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TMC2100-LA DATASHEET

Standalone intelligent Step/Direction driver for two-phase bipolar stepper motor.
stealthChop™ for quiet movement. Integrated MOSFETs for up to 1.7A motor current per coil.

APPLICATIONS

Textile, Sewing Machines
Office Automation
Consumer, Home
CCTV, Security
ATM, Cash recycler
POS
Printers & Scanners

FEATURES AND BENEFITS

2-phase stepper motors

Standalone Driver

Drive Capability up to 1.2A coil current (1.7A peak)

Step/Dir Interface with microstep interpolation **microPlyer™**

Voltage Range 4.75… 46V DC

Highest Resolution 256 microsteps per full step

stealthChop™ for extremely quiet operation and smooth motion

spreadCycle™ highly dynamic motor control chopper

Integrated Current Sense Option

Standstill Current Reduction

Full Protection & Diagnostics (two outputs)

Small Size 5x6mm² QFN36 package

DESCRIPTION

The TMC2100 is TRINAMICs most autonomous driver IC. This small and intelligent standalone driver for two phase stepper motors offers market-leading features while being configured by seven pins only. CPU interaction is not required. Drive the motor via Step and Direction signals. TRINAMICs sophisticated stealthChop chopper ensures noiseless operation combined with efficiency and best motor torque. Integrated power MOSFETs handle motor currents up to 1.2A RMS continuously or 2.5A short time peak current per coil. For saving energy, the TMC2100 provides standstill current reduction. Protection and diagnostic features support robust and reliable operation. The TMC2100 enables miniaturized designs with low external component count for cost-effective and highly competitive solutions.

BLOCK DIAGRAM

TRINAMIC Motion Control GmbH & Co. KG
Hamburg, Germany
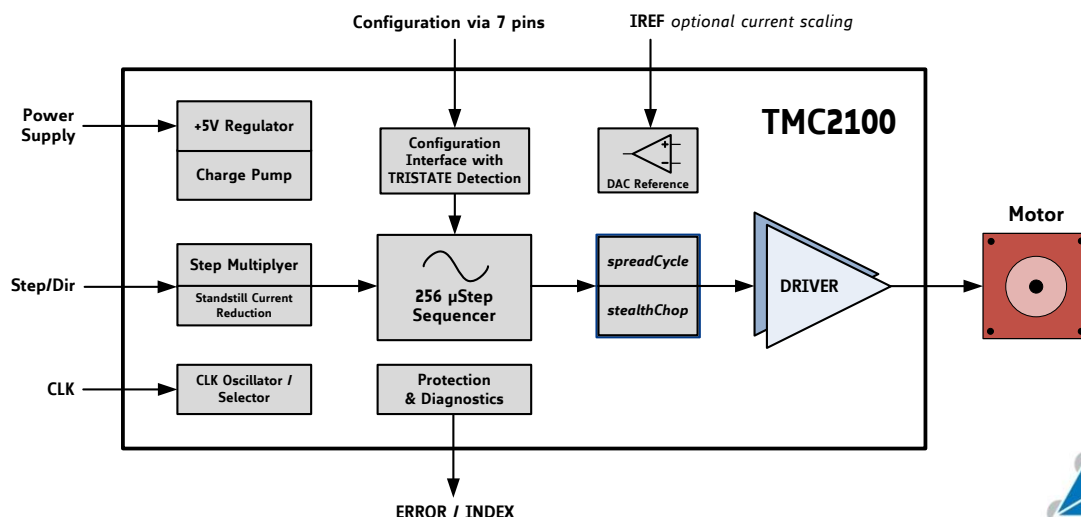
# APPLICATION EXAMPLES: SIMPLE SOLUTIONS – HIGHLY EFFECTIVE

The TMC2100 scores with power density, integrated power MOSFETs, smooth and quiet operation, and a congenial simplicity. The TMC2100 covers a wide spectrum of applications from battery systems up to embedded applications with up to 1.7A motor current per coil. TRINAMICs unique chopper modes spreadCycle and stealthChop optimize drive performance. stealthChop reduces motor noise to the point of silence during low velocities. Standby current reduction keeps costs for power dissipation and cooling down. Extensive support enables rapid design cycles and fast time-to-market with competitive products.

### STANDALONE DESIGN FOR ONE STEPPER MOTOR
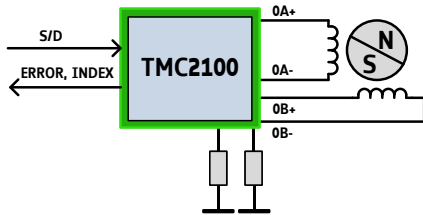
In this example, configuration is hard wired. The motor is driven via step and direction signals. Motion control tasks and interpreting ERROR and INDEX are software based.

MINIATURIZED DESIGN FOR ONE STEPPER MOTOR
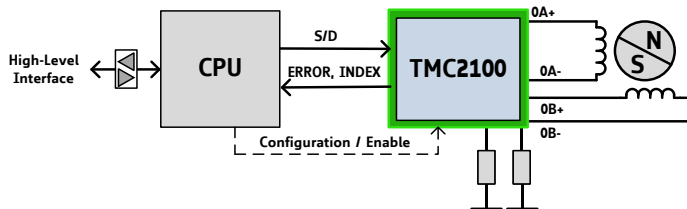
Here, the CPU sends step and direction signals to the TMC2100 and reads out ERROR and INDEX for diagnostic tasks. Further, the CPU configures the TMC2100 and manages motion control. Based on Step/Dir signals, the TMC2100 provides motor currents for each axis and smoothens and optimizes drive performance.

EVALUATION BOARD SYSTEM
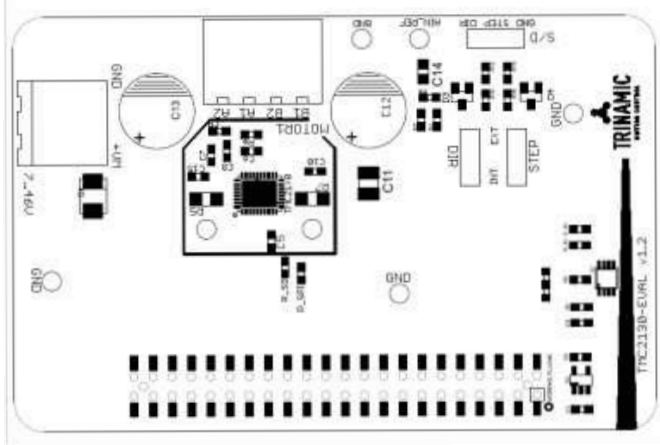
The TMC2100-EVAL is part of TRINAMICs universal evaluation board system which provides a convenient handling of the hardware as well as a user-friendly software tool for evaluation. The TMC2100 evaluation board system consists of three parts: STARTRAMPE (base board), ESELSBRÜCKE (connector board with several test points), and TMC2100-EVAL.

ORDER CODES

Order code	Description	Size [mm²]
TMC2100-LA	1-axis stealthChop standalone driver; QFN36	5 x 6
TMC2100-EVAL	Evaluation board for TMC2100 two phase stepper motor controller/driver	85 x 55
STARTRAMPE	Baseboard for TMC2100-EVAL and further evaluation boards	85 x 55
ESELSBRÜCKE	Connector board for plug-in evaluation board system	61 x 38

Table of Contents

1   Key Concepts

The TMC2100 is easy to use. It can be configured by seven hardware pins. CPU interaction is not necessary. The TMC2100 positions the motor based on step and direction signals and the integrated microPlyer automatically smoothens motion. Basic standby current control can be done by the TMC2100. Optional feedback signals allow error detection and synchronization. Optionally, current scaling is possible by providing an analog reference current IREF.

