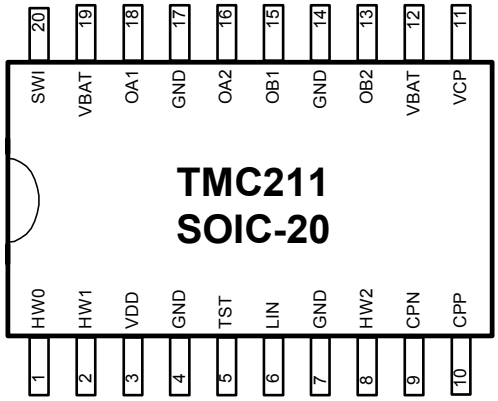
TMC211 – DATASHEET

Micro Stepping Stepper Motor Controller / Driver with LIN Interface



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1 Features

The TMC211 is a combined micro-stepping stepper motor motion controller and driver with RAM and OTP memory. The RAM or OTP memory is used to store motor parameters and configuration settings. The TMC211 allows up to four bit of microstepping and a coil current of up to 800 mA. After initialization it performs all time critical tasks autonomously based on target positions and velocity parameters. Communications to a host takes place via LIN. Together with an inexpensive microcontroller the TMC211 forms a complete motion control system. The main benefits of the TMC211 are:

- **Motor driver**
  - Controls one stepper motor with four bit microstepping
  - Programmable Coil current up to 800 mA
  - Supply voltage operating range 8V ... 29V
  - Fixed frequency PWM current control with automatic selection of fast and slow decay mode
  - Full step frequencies up to 1 kHz
  - High temperature, open circuit, short, over-current and under-voltage diagnostics

- **Motion controller**
  - Internal 16-bit wide position counter
  - Configurable speed and acceleration settings
  - Build-in ramp generator for autonomous positioning and speed control
  - On-the-fly alteration of target position
  - reference switch input available for read out

- **LIN interface**
  - Physical and Data-Link Layers conform to LIN specification rev. 1.3
  - Field-programmable node addresses (128)
  - Dynamically allocated identifiers
  - Diagnostics and status information as well as motion parameters accessable
  - LIN bus short-circuit protection to supply and ground
  - Lost LIN safe operation

Life support policy

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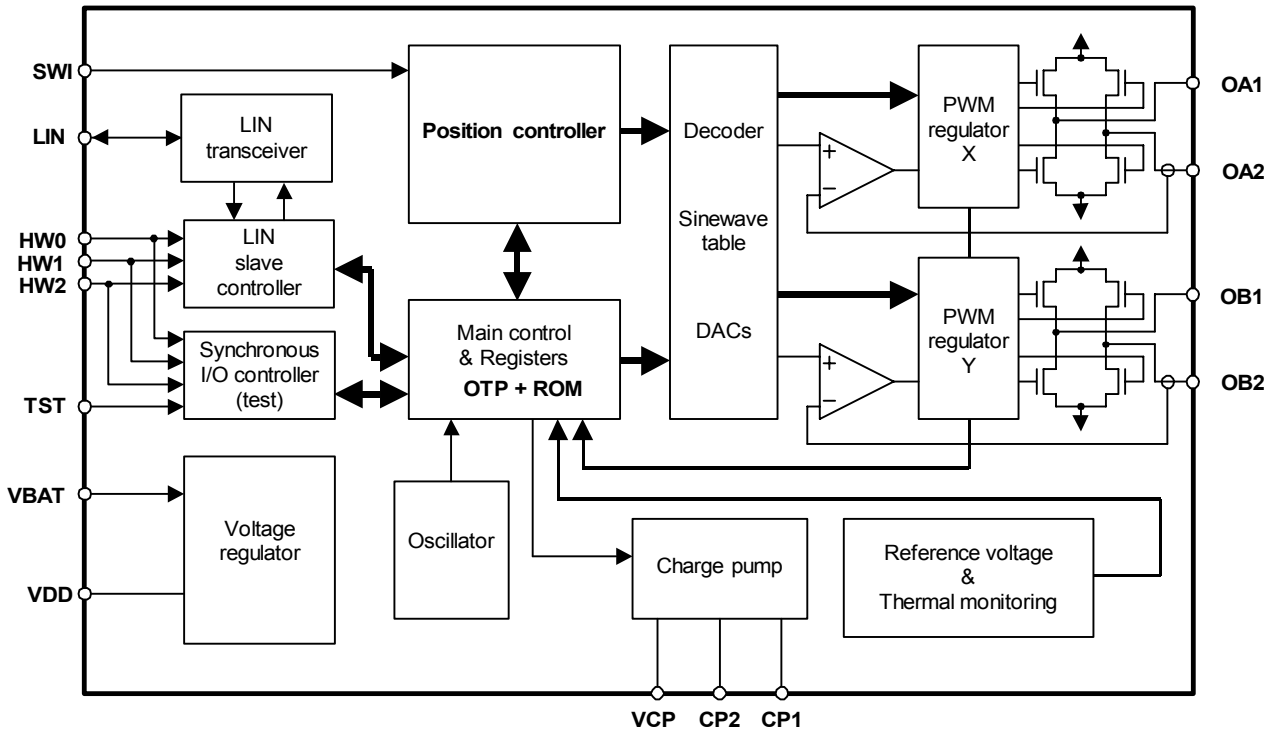
Life support systems are equipment intended to support or sustain life, and whose failure to perform, when properly used in accordance with instructions provided, can be reasonably expected to result in personal injury or death.

Table of Contents

2 General Description

2.1 Block Diagramm



2.2 Position Controller / Main Control

Motor parameters, e.g. acceleration, velocity and position parameters are passed to the main control block via the LIN interface. These information are stored internally in RAM or OTP memory and are accessable by the position controller. This block takes over all time critical tasks to drive a stepper motor to the desired position under abiding the desired motion parameters.
The main controller gets feedback from the stepper motor driver block and is able to arrange internal actions in case of possible problems. Diagnostics information about problems and errors are transferred to the LIN interface block.

2.3 Stepper Motor Driver

Two H-bridges are employed to drive both windings of a bipolar stepper motor. The internal transistors can reach an output current of up to 800 mA. The PWM principle is used to force the given current through the coils. The regulation loop performs a comparison between the sensed output current and the internal reference. The PWM signals to drive the power transistors are derived from the output of the current comparator.

2.4 LIN Interface

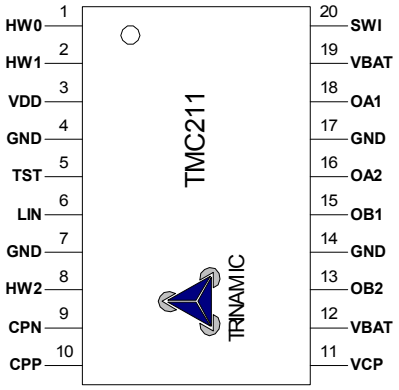
Communication between a host and the TMC211 takes places via the bi-directional LIN interface. Motion Instructions and diagnostic information are provided to or from the Main Control block. It is possible to connect up to 128 devices on the same bus. Slave addresses are programmable via OTP memory or external pins. The LIN interface implements the MAC and LLC layers according to the OSI reference model.

2.5 Miscellaneous

Besides the main blocks the TMC211 contains the following:

- an internal charge pump is used to drive the high side transistors.
- an internal oscillator running at 4 MHz +/- 10% to clock the LIN protocol handler, the positioning unit, and the main control block
- internal voltage reference for precise referencing
- a 5 Volts voltage regulator to supply the digital logic
- protection block featuring Thermal Shutdown, Power-On-Reset, etc.

2.6 Pin and Signal Descriptions



Pin	SOIC20	Description
HW0	1	hard-wired LIN address bit #0 input
HW1	2	hard-wired LIN address bit #1 input
VDD	3	Internal supply (needs external decoupling capacitor)
GND	4,7,14,17	ground, heat sink
TST	5	test pin (to be tied to ground in normal operation)
LIN	6	LIN-bus connection
HW2	8	hard-wired LIN address bit #2 input
CPN	9	negative connection of external charge pump capacitor
CPP	10	positive connection of external charge pump capacitor
VCP	11	connection of external charge pump filter capacitor
VBAT	12,19	battery voltage supply
OB2	13	negative end of phase B coil
OB1	15	positive end of phase B coil
OA2	16	negative end of phase A coil
OA1	18	positive end of phase A coil
SWI	20	reference switch input

Table 1: TMC211 Signal Description

3 Typical Application

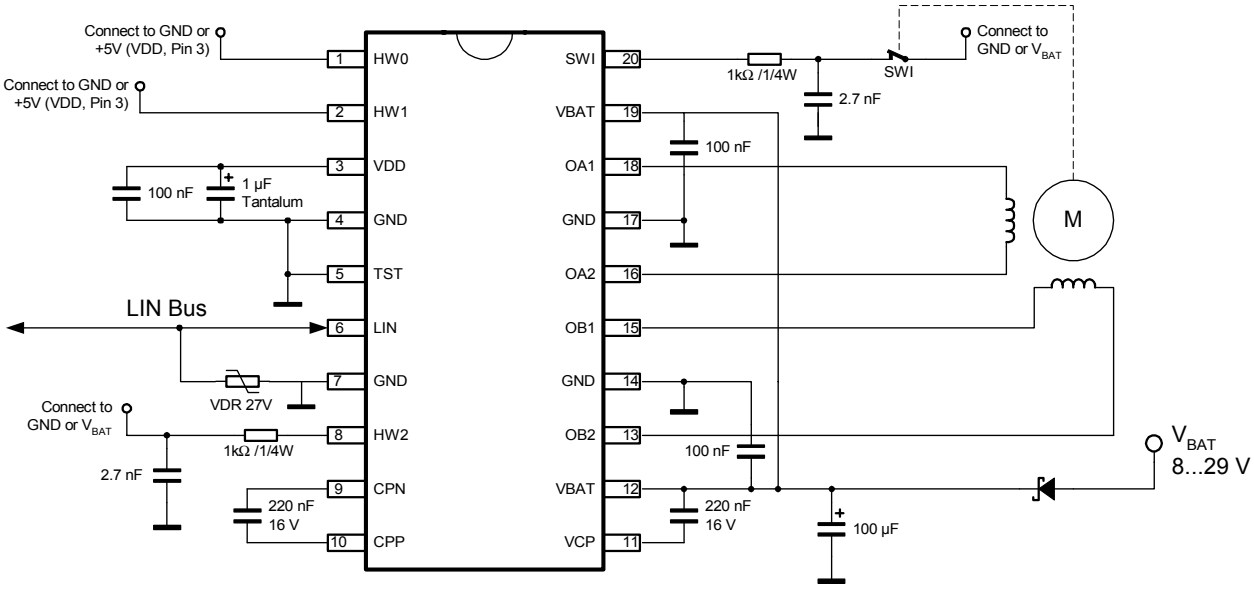


Figure 1: TMC211 Typical Application

Notes :

- Resistors tolerance +- 5%
- 2.7nF capacitors: 2.7nF is the minimum value, 10nF is the maximum value
- the 1µF and 100µF must have a low ESR value
- 100nF capacitors must be close to pins V_{BB} and V_{DD}
- 220nF capacitors must be as close as possible to pins CPN, CPP, V_{CP} and V_{BB} to reduce EMC radiation.

4 Ordering Information

Part No.	Package	Peak Current	Temperature Range
TMC211-PA20 (pre-series marking, same IC as TMC211-SA)	SOIC-20	800 mA	-40°C..125°C
TMC211-SA	SOIC-20	800mA	-40°C..125°C

Table 2: Ordering Information

5 Functional Description

5.1 Position Controller and Main Controller

5.1.1 Stepping Modes

The TMC211 supports up to 16 micro steps per full step, which leads to smooth and low torque ripple motion of the stepping motor. Four stepping modes (micro step resolutions) are selectable by the user: See also 5.3 Stepper Motor Driver on page 21.

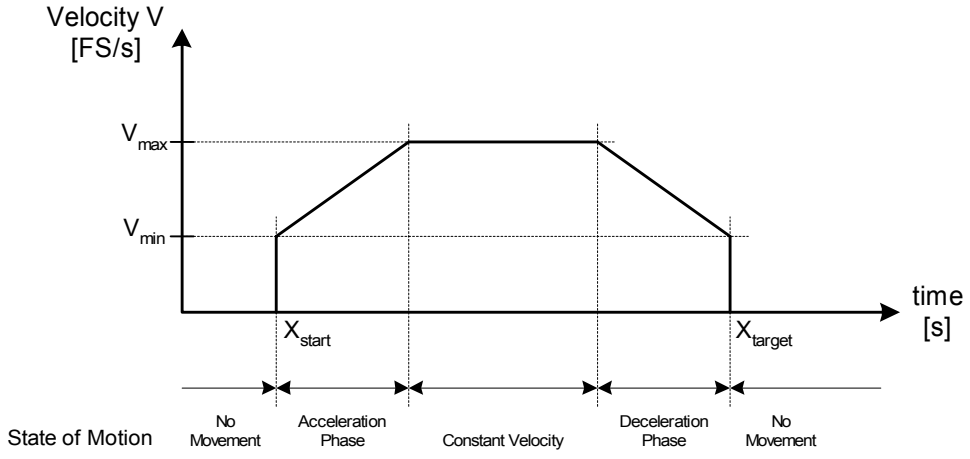
- Half step Mode
- 1/4 Micro stepping
- 1/8 Micro stepping
- 1/16 Micro stepping

5.1.2 Velocity Ramp

A common velocity ramp where a motor drives to a desired position is shown in the figure below. The motion consists of an acceleration phase, a phase of constant speed and a final deceleration phase. Both the acceleration and the deceleration are symmetrical. The acceleration factor can be chosen from a table with 16 entries. (Table 5: Acc Parameter on page 11). A typical motion begins with a start velocity Vmin. During acceleration phase the velocity is increased until Vmax is reached. After acceleration phase the motion is continued with velocity Vmax until the velocity has to be decreased in order to stop at the desired target position. Both velocity parameters Vmin and Vmax are programmable, whereas Vmin is a programmable ratio of Vmax (see Table 3: Vmax Parameter on page 10 and Table 4: Vmin on page 11). The user has to take into account that Vmin is not allowed to change while a motion is ongoing. Vmax is only allowed to change under special circumstances. (See 5.1.4 Vmax Parameter on page 10).

The peak current value to be fed to each coil of the stepper-motor is selectable from a table with 16 possible values. It has to be distinguished between the run current Irun and the hold current Ihold. Irun is fed through the stepper motor coils while a motion is performed, whereas Ihold is the current to hold the stepper motor before or after a motion. More details about Irun and Ihold can be found in 5.3.1 and 5.3.2.

Velocity resp. acceleration parameters are accessable via the LIN interface. These parameters are written via the SetMotorParam command (See Page 42) and read via the GetFullStatus command (See Page 36).



5.1.3 Examples for different Velocity Ramps

The following figures show some examples of typical motions under different conditions:

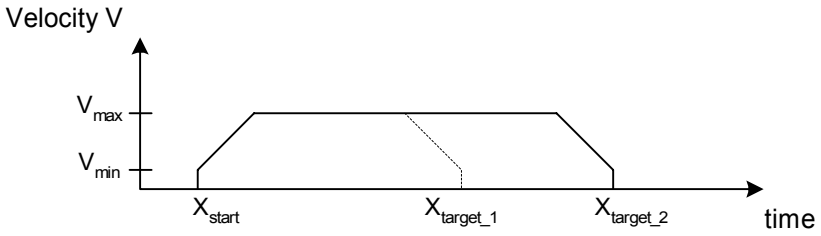


Figure 2: Motion with change of target position

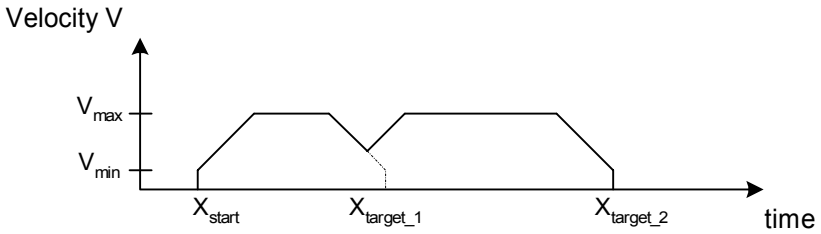


Figure 3: Motion with change of target position while in deceleration phase

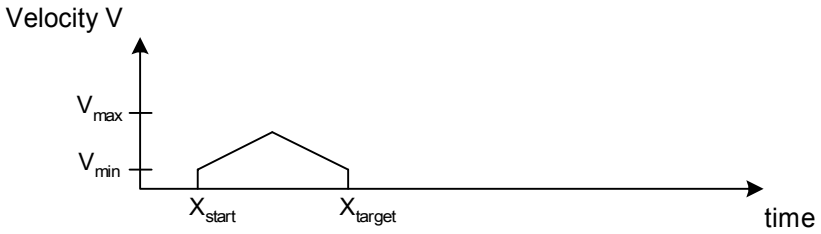


Figure 4: Short Motion Vmax is not reached

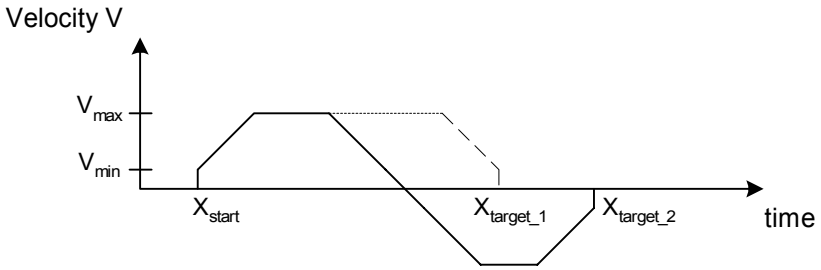


Figure 5: Motion with change of target position in opposite direction (linear zero crossing)

In Figure 5 the motor crosses zero velocity with a linear shape. The velocity can be less than the programmed Vmin value during zero crossing. Linear zero crossing provides very low torque ripple to the stepper motor during crossing.

