TMC 249/A – DATA SHEET

High Current Microstep Stepper Motor Driver with sensorless stall detection, protection / diagnostics and SPI Interface



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Features

The TMC249 / TMC249A (1) is a dual full bridge driver IC for bipolar stepper motor control applications. The TMC249 is realized in a HVCMOS technology and directly drives eight external Low-RDS-ON high efficiency MOSFETs. It supports more than 4000mA coil current. The low power dissipation makes the TMC249 an optimum choice for drives, where a high reliability is desired. With additional drivers, motor current and voltage can be increased. The integrated unique sensorless stall detection (pat. pend.) StallGuard™ makes it a good choice for applications, where a reference point is needed, but where a switch is not desired. Its ability to predict an overload makes the TMC249 an optimum choice for drives, where a high reliability is desired. Internal DACs allow microstepping as well as smart current control. The device can be controlled by a serial interface (SPI™[i]) or by analog / digital input signals. Short circuit, temperature, undervoltage and overvoltage protection are integrated.

- More than 4000mA using 8 external MOS transistors (e.g. 2.8A RMS)
- Sensorless stall detection StallGuard and load measurement integrated
- Control via SPI with easy-to-use 12 bit protocol or external analog / digital signals
- Short circuit, overvoltage and overtemperature protection integrated
- Status flags for overcurrent, open load, over temperature, temperature pre-warning, undervoltage
- Integrated 4 bit DACs allow up to 16 times microstepping via SPI, any resolution via analog control
- Mixed decay feature for smooth motor operation
- Slope control user programmable to reduce electromagnetic emissions
- Chopper frequency programmable via a single capacitor or external clock
- Current control allows cool motor and driver operation
- 7V to 34V motor supply voltage (A-type)
- External drivers can be added for higher motor voltages and higher currents (e.g. 50V, 5A)
- 3.3V or 5V operation for digital part
- Low power dissipation via low RDS-ON power stage
- Standby and shutdown mode available
- Choice of SO28 or chip size MLF package

(1) The term TMC249 in this datasheet always refers to the TMC249A and the TMC249. The major differences in the older TMC249 are explicitly marked with “non-A-type”. The TMC249A brings a number of enhancements and is fully backward compatible to the TMC249.

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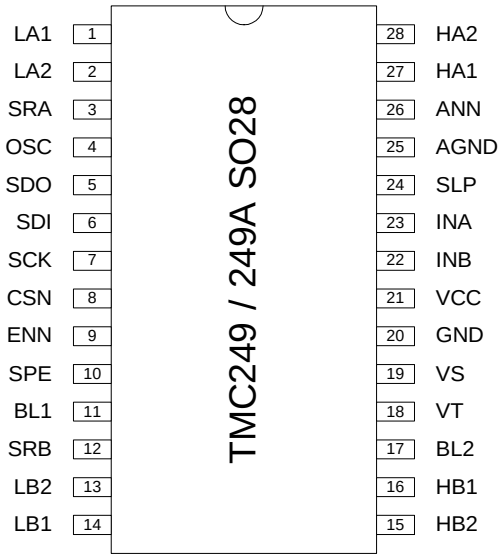
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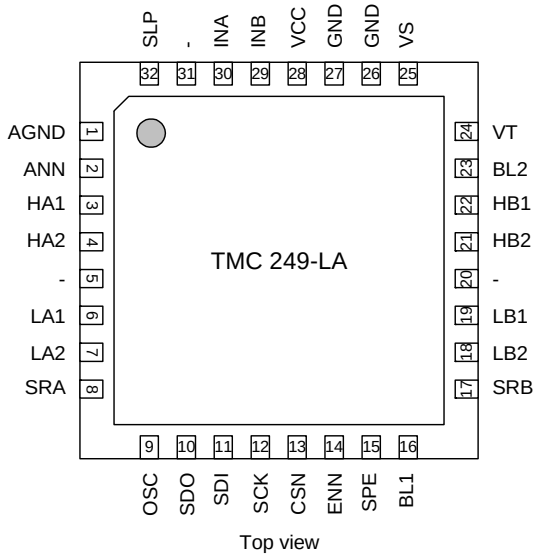
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Pinning





Top view

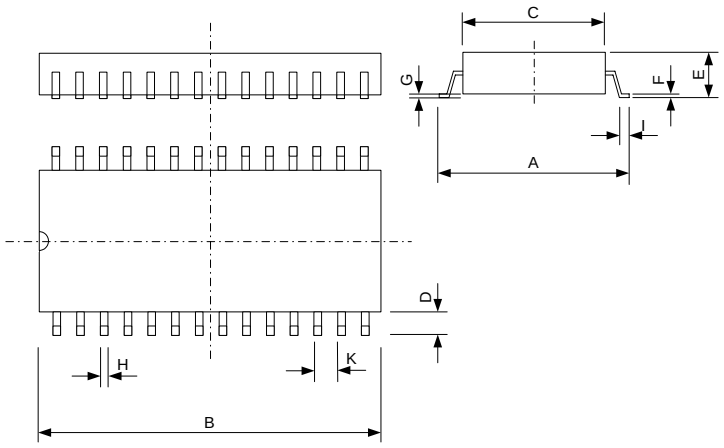
Package codes

Type	Package	Temperature range	Lead free	Code/marking
TMC249A (2)	SO28	automotive (1)	Yes	TMC249A-SA
TMC249	SO28	automotive (1)	From date code 05/05	TMC249-SA
TMC249A (2)	QFN32, 7*7mm	automotive (1)	Yes	TMC249A-LA

(1) ICs are not tested according to automotive standards, but are usable within the complete automotive temperature range.
(2) These devices are available in a reduced offset voltage selection grade, marked with an additional dot.

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SO28 Dimensions



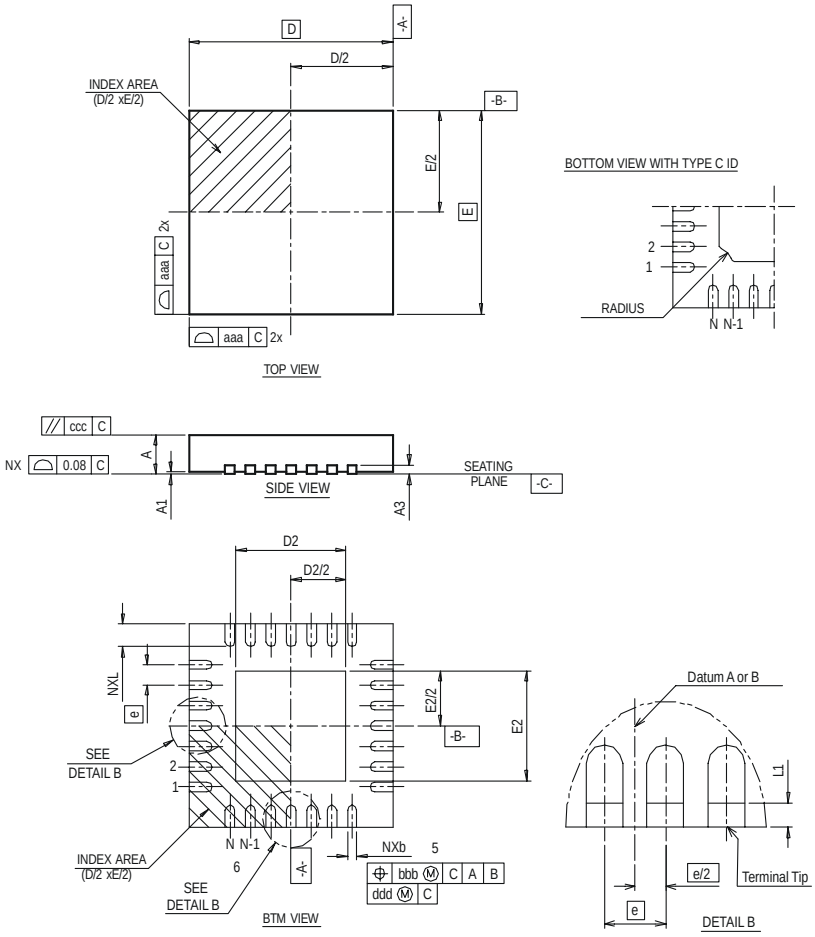
REF	MIN	MAX
A	10	10.65
B	17.7	18.1
C	7.4	7.6
D	1.4	
E	2.65	
F	0.25	
G	0.1	0.3
H	0.36	0.49
I	0.4	1.1
K	1.27	

