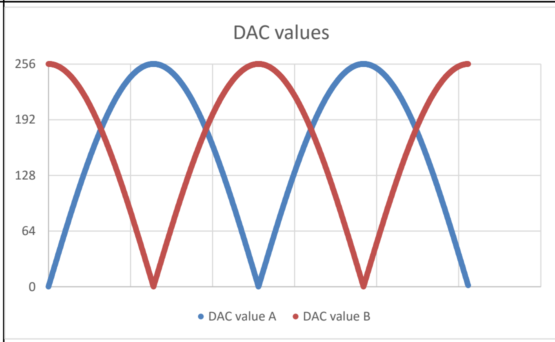
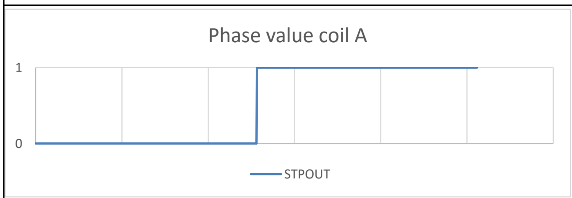
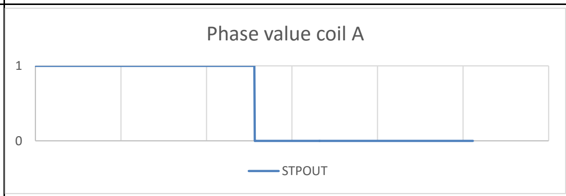
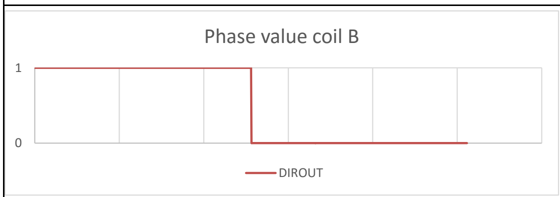
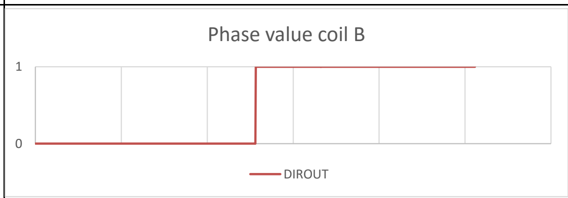
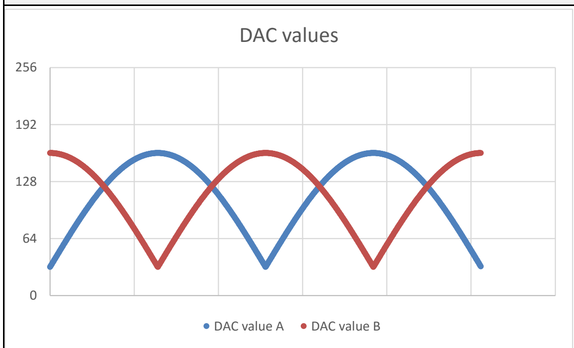
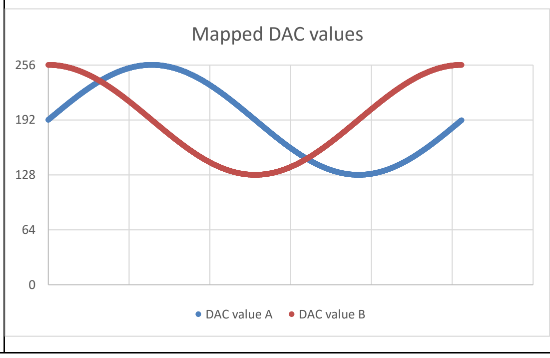
<table>
<tr><th colspan="2">Available DAC Options for the SPI Output Interface</th></tr>
<tr><td>Original SPI Output Curves:</td><td>A Mapped DAC values:</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>B Absolute DAC values (positive phase = 0)</td><td>C Absolute DAC values (positive phase = 1)</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>D Absolute DAC values, original MSLUT values are scaled to ½, DAC value offset=32</td><td>E Mapped DAC values, original MSLUT values are scaled to ½, DAC value offset = 64</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Table 47: Available SPI-DAC Options

11. Current Scaling

The current values of register 0x7A – *CURRENTA* and *CURRENTB* – of the microstep lookup table (MSLUT) represent the maximum 9-bit signed values, which can be sent via the SPIOUT output interface. In most sections of the velocity ramp it is not required to drive the motor with the full current amplitude. Various possibilities are implemented that allow adaptation of actual current values of the MSLUT to the present ramp status. Scale parameters are available for boost current, hold current, and drive current.

These parameters can be assigned independently in the *SCALE_VALUES* register 0x06, and are used automatically for different states of the velocity ramp; if enabled, as described below. Prior to describing the various feasible scaling situations, a brief explanation of the scaling calculation is provided.

Calculation of the Current Output Values

When scaling is enabled for the present ramp state, the actual current values of the MSLUT are multiplied with the MULT_SCALE parameter that is deduced from one of the four *SCALE_VALUES*:

Description of Scaling Calculation

MULT_SCALE = (actual_SCALE_VAL + 1) / 256

with actual_SCALE_VAL = {HOLD, BOOST, DRV1, DRV2}.

Consequently, this MULT_SCALE ranges from 0 to 1: 0 < MULT_SCALE ≤ 1.

MULT_SCALE is then multiplied with the actual current values *CURRENTA* and *CURRENTB*, which are generated by the MSLUT:

CURRENTA_SPI = *CURRENTA* · MULT_SCALE (bit8:0 of 0x7B)

CURRENTB_SPI = *CURRENTB* · MULT_SCALE (bit24:16 of 0x7B)

These values are transferred via SPI output interface. If no current scaling is enabled, the output values *CURRENTA_SPI* and *CURRENTB_SPI* are equal to the MSLUT values *CURRENTA* and *CURRENTB* because the scaling values are equal to the maximum 255, per default. Thus, scaling will only decrease the original MSLUT values.
Also, the actual scale parameter can assume intermediate values because TMC4361 offers possibilities to convert smoothly from one scale value to another. The actual scale parameter *SCALE_PARAM* can be read out at register 0x7C. It has the same range as the four *SCALE_VALUES*.

AREAS OF SPECIAL CONCERN

! **Use of TMC26x and TMC2130 stepper motor drivers in S/D mode:**
If TMC motor stepper drivers are used in S/D mode, scaling values comprise only 5 bits because the CS value of TMC26x, and the IHOLD, IRUN values of TMC2130 motor stepper drivers are adapted directly. Therefore, MULT_SCALE is calculated slightly differently:

MULT_SCALE = (actual_SCALE_VAL + 1) / 32

Read entire documentation; especially the "Supplemental Directives" on page 218.

11.1. Hold Current Scaling

During standstill, the current can be scaled down considerably in most applications because the energy demand is lower than during motion. In addition to the scaling value, the standby delay must be configured. The delay defines the time between ramp stop and startup of hold scaling. Whenever the delay is set to 0, hold scaling is immediately enabled at the end of the velocity ramp. Because most applications require waiting for system oscillations after ramp stop, this delay must be set up in most cases.

In order to set up and enable hold current scaling, do as follows:

Action:
- Set *STDBY_DELAY* register 0x15 according to the duration of the time after ramp stop hold scaling should be enabled.
- Set *HOLD_SCALE_VAL* = *SCALE_VALUES* (31:24) according to the maximum current during motor standstill.
- Set *hold_current_scale_en* = 1 (*CURRENT_CONF* register 0x05).
- Set *closed_loop_scale_en* = 0 (*CURRENT_CONF* register 0x05).

Result:
The standby timer is started as soon as *VACTUAL* reaches 0. After *STDBY_DELAY* clock cycles the standby timer expires that activates the hold scaling phase.

Standby Status

The standby status can be forwarded via STDBY_CLK output pin.

In order to generate an output standby signal, do as follows:

Action:
- Set *stdby_clk_pin_assignment* (1) = 0 (Bit14 of *GENERAL_CONF* register 0x00).
- Set *stdby_clk_pin_assignment* (0) (Bit13 of *GENERAL_CONF* register 0x00) according to the active voltage level of the output pin.

Result:
STDBY_CLK output pin forwards the internally generated standby status. The active output level equals *stdby_clk_pin_assignment* (0).

11.2. Freewheeling

Some applications require a freewheeling behavior after ramp stop. This means that the current values are set to 0. A delay timer can be configured to define the time between standby start and the beginning of freewheeling.

In order to set up and enable freewheeling, do as follows:

Action:
- Set *FREEWHEEL_DELAY* register 0x16 according to the duration of the time after standby start, so that freewheeling is activated accordingly.
- Set *freewheeling_en* = 1 (*CURRENT_CONF* register 0x05).
- Set *closed_loop_scale_en* = 0 (*CURRENT_CONF* register 0x05).

Result:
The freewheeling timer is started as soon as the standby mode is activated. After completion of *FREEWHEEL_DELAY* clock cycles, the freewheeling timer expires that activates the freewheeling phase.

i Just before the velocity ramps starts internal scaling is set to the standby scaling value. This avoids starting the ramp at current values that are equal to 0.

Read entire documentation; especially the “Supplemental Directives” on page 218.

11.3. Current Scaling during Motion

If the current values need to be scaled during motion, several options are available. Up to three scaling values can be selected: Two drive scaling values and one boost scale value. Different scale values can be automatically assigned to the various sections of the velocity ramp.

11.3.1. Drive Scaling

Drive scaling is the preferred direct and mostly unconditional scaling option. If no boost scaling is enabled, the current values are scaled according to the given scale value, independent of the present ramp status.

In order to set up and enable only drive current scaling, do as follows:

Action:

- Set *DRV1_SCALE_VAL* = *SCALE_VALUES* (15:8) according to the maximum current during motion.
- Set *drive_current_scale_en* = 1 (*CURRENT_CONF* register 0x05).
- Set *closed_loop_scale_en* = 0 (*CURRENT_CONF* register 0x05).

Result:

As long as no other motion scale options are activated the current values of the MSLUT are scaled according to *DRV1_SCALE_VAL* during motion (*VACTUAL* <> 0).

11.3.2. Alternative Drive Scaling

A second drive scale parameter can be assigned in order to differentiate the motion scaling according to the internal ramp velocity.

In order to set up and enable drive current scaling with two different scaling values, do as follows:

Action:

- Set *VDRV_SCALE_LIMIT* register 0x17 [pps] according to switching velocity at which drive scaling will change.
- Set *DRV1_SCALE_VAL* = *SCALE_VALUES*(15:8) according to maximum current during motion below *VDRV_SCALE_LIMIT*.
- Set *DRV2_SCALE_VAL* = *SCALE_VALUES*(23:16) according to maximum current during motion beyond *VDRV_SCALE_LIMIT*.
- Set *drive_current_scale_en* = 1 (*CURRENT_CONF* register 0x05).
- Set *sec_drive_current_scale_en* = 1 (*CURRENT_CONF* register 0x05).
- Set *closed_loop_scale_en* = 0 (*CURRENT_CONF* register 0x05).

Result:

As long as no boost scaling is activated, the current values of the MSLUT are scaled according to *DRV1_SCALE_VAL* as long as *VACTUAL* ≤ *VDRV_SCALE_LIMIT*.

Whenever *VACTUAL* > *VDRV_SCALE_LIMIT* the current values are scaled according to *DRV2_SCALE_VAL*.

11.3.3. Boost Current

In certain sections of the velocity ramp it can be useful to boost the current. Boost current can be assigned temporarily either after ramp start or during the whole acceleration/deceleration phase. All options can be selected separately; or in combination.

i All three options use the same scaling value *BOOST_SCALE_VAL*.

OPTION 1: BOOST SCALING AT RAMP START

In order to set up and enable boost current scaling within a defined time frame directly after the velocity ramp start-up, do as follows:

Action:

- Set *BOOST_TIME* register 0x18 according to the delay period at which boost current scaling is activated after a velocity ramp start.
- Set *BOOST_SCALE_VAL* = *SCALE_VALUES* (7:0) according to the maximum current during the boost phase.
- Set *boost_current_after_start_en* = 1 (*CURRENT_CONF* register 0x05).
- Set *closed_loop_scale_en* = 0 (*CURRENT_CONF* register 0x05).

Result:

After the velocity ramp start (*VACTUAL* = 0 before), boost scaling is activated according to *BOOST_SCALE_VAL*. The boost timer expires after *BOOST_TIME* clock cycles. Afterwards, any other selected scaling value is used, if active and selected.

OPTION 2: BOOST SCALING ON ACCELERATION SLOPES

In order to set up and enable boost current scaling for the acceleration phase of the velocity ramp, do as follows:

Action:

- Set *BOOST_SCALE_VAL* = *SCALE_VALUES* (7:0) according to the maximum current during the boost phase.
- Set *boost_current_on_acc_en* = 1 (*CURRENT_CONF* register 0x05).
- Set *closed_loop_scale_en* = 0 (*CURRENT_CONF* register 0x05).

Result:

As long as the absolute internal velocity |*VACTUAL*| increases, the boost scaling function is activated according to *BOOST_SCALE_VAL*. The present ramp state can be read out by the *RAMP_STATE* flag. Acceleration slopes are indicated by *RAMP_STATE* = b'01.

OPTION 3: BOOST SCALING ON DECELERATION SLOPES

In order to set up and enable boost current scaling for the deceleration phase of the velocity ramp, do as follows:

Action:

- Set *BOOST_SCALE_VAL* = *SCALE_VALUES*(7:0) according to maximum current during the boost phase.
- Set *boost_current_on_dec_en* = 1 (*CURRENT_CONF* register 0x05).
- Set *closed_loop_scale_en* = 0 (*CURRENT_CONF* register 0x05).

Result:

As long as the absolute internal velocity |*VACTUAL*| decreases, boost scaling is activated according to *BOOST_SCALE_VAL*. The present ramp state can be read out at the *RAMP_STATE* flag. Deceleration slopes are indicated by *RAMP_STATE* = b'10.

11.4. Scale Mode Transition Process Control

Transition from one scale value to the next active value can be configured as slight conversion. It is advisable to avoid abrupt scaling alterations, which can cause unwanted oscillations and/or motor stall. Three different parameters can be set to convert to higher or lower current scale values.

Transition to Hold Current Scaling

! It is often required to peter out the motion (by smoothening the transition process from motion scaling to hold scaling) in order to avoid system standstill oscillations.

In order to configure a smooth transition from motion current scaling to hold current scaling, do as follows:

Action:

➢ Set *HOLD_SCALE_DELAY* register 0x19 according to the delay period after which the actual scale parameter is decreased by one step towards hold current scale value.

Result:

Immediately after the hold scaling current is activated, the actual scale parameter is decreased by one step per *HOLD_SCALE_DELAY* clock cycles until *SCALE_PARAM = HOLD_SCALE_VAL*.

i If *HOLD_SCALE_DELAY* = 0, the hold current scaling value *HOLD_SCALE_VAL* is assigned immediately whenever the hold current scaling is activated.

Transition to higher Motion Current Scaling

! To avoid step loss – in case a higher scale value is assigned during motion – the transition from low to high current scale values can also be adapted.

In order to configure a smooth transition from a lower motion current scaling value to a higher motion current scaling value, do as follows:

Action:

➢ Set *UP_SCALE_DELAY* register 0x18 according to the delay period after which the actual scale parameter is increased by one step towards the higher current scale value.

Result:

Whenever a higher current scale value is assigned internally, the actual scale parameter is increased by one step per *UP_SCALE_DELAY* clock cycles until the assigned scale parameter is reached.

i If *UP_SCALE_DELAY* = 0, the higher current scaling value is assigned immediately whenever the corresponding current scaling phase is activated.

•→ *Description continued on next page.*

Transition to lower Motion Current Scaling

! **To avoid step loss or unwanted oscillations – in case a lower scale value is assigned during motion – the transition from high to low current scale values can be adapted also.**

In order to configure a smooth transition from a higher motion current scaling value to a lower motion current scaling value, do as follows:

Action:

- Set *DRIVE_SCALE_DELAY* register 0x1A according to the delay period after which the actual scale parameter is decreased by one step towards the lower current scale value.

Result:

Whenever a lower current scale value is assigned internally, the actual scale parameter is decreased by one step per *DRIVE_SCALE_DELAY* clock cycles until the assigned scale parameter is reached.

i If *DRIVE_SCALE_DELAY* = 0, the lower current scaling value is assigned immediately whenever the corresponding current scaling phase is activated.

Two examples are provided on the following pages that illustrate how scaling modes can be used.

The scale parameter *SCALE_PARAM* is shown in combination with its related scale timers in clock cycles and in combination with the underlying velocity ramp.

Read entire documentation; especially the "Supplemental Directives" on page 218.

11.5. Current Scaling Examples

Scaling Mode Example 1

In this example, the following scale options are enabled:

- Standby scaling
- Freewheeling
- Boost scaling at start
- Boost scaling on deceleration ramps
- Drive scaling

The different scaling stages of the trapezoidal velocity ramp are shown in different colors in the **Figure A** below.
Figure B shows the internal scale parameter *SCALE_PARAM* as function of time. The scale parameter is not switched immediately whenever the scaling situations alters; because delay timers are used. A transition time between the assigned values is generated. Four transition phases are shown that are calculated as follows:

$$t_{START\_SCALE} = (BOOST\_SCALE\_VAL - HOLD\_SCALE\_VAL) \cdot UP\_SCALE\_DELAY \cdot f_{CLK}$$

$$t_{DN\_SCALE} = (BOOST\_SCALE\_VAL - DRV1\_SCALE\_VAL) \cdot DRV\_SCALE\_DELAY \cdot f_{CLK}$$

$$t_{UP\_SCALE} = (BOOST\_SCALE\_VAL - DRV1\_SCALE\_VAL) \cdot UP\_SCALE\_DELAY \cdot f_{CLK}$$

$$t_{HOLD\_SCALE} = (DRV1\_SCALE\_VAL - HOLD\_SCALE\_VAL) \cdot HOLD\_SCALE\_DELAY \cdot f_{CLK}$$

Figure C shows the different timers that are used:

- To finish boost scaling after start.
- To start standby scaling.
- To start freewheeling.

i These three delay values are directly determined by their respective register values 0x1B, 0x15, and 0x16.

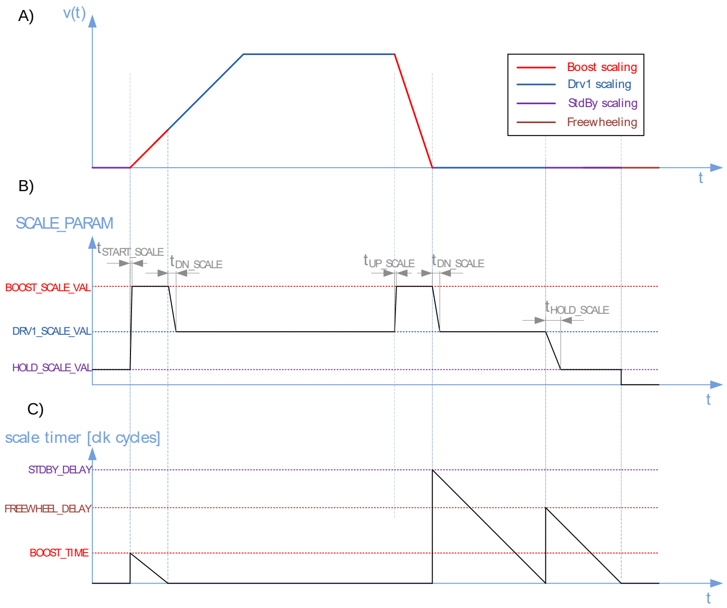


Figure 52: Scaling Example 1

Scaling Mode Example 2

In this example, the following scale options are enabled:

- Boost scaling on acceleration ramps
- Drive scaling 1 and 2

As long as |*VACTUAL*| < *VDRV_SCALE_LIMIT,* Drv1 scaling is active. Both drive scaling modes are used for the deceleration ramp because boost current is not enabled during deceleration slopes (*boost_current_on_dec* = 0).
Whenever *VACTUAL* traverses 0 the *RAMP_STATUS* switches to acceleration ramp, and boost scaling becomes enabled again.
This is shown in Figure 53 A. Figure 53 B depicts the actual scale parameter, which is altered with the formerly specified delays. In contrast to example 1, t_{START_SCALE} is changed to the following calculation:

$$t_{DN\_SCALE} = (BOOST\_SCALE\_VAL - DRV1\_SCALE\_VAL) \cdot DRV\_SCALE\_DELAY \cdot f_{CLK}$$

Whereas the other transition phases depend on whether *DRV1_SCALE_VAL* or *DRV2_SCALE_VAL* is used either; before or after the transition process.

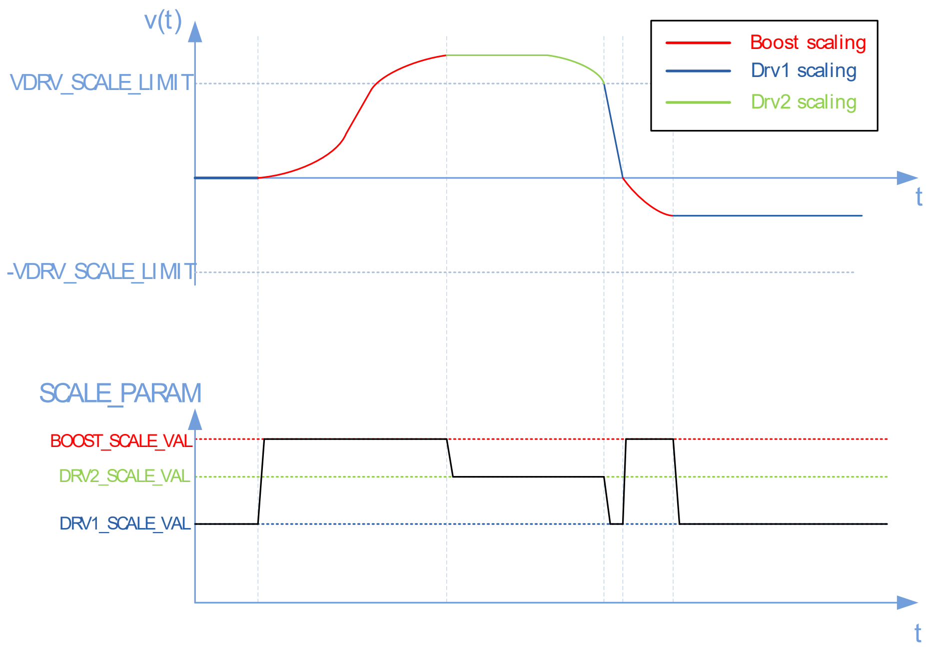


Figure 53: Scaling Example 2

12. NFREEZE and Emergency Stop

In case dysfunctions at board level occur, some applications require an additional strategy to end current operations without any delay. Therefore, TMC4361 provides the low active safety pin NFREEZE.

NFREEZE Operational Principle

NFREEZE is low active. An active NFREEZE input transition from high to low level stops the current ramp immediately in a user configured way.

At the moment - *when NFREEZE switches to low* - an event *FROZEN* is triggered at *EVENTS* (10). *FROZEN* remains active until the reset of the TMC4361.

AREAS OF SPECIAL CONCERN

! **It is necessary to tie NFREEZE low for at least three clock cycles because of the input filter of three consecutive sample points.**

Pin Description: NFREEZE		
Pin Name	**Type**	**Remarks**
NFREEZE	Input	External enable pin; low active.

Table 48: Pin Description: NFREEZE

Pin Descriptions: DFREEZE and IFREEZE			
Register Name	**Register Address**		**Remarks**
DFREEZE	0x4E (23:0)	RW	Deceleration value in the case of an active FREEZE event.
IFREEZE	0x4E (31:24)	RW	Current scaling value in the case of an active FREEZE event.

Table 49: Pin Descriptions DFREEZE and IFREEZE

12.1.1. Configuration of FREEZE Function

Two parameters (*DFREEZE* and *IFREEZE*) are necessary in order to be able to use the TMC4361 freeze function. They are integrated in the freeze register, which can be written only once after an active reset; assuming that there has not been a ramp start before. Thus, the freeze parameters should be set directly before operation.

NOTE:

→ *Selected values cannot be altered until the next active reset. These restrictions are necessary to protect the TMC4361 freeze configuration from incorrect SPI data sent from the microcontroller in case of error.*

AREAS OF SPECIAL CONCERN

! **Keep in mind that:**

- The polarity of NFREEZE input cannot be assigned.
- The freeze register can always be read out.
- During freeze state ramp register values can be read out.

Read entire documentation; especially the "Supplemental Directives" on page 218.

12.1.2. Configuration of *DFREEZE* for automatic Ramp Stop

***DFREEZE* can be used for an automatic ramp stop configuration. Two options are available:**

- **Option 1:** Use of *DFREEZE* = 0 for a hard stop.
- **Option 2:** Use of *DFREEZE* ≠ 0 for a linear deceleration ramp.

PRINCIPLE:

Due to the independence of *DFREEZE* from internal register values like *direct_acc_val_en* or the given clock frequency f_{CLK} (which can be altered by erroneous SPI signals) the deceleration value *DFREEZE* is always given as velocity value change per clock cycle. Therefore, the *DFREEZE* value is calculated as follows:

$$d\_freeze\ [pps^2] = DFREEZE / 2^{37} \cdot f_{CLK}^2$$

This leads to the same behavior of the motor and is like setting *direct_acc_val_en* to 1 for the other acceleration values during normal operation.

Configuration of *IFREEZE* current Scaling Value

***IFREEZE* can be used to configure the current scaling value during a freeze event. Two options are available:**

- **Option 1:** Use of *IFREEZE* = 0 for assigning the last specified current scaling value before the freeze event.
- **Option 2:** Use of *IFREEZE* ≠ 0 for assigning a defined current scaling value.

PRINCIPLE:

IFREEZE is a current scaling value which becomes valid in case *NFREEZE* has been tied to low and the related event (*FROZEN*) has been released.
In case *IFREEZE* is set to 0, the last scaling value before the emergency event is assigned permanently.
The scale value *IFREEZE* then manipulates the current value in the same way as explained in chapter 11, page 120.

13. Controlled PWM Output

TMC4361 offers controlled PWM (Pulse Width Modulation) signals at STPOUT and DIROUT output pins. These PWM signals can be scaled, depending on the internal velocity. If a TMC23x/24x stepper motor driver is connected and configured properly, the PWM signals are redirected to two SPI output interface pins. This avoids rerouting of signal lines at board level if SPI mode is switched to PWM mode, or vice versa.

In this chapter information is provided on the basic setup of the PWM output configuration; and also on TMC23x/24x control PWM input support.

Dedicated PWM Output Pins		
Pin Names	**Type**	**Remarks**
STPOUT_PWMA	Output	PWM output for coil A.
DIROUT_PWMB	Output	PWM output for coil B.
Connected and selected TMC23x/24x stepper motor drivers only:		
SDODRV	Output	PWM output for coil A.
NSCSDRV	Output	PWM output for coil B.

Table 50: Dedicated PWM Output Pins

Dedicated PWM Output Registers			
Register Name	**Register Address**		**Remarks**
GENERAL_CONF	0x00	RW	Bit 21: *pwm_out_en.*
CURENT_CONF	0x05	RW	*pwm_scale_en* = *CURRENT_CONF* (8): PWM scale enable switch *PWM_AMPL* = *CURRENT_CONF* (31:16): PWM amplitude at *VACTUAL* = 0.
PWM_VMAX	0x17	RW	Second assignment to *VDRV_SCALE_LIMIT*: velocity at which the PWM scale parameter reaches 1 (maximum).
PWM_FREQ	0x1F	RW	Number of clock cycles that forms one PWM period.

Table 51: Dedicated PWM Output Registers

13.1. PWM Output Generation and Scaling Possibilities

Enable PWM Output Generation

The STPOUT and DIROUT output pins generally forward internal generated microsteps and motion direction. In contrast to that, it is possible to forward the internal MSLUT value as PWM output signals, which is dependent on the PWM frequency.

In order to generate PWM output, do as follows:

Action:

- Set *PWM_FREQ* register 0x1F to the number of clock cycles for one PWM cycle.
- Set *pwm_out_en* = 1 (*GENERAL_CONF* register 0x00).

Result:

Step/Dir output is disabled and PWM signals are forwarded via STPOUT_PWMA and DIROUT_PWMB. PWM frequency f_{PWM} is calculated by:

$f_{PWM} = f_{CLK} / PWM\_FREQ$

If PWM Voltage mode is selected:

NOTICE

Avoid unintended overheating to prevent motor damage during PWM mode!