A CPU for configuration, motion control, and diagnostics can be connected, but this is not basically needed to drive the motor.
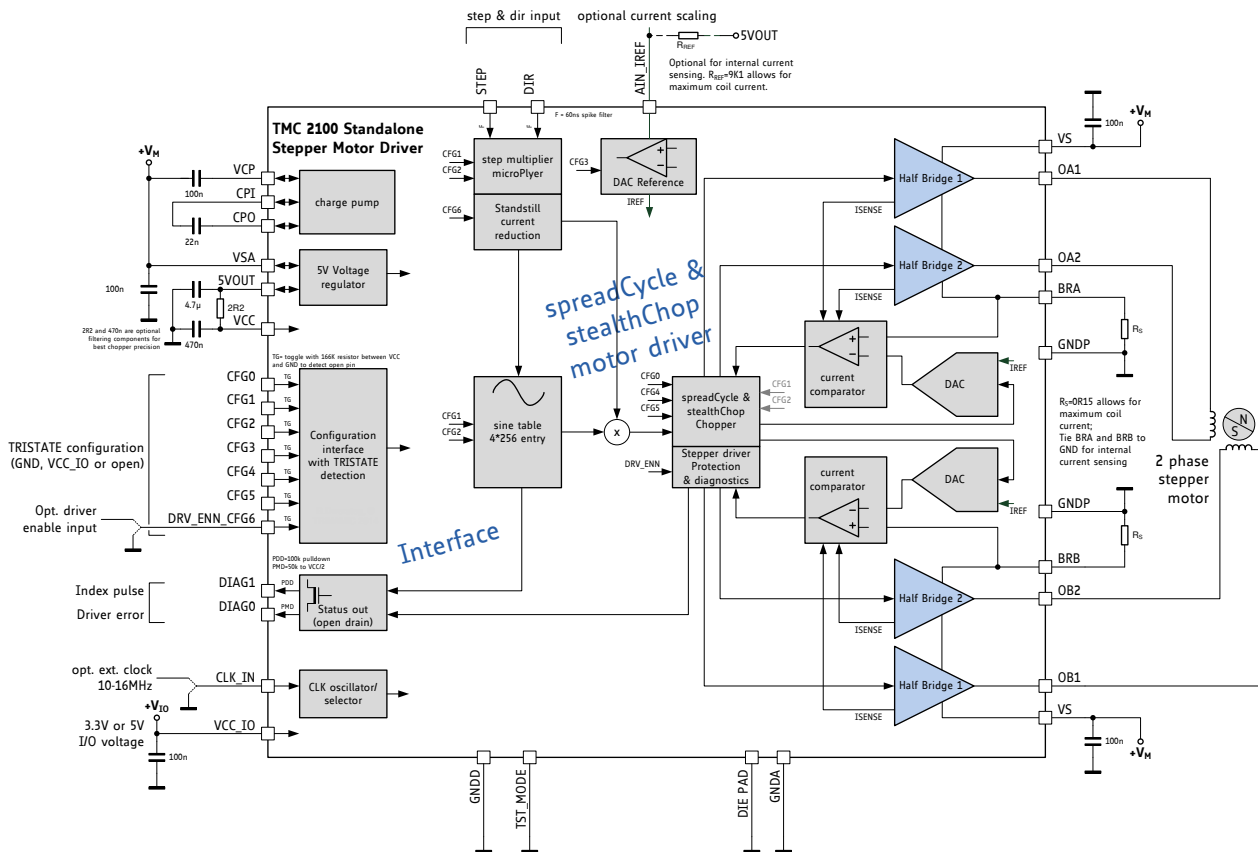
Figure 1.1 TMC2100 standalone driver application diagram

The TMC2100 implements advanced features which are exclusive to TRINAMIC products. These features contribute toward greater precision and smoother motion in many stepper motor applications. Particularly, the TMC2100 provides special chopper algorithms in order to reduce engine noise and react extremely fast to changes in velocity and motor load.

stealthChop™   is a voltage chopper based principle. It guarantees that the motor is absolutely quiet in standstill and in slow motion, except for noise generated by ball bearings. The extremely smooth motion is beneficial for many applications.

spreadCycle™   offers smooth operation and great power efficiency over a wide range of speed and load. The spreadCycle chopper scheme automatically integrates a fast decay cycle and guarantees smooth zero crossing performance.

microPlyer™   microstep interpolator for obtaining increased smoothness of microstepping.

1.1 Software

Usually, the TMC2100 is configured to a fixed configuration using the related hardware pins. Status bits for error detection can be read out using ERROR and INDEX. The TMC2100 is a stepper motor driver chip that can be driven software based with only little effort. It does not need a master CPU or a motion controller IC, but step and direction signals have to be provided to drive a motor.

1.2 STEP/DIR Interface

The motor is controlled by a step and direction input. Active edges on the STEP input are rising ones. On each active edge, the state sampled from the DIR input determines whether to step forward or back. Each step can be a fullstep or a microstep, in which there are 2, 4, 8, 16, 32, 64, 128, or 256 microsteps per fullstep. During microstepping, a step impulse with a low state on DIR increases the microstep counter and a high decreases the counter by an amount controlled by the microstep resolution. An internal table translates the counter value into the sine and cosine values which control the motor current for microstepping.

1.3 Standstill Current Reduction

The automatic standstill current reduction allows to automatically reduce the motor current by nearly two-thirds to save energy in standstill. This is possible in many applications, as normally less holding torque is required. In case the standstill current option has been enabled, the motor current becomes softly ramped down from 100% to 34% in 44M clock cycles (3 to 4 seconds) if no step pulse has been issued for more than 3M clock cycles (standby delay time). The soft current ramp avoids a jerk on the motor.
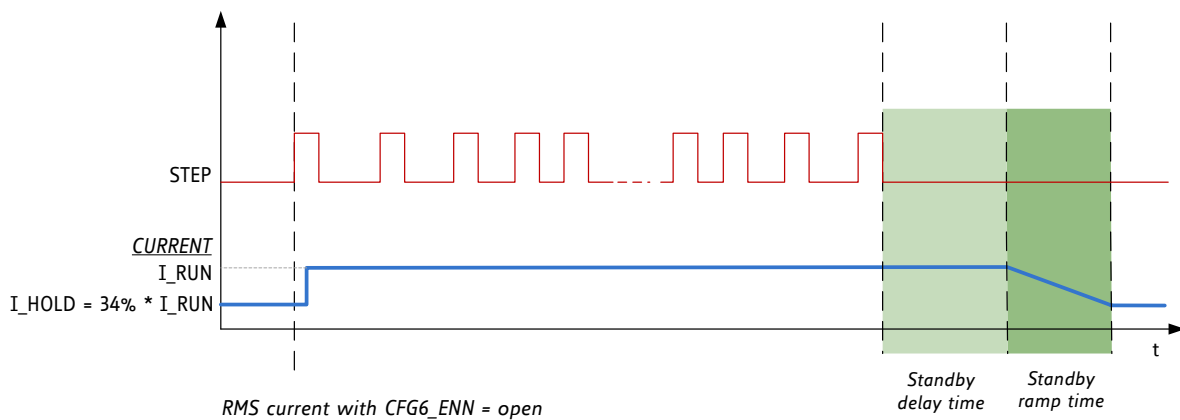

Figure 1.2 Standstill current reduction

1.4 Diagnostics and Protection

The TMC2100 offers safeguards to detect and protect against shorted outputs, overtemperature, and undervoltage conditions for enhancing safety and recovery from equipment malfunctions.
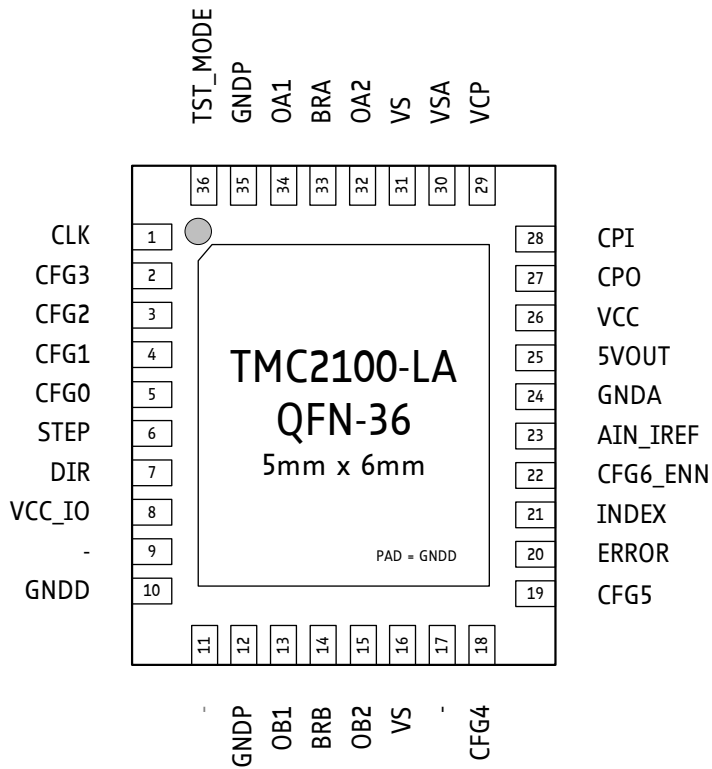
2 Pin Assignments

2.1 Package Outline

Figure 2.1 TMC2100-LA package and pinning QFN-36 (5x6mm)

2.2　Signal Descriptions

Pin	Number	Type	Function
CLK	1	DI	CLK input. Tie to GND using short wire for internal clock or supply external clock.
CFG3	2	DI	Configuration input
CFG2	3	DI	Configuration input
CFG1	4	DI	Configuration input
CFG0	5	DI	Configuration input
STEP	6	DI	STEP input
DIR	7	DI	DIR input
VCC_IO	8		3.3 V to 5 V IO supply voltage for all digital pins.
N.C.	9		Unused pin, leave open.
GNDD	10		Digital GND. Connect to GND.
N.C.	11		Unused pin, connect to GND for compatibility to future versions.
GNDP	12, 35		Power GND. Connect to GND plane near pin.
OB1	13		Motor coil B output 1
BRB	14		Sense resistor connection for coil B. Place sense resistor to GND near pin.
OB2	15		Motor coil B output 2
VS	16, 31		Motor supply voltage. Provide filtering capacity near pin with short loop to nearest GNDP pin (respectively via GND plane).
N.C.	17		Unused pin, leave open.
CFG4	18	DI	Configuration input
CFG5	19	DI	Configuration input
ERROR	20	DO	Diagnostic open drain output: driver error
INDEX	21	DO	Diagnostic open drain output: microstep table position index
CFG6_ENN	22	DI	Enable input and power down configuration
AIN_IREF	23	AI	Analog reference voltage for current scaling (optional mode) or reference current for use of internal sense resistors
GNDA	24		Analog GND. Tie to GND plane.
5VOUT	25		Output of internal 5V regulator. Attach 2.2 µF or larger ceramic capacitor to GNDA near to pin for best performance. May be used to supply VCC of chip.
VCC	26		5V supply input for digital circuitry within chip and charge pump. Attach 470nF capacitor to GND (GND plane). May be supplied by 5VOUT. A 2.2 or 3.3 Ohm resistor is recommended for decoupling noise from 5VOUT. When using an external supply, make sure, that VCC comes up before or in parallel to 5VOUT or VCC_IO, whichever comes up later!
CPO	27		Charge pump capacitor output.
CPI	28		Charge pump capacitor input. Tie to CPO using 22nF 50V capacitor.
VCP	29		Charge pump voltage. Tie to VS using 100nF 16V capacitor.
VSA	30		Analog supply voltage for 5V regulator. Normally tied to VS. Provide a 100nF filtering capacitor.
OA2	32		Motor coil A output 2
BRA	33		Sense resistor connection for coil A. Place sense resistor to GND near pin.
OA1	34		Motor coil A output 1
TST_MODE	36	DI	Test mode input. Tie to GND using short wire.
Exposed die pad	-		Connect the exposed die pad to a GND plane. Provide as many as possible vias for heat transfer to GND plane. Serves as GND pin for digital circuitry.

