

Revision History

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Initial Version		November 22, 2002	Technical Department
0.4	Corrected Array Switching Frequency	January 23, 2003	Technical Department
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1.3	Figure 4 and Figure 5: TMC423 clock input corrected; more detailed flag description	June 20 th , 2007	HC, Dw

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1 Pinout

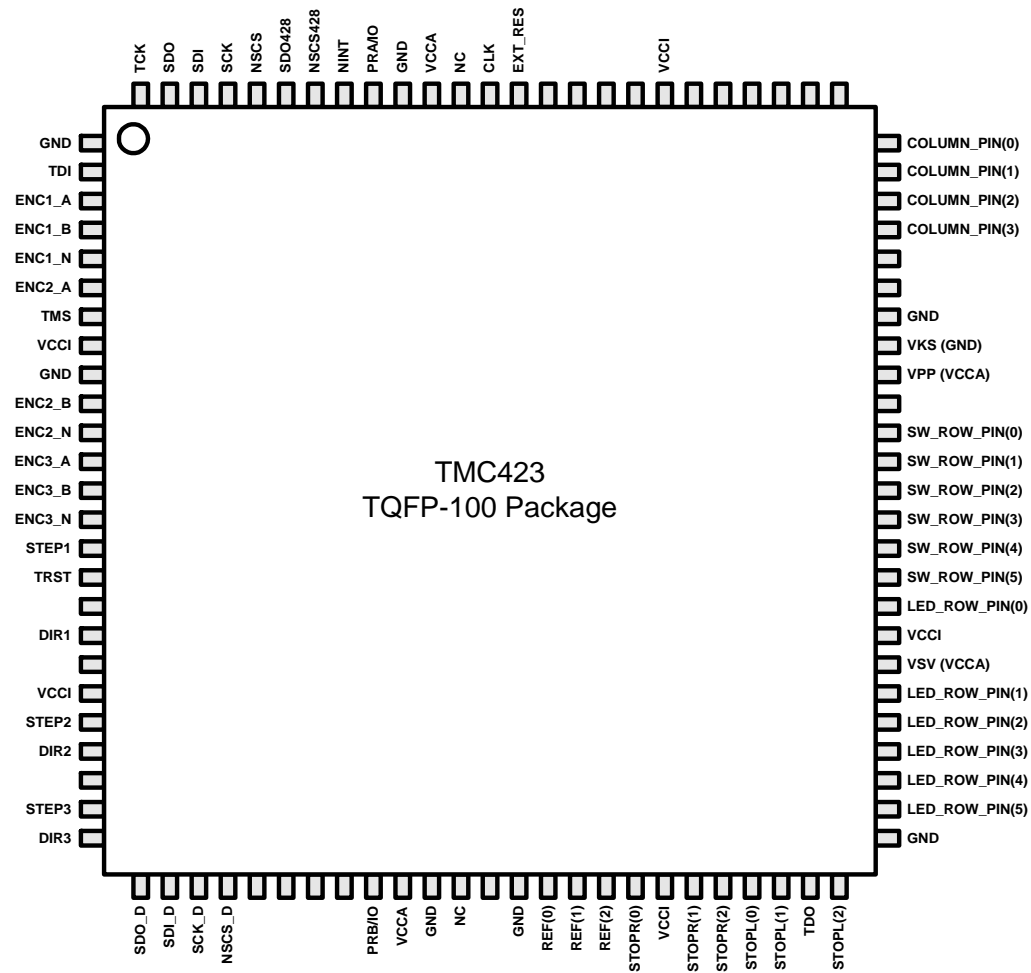


Figure 1: Pinout TMC423

1.1 Pin Description

Pin	Location	Dir	Description
GND	1, 9, 36, 39, 51, 68, 69, 91	In	Ground
ENC1_A	3	In	Incremental Encoder Interface 1 Channel A
ENC1_B	4	In	Incremental Encoder Interface 1 Channel B
ENC1_N	5	In	Incremental Encoder Interface 1 Channel N (Connect to +5V if not used)
ENC2_A	6	In	Incremental Encoder Interface 2 Channel A
ENC2_B	10	In	Incremental Encoder Interface 2 Channel B
ENC2_N	11	In	Incremental Encoder Interface 2 Channel N (Connect to +5V if not used)
ENC3_A	12	In	Incremental Encoder Interface 3 Channel A
ENC3_B	13	In	Incremental Encoder Interface 3 Channel B
ENC3_N	14	In	Incremental Encoder Interface 3 Channel N (Connect to +5V if not used)
TDI	2		Connect to Ground
TMS	7		Connect to 5 Volt via Pull-Up Resistor
TRST	16		Connect to 5 Volt via Pull-Up Resistor
TDO	49		To be left open
TCK	100		Connect to Ground
VCCI	8, 20, 44, 58, 82	In	Positive Power Supply 5 Volt
VCCA	35, 57, 67, 90	In	Positive Power Supply 2.5 Volt
GND	39	In	Unused input: Connect to Ground
CLK	88	In	System Clock 16MHz
EXT_RES	87	In	External Reset Low Active
NC	37, 89	In	Connect to Ground
PRA / IO	92		To be left open
PRB / IO	34		To be left open
Step 1	15	Out	Step/Direction Interface – Step Output Motor 1
Dir 1	18	Out	Step/Direction Interface – Direction Output Motor 1
Step 2	21	Out	Step/Direction Interface – Step Output Motor 2
Dir 2	22	Out	Step/Direction Interface – Direction Output Motor 2
Step 3	24	Out	Step/Direction Interface – Step Output Motor 3
Dir 3	25	Out	Step/Direction Interface – Direction Output Motor 3
SDO_D	26	Out	Step / Direction SPI MISO
SDI_D	27	In	Step / Direction SPI MOSI
SCK_D	28	In	Step / Direction SPI SCK
NSCS_D	29	In	Step / Direction SPI NSCS
REF0	40	Out	Reference switch output 1
REF1	41	Out	Reference switch output 2
REF2	42	Out	Reference switch output 3
STOPR0	43	In	Right Stop Switch Motor 1
STOPR1	45	In	Right Stop Switch Motor 2
STOPR2	46	In	Right Stop Switch Motor 3
STOPL0	47	In	Left Stop Switch Motor 1
STOPL1	48	In	Left Stop Switch Motor 2
STOPL2	50	In	Left Stop Switch Motor 3
COLUMN_PIN0	75	Out	Column Drive Pin 0
COLUMN_PIN1	74	Out	Column Drive Pin 1
COLUMN_PIN2	73	Out	Column Drive Pin 2
COLUMN_PIN3	72	Out	Column Drive Pin 3
SW_ROW_PIN0	65	In	Switch Matrix Pin 0
SW_ROW_PIN1	64	In	Switch Matrix Pin 1
SW_ROW_PIN2	63	In	Switch Matrix Pin 2
SW_ROW_PIN3	62	In	Switch Matrix Pin 3

