TMCM-302

Stepper Motor Motion Control Module

Documentation

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Version

Version	Date	Author(s)	Remarks
0.1	01.07.2002	ME/AR	Initial Version
1.00	1.9.2003	OK	Error corrections
1.01	3.9.2003	OK	Error corrections
1.02	17.3.2004	OK	Errors in tables 1 and 7 corrected
1.04	13.2.2005	OK	Ordering information added

List of Figures

List of Tables

Table of Contents

1 General Description

The TMCM-302 is a triple axis 2-phase stepper motor motion control module based on the high performance TMC428 stepper motor control chip. This module creates the Step and Direction signals to drive an external power driver module. It also provides a complete motion control system at low cost and very small physical size by just adding external stepper motor drivers with an SPI-Interface.
The TMCM-302 can be remote controlled via the CAN- or RS-232/RS-485-interface. A stand-alone operation is also possible. Communication traffic is kept very low since all CPU-intensive operations, e.g. ramp calculation are performed by the TMC-428 motion controller.
The TMCM-302 provides a complete software development environment and by using the Trinamic Motion Control Language (TMCL), rapid and fast development of motion control applications is guaranteed. The TMCL Operations are stored in the on-board 16KByte EEPROM, which is accessible via one of the different interfaces.

1.1 Ordering Information

Order code	Features
TMCM-302-H	Horizontal mount (standard)
TMCM-302-V	Vertical mount (available on demand)

2 Main Features

- up to three 2-phase stepper motors can be driven and controlled
  - by adding external power driver modules with a Step/Direction-Interface
  - by adding external stepper motor driver with an SPI-Interface
- TMC428 high performance motion controller
- CAN 2.0b Interface with Transceiver
- RS-232 Interface (without level-shifter)
- RS-485 Interface (without tranceiver)
- Trinamic Motion Control Language integrated
- In-system programmable microcontroller with 32Kbyte flash memory
- 16 KByte EEPROM
- Build-in ramp generator for autonomous positioning and speed control
- On the fly alteration of target motion parameters (e.g. position, velocity, acceleration)
- Full step frequencies up to 300KHz
- Limit and reference switch inputs
- 5 VDC Supply
- Compact size: TMCM Standard Format 80x50 mm^2

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3 Operational Conditions

3.1 Power supply

The 5VDC supply voltage must be in the range of 4.75VDC to 5.25VDC. The current which is needed by the TMCM-302 module amounts approximately 300 mA.

The motor supply voltage is not needed for the module, because the drivers must be applied externally.

3.2 Inputs

The input voltage range for all inputs (if not labelled different) is from 0V to 5VDC or TTL level. The voltages for the differential CAN inputs range between –8VDC to +18VDC.

3.3 Outputs

The output ports are following TTL levels, with an maximum current of 50mA (µC output ports) and 35mA (shift register outputs).

3.4 Temperature Range

The TMCM-302 is suitable for ambient temperature of up to 70°C.

4 Ramp Profiles

The speed profile is automatically worked out by the TMCM-302 from the values for the minimum speed, maximum speed and acceleration specified by the user with the TMCL. Two modes of operation for the course of velocity are available for selection.

- In the **Ramp-Mode** the maximum acceleration (a_max), maximum (v_max) and minimum (v_min) speed and the target position (x_target) are specified to calculate the actual velocity. By giving the target position, the TMCM-302 calculates the speed profile of each stepper motor from the current position and the specified parameters and immediately converts it into a motion sequence.
  In Figure 1, an example of the motion sequence is shown. Here the motor accelerates from t_0 onwards with a_max till it reaches v_max in t_1, then it moves itself with v_max up to t_2, it then slows down with a_max till it reaches v_min in t_3 and then it travels with v_min till it reaches its target (x_target) in t_4.
  On the right side of the Figure it can be seen that v_max cannot be reached if a_max is too small or the target (x_target) is too close.

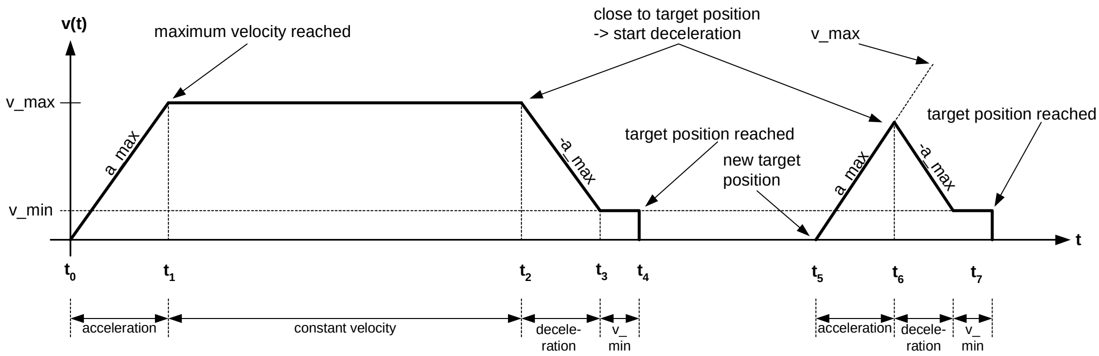

Figure 1: Velocity profile in ramp mode

- In **Velocity-Mode** the acceleration and the maximum speed is specified in the TMCM-302. Then the motor accelerates immediately with the specified value to the maximum speed and continues to run at constant speed till new values are sent to the TMCM-302.
  In Figure 2 the motion sequence for the velocity mode is shown as an example. Here the motor accelerates with a_max till it reaches the maximum velocity and then continues to run at constant speed with v_max till new a_max and v_max is specified. On the right side and at t_5 the v_max is not distinctly reached if a new parameter is prematurely given.