5.1.4 Vmax Parameter

The desired maximum velocity Vmax can be chosen from the table below:

Vmax index	Vmax [FS/s]	Vmax group	Stepping Mode			
			Half-Step Mode [half-steps/s]	1/4 micro stepping [micro-steps/s]	1/8 micro stepping [micro-steps/s]	1/16 micro stepping [micro-steps/s]
0	99	A	197	395	790	1579
1	136	B	273	546	1091	2182
2	167		334	668	1335	2670
3	197		395	790	1579	3159
4	213		425	851	1701	3403
5	228		456	912	1823	3647
6	243		486	973	1945	3891
7	273	C	546	1091	2182	4364
8	303		607	1213	2426	4852
9	334		668	1335	2670	5341
10	364		729	1457	2914	5829
11	395		790	1579	3159	6317
12	456		912	1823	3647	7294
13	546	D	1091	2182	4364	8728
14	729		1457	2914	5829	11658
15	973		1945	3891	7782	15564

Table 3: Vmax Parameter

Under special circumstances it is possible to change the Vmax parameters while a motion is ongoing. All 16 entries for the Vmax parameter are divided into four groups A, B, C and D. When changing Vmax during a motion take care that the new Vmax value is within the same group. Background: The TMC211 uses an internal pre-divider for positioning calculations. Within one group the pre-divider is equal. When changing Vmax between different groups during a motion, correct positioning is not ensured anymore.

5.1.5 Vmin Parameter

The minimum velocity parameter is a programmable ratio between 1/32 and 15/32 of Vmax. It is also possible to set Vmin to the same velocity as Vmax by setting Vmin index to zero. The table below shows the possible rounded values.

Vmin index	Vmax factor	Vmax group [A...D] and Vmax index [0…15]															
		A	B						C						D		
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	1	99	136	167	197	213	228	243	273	303	334	364	395	456	546	729	973
1	1/32	3	4	5	6	6	7	7	8	8	10	10	11	13	15	19	26
2	2/32	6	8	10	11	12	13	14	15	17	19	21	23	27	30	42	57
3	3/32	9	12	15	18	19	21	22	25	27	30	32	36	42	50	65	88
4	4/32	12	16	20	24	26	28	30	32	36	40	44	48	55	65	88	118
5	5/32	15	21	26	30	32	35	37	42	46	52	55	61	71	84	111	149
6	6/32	18	25	30	36	39	42	45	50	55	61	67	72	84	99	134	179
7	7/32	22	30	36	43	46	50	52	59	65	72	78	86	99	118	156	210
8	8/32	24	33	41	49	52	56	60	67	74	82	90	97	112	134	179	240
9	9/32	28	38	47	55	59	64	68	76	84	94	101	111	128	153	202	271
10	10/32	30	42	52	61	66	71	75	84	94	103	112	122	141	168	225	301
11	11/32	34	47	57	68	72	78	83	94	103	114	124	135	156	187	248	332
12	12/32	37	50	62	73	79	85	91	101	112	124	135	147	170	202	271	362
13	13/32	40	55	68	80	86	92	98	111	122	135	147	160	185	221	294	393
14	14/32	43	59	72	86	92	99	106	118	132	145	158	172	198	236	317	423
15	15/32	46	64	78	92	99	107	114	128	141	156	170	185	214	256	340	454

Table 4: Vmin values for all Vmin index – Vmax index combinations

5.1.6 Acceleration Parameter

The acceleration parameter can be chosen from a wide range of available values as described in the table below. Please note that the acceleration parameter is not to change while a motion is ongoing.

Acceleration Values in [FS/s^2] dependent on Vmax																
Acc index	Vmax [FS/s]															
	99	136	167	197	213	228	243	273	303	334	364	395	456	546	729	973
0	49							106						473		
1	218													735		
2	1004															
3	3609															
4	6228															
5	8848															
6	11409															
7	13970															
8	16531															
9	14785	19092														
10		21886														
11		24447														
12		27008														
13		29570														
14		29570						34925								
15								40047								

Table 5: Acc Parameter

The amount of equivalent full steps during acceleration phase can be computed by the next equation:

$$N_{step} = \frac{V_{max}^2 - V_{min}^2}{2 \cdot Acc}$$

5.1.7 Position Ranges

Position information is coded by using two's complement format. Depending on the stepping mode (see 5.1.1) the position ranges are as listed in the following table:

Stepping Mode	Position Range	Full range excursion
Half-stepping	-4096…+4095 (-2^{12}…$+2^{12}-1$)	8192 half-steps 2^{13}
1/4 micro-stepping	-8192…+8191 (-2^{13}…$+2^{13}-1$)	16384 micro-steps 2^{14}
1/8 micro-stepping	-16384…+16383 (-2^{14}…$+2^{14}-1$)	32768 micro-steps 2^{15}
1/16 micro-stepping	-32768…+32767 (-2^{15}…$+2^{15}-1$)	65536 micro-steps 2^{16}

Table 6: Position Ranges

Target positions can be programmed via LIN interface by using the SetPosition command (see 6.11.11). The actual motor position can be read by the GetActualPos command (see 6.11.1).

5.1.8 Secure Position

In case of emergency (communication loss) or GotoSecurePosition command (6.11.5) the motor drives to the secure position. The secure position is programmable by the user. Secure position is coded with 11 bits, therefore the resolution is lower than for normal positioning commands, as shown in the following table.

Stepping Mode	Secure Position Resolution
Half-stepping	4 half steps
1/4 micro stepping	8 micro steps ($1/4^{th}$)
1/8 micro stepping	16 micro steps ($1/8^{th}$)
1/16 micro stepping	32 micro steps ($1/16^{th}$)

Table 7: Secure Position Resolution

5.1.9 External Switch

Pin SWI will alternately attempt to source and sink current in/from the external switch (Figure 1: TMC211 Typical Application on page 7). This is to check whether the external switch is open or closed, resp. if the pin is connected to ground or Vbat. The status of the switch can be read by using the GetFullStatus or the GetActualPos command. As long as the switch is open, the <ESW> flag is set to zero.

5.1.10 Motor Shutdown Management

The TMC211 is set into motor shutdown mode as soon as one of the following conditions occur:

- The chip temperature rises above the thermal shutdown threshold T_{tsd}. See 5.1.13 Temperature Management on Page 15
- The battery voltage drops below UV2 See 5.1.14 Battery Voltage Management on Page 16.
- An electrical problem occurred, e.g. short circuit, open circuit, etc. In case of such a problem flag <ElDef> is set to one.
- Chargepump failure, indicated by <CPFail> flag set to one.

During motor shutdown the following actions are performed by the main controller:

- H-bridges are set into high impedance mode
- The target position register TagPos is loaded with the contents of the actual position register ActPos.

The LIN interface remains active during motor shutdown. To leave the motor shutdown state the following conditions must be true:

- Conditions which led to a motor shutdown are not active anymore
- A GetFullStatus command is performed via LIN interface.

Leaving the motor shutdown state initiates the following

- H-bridges in Ihold mode
- Clock for the motor control digital circuitry is enabled
- The charge pump is active again

Now the TMC211 is ready to execute any positioning command.

IMPORTANT NOTE:
First, a GetFullStatus command has to be executed after power-on to activate the TMC211.

5.1.11 Reference Search / Position initialization

A stepper motor does not provide information about the actual position of the motor. Therefore it is recommended to perform a reference drive after power-up or if a motor shutdown happened in case of a problem. The RunInit command initiates the reference search. The RunInit command consists of a Vmin and a Vmax parameter and also position information about the end of first and second motion. (6.11.9 RunInit).

A reference drive consists of two motions (Figure 6: RunInit): The first motion is to drive the motor into a stall position or a reference switch. The first motion is performed under compliance of the selected Vmax and Vmin parameter and the acceleration parameter specified in the RAM. The second motion has got a rectangular shape without an acceleration phase and is to drive the motor out of the stall position or slowly towards the stall position again to compensate for the bouncing of the faster first motion to stop as close to the stall position as possible. The maximum velocity of the second motion equals to Vmin. After the second motion the actual position register is set to zero. Finally, the secure position will be traveled to if it is enabled (different from the most negative decimal value of –1024).

Once the RunInit command is started it can not be interrupted by any other command except a condition occurs which leads to a motor shutdown (See 5.1.10 Motor Shutdown Management) or a HardStop command is received. Furthermore the master has to ensure that the target position of the first motion is **not** equal to the actual position of the stepper motor and that the target positions of the first and the second motion are not equal. This is very important otherwise the circuit goes into a deadlock state. Once the circuit finds itself in a deadlock state only a HardStop command followed by a GetFullStatus command will cause the circuit to leave the deadlock state.

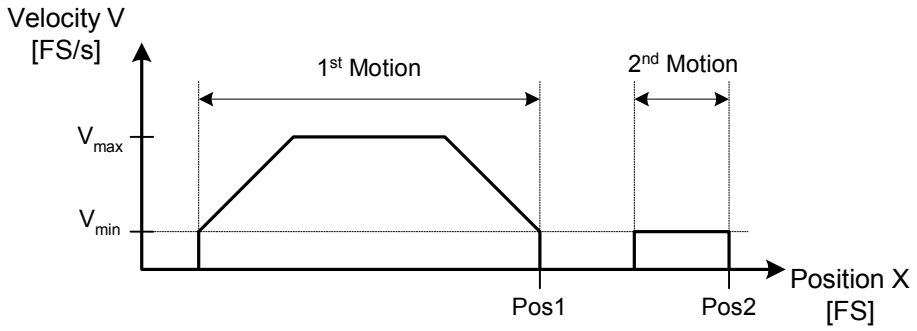


Figure 6: RunInit

5.1.12 Sleep Mode

When entering Sleep mode, the stepper-motor is driven to the secure position if the secure position is enabled (SecPos[10:0] different from the most negative decimal value of –1024). Then the circuit is completely powered down, apart from the LIN receiver which remains active to detect a dominant state on the bus. In case sleep mode is entered while a motion is ongoing, a transition will occur towards secure position as described above.

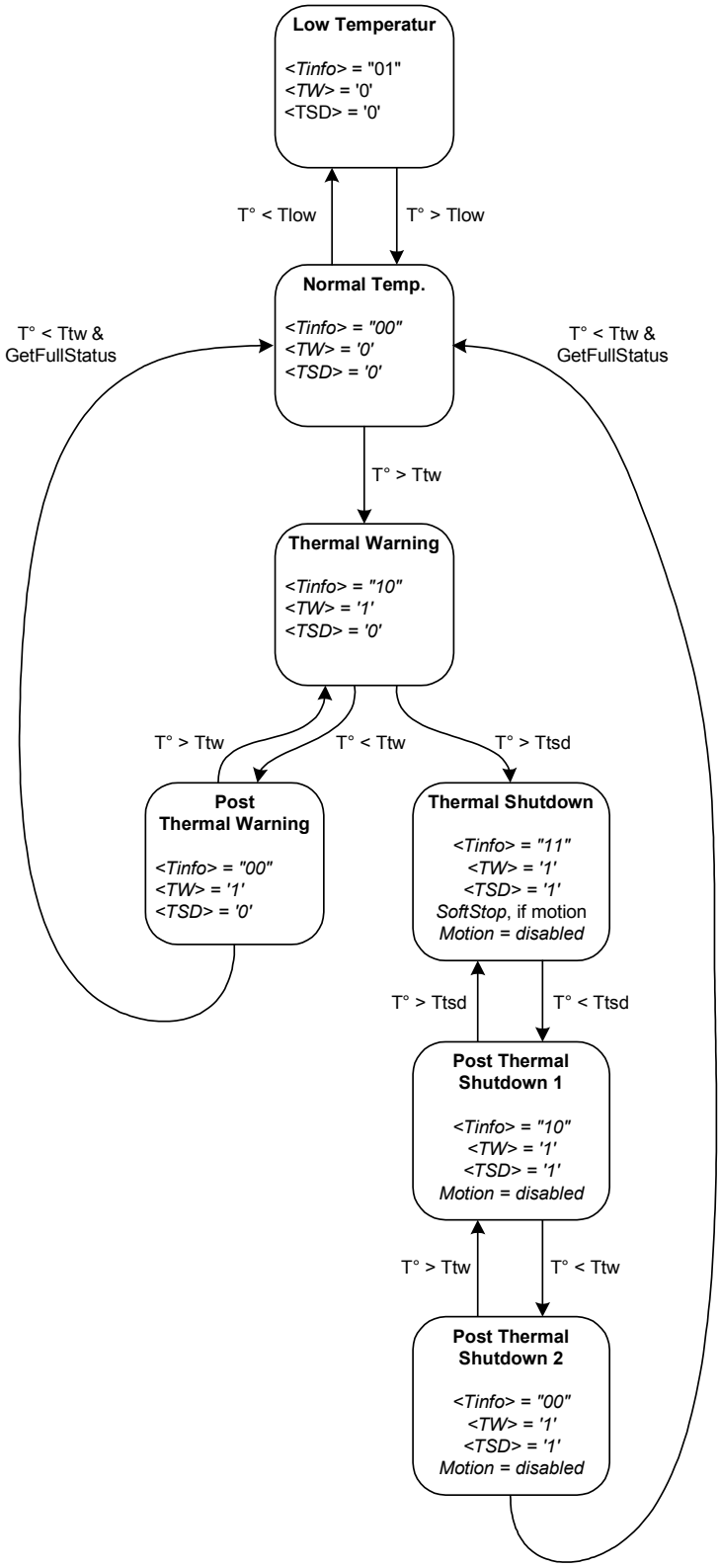
The Sleep mode can be entered in the following cases:

- The circuit receives a LIN frame with identifier 0x3C and first data byte containing 0x00, as required by LIN specification rev. 1.3.
- The LIN bus remains inactive or is lost during more than 25000 LIN bit times (1.30s at 19.2 kbit/s).

The circuit will return to normal mode once a valid LIN frame is received while in the Sleep mode (this valid frame can be addressed to another slave). For more information refer to 6.11.15 Sleep Mode on page 45.

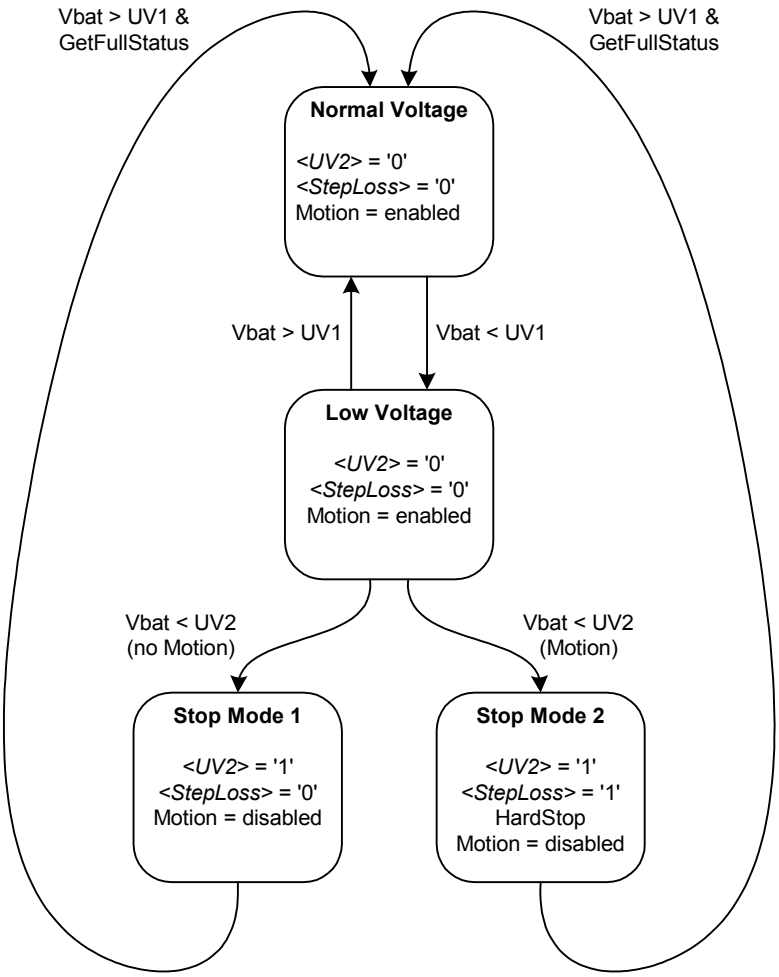
5.1.13 Temperature Management

The TMC211 provides an internal temperature monitoring. The circuit goes into shutdown mode if the temperature exceeds threshold T_{tsd}, furthermore two thresholds are implemented to generate a temperature pre-warning.