SW_ROW_PIN4	61	In	Switch Matrix Pin 4
SW_ROW_PIN5	60	In	Switch Matrix Pin 5
LED_ROW_PIN0	59	Out	LED Matrix Drive Pin 0
LED_ROW_PIN1	56	Out	LED Matrix Drive Pin 1
LED_ROW_PIN2	55	Out	LED Matrix Drive Pin 2
LED_ROW_PIN3	54	Out	LED Matrix Drive Pin 3
LED_ROW_PIN4	53	Out	LED Matrix Drive Pin 4
LED_ROW_PIN5	52	Out	LED Matrix Drive Pin 5
SDO	99	Out	SPI MISO
SDI	98	In	SPI MOSI
SCK	97	In	SPI SCK
NSCS	96	In	SPI NSCS
SDO428	95	In	SPI MISO Pin of TMC428
NSCS428	94	In	SPI NSCS Pin of TMC428
NINT	93	Out	Interrupt Output (low active)

Table 1: TMC423 Pinout

Note: Pins which are not marked in Figure 1: Pinout TMC423 on page 5 must be left open.

1.2 Recommended Operating Conditions

Parameter	Value	Unit
Clock Frequency ⁽¹⁾	16	MHz
Temperature	0 ... + 70	°C
2.5 V Power Supply	2.25 ... 2.75	V _{CCA}
5.0 V Power Supply	4.50 ... 5.50	V _{CCT}

Table 2: Operating Conditions

1 – slower frequencies are also supported. Please take care about the timing information in this datasheet, since they are based on 16MHz Clock Frequency.

1.3 Electrical Characteristics

Parameter	Min	Max	Unit
Supply Current 2.5V		100	mA
Supply Current 5.0V (Output current = 0)		10	mA
LED driver current per pin		20	mA
Input voltage level Low		0.8	V
Input voltage level High	2.4		V
Encoder input pulse length	2 t _{CLK}		
Encoder count rate		f _{CLK}	