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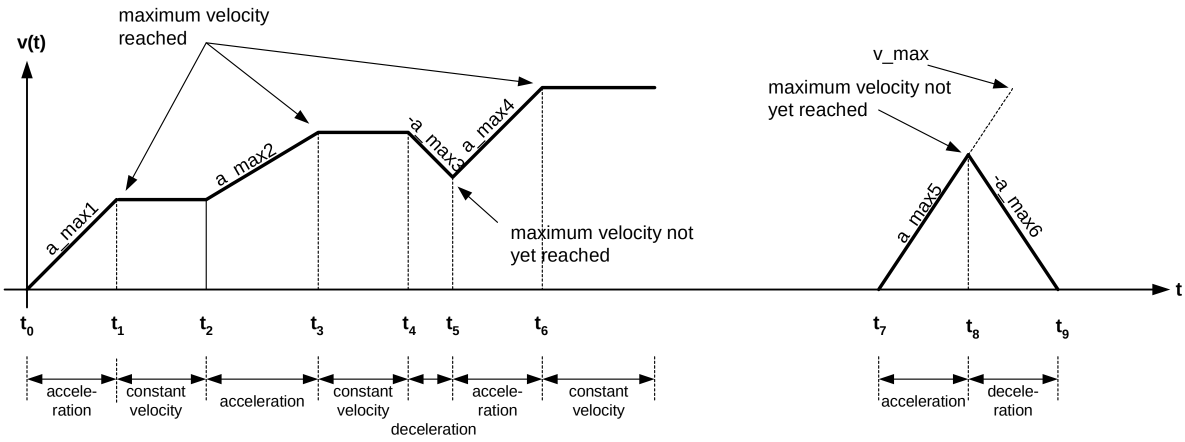

Figure 2: Velocity profile in velocity mode

A detailed explanation of the parameters and its calculation is given in the software description.

5 Getting started

5.1 The TMCM-302 Module

Front:

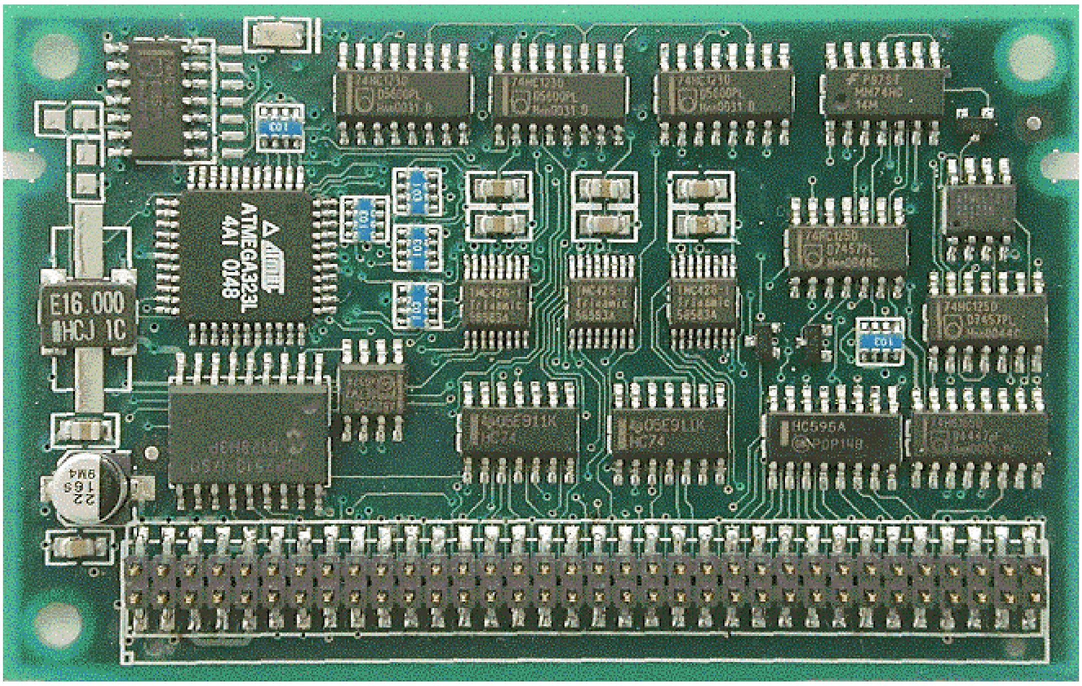

Figure 3: TMCM-302 Top Side

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5.2 TMCM-302 Mechanical Data:

