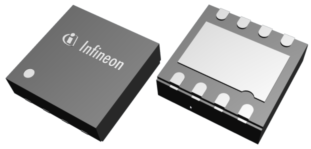
XENSIV™ TLE49012 magnetic angle sensor with SPI, ABZ, UVW, PWM interfaces

Features

- Absolute angle measurement with up to 16-bit resolution
- Flexible use and highly accurate angle sensing with on-device compensation capabilities
  - End-of-Shaft: 0.1°
  - Out-of-Shaft: 0.3°
- System self-calibration (SysCal) for continuous angle error compensation e.g., due to assembly tolerances
- <2 µs latency supporting high dynamic applications with up to 238000 rpm/s
- Ambient temperature range: -40°C to +150°C
- Non-volatile memory (NVM) for storing configuration settings
- ISO 26262 Safety Element out of Context for safety requirements up to ASIL B(D)
- Magnet loss detection, voltage and temperature monitoring
- RoHS (Restriction of Hazardous Substances) compliant and halogen-free PG-VSON-8 package (3×3×0.9 mm^3)



AEC Qualified

RoHS

Green

ISO 26262 compliant

Potential applications

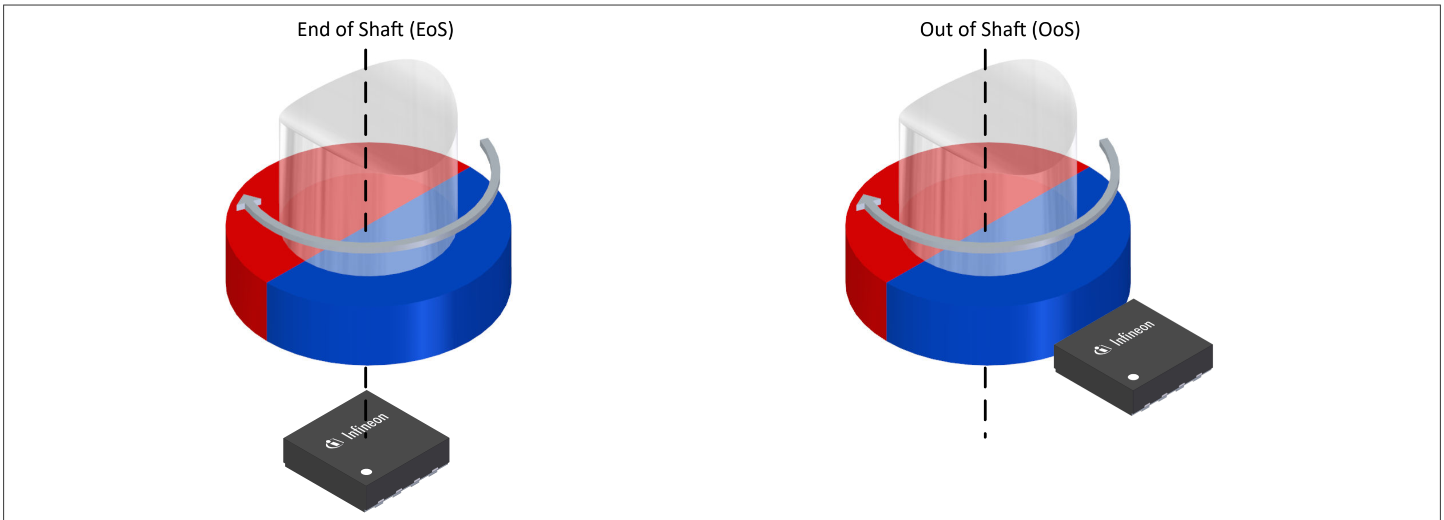
- Steering and braking systems
- Thermal management (pumps, valves)
- Wiper and cleaning systems
- Seat adjustment, seat-belt tensioner
- Window, sunroof, trunk automation
- Brushless direct current (BLDC) motor application to achieve high motor efficiency and high drive performance
- Angular position sensing

Product validation

Product validation according to AEC-Q100, Grade 0. Qualified for automotive applications.

Description

The angle sensor uses vertical Hall technology to provide the absolute magnetic angle via SPI (Serial Peripheral Interface), ABZ (encoder interface), UVW (hall switch mode) or PWM interface. The digital interfaces allow a smooth integration with Infineon's microcontroller and motor driver solutions (MOTIX™, iMOTION™, AURIX™, XMC™, TRAVEO™, PSOC™). The sensor contains advanced processing modules with static and dynamic angle error compensation to eliminate time consuming calibration efforts in the application. The compact PG-VSON-8 package reduces the required board area to a bare minimum. Support for End-of-Shaft (EoS) and Out-of-Shaft (OoS) sensor positioning enables modular integration into drive systems with limited installation space. The sensor is designed to fulfill automotive related quality and safety requirements.



Please read the sections "Important notice" and "Warnings" at the end of this document

Product type	Package	Marking	Ordering code
TLE49012-S0001	PG-VSON-8-2	E12S1	SP005858906

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1 Block diagram

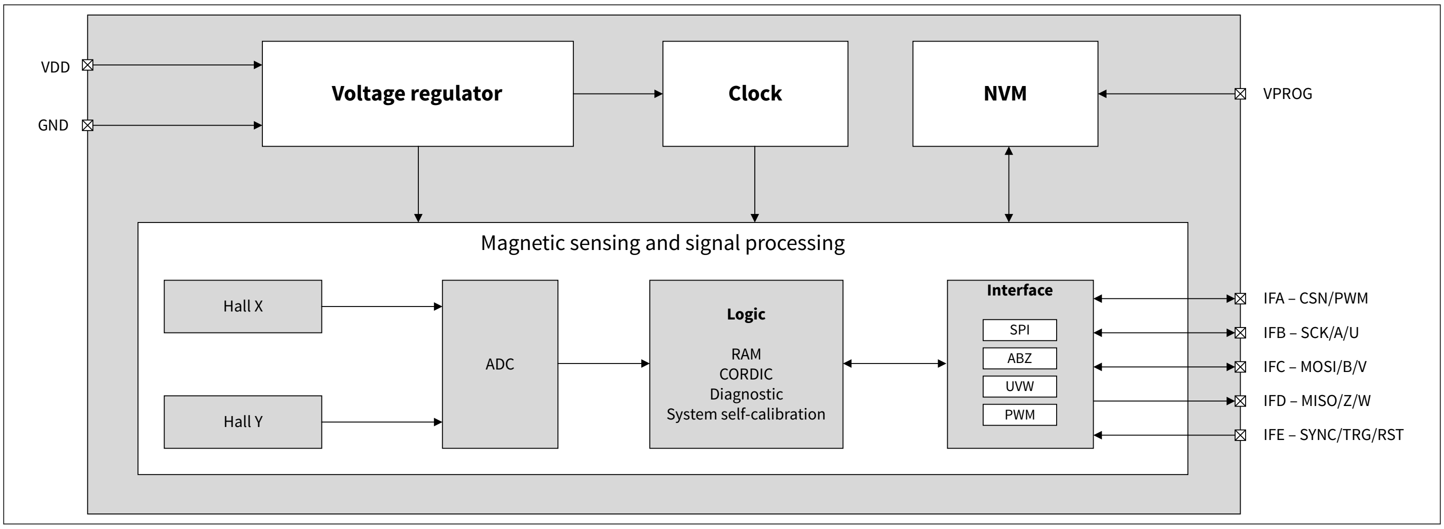

Figure 1 Block diagram

2 Pin configuration

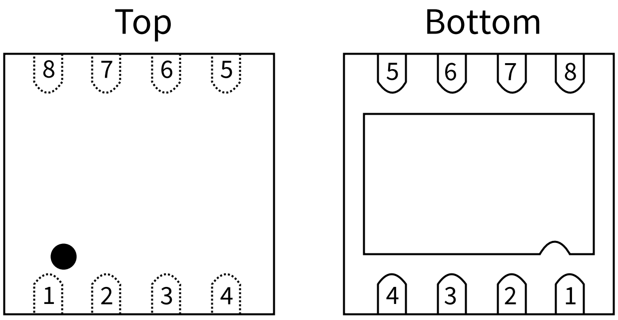

Figure 2 Pin out (PG-VSON-8)

Table 1 Pin definitions and function

Pin No.	Symbol	SPI	ABZ	UVW	PWM
1	IFE	Measurement synchronization (input); *GND*, if unused	Trigger initial pulses or sensor reset (input); *GND* or N.C. , if unused	Trigger sensor reset (input); *GND* or N.C. , if unused	Trigger measurement synchronization or sensor reset (input); *GND* or N.C. , if unused
2	GND	*GND* (supply)	*GND* (supply)	*GND* (supply)	*GND* (supply)
3	VPROG	Programming voltage V_{PROG} (supply); *GND* or N.C. in the application	Programming voltage V_{PROG} (supply); *GND* or N.C. in the application	Programming voltage V_{PROG} (supply); *GND* or N.C. in the application	Programming voltage V_{PROG} (supply); *GND* or N.C. in the application
4	VDD	Supply voltage V_{DD} (supply)	Supply voltage V_{DD} (supply)	Supply voltage V_{DD} (supply)	Supply voltage V_{DD} (supply)
5	IFA	CSN (input)	PWM (output); V_{VDD} or N.C. , if unused	PWM (output); V_{VDD} or N.C. , if unused	PWM (output)
6	IFB	SCK (input)	A (output)	U (output)	A/U (output); *GND* or N.C. , if unused
7	IFC	MOSI (input)	B (output)	V (output)	B/V (output); *GND* or N.C. , if unused
8	IFD	MISO (output)	Z (output)	W (output)	Z/W (output); *GND* or N.C. , if unused
Exposed pad	-	*GND*	*GND*	*GND*	*GND*

***Note**: N.C.: not connected. More information can be found in the interface-specific application diagrams (see Chapter 5).*

3 General product characteristics

3.1 Absolute maximum ratings

Attention: ***Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the section "functional range" of this data sheet is not implied. Furthermore, only single stress/error cases are assumed. Multiple stress/error case may also damage the device. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. During absolute maximum rating overload conditions the voltage on VDD pins with respect to ground (GND) must not exceed the values defined by the absolute maximum ratings. Lifetime statements are an estimation based on an extrapolation of Infineon's qualification test results. The actual lifetime of a component depends on its application conditions, type of use, etc. and may deviate from such statement. Lifetime statements shall in no event extend the agreed warranty period.***

Table 2 Absolute maximum ratings

positive current flowing into pin

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Max. supply voltage (VDD)	$V_{DD,max}$	-0.3	–	7.0	V	limited to 40 h over lifetime
Max. voltage (VPROG)	$V_{PROG,max}$	-0.3	–	24	V	limited to 40 h over lifetime
Max. voltage (IFx)	$V_{x,max}$	-0.3	–	7	V	x = IFA, IFB, IFC, IFD, IFE $V_{x,max} \leq V_{DD} + 0.5V$ limited to 40 h over lifetime
Max. current (IFx)	$I_{x,max}$	–	–	8	mA	x = IFA, IFB, IFC, IFD, IFE limited to 40 h over lifetime
Max. magnetic field	$B_{XY,max}$	-1	–	1	T	magnetic field at the sensor
Max. junction temperature	$T_{J,max}$	-40	–	170	°C	165°C for 1500 h
Storage and shipment temperature	$T_{st,max}$	5	–	40	°C	36 months [1)]
ESD robustness - HBM - all	$V_{HBM,all}$	-2	–	2	kV	all pins [2)]
ESD robustness - CDM - all	$V_{CDM,all}$	-500	–	500	V	all pins [3)]
ESD robustness - CDM - corner	$V_{CDM,corner}$	-750	–	750	V	corner pins [3)]

1) See Application Note "Storage of Products Supplied by Infineon Technologies"
2) Human Body Model (HBM) robustness according to AEC-Q100-002
3) Charged Device Model (CDM) robustness according to AEC-Q100-011 Rev-D; voltage level refers to test condition (TC) mentioned in the standard
Latchup robustness: class II according to AEC - Q100-004.
JEDEC document JEP-155/157 states, that an ESD robustness ≥ 500VHBM and ≥ 250VCDM allows safe manufacturing with basic ESD control.

3.2 Functional range

The following operating conditions must not be exceeded in order to ensure correct operation of the device. All parameters specified in the following sections refer to these operating conditions, unless otherwise noted.

Table 3 Functional Range

positive current flowing into pin

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Supply voltage (VDD)	V_{DD}	3.0	–	5.5	V	
Supply current (VDD)	I_{DD}	–	–	15	mA	
Capacitor (VDD, VPROG)	C_{VDD} C_{VPROG}	80	100	120	nF	connect to GND
Programming voltage (VPROG)	V_{PROG}	14	–	18	V	only required for programming of NVM
Programming current (VPROG)	I_{PROG}	–	–	40	mA	only required for programming of NVM
Start-up time	$t_{start\text{-}up}$	–	1.5	1.7	ms	time from $V_{DD} > V_{DD,UV,th}$ or sensor reset trigger or interface re-configuration until first measurement sample is available to be transmitted on interface
VDD undervoltage reset threshold	$V_{DD,UV,th}$	–	–	2.0	V	
Magnetic induction	B_{XY}	30	–	120	mT	1)
Extended magnetic induction	$B_{XY,ext}$	20	–	30	mT	additional angle error possible 1)
Angle range	α_{range}	0	–	360	°	
Angular velocity range - mech.	n	–	–	30	krpm	optimized range of sensor signal path technically feasible up to 90 krpm
Angular acceleration range	α	-25	–	25	krad/s^2	
Operating temperature range	T_A	-40	–	150	°C	

1) Infineon's online magnetic simulation tool supports the evaluation of magnetic fields based on application conditions.