Table 3: Operating Conditions

2 Block Diagram

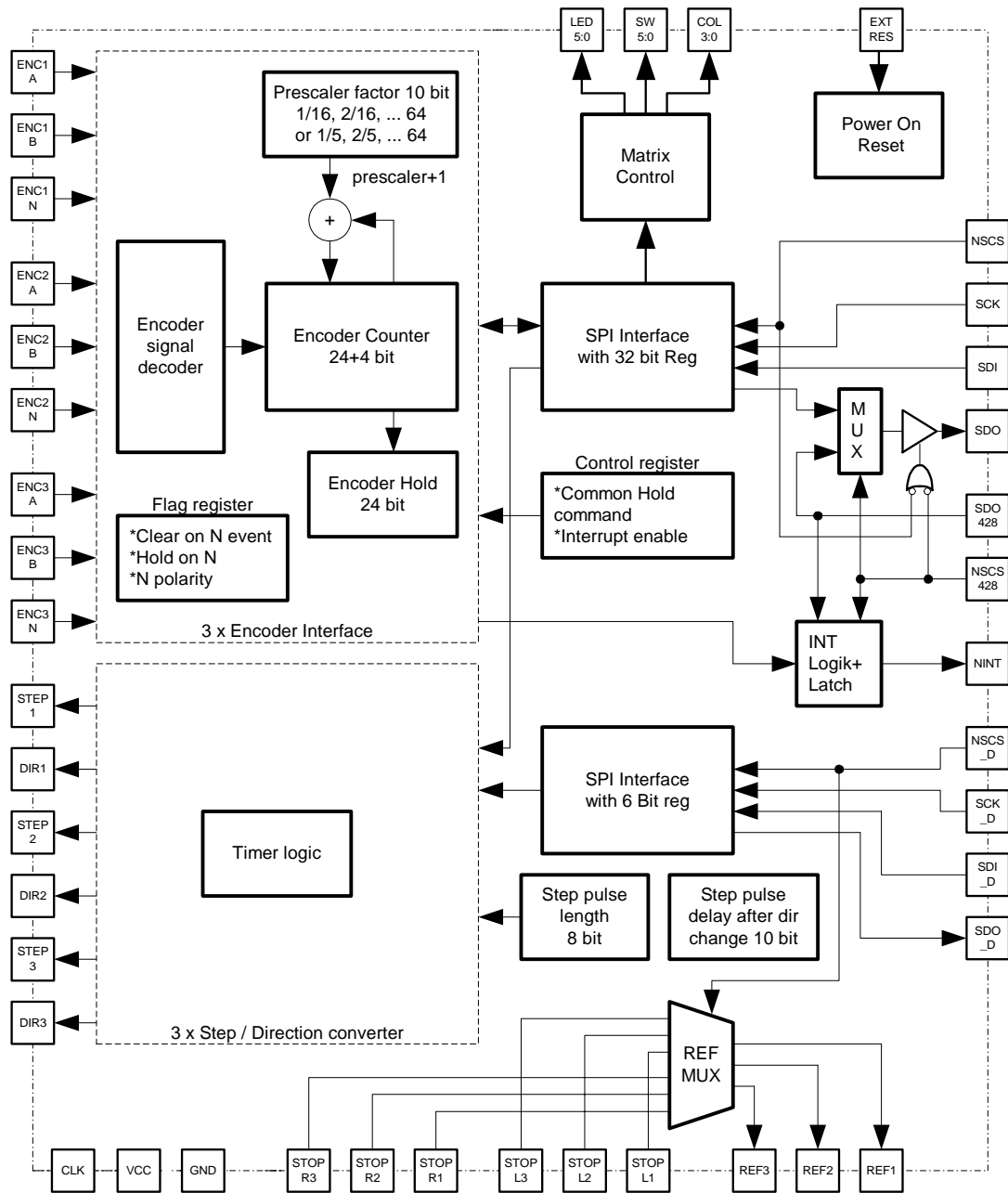


Figure 2: Block diagram of the TMC423

3 Application Environment

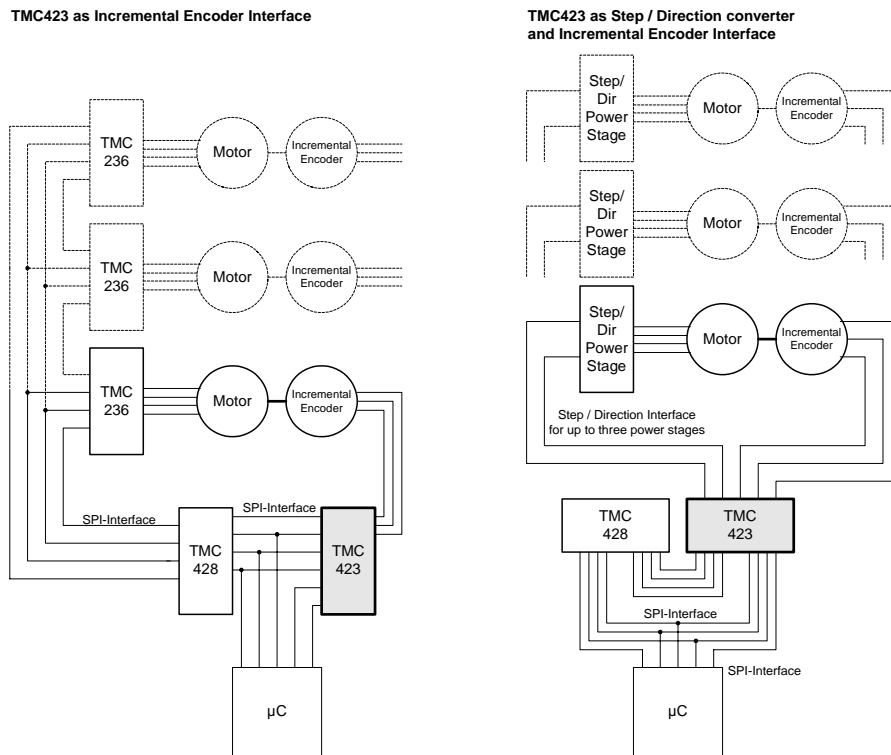


Figure 3: Application Environment

3.1 Application Description

3.1.1 Application with TMC236 Stepper Motor Driver

A complete close-loop motion control system consists of the TMC428 three-axis motion controller, the powerful TMC236 stepper motor driver and the TMC423 Encoder Interface. The system is controlled by an inexpensive microcontroller.

The main advantage of the system is that time critical communication to the TMC236 driver is performed by the TMC428. The main purpose of the inexpensive microcontroller is to parameterize the TMC428 and TMC423 and to send motion parameters like maximum speed or target position to the TMC428. Position validation is done by reading the actual position of the TMC428 and the TMC423.

3.1.2 Application with Step / Direction Power Stage

Another possibility to build a close loop motion control system is to use the TMC423 as encoder interface and also as a step direction converter. Thereto the TMC423 converts the SPITM datagrams sent by the TMC428 into parameterizeable step and direction pulses. For parameterizing both the TMC428 and TMC423 have to be connected via SPITM interface to an inexpensive microcontroller.

3.2 Application Examples

3.2.1 Application with TMC236 Stepper Motor Driver

This example illustrates the encoder connection and the use of reference switches with the TMC423 and additionally the SPI interface connections between TMC423, TMC428 and a microcontroller. The communication to the drivers (e.g. TMC236) is performed via SPI by the TMC428 motion control chip.

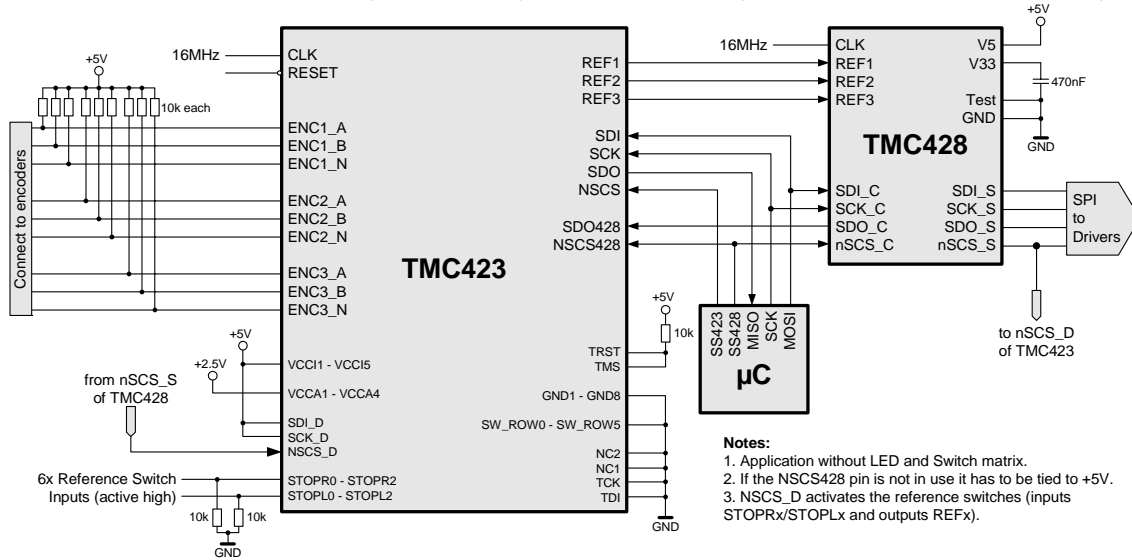


Figure 4: Example for Application with TMC236 Stepper Motor Driver

3.2.2 Application with Step / Direction Power Stage

Additionally to the previous example the use of the TMC423 as step/direction power stage is shown. The reference switches can be used as above.