- **At lower velocity values PWM voltage scaling MUST be enabled.**

This will ensure smooth operation during controlled PWM mode.

PWM Duty Cycle Scaling

The duty cycle of both signals represent the sine (STPOUT) and cosine (DIROUT) values of the MSLUT.
PWM voltage scaling does not work the same way as presented for the SPI current output interface (see chapter 11, page 120). PWM scaling is adapted linearly, which depends on the internal ramp velocity. During Voltage PWM mode the scaling value at *VACTUAL* = 0 must be assigned, and also the velocity at which full scaling is reached.

In order to generate a scaled PWM output, do as follows:

Action:

- Set *PWM_AMPL* (bit31:16 of register 0x05) as start PWM scaling value.
- Set *PWM_VMAX* register 0x17 to the internal ramp velocity [pps] at which full PWM scaling is reached.
- Set *pwm_scale* = 1 (bit8 of *CURRENT_CONF* register 0x05).

Result:

- PWM_SCALE is the actual scaling value.
- In case *VACTUAL* = 0, $PWM\_SCALE = (PWM\_AMPL + 1) / 2^{17}$.

i Whenever the absolute velocity value increases, the scale parameter also increases linearly until it reaches the maximum of PWM_SCALE = 0.5 at *VACTUAL* = *PWM_VMAX*.

i The minimum duty cycle is calculated by DUTY_MIN = (0.5 – PWM_SCALE).

i The maximum duty cycle is calculated by DUTY_MAX = (0.5 + PWM_SCALE).

i These values set the PWM duty cycle limits of any internal ramp velocity.

13.1.1. PWM Scale Example

In *Figure* 54 below, the calculation of minimum/maximum PWM duty cycles with *PWM_AMPL* = 32767 is shown on the left side. Resulting duty cycles for different positions in the sine voltage curve are depicted on the right side. Calculated delays of minimum/maximum duty cycles are also shown.

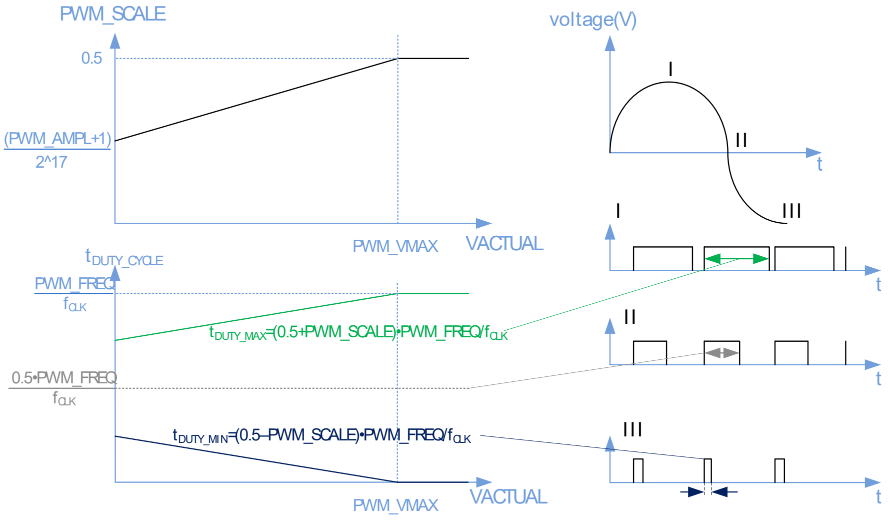


Figure 54: Calculation of PWM Duty Cycles (PWM_AMPL)

13.2. PWM Output Generation for TMC23x/24x

Controlled PWM Signals for TMC23x/24x

PWM output signals can be used for TMC23x/24x stepper motor drivers Voltage PWM mode. TMC4361 forwards the internal PWM output signals at the corresponding SPI output interface pins because the drivers share input and output pins for the SPI mode and the Voltage PWM mode. This feature enables variable operation of the TMC23x/24x in the one or the other mode without rerouting the particular signal lines at board level.

In order to generate a PWM output for TMC23x/24x stepper motor drivers, do as follows:

Action:

- ➢ Set *PWM_FREQ* register 0x1F to the number of clock cycles for one PWM cycle.
- ➢ Set *spi_output_format* = b'1000 (TMC23x) or
  spi_output_format = b'1001 (TMC24x).
- ➢ Set *pwm_out_en* = 1 (*GENERAL_CONF* register 0x00).
- ➢ Set *SPI_SWITCH_VEL* register 0x1D to 0.

Result:

- SPI output interface is disabled, controlled PWM output for TMC23x/24x is enabled.
- SDODRV_SCLK output pin forwards PWM PHA signal.
- NSCSDRV_SDO output pin forwards PWM PHB signal.
- MP2 is set to low voltage level that disables TMC23x/24x SPI mode.
- SDODRV_SCLK analyses the error flags that are forward via SDO output pin of TMC23x/24x. These error flags indicate overcurrent on any bridge or the overtemperature flag. Therefore, these three status bits of TMC4361 are altered according to the ERR flag.
- SCKDRV_NSDO is set to high voltage level to set MDBN of TMC23x/24x to high voltage level.

NOTE:

→ *Only the five pins mentioned above are set accordingly by TMC4361.*

→ *Please be aware that all other pins of TMC23x/24x must be set according to your requirements, especially ANN/MDAN = high voltage level, and INA resp. INB according to the current limit.*

i For correct hardware setup information refer to TMC23x/24x manuals.

TMC4361 with TMC23x/24x Stepper Driver

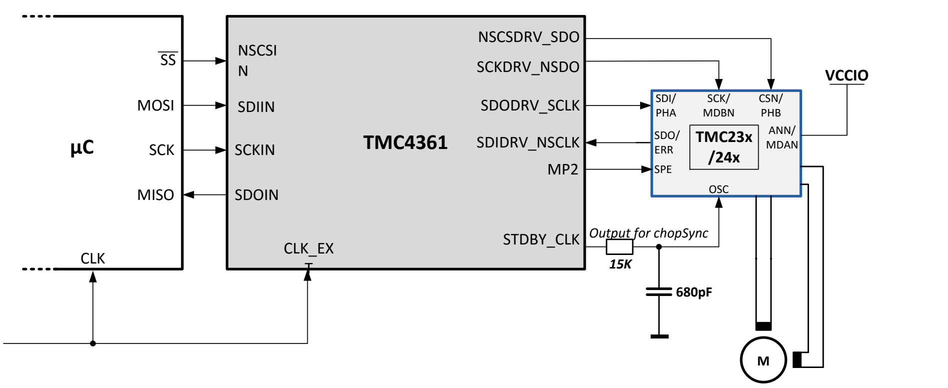


Figure 55: TMC4361 connected with TMC23x/24x operating in SPI Mode or PWM Mode

13.3. Switching between SPI and Voltage PWM Modes

The hardware setup scenario, as shown on the previous page, also allows switching between SPI and Voltage PWM mode. It is advisable to enable or disable the Voltage PWM mode during standstill of the internal ramp.

In order to disable Voltage PWM mode for TMC23x/24x, do as follows:

Action:

- Set *pwm_out_en* = 0 (*GENERAL_CONF* register 0x00).

Result:
SPI output interface is enabled and controlled PWM output for TMC23x/24x is disabled. MP2 – that must be connected with SPE@TMC23x/24x – is set to high voltage level, which enables TMC23x/24x SPI mode.

However, it is also possible to switch between both modes during motion. Because the internal MSLUT is used either as voltage specification or as current specification, microstep loss can occur whenever the mode is switched in case the switching velocity is passed by.

i In order to overcome this, issue a microstep offset during PWM mode can be assigned.

In order to set up a TMC23x/24x configuration that switches between SPI and PWM voltage mode, do as follows:

Action:

- Set *PWM_FREQ* register 0x1F to the number of clock cycles for one PWM cycle.
- Set *pwm_out_en* = 1 (*GENERAL_CONF* register 0x00).
- Set *spi_output_format* = b'1000 (TMC23x) or
  spi_output_format = b'1001 (TMC24x).
- Set *SPI_SWITCH_VEL* register 0x1D to a value [pps] at which the mode change should happen.
- Set *MS_OFFSET* register 0x79 (only write access) to a value between 0 and 255.

Result:
Whenever the internal velocity |*VACTUAL*|< *SPI_SWITCH_VEL*, Voltage PWM mode is activated automatically.
Whenever |*VACTUAL*| ≥ *SPI_SWITCH_VEL,* SPI mode is activated automatically. During PWM mode the internal MSLUT value is modified by *MS_OFFSET*; in order to shift the resulting voltage curve of the motor coils.

Determining *MS_OFFSET*

Observing the motor coil currents with current probes is the best method for determining the required *MS_OFFSET*:

- Triggering the SPE signal will gain the switching point.
- At this point the current curves show a crack if no offset is assigned. This could lead to step loss.

i The offset can attenuate this crack to overcome this step loss.

Read entire documentation; especially the "Supplemental Directives" on page 218.

14. dcStep Support for TMC26x or TMC2130

dcStep is an automatic commutation mode for stepper motor drivers. It allows to run the stepper with its nominal velocity, which is generated by the internal ramp generator for as long as it can cope with the motor load.

In case the motor becomes overloaded, it slows down to a lower velocity at which the motor can still drive the load. This avoids that the stepper motor stalls, and enables the stepper motor to drive heavy loads as fast as possible. Its higher torque - *available at lower velocity* – in combination with dynamic torque (from its flywheel mass) compensates mechanical torque peaks without feedback.

Dedicated dcStep Pins		
Pin Name	**Pin Type**	Remarks
MP1	Input	dcStep input signal.
MP2	Inout as Output	dcStep output signal.

Table 52: Dedicated dcStep Pins

Dedicated dcStep Registers			
Register Name	**Register Address**		**Remarks**
GENERAL_CONF	0x00	RW	Bit22:21: dc_step_mode.
DC_VEL	0x60	W	Velocity at which dcStep starts (fullstep); 24 bit.
DC_TIME	0x61(7:0)	W	Upper PWM on time limit for internal dcStep calculation.
DC_SG	0x61(15:8)	W	Maximum PWM on time for step loss detection (multiplied by 16!).
DC_BLKTIME	0x61(31:16)	W	dcStep blank time after fullstep release.
DC_LSPTM	0x62	W	dcStep low speed timer; 32 bit.

Table 53: Dedicated dcStep Registers

•→*Turn page for more information on how dcStep increases the usable motor torque.*

dcStep increases usable Motor Torque

In a classical application, the operation area is limited by the maximum torque required at maximum application velocity. A safety margin of up to 50% torque is required, in order to compensate unforeseen load peaks, torque loss due to resonance, and aging of mechanical components. dcStep makes it possible to use the available motor torque to its fullest. Even higher short-time dynamic loads can be overcome by using motor and application flywheel mass without the danger of causing a motor stall. With dcStep, the nominal application load can be extended to a higher torque, which is only limited by the safety margin near the holding torque area (which is the highest torque the motor can provide). Additionally, maximum application velocity can be increased up to conditional maximum motor velocity.

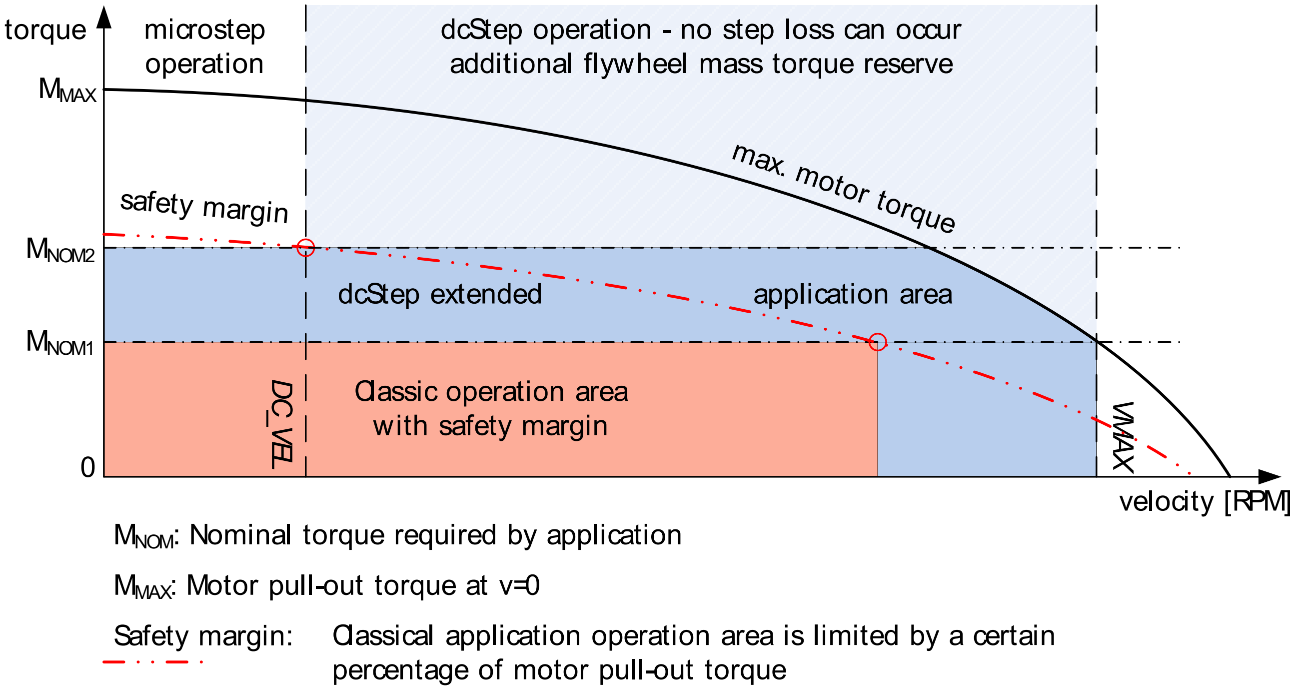


Figure 56: dcStep extended Application Operation Area

•→ Turn page for more information about enabling dcStep forTMC26x stepper motor drivers.

14.1. Enabling dcStep for TMC26x Stepper Motor Drivers

If connected to TMC26x drivers, TMC4361 must generate the dcStep signal internally; despite particular motor settings dcStep requires only very few settings, which could be tunneled via SPI through TMC4361.
dcStep directly feeds motor motion back to the ramp generator so that it becomes seamlessly integrated into the motion ramp; even if the motor becomes overloaded with respect to the target velocity. In order to set up the hardware correctly the SG_TST output pin of TMC26x must be connected to the MP1 input pin of TMC4361; and the TST_MODE pin of TMC26x must be connected to VCCIO.

i Please also refer to the corresponding TMC26x manuals for the correct motor driver settings.

In order to set up a TMC26x dcStep configuration, do as follows:

PRECONDITION: TMC26X MOTOR DRIVER SETUP:

- Set CHM = 1 (constant tOFF-Chopper).
- Set HSTRT = 0 (slow decay only).
- Set SGTO = 1 and SGT1 = 1 (on_state_xy as test signal output).
- Set TST = 1 (Test mode on).

Action:

- Set *spi_output_format* = b'1011 or b'1010 (automatic TMC26x setting).
- Set the upper PWM time *DC_TIME* slightly higher than the driver effective blank time TBL (register 0x61).
- Set *DC_BLKTIME* [clock cycles] when no comparison should happen after a fullstep release (register 0x61).
- Set *DC_SG* [clock cycles · 16] as PWM ON-time for step loss detection (0x61).
- Set *dcstep_mode* = b'01 (*GENERAL_CONF* register 0x00).

Result:

The internal dcStep at MP1 input signal approves further step generation in case the input step signals are smaller than the *DC_TIME* step length in clock cycles.

NOTE:

→ ***Even though dcStep is able to decelerate the motor during overload, stalls can occur due to certain negative influences, such as:***

The motor may stall and lose steps, e.g. because deceleration drops below obligational minimum velocity. In order to safely detect a step loss and avoid restarting of the motor, the stop on stall can be enabled (see section 10.4.4 (page 104).
Concerning dcStep operation with TMC26x: the stall bit from the driver status is substituted by the dcStep stall detection bit.
Therefore, the first step at MP1 input directly after a step release is checked against the DC_SG value, which is the maximum PWM ON-time. In case the signal step length is smaller than DC_SG, a stall has occurred.
DC_BLKTIME specifies the number of clock cycles after a fullstep release in case nothing must be compared; because fragmented steps could occur at MP1. The first step after release that is checked is the first step after blank time. The switch to fullstep drive is performed automatically, as explained in section 10.6.4 and 10.6.5, page 111).

14.2. Setup: Minimum dcStep Velocity

dcStep requires a minimum operation velocity *DC_VEL* [pps]. *DC_VEL* must be set to the lowest operating velocity at which dcStep provides a reliable detection of motor operation. In case an overload appears, an internal dcStep signal is generated that pauses internal step generation. Because dcStep operates the motor in fullstep mode, a minimum fullstep frequency f_{FS} can be assigned.
Therefore, a dcStep low speed timer must be assigned to achieve the following minimum fullstep frequency:

$f_{FS} = f_{CLK}$ / *DC_LSPTM*.

In order to set up a minimum dcStep velocity, do as follows:

Action:

- Set the low speed timer *DC_LSPTM* register 0x62, as explained above.
- Set *DC_VEL* register 0x60 as threshold velocity value [pps] at which dcStep is activated.

Result:
Whenever the internal velocity |*VACTUAL*| > *DC_VEL*, dcStep is activated, if enabled.

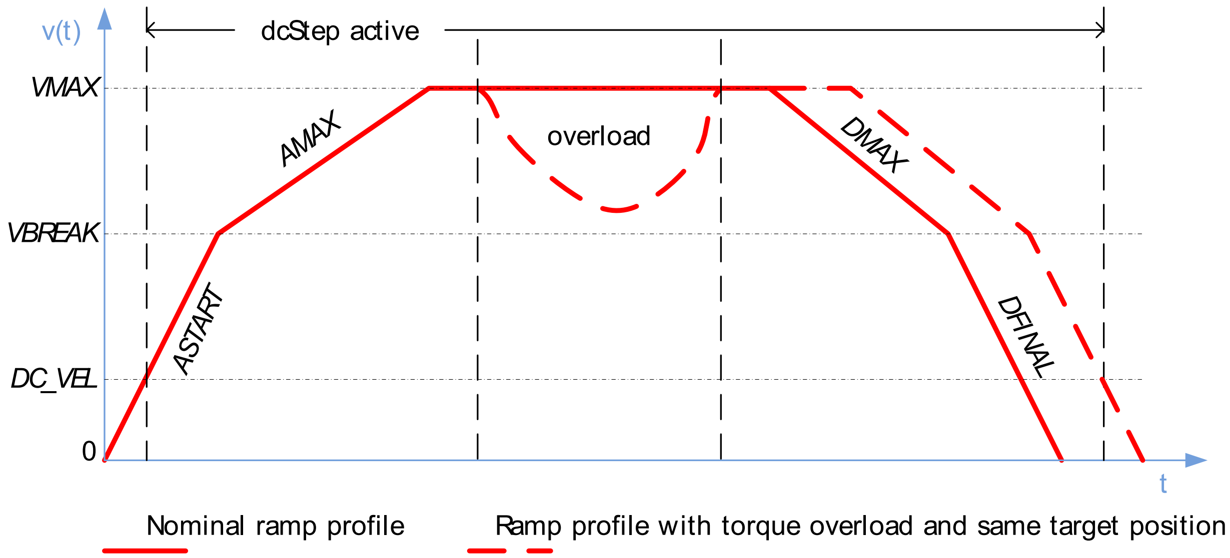


Figure 57: Velocity Profile with Impact through Overload Situation

•→*Turn Page for important information about the chopper settings for microstep and fullstep/dcStep mode.*

AREAS OF SPECIAL CONCERN

!

Different chopper settings for microstep and fullstep/dcStep mode of TMC26x stepper driver can be transferred automatically during motion.

Switching between dcStep mode and microstep mode often requires different chopper settings for TMC26x stepper motor drivers.

It is possible to automatically transfer cover datagrams to TMC26x (see Section 10.3.6, page 101). Thereby, it is possible to switch the chopper settings of TMC26x rapidly, shortly before reaching the dcStep velocity.

NOTE:

→ *It is recommended to use this feature because dcStep requires constant OFF-time chopper settings; whereas driving with µSteps and a spreadCycle chopper provides better driving characteristics.*

In order to set up a TMC26x dcStep configuration, do as follows:

Action:

- Set the *SPI_SWITCH_VEL* register 0x1D value a little bit smaller than the *DC_VEL* register 0x60 value.
- Fill in the *COVER_LOW* 0x6C register the chopper settings for spreadCycle chopper below the *DC_VEL.*
- Fill in the *COVER_HIGH* 0x6D register the chopper settings for a constant OFF-time chopper during dcStep operation (fullstep mode).
- Set *automatic_cover* = 1 (*REFERENCE_CONF* register 0x01).

Result:

In case dcStep mode is not activated – because |*VACTUAL*| < *DC_VEL* – the spreadCycle chopper mode is activated, which is best suited for microstep operation.

In case dcStep is activated, the more suited constant OFF-time chopper mode for fullstep operation is activated.

•→ *Turn Page for more information on enabling dcStep for TMC2130 stepper motor driver.*

14.3. Enabling dcStep for TMC2130 Stepper Motor Drivers

dcStep operation with TMC2130 is similar to a handshake procedure: The MP1 input must be connected to the DCO output pin of TMC2130, whereas MP2 must be connected to the DCEN input pin of TMC2130.

In order to set up a TMC2130 dcStep configuration, do as follows:

The mandatory TMC2130 configuration MUST be executed with cover datagrams, as follows:

i Please refer to the TMC2130 manual for correct settings pertaining to the TMC2130 CHOPCONF and DCCTRL registers.

Action:
- Set *spi_output_format* = b'1101 or b'1100 (automatic TMC2130 setting)
- Set *dcstep_mode* = b'01 (*GENERAL_CONF* register 0x00).

Result:
In case *VACTUAL* ≥ *DC_VEL*, MP2 output is set to high voltage level to indicate that dcStep can be activated.
TMC2130 will wait for the next fullstep position to switch to dcStep operation. The dcStep signal is provided by the TMC2130 at DCO output pin.
TMC4361 is continually providing microsteps even though dcStep is enabled and activated. TMC2130 auto-generates the dcStep behavior internally.

Set up minimum dcStep/Fullstep Frequency

Because dcStep operates the motor in fullstep mode, a minimum fullstep frequency f_{FS} can be assigned. Therefore, a dcStep low speed timer must be assigned to achieve the following minimum fullstep frequency:

$f_{FS} = f_{CLK} / DC\_LSPTM$.

In order to set up a minimum dcStep fullstep frequency, do as follows:

Action:
- Set *DC_LSPTM* register 0x62.

Result:
After *DC_LSPTM* clock cycles expires – without lifting the internal dcStep signal – a step is enforced when dcStep is enabled.

Read entire documentation; especially the "Supplemental Directives" on page 218.

15. Decoder Unit: Connecting ABN, SSI, or SPI Encoders correctly

TMC4361 is equipped with an encoder input interface for incremental ABN encoders, absolute SSI or SPI encoders. This chapter provides basic setup information for correct analysis of connected encoder signals.

Decoder and Closed-Loop Pins		
Pin Names	**Type**	**Remarks**
A_SCLK	Input or Output	A signal of ABN encoder or Serial Clock output for absolute SSI, or SPI encoders.
ANEG_NSCLK	Input or Output	Negated A signal of ABN encoder or Negated Serial Clock output for SSI encoder or Low active Chip Select signal for SPI encoders.
B_SDI	Input	B signal of ABN encoder or Serial Data Input of SSI, or SPI encoders.
BNEG_NSDI	Input or Output	Negated B signal of ABN encoder or Negated Serial Data Input of SSI encoders or Serial Data Output of SPI encoder.
N	Input	N signal of ABN encoder.
NNEG	Input	Negated N signal of ABN encoder.

Table 54: Dedicated Decoder Unit Pins

Decoder Unit and Closed-Loop Registers			
Register Name	**Register address**		**Remarks**
GENERAL_CONF	0x00	RW	Bit11:10: serial_enc_in_mode, Bit12: diff_enc_in_disable
INPUT_FILT_CONF	0x03	RW	Input filter configuration (SR_ENC_IN, FILT_L_ENC_IN).
ENC_IN_CONF	0x07	RW	Encoder configuration register.
ENC_IN_DATA	0x08	RW	Serial encoder input data structure.
STEP_CONF	0x0A	RW	Motor configurations.
ENC_POS	0x50	RW	Current absolute encoder position in microsteps.
ENC_LATCH	0x51	R	Latched absolute encoder position.
ENC_POS_DEV	0x52	R	Deviation between *XACTUAL* and *ENC_POS*.
ENC_CONST	0x54	R	Internally calculated encoder constant.
Encoder Register Set	0x51…58 0x62…63	W	Encoder configuration parameter.
Encoder velocity	0x65 0x66	R	Current encoder velocity (unsigned). Current filtered encoder velocity (signed).
ADDR_TO_ENC *DATA_TO_ENC*	0x68 0x69	W	Serial encoder request data.
ADDR_FROM_ENC *DATA_FROM_ENC*	0x6A 0x6B	R	Serial encoder request data response.
Encoder compensation	0x7D	W	Encoder compensation register set.

Table 55: Dedicated Decoder Unit Registers

15.1.1. Selecting the correct Encoder

The encoder interface consists of six pins that can be connected with different encoder types. Depending on the encoder type, the pins serve as inputs or as outputs. If inputs are assigned, the incoming signals can be filtered, as explained in chapter 4, page 20. Consequently, *SR_ENC_IN* and *FILT_L_ENC_IN* must be set accordingly. In the following, three options are presented to select a connected encoder properly.

OPTION 1: INCREMENTAL ABN ENCODERS

In order to set up a connected incremental ABN encoder, do as follows:

Action:

➢ Set *serial_enc_in_mode* = b'00 (*GENERAL_CONF* register 0x00).

Result:
An incremental ABN encoder is selected.

OPTION 2: ABSOLUTE SSI ENCODERS

In order to set up a connected absolute SSI encoder, do as follows:

Action:

➢ Set *serial_enc_in_mode* = b'01 (*GENERAL_CONF* register 0x00).

Result:
An absolute SSI encoder is selected.

i In order to avoid an erroneous status of the connected absolute SSI encoder, a proper configuration is necessary prior to enabling; as described further down below on the subsequent pages: see section 15.4. on page 150.

OPTION 3: ABSOLUTE SPI ENCODERS

In order to set up a connected absolute SPI encoder:

Action:

➢ Set *serial_enc_in_mode* = b'11 (*GENERAL_CONF* register 0x00).

Result:
An absolute SPI encoder is selected.

i In order to avoid an erroneous status of the connected absolute SPI encoder, a proper configuration is necessary prior to enabling; as described further down below on the subsequent pages: see section 15.4. on page 150.

•→*Turn page for encoder pin assignment overview.*

15.1.2. Disabling digital differential Encoder Signals

If incremental ABN or absolute SSI encoders are selected, the dedicated encoder signals are treated as digital differential signals per default. For internally displaying a valid input level, the levels of a dedicated pair must be digitally inversed.

i No analog differential circuit is available.

In order to disable the digital differential input signals, do as follows:

Action:
➢ Set *diff_enc_in_disable* = 1 (*GENERAL_CONF* register 0x00).

Result:
Dedicated encoder signals are treated as single signals and every negated pin is ignored.

i Concerning absolute SPI encoders, this is done automatically.

Pin Assignment based on selected Encoder Setup						
Pin No.	Pin Name	Incremental ABN		Absolute SSI		Absolute SPI
		Differential	Single-ended	Differential	Single-ended	Single-ended
40	A_SCLK	A	A	SCLK	SCLK	SCLK
1	ANEG_NSCLK	¬A	-	¬SCLK	-	CS
10	B_SDI	B	B	SDI	SDI	SDI
11	BNEG_NSDI	¬B	-	¬SDI	-	SDO
21	N	N	N	-	-	-
22	NNEG	¬N	-	-	-	-

Table 56: Pin Assignment based on selected Encoder Setup

15.1.3. Inverting of Encoder Direction

In order to easily align the encoder direction with the motor direction it is possible to invert the encoder direction by setting one switch.

In order to invert the encoder direction, do as follows:

Action:
➢ Set *invert_direction* = 1 (*ENC_CONF* register 0x07).

Result:
The calculation of the in external position *ENC_POS* is inverted, turning increment to decrement and vice versa.

Read entire documentation; especially the "Supplemental Directives" on page 218.