All dimensions are in mm.

QFN32 Dimensions

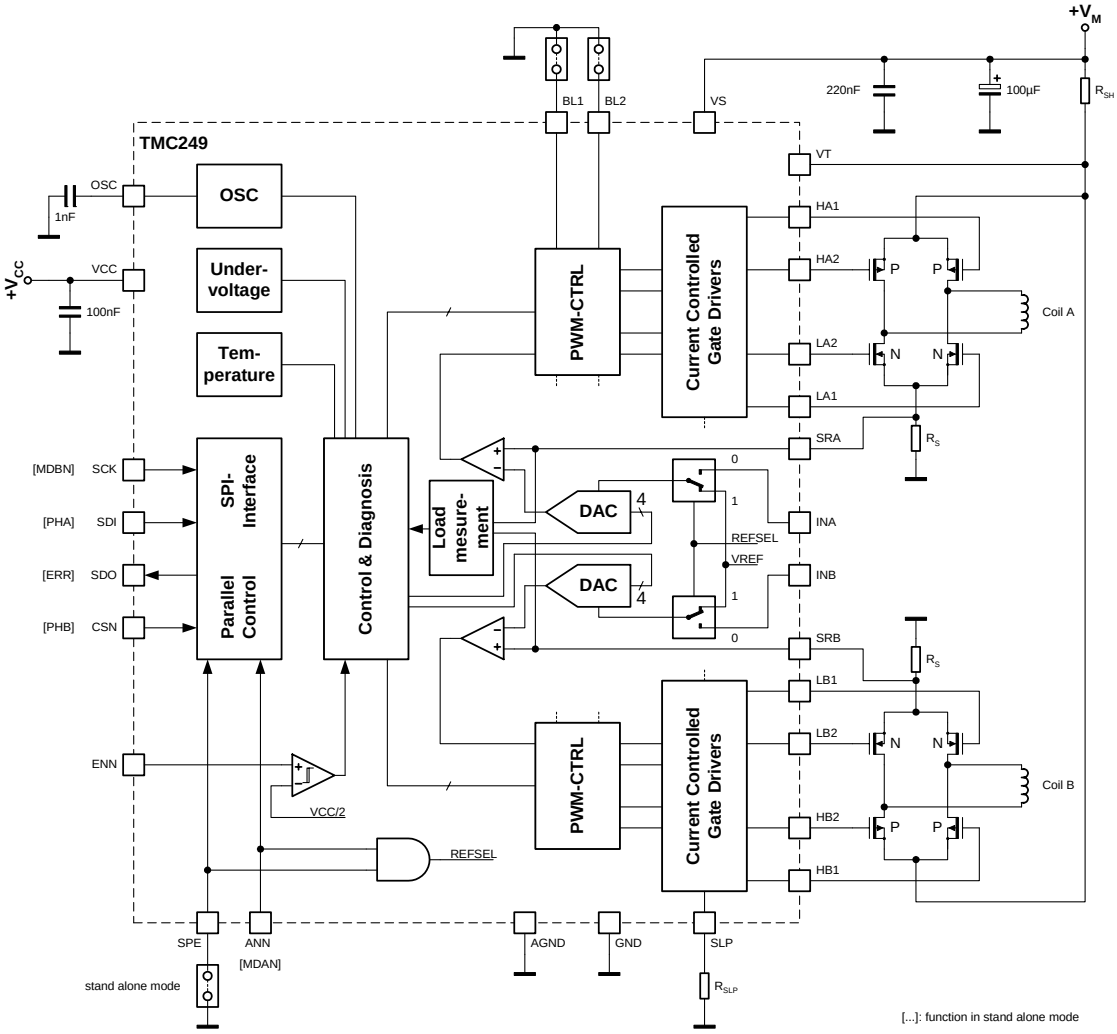
REF	MIN	NOM	MAX
A	0.80	0.90	1.00
A1	0.00	0.02	0.05
A3		0.20	
L1	0.03		0.15
D		7.0	
E		7.0	
D2	5.00	5.15	5.25
E2	5.00	5.15	5.25
L	0.45	0.55	0.65
b	0.25	0.30	0.35
e		0.65	

All dimensions are in mm.



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Application Circuit / Block Diagram



Pin Functions

Pin	Function	Pin	Function
VS	Motor supply voltage	VT	Short to GND detection comparator – connect to VS if not used
VCC	3.0-5.5V supply voltage for analog and logic circuits	GND	Digital / Power ground
AGND	Analog ground (Reference for SRA, SRB, OSC, SLP, INA, INB, SLP)	OSC	Oscillator capacitor or external clock input for chopper
INA	Analog current control phase A	INB	Analog current control input phase B
SCK	Clock input of serial interface	SDO	Data output of serial interface (tri-state)
SDI	Data input of serial interface	CSN	Chip select input of serial interface
ENN	Device enable (low active), and overvoltage shutdown input	SPE	Enable SPI mode (high active). Tie to GND for non-SPI applications
ANN	Enable analog current control via INA and INB (low active)	SLP	Slope control resistor. Tie to GND for fastest slope
BL1, BL2	Digital blank time select	SRA, SRB	Bridge A/B current sense resistor input
HA1, HA2, HB1, HB2	Outputs for high side P-channel transistors	LA1, LA2, LB1, LB2	Outputs for low side N-channel transistors

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Selecting Power Transistors

Selection of power transistors for the TMC249 depends on required current, voltage and thermal conditions. Driving transistors directly with the TMC249 is only limited by the gate capacity of these transistors. If the total gate charge is too high, slope time increases and leads to a higher switching power dissipation. Typical applications can reach a current in excess of 4A, while the maximum voltage is limited to 30V. A total gate charge of below 10nC per transistor is recommended. The table below shows a choice of transistors which can be driven directly by the TMC249. The maximum application current mainly is a function of cooling and environment temperature. The given values are more conservative. Peak currents typically can be higher by a factor of 1.5 for a limited time.