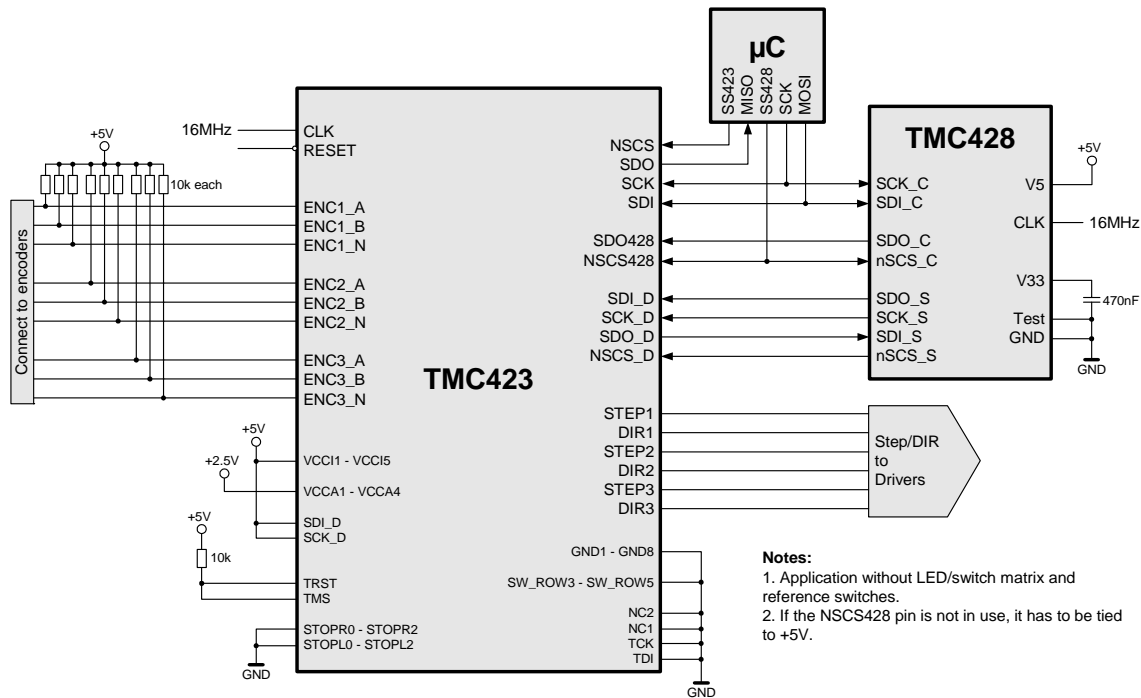


Figure 5: Example for Application with Step / Direction Power Stage

4 Dynamic Resolution Adaptation

The dynamic resolution adaptation is needed to link stepper motors and encoders with different resolutions. The characteristics of the connected hardware must be provided to the TMC423 by sending the corresponding SPI telegram. (See 5.3.1 Overview on page 13 in this issue). The TMC423 multiplies the encoder counter by a user selectable value in the range 1..1024, and then divides it by 16. When using incremental encoders with N channel it is also possible to select between different behaviors when the N channel is triggered.

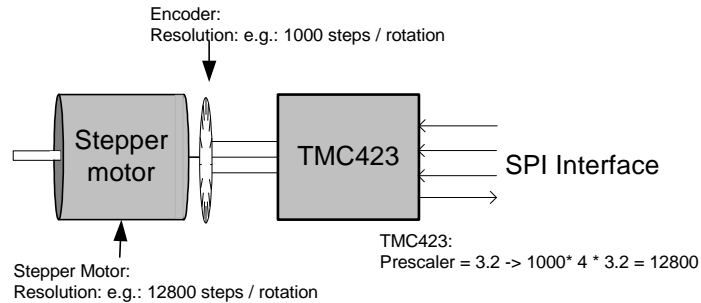


Figure 6: TMC423 Application

Table 4 shows a number of prescaler factors for possible combinations of micro step resolution and encoder resolution. Note: The given number of pulses have to be multiplied by four since 4-times encoder signal evaluation is used. (See Figure 10: Encoder Output and Evaluation on page 14).

Microstep s	Encoder Resolution [Pulses / Rotation]									
	1024	1000	512	500	256	250	200	125	50	25
12800	3.125	3.2	6.25	6.4	12.5	12.8	16	25.6	64	----
6400	1.5625	1.6	3.125	3.2	6.25	6.4	8	12.8	32	64
3200	----	----	1.5625	1.6	3.125	3.2	4	6.4	16	32
1600	----	----	----	----	1.5625	1.6	2	3.2	8	16
800	----	----	----	----	----	----	1	1.6	4	8
400	----	----	----	----	----	----	----	----	2	4

Table 4: Prescaler factors for different motors and encoders

5 Serial Peripheral Interface (SPI) with 32-bit Register

5.1 Description and Specification

Four pins named nSCS, SCK, SDI and SDO form the serial peripheral interface from a microcontroller to the TMC423. The communication between the microcontroller and the TMC423 takes place via datagrams with a fixed length of 32 bit. The microcontroller acts always as master and the TMC423 as slave.

The SPI™ of the TMC423 behaves like a simple 32-bit shift register. Incoming serial data at pin SDI is shifted with the rising edge of the clock signal SCK into the 32-bit register. The content of this register is copied after 32-bits with the rising edge of the selection signal nSCS into a buffer register of 32-bit length. The SPI™ of the TMC423 sends back data read from registers immediately via the SDO signal. It processes serial data synchronously to the clock signal CLK.

Because of on-the-fly processing of the input data stream, the serial microcontroller interface of the TMC423 requires the serial data clock signal SCK to have a minimum low / high time of three clock cycles. The data signal SDI driven by the microcontroller has to be valid at the rising edge of the serial data clock input SCK. The maximum duration of the serial data clock period is unlimited.

A complete serial datagram frame has a fixed length of 32 bit. While the data transmission from the microcontroller to the TMC423 is idle, the low active serial chip select input nSCS and also the serial data clock signal SCK are set to high. The serial data input SDI of the TMC423 has to be driven by the microcontroller. Like other SPI compatible devices, the SDO signal of the TMC423 is high impedance 'Z' as long as nSCS is high.