15.1.4. Encoder Misalignment Compensation

If the encoder is installed correctly, the encoder values form a circle for one motor revolution. Thus, the deviation *ENC_POS_DEV* between real position *ENC_POS* und internal position *XACTUAL* forms a constant function over the whole motor revolution.

Consequently, the resulting form of a deficiently installed encoder is oval-shaped. This system failure results in a new function of *ENC_POS_DEV* that is similar to a sine function. In Figure 58 A below, the position deviation is shown as function of one motor revolution, which comprises 51200 microsteps.

TMC4361 provides an option to compensate this kind of misalignment by adding a triangular shape function that counteracts the system error. This can improve the encoder value evaluation significantly. Per default, this function is constant at 0.

In order to setup the triangular compensation function, do as follows:

Action:

- Set proper *ENC_COMP_XOFFSET* register 0x7D (15:0).
- Set proper *ENC_COMP_YOFFSET* register 0x7D (23:16).
- Set proper *ENC_COMP_AMPL* register 0x7D (31:24).

Result:

ENC_COMP_XOFFSET is 16-bit register which represents a numeral figure between 0 and 1. The resulting offset on the abscissa is calculated by:

XOFF_LOW = *ENC_COMP_XOFFSET* · microsteps/rev / 65536.

A triangular function is generated, which has its **lowest point at (XOFF_LOW; *ENC_COMP_YOFFSET*)**.

The peak is shifted at a distance of half a revolution. The **peak coordinate (XOFF_PEAK;YOFF_PEAK)** is calculated as follows:

XOFF_PEAK = *ENC_COMP_XOFFSET* · microsteps/rev / 65536 + microsteps/rev / 2.

YOFF_PEAK = *ENC_COMP_YOFFSET* + *ENC_COMP_AMPL*.

In Figure 58 A, the red line illustrates this compensation function.

Internally, the triangular function is added to the *ENC_POS* value. As a result, the position deviation is harmonized as a function of the motor revolution; which can be seen in Figure 58 B.

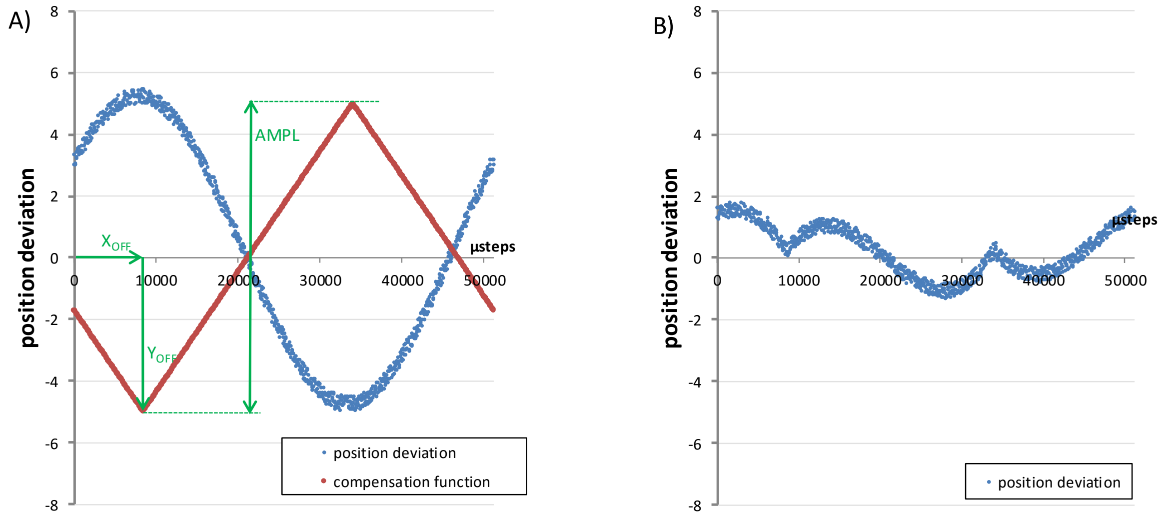


Figure 58: Triangular Function that compensates Encoder Misalignments

15.2. Incremental ABN Encoder Settings

Incremental ABN encoders increment or decrement the external position counter register *ENC_POS* 0x50. This is based on A- and B-signal level transitions.

15.2.1. Automatic Constant Configuration of incremental ABN Encoder

The external position register *ENC_POS* 0x50 is based on internal microsteps. Thus, every AB transition is transferred to microsteps by a fixed constant value. TMC4361 is able to calculated this constant automatically.

In order to configure the incremental ABN encoder constant automatically, do as follows:

Action:

- Set fullstep resolution of the motor in *FS_PER_REV* (*STEP_CONF* register 0x0A).
- Set microstep resolution *MSTEP_PER_FS* (*STEP_CONF register* 0x0A).
- Set encoder resolution – the number of AB transitions during one revolution - in register *ENC_IN_RES* 0x54 (write access).

Result:

The encoder constant value *ENC_CONST* (readable at register 0x54) is calculated as follows:

ENC_CONST = MSTEP_PER_FS · FS_PER_REV / ENC_IN_RES

This constant is the number of microsteps through which *ENC_POS* is incremented or decremented by one AB transition.

i *ENC_CONST* consists of 15 digits and 16 decimal places.

i In case 16 bits are not sufficient for a binary representation of the decimal places, TMC4361 tries to match them to a multiple of 10000 within these 16 decimal places. Thereby, a perfect match can be achieved in case decimal representation is preferred to a binary one.

i In case the decimal representation also does not fit completely, the type of the decimal places of *ENC_CONST* can be selected manually with *ENC_IN_CONF* (0). Set *ENC_IN_CONF* (0) to 0 for binary representation; or set it to 1 for the decimal one. Keep in mind that with this approach *ENC_POS* can slightly differ from the real position; especially the further away the position moves from 0.

15.2.2. Manual Constant Configuration of Incremental ABN Encoder

For some applications it can be useful to define the encoder constant value, which in this case does not correspond to the number of microsteps per revolution; e.g. if the encoder is not mounted directly on the motor.

In order to configure the incremental ABN encoder constant manually, do as follows:

Action:

- Set *ENC_IN_RES*(31) =1.
- Set *ENC_IN_CONF*(0) to 0 for a binary or to 1 for a decimal representation as explained in the previous section.
- Set required encoder resolution in *ENC_IN_RES* (30:0) register 0x54.

Result:

ENC_CONST consists of 15 digits and 16 decimal places. The constant is the number of microsteps by which *ENC_POS* is incremented or decremented by one AB transition.

Read entire documentation; especially the "Supplemental Directives" on page 218.

15.3. Incremental Encoders: Index Signal: N resp. Z

The index signal (N or Z channel) represents a recurrence of the same position in one motor encoder revolution. TMC4361 makes use of this signal to clear the external position counter, or to take a snapshot of the external or internal position, which then can be used to refine the home position more precisely.

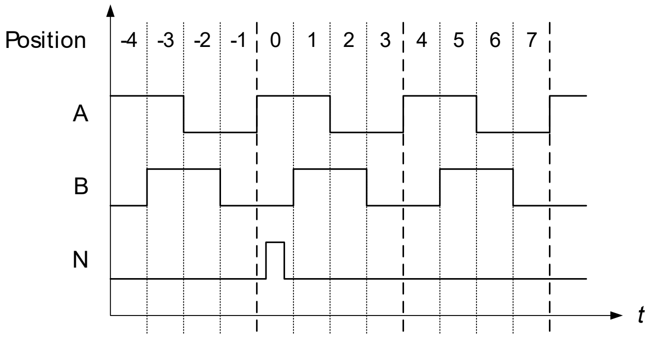


Figure 59: Outline of ABN signals of an incremental Encoder

15.3.1. Setup of Active Polarity for Index Channel

Per default, the index channel is configured low active.

In order to set up high active polarity for the index channel, do as follows:

Action:

➢ Set *pol_n* =1 (register *ENC_CONF* 0x07).

Result:
The index channel is high active.

15.3.2. Configuration of N Event

The active polarity of the index channel can be used to clear the external position counter or to take a snapshot of the external or internal position. Therefore, N event is created internally. N event is based on the active polarity of the index channel. As addition, they can also be based on the polarities of the A and B channels.

Index Channel Sensitivity

Four active polarity configuration options for the index channel are available, which are presented below. Configuration choice depends on customer-specific design wishes.

In order to set up the index channel sensitivity based on active polarity, do as follows:

Action:

➢ Set *n_chan_sensitivity* (register *ENC_CONF* 0x07) to:

Index Channel Sensitivity	
n_chan_sensitivity	**Result:**
b'00	N event is active in case index voltage level fits *pol_n.*
b'01	N event is triggered when the index channel switches to active polarity.
b'10	N event is triggered when the index channel switches to inactive polarity.
b'11	N event is triggered at both edges when the index channel switches to either active or inactive polarity.

Table 57: Index Channel Sensitivity

A and B Channel Signal Polarities for N Event

It can be useful to specify A and B channel signal polarities for N event. Per default, the polarities of both signal lines are set to 0 (low active).

In order to set up A channel polarity to high active for N event, do as follows:

Action:
- Set *pol_a_for_n* = 1 (*ENC_CONF* register 0x07).

Result:
Now, A channel signal polarity for N event is high active.

In order to set up B channel polarity to high active for N event, do as follows:

Action:
- Set *pol_b_for_n* = 1 (*ENC_CONF* register 0x07).

Result:
Now, B channel signal polarity for N event is high active.

In case A and B channel polarities do not have an influence on N event, both A and B channel polarity signals can be ignored.

In order to ignore A and B channel polarities, do as follows:

Action:
- Set *ignore_ab* = 1 (*ENC_CONF* register 0x07).

Result:
Now, the A and B channel signal polarities have no influence on N event.

15.3.3. External Position Counter *ENC_POS* Clearing

N event can be used to clear the external position register *ENC_POS* 0x50. Two choices are available: continous clearing and single clearing.

i Common practice is to clear to 0. However, TMC4361 offers the possibility to clear to any single microstep count.

ENC_POS Continous Clearing

In order to set *ENC_POS* on N event to continuous clearing, do as follows:

Action:
- Set *ENC_RESET_VAL* register 0x51 to the requested microstep position.
- Set *clr_latch_cont_on_n* = 1 (*ENC_CONF* register 0x07).
- Set *clear_on_n* = 1 (*ENC_CONF* register 0x07).

Result:
On every N event *ENC_POS* is set to *ENC_RESET_VAL*.

•→*Continued on next page.*

ENC_POS Single Clearing

In order to only clear *ENC_POS* for the next N event, do as follows:

Action:

- Set *ENC_RESET_VAL* register 0x51 to the requested microstep position.
- Set *clr_latch_cont_on_n* = 0 (*ENC_CONF* register 0x07).
- Set *clr_latch_once_on_n* = 1 (*ENC_CONF* register 0x07).
- Set *clear_on_n* = 1 (*ENC_CONF* register 0x07).

Result:

When the next N event occurs, *ENC_POS* is set to *ENC_RESET_VAL*. After the particular N event, *clr_latch_once_on_n* is automatically reset to 0.

15.3.4. Latching External Position

N event can be used to latch external position register *ENC_POS* 0x50 to storage register *ENC_LATCH* 0x51 (read access). Two choices are available: Continous latching and single latching.

Continous Encoder Latching

In order to continuously latch *ENC_POS* to *ENC_LATCH* on N event, do as follows:

Action:

- Set *clr_latch_cont_on_n* = 1 (*ENC_CONF* register 0x07).
- Set *latch_enc_on_n* = 1 (*ENC_CONF* register 0x07).

Result:

On every N event *ENC_POS* register 0x50 is latched to *ENC_LATCH* register 0x51.

Single Encoder Latching

In order to only latch *ENC_POS* to *ENC_LATCH* for the next N event, do as follows:

Action:

- Set *clr_latch_cont_on_n* = 0 (*ENC_CONF* register 0x07).
- Set *clr_latch_once_on_n* = 1 (*ENC_CONF* register 0x07).
- Set *latch_enc_on_n* = 1 (*ENC_CONF* register 0x07).

Result:

When the next N event occurs, *ENC_POS* register 0x50 is latched to *ENC_LATCH* register 0x51. After the particular N event, *clr_latch_once_on_n* is automatically reset to 0.

•→For information on latching internal position turn page.

15.3.5. Latching Internal Position

N event can be used to latch internal position register *X_ACTUAL* 0x21 to storage register *X_LATCH* 0x36 (read access). Two choices are available: Continous latching and single latching.

Continous Latching

In order to continuously latch *X_ACTUAL* to *X_LATCH* on N event, do as follows:

Action:

- Set *clr_latch_cont_on_n* = 1 (*ENC_CONF* register 0x07).
- Set *latch_enc_on_n* = 1 (*ENC_CONF* register 0x07).
- Set *latch_x_on_n* = 1 (*ENC_CONF* register 0x07).

Result:
On every N event *X_ACTUAL* register 0x21 is latched to *X_LATCH* register 0x36.

Single Latching

In order to only latch *X_ACTUAL* to *X_LATCH* for the next N event, do as follows:

Action:

- Set *clr_latch_cont_on_n* = 0 (*ENC_CONF* register 0x07).
- Set *clr_latch_once_on_n* = 1 (*ENC_CONF* register 0x07).
- Set *latch_enc_on_n* = 1 (*ENC_CONF* register 0x07).
- Set *latch_x_on_n* = 1 (*ENC_CONF* register 0x07).

Result:
When the next N event occurs, *X_ACTUAL* register 0x21 is latched to *X_LATCH* register 0x36. After the particular N event, *clr_latch_once_on_n* is automatically reset to 0.

Read entire documentation; especially the "Supplemental Directives" on page 218.

15.4. Absolute Encoder Settings

Serial encoders provide absolute encoder angle data in contrast to step transitions, which are delivered from incremental encoders.
TMC4361 provides an external clock for the encoder in order to trigger serial data input,

15.4.1. Singleturn or Multiturn Data

TMC4361 offers singleturn and multiturn options for the serial data stream interpretation. Per default, multiturn data is not enabled. In case multiturn data is enabled, it is interpreted as unsigned count of revolutions.

In case multiturn encoder data is transmitted, do as follows:

Action:

- Set *multi_turn_in_en* = 1 (*ENC_CONF* register 0x07).
- ***OPTIONAL CONFIGURATION:*** Set *multi_turn_in_signed* = 1.
  In case multiturn data is provided as signed count of encoder revolutions.

Result:
Data from connected encoders are interpreted as multiturn data.

In case only singleturn data is transmitted TMC4361 is able to permanently calculate internally the number of encoder revolutions as if it where externally transferred multiturn data.

In case singleturn encoder data is transmitted but internally multiturn data is required, do as follows:

Action:

- Set *multi_turn_in_en* = 0 (*ENC_CONF* register 0x07).
- Set *calc_multi_turn_behav* = 1 (*ENC_CONF* register 0x07).

Result:
Data from connected singleturn encoders is internally transferred to multiturn data.

NOTE:

→ *Multiturn calculations are only correct in case two consecutive singleturn data values differ only by one step less than a half turn difference, or even less.*

15.4.2. Automatic Constant Configuration of Absolute Encoder

The external position register *ENC_POS* 0x50 is based on internal microsteps. Thus, every input data angle is transferred to microsteps by a fixed constant value. TMC4361 is able to automatically calculate this constant.

In order to configure the absolute encoder constant automatically, do as follows:

Action:
- Set fullstep resolution of the motor in *FS_PER_REV* (*STEP_CONF* register 0x0A).
- Set microstep resolution *MSTEP_PER_FS* (*STEP_CONF* register 0x0A).
- Set encoder resolution in register *ENC_IN_RES* 0x54 (write access).

Result:
The encoder constant value *ENC_CONST* (readable at register 0x54) is calculated as follows:

ENC_CONST = MSTEP_PER_FS · FS_PER_REV / ENC_IN_RES

The external position *ENC_POS* 0x50 is calculated by multiplying the constant with the transmitted input angle.

i *ENC_CONST* consists of 15 digits and 16 decimal places.

i In contrast to incremental ABN encoders, *ENC_CONST* is always represented as binary constant.

15.4.3. Manual Constant Configuration of Incremental ABN Encoder

For some applications it can be useful to define the encoder constant value, which in this case does not correspond to the number of microsteps per revolution; e.g. if the encoder is not mounted directly on the motor.

In order to configure the absolute encoder constant manually, do as follows:

Action:
- Set *ENC_IN_RES* (31) =1.
- Set required encoder resolution in *ENC_IN_RES* (30:0) register 0x54.

Result:
ENC_CONST consists of 15 digits and 16 decimal places. The external position *ENC_POS* 0x50 is calculated by multiplying the constant with the transmitted input angle.

Read entire documentation; especially the "Supplemental Directives" on page 218.

15.4.4. Absolute Encoder Data Setup

Encoder Data must be maintained correctly. Consequently, certain settings must be configured so that TMC4361 displays them as specified.

In order to configure absolute encoder data, do as follows:

Action:

- Set *SINGLE_TURN_RES* (*ENC_IN_DATA* register 0x08) to the number of singleturn data bits −1.

  OPTION A1: IF MULTITURN DATA IS TRANSMITTED

  - Set *MULTI_TURN_RES* (*ENC_IN_DATA* register 0x08) to the number of multiturn data bits −1.

  OR OPTION A2: IF MULTITURN DATA IS NOT TRANSMITTED

  - Set *MULTI_TURN_RES* = 0 (*ENC_IN_DATA* register 0x08).

- Set *STATUS_BIT_CNT* (*ENC_IN_DATA* register 0x08) to the number of status bits.

  OPTION B1: IF STATUS FLAGS ARE ORDERED IN FRONT

  - Set *left_aligned_data* = 0 (*ENC_IN_CONF* register 0x07).

  OR OPTION B2: IF STATUS FLAGS ARE ORDERED IN FRONT

  - Set *left_aligned_data* = 1 (*ENC_IN_CONF* register 0x07).

Result:
SINGLE_TURN_RES defines the most significant bit (MSB) of the angle data bits, whereas *MULTI_TURN_RES* defines the MSB of the revolution counter bits. Up to three status bits can be received. The number of transferred clock bits that are sent to the encoder is calculated as follows:

#SCLK Cycles= (*SINGLE_TURN_RES*+1) + (*MULTI_TURN_RES*+1) + *STATUS_BIT_CNT*

Also, the order in which the status bits occur in one encoder data stream can be configured. In Figure 59 on the next page, example setups are depicted.

NOTE:

→ *In case more than three status bits or additional fill bits are sent from the encoder, clock errors can occur because the number of transferred clock bits does not fit.*

→ *In order to prevent clock failures, MULTI_TURN_RES can be set to a higher value than otherwise required; even if the encoder does not provide multiturn data. This can result in erroneous multiturn data, which can be corrected by setting multi_turn_in_en=0 in order to skip multiturn data automatically.*

→ *In order to compensate unavailable multiturn data make use of calc_multi_turn_behav, as explained in section 15.4.1 on page 150.*

•→*Turn page for serial data output examples.*

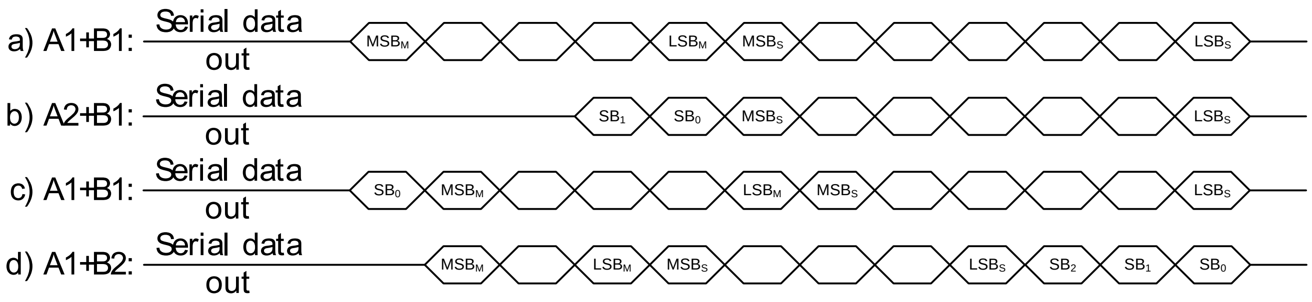


Figure 60:Serial Data Output: Four Examples

Key:

a) SINGLE_TURN_RES=6; MULTI_TURN_RES=4; STATUS_BIT_CNT=0; left_aligned_data=0

b) SINGLE_TURN_RES=6; MULTI_TURN_RES=0; STATUS_BIT_CNT=2; left_aligned_data=0

c) SINGLE_TURN_RES=5; MULTI_TURN_RES=4; STATUS_BIT_CNT=1; left_aligned_data=0

d) SINGLE_TURN_RES=4; MULTI_TURN_RES=2; STATUS_BIT_CNT=3; left_aligned_data=1

15.4.5. Emitting Encoder Data Variation

For some applications it can be useful to limit the difference between two consecutive encoder data values; for instance, if encoder data lines are subject to too much noise.
Per default, encoder data values can show a difference of 1/8th per encoder revolution, only if the limitation is enabled. The difference can be configured to a smaller value, if necessary.

In order to enable and configure encoder data variation limitation, do as follows:

Action:

- ***OPTIONAL:*** Set proper *SER_ENC_VARIATION* register 0x63 (7:0).
- Set *serial_enc_variation_limit* =1 (*ENC_IN_CONF* register 0x07).

Result:
The encoder data value that is received subsequently must not exceed the previous data more than:

Maximum tolerated deviation = *SER_ENC_VARIATION* / 256 · 1/8 · *ENC_IN_RES.*

In case the variation exceeds the above mentioned limit, the new data value is rejected internally and the status flag *SER_ENC_DATA_FAIL* is raised.

i In case *SER_ENC_VARIATION* = 0, the limit is defined by 1/8 · *ENC_IN_RES*.

15.4.6. SSI Clock Generation

In order to receive encoder data from the absolute encoder, TMC4361 generates clock patterns according to SSI standard. Data transfer is initiated by switching the clock line SCLK from high to low level. The transfer starts with the next rising edge of SCLK. The number of emitted clock cycles depends on the expected data width, as explained in section 15.4.4.

Configuration Details

One clock cycle has a high and a low phase, which can be defined separately according to internal clock cycles. Per default, sample points of serial data are set at the falling edges of SCLK. Some encoders need more clock cycles – than are available during the low clock phase – in order to prepare data for transfer. Also, due to long wires, data transfer can take more time. To counteract the above mentioned issues, the delay time *SSI_IN_CLK_DELAY* (default value equals 0) for compensation can be specified in order to prolong the sampling start. Therefore, this delay configuration can automatically generate more clock cycles.
After a data request – when all clock cycles have been emitted – the serial clock must remain idle for a certain interval before the next request is automatically initiated. This interval *SER_PTIME* can also be configured in internal clock cycles.

i According to SSI standard, select an interval that is longer than 21 µs.

In order to configure the SSI clock generation, do as follows:

Action:

- Set *SINGLE_TURN_RES* (*ENC_IN_DATA* register 0x08) to the number of singleturn data bits −1.
- Set *MULTI_TURN_RES* (*ENC_IN_DATA* register 0x08) to the number of multiturn data bits −1 in case multiturn data is enabled and used.
- Set *STATUS_BIT_CNT* (*ENC_IN_DATA* reg. 0x08) to the number of status bits.
- Set proper *left_aligned_data* (*ENC_IN_CONF* register 0x07).
- Set proper *SER_CLK_IN_LOW* (register 0x56) in internal clock cycles.
- Set proper *SER_CLK_IN_HIGH* (register 0x56) in internal clock cycles.
- ***OPTIONAL CONFIG:*** Set proper *SSI_IN_CLK_DELAY* (register 0x57) in internal clock cycles.
- ***OPTIONAL CONFIG:*** Set proper *SER_PTIME* (reg. 0x58) in internal clk cycles.
- **Finally, set *serial_enc_in_mode* = b'01.**

Result:

TMC4361 emits serial clock streams at SCLK in order to receive absolute encoder data at SDI. If *SSI_IN_CLK_DELAY* > 0, the SDI sample points are delayed (see figures below). *SER_PTIME* defines the interval between two consecutive data requests.

i If differential encoder is selected, the negated clock emits at ¬SCLK; and ¬SDI is also evaluated.

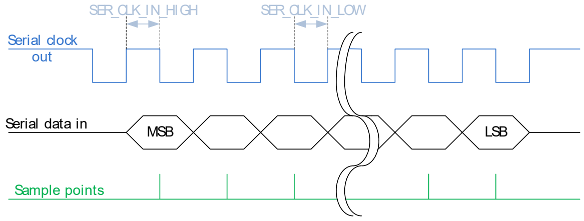


Figure 61: SSI: SSI_IN_CLK_DELAY=0

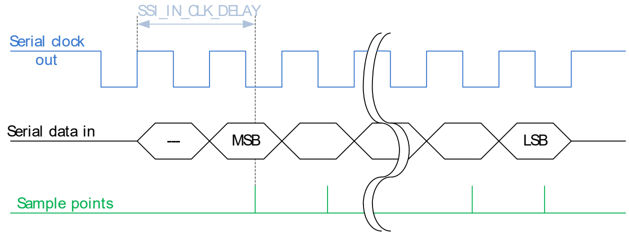


Figure 62: SSI: SSI_IN_CLK_DELAY>SER_CLK_IN_HIGH

15.4.7. Enabling Multicycle SSI request

If safe transmission must be determined, it is possible to send a second request so that the encoder repeats the same encoder data. Therefore, a second interval *SSI_WTIME* must be defined.

i According to SSI standard, select an interval that is shorter than 19 µs.

In order to enable multicycle requests, do as follows:

Action:

- Set *ssi_multi_cycle_data* =1 (*ENC_IN_CONF* register 0x07).
- Set proper *SSI_WTIME* (register 0x57) in internal clk cycles.

Result:

After a data request – when all clock cycles have been emitted – the serial clock remains idle for *SSI_WTIME* clock cycles. Afterwards, the second request is automatically initiated to receive the same encoder data. If the second encoder data differs from the first one, error flag *MULTI_CYCLE_FAIL* (register 0x0F) and error event *SER_ENC_DATA_FAIL* (register 0x0E) is generated.
After the second data request, the next interval lasts *SER_PTIME* clock cycles to request new encoder data.

15.4.8. Gray-encoded SSI Data Streams

Several but not all SSI encoders emit angle data, which is gray-encoded. TMC4361 is able to decode this data automatically.

In order to enable gray-encoded angle data, do as follows:

Action:

- Set *ssi_gray_code_en* =1 (*ENC_IN_CONF* register 0x07).

Result:

Encoder data is recognized as gray-encoded and thus also decoded accordingly.

Read entire documentation; especially the "Supplemental Directives" on page 218.

15.4.9. SPI Encoder Data Evaluation

SPI encoder interfaces typically consist of four signal lines. In addition to SSI encoder signal lines (SCLK, MISO), a chip select line (CS) and a data input (MOSI) to the master is provided.

SPI Encoder Communication Process

The number of bits per transfer is calculated automatically; based on proper *multi_turn_in_en*, *SINGLE_TURN_RES*, *MULTI_TURN_RES*, and *STATUS_BIT_CNT*, as explained in sections 15.4.1 (page 150) and 15.4.4 (page 152).

A typical SPI communication process responds to any SPI data transfer request when the next transmission occurs. When TMC4361 receives an answer from the encoder, it calculates *ENC_POS* immediately. The encoder slave does not send any data without receiving a request first.
Therefore, TMC4361 always sends *ADDR_TO_ENC* value to request encoder data from the SPI encoder slave device. The LSB of the serial data output is *ADDR_TO_ENC* (0).
Received encoder data is stored in *ADDR_FROM_ENC*. Thus, encoder values can be verified and compared to microcontroller data later on.

i The clock generation works similarly to SSI clock generation, as described in section 15.4.5 on page 154; based on proper *SER_CLK_IN_HIGH, SER_CLK_IN_LOW,* and *SER_PTIME*.

In order to configure a basic SPI communication procedure, do as follows:

Action:

- Set *SINGLE_TURN_RES* (*ENC_IN_DATA* register 0x08) to the number of singleturn data bits −1.
- Set *MULTI_TURN_RES* (*ENC_IN_DATA* register 0x08) to the number of multiturn data bits −1 in case multiturn data is enabled and used.
- Set *STATUS_BIT_CNT* (*ENC_IN_DATA* register 0x08) to the number of status bits.
- Set proper *left_aligned_data* (*ENC_IN_CONF* register 0x07).
- **Set correct SPI transfer mode that is described in the next section**.
- Set *ADDR_TO_ENC* register 0x68 to the specified SPI encoder address that contains angle data.
- Set proper *SER_CLK_IN_LOW* (register 0x56) in internal clock cycles.
- Set proper *SER_CLK_IN_HIGH* (register 0x56) in internal clock cycles.
- ***OPTIONAL CONFIG:*** Set proper *SER_PTIME* (register 0x58) in internal clk cycles.
- **Finally, set *serial_enc_in_mode* = b'11**.