3.3 Thermal resistance

Table 4 Thermal Resistance

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Thermal resistance JC	$R_{th,jc}$	–	–	8	K/W	junction-to-case
Thermal resistance JA - 2s2p	$R_{th,ja}$	–	–	50	K/W	junction-to-ambient 1)
Thermal resistance JA - 2s0p	$R_{th,ja,2s0p}$	–	–	166	K/W	junction-to-ambient 2)

1) Simulated on a JEDEC51-7 2s2p (2×70 µm, 2×35 µm CU) FR4 (Flame Retardant class 4) reference board (76.2×114.3×1.5 mm^3) at natural convection

2) Simulated on a 2s0p (2×35 µm CU) FR4 (Flame Retardant class 4) reference board (76.2×114.3×1.5 mm^3) at natural convection

4 Product features

4.1 Angle sensing

The magnetic field applied planar to the sensor package top is measured with two vertical Hall elements X and Y. The orthogonally aligned sensing elements measure the X (cosine) and Y (sine) component of the applied magnetic field. The CORDIC (Coordinate Rotation Digital Computer) implementation calculates the absolute angle from the measured X and Y signals.

A diametrically magnetized two-pole magnet (for example, a disc or ring magnet) is sufficient to measure the rotational position of the magnetic field.

The sensor is capable of sensing the angle of a magnetic field in End-of-shaft (EoS) as well as Out-of-Shaft (OoS) position.

The sensor provides an absolute integral non-linearity (INL) angle error of maximum $\alpha_{err,tot}$ after zero angle calibration. The angle error $\alpha_{err,tot}$ includes all environmental conditions such as device aging, full operating temperature T_A and full operating magnetic field strength B_{XY}.

If the sensor is used in extended magnetic field range $B_{XY,ext}$, an angle error adder $\alpha_{err,tot,ext}$ must be considered. Please note that all angle error specifications reflect the intrinsic sensor performance and therefore assume an ideal magnetic field stimulus, which is not the case, for example, in Out-of-Shaft alignment conditions.

The sensor integrates filter options to optimize the trade-off between dynamic angle error and angle/velocity noise based on the targeted application dynamics. The filter bandwidth can be configured via two gain parameters to improve the specified root mean square (RMS) angle noise α_{noise} and angular velocity noise n_{noise}. The filter gains are optimized for rotation speeds up to n and acceleration ratings up to α.

***Note**:* *Please refer to the sensor user´s manual for further information about the dynamic filter settings.*

The angular velocity can be read back via SPI with an accuracy of n_{err} for efficient speed control.

The positive direction of rotation encoding can be configured to clockwise (CW) or counter-clockwise (CCW). By default, a positive direction (angle increase) corresponds to a counter-clockwise (CCW) rotation (see Chapter 6).

The sensor does not have an intrinsic angle hysteresis.

Optionally, an angle hysteresis of ±0.2°, ±0.4°, or ±0.8° can be configured to be robust against mechanical vibrations.

The sensor provides access to the measured field components X and Y, e.g., for calibration purposes. The measurement tolerances of the field components are provided in Table 7.

Table 5 Functional characteristic angle error up to 125°C

If not otherwise specified, T_A= -40°C to 125°C, B_{XY} = 30mT to 120mT, incl. lifetime drift

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
System Self-Calibration (SysCal) enabled - quadrature mode <syscal_mode> = 2						
Angle error (INL) - SysCal	$\|\alpha_{err}\|$	–	–	0.3	°	system self-calibration enabled
Angle error (INL) - SysCal - RT	$\|\alpha_{err,RT}\|$	–	0.03	0.1	°	T_A = 25°C system self-calibration enabled $B_{XY,typ}$ = 55 mT for typ. value
Angle error adder - SysCal - low field	$\|\alpha_{err,ext}\|$	–	–	0.1	°	system self-calibration enabled B_{XY} = 20mT to 30mT

(table continues...)

Table 5 (continued) Functional characteristic angle error up to 125°C

If not otherwise specified, T_A= -40°C to 125°C, B_{XY} = 30mT to 120mT, incl. lifetime drift

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
System Self-Calibration (SysCal) disabled						
Angle error (INL)	$\|\alpha_{err,tot}\|$	–	–	0.7	°	
Angle error (INL) - RT	$\|\alpha_{err,tot,RT}\|$	–	–	0.5	°	T_A = 25°C
Angle error adder - low field	$\|\alpha_{err,tot,ext}\|$	–	–	0.3	°	B_{XY} = 20 mT to 30 mT

Table 6 Functional characteristic angle error up to 150°C

If not otherwise specified, T_A= -40°C to 150°C, B_{XY} = 30mT to 120mT, incl. lifetime drift

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
System Self-Calibration (SysCal) enabled - quadrature mode <syscal_mode> = 2						
Angle error (INL) - SysCal - HT	$\|\alpha_{err,HT}\|$	–	–	0.6	°	system self-calibration enabled
Angle error adder - SysCal - low field - HT	$\|\alpha_{err,ext,HT}\|$	–	–	0.5	°	system self-calibration enabled B_{XY} = 20 mT to 30 mT
System Self-Calibration (SysCal) disabled						
Angle error (INL) - HT	$\|\alpha_{err,tot,HT}\|$	–	–	1.3	°	
Angle error adder - low field - HT	$\|\alpha_{err,tot,ext}\|$	–	–	0.5	°	B_{XY} = 20 mT to 30 mT

Table 7 Functional characteristics sensing

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Measurement Latency	$t_{latency}$	–	–	2	µs	constant velocity
Update time	t_{upd}	–	25	26	ns	new angle available
Angle noise (RMS) - slow	$\alpha_{n,slow}$	–	–	0.02	°	T_A = 25°C; B_{XY} = 70 mT; k1=2; k2=9
Angle noise (RMS) - medium	$\alpha_{n,med}$	–	–	0.035	°	T_A = 25°C; B_{XY} = 70 mT; k1=6; k2=51
Angle noise (RMS) - fast	$\alpha_{n,fast}$	–	–	0.04	°	T_A = 25°C; B_{XY} = 70 mT; k1=11; k2=108
Angle noise (RMS)	α_{noise}	–	–	0.05	°	T_A = -40°C to 150°C; B_{XY} = 70 mT; k1=2; k2=9

(table continues...)

Table 7 (continued) Functional characteristics sensing

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Angular velocity error - high rpm	n_{err}	-4	±1	4	%	$n \geq 1250$ rpm
Angular velocity error - low rpm	n_{err}	-50	–	50	rpm	$n < 1250$ rpm
Angular velocity noise (RMS) - slow	$n_{n,slow}$	–	–	5	rpm	T_A = 25°C; B_{XY} = 70 mT; k1=2; k2=9
Angular velocity noise (RMS) - med.	$n_{n,med}$	–	–	10	rpm	T_A = 25°C; B_{XY} = 70 mT; k1=6; k2=51
Angular velocity noise (RMS) - fast	$n_{n,fast}$	–	–	15	rpm	T_A = 25°C; B_{XY} = 70 mT; k1=11; k2=108
Angular velocity noise (RMS)	n_{noise}	–	–	8	rpm	T_A = -40 to 150°C; B_{XY} = 70 mT; k1=2; k2=9
Hall measurements						
X, Y offset	B_{off}	-0.6	–	0.6	mT	
X, Y sensitivity error	$S_{XY,err}$	-15	–	15	%	$S_{XY} = (S_X + S_Y)/2$ $S_{XY,err}$ = 100% * ($S_{XY} - S_{XY,ideal}$) / $S_{XY,ideal}$ $1/S_{XY,ideal}$ = 6.4 µT/LSB
X, Y mismatch	M_{XY}	-1.7	–	1.7	%	M_{XY} = 100% * 2 * ($S_X - S_Y$) / ($S_X + S_Y$)
X, Y orthogonality	φ_{XY}	-1.4	–	1.4	°	

4.2 Angle calibration

Non-idealities in the sensing system such as magnet tolerances or magnet-sensor position misalignments cause measurement errors. As a result, the measurement system shows a non-linear characteristic over the desired angle range. In particular, a sensor placed Out-of-Shaft will measure an intrinsic angle error caused by the magnet-sensor positioning.

The sensor features two options to calibrate the angle error.

- System self-calibration: the intelligent on-device algorithm continuously compensates and linearizes system-related measurement inaccuracies
- Look-up table: the sensor can be programmed with 32 equidistant or 16 freely programmable correction values to calibrate systematic angle errors

The sensor supports the configuration of a zero angle. The zero angle value is considered as rotational offset and continuously subtracted from the actual measurement.

Note: *The zero angle must be programmed to the sensor after the configuration of the look-up table or initialization of the system self-calibration.*

4.2.1 System self-calibration

The system self-calibration continuously compensates measurement errors caused by non-idealities in the magneto-mechanical measurement system by calculating values for self-calibration. The calibration values are calculated from measurement samples acquired during one to three revolutions depending on the selected calibration mode.

The self-calibrating values to correct system-related inaccuracies comprise of

- Offset O_X, O_Y
- Ellipticity E
- Rotation R

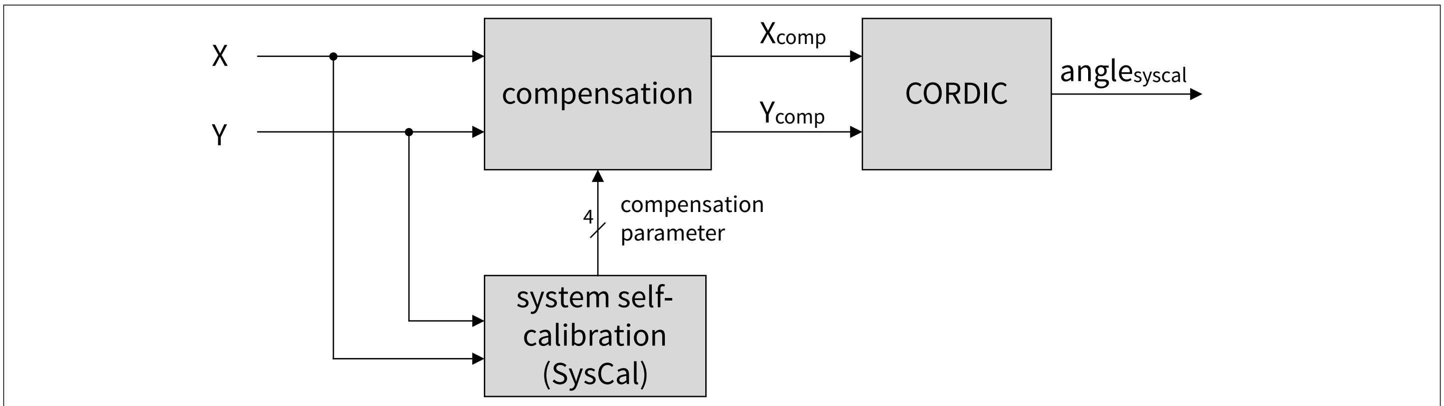

Figure 3 Block diagram of system self-calibration

The calibration values calculated by the system self-calibration can be read back via SPI. The system self-calibration can be initialized by programming calibration values to the NVM. The calibration values from the NVM are used for initial compensation until new calibration values are calculated by the system self-calibration.

The system self-calibration and therefore the calculation and update of the calibration values can be disabled.

4.2.2 Look-up table (LUT)

The sensor allows configuration of 32 equidistant distributed correction values over 360° or 16 freely programmable correction values. The sensor interpolates linearly between the look-up table points.