The signal nSCS has to be high for at least three clock cycles before starting a datagram transmission. To initiate a transmission, the signal nSCS has to be set to low. Three clock cycles later the serial data clock may go low. The most significant bit (MSB) of a 32 bit wide datagram comes first and the least significant bit (LSB) is transmitted as the last one. A data transmission is finished by setting nSCS high for three or more CLK cycles after the last rising SCK slope. nSCS and SCK change in opposite order from low to high at the end of a transmission as these signals change from high to low at the beginning. The timing of the serial microcontroller interface is outlined in Figure 7: *Timing diagram of the Serial Interface*.

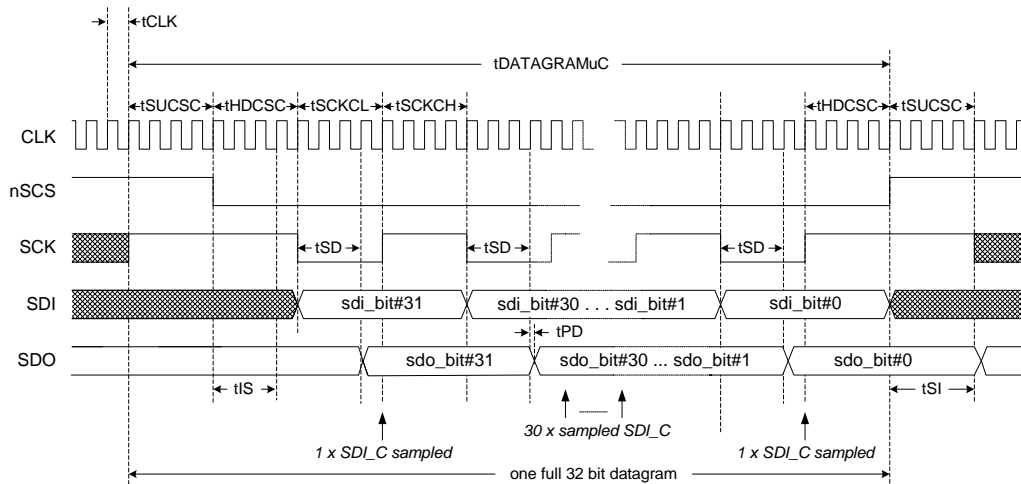


Figure 7: Timing diagram of the Serial Interface

5.2 32-bit SPI Datagram Structure

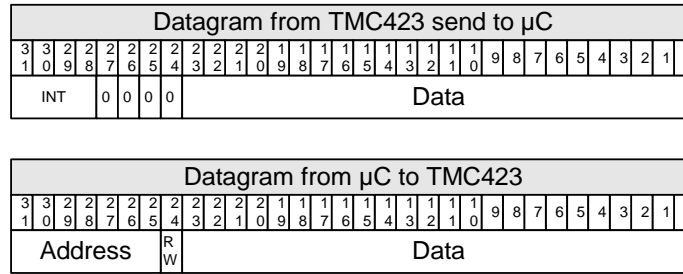


Figure 8: Structure 32-Bit Interface

Interrupt Flags [Bit]	Name	Description
31	INT_ext	external Interrupt, e.g. TMC428
30	INT_enc1	N Signal of Encoder Interface 1 detected
29	INT_enc2	N Signal of Encoder Interface 2 detected
28	INT_enc3	N Signal of Encoder Interface 3 detected

Table 5: Interrupt Flags

5.3 SPI 32-bit Datagram Specification

5.3.1 Overview

Byte #	Byte 3								Byte 2								Byte 1								Byte 0															
Bit #	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0								
	Address								R		W																													
Control	0	0	0	0	0	0	0	1	Encoder 1 Prescaler								N Polarity	N Hold	N Clear	N Trigger	Direction	Reserved																		
	0	0	0	0	0	0	1	1	Encoder 2 Prescaler													Reserved																		
	0	0	0	0	0	1	0	1	Encoder 3 Prescaler													Reserved																		
	0	0	0	0	0	1	1	1	Encoder 1, 2, 3 Prescaler - set all commonly													Reserved																		
Data	0	0	0	0	1	0	0									Encoder 1 Position Register																								
	0	0	0	0	1	0	1									Encoder 2 Position Register																								
	0	0	0	0	1	1	0									Encoder 3 Position Register																								
Step /Dir	0	0	0	0	1	1	1	1	Step Pulse Length								Step Pulse Delay								Reserved															
INT	0	0	0	1	0	0	0	1	Reg Hold	INT EN	Clear	Flags	Reserved																											
Matrix	0	0	0	1	0	0	1	0	Switch Row 3								Switch Row 2								Switch Row 1								Switch Row 0							
	0	0	0	1	0	1	0	1	LED Row 3								LED Row 2								LED Row 1								LED Row 0							

Figure 9: Overview TMC423 Registers

6 Incremental Encoder

Incremental Encoders are translating the rotary motion of a shaft into a two-channel digital quadrature output. The light emitted from a LED is focused onto a reflective code wheel. As the shaft moves, the code wheel rotates, reflecting light from an alternating bright and dark pattern.

The TMC423 samples the incoming signals $ENCx_A$ and $ENCx_B$ from the incremental encoder. An internal algorithm block counts the amount of edges generated by the encoder. A prescaler value can be used to adapt the incremental encoder resolution to the stepper motor resolution.

For high resolution the TMC423 evaluates the encoder signals 4-times during each encoder step. This has to be kept in mind when choosing the prescaler value.

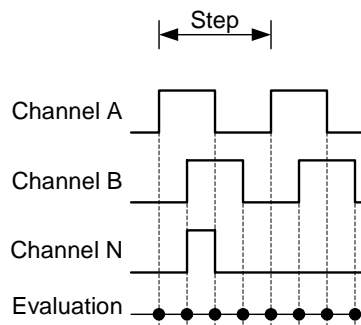


Figure 10: Encoder Output and Evaluation

Note: It is possible that the encoder signals $ENCx_A$, $ENCx_B$ and $ENCx_N$ are polluted with crosstalk noise. Crosstalk could influence the internal logic, to overcome this problem internal filters are applied to ensure correct functionality. Furthermore it saves the need for external analog filters. e.g.: Figure 11: Crosstalk on Encoder Wire shows crosstalk from channel A to channel B.

