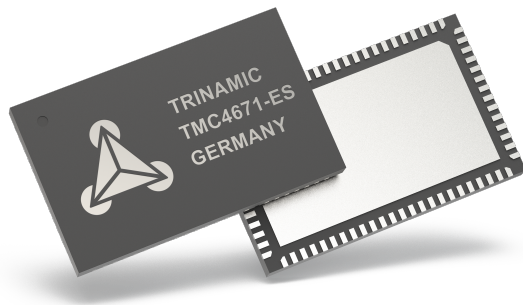


TMC4671 Datasheet

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The TMC4671 is a fully integrated servo controller, providing Field Oriented Control for BLDC/PMSM and 2-phase Stepper Motors as well as DC motors and voice coils. All control functions are implemented in hardware. Integrated ADCs, position sensor interfaces, position interpolators, enable a fully functional servo controller for a wide range of servo applications.



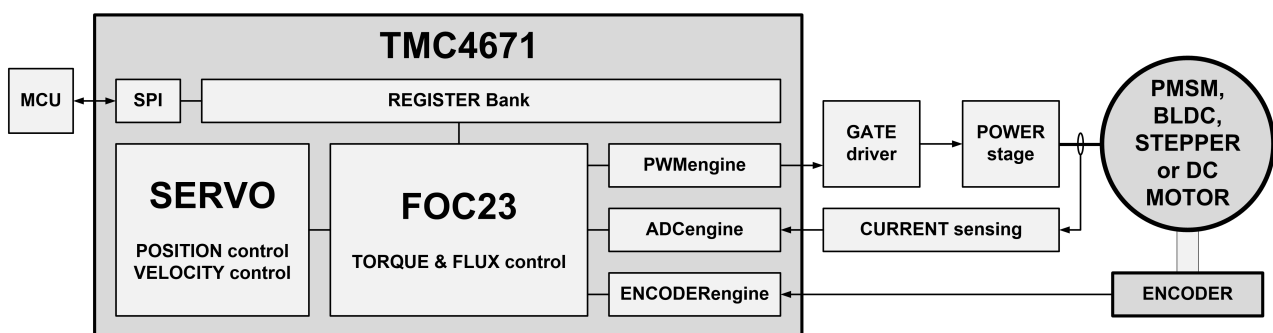
Features

- Servo Controller w/ Field Oriented Control (FOC)
- Torque Control (FOC), Velocity Control, Position Control
- Feed Forward Control Inputs
- Integrated ADCs, $\Delta\Sigma$ -ADC Frontend
- Encoder Engine: Hall analog/digital, Encoder analog/digital
- Supports 3-Phase PMSM/BLDC, 2-Phase Stepper Motors, and DC Motors
- Advanced PWM Engine (25kHz...100kHz)
- Application SPI + Debug (UART, SPI)
- Step-Direction Interface (S/D)

Applications

- Robotics
- Pick and Place Machines
- Factory Automation
- E-Mobility
- Laboratory Automation
- Blowers
- Pumps

Simplified Block Diagram



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1 Order Codes

Order Code	Description	Size [mm ²]
TMC4671-ES	TMC4671 FOC Servo Controller IC	10.5 x 6.5
TMC4671-EVAL	TMC4671 Evaluation Board	55 x 85
TMC4671-BOB	TMC4671 Breakout Board	38 x 40

Table 1: Order codes



2 Functional Summary

• Servo Controller with Field Oriented Control (FOC)

- Torque (and flux) control mode
- Velocity control mode
- Position control mode
- update rate of current controller and PWM at maximum frequency of 100 kHz (speed and position controller update rate is configurable by setting a divider of current controller update rate)

• Control Functions/PI Controllers

- Programmable clipping of inputs and outputs of interim results
- Integrator windup protection for all controllers
- Programmable field oriented voltage circular ($\sqrt{U_D^2 + U_Q^2}$) limiter
- Feed-forward offsets for target values and feed-forward friction compensation
- Advanced feed-forward control structure for optimal trajectory tracking performance
- Extended IRQ event masking options and limiter status register
- Advanced encoder initialization algorithms with Hall sensor or/and with minimal movement

• Motion Control and Ramping

- Trapezoidal velocity ramps by control structure
- Step/Direction interface for easy positioning

• Supported Motor Types

- FOC3 : 3-phase permanent magnet synchronous motors (PMSM)
- FOC2 : 2-phase stepper motors
- DC1 : brushed DC motors, or linear voice coil motors

• ADC Engine with Offset Correction and Scaling

- Integrated $\Delta\Sigma$ ADCs for current sense voltage, motor supply voltage, analog encoder, two AGPIs
- Integrated $\Delta\Sigma$ -Interface for external $\Delta\Sigma$ -Modulators

• Position Feedback Evaluation

- Open loop position generator (programmable [rpm], [rpm/s]) for initial setup
- Digital incremental encoder (ABN resp. ABZ, up to 5 MHz)
- Secondary digital incremental encoder
- Digital Hall sensor interface (H_1 , H_2 , H_3 resp. H_U , H_V , H_W) with interpolation of interim positions
- Analog encoder/analog Hall sensor interface (SinCos (0° , 90°) or 0° , 120° , 240°)
- multi-turn position counter (32-bit)
- Position target, velocity and target torque filters (Biquad)

• PWM Engine Including SVPWM

- Programmable PWM frequency within the range of 20 kHz ... 100 kHz
- Programmable Brake-Before-Make (BBM) times (high side, low side) 0 ns ... 2.5 μ s in 10 ns steps and gate driver input signals



- PWM auto scaling for transparent change of PWM frequency during motion
- **SPI Communication Interface**
 - 40-bit datagram length (1 ReadWrite bit + 7 address bits + 32 data bits)
 - Immediate SPI read response (register read access by single datagram)
 - SPI clock frequency up to 1MHz (8MHz in future version)
- **TRINAMIC RealTime Monitoring Interface**
 - High frequency sampling of real-time data via TRINAMIC's real-time monitoring system
 - Only single 10-pin high density connector on PCB needed
 - Advanced controller tuning support by frequency response identification and advanced auto tuning options with TRINAMIC's IDE
- **UART Debug Interface**
 - Three pin (GND, RxD, TxD) 3.3 V UART interface (1N8; 9600 (default), 115200, 921600, or 3M bps)
 - Transparent register access parallel to embedded user application interface (SPI)
- **Supply Voltages**
 - 5V and 3.3V; VCC_CORE is internally generated
- **IO Voltage**
 - 3.3V for all digital IOs (choosable by VCCIO Supply), 5V input range for differential analog inputs, 1.25V input range for single ended inputs
- **Clock Frequency**
 - 25 MHz (external oscillator needed)
- **Packages**
 - QFN76



3 FOC Basics

This section gives a short introduction into some basics of Field Oriented Control (FOC) of electric motors.

3.1 Why FOC?

The Field Oriented Control (FOC), alternatively named Vector Control (VC), is a method for the most energy-efficient way of turning an electric motor.

3.2 What is FOC?

The Field Oriented Control was independently developed by K. Hasse, TU Darmstadt, 1968, and by Felix Blaschke, TU Braunschweig, 1973. The FOC is a current regulation scheme for electro motors that takes the orientation of the magnetic field and the position of the rotor of the motor into account, regulating the strength in such way that the motor gives that amount of torque that is requested as target torque. The FOC maximizes active power and minimizes idle power - that finally results in power dissipation - by intelligent closed-loop control illustrated by figure 1.

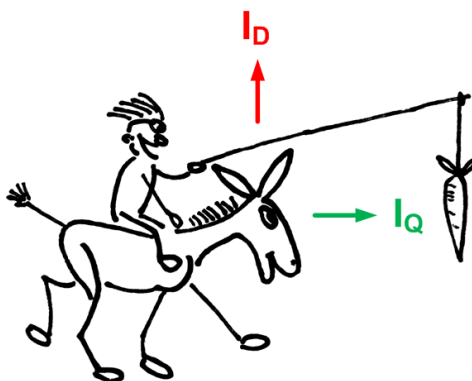


Figure 1: Illustration of the FOC basic principle by cartoon: Maximize active power and minimize idle power and power dissipation by intelligent closed-loop control.

3.3 Why FOC as pure Hardware Solution?

The initial setup of the FOC is usually very time consuming and complex, although source code is freely available for various processors. This is because the FOC has many degrees of freedom that all need to fit together in a chain in order to work.

The hardware FOC as an existing standard building block drastically reduces the effort in system setup. With that off the shelf building block, the starting point of FOC is the setup of the parameters for the FOC. Setting up and implement the FOC itself and building and programming required interface blocks is no longer necessary. The real parallel processing of hardware blocks de-couples the higher lever application software from high speed real-time tasks and simplifies the development of application software. With the TMC4671, the user is free to use its qualified CPU together with its qualified tool chain, freeing the user from fighting with processer-specific challenges concerning interrupt handling and direct memory access. There is no need for a dedicated tool chain to access the TMC4671 registers and to operate it - just SPI (or UART) communication needs to be enabled for any given CPU.

The integration of the FOC as a SoC (System-on-Chip) drastically reduces the number of required components and reduces the required PCB space. This is in contrast to classical FOC servos formed by motor



block and separate controller box wired with motor cable and encoder cable. The high integration of FOC, together with velocity controller and position controller as a SoC, enables the FOC as a standard peripheral component that transforms digital information into physical motion. Compact size together with high performance and energy efficiency especially for battery powered mobile systems are enabling factors when embedded goes autonomous.

3.4 How does FOC work?

Two force components act on the rotor of an electric motor. One component is just pulling in radial direction (I_D) where the other component is applying torque by pulling tangentially (I_Q). The ideal FOC performs a closed loop current control that results in a pure torque generating current I_Q – without direct current I_D .

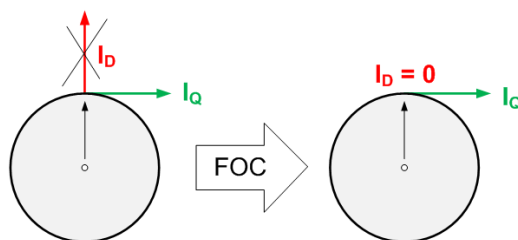


Figure 2: FOC optimizes torque by closed loop control while maximizing I_Q and minimizing I_D to 0

From top point of view, the FOC for 3-phase motors uses three phase currents of the stator interpreted as a current vector (I_u ; I_v ; I_w) and calculates three voltages interpreted as a voltage vector (U_u ; U_v ; U_w) taking the orientation of the rotor into account in a way that only a torque generating current I_Q results.

From top point of view, the FOC for 2-phase motors uses two phase currents of the stator interpreted as a current vector (I_x ; I_y) and calculates two voltages interpreted as a voltage vector (U_x ; U_y) taking the orientation of the rotor into account in a way that only a torque generating current I_Q results.

To do so, the knowledge of some static parameters (number of pole pairs of the motor, number of pulses per revolution of an used encoder, orientation of encoder relative to magnetic axis of the rotor, count direction of the encoder) is required together with some dynamic parameters (phase currents, orientation of the rotor).

The adjustment of P parameter P and I parameters of two PI controllers for closed loop control of the phase currents depends on electrical parameters of the motor (resistance, inductance, back EMF constant of the motor that is also the torque constant of the motor, supply voltage).

3.5 What is Required for FOC?

The FOC needs to know the direction of the magnetic axis of the rotor of the motor in reference to the magnetic axis of the stator of the motor. The magnetic flux of the stator is calculated from the currents through the phases of the motor. The magnetic flux of the rotor is fixed to the rotor and thereby determined by an encoder device.

For the FOC, the user needs to measure the currents through the coils of the stator and the angle of the rotor. The measured angle of the rotor needs to be adjusted to the magnetic axes.

The challenge of the FOC is the high number of degrees of freedom in all parameters.



3.5.1 Coordinate Transformations - Clarke, Park, iClarke, iPark

The FOC requires different coordinate transformations formulated as a set of matrix multiplications. These are the Clarke Transformation (Clarke), the Park Transformation (Park), the inverse Park Transformation (iPark) and the inverse Clarke Transformation (iClarke). Some put Park and Clarke together as DQ transformation and Park and Clarke as inverse DQ transformation.

The TMC4671 takes care of the required transformations so the user no longer has to fight with implementation details of these transformations.

3.5.2 Measurement of Stator Coil Currents

The measurement of the stator coil currents is required for the FOC to calculate a magnetic axis out of the stator field caused by the currents flowing through the stator coils.

Coil current stands for motor torque in context of FOC. This is because motor torque is proportional to motor current, defined by the torque constant of a motor. In addition, the torque depends on the orientation of the rotor of the motor relative to the magnetic field produced by the current through the coils of the stator of the motor.

3.5.3 Stator Coil Currents I_U, I_V, I_W and Association to Terminal Voltages U_U, U_V, U_W

The correct association between stator terminal voltages U_U, U_V, U_W and stator coil currents I_U, I_V, I_W is essential for the FOC. In addition to the association, the signs of each current channel need to fit. Signs of the current can be adapted numerically by the ADC scaler. The mapping of ADC channels is programmable via configuration registers for the ADC selector. Initial setup is supported by the integrated open loop encoder block, that can support the user to turn a motor open loop.

3.5.3.1 Chain of Gains for ADC Raw Values

An ADC raw value is a result of a chain of gains that determine it. A coil current I_SENSE flowing through a sense resistor causes a voltage difference according to Ohm's law. The resulting ADC raw value is a result of the analog signal path according to

$$\text{ADC_RAW} = (\text{I_SENSE} * \text{ADC_GAIN}) + \text{ADC_OFFSET}. \quad (1)$$

The ADC_GAIN is a result of a chain of gains with individual signs. The sign of the ADC_GAIN is positive or negative, depending on the association of connections between sense amplifier inputs and the sense resistor terminals. The ADC_OFFSET is the result of electrical offsets of the phase current measurement signal path. For the TMC4671, the maximum ADC_RAW value $\text{ADC_RAW_MAX} = (2^{16} - 1)$ and the minimum ADC raw value is $\text{ADC_RAW_MIN} = 0$.

$$\begin{aligned} \text{ADC_GAIN} = & \left(\text{I_SENSE_MAX} * \text{R_SENSE} \right) \\ & * \text{SENSE_AMPLIFIER_GAIN} \\ & * \left(\text{ADC_RAW_MAX} / \text{ADC_U_MAX} \right) \end{aligned} \quad (2)$$

For the FOC, the ADC_RAW is scaled by the ADC scaler of the TMC4671 together with subtraction of offset to compensate it. Internally, the TMC4671 FOC engine calculates with s16 values. Thus, the ADC scaling needs to be chosen so that the measured currents fit into the s16 range. With the ADC scaler, the user can choose a scaling with physical units like [mA].



3.5.4 Measurement of Rotor Angle

Determination of the rotor angle is either done by sensors (digital encoder, analog encoder, digital Hall sensors, analog Hall sensors) or sensorless by a reconstruction of the rotor angle. Currently, there are no sensorless methods available for FOC that work in a general purpose way as a sensor down to velocity zero.

The TMC4671 does not support sensorless FOC.

3.5.5 Measured Rotor Angle vs. Magnetic Axis of Rotor vs. Magnetic Axis of Stator

The rotor angle, measured by an encoder, needs to be adjusted to the magnetic axis of the rotor. This is because an incremental encoder has an arbitrary orientation relative to the magnetic axis of the rotor, and the rotor has an arbitrary orientation to magnetic axis of the stator.

The direction of counting depends on the encoder, its mounting, and wiring and polarities of encoder signals and motor type. So, the direction of encoder counting is programmable for comfortable definition for a given combination of motor and encoder.

3.5.5.1 Direction of Motion - Magnetic Field vs. Position Sensor

For FOC it is essential, that the direction of revolution of the magnetic field is compatible with the direction of motion of the rotor position reconstructed from encoder signals: For revolution of magnetic field with positive direction, the decoder position needs to turn into the same positive direction. For revolution of magnetic field with negative direction, the decoder position needs to turn into the same negative direction.

With an absolute encoder, once adjusted to the relative orientation of the rotor and to the relative orientation of the stator, one could start the FOC without initialization of the relative orientations.

3.5.5.2 Bang-Bang Initialization of the Encoder

A Bang-Bang initialization is an initialization where the motor is forced with high current into a specific position. For Bang-Bang initialization, the user sets a current into direction D that is strong enough to move the rotor into the desired direction. Other initialization methods ramp up the current smoothly and adjust the current vector to rotor movement detected by the encoder.

3.5.5.3 Encoder Initialization using Hall Sensors

The encoder can be initialized using digital Hall sensor signals. Digital Hall sensor signals give absolute positions within each electrical period with a resolution of sixty degrees. If the Hall sensor signals are used to initialize the encoder position on the first change of a Hall sensor signal, an absolute reference within the electrical period for commutation is given.

3.5.5.4 Minimum Movement Initialization of the Encoder

For minimal movement initialization of the encoder, the user slowly increases a current into direction D and adjusts an offset of the measured angle in a way that the rotor of the motor does not move during initialization while the offset of the measured angle is determined.



3.5.6 Knowledge of Relevant Motor Parameters and Position Sensor (Encoder) Parameters

3.5.6.1 Number of Pole Pairs of a Motor

The number of pole pairs is an essential motor parameter. It defines the ratio between electrical revolutions and mechanical revolutions. For a motor with one pole pair, one mechanical revolution is equivalent to one electrical revolution. For a motor with n_{pp} pole pairs, one mechanical revolution is equivalent to n_{pp} electrical revolutions, with $n = 1, 2, 3, 4, \dots$

Some define the number of poles NP instead of number of pole pairs NPP for a motor, which results in a factor of two that might cause confusion. For the TMC4671, we use NPP number of pole pairs.

3.5.6.2 Number of Encoder Positions per Revolution

For the encoder, the number of positions per revolution (PPR) is an essential parameter. The number of positions per revolution is essential for the FOC.

Some encoder vendors give the number of lines per revolution (LPR) or just named line count (LC) as encoder parameter. Line count and positions per revolution might differ by a factor of four. This is because of the quadrature encoding - A signal and B signal with phase shift - that give four positions per line, enabling the determination of the direction of revolution. Some encoder vendors associate counts per revolution (CPR) or pulses per revolution associated to PPR acronym.

The TMC4671 uses Positions Per Revolution (PPR) as encoder parameter.

3.5.7 Proportional Integral (PI) Controllers for Closed Loop Current Control

Last but not least, two PI controllers are required for the FOC. The TMC4671 is equipped with two PI controllers - one for control of torque generating current I_Q and one to control current I_D to zero.

3.5.8 Pulse Width Modulation (PWM) and Space Vector Pulse Width Modulation (SVPWM)

The PWM power stage is a must-have for energy efficient motor control. The PWM engine of the TMC4671 just needs a couple of parameters to set PWM frequency f_{PWM} and switching pauses for both high side switches t_{BBM_H} and low side switches t_{BBM_L} . Some control bits are for the programming of power switch polarities for maximum flexibility in the selection in gate drivers for the power MOS-FETs. An additional control bit selects SVPWM on or off. The TMC4671 allows for change of PWM frequency by a single parameter during operation.

With this, the TMC4671 is advanced compared to software solutions where PWM and SVPM configuration of CPU internal peripherals normally needs settings of many parameters.



3.5.9 Orientations, Models of Motors, and Coordinate Transformations

The orientation of magnetic axes (U, V, W for FOC3 resp. X, Y for FOC2) is essential for the FOC together with the relative orientation of the rotor. Here, the rotor is modeled by a bar magnet with one pole pair ($n_{\text{pole_pairs}} = 1$) with magnetic axis in north-south direction.

The actual magnetic axis of the stator - formed by the motor coils - is determined by measurement of the coil currents.

The actual magnetic axis of the rotor is determined by incremental encoder or by Hall sensors. Incremental encoders need an initialization of orientation, where Hall sensors give an absolute orientation, but with low resolution. A combination of Hall sensor and incremental encoder is useful for start-up initialization.

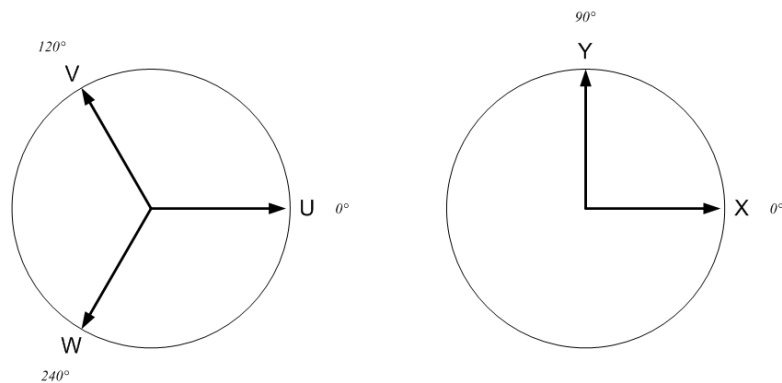


Figure 3: Orientations UVW (FOC3) and XY (FOC2)

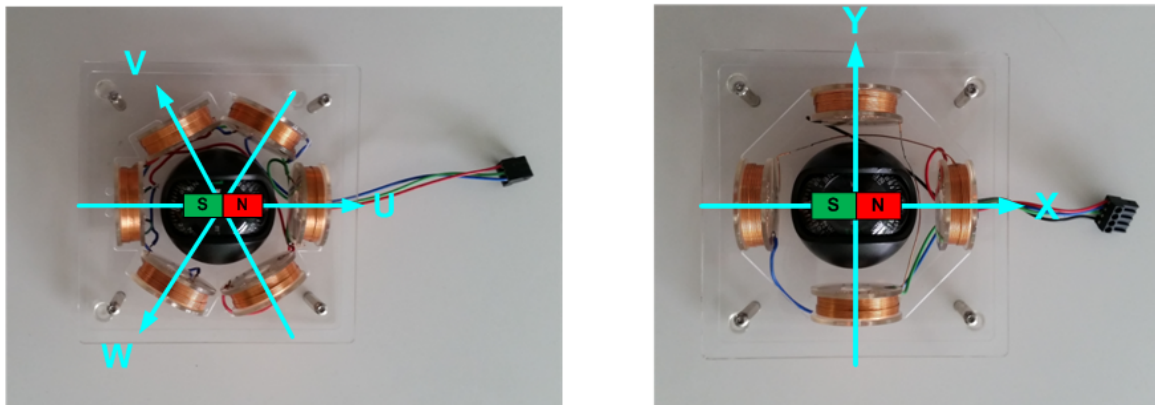


Figure 4: Compass Motor Model w/ 3 Phases UVW (FOC3) and Compass Motor Model w/ 2 Phases (FOC2)



4 Functional Description

The TMC4671 is a fully integrated controller for field-oriented control (FOC) of either one 2-phase stepper motor (FOC2) or one 3-phase brushless motor (FOC3), as well as DC motors or voice coil actuators. Containing the complete control loop core architecture (position, velocity, torque), the TMC4671 also has the required peripheral interfaces for communication with an application controller, for feedback (digital encoder, analog interpolator encoder, digital Hall with interpolator, analog inputs for current and voltage measurement), and helpful additional IOs. The TMC4671 supports highest control loop speed and PWM frequencies.

The TMC4671 is the building block which takes care of all real-time critical tasks of field-oriented motor control. It decouples the real-time field-oriented motor control and its real-time sub-tasks such as current measurement, real-time sensor signal processing, and real-time PWM signal generation from the user application layer as outlined by figure 5.

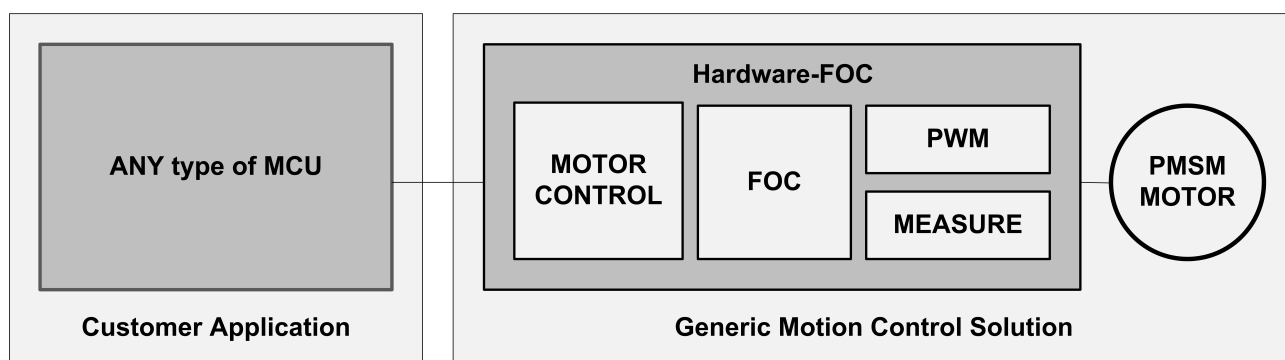


Figure 5: Hardware FOC Application Diagram

4.1 Functional Blocks

The Application interface, register bank, ADC engine, encoder engine, FOC torque PI controller, velocity PI controller, position P controller, and PWM engine make up the TMC4671.

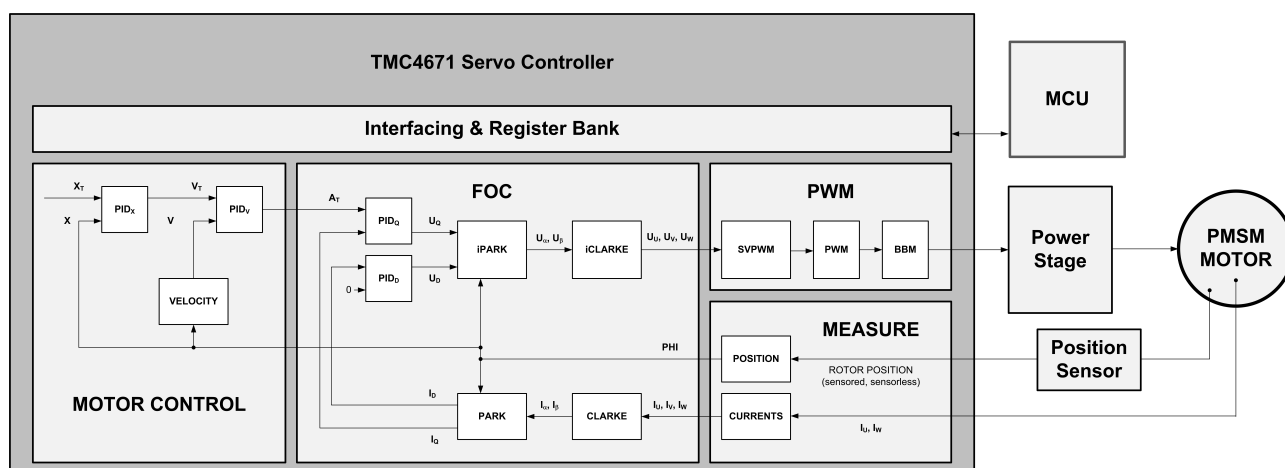


Figure 6: Hardware FOC Block Diagram



The ADC engine interfaces the integrated ADC channels and maps raw ADC values to signed 16 bit (s16) values for the inner FOC current control loop based on programmable offset and scaling factors. The FOC torque PI controller forms the inner base component including required transformations (Clark, Park, inverse Park, inverse Clark). All functional blocks are pure hardware.

4.2 Communication Interfaces

The TMC4671 is equipped with an SPI interface for access to all registers of the TMC4671. The SPI interface is the main application interface.

An additional UART interface is intended for system setup. With that interface, the user can access all registers of the TMC4671 in parallel to the application accessing them via the SPI communication interface - via the user's firmware or via evaluation boards and the TMCL-IDE. The data format of the UART interface is similar to the SPI communication interface - SPI 40 bit datagrams sent to the TMC4671 and SPI 40 bit datagrams received by the MCU vs. five bytes sent via UART and five bytes received via UART. Sending a burst of different real-time data for visualization and analysis via the TMCL-IDE can be triggered using special datagrams. With that, the user can set up an embedded application together with the TMCL-IDE, without having to write a complex set of visualization and analysis functions. The user can focus on its application.

The TMC4671 is also equipped with an additional SPI master interface (TRINAMIC Real-time Monitoring Interface, DBGSPI) for high-speed visualization of real-time data together with the TMCL-IDE.

4.2.1 SPI Slave User Interface

The SPI of the TMC4671 for the user application has an easy command and control structure. The TMC4671 user SPI acts as a slave. The SPI datagram length is 40 bit with a clock rate up to 1 MHz (8 MHz in future chip version).

- The MSB (bit#39) is sent first. The LSB (bit#0) is sent last.
- The MSB (bit#39) is the WRITE_notREAD (WRnRD) bit.
- The bits (bit#39 to bit#32) are the address bits (ADDR).
- Bits (bit#31) to (bit#0) are 32 data bits.

The SPI of the TMC4671 immediately responses within the actual SPI datagram on read and write for ease-of-use communication.

40 BIT DATAGRAM		
	8 BIT ADDR	32 DATA
WRnRD	7 BIT ADDR	32 DATA

Figure 7: SPI Datagram Structure

A simple SPI datagram example:

```
0x8100000000 // 1st write 0x00000000 into address 0x01 (CHIPINFO_ADDR)
0x0000000000 // 2nd read register 0x00 (CHIPINFO_DATA), returns 0x34363731 <=> ACSII "4671"
```



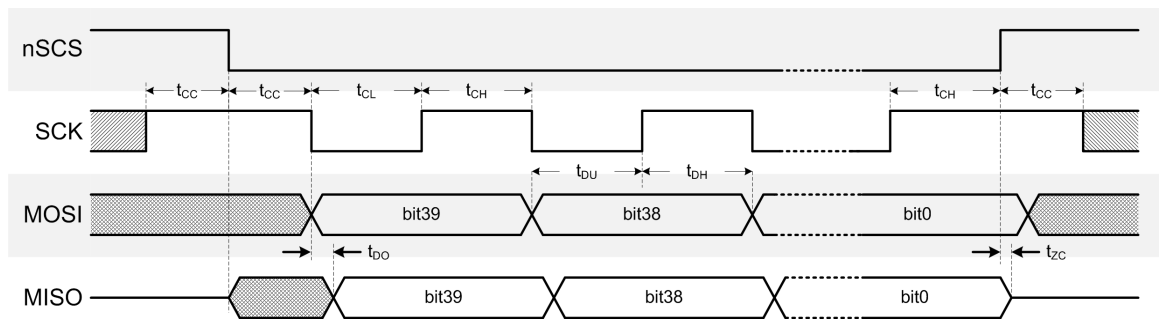


Figure 8: SPI Timing

SPI Interface Timing		Characteristics, fCLK = 25MHz				
Parameter	Symbol	Condition	Min	Typ	Max	Unit
SCK valid before or after change of nSCS	t_{CC}		62.5			ns
nSCS high time	t_{CSH}		62.5			ns
nSCS low time	t_{CSL}		62.5			ns
SCK high time	t_{CH}		62.5			ns
SCK low time	t_{CL}		62.5			ns
SCK low time	t_{CL}		62.5			ns
SCK frequency	f_{SCK}				8	MHz
MOSI setup time before rising edge of SCK	t_{DU}		62.5			ns
MOSI hold time after falling edge of SCK	t_{DH}		62.5			ns
MISO data valid time after falling edge of SCK	t_{DO}				10	ns

Table 2: SPI Timing Parameter

Info

The SPI in the TMC4671-ES shows following error: During transaction of read data the MSB (Bit#31) might get corrupted. This shows in two different ways. The first one being a 40 ns pulse (positive or negative) on MISO at the beginning of transfer of that particular bit. This pulse can corrupt the MSB of read data and this error can be avoided when SPI clock frequency is set to 1 MHz. The second error also corrupts MSB of read data when MSB of register is unstable. Such as current measurement noise around zero. In this case, MSB should be ignored when possible. Please also consider that e.g. actual torque value can be read from register PID_TORQUE_FLUX_ACTUAL or from INTERIM_DATA register, where it is showing up in the lower 16 bits. These errors will be fixed in the next IC version. SPI write access is not affected and can be performed at 8 MHz clock frequency.