***Note**:* *It is possible to combine system self-calibration with LUT linearization to achieve the most effective compensation of angle errors.*

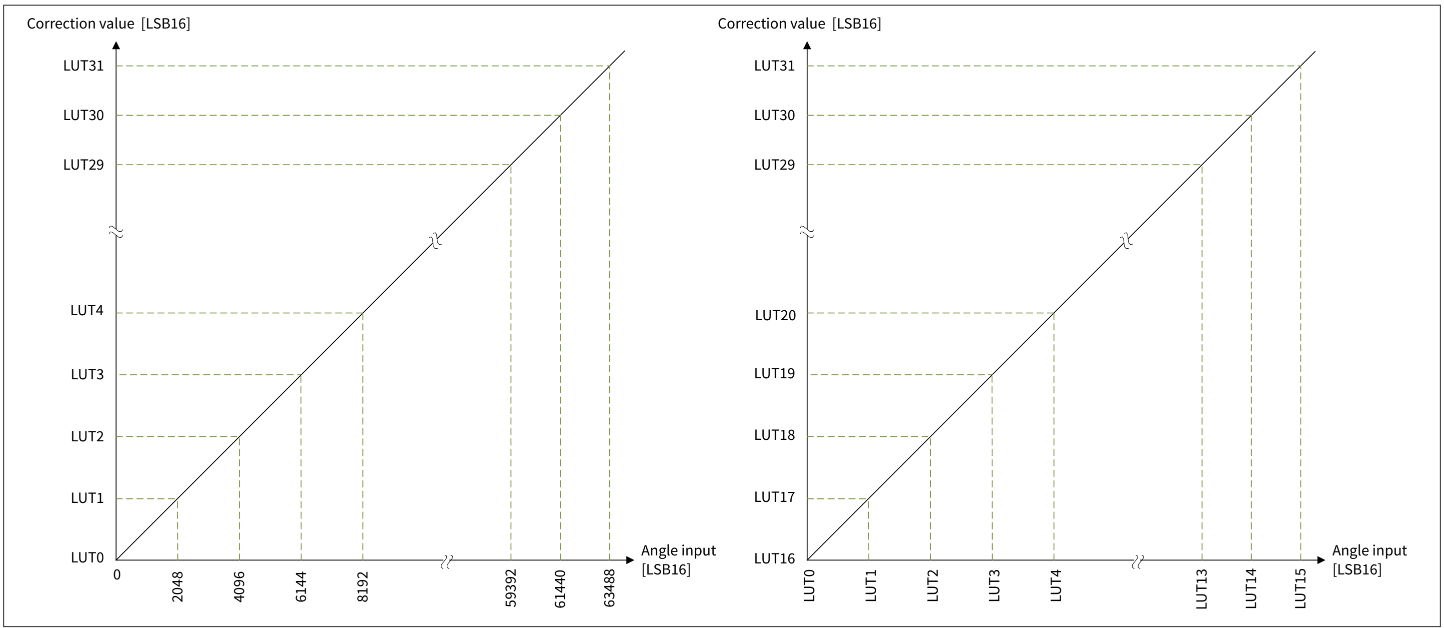

Figure 4 32 equidistant correction values (left) and 16 freely programmable correction values (right)

4.3 Measurement synchronization & reset

The sensor allows different control functions on the IFE pin to ease the application specific implementation effort.

The function assigned to the IFE pin depends on the used interface and configured setting.

- SPI: latches the measured angle and angular velocity to dedicated synchronization registers
- ABZ: triggers initial position pulses or a reset of the sensor logic
- UVW: triggers a reset of the sensor logic
- PWM: synchronizes the measured angle and continuously provides it via the PWM interface or triggers a reset of the sensor logic

The synchronization function (SYNC) provides measurement samples at a defined point in time triggered via the IFE pin. Hence, measurement errors introduced by timing delays due to asynchronous sampling are eliminated. The position measurement can be synchronized with external references such as

- motor current measurement
- PWM pattern used for motor commutation
- microcontroller general purpose output pin (GPIO) for a dual-sensor application

The position trigger function (TRG) offers the possibility to re-trigger the initial position pulses when using the ABZ interface. Therefore, the initialization sequence of the microcontroller is independent of the sensor's start-up time.

The reset function (RST) sets the sensor logic to default configuration.

The sensitive edge at the IFE pin can be programmed to

- a falling edge
- a rising edge (default)
- falling and rising edge
- no edge (pin function deactivated)

4.4 Monitoring

The sensor features following monitoring functions:

- Magnet loss detection with variable thresholds
- Voltage monitoring
- Overtemperature monitoring

The device monitors the magnetic field strength applied at the sensor. The monitoring range is determined by a minimum detection threshold $B_{min,th}$ and a maximum detection threshold $B_{max,th}$. The minimum and maximum detection thresholds are programmable. A magnetic field below the minimum detection threshold $B_{min,th}$ or above the maximum detection threshold $B_{max,th}$ is indicated at the used interface.

In End-of-Shaft configuration, the monitoring thresholds refer to the magnetic vector length. In Out-of-Shaft configuration, the monitoring thresholds refer to the radial magnetic field component.

The magnet loss detection can be disabled with the corresponding configuration bit.

An overtemperature is detected if the measured sensor temperature rises above $T_{OT,th}$. A sensor operation in the overtemperature range is indicated at the used interface.

The sensor temperature can be read via SPI.

The device monitors the internal and external voltage domains. The operation of the sensor in the extended VDD undervoltage range is indicated at used interface.

A power-on reset (POR) is triggered for VDD voltage levels below the undervoltage reset threshold $V_{DD,UV,th}$. The sensor indicates a reset if the VDD voltage rises above $V_{DD,UV,th}$.

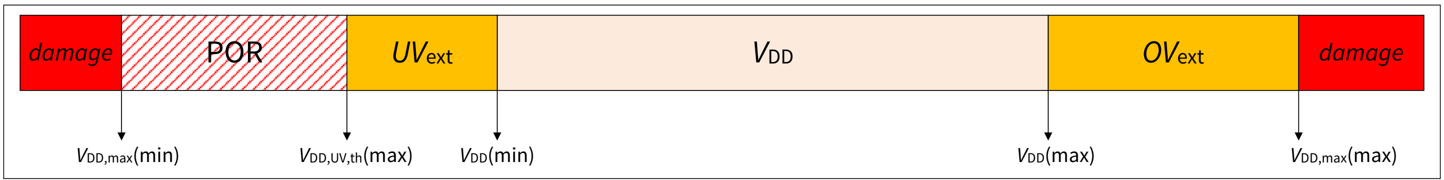

Figure 5 Voltage range overview

Table 8 Functional characteristics monitoring

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Min. magnetic threshold	$B_{min,th}$	16	–	40	mT	configurable threshold range with 3 mT resolution; threshold accuracy refer to S_{XY}
Max. magnetic threshold	$B_{max,th}$	40	–	139	mT	configurable threshold range with 3 mT resolution; threshold accuracy refer to S_{XY}
Overtemperature warning threshold	$T_{OT,th}$	165	–	–	°C	refers to T_J

4.5 Interfaces

The pre-configured interface is SPI.

The pre-configured interface type is available after the start-up time $t_{start\text{-}up}$ has elapsed. The SPI interface can be kept active for programming purpose if SPI is not the pre-configured interface. The SPI interface is kept active if a specific SPI command is sent to the sensor within a timing window at sensor start-up. The timing window begins after t_{SPI_active} and ends with $t_{start\text{-}up}$.

4.5.1 Serial peripheral interface (SPI)

The sensor comprises a four pin (MISO, MOSI, SCK, CSN) Serial Peripheral Interface (SPI) to access the register information or program the NVM, respectively. The SPI is a full-duplex interface and supports multi-slave operation with dedicated CSN lines per slave.

The falling edge of CSN indicates the beginning of a data transmission. The sensor samples data from the microcontroller on MOSI at the falling edge of SCK. The sensor shifts-out data to the microcontroller on MISO at the rising edge of SCK. The communication is terminated by a rising edge of CSN. The MISO line is in high-impedance while there is no communication. The SPI of the device is not daisy chain capable. The SPI frame transmission starts with most significant bit (MSB) first.

The SPI clock polarity is 0 and clock phase is 1 (SPI mode 1).

Note:

- clock polarity 0 (CPOL = 0): first edge = rising edge, second edge = falling edge
- clock phase 1 (CPHA = 1): first edge = shifting data, second edge = sampling data

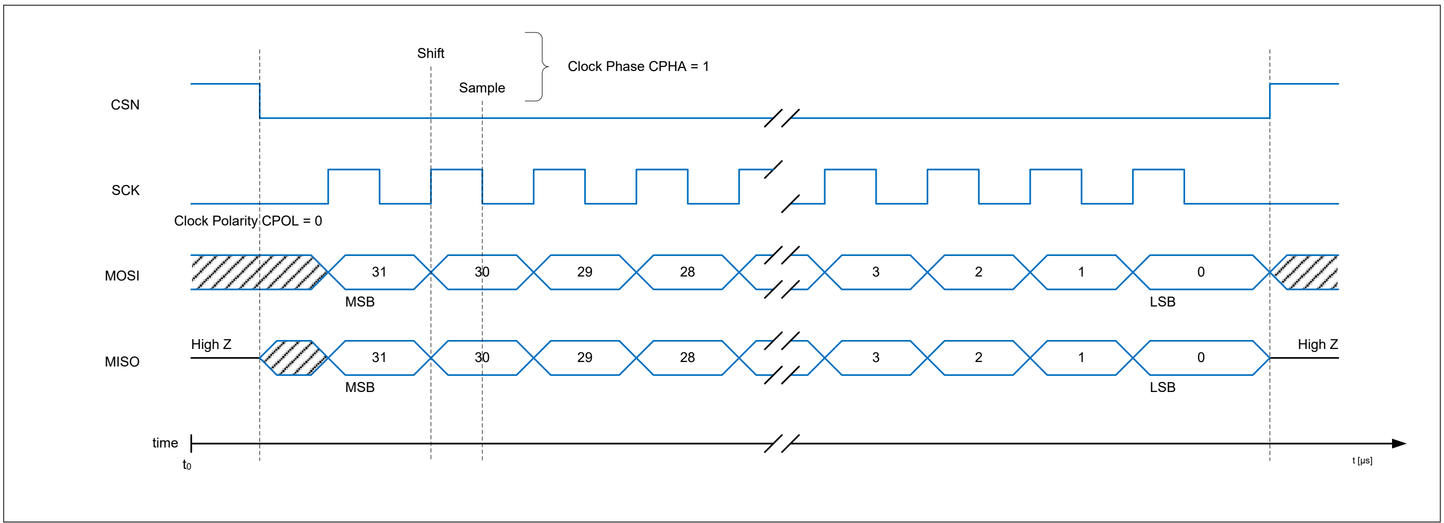

Figure 6 SPI mode 1

The SPI supports a MISO "in-frame" response besides the usual "next-frame" response scheme. The next-frame scheme takes two subsequent read commands to get the logic response from the slave. The in-frame scheme provides the read data within the same transmission frame.

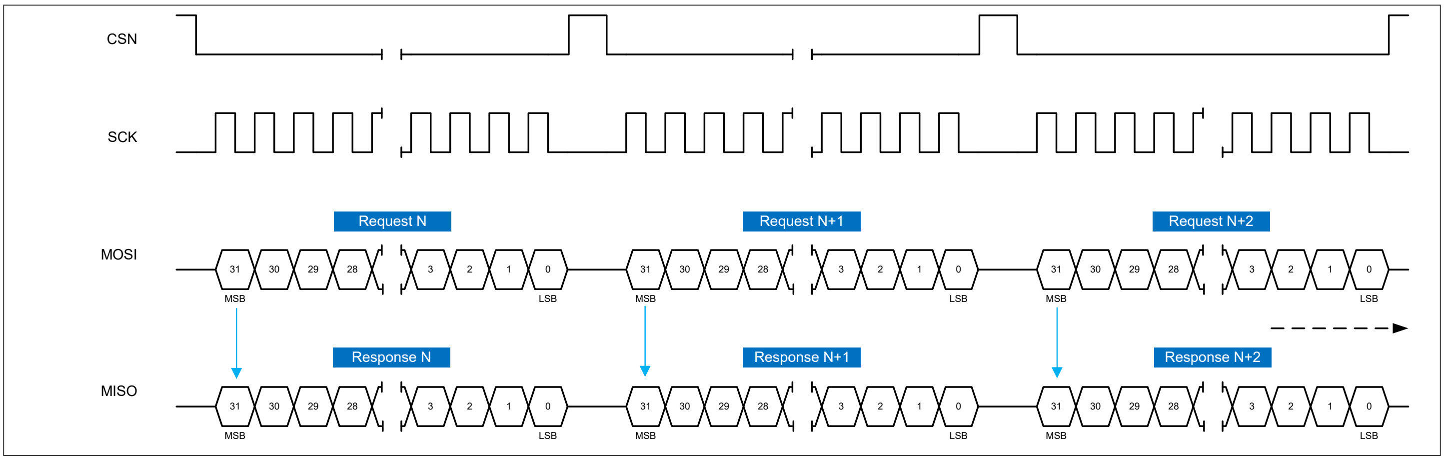

Figure 7 SPI in-frame response scheme

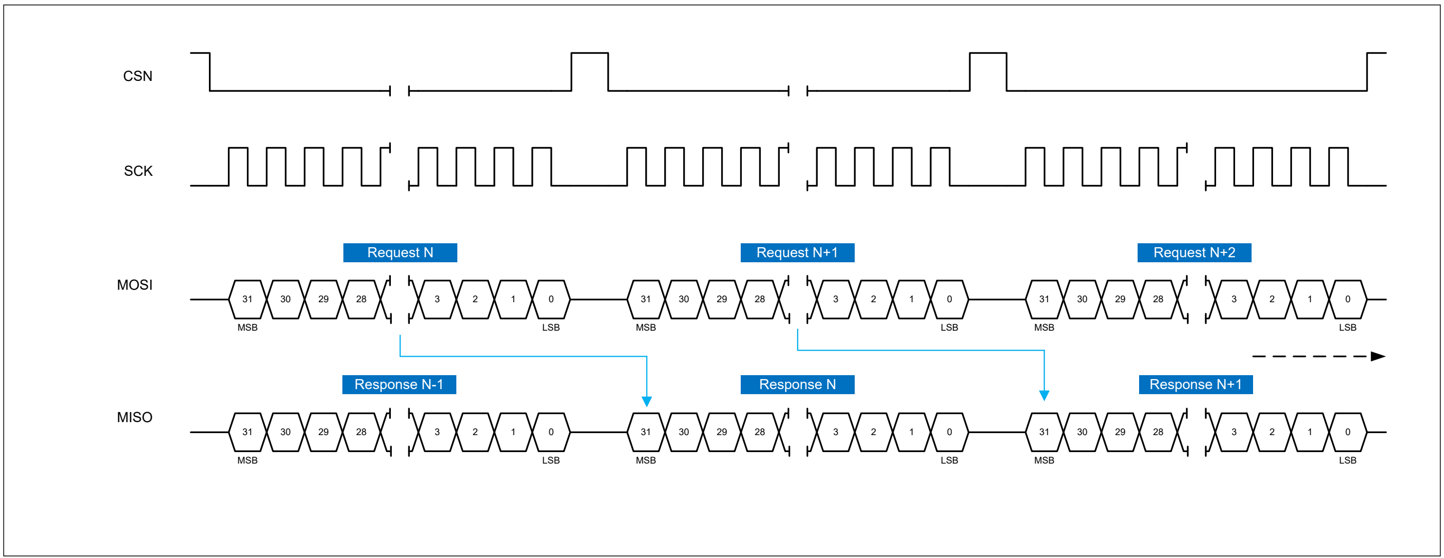

Figure 8 SPI next-frame response scheme

4.5.1.1 Frame definition

The sensor is capable of providing the read data of following registers as in-frame response:

- Angle
- Angle synchronization freeze
- Angle velocity
- Angle velocity synchronization freeze
- Field strength of component X and Y
- Field strength magnitude (vector length)
- Diagnosis information
- Sensor temperature

Data can be written to sensor registers using a write frame. Information can be read from the sensor by using a read frame architecture.