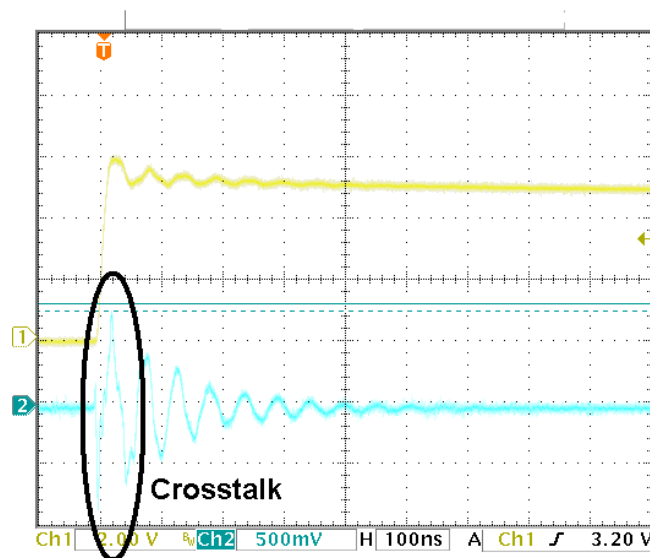


Figure 11: Crosstalk on Encoder Wire

7 Configuration Datagrams

7.1 Encoder Interface Prescaler and Null Event Configuration

The Encoder Interface Initialization datagram configures the parameterizeable encoder prescaler to adapt the TMC423 for different incremental encoders. Furthermore the TMC423 behavior concerning the N channel can be selected.

Example: A 1000 steps per rotation encoder is to connect at a stepper motor with 12800 microsteps per rotation. When the next event at the high active N channel is found, the position register must set to zero. Only Encoder Interface 1 is connected.

The following datagram performs this task:

- Bits 31 down to 24 have to be set to 01_{HEX} to select encoder interface 1
- The prescaler value has to set to 12800 / (1000*4) = 3.2. Therefore bits 23 down to 12 must set to 831_{HEX}.
- The N channel is set up correctly when bits 11 down to 0 are set to A0_{HEX}.

Bit	Encoder Interface Initialization
31...28	"0000" Register Address
27...25	Interface Selection 000 = Interface 1 001 = Interface 2 010 = Interface 3 011 = Interface 1, 2 and 3
24	'1'
23...12	External Encoder Resolution and Corresponding Prescaler Factor Bits 15 ... 12: Fractional part of Factor. Unit: 1/16 (when bit 23 = 0) resp. 1/5 (bit 23 = 1) Bits 22 ... 16: Integer part of Factor Bit 23: Switches Fractional part between 1/5 resolution or 1/16 resolution <i>Default:</i> (010) _h (prescaler 1) (default value after power on) <i>Example settings:</i> Encoder: 1024 lines (4096 steps per rotation) (032) _h for 12800 micro steps per rotation (prescaler 3.125) (019) _h for 6400 micro steps (prescaler 1.5625) Encoder: 1000 lines (831) _h for 12800 micro steps (prescaler 3.2) (813) _h for 6400 micro steps (prescaler 1.6) Encoder: 512 lines (064) _h for 12800 micro steps (prescaler 6.25) (032) _h for 6400 micro steps (prescaler 3.125) (019) _h for 3200 micro steps (prescaler 1.5625) Encoder: 500 lines (862) _h for 12800 micro steps (prescaler 6.4) (831) _h for 6400 micro steps (prescaler 3.2) (813) _h for 3200 micro steps (prescaler 1.6) Encoder: 256 lines (0C8) _h for 12800 micro steps (prescaler 12.5) (064) _h for 6400 micro steps (prescaler 6.25) (032) _h for 3200 micro steps (prescaler 3.125) (019) _h for 1600 micro steps (prescaler 1.5625) Encoder: 250 lines (8C4) _h for 12800 micro steps (prescaler 12.8) (862) _h for 6400 micro steps (prescaler 6.4) (831) _h for 3200 micro steps (prescaler 3.2) (813) _h for 1600 micro steps (prescaler 1.6) Encoder: 200 lines (100) _h for 12800 micro steps (prescaler 16) (080) _h for 6400 micro steps (prescaler 8) (040) _h for 3200 micro steps (prescaler 4) (020) _h for 1600 micro steps (prescaler 2)

	<p>(010)_h for 800 micro steps (prescaler 1)</p> <p>Encoder: 125 lines (993)_h for 12800 micro steps (prescaler 25.6) (8C4)_h for 6400 micro steps (prescaler 12.8) (862)_h for 3200 micro steps (prescaler 6.4) (831)_h for 1600 micro steps (prescaler 3.2) (813)_h for 800 micro steps (prescaler 1.6)</p> <p>Encoder: 50 lines (200 steps per rotation) (400)_h for 12800 micro steps (prescaler 64) (200)_h for 6400 micro steps (prescaler 32) (100)_h for 3200 micro steps (prescaler 16) (080)_h for 1600 micro steps (prescaler 8) (040)_h for 800 micro steps (prescaler 4) (020)_h for 400 micro steps (prescaler 2) (010)_h for 200 steps per rotation (prescaler 1)</p>
11	<p>N Polarity for Selected Interface 0 = active low (default) 1 = active high</p> <p><i>When changing the polarity, please be aware that a single clear on N Event might be triggered, and thus should not be initiated in the same write access.</i></p>
10	<p>Hold on N for Selected Interface 0 = no hold (default) 1 = active: Encoder counter freezes during 0 channel event.</p>
9	<p>Clear on N Event for Selected Interface 0 = no clear (default) 1 = active</p> <p><i>When switched to active, then it depends on bit 8, if a clear event is issued only once, or always when the N channel becomes active.</i></p>
8	<p>N Trigger Selection 0 = only at next N signal (default) 1 = always at N signal</p> <p><i>The clear event last until the N signal goes inactive again. If earlier termination is desired, i.e. to preset the encoder counter to a different value, disable "Clear on N" prior to changing the position register.</i></p>
7	<p>add or sub register for each step (CW = looking onto the axis) 0= add for CW, sub for CCW (default) 1= add for CCW, sub for CW</p>
6...0	Reserved