5.1.14 Battery Voltage Management

The TMC211 provides an internal battery voltage monitoring. The circuit goes into shutdown mode if the battery voltage falls below threshold UV2, furthermore one threshold UV1 is implemented to generate a low voltage warning.



5.1.15 Internal handling of commands and flags

Due to the sleep mode, the internal handling of commands and flags differs. Commands are handled with different priorities depending on the current state and the current status of internal flags, see figure below. Details can be found in Table 8: Priority Encoder.

Note: A HardStop command is sent by the master or triggered internally in case of an electrical defect or over temperature.

A description of the available commands can be found in 6.11 Command Description. A list of the internal flags can be found in 5.2.2 Status Flags.

As an example: When the circuit drives the motor to its programmed target position, state “GotoPos” is entered. There are three events which can cause to leave this state: HardStop command received, SoftStop command received or target position reached. If all three events occur at the same time the HardStop command is executed since it has the highest priority. The Motion finished event (target position reached) has the lowest priority and thus will only cause transition to “Stopped” state when both other events do not occur.

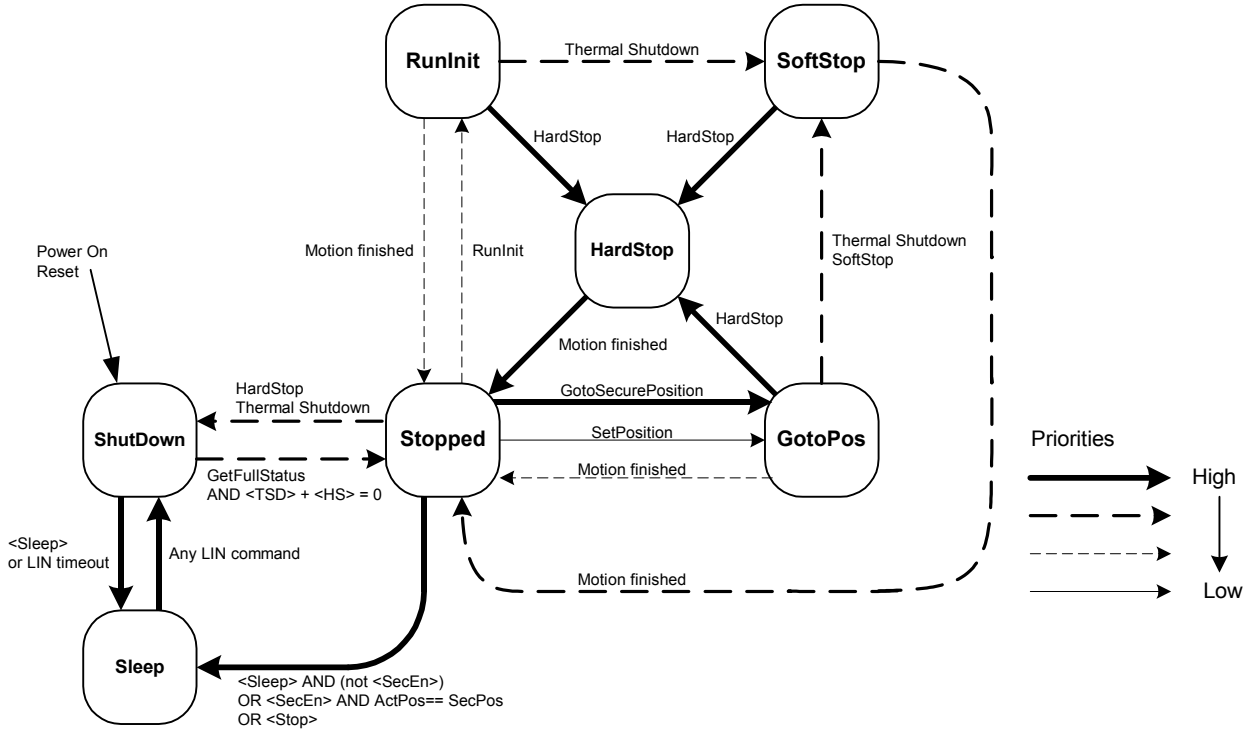


Figure 7: Internal handling of commands and flags

State → / Command ↓	Stopped motor stopped, Ihold in coils	GotoPos motor motion ongoing	RunInit no influence on RAM and TagPos	SoftStop motor decelerating	HardStop motor forced to stop	ShutDown motor stopped, H-bridges in Hi-Z	Sleep no power (note 1)
GetActualPos	LIN in-frame response	LIN in-frame response	LIN in-frame response	LIN in-frame response	LIN in-frame response	LIN in-frame response	
GetOTPParam	OTP refresh; LIN in-frame	OTP refresh; LIN in-frame	OTP refresh; LIN in-frame	OTP refresh; LIN in-frame	OTP refresh; LIN in-frame	OTP refresh; LIN in-frame	
GetFullStatus or GetStatus [attempt to clear <TSD> and <HS> flags]	LIN in-frame response	LIN in-frame response	LIN in-frame response	LIN in-frame response	LIN in-frame response	LIN in-frame response; if (<TSD> or <HS>) = '1' then **→ Stopped**	
ResetToDefault [ActPos and TagPos are not altered]	OTP refresh; OTP to RAM; AccShape reset	OTP refresh; OTP to RAM; AccShape reset	OTP refresh; OTP to RAM; AccShape reset (note 3)	OTP refresh; OTP to RAM; AccShape reset	OTP refresh; OTP to RAM; AccShape reset	OTP refresh; OTP to RAM; AccShape reset	
SetMotorParam [Master takes care about proper update]	RAM update	RAM update	RAM update	RAM update	RAM update	RAM update	
ResetPosition	TagPos and ActPos reset					TagPos and ActPos reset	
SetPosition	TagPos updated; **→GotoPos**	TagPos updated	TagPos updated				
SetPositionShort [half-step mode only)]	TagPos updated; **→GotoPos**	TagPos updated	TagPos updated				
GotoSecurePosition	If <SecEn> = '1' then TagPos = SecPos; **→GotoPos**	If <SecEn> = '1' then TagPos = SecPos	If <SecEn> = '1' then TagPos = SecPos				
RunInit	**→RunInit**						
HardStop		**→HardStop**; <StepLoss> = '1'	**→HardStop**; <StepLoss> = '1'	**→HardStop**; <StepLoss> = '1'			
SoftStop		**→SoftStop**					
Sleep or LIN timeout [⇒ <Sleep> = '1', reset by any LIN command received later]	See note 9	If <SecEn> = '1' then TagPos = SecPos else → **SoftStop**	If <SecEn> = '1' then TagPos = SecPos; will be evaluated after RunInit	No action; <Sleep> flag will be evaluated when motor stops	No action; <Sleep> flag will be evaluated when motor stops	**→Sleep**	
HardStop [⇔ (<CPFail> or <UV2> or <ElDef>) = '1' ⇒ <HS> = '1']	**→Shutdown**	**→HardStop**	**→HardStop**	**→HardStop**			
Thermal shutdown [<TSD> = '1']	**→Shutdown**	**→SoftStop**	**→SoftStop**				
Motion finished	n.a.	**→Stopped**	**→Stopped**	**→Stopped**; TagPos =ActPos	**→Stopped**; TagPos =ActPos	n.a.	n.a.

Table 8: Priority Encoder

Color code:

- Command ignored
- Transition to another state
- Master is responsible for proper update (see note 7)

Notes:

1 Leaving Sleep state is equivalent to Power on reset.

2 After Power on reset, the Shutdown state is entered. The Shutdown state can only be left after a GetStatus or a GetFullStatus command (so that the Master could read the <VddReset> flag).

3 A RunInit sequence runs with a separate set of RAM registers. The parameters which are not specified in a RunInit command are loaded with the values stored in RAM at the moment the RunInit sequence starts. AccShape is forced to '1' during second motion even if a ResetToDefault command is issued during a RunInit sequence, in which case AccShape at '0' will be taken into account after the RunInit sequence.

4 The <Sleep> flag is set to '1' when a LIN timeout or a Sleep command occurs. It is reset by the next LIN command (<Sleep> is cancelled if not activated yet).
5 Shutdown state can be left only when <TSD> and <HS> flags are reset.
6 Flags can be reset only after the master could read them via a GetStatus or GetFullStatus command, and provided the physical conditions allow for it (normal temperature, correct battery voltage and no electrical or charge pump defect).
7 A SetMotorParam command sent while a motion is ongoing (state GotoPos) should not attempt to modify Acc and Vmin values. This can be done during a RunInit sequence since this motion uses its own parameters, the new parameters will be taken into account at the next SetPosition or SetPositionShort command.
8 Some transitions like GotoPos → Sleep are actually done via several states: GotoPos → SoftStop → Stopped → Sleep (see diagram below).
9 Two transitions are possible from state Stopped when <Sleep> = '1':
   1) Transition to state Sleep if (<SecEn> = '0') or ((<SecEn> = '1') and (ActPos = SecPos)) or <Stop> = '1'
   2) Otherwise transition to state GotoPos, with TagPos = SecPos
10 <SecEn> = '1' when register SecPos is loaded with a value different from the most negative value (i.e. different from 0x400 = "100 0000 0000")
11 <Stop> flag allows to distinguish whether state Stopped was entered after HardStop/SoftStop or not. <Stop> is set to '1' when leaving state HardStop or SoftStop and is reset during first clock edge occurring in state Stopped.
12 Command for dynamic assignment of IDs is decoded in all states except Sleep and has not effect on the current state
13 While in state Stopped, if ActPos ≠ TagPos there is a transition to state GotoPos. This transition has the lowest priority, meaning that <Sleep>, <Stop>, <TSD>, etc. are first evaluated for possible transitions.
14 If <StepLoss> is active, then SetPosition, SetPositionShort and GotoSecurePosition commands are ignored (they will not modify TagPos register whatever the state), and motion to secure position is forbidden after a Sleep command or a LIN timeout (the circuit will go into Sleep state immediately, without positioning to secure position). Other command like RunInit or ResetPosition will be executed if allowed by current state. <StepLoss> can only be cleared by a GetStatus or GetFullStatus command.

5.2 RAM and OTP Memory

5.2.1 RAM Registers

Register	Mnemonic	Length (bit)	Related commands	Comment	Reset State
Actual Position	ActPos	16	GetFullStatus ResetPosition	Actual Position of the Stepper Motor. 16-bit signed	0x0000
Target Position	TagPos	16	SetPosition GetFullStatus ResetPosition	Target Position of the Stepper Motor. 16-bit signed	
Acceleration Shape	AccShape	1	GetFullStatus SetMotorParam ResetToDefault	0 = Acceleration with Acc Parameter. 1 = Velocity set to Vmin, without acceleration	
Coil Peak Current	Irun	4	GetFullStatus SetMotorParam ResetToDefault	Coil current when motion is ongoing (Table 12: Irun / Ihold Settings)	OTP Memory
Coil Hold Current	Ihold	4	GetFullStatus SetMotorParam ResetToDefault	Coil current when motor stands still (Table 12: Irun / Ihold Settings)	
Minimum Velocity	Vmin	4	GetFullStatus SetMotorParam ResetToDefault	Start Velocity of the stepper motor (Table 4: Vmin)	
Maximum Velocity	Vmax	4	GetFullStatus SetMotorParam ResetToDefault	Target Velocity of the stepper motor (Table 3: Vmax Parameter)	
Shaft	Shaft	1	GetFullStatus SetMotorParam ResetToDefault	Direction of motion	
Acceleration Deceleration	Acc	4	GetFullStatus SetMotorParam ResetToDefault	Parameter for acceleration (Table 5: Acc Parameter)	
Secure Position	SecPos	11	GetFullStatus ResetToDefault	Target Position for GotoSecurePosition command (6.11.5 GotoSecurePosition) or when LIN connection fails; 11 MSBs of 16-bit position (LSBs fixed to '0')	
Stepping Mode	StepMode	2	GetFullStatus ResetToDefault	Micro stepping mode (5.1.1 Stepping Modes)	

5.2.2 Status Flags

The table below shows the flags which are accessable by the LIN interface in order to receive information about the internal status of the TMC211.

Flag	Mnemonic	Length (bit)	Related Command	Comment	Reset state
Digital supply Reset	VddReset	1	GetFullStatus	Set to '1' after power-up or after a micro-cut in the supply voltage to warn that RAM contents may have been lost. Is set to '0' after GetFullStatus command.	'1'
Over current in coil A	OVC1	1	GetFullStatus	Set to '1' if an over current in coil #1 was detected. Is set to '0' after GetFullStatus command.	'0'
Over current in coil B	OVC2	1	GetFullStatus	Set to '1' if an over current in coil #2 was detected. Is set to '0' after GetFullStatus command.	'0'
StepLoss	StepLoss	1	GetFullStatus	Set to '1' when under voltage, over current or over temperature event was detected. Is set to '0' after GetFullStatus command. SetPosition and GotoSecurePosition commands are ignored when <StepLoss> = 1	'0'
Secure position enabled	SecEn	1	Internal use	'0' if SecPos = "100 0000 0000" '1' otherwise	n.a.
Circuit in Sleep mode	Sleep	1	Internal use	'1' = Sleep mode reset by LIN command	'0'
Electrical Defect	ElDef	1	GetFullStatus	Set to '1' if open circuit or a short was detected, (<OVC1> or <OVC2>). Is set to '0' after GetFullStatus command.	'0'
Temperature Info	Tinfo	2	GetFullStatus	Indicates the chip temperature "00" = normal temperature "01 = low temperature warning "10" = high temperature warning "11" = motor shutdown	"00"
Thermal Warning	TW	1	GetFullStatus	Set to one if temperature raises above 145 °C. Is set to '0' after GetFullStatus command.	'0'
Thermal Shutdown	TSD	1	GetFullStatus	Set to one if temperature raises above 155° C. Is set to '0' after GetFullStatus command and Tinfo = "00".	'0'
Motion Status	Motion	3	GetFullStatus	Indicates the actual behavior of the position controller. "000": Actual Position = Target Position; Velocity = 0 "001": Positive Acceleration; Velocity > 0 "010": Negative Acceleration; Velocity > 0 "011": Acceleration = 0 Velocity = maximum pos Velocity "100": Actual Position /= Target Position; Velocity = 0 "101": Positive Acceleration; Velocity < 0 "110": Positive Acceleration; Velocity < 0 "111": Acceleration = 0 Velocity = maximum neg Velocity	"000"
External Switch Status	ESW	1	GetFullStatus	Indicates the status of the external switch. '0' = open '1' = close	'0'
Charge Pump failure	CPFail	1	GetFullStatus	'0' charge pump OK '1' charge pump failure	'0'
Electrical flag	HS	1	Internal use	<CPFail> or <UV2> or <ElDef>	'0'

5.2.3 OTP Memory Structure

The table below shows where the OTP parameters are stored in the OTP memory.

Note: If the OTP memory has not been programmed, or if the RAM has not been programmed by a SetMotorParam command, or if anyhow <VddReset> = '1', any positioning command will be ignored, in order to avoid any consequence due to unwanted RAM content. Please check that the correct supply voltage is applied to the circuit before zapping the OTP (See: Table 25: DC Parameters Supply and Voltage regulator on page 54), otherwise the circuit will be destroyed.

OTP Address	OTP Bit Order							
	7	6	5	4	3	2	1	0
0x00	OSC3	OSC2	OSC1	OSC0	IREF3	IREF2	IREF1	IREF0
0x01	EnableLIN	TSD2	TSD1	TSD0	BG3	BG2	BG1	BG0
0x02	ADM				AD3	AD2	AD1	AD0
0x03	Irun3	Irun2	Irun1	Irun0	Ihold3	Ihold2	Ihold1	Ihold0
0x04	Vmax3	Vmax2	Vmax1	Vmax0	Vmin3	Vmin2	Vmin1	Vmin0
0x05	SecPos10	SecPos9	SecPos8	Shaft	Acc3	Acc2	Acc1	Acc0
0x06	SecPos7	SecPos6	SecPos5	SecPos4	SecPos3	SecPos2	SecPos1	SecPos0
0x07					StepMode1	StepMode0	LOCKBT	LOCKBG

Table 9: OTP Memory Structure

Parameters stored at address 0x00 and 0x01 and bit LOCKBT are already programmed in the OTP memory at circuit delivery, they correspond to the calibration of the circuit and are just documented here as an indication. Each OPT bit is at '0' when not zapped. Zapping a bit will set it to '1'. Thus only bits having to be at '1' must be zapped. Zapping of a bit already at '1' is disabled, to avoid any damage of the Zener diode. It is important to note that only one single OTP byte can be programmed at the same time (see command SetOTPParam).