Result:

TMC4361 emits serial clock streams at SCLK in order to receive absolute encoder data at SDI pin. The number of generated clock cycles depends on *SINGLE_TURN_RES*, *MULTI_TURN_RES*, and *STATUS_BIT_CNT*.
Pin ANEG_NSCLK functions as negated chip select line for the SPI encoder that is generated according to the serial clock and the selected SPI mode; which is described in the next section.
Pin BNEG_NSDI is the MOSI line that transfers SPI datagrams to the SPI encoder. Datagrams, which are transferred permanently to receive angle data, consists of *ADDR_TO_ENC* data.
SER_PTIME defines the interval between two consecutive data requests.

•→Turn page for information on SPI mode selection.

15.4.10. SPI Encoder Mode Selection

Per default, SPI encoder data transfer is managed in the same way as the communication between microcontroller and TMC4361. TMC4361 supports all four SPI modes with proper setting of switches *spi_low_before_cs* and *spi_data_on_cs*.

THE PROCESS IS AS FOLLOWS:

By setting ***spi_low_before_cs* = 0**, negated chip select line at ANEG_NSCLK is switched to active low **before** the serial clock line SCLK switches.

By setting ***spi_low_before_cs* = 1**, negated chip select line at ANEG_NSCLK is switched to active low **after** the serial clock line SCLK switches.

By setting ***spi_data_on_cs* = 0**, the first data bit at BNEG_NSDI is changed at the same time as the first slope of the serial clock SCLK.

By setting ***spi_data_on_cs* = 1**, the first data bit at BNEG_NSDI is changed at the same time as the negated chip select signal at BNEG_NSDI switches to active level.

In the table below, all four SPI modes are presented.

Per default, the delay between serial clock line and negated chip select line has a time frame of either *SER_CLK_IN_HIGH* or *SER_CLK_IN_LOW* clock cycles, which depends on the actual voltage level of the serial clock.
This particular interval does not always match the encoder behavior perfectly. Therefore, both the first and last intervals between the serial clock line and the negated chip select line can be specified separately in clock cycles at *SSI_IN_CLK_DELAY* register 0x57.

Below, the *SSI_IN_CLK_DELAY* interval is highlighted in red in all four diagrams.

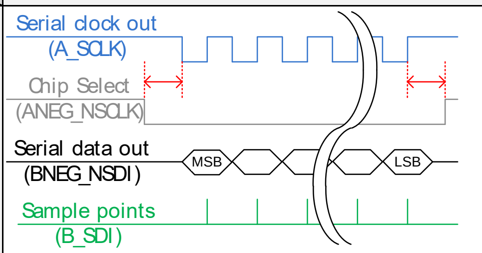
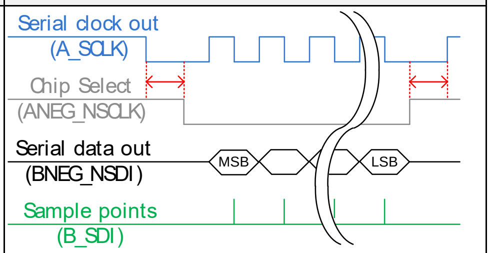
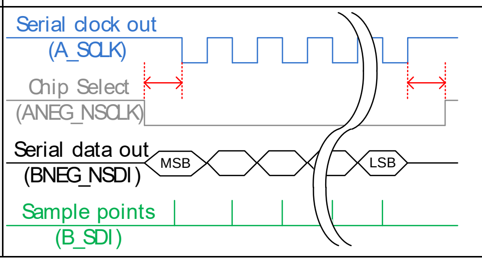
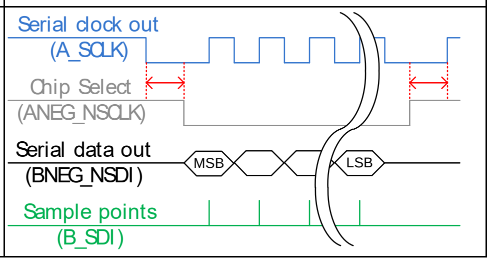
Supported SPI Encoder Data Transfer Modes		
spi_low_before_cs: / **spi_data_on_cs**	**0**	**1**
0		
1		

Table 58: Supported SPI Encoder Data Transfer Modes

15.4.11. SPI Encoder Configuration via TMC4361

Connected SPI encoder can be configured via TMC4361., which renders a connection between microcontroller and encoder unnecessary.

SPI Encoder Configuration Communication Process

A configuration request is sent using the settings of *SERIAL_ADDR_BITS* and *SERIAL_DATA_BITS*, which define the transferring bit numbers.

In order to prepare SPI encoder configuration procedures, do as follows:

Action:

- Set *SERIAL_ADDR_BITS* (*ENC_IN_DATA* register 0x08) to the number of address bits of any SPI encoder configuration datagram.
- Set *SERIAL_DATA_BITS* (*ENC_IN_DATA* register 0x08) to the number of data bits of any SPI encoder configuration datagram.

Result:
In case configuration data is transferred to the SPI encoder, *SERIAL_ADDR_BITS* bits and *SERIAL_DATA_BITS* bits are sent in two SPI configuration datagrams; exactly in this order.

Because encoder data requests occur as an endless stream, it is necessary to interrupt data requests when a configuration request occurs. Consequently, a handshake behavior is implemented.

In order to transfer configuration data to the SPI encoder, do as follows:

Action:

- Set *DATA_TO_ENC* register 0x69 to any value.
- Set *ADDR_TO_ENC* register 0x68 to the configuration address of the SPI encoder.
- Set *DATA_TO_ENC* register 0x69 to the configuration data of the SPI encoder.

Result:
The first *DATA_TO_ENC* access stops the repetitive encoder data request.
After the second *DATA_TO_ENC* access, three datagrams are sent to SPI encoder:

1. One address datagram is transmitted, which contains the *ADDR_TO_ENC* value. Data that is received simultaneously with the request is not stored.
2. One data datagram is transmitted that contains the *DATA_TO_ENC* value. Data that is received simultaneously with the request is stored in *ADDR_FROM_ENC* register 0x6A because this is the response of the *ADDR_TO_ENC* request.
3. One no-operation datagram (NOP) is transmitted. Data that is received simultaneously with the request is stored in *DATA_FROM_ENC* register 0x6B because this is the response of the *DATA_TO_ENC* request.

In order to finalize the configuration procedure and continue with the encoder data requests, do as follows:

- Read out *ADDR_FROM_ENC* register 0x6A first.
- Set *ADDR_TO_ENC* register 0x68 to the specified SPI encoder address that contains angle data.
- **Obligatory at finalization: Read out *DATA_FROM_ENC* register 0x6B.**

Result:
The configuration request data is read out. After *DATA_FROM_ENC* register readout, the encoder data request stream of angle data continues.

16. Possible Regulation Options with Encoder Feedback

Beyond simple feedback monitoring, encoder feedback can be used for controlling motion controller outputs in such a way that the internal actual position matches or follows the real position *ENC_POS*. Two options are provided: PID control and closed-loop operation.
Closed-loop operation is preferable if the encoder is mounted directly on the back of the motor and position data is evaluated precisely. PID control is preferable if the encoder is located on the drive side with no fixed connection between motor and drive side; e.g. belt drives.

Closed-Loop and PID Registers			
Register Name	**Register address**		**Remarks**
ENC_IN_CONF	0x07	RW	Encoder configuration register: Closed-Loop configuration switches.
CL_TR_TOLERANCE	0x51	R	Absolute tolerated deviation to trigger TARGET_REACHED during regulation.
ENC_POS_DEV	0x52	R	Deviation between *XACTUAL* and *ENC_POS*.
Closed-Loop and PID Register Set	0x59…5F 0x60…61	W	Closed-Loop and PID configuration parameters.
Encoder velocity configuration	0x63	W	Encoder velocity filter configuration parameters.
Encoder velocity	0x65 0x66	R	Current encoder velocity (unsigned). Current filtered encoder velocity (signed).

Table 59: Dedicated Closed-Loop and PID Registers

16.1. Feedback Monitoring

Based on the difference *ENC_POS_DEV* (readout at register 0x52) between internal position *XACTUAL* and external position *ENC_POS*, a status flag *ENC_FAIL_F* and a corresponding error event *ENC_FAIL* is generated automatically.

In order to set a tolerated position mismatch, do as follows:

Action:

- Set *ENC_POS_DEV_TOL* register 0x53 to the maximum microstep value that represents no mismatch failure.

Result:

In case |*ENC_POS_DEV*| ≤ *ENC_POS_DEV_TOL*, no encoder failure flag is set.
In case |*ENC_POS_DEV*| > *ENC_POS_DEV_TOL*, *ENC_FAIL_F*lag is set.

i At this point, the corresponding encoder event *ENC_FAIL* is also triggered.

16.1.1. Target-Reached during Regulation

In case one of the regulation modes is selected, TARGET_REACHED event and status flag is only released when:

XACTUAL = XTARGET and |*ENC_POS_DEV*| ≤ *CL_TR_TOLERANCE*.

Consequently, *CL_TR_TOLERANCE* register 0x52 (only write access) is the maximal tolerated position mismatch for target reached status.

16.2. PID-based Control of *XACTUAL*

Based on a position difference error *PID_E = XACTUAL – ENC_POS* the PID (proportional integral differential) controller calculates a signed velocity value (v_{PID}), which is used for minimizing the position error. During this process, TMC4361 moves with v_{PID} until *|PID_E| – PID_TOLERANCE* ≤ 0 is reached and the position error is removed.

v_{PID} is calculated by:

$$v_{PID} = \frac{PID\_P}{256} \cdot PID\_E \cdot \left[\frac{1}{s}\right] + \frac{PID\_I}{256} \cdot \int_0^t PID\_E \cdot dt \; + \; PID\_D \cdot PID\_E \cdot \frac{d}{dt}$$

$$v_{PID} = \frac{PID\_P}{256} \cdot PID\_E \cdot \left[\frac{1}{s}\right] + \frac{PID\_I}{256} \cdot PID\_ISUM + PID\_D \cdot PID\_E \cdot \frac{d}{dt}$$

$$v_{PID} = \frac{PID\_P}{256} \cdot PID\_E \cdot \left[\frac{1}{s}\right] + \frac{PID\_I}{256} \cdot PID\_E \cdot \frac{f_{CLK}}{128} + PID\_D \cdot PID\_E \cdot \frac{d}{dt}$$

Key:

PID_P = proportional term; PID_I = integral term; PID_D = derivate term

16.2.1. PID Readout Parameters

The following parameters can be read out during PID operation.

PID_VEL 0x5A Actual PID output velocity.

PID_E 0x5D Actual PID position deviation between *XACTUAL* and *ENC_POS*.

PID_ISUM 0x5B Actual PID integrator sum (update frequency: f_{CLK}/128), which is calculated by:

$PID\_ISUM = PID\_E \cdot f_{CLK} / 128$

•→*Turn page for information on configuration of PID regulation.*

Read entire documentation; especially the "Supplemental Directives" on page 218.

16.2.2. PID Control Parameters and Clipping Values

In order to set parameters and clipping values for PID regulation correctly, consider the following details:

PID_DV_CLIP 0x5E

Large velocity variations are avoided by limiting v_{PID} value with *PID_DV_CLIP* (register 0x5E). This clipping parameter limits both v_{PID} and *PID_VEL*.

PID_I_CLIP 0x5D (14:0)

The error sum *PID_ISUM* (read out at 0x5B) is generated by the integral term. *PID_ISUM* is limited by setting *PID_I_CLIP* register 0x5D.

i The maximum value of *PID_I_CLIP* must meet the condition *PID_I_CLIP ≤ PID_DV_CLIP / PID_I*.

i If the error sum *PID_ISUM* is not clipped, it is increased with each time step by *PID_I · PID_E*. This continues as long as the motor does not follow.

PID_D_CLKDIV 0x5D (23:16)

Time scaling for deviation (with respect to error correction periods) is controlled by *PID_D_CLKDIV* register.

i During error correction, fixed clock frequency $f_{PID\_INTEGRAL}$ is valid:

$f_{PID\_INTEGRAL}[Hz] = f_{CLK}[Hz] / 128$

VEL_ACT_PID

The internal velocity VEL_ACT_PID alters actual ramp velocity *VACTUAL*. Two settings are provided:
In case *regulation_modus* = b'11, *VACTUAL* is assigned as pulse generator base value and VEL_ACT_PID is calculated by VEL_ACT_PID = *VACTUAL* + v_{PID}.
In case *regulation_modus* = b'10, zero is assigned as pulse generator base value. Now, VEL_ACT_PID = v_{PID} is valid.

PID_TOLERANCE 0x5F

TMC4361 provides the programmable hysteresis *PID_TOLERANCE* for target position stabilization; which avoids oscillations through error correction in case *XACTUAL* is close to the real mechanical position.

The PID controller of TMC4361 is programmable up to approximate 100 kHz update rate (at f_{CLK} = 16 MHz). This high speed update rate qualifies PID regulation for motion stabilization.

16.2.3. Enabling PID Regulation

Now that PID control parameters and clipping values are configured, as explained above, PID regulation can be enabled. Two options can be selected.

In order to enable PID control, do as follows:

Action:

OPTION 1: BASE PULSE GENERATOR VELOCITY = 0

➢ Set *regulation_modus* = b'10 (*ENC_IN_CONF* register 0x07).

OPTION 2: BASE PULSE GENERATOR VELOCITY = VACTUAL

➢ Set *regulation_modus* = b'11 (*ENC_IN_CONF* register 0x07).

Result:
PID regulation is enabled.

NOTE

→ *Detailed knowledge of a particular application (including dynamics of mechanics) is necessary for PID controller parameterization.*

Read entire documentation; especially the "Supplemental Directives" on page 218.

16.3. Closed-Loop Operation

The closed-loop unit of TMC4361 directly modifies output currents and Step/Dir outputs of the internal step generator; which is dependent on the feedback data. The 2-phase closed-loop control of TMC4361 follows a different approach than field-oriented control (FOC); which is similar to PID control cascades. The ramp generator, which assigns target and velocity, is independent of position control (commutation angle control); which is also independent of current control. Closed-loop operation can only be used in combination with 256 microsteps per fullstep.

16.3.1. Basic Closed-Loop Parameters

Closed-loop does not control current values via the internal step generator. The currents values at the SPI output and the Step/Dir outputs are verified using the evaluated difference between internal position *XACTUAL* and external position *ENC_POS*; considering the calibrated offset parameter *CL_OFFSET*.

In order to set parameters and clipping values for closed-loop regulation correctly, consider the following details:

CL_OFFSET 0x59

This register contains the basic offset value between internal and external position during calibration process, which is necessary for closed-loop operation, and offers read-write access. The write access can be used if a defined fixed offset value is preferred, which is verified beforehand.

ENC_POS_DEV 0x52

The continuously updated parameter *ENC_POS_DEV* displays the deviation between *XACTUAL* and *ENC_POS*; considering *CL_OFFSET*.

CL_BETA 0x1C (8:0)

CL_BETA is the maximum commutation angle that is used to compensate an evaluated deviation *ENC_POS_DEV*. In case the deviation reaches *CL_BETA* value, the commutation angle remains stable at this value to follow the overload. Also, *CL_MAX* event is triggered at this point.

CL_TOLERANCE 0x5F (7:0)

This parameter is set to select the tolerance range for position deviation. In case |*ENC_POS_DEV*| ≤ *CL_TOLERANCE*, *CL_FIT_F* lag becomes set.
In case a mismatch between internal and external position occurs, *CL_FIT* event is triggered to signify when the mismatch is removed.

CL_DELTA_P 0x5C

CL_DELTA_P is a proportional controller that compensates a detected position deviation between internal and external position. See also Figure 63, page 163.
In case |*ENC_POS_DEV*| ≤ *CL_TOLERANCE*, *CL_DELTA_P* is automatically set to 1.0.
In case |*ENC_POS_DEV*| > *CL_TOLERANCE*, the closed-loop unit of TMC4361 multiplies *ENC_POS_DEV* with *CL_DELTA_P* and adds the resulting value to the current *ENC_POS*. Thus, a current commutation angle for higher stiffness position maintenance, which is clipped at *CL_BETA*, is calculated.

i *CL_DELTA_P* consists of 24 bits. The last 16 bits represent decimal places. The final proportional term is thus calculated by: p_{PID} = *CL_DELTA_P* / 65536.

i Therefore, the higher p_{PID} the faster the reaction on position deviations.

NOTE:

→ *A high p_{PID} term can lead to oscillations that must be avoided.*

CL_CYCLE 0x63 (31:16)

In case, one absolute encoder is connected, this value represents the delay time in numbers of clock cycles between two consecutive regulation cycles. It is recommended to adjust this value to the regulation cycle; which is either equal or slower than the encoder request rate. In case incremental ABN encoder is selected, this value is automatically set to fetch the fastest possible regulation rate; which in most cases are five clock cycles.

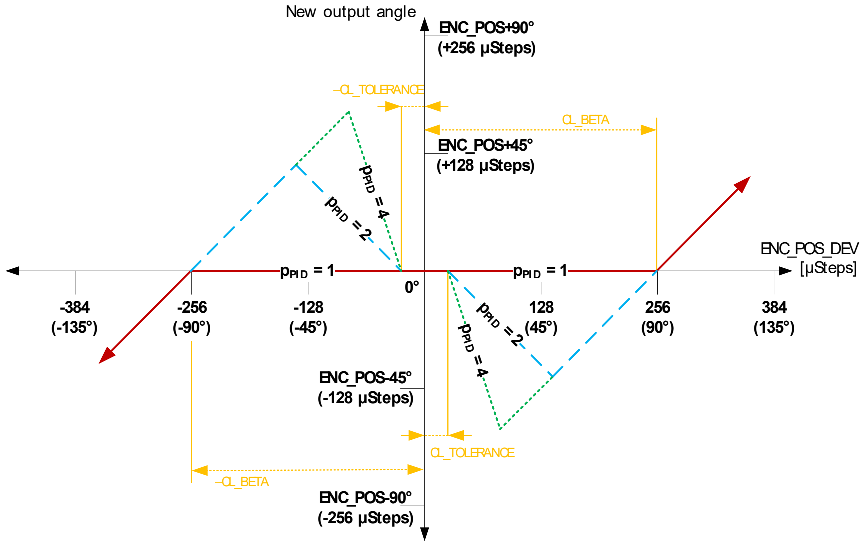


Figure 63: Calculation of the Output Angle with appropriate CL_DELTA_P

16.3.2. Enabling and calibrating Closed-Loop Operation

Now that basic closed-loop control parameters are configured, as explained above, closed-loop regulation can be enabled.

i The presented calibration process is very basic. Refer to the closed-loop Application Note for detailed calibration process information.

In order to enable and calibrate closed-loop control, do as follows:

PRECONDITION: SET TO BEST POSSIBLE MAXIMUM CURRENT SCALING

PROCEED WITH: OPTION 1: CL_OFFSET IS GENERATED DURING CALIBRATION

Action:

- Set *MSTEPS_PER_FS* = 0 (*STEP_CONF* register 0x0A) [256 microsteps per fullstep].
- Move to any fullstep position (*MSCNT* mod 128 = 0).
- Set *regulation_modus* = b'01 (*ENC_IN_CONF* register 0x07).
- Set *cl_caclibration_en* =1 (*ENC_IN_CONF* register 0x07).
- Wait for a defined time span (system settle down).
- Set *cl_caclibration_en* =0 (*ENC_IN_CONF* register 0x07).

Result:
Closed-loop operation is enabled with basic calibration. *CL_OFFSET* is set to position mismatch during calibration process.

OR PROCEED WITH OPTION 2: CL_OFFSET IS USED FOR CALIBRATION

In case *CL_OFFSET* was saved and no position loss has occurred while closed-loop operation was disabled, it can be used to replace the calibration process.

Action:
- Set *MSTEPS_PER_FS* = 0 (*STEP_CONF* register 0x0A) [256 microsteps per fullstep].
- Set *regulation_modus* = b'01 (*ENC_IN_CONF* register 0x07).
- Set *CL_OFFSET* to any preferred microstep value.

Result:
Closed-loop operation is enabled.

16.3.3. Limiting Closed-Loop Catch-Up Velocity

In order to limit catch-up velocities in case a disturbance of regular motor motion must be compensated, the following parameters can be configured accordingly:

i Refer to section 16.2. on page 160 for more information about PI regulation of the maximum velocity because it uses the same PI regulator like the position PID regulator. The base velocity is the actual ramp velocity *VACTUAL*.

CL_VMAX_CALC_P 0x5A P parameter of the PI regulator, which controls the maximum velocity.

CL_VMAX_CALC_I 0x5B I parameter of the PI regulator, which controls the maximum velocity.

PID_DV_CLIP 0x5E *PID_DV_CLIP can* be set in order to avoid large velocity variations; and also to limit the maximum velocity deviation above the maximum velocity *VMAX*.

PID_I_CLIP 0x5D This parameter is used together with *PID_DV_CLIP* in order to limit the velocity for error compensation. The error sum *PID_ISUM* is generated by the integral term. In case this error sum must be limited, set *PID_I_CLIP*.
It is advisable to set the maximum value of *PID_I_CLIP* to:

PID_I_CLIP ≤ PID_DV_CLIP / PID_I.

i In case the error sum *PID_ISUM* is not clipped, it is increased with each time step by *PID_I · PID_E*. This continues as long as the motor does not follow.

16.3.4. Enabling the Limitation of the Catch-Up Velocity

Now that PI control parameters and clipping values are configured, as explained above, limiting catch-up velocities can be enabled.

In order to enable limitation of closed-loop catch-up velocity, do as follows:

Action:
➢ Set *cl_vlimit_en* = 1 (*ENC_IN_CONF* register 0x07).

Result:
Closed-loop catch-up velocity is limited according to the configured parameters.

NOTE:

→ *A higher motor velocity than specified VMAX (for negative velocity: -VMAX) is possible if the following conditions are met:*

Closed-loop operation is enabled.
Closed-loop catch-up velocity is not enabled, or is enabled with PID_DV_CLIP > 0; and CL_VMAX_CALC_P and CL_VMAX_CALC_I are higher than 0.
ENC_POS_DEV > CL_TOLERANCE resp. ENC_POS_DEV < CL_TOLERANCE.

AREAS OF SPECIAL CONCERN !

In case the internal ramp has stopped, and the position mismatch still needs to be corrected, the base velocity for catch-up velocity limitation is zero.

The mismatch correction ramp is a linear deceleration ramp, independent of the specified ramp profile. This occurs because the catch-up velocity is regulated via PI regulation, as explained above.
Thus, this final ramp for error compensation is a function of both *ENC_POS_DEV* and the PI control parameters.

•→Turn page for information on closed-loop velocity mode.

16.3.5. Enabling Closed-Loop Velocity Mode

Some applications only require maintaining a specified velocity value during closed-loop behavior, regardless of position mismatches. TMC4361 also provides this option.

NOTE:

→ *The closed-loop velocity mode is set independent of the internal ramp operation mode (velocity or positioning mode).*

In order to enable and calibrate closed-loop control, do as follows:

Action:

- Set the catch-up velocity parameters, as explained in detail in section 16.3.3, page 164.
- Set *cl_vlimit_en* = 1 (*ENC_IN_CONF* register 0x07).
- Set *cl_velocity_mode_en* = 1 (*ENC_IN_CONF* register 0x07).

Result:

Closed-loop operation velocity mode is enabled.
In case position mismatch |*ENC_POS_DEV*| exceeds 768 microsteps, internal position counter *XACTUAL* is set automatically to *ENC_POS* ± 768 to limit the position mismatch.
Thus, closed-loop operation maintains the specified velocity value *VMAX*.

i A higher motor velocity than specified *VMAX* (for negative velocity: −*VMAX*) is possible if *PID_DV_CLIP* > 0.

16.3.6. Closed-loop Scaling

In order to save energy, current scaling can be adjusted according to actual load during closed-loop operation.

Closed-Loop Scaling Configuration and Enabling

Closed-loop scaling slightly alters the use of the scaling register while remaining consistent in its use of internal scaling and the transmission to the stepper drivers:

1. Closed-loop scaling uses the same scaling register that is also used for open-loop configuration, as explained in chapter 11, page 120. However, the specified values that are used – and thus are also named – differently.

2. Internal scaling of MSLUT current values and transfer of these values to the motor stepper drivers function exactly in the same way as explained in chapter 10, page 88.

In order to configure and enable closed-loop scaling, do as follows:

Action:

- Set proper *CL_IMIN* (*SCALE_VALUES* register 0x06).
- Set proper *CL_IMAX* (*SCALE_VALUES* register 0x06).
- Set proper *CL_START_UP* (*SCALE_VALUES* register 0x06).
- Set *SCALE_VALUES* (31:24) to 0.
- Set *closed_loop_scale_en* = 1 (*CURRENT_CONF* register 0x05).

Result:

As soon as closed-loop scaling is enabled, all other open-loop scaling options are automatically disabled. The following scaling situations are possible:

1. In case |*ENC_POS_DEV*| ≤ *CL_START_UP*, current values are scaled with *CL_IMIN*.
2. In case |*ENC_POS_DEV*| > *CL_START_UP* and |*ENC_POS_DEV*| ≤ *CL_BETA*, current values are scaled with a factor that increases linearly from *CL_IMIN* to *CL_IMAX*.
3. In case |*ENC_POS_DEV*| > *CL_BETA*, current values are scaled with *CL_IMAX*.

The chart below identifies the actual scaling parameter SCALE_PARAM, which is dependent on the above described situations:

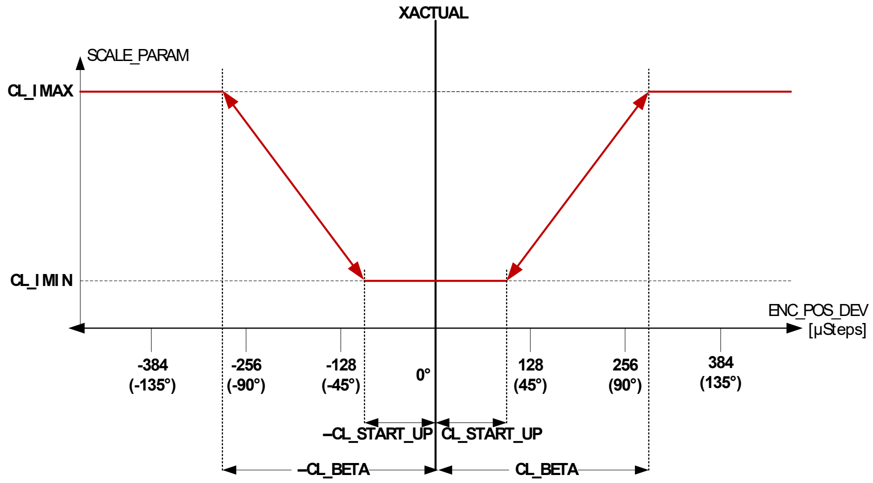


Figure 64: Closed-Loop Current Scaling

•→*Turn page for information on closed-loop velocity mode.*

16.3.7. Closed-Loop Scaling Transition Process Control

Transition from one scale value to the next active value can be configured as slight conversion. Two different parameters can be set in order to convert to higher or lower closed-loop current scale values, as depicted in the chart below.

In order to configure a smooth transition from a lower motion current scaling value to a higher motion current scaling value, do as follows:

Action:

➢ Set *CL_UPSCALE_DELAY* register 0x18 according to the delay period after which the actual scale parameter is increased by one step towards the higher current scale value.

Result:

Whenever a higher current scale value is assigned internally, the actual scale parameter is increased by one step per *CL_UPSCALE_DELAY* clock cycles until the assigned scale parameter is reached.

i If *CL_UPSCALE_DELAY* = 0, the higher current scaling value is immediately assigned whenever the corresponding current scaling phase is activated.

In order to configure a smooth transition from a higher motion current scaling value to a lower motion current scaling value, do as follows:

Action:

➢ Set *CL_DNSCALE_DELAY* register 0x19 according to the delay period after which the actual scale parameter is decreased by one step towards the lower current scale value.