3 Operation

STEP/DIR inputs control the driver. The TMC2100 works in spreadCycle mode or stealthChop mode. It provides microstep interpolation and automatic standstill current reduction. ERROR signals driver error and INDEX signals the microstep table index position (low active open drain outputs).
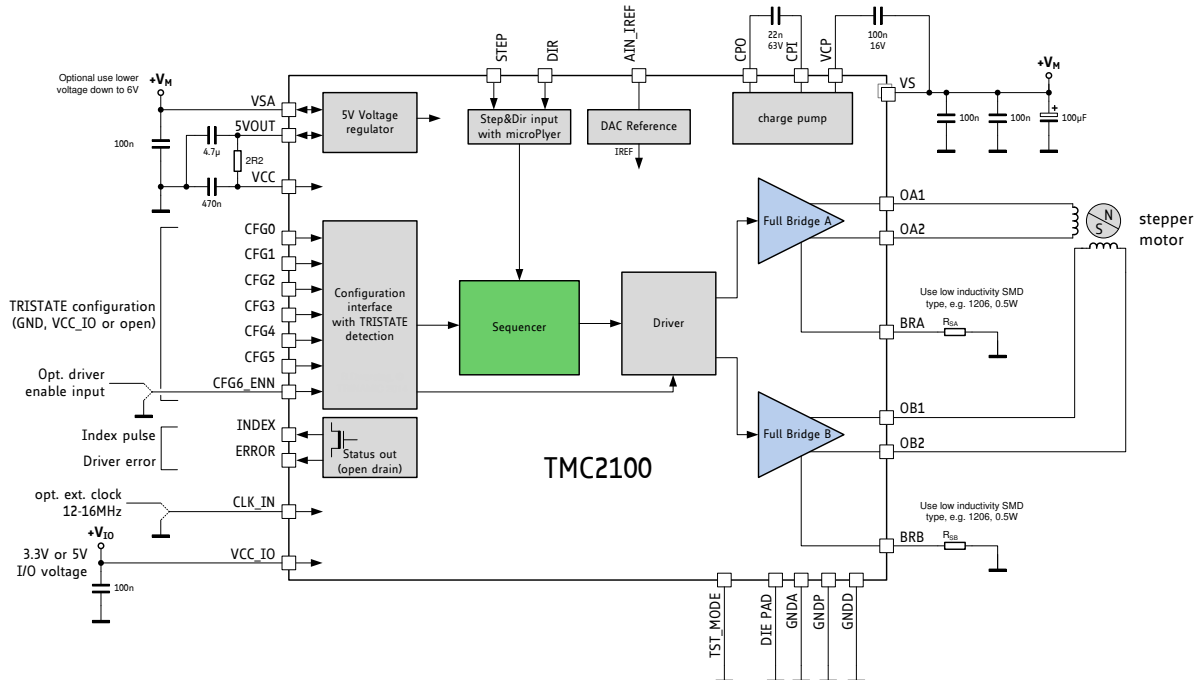
Figure 3.1 Standalone operation example circuit

3.1 CFG Pin Configuration

TMC2100 configuration is hard wired. All pins with suffix CFG0 to CFG6 are evaluated using tristate detection in order to differentiate between:

- CFG pin tied to GND
- CFG pin open (no connection)
- CFG pin tied to VCC_IO

CFG6_ENN is used to enable the driver chip. Further, it selects whether standby current reduction is used or not.

CFG6_ENN: ENABLE PIN AND CONFIGURATION OF STANDSTILL POWER DOWN		
CFG6	**Motor driver enable**	**Standstill power down**
GND	Enable	N
VCC_IO	Disable	Driver disabled.
open	Enable	Y, ramp down from 100% to 34% motor current in 44M clock cycles (3 to 4 seconds) if no step pulse for more than 1M clock cycles (standstill). In combination with stealthChop be sure not to work with too low overall current setting, as regulation will not be able to measure the motor current after stand still current reduction. This will result in very low motor current after the stand-still period.

Please refer to Figure 1.2 for more information about standstill power down.

A current control mode can be set with CFG3. In particular, the source for the reference voltage (on chip or external) and the method of current scaling can be chosen.

CFG3 SETS MODE OF CURRENT SETTING	
CFG3	**Current Setting**
GND	Internal reference voltage. Current scale set by external sense resistors, only.
VCC_IO	Internal sense resistors. Use analog input current on AIN as reference current for internal sense resistor. This setting gives best results when combined with stealthChop voltage PWM chopper.
open	External reference voltage on pin AIN. Current scale set by sense resistors and scaled by AIN.

The desired microstep resolution for the STEP input can be chosen via CFG2 and CFG1 configurations. The driver automatically uses microstep positions which result in a symmetrical wave especially when switching to a lower microstep resolution.

Note that spreadCycle mode is possible with and without step interpolation to 256 microsteps. TRINAMIC recommends using step interpolation for achieving a smoother drive. While the parameters for spreadCycle can be configured for best microstep performance, stealthChop has a fixed setting. CFG0 and CFG4 settings do not influence the stealthChop configuration. This way, it is possible to switch between spreadCycle and stealthChop mode by simply switching CFG1 and CFG2.

CFG1 AND CFG2: SET MICROSTEP RESOLUTION FOR STEP INPUT				
CFG2, CFG1	**Microsteps**	**Interpolation**	**Chopper Mode**	
GND, GND	1 (Fullstep)	N	*spreadCycle*	
GND, VCC_IO	2 (Halfstep)	N		
GND, open	2 (Halfstep)	Y, to 256 µsteps		
VCC_IO, GND	4 (Quarterstep)	N		
VCC_IO, VCC_IO	16 µsteps	N		
VCC_IO, open	4 (Quarterstep)	Y, to 256 µsteps		
open, GND	16 µsteps	Y, to 256 µsteps		
open, VCC_IO	4 (Quarterstep)	Y, to 256 µsteps	*stealthChop*	
open, open	16 µsteps	Y, to 256 µsteps		

Hint
Be sure to allow the motor to rest for at least 100 ms (assuming a minimum of 10 MHz f_{CLK}) before starting a motion using stealthChop. This will allow the current regulation to ramp up to the initial motor current.

CFG0, CFG4 and CFG5 are intended for chopper configuration. CFG0 is used to set the chopper off time. This setting also limits the maximum chopper frequency. For operation with stealthChop, this parameter is not used. In case of operation with stealthChop only, any CFG0 setting is OK.

CFG0: SETS CHOPPER OFF TIME (DURATION OF SLOW DECAY PHASE)		
CFG0	***TOFF* Setting**	
GND	140 t_{CLK} (recommended, most universal choice)	*low setting*
VCC_IO	236 t_{CLK}	*medium setting*
open	332 t_{CLK}	*high setting*

CFG4: SETS CHOPPER HYSTERESIS (TUNING OF ZERO CROSSING PRECISION)	
CFG4	**Hysteresis Setting**
GND	5 (recommended most universal choice): low hysteresis with ≈4% of full scale current.
VCC_IO	9: medium setting with ≈5% of the full scale current at sense resistor.
open	13: high setting with ≈6% of full scale current at sense resistor.

CFG5 selects the comparator blank time. This time needs to safely cover the switching event and the duration of the ringing on the sense resistor. For most applications, a setting of 24 clock cycles is good. For higher capacitive loads, e.g. when filter networks are used, a setting 36 clock cycles will be required.