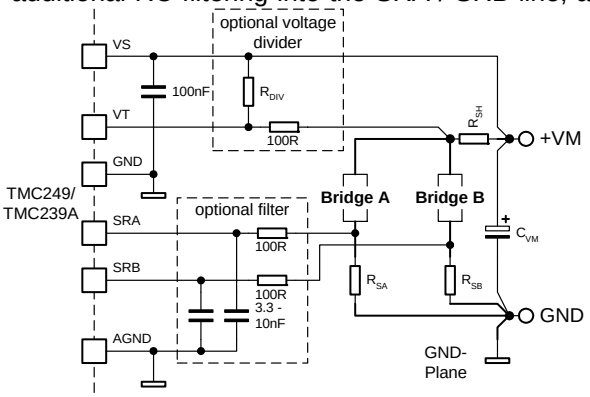
List of recommended transistors

Manufacturer and type	Package (#Trans)	Volts N-type Volts P-type	RDS_{ON} [Ohm]	Total gate charge [nC]	Typical maximum application current	Remark
Siliconix SI 7501DN	PPack (1N,1P)	30V 30V	0.03 0.05	5.0 8.0	4000mA	(1)
Siliconix SI 4539ADY	SO8 (1N,1P)	30V 30V	0.04 0.06	7.5 9.0	3500mA	
Siliconix SI 5504	1206-8 (1N,1P)	30V 30V	0.09 0.17	3.0 3.2	2000mA	
IRF 9952 (/ IRF 7509)	SO8 (1N,1P)	30V 30V	0.10 0.25	4.5 4.0	2500mA	
Siliconix SI 1901	SOT363-6 (2P)	30V	0.48	0.8	200mA unipolar	
Fairchild Semi FDS 8333C	SO8 (1N,1P)	30V 30V	0.08 0.13	2.9 3.0	3000mA 6000mA (2 devices in parallel)	

(1) These transistor types have a very high drain to gate capacity (P-channel), which may introduce destructive current impulses into the HA/HB outputs by forcing them above the power supply level, depending on the low-side slope. To ensure reliability, connect one ZHCS1000 SOT23 or an SS16 1A schottky diode or similar to both HA and HB outputs against VS to protect them.

Layout Considerations

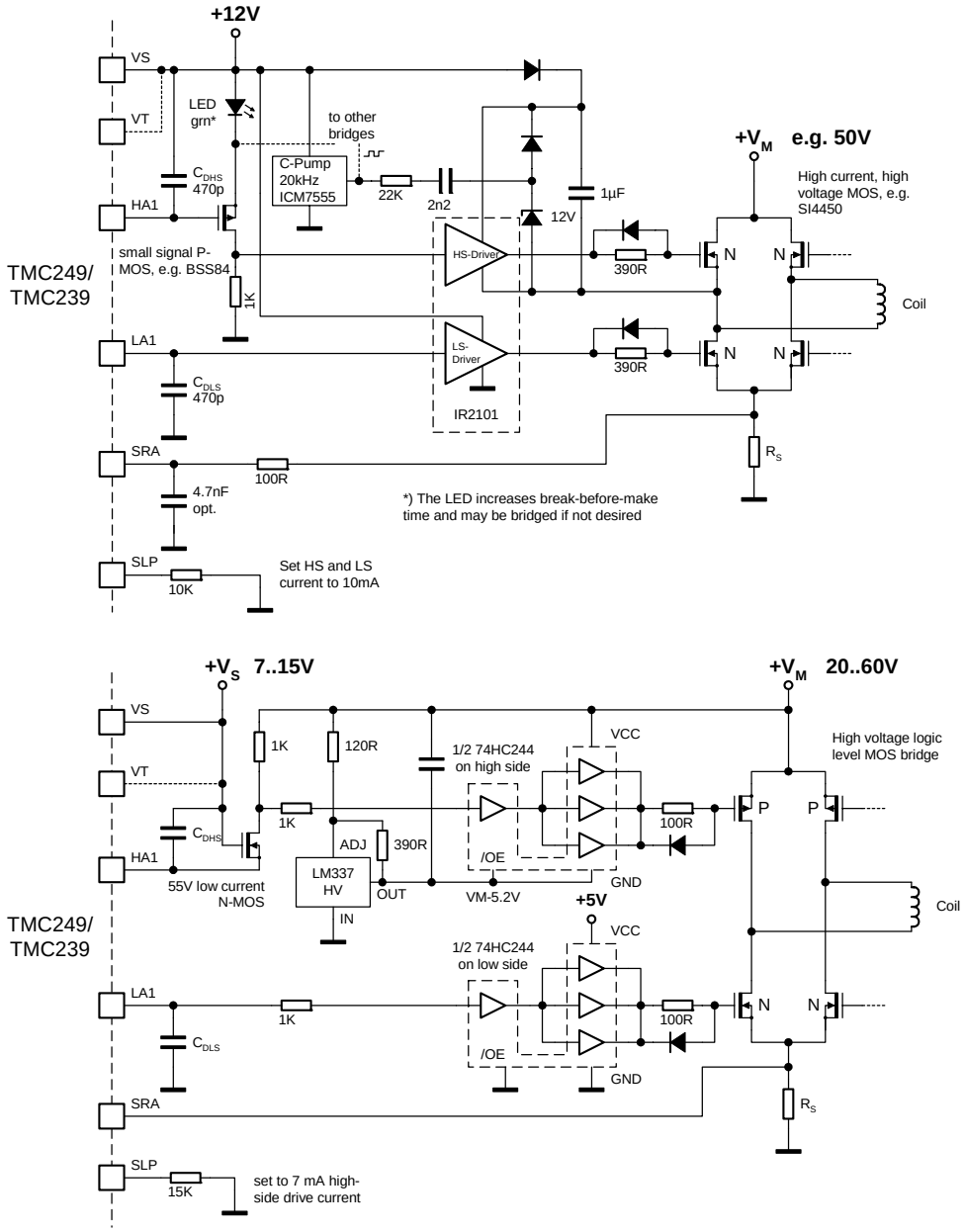
For optimal operation of the circuit a careful board layout is important, because of the combination of high current chopper operation coupled with high accuracy threshold comparators. Please pay special attention to massive grounding. Depending on the required motor current, either a single massive ground plane or a ground plane plus star connection of the power traces may be used. The schematic shows how the high current paths can be routed separately, so that the chopper current does not flow through the system's GND-plane. Tie the TMC249's AGND and GND to the GND plane. Additionally, use enough filtering capacitors located near to the board's power supply input and small ceramic capacitors near to the power supply connections of the TMC249. Use low inductance sense resistors, or add a ceramic capacitor in parallel to each resistor to avoid high voltage spikes. In some applications it may become necessary to introduce additional RC-filtering into the SRA / SRB line, as shown in the schematic, to prevent spikes from triggering the short circuit protection or the chopper comparator. If you want to take advantage of the thermal protection and diagnosis, ensure, that the power transistors are very close to the package, and that there is a good thermal contact between the TMC249 and the external transistors. Please be aware, that long or thin traces to the sense resistors may add substantial resistance and thus reduce output current. The same is valid for the high side shunt resistor.