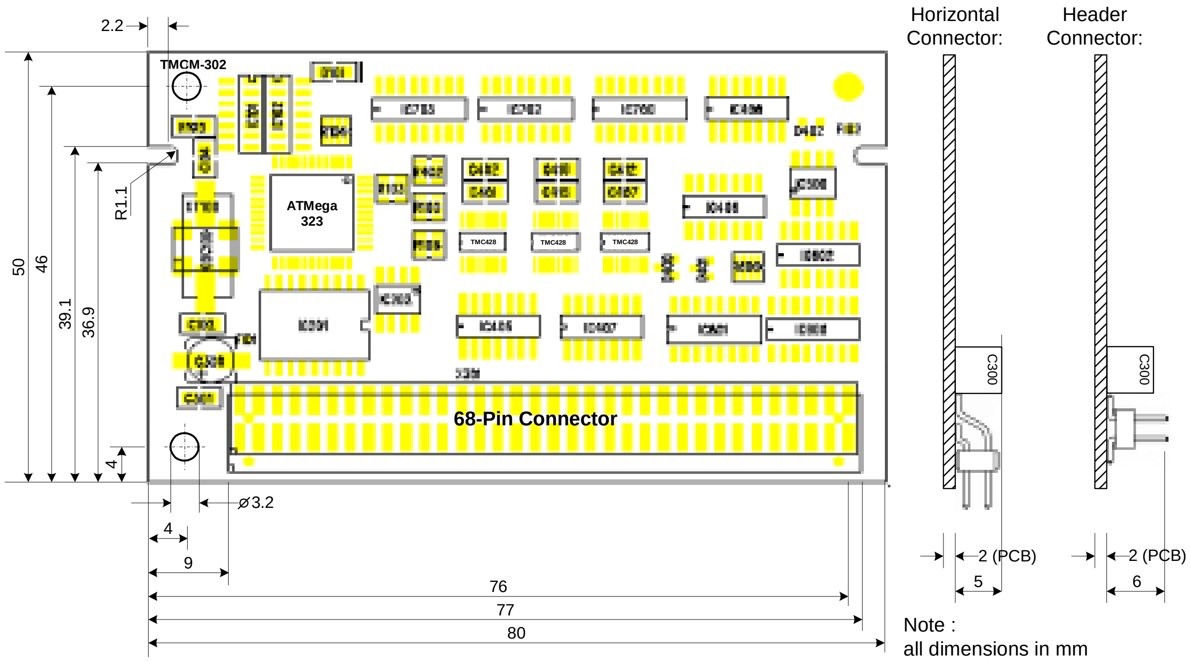

Figure 4: Physical Size

5.3 TMCM-302 Application Environment

5.3.1 Application Environment using the Step/Direction-Interface

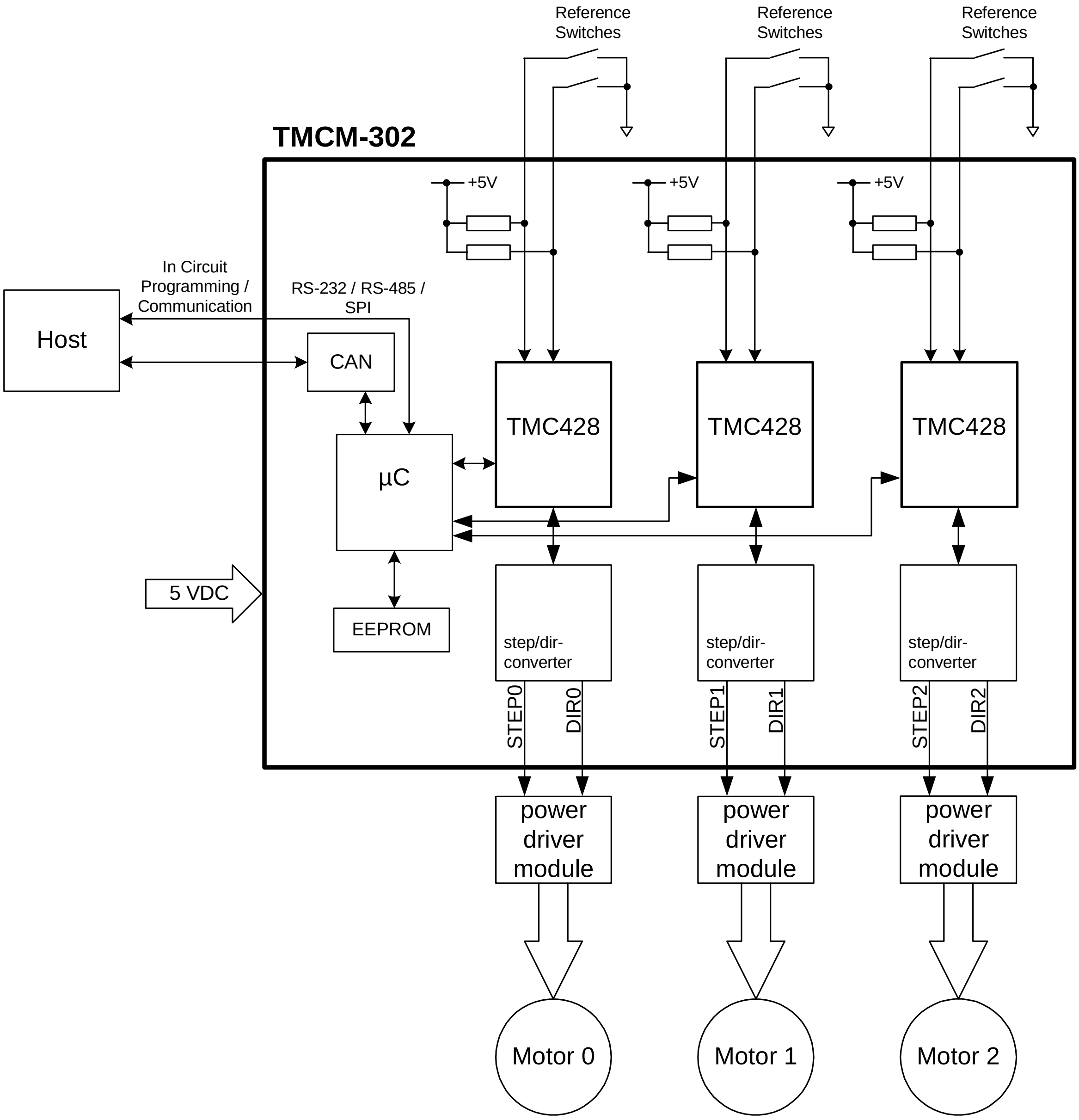

Figure 5: Application Environment using the Step/Direction-Interface

5.3.2 Application Environment using SPI-Interface

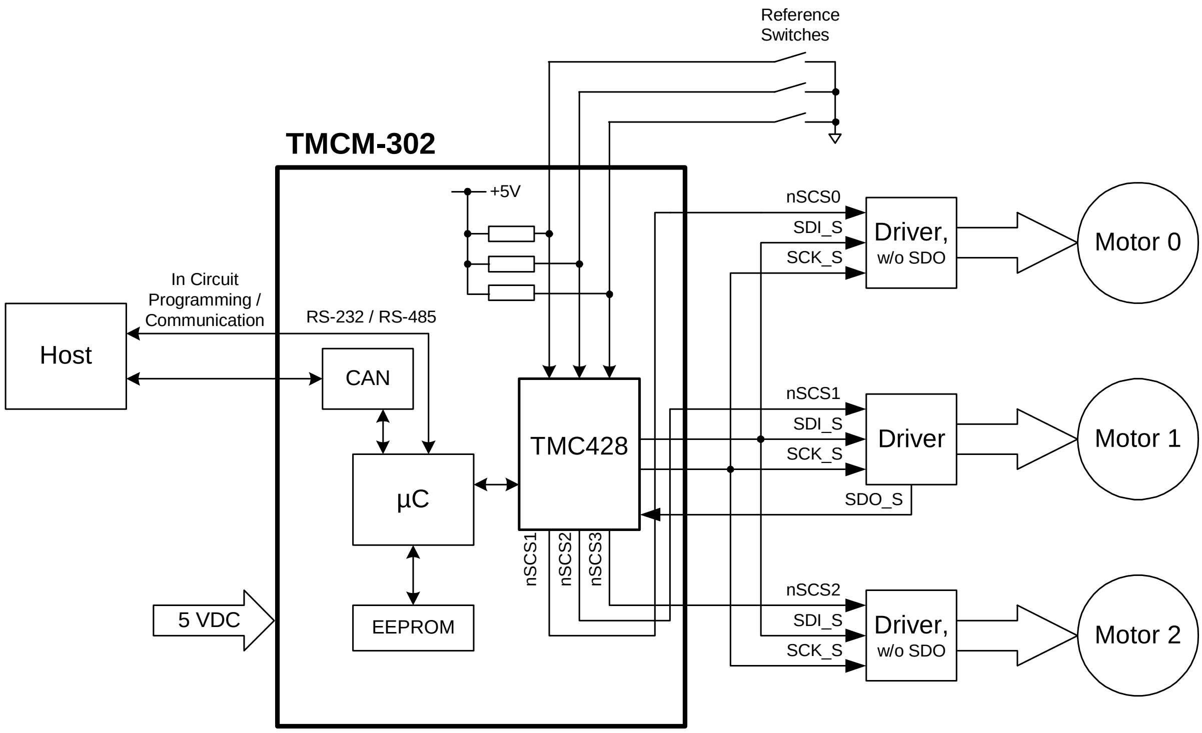

Figure 6: Application Environment using the SPI-Interface

5.3.3 Functional Description

Communication Interface

The communication between the host and the module can be done via RS232, RS485 or CAN-Interface. These interfaces are used to send motion to the microcontroller. Additionally they can be used to program the microcontroller and the on-board-EEPROM using TMCL. A ready-to-use CAN-Interface is included on the board. The level-shifter and transceiver for the UART-interfaces have to be added.

Microcontroller (µC)

On this module, the Atmel ATmega32 is included to communicate wih the host and the EEPROM and to control the TMC428. The µC has 32Kbyte flash memory and a 1Kbyte EEPROM. The operating system of the µC (TMCL) can be updated via the RS232-interface from the host.

In normal operation the microcontroller is receiving TMCL (Trinamic Motion Control Language) commands. These commands are interpreted by the microcontroller and then converted into SPI-datagrams which are then sent to the TMC428.

EEPROM
To use the module without a host or to store special data permanently, the EEPROM can be used. One example is to store a program written in TMCL in the EEPROM, which will be automatically executed after ramping up the module. The EEPROM can be programmed by the host or by the µC and has a capacity of 16 KByte.

TMC428
The TMC428 is a high-performance stepper motor control IC and can control up to three 2-phase-stepper-motors. Motion parameters like speed or acceleration are sent to the TMC428 via SPI by the microcontroller. Calculation of ramps and speed profiles are done internally by hardware based on target motion parameters.

Interface to the external drivers
Drivers are not included on the module. To drive stepper motors with this module, stepper motor drivers have to be added externally. To drive a stepper motor with the Step/Direction-Interface, a power driver module has to be added, which can evaluate the Step/Direction-signals. Also stepper motor drivers with an SPI-Interface can be added. It can be chosen, if the drivers are used cascaded or not, because three Chip Select signals are available.