Result:

Whenever a lower current scale value is assigned internally, the actual scale parameter is decreased by one step per *CL_DNSCALE_DELAY* clock cycles until the assigned scale parameter is reached.

i If *CL_DNSCALE_DELAY* = 0, the lower current scaling value is immediately assigned whenever the corresponding current scaling phase is activated.

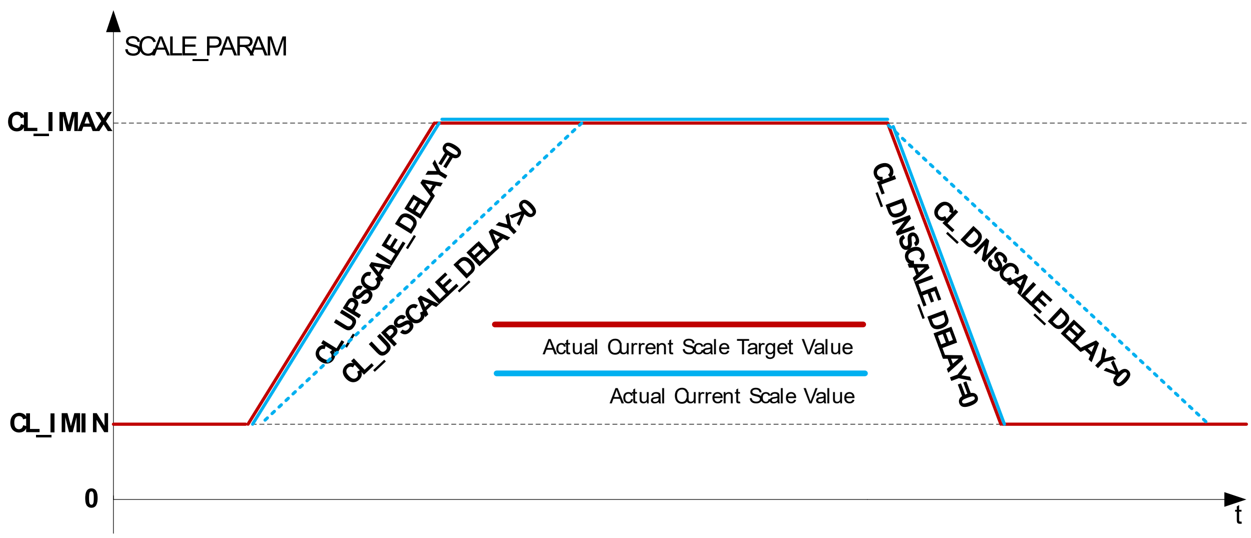


Figure 65: Closed-Loop Current Scaling Timing Behavior

16.3.8. Back-EMF Compensation during Closed-Loop Operation

When higher velocities are reached, a phase shift between current and voltage occurs at the motor coils. Consequently, current control is transformed into voltage control.
This motor- and setup-dependent effect must be compensated because currents are still continuously assigned for motor control. TMC4361 attributes γ-correction to the compensation process, which adds a velocity-dependent angle - *in motion direction* - to the current commutation angle.

Load Angle Calculation

Gamma correction constantly adds one compensation angle, GAMMA, to the actual commutation angle; because the velocity-dependent amount of the influence of Back-EMF, GAMMA is also velocity-dependent. Thus, velocity limits are assigned. These limits are based on REAL motor velocity *V_ENC* (register 0x65). The value of the motor velocity is internally calculated and can be filtered (*V_ENC_MEAN* register 0x66) to smoothen the γ-correction, which is explained in the next section.

In order to configure and enable Back-EMF compensation during closed-loop operation, do as follows:

Action:

- Set proper *CL_GAMMA* register 0x1C.
- Set proper *CL_VMIN_EMF* register 0x60.
- Set proper *CL_VMAX_EMF* register 0x61.
- Set *cl_emf_en* = 1 (*ENC_IN_CONF* register 0x07).

Result:
Back-EMF compensation during closed-loop operation is enabled. *CL_GAMMA* represents the maximum value of GAMMA. Per default, *CL_GAMMA* is set to its maximal possible value of 255, which represents a 90° angle.
The following compensation situations are possible:

1. In case |*V_ENC_MEAN*| ≤ *CL_VMIN_EMF*, GAMMA is set to 0.
2. In case |*V_ENC_MEAN*| > *CL_VMIN_EMF* and |*V_ENC_MEAN*| ≤ (*CL_VMIN_EMF* + *CL_VADD_EMF*), GAMMA is scaled linearly between 0 and its maximum value.
3. In case |*V_ENC_MEAN*| > (*CL_VMIN_EMF* + *CL_VADD_EMF*), GAMMA = *CL_GAMMA*.

The chart below identifies the actual parameter GAMMA, which is dependent on the above described situations:

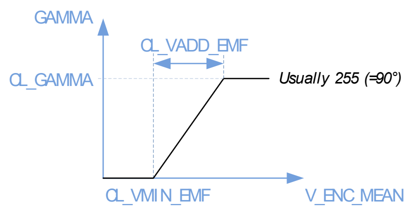


Figure 66: Calculation of the actual Load Angle GAMMA

Areas of Special Concern

! **If γ-correction is turned on, the maximum possible commutation is (*CL_BETA* + *CL_GAMMA*).**

This value must not exceed 180° (511 microsteps at 256 microsteps per fullstep) because angles of 180° or more will result in unwanted motion direction changes.

16.3.9. Encoder Velocity Readout Parameters

In case an encoder is connected, REAL motor velocity can be read out. The actual encoder velocity flickers. This is system-immanent. TMC4361 provides filter options that back-EMF compensation is based on. The following velocity parameters can be read out.

V_ENC 0x65

Actual encoder velocity in pulses (microsteps) per second [pps].

V_ENC_MEAN 0x66

Actual filtered encoder velocity in pulses (microsteps) per second [pps].

16.3.10. Encoder Velocity Filter Configuration

In order to set filter parameters correctly, consider the following details:

ENC_VMEAN_WAIT 0x63 (7:0)

ENC_VMEAN_WAIT represents the delay period in number of clock cycles between two consecutive *V_ENC* values that are used for the encoder filter velocity calculation. The lower this value, the faster the adaptation process of *V_ENC_MEAN* is. Accordingly: The higher the gradient of *V_ENC_MEAN* is.
In case incremental ABN encoders are connected, *ENC_VMEAN_WAIT* must be set above 32.
In case absolute encoders are connected, *ENC_VMEAN_WAIT* is automatically set to *SER_PTIME*.

ENC_VMEAN_FILTER 0x63 (11:8)

This filter exponent is used for filter calculations. The lower this value, the faster the adaptation process of *V_ENC_MEAN* is. Accordingly: The higher the gradient of *V_ENC_MEAN* is. Every *ENC_VMEAN_WAIT* clock cycles, the following calculation applies:

$$V_{ENC_{MEAN}} = \mathrm{V}_{\mathrm{ENC}_{\mathrm{MEAN}}} - \frac{\mathrm{V}_{\mathrm{ENC}_{\mathrm{MEAN}}}}{2^{ENC\_VMEAN\_FILTER}} + \frac{\mathrm{V}_{ENC}}{2^{ENC\_VMEAN\_FILTER}}$$

ENC_VMEAN_INT 0x63 (31:16)

The refresh frequency of high encoder velocity values *V_ENC* is determined by this encoder velocity update period.
In case incremental ABN encoders are connected, the minimum value of *ENC_VMEAN_INT* is automatically set to 256.
In case absolute encoders are connected, *ENC_VMEAN_INT* is automatically adapted to encoder value request rate.

16.3.11. Encoder Velocity equals 0 Event

Because internal calculation of low *V_ENC* values is triggered by AB signal changes and not by the refresh frequency defined by *ENC_VMEAN_INT*, any occurring idle state of the encoder is not recognized.
In order to determine that *V_ENC* = 0, it is possible to limit the number of clock cycles while no AB signal changes occur; which then signifies encoder idle state.

In order to evoke encoder idle state, do as follows:

Action:
- Set proper *ENC_VEL_ZERO* register 0x62.

Result:
In case no AB signal changes occur during *ENC_VEL_ZERO* clock cycles, *ENC_VEL0* event is triggered, which indicates encoder idle state.

TECHNICAL SPECIFICATIONS

17. Complete Register and Switches List

17.1. General Configuration Register GENERAL_CONF 0x00

GENERAL_CONF 0x00 *(Default value: 0x00006020)*			
R/W	**Bit**	**Val**	**Remarks**
RW	0	*use_astart_and_vstart*	***(only valid for S-shaped ramps)***
		0	Sets *AACTUAL* = *AMAX* or –*AMAX* at ramp start and in the case of *VSTART* ≠ 0.
		1	Sets *AACTUAL* = *ASTART* or –*ASTART* at ramp start and in the case of *VSTART* ≠ 0.
	1	*direct_acc_val_en*	
		0	Acceleration values are divided by *CLK_FREQ*.
		1	Acceleration values are set directly as steps per clock cycle.
	2	*direct_bow_val_en*	
		0	Bow values are calculated due to division by *CLK_FREQ*.
		1	Bow values are set directly as steps per clock cycle.
	3	*step_inactive_pol*	
		0	STPOUT = 1 indicates an active step.
		1	STPOUT = 0 indicates an active step.
	4	*toggle_step*	
		0	Only STPOUT transitions from inactive to active polarity indicate steps.
		1	Every level change of STPOUT indicates a step.
	5	*pol_dir_out*	
		0	DIROUT = 0 indicates negative direction.
		1	DIROUT = 1 indicates negative direction.
	7:6	*sdin_mode*	
		0	Internal step control (internal ramp generator will be used)
		1	External step control via STPIN / DIRIN interface with high active steps at STPIN
		2	External step control via STPIN / DIRIN interface with low active steps at STPIN
		3	External step control via STPIN / DIRIN interface with toggling steps at STPIN
	8	*pol_dir_in*	
		0	DIRIN = 0 indicates negative direction.
		1	DIRIN = 1 indicates negative direction.
	9	*sd_indirect_control*	
		0	STPIN/DIRIN input signals will manipulate internal steps at *XACTUAL* directly.
		1	STPIN/DIRIN input signals will manipulate *XTARGET* register value, the internal ramp generator is used.
			•→Turn Page.

GENERAL_CONF 0x00 *(Default value: 0x00006020)*

R/W	Bit	Val	Remarks
RW	11:10		*serial_enc_in_mode*
		0	An incremental encoder is connected to encoder interface.
		1	An absolute SSI encoder is connected to encoder interface.
		2	Reserved
		3	An absolute SPI encoder is connected to encoder interface.
	12		*diff_enc_in_disab*
		0	Differential encoder interface inputs enabled.
		1	Differential encoder interface inputs is disabled (automatically set for SPI encoder).
	14:13		*stdby_clk_pin_assignment*
		0	Standby signal becomes forwarded with an active low level at STDBY_CLK output.
		1	Standby signal becomes forwarded with an active high level at STDBY_CLK output.
		2	STDBY_CLK passes ChopSync clock (TMC23x, TMC24x stepper motor drivers only).
		3	Internal clock is forwarded to STDBY_CLK output pin.
	15		*intr_pol*
		0	INTR=0 indicates an active interrupt.
		1	INTR=1 indicates an active interrupt.
	16		*invert_pol_target_reached*
		0	TARGET_REACHED signal is set to 1 to indicate a target reached event.
		1	TARGET_REACHED signal is set to 0 to indicate a target reached event.
	18:17	Reserved. Set to 0x0.	
	19		*fs_en*
		0	Fullstep switchover is disabled.
		1	SPI output forwards fullsteps, if |*VACTUAL*| > *FS_VEL*.
	20		*fs_sdout*
		0	No fullstep switchover for Step/Dir output is enabled.
		1	Fullsteps are forwarded via Step/Dir output also if fullstep operation is active.
	22:21		*dcstep_mode*
		0	dcStep is disabled.
		1	dcStep signal generation will be selected automatically
		2	dcStep with external STEP_READY signal generation (TMC2130).
		3	dcStep with internal STEP_READY signal generation (TMC26x). i **TMC26x config: use const_toff-Chopper (CHM = 1);** **slow decay only (HSTRRT = 0);** **TST = 1 and SGT0=SGT1=1 (on_state_xy).**

•→*Continued on next page.*

GENERAL_CONF 0x00 *(Default value: 0x00006020)*			
R/W	**Bit**	**Val**	**Remarks**
RW	23		*pwm_out_en*
		0	PWM output is disabled. Step/Dir output is enabled at STPOUT/DIROUT.
		1	STPOUT/DIROUT output pins are used as PWM output (PWMA/PWMB).
	24		*serial_enc_out_enable*
		0	No encoder is connected to SPI output.
		1	SPI output is used as SSI encoder interface to forward absolute SSI encoder data.
	25		*serial_enc_out_diff_disable*
		0	Differential serial encoder output is enabled.
		1	Differential serial encoder output is disabled.
	26		*automatic_direct_sdin_switch_off*
		0	*VACTUAL*=0 & *AACTUAL*=0 after switching off direct external step control.
		1	*VACTUAL* = *VSTART* and *AACTUAL* = *ASTART* after switching off direct external step control.
	27		*circular_cnt_as_xlatch*
		0	The register value of *X_LATCH* is forwarded at register 0x36.
		1	The register value of *REV_CNT* (#internal revolutions) is forwarded at register 0x36.
	28		*reverse_motor_dir*
		0	The direction of the internal SinLUT is regularly used.
		1	The direction of internal SinLUT is reversed
	29		*intr_tr_pu_pd_en*
		0	INTR and TARGET_REACHED are outputs with strongly driven output values..
		1	INTR and TARGET_REACHED are used as outputs with gated pull-up and/or pull-down functionality.
	30		*intr_as_wired_and*
		0	INTR output function is used as Wired-Or in case of *intr_tr_pu_pd_en* = 1.
		1	INTR output function is used as Wired-And in case of *intr_tr_pu_pd_en* = 1.
	31		*tr_as_wired_and*
		0	TARGET_REACHED output function is used as Wired-Or in the case of *intr_tr_pu_pd_en* = 1.
		1	TARGET_REACHED output function is used as Wired-And in the case of *intr_tr_pu_pd_en* = 1.

Table 60: General Configuration 0x00

17.2. Reference Switch Configuration Register REFERENCE_CONF 0x01

REFERENCE_CONF 0x01 *(Default value: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
RW	0		*stop_left_en*
		0	STOPL signal processing disabled.
		1	STOPL signal processing enabled.
	1		*stop_right_en*
		0	STOPR signal processing disabled.
		1	STOPR signal processing enabled.
	2		*pol_stop_left*
		0	STOPL input signal is low active.
		1	STOPL input signal is high active.
	3		*pol_stop_right*
		0	STOPR input signal is low active.
		1	STOPR input signal is high active.
	4		*invert_stop_direction*
		0	STOPL/STOPR stops motor in negative/positive direction.
		1	STOPL/STOPR stops motor in positive/negative direction.
	5		*soft_stop_en*
		0	Hard stop enabled. *VACTUAL* is immediately set to 0 on any external stop event.
		1	Soft stop enabled. A linear velocity ramp is used for decreasing *VACTUAL* to v = 0.
	6		*virtual_left_limit_en*
		0	Position limit VIRT_STOP_LEFT disabled.
		1	Position limit VIRT_STOP_LEFT enabled.
	7		*virtual_right_limit_en*
		0	Position limit VIRT_STOP_RIGHT disabled.
		1	Position limit VIRT_STOP_RIGHT enabled.
	9:8		*virt_stop_mode*
		0	Reserved.
		1	Hard stop: *VACTUAL* is set to 0 on a virtual stop event.
		2	Soft stop is enabled with linear velocity ramp (from *VACTUAL* to v = 0).
		3	Reserved.
	10		*latch_x_on_inactive_l*
		0	No latch of *XACTUAL* if STOPL becomes inactive.
		1	*X_LATCH* = *XACTUAL* is stored in the case STOPL becomes inactive.
	11		*latch_x_on_active_l*
		0	No latch of *XACTUAL* if STOPL becomes active.
		1	*X_LATCH* = *XACTUAL* is stored in the case STOPL becomes active.

•→*Continued on next page.*

REFERENCE_CONF 0x01 *(Default value: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
RW	12	*latch_x_on_inactive_r*	
		0	No latch of *XACTUAL* if STOPR becomes inactive.
		1	*X_LATCH* = *XACTUAL* is stored in the case STOPL becomes inactive.
	13	*latch_x_on_active_r*	
		0	No latch of *XACTUAL* if STOPR becomes active.
		1	*X_LATCH* = *XACTUAL* is stored in the case STOPL becomes active.
	14	*stop_left_is_home*	
		0	STOPL input signal is not also the HOME position.
		1	STOPL input signal is also the HOME position.
	15	*stop_right_is_home*	
		0	STOPR input signal is not lso the HOME position.
		1	STOPR input signal is also the HOME position.
	19:16	*home_event*	
		0	Next active N event of connected ABN encoder signal indicates HOME position.
		2	HOME_REF = 1 indicates an active home event *X_HOME* is located at the rising edge of the active range.
		3	HOME_REF = 0 indicates negative region/position from the home position.
		4	HOME_REF = 1 indicates an active home event *X_HOME* is located at the falling edge of the active range.
		6	HOME_REF = 1 indicates an active home event *X_HOME* is located in the middle of the active range.
		9	HOME_REF = 0 indicates an active home event *X_HOME* is located in the middle of the active range.
		11	HOME_REF = 0 indicates an active home event *X_HOME* is located at the rising edge of the active range.
		12	HOME_REF = 1 indicates negative region/position from the home position.
		13	HOME_REF = 0 indicates an active home event *X_HOME* is located at the falling edge of the active range.
	20	*start_home_tracking*	
		0	No storage to *X_HOME* by passing home position.
		1	Storage of *XACTUAL* as *X_HOME* at next regular home event. This switch is reset after an executed homing. An XLATCH_DONE event will be also released then.
	21	*clr_pos_at_target*	
		0	Ramp stops at *XTARGET* if positioning mode is active.
		1	Set *XACTUAL* = 0 after *XTARGET* has been reached. The next ramp starts immediately.
	22	*circular_movement_en*	
		0	Range of *XACTUAL* is not limited: $-2^{31} \leq XACTUAL \leq 2^{31}-1$
		1	Range of *XACTUAL* is limited by *X_RANGE*: $-X\_RANGE \leq XACTUAL \leq X\_RANGE - 1$

•→ *Continued on next page.*

REFERENCE_CONF 0x01 *(Default value: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
RW	24:23		*pos_comp_output*
		0	TARGET_REACHED is set active on *TARGET_REACHED* event.
		1	Reserved.
		2	Reserved.
		3	TARGET_REACHED triggers on *POSCOMP_REACHED* event.
	25		*pos_comp_source*
		0	*POS_COMP* is compared to internal position *XACTUAL*.
		1	*POS_COMP* is compared with external position *ENC_POS*.
	26		*stop_on_stall*
		0	SPI and S/D output interface remain active in case of an stall event.
		1	SPI and S/D output interface stops motion in case of an stall event (hard stop).
	27		*drv_after_stall*
		0	No further motion in case of an active Stop-on-Stall event.
		1	Motion is possible in case of an active Stop-on-Stall event and after the Stop-on-Stall event is reset.
	29:28		*modified_pos_compare: POS_COMP_REACHED_F / event is based on comparison between XACTUAL resp. ENC_POS and*
		0	*POS_COMP*
		1	*X_HOME*
		2	*X_LATCH* resp. *ENC_LATCH*
		3	*REV_CNT*
	30		*automatic_cover*
		0	SPI output interface will not transfer automatically any cover datagram.
		1	SPI output interface sends automatically cover datagrams when *VACTUAL* crosses *SPI_SWITCH_VEL*.
	31		*circular_enc_en*
		0	Range of *ENC_POS* is not limited: $-2^{31} \leq ENC\_POS \leq 2^{31}-1$
		1	Range of *ENC_POS* is limited by *X_RANGE*: $-X\_RANGE \leq ENC\_POS \leq X\_RANGE - 1$

Table 61: Reference Switch Configuration 0x01

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.3. Start Switch Configuration Register START_CONF 0x02

START_CONF 0x02 *(Default value: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
RW	4:0		*start_en*
		xxxx1	Alteration of *XTARGET* value requires distinct start signal.
		xxx1x	Alteration of *VMAX* value requires distinct start signal.
		xx1xx	Alteration of *RAMPMODE* value requires distinct start signal.
		x1xxx	Alteration of *GEAR_RATIO* value requires distinct start signal.
		1xxxx	Shadow Register Feature Set is enabled.
	8:5		*trigger_events*
		0000	Timing feature set is disabled because start signal generation is disabled.
		xxx0	START pin is assigned as output.
		xxx1	External start signal is enabled as timer trigger. START pin is assigned as input.
		xx1x	*TARGET_REACHED* event is assigned as start signal trigger.
		x1xx	*VELOCITY_REACHED* event is assigned as start signal trigger.
		1xxx	*POSCOMP_REACHED* event is assigned as start signal trigger.
	9		*pol_start_signal*
		0	START pin is low active (input resp. output).
		1	START pin is high active (input resp. output).
	10		*immediate_start_in*
		0	Active START input signal starts internal start timer.
		1	Active START input signal is executed immediately.
	11		*busy_state_en*
		0	START pin is only assigned as input or output.
		1	Busy start state is enabled. START pin is assigned as input with a weakly driven active start polarity or as output with a strongly driven inactive start polarity.
	15:12		*pipeline_en*
		0000	No pipelining is active.
		xxx1	*X_TARGET* is considered for pipelining.
		xx1x	*POS_COMP* is considered for pipelining.
		x1xx	*GEAR_RATIO* is considered for pipelining.
		1xxx	*GENERAL_CONF* is considered for pipelining.
	17:16		*shadow_option*
		0	Single-level shadow registers for 13 relevant ramp parameters.
		1	Double-stage shadow registers for S-shaped ramps.
		2	Double-stage shadow registers for trapezoidal ramps (excl. *VSTOP*).
		3	Double-stage shadow registers for trapezoidal ramps (excl. *VSTART*).

•→ Continued on next page.

START_CONF 0x02 *(Default value: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
	18	*cyclic_shadow_regs*	
		0	Current ramp parameters are not written back to the shadow register.
		1	Current ramp parameters are written back to the appropriate shadow register.
RW	19	Reserved. Set to 0.	
	23:20	*SHADOW_MISS_CNT*	
		U	Number of unused start internal start signals between two consecutive shadow register transfers.
	31:24	*XPIPE_REWRITE_REG*	
			Current assigned pipeline registers – *START_CONF*(15:12) – are written back to *X_PIPEx* in the case of an internal start signal generation and if assigned in this register with a '1': *XPIPE_REWRITE_REG*(0) → *X_PIPE0* *XPIPE_REWRITE_REG*(1) → *X_PIPE1* *XPIPE_REWRITE_REG*(2) → *X_PIPE2* *XPIPE_REWRITE_REG*(3) → *X_PIPE3* *XPIPE_REWRITE_REG*(4) → *X_PIPE4* *XPIPE_REWRITE_REG*(5) → *X_PIPE5* *XPIPE_REWRITE_REG*(6) → *X_PIPE6* *XPIPE_REWRITE_REG*(7) → *X_PIPE7* Ex.: *START_CONF*(15:12) = b'0011. *START_CONF*(31:24) = b'01000010. If an internal start signal is generated, the value of *X_TARGET* is written back to *X_PIPE1*, whereas the value of *POS_COMP* is written back to *X_PIPE6*.

Table 62: Start Switch Configuration START_CONF 0x02

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.4. Input Filter Configuration Register INPUT_FILT_CONF 0x03

INPUT_FILT_CONF 0x03 *(Default value: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
RW	2:0		*SR_ENC_IN*
		U	Input sample rate = f_{clk} / $2^{SR\_ENC\_IN}$ for the following pins: A_SCLK, ANEG_NSCLK, B_SDI, BNEG_NSDI, N, NNEG
	3		Reserved. Set to 0.
	6:4		*FILT_L_ENC_IN*
		U	Filter length for these pins: A_SCLK, ANEG_NSCLK, B_SDI, BNEG_NSDI, N, NNEG. Number of sample input bits that must have equal voltage levels to provide a valid input bit.
	7		*SD_FILT0*
		0	S/D input pins (STPIN/DIRIN) are not assigned to the ENC_IN input filter group.
		1	S/D input pins (STPIN/DIRIN) are also assigned to the ENC_IN input filter group.
	10:8		*SR_REF*
		U	Input sample rate = f_{clk} / 2^{REF} for the following pins: STOPL, HOME_REF, STOPL
	11		Reserved. Set to 0.
	14:12		*FILT_L_ENC_IN*
		U	Filter length for the following pins: STOPL, HOME_REF, STOPL. Number of sample input bits that must have equal voltage levels to provide a valid input bit.
	15		*SD_FILT1*
		0	S/D input pins (STPIN/DIRIN) are not assigned to the REF input filter group.
		1	S/D input pins (STPIN/DIRIN) are also assigned to the REF input filter group.
	18:16		*SR_S*
		U	Input sample rate = f_{clk} / 2^{S} for the START pin.
	19		Reserved. Set to 0.
	22:20		*FILT_L_S*
		U	Filter length for the START pin. Number of sample input bits that must have equal voltage levels to provide a valid input bit.
	23		*SD_FILT2*
		0	S/D input pins (STPIN/DIRIN) are not assigned to the S input filter group.
		1	S/D input pins (STPIN/DIRIN) are also assigned to the S input filter group.
	26:24		*SR_ENC_OUT*
		U	Input sample rate = f_{clk} / $2^{SR\_ENC\_OUT}$ for these pins: SDODRV_SCLK, SDIDRV_NSCLK
	27		Reserved. Set to 0.
	30:28		*FILT_L_ENC_OUT*
		U	Filter length for the following pins: SDODRV_SCLK, SDIDRV_NSCLK. Number of sample input bits that must have equal voltage levels to provide a valid input bit.
	31		*SD_FILT3*
		0	S/D input pins (STPIN/DIRIN) are not assigned to the ENC_OUT input filter group.
		1	S/D input pins (STPIN/DIRIN) are assigned to the ENC_OUT input filter group.