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Using additional Power Drivers

For higher voltage and higher output current it is possible to add external MOSFET gate drivers. Both, dedicated transistor drivers are suitable, as well as a circuit based on standard HCMOS drivers. It is important to understand the function of dedicated gate drivers for N-channel transistors: Since the chopping also can be stopped in open load conditions, the gate drive circuit for the upper transistors should allow for continuous ON conditions. In the schematic below this is satisfied by attaching a weak additional charge pump oscillator and pumping the VS up to the high voltage supply. Do not enable the TMC249, before the gate driver capacitors are charged to an appropriate voltage. A current sensing comparator in the VM line pulling down the VT pin by some 100mV on overcurrent can be added, if required. Since the TMC249 in this application can not sense switch-off of the transistor gates to ensure break-before-make operation, the break before-make-delays have to be set by capacitive loading of its transistor drive outputs. The capacitors CdHS and CdLS are charged / discharged with the nominal gate current. The opposite output is not enabled, before the switching-off output has been discharged to 0.5V. To calculate the timing, refer to the required logic levels of the attached power driver, resp. the attached PMOS. For CdHS and CdLS 470pF give about 100ns. Both circuits do not show decoupling capacitors and further details.



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Control via the SPI Interface

The SPI data word sets the current and polarity for both coils. By applying consecutive values, describing a sine and a cosine wave, the motor can be driven in microsteps. Every microstep is initiated by its own telegram. Please refer to the description of the analog mode for details on the waveforms required. The SPI interface timing is described in the timing section. We recommend the TMC428 to automatically generate the required telegrams and motor ramps for up to three motors.

Serial data word transmitted to TMC249

(MSB transmitted first)

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

Serial data word transmitted from TMC249

(MSB transmitted first)

Bit	Name	Function	Remark
11	LD2	load indicator bit 2	MSB
10	LD1	load indicator bit 1	
9	LD0	load indicator bit 0	LSB
8	1	always “1”	
7	OT	overtemperature	“1” = chip off due to overtemperature
6	OTPW	temperature prewarning	“1” = prewarning temperature exceeded
5	UV	driver undervoltage	“1” = undervoltage on VS
4	OCHS	overcurrent high side	3 PWM cycles with overcurrent within 63 PWM cycles
3	OLB	open load bridge B	no PWM switch off for 14 oscillator cycles
2	OLA	open load bridge A	no PWM switch off for 14 oscillator cycles
1	OCB	overcurrent bridge B low side	3 PWM cycles with overcurrent within 63 PWM cycles
0	OCA	overcurrent bridge A low side	3 PWM cycles with overcurrent within 63 PWM cycles

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Typical winding current values

Current setting CA3..0 / CB3..0	Percentage of current	Typical trip voltage of the current sense comparator (internal reference or analog input voltage of 2V is used)
0000	0%	0 V (bridge continuously in slow decay condition)
0001	6.7%	23 mV
0010	13.3%	45 mV
...	...	
1110	93.3%	317 mV
1111	100%	340 mV

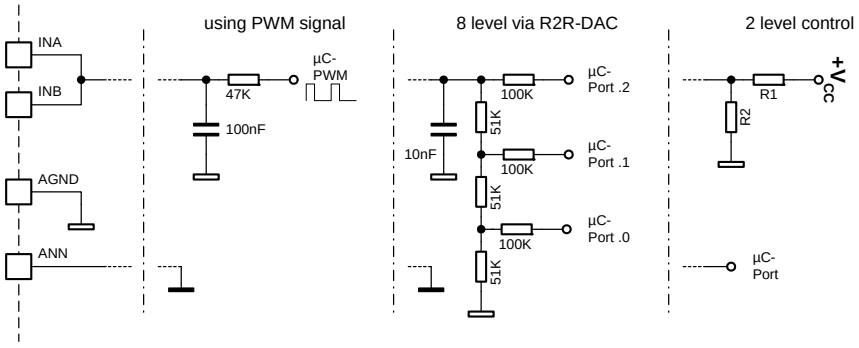
The current values correspond to a standard 4 Bit DAC, where 100%=15/16. The contents of all registers is cleared to “0” on power-on reset or disable via the ENN pin, bringing the IC to a low power standby mode. All SPI inputs have Schmitt-Trigger function.

Base current control via INA and INB in SPI mode

In SPI mode, the IC can use an external reference voltage for each DAC. This allows the adaptation to different motors. This mode is enabled by tying pin ANN to GND. A 2.0V input voltage gives full scale current of 100%. In this case, the typical trip voltage of the current sense comparator is determined by the input voltage and the DAC current setting (see table above) as follows:

$V_{TRIP,A} = 0.17\ V_{INA} \times$ “percentage SPI current setting A”
$V_{TRIP,B} = 0.17\ V_{INB} \times$ “percentage SPI current setting B”

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



Controlling the power down mode via the SPI interface

Bit	11	10	9	8	7	6	5	4	3	2	1	0
Standard function	MxA	CA3	CA2	CA1	CA0	PhA	MxB	CB3	CB2	CB1	CB0	PhB
Control word function	-	0	0	0	0	-	-	0	0	0	0	-

Enable standby mode and clear error flags

Programming current value “0000” for both coils at a time clears the overcurrent flags and switches the TMC249 into a low current standby mode with coils switched off.

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Open load detection

Open load is signaled, whenever there are more than 14 oscillator cycles without PWM switch off. Note that open load detection is not possible while coil current is set to “0000”, because the chopper is off in this condition. The open load flag will then always be read as inactive (“0”). During overcurrent and undervoltage or overtemperature conditions, the open load flags also become active!

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

Standby and shutdown mode

The circuit can be put into a low power standby mode by the user, or, automatically goes to standby on Vcc undervoltage conditions. Before entering standby mode, the TMC249 switches off all power transistors, and holds their gates in a disable condition using high ohmic resistors. In standby mode the oscillator becomes disabled and the oscillator pin is held at a low state. The standby mode is available via the interface in SPI-mode and via the ENN pin in non-SPI mode.

The shutdown mode even reduces supply current further. It can only be entered in SPI-mode by pulling the ENN pin high. In shutdown additionally all internal reference voltages become switched off and the SPI circuit is held in reset.

Power saving

The possibility to control the output current can dramatically save energy, reduce heat generation and increase precision by reducing thermal stress on the motor and attached mechanical components. Just reduce motor current during stand still: Even a slight reduction of the coil currents to 70% of the current of the last step of the movement, halves power consumption! In typical applications a 50% current reduction during stand still is reasonable.

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Stall Detection

Using the sensorless load measurement

The TMC249 provides a patented sensorless load measurement, which allows a digital read out of the mechanical load on the motor via the serial interface. To get a readout value, just drive the motor using sine commutation and mixed decay switched off. The load measurement then is available as a three bit load indicator during normal motion of the motor. A higher mechanical load on the motor results in a lower readout value. The value is updated once per fullstep.