Registers that are not supporting an in-frame transfer scheme are addressed with a next-frame SPI transmission. The next-frame architecture offers access to an extended address range which is required e.g. for programming the LUT. A next-frame access is initiated with a command frame. The command frame defines the register address and the register access type for the next-frame scheme. Subsequent to a command frame the register access can be performed as follows.

- Next-frame read
  - use of "command next-frame" addressing the next-frame read register
  - use of "read next-frame" to read the addressed registers and clear the device status (burst read with address increment)
- Next-frame write
  - use of "write next-frame" to write data to the addressed register (address increment if burst write is selected)

When sending an in-frame transfer request the next-frame transmission is aborted and the data from addressed in-frame register is provided.

4.5.1.1.1 Write in-frame

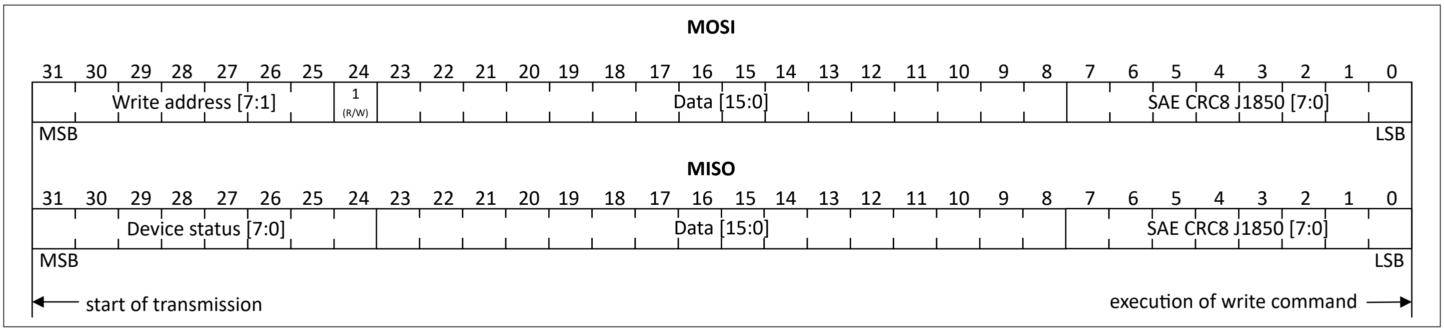

Figure 9 SPI write in-frame

MOSI	
Field [bits]	**Description**
Write address [31:25]	Register address where the data should be written Note: addresses 0x7F and 0x7E are used for next-frame transmission
R/W [24]	**Read/Write** 0_B: read data 1_B: write data
Data [23:8]	Data to be written
SAE CRC8 J1850 [7:0]	8-bit CRC according to AUTOSAR standard SAE-J1850

MISO	
Field [bits]	**Description**
Device status [31:24]	Error and diagnosis information detected by the sensor
Data [23:8]	Provides the data from the addressed register before the write action.
SAE CRC8 J1850 [7:0]	8-bit CRC according to AUTOSAR standard SAE-J1850

4.5.1.1.2 Read in-frame

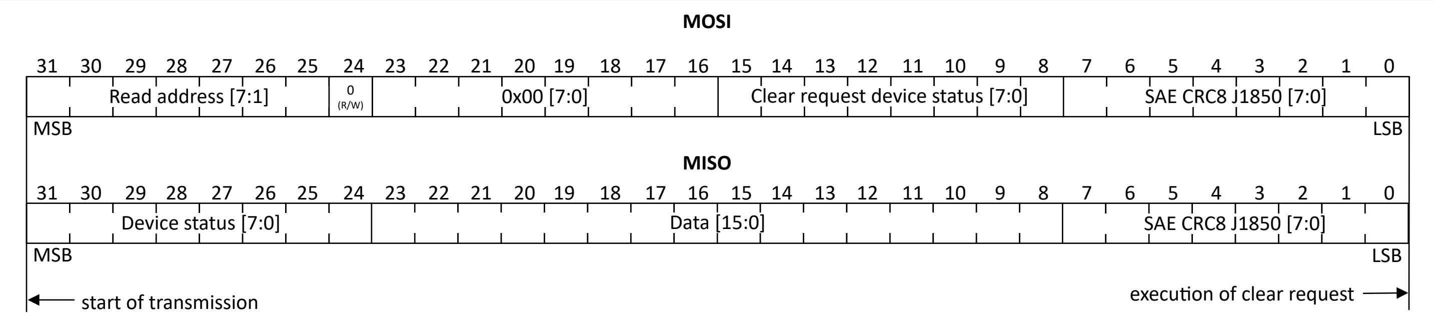

Figure 10 SPI read frame

MOSI	
Field [bits]	**Description**
Read address [31:25]	Register address where the data should be read
R/W [24]	**Read/Write** 0_B: read data 1_B: write data
0x0 [23:16]	unused; write "0"
Clear request device status [15:8]	**Input vector to reset the device status field** 0_B: No clearing of device status bit 1_B: Clear device status bit Note: a reset action to read-only status bits is ignored Note: a reset action of the device status diagnosis field also clears the diagnosis register (OR-combination)
SAE CRC8 J1850 [7:0]	8-bit CRC according to AUTOSAR standard SAE-J1850

MISO	
Field [bits]	**Description**
Device status [31:24]	Error and diagnosis information detected by the sensor
Data [23:8]	Provides the data from the addressed read register
SAE CRC8 J1850 [7:0]	8-bit CRC according to AUTOSAR standard SAE-J1850

4.5.1.1.3 Command next-frame

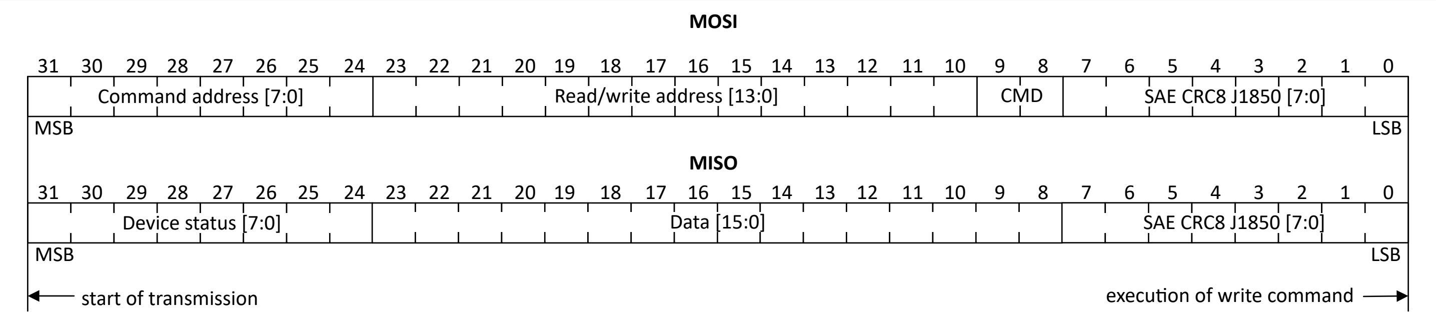

Figure 11 **SPI command next-frame**

MOSI	
Field [bits]	**Description**
Command address [31:24]	0xFF: Command frame address for next-frame transmission and access to extended address range
Read/write address [23:10]	Register address where data should be written or read
CMD [9:8]	**Register access type** 00_B: read with address increment starting from "read/write address" 01_B: continuous write to provided "read/write address" 10_B: burst write with address increment starting from "read/write address" 11_B: reserved
SAE CRC8 J1850 [7:0]	8-bit CRC according to AUTOSAR standard SAE-J1850

MISO	
Field [bits]	**Description**
Device status [31:24]	Error and diagnosis information detected by the sensor
Data [23:8]	Data depends on previous communication frame: • in-frame read: not defined • next-frame read: read data from previously addressed register • in-frame write: not defined • next-frame write: provides data from previously addressed register • after start-up: not defined
SAE CRC8 J1850 [7:0]	8-bit CRC according to AUTOSAR standard SAE-J1850

4.5.1.1.4 Write next-frame

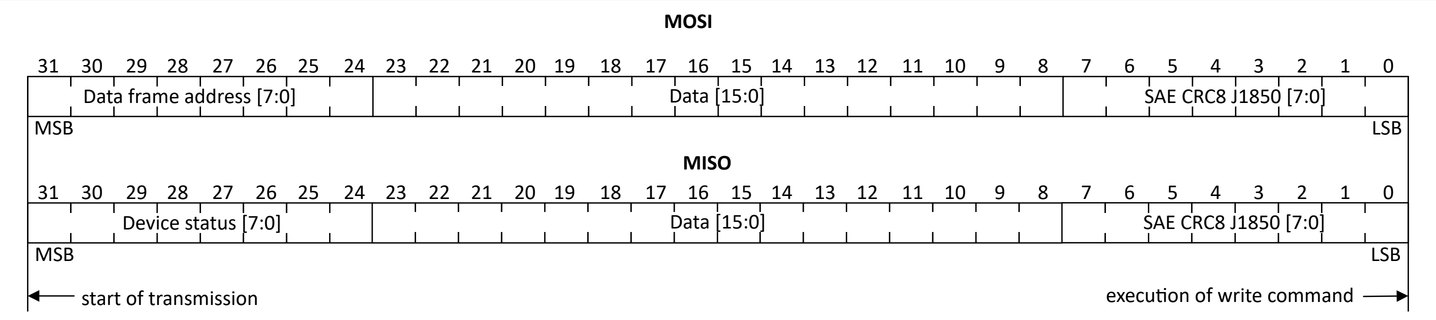

Figure 12 **SPI write next-frame**

MOSI	
Field [bits]	**Description**
Data frame address [31:24]	0xFD: Data frame address for next-frame transmission Note: Read or write access is defined in "command frame"
Data [23:8]	Data to be written to the addressed register
SAE CRC8 J1850 [7:0]	8-bit CRC according to AUTOSAR standard SAE-J1850
MISO	
Field [bits]	**Description**
Device status [31:24]	Error and diagnosis information detected by the sensor
Data [23:8]	Provides the data from the addressed register before write action
SAE CRC8 J1850 [7:0]	8-bit CRC according to AUTOSAR standard SAE-J1850

4.5.1.1.5 Read next-frame

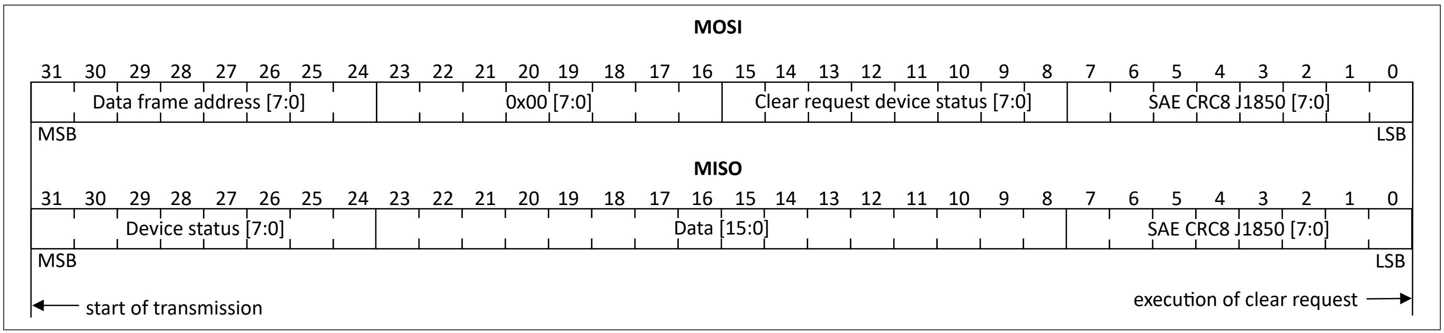

Figure 13 **SPI read next-frame**

MOSI	
Field [bits]	**Description**
Data frame address [31:24]	0xFD: Data frame address for next-frame transmission Note: Read or write access is defined in "command frame"
0x0 [23:16]	unused; write "0"
Clear request device status [15:8]	**Input vector to reset the device status field** 0_B: No clearing of device status bit 1_B: Clear device status bit Note: a reset action to read-only status bits is ignored Note: a reset action of the device status diagnosis field also clears the diagnosis register (OR-combination)
SAE CRC8 J1850 [7:0]	8-bit CRC according to AUTOSAR standard SAE-J1850