CFG5: SETS CHOPPER BLANK TIME (DURATION OF BLANKING OF SWITCHING SPIKE)		
CFG5	**Blank time (in number of clock cycles)**	
GND	16 (best performance for stealthChop)	*low setting*
VCC_IO	24 (recommended, most universal choice)	*medium setting*
open	36 (may be necessary with high capacitive loads on motor outputs)	*high setting*

EXAMPLE 1

It is desired to do slow motions in smooth and noiseless stealthChop mode. For quick motions, spreadCycle is to be used. The controller can deliver 1/16 microstep step signals. Leave open CFG2 and drive CFG1 with a three state driver. Switch CFG1 to VCC_IO to operate in spreadCycle, switch it to hi-Z (open) state for a motion in stealthChop. Be sure to switch during standstill only, because when switching from a fixed level to an open input, a different mode may be passed for a short time.
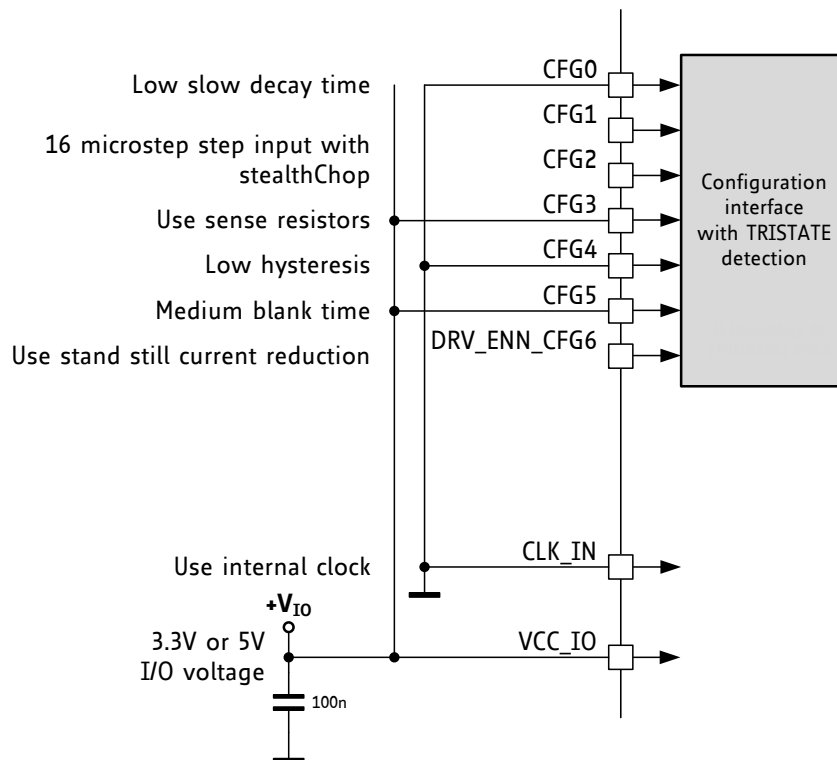
EXAMPLE 2

Figure 3.2 TMC2100 example configuration for stealthChop

4 Suggestions for Layout

The sample circuits show the connection of external components in different operation and supply modes.

4.1 Basic Hints for Power Supply

Use low ESR capacitors for filtering the power supply which are capable to cope with the current ripple. The current ripple often depends on the power supply and cable length. The VCC_IO voltage can be supplied from 5VOUT, or from an external source, e.g. a low drop 3.3V regulator. In order to minimize linear voltage regulator power dissipation of the internal 5V voltage regulator in applications where VM is high, a different (lower) supply voltage can be used for VSA, if available. For example, many applications provide a 12V supply in addition to a higher supply voltage, like 24V or 36V. Using the 12V supply for VSA will reduce the power dissipation of the internal 5V regulator to about 37% resp. 23% of the dissipation caused by supply with the full motor voltage.

> *Basic Layout Hints*
> Place sense resistors and all filter capacitors as close as possible to the related IC pins. Use a solid common GND for all GND connections, also for sense resistor GND. Connect 5VOUT filtering capacitor directly to 5VOUT and GNDA pin. See layout hints for more details. Low ESR electrolytic capacitors are recommended for VS filtering.

> *Attention*
> In case VSA is supplied by a different voltage source, make sure that VSA does not exceed VS by more than one diode drop upon power up or power down.

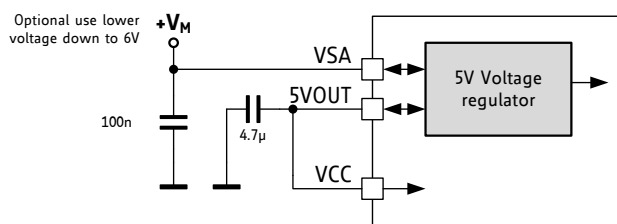## 4.2 Reduced Number of Components

Figure 4.1 Reduced number of filtering components

The standard application circuit uses RC filtering to de-couple the output of the internal linear regulator from high frequency ripple caused by digital circuitry supplied by the VCC input. For cost sensitive applications, the RC-filtering on VCC can be eliminated. This leads to more noise on 5VOUT caused by operation of the charge pump and the internal digital circuitry. There is a slight impact on microstep vibration and chopper noise performance.

4.3 Internal Current Sensing

For cost critical or space limited applications, it may be desired to eliminate the sense resistors. The TMC2100 allows using the resistance of the internal MOSFETs as a sense resistor. Further, this slightly reduces power dissipation, because the effective resistance of the driver bridge is reduced. In this application, a reference current set by a tiny external resistor programs the output current. For calculation of the reference resistor, refer chapter 9.
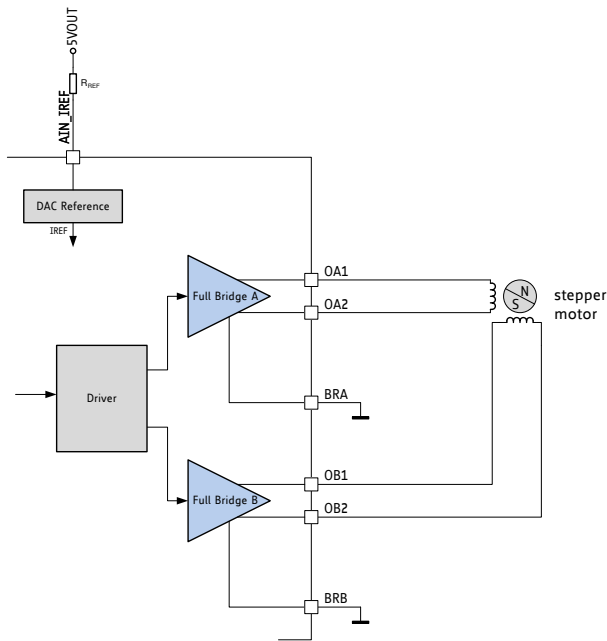
Figure 4.2 RDSon based sensing eliminates high current sense resistors

4.4   External 5V Power Supply

When an external 5V power supply is available, the power dissipation caused by the internal linear regulator can be eliminated. This especially is beneficial in high voltage applications, and when thermal conditions are critical. There are two options for using an external 5V source: either the external 5V source is used to support the digital supply of the driver by supplying the VCC pin, or the complete internal voltage regulator becomes bridged and is replaced by the external supply voltage.

4.4.1   Support for the VCC Supply

This scheme uses an external supply for all digital circuitry within the driver (Figure 4.3). As the digital circuitry makes up for most of the power dissipation, this way the internal 5V regulator sees only low remaining load. The precisely regulated voltage of the internal regulator is still used as the reference for the motor current regulation as well as for supplying internal analog circuitry.

When cutting VCC from 5VOUT, make sure that the VCC supply comes up before or synchronously with the 5VOUT supply to ensure a correct power up reset of the internal logic. A simple schematic uses two diodes forming an OR of the internal and the external power supplies for VCC. In order to prevent the chip from drawing part of the power from its internal regulator, a low drop 1A Schottky diode is used for the external 5V supply path, while a silicon diode is used for the 5VOUT path.

In certain setups, switching of VCC voltage can be eliminated. A different variant uses the VCC_IO supply to ensure power-on reset. This is possible, if VCC_IO comes up synchronously with or delayed to VCC. Use a linear regulator to generate a 3.3V VCC_IO from the external 5V VCC source. This 3.3V regulator will cause a certain voltage drop. A voltage drop in the regulator of 0.9V or more (e.g. LD1117-3.3) ensures that the 5V supply already has exceeded the lower limit of about 3.0V once the reset conditions ends. The reset condition ends earliest, when VCC_IO exceeds the undervoltage limit of minimum 2.1V. Make sure that the power-down sequence also is safe. Undefined states can result when VCC drops well below 4V without safely triggering a reset condition. Triggering a reset upon power-down can be ensured when VSA goes down synchronously with or before VCC.
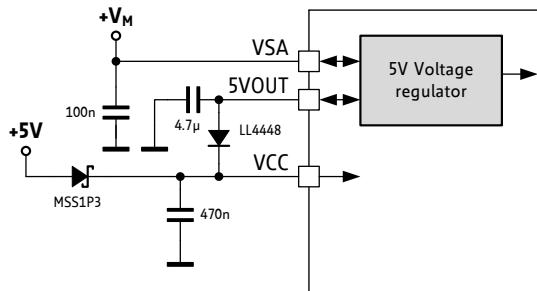
VCC supplied from external 5V. 5V or 3.3V IO voltage.