Since the load detection is based on the motor's back EMF, the readout results depend on several factors:

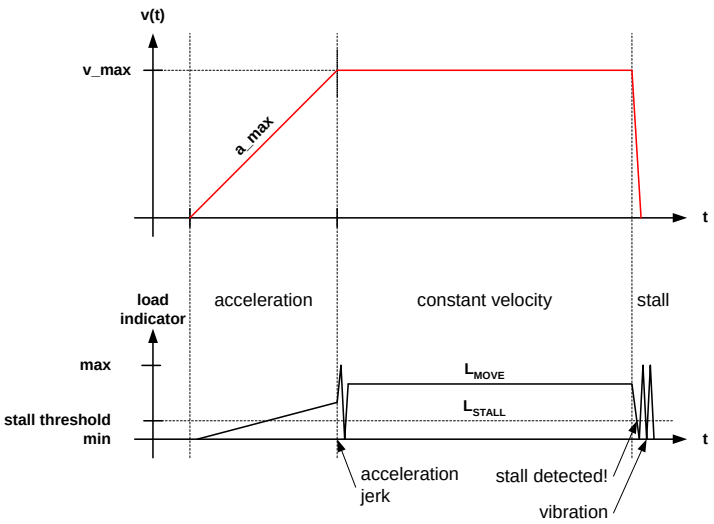
- Motor velocity: A higher velocity leads to a higher readout value
- Motor resonance: Motor resonances cause a high dynamic load on the motor, and thus measurement may give unsatisfactory results.
- Motor acceleration: Acceleration phases also produce dynamic load on the motor.
- Mixed decay setting: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

Implementing sensorless stall detection

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

To get a reliable stall detection, follow these steps:

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



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Protection Functions

Overcurrent protection and diagnosis

The TMC249 uses the current sense resistors on the low side to detect an overcurrent: Whenever a voltage above 0.61V is detected, the PWM cycle is terminated at once and all transistors of the bridge are switched off for the rest of the PWM cycle. The error counter is increased by one. If the error counter reaches 3, the bridge remains switched off for 63 PWM cycles and the error flag is read as “active”. The user can clear the error condition in advance by clearing the error flag. The error counter is cleared, whenever there are more than 63 PWM cycles without overcurrent. There is one error counter for each of the low side bridges, and one for the high side. The overcurrent detection is inactive during the blank pulse time for each bridge, to suppress spikes which can occur during switching.

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

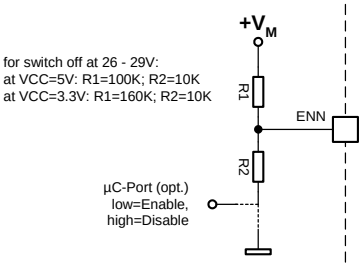
The overcurrent flags can be cleared by disabling and re-enabling the chip either via the ENN pin or by sending a telegram with both current control words set to “0000”. In high side overcurrent conditions the user can determine which bridge sees the overcurrent, by selectively switching on only one of the bridges with each polarity (therefore the other bridge should remain programmed to “0000”).

Overtemperature protection and diagnosis

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

Overvoltage protection and ENN pin behavior

During disable conditions the circuit switches off all output power transistors and goes into a low current shutdown mode. All register contents is cleared to “0”, and all status flags are cleared. The circuit in this condition can also stand a higher voltage, because the voltage then is not limited by the maximum power MOSFET voltage. The enable pin ENN provides a fixed threshold of ½ V_{CC} to allow a simple overvoltage protection up to 40V using an external voltage divider (see schematic).

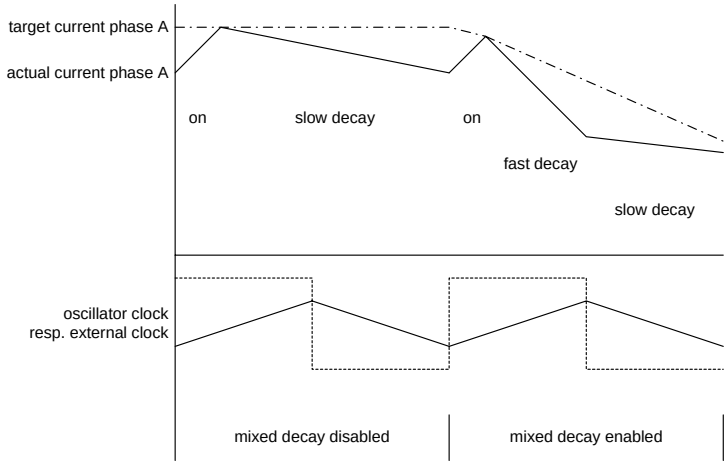


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Chopper Principle

Chopper cycle / Using the mixed decay feature

The TMC249 uses a quiet fixed frequency chopper. Both coils are chopped with a phase shift of 180 degrees. The mixed decay option is realized as a self stabilizing system (pat. fi.), by shortening the fast decay phase, if the ON phase becomes longer. It is advised to enable the mixed decay for each phase during the second half of each microstepping half-wave, when the current is meant to decrease. This leads to less motor resonance, especially at medium velocities. With low velocities or during standstill mixed decay should be switched off. In applications requiring high resolution, or using low inductivity motors, the mixed decay mode can also be enabled continuously, to reduce the minimum motor current which can be achieved. When mixed decay mode is continuously on or when using high inductivity motors at low supply voltage, it is advised to raise the chopper frequency to 36kHz, because the half chopper frequency could be audible under these conditions.



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

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

Blank Time

The TMC249 uses a digital blanking pulse for the current chopper comparators. This prevents current spikes, which can occur during switching action due to capacitive loading, from terminating the chopper cycle. The lowest possible blanking time gives the best results for microstepping: A long blank time leads to a long minimum turn-on time, thus giving an increased lower limit for the current. Please remark, that the blank time should cover both, switch-off time of the lower side transistors and turn-on time of the upper side transistors plus some time for the current to settle. Thus the complete switching duration should never exceed 1.5µs. With slow external power stages it will become necessary to add additional RC-filtering for the sense resistor inputs.

The TMC249 allows to adapt the blank time to the load conditions and to the selected slope in four steps (the effective resulting blank times are about 200ns shorter in the non-A-type):

Blank time settings

BL2	BL1	Typical blank time
GND	GND	0.6 µs
GND	VCC	0.9 µs
VCC	GND	1.2 µs
VCC	VCC	1.5 µs

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Classical non-SPI control mode (stand alone mode)

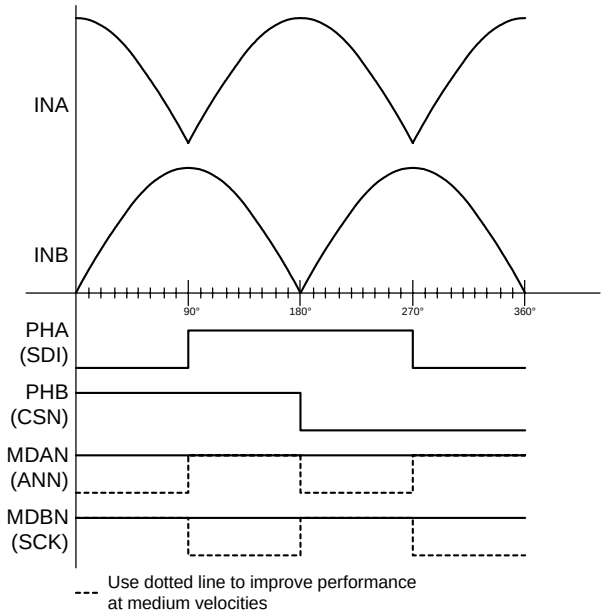
The driver can be controlled by analog current control signals and digital phase signals. To enable this mode, tie pin SPE to GND. In this mode, the SPI interface is disabled and the SPI input pins have alternate functions. The internal DACs are forced to “1111”.

Pin functions in stand alone mode

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

Input signals for microstep control in stand alone mode

Attention: When transferring these waves to SPI operation, please remark, that the mixed decay bits are inverted when compared to stand alone mode.