MISO	
Field [bits]	**Description**
Device status [31:24]	Error and diagnosis information detected by the sensor
Data [23:8]	Provides the data from the addressed register before clear request
SAE CRC8 J1850 [7:0]	8-bit CRC according to AUTOSAR standard SAE-J1850

4.5.1.1.6 Device status

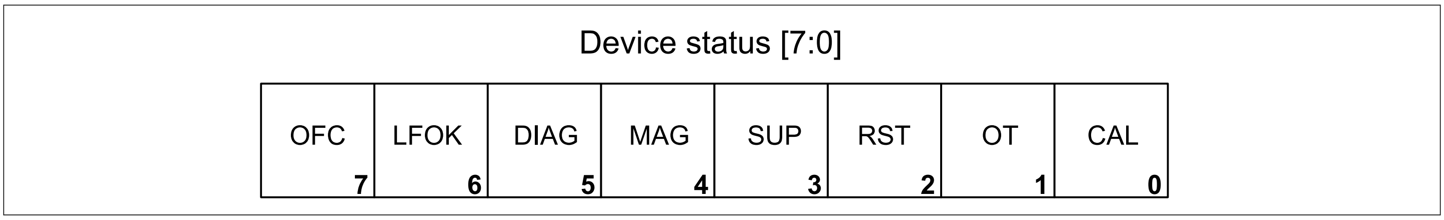

Figure 14 **SPI device status field**

Field [bit]	Type	Description
OFC [7]	r/w	**One frame corrupted** 0_B: SPI frame ok 1_B: at least one SPI frame corrupted
LFOK [6]	r/w	**Last frame ok** 0_B: last MOSI frame was corrupted 1_B: last MOSI frame ok
DIAG [5]	r/w	**Sensor diagnosis information** (OR combination of all diagnosis bits except MAG, SUP, RST and OT) 0_B: no fault diagnosed 1_B: fault occurred Note: The diagnosis register can be read for more detailed diagnosis information Note: A "clear request device status" of 0_B clears all OR-combined diagnosis bits
MAG [4]	r/w	**Magnetic field too high or too low detection** 0_B: magnetic field is within the minimum and maximum magnetic thresholds 1_B: magnetic field exceeded the minimum or maximum magnetic threshold
SUP [3]	r/w	**Extended supply range warning** 0_B: sensor supply is within functional range 1_B: sensor supply operates in extended supply voltage range - warning
RST [2]	r/w	**Reset occurred** 0_B: no sensor reset occurred 1_B: a sensor reset occurred
OT [1]	r/w	**Overtemperature warning** 0_B: sensor temperature within functional range 1_B: sensor operates in overtemperature range - warning
CAL [0]	r	**Indicates the status of the system self-calibration** 0_B: the system self-calibration is disabled or inactive (in initialization phase or failed) 1_B: the system self-calibration is enabled and active (succeeded and the determined calibration parameters are used for angle compensation)

4.5.1.2 Communication error

If the sensor detects an error in the received SPI frame, the data is ignored and discarded by the sensor after the rising CSN edge. The device status bits OFC and LFOK indicate a communication error. The bit OFC is set to 1_B until it is cleared by a "clear request device status". The bit LFOK is set to 0_B in the communication frame subsequent to the erroneous communication frame. Table 9 provides an overview of the communication errors.

If the access of read data is unsuccessful, the sensor will invert the MISO-CRC within the same communication frame to indicate that the provided data is invalid. Additionally, the invalid read data is indicated via OFC and LFOK in the next communication frame.

Table 9 SPI communication error overview

Error type	**Description**	**Response in same MISO frame**	**Indication in next valid MISO frame**	
			OFC bit	LFOK bit
No error	no communication error detected	as defined	0_B	1_B
Timing error	The transfer delay time was too short (MISO data not available yet, MOSI data not processed yet)	device status and data field provide 0x00	1_B	0_B
Polarity error	The SCK signal is high during CSN rising or falling edges	as defined or 0x00	1_B	0_B
Frame error	While CSN = "0", the number of received SCK clock pulses is not equal to 32	as defined	1_B	0_B
In-frame read error	The microcontroller accesses a "next-frame" register with an "in-frame" request (read access time-out)	data field provide 0x00	1_B	0_B
Next-frame command error	The microcontroller performs a "next-frame" write/read without providing the "read/write address" in the previous communication (command frame)	data field provide 0x00	1_B	0_B
CRC error	Incorrect CRC detection in received MOSI frame if MOSI-CRC check is enabled.	as defined	1_B	0_B

4.5.1.3 CRC

The sensor performs a cyclic redundancy check (CRC) for each received SPI frame. A transmitted SPI frame is secured with a CRC to enable data transfer protection.

The 8-bit CRC value is calculated according to *CRC-8 SAE-J1850* (polynomial: 0x1D, seed value: 0xFF, XOR value: 0xFF).

If the microcontroller detects a CRC error on the MISO line, the data should be discarded and the register access should be repeated.

Each MOSI frame contains an 8 bit CRC field at the end of the frame calculated with 24 MOSI frame payload bits:

- payload-byte 0: MOSI bits [31:24]
- payload-byte 1: MOSI bits [23:16]
- payload-byte 2: MOSI bits [15:8]

Note: The calculation starts with payload-byte 0

Each MISO frame contains an 8-bit CRC field at the end of the frame calculated with 8 MOSI payload bits and 24 MISO frame payload bits:

- payload-byte 0: dummy 0_B [MSB] + MOSI bits [31:25]
- payload-byte 1: MISO bits [31:24]
- payload-byte 2: MISO bits [23:16]
- payload-byte 3: MISO bits [15:8]

Note: The calculation starts with payload-byte 0

The MOSI frame CRC check of the sensor can be disabled. The data in the MOSI-CRC-bitfield is ignored.

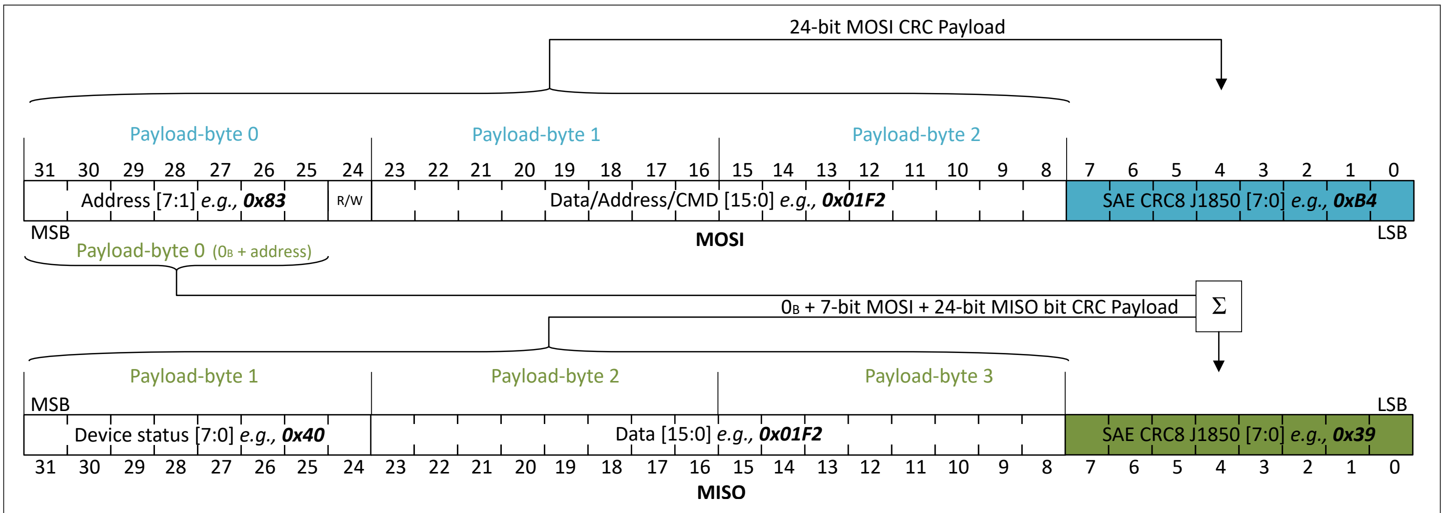

Figure 15 **Illustration of SPI CRC payload for MOSI and MISO frame with pseudo data as example (valid for all frame types)**

4.5.1.4 SPI timing

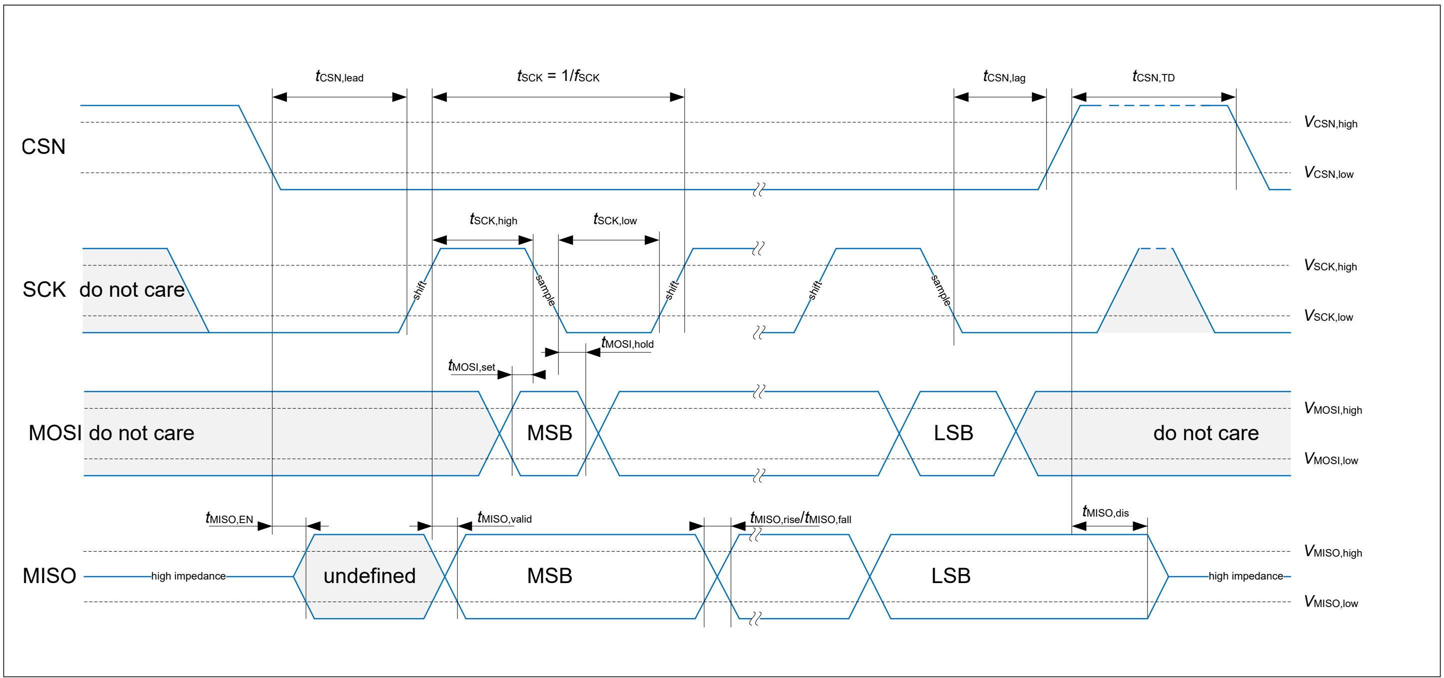

Figure 16 **SPI timing diagram**

Table 10 **Timing characteristics SPI interface**

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Serial clock period	t_{SCK}	100	–	–	ns	$f_{SCK} = 1/t_{SCK}$ = 10 MHz
Serial clock high time	$t_{SCK,high}$	40	–	–	ns	
Serial clock low time	$t_{SCK,low}$	40	–	–	ns	
Enable lead time	$t_{CSN,lead}$	100	–	–	ns	falling CSN to rising SCK
Enable lag time	$t_{CSN,lag}$	100	–	–	ns	falling SCK to rising CSN
Transfer delay time	$t_{CSN,TD}$	500	–	–	ns	rising CSN to falling CSN
Data setup time	$t_{MOSI,set}$	20	–	–	ns	MOSI to falling SCK
Data hold time	$t_{MOSI,hold}$	20	–	–	ns	falling SCK to MOSI
Output rise/fall time	$t_{MISO,rise}$ $t_{MISO,fall}$	–	–	25	ns	output load capacitance < $C_{x,load}$
Output enable time	$t_{MISO,en}$	–	–	50	ns	falling CSN to MISO valid output load capacitance < $C_{x,load}$
Output disable time	$t_{MISO,dis}$	–	–	50	ns	rising CSN to MISO tri-state output load capacitance < $C_{x,load}$

(table continues...)