Figure 4.3 Using an external 5V supply for digital circuitry of driver

4.4.2 Internal Regulator Bridged

In case a clean external 5 V supply is available, it can be used for complete supply of analog and digital part (Figure 4.4). The circuit will benefit from a well regulated supply, e.g. when using a +/-1% regulator. A precise supply guarantees increased motor current precision, because the voltage at 5VOUT directly is the reference voltage for all internal units of the driver, especially for motor current control. For best performance, the power supply should have low ripple to give a precise and stable supply at 5VOUT pin with remaining ripple well below 5 mV. Some switching regulators have a higher remaining ripple, or different loads on the supply may cause lower frequency ripple. In this case, increase capacity attached to 5VOUT. In case the external supply voltage has poor stability or low frequency ripple, this would affect the precision of the motor current regulation as well as add chopper noise.
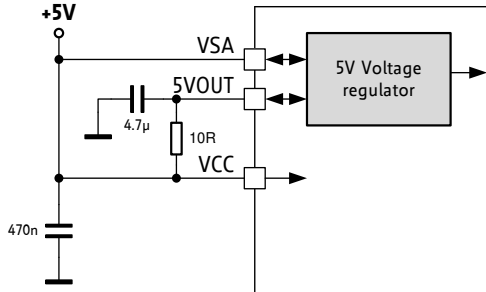

Figure 4.4 Using an external 5V supply to bypass internal regulator
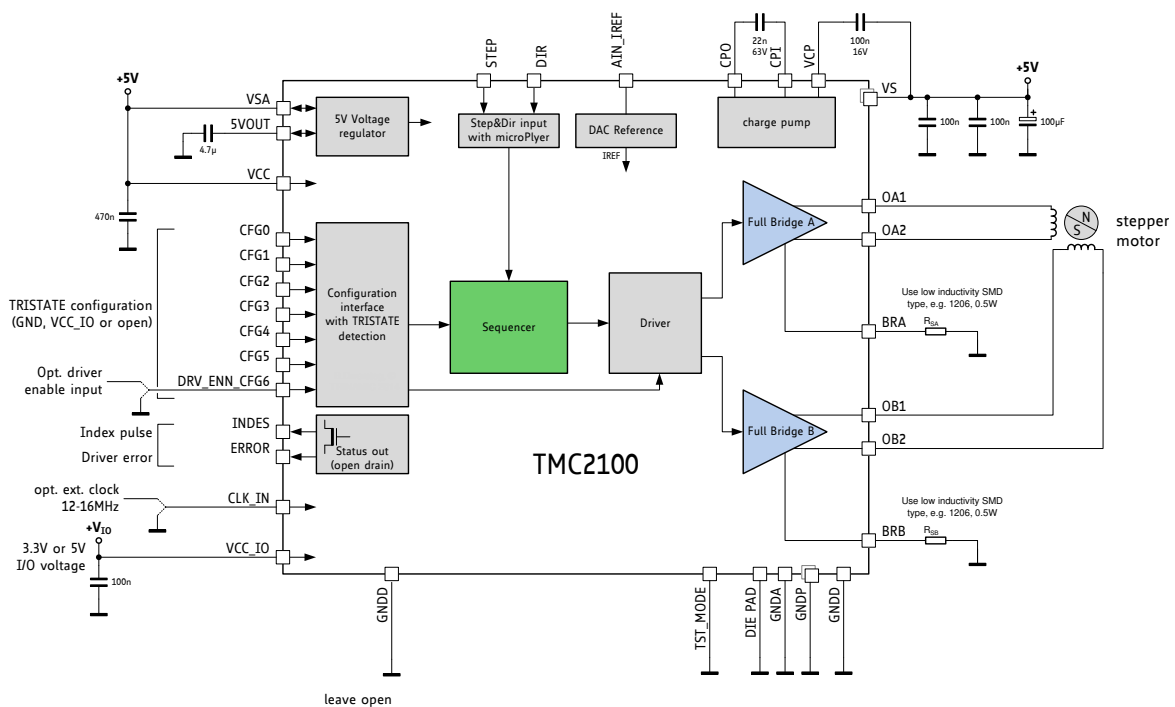
4.5　5V Only Supply

Figure 4.5 5V only operation

While the standard application circuit is limited to roughly 5.5 V lower supply voltage, a 5 V only application lets the IC run from a normal 5 V +/-5% supply. In this application, linear regulator drop must be minimized. Therefore, the major 5 V load is removed by supplying VCC directly from the external supply. In order to keep supply ripple away from the analog voltage reference, 5VOUT should have an own filtering capacity and the 5VOUT pin does not become bridged to the 5V supply.

4.6　High Motor Current

When operating at a high motor current, the driver power dissipation due to MOSFET switch on-resistance significantly heats up the driver. This power dissipation will heat up the PCB cooling infrastructure also, if operated at an increased duty cycle. This in turn leads to a further increase of driver temperature. An increase of temperature by about 100 °C increases MOSFET resistance by roughly 50%. This is a typical behavior of MOSFET switches. Therefore, under high duty cycle, high load conditions, thermal characteristics have to be carefully taken into account, especially when increased environment temperatures are to be supported. Refer the thermal characteristics and the layout hints for more information. As a thumb rule, thermal properties of the PCB design become critical for the QFN-36 at or above about 1000 mA RMS motor current for increased periods of time. Keep in mind that resistive power dissipation raises with the square of the motor current. On the other hand, this means that a small reduction of motor current significantly saves heat dissipation and energy.

An effect which might be perceived at medium motor velocities and motor sine wave peak currents above roughly 1.2 A peak is an increasing negative impact of increased internal diode conduction on the duration of the fast decay cycle of the spreadCycle chopper. This is, because the current measurement does not see the full coil current during this phase of the sine wave, because an increasing part of the current flows directly from the power MOSFETs' drain to GND and does not flow through the sense resistor. This in turn under some conditions may lead to a slight sine distortion of the current wave when using spreadCycle. This effect with most motors does not negatively influence the smoothness of operation, as it does not impact the critical current zero transition. It does not occur with stealthChop.

4.6.1   Reduce Linear Regulator Power Dissipation

When operating at high supply voltages, as a first step the power dissipation of the integrated 5V linear regulator can be reduced, e.g. by using an external 5V source for supply. This will reduce overall heating. It is advised to reduce motor stand still current in order to decrease overall power dissipation. If applicable, also use coolStep. A decreased clock frequency will reduce power dissipation of the internal logic. Further a decreased clock frequency also reduces power dissipation.

4.6.2   Operation near to / above 2A Peak Current

The driver can deliver up to 2.5 A motor peak current. Considering thermal characteristics, this only is possible in duty cycle limited operation. When a peak current up to 2.5 A is to be driven, the driver chip temperature is to be kept at a maximum of 105 °C. Linearly derate the design peak temperature from 125 °C to 105 °C in the range 2 A to 2.5 A output current (see Figure 4.6). Exceeding this may lead to triggering the short circuit detection.
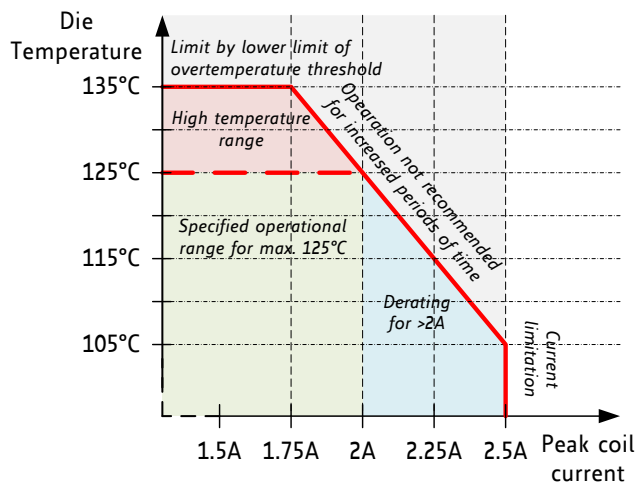

Figure 4.6 Derating of maximum sine wave peak current at increased die temperature

4.7   Driver Protection and EME Circuitry

Some applications have to cope with ESD events caused by motor operation or external influence. Despite ESD circuitry within the driver chips, ESD events occurring during operation can cause a reset or even a destruction of the motor driver, depending on their energy. Especially plastic housings and belt drive systems tend to cause ESD events. It is best practice to avoid ESD events by attaching all conductive parts, especially the motors themselves to PCB ground, or to apply electrically conductive plastic parts. In addition, the driver can be protected up to a certain degree against ESD events or live plugging / pulling the motor, which also causes high voltages and high currents into the motor connector terminals. A simple scheme uses capacitors at the driver outputs to reduce the dV/dt caused by ESD events. Larger capacitors will bring more benefit concerning ESD suppression, but cause additional current flow in each chopper cycle, and thus increase driver power dissipation, especially at high supply voltages. The values shown are example values – they might be varied between 100pF and 1nF. The capacitors also dampen high frequency noise injected from digital parts of the circuit and thus reduce electromagnetic emission. A more elaborate scheme uses LC filters to de-couple the driver outputs from the motor connector. Varistors in between of the coil terminals eliminate coil overvoltage caused by live plugging. Optionally protect all outputs by a varistor against ESD voltage.
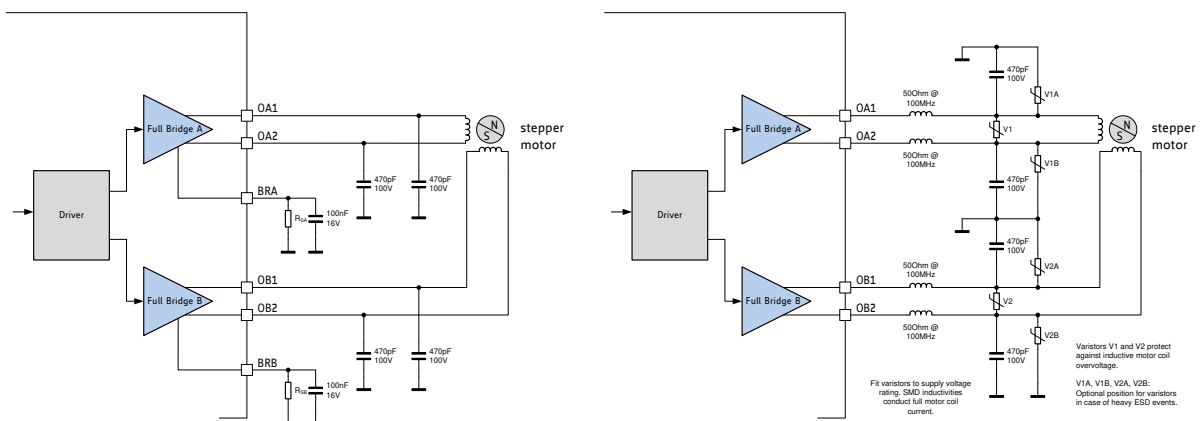