4.2.2 TRINAMIC Real-Time Monitoring Interface (SPI Master)

The TRINAMIC Real-Time Monitoring Interface (SPI Master) is an additional fast interface enabling real-time identification of motor parameters and system parameters. The user can check configuration and access registers in the TMC4671 via the TMCL-IDE with its build-in configuration wizards for FOC setup in parallel to the user firmware. TRINAMIC provides a Monitoring Adapter to access the interface, which connects easily to a single 10 pin high density connector (Type: Hirose DF20F-10DP-1V) on the user's PCB. If the interface is not needed, pins must be left open or can be used as GPIOs according to the specification.

The connector needs to be placed near the TMC4671 and assignment needs to be as displayed in figure 9.

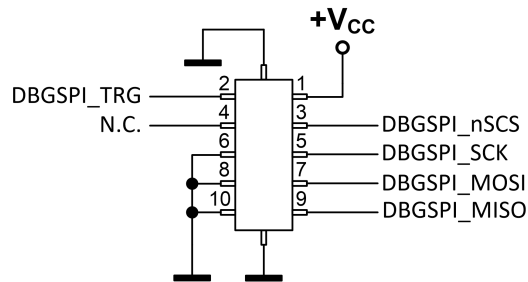


Figure 9: Connector for Real-Time Monitoring Interface (Connector Type: Hirose DF20F-10DP-1V)

i Info

The TRINAMIC Real-Time Monitoring Interface can not be used with galvanic isolation, as the timing of SPI communication is too strict. This will be fixed in the next version so that galvanic isolation of SPI signals will be possible with a defined latency of isolators.



4.2.3 UART Debug Interface

The UART debug interface is a simple three pin (GND, RxD, TxD) 3.3V UART interface with up to 3 Mbit/s transfer speed with one start bit, eight data bits, one stop bit, and no parity bits (1N8). The default speed is 9600 bps. Other supported speeds are 115200 bps, 921600 bps, and 3000000 bps.

With an 3.3V-UART-to-USB adapter cable (e.g. FTDI TTL-232R-RPi), the user can communicate with up to 3Mbps. The UART debug port enables In-System-Setup-Support by multiple-ported register access.

An UART datagram consists of five bytes - similar to the datagrams of the embedded user application interface (SPI). In contrast to the embedded user application interface (SPI), the UART interface has a time out feature. So, the five bytes of a UART datagram need to be send within one second. A pause of sending more than one second causes a time out and sets the UART protocol handler back into IDLE state. In other words, waiting for more than one second in sending via UART ensures that the UART protocol handler is in IDLE state.

A simple UART example (similar to the simple SPI example):

```
0x81 0x00 0x00 0x00 0x00 // 1st write 0x00000000 into address 0x01 (CHIPINFO_ADDR)
0x00 0x00 0x00 0x00 0x00 // 2nd read register 0x00 (CHIPINFO_DATA), returns 0x34363731
```

Why UART Interface? It might become necessary during the system setup phase to simply access some internal registers without disturbing the application, without changing the actual user application software, and without adding additional debugging code that might disturb the application software itself. The UART enables this supporting function. In addition, it also enables easy access for monitoring purposes with its very simple and direct five byte protocol.

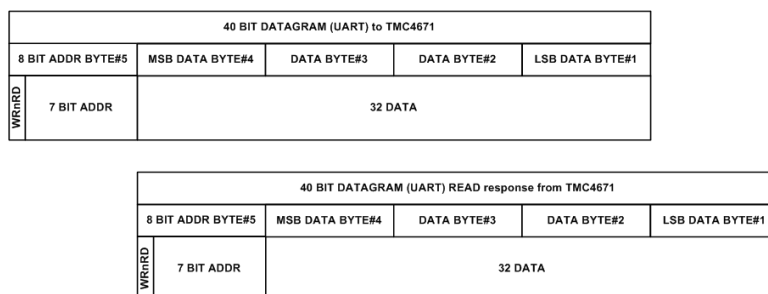


Figure 10: UART Read Datagram (TMC4671 register read via UART)

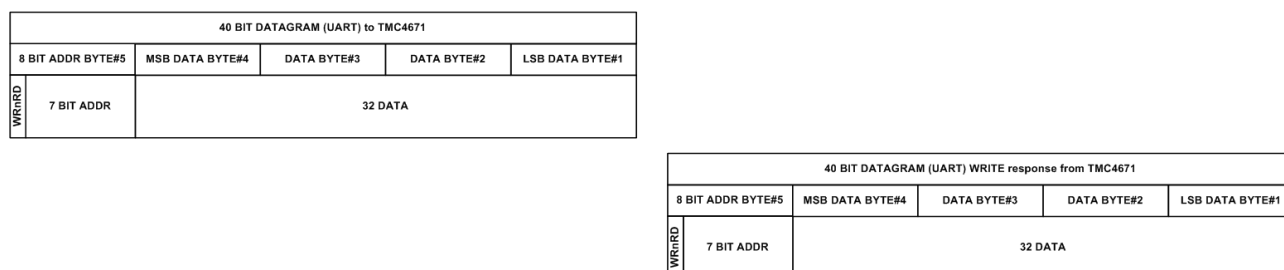


Figure 11: UART Write Datagram (TMC4671 register write via UART)



4.3 Numerical Representation, Electrical Angle, Mechanical Angle, and Pole Pairs

The TMC4671 uses different numerical representations for different parameters, measured values, and interim results. The terms electrical angle PHI_E , mechanical angle PHI_M , and number of pole pairs (N_POLE_PAIRS) of the motor are important for setup of FOC. This section describes the different numerical representations of parameters and terms.

4.3.1 Numerical Representation

The TMC4671 uses signed and unsigned values of different lengths and fixed point representations for parameters that require a non-integer granularity.

Symbol	Description	Min	Max
u16	unsigned 16 bit value	0	65535
s16	signed 16 bit values, 2'th complement	-32767	32767
u32	unsigned 32 bit value	0	$2^{32} = 4294967296$
s32	signed 32 bit values, 2'th complement	-2147483647	$2^{31} - 1 = 2147483647$
q8.8	signed fix point value with 8 bit integer part and 8 bit fractional part	-32767/256	32767/256
q4.12	signed fix point value with 4 bit integer part and 12 bit fractional part	-32767/4096	32767/4096

Table 3: Numerical Representations

i Info

Two's complement of n bit is $-2^{(n-1)} \dots -2^{(n-1)} - 1$. To avoid unwanted overflow, the range is clipped to $-2^{(n-1)} + 1 \dots -2^{(n-1)} - 1$.

Because the zero is interpreted as a positive number for 2'th complement representation of integer n bit number, the smallest negative number is $-2^{(n-1)}$ where the largest positive number is $2^{(n-1)} - 1$. Using the smallest negative number $-2^{(n-1)}$ might cause critical underflow or overflow. Internal clipping takes this into account by mapping $-2^{(n-1)}$ to $-2^{(n-1)} + 1$.

Hexadecimal Value	u16	s16	q8.8	q4.12
0x0000 _h	0	0	0.0	0.0
0x0001 _h	1	1	1 / 256	1 / 4096
0x0002 _h	2	2	2 / 256	2 / 4096
0x0080 _h	128	128	0.5	0.03125
0x0100 _h	256	256	1.0	0.0625
0x0200 _h	512	512	2.0	0.125
0x3FFF _h	16383	16383	16383 / 256	16383 / 4096
0x5A81 _h	23169	23169	23169 / 256	23169 / 4096
0x7FFF _h	32767	32767	32767 / 256	32767 / 4096



Hexadecimal Value	u16	s16	q8.8	q4.12
0x8000 _h	32768	-32768	-32768 / 256	-32768 / 4096
0x8001 _h	32769	-32767	-32767 / 256	-32767 / 4096
0x8002 _h	32770	-32766	-32766 / 256	-32766 / 4096
0xC001 _h	49153	-16383	-16383 / 256	-16383 / 4096
0xFFFE _h	65534	-2	-2 / 256	-2 / 4096
0xFFFF _h	65535	-1	-1 / 256	-1 / 4096

Table 4: Examples of u16, s16, q8.8, q4.12

The q8.8 and q4.12 are used for P and I parameters which are positive numbers. Note that q8.8 and q4.12 are used as signed numbers. This is because these values are multiplied with signed error values resp. error integral values.

4.3.2 N_POLE_PAIRS, PHI_E, PHI_M

The parameter N_POLE_PAIRS defines the factor between electrical angle PHI_E and mechanical angle PHI_M of a motor (pls. refer figure 12).

A motor with one (1) pole pair turns once for each electrical period. A motor with two (2) pole pairs turns once for every two electrical periods. A motor with three (3) pole pairs turns once for every three electrical periods. A motor with four pole (4) pairs turns once for every four electrical periods.

The electrical angle PHI_E is relevant for the commutation of the motor. It is relevant for the torque control of the inner FOC loop.

$$\text{PHI_E} = \text{PHI_M} \cdot \text{N_POLE_PAIRS} \quad (3)$$

The mechanical angle PHI_M is primarily relevant for velocity control and for positioning. This is because one wants to control the motor speed in terms of mechanical turns and not in terms of electrical turns.

$$\text{PHI_M} = \text{PHI_E} / \text{N_POLE_PAIRS} \quad (4)$$

Different encoders give different kinds of position angles. Digital Hall sensors normally give the electrical position PHI_E that can be used for commutation. Analog encoders give - depending on their resolution - angles that have to be scaled first to mechanical angles PHI_M and to electrical angles PHI_E for commutation.



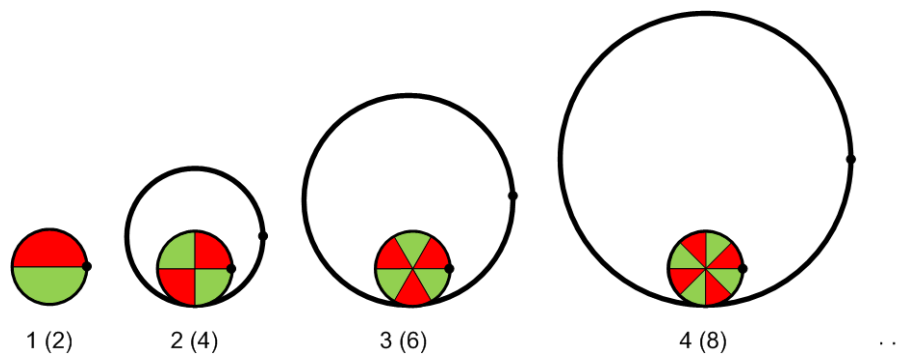


Figure 12: N_POLE_PAIRS - Number of Pole Pairs (Number of Poles)

4.3.3 Numerical Representation of Angles PHI

Electrical angles and mechanical angles are represented as 16 bit integer values. One full revolution of 360 deg is equivalent to $2^{16} = 65536$ steps. Any position coming from a sensor is mapped to this integer range. Adding an offset of PHI_OFFSET causes a rotation of an angle $PHI_OFFSET/2^{16}$. Subtraction of an offset causes a rotation of an angle PHI_OFFSET in opposite direction.

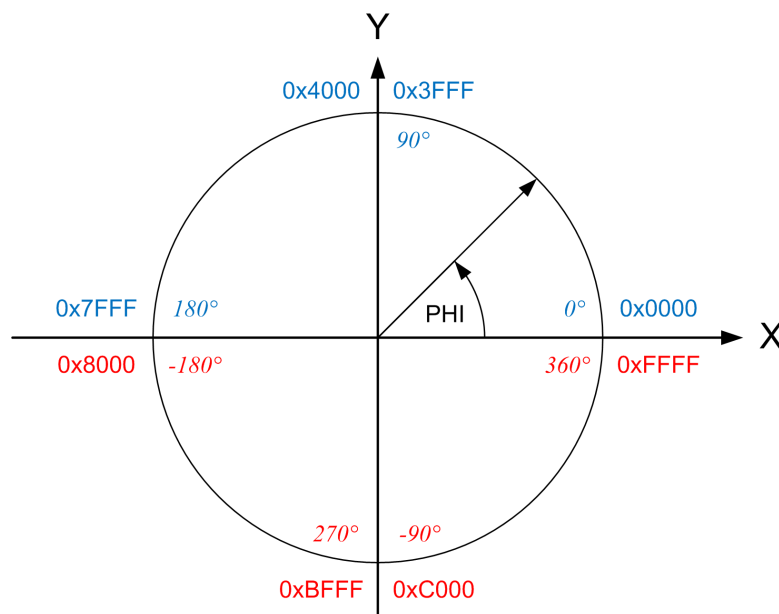


Figure 13: Integer Representation of Angles as 16 Bit signed (s16) resp. 16 Bit unsigned (u16)

Hexadecimal Value	u16	s16	PHI[°]	±PHI[°]
0x0000 _h	0	0	0.0	0.0
0x1555 _h	5461	5461	30.0	-330.0
0x2AAA _h	10922	10922	60.0	-300.0
0x4000 _h	16384	16384	90.0	-270.0



Hexadecimal Value	u16	s16	PHI[°]	±PHI[°]
0x5555 _h	21845	21845	120.0	-240.0
0x6AAA _h	27306	27768	150.0	-210.0
0x8000 _h	32768	-32768	180.0	-180.0
0x9555 _h	38229	-27307	210.0	-150.0
0xAAAA _h	43690	-21846	240.0	-120.0
0xC000 _h	49152	-16384	270.0	-90.0
0xD555 _h	54613	-10923	300.0	-60.0
0xEAAA _h	60074	-5462	330.0	-30.0

Table 5: Examples of u16, s16, q8.8

The option of adding an offset is for adjustment of angle shift between the motor and stator and the rotor and encoder. Finally, the relative orientations between the motor and stator and the rotor and encoder can be adjusted by just one offset. Alternatively, one can set the counter position of an incremental encoder to zero on initial position. For absolute encoders, one needs to use the offset to set an initial position.

4.4 ADC Engine

The ADC engine controls the sampling of different available ADC channels. The ADC channels (ADC_I0_POS, ADC_I0_NEG, ADC_I1_POS, ADC_I1_NEG) for current measurement are differential inputs. For analog Hall and for analog encoder, the ADC channels have differential inputs (AENC_UX_POS, AENC_UX_NEG, AENC_VN_POS, AENC_VN_NEG, AENC_WY_POS, AENC_WY_NEG). Two general purpose ADC channels are single-ended analog inputs (AGPI_A, AGPI_B). The ADC channel for measurement of supply voltage (ADC_VM) is associated with the brake chopper.

The FOC engine expects offset corrected ADC values, scaled into the FOC engine's 16 bit (s16) fixed point representation. The integrated scaler and offset compensator maps raw ADC samples of current measurement channels to 16 bit two's complement values (s16). While the offset is compensated by subtraction, the offset is represented as an unsigned value. The scaling value is signed to compensate wrong measurement direction. The s16 scaled ADC values are available for read out from the register by the user.

Info

Wrong scaling factors (ADC_SCALE) or wrong offsets (ADC_OFFSET) might cause damages when the FOC is active. Integrated hardware limiters allow protection - especially in the setup phase when using careful limits.

ADC samples for measurement of supply voltage (VM) and the general purpose analog ADC inputs are available as raw values only without digital scaling. This is because these values are not processed by the FOC engine. They are just additional ADC channels for the user. The general purpose analog inputs (AGPI) are intended to monitor analog voltage signals representing MOSFET temperature or motor temperature. AGPI_A can also be used for the Single Pin Interface (please see section 4.8.10).

Info

ADC_VM must be scaled down by voltage divider to the allowed voltage range, and might require additional supply voltage spike protection.



4.4.1 ADC Group A and ADC Group B

ADC inputs of the TMC4671 are grouped into two groups, to enable different sample rates for two groups of analog signals if needed. For all applications both groups should work with the same sampling rates. necessary to run its ADC channels with a much higher bandwidth than the ADC channels for current measurement.

4.4.2 Internal Delta Sigma ADCs

The TMC4671 is equipped with internal delta sigma ADCs for current measurement, supply voltage measurement, analog GPIs and analog encoder signal measurement. Delta sigma ADCs, as integrated within the TMC4671, together with programmable digital filters are flexible in parameterizing concerning resolution vs. speed. The advantage of delta sigma ADCs is that the user can adjust measurement from lower speed with higher resolution to higher speed with lower resolution. This fits with motor control application. Higher resolution is required for low speed signals, while lower resolution satisfies the needs for high speed signals.

Due to high oversampling, the analog input front-end is easier to implement than for successive approximation register ADCs as anti aliasing filters can be chosen to a much higher cutoff frequency. The ADC Engine processes all ADC channels in parallel hardware - avoiding phase shifts between the channels compared to ADC channels integrated in MCUs.

An analog voltage V_{IN} of an analog input is mapped to a raw ADC value ADC_RAW .

4.4.3 External Delta Sigma ADCs

The delta sigma front-end of the ADC engine supports external delta sigma modulators to enable isolated delta sigma modulators for the TMC4671. Additionally, the delta sigma front-end supports low-cost comparators together with two resistors and one capacitor (R-C-R-CMP) forming first order delta sigma modulators, as generic analog front-end for pure digital variants of the TMC4671 core.

4.4.3.1 ADC RAW

The sampled raw ADC values are available for read out by the user. This is important during the system setup phase to determine offset and scaling factors.

4.4.3.2 ADC EXT

The user can write ADC values into the ADC_EXT registers of the register bank from external sources. These values can be selected as raw current ADC values by selection. ADC_EXT registers are primarily intended for test purposes as optional inputs for external current measurement sources.

4.5 Delta Sigma Configuration and Timing Configuration

The delta sigma configuration is programmed via MCFG register that selects the mode (internal/external delta sigma modulator with fixed internal 100MHz system clock or with programmable MCLK; delta sigma modulator clock mode (MCLK output, MCLK input, MCLK used as MDAC output with external R-C-R-CMP configuration); delta sigma modulator clock and its polarity; and the polarity of the delta sigma modulator data signal MDAT).



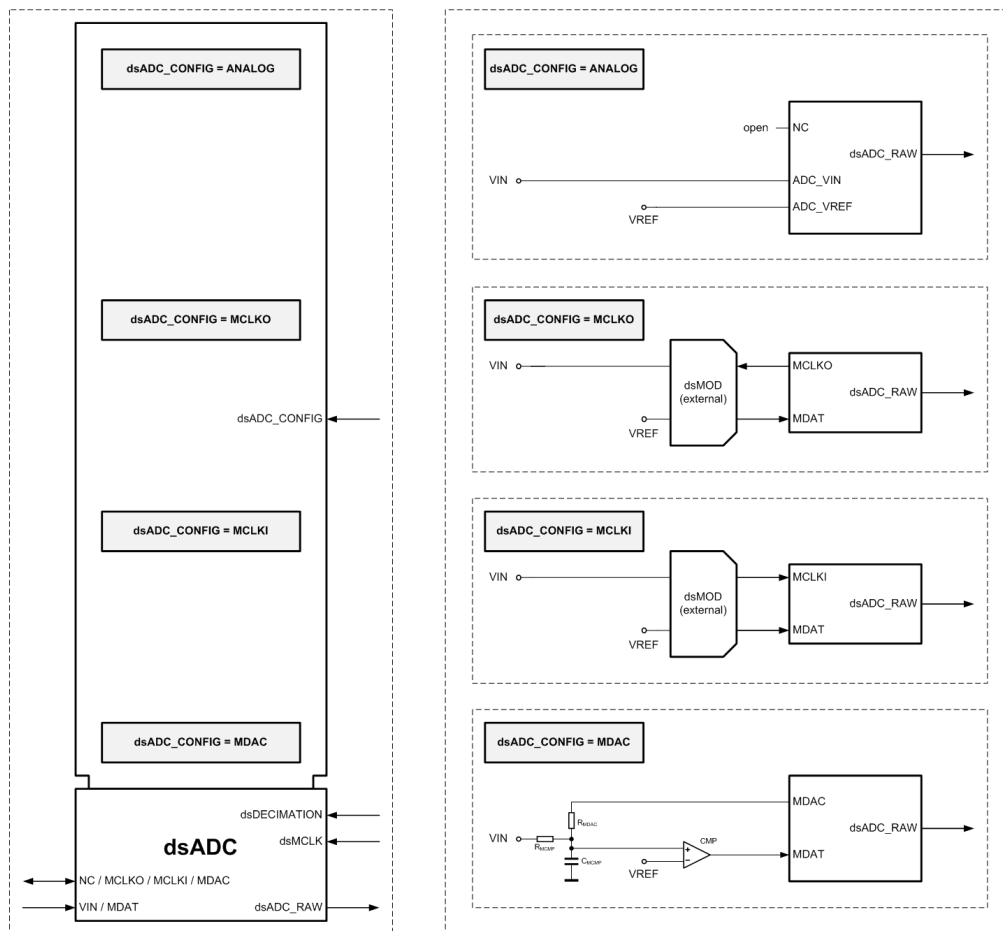


Figure 14: Delta Sigma ADC Configurations *dsADC_CONFIG* (internal: ANALOG vs. external: MCLKO, MCLKI, MDAC)

dsADC_CONGIG	Description	NC_MCLKO_MCLKI_MDAC	VIN_MDAT
ANALOG	integrated internal ADC mode, VIN_MDAT is analog input VIN	MCLK not connected (NC)	VIN (analog)
MCLKO	external dsModulator (e.g. AD7403) with MCLK input driven by MCLKO	MCLK output	MDAT input
MCLKI	external dsModulator (e.g. AD7400) with MCLK output that drives MCLKI	MCLK input	MDAT input
MDAC	external dsModulator (e.g. LM339, LM319) realized by external comparator CMP with two R and one C	MDAC output (= MCLK out)	MDAT input for CMP

Table 6: Delta Sigma ADC Configurations (figure 14), selected with *dsADC_MCFG_A* and *dsADC_MCFG_B*.



register	function
dsADC_MCFG_B	delta sigma modulator configuration MCFG (ANALOG, MCLKI, MCLKO, MDAC), group B
dsADC_MCFG_A	delta sigma modulator configuration MCFG (ANALOG, MCLKI, MCLKO, MDAC), group A
dsADC_MCLK_B	delta sigma modulator clock MCLK, group B
dsADC_MCLK_A	delta sigma modulator clock MCLK, group A
dsADC_MDEC_B	delta sigma decimation parameter MDEC, group B
dsADC_MDEC_A	delta sigma decimation parameter MDEC, group A

Table 7: Registers for Delta Sigma Configuration

4.5.0.1 Timing Configuration MCLK

When the programmable MCLK is selected, the MCLK_A and MCLK_B parameter registers define the programmable clock frequency fMCLK of the delta sigma modulator clock signal MCLK for delta sigma modulator group A and group B. For a given target delta sigma modulator frequency fMCLK, together with the internal clock frequency fCLK = 100MHz, the MCLK frequency parameter is calculated by

$$\text{MCLK} = 2^{31} * \text{fMCLK}[\text{Hz}] / \text{fCLK}[\text{Hz}] \quad (5)$$

Due to the 32 bit's length of the MCLK frequency parameter, the resulting frequency fMCLK might differ from the desired frequency fMCLK. The back calculation of the resulting frequency fMCLK for a calculated MCLK parameter with 32 bit length is defined by

$$\text{fMCLK}[\text{Hz}] = \text{fCLK}[\text{Hz}] * \text{MCLK} / 2^{31} \quad (6)$$

The precise programming of the MCLK frequency is primarily intended for external delta sigma modulators to meet given EMI requirements. With that, the user can program frequencies fMCLK with a resolution better than 0.1 Hz. This advantage concerning EMI might cause trouble when using external delta signal modulators if they are sensitive to slight frequency alternating. This is not an issue when using external first-order delta sigma modulators based on R-C-R-CMP (e.g. LM339). But for external second-order delta signal modulators, it is recommended to configure the MCLK parameter for frequencies fMCLK with kHz quantization (e.g. 10,001,000 Hz instead of 10,000,001 Hz). Table 8 gives an overview of MCLK parameter settings for different frequencies fMCLK.

fMCLK_target	MCLK	fMCLK_resulting	comment
25 MHz	0x20000000	25 MHz	w/o fMCLK frequency jitter, recommended
20 MHz	0x19000000	20 MHz -468750 Hz	recommended for ext. $\Delta\Sigma$ modulator
20 MHz	0x19999999	20 MHz -0.03 Hz	might be critical for ext. $\Delta\Sigma$ modulator
12.5 MHz	0x10000000	12.5 MHz	w/o fMCLK frequency jitter, recommended
10 MHz	0x0CCCCCCC	10 MHz -0.04 Hz	might be critical for ext. $\Delta\Sigma$ modulator
10 MHz	0x0CC00000	10 MHz -39062.5 Hz	recommended for ext. $\Delta\Sigma$ modulator

Table 8: Delta Sigma MCLK Configurations



Info

Parametrization of fMCLK will be changed in a future version of the chip to match usual modulator frequencies like 10MHz and 20MHz better. It is recommended to use a Modulatorfrequency of 25kHz for all applications. If the second ADC group is not needed, it is recommended to shut it off by setting the MCLK_B register to 0x0.

4.5.0.2 Decimation Configuration MDEC

The high oversampled single bit delta sigma data stream (MDAT) is digitally filtered by Sinc3 filters. To get raw ADC data, the actual digitally filtered values need to be sampled periodically with a lower rate called decimation ratio. The decimation is controlled by parameter MDEC_A for ADC group A and MDEC_B for ADC group B. A new ADC_RAW value is available after MDEC delta sigma pulses of MCLK. As such, the parameters MCLK and MDEC together define the sampling rate of the 16 bit ADC_RAW values.

The delta sigma modulator with Sinc3 filter works with best noise reduction performance when the length of the step response time tSINC3 of the Sinc3 filter is equal to the length of the PWM period tPWM = (PWM_MAXCNT+1) / fPWMCLK = ((PWM_MAXCNT+1) * 10 ns) of the period. The length of the step function response of a Sinc3 filter is

$$t_{SINC3} = (3 \cdot (MDEC - 1) + 1) \cdot t_{MCLK} \quad (7)$$

$$MDEC_{recommended} = \frac{t_{PWM}}{3 \cdot t_{MCLK}} - 2 \quad (8)$$

fMCLK	tMCLK	MDEC25 (25 kHz, 40 μ s)	MDEC50 (50 kHz, 20 μ s)	MDEC100 (100 kHz, 10 μ s)
50 MHz	20 ns	665	331	165
25 MHz	40 ns	331	165	81
20 MHz	50 ns	265	131	65
12.5 MHz	80 ns	165	81	40
10 MHz	100 ns	131	65	31

Table 9: Recommended Decimation Parameter MDEC (equation (8)) for different PWM frequencies fPWM (MDEC25 for fPWM=25kHz w/ PWM_MAXCNT=3999, MDEC50 for fPWM=50kHz w/ PWM_MAXCNT=1999, MDEC100 for fPWM=100kHz w/ PWM_MAXCNT=999).

Info

Internal structure of the Sinc3 and synchronization to PWM will be enhanced in future version of the chip. This might need the user's application controller software to be changed.

4.5.1 Internal Delta Sigma Modulators - Mapping of V_RAW to ADC_RAW

Generally, delta sigma modulators work best for a typical input voltage range of 25% V_MAX ... 75% V_MAX. For the integrated delta sigma modulators, this input voltage operation range is recommended with V_MAX



= 5V where $V_{MAX} = 3.3V$ is possible. The table 10 defines the recommended voltage ranges for both 5V and 3.3V analog supply voltages.

$V_{SUPPLY}[V]$	$(V_{MIN}[V])$	$V_{MIN25\%}[V]$	$V_{MAX50\%}[V]$	$V_{MAX75\%}[V]$	$(V_{MAX}[V])$
(3.3)	(0.0)	(0.825)	(1.65)	(2.75)	(3.3)
5.0	(0.0)	1.250	2.50	3.75	(5.0)

Table 10: Recommended input voltage range from $V_{MIN25\%}[V]$ to $V_{MAX75\%}[V]$ for internal Delta Sigma Modulators; $V_{SUPPLY}[V] = 5V$ is recommended for the analog part of the TMC4671.

$$V_{RAW} = \begin{cases} V_{MAX} & \text{for } V_{IN} > V_{MAX} \\ (V_{IN} - V_{REF}) & \text{for } V_{MIN} < (V_{IN} - V_{REF}) < V_{MAX} \\ V_{MIN} & \text{for } V_{IN} < V_{MIN} \end{cases} \quad (9)$$

The resulting raw ADC value is

$$ADC_{RAW} = (2^{16} - 1) \cdot \frac{V_{RAW}}{V_{MAX}} \quad \text{for } V_{MIN25\%}[V] < V_{RAW} < V_{MAX75\%}[V]. \quad (10)$$

The idealized expression (equation 9) is valid for recommended voltage ranges (table 10) neglecting deviations in linearities. These deviations primarily depend on different impedance on the analog signal path, but also on digital parameterization. Finally, the deviation is quantified in terms of resulting ADC resolution.

So, the Delta Sigma ADC engine maps the analog input voltages $V_{RAW} = V_{IN} - V_{REF}$ of voltage range $V_{MIN} < V_{RAW} < V_{MAX}$ to ADC_{RAW} values of range $\{0 \dots (2^{16}) - 1\} \Leftrightarrow \{0 \dots 65535\} \Leftrightarrow 0x0000 \dots 0xFFFF$.

$V_{min}[V]$	$V_{ref}[V]$	$V_{max}[V]$	$V_{IN}[V]$	DUTY[%]	ADC_{RAW}
0.0	2.5	5.0	(0.0)	(0%)	(0x0000)
0.0	2.5	5.0	1.0	25%	0x4000
0.0	2.5	5.0	2.5	50%	0x7fff
0.0	2.5	5.0	3.75	75%	0xc000
0.0	2.5	5.0	(5.0)	(100%)	(0xffff)

Table 11: Delta Sigma input voltage mapping of internal Delta Sigma Modulators)

Info

For calibrating purposes, the input voltage of the delta sigma ADC inputs can be programmed to fixed voltages (25%, 50%, 75% of analog supply voltage) via the associated configuration register `DS_ANALOG_INPUT_STAGE_CFG`.



4.5.2 External Delta Sigma Modulator Interface

The TMC4671 is equipped with integrated digital filters for extraction of ADC raw values from delta sigma data stream for both internal and external delta sigma modulators. The interface for external delta sigma modulators is intended for external isolated sigma delta modulators, such as AD7401 (with MCLK input driven by TMC4671), or AD7402 (with MCLK output to drive TMC4671). In addition, the external delta sigma interface supports the use of simple comparator with a R-C-R network as external low cost delta sigma modulators (R-C-R-CMP, e.g. LM339).

i Info

When selecting the external delta sigma ADC Interface, the high-performance Debug SPI Interface (RTMI) is not available in parallel due to pin sharing. The UART is always available, but with less performance than the RTMI.

Each external delta sigma modulator channel (dsMOD) has two signals (pls. refer figure 14), one dedicated input, and one programmable input/output. The configuration of the external delta sigma modulator interface is defined by programming associated registers. When selecting external delta signal ADC, the associated analog ADC inputs are configured as digital inputs for the delta sigma signal data stream MDAT.

4.5.3 ADC Configuration - MDAC

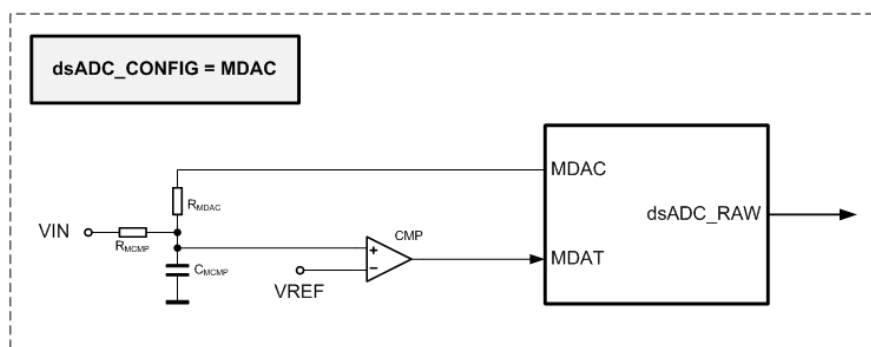


Figure 15: $\Delta\Sigma$ ADC Configuration - MDAC (Comparator-R-C-R as $\Delta\Sigma$ -Modulator)

In the MDAC delta sigma modulator, the delay of the comparator CMP determines the MCLK of the comparator modulator. A capacitor C_{MCMP} within a range of 100 pF ... 1 nF fits in most cases. The time constant τ_{RC} should be in a range of 0.1 t_{CMP} ... t_{CMP} of the comparator. The resistors should be in the range of 1K to 10K. The f_{MAXtyp} depends also on the choice of the decimation ratio.