Once OTP programming is completed, bit LOCKBG can be zapped, to disable unwanted future zapping, otherwise any OTP bit at '0' could still be zapped.

Lock bit	Protected byte
LOCKBT (zapped before delivery)	0x00 to 0x01
LOCKBG	0x02 to 0x07

Table 10: OTP Lock bits

The command used to load the application parameters via the LIN bus into the RAM prior to an OTP memory programming is SetMotorParam. This allows for a functional verification before using a SetOTPParam command to program and zap separately one OTP memory byte. A GetOTPParam command issued after each SetOTPParam command allows to verify the correct byte zapping.

5.3 Stepper Motor Driver

The StepMode parameter in SetMotorParam command (6.11.10 SetMotorParam on page 42) is used to select different stepping modes. Following modes are available:

StepMode parameter	Mode
00	Half Stepping
01	¼ µStepping
10	1/8 µStepping
11	1/16 µStepping

Table 11: StepMode

5.3.1 Coil current shapes

The next four figures show the current shapes fed to each coil of the motor in different stepping modes.

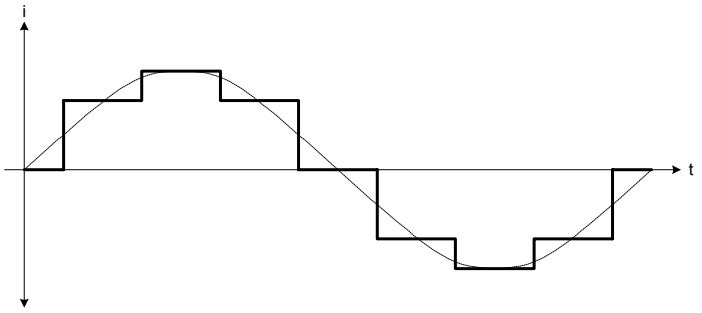


Figure 8: Coil Current for Half Stepping Mode

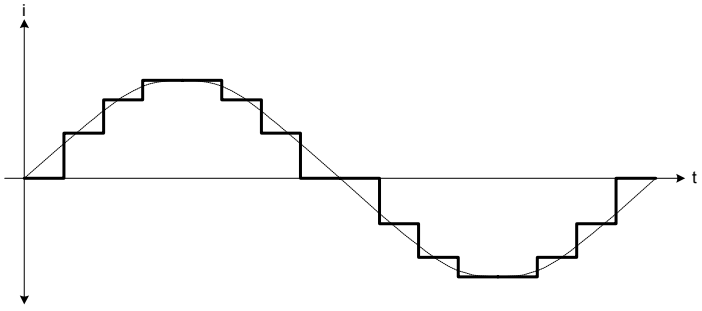


Figure 9: Coil Current for 1/4 Micro Stepping Mode

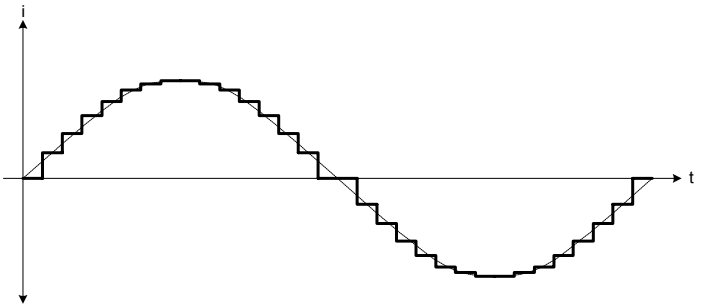


Figure 10: Coil Current for 1/8 Micro Stepping Mode

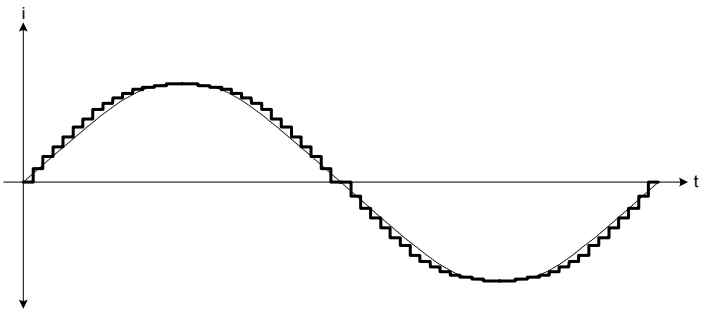


Figure 11: Coil Current for 1/16 Micro Stepping Mode

5.3.2 Transition Irun to Ihold

At the end of a motor motion the actual coil currents Irun are maintained in the coils at their actual DC level for a quarter of an electrical period (two half steps) at minimum velocity. Afterwards the currents are then set to their hold values Ihold. The figure below illustrates the mechanism:

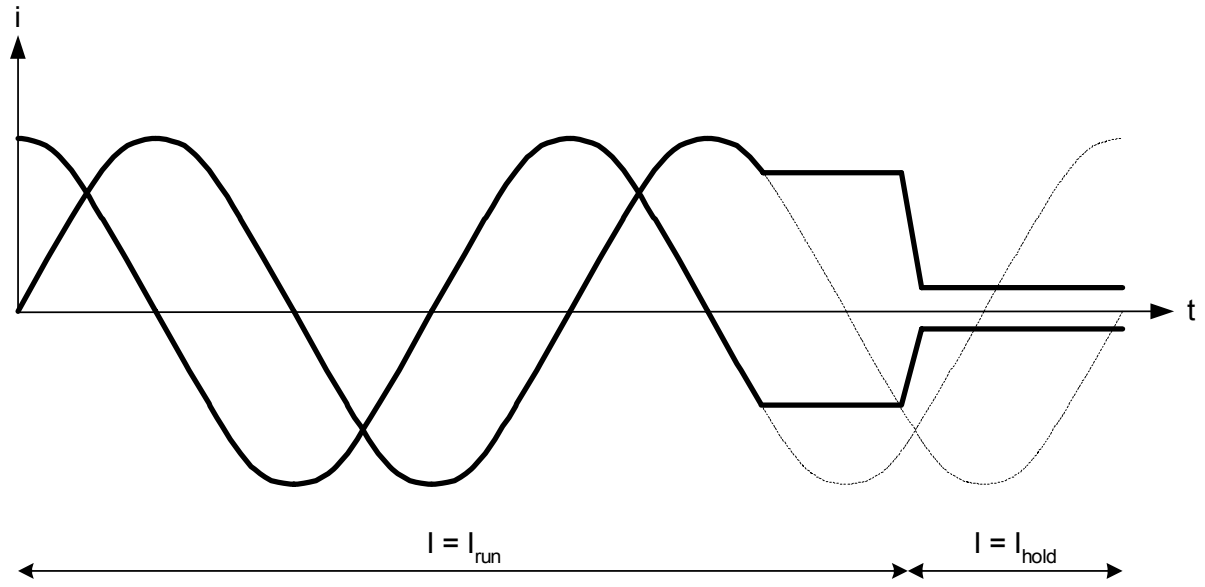


Figure 12: Transition Irun to Ihold

Both currents Irun and Ihold are parameterizeable using the command SetMotorParam. 16 values are available for Irun current and 16 values for Ihold current. The table below shows the corresponding current values.

Irun / Ihold setting (hexadecimal)	Peak Current [mA]
0x0	59
0x1	71
0x2	84
0x3	100
0x4	119
0x5	141
0x6	168
0x7	200
0x8	238
0x9	283
0xA	336
0xB	400
0xC	476
0xD	566
0xE	673
0xF	800

Table 12: Irun / Ihold Settings

5.3.3 Chopper Mechanism

The chopper frequency is fixed as specified in chapter 10.4 AC Parameters on page 55. The TMC211 uses an intelligent chopper algorithm to provide a smooth operation with low resonance. The TMC211 uses internal measurements to derive current flowing through coils. If the current is less than the desired current, the TMC211 switches a H-bridge in a way that the current will increase. Otherwise if the current is too high, the H-bridge will be switched to decrease the current. For decreasing two modes are available, slow decay and fast decay, whereas fast decay decreases the current faster than slow decay. The figure below shows the chopper behavior.

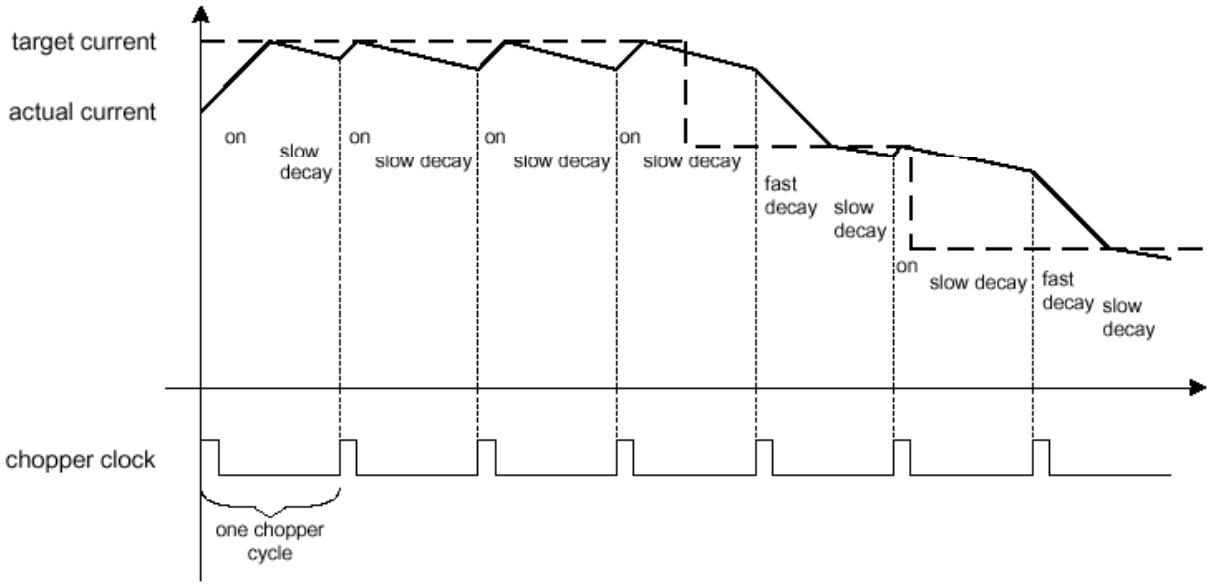


Figure 13: Different Chopper Cycles with Fast and Slow Decay

6 LIN Interface

6.1 General Description

The LIN (Local Interconnect Network) is a serial communication protocol that is used mainly for distributed mechatronic systems in automotive applications. The LIN implementation in the TMC211 corresponds to one slave node which follows to LIN specification rev. 1.2.

Features:

- Single master / multiple-slave communication
- Self synchronizing slave nodes / no quartz or ceramics resonator necessary
- Deterministic latency times for signal transmission
- Single-wire communication
- Transmission speed 19.2 kbit/s
- Selectable length of Message Frame: 2, 4, and 8 bytes
- Configuration flexibility
- Data checksum security and error detection
- Detection of defective nodes in the network

For more information about the LIN protocol please refer to the official website and the LIN Protocol Specification. Both can be found at http://www.lin-subbus.org/.

6.2 Physical Layer

The physical layer is a single wire with pull-up resistor in every node. The bus is directly powered from the vehicle power net V_{bb}.

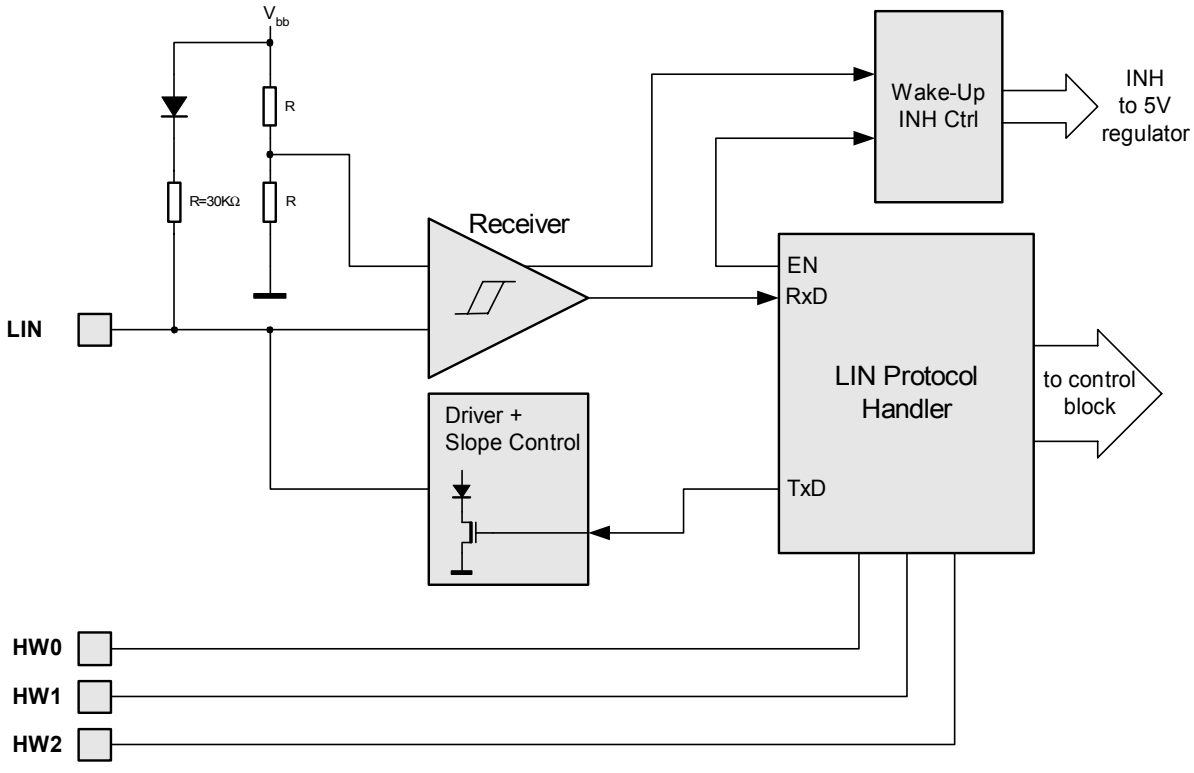


Figure 14: LIN Physical Layer

6.3 Analog Part

The transmitter is a low-side driver with a pull-up resistor and slope control. The figure below shows the characteristics of the transmitted signal, including the delay between internal TxD Signal and LIN Signal. See Table 32: AC Parameters LIN Transmitter on page 55 and Table 33: AC Parameters LIN Receiver on page 55 for timing values.

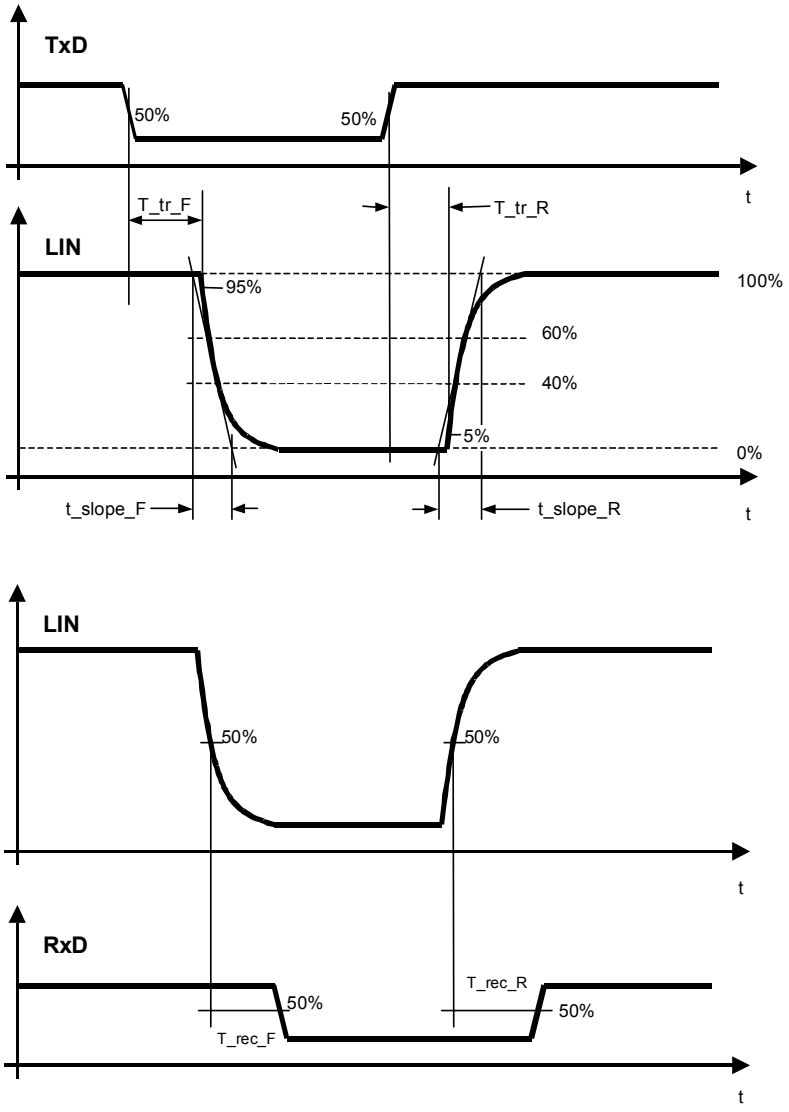


Figure 15: LIN Signal Characteristics

6.4 Slave operational range for proper self synchronization

The internal oscillator having a ± 10% accuracy over the voltage and temperature range, will synchronize properly in the following conditions:

- Vbb ≥ 8 V
- Ground shift between Master node and Slave node < ± 1 Volt

It is highly recommended to use the same type of reverse battery voltage protection diode for the Master and the Slave nodes.