Figure 4.7 Simple ESD enhancement and more elaborate motor output protection

5   stealthChop™

stealthChop is an extremely quiet mode of operation for low and medium velocities. It is based on a voltage mode PWM. In case of standstill and at low velocities, the motor is absolutely noiseless. Thus, stealthChop operated stepper motor applications are very suitable for indoor or home use. The motor operates absolutely free of vibration at low velocities. With stealthChop, the motor current is applied by driving a certain effective voltage into the coil, using a voltage mode PWM. There are no more configurations required except for the regulation of the PWM voltage to yield the motor target current.
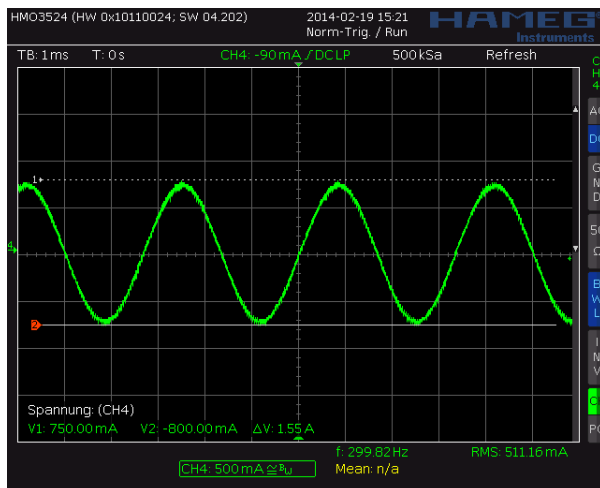

Figure 5.1 Motor coil sine wave current with stealthChop (measured with current probe)

5.1   Current Regulation

In order to match the motor current to a certain level, the voltage mode PWM voltage must be scaled depending on the actual motor velocity. Several additional factors influence the required voltage level to drive the motor at the target current: the motor resistance, its back EMF (i.e. directly proportional to its velocity) as well as actual level of the supply voltage. For the ease of use, the TMC2100 uses an automatic mode for current regulation which considers current feedback. The PWM frequency is internally divided from the clock frequency.

A higher PWM frequency leads to increased dynamic power dissipation, but it may bring a benefit for higher motor velocity.

PWM FREQUENCY FOR STEALTHCHOP	
Clock frequency f_{CLK}	**f_{PWM}=2/683 f_{CLK}**
18MHz	52.7kHz
16MHz	46.8kHz
(internal)	~38kHz
12MHz	35.1kHz
10MHz	29.3kHz
8MHz	23.4kHz

Table 5.1 PWM frequency – green: recommended

5.2   Automatic Scaling

In stealthChop voltage PWM mode, the internal autoscaling function regulates the motor current to the desired current setting. The driver measures the motor current during the chopper on time and uses a proportional regulator in order match the motor current to the target current. The quality of the regulation can be examined when monitoring the motor coil current at different velocities and

during fastest applicable acceleration. Just as in the acceleration phase, during a deceleration phase the voltage PWM amplitude must be adapted in order to keep the motor coil current constant.
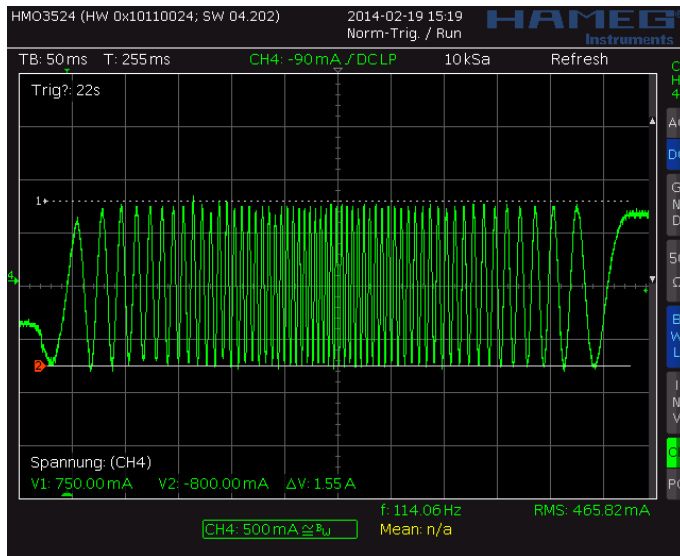

Figure 5.2 Scope shot: current can follow on acceleration phase

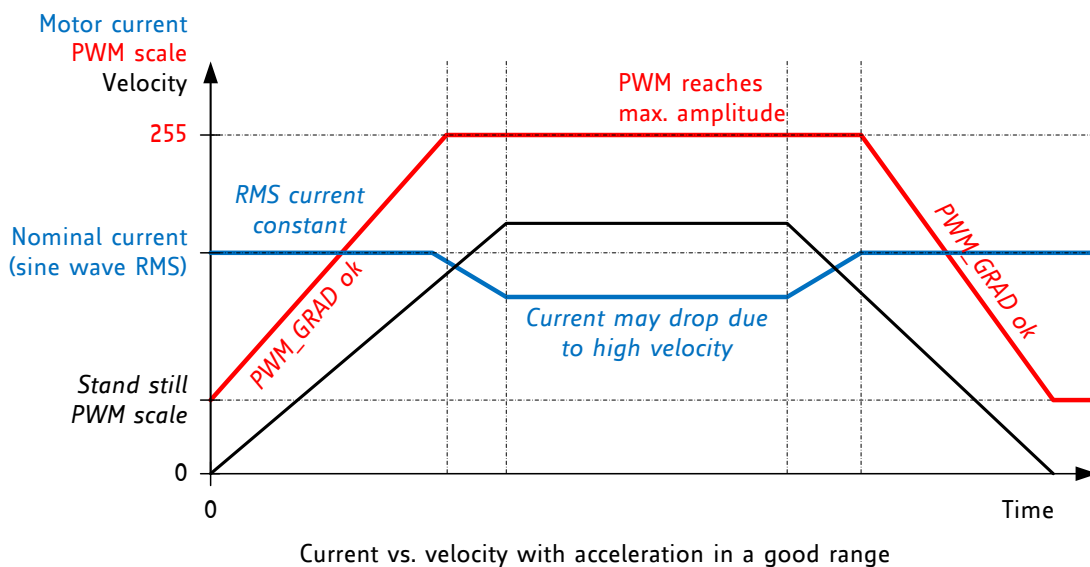Current vs. velocity with acceleration in a good range

Figure 5.3 Current vs. velocity diagram

Be sure to use a symmetrical sense resistor layout and sense resistor traces of identical length and well matching sense resistors for best performance.

The auto scaling function only starts up regulation during motor standstill. After enabling stealthChop be sure to wait until the current regulation has reached a stable state before starting a motion. Failure to do so will result in zero motor current!

In case the automatic scaling regulation is instable at your desired motion velocity, try modifying the clock frequency. Also adapt the blank time (CFG5) and motor current for best result.

5.2.1   Lower Current Limit

stealthChop imposes a lower limit for motor current regulation. As the coil current can be measured in the shunt resistor during chopper on phase, only, a minimum chopper duty cycle allowing coil current regulation is given by the blank time as set by *TBL* and by the chopper frequency. Therefore, the motor specific minimum coil current in stealthChop autoscaling mode rises with the supply

voltage. A lower blanking time allows a lower current limit. The run current needs to be kept above the lower limit: In case the PWM scale drops to a too low value, e.g. because AIN pin scaling was too low, the regulator may not be able to recover. The regulator will recover once the motor is in standstill. The lower motor coil current limit can be calculated from motor parameters and chopper settings:

$$I_{Lower\ Limit} = t_{BLANK} * f_{PWM} * \frac{V_M}{R_{COIL}}$$

With V_M the motor supply voltage and R_{COIL} the motor coil resistance.
$I_{Lower\ Limit}$ can be treated as a thumb value for the minimum possible motor current setting.

EXAMPLE:

A motor has a coil resistance of 5Ω, the supply voltage is 24V. t_{BLANK} setting is 24 clock cycles:

$$I_{Lower\ Limit} = 24\ t_{CLK} * \frac{2}{683\ t_{CLK}} * \frac{24V}{5\Omega} = \frac{2*24}{683} * \frac{24V}{5\Omega} = 337mA$$

For *pwm_autoscale* mode, a lower coil current limit applies. This limit can be calculated or measured using a current probe. Keep the motor run-current setting well above this lower current limit.