CMP	$t_{CMPtyp} [ns]$	$R_{MCMP} [k\Omega]$	$R_{MDAC} [k\Omega]$	$C_{MCMP} [pF]$	$f_{MCLKmaxTYP}$
LM319	100	1	1	100	10 MHz
LM319	100	10	10	100	1 MHz
LM319	100	100	100	100	100 kHz
CMP	$t_{CMPtyp} [ns]$	$R_{MCMP} [k\Omega]$	$R_{MDAC} [k\Omega]$	$C_{MCMP} [pF]$	$f_{MCLKmaxTYP}$
LM339	1000	1	1	100	1 MHz



CMP	tCMPtyp [ns]	R_{MCMP} [k Ω]	R_{MDAC} [k Ω]	C_{MCMP} [pF]	fMCLKmaxTYP
LM339	1000	10	10	100	100 kHz
LM339	1000	100	100	100	10 kHz

Table 12: Delta Sigma R-C-R-CMP Configurations (pls. refer 14)



Vmin[V]	Vref[V]	Vmax[V]	VIN[V]	DUTY[%]	ADC_RAW
0.0	1.65	3.3	0.0	0%	0x0000
0.0	1.65	3.3	0.825	25%	0x4000
0.0	1.65	3.3	1.65	50%	0x7fff
0.0	1.65	3.3	2.475	75%	0xC000
0.0	1.65	3.3	3.3	100%	0xffff
Vmin[V]	Vref[V]	Vmax[V]	VIN[V]	DUTY[%]	ADC_RAW
0.0	2.5	5.0	0.0	0%	0x0000
0.0	2.5	5.0	1.0	25%	0x4000
0.0	2.5	5.0	2.5	50%	0x7fff
0.0	2.5	5.0	3.75	75%	0xC000
0.0	2.5	5.0	5.0	100%	0xffff

Table 13: Delta Sigma input voltage mapping of external comparator (CMP)

4.6 Analog Signal Conditioning

The range of measured coil currents, resp. the measured voltages of sense resistors, needs to be mapped to the valid input voltage range of the delta sigma ADC inputs. This analog preprocessing is the task of the analog signal conditioning.

4.6.0.1 Chain of Gains for ADC Raw Values

An ADC raw value is a result of a chain of gains that determine it. A coil current I_{SENSE} flowing through a sense resistor causes a voltage difference according to Ohm's law. Finally, a current is mapped to an ADC raw value

$$\text{ADC_RAW} = (I_{\text{SENSE}} * \text{ADC_GAIN}) + \text{ADC_OFFSET}. \quad (11)$$

The ADC_GAIN is a result of a chain of gains with individual signs. The sign of the ADC_GAIN is positive or negative, depending on the association of connections between sense amplifier inputs and the sense resistor terminals. The ADC_OFFSET is the result of electrical offsets of the phase current measurement signal path. For the TMC4671, the maximum ADC_RAW value is $\text{ADC_RAW_MAX} = (2^{16} - 1)$ and the minimum ADC raw value is $\text{ADC_RAW_MIN} = 0$.



$$\begin{aligned} \text{ADC_GAIN} = & \left(\text{I_SENSE_MAX} * \text{R_SENSE} \right) \\ & * \text{SENSE_AMPLIFIER_GAIN} \\ & * \left(\text{ADC_RAW_MAX} / \text{ADC_U_MAX} \right) \end{aligned} \quad (12)$$

Rsense [$m\Omega$]	Isense [A]	Usense [mV]	GAIN[V/V]	ADC_GAIN[A/V]	Sense Amplifier
5	10	50	20	10	AD8204
10	5	50	20	5	AD8204

Table 14: Example Parameters for ADC_GAIN

For the FOC, the ADC_RAW is scaled by the ADC scaler of the TMC4671 together with subtraction of offset to compensate it. Internally, the TMC4671 FOC engine calculates with s16 values. So, the ADC scaling needs to be chosen so that the measured currents fit into the s16 range. With the ADC scaler, the user can choose a scaling with physical units like [mA]. A scaling to [mA] covers a current range of $-32A \dots +32A$ with $m[A]$ resolution. For higher currents, the user can choose unusual units like centi Ampere [cA] covering $-327A \dots +327A$ or deci Ampere $-3276A \dots +3276A$.

ADC scaler and offset compensators are for mapping raw ADC values to s16 scaled and offset cleaned current measurement values that are adequate for the FOC.

4.6.1 FOC3 - Stator Coil Currents I_U, I_V, I_W and Association to Terminal Voltages U_U, U_V, U_W

The correct association between stator terminal voltages U_U, U_V, U_W and stator coil currents I_U, I_V, I_W is essential for the FOC.

For three-phase motors with three terminals U, V, W, the voltage U_U is in phase with the current I_U, U_V is in phase with I_V, and U_W is in phase with I_W according to equations (13) and (14) for FOC3.

$$\text{U_UVW_FOC3}(\text{U_D}, \text{PHI_E}) = \begin{cases} U_U(\phi_e) = U_D \cdot \sin(\phi_e) \\ U_V(\phi_e) = U_D \cdot \sin(\phi_e + 120^\circ) \\ U_W(\phi_e) = U_D \cdot \sin(\phi_e - 120^\circ) \end{cases} \quad (13)$$

$$\text{I_UWV_FOC3}(\text{I_D}, \text{PHI_E}) = \begin{cases} I_U(\phi_e) = I_D \cdot \sin(\phi_e) \\ I_V(\phi_e) = I_D \cdot \sin(\phi_e + 120^\circ) \\ I_W(\phi_e) = I_D \cdot \sin(\phi_e - 120^\circ) \end{cases} \quad (14)$$



4.6.2 Stator Coil Currents I_X, I_Y and Association to Terminal Voltages U_X, U_Y

For two-phase motors (stepper) with four terminals X1, X2, and Y1, Y2, voltage U_{Ux} = U_{X1} - U_{X2} is in phase with the measured current I_X and U_{Wy} = U_{Y1} - U_{Y2} is in phase with the measured current I_Y according to equations (15) and (16) for FOC2.

$$U_{XY_FOC2} = \begin{cases} U_X(\phi_e) = U_X * \sin(\phi_e) \\ U_Y(\phi_e) = U_Y * \sin(\phi_e + 90^\circ) \end{cases} \quad (15)$$

$$I_{XY_FOC2} = \begin{cases} I_X(\phi_e) = I_D * \sin(\phi_e) \\ I_Y(\phi_e) = I_D * \sin(\phi_e + 90^\circ) \end{cases} \quad (16)$$

4.6.3 ADC Selector & ADC Scaler w/ Offset Correction

The ADC selector selects ADC channels for FOC. The 3-phase FOC uses two of three ADC channels for measurement and calculates the third channel via Kirchhoff's Law using the scaled and offset-corrected ADC values. The 2-phase FOC just uses two ADC channels because for a 2-phase stepper motor, the two phases are independent from each other.

Note The open-loop encoder is useful for setting up ADC channel selection, scaling, and offset by running a motor open-loop.

The FOC23 Engine processes currents as 16 bit signed (s16) values. Raw ADC values are expanded to 16 bit width, regardless of their resolution. With this, each ADC is available for read out as a 16 bit number. The ADC scaler w/ offset correction is for the preprocessing of measured raw current values. It might be used to map to user's own units (e.g. A or mA). For scaling, gains of current amplifiers, reference voltages, and offsets have to be taken into account.

i Info Raw ADC values generally are of 16 bit width, regardless of their real resolution.

i Info The ADC scaler maps raw ADC values to the 16 bit signed (s16) range and centers the values to zero by removing offsets.



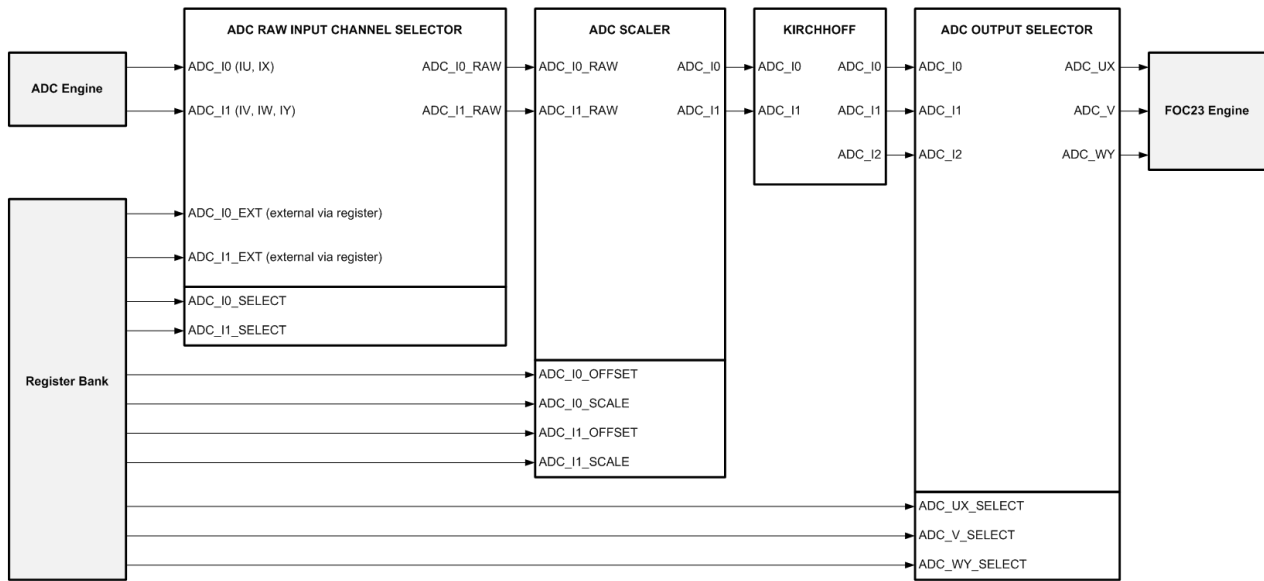


Figure 16: ADC Selector & Scaler w/ Offset Correction

ADC offsets and ADC scalars for the analog current measurement input channels need to be programmed into the associated registers. Each ADC_I_U , ADC_I_V , ADC_I_UX , ADC_I_WY , $ADCSD_I_UX$, $ADCSD_I_WY$, ADC_I0_EXT , and ADC_I1_EXT is mapped either to ADC_I0_RAW or to ADC_I1_RAW by ADC_I0_SELECT and ADC_I1_SELECT .

In addition, the ADC_OFFSET is for conversion of unsigned ADC values into signed ADC values as required for the FOC.

$$ADC_I0 = (ADC_I0_RAW + ADC_I0_OFFSET) \cdot ADC_I0_SCALE \quad (17)$$

$$ADC_I1 = (ADC_I1_RAW + ADC_I1_OFFSET) \cdot ADC_I1_SCALE \quad (18)$$

For FOC3, the third current ADC_I2 is calculated via Kirchhoff's Law. This requires the correct scaling and offset correction beforehand. For FOC2, there is no calculation of a third current.

The ADC_UX_SELECT selects one of the three ADC channels ADC_I0 , ADC_I1 , or ADC_I2 for ADC_UX .

The ADC_V_SELECT selects one of the three ADC channels ADC_I0 , ADC_I1 , or ADC_I2 for ADC_V .

The ADC_WY_SELECT selects one of the three ADC channels ADC_I0 , ADC_I1 , or ADC_I2 for ADC_WY .

The ADC_UX , ADC_V , and ADC_WY are for the FOC3 (U, V, W). The ADC_UX and ADC_WY (X, Y) are for the FOC2.

Note

The open-loop encoder is useful to run a motor open loop for setting up the ADC channel selection with correct association between phase currents I_U , I_V , I_W and phase voltages U_U , U_V , U_W .



4.7 Encoder Engine

The encoder engine is an unified position sensor interface. It maps the selected encoder position information to electrical position (ϕ_e) and to mechanical position (ϕ_m). Both are 16 bit values. The encoder engine maps single turn positions from position sensors to multi-turn positions. The user can overwrite the multi-turn position for initialization.

The different position sensors are the position sources for torque and flux control via FOC, for velocity control, and for position control. The `PHI_E_SELECTION` selects the source of the electrical angle ϕ_e for the inner FOC control loop. `VELOCITY_SELECTION` selects the source for velocity measurement. With ϕ_e selected as source for velocity measurement, one gets the electrical velocity. With the mechanical angle ϕ_m selected as source for velocity measurement, one gets the mechanical velocity taking the set number of pole pairs (`N_POLE_PAIRS`) of the motor into account. Nevertheless, for a highly precise positioning, it might be useful to do positioning based on the electrical angle ϕ_e .

4.7.1 Open-Loop Encoder

For initial system setup, the encoder engine is equipped with an open-loop position generator. This allows for turning the motor open-loop by specifying speed in rpm and acceleration in rpm/s, together with a voltage `UD_EXT` in D direction. As such, the open-loop encoder is not a real encoder. It simply gives positions as an encoder does. The open-loop decoder has a direction bit to define direction of motion for the application.

Note

The open-loop encoder is useful for initial ADC setup, encoder setup, Hall signal validation, and for validation of the number of pole pairs of a motor. The open-loop encoder turns a motor open with programmable velocity in unit [RPM] with programmable acceleration in unit [RPM/s].

With the open-loop encoder, the user can turn a motor without any position sensor and without any current measurement as a first step of doing the system setup. With the turning motor, the user can adjust the ADC scales and offsets and set up position sensors (Hall, incremental encoder, ...) according to resolution, orientation, and direction of rotation.

4.7.2 Incremental ABN Encoder

The incremental encoders give two phase shifted incremental pulse signals A and B. Some incremental encoders have an additional null position signal N or zero pulse signal Z. An incremental encoder (called ABN encoder or ABZ encoder) has an individual number of incremental pulses per revolution. The number of incremental pulses define the number of positions per revolution (PPR). The PPR might mean pulses per revolution or periods per revolution. Instead of positions per revolution, some incremental encoder vendors call these CPR counts per revolution.

The PPR parameter is the most important parameter of the incremental encoder interface. With that, it forms a modulo (PPR) counter, counting from 0 to (PPR-1). Depending on the direction, it counts up or down. The modulo PPR counter is mapped into the register bank as a dual ported register. The user can overwrite it with an initial position. The ABN encoder interface provides both the electrical position and the multi-turn position, which are accessible through dual-ported read-write registers.

Note

The PPR parameter must be set exactly according to the used encoder.

The N pulse from an encoder triggers either sampling of the actual encoder count to fetch the position at the N pulse or it re-writes the fetched n position on an N pulse. The N pulse can either be used as stand



alone pulse or and-ed with $NAB = N$ and A and B. It depends on the decoder what kind of N pulse has to be used - either N or NAB. For those encoders with precise N pulse within one AB quadrant, the N pulse must be used. For those encoders with N pulse over four AB quadrants the user can enhance the precision of the N pulse position detection by using NAB instead of N.

Note Incremental encoders are available with N pulse and without N pulse.

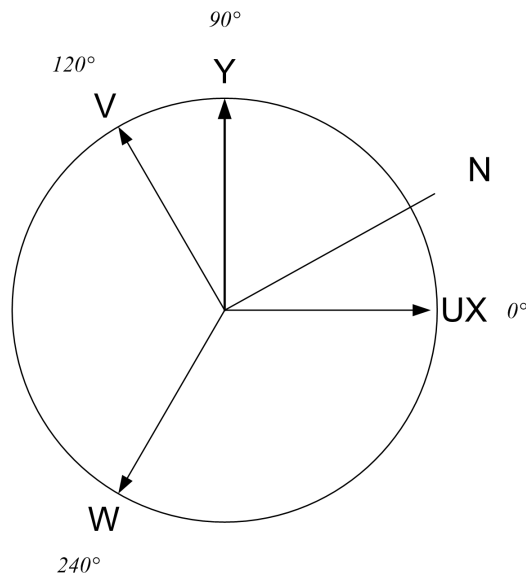


Figure 17: ABN Incremental Encoder N Pulse

The polarity of N pulse, A pulse and B pulse are programmable. The N pulse is for reinitialization with each turn of the motor. Once fetched, the ABN decoder can be configured to write back the fetched N pulse position with each N pulse.

Note The ABN encoder interface has a direction bit to set to match wiring of motor to direction of encoder.

Logical $ABN = A$ and B and N might be useful for incremental encoders with low resolution N pulse to enhance the resolution. On the other hand, for incremental encoders with high resolution N pulse a logical $ABN = A$ and B and N might totally suppress the resulting N pulse.



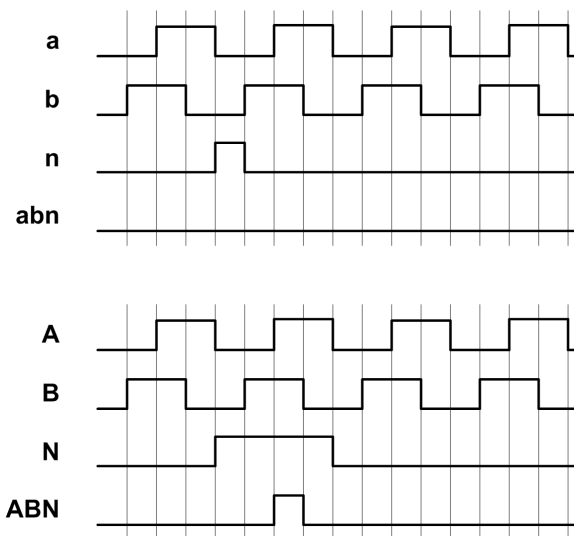


Figure 18: Encoder ABN Timing - high precise N pulse and less precise N pulse

4.7.3 Secondary Incremental ABN Encoder

For commutating a motor with FOC, the user selects a position sensor source (digital incremental encoder, digital Hall, analog Hall, analog incremental encoder, ...) that is mounted close to the motor. The inner FOC loop controls torque and flux of the motor based on the measured phase currents and the electrical angle of the rotor.

The TMC4671 is equipped with a secondary incremental encoder interface. This secondary encoder interface is available as source for velocity control or position control. This is for applications where a motor with a gearing positions an object.

i Info

The secondary incremental encoder is not available for commutation (ϕ_e) for the inner FOC. In others words, there is no electrical angle ϕ_e selectable from the secondary encoder.

4.7.4 Digital Hall Sensor Interface with optional Interim Position Interpolation

The digital Hall interface is the position sensor interface for digital Hall signals. The digital Hall signal interface first maps the digital Hall signals to an electrical position PHI_E_RAW . An offset PHI_E_OFFSET can be used to rotate the orientation of the Hall signal angle. The electrical angle PHI_E is for commutation. Optionally, the default electrical positions of the Hall sensors can be adjusted by writes into the associated registers.



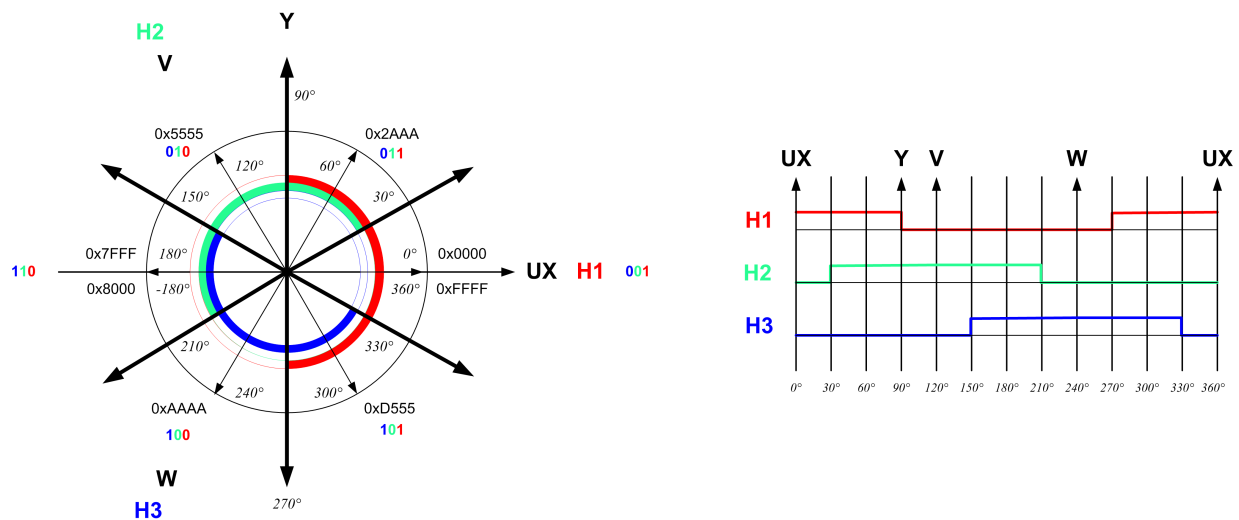


Figure 19: Hall Sensor Angles

Hall sensors give absolute positions within an electrical period with a resolution of 60° as 16 bit positions (s16 resp. u16) PHI. With activated interim Hall position interpolation, the user gets high resolution interim positions when the motor is running at a speed above 60 rpm.

4.7.5 Digital Hall Sensor - Interim Position Interpolation

For lower torque ripple the user can switch on the position interpolation of interim Hall positions. This function is useful for motors that are compatible with sine wave commutation, but equipped with digital Hall sensors.

When the position interpolation is switched on, it becomes active on speeds above 60 rpm. For lower speeds it automatically disables itself. This is especially important when the motor has to be at rest. Hall sensor position interpolation might fail when Hall sensors are not properly placed in the motor. Please adjust Hall sensor positions for this case.

4.7.6 Digital Hall Sensors - Masking and Filtering

Sometimes digital Hall sensor signals get disturbed by switching events in the power stage. The TMC4671 can automatically mask switching distortions by correct setting of the HALL_MASKING register. When a switching event occurs, the Hall sensor signals are held for HALL_MASKING value times 10 ns. This way, Hall sensor distortions are eliminated. Uncorrelated distortions can be filtered via a digital filter of parameterizable length. If the input signal to the filter does not change for HALL_DIG_FILTER times 5 us, the signal can pass the filter. This filter eliminates issues with bouncing Hall signals.

4.7.7 Digital Hall Sensors together with Incremental Encoder

If a motor is equipped with both Hall sensors and incremental encoder, the Hall sensors can be used for the initialization as a low resolution absolute position sensor. Later on, the incremental encoder can be used as a high resolution sensor for commutation.



4.7.8 Analog Hall and Analog Encoder Interface (SinCos of 0° 90° or 0° 120° 240°)

An analog encoder interface is part of the decoder engine. It is able to handle analog position signals of 0° and 90° and of 0° 120° 240°. The analog decoder engine adds offsets and scales the raw analog encoder signals, while also calculating the electrical angle PHI_E from these analog position signals by an ATAN2 algorithm.

An individual signed offset is added to each associated raw ADC channel and scaled by its associated scaling factors according to

$$\text{AENC_VALUE} = (\text{AENC_RAW} + \text{AENC_OFFSET}) \cdot \text{AENC_SCALE} \quad (19)$$

In addition, the AENC_OFFSET is for conversion of unsigned ADC values into signed ADC values as required for the FOC.

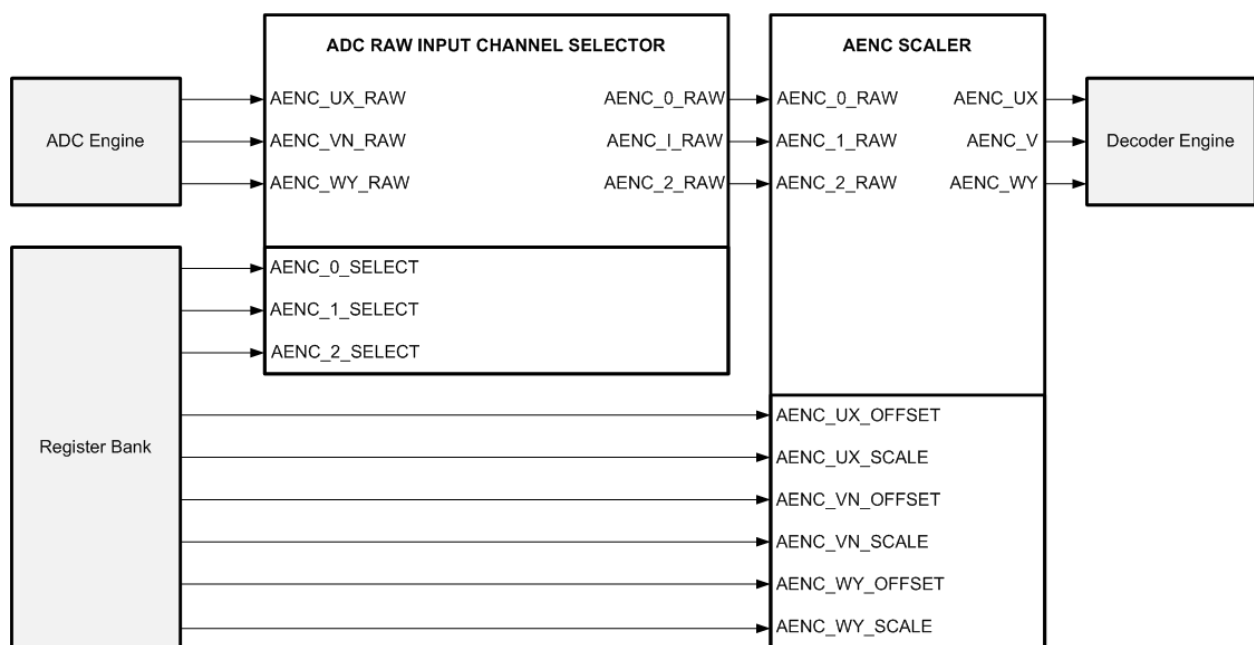


Figure 20: Analog Encoder (AENC) Selector & Scaler w/ Offset Correction



i Info

The analog N pulse is just a raw ADC value. Handling of analog N pulse similar to N pulse handling of digital encoder N pulse is not implemented for analog encoder.

4.7.9 Analog Position Decoder (SinCos of 0°90° or 0°120°240°)

The extracted positions from the analog decoder are available for read out from registers.

4.7.9.1 Multi-Turn Counter

Electrical angles are mapped to a multi-turn position counter. The user can overwrite this multi-turn position for initialization purposes.

4.7.9.2 Encoder Engine Phi Selector

The angle selector selects the source for the commutation angle PHI_E. That electrical angle is available for commutation.

4.7.9.3 External Position Register

A register value written into the register bank via the application interface is available for commutation as well. With this, the user can interface to any encoder by just writing positions extracted from external encoder into this regulator. From the decoder engine point of view this is just one more selectable encoder source.

4.7.10 Encoder Initialization Support

The TMC4671 needs proper feedback for correct and stable operation. One main parameter is the commutation angle offset PHI_E_OFFSET. This offset must not be calculated when an absolute sensor system like analog or digital Hall sensors is used. All other supported feedback systems need to be initialized - their PHI_E_OFFSETs need to be identified. The user has several options to determine PHI_E_OFFSET with support of the TMC4671.

4.7.10.1 Encoder Initialization in Open-Loop Mode

In the case of a free driving motor, the motor can be switched to Open-Loop Mode. In this mode, the used commutation angle (PHI_OPEN_LOOP) can be used to match the measured PHI_E. This method is supported by the TMCL-IDE.

4.7.10.2 Encoder Initialization by Minimal Movement

If the motor shall not make a big move during initialization, the MOTION_MODE ENCODER_INIT_MINI_MOVE can be used which determines PHI_E_OFFSET by ramping up the flux and controlling the movement to a minimum by manipulating the used PHI_E_OFFSET. After the procedure is finished, the estimated PHI_E_OFFSET can be read from the register and used as the corresponding PHI_E_OFFSET for the feedback system.



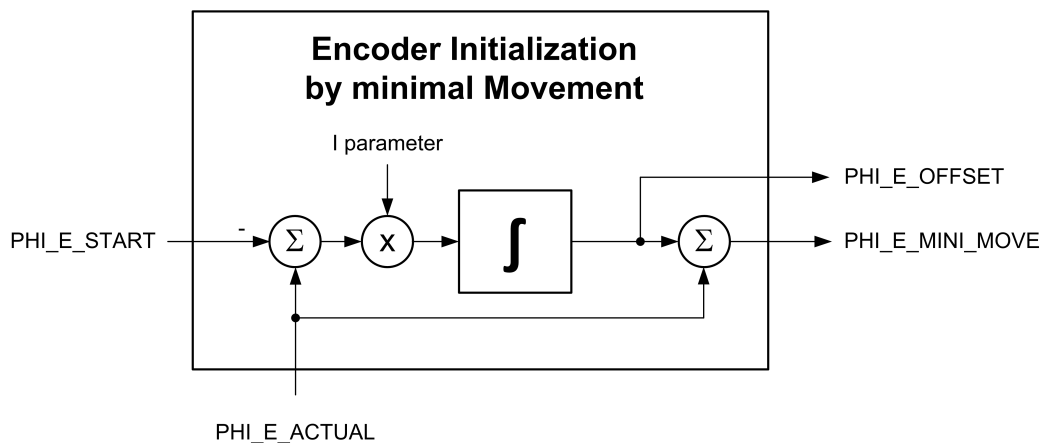


Figure 21: Encoder Initialization by minimal Movement

The flux ramping can be controlled by setting the U_D_INKR - which manipulates the slope of the ramp. The maximum voltage can be set by the parameter U_D_MAX . During operation, the current is monitored and the process is stopped when the current limit I_D_MAX is reached.

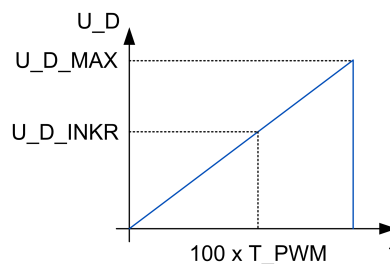


Figure 22: Flux Ramping

Info

For correct operation of this module a few parameters have to be set. Please try TRINAMIC TMCL-IDE Support for first usage and parameter tuning.

4.7.10.3 Encoder Initialization by Hall sensors

The TMC4671 can calculate PHI_E_OFFSET very precisely at a Hall state change for a second encoder system, when Hall sensors are correctly aligned. Therefore, the function needs to be enabled and calculate a new offset at the next Hall state change. After disabling of the module, the process can be started again. This function can also be used as a rough plausibility check during longer operation.

4.7.10.4 Encoder Initialization by N Pulse Detection

After determination of a correct offset, the value can be used again after power cycle. The encoder's N pulse can be used as reference for this. For starters the user can drive the motor in open-loop mode or by using digital Hall sensor signals. After passing the encoder's N pulse, the ABN encoder is initialized and can be used for operation.



4.7.11 Velocity Measurement

Servo control comprises position, velocity and current control. The position and the current are measured by separate sensors. The actual velocity has to be calculated by time discrete differentiation from the position signal. The user can choose a calculated position from the various encoder interfaces for velocity measurement by parameter VELOCITY_SELECTION.

The user can switch between two different velocity calculation algorithms with the parameter VELOCITY_METER_SELECTION. Default setting (VELOCITY_METER_SELECTION = 0) is the standard velocity meter, which calculates the velocity at a sampling rate of about 4369.067 Hz by differentiation. Output value is displayed in rpm (revolutions per minute). This option is recommended for usage with the standard PI controller structure.

By choosing the second option (VELOCITY_METER_SELECTION = 1), the sampling frequency is synchronized to the PWM frequency. This option is recommended for usage with the advanced PI controller structure. Otherwise, the controller structure might tend to be unstable due to non-matched sampling.