6.5 Physical Address of the circuit

The circuit must be provided with a physical address in order to discriminate this circuit from other ones on the LIN bus. This address is coded on seven bits, yielding the theoretical possibility of 128 different circuits on the same bus. It is a combination of four OTP memory bits (see 5.2.3 OTP Memory Structure) and three hardwired address bits (pins HW0, HW1 and HW2). Pins HW0 and HW1 are 5V digital inputs, whereas pin HW2 is compliant with a 12V level. HW2 must either be connected to Vbat or ground. Pin HW2 uses the same principle to check whether it is connected to ground or Vbat like the SWI input (see 5.1.9 External Switch).

The TCM211 supports broadcasting. When the <Broad> bit is set to zero, broadcasting is active and each slave on the LIN bus will be addressed.

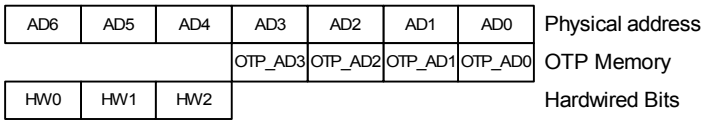


Figure 16: Physical Slave Address

The amount of physical addresses can be expanded by using bit ADM. This bit allows for the following expansion:

ADM	AD6	AD5	AD4	AD3	AD2	AD1	AD0
0	HW0	HW1	HW2	PA3	PA2	PA1	PA0
1	PA0	HW0	HW1	HW2	PA3	PA2	PA1

Table 13: Physical Address Expansion

6.6 Electro Magnetic Compability

EMC behavior fulfills requirements defined by LIN specification rev. 1.3.

6.7 Error Status Register

The LIN interface implements a register containing an error status of the LIN communication. This register is specified as follows:

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
Not used	Not used	Not used	Not used	Timeout Error Flag	Data Error Flag	Header Error Flag	Bit Error Flag

Table 14: LIN Error Status Register

Note:
Data Error Flag = Checksum error OR StopBit error OR Length error
Header Error Flag = Parity error OR Synch Field error

A GetFullStatus command will reset the error status register

6.8 Dynamic Assignment of LIN Identifiers

The identifier field in the LIN message frame denotes the content of the message. Six identifier bits and two parity bits are used to represent the content. The identifiers 0x3C to 0x3F are reserved for command frames and extended frames. Slave nodes need to be very flexible to adapt itself to a given LIN network in order to avoid conflicts with slave nodes from different manufacturers. Dynamic assignment of identifiers fulfills this requirement by writing identifiers into the circuits RAM. ROM pointers are linking commands and dynamic identifiers together.

A writing frame with identifier 0x3C issued by the LIN master writes dynamic identifiers into the RAM. One writing frame is able to assign 4 identifiers, therefore 3 frames are needed to assign all identifiers. Each ROM pointer ROMp_x [3:0] places the corresponding dynamic identifier Dyn_ID_x [5:0] at the correct place in the RAM, see table below. When setting <BROAD> to zero broadcasting is active and each slave on the LIN bus will store the same dynamic identifiers, otherwise only the slave with the corresponding slave address is programmed.

Dynamic Identifiers Writing Frame									
Byte	**Content**	**Structure**							
		Bit7	**Bit6**	**Bit5**	**Bit4**	**Bit3**	**Bit2**	**Bit1**	**Bit0**
0	Identifier	0x3C							
1	AppCMD	0x80							
2	CMD	1	0x11						
3	Address	Broad	AD6	AD5	AD4	AD3	AD2	AD1	AD0
4	Data	DynID_1 [3:0]				ROMp_1 [3:0]			
5	Data	DynID_2 [1:0]		ROMp_2 [3:0]				DynID_1 [5:4]	
6	Data	ROMp_3 [3:0]				DynID_2 [5:2]			
7	Data	ROMp_4 [1:0]		DynID_3 [5:0]					
8	Data	DynID_4 [5:0]						ROMp_4 [3:2]	

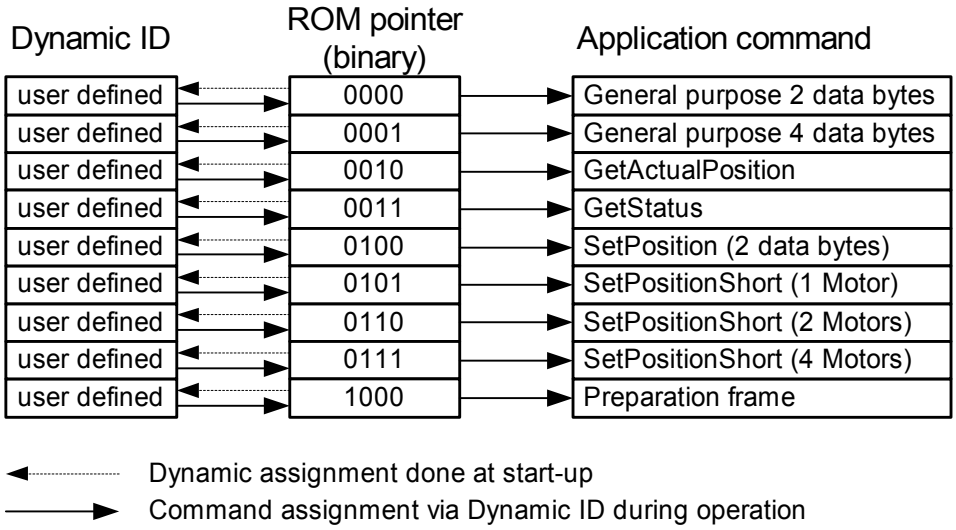


Figure 17: Principle of dynamic command assignment

Command Mnemonic	Command Byte (CMD)		Dynamic ID (binary; example)	ROM pointer (binary)
	binary	hex		
GetActualPos	000000	0x00	100xxx	0010
GetFullStatus	000001	0x01	Not used	
GetOTPParam	000010	0x02	Not used	
GetStatus	000011	0x03	000xxx	0011
GotoSecurePosition	000100	0x04	Not used	
HardStop	000101	0x05	Not used	
ResetPosition	000110	0x06	Not used	
ResetToDefault	000111	0x07	Not used	
RunInit	001000	0x08	Not used	
SetMotorParam	001001	0x09	Not used	
SetPosition	001011	0x0B	010xxx	0100
SetPositionShort (1 Motor)	001100	0x0C	001001	0101
SetPositionShort (2 Motors)	001101	0x0D	101001	0110
SetPositionShort (4 Motors)	001110	0x0E	111001	0111
Sleep	Not used		Not used	
SoftStop	001111	0x0F	Not used	
SetOTPParam	010000	0x10	Not used	
Dynamic ID assignment	010001	0x11	Not used	
General Purpose 2 Data Bytes			011000	0000
General Purpose 4 Data Bytes			101000	0001
Preparing Frame			011010	1000

Table 15: Commands and Corresponding Dynamic IDs

Note: xxx allows to address physically a slave node. Therefore, these dynamic IDs cannot be used for more than 8 stepper motors.

6.9 LIN Message Frames

As specified in LIN specification rev. 1.3 a LIN frame consists of an 8-bit identifier field, followed by 2, 4 or 8 data fields and a checksum field. A LIN frame can either be a writing frame, with one of the following tasks:

- Program the OTP memory
- Provide motion parameters, e.g. velocity, position, torque to the TMC211

Or a LIN frame can be a reading frame which is used to:

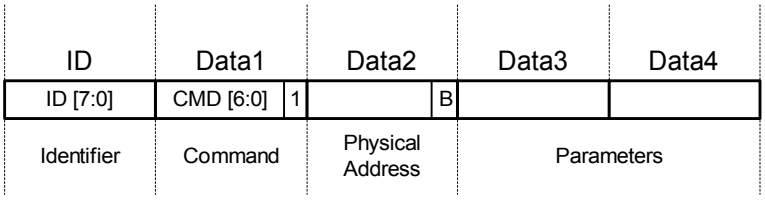
- Read actual position or status information of the stepper motor
- Verify correct programming and configuration

6.9.1 Writing Frames

According to the LIN specification there is only a fixed amount of identifiers available. In order to expand the amount of identifiers resp. the amount of commands different types of writing frames are introduced. The TMC211 supports four different writing frames. The following figures illustrate the differences.

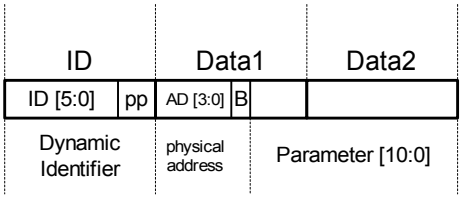
6.9.2 Writing Frame Type#1 (2 or 4 bytes)

General purpose 2 or 4 data bytes writing frame with a dynamically assigned identifier. This type is used to provide 2 or 4 bytes of data to the slave nodes. When <Broad> is set to zero, broadcasting is active and the command is valid for all slave nodes. When <Broad> is one the command is only valid for one slave node whose physical address corresponds to the one provided by the writing frame.
A writing frame of 2 bytes issues only a defined command to the slave node(s), e.g. HardStop command. Whereas a writing frame of 4 bytes issues a command and 2 bytes of data to the slave node(s), e.g. SetPosition command.



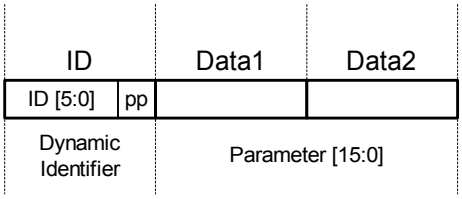
6.9.3 Writing Frame Type#2 (2, 4 or 8 bytes)

2, 4 or 8 data bytes writing frame with an identifier dynamically assigned to a particular application command, regardless of the physical address of the circuit. e.g. SetPositionShort command.



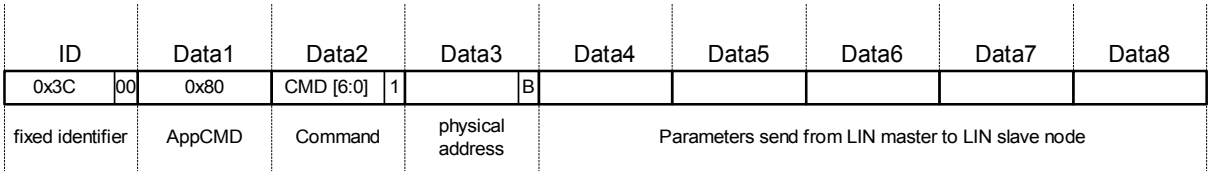
6.9.4 Writing Frame Type#3 (2 bytes)

2 data bytes writing frame with an identifier dynamically assigned to a particular slave node and application command. This type of frame requires that there are as many dynamically assigned identifiers as there are TMC211 circuits connected to the LIN bus using this command.



6.9.5 Writing Frame Type#4 (8 bytes)

8 data bytes writing frame with fixed identifier 0x3C. The structure is similar to type#1 but uses the reserved identifier 0x3C. Using a reserved identifier followed by a particular application command will expand the amount of possible LIN commands.



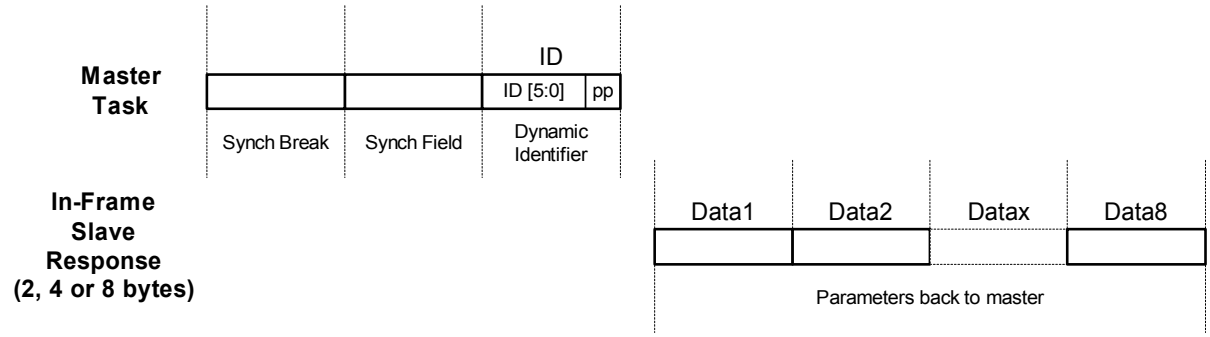
6.9.6 Reading Frames

When using reading frames the master initiates the communication by sending a header field, which contains the synchronization and identifier field. The TMC211 supports two types of identifiers:

- Direct ID: The identifier points to a particular slave node. As described in the LIN specification the slave sends the data as in-frame response. Direct ID gives the fastest access to the required data.
- Indirect ID: Indirect ID contains of two datagrams. The first datagram, called preparing frame, issues the slave's physical address to the particular slave node. The second datagram specifies only a reading command by using the reserved identifier 0x3D. Indirect ID has the advantage to use a reserved identifier and therefore provides more flexibility.

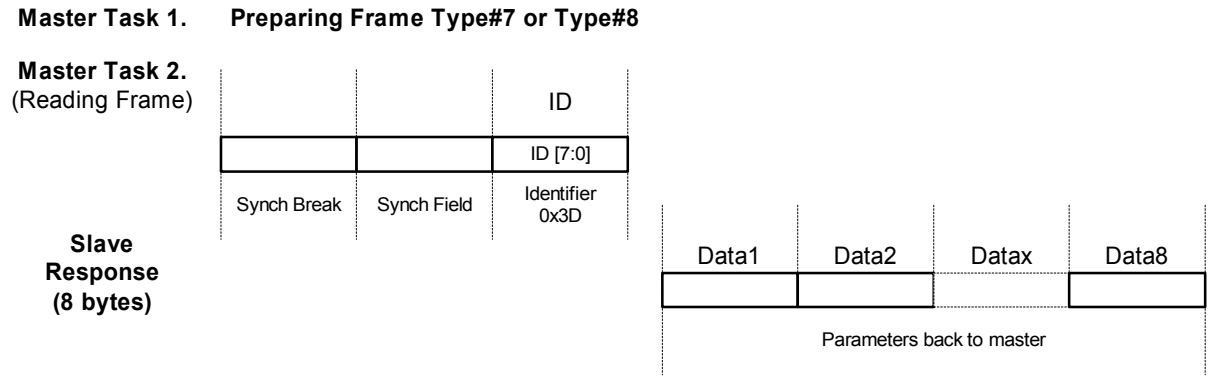
6.9.7 Reading Frame Type#5 (2, 4 or 8 bytes)

Type#5 is a reading frame, which uses a direct ID, therefore the master initiates the communication and the slave responds after receiving the identifier. Dependent on the identifier the slave transmits 2, 4 or 8 bytes of data. GetActualPos command uses Type#5 reading frame.



6.9.8 Reading Frame Type#6 (8 bytes)

Reading frame Type#6 uses indirect ID and therefore a preparing frame of Type#7 or #8 is needed. The preparing frame dumps the reading command into a particular slave node. Data from the slave is then transmitted after the next reading frame. The reading frame must always be consecutive to a preparing frame, otherwise it is not valid and not taken into account.



6.9.9 Reading Frame Type#7 (Preparing frame)

A preparing frame prepares a particular slave node, that it has to answer after the next reading frame. Preparing frames are needed when using indirect ID. Type#7 preparing frame consists of a dynamically assigned identifier, the command indicating which kind of information is to provide to the master and the physical address of the slave.