5.3   Acceleration

The automatic current regulation compensates for the change of back-EMF at different velocities (see Figure 5.2 and Figure 5.3). It measures the actual current with each fullstep and subsequently does a limited correction of the PWM voltage. Therefore, at very high acceleration or deceleration, the internal regulation might not react quickly enough to stabilize the motor current within a range near the target current. Use a current probe and check the motor current during (quick) acceleration. In case the current regulation cannot follow (see Figure 5.4), motor current will sink in acceleration phases, and thus lead to reduced motor torque. During a deceleration phase it will rise for a short time. If the current deviates too much, the motor cannot bring the required torque during the acceleration phase.

In case motor current drops significantly during acceleration phases with stealthChop there are several ways to improve current regulation:

- Reduce acceleration
- Switch from hold current to run current in time before starting the motion
- Increase driver supply voltage (at double voltage, the reaction speed is also doubled)
- Use motor with higher current coil winding (back-EMF sinks proportionally)
- Increase driver clock frequency (this will speed up regulation when accelerating from standstill current reduction)
- Switch configuration from stealthChop to spreadCycle before starting a high velocity motion
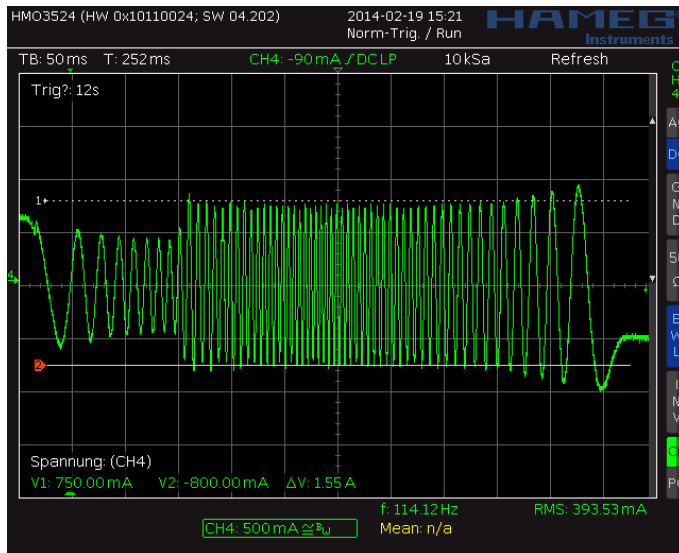
Figure 5.4 Current regulation cannot follow during high acceleration phase

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Hint
Operate the motor within your application when exploring stealthChop. Motor performance often is better with a mechanical load, because it prevents the motor from stalling due mechanical oscillations which can occur without load.

5.4   Switching between stealthChop and spreadCycle

It is principally possible to combine stealthChop and spreadCycle by toggling between two configurations using the related CFG pins. But care must be taken to avoid operating in a wrong microstepping mode. As the tristate detection logic needs a number of cycles to detect transition to or from an open pin, the switching should only be done during standstill. Allow 3072 t_{CLK} for detection of the changed mode selection, before driving a new step. With internal clock, a 3ms delay will ensure proper transition to the new mode, before the next step is done.

When enabling the stealthChop mode the first time using automatic current regulation, the motor must be at stand still in order to allow a proper current regulation. When the drive switches to a different chopper mode at a higher velocity, stealthChop logic stores the last current regulation setting until the motor returns to a lower velocity again. This way, the regulation has a known starting point when returning to a lower velocity, where stealthChop becomes re-enabled. Therefore, neither the velocity threshold nor the supply voltage must be considerably changed during the phase while the chopper is switched to a different mode, because otherwise the motor might lose steps or the instantaneous current might be too high or too low.

Attention
A motor stall or a sudden change in the motor velocity may lead to the driver detecting a short circuit, as the current can exceed the upper limit in these situations. In these situations, the automatic current regulation may also reach a state of low current from which it cannot recover.
Stop motion, disable and re-enable the driver (using the ENN pin) and restart the motor from zero velocity to recover from this situation.

Hint
Start the motor from standstill when switching on stealthChop the first time and keep it stopped for at least 128 chopper periods to allow stealthChop to do initial standstill current control.

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6   spreadCycle

While stealthChop is a voltage mode PWM controlled chopper, spreadCycle is a cycle-by-cycle current control. Therefore, it can react extremely fast to changes in motor velocity or motor load. The currents through both motor coils are controlled using choppers. The choppers work independently of each other. In Figure 6.1 the different chopper phases are shown.
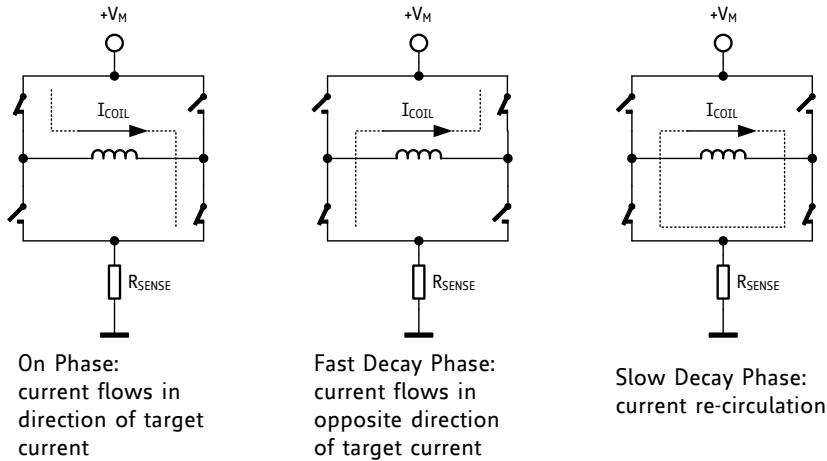

On Phase:
current flows in
direction of target
current

Fast Decay Phase:
current flows in
opposite direction
of target current

Slow Decay Phase:
current re-circulation

Figure 6.1 Chopper phases

Although the current could be regulated using only on phases and fast decay phases, insertion of the slow decay phase is important to reduce electrical losses and current ripple in the motor. The duration of the slow decay phase is specified in a control parameter and sets an upper limit on the chopper frequency. The current comparator can measure coil current during phases when the current flows through the sense resistor, but not during the slow decay phase, so the slow decay phase is terminated by a timer. The on phase is terminated by the comparator when the current through the coil reaches the target current. The fast decay phase may be terminated by either the comparator or another timer.

When the coil current is switched, spikes at the sense resistors occur due to charging and discharging parasitic capacitances. During this time, typically one or two microseconds, the current cannot be measured. Blanking is the time when the input to the comparator is masked to block these spikes.

The spreadCycle mode cycles through four phases: on, slow decay, fast decay, and a second slow decay.

The chopper frequency is an important parameter for a chopped motor driver. A too low frequency might generate audible noise. A higher frequency reduces current ripple in the motor, but with a too high frequency magnetic losses may rise. Also power dissipation in the driver rises with increasing frequency due to the increased influence of switching slopes causing dynamic dissipation. Therefore, a compromise needs to be found. Most motors are optimally working in a frequency range of 16 kHz to 30 kHz. The chopper frequency is influenced by a number of parameter settings as well as by the motor inductivity and supply voltage.

Hint
A chopper frequency in the range of 16 kHz to 30 kHz gives a good result for most motors when using spreadCycle. A higher frequency leads to increased switching losses.

Please refer to chapter 3.1 for more information about CFG0 and CFG4 (chopper off time and chopper hysteresis).

6.1 spreadCycle Chopper

The patented spreadCycle chopper algorithm is a precise and simple to use chopper mode which automatically determines the optimum length for the fast-decay phase. The spreadCycle will provide superior microstepping quality even with default settings. Several parameters are available to optimize the chopper to the application.

Each chopper cycle is comprised of an on phase, a slow decay phase, a fast decay phase and a second slow decay phase (see Figure 6.3). The two slow decay phases and the two blank times per chopper cycle put an upper limit to the chopper frequency. The slow decay phases typically make up for about 50%-75% of the chopper cycle in standstill and are important for low motor and driver power dissipation.

EXAMPLE

At 16MHz clock frequency a low t_{OFF} setting (140 t_{CLK}) sets $t_{OFF} = 140 * \frac{1}{16MHz} = 8.75\mu s$. Each chopper cycle then uses 2 * 8.75µs = 17.2 µs of slow decay time.

The hysteresis setting forces the driver to introduce a minimum amount of current ripple into the motor coils. The current ripple must be higher than the current ripple which is caused by resistive losses in the motor in order to give best microstepping results. This will allow the chopper to precisely regulate the current both for rising and for falling target current. The time required to introduce the current ripple into the motor coil also reduces the chopper frequency. Therefore, a higher hysteresis setting will lead to a lower chopper frequency. The motor inductance limits the ability of the chopper to follow a changing motor current. Further the duration of the on phase and the fast decay must be longer than the blanking time, because the current comparator is disabled during blanking.