Velocity filters can be applied to reduce noise on velocity signals. Section 4.9 describes filtering opportunities in detail.

4.7.12 Reference Switches

The TMC4671 is equipped with three input pins for reference switches (REF_SW_L, REF_SW_H and REF_SW_R). These pins can be used to determine three reference positions. The TMC4671 displays the status of the reference switches in the register TMC_INPUTS_RAW and is able to store the actual position at rising edge of the corresponding signal. The signal polarities are programmable and the module reacts only on toggling the ENABLE register. The signals can be filtered with a configurable digital filter, which suppresses spike errors.

4.8 FOC23 Engine

i Info

Support for the TMC4671 is integrated into the TMCL-IDE including wizards for set up and configuration. With the TMCL-IDE, configuration and operation can be done in a few steps and the user gets direct access to all registers of the TMC4671.

The FOC23 engine performs the inner current control loop for the torque current I_Q and the flux current I_D including the required transformations. Programmable limiters take care of clipping of interim results. Per default, the programmable circular limiter clips U_D and U_Q to $U_{D_R} = \sqrt{2} \cdot U_Q$ and $U_{R_R} = \sqrt{2} \cdot U_D$. PI controllers perform the regulation tasks.

4.8.1 PI Controllers

PI controllers are used for current control and velocity control. A P controller is used for position control. The D part is not yet supported. The user can choose between two PI controller structures: The classic PI controller structure, which is also used in the TMC4670, and the advanced PI controller structure. The advanced PI controller structure shows better performance in dynamics and is recommended for high performance applications.

4.8.2 PI Controller Calculations - Classic Structure

The PI controllers in the classic structure perform the following calculation

$$dXdT = P \cdot e + I \cdot \int_0^t e(t) dt \quad (20)$$



with

$$e = X_TARGET - X \quad (21)$$

where X_TARGET stands for target flux, target torque, target velocity, or target position with error e , which is the difference between target value and actual values. The time constant dt is $1\mu s$ with the integral part is divided by 256.

Info

Changing the I-parameter of the classic PI controller during operation causes the controller output to jump, as the control error is first integrated and then gained by the I parameter. Be careful during controller tuning or use the advanced PI controller structure instead. The normalization of the PI parameters might be changed due to low performance at high PWM frequencies. This will need small changes in user's application controller software.

4.8.3 PI Controller Calculations - Advanced Structure

The PI controllers in the advanced controller structure perform the calculation

$$dXdT = P \cdot e + \int_0^t P \cdot I \cdot e(t) dt \quad (22)$$

with

$$e = X_TARGET - X \quad (23)$$

where X_TARGET represents target flux, target torque, target velocity, or target position with control error e , which is the difference between target value and actual values. The time constant dt is set according to the PWM period. Velocity and position controller evaluation can be down-sampled by a constant factor when needed.

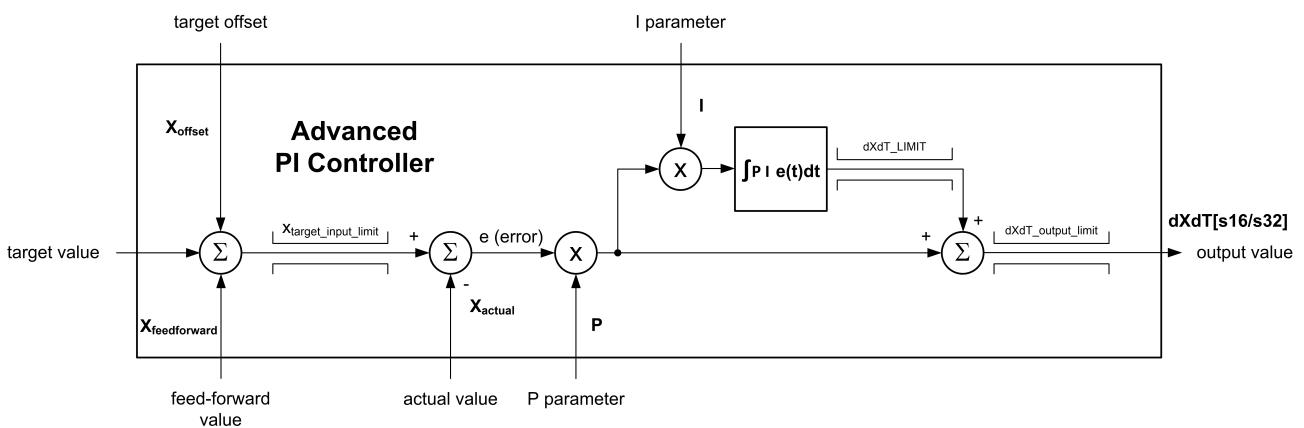


Figure 23: Advanced PI Controller



i Info

The PI velocity controller will be given a derivative part (so it will be a PID controller) in a future version of the chip. Also, the normalization of the PI parameters might be changed due to low performance at high PWM frequencies. This will need changes in the user's application controller software.

i Info

The P Factor in the advanced position controller is not properly scaled. Due to the high gain in velocity control loop, the position controller gain should be respectively low. The P Factor normalization of Q8.8 does not match these needs. This will be changed in a future version of the chip to a different Q format. This change will need changes in the user's application controller software. We recommend to use the classical PI control structure if performance is not sufficient.

4.8.4 PI Controller - Clipping

The limiting of target values for PI controllers and output values of PI controllers is programmable. Per power on default these limits are set to maximum values. During initialization, these limits should be set properly for correct operation and clipping.

The target input is clipped to `X_TARGET_LIMIT`. The output of a PI controller is named `dXdT` because it gives the desired derivative d/dt as a target value to the following stage: The position (x) controller gives velocity (dx/dt). The output of the PI Controller is clipped to `dXdT_LIMIT`. The error integral of (20) is clipped to `dXdT_LIMIT / I` in the classic controller structure, and the integrator output is clipped to `dXdT_LIMIT` in the advanced controller structure.



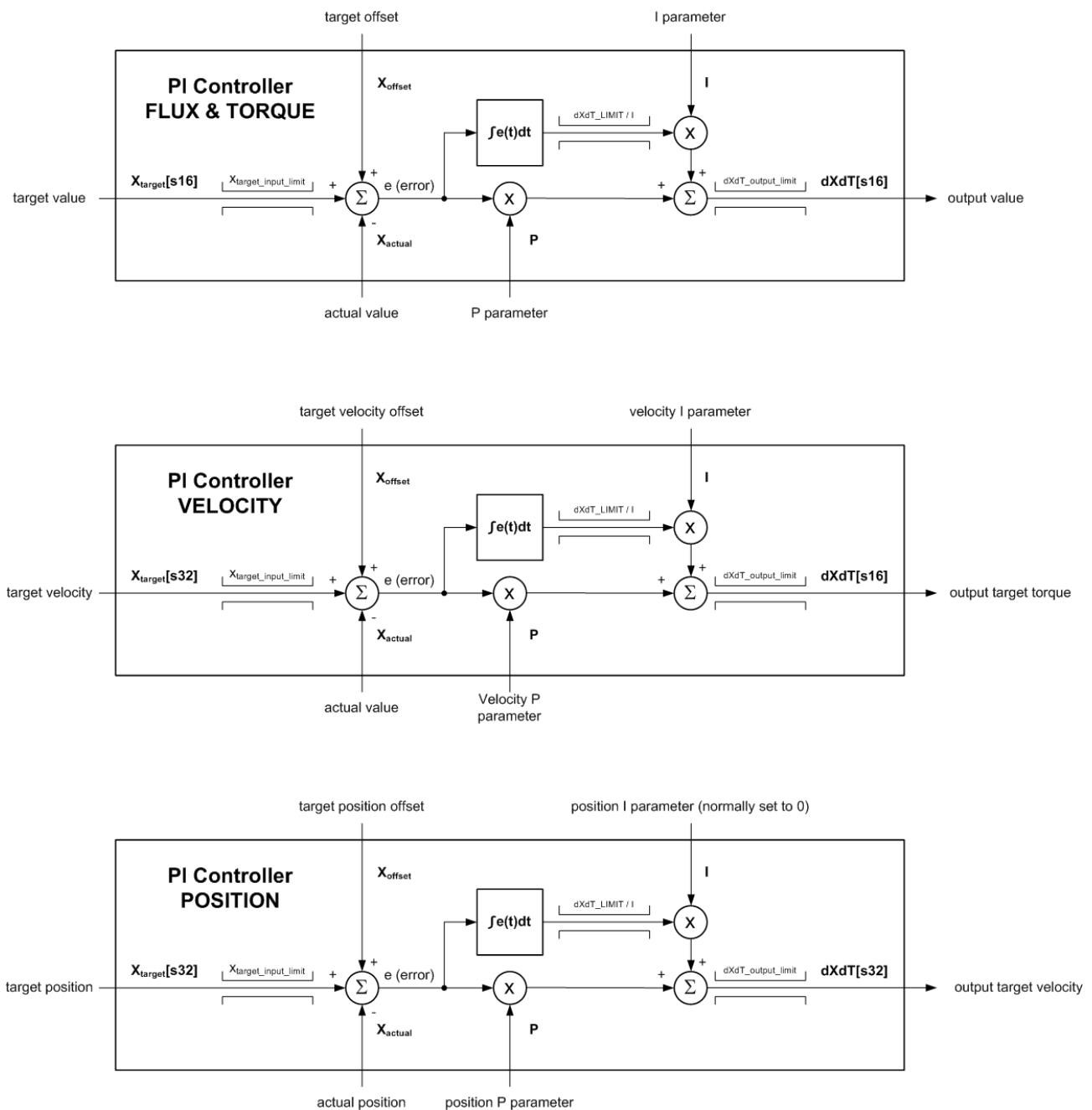


Figure 24: PI Architectures

4.8.5 PI Flux & PI Torque Controller

The P part is represented as q8.8 and I is the I part represented as q0.15.

4.8.6 PI Velocity Controller

The P part is represented as q8.8 and I is the I part represented as q0.15.



4.8.7 P Position Controller

For the position regulator, the P part is represented as q4.12 to be compatible with the high resolution positions - one single rotation is handled as an s16.

4.8.8 Inner FOC Control Loop - Flux & Torque

The inner FOC loop (figure 25) controls the flux current to the flux target value and the torque current to the desired torque target. The inner FOC loop performs the desired transformations according to figure 26 for 3-phase motors (FOC3). For 2-phase motors (FOC2) both Clarke (CLARKE) transformation and inverse Clarke (iCLARKE) are bypassed. For control of DC motors, transformations are bypassed and only the first full bridge (connected to X1 and X2) is used.

The inner FOC control loop gets a target torque value (I_Q_TARGET) which represents acceleration, the rotor position, and the measured currents as input data. Together with the programmed P and I parameters, the inner FOC loop calculates the target voltage values as input for the PWM engine.

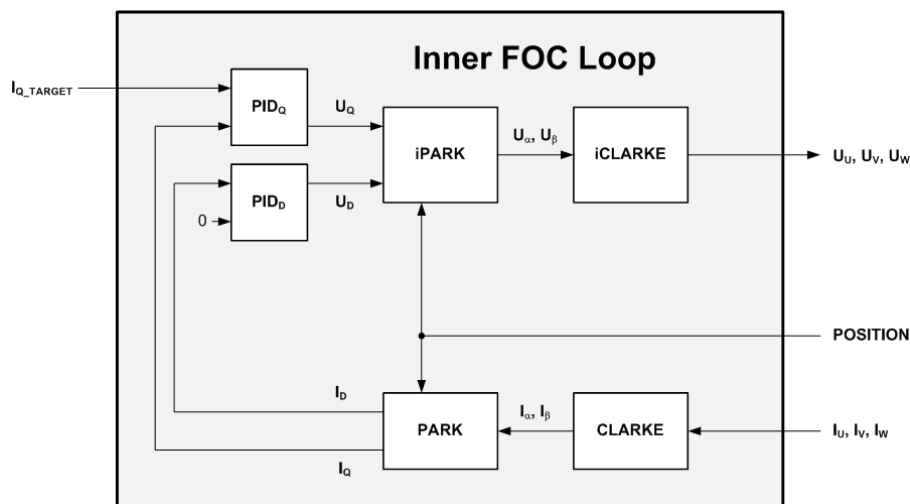


Figure 25: Inner FOC Control Loop

4.8.9 FOC Transformations and PI(D) for control of Flux & Torque

The Clarke transformation (CLARKE) maps three motor phase currents (I_U, I_V, I_W) to a two-dimensional coordinate system with two currents (I_α, I_β). Based on the actual rotor angle determined by an encoder or via sensorless techniques, the Park transformation (PARK) maps these two currents to a quasi-static coordinate system with two currents (I_D, I_Q). The current I_D represents flux and the current I_Q represents torque. The flux just pulls on the rotor but does not affect torque. The torque is affected by I_Q . Two PI controllers determine two voltages (U_D, U_Q) to drive desired currents for a target torque and a target flux. The determined voltages (U_D, U_Q) are re-transformed into the stator system by the inverse Park transformation (iPARK). The inverse Clarke Transformation (iCLARKE) transforms these two currents into three voltages (U_U, U_V, U_W). These three voltage are the input of the PWM engine to drive the power stage.

In case of the FOC2, Clarke transformation CLARKE and inverse Clarke Transformation iCLARKE are skipped.



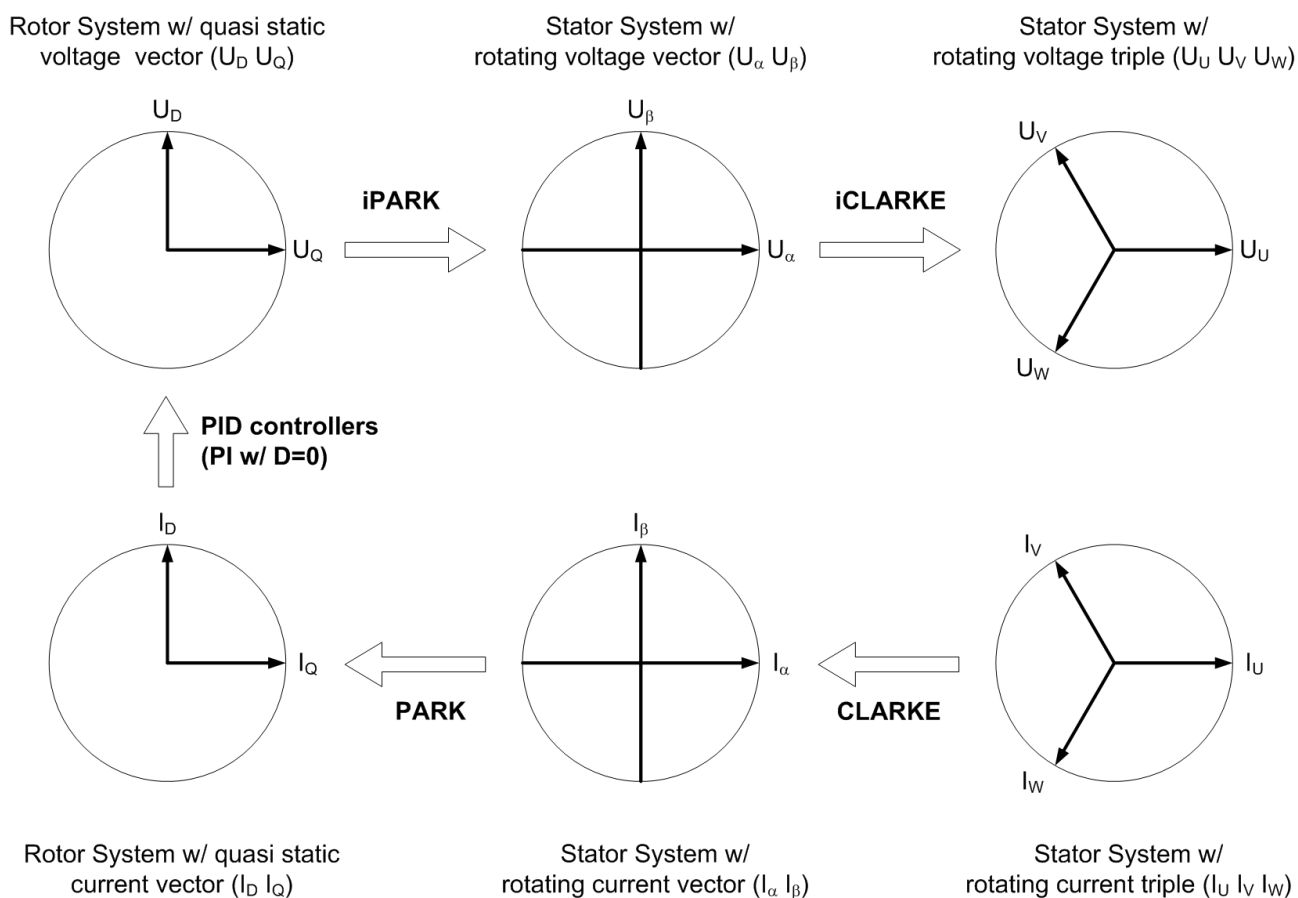


Figure 26: FOC3 Transformations (FOC2 just skips CLARKE and iCLARKE)

4.8.10 Motion Modes

The user can operate the TMC4671 in several motion modes. Standard motion modes are position control, velocity control and torque control, where target values are fed into the controllers via register access. The motion mode UD_UQ_EXTERN allows the user to set voltages for open-loop operation and for tests during setup.

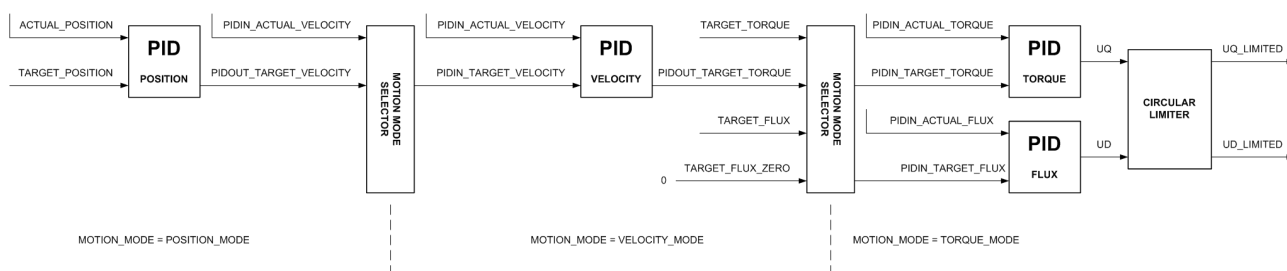


Figure 27: Standard Motion Modes

In position control mode, the user can feed the step and direction interface to generate a position target value for the controller cascade. Additional motion modes are the motion mode for encoder initialisation



(ENCODER_INIT_MINI_MOVE), and motion modes where target values are fed into the TMC4671 via PWM interface (Pin: PWM_IN) or analog input via pin AGPI_A.

There are additional motion modes, which are using input from the PWM_I input and the AGPI_A input. Input signals can be scaled via a standard scaler providing offset and gain correction. The interface can be configured via the registers SINGLE_PIN_IF_OFFSET_SCALE and SINGLE_PIN_IF_STATUS_CFG, where the status of the interface can be monitored as well. PWM input signals which are out of frequency range can be neglected. In case of wrong input data, last correct position is used or velocity and torque are set to zero.

4.9 Filtering and Feed-Forward Control

The TMC4671 uses different filters for certain target and actual values. When using standard velocity meter, a standard velocity filter is used which is optimized for velocity signals from Hall sensors. Additional Biquad filters can be used to suppress measurement noise or damp resonances.

4.9.1 Biquad Filters

The TMC4671 uses standard biquad filters (standard IIR filter of second order) in the following structure.

$$Y(n) = X(n) \cdot b_0 + X(n-1) \cdot b_1 + X(n-2) \cdot b_2 + Y(n-1) \cdot a_1 + Y(n-2) \cdot a_2 \quad (24)$$

In this equation $X(n)$ is the actual input sample, while $Y(n-1)$ is the filter output of the last cycle. All coefficients are S32 values and are normalized to a Q3.29 format. Users must take care of correct parametrization of the filter. There is no built-in plausibility or stability check. All filters can be disabled or enabled via register access. Biquad state variables are reset when parameters are changed. The TRINAMIC IDE supports parametrization with wizards.

A standard biquad filter has the following transfer function in the Laplace-Domain:

$$G(s) = \frac{b_{2_cont} \cdot s^2 + b_{1_cont} \cdot s + b_{0_cont}}{a_{2_cont} \cdot s^2 + a_{1_cont} \cdot s + a_{0_cont}} \quad (25)$$



The transfer function needs to be transformed to time discrete domain by Z-Transformation and coefficients need to be normalized. This is done by the following equations.

$$b_{2_z} = (b_{0_cont} \cdot T^2 + 2 \cdot b_{1_cont} \cdot T + 4 \cdot b_{2_cont}) / (T^2 - 2 \cdot a_{1_cont} \cdot T + 4 \cdot a_{2_cont}) \quad (26)$$

$$b_{1_z} = (2 \cdot b_{0_cont} \cdot T^2 - 8 \cdot b_{2_cont}) / (T^2 - 2 \cdot a_{1_cont} \cdot T + 4 \cdot a_{2_cont}) \quad (27)$$

$$b_{0_z} = (b_{0_cont} \cdot T^2 - 2 \cdot b_{1_cont} \cdot T + 4 \cdot b_{2_cont}) / (T^2 - 2 \cdot a_{1_cont} \cdot T + 4 \cdot a_{2_cont}) \quad (28)$$

$$a_{2_z} = (T^2 + 2 \cdot a_{1_cont} \cdot T + 4 \cdot a_{2_cont}) / (T^2 - 2 \cdot a_{1_cont} \cdot T + 4 \cdot a_{2_cont}) \quad (29)$$

$$a_{1_z} = (2 \cdot T^2 - 8 \cdot a_{2_cont}) / (T^2 - 2 \cdot a_{1_cont} \cdot T + 4 \cdot a_{2_cont}) \quad (30)$$

$$b_0 = \text{round}(b_{0_z} \cdot 2^{29}) \quad (31)$$

$$b_1 = \text{round}(b_{1_z} \cdot 2^{29}) \quad (32)$$

$$b_2 = \text{round}(b_{2_z} \cdot 2^{29}) \quad (33)$$

$$a_1 = \text{round}(-a_{1_z} \cdot 2^{29}) \quad (34)$$

$$a_2 = \text{round}(-a_{2_z} \cdot 2^{29}) \quad (35)$$

while T is the sampling time according to PWM_MAX_COUNT · 10 ns and variables with index z are auxiliary variables.

There are four biquad filters in the control structure. Figure 28 illustrates their placement in the control structure.

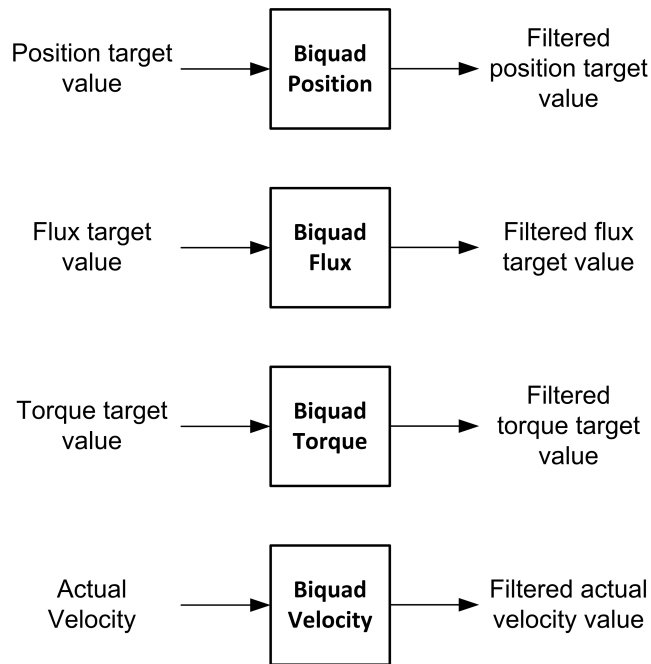


Figure 28: Biquad Filters

The biquad filter for the position target value is intended to be used as a low-pass filter for smoothing position input to the control structure. It is evaluated in every PWM cycle, or down-sampled according to the down-sampling factor for the velocity and position controllers. After powering on it is disabled.

The biquad filter for the flux target value is also intended to be used as a low-pass filter for input values from the user's microcontroller. Sampling frequency is fixed to the PWM frequency.

The biquad filter for the torque target value can be used as a low-pass filter for bandwidth limitation and noise suppression. Moreover, it can be designed to suppress a resonance or anti-resonance. Same



statements are correct for the velocity biquad filter. Both filters' sampling times are fixed to the PWM period.

The velocity target value biquad is configured as a second order low-pass with a cutoff frequency at 200 Hz - by default at a sampling frequency of 25 kHz. Biquad filters can be activated separately.

4.9.2 Standard Velocity Filter

By using the standard velocity measurement algorithm, the default velocity filter is enabled and can not be switched off. The standard velocity filter is a low-pass filter with a cutoff frequency of 20 Hz (slope of -20 dB/Decade). In this configuration, a new velocity is calculated at a sample rate of approx. 4369.067 Hz. This configuration is intended to be used in low-performance applications with a simple position feedback system like digital Hall sensors.

4.9.3 Feed-Forward Control Structure

The TMC4671 provides a feed-forward control structure for torque target value and velocity target value. The structure is intended to support controllers at high dynamic input profiles. It can be switched on when using the advanced PI controller structure. The feed-forward value is calculated with a DT1 (29) element. Each DT1 element can be parametrized with two parameters.

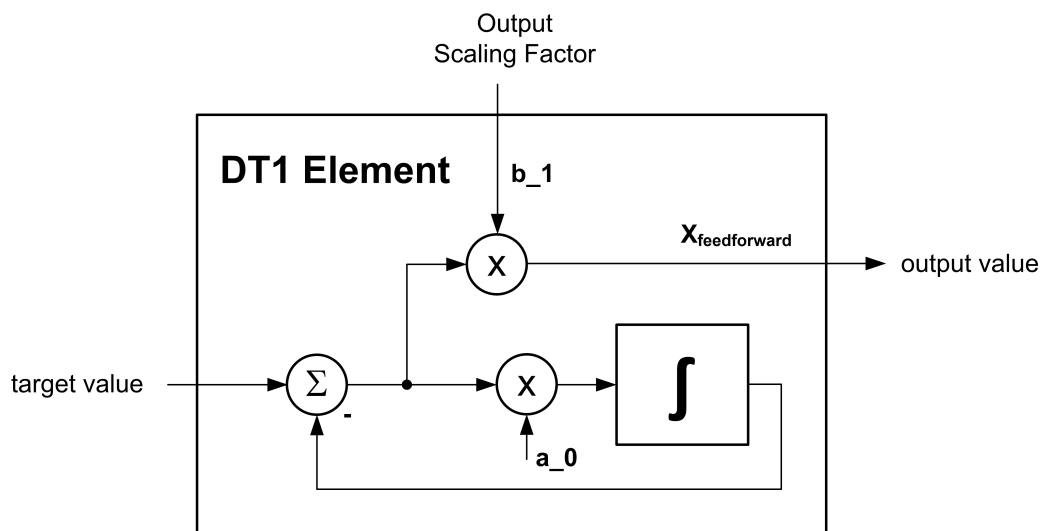


Figure 29: DT1 Element Structure

Equations:

$$e = X - \text{int_val} \quad (36)$$

$$\text{int_val} = \int e \, dt \quad (37)$$

$$Y = b_1 \cdot e \quad (38)$$

i Info

Tuning of feed-forward control structure is supported by the TRINAMIC TMCL-IDE wizard.

The coefficients a_0 and b_1 are represented in Q2.30 format.



The input target value to the velocity feed-forward entity is the filtered position target value. For the torque feed-forward entity the output of the velocity feed-forward entity is used. Sampling time for both entities' integrators is fixed to the PWM frequency.

4.10 PWM Engine

The PWM engine takes care of converting voltage vectors to pulse width modulated (PWM) control signals. These digital PWM signals control the gate drivers of the power stage. For a detailed description of the PWM control registers and PWM register control bits pls. refer section 6 page 53.

The ease-of-use PWM engine requires just a couple of parameter settings. Primarily, the polarities for the gate control signal of high-side and low-side must be set. The power on default PWM mode is 0, meaning PWM = OFF. For operation, the centered PWM mode must be switched on by setting the PWM mode to 7. A single bit switches the space vector PWM (SVPWM) on. For 3-phase PMSM, the SVPWM = ON gives more effective voltage. Nevertheless, for some applications it makes sense to switch the SVPWM = OFF to keep the star point voltage of a motor almost at rest.

4.10.1 PWM Polarities

The PWM polarities register (PWM_POLARITIES) controls the polarities of the control signals. Positive polarity for gate control means 1 represents ON and 0 represents OFF. The gate control signal polarities are individually programmable for low-side gate control and for high-side gate control. The PWM polarities register controls the polarity of other control signals as well.

4.10.2 PWM Frequency

The PWM counter maximum length register PWM_MAXCNT controls the PWM frequency. For a clock frequency $f_{CLK} = 25 \text{ MHz}$, the PWM frequency $f_{PWM}[\text{Hz}] = (4.0 \cdot f_{CLK}[\text{Hz}]) / (\text{PWM_MAXCNT} + 1)$. With $f_{CLK} = 25 \text{ MHz}$ and power-on reset (POR) default of PWM_MAXCNT=3999, the PWM frequency $f_{PWM} = 25 \text{ kHz}$. The PWM frequency f_{PWM} is recommended to be in the range of 25 kHz to 100 kHz by setting PWM_MAXCNT between 3999 to 999.

Note

The PWM frequency is the fundamental frequency of the control system. It can be changed at any time, also during motion for the classic PI controller structure. The advanced PI controller structure is tied to the PWM frequency and integrator gains have to be changed. Please make sure to set current measurement decimation rates to fit PWM period in high performance applications.

Info

Please be informed that later versions of the chip will support lower PWM frequencies. This might affect the user's software.

4.10.3 PWM Resolution

The base resolution of the PWM is 12 bit internally mapped to 16 bit range. The minimal PWM increment is 20ns due to the symmetrical PWM with 100 MHz counter frequency. MAX_PWMCNT = 4095 gives the full resolution of 12 bit with $\approx 25 \text{ kHz}$ w/ $f_{CLK}=25 \text{ MHz}$. MAX_PWMCNT=2047 results in 11 bit resolution, but with $\approx 50 \text{ kHz}$ w/ $f_{CLK}=25 \text{ MHz}$. So the PWM_MAXCNT defines the PWM frequency, but also affects the resolution of the PWM.

Info

The PWM resolution might be increased in a future version of the chip.



4.10.4 PWM Modes

The power-on reset (POR) default of the PWM is OFF. The standard PWM scheme is the centered PWM. Passive braking and freewheeling modes are available on demand. Please refer to section 6 concerning the settings.

Info

The PWM modes might be changed in a future version of the chip to support so-called two-switch modulation or flat-bottom modulation.

4.10.5 Break-Before-Make (BBM)

One register controls BBM time for the high side. One register controls BBM time for the low side. The BBM times are programmable in 10 ns steps. The BBM time can be set to zero for gate drivers that have their own integrated BBM timers.