ID	Data1	Data2
ID [7:0]	CMD [6:0]	AD [6:0]
Identifier	Command	Physical Address

6.9.10 Reading Frame Type#8 (Preparing frame)

Type#8 preparing frame uses the reserved identifier 0x3C, followed by the application command 0x80, then the particular reading command and the physical address is provided to the slave.

ID	Data1	Data2	Data3	Data4		Data8
ID [7:0]	AppCMD [7:0]	CMD [6:0]	AD [6:0]	0xFF	0xFF	0xFF
Identifier 0x3C	AppCMD 0x80	Command	Slave Address	Data 4...8 = 0xFF		

6.10 Application Commands Overview

Communications between the TMC211 and a LIN Master takes place via a set of commands.

Reading commands are used to:
- Get actual status information, e.g. error flags
- Get actual position of the Stepper Motor
- Verify the right programming and configuration of the TMC211

Writing commands are used to:
- Program the OTP Memory
- Configure the TMC211 with motion parameters (e.g. max/min speed, acceleration, stepping mode, etc.)
- Provide target positions to the Stepper motor

Command Mnemonic	Function
GetActualPos	Returns actual position of the motor
GetFullStatus	Returns actual, target and secure position and also the complete status of the circuit
GetOTPParam	Returns OTP memory content
GetStatus	Returns quick status of the circuit
GotoSecurePosition	Drives motor to secure position
HardStop	Immediate full stop
ResetPosition	Actual and target position becomes zero
ResetToDefault	Overwrites the chip RAM with OTP contents
RunInit	Reference Search
SetMotorParam	Sets motor parameter
SetPosition	Drives the motor to the target position
SetPositionShort (1 Motor)	Drives the motor to the target position (Half stepping mode only)
SetPositionShort (2 Motors)	Drives 2 motors to the target position (Half stepping mode only)
SetPositionShort (4 Motors)	Drives 4 motors to the target position (Half stepping mode only)
SoftStop	Stops the motor with deceleration phase
SetOTPParam	Programs the selected byte of OTP memory
Sleep	Causes circuit to go into sleep mode

Table 16: Command Overview

6.11 Command Description

6.11.1 GetActualPos

This command is provided to the circuit by the LIN master to get the actual position of the stepper motor. GetActualPos provides also a quick status of the circuit and of the stepper motor, identical to that obtained by command GetFullStatus. The GetActualPos will not attempt to reset any flags. This command can be sent using direct or indirect ID:

1. Direct ID (immediate in-frame slave response):

GetActualPos direct ID reading frame(type#5)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	1	0	ID3	ID2	ID1	ID0
Slave	1	Slave Address	ESW	AD [6:0]						
	2	Actual Position	ActPos [15:8]							
	3		ActPos [7:0]							
	4	Status	VddReset	StepLoss	ElDef	UV2	TSD	TW	Tinfo [1:0]	

Note: * according to parity calculation
ID [3:0]: Dynamically allocated identifier to GetActualPos command.

Or:
2. Indirect ID (preparing frame followed by indirect ID reading frame):

The master sends **either** type#7 **or** type#8 preparing frame:

GetActualPos preparing frame (type#7)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
	1	Command	1	CMD [6:0] = 0x00						
	2	Slave Address	1	AD [6:0]						

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to type#7 preparing frame.

GetActualPos preparing frame (type#8)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	0	1	1	1	1	0	0
	1	AppCMD	AppCMD = 0x80							
	2	Command	1	CMD [6:0] = 0x00						
	3	Slave Address	1	AD [6:0]						
	4	Data4	0xFF							
	5	Data5	0xFF							
	6	Data6	0xFF							
	7	Data7	0xFF							
	8	Data8	0xFF							

After type#7 or type#8 preparing frame the master sends reading frame type#6 to retrieve the circuit's in-frame response:

GetActualPos indirect ID reading frame (type#6)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**Bit 6**	**bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	1	1	1	1	1	0	1
Slave	1	Slave Address	1	AD [6:0]						
	2	ActualPosition	ActPos [15:8]							
	3		ActPos [7:0]							
	4	Status	VddReset	StepLoss	ElDef	UV2	TSD	TW	Tinfo [1:0]	
	5	Do not care	0xFF							
	6	Do not care	0xFF							
	7	Do not care	0xFF							
	8	Do not care	0xFF							

6.11.2 GetFullStatus

This command is provided to the circuit by the Master to get a complete status of the circuit and of the Stepper-motor. The parameters sent via LIN interface to the master are:

- coil peak and hold currents value (Irun and Ihold)
- maximum and minimum velocities for the Stepper-motor (Vmax and Vmin)
- direction of motion clockwise / counterclockwise (Shaft)
- stepping mode (StepMode) (Table 11: StepMode on page 21)
- acceleration (deceleration) for the Stepper motor (Acc)
- acceleration shape (AccShape)
- status information (see further)
  - motion status <Motion [2:0]>
  - over current flags for coil #1 <OVC1> and coil #2 <OVC2>
  - digital supply reset <VddReset>
  - charge pump status <CPFail>
  - external switch status <ESW>
  - step loss <StepLoss>
  - electrical defect <ElDef>
  - under voltage <UV2>
  - temperature information <Tinfo>
  - temperature warning <TW>
  - temperature shutdown <TSD>

The following flags are attempt to reset:
<TW>, <TSD>, <UV2>, <ElDef>, <StepLoss>, <CPFail>, <OVC1>, <OVC2> and <VddReset>

The master sends **either** type#7 **or** type#8 preparing frame:

GetFullStatus preparing frame (type#7)									
Source	**Byte**	**Content**	**Structure**							
			bit 7	**bit 6**	**bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
	1	Command	1	CMD [6:0] = 0x01						
	2	Slave Address	1	AD [6:0]						

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to type#7 preparing frame.

GetFullStatus preparing frame (type#8)									
Source	**Byte**	**Content**	**Structure**							
			bit 7	**bit 6**	**bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	0	1	1	1	1	0	0
	1	AppCMD	AppCMD = 0x80							
	2	Command	1	CMD [6:0] = 0x01						
	3	Slave Address	1	AD [6:0]						
	4	Data4	0xFF							
	5	Data5	0xFF							
	6	Data6	0xFF							
	7	Data7	0xFF							
	8	Data8	0xFF							

After type#7 or type#8 preparing frame the master sends two successive LIN type#6 reading frames to retrieve the circuit's in-frame responses. It is not mandatory to send the second reading frame if position information are not needed by the application.

GetFullStatus indirect ID reading frame 1 (type#6)									
Source	**Byte**	**Content**	**Structure**							
			bit 7	**bit 6**	**Bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	1	1	1	1	1	0	1
Slave	1	Slave Address	1	AD [6:0]						
	2	Irun + Ihold	Irun [3:0]				Ihold [3:0]			
	3	Vmax + Vmin	Vmax [3:0]				Vmin [3:0]			
	4	Status + Acc	Acc Shape	StepMode [1:0]		Shaft	Acc [3:0]			
	5	Status	VddReset	StepLoss	ElDef	UV2	TSD	TW	Tinfo [1:0]	
	6	Status	Motion [2:0]			ESW	OVC1	OVC2	1	CPFail
	7	LIN error status register	See Table 14: LIN Error Status Register on page 27							
	8	Do not care	0xFF							

GetFullStatus indirect ID reading frame 2 (type#6)									
Source	**Byte**	**Content**	**Structure**							
			bit 7	**bit 6**	**Bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	1	1	1	1	1	0	1
Slave	1	Slave Address	1	AD [6:0]						
	2	ActualPosition	ActPos [15:8]							
	3		ActPos [7:0]							
	4	TargetPosition	TagPos [15:8]							
	5		TagPos [7:0]							
	6	SecurePosition	SecPos [7:0]							
	7		1	1	1	1	1	SecPos [10:8]		
	8	Do not care	0xFF							

6.11.3 GetOTPParam

This command is provided to the circuit by the master to read the content of the OTP Memory. For more information refer to Table 9: OTP Memory Structure on page 21.

The master sends **either** type#7 **or** type#8 preparing frame:

GetOTPParam preparing frame (type#7)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**Bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
	1	Command	1	CMD [6:0] = 0x02						
	2	Slave Address	1	AD [6:0]						

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to type#7 preparing frame.

GetOTPParam preparing frame (type#8)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	0	1	1	1	1	0	0
	1	AppCMD	AppCMD = 0x80							
	2	Command	1	CMD [6:0] = 0x02						
	3	Slave Address	1	AD [6:0]						
	4	Data4	0xFF							
	5	Data5	0xFF							
	6	Data6	0xFF							
	7	Data7	0xFF							
	8	Data8	0xFF							

After type#7 or type#8 preparing frame the master sends a type#6 reading frame to retrieve the circuit's in-frame response:

GetOTPParam indirect ID reading frame (type#6)									
Source	**Byte**	**Content**	**Structure**						
			Bit 7	**bit 6**	**bit 5**	**bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	1	1	1	1	1	0	1
Slave	1	OTP Memory	OTP byte @0x00							
	2	OTP Memory	OTP byte @0x01							
	3	OTP Memory	ADM	HW2	HW1	HW0	PA3	PA2	PA1	PA0
	4	OTP Memory	OTP byte @0x03							
	5	OTP Memory	OTP byte @0x04							
	6	OTP Memory	OTP byte @0x05							
	7	OTP Memory	OTP byte @0x06							
	8	OTP Memory	OTP byte @0x07							

HW[2:0]: Not stored in OTP memory, the hardwired address is returned by GetOTPParam as if stored at address 0x02 of the OTP memory.

6.11.4 GetStatus

This command is provided to the circuit by the LIN master to get a quick status (compared to that of GetFullStatus command) of the circuit and the stepper motor.

The following flags are attempt to reset:

<TW>, <TSD>, <UV2>, <ElDef>, <StepLoss>, <CPFail>, <OVC1>, <OVC2> and <VddReset>

GetStatus direct ID reading frame (type#5)									
Source	**Byte**	**Content**	**Structure**						
			Bit 7	**bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
Slave	1	Slave Address	ESW	AD [6:0]						
	2	Status	VddReset	StepLoss	ElDef	UV2	TSD	TW	Tinfo[1:0]	

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to GetStatus command.

6.11.5 GotoSecurePosition

This command is provided by the LIN master to one or all stepper motors to move to the secure position SecPos[10:0]. It can also be triggered if the LIN communication is lost or at the end of a RunInit initialization phase. If <Broad> is set to zero all stepper motors connected to the LIN bus will reach their secure position. If SecPos[10:0] equals 0x400 (the most negative decimal value of –1024) the secure position is disabled and the GotoSecurePosition command is ignored.

GotoSecurePosition general purpose writing frame (type#1)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
	1	Command	1	CMD [6:0] = 0x04						
	2	Slave Address	Broad	AD [6:0]						

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to general purpose 2 data bytes writing frame.

6.11.6 HardStop

This command is internally triggered when an electrical problem is detected in one or both coils, leading to switching off of the H-bridges. If this problem is detected while the motor is moving, the <StepLoss> flag is raised allowing to warn the Master with the next GetStatus command that steps may have been lost. A HardStop command can also be issued by the Master for some safety reasons. If <Broad> is set to zero all the stepper motors connected to the LIN bus will stop.

HardStop general purpose writing frame (type#1)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
	1	Command	1	CMD [6:0] = 0x05						
	2	Slave Address	Broad	AD [6:0]						

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to general purpose 2 data bytes writing frame.

6.11.7 ResetPosition

This command is provided to the circuit by the Master to reset ActPos and TagPos registers, in order to allow for an initialization of the Stepper-motor position. If <Broad> is set to zero all circuits connected to the LIN bus will reset their ActPos and TagPos registers.

Hint: This command is ignored during motion. It has no effect during motion. The Status Flags (section 5.2.2, page 20) named 'Motion Status' indicate if the motor is at rest (velocity=0).

ResetPosition general purpose writing frame (type#1)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
	1	Command	1	CMD [6:0] = 0x06						
	2	Slave Address	Broad	AD [6:0]						

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to general purpose 2 data bytes writing frame.

6.11.8 ResetToDefault

This command is provided to the circuit by the Master in order to reset the whole Slave node into the initial state. ResetToDefault for instance **overloads the RAM** contents with the reset state of the parameters. This is another way for the Master to initialize a slave node in case of emergency, or simply to refresh the RAM content.
Note: ActPos is not modified by a ResetToDefault command, and it's value is copied into TagPos register in order to avoid an attempt to position the motor to '0'. If <Broad> is set to zero all circuits connected to the LIN bus will reset to default.

ResetToDefault general purpose writing frame (type#1)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**Bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
	1	Command	1	CMD [6:0] = 0x07						
	2	Slave Address	Broad	AD [6:0]						

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to general purpose 2 data bytes writing frame.

6.11.9 RunInit

This command is provided to the circuit by the Master in order to initialize positioning of the motor by seeking the zero (or reference) position. Refer to 5.1.11 Reference Search / Position initialization on page 14. It leads to a sequence of the following commands:

- SetMotorParam(Vmax, Vmin);
- SetPosition(Pos1);
- SetMotorParam(Vmin, Vmin);
- SetPosition(Pos2);
- ResetPosition
- GotoSecurePosition

Once the RunInit command is started it can not be interrupted by any other command. Except a condition occurs which leads to a motor shutdown (See 5.1.10 Motor Shutdown Management) or a HardStop command is received. If SecPos[10:0] equals 0x400 (the most negative decimal value of -1024) the final travel to the secure position is omitted.

The master has to ensure that the target position of the first motion is **not** equal to the actual position of the stepper motor and that the target positions of the first and second motion are different, too. This is very important, otherwise the circuit goes into a deadlock state. Once the circuit is in deadlock state only a HardStop command followed by a GetFullStatus command will cause the circuit to leave the deadlock state. If <Broad> is set to zero all circuits connected to the LIN bus will run the init sequence.

RunInit reserved ID writing frame (type#4)										
Source	**Byte**	**Content**	**Structure**							
			bit 7	**bit 6**	**Bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	0	1	1	1	1	0	0
	1	AppCMD	AppCMD = 0x80							
	2	Command	1	CMD [6:0] = 0x08						
	3	Slave Address	Broad	AD [6:0]						
	4	Vmax + Vmin	Vmax [3:0]				Vmin [3:0]			
	5	Target Position 1	Pos1 [15:8]							
	6		Pos1 [7:0]							
	7	Target Position 2	Pos2 [15:8]							
	8		Pos2 [7:0]							

Note: Vmax [3:0]: Maximum Velocity for first motion of the run
Vmin [3:0]: Minimum Velocity for first motion and maximum velocity for the second motion of the run
Pos1 [15:0]: First target position to be reached during the init run.
Pos2 [15:0]: Second target position to be reached during the init run.

6.11.10 SetMotorParam

This command is provided to the circuit by the Master to set the values for the Stepper motor parameters in RAM. Note: it is not recommended to change Vmax, Vmin or Acc while a motion is ongoing, otherwise correct positioning is not guaranteed. The following parameter values are set in RAM:

- coil peak current value (Irun)
- coil hold current value (Ihold)
- maximum velocity for the Stepper-motor (Vmax)
- minimum velocity for the Stepper-motor (Vmin)
- acceleration shape (AccShape)
- stepping mode (StepMode)
- indicator of the Stepper-motor moving direction (Shaft)
- acceleration (deceleration) for the Stepper-motor (Acc)
- secure position for the Stepper-motor (SecPos)

If <Broad> is set to zero all stepper motors connected to the LIN bus will set the parameters in their RAMs. If SecPos[10:0] is set to 0x400 (the most negative decimal value of –1024) the secure position is disabled and the GotoSecurePosition command is ignored.

SetMotorParam reserved ID writing frame (type#4)									
Source	**Byte**	**Content**	**Structure**							
			bit 7	**bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	0	1	1	1	1	0	0
	1	AppCMD	AppCMD = 0x80							
	2	Command	1	CMD [6:0] = 0x09						
	3	Slave Address	Broad	AD [6:0]						
	4	Irun + Ihold	Irun [3:0]				Ihold [3:0]			
	5	Vmax + Vmin	Vmax [3:0]				Vmin [3:0]			
	6	SecPos + Acc	SecPos [10:8]			Shaft	Acc [3:0]			
	7	Secure Position2	SecPos [7:0]							
	8	Status	1	1	1	Acc Shape	StepMode [1:0]		1	1

6.11.11 SetOTPParam

This command is provided to the circuit by the Master in order to zap the OTP memory. If <Broad> is set to zero all circuits connected to the LIN bus will zap their OTP memories. Please refer to Table 25: DC Parameters Supply and Voltage regulator on page 54 to ensure that the correct supply voltage is applied to the chip, otherwise the circuit will be damaged.