Table 63: Input Filter Configuration Register INPUT_FILT_CONF 0x03

17.5. SPI Output Configuration Register SPI_OUT_CONF 0x04

SPI_OUT_CONF 0x04 *(Default value: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
RW	3:0		*spi_output_format*
		0	SPI output interface is **off**.
		1	SPI output interface is connected with a **SPI-DAC**. SPI output values are **mapped** to full amplitude: Current=0 → VCC/2 Current=−max → 0 Current=max → VCC
		2	SPI output interface is connected with a **SPI-DAC**. SPI output values are **absolute values**. Phase of coilA is forwarded via STPOUT, whereas phase of coilB is forwarded via DIROUT. Phase bit = 0:positive value.
		3	SPI output interface is connected with a **SPI-DAC**. SPI output values are **absolute values**. Phase of coilA is forwarded via STPOUT, whereas phase of coilB is forwarded via DIROUT. Phase bit = 0: negative value.
		4	The **actual unsigned scaling** factor is forwarded via SPI output interface.
		5	Both **actual signed current values** CURRENTA and CURRENTB are forwarded in one datagram via SPI output interface.
		6	SPI output interface is connected with a **SPI-DAC**. The actual **unsigned scaling factor** is merged with DAC_ADDR_A value to an output datagram.
		8	SPI output interface is connected with a **TMC23x** stepper motor driver.
		9	SPI output interface is connected with a **TMC24x** stepper motor driver.
		10	SPI output interface is connected with a **TMC26x/389** stepper motor driver. Configuration and current data are transferred to the stepper motor driver.
		11	SPI output interface is connected with a **TMC26x** stepper motor driver. Only configuration data is transferred. S/D output interface provides steps.
		12	SPI output interface is connected with a **TMC2130** stepper motor driver. Only configuration data is transferred to the stepper motor driver. S/D output interface provides steps.
		13	SPI output interface is connected with a **TMC2130** stepper motor driver. Configuration and current data are transferred to the stepper motor driver.
		15	**Only cover** datagrams are transferred via SPI output interface.
	19:13		*COVER_DATA_LENGTH*
		U	Number of bits for the complete datagram length. Maximum value = 64 Set to 0 in case a TMC stepper motor driver is selected. The datagram length is then selected automatically.
	23:20		*SPI_OUT_LOW_TIME*
		U	Number of clock cycles the SPI output clock remains at low level.
	27:24		*SPI_OUT_HIGH_TIME*
		U	Number of clock cycles the SPI output clock remains at high level.
	31:28		*SPI_OUT_BLOCK_TIME*
		U	Number of clock cycles. The NSCSDRV output remains high (inactive) after SPI output transmission.
	•→ *Continued on next page.*		

SPI_OUT_CONF 0x04 *(Default value: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
RW	5:4	*mixed_decay*	***(TMC23x/24x only)***
		0	Both mixed decay bits are always off.
		1	Mixed decay bits are on during falling ramps until reaching a current value of 0.
		2	Mixed decay bits are always on, except during standstill.
		3	Mixed decay bits are always on.
	6	*stdby_on_stall_for_24x*	***(TMC24x only)***
		0	No standby datagram is sent.
		1	In case of a Stop-on-Stall event, a standby datagram is sent to the TMC24x.
	7	*stall_flag_instead_of_uv_en*	***(TMC24x only)***
		0	Undervoltage flag of TMC24x is mapped at *STATUS*(24).
		1	Calculated stall status of TMC24x is forwarded at *STATUS*(24).
	10:8	*STALL_LOAD_LIMIT*	***(TMC24x only)***
		U	A stall is detected if the stall limit value *STALL_LOAD_LIMIT* is higher than the combination of the load bits (LD2&LD1&LD0).
	11	*pwm_phase_shft_en*	***(TMC24x only)***
		0	No phase shift during PWM mode.
		1	During PWM mode, the internal SinLUT microstep position *MSCNT* is shifted to *MS_OFFSET* microsteps. Consequently, the sine/cosine values have a phase shift of (*MS_OFFSET* / 1024 · 360°)
	4	*three_phase_stepper_en*	***(TMC389 only)***
		0	A 2-phase stepper motor driver is connected to the SPI output (TMC26x).
		1	A 3-phase stepper motor driver is connected to the SPI output (TMC389).
	5	*scale_val_transfer_en*	***(TMC26x/2130 in SD mode only)***
		0	No transfer of scale values.
		1	Transmission of current scale values to the appropriate driver registers.
	6	*disable_polling*	***(TMC26x/2130 in SD mode only)***
		0	Permanent transfer of polling datagrams to check driver status.
		1	No transfer of polling datagrams.
	11:7	*POLL_BLOCK_MULT*	***(TMC26x/2130 in SD mode only)***
		U	Multiplier for calculating the time interval between two consecutive polling datagrams: t_{POLL} = (*POLL_BLOCK_MULT*+1) · *SPI_OUT_BLOCK_TIME* / f_{CLK}
	4	*sck_low_before_csn*	***(No TMC driver)***
		0	NSCSDRV_SDO is tied low before SCKDRV_NSDO to initiate a new data transfer.
		1	SCKDRV_NSDO is tied low before NSCSDRV_SDO to initiate a new data transfer.
	5	*new_out_bit_at_rise*	***(No TMC driver)***
		0	New value bit at SDODRV_SCLK is assigned at falling edge of SCKDRV_NSDO.
		1	New value bit at SDODRV_SCLK is assigned at rising edge of SCKDRV_NSDO.

•→ *Continued on next page.*

SPI_OUT_CONF 0x04 *(Default value: 0x00000000)*

R/W	Bit	Val	Remarks
RW	11:7		*DAC_CMD_LENGTH* ***(SPI-DAC only)***
		U	Number of bits for command address if one of the SPI-DAC options is selected
	12		Reserved. Set to 0.
	23:4		*SSI_OUT_MTIME* ***(Serial encoder output only)***
		U	Monoflop time for SSI output interface: Delay time [clock cycles] during which the absolute encoder data remain stable after the last master request.

Table 64: SPI Output Configuration Register SPI_OUT_CONF 0x04

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.6. Current Scaling Configuration Register CURRENT_CONF 0x05

CURRENT_CONF 0x05 *(Default: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
RW	0		*hold_current_scale_en*
		0	No hold current scaling during standby phase.
		1	Hold current scaling during standby phase.
	1		*drive_current_scale_en*
		0	No drive current scaling during motion.
		1	Drive current scaling during motion.
	2		*boost_current_on_acc_en*
		0	No boost current scaling for deceleration ramps.
		1	Boost current scaling if *RAMP_STATE* = b'01 (acceleration slopes).
	3		*boost_current_on_dec_en*
		0	No boost current scaling for deceleration ramps.
		1	Boost current scaling if *RAMP_STATE* = b'10 (deceleration slopes).
	4		*boost_current_after_start_en*
		0	No boost current at ramp start.
		1	Temporary boost current if *VACTUAL* = 0 and new ramp starts.
	5		*sec_drive_current_scale_en*
		0	One drive current value for the whole motion ramp.
		1	Second drive current scaling for *VACTUAL* > *VDRV_SCALE_LIMIT*.
	6		*freewheeling_en*
		0	No freewheeling.
		1	Freewheeling after standby phase.
	7		*closed_loop_scale_en*
		0	No closed-loop current scaling.
		1	Closed-loop current scaling – *CURRENT_CONF*(6:0) = 0 is set automatically ! **Turn off for closed-loop calibration with maximum current!**
	8		*pwm_scale_en*
		0	PWM scaling is disabled.
		1	PWM scaling is enabled.
	15:9	Reserved. Set to 0x00.	
	31:16		*PWM_AMPL*
		U	PWM amplitude during Voltage PWM mode at *VACTUAL* = 0. i **Maximum duty cycle = (0.5 + (*PWM_AMPL* + 1) / 2^{17})** **Minimum duty cycle = (0.5 – (*PWM_AMPL* + 1) / 2^{17})** **PWM_AMPL = 2^{16} – 1 at *VACTUAL* = *PWM_VMAX***

Table 65: Current Scale Configuration (0x05)

17.7. Current Scale Values Register SCALE_VALUES 0x06

SCALE_VALUES 0x06 *(Default: 0xFFFFFFFF)*				
R/W	**Bit**	**Val**	**Scaling Value Name**	**Remarks**
RW	7:0	U	*BOOST_SCALE_VAL*	**Open-loop** boost scaling value.
			CL_IMIN	**Closed-loop** minimum scaling value.
	15:8	U	*DRV1_SCALE_VAL*	**Open-loop** first drive scaling value.
			CL_IMAX	**Closed-loop** maximum scaling value.
	23:16	U	*DRV2_SCALE_VAL*	**Open-loop** second drive scaling value.
			CL_START_UP	|*ENC_POS_DEV*| value at which **closed-loop** scaling increases the current scaling value above *CL_IMIN*.
	31:24	U	*HOLD_SCALE_VAL*	**Open-loop** standby scaling value.
			CL_START_DOWN	|*ENC_POS_DEV*| value at which **closed-loop** scaling decreases the current scaling value below *CL_IMAX*. i **Recommended: Set to 0 to automatically assign to *CL_BETA*.**

Table 66: Current Scale Values (0x06)

NOTE:

→ *BOOST_SCALE_VAL, DRV1/DRV2_SCALE_VAL, HOLD_SCALE_VAL, CL_IMIN, CL_IMAX.*

→ *Real scaling value = (x+1) / 32 if spi_output_format = b'1011 or b'1100.*

→ *= (x+1) / 256 any other spi_output_format setting.*

17.8. Encoder Signal Configuration (0x07)

***ENC_IN_CONF* 0x07** *(Default 0x00000400)*			
R/W	**Bit**	**Val**	**Description**
RW	0		*enc_sel_decimal*
		0	Encoder constant represents a binary number.
		1	Encoder constant represents a decimal number (for ABN only).
	1		*clear_on_n*
		0	*ENC_POS* is not set to *ENC_RESET_VAL*.
		1	*ENC_POS* is set to *ENC_RESET_VAL* on every N event in case *clr_latch_cont_on_n*=1, or on the next N event in case *clr_latch_once_on_n*=1. ! **Do NOT use during closed-loop operation!**
	2		*clr_latch_cont_on_n*
		0	Value of *ENC_POS* is not cleared and/or latched on every N event.
		1	Value of *ENC_POS* is cleared and/or latched on every N event.
	3		*clr_latch_once_on_n*
		0	Value of *ENC_POS* is not cleared and/or latched on the next N event.
		1	Value of *ENC_POS* is cleared and/or latched on the next N event. i **This bit is set to 0 after latching/clearing once.**
	4		*pol_n*
		0	Active polarity for N event is low active.
		1	Active polarity for N event is high active.
	6:5		*n_chan_sensitivity*
		0	N event is active as long as N equals active N event polarity.
		1	N event triggers when N switches to active N event polarity.
		2	N event triggers when N switches to inactive N event polarity.
		3	N event triggers when N switches to in-/active N event polarity (both slopes).
	7		*pol_a_for_n*
		0	A polarity has to be low for a valid N event.
		1	A polarity has to be high for a valid N event.
	8		*pol_b_for_n*
		0	B polarity has to be low for valid N event
		1	B polarity has to be high for valid N event
	9		*ignore_ab*
		0	TMC4361 considers A and B polarities for valid N event.
		1	Polarities of A and B signals for a valid N event are ignored.

•→*Continued on next page.*

Read entire documentation; especially the "Supplemental Directives" on page 218.

ENC_IN_CONF **0x07** *(Default 0x00000400)*			
R/W	**Bit**	**Val**	**Description**
RW	10		*latch_enc_on_n*
		0	*ENC_POS* is not latched.
		1	*ENC_POS* is latched to *ENC_LATCH* on every N event in case *clr_latch_cont_on_n*=1, or on the next N event in case *clr_latch_once_on_n*=1.
	11		*latch_x_on_n*
		0	*XACTUAL* is not latched.
		1	*XACTUAL* is latched to *X_LATCH* on every N event in case *clr_latch_cont_on_n*=1, or on the next N event in case *clr_latch_once_on_n*=1.
	12		*multi_turn_in_en* ***(Absolute encoder only)***
		0	Connected serial encoder transmits singleturn values.
		1	Connected serial encoder input transmits singleturn and multiturn values.
	13		*multi_turn_in_signed* ***(Absolute encoder only)***
		0	Multiturn values from serial encoder input are unsigned numbers.
		1	Multiturn values from serial encoder input are signed numbers.
	14		*multi_turn_out_en* ***(Serial encoder output only)***
		0	Serial encoder output transmits singleturn values.
		1	Serial encoder output transmits singleturn and multiturn values.
	15		*use_usteps_instead_of_xrange*
		0	*X_RANGE* is valid in case circular motion is also enabled for encoders.
		1	*USTEPS_PER_REV* is valid in case circular motion is also enabled for encoders.
	16		*calc_multi_turn_behav* ***(Absolute encoder only)***
		0	No multiturn calculation.
		1	TMC4361 calculates internally multiturn data for singleturn encoder data.
	17		*ssi_multi_cycle_data* ***(Absolute encoder only)***
		0	Every SSI value request is executed once.
		1	Every SSI value request is executed twice.
	18		*ssi_gray_code_en* ***(Absolute encoder only)***
		0	SSI input data is binary-coded.
		1	SSI input data is gray-coded.
	19		*left_aligned_data* ***(Absolute encoder only)***
		0	Serial input data is aligned right (first flags, then data).
		1	Serial input data is aligned left (first data, then flags).
			•→*Turn page.*

***ENC_IN_CONF* 0x07** *(Default 0x00000400)*			
R/W	**Bit**	**Val**	**Description**
RW	20		*spi_data_on_cs* ***(SPI encoder only)***
		0	BNEG_NSDI provides serial output data at next serial clock line (A_SCLK) transition.
		1	BNEG_NSDI provides serial output data immediately in case negated chip select line ANEG_NSCLK switches to low level.
	21		*spi_low_before_cs* ***(SPI encoder only)***
		0	Serial clock line A_SCLK switches to low level after negated chip select line ANEG_NSCLK switches to low level.
		1	Serial clock line A_SCLK switches to low level before negated chip select line ANEG_NSCLK switches to low level.
	23:22		*regulation_modus*
		0	No internal regulation on encoder feedback data.
		1	Closed-loop operation is enabled. ! **Use full microstep resolution only! (256 µSteps/FS → MSTEPS_PER_FS=0)**
		2	PID regulation is enabled. Pulse generator base velocity equals 0.
		3	PID regulation is enabled. Pulse generator base velocity equals *VACTUAL*.
	24		*cl_calibration_en* ***(Closed-loop operation only)***
		0	Closed-loop calibration is deactivated.
		1	Closed-loop calibration is active. ! **Use maximum current without scaling during calibration.** ! **It is recommend to keep the motor driver at fullstep position with no motion occurrence during the calibration process.**
	25		*cl_emf_en* ***(Closed-loop operation only)***
		0	Back-EMF compensation deactivated during closed-loop operation.
		1	Back-EMF compensation is enabled during closed-loop operation. Closed-loop operation compensates Back-EMF in case |*VACTUAL*| > *CL_VMIN*.
	26		*cl_clr_xact* ***(Closed-loop operation only)***
		0	*XACTUAL* is not reset to *ENC_POS* during closed-loop operation.
		1	*XACTUAL* is set to *ENC_POS* in case |*ENC_POS_DEV*| > *ENC_POS_DEV_TOL* during closed-loop operation. ! **This feature must only be used if understood completely.**
	27		*cl_vlimit_en* ***(Closed-loop operation only)***
		0	No catch-up velocity limit during closed-loop regulation.
		1	Catch-up velocity during closed-loop operation is limited by internal PI regulator.
	28		*cl_velocity_mode_en* ***(Closed-loop operation only)***
		0	Closed-loop velocity mode is deactivated.
		1	Closed-loop velocity mode is deactivated. In case |*ENC_POS_DEV*| > 768, *XACTUAL* is adjusted accordingly.
	29		*invert_enc_dir*
		0	Encoder direction is NOT inverted internally.
		1	Encoder direction is inverted internally.
			•→*Turn page.*

***ENC_IN_CONF* 0x07** *(Default 0x00000400)*			
R/W	**Bit**	**Val**	**Description**
RW	30		*enc_out_gray* **(Serial encoder output only)**
		0	SSI output data is binary-encoded.
		1	SSI output data is gray-encoded.
	31		*no_enc_vel_preproc* **(Incremental ABN encoder)**
		0	AB signal is preprocessed for internal encoder velocity calculation.
		1	No AB signal preprocessing. ! **It is recommend to maintain AB preprocessing in order to filter encoder resonances.**
			serial_enc_variation_limit **(Absolute encoder)**
		0	No variation limit on absolute encoder data.
		1	Two consecutive serial encoder values must no deviate from specified limit to be valid. In case $\vert ENC\_POS_X - ENC\_POS_{X-1} \vert > 1/8 \cdot SER\_ENC\_VARIATION \cdot ENC\_IN\_RES$, ENC_POS_X is not valid and is not assigned to *ENC_POS*.

Table 67: Encoder Signal Configuration ENC_IN_CONF (0x07)

17.9. Serial Encoder Data Input Configuration (0x08)

***ENC_IN_DATA* 0x08** *(Default: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
RW	4:0		*SINGLE_TURN_RES (Default: 0x00)*
		U	Number of angle data bits within one revolution = *SINGLE_TURN_RES* + 1
	9:5		*MULTI_TURN_RES (Default: 0x00)*
		U	Number of data bits for revolution count = *MULTI_TURN_RES* + 1
	11:10		*STATUS_BIT_CNT (Default: 0x0)*
		U	Number of status data bits
	15:12	Reserved. Set to 0x0.	
	23:16		*SERIAL_ADDR_BITS (Default: 0x00)* **(SPI encoder only)**
		U	Number of address bits within one SPI datagram for SPI encoder configuration
	31:24		*SERIAL_DATA_BITS (Default: 0x00)* **(SPI encoder only)**
		U	Number of data bits within one SPI datagram for SPI encoder configuration

Table 68: Serial Encoder Data Input Configuration ENC_IN_DATA (0x08)

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.10. Serial Encoder Data Output Configuration (0x09)

ENC_OUT_DATA 0x09 *(Default: 0x00000000)*			
R/W	**Bit**	**Val**	**Remarks**
RW	4:0	*SINGLE_TURN_RES_OUT (Default: 0x00)*	
		U	Number of angle data bits within one revolution = *SINGLE_TURN_RES_OUT* + 1
	9:5	*MULTI_TURN_RES_OUT (Default: 0x00)*	
		U	Number of data bits for revolution count = *MULTI_TURN_RES_OUT* + 1
	31:12	Reserved. Set to 0x00000.	

Table 69: Serial Encoder Data Output Configuration ENC_OUT_DATA (0x09)

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.11. Motor Driver Settings Register STEP_CONF 0x0A

***STEP_CONF 0x0A** (Default: 0x00FB0C80)*			
R/W	**Bit**	**Val**	**Remarks**
RW	3:0	*MSTEP_PER_FS (Default: 0x0)*	
		0	Highest microsteps resolution: 256 microsteps per fullstep. i **Set to 256 for closed-loop operation.** i **When using a Step/Dir driver, it must be capable of a 256 resolution via Step/Dir input for best performance (but lower resolution Step/Dir drivers can be used as well).**
		1	128 microsteps per fullstep.
		2	64 microsteps per fullstep.
		3	32 microsteps per fullstep.
		4	16 microsteps per fullstep.
		5	8 microsteps per fullstep.
		6	4 microsteps per fullstep.
		7	Halfsteps: 2 microsteps per fullstep.
		8	Full steps (maximum possible setting)
	15:4	*FS_PER_REV (Default: 0x0C8)*	
		U	Fullsteps per motor axis revolution
	23:16	*MSTATUS_SELECTION (Default: 0xFB)*	
			Selection of motor driver status bits for SPI response datagrams: ORed with Motor Driver Status Register Set (7:0): if set here and a particular flag is set from the motor stepper driver, an event will be generated at *EVENTS*(30)
	31:24	Reserved. Set to 0x00.	

Table 70: Motor Driver Settings (0x0A)

17.12. Event Selection Registers 0x0B..0X0D

Event Selection Registers			
R/W	**Addr**	**Bit**	**Remarks**
RW	0x0B		*SPI_STATUS_SELECTION (Default: 0x82029805)*
		31:0	Events selection for SPI datagrams: Event bits of *EVENTS* register 0x0E that are selected (=1) in this register are forwarded to the eight status bits that are transferred with every SPI datagram (first eight bits from LSB are significant!).
	0x0C		*EVENT_CLEAR_CONF (Default: 0x00000000)*
		31:0	Event protection configuration: Event bits of *EVENTS* register 0x0E that are selected in this register (=1) are not cleared during the readout process of *EVENTS* register 0x0E.
	0x0D		*INTR_CONF (Default: 0x00000000)*
		31:0	Event selection for INTR output: All Event bits of *EVENTS* register 0x0E that are selected here (=1) are ORed with interrupt event register set: if any of the selected events is active, an interrupt at INTR is generated.

Table 71: Event Selection Regsiters 0x0B...0x0D

17.13. Status Event Register (0x0E)

Status Event Register *EVENTS 0x0E*		
R/W	**Bit**	**Description**
R+C	0	*TARGET_REACHED* has been triggered.
	1	*POS_COMP_REACHED* has been triggered.
	2	*VEL_REACHED* has been triggered.
	3	*VEL_STATE* = b'00 has been triggered (*VACTUAL* = 0).
	4	*VEL_STATE* = b'01 has been triggered (*VACTUAL* > 0).
	5	*VEL_STATE* = b'10 has been triggered (*VACTUAL* < 0).
	6	*RAMP_STATE* = b'00 has been triggered (*AACTUAL* = 0, *VACTUAL* is constant).
	7	*RAMP_STATE* = b'01 has been triggered (|*VACTUAL*| increases).
	8	*RAMP_STATE* = b'10 has been triggered (|*VACTUAL*| increases).
	9	*MAX_PHASE_TRAP*: Trapezoidal ramp has reached its limit speed using maximum values for *AMAX* or *DMAX* (|*VACTUAL*| > *VBREAK*; *VBREAK*≠0).
	10	*FROZEN:* NFREEZE has switched to low level. ℹ **Reset TMC4361 for further motion.**
	11	STOPL has been triggered. Motion in negative direction is not executed until this event is cleared and (STOPL is not active any more or *stop_left_en* is set to 0).
	12	STOPR has been triggered. Motion in positive direction is not executed until this event is cleared and (STOPR is not active any more or *stop_right_en* is set to 0).
	13	*VSTOPL_ACTIVE: VSTOPL* has been activated. No further motion in negative direction until this event is cleared and (a new value is chosen for *VSTOPL* or *virtual_left_limit_en* is set to 0).
	14	*VSTOPR_ACTIVE: VSTOPR* has been activated. No further motion in positive direction until this event is cleared and (a new value is chosen for *VSTOPR or virtual_right_limit_en* is set to 0).
	15	*HOME_ERROR:* Unmatched *HOME_REF* polarity and HOME is outside of safety margin.
	16	*XLATCH_DONE* indicates if *X_LATCH* was rewritten or homing process has been completed.
	17	*FS_ACTIVE*: Fullstep motion has been activated.
	18	*ENC_FAIL*: Mismatch between *XACTUAL* and *ENC_POS* has exceeded specified limit.
	19	*N_ACTIVE:* N event has been activated.
	20	*ENC_DONE* indicates if *ENC_LATCH* was rewritten.
	21	*SER_ENC_DATA_FAIL:* Failure during multi-cycle data evaluation or between two consecutive data requests has occured.
	22	Reserved.
	23	*SER_DATA_DONE:* Configuration data was received from serial SPI encoder.
	24	One of the *SERIAL_ENC_F*lags was set.
	25	*COVER_DONE:* SPI datagram was sent to the motor driver.
	26	*ENC_VEL0:* Encoder velocity has reached 0.
	27	*CL_MAX:* Closed-loop commutation angle has reached maximum value.
	28	*CL_FIT:* Closed-loop deviation has reached inner limit.
	29	*STOP_ON_STALL:* Motor stall detected. Motor ramp has stopped.
	30	*MOTOR_EV:* One of the selected TMC motor driver flags was triggered.
	31	Reset was triggered.

Table 72: Status Event Register EVENTS (0x0E)

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.14. Status Flag Register (0x0F)

Status Flag Register *STATUS 0x0F*		
R/W	**Bit**	**Description**
R	0	*TARGET_REACHED_F* is set high if *XACTUAL* = *XTARGET*
	1	*POS_COMP_REACHED_F* is set high if *XACTUAL* = *POS_COMP*
	2	*VEL_REACHED_F* is set high if *VACTUAL* = |*VMAX*|
	4:3	*VEL_STATE_F*: Current velocity state: 0 → *VACTUAL* = 0; 1 → *VACTUAL* > 0; 2 → *VACTUAL* < 0
	6:5	*RAMP_STATE_F*: Current ramp state: 0 → *AACTUAL* = 0; 1 → *AACTUAL* increases (acceleration); 2 → *AACTUAL* decreases (deceleration)
	7	*STOPL_ACTIVE_F*: Left stop switch is active.
	8	*STOPR_ACTIVE_F*: Right stop switch is active.
	9	*VSTOPL_ACTIVE_F*: Left virtual stop switch is active.
	10	*VSTOPR_ACTIVE_F*: Right virtual stop switch is active.
	11	*ACTIVE_STALL_F*: Motor stall is detected and *VACTUAL* > *VSTALL_LIMIT*.
	12	*HOME_ERROR_F*: HOME_REF input signal level is not equal to expected home level.
	13	*FS_ACTIVE_F*: Fullstep operation is active.
	14	*ENC_FAIL_F*: Mismatch between *XACTUAL* and *ENC_POS* is out of tolerated range.
	15	*N_ACTIVE_F*: N event is active.
	16	*ENC_LATCH_F*: *ENC_LATCH* is rewritten.
	17	Applies to absolute encoders only: *MULTI_CYCLE_FAIL_F* indicates a failure during last multi cycle data evaluation.
		Applies to absolute encoders only: *SER_ENC_VAR_F* indicates a failure during last serial data evaluation due to a substantial deviation between two consecutive serial data values.
	18	Reserved.
	19	*CL_FIT_F*: Active if ENC_POS_DEV < CL_TOLERANCE. The current mismatch between XACTUAL and ENC_POS is within tolerated range.
	23:20	Applies to absolute encoders only: *SERIAL_ENC_F*LAGS received from encoder. These flags are reset with a new encoder transfer request.
	24	**TMC26x / TMC2130 only:** *SG*: StallGuard2 status **Optional for TMC24x only:** Calculated stallGuard status.
		TMC23x / TMC24x only: *UV_SF*: Undervoltage flag.
	25	**All TMC motor drivers**: *OT*: Overtemperature shutdown.
	26	**All TMC motor drivers**: *OTPW*: Overtemperature warning.
	27	**TMC26x / TMC2130 only:** *S2GA*: Short to ground detection bit for high side MOSFET of coil A.
		TMC23x / TMC24x only: *OCA*: Overcurrent bridge A.
	28	**TMC26x / TMC2130 only:** *S2GB*: Short to ground detection bit for high side MOSFET of coil B.
		TMC23x / TMC24x only: *OCB*: Overcurrent bridge B.
	29	**All TMC motor drivers**: *OLA*: Open load indicator of coil A.
	30	**All TMC motor drivers**: *OLB*: Open load indicator of coil B.
	31	**TMC26x / TMC2130 only:** *STST*: Standstill indicator.
		TMC23x / TMC24x only: *OCHS*: Overcurrent high side.

Table 73: Status Flag Register STATUS (0x0F)

17.15. Configuration Registers: Closed-Loop, Switches, etc.

Various Configuration Registers: Closed-loop, Switches...				
R/W	**Addr**	**Bit**	**Val**	**Description**
RW	0x10	15:0		*STP_LENGTH_ADD (Default: 0x0000)*
			U	Additional length [# clock cycles] for active step polarity to indicate an active output step at STPOUT.
		31:16		*DIR_SETUP_TIME (Default: 0x0000)*
			U	Delay [# clock cycles] between DIROUT and STPOUT voltage level changes.
	0x11	31:0		*START_OUT_ADD (Default:0x00000000)*
			U	Additional length [# clock cycles] for active start signal. Active start signal length = 1+START_OUT_ADD
	0x12	31:0		*GEAR_RATIO (Default:0x01000000)*
			S	Constant value that is added to the internal position counter by an active step at STPIN. Value representation: 8 digits and 24 decimal places.
	0x13	31:0		*START_DELAY (Default:0x00000000)*
			U	Delay time [# clock cycles] between start trigger and internal start signal release.
	0x14	31:0		Reserved. Set to 0x00000000.
	0x15	31:0		*STDBY_DELAY (Default:0x00000000)*
			U	Delay time [# clock cycles] between ramp stop and activating standby phase.
	0x16	31:0		*FREEWHEEL_DELAY (Default:0x00000000)*
			U	Delay time [# clock cycles] between initialization of active standby phase and freewheeling initialization.
	0x17	23:0		*VDRV_SCALE_LIMIT (Default:0x00000000)* ***(Voltage PWM mode is not active)***
			U	Drive scaling separator: *DRV2_SCALE_VAL* is active in case *VACTUAL* > *VDRV_SCALE_LIMIT* *DRV1_SCALE_VAL* is active in case *VACTUAL* ≤ *VDRV_SCALE_LIMIT*
				PWM_VMAX (Default:0x00000000) ***(Voltage PWM is enabled)***
			U	PWM velocity value at which maximal scale parameter value 1.0 is reached.
	0x18	23:0		*UP_SCALE_DELAY (Default:0x000000)* ***(Open-loop operation)***
			U	Increment delay [# clock cycles]. The value defines the clock cycles, which are used to increase the current scale value for one step towards higher values.
				CL_UPSCALE_DELAY (Default:0x000000) ***(Closed-loop operation)***
			U	Increment delay [# clock cycles]. The value defines the clock cycles, which are used to increase the current scale value for one step towards higher current values during closed-loop operation.
	0x19	23:0		*HOLD_SCALE_DELAY (Default:0x000000)* ***(Open-loop operation)***
			U	Decrement delay [# clock cycles] to decrease the actual scale value by one step towards hold current.
				CL_DNSCALE_DELAY(Default: 0x000000) ***(Closed-loop operation)***
			U	Decrement delay [# clock cycles] to decrease the current scale value by one step towards lower current values during closed-loop operation.

Read entire documentation; especially the "Supplemental Directives" on page 218.