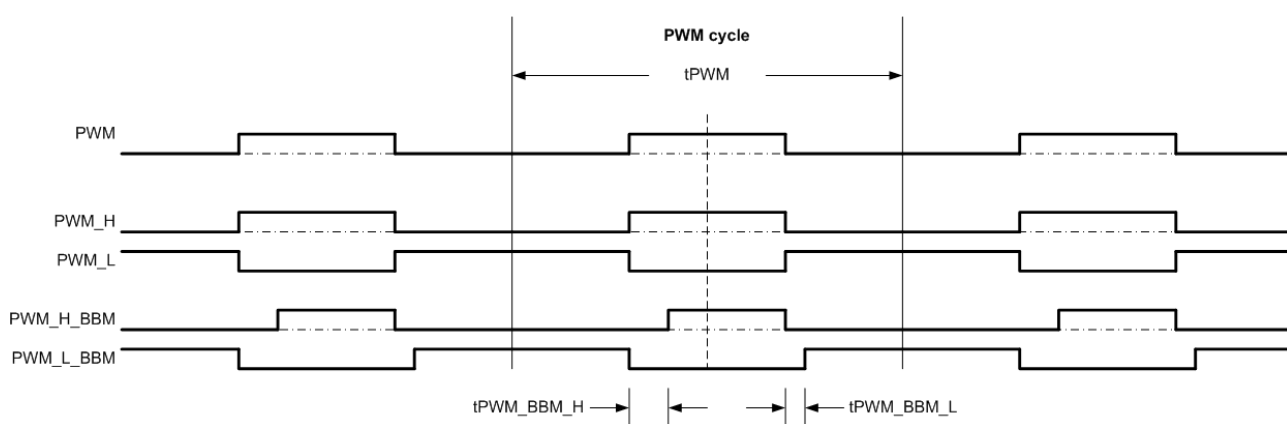


Figure 30: BBM Timing

Info

Measured BBM times at MOS-FET gates differ from programmed BBM times due to driver delays and possible additional gate driver BBM times. The programmed BBM times are for the digital control signals.

Note

Too short BBM times cause electrical shortcuts of the MOS-FET bridges - so called shoot through - that shorts the power supply and might damage the power stage and the power supply.

Info

BBM time registers might be changed in a future version of this chip to support longer BBM times than 2.55 μ s.

4.10.6 Space Vector PWM (SVPWM)

Note

The Space Vector PWM does not allow higher voltage utilization. This will be fixed in next version of the chip.



A single bit enables the Space Vector PWM (SVPWM). No further settings are required for the space vector PWM - just ON or OFF. The power on default for the SVPWM is OFF. Space Vector PWM can be enabled to maximize voltage utilization in the case of an isolated star point of the motor. If the star point is not isolated, unintended current flows through the star point. Space Vector PWM is only used for three-phase motors. For other motors the SVPWM must be switched off.

5 Safety Functions

Different safety functions are integrated and mapped to status bits. A programmable mask registers selects bits for activation of the STATUS output.

Internal hardware limiters for real time clipping and monitoring of interim values are available. LIMIT or LIMITS is part of register names of registers associated to internal limiters. Please refer [6](#).

5.1 Watchdog

The TMC4671 uses an internal RC oscillator to monitor the clock input signal CLK. If during operation the CLK signal is lost, the user can program the TMC4671 for different responses via register WATCHDOG_CFG. Power on default action is: no action, otherwise the ENABLE_OUT signal can be removed to disable the power stage or the TMC4671 can be reset.



6 Register Map

The TMC4671 has an register address range of 128 addresses with registers up to 32 bit data width. Some registers hold 32 bit data, some hold 2 x 16 bit data and other hold combinations of data defined by data masks. This section describes the register bank of the TMC4671.

Section 6.1 gives an overview over all registers and section 6.2 gives the detailed description of all registers.

6.1 Register Map Overview

Address	Registername	Access
0x00 _h	CHIPINFO_DATA	R
0x01 _h	CHIPINFO_ADDR	RW
0x02 _h	ADC_RAW_DATA	R
0x03 _h	ADC_RAW_ADDR	RW
0x04 _h	dsADC_MCFG_B_MCFG_A	RW
0x05 _h	dsADC_MCLK_A	RW
0x06 _h	dsADC_MCLK_B	RW
0x07 _h	dsADC_MDEC_B_MDEC_A	RW
0x08 _h	ADC_I1_SCALE_OFFSET	RW
0x09 _h	ADC_I0_SCALE_OFFSET	RW
0x0A _h	ADC_I_SELECT	RW
0x0B _h	ADC_I1_I0_EXT	RW
0x0C _h	DS_ANALOG_INPUT_STAGE_CFG	RW
0x0D _h	AENC_0_SCALE_OFFSET	RW
0x0E _h	AENC_1_SCALE_OFFSET	RW
0x0F _h	AENC_2_SCALE_OFFSET	RW
0x11 _h	AENC_SELECT	RW
0x12 _h	ADC_IWY_IUX	R
0x13 _h	ADC_IV	R
0x15 _h	AENC_WY_UX	R
0x16 _h	AENC_VN	R
0x17 _h	PWM_POLARITIES	RW
0x18 _h	PWM_MAXCNT	RW
0x19 _h	PWM_BBM_H_BBM_L	RW
0x1A _h	PWM_SV_CHOP	RW
0x1B _h	MOTOR_TYPE_N_POLE_PAIRS	RW
0x1C _h	PHI_E_EXT	RW



Address	Registername	Access
0x1D _h	PHI_M_EXT	RW
0x1E _h	POSITION_EXT	RW
0x1F _h	OPENLOOP_MODE	RW
0x20 _h	OPENLOOP_ACCELERATION	RW
0x21 _h	OPENLOOP_VELOCITY_TARGET	RW
0x22 _h	OPENLOOP_VELOCITY_ACTUAL	RW
0x23 _h	OPENLOOP_PHI	RWI
0x24 _h	UQ_UD_EXT	RW
0x25 _h	ABN_DECODER_MODE	RW
0x26 _h	ABN_DECODER_PPR	RW
0x27 _h	ABN_DECODER_COUNT	RW
0x28 _h	ABN_DECODER_COUNT_N	RW
0x29 _h	ABN_DECODER_PHI_E_PHI_M_OFFSET	RW
0x2A _h	ABN_DECODER_PHI_E_PHI_M	R
0x2C _h	ABN_2_DECODER_MODE	RW
0x2D _h	ABN_2_DECODER_PPR	RW
0x2E _h	ABN_2_DECODER_COUNT	RW
0x2F _h	ABN_2_DECODER_COUNT_N	RW
0x30 _h	ABN_2_DECODER_PHI_M_OFFSET	RW
0x31 _h	ABN_2_DECODER_PHI_M	R
0x33 _h	HALL_MODE	RW
0x34 _h	HALL_POSITION_060_000	RW
0x35 _h	HALL_POSITION_180_120	RW
0x36 _h	HALL_POSITION_300_240	RW
0x37 _h	HALL_PHI_E_PHI_M_OFFSET	RW
0x38 _h	HALL_DPHI_MAX	RW
0x39 _h	HALL_PHI_E_INTERPOLATED_PHI_E	R
0x3A _h	HALL_PHI_M	R
0x3B _h	AENC_DECODER_MODE	RW
0x3C _h	AENC_DECODER_N_THRESHOLD	RW
0x3D _h	AENC_DECODER_PHI_A_RAW	R
0x3E _h	AENC_DECODER_PHI_A_OFFSET	RW
0x3F _h	AENC_DECODER_PHI_A	R
0x40 _h	AENC_DECODER_PPR	RW



Address	Registername	Access
0x41 _h	AENC_DECODER_COUNT	R
0x42 _h	AENC_DECODER_COUNT_N	RW
0x45 _h	AENC_DECODER_PHI_E_PHI_M_OFFSET	RW
0x46 _h	AENC_DECODER_PHI_E_PHI_M	R
0x47 _h	AENC_DECODER_POSITION	R
0x4B _h	PIDIN_VELOCITY_TARGET	R
0x4C _h	PIDIN_POSITION_TARGET	R
0x4D _h	CONFIG_DATA	RW
0x4E _h	CONFIG_ADDR	RW
0x50 _h	VELOCITY_SELECTION	RW
0x51 _h	POSITION_SELECTION	RW
0x52 _h	PHI_E_SELECTION	RW
0x53 _h	PHI_E	R
0x54 _h	PID_FLUX_P_FLUX_I	RW
0x56 _h	PID_TORQUE_P_TORQUE_I	RW
0x58 _h	PID_VELOCITY_P_VELOCITY_I	RW
0x5A _h	PID_POSITION_P_POSITION_I	RW
0x5C _h	PID_TORQUE_FLUX_TARGET_DDT_LIMITS	RW
0x5D _h	PIDOUT_UQ_UD_LIMITS	RW
0x5E _h	PID_TORQUE_FLUX_LIMITS	RW
0x5F _h	PID_ACCELERATION_LIMIT	RW
0x60 _h	PID_VELOCITY_LIMIT	RW
0x61 _h	PID_POSITION_LIMIT_LOW	RW
0x62 _h	PID_POSITION_LIMIT_HIGH	RW
0x63 _h	MODE_RAMP_MODE_MOTION	RW
0x64 _h	PID_TORQUE_FLUX_TARGET	RW
0x65 _h	PID_TORQUE_FLUX_OFFSET	RW
0x66 _h	PID_VELOCITY_TARGET	RW
0x67 _h	PID_VELOCITY_OFFSET	RW
0x68 _h	PID_POSITION_TARGET	RW
0x69 _h	PID_TORQUE_FLUX_ACTUAL	R
0x6A _h	PID_VELOCITY_ACTUAL	R
0x6B _h	PID_POSITION_ACTUAL	RW
0x6C _h	PID_ERROR_DATA	R



Address	Registername	Access
0x6D _h	PID_ERROR_ADDR	RW
0x6E _h	INTERIM_DATA	RW
0x6F _h	INTERIM_ADDR	RW
0x74 _h	WATCHDOG_CFG	RW
0x75 _h	ADC_VM_LIMITS	RW
0x76 _h	TMC4671_INPUTS_RAW	R
0x77 _h	TMC4671_OUTPUTS_RAW	R
0x78 _h	STEP_WIDTH	RW
0x79 _h	UART_BPS	RW
0x7A _h	UART_ADDRS	RW
0x7B _h	GPIO_dsADCI_CONFIG	RW
0x7C _h	STATUS_FLAGS	RW
0x7D _h	STATUS_MASK	RW

Table 15: TMC4671 Registers



6.2 Register Map Full

Register Map for TMC4671						
Address	Registername				Access	
0x00 _h	CHIPINFO_DATA				R	
	Variant 0					
	Mask	Name		Type		
	0xFFFFFFFF _h	SI_TYPE		ASCII		
		Min	Max	Default		Unit
		0	4294967295	0		
	Hardware type (ASCII).					
	Variant 1					
	Mask	Name		Type		
	0xFFFFFFFF _h	SI_VERSION		Version		
		Min	Max	Default		Unit
		0	4294967295	0		
	Hardware version (u16.u16).					
	Variant 2					
	Mask	Name		Type		
	0xFFFFFFFF _h	SI_DATE		Date		
		Min	Max	Default		Unit
		0	4294967295	0		
	Hardware date (nibble wise date stamp yyyyymmdd).					
	Variant 3					
	Mask	Name		Type		
	0xFFFFFFFF _h	SI_TIME		Time		
		Min	Max	Default		Unit
		0	16777215	0		
	Hardware time (nibble wise time stamp -hhmmss)					
	Variant 4					
	Mask	Name		Type		
	0xFFFFFFFF _h	SI_VARIANT		Unsigned		
		Min	Max	Default		Unit
		0	4294967295	0		
	Variant 5					
	Mask	Name		Type		



Address	Registername					Access
	0xFFFFFFFF _h	SI_BUILD			Unsigned	
		Min	Max	Default	Unit	
		0	4294967295	0		
0x01 _h	CHIPINFO_ADDR					RW
	Mask	Name			Type	
	0x000000FF _h	CHIP_INFO_ADDRESS			Choice	
		Min	Max	Default	Unit	
		0	5	0		
		0: SI_TYPE				
1: SI_VERSION						
2: SI_DATE						
3: SI_TIME						
4: SI_VARIANT						
5: SI_BUILD						
0x02 _h	ADC_RAW_DATA					R
	Variant 0					
	Mask	Name			Type	
	0x0000FFFF _h	ADC_I0_RAW			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Raw phase current I0					
	Mask	Name			Type	
	0xFFFF0000 _h	ADC_I1_RAW			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Raw phase current I1					
	Variant 1					
	Mask	Name			Type	
	0x0000FFFF _h	ADC_VM_RAW			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
aw supply voltage value.						
Mask	Name			Type		
0xFFFF0000 _h	ADC_AGPI_A_RAW			Unsigned		
	Min	Max	Default	Unit		



Address	Registername					Access
		0	65535	0		
	Raw analog gpi A value.					
	Variant 2					
	Mask	Name			Type	
	0x0000FFFF _h	ADC_AGPI_B_RAW			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Raw analog gpi B value.					
	Mask	Name			Type	
	0xFFFF0000 _h	ADC_AENC_UX_RAW			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Raw analog encoder signal.					
	Variant 3					
	Mask	Name			Type	
	0x0000FFFF _h	ADC_AENC_VN_RAW			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Raw analog encoder signal.					
	Mask	Name			Type	
	0xFFFF0000 _h	ADC_AENC_WY_RAW			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Raw analog encoder signal.					
0x03 _h	ADC_RAW_ADDR					RW
	Mask	Name			Type	
	0x000000FF _h	ADC_RAW_ADDR			Choice	
		Min	Max	Default	Unit	
		0	3	0		
		0: ADC_I1_RAW & ADC_I0_RAW 1: ADC_AGPI_A_RAW & ADC_VM_RAW 2: ADC_AENC_UX_RAW & ADC_AGPI_B_RAW 3: ADC_AENC_WY_RAW & ADC_AENC_VN_RAW				
0x04 _h	dsADC_MCFG_B_MCFG_A					RW
	Mask	Name			Type	



Address	Registername				Access
	0x00000003 _h	cfg_dsmodulator_a			Choice
		Min	Max	Default	Unit
		0	3	0	
		0: int. dsMOD 1: ext. dsMOD with MCLK input 2: ext. dsMOD with MCLK output 3: ext. dsMOD with ext. CMP			
	Mask	Name			Type
	0x00000004 _h	mclk_polarity_a			Bool
		Min	Max	Default	Unit
		0	1	0	
		0: off 1: on			
	Mask	Name			Type
	0x00000008 _h	mdat_polarity_a			Bool
		Min	Max	Default	Unit
		0	1	0	
		0: off 1: on			
	Mask	Name			Type
	0x00000010 _h	sel_nclk_mclk_i_a			Bool
		Min	Max	Default	Unit
		0	1	0	
		0: off 1: on			
	Mask	Name			Type
	0x000000FF00 _h	blanking_a			Unsigned
		Min	Max	Default	Unit
		0	255	0	
		Name			Type
	0x00030000 _h	cfg_dsmodulator_b			Choice
		Min	Max	Default	Unit
		0	3	0	
		0: int. dsMOD 1: ext. dsMOD with MCLK input			



Address	Registername					Access
		2: ext. dsMOD with MCLK output 3: ext. dsMOD with ext. CMP				
	Mask	Name			Type	
	0x00040000 _h	mclk_polarity_b			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		0: off 1: on				
	Mask	Name			Type	
	0x00080000 _h	mdat_polarity_b			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		0: off 1: on				
	Mask	Name			Type	
	0x00100000 _h	sel_nclk_mclk_i_b			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		0: off 1: on				
	Mask	Name			Type	
	0xFF000000 _h	blanking_b			Unsigned	
		Min	Max	Default	Unit	
		0	255	0		
0x05 _h	dsADC_MCLK_A					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	dsADC_MCLK_A			Unsigned	
		Min	Max	Default	Unit	
		0	4294967295	214748365		
fMCLK_A = 2 ³¹ / (fCLK * (dsADC_MCLK_A+1)), dsADC_MCLK_A = (2 ³¹ / (fMCLK * fCLK)) - 1						
0x06 _h	dsADC_MCLK_B					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	dsADC_MCLK_B			Unsigned	
		Min	Max	Default	Unit	



Address	Registername					Access
		0	4294967295	214748365		
	fMCLK_B = 2 ³¹ / (fCLK * (dsADC_MCLK_B+1)), dsADC_MCLK_B = (2 ³¹ / (fMCLK * fCLK)) - 1					
0x07 _h	dsADC_MDEC_B_MDEC_A					RW
	Mask	Name			Type	
	0x0000FFFF _h	dsADC_MDEC_A			Unsigned	
		Min	Max	Default	Unit	
		0	65535	256		
	Mask	Name			Type	
	0xFFFF0000 _h	dsADC_MDEC_B			Unsigned	
		Min	Max	Default	Unit	
		0	65535	256		
0x08 _h	ADC_I1_SCALE_OFFSET					RW
	Mask	Name			Type	
	0x0000FFFF _h	ADC_I1_OFFSET			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Offset for current ADC channel 1.					
	Mask	Name			Type	
	0xFFFF0000 _h	ADC_I1_SCALE			Signed	
		Min	Max	Default	Unit	
-32768		32767	256			
Scaling factor for current ADC channel 1.						
0x09 _h	ADC_I0_SCALE_OFFSET					RW
	Mask	Name			Type	
	0x0000FFFF _h	ADC_I0_OFFSET			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Offset for current ADC channel 0.					
	Mask	Name			Type	
	0xFFFF0000 _h	ADC_I0_SCALE			Signed	
		Min	Max	Default	Unit	
-32768		32767	256			
Scaling factor for current ADC channel 0.						
0x0A _h	ADC_I_SELECT					RW



Address	Registername				Access
	Mask	Name			Type
	0x000000FF _h	ADC_I0_SELECT			Choice
		Min	Max	Default	Unit
		0	3	0	
	Select input for raw current ADC_I0_RAW. 0: ADCSD_I0_RAW (sigma delta ADC) 1: ADCSD_I1_RAW (sigma delta ADC) 2: ADC_I0_EXT (from register) 3: ADC_I1_EXT (from register)				
	Mask	Name			Type
	0x0000FF00 _h	ADC_I1_SELECT			Choice
		Min	Max	Default	Unit
		0	3	1	
	Select input for raw current ADC_I1_RAW. 0: ADCSD_I0_RAW (sigma delta ADC) 1: ADCSD_I1_RAW (sigma delta ADC) 2: ADC_I0_EXT (from register) 3: ADC_I1_EXT (from register)				
	Mask	Name			Type
	0x03000000 _h	ADC_I_UX_SELECT			Choice
		Min	Max	Default	Unit
		0	2	0	
	0: UX = ADC_I0 (default) 1: UX = ADC_I1 2: UX = ADC_I2				
	Mask	Name			Type
	0x0C000000 _h	ADC_I_V_SELECT			Choice
		Min	Max	Default	Unit
		0	2	1	
	0: V = ADC_I0 1: V = ADC_I1 (default) 2: V = ADC_I2				
	Mask	Name			Type
	0x30000000 _h	ADC_I_WY_SELECT			Choice
		Min	Max	Default	Unit



Address	Registername					Access
		0	2	2		
		0: WY = ADC_I0				
		1: WY = ADC_I1				
		2: WY = ADC_I2 (default)				
0x0B _h	ADC_I1_I0_EXT					RW
	Mask	Name			Type	
	0x0000FFFF _h	ADC_I0_EXT			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
		Register for write of ADC_I0 value from external source (eg. CPU).				
	Mask	Name			Type	
	0xFFFF0000 _h	ADC_I1_EXT			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Register for write of ADC_I1 value from external source (eg. CPU).					
0x0C _h	DS_ANALOG_INPUT_STAGE_CFG					RW
	Mask	Name			Type	
	0x0000000F _h	ADC_I0			Choice	
		Min	Max	Default	Unit	
		0	7	0		
		0: INP vs. INN				
		1: GND vs. INN				
		2: VDD/4				
		3: 3*VDD/4				
		4: INP vs. GND				
	5: VDD/2					
	6: VDD/4					
	7: 3*VDD/4					
Mask	Name			Type		
0x000000F0 _h	ADC_I1			Choice		
	Min	Max	Default	Unit		
	0	7	0			
	0: INP vs. INN					
	1: GND vs. INN					



Address	Registername				Access
	2: VDD/4 3: 3*VDD/4 4: INP vs. GND 5: VDD/2 6: VDD/4 7: 3*VDD/4				
	Mask	Name		Type	
	0x00000F00 _h	ADC_VM		Choice	
		Min	Max	Default	Unit
		0	7	0	
	0: INP vs. INN 1: GND vs. INN 2: VDD/4 3: 3*VDD/4 4: INP vs. GND 5: VDD/2 6: VDD/4 7: 3*VDD/4				
	Mask	Name		Type	
	0x0000F000 _h	ADC_AGPI_A		Choice	
		Min	Max	Default	Unit
		0	7	0	
	0: INP vs. INN 1: GND vs. INN 2: VDD/4 3: 3*VDD/4 4: INP vs. GND 5: VDD/2 6: VDD/4 7: 3*VDD/4				
	Mask	Name		Type	
	0x000F0000 _h	ADC_AGPI_B		Choice	
		Min	Max	Default	Unit
		0	7	0	
	0: INP vs. INN				



Address	Registername				Access
		1: GND vs. INN 2: VDD/4 3: 3*VDD/4 4: INP vs. GND 5: VDD/2 6: VDD/4 7: 3*VDD/4			
	Mask	Name		Type	
	0x00F00000 _h	ADC_AENC_UX		Choice	
		Min	Max	Default	Unit
		0	7	0	
		0: INP vs. INN 1: GND vs. INN 2: VDD/4 3: 3*VDD/4 4: INP vs. GND 5: VDD/2 6: VDD/4 7: 3*VDD/4			
	Mask	Name		Type	
	0x0F000000 _h	ADC_AENC_VN		Choice	
		Min	Max	Default	Unit
		0	7	0	
		0: INP vs. INN 1: GND vs. INN 2: VDD/4 3: 3*VDD/4 4: INP vs. GND 5: VDD/2 6: VDD/4 7: 3*VDD/4			
	Mask	Name		Type	
	0xF0000000 _h	ADC_AENC_WY		Choice	
		Min	Max	Default	Unit
		0	7	0	



Address	Registername					Access
		0: INP vs. INN 1: GND vs. INN 2: VDD/4 3: 3*VDD/4 4: INP vs. GND 5: VDD/2 6: VDD/4 7: 3*VDD/4				
0x0D _h	AENC_0_SCALE_OFFSET					RW
	Mask	Name			Type	
	0x0000FFFF _h	AENC_0_OFFSET			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Offset for Analog Encoder ADC channel 0.					
	Mask	Name			Type	
	0xFFFF0000 _h	AENC_0_SCALE			Signed	
		Min	Max	Default	Unit	
		-32768	32767	256		
	Scaling factor for Analog Encoder ADC channel 0.					
0x0E _h	AENC_1_SCALE_OFFSET					RW
	Mask	Name			Type	
	0x0000FFFF _h	AENC_1_OFFSET			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Offset for Analog Encoder ADC channel 1.					
	Mask	Name			Type	
	0xFFFF0000 _h	AENC_1_SCALE			Signed	
		Min	Max	Default	Unit	
		-32768	32767	256		
	Scaling factor for Analog Encoder ADC channel 1.					
0x0F _h	AENC_2_SCALE_OFFSET					RW
	Mask	Name			Type	
	0x0000FFFF _h	AENC_2_OFFSET			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		



Address	Registername					Access
		Offset for Analog Encoder ADC channel 2.				
	Mask	Name			Type	
	0xFFFF0000 _h	AENC_2_SCALE			Signed	
		Min	Max	Default	Unit	
		-32768	32767	256		
	Scaling factor for Analog Encoder ADC channel 2.					
0x11 _h	AENC_SELECT					RW
	Mask	Name			Type	
	0x000000FF _h	AENC_0_SELECT			Choice	
		Min	Max	Default	Unit	
		0	2	0		
	Select analog encoder ADC channel for raw analog encoder signal AENC_0_RAW. 0: AENC_UX_RAW (default) 1: AENC_VN_RAW 2: AENC_WY_RAW					
	Mask	Name			Type	
	0x0000FF00 _h	AENC_1_SELECT			Choice	
		Min	Max	Default	Unit	
		0	2	1		
	Select analog encoder ADC channel for raw analog encoder signal AENC_1_RAW. 0: AENC_UX_RAW 1: AENC_VN_RAW (default) 2: AENC_WY_RAW					
	Mask	Name			Type	
	0x00FF0000 _h	AENC_2_SELECT			Choice	
		Min	Max	Default	Unit	
		0	2	2		
Select analog encoder ADC channel for raw analog encoder signal AENC_2_RAW. 0: AENC_UX_RAW 1: AENC_VN_RAW 2: AENC_WY_RAW (default)						
0x12 _h	ADC_IWY_IUX					R
	Mask	Name			Type	



Address	Registername					Access
	0x0000FFFF _h	ADC_IUX			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
		Register of scaled current ADC value including signed added offset as input for the FOC.				
	Mask	Name			Type	
	0xFFFF0000 _h	ADC_IWY			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
		Register of scaled current ADC value including signed added offset as input for the FOC.				
0x13 _h	ADC_IV					R
	Mask	Name			Type	
	0x0000FFFF _h	ADC_IV			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
		Register of scaled current ADC value including signed added offset as input for the FOC.				
0x15 _h	AENC_WY_UX					R
	Mask	Name			Type	
	0x0000FFFF _h	AENC_UX			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
		Register of scaled analog encoder value including signed added offset as input for the interpolator.				
	Mask	Name			Type	
	0xFFFF0000 _h	AENC_WY			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
		Register of scaled analog encoder value including signed added offset as input for the interpolator.				
0x16 _h	AENC_VN					R
	Mask	Name			Type	
	0x0000FFFF _h	AENC_VN			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		



Address	Registername					Access
		Register of scaled analog encoder value including signed added offset as input for the interpolator.				
0x17 _h	PWM_POLARITIES					RW
	Mask	Name			Type	
	0x00000001 _h	PWM_POLARITIES[0]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
	polarity of Low Side (LS) gate control signal 0: off 1: on					
	Mask	Name			Type	
	0x00000002 _h	PWM_POLARITIES[1]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
polarity of High Side (HS) gate control signal 0: off 1: on						
0x18 _h	PWM_MAXCNT					RW
	Mask	Name			Type	
	0x0000FFFF _h	PWM_MAXCNT			Unsigned	
		Min	Max	Default	Unit	
		0	65535	3999		
	PWM maximum (count-1), PWM frequency is fPWM[Hz] = 100MHz/(PWM_MAXCNT+1)					
0x19 _h	PWM_BBM_H_BBM_L					RW
	Mask	Name			Type	
	0x000000FF _h	PWM_BBM_L			Unsigned	
		Min	Max	Default	Unit	
		0	255	20		
	Break Before Make time tBBM_L[10ns] for low side MOS-FET gate control					
	Mask	Name			Type	
	0x0000FF00 _h	PWM_BBM_H			Unsigned	
		Min	Max	Default	Unit	
		0	255	20		



Address	Registername					Access
		Break Before Make time tBBM_H[10ns] for high side MOS-FET gate control				
0x1A _h	PWM_SV_CHOP					RW
	Mask	Name			Type	
	0x000000FF _h	PWM_CHOP			Choice	
		Min	Max	Default	Unit	
		0	7	0		
		PWM chopper mode, defining how to chopper 0: PWM = OFF, free running 1: PWM = OFF, Low Side (LS) permanent = ON 2: PWM = OFF, High Side (HS) permanent = ON 3: PWM off, free running 4: PWM off, free running 5: PWM low side (LS) chopper only, high side (HS) off; not suitable for FOC 6: PWM high side (HS) chopper only, low side (LS) off; not suitable for FOC 7: centered PWM for FOC				
	Mask	Name			Type	
	0x00000100 _h	PWM_SV			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		use Space Vector PWM 0: Space Vector PWM disabled 1: Space Vector PWM enabled				
0x1B _h	MOTOR_TYPE_N_POLE_PAIRS					RW
	Mask	Name			Type	
	0x0000FFFF _h	N_POLE_PAIRS			Unsigned	
		Min	Max	Default	Unit	
		1	65535	1		
		Number n of pole pairs of the motor for calcualtion phi_e = phi_m / N_POLE_PAIRS.				
	Mask	Name			Type	
	0x00FF0000 _h	MOTOR_TYPE			Choice	
		Min	Max	Default	Unit	
		0	3	0		



Address	Registername						Access	
		0: No motor 1: Single phase DC motor 2: Two phase Stepper motor 3: Three phase BLDC motor						
0x1C _h	PHI_E_EXT							RW
	Mask	Name				Type		
	0x0000FFFF _h	PHI_E_EXT				Signed		
		Min	Max	Default	Unit			
		-32768	32767	0				
		Electrical angle phi_e_ext for external writing into this register.						
0x1D _h	PHI_M_EXT							RW
	Mask	Name				Type		
	0x0000FFFF _h	PHI_M_EXT				Signed		
		Min	Max	Default	Unit			
		-32768	32767	0				
		Mechanical angle phi_m_ext for external writing into this register.						
0x1E _h	POSITION_EXT							RW
	Mask	Name				Type		
	0xFFFFFFFF _h	POSITION_EXT				Signed		
		Min	Max	Default	Unit			
		-2147483648	2147483647	0				
		Mechanical (multi turn) position for external writing into this register.						
0x1F _h	OPENLOOP_MODE							RW
	Mask	Name				Type		
	0x00001000 _h	OPENLOOP_PHI_DIRECTION				Bool		
		Min	Max	Default	Unit			
		0	1	0				
		Open loop phi direction. 0: positive 1: negative						
0x20 _h	OPENLOOP_ACCELERATION							RW
	Mask	Name				Type		
	0xFFFFFFFF _h	OPENLOOP_ACCELERATION				Unsigned		



Address	Registername					Access
		Min	Max	Default	Unit	
		0	4294967295	0		
		Acceleration of open loop phi.				
0x21 _h	OPENLOOP_VELOCITY_TARGET					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	OPENLOOP_VELOCITY_TARGET			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
Target velocity of open loop phi.						
0x22 _h	OPENLOOP_VELOCITY_ACTUAL					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	OPENLOOP_VELOCITY_ACTUAL			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
Actual velocity of open loop generator.						
0x23 _h	OPENLOOP_PHI					RWI
	Mask	Name			Type	
	0x0000FFFF _h	OPENLOOP_PHI			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
Angle phi open loop (either mapped to electrical angel phi_e or mechanical angle phi_m).						
0x24 _h	UQ_UD_EXT					RW
	Mask	Name			Type	
	0x0000FFFF _h	UD_EXT			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	External writable parameter for open loop voltage control mode, usefull during system setup, U_D component.					
	Mask	Name			Type	
	0xFFFF0000 _h	UQ_EXT			Signed	
		Min	Max	Default	Unit	
-32768		32767	0			
External writable parameter for open loop voltage control mode, usefull during system setup, U_Q component.						
0x25 _h	ABN_DECODER_MODE					RW



Address	Registername				Access
	Mask	Name			Type
	0x00000001 _h	apol			Bool
		Min	Max	Default	Unit
		0	1	0	
		Polarity of A pulse. 0: off 1: on			
	Mask	Name			Type
	0x00000002 _h	bpol			Bool
		Min	Max	Default	Unit
		0	1	0	
		Polarity of B pulse. 0: off 1: on			
	Mask	Name			Type
	0x00000004 _h	npol			Bool
		Min	Max	Default	Unit
		0	1	0	
		Polarity of N pulse. 0: off 1: on			
	Mask	Name			Type
	0x00000008 _h	use_abn_as_n			Bool
		Min	Max	Default	Unit
		0	1	0	
		0: Ignore A and B polarity with Npulse = N, 1 : Npulse = N and A and B 0: Ignore A and B polarity with Npulse = N 1: Npulse = N and A and B			
	Mask	Name			Type
	0x00000100 _h	cln			Bool
		Min	Max	Default	Unit
		0	1	0	
		Clear writes ABN_DECODER_COUNT_N into decoder count at Npulse. 0: off			