Table 6: SPI Datagram Prescaler

7.2 Encoder Interface Hold Register Operation

To read the actual contents of the position register or to preset the position register the following command is to be used:

Bit	Encoder Interface Control (Read/Preload Encoder Hold Register)
31...28	"0000" Register Address
27...25	Select Encoder Hold Register 100 = Hold register in encoder interface 1 101 = Hold register in encoder interface 2 110 = Hold register in encoder interface 3
24	Read or Preload Selection 0 = Read encoder hold register 1 = Preload encoder hold register
23...0	Encoder Hold Register Data

Table 7: SPI Datagram Hold Register

7.3 Timer Logic Step Pulse Length and Delay

To parameterize the step length and delay the next datagram is to be used:

Bit	Write Step Pulse Length / Delay
31...25	"0000111" Register Address
24	'1'
23...16	Step Pulse Length (default value = 48 _(t₀) after PON)
15...6	Step Pulse Delay after Direction Change (default value = 160 _(t₀) after PON)
5...0	Reserved

Table 8: SPI Datagram Step-/Dir logic

7.4 Control Register and Interrupt Control

This datagram configures the interrupt control of the TMC423. When enabled, the N channel pulse of all encoders is fed to the NINT pin.

Bit	Control Register
31...25	"0001000" Register Address
24	'1'
23	Set Common Hold for Encoder Hold Registers 0 = no hold (default) 1 = freeze encoder hold registers
22	Encoder Interrupt Enable, if Null signal 0 = interrupt disable (default) 1 = interrupt enable
21	Clear Interrupt Flags 0 = no clear (default) 1 = clear flags
20...0	Reserved

Table 9: SPI Datagram Control Register

7.5 Switch Matrix Read

Bit	Control Register
31...25	"0001001" Register Address
24	'0'
23...18	Switch Matrix Register Row 3
17...12	Switch Matrix Register Row 2
11...6	Switch Matrix Register Row 1
5...0	Switch Matrix Register Row 0

Table 10: Switch Matrix Read

7.6 LED Matrix Write

Bit	Control Register
31...25	"0001010" Register Address
24	'1'
23...18	LED Matrix Register Row 3
17...12	LED Matrix Register Row 2
11...6	LED Matrix Register Row 1
5...0	LED Matrix Register Row 0

Table 11: LED Matrix Write

8 SPI-Protocol for Interface with 6-bit Register

The 6-bit SPI Interface is used to receive step / direction information from the TMC428. The TMC423 processes the data and issues the corresponding step / direction signals via the step / direction pins. Bit 0 (Pulse 1) have to be sent first to the TMC423.

Bit	Step / Direction Converter
0	Pulse 1
1	Direction 1
2	Pulse 2
3	Direction 2
4	Pulse 3
5	Direction 3

Table 12: SPI Datagram Step / Direction Converter

The order of the control signals serially sent from the TMC428 has to be defined. This can be done by writing so called primary signal codes into the stepper motor driver datagram configuration area of the on-chip configuration RAM of the TMC428. This signals codes are \$13 (step first) and \$12 (direction). To switch to the next motor the next motor bit (NxM) has to be set.

Position within datagram	Driver/motor	NxM bit	TMC428 signal code	RAM data	TMC428 mnemonic of primary signal
0	1	0	\$13	\$13	Step
1		1	\$12	\$32	Direction
2	2	0	\$13	\$13	Step
3		1	\$12	\$32	Direction
4	3	0	\$13	\$13	Step
5		1	\$12	\$32	Direction

Table 13: Datagram example and RAM contents for three step-direction drivers

8.1 Step and Direction Pulse conversion

Step pulses can be modified in their pulse width and delayed after an direction change was done. The corresponding datagram (See 7.3) on page 17) is used to parameterize the Step / Dir interface.

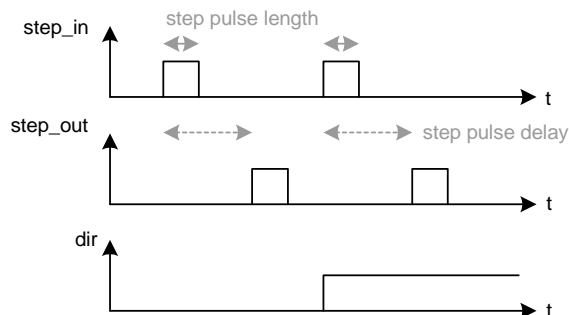


Figure 12: Step Direction conversion

9 LED and Switch Matrix

The TMC423 can be used to drive a LED matrix or to get information from a switch matrix, whether the switches are on or off. LEDs or switches are only active when the corresponding column is selected by setting it to zero. The switch frequency of the column pins is fixed to 500 Hz at a clock frequency of 16MHz. The LEDs are driven with a maximum current of 20mA.

The following Table 14: TMC423 LED Matrix Pins shows how the LED Matrix Write register is mapped to the corresponding TMC423 pins to drive the LEDs.

TMC423 Pin: COLUMN_PIN [3:0]				TMC423 Pin: LED_ROW_PIN [5:0]					
Bit 3	Bit 2	Bit 1	Bit 0	LED_Matrix_Write [23:0]					
0	1	1	1	23	22	21	20	19	18
1	0	1	1	17	16	15	14	13	12
1	1	0	1	11	10	9	8	7	6
1	1	1	0	5	4	3	2	1	0

Table 14: TMC423 LED Matrix Pins

For correct external connection of the matrix please refer to the following Figure 13: Connection to the matrix. If distortions caused by long PCB traces are to be expected, then filter capacitors C_{filter} of 100pF have to be added.