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5.4 Connecting the Module

5.4.1 Pinout of the 68-pin Connector

The 68-pin connector provides communication to a host, configuration of the EEPROM and connection of motors as well as connection of reference switches. Pin 1 of this connector is located in the lower left corner on the top site, while the connector is pointing towards the user.

Pin	Direction	Description	Pin	Direction	Description
1	In	+5VDC (+/- 5%) I_{max}=300mA	35	Out	STEP_M1
2	In	GND	36	Out	SPI_M2_CLK
3	In	+5VDC (+/- 5%)	37	Out	DIR_M1
4	In	GND	38	In	SPI_M0_IN
5	In	V_Motor (+10 to 30VDC)	39	Out	STEP_M2
6	In	GND	40	In	SPI_M1_IN
7	In	V_Motor (+10 to 30VDC)	41	Out	DIR_M2
8	In	GND	42	In	SPI_M2_IN
9	In	V_Motor (+10 to 30VDC)	43	In	Shutdown
10	In	GND	44	-	Reserved
11	Out	SPI Select 0	45	In	General Purpose
12	Out	SPI Clock	46	Out	General Purpose
13	Out	SPI Select 1	47	In	General Purpose
14	In	SPI MISO	48	Out	General Purpose
15	Out	SPI Select 2	49	In	General Purpose
16	Out	SPI MOSI	50	Out	General Purpose
17	In	Reset, active low	51	In	General Purpose
18	Out	Alarm	52	Out	General Purpose
19	In	Reference Switch Motor 0 left	53	In	General Purpose
20	Out	nSCS0	54	Out	General Purpose
21	In	Reference Switch Motor 0 right	55	In	General Purpose
22	Out	nSCS1	56	Out	General Purpose
23	In	Reference Switch Motor 1 left	57	In	General Purpose
24	Out	nSCS2	58	Out	General Purpose
25	In	Reference Switch Motor 1 right	59	In	General Purpose
26	Out	SPI_M0_OUT	60	Out	General Purpose
27	In	Reference Switch Motor 2 left	61	In	GND
28	Out	SPI_M0_CLK	62	In	GND
29	In	Reference Switch Motor 2 right	63	-	Reserved
30	Out	SPI_M1_OUT	64	Out	RS-485 Direction
31	Out	STEP_M0	65	InOut	CAN -
32	Out	SPI_M1_CLK	66	In	RS-232 RxD
33	Out	DIR_M0	67	InOut	CAN +
34	Out	SPI_M2_OUT	68	Out	RS-232 TxD

Table 1: Pinout 68-Pin Connector

5.4.2 Host Communication

Communication to a host takes place via one or more of the onboard interfaces. The module provides a wide range of different interfaces, like CAN, RS-232 and RS-485. The following chapters explain how the interfaces are connected with the 68-pin connector.