SetOTPParam with reserved ID (type#4)									
Source	**Byte**	**Content**	**Structure**							
			bit 7	**bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	0	1	1	1	1	0	0
	1	AppCMD	AppCMD = 0x80							
	2	Command	1	CMD [6:0] = 0x10						
	3	Slave Address	Broad	AD [6:0]						
	4	OTP Address	1	1	1	1	1	OTPA [2:0]		
	5	OTP Data	Data [7 :0]							
	6	Do not care	0xFF							
	7	Do not care	0xFF							
	8	Do not care	0xFF							

6.11.12 SetPosition

This command is provided to the circuit by the Master to drive a motor to a given position relative to the zero position, defined in number of half or micro steps, according to StepMode[1:0] value.
SetPosition will not be performed if one of the following flags is set to one:

- temperature shutdown <TSD>
- under voltage <UV2>
- step loss <StepLoss>
- electrical defect <ElDef>

This command can be sent using dynamic ID, general purpose ID or reserved ID:

1. Dynamic ID:

SetPosition dynamic ID writing frame (type#3)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
	1	TargetPosition	TagPos [15:8]							
	2		TagPos [7:0]							

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to SetPosition command for a specific slave.

2. General purpose ID:

SetPositon general purpose writing frame (type#1)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	1	0	ID3	ID2	ID1	ID0
	1	Command	1	CMD [6:0] = 0x0B						
	2	Slave Address	Broad	AD [6:0]						
	3	Target Position	TagPos [15:8]							
	4		TagPos [7:0]							

Note: * according to parity calculation.
ID [3:0]: Dynamically allocated identifier to general purpose 4 data bytes writing frame
If <Broad> is set to zero all stepper motors connected to the LIN bus are going to TagPos.

3. Reserved ID (SetPosition for two motors):

SetPosition for 2 motors with reserved ID (type#4)									
Source	**Byte**	**Content**	**Structure**						
			bit 7	**bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	0	1	1	1	1	0	0
	1	AppCMD	AppCMD = 0x80							
	2	Command	1	CMD [6:0] = 0x0B						
	3	Slave Address 1	1	AD1 [6:0]						
	4	Target Position 1	TagPos1 [15:8]							
	5		TagPos1 [7:0]							
	6	Slave Address 2	1	AD2 [6:0]						
	7	Target Position 2	TagPos2 [15:8]							
	8		TagPos2 [7:0]							

Note: ADn [6:0]: Motor #n physical address
TagPosn [15:0]: Signed 16-bit position set-point for motor #n.

6.11.13 SetPositionShort

This command is provided to the circuit by the LIN master to drive one, two or four motors to a given absolute position. This command is valid for half stepping mode (<StepMode> = “00”) and is ignored for other stepping modes. If <Broad> is set to zero all circuits connected to the LIN bus will go to the desired position (only valid for SetPositionShort (1 Motor)).

The physical address is coded on 4 bits, hence SetPositionShort can only be used within a network implementing a maximum of 16 slave nodes. These 4 bits are normally corresponding to the bits PA [3:0] in OTP memory (Address 0x00), while bits AD [6:4] must be at ‘1’. Two different cases must in fact be considered, depending on the programmed value of bit ADM in the OTP memory. See 5.2.3 OTP Memory Structure on page 21.

ADM	AD[3]	Pin HW0	Pin HW1	Pin HW2	Bit PA0 in OTP memory
0	X	Tied to Vdd		Tied to Vbat	AD[0]
1	0			Tied to Gnd	1
1	1			Tied to Vbat	1

Table 17: ADM bit in SetPositionShort Command

SetPositionShort (1 Motor) with dynamic ID (type#2)									
Source	Byte	Content	Structure							
			bit 7	bit 6	bit 5	Bit 4	bit 3	Bit 2	bit 1	bit 0
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
	1	Slave Address	Pos [10:8]			Broad	AD [3:0]			
	2	Target Position	Pos [7:0]							

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to SetPositionShort command with 2 data bytes.

SetPositionShort (2 Motors) with dynamic ID (type#2)									
Source	Byte	Content	Structure							
			bit 7	Bit 6	bit 5	Bit 4	bit 3	bit 2	bit 1	bit 0
Master	0	Identifier	*	*	1	0	ID3	ID2	ID1	ID0
	1	Slave Address 1	Pos1 [10:8]			1	AD1 [3:0]			
	2	Target Position 1	Pos1 [7:0]							
	3	Slave Address 2	Pos2 [10:8]			1	AD2 [3:0]			
	4	Target Position 2	Pos2 [7:0]							

SetPositionShort (4 Motors) with dynamic ID (type#2)									
Source	Byte	Content	Structure							
			bit 7	Bit 6	bit 5	Bit 4	bit 3	bit 2	bit 1	bit 0
Master	0	Identifier	*	*	1	1	ID3	ID2	ID1	ID0
	1	Slave Address 1	Pos1 [10:8]			1	AD1 [3:0]			
	2	Target Position 1	Pos1 [7:0]							
	3	Slave Address 2	Pos2 [10:8]			1	AD2 [3:0]			
	4	Target Position 2	Pos2 [7:0]							
	5	Slave Address 3	Pos3[10:8]			1	AD3 [3:0]			
	6	Target Position 3	Pos3 [7:0]							
	7	Slave Address 4	Pos4[10:8]			1	AD4 [3:0]			
	8	Target Position 4	Pos4 [7:0]							

Note: * according to parity calculation
ID [3:0]: Dynamically allocated identifier to SetPositionShort command with 8 data bytes.
ADn [3:0]: Motor #n physical address least significant bits
Posn [10:0]: Unsigned 11-bit position set point for Motor #n

6.11.14 SoftStop

If a SoftStop command occurs during a motion of the Stepper motor, it provokes an immediate deceleration to Vmin followed by a stop, regardless of the position reached. Once the motor is stopped TagPos register is overwritten with the value in ActPos register to ensure keeping the stop position. This command is executed if:

- the chip temperature rises the Thermal shutdown threshold or
- the Master sends a SoftStop command

If <Broad> is set to zero all the stepper motors connected to the LIN bus will stop with deceleration.

SoftStop general purpose writing frame (type#1)										
Source	**Byte**	**Content**	**Structure**							
			bit 7	**Bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	*	*	0	ID4	ID3	ID2	ID1	ID0
	1	Command	1	CMD [6:0] = 0x0F						
	2	Slave Address	Broad	AD [6:0]						

Note: * according to parity calculation
ID [4:0]: Dynamically allocated identifier to general purpose 2 data bytes writing frame.

6.11.15 Sleep Mode

According to LIN specification rev. 1.3, sleep mode and stand-by mode (wake-up) are implemented. The interface can work in one of the following modes (refer to Figure 14: LIN Physical Layer):

- Normal mode: EN = '1', Vdd = high, INH = '1'
- Sleep mode: in the normal mode EN is set to '0' to go to sleep mode after reception of a LIN Sleep command or more than 25,000 bit times (1.30 seconds) of LIN bus inactivity. The interface current consumption is limited to Isleep. Only the receiver is working.
- Stand-by mode (wake-up): when a LIN message frame is received in sleep mode or when Vbb goes high (power-on), INH is immediately activated. The initial state of INH signal is ensured by an internal power-on-reset circuitry inside the wake-up control.

The TMC211 can be immediately forced to sleep mode to reduce current consumption down to Isleep by sending the sleep mode command depicted below:

Sleep Mode Command with reserved ID (type#4)										
Source	**Byte**	**Content**	**Structure**							
			bit 7	**bit 6**	**bit 5**	**Bit 4**	**bit 3**	**bit 2**	**bit 1**	**bit 0**
Master	0	Identifier	0	0	1	1	1	1	0	0
	1	Sleep	0x00							
	2		0xFF							
	3		0xFF							
	4		0xFF							
	5		0xFF							
	6		0xFF							
	7		0xFF							
	8		0xFF							

6.12 Positioning Task Example

The TMC211 has to perform a positioning task, where the actual position of the stepper motor is unknown. The desired target position is 3000 µsteps away from position 0. See Figure 18: Positioning Example: Initial situation.

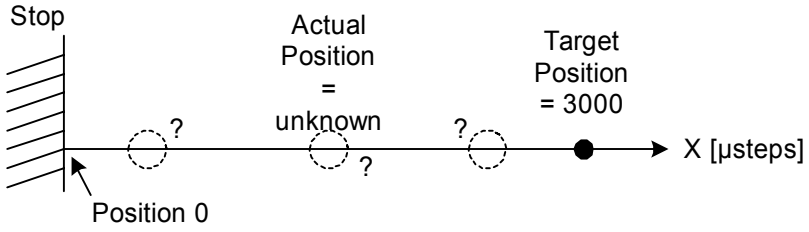


Figure 18: Positioning Example: Initial situation

The following sequence of commands has to be sent to the slave in order to complete the scenario described above (assumed after power on):

GetFullStatus
The command is used to read the current status of the TMC211. Electrical or environmental problems will be reported, furthermore the circuit leaves the shutdown state and is ready for action.
Furthermore the circuit provides the actual and target position. This information is very important, because if the actual position corresponds to the first target position of the RunInit command the circuit will enter a deadlock state. The master must take care that both positions are containing different values.
See 6.11.2 GetFullStatus command on page 36 and for deadlock problems see 5.1.11 Reference Search / Position initialization on page 14.

SetMotorParam
In order to drive the stepper motor with desired motion parameters like torque, velocity, a.s.o.. the SetMotorParam command must issued. See 6.11.10 SetMotorParam on page 42.

RunInit
Hence the actual position is unknown, a position initialization has to be performed. The first motion must drive the stepper motor into the stop for sure. The second motion is a very short motion to bring the motor out of the stop. The actual position is then set to zero automatically after the second motion is finished. See 6.11.9 RunInit command on page 41.

After reference search the actual situation looks like as described in Figure 19: Positioning Example: Situation after reference search. Actual position of the stepper motor corresponds to zero, the target position is 3000 µsteps away from the actual position.

Figure 19: Positioning Example: Situation after reference search

Now the positioning command SetPosition can be issued in order to drive the stepper motor to the desired position.

SetPosition
This command will cause the stepper motor to move to the desired target position. See 6.11.12 SetPosition on page 42. After the motion has been finished the situation looks like as described in Figure 20: Positioning Example: Motion finished.

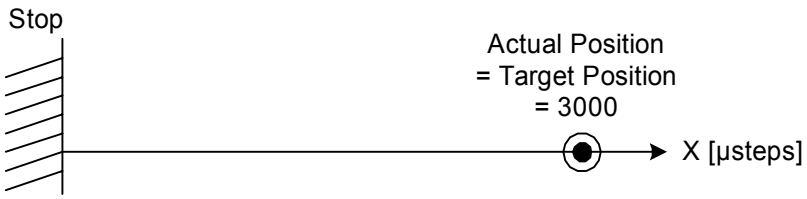


Figure 20: Positioning Example: Motion finished

Afterwards the actual status and position can be verified by using GetFullStatus commands. The master can check if a problem, caused by electrical or temperature problems, occurred. Furthermore the actual position is read.

7 Frequently Asked Questions

7.1 Using the bus interface

Q: How many devices can be operated on the same bus?
A: 128 devices can be discriminated by means of the physical address. However, it depends on some factors if this high number really makes sense. First of all it has to be checked if each device can be serviced under any circumstances in the maximum allowed time taking the bus speed and the individual real-time requirements of each device into account. Second, the idea of reserving address 0 for OTP physical address programming during system installation and defective parts replacement reduces the number to 120. Third, the TMC211 has faster and slower types of the GetActualPos, GetStatus and SetPosition commands. The faster types of course can satisfy harder real-time requirements but can only be addressed to 8 different physical devices. If the faster types shall be used only 8 TMC211 devices can be connected to the same LIN bus.

Q: How to program the OTP physical address bits of a device if there are more devices connected to the same bus?
A: The problem here is that all new devices are shipped with the OTP physical address bits set to zero making it difficult to address just one device with the SetOTPParam command. Use HW0, HW1 or HW2 input as chip select line to address just one device by SetOTPParam. If this is impractible since the HW0/HW1/HW2 inputs are hardwired or not controllable for any other reason the only alternative is to assemble and program one device after the other. I.e., assemble only first device and program the desired non-zero address, then assemble the second device and program the desired non-zero address, and so on until all devices are assembled and programmed. This is also a good service concept when replacing defective devices in the field: The idea is that all devices are programmed to different non-zero physical addresses at production/installation time. Once a defective device is being replaced the replacement part can easily be addressed by SetOTPParam since it is the only part with physical address zero.

7.2 General problems when getting started

Q: What is the meaning of ElDef?
A: The ElDef flag ('Electrical Defect') is the logical ORing of the OVC1 and OVC2 flags. OVC1 is set to one in case of an overcurrent (coil short) or open load condition (selected coil current is not reached) for coil A. OVC2 is the equivalent for coil B.

Q: What could be the reason for ElDef / OVC1 / OVC2 being set to one?
A: There are a number of possible causes:

- Motor not connected (→ open load)
- Connected motor has shorted coils (→ overcurrent) or broken coils (→ open load)
- Motor coils connected to the wrong device pins
- Selected coil current can not be reached (→ open load) due to high coil impedance or low supply voltage. Solution: Select a lower coil run/hold current or rise the supply voltage. Generally: the calculated voltage required to reach a desired coil current at a given coil resistance (V = I • R) must be significantly lower than actual supply voltage due to the coil inductivity.

Q: Should the external switch be normally closed or open when the reference position is hit?
A: The SWI input resp. the ESW flag have neither effect on any internal state machine nor on command processing, even not on the RunInit command. ESW must be polled by software using GetActualPos or GetFullStatus commands. The software can simply be adapted to whatever state the switch is in when the reference position is hit, i.e. closed or open.

7.3 Using the device

Q: What is the meaning of the 'Shaft' bit?
A: The Shaft bit determines the rotating direction of the motor, i.e. clockwise or counter-clockwise rotation.

Q: How to generate an interrupt when the target position is reached?
A: This is not possible. The device hasn't any interrupt output at all. Just poll ActPos or Motion[2:0] using an appropriate command.

Q: How can I ensure that I always get consistent data for ActPos and ESW?
A: This is ensured by design. ActPos and ESW are latched synchronously by the same internal signal edge. The update period is about one millisecond (typ. 1024 µs). Each time ActPos and ESW are read by the GetActualPos command the result will be a snapshot of both values taken at the same point in time.

Q: How to specify a second target position to go to immediately after a first target position has been reached?
A: This is possible using the RunInit command. Note, that after the second target position has been reached the internal position counter ActPos is reset to zero.

Q: Is it possible to change Vmax on-the-fly?
A: Yes, it is, if the new velocity is in the same group as the old one (see Vmax Parameters). Otherwise correct positioning is not ensured anymore. Vmax values are divided into four groups:

- group A: Vmax index = 0
- group B: Vmax index = 1, 2, 3, 4 ,5 or 6
- group C: Vmax index = 7, 8, 9, 10 ,11 or 12
- group D: Vmax index = 13, 14 or 15

Q: Is it possible to change the stepping mode on-the-fly?
A: Yes, it is possible and it has immediate effect on the current motion.

Q: How to operate in continuous velocity mode rather than positioning (ramp) mode?
A: There is no velocity mode. The device was designed primarily for positioning tasks so for each motion there has to be specified a target position by the respective command. However, velocity mode can be emulated by repeating the following two commands again and again:

- Read ActPos using GetActualPos command
- Set lower 16 bits of [ActPos+32767] as the next target position using SetPosition command

For real continuous motion this sequence has to be repeated before the current target position has been reached.

Q: Which units, formats and ranges does position information have?
A: All 16-bit position data fields in commands and responses are coded in two's complement format with bit 0 representing 1/16 micro-steps. Hence a position range of –32768…+32767 in units of 1/16 micro-steps is covered regardless of the selected stepping mode (1/2, 1/4, 1/8 or 1/16 micro-stepping). The difference between the stepping modes is the resolution resp. the position of the LSB in the 16-bit position data field: it's bit 0 for 1/16, bit 1 for 1/8, bit 2 for 1/4 and bit 3 for 1/2 micro-stepping. The position range can be regarded as a circle since position –32768 is just 1/16 micro-step away from position +32767. The device will always take the shortest way from the current to the target position, i.e., if the current position is +32767 and the target position is –32768 just 1/16 micro-step will be executed. 65535 1/16 micro-steps in the opposite direction can be achieved for example by two consecutive SetPosition commands with target positions 0 and –32768.

The 11-bit secure position data field can be treated as the upper 11 MSBs of the 16-bit position data fields described above with the 5 LSBs hardwired to zero. Hence it covers the same position range with a reduced resolution: The position range is –1024…+1023 in units of two full-steps.