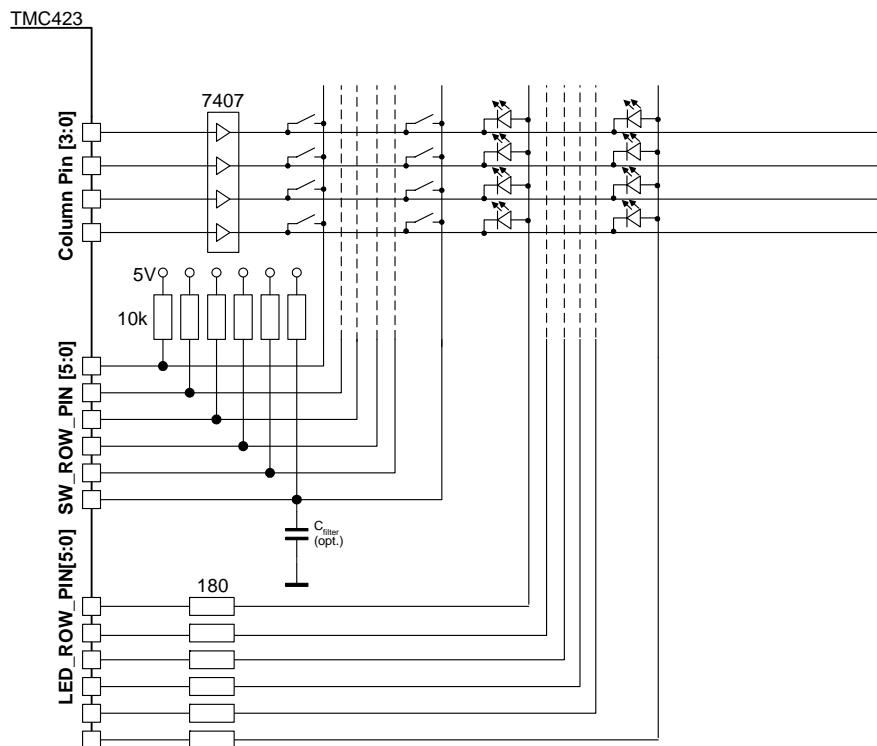


Figure 13: Connection to the matrix

10 Package dimensions

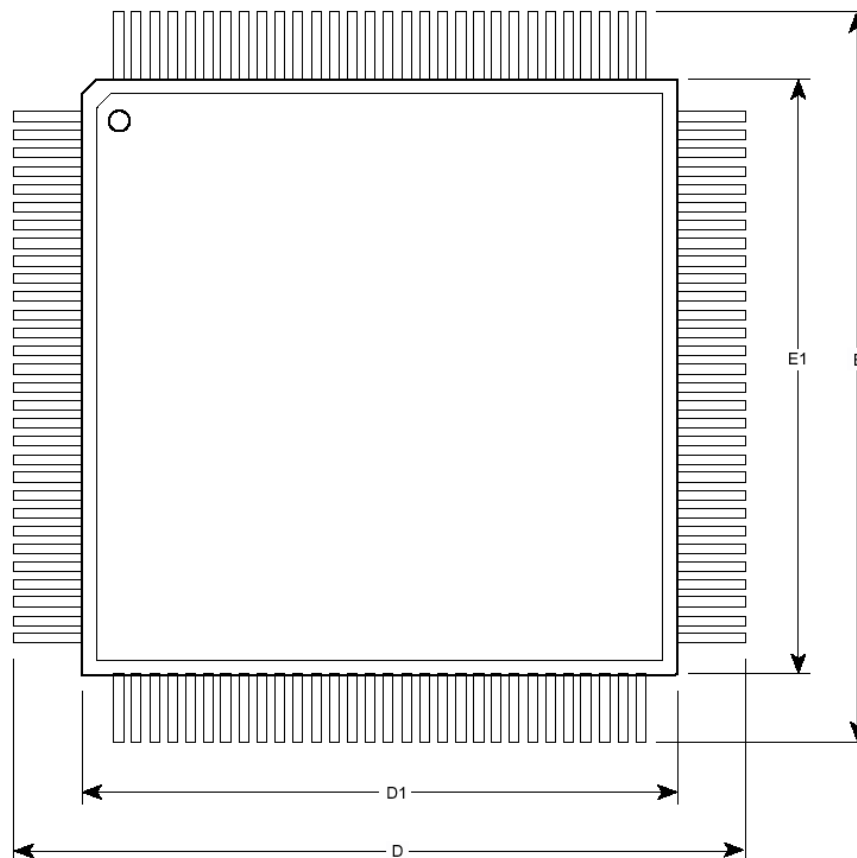


Figure 14: 100-Pin TQFP Top View

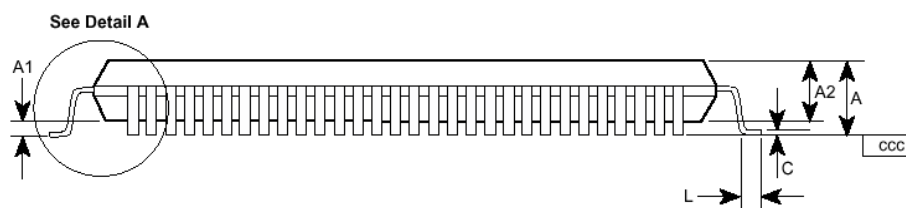


Figure 15: 100-Pin TQFP Side View

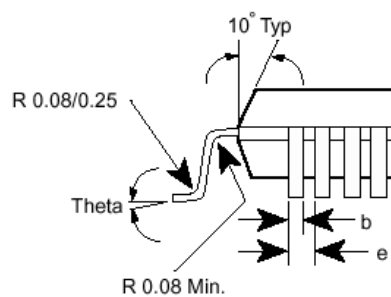


Figure 16: 100-Pin TQFP Side View Detail A

JEDEC Equivalent	TQFP100 MS-026 VAR BED			
	Dimension	Min	Nom	Max
A				1.60
A1	0.05			0.15
A2	1.35	1.40		1.45
b	0.17	0.22		0.27
c	0.09			0.20
D/E		16.00 BSC		
D1/E1		14.00 BSC		
e		0.50 BSC		
L	0.45	0.60		0.75
ccc		0.08		
Theta	0	3.50 deg		7 deg

Table 15: TQFP Dimensions

Notes :

- all dimensions are in millimeters
- BSC Basic Spacing between Centers

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