5.4.2.1 CAN 2.0b

Pin Number	Direction	Name	Limits	Description
65	InOut	CAN -	-8…+18V	CAN Input / Output
67	InOut	CAN +	-8…+18V	CAN Input / Output

Table 2: Pinout for CAN Connection

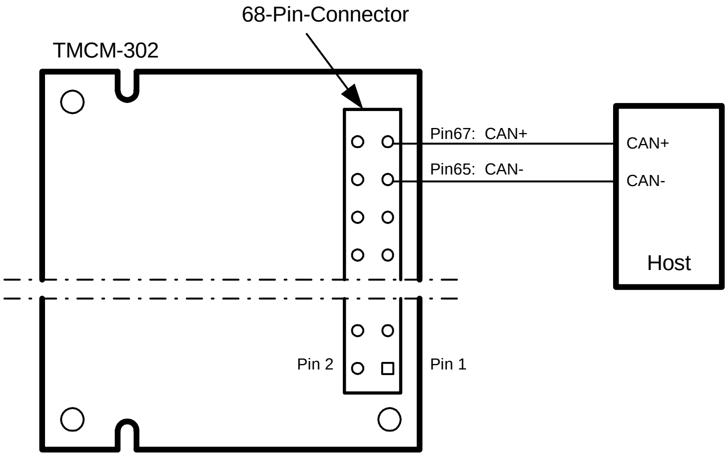

Figure 7: Connecting CAN

5.4.2.2 RS-232

Pin Number	Direction	Name	Limits	Description
66	In	RxD	TTL	RS-232 Receive Data
68	Out	TxD	TTL	RS-232 Transmit Data
2, 4, 6, 8, 10	In	GND	0V	Connect to ground

Table 3: Pinout for RS-232 Connection

Note: The RS-232 must operated with TTL-Levels (0V, 5V), since there is no level shifter onboard!

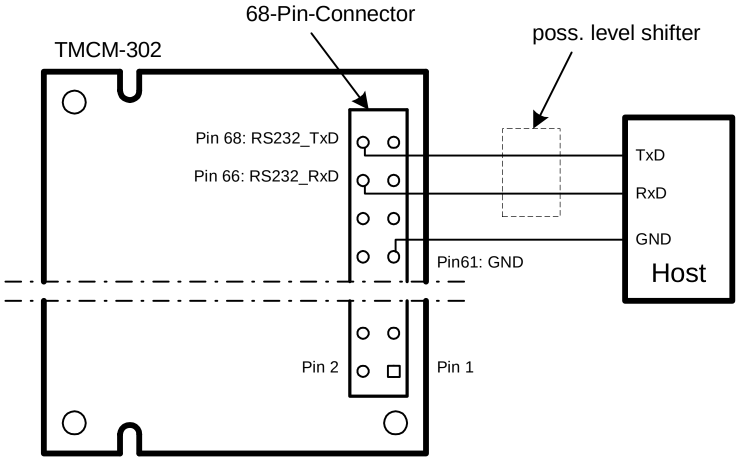

Figure 8: Connecting RS-232

5.4.2.3 RS-485

Pin Number	Direction	Name	Limits	Description
64	Out	RS485_DIR	TTL	Driver / Receiver enable for RS-485 Transceiver. 0: Receiver enable 1: Driver enable
66	In	RxD	TTL	RS-485 Receive Data
68	Out	TxD	TTL	RS-485 Transmit Data
2, 4, 6, 8, 10	In	GND	0V	Connect to ground

Table 4: Pinout for RS-485 Connection

Note: The TMCM-302 Module is not containing any RS-485 transceivers!

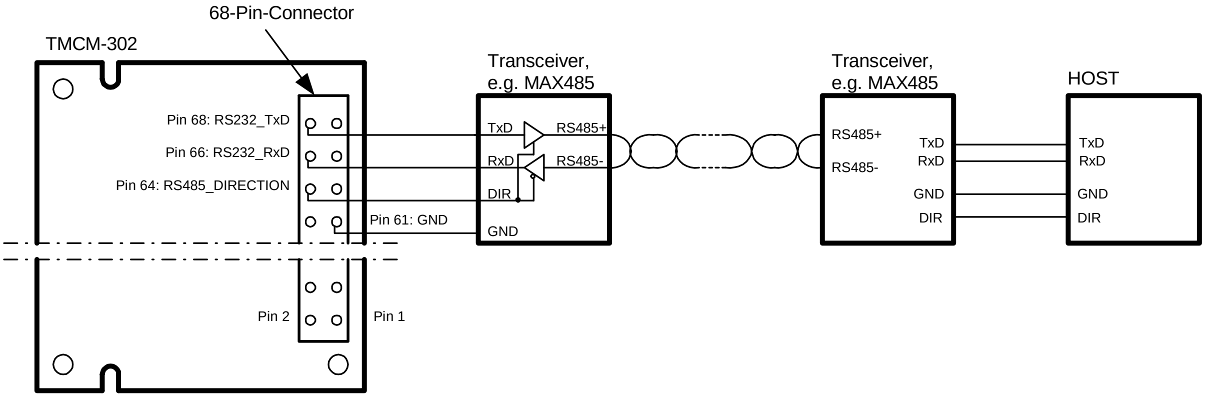

Figure 9: Connecting the RS-485

Via RS-485 Interface it is possible to build up systems with of 31 (with repeater 254) modules, which are adressable by one host.

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5.4.3 Connecting the drivers

Because there are no stepper motor drivers included on the TMCM302, an Add-On-Board has to be developed to drive the stepper motors.:

5.4.3.1 Connecting the TMCM-302 to a power driver module with Step/Direction-Interface

Pin Number	Direction	Name	Limits	Description
31	Out	STEP_M0	TTL	Step-Signal for Driver 0
33	Out	DIR_M0	TTL	Direction-Signal for Driver 0
35	Out	STEP_M1	TTL	Step-Signal for Driver 1
37	Out	DIR_M1	TTL	Direction-Signal for Driver 1
39	Out	STEP_M2	TTL	Direction-Signal for Driver 2
41	Out	DIR_M2	TTL	Serial Clock for the Driver 2

Table 5: Pinout for using the Step/Direction-Interface

Example : Connection of the TMCM-302 with the Monopack (power driver module with a Step/Direction-Interface)

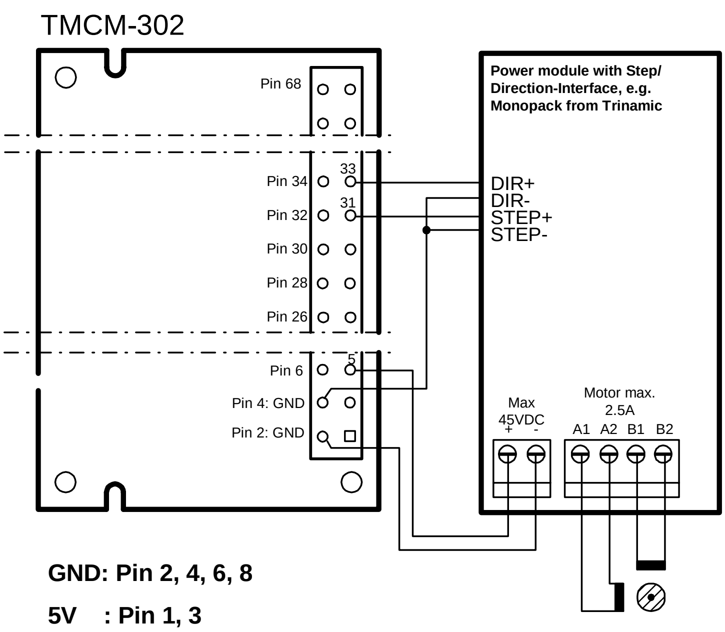

Figure 10: Application with power module with a Step/Direction-Interface

5.4.3.2 Connecting the TMCM-302 to drivers with an SPI-Interface

The pins connecting the TMCM-302 with the Add-On-Board using the SPI-Interface are listed in Table 6.