The 11-bit position data fields of the TMC211 SetPositionShort commands are coded in two's complement format with bit 0 representing half-steps resulting in a position range of –1024…+1023 half-steps. Hence only a quarter of the range of the other position data fields described above is covered. Note, that SetPositionShort command is valid for half-stepping mode only and is ignored for other stepping modes. Furthermore, SetPositionShort can only be used with a maximum of 16 TMC211 devices connected to the LIN bus.

7.4 Finding the reference position

Q: How do I find a reference position?
A: The recommended way is to use the RunInit command. Two motions are specified through RunInit. The first motion is to reach the mechanical stop. Its target position should be specified far away enough so that the mechanical stop will be reached from any possible starting position. There is no internal stall detection so that at the end of the first motion the step motor will bounce against the mechanical stop loosing steps until the internal target position is reached. The second motion then can be used either to drive in the opposite direction out of the mechanical stop right into the reference position which is a known number of steps away from the mechanical stop. Or the second motion can slowly drive a few steps in the same direction against the mechanical stop to compensate for the bouncing of the faster first motion and stop as close to the mechanical stop as possible.

Q: Can the SWI input help in finding a reference position?
Not directly. The current state of the SWI input is reflected by the ESW flag which can only be polled using the commands GetActualPos or GetFullStatus. The SWI input resp. the ESW flag have neither influence on any internal state machine nor on command processing. The recommended way to find a reference position is to use the RunInit command. Alternatively one could initiate a long distance motion at very low speed using SetPosition and then poll ESW as frequently as possible to be able to stop the motion using HardStop right in the moment the switch position is reached. Then one would reset the internal position counters ActPos and TagPos using the ResetPosition command.

Q: What is the logic of the ESW flag?
A: The ESW flag reflects the state of the SWI input. ESW is set to one if SWI is high or low, i.e. pulled to VBAT or to GND. ESW is set to zero if SWI is left open, i.e. floating. ESW is updated synchronously with ActPos every 1024 µs.

Q: Is it possible to swap the logic of the ESW flag?
A: No, it's not. Actually this is not necessary since the ESW flag must be polled and evaluated by software anyway. The state of ESW has neither effect on any internal state machine nor on command processing.

Q: What else is important for the RunInit command?
A: The first target position of RunInit must be different from the current position before sending RunInit and the second target position must be different from the first one. Otherwise a deadlock situation can occur. During execution of RunInit only Get… commands should be sent to the device.

Q: Does the second motion of RunInit stop when the ESW flag changes, or does it continue into the mechanical stop?
A: Neither nor. The SWI input resp. the ESW flag have neither effect on any internal state machine nor on command processing, i.e. the RunInit command is not influenced by SWI / ESW. The same is true for the mechanical stop: as there isn't any internal stall detection the RunInit command can not detect a mechanical stop. When the mechanical stop is hit the first or second motion of RunInit (or the motion of any other motion command) will be continued until the internal position counter ActPos has reached the target position of this motion. This results in the motor bouncing against the mechanical stop and loosing steps. The intention of the second motion of RunInit is to drive out of the mechanical stop (reached by the first motion) to the desired reference position at a known distance from the mechanical stop or to drive slowly against the mechanical stop again to compensate for the bouncing of the first motion and to come to a standstill as close to the mechanical stop as possible.

Q: Does RunInit reset the position?
A: Yes, it does. After the second motion of RunInit has been finished the internal position counter ActPos is reset to zero.

8 Package Outline

8.1 SOIC-20

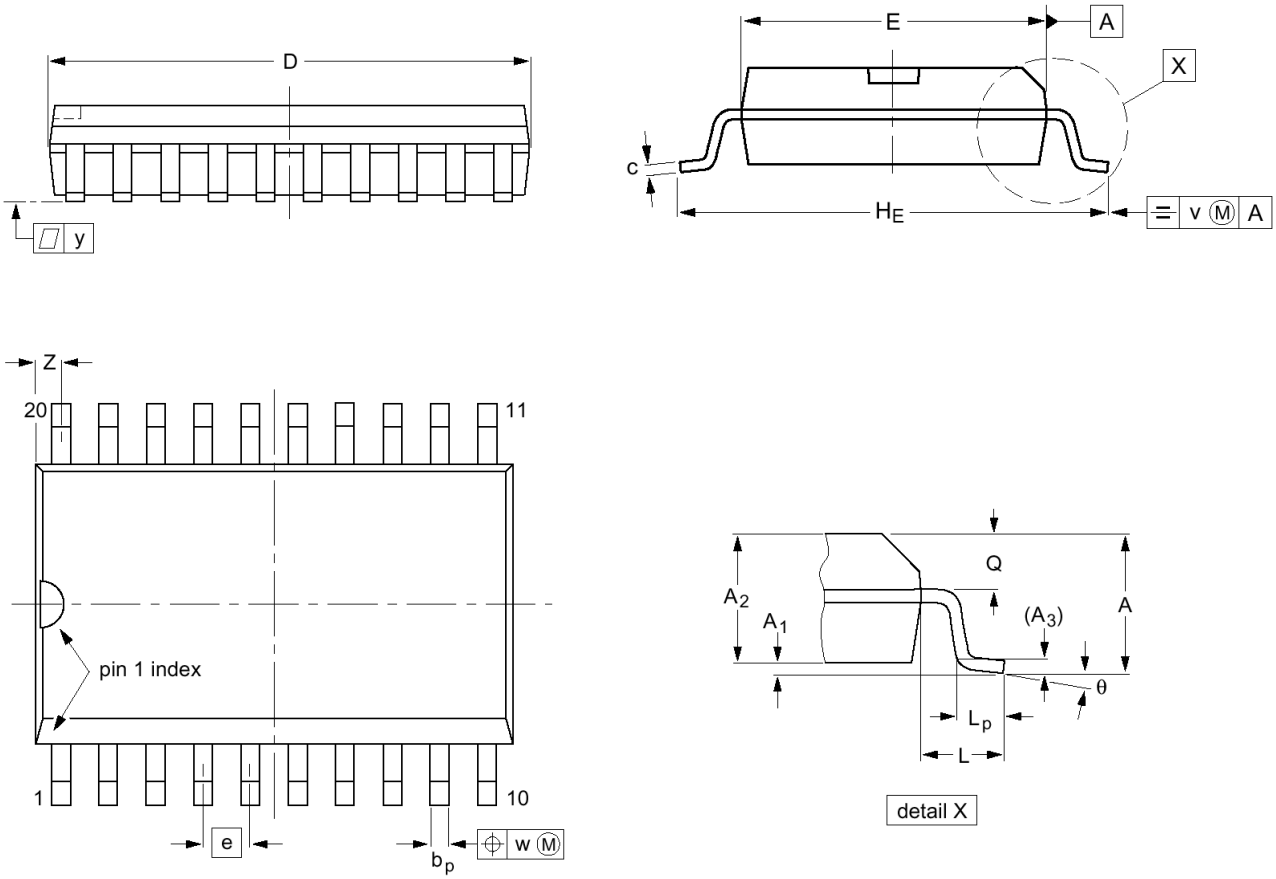


Figure 21: Package Outline SOIC-20

UNIT	A max.	A_1	A_2	A_3	b_p	c	$D^{(1)}$	$E^{(1)}$	e	H_E	L	L_p	Q	v	w	y	$Z^{(1)}$	Θ
mm	2.65	0.30 0.10	2.45 2.25	0.25	0.49 0.36	0.32 0.23	13.0 12.6	7.6 7.4	1.27	10.65 10.00	1.4	1.1 0.4	1.1 1.0	0.25	0.25	0.1	0.9 0.4	8° 0°
inches	0.10	0.012 0.004	0.096 0.089	0.01	0.019 0.014	0.013 0.009	0.51 0.49	0.30 0.29	0.050	0.419 0.394	0.055	0.043 0.016	0.043 0.039	0.01	0.01	0.004	0.035 0.016	

Table 18: SOIC-20 Mechanical Data

Note: inch dimensions are derived from the original mm dimensions

9 Package Thermal Resistance and Layout Considerations

9.1 SOIC-20 Package

The junction case thermal resistance is 28°C/W, leading to a junction ambient thermal resistance of 63°C/W, with the PCB ground plane layout condition given in the figure below and with

- PCB thickness = 1.6mm
- 1 layer
- Copper thickness = 35µm

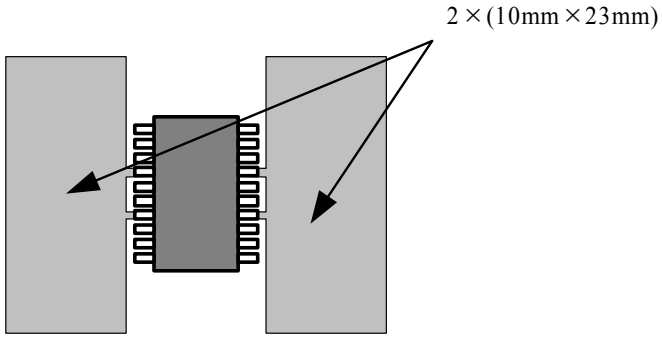


Figure 22: Layout consideration

10 Electrical Characteristics

10.1 Absolute Maximum Ratings

Parameter		Min	Max	Unit
Vbat	Supply Voltage	-0.3	+35	V
Vlin	Bus input voltage	-80	+80	V
Tamb	Ambient temperature under bias (*)	-50	+150	°C
Tst	Storage temperature	-55	+160	°C
Vesd (**)	Electrostatic discharge voltage on LIN pin	-4	+4	kV
	Electrostatic discharge voltage on other pins	-2	+2	kV

Table 19: Absolute Maximum Ratings

(*) The circuit functionality is not guaranteed
(**) Human body model (100pF via 1.5 KΩ)

10.2 Operating Ranges

Parameter			Min	Max	Unit
Vbat	Supply Voltage		+8	+29	V
Top	Operating temperature range	Vbat <= 18V	-40	+125	°C
		Vbat <= 29V	-40	+85	°C

Table 20: Operating Ranges

10.3 DC Parameters

Motor Driver							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
IMSmax Peak	OA1 OA2 OB1 OB2	Max current through motor coil in normal operation			800		mA
IMSmax RMS		Max RMS current through coil in normal operation			570		mA
RDSon		On resistance for each pin (including bond wire)	To be confirmed by characterization			1	Ω
IMSL		Leakage current	HZ Mode, 0V < V(pin) < Vbb	-50		+50	µA

Table 21: DC Parameters Motor Driver

LIN Transmitter							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Ibus_on	LIN	Dominant state, driver on	Vbus = 1.4V	40			mA
Ibus_off		Dominant state, driver off	Vbus = 0V	-1			mA
Ibus_off		Recessive state, driver off	Vbus = Vbat			20	µA
Ibus_lim		Current limitation		50		200	mA
Rslave		Pull-up resistance		20	30	47	kΩ

Table 22: DC Parameters LIN Transmitter

LIN Receiver							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Vbus_dom	LIN	Receiver dominant state		0		0.4	Vbb
Vbus_rec		Receiver recessive state		0.6		1	Vbb
Vbus_hys		Receiver hysteresis		0.05		0.2	Vbb

Table 23: DC Parameters LIN Receiver

Thermal Warning and shutdown							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Ttw		Thermal Warning		138	145	152	°C
Ttsd (*)		Thermal Shutdown			Ttw + 10		°C
Tlow		Low Temperature Warning			Ttw - 155		°C

Table 24: DC Parameters Thermal Warning and shutdown

(*) NO more than 100 cumulated hours in life time above Ttsd

Supply and Voltage regulator							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Vbb	VBB	Nominal operating supply range (*)		6.5		18	V
VbbOTP		Supply Voltage for OTP zapping		8.5		9.5	V
UV1		Low voltage high threshold		8.8	9.4	9.8	V
UV2		Stop voltage low threshold		8.1	8.5	8.9	V
Ibat		Total current consumption	Unloaded Outputs		10		mA
Isleep		Sleep mode current consumption (**)				50	µA
Vdd	VDD	Internal regulated output (***)	8V < Vbb < 18V Cload = 1µF (+100nF cer.)	4.75	5	5.25	V
IddStop		Digital current consumption	Vbb < UV2		2		mA
VddReset		Digital supply reset level (****)				4.4	V
IddLim		Current limitation	Pin shorted to ground			40	mA

Table 25: DC Parameters Supply and Voltage regulator

(*) Communication over serial bus is operating. Motordriver is disabled when Vbb < UV2.
(**) To be confirmed by measurements.
(***) Pin VDD must not be used for any external supply.
(****) The RAM content will not be altered above this voltage

Switch Input and hardwired address input HW2							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Rt_OFF	SWI HW2	Switch OFF resistance (*)	Switch to GND or Vbat	10			kΩ
Rt_ON		Switch ON resistance (*)				2	kΩ
Vbb_sw		Vbb range for guaranteed operation of SWI and HW2		6		18	V
Vmax_sw		Maximum Voltage	T < 1s			40	V
Ilim_sw		Current limitation	Short to GND or Vbat		30		mA

Table 26: DC Parameters Switch Input and hardwired address input

(*) External resistance value seen from pin SWI or HW2, including 1kΩ series resistor

Hardwired address inputs and Test pin							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Vhigh	HW0 HW1 TST	Input level high		0.7			Vdd
Vlow		Input level low				0.3	Vdd
HWhyst		Hysteresis		0.075			Vdd

Table 27: DC Parameters and Hardwired address inputs and Test pin

Charge Pump							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Vcp	VCP	Output Voltage	Vbb > 15V	Vbb+10	Vbb+12.5	Vbb+15	V
			Vbb > 8V	Vbb+5.8			V
Cbuffer		External Buffer Capacitor		220		470	nF
Cpump	CPP CPN	External pump Capacitor		220		470	nF

Table 28: DC Parameters Charge Pump

10.4 AC Parameters

Power-Up							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Tpu		Power-Up time				10	ms

Table 29: AC Parameters Power-Up

Switch Input and hardwired address input HW2							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Tsw	SWI	Scan Pulse Period		921	1024	1127	µs
Tsw_on	HW2	Scan Pulse Duration			1/16		Tsw

Table 30: AC Parameters Switch Input and hardwired address input

Motor Driver							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Fpwm	OA1	PWM frequency		18	20	22	kHz
Tbrise	OA2	Turn-On transient time	Between 10% and 90%		350		ns
Tbfall	OB1 OB2	Turn-Off transient time			250		ns

Table 31: AC Parameters Motor Driver

LIN Transmitter							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
Slope_F/R	LIN	Slope falling (or rising) edge	Between 40% and 60%	0.1		3	V/µs
t_slope_F/R		Slope time falling (or rising) edge	extrapolated	2.6		22.5	µs
T_tr_F		Propagation delay TxD low to bus		0.1	1	4	µs
T_tr_R		Propagation delay TxD high to bus		0.1	1	4	µs
t_slope_Sym		Slope time symmetry	t_slope_F – t_slope_R	-4		4	µs
Tsym_tr		Transmitter delay symmetry	T_tr_F – T_tr_R	-2		2	µs

Table 32: AC Parameters LIN Transmitter

LIN Receiver							
Symbol	**Pin(s)**	**Parameter**	**Test condition**	**Min**	**Typ**	**Max**	**Unit**
T_rec_F	LIN	Propagation delay bus dominant to TxD low		0.1	4	6	µs
T_rec_R		Propagation delay bus recessive to TxD high		0.1	4	6	µs
Tsym,Rec		Receiver delay symmetry		-2		2	µs
Twake		Wake-up delay time		50	100	200	µs

Table 33: AC Parameters LIN Receiver

11 Revision History

Version	Date	Comments
up to 0.90p	July 9, 2003	before v. 0.90 changes on unpublished internal versions only
0.91p	September 18, 2003	pins renamed according to TRINAMIC conventions; corrections concerning cross references, drawings in PDF
0.92p	January 28, 2004	Order Code Update (Table 2: Ordering Information, page 7)
0.93p	March 25, 2004	new logo; table Acc Parameters: combined cells with same value; ESW is zero when switch is open; table Priority Encoder: made shaded cells more distinguishable; added table Status Flags; table OTP Memory Structure: exchanged locations of SecPos10:8 and StepMode1:0; corrected Command Descriptions
1.01	August 24, 2004	added LIN rev. 1.3 compliance; velocity groups integrated into Vmax table; corrected and enhanced Vmin table; clarified description of commands using frame types #7 and #8; corrected meaning of Shaft bit; FAQ included
1.02	September 15, 2004	Updated ordering information; improved description of 2nd motion of RunInit command; combined tables for Irun and Ihold settings; some corrections to DC characteristics; added final travel to secure position during RunInit command; corrected figures Temperature Management and Battery Voltage Management; reworked and clarified Sleep Mode
1.03	October 1, 2004	New company address
1.04	January 7, 2005	Order code updated (Table 2: Ordering Information, page 7); hint concerning ResetPosition added (section 6.11.7, page 40)

Please refer to www.trinamic.com for updated data sheets and application notes on this product and on other products.

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 Motion Control GmbH & Co. KG by request to info@trinamic.com