Various Configuration Registers: Closed-loop, Switches…				
R/W	**Addr**	**Bit**	**Val**	**Description**
RW	0x1A	23:0		*DRV_SCALE_DELAY (Default:0x000000)*
			U	Decrement delay [# clock cycles], which signifies current scale value decrease by one step towards lower value.
	0x1B	31:0		*BOOST_TIME (Default:0x00000000)*
			U	Time [# clk cycles] after a ramp start when boost scaling is active.
	0x1C	8:0		*CL_BETA (0x0FF)*
			U	Maximum commutation angle for closed-loop regulation. ➤ **Set CL_BETA > 255 carefully (esp. if *cl_vlimit_en* = 1).** i **Exactly 255 is recommended for best performance.**
		23:16		*CL_GAMMA (Default:0xFF)*
			U	Maximum balancing angle to compensate back-EMF at higher velocities during closed-loop regulation.
	0x1D	15:0		*DAC_ADDR_A (Default:0x0000)*
			U	Fixed command/address, which is sent via SPI output before sending CURRENTA_SPI values.
		31:16		*DAC_ADDR_B (Default: 0x0000)*
			U	Fixed command/address, which is sent via SPI output before sending current CURRENTB_SPI values.
	0x1E	15:0		*HOME_SAFETY_MARGIN (Default: 0x0000)*
			U	HOME_REF polarity can be invalid within *X_HOME* ± *HOME_SAFETY_MARGIN*, which is not flagged as error.
	0x1F	15:0		*PWM_FREQ (Default: 0x0280)* ***(Voltage PWM is enabled)***
			U	Number of clock cycles for one PWM period.
		11:0		*CHOPSYNC_DIV (Default: 0x0280)* ***(ChopSync for TMC23x/24x is enabled)***
			U	Chopper clock divider that defines the chopper frequency f_{OSC}: $f_{OSC} = f_{CLK}/CHOPSYNC\_DIV$ with $96 \leq CHOPSYNC\_DIV \leq 818$

Table 74: Various Configuration Registers: Closed-loop, Switches, etc.

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.16. Ramp Generator Registers

Ramp Generator Registers

R/W	Addr	Bit	Val	Description
RW	0x20			*RAMPMODE* (Default:0x0)
		2		Operation Mode:
			1	**Positioning mode**: *XTARGET* is superior target of velocity ramp.
			0	**Velocitiy mode**: *VMAX* is superior target of velocity ramp.
		1:0		Motion Profile:
			0	**No ramp:** *VACTUAL* follows only *VMAX* (rectangle velocity shape).
			1	**Trapezoidal ramp (incl. sixPoint ramp):** Consideration of acceleration and deceleration values for generating *VACTUAL* without adapting the acceleration values.
			2	**S-shaped ramp:** Consideration of all ramp values (incl. bow values) for generating *VACTUAL*.
RW	0x21	31:0		*XACTUAL (Default: 0x00000000)*
			S	Actual internal motor position [pulses]: $-2^{31} \leq XACTUAL \leq 2^{31} - 1$
R	0x22	31:0		*VACTUAL (Default: 0x00000000)*
			S	Actual ramp generator velocity [pulses per second]: 1 pps ≤ |*VACTUAL*| ≤ *CLK_FREQ* · ½ pulses (f_{CLK} = 16 MHz → 8 Mpps)
R	0x23	31:0		*AACTUAL (Default: 0x00000000)*
			S	Actual acceleration/deceleration value [pulses per sec²]: -2^{31} pps² ≤ *AACTUAL* ≤ $2^{31} - 1$ 1 pps² ≤ |*AACTUAL*|
RW	0x24	31:0		*VMAX (Default: 0x00000000)*
			S	Maximum ramp generator velocity in positioning mode or
				Target ramp generator velocity in velocity mode and no ramp motion profile.
				Value representation: 23 digits and 8 decimal places 4 mpps ≤ |*VMAX* [pps]| ≤ *CLK_FREQ* • ½ pulses f_{CLK} = 16 MHz → |*VMAX*| ≤ 8 Mpps
RW	0x25	30:0		*VSTART (Default: 0x00000000)*
			U	Absolute start velocity in *positioning mode* and *velocity mode* In case *VSTART* is used: no first bow phase B_1 for S-shaped ramps
				VSTART in positioning mode: In case *VACTUAL* = 0 and *XTARGET* ≠ *XACTUAL*: no acceleration phase for *VACTUAL* = 0 → *VSTART*.
				VSTART in velocity mode: In case *VACTUAL* = 0 and *VACTUAL* ≠ *VMAX*: no acceleration phase for *VACTUAL* = 0 → *VSTART*.
				Value representation: 23 digits and 8 decimal places.

•→ *Continued on next page.*

Ramp Generator Registers

R/W	**Addr**	**Bit**	**Val**	**Description**
RW	0x26	30:0		*VSTOP (Default:0x00000000)*
			U	Absolute stop velocity in positioning mode and velocity mode. In case *VSTOP* is used: no last bow phase B_4 for S-shaped ramps. In case *VSTOP* is very small and positioning mode is used, it is possible that the ramp is finished with a constant *VACTUAL* = *VSTOP* until *XTARGET* is reached.
				VSTOP in positioning mode: In case *VACTUAL*≤*VSTOP* and *XTARGET*=*XACTUAL*: *VACTUAL* is immediately set to 0.
				VSTOP in velocity mode: In case *VACTUAL* ≤ *VSTOP* and *VMAX* = 0: *VACTUAL* is immediately set to 0.
				Value representation: 23 digits and 8 decimal places.
	0x27	30:0		*VBREAK (Default:0x00000000)*
			U	Absolute break velocity in positioning mode and in velocity mode, This only applies for trapezoidal ramp motion profiles. In case *VBREAK* = 0: pure linear ramps are generated with *AMAX* / *DMAX* only.
				In case |*VACTUAL*| < *VBREAK*: |*AACTUAL*| = *ASTART* or *DFINAL* In case |*VACTUAL*| ≥ *VBREAK*: |*AACTUAL*| = *AMAX* or *DMAX*
				! **Always set *VBREAK* > *VSTOP*! If VBREAK ≠ 0.**
				Value representation: 23 digits and 8 decimal places.
	0x28	23:0		*AMAX (Default: 0x000000)*
			U	S-shaped ramp motion profile: Maximum acceleration value.
				Trapezoidal ramp motion profile: Acceleration value in case |*VACTUAL*| ≥ *VBREAK* or in case *VBREAK* = 0.
				Value representation: **Frequency mode**: [pulses per sec²] 22 digits and 2 decimal places: 250 mpps² ≤ *AMAX* ≤ 4 Mpps² **Direct mode:** [Δv per clk cycle] a[Δv per clk_cycle]= $AMAX / 2^{37}$ *AMAX* [pps²] = $AMAX / 2^{37} \cdot f_{CLK}^2$! **Set *AMAX* ≤ 65536.**
	0x29	23:0		*DMAX (Default: 0x000000)*
			U	S-shaped ramp motion profile: Maximum deceleration value.
				Trapezoidal ramp motion profile: Deceleration value if |*VACTUAL*| ≥ *VBREAK* or if *VBREAK* = 0.
				Value representation: **Frequency mode**: [pulses per sec²] 22 digits and 2 decimal places: 250 mpps² ≤ *DMAX* ≤ 4 Mpps² **Direct mode:** [Δv per clk cycle] d[Δv per clk_cycle]= $DMAX / 2^{37}$ *DMAX* [pps²] = $DMAX / 2^{37} \cdot f_{CLK}^2$! **Set *DMAX* ≤ 65536.**

Read entire documentation; especially the "Supplemental Directives" on page 218.

Ramp Generator Registers

R/W	Addr	Bit	Val	Description
RW	0x2A	23:0		*ASTART (Default: 0x000000)*
			U	S-shaped ramp motion profile: start acceleration value.
				Trapezoidal ramp motion profile: Acceleration value in case |*VACTUAL*| < *VBREAK*.
				Acceleration value after switching from external to internal step control.
				Value representation: **Frequency mode**: [pulses per sec^2] 22 digits and 2 decimal places: 250 mpps^2 ≤ *ASTART* ≤ 4 Mpps^2 **Direct mode:** [Δv per clk cycle] a[Δv per clk_cycle]= *ASTART* / 2^{37} *ASTART* [pps^2] = *ASTART* / 2^{37} • f_{CLK}^2 **! Set *ASTART* ≤ 65536.**
		31		Sign of *AACTUAL* after switching from external to internal step control.
	0x2B	23:0		*DFINAL (Default: 0x000000)*
			U	S-shaped ramp motion profile: Stop deceleration value, which is not used during positioning mode.
				Trapezoidal ramp motion profile: Deceleration value in case |*VACTUAL*| < *VBREAK*.
				Value representation: **Frequency mode**: [pulses per sec^2] 22 digits and 2 decimal places: 250 mpps^2 ≤ *DFINAL* ≤ 4 Mpps^2 **Direct mode:** [Δv per clk cycle] d[Δv per clk_cycle]= *DFINAL* / 2^{37} *DFINAL* [pps^2] = *DFINAL* / 2^{37} • f_{CLK}^2 **! Set *DFINAL* ≤ 65536.**
	0x2C	23		*DSTOP (Default: 0x000000)*
			U	Deceleration value for an automatic linear stop ramp to *VACTUAL* = 0. *DSTOP* is used with activated external stop switches (STOPL or STOPR) if *soft_stop_enable* is set to 1; or with activated virtual stop switches and *virt_stop_mode* is set to 2.
				Value representation: **Frequency mode**: [pulses per sec^2] 22 digits and 2 decimal places: 250 mpps^2 ≤ *DSTOP* ≤ 4 Mpps^2 **Direct mode:** [Δv per clk cycle] d[Δv per clk_cycle]= *DSTOP* / 2^{37} *DSTOP* [pps^2] = *DSTOP* / 2^{37} • f_{CLK}^2 **! Set *DSTOP* ≤ 65536.**

•→ *Continued on next page.*

<table>
<tr><th colspan="5">Ramp Generator Registers</th></tr>
<tr><th>R/W</th><th>Addr</th><th>Bit</th><th>Val</th><th>Description</th></tr>
<tr><td rowspan="12">RW</td><td rowspan="3">0x2D</td><td rowspan="3">23:0</td><td colspan="2">BOW1 (Default: 0x000000)</td></tr>
<tr><td rowspan="2">U</td><td>Bow value 1 (first bow B_1 of the acceleration ramp).</td></tr>
<tr><td>Value representation:
Frequency mode: [pulses per sec^3]
24 digits and 0 decimal places: 1 $pps^3 \leq$ BOW1 $\leq$ 16 $Mpps^3$
Direct mode: [Δa per clk cycle]
bow[av per clk_cycle]= $BOW1 / 2^{53}$
BOW1 [pps^3] = $BOW1 / 2^{53} \cdot f_{CLK}^3$
! Set BOW1 ≤ 4096.</td></tr>
<tr><td rowspan="3">0x2E</td><td rowspan="3">23:0</td><td colspan="2">BOW2 (Default: 0x000000)</td></tr>
<tr><td rowspan="2">U</td><td>Bow value 2 (second bow B2 of the acceleration ramp).</td></tr>
<tr><td>Value representation:
Frequency mode: [pulses per sec^3]
24 digits and 0 decimal places: 1 $pps^3 \leq$ BOW2 $\leq$ 16 $Mpps^3$
Direct mode: [Δa per clk cycle]
bow[av per clk_cycle]= $BOW2 / 2^{53}$
BOW2 [pps^3] = $BOW2 / 2^{53} \cdot f_{CLK}^3$
! Set BOW2 ≤ 4096.</td></tr>
<tr><td rowspan="3">0x2F</td><td rowspan="3">23:0</td><td colspan="2">BOW3 (Default: 0x000000)</td></tr>
<tr><td rowspan="2">U</td><td>Bow value 3 (first bow B3 of the deceleration ramp).</td></tr>
<tr><td>Value representation:
Frequency mode: [pulses per sec^3]
24 digits and 0 decimal places: 1 $pps^3 \leq$ BOW3 $\leq$ 16 $Mpps^3$
Direct mode: [Δa per clk cycle]
bow[av per clk_cycle]= $BOW3 / 2^{53}$
BOW3 [pps^3] = $BOW3 / 2^{53} \cdot f_{CLK}^3$
! Set BOW3 ≤ 4096.</td></tr>
<tr><td rowspan="3">0x30</td><td rowspan="3">23:0</td><td colspan="2">BOW 4 (Default: 0x000000)</td></tr>
<tr><td rowspan="2">U</td><td>Bow value 4 (second bow B4 of the deceleration ramp).</td></tr>
<tr><td>Value representation:
Frequency mode: [pulses per sec^3]
24 digits and 0 decimal places: 1 $pps^3 \leq$ BOW4 $\leq$ 16 $Mpps^3$
Direct mode: [Δa per clk cycle]
bow[av per clk_cycle]= $BOW4 / 2^{53}$
BOW4 [pps^3] = $BOW4 / 2^{53} \cdot f_{CLK}^3$
! Set BOW4 ≤ 4096.</td></tr>
</table>

Table 75: Ramp Generator Registers

17.17. External Clock Frequency Register

External Clock Frequency Register				
R/W	**Addr**	**Bit**	**Val**	**Description**
RW	0x31	24:0	*CLK_FREQ (Default: 0x0F42400)*	
			U	External clock frequency value f_{CLK} [Hz] with 4.2 MHz ≤ f_{CLK} ≤ 30 MHz.

Table 76: External Clock Frequency Register

17.18. Target and Compare Registers

Target and Compare Registers				
R/W	**Addr**	**Bit**	**Val**	**Description**
RW	0x32	31:0	*POS_COMP (Default: 0x00000000)*	
			S	Compare position.
RW	0x33	31:0	*VIRT_STOP_LEFT (Default: 0x00000000)*	
			S	Virtual left stop position.
RW	0x34	31:0	*VIRT_STOP_RIGHT (Default: 0x00000000)*	
			S	Virtual right stop position.
RW	0x35	31:0	*X_HOME (Default: 0x00000000)*	
			S	Actual home position.
R	0x36	31:0	*X_LATCH (Default: 0x00000000)* ***(if circular_cnt_as_xlatch = 0)***	
			S	Storage position for certain triggers.
			REV_CNT (Default: 0x00000000) ***(if circular_cnt_as_xlatch = 1)***	
			S	Number of revolutions during circular motion.
W		30:0	*X_RANGE (Default: 0x00000000)*	
			U	Limitation for *X_ACTUAL* during circular motion: −*X_RANGE* ≤ *X_ACTUAL* ≤ *X_RANGE* − 1
RW	0x37	31:0	*X_TARGET (Default: 0x00000000)*	
			U	Target motor position in positioning mode. **! Set all other motion profile parameters before!**

Table 77: Target and Compare Registers

17.19. Pipeline Registers

Pipeline Register				
R/W	**Addr**	**Bit**	**Val**	**Description**
RW	0x38	31:0	S	*X_PIPE0 (Default: 0x00000000): 1st pipeline register.*
	0x39	31:0	S	*X_PIPE1 (Default: 0x00000000): 2nd pipeline register.*
	0x3A	31:0	S	*X_PIPE2 (Default: 0x00000000): 3rd pipeline register.*
	0x3B	31:0	S	*X_PIPE3 (Default: 0x00000000): 4th pipeline register.*
	0x3C	31:0	S	*X_PIPE4 (Default: 0x00000000): 5th pipeline register.*
	0x3D	31:0	S	*X_PIPE5 (Default: 0x00000000): 6th pipeline register.*
	0x3E	31:0	S	*X_PIPE6 (Default: 0x00000000): 7th pipeline register.*
	0x3F	31:0	S	*X_PIPE7 (Default: 0x00000000): 8th pipeline register.*

Table 78: External Clock Frequency Register

17.20. Shadow Register

Shadow Register				
R/W	**Addr**	**Bit**	**Val**	**Description**
RW	0x40	31:0	S	*SH_REG0 (Default: 0x00000000) : 1st shadow register.*
	0x41	31:0	U	*SH_REG1 (Default: 0x00000000) : 2nd shadow register.*
	0x42	31:0	U	*SH_REG2 (Default: 0x00000000) : 3rd shadow register.*
	0x43	31:0	U	*SH_REG3 (Default: 0x00000000) : 4th shadow register.*
	0x44	31:0	U	*SH_REG4 (Default: 0x00000000) : 5th shadow register.*
	0x45	31:0	U	*SH_REG5 (Default: 0x00000000) : 6th shadow register.*
	0x46	31:0	U	*SH_REG6 (Default: 0x00000000) : 7th shadow register.*
	0x47	31:0	S/U	*SH_REG7 (Default: 0x00000000) : 8th shadow register.*
	0x48	31:0	U	*SH_REG8 (Default: 0x00000000) : 9th shadow register.*
	0x49	31:0	U	*SH_REG9 (Default: 0x00000000) : 10th shadow register.*
	0x4A	31:0	U	*SH_REG10 (Default: 0x00000000) : 11th shadow register.*
	0x4B	31:0	U	*SH_REG11 (Default: 0x00000000) : 12th shadow register.*
	0x4C	31:0	U	*SH_REG12 (Default: 0x00000000) : 13th shadow register.*
	0x4D	31:0	U	*SH_REG13 (Default: 0x00000000) : 14th shadow register.*

Table 79: External Clock Frequency Register

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.21. Freeze Register

The freeze register can only be written once after an active reset and before motion starts. It is always readable.

FREEZE Register				
R/W	**Addr**	**Bit**	**Val**	**Description**
RW	0x4E	23:0		*DFREEZE (Default: 0x000000)*
			U	Freeze event deceleration value. In case NFREEZE switches to low level, this parameter is used for an automatic linear ramp stop. Setting *DFREEZE* to 0 leads to an hard stop.
				Value representation: **Frequency mode**: not available **Direct mode:** [Δv per clk cycle] a[Δv per clk_cycle]= $DFREEZE / 2^{37}$ *DFREEZE* [pps^2] = $DFREEZE / 2^{37} \cdot f_{CLK}^2$! **Set *DFREEZE* ≤ 65536.**
		31:24		*IFREEZE (Default: 0x00)*
			U	Scaling value in case NFREEZE is tied low. In case *IFREEZE*=0, actual active scaling value is valid at FROZEN event.

Table 80: Freeze Register

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.22. Encoder Registers

Encoder Registers				
R/W	**Addr**	**Bit**	**Val**	**Description**
RW	0x50	31:0		*ENC_POS (Default: 0x00000000)*
			S	Actual encoder position [µsteps].
R	0x51	31:0		*ENC_LATCH (Default: 0x00000000)*
			S	Latched encoder position.
W				*ENC_RESET_VAL(Default: 0x00000000)*
			S	Defined reset value for *ENC_POS* in case the encoder position must be cleared to another value than 0.
R	0x52	31:0		*ENC_POS_DEV (Default: 0x00000000)*
			S	Deviation between *XACTUAL* and *ENC_POS*.
W				*CL_TR_TOLERANCE (Default: 0x00000000)* ***(Closed-loop operation)***
			S	Tolerated absolute tolerance between *XACTUAL* and *ENC_POS* to trigger TARGET_REACHED (incl. *TARGET_REACHED_F*lag and event).
W	0x53	31:0		*ENC_POS_DEV_TOL (Default: 0xFFFFFFFF)*
			U	Maximum tolerated value of *ENC_POS_DEV*, which is not flagged as error.
W	0x54	30:0		*ENC_IN_RES (Default: 0x00000000)*
			U	Resolution [encoder steps per revolution] of the encoder connected to the encoder inputs.
R				*ENC_CONST (Default: 0x00000000)*
			U	Encoder constant. i **Value representation: 15 digits and 16 decimal places**
W		31		*manual_enc_const (Default: 0)*
				0 ENC_CONST will be calculated automatically. **1 Manual definition of ENC_CONST = ENC_IN_RES**
W	0x55	31:0		*ENC_OUT_RES (Default: 0x00000000)*
			U	Resolution [encoder steps per revolution] of the serial encoder output interface.

•→ *Continued on next page.*

Encoder Registers				
R/W	**Addr**	**Bit**	**Val**	**Description**
W	0x56	15:0		*SER_CLK_IN_HIGH (Default: 0x00A0)*
			U	High voltage level time of serial clock output [# clock cycles].
		31:16		*SER_CLK_IN_LOW (Default: 0x00A0)*
			U	Low voltage level time of serial clock output [# clock cycles].
	0x57	15:0		*SSI_IN_CLK_DELAY (Default: 0x0000)*
			U	**SSI encoder:** Delay time [# clock cycles] between next data transfer after a rising edge of serial clock output. i **In case *SSI_IN_CLK_DELAY* = 0: *SSI_IN_CLK_DELAY* = *SER_CLK_IN_HIGH***
				SPI encoder: Delay [# clock cycles] at start and end of data transfer between serial clock output and negated chip select. i **In case *SSI_IN_CLK_DELAY* = 0: *SSI_IN_CLK_DELAY* = *SER_CLK_IN_HIGH***
		31:16		*SSI_IN_WTIME (Default: 0x0F0)*
			U	Delay parameter tw [# clock cycles] between two clock sequences for a multiple data transfer (of the same data). i **SSI recommendation: tw < 19 µs.**
	0x58	19:0		*SER_PTIME (Default: 0x00190)*
			U	**SSI and SPI encoder:** Delay time period tp [# clock cycles] between two consecutive clock sequences for new data request. i **SSI recommendation: tp > 21 µs.**

Table 81: Encoder Registers

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.23. PID & Closed-Loop Registers

PID and Closed-Loop Registers				
R/W	**Addr**	**Bit**	**Val**	**Description**
RW	0x59	31:0		*CL_OFFSET (Default: 0x00000000)* ***(Closed-loop operation)***
			S	Offset between *ENC_POS* and *XACTUAL* after closed-loop calibration. It is set during closed-loop calibration process. It can be written manually.
W	0x5A	23:0		*PID_P (Default: 0x000000)* ***(PID regulation)***
			U	Parameter P of PID regulator. Proportional term = PID_E · *PID_P* / 256
W				*CL_VMAX_CALC_P (Default: 0x000000)* ***(Closed-loop operation)***
			U	Parameter P of PI regulator controls maximum catch-up velocity limitation.
R		31:0		*PID_VEL (Default: 0x00000000)* ***(PID regulation)***
			S	Actual PID output velocity.
W	0x5B	23:0		*PID_I (Default: 0x000000)* ***(PID regulation)***
			U	Parameter I of PID regulator. Integral term = PID_ISUM / 256 · PID_I / 256
W				*CL_VMAX_CALC_I (Default: 0x000000)* ***(Closed-loop operation)***
			U	Parameter I of PI regulator controls maximum catch-up velocity limitation.
R		31:0		*PID_ISUM_RD (Default: 0x00000000)* ***(PID regulation)***
			S	Actual PID integrator sum. Update frequency = f_{CLK}/128
W	0x5C	23:0		*PID_D (Default: 0x000000)* ***(PID regulation)***
			U	Parameter D of PID regulator. PID_E is sampled with f_{CLK} / 128 / *PID_D_CLKDIV*. Derivative term = (PID_E_{LAST} – PID_E_{ACTUAL}) · *PID_D*
W				*CL_DELTA_P (Default: 0x000000)* ***(Closed-loop operation)***
			U	Gain parameter that is multiplied with the actual position difference in order to calculate the actual commutation angle for position maintenance stiffness. Clipped at *CL_BETA*. Real value =*CL_DELTA_P* / 2^{16} ;Ex: 65536 → 1.0 (gain=1) Value representation: 8 digits and 16 decimal places.
W	0x5D	14:0		*PID_I_CLIP (Default: 0x0000)* ***(PID regulation) (Closed-loop operation)***
			U	Clipping parameter for *PID_ISUM*. Real value = *PID_ISUM* • 2^{16} • *PID_ICLIP*
W		23:16		*PID_D_CLKDIV (Default:0x00)* ***(PID regulation)***
			U	Clock divider for D part calculation.
R		31:0		*PID_E (Default:0x00000000)* ***(PID regulation)***
			S	Actual position deviation.
W	0x5E	30:0		*PID_DV_CLIP* (Default:0x00000000) ***(PID regulation) (Closed-loop operation)***
			U	Clipping parameter for *PID_VEL*.
W	0x5F	19:0		*PID_TOLERANCE (Default:0x00000)* ***(PID regulation)***
			U	Tolerated position deviation: *PID_E* = 0 in case |*PID_E*| < *PID_TOLERANCE*
W		7:0		*CL_TOLERANCE (Default:0x00)* ***(Closed-loop operation)***
			U	Tolerated position deviation: *CL_DELTA_P* = 65536 (gain=1) in case |*ENC_POS_DEV*| < *CL_TOLERANCE*

Table 82: PID and Closed-Loop Registers

17.24. Miscellaneous Registers

Micellaneous Registers				
R/W	**Addr**	**Bit**	**Val**	**Description**
W	0x60	23:0		*FS_VEL(Default:0x000000)* ***(Open-loop operation)***
			U	Minimum fullstep velocity [pps]. In case |*VACTUAL*| > *FS_VEL* fullstep operation is active, if enabled.
				DC_VEL (Default:0x000000) ***(dcStep only)***
			U	Minimum dcStep velocity [pps]. In case|*VACTUAL*| > *DC_VEL* dcStep is active, if enabled.
				CL_VMIN_EMF (Default:0x000000) ***(Closed-loop operation)***
			U	Encoder velocity at which back-EMF compensation starts.
	0x61	7:0		*DC_TIME (Default:0x00)* ***(TMC26x only and dcStep only)***
			U	Upper PWM on-time limit for commutation. i **Set slightly above effective blank time TBL of the driver.**
		15:8		*DC_SG (Default:0x0000)* ***(TMC26x and dcStep only)***
			U	Maximum PWM on-time [# clock cycles · 16] for step loss detection. If a loss is detected (step length of first regular step after blank time of the dcStep input signal is below *DC_SG*), a stall event will be released.
		31:16		*DC_BLKTIME (Default:0x0000)* ***(TMC26x and dcStep only)***
			U	Blank time [# clock cycles] after fullstep release when no signal comparison should happen.
		23:0		*CL_VADD_EMF (Default:0x000000)* ***(Closed-loop operation)***
			U	Additional velocity value to calculate the encoder velocity at which back-EMF compensation reaches the maximum angle *CL_GAMMA*.
	0x62	31:0		*DC_LSPTM (Default:0x00FFFFFF)* ***(dcStep only)***
			U	dcStep low speed timer [# clock cycles]
		23:0		*ENC_VEL_ZERO (Default:0xFFFFFF)* ***(dcStep is not enabled)***
			U	Delay time [# clock cycles] after the last incremental encoder change to set *V_ENC_MEAN* = 0.

•→ *Continued on next page.*

Micellaneous Registers				
R/W	**Addr**	**Bit**	**Val**	**Description**
W	0x63	7:0		*ENC_VMEAN_WAIT (Default:0x00)* ***(incremental encoders only)***
			U	Delay period [# clock cycles] between two consecutive actual encoder velocity values that account for calculaton of mean encoder velocity. ! **Set *ENC_VMEAN_WAIT* > 32.** i **Is set automatically to *SER_PTIME* for absolute SSI/SPI encoder.**
		7:0		*SER_ENC_VARIATION (Default:0x00)* ***(absolute encoders only)***
			U	Multiplier for maximum permitted serial encoder variation between consecutive absolute encoder requests. ! **Maximum permitted value = *ENC_VARIATION* / 256 • 1/8 • *ENC_IN_RES*.** ! **If *ENC_VARIATION* = 0: Maximum permitted value = 1/8 • *ENC_IN_RES*.**
		11:8		*ENC_VMEAN_FILTER (Default:0x0)*
			U	Filter exponent to calculate mean encoder velocity.
		31:16		*ENC_VMEAN_INT (Default:0x0000)* ***(incremental encoders only)***
			U	Encoder velocity update time [# clock cycles]. i **Minimum value is set automatically to 256.**
		31:16		*CL_CYCLE (Default:0x0000)* ***(absolute encoders only)***
			U	Closed-loop control cycle [# clock cycles]. i **Is set automatically to *fastest* possible cycle for ABN encoders.**
W	0x64	31:0		Reserved. Set to 0x00000000.
R	0x65	31:0		*V_ENC (Default:0x00000000)*
			U	Actual encoder velocity [pps].
	0x66	31:0		*V_ENC_MEAN (Default:0x00000000)*
			S	Filtered encoder velocity [pps].
W	0x67	23:0		*VSTALL_LIMIT (Default:0x00000000)*
			U	Stop on stall velocity limit [pps]: Only above this limit an active stall leads to a stop on stall, if enabled.
W	0x7C	31:0		*CIRCULAR_DEC (Default:0x000)*
			U	Decimal places for circular motion if one revolution is not exactly mapped to an even number of µSteps per revolution. Value representation: 1 digit and 31 decimal places.
W	0x7D	15:0		*ENC_COMP_XOFFSET (Default:0x0000)*
			U	Start offset for triangular compensation in horizontal direction. $0 \leq ENC\_COMP\_XOFFSET < 2^{16}$
		23:16		*ENC_COMP_YOFFSET (Default:0x00)*
			S	Start offset for triangular compensation in vertical direction. $-128 \leq ENC\_COMP\_YOFFSET \leq 127$
		31:24		*ENC_COMP_AMPL (Default:0x00)*
			U	Maximum amplitude for encoder compensation.