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Unipolar Operation

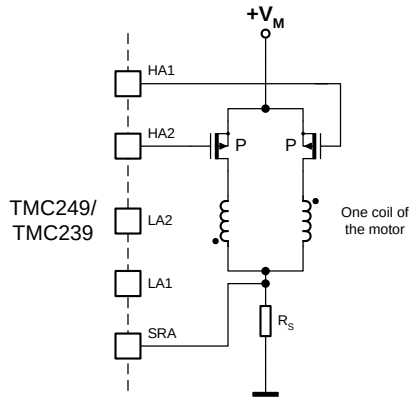
The TMC249 can also be used in an unipolar motor application with microstepping. In this configuration, only the four upper power transistors are required.

Differences of short circuit behavior in unipolar operation mode

Since there is no possibility to disable a short to VS condition, the circuit is not completely short circuit proof. In a low cost application a motor short would be covered, just using the bottom sense resistors (see schematic).

Differences in chopper cycle in unipolar operation mode

In unipolar mode, one of the upper side transistors is chopped, depending on the phase polarity. Slow decay mode always means, that both transistors are disabled. There is no difference between slow and fast decay mode, and the mixed decay control bits are “don’t care”. The transistors have to stand an off voltage, which is slightly higher than the double of the supply voltage. Voltage decay in the coil can be adapted to the application by adding additional diodes and a zener diode to feed back coil current in flyback conditions to the supply.



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Calculation of the external components

Sense Resistor

Choose an appropriate sense resistor (R_S) to set the desired motor current. The maximum motor current is reached, when the coil current setting is programmed to “1111”. This results in a current sense trip voltage of 0.34V when the internal reference or a reference voltage of 2V is used.
When operating your motor in fullstep mode, the maximum motor current is as specified by the manufacturer. When operating in sinestep mode, multiply this value by 1.41 for the maximum current (I_{max}).

$$R_S = V_{TRIP} / I_{max}$$

In a typical application:

$$R_S = 0.34V / I_{max}$$

R_S: Current sense resistor of bridge A, B
V_{TRIP}: Programmed trip voltage of the current sense comparators
I_{max}: Desired maximum coil current

Examples for sense resistor settings

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

High side overcurrent detection resistor R_{SH}

The TMC249 detects an overcurrent to ground, when the voltage between VS and VT exceeds 150mV. The high side overcurrent detection resistor should be chosen in a way that 100mV voltage drop are not exceeded between VS and VT, when both coils draw the maximum current. In a sinestep application, this is when sine and cosine wave have their highest sum, i.e. at 45 degrees, corresponding to 1.41 times the maximum current setting for one coil. In a fullstep application this is the double coil current.

In a microstep application:

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

In a fullstep application:

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

R_{SH}: High side overcurrent detection resistor
I_{max}: Maximum coil current

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

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

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Making the circuit short circuit proof

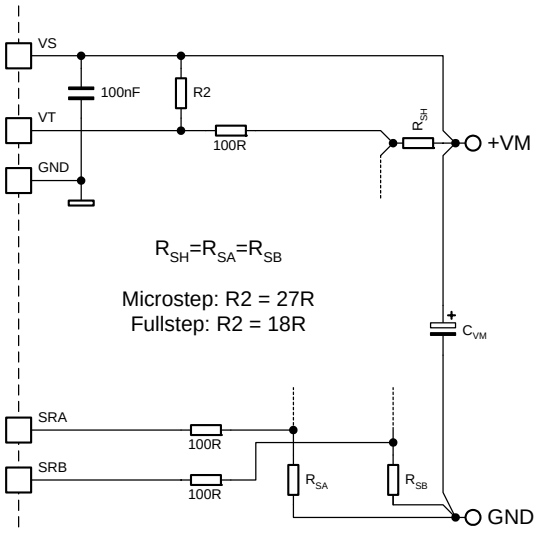
In practical applications, a short circuit does not describe a static condition, but can be of very different nature. It typically involves inductive, resistive and capacitive components. Worst events are unclamped switching events, because huge voltages can build up in inductive components and result in a high energy spark going into the driver, which can destroy the power transistors. The same is true when disconnecting a motor during operation: Never disconnect the motor during operation!

There is no absolute protection against random short circuit conditions, but pre-cautions can be taken to improve robustness of the circuit:
In a short condition, the current can become very high before it is interrupted by the short detection, due to the blanking during switching and internal delays. The high-side transistors allow a high current flowing for the selected blank time. The lower the external inductivity, the faster the current climbs. If inductive components are involved in the short, the same current will shoot through the low-side resistor and cause a high negative voltage spike at the sense resistor. Both, the high current and the voltage spikes are a danger for the driver.

Thus there are a three things to be done, if short circuits are expected:
1. Protect SRA/SRB inputs using a series resistance
2. Increase R_{SH} to limit maximum transistor current: Use same value as for sense resistors
3. Use as short as possible blank time

The second measure effectively limits short circuit current, because the upper driver transistor with its fixed ON gate voltage of 6V forms a constant current source together with its internal resistance and R_{SH}. A positive side effect is, that only one type of low ohmic resistor is required. The drawback is, that power dissipation increases. A high side short detection resistor of 0.33 Ohms limits maximum high side transistor current to typically 4A. The schematic shows the modifications to be done.

However, the effectiveness of these measures should be tested in the given application.



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Oscillator Capacitor

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

$$f_{OSC} \approx \frac{1}{40\mu s \times C_{OSC}\,[nF]}$$

f_{OSC}: PWM oscillator frequency
C_{OSC}: Oscillator capacitor in nF

Table of oscillator frequencies

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

Please remark, that an unnecessary high frequency leads to high switching losses in the power transistors and in the motor. For most applications a chopper frequency slightly above audible range is sufficient. When audible noise occurs in an application, especially with mixed decay continuously enabled, the chopper frequency should be two times the audible range.

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Slope Control Resistor

The output-voltage slope of the full bridge is controlled by a constant current gate charge / discharge of the MOSFETs. The charge / discharge current for the MOSFETs can be controlled by an external resistor: A reference current is generated by internally pulling the SLP-Pin to 1.25V via an integrated 4.7KΩ resistor. This current is used to generate the current for switching ON and OFF the power transistors. (In non-A-type the low side slopes are fixed to typ. +/-15mA corresponding to a 5KΩ to 10KΩ slope control resistor!)