Pin Number	Direction	Name	Limits	Description
20	Out	nSCS0	TTL	Chip Select for Driver 0
22	Out	nSCS1	TTL	Chip Select for Driver 1
24	Out	nSCS2	TTL	Chip Select for Driver 2
26	Out	SPI_M0_OUT	TTL	SPI Data In for Driver 0
28	Out	SPI_M0_CLK	TTL	SPI Clock for Driver 0
30	Out	SPI_M1_OUT	TTL	SPI Data In for Driver 1
32	Out	SPI_M1_CLK	TTL	SPI Clock for Driver 1
34	Out	SPI_M2_OUT	TTL	SPI Data In for Driver 2
36	Out	SPI_M2_CLK	TTL	SPI Clock for Driver 2
38	In	SPI_M0_IN	TTL	SPI Data Out for Driver 0
40	In	SPI_M1_IN	TTL	SPI Data Out for Driver 1
42	In	SPI_M2_IN	TTL	SPI Data Out for Driver 2

Table 6: Pinout for the connections using the SPI-Interface

Example : Using the TMC236 stepper motor driver with an SPI-interface

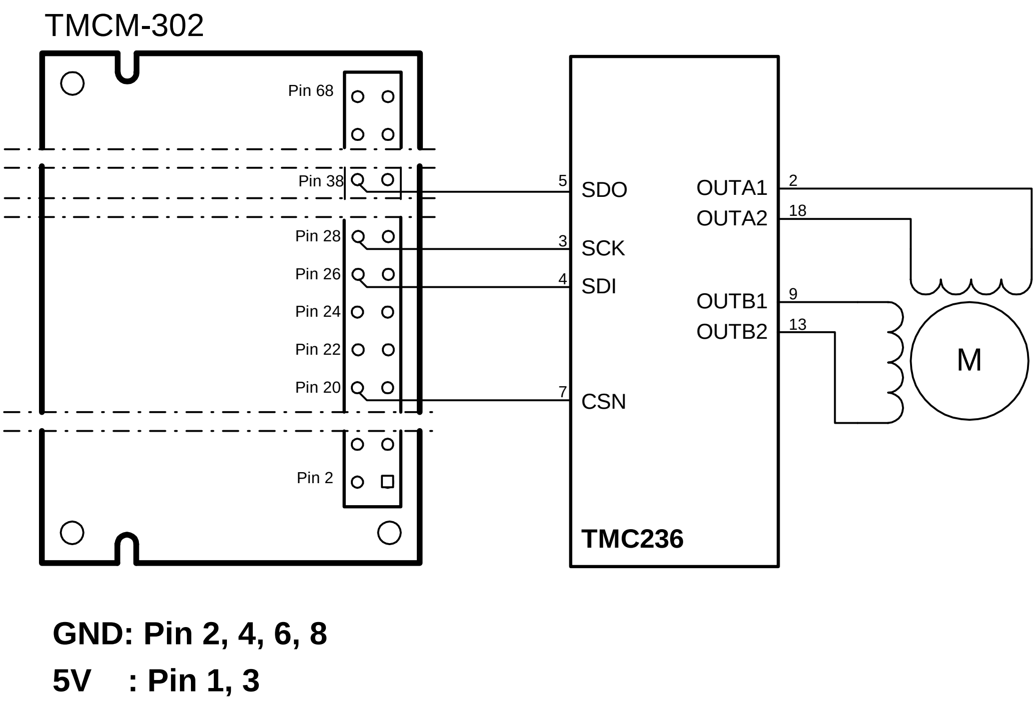

Figure 11: Application with an SPI-stepper motor driver

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Example : Using the parallel stepper motor driver NJM3771

The module's interface to the stepper motor driver is an SPI-Interface. But it is also easy to use parallel stepper motor drivers like the NJM3771, only by adding an 8-bit-shift-register like the 74HC595 (Figure 12).