Table 10 (continued) Timing characteristics SPI interface

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Output data valid time	$t_{MISO,valid}$	–	–	30	ns	SCK rising to MISO output load capacitance < $C_{x,load}$
SPI activation time	t_{SPI_active}	500	–	–	µs	after V_{DD} > $V_{DD,UV,th}$ or reset trigger

4.5.2 Incremental interface (ABZ)

The ABZ interface is the perfect choice for high-speed applications such as electrically commutated motor drives. The incremental interface (ABZ interface) emulates an optical encoder. The interface consists of three uni-directional signal lines. The signals A and B provide the angle and the direction information. The incremental interface encodes the relative position (angle change) with digital pulses. The summed up pulse count with respect to a reference position decodes the absolute position. An index pulse on the Z line indicates a 0° crossover (full rotation). The index pulse can be used for reference and synchronization purpose.

The quadrature resolution *QR* of the ABZ interface represents the number of angle increments per revolution. The quadrature resolution *QR* is determined by the number of pulses per revolution *PPR.* The number of pulses per revolution is configurable. An angle hysteresis can be configured for robustness against mechanical vibrations (see Chapter 4.1).

The incremental (ABZ) interface is configurable in either A/B-Mode or Step-Direction-Mode. The selected mode determines the rotation direction encoding.

- In A/B-mode, the phase shift between phases A and B indicates either a positive (if B follows A), or a negative (if A follows B) rotation direction of the magnet.
- In Step-Direction-Mode, the level of the B signal represents either a positive (if B is high-level), or a negative (if B is low-level) rotation direction of the magnet.

The Z line transmits an index pulse at each 0° crossing in both ABZ-modes.

All communication lines (A, B, Z) are kept in a high level state as long as a detected fault is present.

The ABZ is kept active and a detected fault is indicated on the PWM interface if the PWM interface is used in parallel.

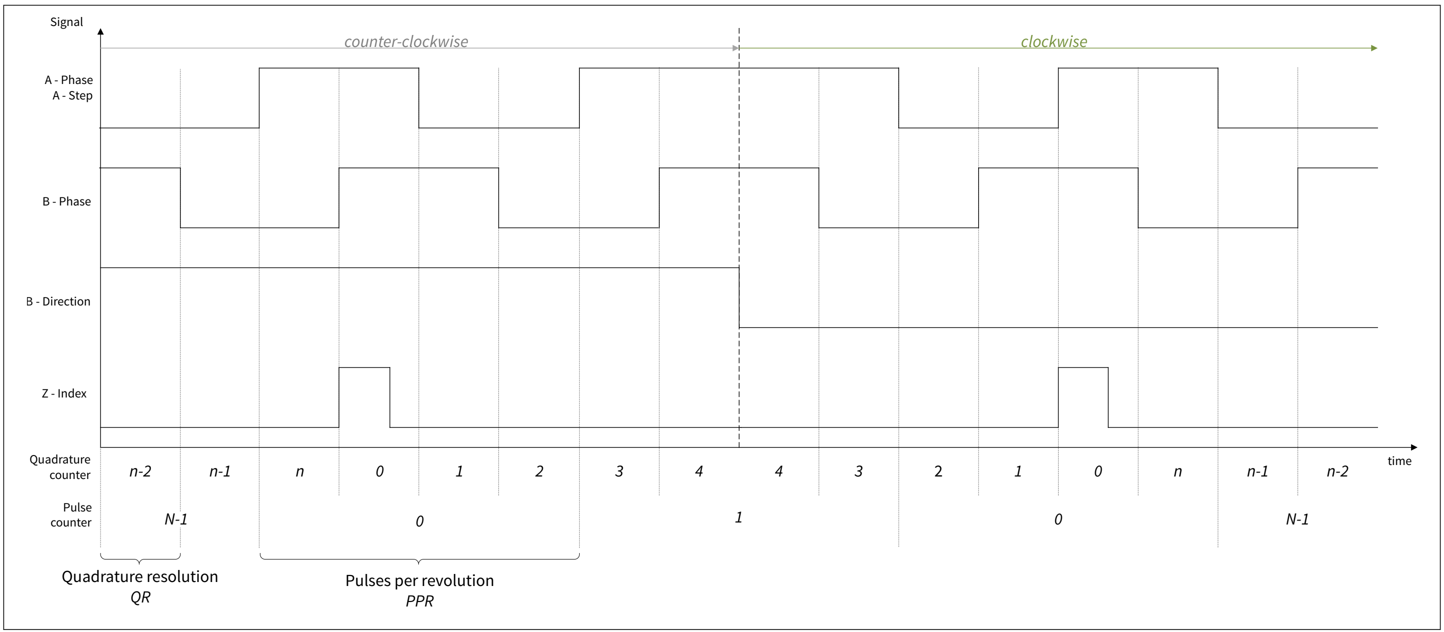

Figure 17 **Incremental interface modes and the corresponding signals (simplified)**

4.5.2.1 Index pulse

The index pulse Z is configured to be either gated or ungated with the A/B phase signals.

- Gated with
  - both A and B high phase

  - only A high phase
  - only B high phase
- Ungated with pulse length τ_Z
  - The rising edge of the index pulse Z is synchronized with the rising edge of the B phase at counter-clockwise magnet rotation.
  - The rising edge of the index pulse Z is synchronized with the rising edge of the A phase at clockwise magnet rotation.

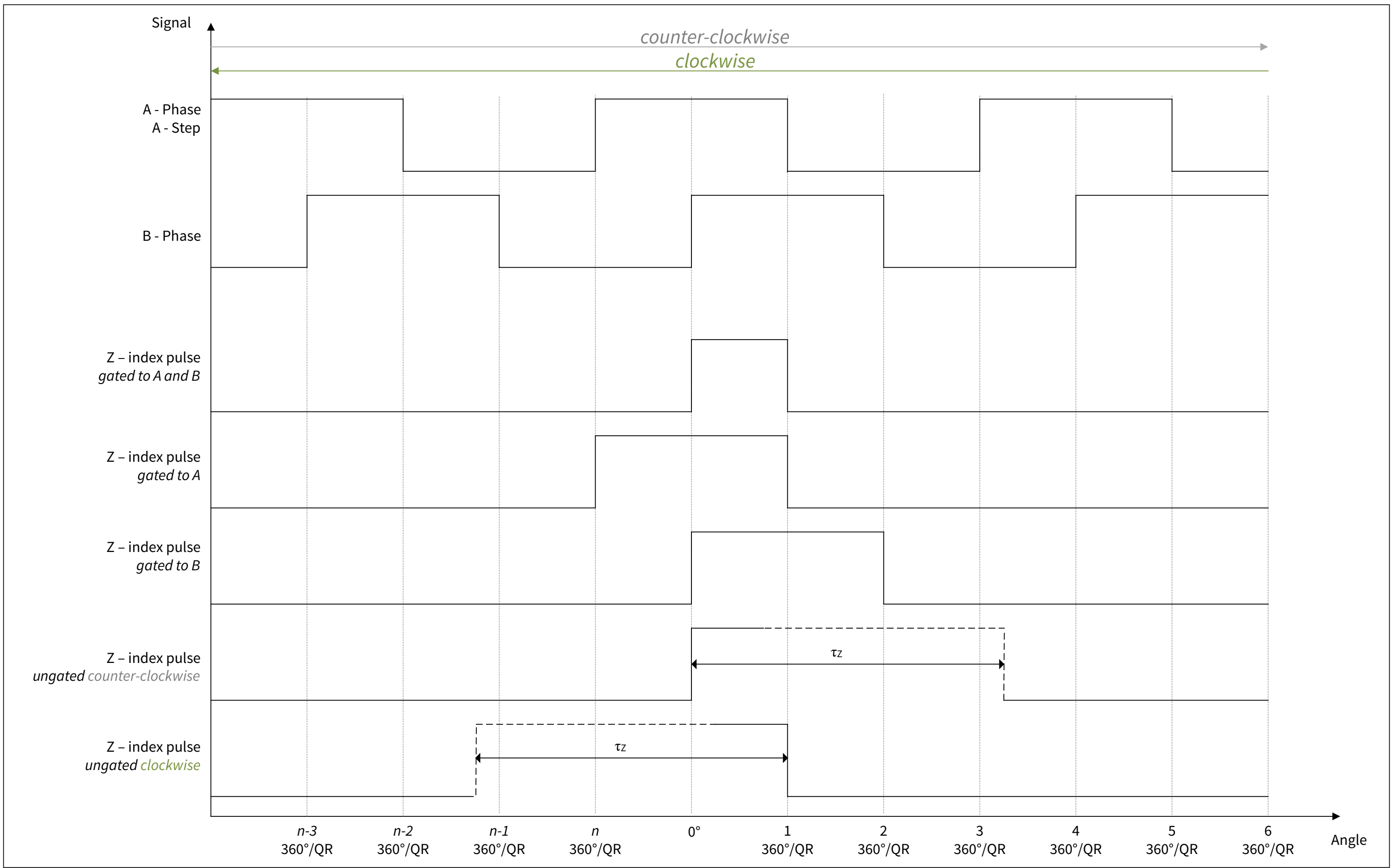

Figure 18 **Index pulse configuration options (simplified)**

4.5.2.2 Initial position

The sensor provides the absolute position after start-up to avoid the need for a partial rotation to the home position (index pulse at 0°).

The ABZ interface provides the absolute angle value by outputting angle increments starting from 0°. The absolute position is output after sensor start-up, sensor reset, or after triggering an initial position request via IFE (see Chapter 4.3). The frequency of the initial position pulses is $f_{ABZ,init}$. The amount of pulses depends on the initial position and the configured pulses per revolution. The absolute angle value that is closer to 0° determines the direction encoding. The direction encoding at 180° is counter-clockwise.

Example: An initial position of 270° is indicated by outputting 90° clockwise instead of outputting 270° counter-clockwise.

The initial position output pulses can be deactivated.

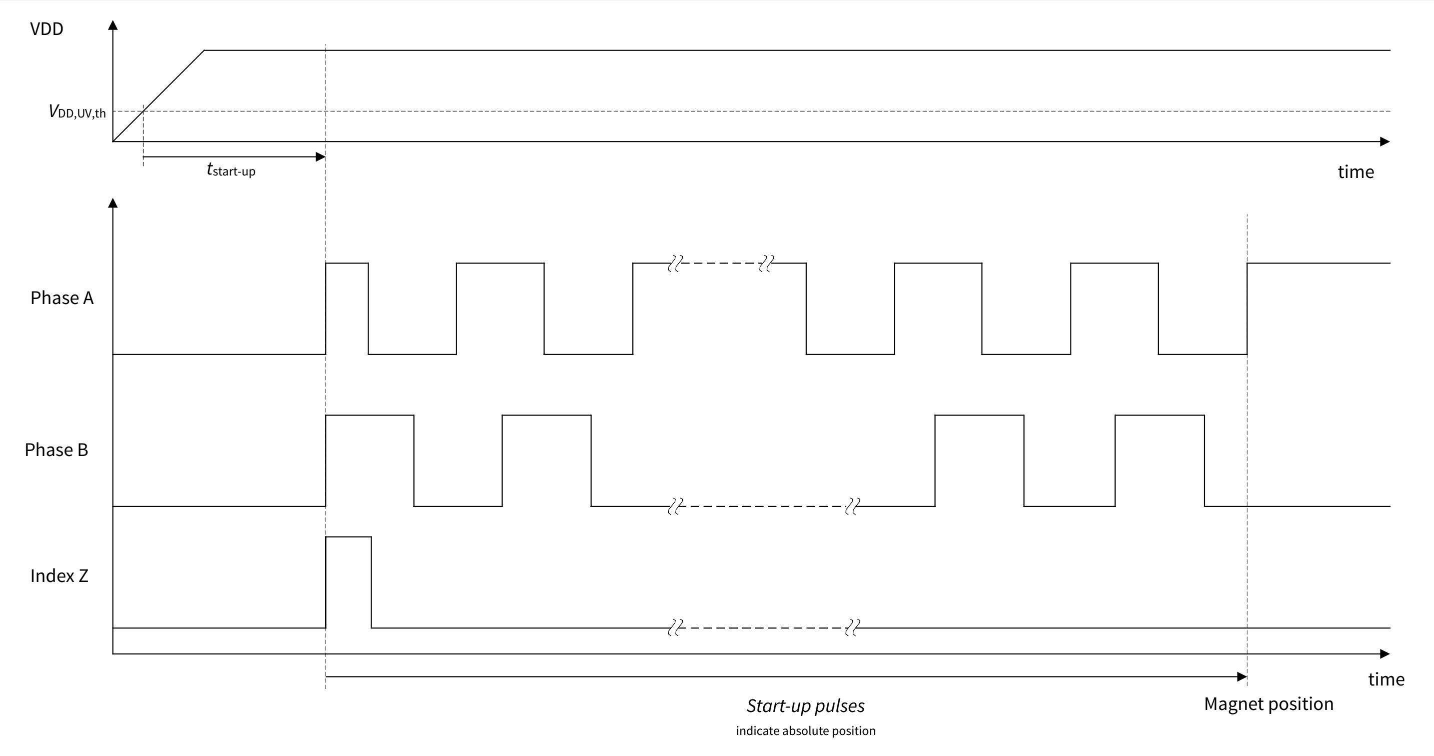

Figure 19 **Start-up pulses for initial magnet position in A/B-mode (simplified)**

4.5.2.3 ABZ characteristic

Table 11 **Electrical characteristic ABZ**

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Pulses per revolution	*PPR*	1	–	4096	counts	quadrature resolution *QR* = 4 * *PPR*
Z pulse length - ungated	τ_Z	4.8	5	5.2	µs	ungated index pulse
Frequency initial position pulses	$f_{ABZ,init}$	3.6	4	4.4	MHz	phase frequency

4.5.3 Hall switch mode (UVW)

The UVW interface emulates the signals of three hall switches. An array of three hall switches aligned with a rotational offset is typically used for motor commutation. The UVW signals can be directly used to feed the commutation logic. The output pattern of the UVW signals represents the electrical angular sector of the rotor position. The amount of angular sectors per mechanical revolution scales with the number of motor pole pairs n_{pp}. The number of pole pairs n_{pp} can be configured. An angle hysteresis can be configured for robustness against mechanical vibrations (see Chapter 4.1).