Address	Registername				Access
		1: on			
	Mask	Name		Type	
	0x00001000 _h	direction		Bool	
		Min	Max	Default	Unit
		0	1	0	
		Decoder count direction. 0: positive 1: negative			
0x26 _h	ABN_DECODER_PPR				RW
	Mask	Name		Type	
	0x00FFFFFF _h	ABN_DECODER_PPR		Unsigned	
		Min	Max	Default	Unit
		0	16777215	65536	
		Decoder pules per mechanical revolution.			
0x27 _h	ABN_DECODER_COUNT				RW
	Mask	Name		Type	
	0x00FFFFFF _h	ABN_DECODER_COUNT		Unsigned	
		Min	Max	Default	Unit
		0	16777215	0	
		Raw decoder count; the digital decoder engine counts modulo (decoder_ppr).			
0x28 _h	ABN_DECODER_COUNT_N				RW
	Mask	Name		Type	
	0x00FFFFFF _h	ABN_DECODER_COUNT_N		Unsigned	
		Min	Max	Default	Unit
		0	16777215	0	
		Decoder count latched on N pulse, when N pulse clears decoder_count also decoder_count_n is 0.			
0x29 _h	ABN_DECODER_PHI_E_PHI_M_OFFSET				RW
	Mask	Name		Type	
	0x0000FFFF _h	ABN_DECODER_PHI_M_OFFSET		Signed	
		Min	Max	Default	Unit
		-32768	32767	0	
		ABN_DECODER_PHI_M_OFFSET to shift (rotate) angle DECODER_PHI_M.			
	Mask	Name		Type	



Address	Registername					Access
	0xFFFF0000 _h	ABN_DECODER_PHI_E_OFFSET			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
		ABN_DECODER_PHI_E_OFFSET to shift (rotate) angle DECODER_PHI_E.				
0x2A _h	ABN_DECODER_PHI_E_PHI_M					R
	Mask	Name			Type	
	0x0000FFFF _h	ABN_DECODER_PHI_M			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	ABN_DECODER_PHI_M = ABN_DECODER_COUNT * 2 ¹⁶ / ABN_DECODER_PPR + ABN_DECODER_PHI_M_OFFSET;					
	Mask	Name			Type	
	0xFFFF0000 _h	ABN_DECODER_PHI_E			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	ABN_DECODER_PHI_E = (ABN_DECODER_PHI_M * N_POLE_PAIRS_) + ABN_DECODER_PHI_E_OFFSET					
0x2C _h	ABN_2_DECODER_MODE					RW
	Mask	Name			Type	
	0x00000001 _h	apol			Bool	
		Min	Max	Default	Unit	
		0	1	0		
	Polarity of A pulse. 0: off 1: on					
	Mask	Name			Type	
	0x00000002 _h	bpol			Bool	
		Min	Max	Default	Unit	
		0	1	0		
	Polarity of B pulse. 0: off 1: on					
	Mask	Name			Type	
	0x00000004 _h	npol			Bool	
Min		Max	Default	Unit		



Address	Registername					Access
		0	1	0		
		Polarity of N pulse. 0: off 1: on				
	Mask	Name			Type	
	0x00000008 _h	use_abn_as_n			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		0: Ignore A and B polarity with Npulse = N, 1 : Npulse = N and A and B 0: Ignore A and B polarity with Npulse = N 1: Npulse = N and A and B				
	Mask	Name			Type	
	0x00000100 _h	cln			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		Clear writes ABN_2_DECODER_COUNT_N into decoder count at Npulse. 0: off 1: on				
	Mask	Name			Type	
	0x00001000 _h	direction			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		Decoder count direction. 0: positive 1: negative				
0x2D _h	ABN_2_DECODER_PPR					RW
	Mask	Name			Type	
	0x00FFFFFF _h	ABN_2_DECODER_PPR			Unsigned	
		Min	Max	Default	Unit	
		1	16777215	65536		
	Decoder_2 pules per mechanical revolution. This 2nd ABN encoder interface is for positioning or velocity control but NOT for motor commutation.					
0x2E _h	ABN_2_DECODER_COUNT					RW



Address	Registername					Access
	Mask	Name			Type	
	0x00FFFFFF _h	ABN_2_DECODER_COUNT			Unsigned	
		Min	Max	Default	Unit	
		0	16777215	0		
	Raw decoder_2 count; the digital decoder engine counts modulo (decoder_2_ppr).					
0x2F _h	ABN_2_DECODER_COUNT_N					RW
	Mask	Name			Type	
	0x00FFFFFF _h	ABN_2_DECODER_COUNT_N			Unsigned	
		Min	Max	Default	Unit	
		0	16777215	0		
Decoder_2 count latched on N pulse, when N pulse clears decoder_2_count also decoder_2_count_n is 0.						
0x30 _h	ABN_2_DECODER_PHI_M_OFFSET					RW
	Mask	Name			Type	
	0x0000FFFF _h	ABN_2_DECODER_PHI_M_OFFSET			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
ABN_2_DECODER_PHI_M_OFFSET to shift (rotate) angle DECODER_2_PHI_M.						
0x31 _h	ABN_2_DECODER_PHI_M					R
	Mask	Name			Type	
	0x0000FFFF _h	ABN_2_DECODER_PHI_M			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
ABN_2_DECODER_PHI_M = ABN_2_DECODER_COUNT * 2 ¹⁶ / ABN_2_DECODER_PPR + ABN_2_DECODER_PHI_M_OFFSET;						
0x33 _h	HALL_MODE					RW
	Mask	Name			Type	
	0x00000001 _h	polarity			Bool	
		Min	Max	Default	Unit	
		0	1	0		
	polarity 0: off 1: on					
Mask	Name			Type		



Address	Registername					Access
	0x00000100 _h	interpolation			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		interpolation 0: off 1: on				
	Mask	Name			Type	
	0x00001000 _h	direction			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		direction 0: off 1: on				
	Mask	Name			Type	
	0x0FFF0000 _h	HALL_BLANK			Unsigned	
		Min	Max	Default	Unit	
0		4095	0			
tBLANK = 10ns * HALL_BLANK						
0x34 _h	HALL_POSITION_060_000					RW
	Mask	Name			Type	
	0x0000FFFF _h	HALL_POSITION_000			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	s16 hall sensor position at 0°					
	Mask	Name			Type	
	0xFFFF0000 _h	HALL_POSITION_060			Signed	
		Min	Max	Default	Unit	
-32768		32767	10922			
s16 hall sensor position at 60°.						
0x35 _h	HALL_POSITION_180_120					RW
	Mask	Name			Type	
	0x0000FFFF _h	HALL_POSITION_120			Signed	
		Min	Max	Default	Unit	
		-32768	32767	21845		
s16 hall sensor position at 120°.						



Address	Registername					Access
	Mask	Name			Type	
	0xFFFF0000 _h	HALL_POSITION_180			Signed	
		Min	Max	Default	Unit	
		-32768	32767	-32768		
	s16 hall sensor position at 180°.					
0x36 _h	HALL_POSITION_300_240					RW
	Mask	Name			Type	
	0x0000FFFF _h	HALL_POSITION_240			Signed	
		Min	Max	Default	Unit	
		-32768	32767	-21846		
	s16 hall sensor position at 240°.					
	Mask	Name			Type	
	0xFFFF0000 _h	HALL_POSITION_300			Signed	
		Min	Max	Default	Unit	
		-32768	32767	-10923		
	s16 hall sensor position at 300°.					
0x37 _h	HALL_PHI_E_PHI_M_OFFSET					RW
	Mask	Name			Type	
	0x0000FFFF _h	HALL_PHI_M_OFFSET			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Offset of mechanical angle hall_phi_m of hall decoder.					
	Mask	Name			Type	
	0xFFFF0000 _h	HALL_PHI_E_OFFSET			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Offset for electrical angle hall_phi_e of hall decoder.					
0x38 _h	HALL_DPHI_MAX					RW
	Mask	Name			Type	
	0x0000FFFF _h	HALL_DPHI_MAX			Unsigned	
		Min	Max	Default	Unit	
		0	65535	10922		
	Maximum dx for interpolation (default for digital hall: u16/6).					
0x39 _h	HALL_PHI_E_INTERPOLATED_PHI_E					R
	Mask	Name			Type	



Address	Registername					Access
	0x0000FFFF _h	HALL_PHI_E			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
		Raw electrical angle hall_phi_e of hall decoder, selection programmed via HALL_MODE control bit.				
	Mask	Name			Type	
	0xFFFF0000 _h	HALL_PHI_E_INTERPOLATED			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
Interpolated electrical angle hall_phi_e_interpolated, selection programmed via HALL_MODE control bit.						
0x3A _h	HALL_PHI_M					R
	Mask	Name			Type	
	0x0000FFFF _h	HALL_PHI_M			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
		Mechanical angle hall_phi_m of hall decoder.				
0x3B _h	AENC_DECODER_MODE					RW
	Mask	Name			Type	
	0x00000001 _h	AENC_DECODER_MODE[0]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		nXY_UVW : 0: SinCos Mode // 1: 0° 120° 240° Mode 0: off 1: on				
	Mask	Name			Type	
	0x00001000 _h	AENC_DECODER_MODE[12]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
decoder count direction 0: positive 1: negative						
0x3C _h	AENC_DECODER_N_THRESHOLD					RW
	Mask	Name			Type	
	0x0000FFFF _h	AENC_DECODER_N_THRESHOLD			Unsigned	



Address	Registername					Access	
		Min	Max	Default	Unit		
		0	65535	0			
		Threshold for generating of N pulse from analog AENC_N signal (only needed for analog SinCos encoders with analog N signal).					
	Mask	Name			Type		
	0xFFFF0000 _h	AENC_DECODER_N_MASK			Signed		
		Min	Max	Default	Unit		
		-32768	32767	0			
Optional position mask (position) for the analog N pulse within phi_a period to be and-ed with the digital N pulse generated via aenc_decoder_n_threshold.							
0x3D _h	AENC_DECODER_PHI_A_RAW					R	
	Mask	Name			Type		
	0x0000FFFF _h	AENC_DECODER_PHI_A_RAW			Signed		
		Min	Max	Default	Unit		
		-32768	32767	0			
Raw analog angle phi calculated from analog AENC inputs (analog hall, analog SinCos, ...).							
0x3E _h	AENC_DECODER_PHI_A_OFFSET					RW	
	Mask	Name			Type		
	0x0000FFFF _h	AENC_DECODER_PHI_A_OFFSET			Signed		
		Min	Max	Default	Unit		
		-32768	32767	0			
Offset for angle phi from analog decoder (analog hall, analog SinCos, ...).							
0x3F _h	AENC_DECODER_PHI_A					R	
	Mask	Name			Type		
	0x0000FFFF _h	AENC_DECODER_PHI_A			Signed		
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
Resulting phi available for the FOC (phi_e might need to be calculated from this angle via aenc_decoder_ppr, for analog hall sensors phi_a might be used directly as phi_e depends on analog hall signal type).							
0x40 _h	AENC_DECODER_PPR					RW	
	Mask	Name			Type		
	0x0000FFFF _h	AENC_DECODER_PPR			Signed		



Address	Registername					Access
		Min	Max	Default	Unit	
		-32768	32767	1		
		Number of periods per revolution also called lines per revolution (different nomenclatur compared to digital ABN encoders).				
0x41 _h	AENC_DECODER_COUNT					R
	Mask	Name			Type	
	0xFFFFFFFF _h	AENC_DECODER_COUNT			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
Decoder position, raw unscaled.						
0x42 _h	AENC_DECODER_COUNT_N					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	AENC_DECODER_COUNT_N			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
Latched decoder position on analog N pulse event.						
0x45 _h	AENC_DECODER_PHI_E_PHI_M_OFFSET					RW
	Mask	Name			Type	
	0x0000FFFF _h	AENC_DECODER_PHI_M_OFFSET			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Offset for mechanical angle phi_m.					
	Mask	Name			Type	
	0xFFFF0000 _h	AENC_DECODER_PHI_E_OFFSET			Signed	
		Min	Max	Default	Unit	
-32768		32767	0			
Offset for electrical angle phi_e.						
0x46 _h	AENC_DECODER_PHI_E_PHI_M					R
	Mask	Name			Type	
	0x0000FFFF _h	AENC_DECODER_PHI_M			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Resulting angle phi_m.					
Mask	Name			Type		
0xFFFF0000 _h	AENC_DECODER_PHI_E			Signed		



Address	Registername					Access
		Min	Max	Default	Unit	
		-32768	32767	0		
		Resulting angle phi_e.				
0x47 _h	AENC_DECODER_POSITION					R
	Mask	Name			Type	
	0xFFFFFFFF _h	AENC_DECODER_POSITION			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
Multi-turn position.						
0x4B _h	PIDIN_VELOCITY_TARGET					R
	Mask	Name			Type	
	0xFFFFFFFF _h	PIDIN_VELOCITY_TARGET			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
Target velocity at PI controller input.						
0x4C _h	PIDIN_POSITION_TARGET					R
	Mask	Name			Type	
	0xFFFFFFFF _h	PIDIN_POSITION_TARGET			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
Target position at PI controller input.						
0x4D _h	CONFIG_DATA					RW
	Variant 1					
	Mask	Name			Type	
	0xFFFFFFFF _h	biquad_x_a_1			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 2					
	Mask	Name			Type	
	0xFFFFFFFF _h	biquad_x_a_2			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 4					
Mask	Name			Type		
0xFFFFFFFF _h	biquad_x_b_0			Signed		



Address	Registername					Access	
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
	Variant 5						
	Mask	Name			Type		
	0xFFFFFFFF _h	biquad_x_b_1			Signed		
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
	Variant 6						
	Mask	Name			Type		
	0xFFFFFFFF _h	biquad_x_b_2			Signed		
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
	Variant 7						
	Mask	Name			Type		
	0xFFFFFFFF _h	biquad_x_enable			Bool		
		Min	Max	Default	Unit		
		0	1	0			
		0: off					
		1: on					
	Variant 9						
	Mask	Name			Type		
	0xFFFFFFFF _h	biquad_v_a_1			Signed		
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
	Variant 10						
	Mask	Name			Type		
	0xFFFFFFFF _h	biquad_v_a_2			Signed		
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
	Variant 12						
	Mask	Name			Type		
	0xFFFFFFFF _h	biquad_v_b_0			Signed		
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
	Variant 13						



Address	Registername				Access
	Mask	Name			Type
	0xFFFFFFFF _h	biquad_v_b_1			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
	Variant 14				
	Mask	Name			Type
	0xFFFFFFFF _h	biquad_v_b_2			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
	Variant 15				
	Mask	Name			Type
	0xFFFFFFFF _h	biquad_v_enable			Bool
		Min	Max	Default	Unit
		0	1	0	
		0: off			
		1: on			
	Variant 17				
	Mask	Name			Type
	0xFFFFFFFF _h	biquad_t_a_1			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
	Variant 18				
	Mask	Name			Type
	0xFFFFFFFF _h	biquad_t_a_2			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
	Variant 20				
	Mask	Name			Type
	0xFFFFFFFF _h	biquad_t_b_0			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
	Variant 21				
	Mask	Name			Type
	0xFFFFFFFF _h	biquad_t_b_1			Signed
Min		Max	Default	Unit	



Address	Registername					Access
		-2147483648	2147483647	0		
	Variant 22					
	Mask	Name			Type	
	0xFFFFFFFF _h	biquad_t_b_2			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 23					
	Mask	Name			Type	
	0xFFFFFFFF _h	biquad_t_enable			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		0: off 1: on				
	Variant 25					
	Mask	Name			Type	
	0xFFFFFFFF _h	biquad_f_a_1			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 26					
	Mask	Name			Type	
	0xFFFFFFFF _h	biquad_f_a_2			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 28					
	Mask	Name			Type	
	0xFFFFFFFF _h	biquad_f_b_0			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 29					
	Mask	Name			Type	
	0xFFFFFFFF _h	biquad_f_b_1			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
Variant 30						
Mask	Name			Type		



Address	Registername					Access
	0xFFFFFFFF _h	biquad_f_b_2			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 31					
	Mask	Name			Type	
	0xFFFFFFFF _h	biquad_f_enable			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		0: off 1: on				
	Variant 32					
	Mask	Name			Type	
	0xFFFFFFFF _h	prbs_amplitude			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 33					
	Mask	Name			Type	
	0xFFFFFFFF _h	prbs_down_sampling_ratio			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 40					
	Mask	Name			Type	
	0xFFFFFFFF _h	feed_forward_velocity_gain			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 41					
	Mask	Name			Type	
	0xFFFFFFFF _h	feed_forward_velocity_filter_constant			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 42					
	Mask	Name			Type	
	0xFFFFFFFF _h	feed_forward_torque_gain			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		



Address	Registername					Access
	Variant 43					
	Mask	Name			Type	
	0xFFFFFFFF _h	feed_forward_torgue_filter_constant			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 50					
	Mask	Name			Type	
	0x0000FFFF _h	VELOCITY_METER_PPTM_MIN_POS_DEV			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 51					
	Mask	Name			Type	
	0x0000FFFF _h	ref_switch_config			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 52					
	Mask	Name			Type	
	0x00000001 _h	Encoder_Init_hall_Enable			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		0: off				
1: on						
0x4E _h	CONFIG_ADDR					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	CONFIG_ADDR			Choice	
		Min	Max	Default	Unit	
		1	52	0		
		1: biquad_x_a_1				
		2: biquad_x_a_2				
		4: biquad_x_b_0				
		5: biquad_x_b_1				
		6: biquad_x_b_2				
		7: biquad_x_enable				
		9: biquad_v_a_1				
10: biquad_v_a_2						



Address	Registername				Access	
		12: biquad_v_b_0 13: biquad_v_b_1 14: biquad_v_b_2 15: biquad_v_enable 17: biquad_t_a_1 18: biquad_t_a_2 20: biquad_t_b_0 21: biquad_t_b_1 22: biquad_t_b_2 23: biquad_t_enable 25: biquad_f_a_1 26: biquad_f_a_2 28: biquad_f_b_0 29: biquad_f_b_1 30: biquad_f_b_2 31: biquad_f_enable 32: prbs_amplitude 33: prbs_down_sampling_ratio 40: feed_forward_velocity_gain 41: feed_forward_velocity_filter_constant 42: feed_forward_torque_gain 43: feed_forward_torque_filter_constant 50: VELOCITY_METER_PPTM_MIN_POS_DEV 51: ref_switch_config 52: Encoder_Init_hall_Enable				
0x50 _h	VELOCITY_SELECTION				RW	
	Mask	Name		Type		
	0x000000FF _h	VELOCITY_SELECTION		Choice		
		Min	Max	Default		
		0	12	0		
	Selects the source of the velocity source for velocity measurement. 0: phi_e selected via PHI_E_SELECTION 1: phi_e_ext 2: phi_e_openloop					



Address	Registername				Access
	3: phi_e_abn 4: reserved 5: phi_e_hal 6: phi_e_aenc 7: phi_a_aenc 8: reserved 9: phi_m_abn 10: phi_m_abn_2 11: phi_m_aenc 12: phi_m_hal				
	Mask	Name		Type	
	0x0000FF00 _h	VELOCITY_METER_SELECTION			Choice
		Min	Max	Default	Unit
		0	1	0	
		0: default velocity meter (fixed frequency sampling) 1: advanced velocity meter (time difference measurement)			
0x51 _h	POSITION_SELECTION				RW
	Mask	Name		Type	
	0x000000FF _h	POSITION_SELECTION			Choice
		Min	Max	Default	Unit
		0	12	0	
		0: phi_e selected via PHI_E_SELECTION 1: phi_e_ext 2: phi_e_openloop 3: phi_e_abn 4: reserved 5: phi_e_hal 6: phi_e_aenc 7: phi_a_aenc 8: reserved 9: phi_m_abn 10: phi_m_abn_2 11: phi_m_aenc 12: phi_m_hal			
0x52 _h	PHI_E_SELECTION				RW



Address	Registername					Access
	Mask	Name			Type	
	0x000000FF _h	PHI_E_SELECTION			Choice	
		Min	Max	Default	Unit	
		0	7	0		
		0: reserved				
		1: phi_e_ext				
2: phi_e_openloop						
3: phi_e_abn						
4: reserved						
5: phi_e_hal						
6: phi_e_aenc						
7: phi_a_aenc						
0x53 _h	PHI_E					R
	Mask	Name			Type	
	0x0000FFFF _h	PHI_E			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
		Angle used for the inner FOC loop.				
0x54 _h	PID_FLUX_P_FLUX_I					RW
	Mask	Name			Type	
	0x0000FFFF _h	PID_FLUX_I			Signed	
		Min	Max	Default	Unit	
		0	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_FLUX_P			Signed	
		Min	Max	Default	Unit	
		0	32767	0		
0x56 _h	PID_TORQUE_P_TORQUE_I					RW
	Mask	Name			Type	
	0x0000FFFF _h	PID_TORQUE_I			Signed	
		Min	Max	Default	Unit	
		0	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_TORQUE_P			Signed	
Min		Max	Default	Unit		



Address	Registername					Access
		0	32767	0		
0x58 _h	PID_VELOCITY_P_VELOCITY_I					RW
	Mask	Name			Type	
	0x0000FFFF _h	PID_VELOCITY_I			Signed	
		Min	Max	Default	Unit	
		0	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_VELOCITY_P			Signed	
		Min	Max	Default	Unit	
		0	32767	0		
0x5A _h	PID_POSITION_P_POSITION_I					RW
	Mask	Name			Type	
	0x0000FFFF _h	PID_POSITION_I			Signed	
		Min	Max	Default	Unit	
		0	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_POSITION_P			Signed	
		Min	Max	Default	Unit	
		0	32767	0		
0x5C _h	PID_TORQUE_FLUX_TARGET_DDT_LIMITS					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	PID_TORQUE_FLUX_TARGET_DDT_LIMITS			Unsigned	
		Min	Max	Default	Unit	
		0	32767	32767	[1/us]	
		Limits of change in time [d/dt] of the target torque and target flux.				
0x5D _h	PIDOUT_UQ_UD_LIMITS					RW
	Mask	Name			Type	
	0x0000FFFF _h	PIDOUT_UQ_UD_LIMITS			Unsigned	
		Min	Max	Default	Unit	
		0	32767	23169		
		Two dimensional circular limiter for inputs of iPark.				
0x5E _h	PID_TORQUE_FLUX_LIMITS					RW
	Mask	Name			Type	
	0x0000FFFF _h	PID_TORQUE_FLUX_LIMITS			Unsigned	



Address	Registername					Access
		Min	Max	Default	Unit	
		0	32767	32767		
		PID torque limit and PID flux limit, limits the target values coming from the target registers.				
0x5F _h	PID_ACCELERATION_LIMIT					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	PID_ACCELERATION_LIMIT			Unsigned	
		Min	Max	Default	Unit	
		0	4294967295	2147483647		
Acceleration limit.						
0x60 _h	PID_VELOCITY_LIMIT					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	PID_VELOCITY_LIMIT			Unsigned	
		Min	Max	Default	Unit	
		0	4294967295	2147483647		
Velocity limit.						
0x61 _h	PID_POSITION_LIMIT_LOW					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	PID_POSITION_LIMIT_LOW			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	-2147483647		
Position limit low, programmable positon barrier.						
0x62 _h	PID_POSITION_LIMIT_HIGH					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	PID_POSITION_LIMIT_HIGH			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	2147483647		
Position limit high, programmable positon barrier.						
0x63 _h	MODE_RAMP_MODE_MOTION					RW
	Mask	Name			Type	
	0x000000FF _h	MODE_MOTION			Choice	
		Min	Max	Default	Unit	
		0	15	0		
0: stopped_mode 1: torque_mode						



Address	Registername				Access
	2: velocity_mode 3: position_mode 4: prbs_flux_mode 5: prbs_torque_mode 6: prbs_velocity_mode 7: prbs_position_mode 8: uq_ud_ext 9: enc_init_mini_move 10: AGPI_A torque_mode 11: AGPI_A velocity_mode 12: AGPI_A position_mode 13: PWM_I torque_mode 14: PWM_I velocity_mode 15: PWM_I position_mode				
	Mask	Name			Type
	0x0000FF00 _h	MODE_RAMP			Choice
		Min	Max	Default	Unit
		0	7	0	
		0: no velocity ramping 1: reserved 2: reserved 3: reserved 4: reserved 5: reserved 6: reserved 7: reserved			
	Mask	Name			Type
	0x00FF0000 _h	MODE_FF			Choice
		Min	Max	Default	Unit
		0	2	0	
		0: disabled 1: feed forward velocity control 2: feed forward torque control			
	Mask	Name			Type
	0x7F000000 _h	MODE_PID_SMPL			Unsigned



Address	Registername					Access
		Min	Max	Default	Unit	
		0	127	0		
	Mask	Name			Type	
	0x80000000 _h	MODE_PID_TYPE			Choice	
		Min	Max	Default	Unit	
		0	1	0		
	0: Parallel PI architecture 1: Sequential PI architecture					
0x64 _h	PID_TORQUE_FLUX_TARGET					RW
	Mask	Name			Type	
	0x0000FFFF _h	PID_FLUX_TARGET			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_TORQUE_TARGET			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
0x65 _h	PID_TORQUE_FLUX_OFFSET					RW
	Mask	Name			Type	
	0x0000FFFF _h	PID_FLUX_OFFSET			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Flux offset for feed forward control.					
	Mask	Name			Type	
	0xFFFF0000 _h	PID_TORQUE_OFFSET			Signed	
		Min	Max	Default	Unit	
-32768		32767	0			
Torque offset for feed forward control.						
0x66 _h	PID_VELOCITY_TARGET					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	PID_VELOCITY_TARGET			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
Target velocity register (for velocity mode).						
0x67 _h	PID_VELOCITY_OFFSET					RW



Address	Registername						Access
	Mask	Name				Type	
	0xFFFFFFFF _h	PID_VELOCITY_OFFSET				Signed	
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
		Velocity offset for feed forward control.					
0x68 _h	PID_POSITION_TARGET						RW
	Mask	Name				Type	
	0xFFFFFFFF _h	PID_POSITION_TARGET				Signed	
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
Target position register (for position mode).							
0x69 _h	PID_TORQUE_FLUX_ACTUAL						R
	Mask	Name				Type	
	0x0000FFFF _h	PID_FLUX_ACTUAL				Signed	
		Min	Max	Default	Unit		
		-32768	32767	0			
	Mask	Name				Type	
	0xFFFF0000 _h	PID_TORQUE_ACTUAL				Signed	
		Min	Max	Default	Unit		
-32768		32767	0				
0x6A _h	PID_VELOCITY_ACTUAL						R
	Mask	Name				Type	
	0xFFFFFFFF _h	PID_VELOCITY_ACTUAL				Signed	
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
Actual velocity.							
0x6B _h	PID_POSITION_ACTUAL						RW
	Mask	Name				Type	
	0xFFFFFFFF _h	PID_POSITION_ACTUAL				Signed	
		Min	Max	Default	Unit		
		-2147483648	2147483647	0			
Actual multi turn position for positioning. WRITE on PID_POSITION_ACTUAL writes same value into PID_POSITION_TARGET to avoid unwanted move.							
0x6C _h	PID_ERROR_DATA						R



Address	Registername				Access
	Variant 0				
	Mask	Name		Type	
	0xFFFFFFFF _h	PID_TORQUE_ERROR		Signed	
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
	PID torque error.				
	Variant 1				
	Mask	Name		Type	
	0xFFFFFFFF _h	PID_FLUX_ERROR		Signed	
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
	PID flux error.				
	Variant 2				
	Mask	Name		Type	
	0xFFFFFFFF _h	PID_VELOCITY_ERROR		Signed	
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
	PID velocity error.				
	Variant 3				
	Mask	Name		Type	
	0xFFFFFFFF _h	PID_POSITION_ERROR		Signed	
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
	PID position error.				
	Variant 4				
	Mask	Name		Type	
	0xFFFFFFFF _h	PID_TORQUE_ERROR_SUM		Signed	
		Min	Max	Default	Unit
-2147483648		2147483647	0		
PID torque error.					
Variant 5					
Mask	Name		Type		
0xFFFFFFFF _h	PID_FLUX_ERROR_SUM		Signed		
	Min	Max	Default	Unit	
	-2147483648	2147483647	0		



Address	Registername					Access
			PID flux error sum.			
	Variant 6					
	Mask	Name			Type	
	0xFFFFFFFF _h	PID_VELOCITY_ERROR_SUM			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	PID velocity error sum.					
	Variant 7					
	Mask	Name			Type	
	0xFFFFFFFF _h	PID_POSITION_ERROR_SUM			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	PID position error sum.					
0x6D _h	PID_ERROR_ADDR					RW
	Mask	Name			Type	
	0x000000FF _h	PID_ERROR_ADDR			Choice	
		Min	Max	Default	Unit	
		0	7	0		
		0: PID_TORQUE_ERROR				
		1: PID_FLUX_ERROR				
2: PID_VELOCITY_ERROR						
3: PID_POSITION_ERROR						
4: PID_TORQUE_ERROR_SUM						
5: PID_FLUX_ERROR_SUM						
6: PID_VELOCITY_ERROR_SUM						
7: PID_POSITION_ERROR_SUM						
0x6E _h	INTERIM_DATA					RW
	Variant 0					
	Mask	Name			Type	
	0xFFFFFFFF _h	PIDIN_TARGET_TORQUE			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	PIDIN target torque.					
Variant 1						
Mask	Name			Type		



Address	Registername				Access
	0xFFFFFFFF _h	PIDIN_TARGET_FLUX			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
		PIDIN target flux.			
	Variant 2				
	Mask	Name			Type
	0xFFFFFFFF _h	PIDIN_TARGET_VELOCITY			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
		PIDIN target velocity.			
	Variant 3				
	Mask	Name			Type
	0xFFFFFFFF _h	PIDIN_TARGET_POSITION			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
		PIDIN target position.			
	Variant 4				
	Mask	Name			Type
	0xFFFFFFFF _h	PIDOUT_TARGET_TORQUE			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
		PIDOUT target torque.			
	Variant 5				
	Mask	Name			Type
	0xFFFFFFFF _h	PIDOUT_TARGET_FLUX			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
		PIDOUT target flux.			
	Variant 6				
	Mask	Name			Type
	0xFFFFFFFF _h	PIDOUT_TARGET_VELOCITY			Signed
		Min	Max	Default	Unit
		-2147483648	2147483647	0	
		PIDOUT target velocity.			
	Variant 7				



Address	Registername					Access
	Mask	Name			Type	
	0xFFFFFFFF _h	PIDOUT_TARGET_POSITION			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	PIDOUT target position.					
	Variant 8					
	Mask	Name			Type	
	0x0000FFFF _h	FOC_IUX			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	FOC_IWY			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 9					
	Mask	Name			Type	
	0x0000FFFF _h	FOC_IV			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 10					
	Mask	Name			Type	
	0x0000FFFF _h	FOC_IA			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	FOC_IB			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 11					
	Mask	Name			Type	
	0x0000FFFF _h	FOC_ID			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	FOC_IQ			Signed	



Address	Registername					Access
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 12					
	Mask	Name			Type	
	0x0000FFFF _h	FOC_UD			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	FOC_UQ			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 13					
	Mask	Name			Type	
	0x0000FFFF _h	FOC_UD_LIMITED			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	FOC_UQ_LIMITED			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 14					
	Mask	Name			Type	
	0x0000FFFF _h	FOC_UA			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	FOC_UB			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 15					
	Mask	Name			Type	
	0x0000FFFF _h	FOC_UUX			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	



Address	Registername				Access
	0xFFFF0000 _h	FOC_UWY			Signed
		Min	Max	Default	Unit
		-32768	32767	0	
	Variant 16				
	Mask	Name			Type
	0x0000FFFF _h	FOC_UV			Signed
		Min	Max	Default	Unit
		-32768	32767	0	
	Variant 17				
	Mask	Name			Type
	0x0000FFFF _h	PWM_UX			Signed
		Min	Max	Default	Unit
		-32768	32767	0	
	Mask	Name			Type
	0xFFFF0000 _h	PWM_WY			Signed
		Min	Max	Default	Unit
		-32768	32767	0	
	Variant 18				
	Mask	Name			Type
	0x0000FFFF _h	PWM_V			Signed
		Min	Max	Default	Unit
		-32768	32767	0	
	Variant 19				
	Mask	Name			Type
	0x0000FFFF _h	ADC_I_0			Signed
		Min	Max	Default	Unit
		-32768	32767	0	
	Mask	Name			Type
	0xFFFF0000 _h	ADC_I_1			Signed
		Min	Max	Default	Unit
		-32768	32767	0	
	Variant 20				
	Mask	Name			Type
	0x000000FF _h	PID_FLUX_ACTUAL_DIV256			Signed
		Min	Max	Default	Unit