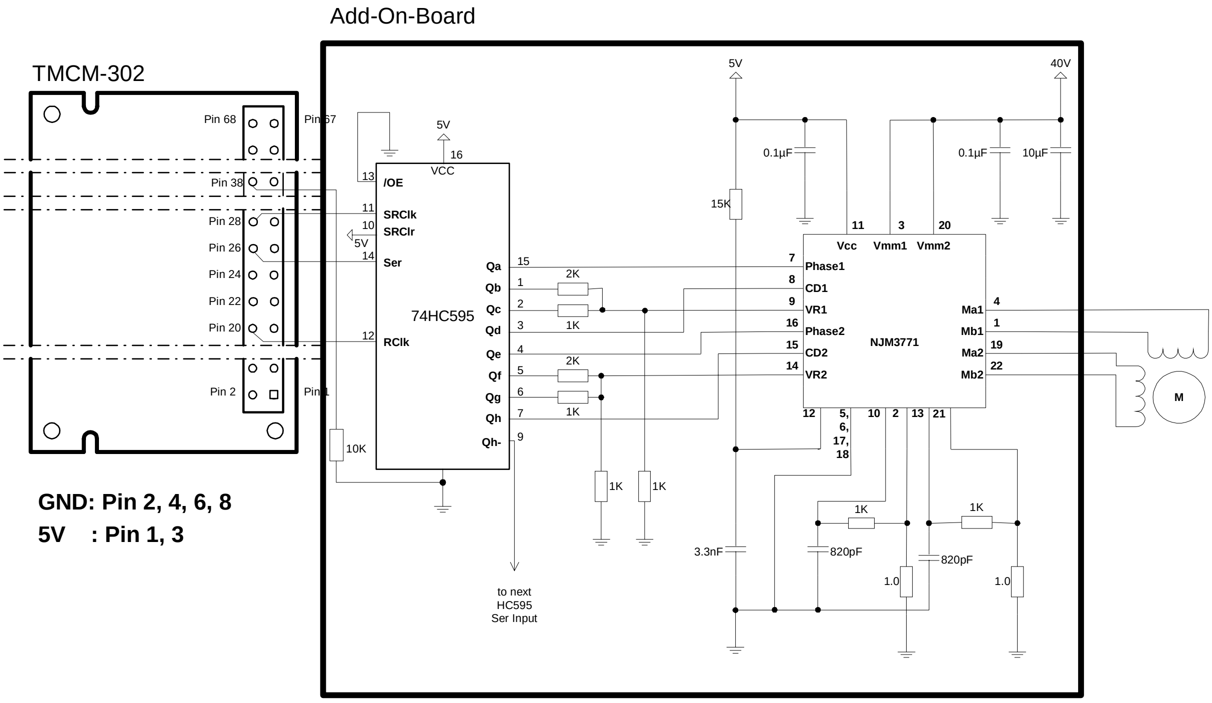

Figure 12: Application with a parallel stepper motor driver

5.4.4 Reference switches

With reference switches, an interval for the movement of the motor or the zero point can be defined. Also a mechanical overloading of the system is avoided if steps are lost, e.g. due to overloading.

Pin Number	Direction	Name	Limits	Description
19	In	STOP0L	TTL	Left reference switch input for Motor #0
21	In	STOP0R	TTL	Right reference switch input for Motor #0
23	In	STOP1L	TTL	Left reference switch input for Motor #1
25	In	STOP1R	TTL	Right reference switch input for Motor #1
27	In	STOP2L	TTL	Left reference switch input for Motor #2
29	In	STOP2R	TTL	Right reference switch input for Motor #2

Table 7: Pinout reference switches

Note: Pullup resistors for reference switches are included on the module.

With reference switches, an interval for the movement of the motor or the zero point can be defined. Also a mechanical overloading of the system is avoided if steps are lost, e.g. due to overloading.

Left and right limit switches

Normally the TMCM-302 is configured in the way, that every motor has a left and a right limit switch (Figure 13).

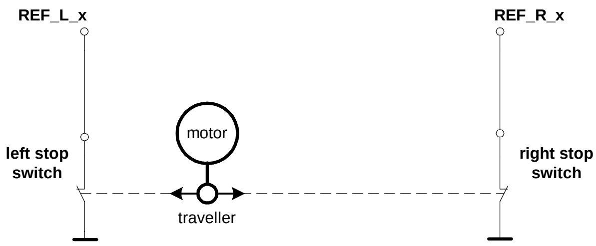

Figure 13: Left and right limit switches

Triple Switch Configuration

It is possible to program a tolerance range around the reference switch position. This is useful for a triple switch configuration, as outlined in Figure 14. In that configuration two switches are used as automatic stop switches, and one additional switch is used as the reference switch between the left stop switch and the right stop switch. The left stop switch and the reference switch are wired or.

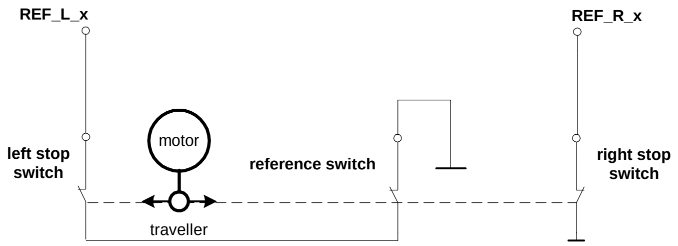

Figure 14: Limit switch and reference switch

One Limit Switch for circular systems

If a circular system is used (Figure 15), only one reference switch is necessary, because there are no end-points in such a system.

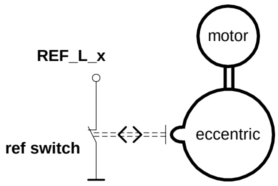

Figure 15: One reference switch

Note:

In the actual TMCL, a function is available, which turns the motor left until the reference switch has been detected. Then the actual and target position are set to zero. In the future, two and three limit switches will also be supported.

5.4.5 Serial Peripheral Interface

On-board communication is performed via the Serial Peripheral Interface, where the microcontroller acts as master. For adaption to user requirements, the user has access to this interface via the 68-pin connector. Furthermore three chip select lines can be used for addressing of external devices.

Pin Number	Direction	Name	Limits	Description
11	Out	SPI_SEL0	TTL	Chip Select Bit0
13	Out	SPI_SEL1	TTL	Chip Select Bit1
15	Out	SPI_SEL2	TTL	Chip Select Bit2
12	Out	SPI_CLK	TTL	SPI Clock
14	In	SPI_MISO	TTL	SPI Serial Data In
16	Out	SPI_MOSI	TTL	SPI Serial Data Out

Table 8: Pinout Serial Peripheral Interface

5.4.6 Port Expansion

For further expansion and adaption to user requirements the module provides a port expansion for the microcontroller. The expansion includes eight input pins and eight output pins, which are accessible via the 68-pin connector.

Pin Number	Direction	Name	Limits	Description
45	In	INP_0	TTL	Port expansion Pin 0, input
47	In	INP_1	TTL	Port expansion Pin 1, input
49	In	INP_2	TTL	Port expansion Pin 2, input
51	In	INP_3	TTL	Port expansion Pin 3, input
53	In	INP_4	TTL	Port expansion Pin 4, input
55	In	INP_5	TTL	Port expansion Pin 5, input
57	In	INP_6	TTL	Port expansion Pin 6, input
59	In	INP_7	TTL	Port expansion Pin 7, input
46	Out	Out_0	TTL	Port expansion Pin 0, output
48	Out	Out_1	TTL	Port expansion Pin 1, output
50	Out	Out_2	TTL	Port expansion Pin 2, output
52	Out	Out_3	TTL	Port expansion Pin 3, output
54	Out	Out_4	TTL	Port expansion Pin 4, output
56	Out	Out_5	TTL	Port expansion Pin 5, output
58	Out	Out_6	TTL	Port expansion Pin 6, output
60	Out	Out_7	TTL	Port expansion Pin 7, output

5.4.7 Miscellaneous Connections

Pin Number	Direction	Name	Limits	Description
17	In	Reset	TTL	Reset, active low
18	Out	Alarm	TTL	Alarm, active high
32	In	Shutdown	TTL	Shutdown TMCM-302

Table 9: Miscellaneous Connections

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6 Putting the TMCM-302 into Operation

On the basis of a small example it is shown step by step how the TMCM-302 is set into operation. Experienced users could skip this chapter and proceed to chapter 6:

Example: The following application is to implement with the TMCL-IDE Software development environment in the TMCM-302 module. For data transfer between the host PC and the module the RS-232 interface is employed.