The signal V lags signal U by 120°(el.). The signal W lags the signal V by 120°(el.). The signal U transitions from low to high at 0° for counter-clock-wise rotation.

All communication lines (U, V, W) are kept in a low level state as long as a detected fault is present.

The UVW is kept active and a detected fault is indicated on the PWM interface if the PWM interface is used in parallel.

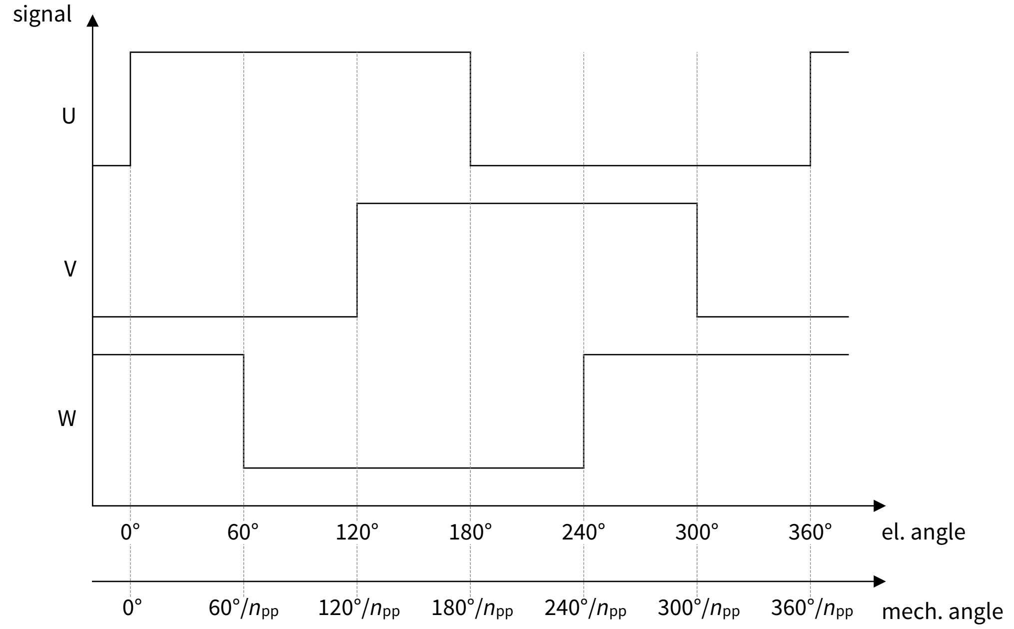

Figure 20 UVW interface switching pattern

Table 12 Electrical characteristic UVW

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Pole Pairs	n_{pp}	1	–	16	pole pairs	configurable

4.5.4 Pulse width modulation (PWM)

The pulse-width-modulated (PWM) output is a uni-directional interface providing a duty cycle *DC* proportional to the measured angle. The target PWM frequency f_{PWM} is configurable. The duty cycle is calculated from the ratio of the "high" time to the period. An increasing duty cycle corresponds to an increasing angle value, with an angle of 0° having the smallest duty cycle. The starting edge of the PWM protocol can be programmed as rising or falling edge.

The PWM interface can be used as standalone one-wire interface or in parallel to the ABZ or UVW interface. The PWM output can be deactivated.

Duty cycles above or below the operational duty cycle *DC* are used for diagnosis purpose. The duty cycle is kept in the low diagnosis range DC_{low} or high diagnosis range DC_{high} as long as the detected fault is persistent.

- DC_{low}: sensor diagnosis detected a fault
- *DC:* functional range with duty cycle proportional to angle
- DC_{high}: sensor reset occurred (indicated once after reset)

Table 13 Electrical characteristic PWM

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
PWM frequency	f_{PWM}	0.25	2	4	kHz	configurable
PWM frequency - tolerance	$f_{PWM,tol}$	-4	–	4	%	relative to configured PWM frequency
PWM resolution	R_{PWM}	12	–	16	bit	R_{PWM} = log2(40MHz / f_{PWM})
Duty cycle - data - maximum	*DC*	94.9	95	95.1	%	angle encoding
Duty cycle - data - minimum	*DC*	4.9	5	5.1	%	angle encoding
Duty cycle - diagnosis low	DC_{low}	1	2	3	%	
Duty cycle - diagnosis high	DC_{high}	97	98	99	%	

4.5.5 Programming interface

The default configuration is loaded from the non-volatile memory (NVM) during start-up phase. The sensor reset configuration can be adapted by overwriting the default register values. A non-volatile storage of the configuration-set requires the programming of the NVM.

The NVM can be programmed via the SPI interface. The programming voltage V_{VPROG} must be applied at the VPROG pin and the SPI interface must be active to program the NVM. Each word of the NVM can be programmed once.

Note: *If SPI is not the default interface, it must be activated for programming as described in* Chapter 4.5

The NVM programming can be triggered with a programming command and takes t_{prog}. After programming is complete, a sensor reset must be performed to load the newly programmed configuration set from the NVM.

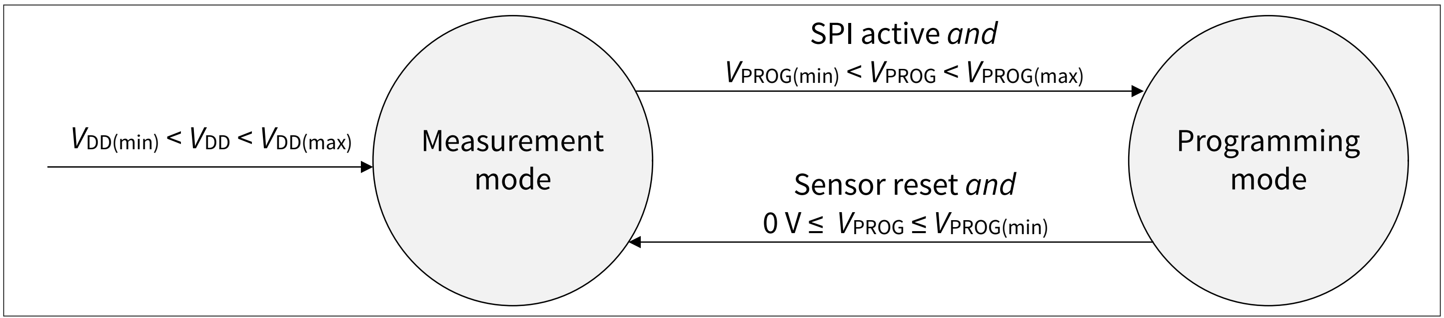

Figure 21 Sensor states for normal operation (measurement mode) and for programming the NVM

Table 14 Electrical characteristic NVM

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Data retention time	t_{ret}	–	–	18	a	includes 15a lifetime and 3a storage time
Programming time	t_{prog}	–	–	500	µs	time interval from programming command until finished programming for one line per NVM

4.6 Input/output characteristic

Table 15 Electrical characteristics input/output

positive current is flowing into pin

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Output voltage - low level	$V_{x,out,low}$	–	–	$0.2*V_{DD}$	V	x = IFA, IFB, IFC, IFD $I_{x,sink}$ = 2 mA
Output voltage - high level	$V_{x,out,high}$	$0.8*V_{DD}$	–	–	V	x = IFA, IFB, IFC, IFD $I_{x,source}$ = -2 mA
Input voltage - low level	$V_{x,in,low}$	–	–	$0.3*V_{DD}$	V	x = IFA, IFB, IFC, IFE
Input voltage - high level	$V_{x,in,high}$	$0.7*V_{DD}$	–	–	V	x = IFA, IFB, IFC, IFE
Input hysteresis voltage	$V_{x,hys}$	100	–	500	mV	x = IFA, IFB, IFC, IFE
Pull down current	$I_{x,PD}$	25	–	60	µA	x = MOSI, SCK $V_x = V_{x,in,low}$
Pull up current	$I_{x,PU}$	-60	–	-25	µA	x = CSN $V_x = V_{x,in,high}$
Tristate leakage current	$I_{IFD,off}$	-10	–	10	µA	MISO $V_{CSN} > V_{x,in,high}$ $0\ V < V_{MISO} < V_{DD}$
Capacitive load	$C_{x,load}$	–	–	50	pF	x = IFA, IFB, IFC, IFD
Pin input capacitance	$C_{x,in}$	–	–	10	pF	x = IFA, IFB, IFC, IFE MISO Tri-State

5 Application information

The SPI application circuit is valid for programming the sensor because the SPI-interface is used as programming interface.

More detailed application diagram for non-volatile programming use case can be found in the user manual.

Not used interface-pins (IFx) can be left floating or connected to nets as shown in the application diagrams.

The sensor must be supplied via VDD during use of interface-pins to avoid reverse sneak-paths through the sensor.

The programming voltage V_{PROG} must only be supplied during non-volatile programing of the sensor. C_{VPROG} is recommended for electromagnetic compatibility (EMC) robustness if VPROG is connected to a global connector (off-PCB connection).

The exposed pad of the sensor can be connected to *GND* potential in all use cases.