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

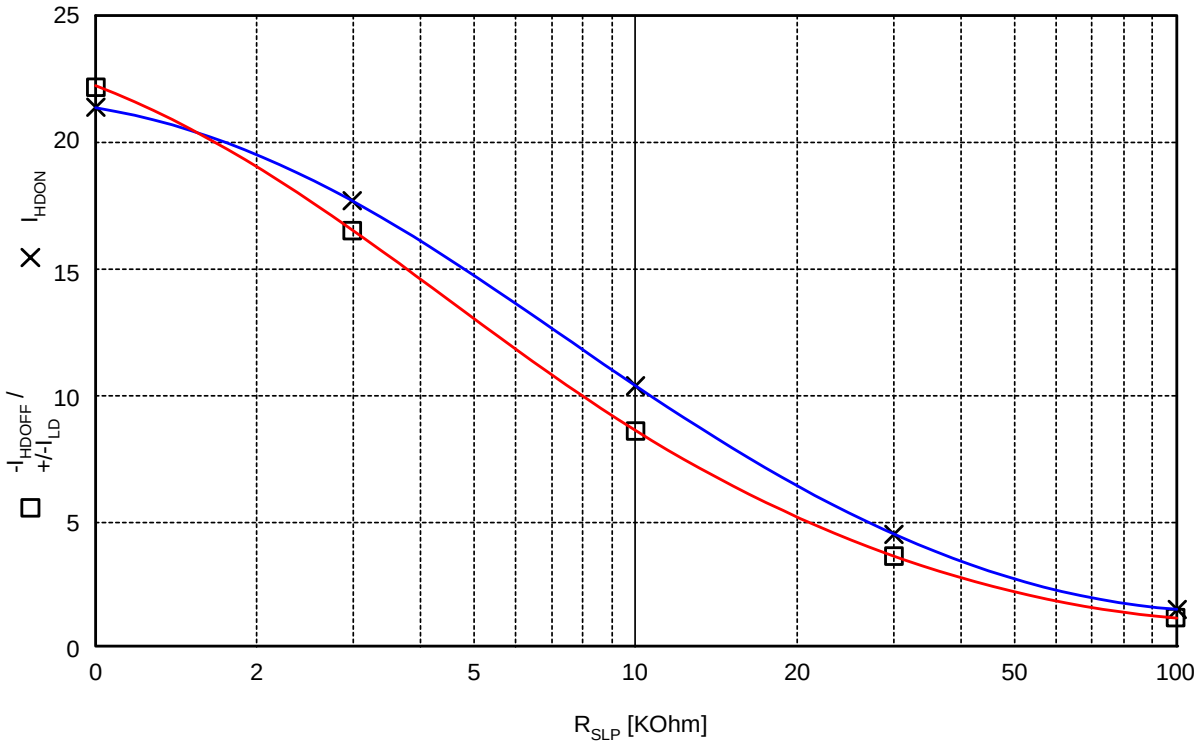
$$R_{SLP}[k\Omega] \approx \frac{123}{I_{OUT}[mA]} - 4.7$$

R_{SLP}: Slope control resistor
I_{OUT}: Controlled output current of the low-side MOSFET driver

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

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

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



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Absolute Maximum Ratings

The maximum ratings may not be exceeded under any circumstances.

Symbol	Parameter	Min	Max	Unit
V_S	Supply voltage		36	V
V_{SM}	Supply and bridge voltage max. 20000s		40	V
V_{CC}	Logic supply voltage	-0.5	6.0	V
I_{OP}	Gate driver peak current (1)		50	mA
I_{OC}	Gate driver continuous current		5	mA
V_I	Logic input voltage	-0.3	V_{CC}+0.3V	V
V_{IA}	Analog input voltage	-0.3	V_{CC}+0.3V	V
I_{IO}	Maximum current to / from digital pins and analog inputs		+/-10	mA
V_{VT}	Short-to-ground detector input voltage	V_S-1V	V_S+0.3V	V
T_J	Junction temperature	-40	150 (1)	°C
T_{STG}	Storage temperature	-55	150	°C

(1) Internally limited

Electrical Characteristics

Operational Range

Symbol	Parameter	Min	Max	Unit
T_{AI}	Ambient temperature industrial (1)	-25	125	°C
T_{AA}	Ambient temperature automotive	-40	125	°C
T_J	Junction temperature	-40	140	°C
V_S	Bridge supply voltage (A-type)	7	34	V
V_S	Bridge supply voltage (non-A-type)	7	30	V
V_{CC}	Logic supply voltage	3.0	5.5	V
f_{CLK}	Chopper clock frequency		100	kHz
R_{SLP}	Slope control resistor	0	470	KΩ

(1) The circuit can be operated up to 140°C, but output power derates.

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DC Characteristics

DC characteristics contain the spread of values guaranteed within the specified supply voltage and temperature range unless otherwise specified. Typical characteristics represent the average value of all parts.
Logic supply voltage: V_{CC} = 3.0 V ... 5.5 V, Junction temperature: T_J = -40°C … 140°C,
Bridge supply voltage : V_S = 7 V…34 V (unless otherwise specified)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
I_{LDON}	Gate drive current low side switch ON (non-A-type)	V_{LD} < 4V	10	15	25	mA
I_{LDOFF5}	Gate drive current low side switch OFF (non-A-type)	V_{LD} > 3V V_{CC} = 5V	-15	-25	-35	mA
I_{LDOFF3}	Gate drive current low side switch OFF (non-A-type)	V_{LD} > 3V VCC = 3.3V	-10	-15	-20	mA
I_{LDON}	Gate drive current low side switch ON (A-type)	V_S > 8V, R_{SLP}= 0K V_{LD} < 4V	15	25	40	mA
I_{LDOFF}	Gate drive current low side switch OFF (A-type)	V_S > 8V, R_{SLP}= 0K V_{LD} > 4V	-15	-25	-40	mA
I_{HDON}	Gate drive current high side switch ON	V_S > 8V, R_{SLP}= 0K V_S - V_{HD} < 4V	-15	-25	-40	mA
I_{HDOFF}	Gate drive current high side switch OFF	V_S > 8V, R_{SLP}= 0K V_S - V_{HD} > 4V	15	30	40	mA
ΔI_{SET}	Deviation of Current Setting with Respect to Characterization Curve [1)]	Deviation from standard value, 10kΩ<R_{SLP}<75kΩ	70	100	130	%
V_{GH1}	Gate drive voltage high side ON	V_S > 8V relative to V_S	-5.1	-6.0	-8.0	V
V_{GL1}	Gate drive voltage low side ON	V_S > 8V	5.1	6.0	8.0	V
V_{GH0}	Gate drive voltage high side OFF	relative to V_S		0	-0.5	V
V_{GL0}	Gate drive voltage low side OFF			0	0.5	V
V_{GCL}	Gate driver clamping voltage	-I_H / I_L = 20mA	12	16	20	V
V_{GCLI}	Gate driver inverse clamping voltage	-I_H / I_L = -20mA		-0.8		V

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Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{CCUV}	VCC undervoltage		2.5	2.7	2.9	V
V_{CCOK}	VCC voltage o.k.		2.7	2.9	3.0	V
I_{CC}	VCC supply current	f_{osc} = 25 kHz		0.85	1.35	mA
I_{CCSTB}	VCC supply current standby			0.45	0.75	mA
I_{CCSD}	VCC supply current shutdown	ENN = 1		37	70	µA
V_{SUV}	VS undervoltage		5.5	5.9	6.2	V
V_{CCOK}	VS voltage o.k.		6.1	6.4	6.7	V
I_{SSM}	VS supply current with maximum current setting (static state)	V_S = 14V, R_{SLP}= 0K		6		mA
I_{SSD}	VS supply current shutdown or standby	V_S = 14V		28	50	µA
V_{IH}	High input voltage (SDI, SCK, CSN, BL1, BL2, SPE, ANN)		2.2		VCC + 0.3 V	V
V_{IL}	Low input voltage (SDI, SCK, CSN, BL1, BL2, SPE, ANN)		-0.3		0.7	V
V_{IHYS}	Input voltage hysteresis (SDI, SCK, CSN, BL1, BL2, SPE, ANN)		100	300	500	mV
V_{OH}	High output voltage (output SDO)	$-I_{OH}$ = 1mA	VCC – 0.6	VCC – 0.2	VCC	V
V_{OL}	Low output voltage (output SDO)	I_{OL} = 1mA	0	0.1	0.4	V
$-I_{ISL}$	Low input current (SDI, SCK, CSN, BL1, BL2, SPE, ANN)	V_I = 0 V_{CC} = 3.3V V_{CC} = 5.0V	2	 10 25	70	µA µA µA
V_{ENNH}	High input voltage threshold (input ENN)			1/2 VCC		
V_{EHYS}	Input voltage hysteresis (input ENN)			0.1 V_{ENNH}		
V_{OSCH}	High input voltage threshold (input OSC)		tbd	2/3 VCC	tbd	V
V_{OSCL}	Low input voltage threshold (input OSC)		tbd	1/3 VCC	tbd	V
V_{VTD}	VT threshold voltage (referenced to VS)		-130	-155	-180	mV
V_{TRIP}	SRA / SRB voltage at DAC="1111"	internal ref. or 2V at INA / INB	315	350	385	mV
V_{SRS}	SRA / SRB overcurrent detection threshold		570	615	660	mV
$V_{SROFFS1}$	SRA / SRB comparator offset voltage (Standard device)		-10	0	10	mV
$V_{SROFFS2}$	SRA / SRB comparator offset voltage (Selected device)		-6	0	6	mV
R_{INAB}	INA / INB input resistance	Vin ≤ 3 V	175	264	360	kΩ