A formula how "speed" is converted into a physical unit like rotations per seconds can be found in chapter 7.1.

- Turn Motor 0 left with speed 500
- Turn Motor 1 right with speed 500
- Turn Motor 2 with speed 500, acceleration 5 and move between position +10000 and –10000.

Step 1: Connect the RS-232 Interface as specified in 5.4.2.2.

Step 2: Connect the motor drivers as specified in 5.4.3.

Step 3: Connect the power supply.
+5 VDC to pins 1 or 3
Ground to pins 2, 4, 6, 8 or 10

Step 4: Connect the motor supply voltage
+10 to 30 VDC to pins 5, 7, 9

Step 5: Switch on the power supply and the motor supply. An on-board LED should starting to flash. This indicates the correct configuration of the microcontroller.

Step 6: Start the TMCL-IDE Software development environment. Open file test2.tmc. The following source code appears on the screen:
A description for the TMCL commands can be found in Appendix A.

```
//test2.tmc – A simple example for using TMCL and TMCL-IDE

        SAP Mode, 0, VelocityMode   //Set velocity Mode
        ROL 0, 500                  //Rotate motor with speed 500
        WAIT TICKS, 0, 500
        MST 0
        SAP Mode, 1, VelocityMode   //Set velocity Mode
        ROR 1, 500                  //Rotate to other direction with same speed
        WAIT TICKS, 0, 500
        MST 1

        SAP Mode, 2, RampMode       //Set Ramp Mode
        SAP VMax, 2, 500            //Set max. Velocity
        SAP AMax, 2, 5              //Set max. Acceleration
Loop:   MVP ABS, 2, 10000           //Move to Position 10000
        WAIT POS, 2, 0              //Wait until position reached
        MVP ABS, 2, -10000          //Move to Position -10000
        WAIT POS, 2, 0              //Wait until position reached
        JA Loop                     //Infinity Loop
```

Step 7: Click on Icon "*Assemble*" to convert the TMCL into machine code. Then download the program to the TMCM-302 module via the Icon "Download".

Step 8: Press Icon "Run". The desired program will be executed.

A documentation about the TMCL operations can be found in "TMCL Reference and Programming Manual". The next chapter discusses additional operations to turn the TMCM-302 into a high performance motion control system.

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7 TMCM-302 Operational Description

7.1 Calculation: Velocity and Acceleration vs. Microstep- and Fullstep-Frequency

The values of the parameters, sent to the TMC428 do not have typical motor values, like rotations per second as velocity. But these values can be calculated from the TMC428-parameters, as shown in this document. The parameters for the TMC428 are:

Signal	Description	Range
f_{CLK}	clock-frequency	0..16 MHz
velocity	-	0..2047
a_max	maximum acceleration	0..2047
pulse_div	divider for the velocity. The higher the value is, the less is the maximum velocity default value = 0	0..13
ramp_div	divider for the acceleration. The higher the value is, the less is the maximum acceleration default value = 0	0..13
Usrs	microstep-resolution (microsteps per fullstep = 2^{usrs})	0..7 (a value of 7 is internally mapped to 6 by the TMC428)

Table 10: TMC428 Velocity parameters

The **microstep-frequency** of the stepper motor is calculated with

$$usf[Hz] = \frac{f_{CLK}[Hz] \cdot velocity}{2^{pulse\_div} \cdot 2048 \cdot 32}$$ where "usf" means microstep-frequency

To calculate the **fullstep-frequency** from the microstep-frequency, the microstep-frequency must be multiplied with the number of microsteps per fullstep.

$$fsf[Hz] = \frac{usf[Hz]}{2^{usrs}}$$ where "fsf" means fullstep-frequency

The change in the pulse rate per time unit (pulse frequency change per second – the **acceleration a**) is given by

$$a = \frac{f_{CLK}{}^{2} \cdot a_{\max}}{2^{pulse\_div + ramp\_div + 29}}$$

This results in an acceleration in fullsteps of:

$af = \frac{a}{2^{usrs}}$ where “af” means acceleration in fullsteps

Example:
f_CLK = 8 MHz
velocity = 1000
a_max = 1000
pulse_div = 1
ramp_div = 1
usrs = 6

$$msf = \frac{8\,MHz \cdot 1000}{2^1 \cdot 2048 \cdot 32} = \underline{\underline{61035{,}16\,Hz}}$$

$$fsf[Hz] = \frac{61035{,}16}{2^6} = \underline{\underline{953{,}67\,Hz}}$$

$$a = \frac{(8Mhz)^2 \cdot 1000}{2^{1+1+29}} = \underline{\underline{29{,}802\,\frac{MHz}{s}}}$$

$$af = \frac{29{,}802\,\frac{MHz}{s}}{2^6} = \underline{\underline{0{,}466\,\frac{MHz}{s}}}$$

If the stepper motor has e.g. 72 fullsteps per rotation, the number of rotations of the motor is:

$$RPS = \frac{fsf}{fullsteps\ per\ rotation} = \frac{953{,}67}{72} = 13{,}25$$

$$RPM = \frac{fsf \cdot 60}{fullsteps\ per\ rotation} = \frac{953{,}67 \cdot 60}{72} = 794{,}73$$

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Appendix A: Further Documentation

Please refer to www.trinamic.com for updated data sheets and application notes.

The TMCtechLIB CD-ROM including data sheets, application notes, schematics of evaluation boards, software of evaluation boards, source code examples, parameter calculation spreadsheets, tools, and more is available from Trinamic by request to info@trinamic.com