Address	Registername					Access
		-128	127	0		
	Mask	Name			Type	
	0x0000FF00 _h	PID_TORQUE_ACTUAL_DIV256			Signed	
		Min	Max	Default	Unit	
		-128	127	0		
	Mask	Name			Type	
	0x00FF0000 _h	PID_FLUX_TARGET_DIV256			Signed	
		Min	Max	Default	Unit	
		-128	127	0		
	Mask	Name			Type	
	0xFF000000 _h	PID_TORQUE_TARGET_DIV256			Signed	
		Min	Max	Default	Unit	
		-128	127	0		
	Variant 21					
	Mask	Name			Type	
	0x0000FFFF _h	PID_TORQUE_ACTUAL			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_TORQUE_TARGET			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 22					
	Mask	Name			Type	
	0x0000FFFF _h	PID_FLUX_ACTUAL			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_FLUX_TARGET			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 23					
	Mask	Name			Type	
	0x0000FFFF _h	PID_VELOCITY_ACTUAL_DIV256			Signed	
		Min	Max	Default	Unit	



Address	Registername					Access
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_VELOCITY_TARGET_DIV256			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 24					
	Mask	Name			Type	
	0x0000FFFF _h	PID_VELOCITY_ACTUAL_LSB			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_VELOCITY_TARGET_LSB			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 25					
	Mask	Name			Type	
	0x0000FFFF _h	PID_POSITION_ACTUAL_DIV256			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_POSITION_TARGET_DIV256			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 26					
	Mask	Name			Type	
	0x0000FFFF _h	PID_POSITION_ACTUAL_LSB			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	PID_POSITION_TARGET_LSB			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 27					
	Mask	Name			Type	
	0xFFFFFFFF _h	FF_VELOCITY			Signed	



Address	Registername					Access
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 28					
	Mask	Name			Type	
	0x0000FFFF _h	FF_TORQUE			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 29					
	Mask	Name			Type	
	0xFFFFFFFF _h	ACTUAL_VELOCITY_PPTM			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 30					
	Mask	Name			Type	
	0x0000FFFF _h	REF_SWITCH_STATUS			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 31					
	Mask	Name			Type	
	0xFFFFFFFF _h	HOME_POSITION			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 32					
	Mask	Name			Type	
	0xFFFFFFFF _h	LEFT_POSITION			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 33					
	Mask	Name			Type	
	0xFFFFFFFF _h	RIGHT_POSITION			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 34					
	Mask	Name			Type	
	0x0000FFFF _h	ENC_INIT_HALL_STATUS			Unsigned	



Address	Registername					Access
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 35					
	Mask	Name			Type	
	0x0000FFFF _h	ENC_INIT_HALL_PHI_E_ABN_OFFSET			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 36					
	Mask	Name			Type	
	0x0000FFFF _h	ENC_INIT_HALL_PHI_E_AENC_OFFSET			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 37					
	Mask	Name			Type	
	0x0000FFFF _h	ENC_INIT_HALL_PHI_A_AENC_OFFSET			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 40					
	Mask	Name			Type	
	0x0000FFFF _h	ENC_INIT_MINI_MOVE_STATUS			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Mask	Name			Type	
	0xFFFF0000 _h	ENC_INIT_MINI_MOVE_U_D			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 41					
	Mask	Name			Type	
	0x0000FFFF _h	ENC_INIT_MINI_MOVE_PHI_E_OFFSET			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Mask	Name			Type	
	0xFFFF0000 _h	ENC_INIT_MINI_MOVE_PHI_E			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		



Address	Registername				Access	
	Variant 192					
	Mask	Name		Type		
	0x0000FFFF _h	DEBUG_VALUE_0		Signed		
		Min	Max	Default		Unit
		-32768	32767	0		
	Mask	Name		Type		
	0xFFFF0000 _h	DEBUG_VALUE_1		Signed		
		Min	Max	Default		Unit
		-32768	32767	0		
	Variant 193					
	Mask	Name		Type		
	0x0000FFFF _h	DEBUG_VALUE_2		Signed		
		Min	Max	Default		Unit
		-32768	32767	0		
	Mask	Name		Type		
	0xFFFF0000 _h	DEBUG_VALUE_3		Signed		
		Min	Max	Default		Unit
		-32768	32767	0		
	Variant 194					
	Mask	Name		Type		
	0x0000FFFF _h	DEBUG_VALUE_4		Signed		
		Min	Max	Default		Unit
		-32768	32767	0		
	Mask	Name		Type		
	0xFFFF0000 _h	DEBUG_VALUE_5		Signed		
		Min	Max	Default		Unit
		-32768	32767	0		
	Variant 195					
	Mask	Name		Type		
	0x0000FFFF _h	DEBUG_VALUE_6		Signed		
		Min	Max	Default		Unit
		-32768	32767	0		
	Mask	Name		Type		
	0xFFFF0000 _h	DEBUG_VALUE_7		Signed		
		Min	Max	Default		Unit



Address	Registername					Access
		-32768	32767	0		
	Variant 196					
	Mask	Name			Type	
	0x0000FFFF _h	DEBUG_VALUE_8			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Mask	Name			Type	
	0xFFFF0000 _h	DEBUG_VALUE_9			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 197					
	Mask	Name			Type	
	0x0000FFFF _h	DEBUG_VALUE_10			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Mask	Name			Type	
	0xFFFF0000 _h	DEBUG_VALUE_11			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 198					
	Mask	Name			Type	
	0x0000FFFF _h	DEBUG_VALUE_12			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Mask	Name			Type	
	0xFFFF0000 _h	DEBUG_VALUE_13			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 199					
	Mask	Name			Type	
	0x0000FFFF _h	DEBUG_VALUE_14			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Mask	Name			Type	
	0xFFFF0000 _h	DEBUG_VALUE_15			Unsigned	



Address	Registername					Access
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 200					
	Mask	Name			Type	
	0xFFFFFFFF _h	DEBUG_VALUE_16			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 201					
	Mask	Name			Type	
	0xFFFFFFFF _h	DEBUG_VALUE_17			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 202					
	Mask	Name			Type	
	0xFFFFFFFF _h	DEBUG_VALUE_18			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 203					
	Mask	Name			Type	
	0xFFFFFFFF _h	DEBUG_VALUE_19			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	Variant 208					
	Mask	Name			Type	
	0xFFFFFFFF _h	CONFIG_REG_0			Unsigned	
		Min	Max	Default	Unit	
		0	4294967295	0		
	Variant 209					
	Mask	Name			Type	
	0xFFFFFFFF _h	CONFIG_REG_1			Unsigned	
		Min	Max	Default	Unit	
		0	4294967295	0		
Variant 210						
Mask	Name			Type		
0x0000FFFF _h	CTRL_PARAM_0			Signed		



Address	Registername					Access
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	CTRL_PARAM_1			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 211					
	Mask	Name			Type	
	0x0000FFFF _h	CTRL_PARAM_2			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Mask	Name			Type	
	0xFFFF0000 _h	CTRL_PARAM_3			Signed	
		Min	Max	Default	Unit	
		-32768	32767	0		
	Variant 212					
	Mask	Name			Type	
	0xFFFFFFFF _h	STATUS_REG_0			Unsigned	
		Min	Max	Default	Unit	
		0	4294967295	0		
	Variant 213					
	Mask	Name			Type	
	0xFFFFFFFF _h	STATUS_REG_1			Unsigned	
		Min	Max	Default	Unit	
		0	4294967295	0		
	Variant 214					
	Mask	Name			Type	
	0x0000FFFF _h	STATUS_PARAM_0			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Mask	Name			Type	
	0xFFFF0000 _h	STATUS_PARAM_1			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Variant 215					



Address	Registername					Access
	Mask	Name			Type	
	0x0000FFFF _h	STATUS_PARAM_2			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	Mask	Name			Type	
	0xFFFF0000 _h	STATUS_PARAM_3			Unsigned	
		Min	Max	Default	Unit	
		0	65535	0		
	0x6F _h	INTERIM_ADDR				
Mask		Name			Type	
0x000000FF _h		INTERIM_ADDR			Choice	
		Min	Max	Default	Unit	
		0	215	0		
		0: PIDIN_TARGET_TORQUE				
		1: PIDIN_TARGET_FLUX				
		2: PIDIN_TARGET_VELOCITY				
		3: PIDIN_TARGET_POSITION				
		4: PIDOUT_TARGET_TORQUE				
	5: PIDOUT_TARGET_FLUX					
	6: PIDOUT_TARGET_VELOCITY					
	7: PIDOUT_TARGET_POSITION					
	8: FOC_IWY_IUX					
	9: FOC_IV					
	10: FOC_IB_IA					
	11: FOC_IQ_ID					
	12: FOC_UQ_UD					
	13: FOC_UQ_UD_LIMITED					
	14: FOC_UB_UA					
15: FOC_UWY_UUX						
16: FOC_UV						
17: PWM_WY_UX						
18: PWM_UV						
19: ADC_I1_I0						
20: PID_TORQUE_TARGET_FLUX_TARGET_TORQUE_ACTUAL_FLUX_ACTUAL_DIV256						
21: PID_TORQUE_TARGET_TORQUE_ACTUAL						



Address	Registername	Access
	22: PID_FLUX_TARGET_FLUX_ACTUAL	
	23: PID_VELOCITY_TARGET_VELOCITY_ACTUAL_DIV256	
	24: PID_VELOCITY_TARGET_VELOCITY_ACTUAL	
	25: PID_POSITION_TARGET_POSITION_ACTUAL_DIV256	
	26: PID_POSITION_TARGET_POSITION_ACTUAL	
	27: FF_VELOCITY	
	28: FF_TORQUE	
	29: ACTUAL_VELOCITY_PPTM	
	30: REF_SWITCH_STATUS	
	31: HOME_POSITION	
	32: LEFT_POSITION	
	33: RIGHT_POSITION	
	34: ENC_INIT_HALL_STATUS	
	35: ENC_INIT_HALL_PHI_E_ABN_OFFSET	
	36: ENC_INIT_HALL_PHI_E_AENC_OFFSET	
	37: ENC_INIT_HALL_PHI_A_AENC_OFFSET	
	40: enc_init_mini_move_u_d_status	
	41: enc_init_mini_move_phi_e_phi_e_offset	
	192: DEBUG_VALUE_1_0	
	193: DEBUG_VALUE_3_2	
	194: DEBUG_VALUE_5_4	
	195: DEBUG_VALUE_7_6	
	196: DEBUG_VALUE_9_8	
	197: DEBUG_VALUE_11_10	
	198: DEBUG_VALUE_13_12	
	199: DEBUG_VALUE_15_14	
	200: DEBUG_VALUE_16	
	201: DEBUG_VALUE_17	
	202: DEBUG_VALUE_18	
	203: DEBUG_VALUE_19	
	208: CONFIG_REG_0	
	209: CONFIG_REG_1	
	210: CTRL_PARAM_10	
	211: CTRL_PARAM_32	
	212: STATUS_REG_0	



Address	Registername					Access
		213: STATUS_REG_1 214: STATUS_PARAM_10 215: STATUS_PARAM_32				
0x74 _h	WATCHDOG_CFG					RW
	Mask	Name			Type	
	0x00000003 _h	WATCHDOG_CFG			Choice	
		Min	Max	Default	Unit	
		0	3	0		
		0: No action on watchdog error 1: PWM and power stage disable on watchdog error 2: Global reset on watchdog error 3: reserved				
0x75 _h	ADC_VM_LIMITS					RW
	Mask	Name			Type	
	0x0000FFFF _h	ADC_VM_LIMIT_LOW			Unsigned	
		Min	Max	Default	Unit	
		0	65535	65535		
		Low limit for brake chopper output BRAKE_OUT.				
	Mask	Name			Type	
	0xFFFF0000 _h	ADC_VM_LIMIT_HIGH			Unsigned	
		Min	Max	Default	Unit	
		0	65535	65535		
		High limit for brake chopper output BRAKE_OUT.				
	0x76 _h	TMC4671_INPUTS_RAW				
Mask		Name			Type	
0x00000001 _h		A of ABN_RAW			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		A of ABN_RAW 0: off 1: on				
Mask		Name			Type	
0x00000002 _h		B of ABN_RAW			Bool	
		Min	Max	Default	Unit	
	0	1	0			



Address	Registername				Access
		B of ABN_RAW			
		0: off			
		1: on			
	Mask	Name		Type	
	0x00000004 _h	N of ABN_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	
		N of ABN_RAW			
		0: off			
		1: on			
	Mask	Name		Type	
	0x00000008 _h	-		Bool	
		Min	Max	Default	Unit
		0	1	0	
		—			
		0: off			
		1: on			
	Mask	Name		Type	
	0x00000010 _h	A of ABN_2_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	
		A of ABN_2_RAW			
		0: off			
		1: on			
	Mask	Name		Type	
	0x00000020 _h	B of ABN_2_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	
		B of ABN_2_RAW			
		0: off			
		1: on			
	Mask	Name		Type	
	0x00000040 _h	N of ABN_2_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	



Address	Registername				Access
		N of ABN_2_RAW			
		0: off			
		1: on			
	Mask	Name		Type	
	0x00000080 _h	-		Bool	
		Min	Max	Default	Unit
		0	1	0	
		—			
		0: off			
		1: on			
	Mask	Name		Type	
	0x00000100 _h	HALL_UX of HALL_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	
		HALL_UX of HALL_RAW			
		0: off			
		1: on			
	Mask	Name		Type	
	0x00000200 _h	HALL_V of HALL_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	
		HALL_V of HALL_RAW			
		0: off			
		1: on			
	Mask	Name		Type	
	0x00000400 _h	HALL_WY of HALL_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	
		HALL_WY of HALL_RAW			
		0: off			
		1: on			
	Mask	Name		Type	
	0x00000800 _h	-		Bool	
		Min	Max	Default	Unit
		0	1	0	



Address	Registername				Access
		— 0: off 1: on			
	Mask	Name		Type	
	0x00001000 _h	REF_SW_R_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	
		REF_SW_R_RAW 0: off 1: on			
	Mask	Name		Type	
	0x00002000 _h	REF_SW_H_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	
		REF_SW_H_RAW 0: off 1: on			
	Mask	Name		Type	
	0x00004000 _h	REF_SW_L_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	
		REF_SW_L_RAW 0: off 1: on			
	Mask	Name		Type	
	0x00008000 _h	ENABLE_IN_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	
		ENABLE_IN_RAW 0: off 1: on			
	Mask	Name		Type	
	0x00010000 _h	STP of DIRSTP_RAW		Bool	
		Min	Max	Default	Unit
		0	1	0	



Address	Registername				Access	
		STP of DIRSTP_RAW				
		0: off				
		1: on				
	Mask	Name		Type		
	0x00020000 _h	DIR of DIRSTP_RAW				Bool
		Min	Max	Default		Unit
		0	1	0		
		DIR of DIRSTP_RAW				
		0: off				
		1: on				
	Mask	Name		Type		
	0x00040000 _h	PWM_IN_RAW				Bool
		Min	Max	Default		Unit
		0	1	0		
		PWM_IN_RAW				
		0: off				
		1: on				
	Mask	Name		Type		
	0x00080000 _h	-				Bool
		Min	Max	Default		Unit
		0	1	0		
		—				
		0: off				
		1: on				
	Mask	Name		Type		
0x00100000 _h	HALL_UX_FILT			Bool		
	Min	Max	Default	Unit		
	0	1	0			
	ESI_0 of ESI_RAW					
	0: off					
	1: on					
Mask	Name		Type			
0x00200000 _h	HALL_V_FILT			Bool		
	Min	Max	Default	Unit		
	0	1	0			



Address	Registername				Access	
		ESI_1 of ESI_RAW 0: off 1: on				
	Mask	Name		Type		
	0x00400000 _h	HALL_WY_FILT				Bool
		Min	Max	Default		Unit
		0	1	0		
		ESI_2 of ESI_RAW 0: off 1: on				
	Mask	Name		Type		
	0x00800000 _h	-				Bool
		Min	Max	Default		Unit
		0	1	0		
		— 0: off 1: on				
	Mask	Name		Type		
	0x01000000 _h	-				Bool
		Min	Max	Default		Unit
		0	1	0		
		CFG_0 of CFG 0: off 1: on				
	Mask	Name		Type		
	0x02000000 _h	-				Bool
		Min	Max	Default		Unit
		0	1	0		
		CFG_1 of CFG 0: off 1: on				
	Mask	Name		Type		
	0x04000000 _h	-				Bool
		Min	Max	Default		Unit
		0	1	0		



Address	Registername				Access	
		CFG_2 of CFG 0: off 1: on				
	Mask	Name		Type		
	0x08000000 _h	-				Bool
		Min	Max	Default		Unit
		0	1	0		
		CFG_3 of CFG 0: off 1: on				
	Mask	Name		Type		
	0x10000000 _h	PWM_IDLE_L_RAW				Bool
		Min	Max	Default		Unit
		0	1	0		
		PWM_IDLE_L_RAW 0: off 1: on				
	Mask	Name		Type		
	0x20000000 _h	PWM_IDLE_H_RAW				Bool
		Min	Max	Default		Unit
		0	1	0		
		PWM_IDLE_H_RAW 0: off 1: on				
	Mask	Name		Type		
	0x40000000 _h	-				Bool
		Min	Max	Default		Unit
		0	1	0		
		DRV_ERR_IN_RAW 0: off 1: on				
	Mask	Name		Type		
	0x80000000 _h	-				Bool
		Min	Max	Default		Unit
		0	1	0		



Address	Registername					Access
		— 0: off 1: on				
0x77 _h	TMC4671_OUTPUTS_RAW					R
	Mask	Name			Type	
	0x00000001 _h	TMC4671_OUTPUTS_RAW[0]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		PWM_UX1_L 0: off 1: on				
	Mask	Name			Type	
	0x00000002 _h	TMC4671_OUTPUTS_RAW[1]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		PWM_UX1_H 0: off 1: on				
	Mask	Name			Type	
	0x00000004 _h	TMC4671_OUTPUTS_RAW[2]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		PWM_VX2_L 0: off 1: on				
	Mask	Name			Type	
	0x00000008 _h	TMC4671_OUTPUTS_RAW[3]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
	PWM_VX2_H 0: off 1: on					
Mask	Name			Type		
0x00000010 _h	TMC4671_OUTPUTS_RAW[4]			Bool		
	Min	Max	Default	Unit		



Address	Registername					Access
		0	1	0		
		PWM_WY1_L				
		0: off				
		1: on				
	Mask	Name			Type	
	0x00000020 _h	TMC4671_OUTPUTS_RAW[5]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		PWM_WY1_H				
		0: off				
		1: on				
	Mask	Name			Type	
	0x00000040 _h	TMC4671_OUTPUTS_RAW[6]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
	PWM_Y2_L					
	0: off					
	1: on					
Mask	Name			Type		
0x00000080 _h	TMC4671_OUTPUTS_RAW[7]			Bool		
	Min	Max	Default	Unit		
	0	1	0			
	PWM_Y2_H					
	0: off					
	1: on					
0x78 _h	STEP_WIDTH					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	STEP_WIDTH			Signed	
		Min	Max	Default	Unit	
		-2147483648	2147483647	0		
	STEP WIDTH = 0 => STP pulses ignored, resulting direction = DIR XOR sign(STEP_WIDTH), effects PID_POSITION_TARGET					
0x79 _h	UART_BPS					RW
	Mask	Name			Type	
	0x00FFFFFF _h	UART_BPS			Unsigned	



Address	Registername					Access
		Min	Max	Default	Unit	
		0	16777215	9600		
		9600, 115200, 921600, 3000000 (default=9600)				
0x7A _h	UART_ADDRS					RW
	Mask	Name			Type	
	0x000000FF _h	ADDR_A			Unsigned	
		Min	Max	Default	Unit	
		0	255	0		
	Mask	Name			Type	
	0x0000FF00 _h	ADDR_B			Unsigned	
		Min	Max	Default	Unit	
		0	255	0		
	Mask	Name			Type	
	0x00FF0000 _h	ADDR_C			Unsigned	
		Min	Max	Default	Unit	
		0	255	0		
	Mask	Name			Type	
	0xFF000000 _h	ADDR_D			Unsigned	
		Min	Max	Default	Unit	
		0	255	0		
	0x7B _h	GPIO_dsADCI_CONFIG				
Mask		Name			Type	
0x00000001 _h		GPIO_dsADCI_CONFIG[0]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
SEL_nDBGSPIM_GPIO						
0: off						
1: on						
Mask		Name			Type	
0x00000002 _h		GPIO_dsADCI_CONFIG[1]			Bool	
	Min	Max	Default	Unit		
	0	1	0			
SEL_nGPIO_dsADCS_A						
0: off						
1: on						



Address	Registername				Access
	Mask	Name			Type
	0x00000004 _h	GPIO_dsADCI_CONFIG[2]			Bool
		Min	Max	Default	Unit
		0	1	0	
		SEL_nGPIO_dsADCS_B			
		0: off			
		1: on			
	Mask	Name			Type
	0x00000008 _h	GPIO_dsADCI_CONFIG[3]			Bool
		Min	Max	Default	Unit
		0	1	0	
		SEL_GPIO_GROUP_A_nIN_OUT			
		0: off			
		1: on			
	Mask	Name			Type
	0x00000010 _h	GPIO_dsADCI_CONFIG[4]			Bool
		Min	Max	Default	Unit
		0	1	0	
		SEL_GPIO_GROUP_B_nIN_OUT			
		0: off			
		1: on			
	Mask	Name			Type
	0x00000020 _h	GPIO_dsADCI_CONFIG[5]			Bool
		Min	Max	Default	Unit
		0	1	0	
		SEL_GROUP_A_DSADCS_nCLKIN_CLKOUT			
		0: off			
		1: on			
	Mask	Name			Type
	0x00000040 _h	GPIO_dsADCI_CONFIG[6]			Bool
		Min	Max	Default	Unit
		0	1	0	
		SEL_GROUP_B_DSADCS_nCLKIN_CLKOUT			
		0: off			
		1: on			



Address	Registername					Access
	Mask	Name			Type	
	0x00FF0000 _h	GPO			Unsigned	
		Min	Max	Default	Unit	
		0	255	0		
	Mask	Name			Type	
	0xFF000000 _h	GPI			Unsigned	
		Min	Max	Default	Unit	
		0	255	0		
	0x7C _h	STATUS_FLAGS				
Mask		Name			Type	
0x00000001 _h		STATUS_FLAGS[0]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		pid_x_target_limit 0: off 1: on				
Mask		Name			Type	
0x00000002 _h		STATUS_FLAGS[1]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		pid_x_target_ddt_limit 0: off 1: on				
Mask		Name			Type	
0x00000004 _h		STATUS_FLAGS[2]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
		pid_x_errsum_limit 0: off 1: on				
Mask		Name			Type	
0x00000008 _h	STATUS_FLAGS[3]			Bool		
	Min	Max	Default	Unit		
	0	1	0			
	pid_x_output_limit					



Address	Registername				Access
		0: off 1: on			
	Mask	Name		Type	
	0x00000010 _h	STATUS_FLAGS[4]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		pid_v_target_limit 0: off 1: on			
	Mask	Name		Type	
	0x00000020 _h	STATUS_FLAGS[5]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		pid_v_target_ddt_limit 0: off 1: on			
	Mask	Name		Type	
	0x00000040 _h	STATUS_FLAGS[6]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		pid_v_errsum_limit 0: off 1: on			
	Mask	Name		Type	
	0x00000080 _h	STATUS_FLAGS[7]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		pid_v_output_limit 0: off 1: on			
	Mask	Name		Type	
	0x00000100 _h	STATUS_FLAGS[8]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		pid_id_target_limit			



Address	Registername				Access
		0: off 1: on			
	Mask	Name			Type
	0x00000200 _h	STATUS_FLAGS[9]			Bool
		Min	Max	Default	Unit
		0	1	0	
		pid_id_target_ddt_limit			
		0: off 1: on			
	Mask	Name			Type
	0x00000400 _h	STATUS_FLAGS[10]			Bool
		Min	Max	Default	Unit
		0	1	0	
		pid_id_errsum_limit			
		0: off 1: on			
	Mask	Name			Type
	0x00000800 _h	STATUS_FLAGS[11]			Bool
		Min	Max	Default	Unit
		0	1	0	
		pid_id_output_limit			
		0: off 1: on			
	Mask	Name			Type
	0x00001000 _h	STATUS_FLAGS[12]			Bool
		Min	Max	Default	Unit
		0	1	0	
		pid_iq_target_limit			
		0: off 1: on			
	Mask	Name			Type
	0x00002000 _h	STATUS_FLAGS[13]			Bool
		Min	Max	Default	Unit
		0	1	0	
		pid_iq_target_ddt_limit			



Address	Registername				Access
		0: off 1: on			
	Mask	Name		Type	
	0x00004000 _h	STATUS_FLAGS[14]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		pid_iq_errsum_limit 0: off 1: on			
	Mask	Name		Type	
	0x00008000 _h	STATUS_FLAGS[15]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		pid_iq_output_limit 0: off 1: on			
	Mask	Name		Type	
	0x00010000 _h	STATUS_FLAGS[16]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		ipark_cirlim_limit_u_d 0: off 1: on			
	Mask	Name		Type	
	0x00020000 _h	STATUS_FLAGS[17]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		ipark_cirlim_limit_u_q 0: off 1: on			
	Mask	Name		Type	
	0x00040000 _h	STATUS_FLAGS[18]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		ipark_cirlim_limit_u_r			



Address	Registername				Access
		0: off 1: on			
	Mask	Name		Type	
	0x00080000 _h	STATUS_FLAGS[19]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		not_PLL_locked 0: off 1: on			
	Mask	Name		Type	
	0x00100000 _h	STATUS_FLAGS[20]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		ref_sw_r 0: off 1: on			
	Mask	Name		Type	
	0x00200000 _h	STATUS_FLAGS[21]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		ref_sw_h 0: off 1: on			
	Mask	Name		Type	
	0x00400000 _h	STATUS_FLAGS[22]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		ref_sw_l 0: off 1: on			
	Mask	Name		Type	
	0x00800000 _h	STATUS_FLAGS[23]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		—			



Address	Registername				Access
		0: off 1: on			
	Mask	Name		Type	
	0x01000000 _h	STATUS_FLAGS[24]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		pwm_min 0: off 1: on			
	Mask	Name		Type	
	0x02000000 _h	STATUS_FLAGS[25]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		pwm_max 0: off 1: on			
	Mask	Name		Type	
	0x04000000 _h	STATUS_FLAGS[26]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		adc_i_clipped 0: off 1: on			
	Mask	Name		Type	
	0x08000000 _h	STATUS_FLAGS[27]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		aenc_clipped 0: off 1: on			
	Mask	Name		Type	
	0x10000000 _h	STATUS_FLAGS[28]		Bool	
		Min	Max	Default	Unit
		0	1	0	
		enc_n			



Address	Registername					Access
		0: off 1: on				
	Mask	Name			Type	
	0x20000000 _h	STATUS_FLAGS[29]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
	enc_2_n 0: off 1: on					
	Mask	Name			Type	
	0x40000000 _h	STATUS_FLAGS[30]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
	aenc_n 0: off 1: on					
	Mask	Name			Type	
	0x80000000 _h	STATUS_FLAGS[31]			Bool	
		Min	Max	Default	Unit	
		0	1	0		
	wd_error 0: off 1: on					
0x7D _h	STATUS_MASK					RW
	Mask	Name			Type	
	0xFFFFFFFF _h	WARNING_MASK			Unsigned	
		Min	Max	Default	Unit	
		0	4294967295	0		

Table 16: Register Map for TMC4671



7 Pinning

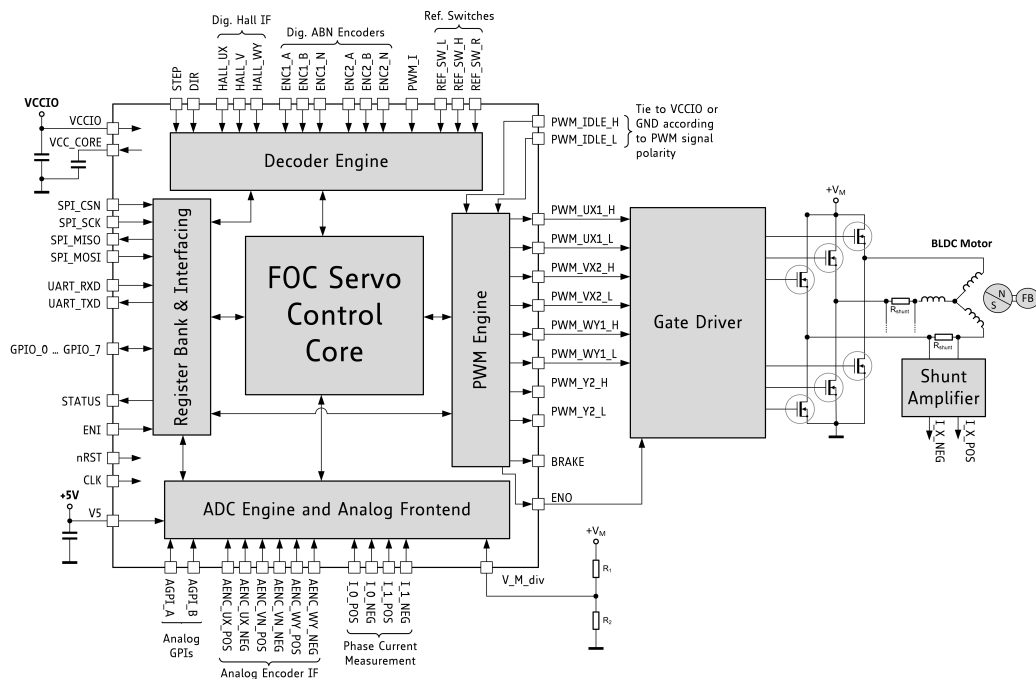


Figure 31: TMC4671 Pinout with 3 phase Power stage and BLDC Motor

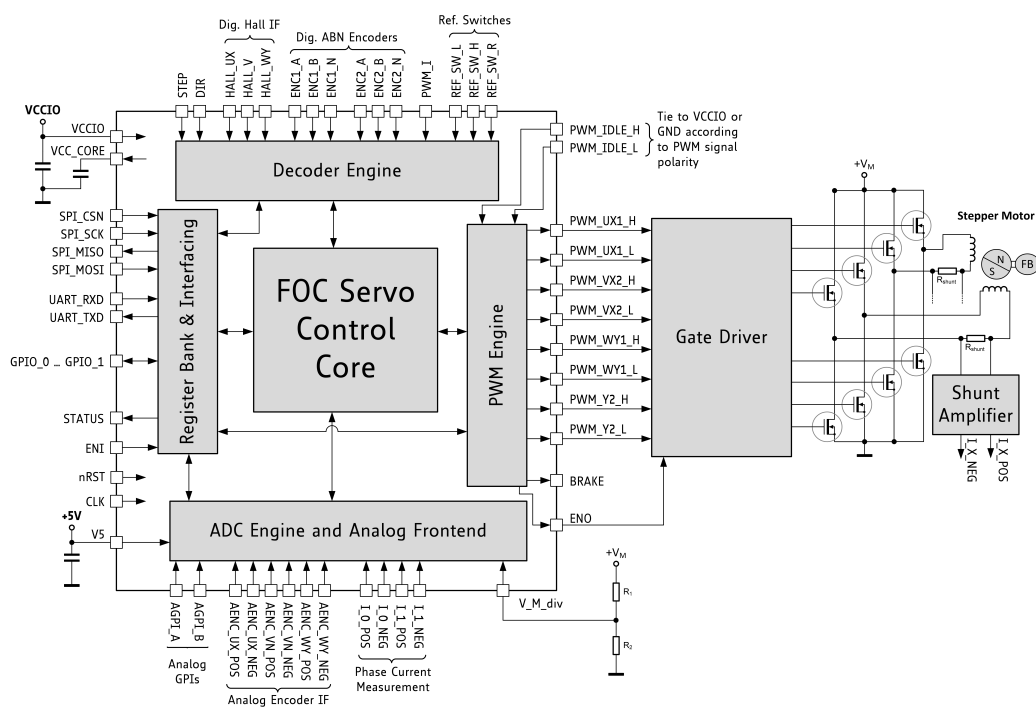


Figure 32: TMC4671 Pinout with Stepper Motor



8 TMC4671 Pin Table

Name	Pin	IO	Description
nRST	50	I	active low reset input
CLK	51	I	clock input; needs to be 25 MHz for correct timing
TEST	54	I	TEST input, must be connected to GND
ENI	55	I	enable input
ENO	32	O	enable output
STATUS	12	O	output for interrupt of CPU (Warning & Status Change)
SPI_nSCS	6	I	SPI active low chip select input
SPI_SCK	7	I	SPI clock input
SPI_MOSI	8	I	SPI master out slave input
SPI_MISO	9	O	SPI master in slave output, high impedance, when SPI_nSCS = '1'
UART_RXD	10	I	UART receive data RxD for in-system-user communication channel
UART_TXD	11	O	UART transmit data TXD for in-system-user secondary communication channel
PWMI	58	I	PWM input
DIR	56	I	direction input of step-direction interface
STP	57	I	step pulse input for step-direction interface
HALL_UX	38	I	digital hall input H1 for 3-phase (U) or 2-phase (X)
HALL_V	37	I	digital hall input H2 for 3-phase (V)
HALL_WY	36	I	digital hall input H3 for 3-phase (W) or 2-phase (Y)
ENC_A	35	I	A input of incremental encoder
ENC_B	34	I	B input of incremental encoder
ENC_N	33	I	N input of incremental encoder
ENC2_A	64	I	A input of incremental encoder
ENC2_B	65	I	B input of incremental encoder
ENC2_N	66	I	N input of incremental encoder
REF_L	67	I	Left (L) reference switch
REF_H	68	I	Home (H) reference switch
REF_R	69	I	Right (R) reference switch
ADC_I0_POS	16	AI	pos. input for phase current signal measurement I0 (I_U, I_X)