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AC Characteristics

AC characteristics contain the spread of values guaranteed within the specified supply voltage and temperature range unless otherwise specified. Typical characteristics represent the average value of all parts.
Logic supply voltage: V_{CC} = 3.3V, Bridge supply voltage: V_S = 14.0V,
Ambient temperature: T_A = 27°C, External MOSFET gate charge = 3.2nC

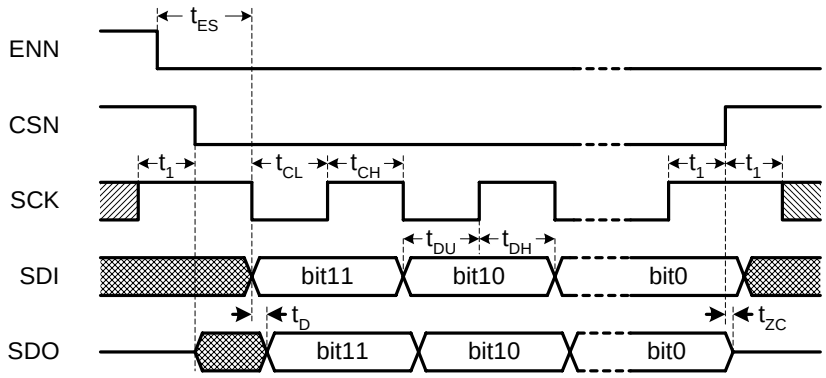
Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{OSC}	Oscillator frequency using internal oscillator	C_{OSC} = 1nF ±1%	20	25	31	kHz
T_{BL}	Effective Blank time	BL1, BL2 = V_{CC}	1.35	1.5	1.65	µs
T_{ONMIN}	Minimum PWM on-time	BL1, BL2 = GND		0.7		µs

Thermal Protection

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
T_{JOT}	Thermal shutdown		145	155	165	°C
T_{JOTHYS}	T_{JOT} hysteresis			15		°C
T_{JWT}	Prewarning temperature		135	145	155	°C
T_{JWTHYS}	T_{JWT} hysteresis			15		°C

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SPI Interface Timing



Propagation Times

(3.0 V ≤ VCC ≤ 5.5 V, -40°C ≤ Tj ≤ 150°C; V_{IH} = 2.8V, V_{IL} = 0.5V; tr, tf = 10ns; C_L = 50pF, unless otherwise specified)

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{SCK}	SCK frequency	ENN = 0	DC		4	MHz
t_1	SCK stable before and after CSN change		50			ns
t_{CH}	Width of SCK high pulse		100			ns
t_{CL}	Width of SCK low pulse		100			ns
t_{DSU}	SDI setup time		40			ns
t_{DH}	SDI hold time		50			ns
t_D	SDO delay time	C_L = 50pF		40	100	ns
t_{ZC}	CSN high to SDO high impedance		50			ns
t_{ES}	ENN to SCK setup time		30			ns
t_{PD}	CSN high to output change delay			3		µs

SDO is tristated whenever ENN is inactive (high) or CSN is inactive (high).

Using the SPI interface

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

SPI Filter

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

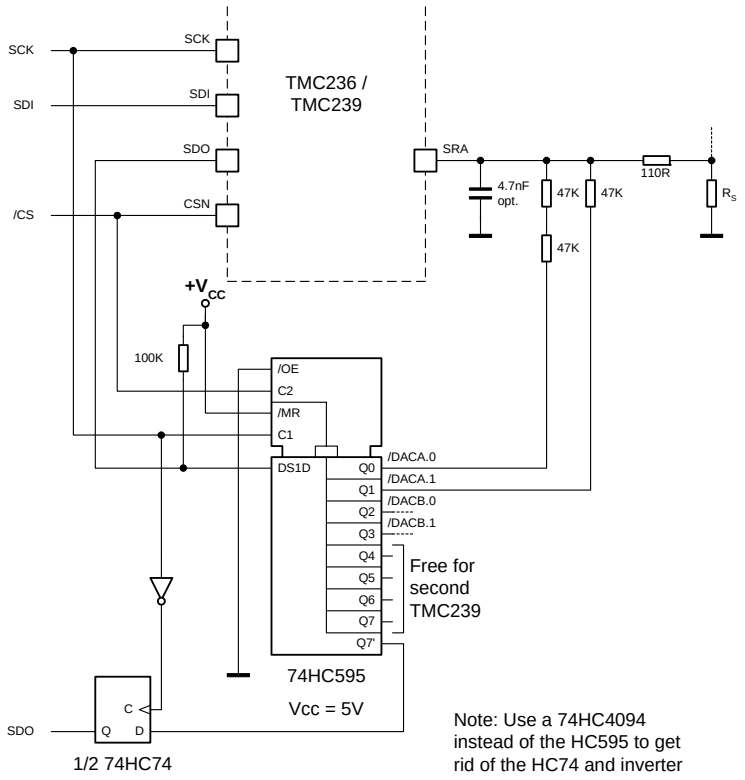
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Application Note: Extending the Microstep Resolution

For some applications it might be desired to have a higher microstep resolution, while keeping the advantages of control via the serial interface. The following schematic shows a solution, which adds two LSBs by selectively pulling up the SRA / SRB pin by a small voltage difference. Please remark, that the lower two bits are inverted in the depicted circuit. A full scale sense voltage of 340mV is assumed. The circuit still takes advantage of completely switching off of the coils when the internal DAC bits are set to “0000”. This results in the following comparator trip voltages:

Current setting (MSB first)	**Trip voltage**
0000xx	0 V
000111	5.8 mV
000110	11.5 mV
000101	17.3 mV
000100	23 mV
...	
111101	334.2 mV
111100	340 mV

SPI bit	15	14	13	12	11	10	9	8
DAC bit	/B1	/B0	/A1	/A0	MDA	A5	A4	A3
SPI bit	7	6	5	4	3	2	1	0
DAC bit	A2	PHA	MDB	B5	B4	B3	B2	PHB



[i] SPI is a trademark of Motorola

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