Table 83: Miscellaneous Registers

17.25. Transfer Registers

Transfer Registers				
R/W	**Addr**	**Bit**	**Val**	**Description**
W	0x68	31:0		*ADDR_TO_ENC (Default:0x00000000)* ***(SPI encoders only)***
			-	Address data permanently sent to get encoder angle data from the SPI encoder slave device.
				Address data sent from TMC4361 to SPI encoder for one-time data transfer.
W	0x69	31:0		*DATA_TO_ENC (Default:0x00000000)* ***(SPI encoders only)***
			-	Configuration data sent from TMC4361 to SPI encoder for one-time data transfer.
R	0x6A	31:0		*ADDR_FROM_ENC (Default:0x00000000)* ***(SPI encoders only)***
			-	Repeated request data is stored here.
				Address data received from SPI encoder as response of the one-time data transfer.
R	0x6B	31:0		*DATA_FROM_ENC (Default:0x00000000)* ***(SPI encoders only)***
			-	Data received from SPI encoder as response of the one-time data transfer.
W	0x6C	31:0		*COVER_LOW (Default:0x00000000)*
			-	Lower configuration bits of SPI orders that can be sent from TMC4361 to the motor drivers via SPI output.
				Automatic cover data transfer (*automatic_cover* = 1): Value in *COVER_LOW* are sent in case |*VACTUAL*| crosses *SPI_SWITCH_VEL* downwards. **! Set *COVER_DATA_LENGTH* ≤ 32.** **! In case *COVER_DATA_LENGTH* = 0, no TMC2130 must be selected.**
W	0x6D	31:0		*COVER_HIGH (Default:0x00000000)*
			-	Upper configuration bits of SPI orders that can be sent from TMC4361 to the motor drivers via SPI output.
				Automatic cover data transfer (*automatic_cover* = 1): Value in *COVER_LOW* are sent if |*VACTUAL*| crosses *SPI_SWITCH_VEL* upwards. **! Set *COVER_DATA_LENGTH* ≤ 32.** **! In case *COVER_DATA_LENGTH* = 0, no TMC2130 must be selected.**
R	0x6E	31:0		*COVER_DRV_LOW (Default:0x00000000)*
			-	Lower configuration bits of SPI response received from the motor driver connected to the SPI output.
R	0x6F	31:0		*COVER_DRV_HIGH (Default:0x00000000)*
			-	Upper configuration bits of SPI response received from the motor driver connected to the SPI output.

Table 84: Transfer Registers

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.26. SinLUT Registers

SinLUT Registers				
R/W	**Addr**	**Bit**	**Val**	**Description**
W	0x70	31:0	*MSLUT[0] (Default:0xAAAAB554)*	
	0x71		*MSLUT[1] (Default:0x4A9554AA)*	
	0x72		*MSLUT[2] (Default:0x24492929)*	
	0x73		*MSLUT[3] (Default:0x10104222)*	
	0x74		*MSLUT[4] (Default:0xFBFFFFFF)*	
	0x75		*MSLUT[5] (Default:0xB5BB777D)*	
	0x76		*MSLUT[6] (Default:0x49295556)*	
	0x 77		*MSLUT[7] (Default:0x00404222)*	
			-	**! Each bit defines the difference between consecutive values in the microstep look-up table MSLUT (in combination with *MSLUTSEL*).**
W	0x78	31:0	*MSLUTSEL (Default:0xFFFF8056)*	
			-	Definition of the four segments within each quarter MSLUT wave.
R	0x79	9:0	*MSCNT (Default:0x000)*	
			U	Actual µStep position of the sine value.
W			*MSOFFSET (Default:0x000)*	***(TMC23x/24x only)***
			U	Microstep offset for PWM mode.
R	0x7A	8:0	*CURRENTA (Default:0x000)*	
			S	Actual current value of coilA (sine values).
		24:16	*CURRENTB (Default:0x000)*	
			S	Actual current value of coilB (sine90_120 values).
R	0x7B	8:0	*CURRENTA_SPI (Default:0x000)*	
			S	Actual scaled current value of coilA (sine values) that are sent to the motor driver.
		24:16	*CURRENTB_SPI (Default:0x000)*	
			S	Actual scaled current value of coilB (sine90_120 values) that are sent to the motor driver.
R	0x7C	8:0	*SCALE_PARAM (Default:0x000)*	
			U	Actual used scale parameter.
W	0x7E	7:0	*START_SIN (Default:0x00)*	
			U	Start value for sine waveform.
		31:16	*START_SIN90_120 (Default:0xF7)*	
			U	Start value for cosine waveform.
		31:24	*DAC_OFFSET (Default:0x00)*	
			U	Offset for absolute sine and cosine values, which are forwarded via SPI output as DAC output values.

Table 85: SinLUT Registers

Read entire documentation; especially the "Supplemental Directives" on page 218.

17.27. TMC Version Register

Version Register				
R/W	**Addr**	**Bit**	**Val**	**Description**
R	0x7F	15:0	*Version No (Default:0x0001)*	
			U	TMC4361 version number.

Table 86: Vision Registers

18. 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.

Maximum Ratings: 3.3V supply				
Parameter (VCC = 3.3V nominal → TEST_MODE = 0V)	**Symbol**	**Min**	**Max**	**Unit**
Supply voltage	V_{CC}	3.0	3.6	V
Input voltage IO	V_{IN}	−0.3	3.6	V

Table 87: Maximum Ratings: 3.3V supply

Maximum Ratings: 5.0V supply				
Parameter (VCC = 5V nominal → TEST_MODE = 1.8V)	**Symbol**	**Min**	**Max**	**Unit**
Supply voltage	V_{CC}	4.8	5.2	V
Input voltage IO	V_{IN}	−0.3	5.2	V

Table 88: Maximum Ratings: 5.0V supply

Maximum Ratings: Temperature				
Parameter	**Symbol**	**Min**	**Max**	**Unit**
Temperature	T	−40	125	°C

Table 89: Maximum Ratings: Temperature

Read entire documentation; especially the "Supplemental Directives" on page 218.

19. Electrical 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.

DC Characteristics						
Parameter	**Symbol**	**Conditions**	**Min**	**Typ**	**Max**	**Unit**
Extended temperature range	T_{COM}		−40°C		125	°C
Nominal core voltage	V_{DD}			1.8		V
Nominal IO voltage	V_{DD}			3.3 / 5.0		V
Nominal input voltage	V_{IN}		0.0		3.3 / 5.0	V
Input voltage low level	V_{INL}	V_{DD} = 3.3V / 5V	−0.3		0.8 / 1.2	V
Input voltage high level	V_{INH}	V_{DD} = 3.3V / 5V	2.3 / 3.5		3.6 / 5.2	V
Input with pull-down		$V_{IN} = V_{DD}$	5	30	110	µA
Input with pull-up		V_{IN} = 0V	−110	−30	−5	µA
Input low current		V_{IN} = 0V	−10		10	µA
Input high current		$V_{IN} = V_{DD}$	−10		10	µA
Output voltage low level	V_{OUTL}	V_{DD} = 3.3V / 5V			0.4	V
Output voltage high level	V_{OUTH}	V_{DD} = 3.3V / 5V	2.64 / 4.0			V
Output driver strength	I_{OUT_DRV}	V_{DD} = 3.3V / 5V		4.0		mA

Table 90: DC Characteristics

19.1. Power Dissipation

Power Dissipation						
Parameter	**Symbol**	**Conditions**	**Min**	**Typ**	**Max**	**Unit**
Static power dissipation	PD_{STAT}	All inputs at VDD or GND V_{DD} = 3.3V / 5V			1.1 / 1.7	mW
Dynamic power dissipation	PD_{DYN}	All inputs at VDD or GND f_{CLK} variable V_{DD} = 3.3V / 5V			2.3 / 3.7	mW / MHz
Total power dissipation	PD	f_{CLK} = 16 MHz V_{DD} = 3.3V / 5V			37.9 / 60.3	mW

Table 91: Power Dissipation

Read entire documentation; especially the "Supplemental Directives" on page 218.

19.2. General IO Timing Parameters

General IO Timing Parameters						
Parameter	**Symbol**	**Conditions**	**Min**	**Typ**	**Max**	**Unit**
Operation frequency	f_{CLK}	$f_{CLK} = 1 / t_{CLK}$	4.2[1)]	16	30	MHz
Clock Period	t_{CLK}	Rising edge to rising edge	33.5	62.5		ns
Clock time low			16.5			ns
Clock time high			16.5			ns
CLK input signal rise time	t_{RISE_IN}	20 % to 80 %			20	ns
CLK input signal fall time	t_{FALL_IN}	80 % to 20 %			20	ns
Output signal rise time	t_{RISE_OUT}	20 % to 80 % load 32 pF		3.5		ns
Output signal fall time	t_{FALL_OUT}	80 % to 20 % load 32 pF		3.5		ns
Setup time for SPI input signals in synchronous design	t_{SU}	Relative to rising clk edge	5			ns
Hold time	t_{HD}	Relative to rising clk edge	5			ns

Table 92: General IO Timing Parameters

[1)] The lower limit for f_{CLK} refers to the limits of the internal unit conversion to physical units. The chip will also operate at lower frequencies.

Read entire documentation; especially the "Supplemental Directives" on page 218.

19.3. Layout Examples

19.3.1. Internal Ciruict Diagram for Layout Example

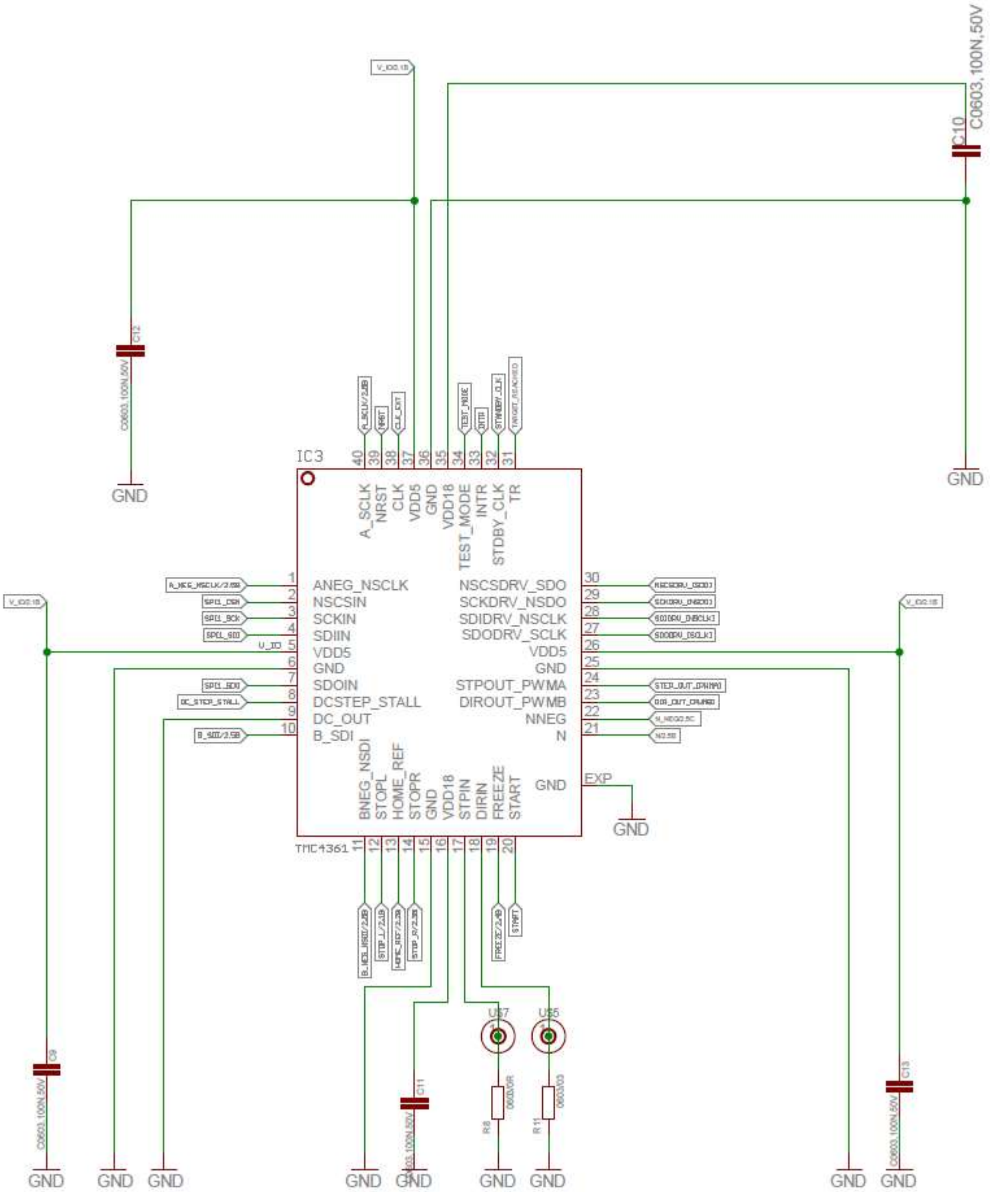


Figure 67: Internal Circuit Diagram for Layout Example

19.3.2. Components Assembly for Application with Encoder

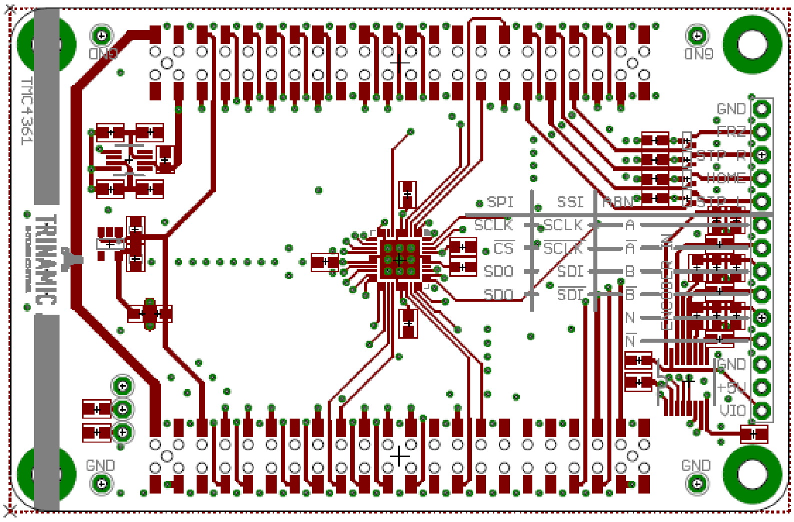


Figure 68: Components Assembly for Application with Encoder

19.3.3. Top Layer: Assembly Side

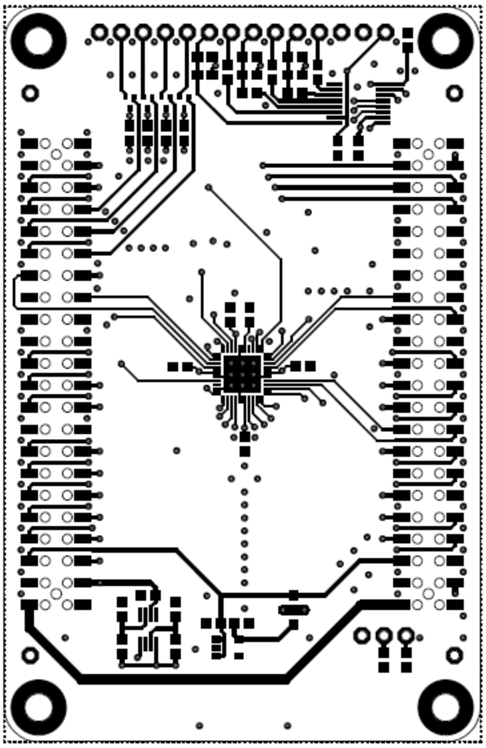


Figure 69: Top Layer: Assembly Side

Read entire documentation; especially the "Supplemental Directives" on page 218.

19.3.4. Inner Layer (GND)

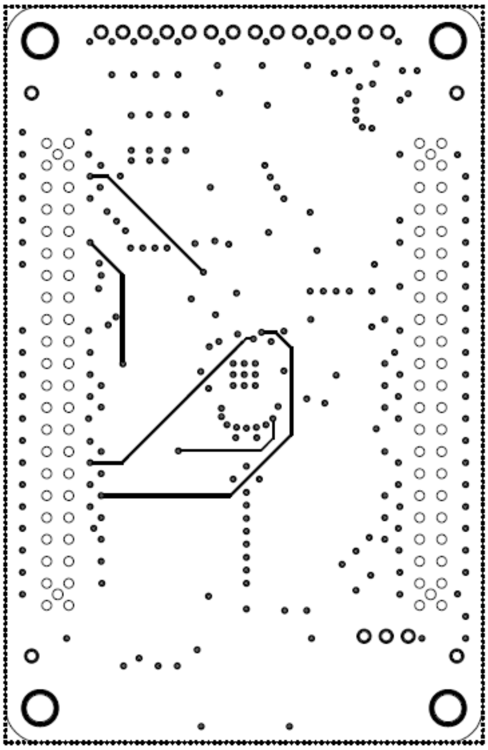


Figure 70: Inner Layer (GND)

19.3.5. Inner Layer (Supply VS)

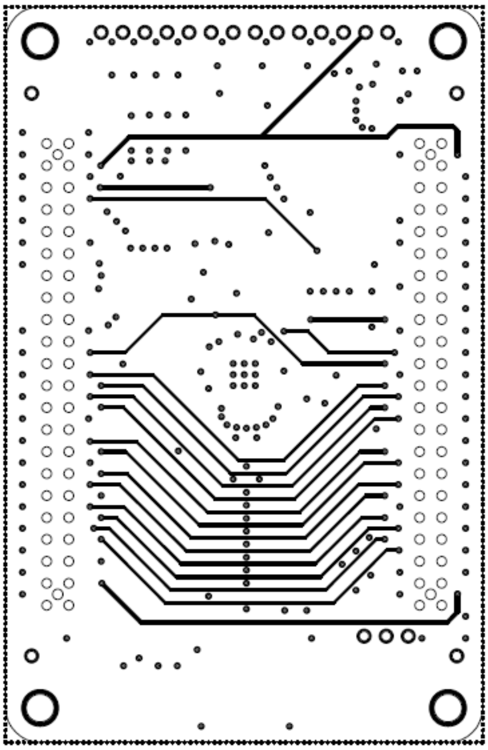
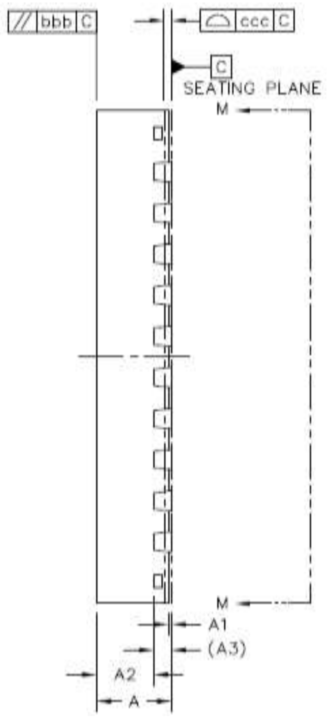


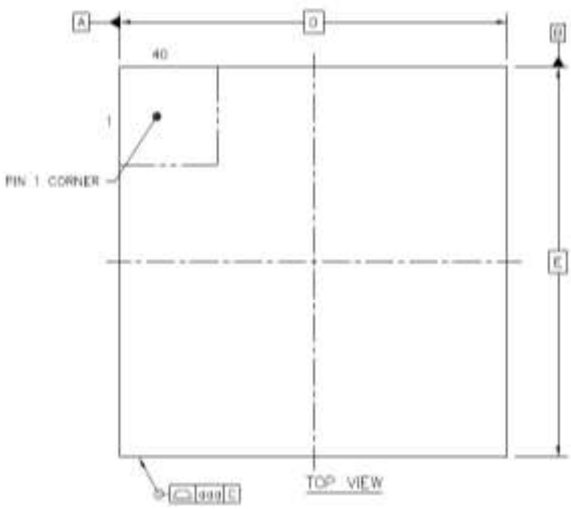
Figure 71: Inner Layer (Supply VS)

19.4. Package Dimensions



Package Dimensions				
Parameter	**Ref**	**Min**	**Nom**	**Max**
Total thickness	A	0.8	0.85	0.9
Stand off	A1	0	0.035	0.05
Mold thickness	A2	-	0.65	0.67
Lead frame thickness	A3	0.203 REF		
Lead width	b	0.2	0.25	0.3
Body size X	D	6 BSC		
Body size Y	E	6 BSC		
Lead pitch	e	0.5 BSC		
Exposed die pad size X	J	4.52	4.62	4.72
Exposed die pad size Y	K	4.52	4.62	4.72
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		

Table 93: Package Dimensions



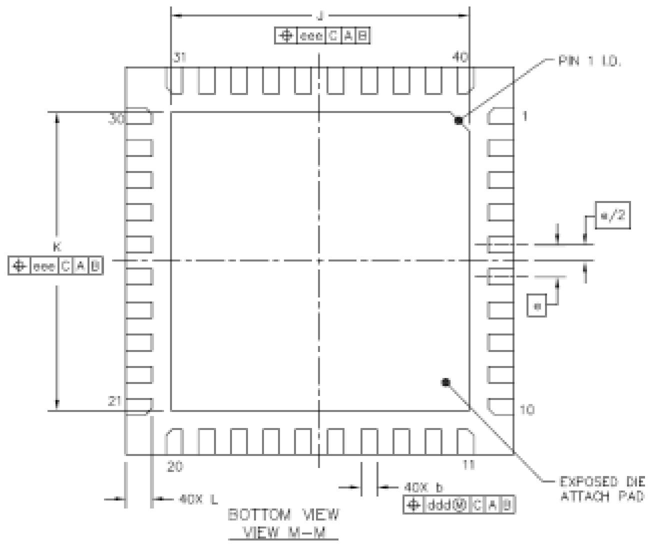


Figure 72: Package Dimensional Drawings

Read entire documentation; especially the "Supplemental Directives" on page 218.

19.5. Package Material Information

Please refer to the associated document "*TMC43xx Package Material Information, V1.00*" for information about available package dimensions and the various tray and reel package options.

This document informs you about outside dimensions per tray and/reel and the number of ICs per tray/reel. It also provides information about available packaging units and their weight, as well as box dimension and weight details for outer packaging.

The document is available for download on the TMC4361 product page at www.trinamic.com.

i Should you require a custom-made component packaging solution or a different outer packaging solution, or have questions pertaining to the component packaging choice, please contact our customer service.

NOTE:

→ *Our trays and reels are JEDEC-compliant.*

19.6. Marking Details provided on Single Chip

The marking on each single chip shows:

❶ Trinamic emblem.

❷ Product code.

❸ Date code.

❹ Location of the copyright holder,
which is TRINAMIC in Hamburg, Germany.

❺ Lot number.

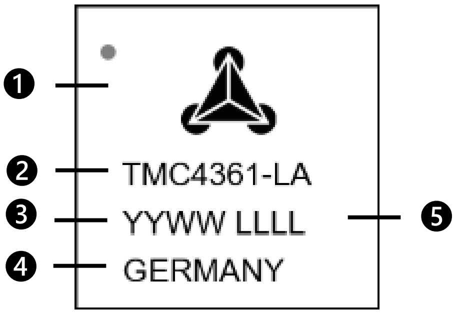


Figure 73: Marking Details on Chip[1]

[1] The image provided is not an accurate rendition of the original product but only serves as illustration.

APPENDICES

20. Supplemental Directives

ESD-DEVICE INSTRUCTIONS

This product is an ESD-sensitive CMOS device. It is sensitive to electrostatic discharge.

- Provide effective grounding to protect personnel and machines.
- Ensure work is performed in a nonstatic environment.
- Use personal ESD control footwear and ESD wrist straps, if necessary.

Failure to do so can result in defects, damages and decreased reliability.

Producer Information

The producer of the product TMC4361 is TRINAMIC GmbH & Co. KG in Hamburg, Germany; hereafter referred to as TRINAMIC. TRINAMIC is the supplier; and in this function provides the product and the production documentation to its customers.

Copyright

TRINAMIC owns the content of this user manual in its entirety, including but not limited to pictures, logos, trademarks, and resources.

Redistributions of source or derived format (for example, Portable Document Format or Hypertext Markup Language) must retain the above copyright notice, and the complete Datasheet User Manual documentation of this product including associated Application Notes; and a reference to other available product-related documentation.

Trademark Designations and Symbols

Trademark designations and symbols used in this documentation indicate that a product or feature is owned and registered as trademark and,'or patent either by TRINAMIC or by ather manufacturers, whose products are used or referred to in combination With TRINAMlC's products and TRINAMlC's product documentation. This documentation is a noncommercial publication that seeks to provide concise scientific and technical user information to the target user. Thus, we only enter trademark designations and symbols in the Short Spec of the documentation that introduces the product at a quick glance. We also enter the trademark designation symbol when the product or feature name occurs for the first time in the document. All trademarks used are property of their respective owners.

Target User

The documentation provided here, is for programmers and engineers only, who are equipped with the necessary skills and have been trained to work with this type of product.

The ***Target User*** knows how to responsibly make use of this product without causing harm to himself or others, and without causing damage to systems or devices, in which the user incorporates the product.

•→Continued on next page.

Disclaimer: Life Support Systems

TRINAMIC Motion Control GmbH & Co. KG does not authorize or warrant any of its products for use in life support systems, without the specific written consent of TRINAMIC Motion Control GmbH & Co. KG.

Life support systems are equipment intended to support or sustain life, and whose failure to perform, when properly used in accordance with instructions provided, can be reasonably expected to result in personal injury or death.

Information given in this document is believed to be accurate and reliable. However, no responsibility is assumed for the consequences of its use nor for any infringement of patents or other rights of third parties which may result from its use. Specifications are subject to change without notice.

Disclaimer: Intended Use

The data specified in this user manual is intended solely for the purpose of product description. No representations or warranties, either express or implied, of merchantability, fitness for a particular purpose or of any other nature are made hereunder with respect to information/specification or the products to which information refers and no guarantee with respect to compliance to the intended use is given.

In particular, this also applies to the stated possible applications or areas of applications of the product. TRINAMIC products are not designed for and must not be used in connection with any applications where the failure of such products would reasonably be expected to result in significant personal injury or death (Safety-Critical Applications) without TRINAMIC's specific written consent.

TRINAMIC products are not designed nor intended for use in military or aerospace applications or environments or in automotive applications unless specifically designated for such use by TRINAMIC. TRINAMIC conveys no patent, copyright, mask work right or other trade mark right to this product. TRINAMIC assumes no liability for any patent and/or other trade mark rights of a third party resulting from processing or handling of the product and/or any other use of the product.

Product Documentation Details

This document ***Datasheet User Manual*** contains the ***User Information*** for the ***Target User***.

The ***Short Spec*** forms the preface of the document and is aimed at providing a general product overview. The Main Manual contains detailed product information pertaining to functions, and configuration settings. It contains all other pages of this document.

Collateral Documents & Tools

This product documentation is related and/or associated with additional tool kits, firmware and other items, as provided on the product page at: www.trinamic.com .

21. Tables Index

Read entire documentation; especially the “Supplemental Directives” on page 218.

22. Figures Index

Read entire documentation; especially the "Supplemental Directives" on page 218.

23. Revision History

Document Revision History			
Version	**Date**	**Author**	**Description**
1.00	2014-APR-11	HS, SD	First complete version.
1.01	2014-APR-28	SD	Cross reference in chapter 9.3 corrected. Internal ramp generator units corrected.
2.00	2014-MAY-19	SD	Design changes. Change of connection scheme.
2.01	2014-MAY-23	SD	Clock frequency range updated.
2.02	2014-DEC-11	JP	Changed package suffice. Addition of "LA"
2.03	2015-MAR-02	JP	Updated temperature ratings.
3.00	2016-MAR-21	HS, SV	New document layout. Reordering of chapters. Better Navigation.
3.10	2016-JUL-04	HS, SV	New Layout, ANSI-compliant safety notices, new release variant.

Table 94: Document Revision History

Read entire documentation; especially the "Supplemental Directives" on page 218.