Name	Pin	IO	Description
ADC_I0_NEG	17	AI	neg. input for phase current signal measurement I0 (I_U, I_X)
ADC_I1_POS	18	AI	pos. input for phase current signal measurement I1 (I_V, I_W, I_Y)
ADC_I1_NEG	19	AI	neg. input for phase current signal measurement I1 (I_V, I_W, I_Y)
ADC_VM	20	AI	analog input for motor supply voltage divider (VM) measurement
AGPI_A	21	AI	analog general purpose input A (analog GPI)
AGPI_B	22	AI	analog general purpose input B (analog GPI)
AENC_UX_POS	25	AI	pos. analog input for Hall or analog encoder signal, 3-phase (U) or 2-phase (X (cos))
AENC_UX_NEG	26	AI	neg. analog input for Hall or analog encoder signal, 3-phase (U) or 2-phase (X (cos))
AENC_VN_POS	27	AI	pos. analog input for Hall or analog encoder signal, 3-phase (V) or 2-phase (N)
AENC_VN_NEG	28	AI	neg. analog input for Hall or analog encoder signal, 3-phase (V) or 2-phase (N)
AENC_WY_POS	29	AI	pos. analog input for Hall or analog encoder signal, 3-phase (W) or 2-phase (Y (sin))
AENC_WY_NEG	30	AI	neg. analog input for Hall or analog encoder signal, 3-phase (W) or 2-phase (Y (sin))
GPIO0 / ADC_I0_MCD	70	IO	GPIO or $\Delta\Sigma$ -Demodulator clock input MCLKI, clock output MCLKO, or single bit DAC output MDAC for ADC_I_0
GPIO1 / ADC_I1_MCD	71	IO	GPIO or $\Delta\Sigma$ -Demodulator clock input MCLKI, clock output MCLKO, or single bit DAC output MDAC for ADC_I_1
GPIO2 / ADC_VM_MCD	74	IO	GPIO or $\Delta\Sigma$ -Demodulator clock input MCLKI, clock output MCLKO, or single bit DAC output MDAC for ADC_VM_MCD
GPIO3 / AGPI_A_MCD / DBGSPI_nSCS	75	IO	GPIO or $\Delta\Sigma$ -Demodulator clock input MCLKI, clock output MCLKO, or single bit DAC output MDAC for AENC_UX_MCD, SPI debug port pin DBGSPI_nSCS
GPIO4 / AGPI_B_MCD / DBGSPI_SCK	76	IO	GPIO or $\Delta\Sigma$ -Demodulator clock input MCLKI, clock output MCLKO, or single bit DAC output MDAC for AENC_VN_MCD, SPI debug port pin DBGSPI_SCK
GPIO5 / AENC_UX_MCD / DBGSPI_MOSI	1	IO	GPIO or $\Delta\Sigma$ -Demodulator clock input MCLKI, clock output MCLKO, or single bit DAC output MDAC for AENC_WY_MCD, SPI debug port pin DBGSPI_MOSI



Name	Pin	IO	Description
GPIO6 / AENC_VN_MCD / DBGSPI_MISO	4	IO	GPIO or $\Delta\Sigma$ -Demodulator clock input MCLKI, clock output MCLKO, or single bit DAC output MDAC for AGPI_A_MCD, SPI debug port pin DBGSPI_MISO
GPIO7 / AENC_WY_MCD / DBGSPI_TRG	5	IO	GPIO or $\Delta\Sigma$ -Demodulator clock input MCLKI, clock output MCLKO, or single bit DAC output MDAC for AGPI_B_MCD, SPI debug port pin DBGSPI_TRG
PWM_IDLE_H	59	I	idle level of high side gate control signals
PWM_IDLE_L	60	I	idle level of low side gate control signals
PWM_UX1_H	39	O	high side gate control output U (3-phase) resp. X1 (2-phase)
PWM_UX1_L	40	O	low side gate control output U (3-phase) resp. X1 (2-phase)
PWM_VX2_H	41	O	high side gate control output V (3-phase) resp. X2 (2-phase)
PWM_VX2_L	42	O	low side gate control output V (3-phase) resp. X2 (2-phase)
PWM_WY1_H	46	O	high side gate control output W (3-phase) resp. Y1 (2-phase)
PWM_WY1_L	47	O	low side gate control output W (3-phase) resp. Y1 (2-phase)
PWM_Y2_H	48	O	high side gate control output Y2 (2-phase only)
PWM_Y2_L	49	O	low side gate control output Y2 (2-phase only)
BRAKE	31	O	brake chopper control output signal

Table 18: Functional Pin Description



Name	Pin	IO	Description
VCCIO1	2	3.3V	digital IO supply voltage; use 100 nF decoupling capacitor
VCCIO2	13	3.3V	digital IO supply voltage; use 100 nF decoupling capacitor
VCCIO3	43	3.3V	digital IO supply voltage; use 100 nF decoupling capacitor
VCCIO4	52	3.3V	digital IO supply voltage; use 100 nF decoupling capacitor
VCCIO5	61	3.3V	digital IO supply voltage; use 100 nF decoupling capacitor
VCCIO6	72	3.3V	digital IO supply voltage; use 100 nF decoupling capacitor
GNDIO1	3	0V	digital IO ground
GNDIO2	14	0V	digital IO ground
GNDIO3	44	0V	digital IO ground
GNDIO4	53	0V	digital IO ground
GNDIO5	62	0V	digital IO ground
GNDIO6	73	0V	digital IO ground
VCCCORE1	15	1.8V	digital core supply voltage output; use 100 nF decoupling capacitor
VCCCORE2	45	1.8V	digital core supply voltage output; use 100 nF decoupling capacitor
VCCCORE3	63	1.8V	digital core supply voltage output; use 100 nF decoupling capacitor
V5	23	5V	analog reference voltage
GNDA	24	0.0V	analog reference ground
GNDPAD	0V	bottom ground pad	

Table 19: Supply Voltage Pins and Ground Pins



9 Electrical Characteristics

9.1 Absolute Maximum Ratings

The maximum ratings may not be exceeded under any circumstances. Operating the circuit at or near more than one maximum rating at a time for extended periods shall be avoided by application design.

Parameter	Symbol	Min	Max	Unit
Digital I/O supply voltage	VCCIO		3.6	V
Logic input voltage	VI		3.6	V
Maximum current drawn on VCCIO with no load on pins	I_IO		70	mA
Maximum current drawn on VCCIO with no load on pins and clock off	I_IO_0Hz		3	mA
Maximum current drawn on V5 at fCLK = 25MHz	I_V5		25	mA
Maximum current to / from digital pins and analog low voltage I/Os	IIO		10	mA
Junction temperature	TJ	-40	125	°C
Storage temperature	TSTG	-55	150	°C
ESD-Protection for interface pins (Human body model, HBM)	VESDAP		2	kV
ESD-Protection for handling (Human body model, HBM)	VESD1		2	kV
ADC input voltage	VAI	0	5	V

Table 20: Absolute Maximum Ratings

VCCCORE is generated internally from VCCIO and shall not be overpowered by external supply.

9.2 Electrical Characteristics

9.2.1 Operational Range

Parameter	Symbol	Min	Max	Unit
Junction temperature	TJ	-40	125	°C
Digital I/O 3.3V supply voltage	VIO3V	3.15	3.45	V
Core supply voltage	VCC_CORE	1.65	1.95	V

Table 21: Operational Range

The $\Delta\Sigma$ ADCs can operate in differential or single ended mode. In differential mode the differential input voltage range must be in between -2.5V and +2.5V. However, it is recommended to use the input voltage range from -1.25V to 1.25V, due to non-linearity of $\Delta\Sigma$ ADCs. In Single ended mode the operational input range of the positive input channel should be between 0V and 2.5V. Recommended maximum input voltage is 1.25V. ADCs have



9.2.2 DC Characteristics

DC characteristics contain the spread of values guaranteed within the specified supply voltage range unless otherwise specified. Typical values represent the average value of all parts measured at +25 °C. Temperature variation also causes stray to some values. A device with typical values will not leave Min/Max range within the full temperature range.

Parameter	Symbol	Condition	Min	Typ	Max	Unit
Input voltage low level	VINL	VCCIO = 3.3V	-0.3		0.8	V
Input voltage high level	VINH	VCCIO = 3.3V	2.3		3.6	V
Input with pull-down		VIN = 3.3V	5	30	110	μA
Input with pull-up		VIN = 0V	-110	-30	-5	μA
Input low current		VIN = 0V	-10		10	μA
Input high current		VIN = VCCIO	-10		10	μA
Output voltage low level	VOUTL	VCCIO = 3.3V	0.4			V
Output voltage high level	VOUTH	VCCIO = 3.3V	2.64			V
Output driver strength standard	IOUT_DRV		4			mA
Input impedance of Analog Input	R_ADC	TJ = 25°C	85	100	115	kΩ

Table 22: DC Characteristics

All I/O lines include Schmitt-Trigger inputs to enhance noise margin.



10 Sample Circuits

Please consider electrical characteristics while designing electrical circuitry. Most Sample Circuits in this chapter were taken from the Evaluation board for the TMC4671 (TMC4671-EVAL).

10.1 Supply Pins

Please provide VCCIO and V5 to the TMC4671. VCC_CORE is internally generated and needs just an external decoupling capacitor. Place one 100nF decoupling capacitor at every supply pin. Table 23 lists additional needed decoupling capacitors.

Pin Name	Supply Voltage	Additional Cap.
V5	5V	4.7uF
VCCIO	3.3V	4.7uF & 470nF
VCCCORE	1.8V	none

Table 23: Additional decoupling capacitors for supply voltages

10.2 Clock and Reset Circuitry

The TMC4671 needs an external oscillator for correct operation. The internal generated active low reset can be externally overwritten. When not used, please apply a 10k Pull up resistor and make sure all supply voltages are stable.

10.3 Digital Encoder, Hall Sensor Interface and Reference Switches

Digital encoders, Hall sensors and reference switches usually operate on a supply voltage of 5V. As the TMC4671 is usually operated at a VCCIO Voltage of 3.3V, a protection circuit for the TMC4671 input pin is needed. In fig. 34 a sample circuit for the ENC_A signal is shown, which can be reused for all encoder and Hall signals as well as for reference switch signals. Parametrization of the components is given in table 24 for different operations.

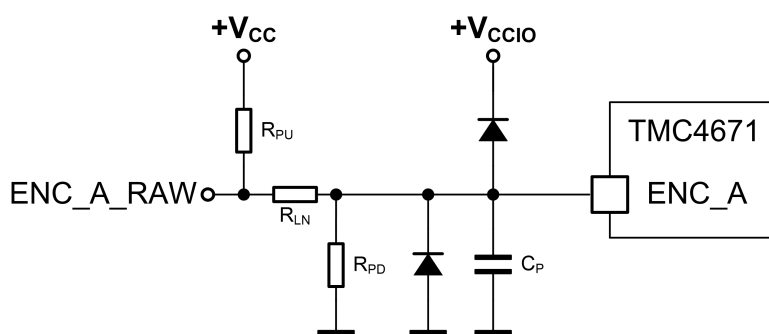


Figure 34: Sample Circuit for Interfacing of an Encoder Signal

Application	R_{PU}	R_{PD}	R_{LN}	C_P
5 V Encoder signal	4K7	n.c.	100R	100pF



Table 24: Reference Values for circuitry components

The raw signal (ENC_A_RAW) is divided by a voltage divider and filtered by a lowpass filter. A pull up resistor is applied for open collector encoder output signals. Diodes protect the input pin (ENC_A) against over- and undervoltage. The cutoff-frequency of the lowpass is:

$$f_c = \frac{1}{2\pi R_{PD}C_P} \quad (39)$$

10.4 Analog Frontend

Analog Encoders are encoding the motor position into sinusoidal signals. These signals need to be digitalized by the TMC4671 in order to determine the rotor position. The input voltage range depends on V5 input, which is usually 5V and GNDA (usually 0V). Due to nonlinearity issues of the ADC near input limits, an ADC input value from 1V to 4V is recommended. For a single ended application, the sample circuit from fig. 35 can be used. All single ended analog input pins (AGPI_A, AGPI_B and ADC_VM) have their negative input value tied to GNDA internally, so this sample circuit can also be used for them.

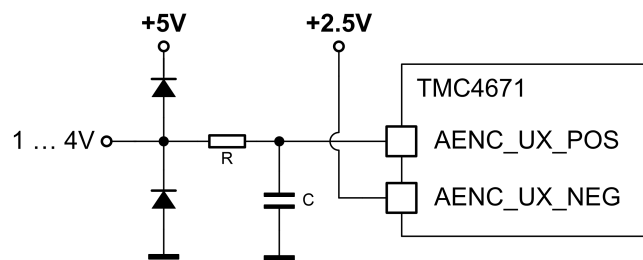


Figure 35: Sample Circuit for Interfacing of a single ended analog signal

If the power stage and the TMC4671 share a common ground, the ADC_VM input signal can be generated by a voltage divider to scale the voltage down to the needed range.

If the analog encoder has differential output signals, these can be used without signal conditioning (no OP AMPs), when voltage range matches. Differential analog inputs can be used to digitize differential analog input signals with high common mode voltage error suppression.

10.5 Phase Current Measurement

The TMC4671 requires two phase currents of a 2 or 3 phase motor to be measured. For a DC Motor only one current in the phase needs to be measured (see Fig. 37). In the ADC engine mapping of current signals to motor phases can be changed. Default setting is I0 to be the current running into the motor in phase U for a 3 phase motor. Respectively the current running into the motor from half-bridge X1 of a 2 phase motor. Figs. 36 and 37 illustrates the currents to be measured and their positive direction.



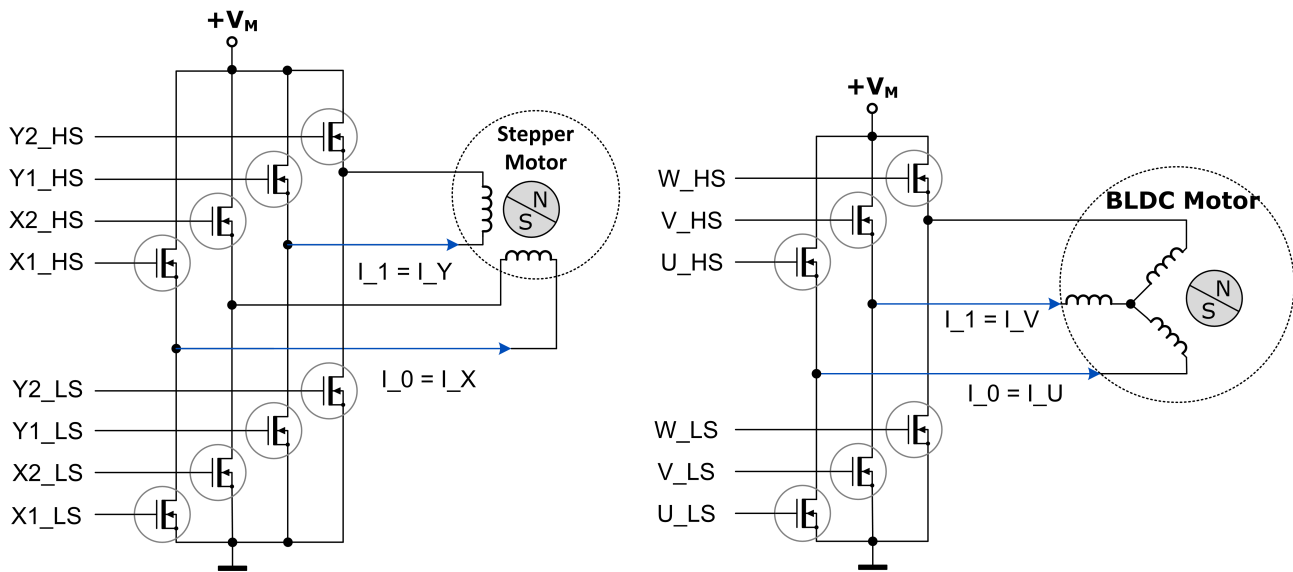


Figure 36: Phase current measurement: Current directions for 2 and 3 phase motors

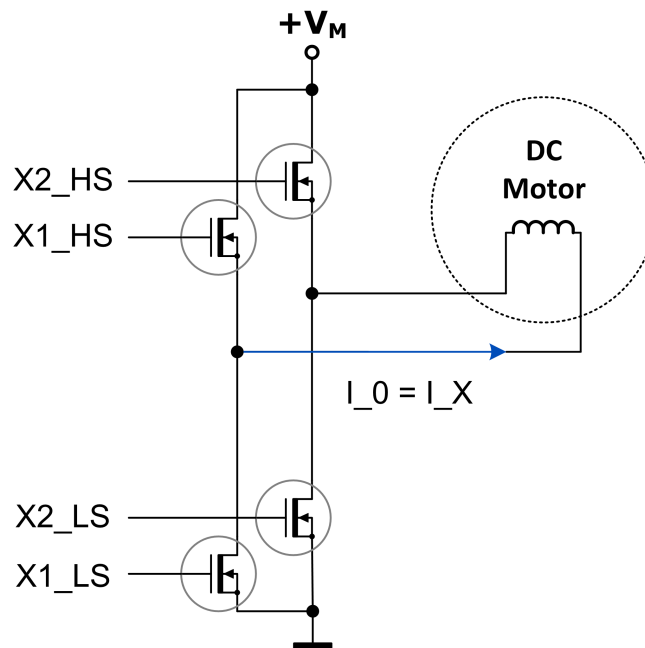


Figure 37: Phase current measurement: Current direction for DC or Voice Coil Motor

There are two main options for measuring the phase currents as described above. First option is to use a shunt resistor and a shunt amplifier like the [LT1999](#) or the [AD8418A](#). The other option is to use a real current sensor, which uses the Hall effect or other magnetic effects to implement an isolated current measurement. Shunt measurement might be the more cost-effective solution for low voltage applications up to 100V, while current sensors are more useful at higher voltage levels.

In general the sample circuit in fig. 38 can be used for shunt measurement circuitry. Please consider design guidelines of shunt amplifier supplier additionally. TRINAMIC also supplies power stage boards with current shunt measurement circuitry (TMC-UPS10A/70V-EVAL).



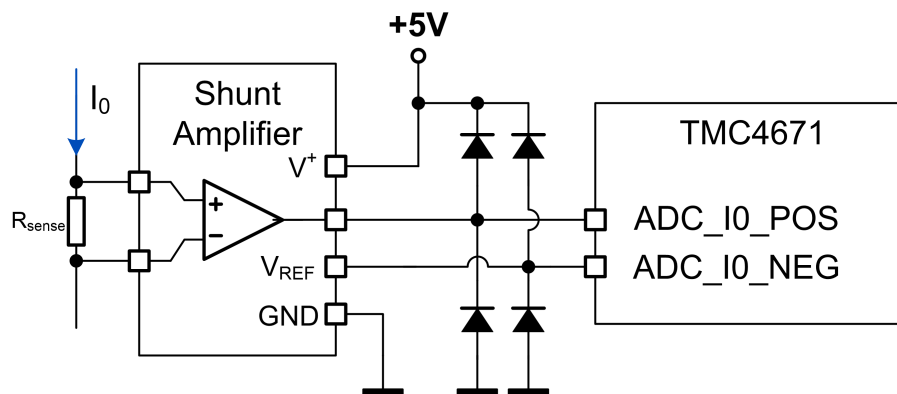


Figure 38: Current Shunt Amplifier Sample Circuit

10.6 Power Stage Interface

The TMC4671 is equipped with a configurable PWM engine for control of various gate drivers. Gate driver switch signals can be matched to power stage needs. This includes signal polarities, frequency, BBM-times for low and high side switches, and an enable signal. Please consider gate driver circuitry, when connecting to the TMC4671.



11 Setup Guidelines

For easy setup of the TMC4671 on a given hardware platform like the TMC4671 Evaluation-Kit, the user should follow these general guidelines in order to safely set up the system for various modes of operation.

Info

These guidelines fit to hardware platforms which are comparable to the TMC4671-Evaluation Kit. If system structure differs, configuration has to be adjusted. Please also make use of the RTMI Adapter and the TMCL IDE to setup the system as it reduces commissioning time significantly.

Step 0: Setup of SPI communication

As a first step of the configuration of the TMC4671 the SPI communication should be tested by reading and writing for example to the first registers for identification of the silicon. If communication fails, please check CLK and nRST signals. For easy software setup the TMC API provided on the TRINAMIC website can be used.

Step 1: Check connections

Register TMC_INPUTS_RAW can be accessed to see if all connected digital inputs are working correctly e.g. sensor signals can be checked by turning the motor manually.

Step 2: Setup of PWM and Gatedriver configuration

The user should choose the connected motor and the number of polepairs by setting register MOTOR_TYPE_N_POLE_PAIRS. For a DC motor the number of pole pairs should be set to one. The PWM can be configured with the corresponding registers PWM_POLARITIES (Gate Driver Polarities), PWM_MAXCNT (PWM Frequency), PWM_BBH_H_BBH_L (BBH times), and PWM_SV_CHOP (PWM mode). After setting the register PWM_SV_CHOP to 7 the PWM is on and ready to use.

Please check PWM outputs after turning on the PWM, if you are using a new hardware design.

Step 3: Open Loop Mode

In the Open Loop Mode the motor is turned by applying voltage to the motor. This mode is useful for test and setup of ADCs and position sensors. It is activated by setting the corresponding registers for PHI_E_SELECTION, and MODE_MOTION. With UD_EXT the applied voltage can be regulated upwards until the motor starts to turn. Acceleration and target velocity can be changed by their respective registers.

Step 4: Setup of ADC for current measurement

Please setup the current measurement by choosing your applications ADC configuration. Make sure to match decimation rate of the Delta Sigma ADCs to your chosen PWM frequency.

When the motor turns in Open Loop Mode the current measurement can be easily calibrated. Please match offset and gain of phase current signals by setting the corresponding registers. Please also make sure for a new hardware setup, that current measurements and PWM channels are matched. This can be done by matching phase voltages and phase currents. Register ADC_I_SELECT can be used to switch relations.

Step 5: Setup of Feedback Systems

In Open Loop Mode also the feedback systems can be checked for correct operation. Please configure registers related to used position sensor(s) and compare against Open Loop angles. Use encoder initialization routines to set angle offsets for relative position encoders according to application needs.

Step 6: Setup of FOC Controllers

Please configure your application's feedback system and configure position and velocity signal switches accordingly inside the FOC. Configure controller output limits according to you needs.

Setup PI controller parameters for used FOC controllers. Start with the current controller, followed by the velocity controller, followed by the position controller. Stop configuration at your desired cascade level. TRINAMIC recommends to set the PI controller parameters by support of the RTMI, as it supports realtime access to registers and the TMCL IDE offers tools for automated controller tuning. Controller tuning without realtime access might lead to poor performance.

Please choose afterwards your desired Motion Mode and feed in reference values.

Step 7: Advanced Functions

For performance improvements Biquad filters and feed forward control can be applied.



12 Package Dimensions

Package: QFN76, 0.4 mm pitch, size 11.5 mm x 6.5 mm, industrial temperature range 0°C . . . 85°C, RoHS compliant.

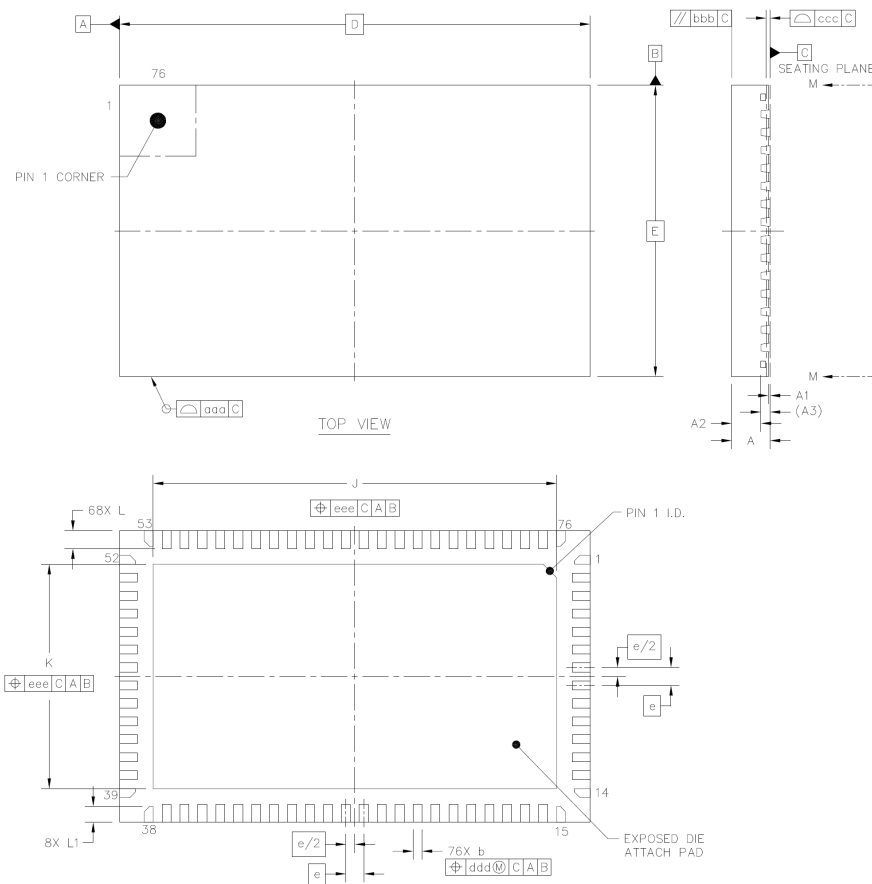


Figure 39: QFN76 Package Outline

QFN76 Package Dimensions in mm				
Description	Dimension[mm]	min.	typ.	max.
Total Thickness	A	0.80	0.85	0.90
Stand Off	A1	0.00	0.035	0.05
Mold Thickness	A2	—	0.65	—
L/F Thickness	A3	0.203 REF		
Lead Width	b	0.15	0.2	0.25
Body Width	D	10.5 BSC		
Body Length	E	6.5 BSC		
Lead Pitch	e	0.4 BSC		
EP Size	J	8.9	9	9.1



QFN76 Package Dimensions in mm				
EP Size	K	4.9	5	5.1
Lead Length	L	0.35	0.40	0.45
Lead Length	L1	0.30	0.35	0.40
Package Edge Tolerance	aaa		0.1	
Mold Flatness	bbb		0.1	
Coplanarity	ccc		0.08	
Lead Offset	ddd		0.1	
Exposed Pad Offset	eee		0.1	

Table 25: Package Outline Dimensions



13 Supplemental Directives

13.1 Producer Information

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14 Errata

The Errata of the TMC4671-ES are listed here and in the particular descriptions they apply to.

1. SPI Slave Interface

The SPI Slave Interface in the TMC4671-ES shows following error. During transaction of MSB of read data might get corrupted. This shows in two different ways. First one is a 40 ns pulse (positive or negative) on MISO at the beginning of transfer of that particular bit. This pulse can corrupt the MSB of read data and this error can be avoided when SPI clock frequency is set to 1 MHz. Second error also corrupts MSB of read data when MSB of register is unstable. For example current measurement noise around zero. In this case MSB should be ignored when possible. Please also make sure that e.g. actual torque value can be read from register PID_TORQUE_FLUX_ACTUAL or from INTERIM_DATA register, where it is showing up in the lower 16 bits. These errors will be fixed in next IC version. SPI write access is not affected and can be performed at 8 MHz clock frequency.

2. Realtime Monitoring Interface

The TRINAMIC Realtime Monitoring Interface can not be used with galvanic isolation as timing of SPI communication is too strict. This will be fixed in future version so galvanic isolation of SPI signals will be possible with defined latency of isolators.

3. PI Controllers

The P Factor in the advanced position controller is not properly scaled. Due to the high gain in Velocity control loop, the position controller gain should be respectively low. The P Factor normalization of Q8.8 does not match these needs. This will be changed in a future version of the chip to a different Q Format. This change will cause changes in user's application controller software. We recommend to use the classical PI control structure if performance is not sufficient.

4. Inbuilt ADCs

The inbuilt Delta Sigma ADCs show an error, where both groups are disturbing each other. When one group is deactivated, everything is fine, but with both groups being active ADC Data might be corrupted. This error occurs if clock signals of both groups are not in phase. Clock phase can be changed by toggling the dsADC_MCLK_B to a non-round figure like 0x30000001 and back to 0x20000000. This toggling has to be repeated until measurement is clean.

If the second ADC Group is not needed, it can be shut down by setting dsADC_MCLK_B to 0. The distortion can be detected by monitoring measurement at reference voltage. Use register DS_ANALOG_INPUT_STAGE_CFG to switch on the reference voltage for monitoring.

5. Pins PWM_IDLE_H and PWM_IDLE_L without function

Pins PWM_IDLE_H and PWM_IDLE_L are intended to determine Power on Reset Gate Driver Polarity. This feature is not working properly as the gate driver polarity always powers up to Low Side Polarity to be Active Low and High Side Polarity to be active high. This will be corrected in the next version of the chip.

6. Space Vector PWM does not allow higher voltage utilization

The Space vector PWM does not allow higher voltage utilization. This will be fixed in next version of the chip.



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13	Delta Sigma input voltage mapping of external comparator (CMP)	30	26	IC Revision	152
			27	Document Revision	152



17 Revision History

17.1 IC Revision

Version	Date	Author	Description
V1.00	2017-JUL-03	LL, OM	Engineering samples TMC4671-ES (1v00 2017-07-03-19:43)

Table 26: IC Revision

17.2 Document Revision

Version	Date	Author	Description
V0.9	2017-SEP-29	LL, OM	Pre-liminary TMC4671-ES datasheet.
V0.91	2018-JAN-30	OM	Changed some typos and added some notes.
V0.92	2018-FEB-28	OM	Changed register descriptions.
V0.93	2018-MAR-07	OM	Changed some typos and bugs in graphics.
V0.94	2018-MAR-14	OM	Added Errata Section.
V0.95	2018-MAY-08	OM	Preparations for launch.

Table 27: Document Revision