It is easy to find the best setting by starting with the lowest hysteresis setting (CFG4=GND). Use a higher setting in case the motor does not run smoothly at low velocity settings. This can best be checked when measuring the motor current either with a current probe or by probing the sense resistor voltages (see Figure 6.2). Checking the sine wave shape near zero transition will show a small ledge between both half waves in case the hysteresis setting is too small. At medium velocities (i.e. 100 to 400 fullsteps per second), a too low hysteresis setting will lead to increased humming and vibration of the motor.
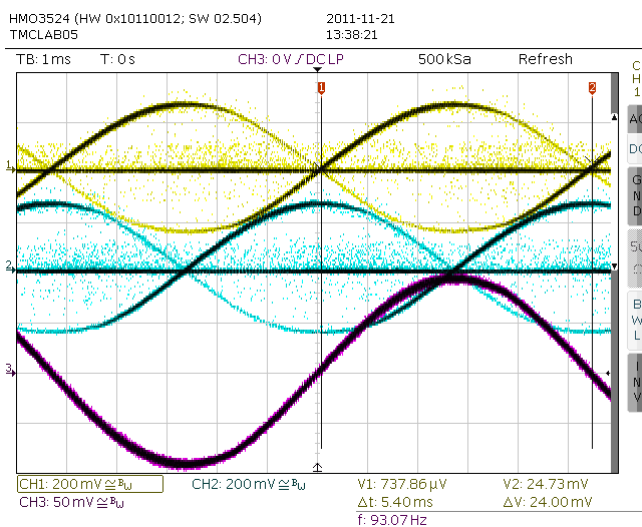

Figure 6.2 No ledges in current wave with sufficient hysteresis (magenta: current A, yellow & blue: sense resistor voltages A and B)

A too high hysteresis setting will lead to reduced chopper frequency and increased chopper noise but will not yield any benefit for the wave shape.

As experiments show, the setting is quite independent of the motor, because higher current motors typically also have a lower coil resistance. Therefore, choosing the low default value for the hysteresis normally fits most applications.
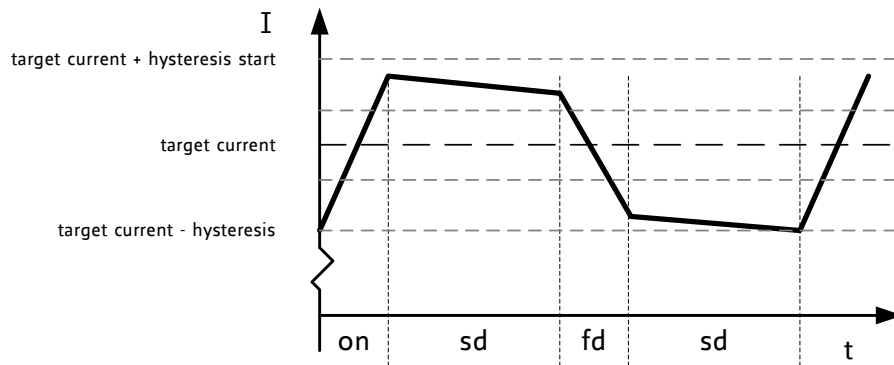

Figure 6.3 spreadCycle chopper scheme showing coil current during a chopper cycle

7   Analog Current Control AIN

When a high flexibility of the output current scaling is desired, the analog input of the driver can be enabled for current control, rather than choosing a different set of sense resistors. This way, a simple voltage divider can be used for the adaptation of a board to different motors. Therefore, leave the CFG3 pin open.

AIN Scales the Motor Current

The TMC2100 provides an internal reference voltage for current control, directly derived from the 5VOUT supply output. Alternatively, an external reference voltage can be used. This reference voltage becomes scaled down for the chopper comparators. The chopper comparators compare the voltages on BRA and BRB to the scaled reference voltage for current regulation. If analogue scaling is enabled (CFG3 open), the external voltage on AIN is amplified and filtered and becomes used as reference voltage. A voltage of 2.5V (or any voltage between 2.5V and 5V) gives the same current scaling as the internal reference voltage. A voltage between 0V and 2.5V linearly scales the current between 0 and the current scaling defined by the sense resistor setting. It is not advised to work with reference voltages below about 0.5V to 1V, because relative analog noise caused by digital circuitry has an increased impact on the chopper precision at low AIN voltages. For best precision, choose the sense resistors in a way that the desired maximum current is reached with AIN in the range 2V to 2.4V. Be sure to optimize the chopper settings for the normal run current of the motor.

Driving AIN

The easiest way to provide a voltage to AIN is to use a voltage divider from a stable supply voltage or a microcontroller's DAC output. A PWM signal can also be used for current control. The PWM becomes transformed to an analog voltage using an additional R/C low-pass at the AIN pin. The PWM duty cycle controls the analog voltage. Choose the R and C values to form a low pass with a corner frequency of several milliseconds while using PWM frequencies well above 10 kHz. AIN additionally provides an internal low-pass filter with 3.5kHz bandwidth. The integration of an NTC into the voltage divider feeding AIN allows the realization of temperature dependent motor current scaling. When a precise reference voltage is available (e.g. from TL431A), the precision of the motor current regulation can be improved when compared to the internal voltage reference.

> Using a low reference voltage (e.g. below 1V), for adaptation of a high current driver to a low current motor will lead to reduced analog performance. Adapting the sense resistors to fit the desired motor current gives a better result.
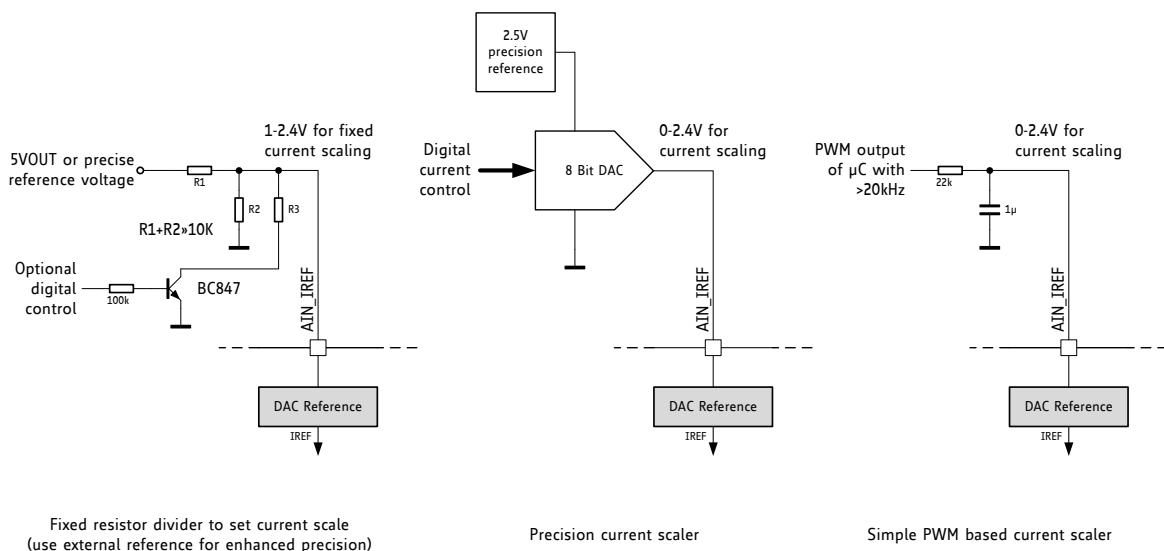

Figure 7.1 Scaling the motor current using the analog input

8   Current Setting

The internal 5 V supply voltage available at the pin 5VOUT is used as a reference for the coil current regulation based on the sense resistor voltage measurement. The desired maximum motor current is set by selecting an appropriate value for the sense resistor. Three modes of current setting can be chosen using the CFG3 pin:

CFG3: SETS MODE OF CURRENT SETTING	
CFG3	**Current Setting**
GND	Internal reference voltage. Current scale set by sense resistors, only.
VCC_IO	Internal sense resistors. Use analog input current on AIN as reference current for internal sense resistor. This setting gives best results when combined with stealthChop voltage PWM chopper.
open	External reference voltage on pin AIN. Current scale set by sense resistors and scaled by AIN.

If pin CFG6_ENN is not connected, the run current can be calculated by:

$$I_{RMS} = \frac{V_{FS}}{R_{SENSE}+20m\Omega} * \frac{1}{\sqrt{2}}$$

The hold current for standby is calculated by:

$$I_{RMS} = \frac{12}{32} * \frac{V_{FS}}{R_{SENSE}+20m\Omega} * \frac{1}{\sqrt{2}}$$

with V_{FS} = full scale voltage (see V_{SRT})

When analog scaling of V_{FS} is enabled, the resulting voltage V_{FS}' is calculated by:

$$V'_{FS} = V_{FS} * \frac{V_{AIN}}{2.5V}$$

with V_{AIN} the voltage on pin AIN_IREF in the range 0V to V_{5VOUT}/2

CHOICE OF R_{SENSE} AND RESULTING MAX. MOTOR CURRENT	
R$_{SENSE}$ [Ω]	**RMS current [A]**
1.00	0.23
0.82	0.27
0.75	0.30
0.68	0.33 (350 mA motor)
0.50	0.44
0.47	0.47 (500 mA motor)
0.33	0.66 (700 mA motor)
0.27	0.79 (800 mA motor)
0.22	0.96 (1 A motor)
0.15	1.35
0.12	1.64
0.10	1.92*)

*) Value exceeds upper current rating.

For best precision of current setting, it is advised to measure and fine tune the current in the application.