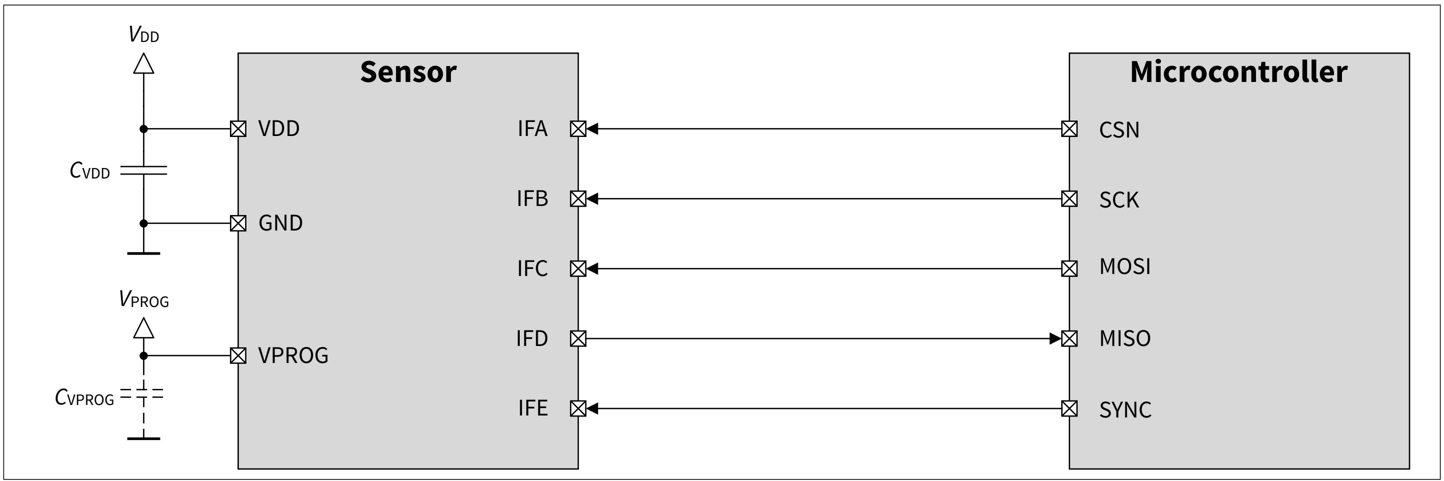

Figure 22 Application diagram - SPI

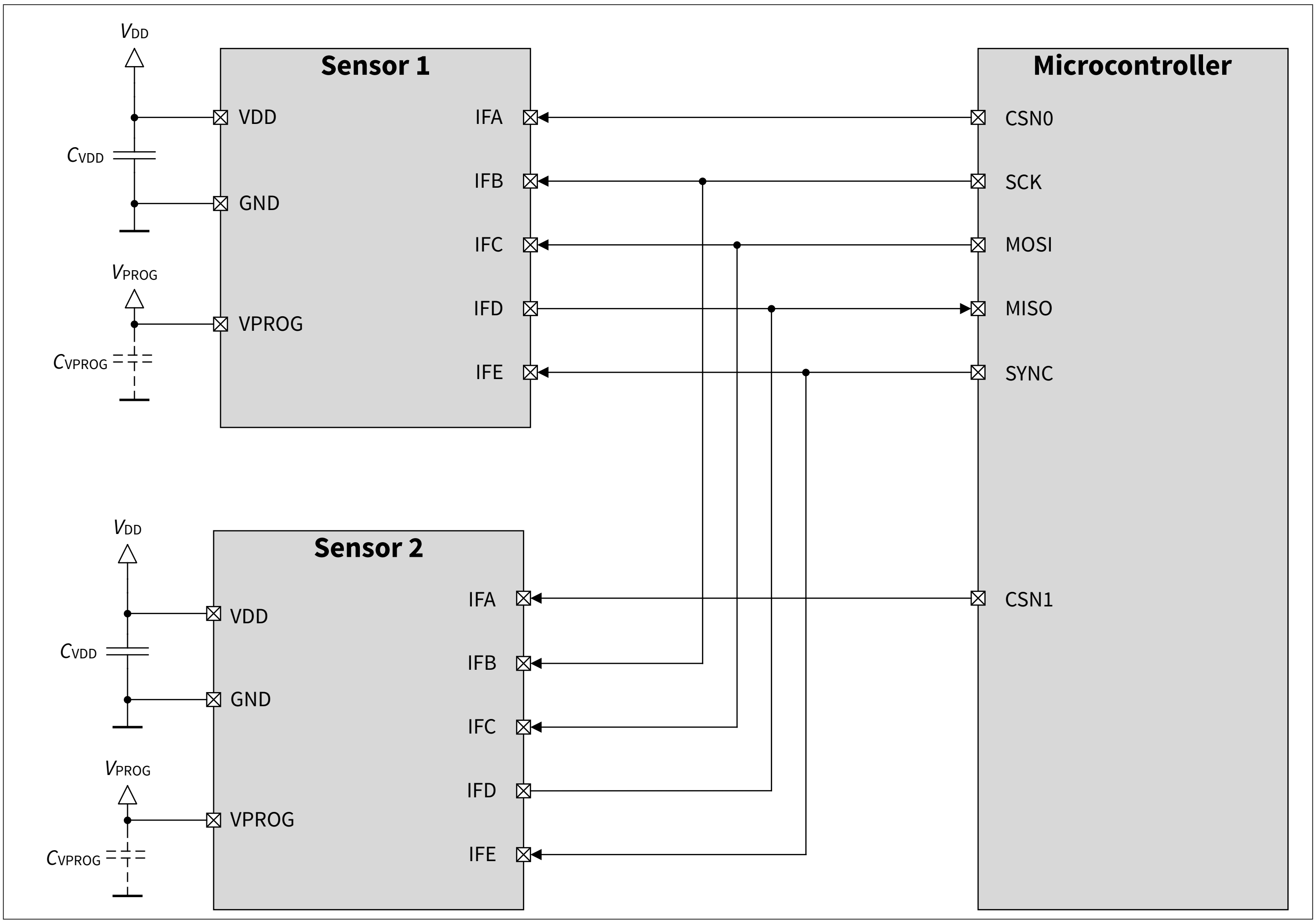

Figure 23 Application diagram - SPI multi slave

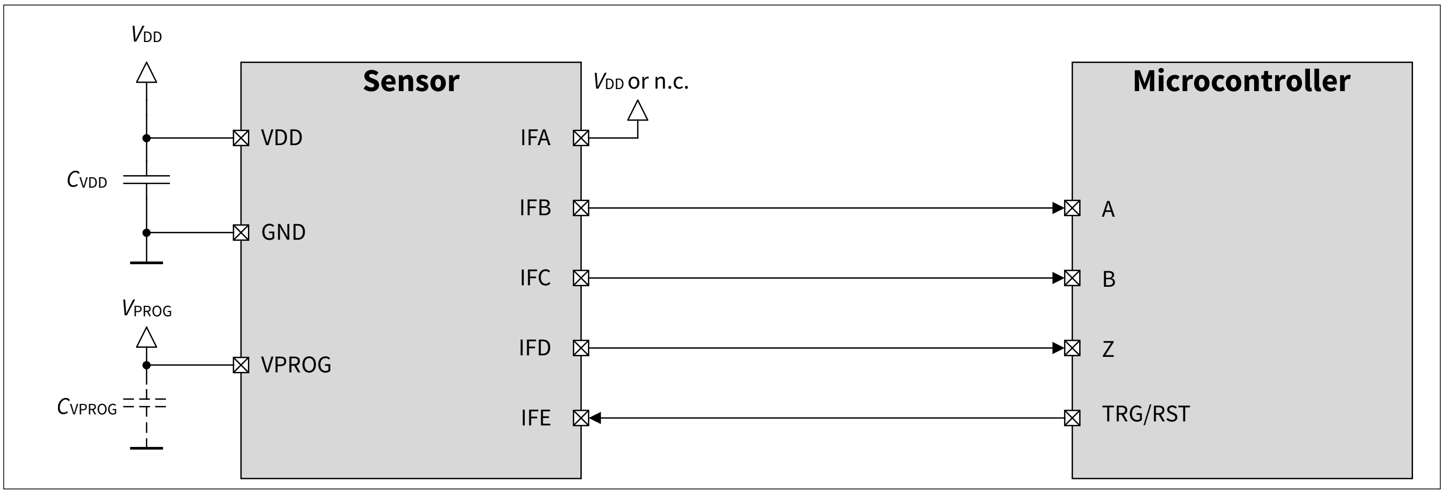

Figure 24 Application diagram - ABZ (encoder mode)

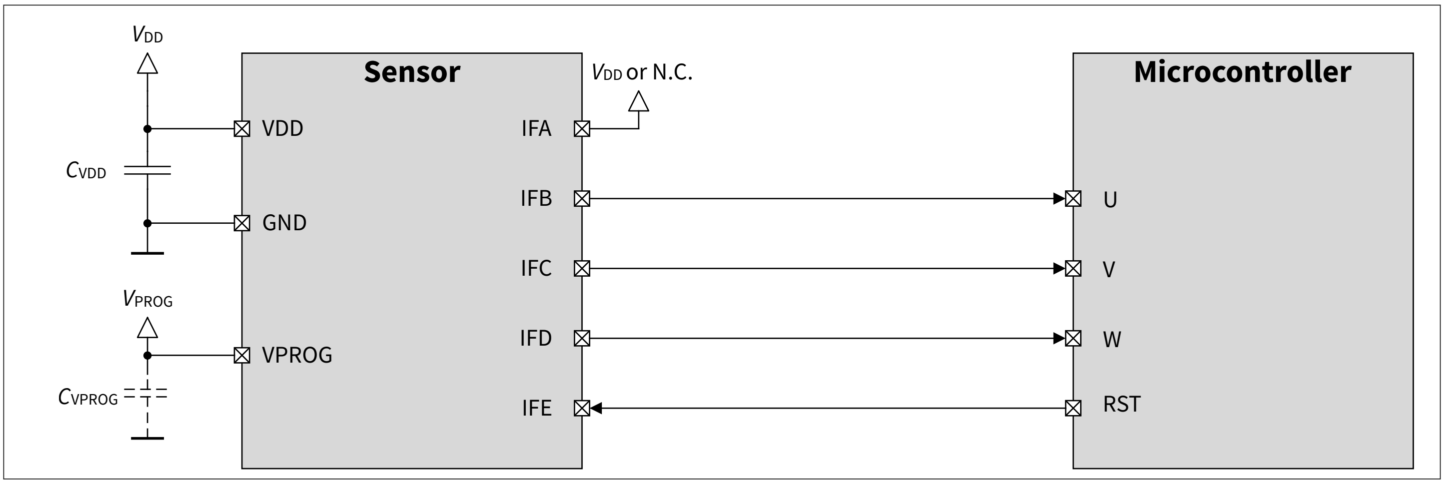

Figure 25 Application diagram - UVW (hall switch mode)

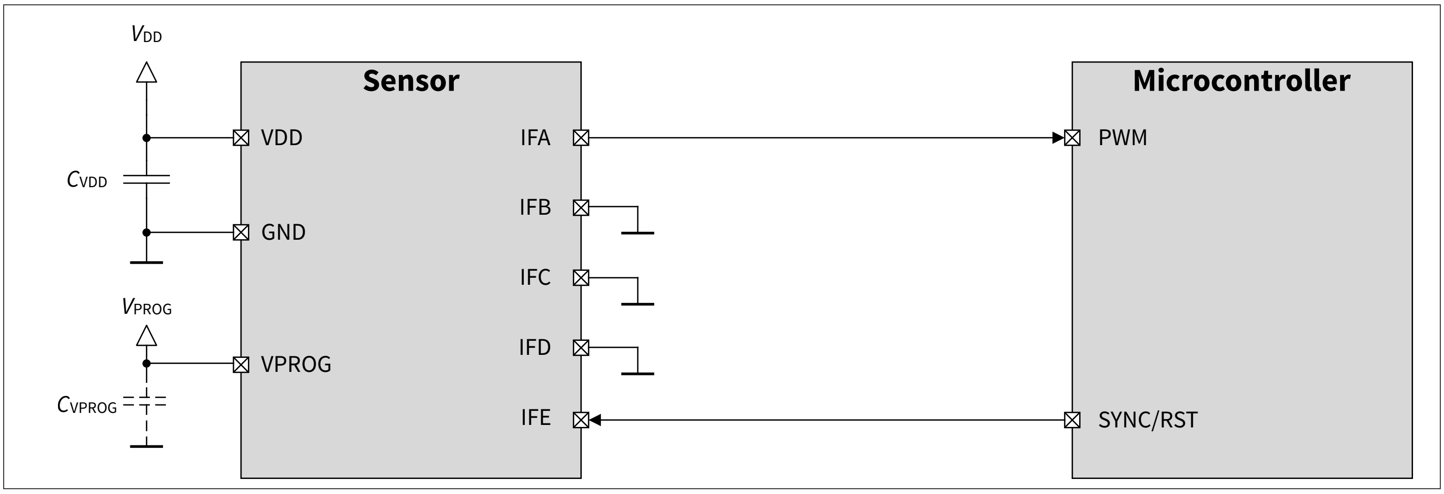

Figure 26 Application diagram - PWM

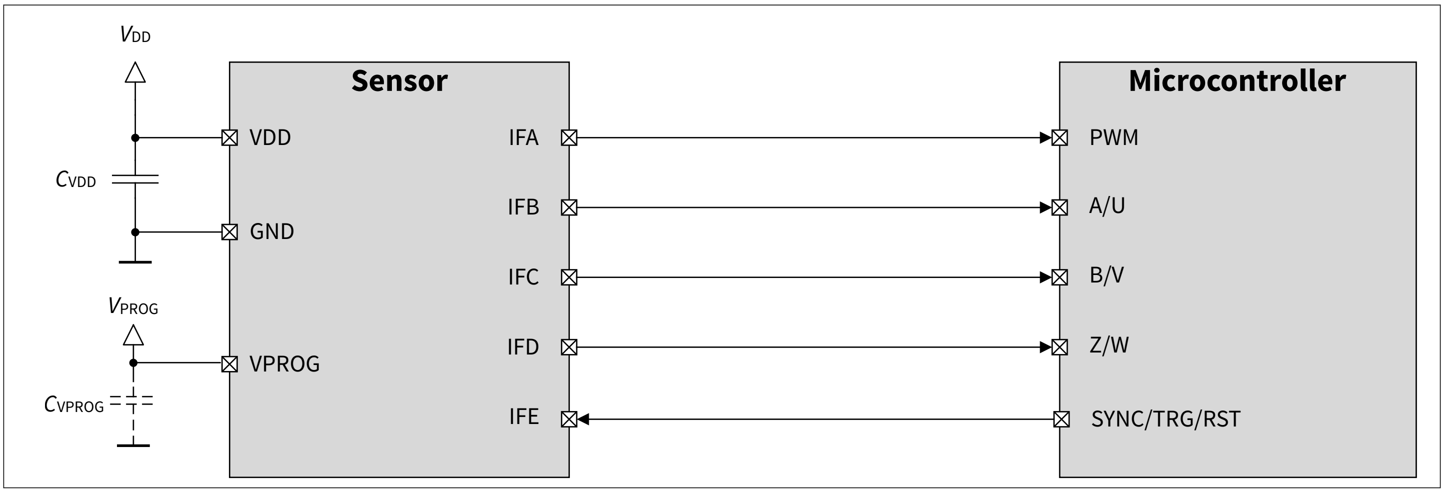

Figure 27 Application diagram - ABZ or UVW in parallel with PWM

6 Package

The sensitive area is located in the package center.

A counter-clockwise (CCW) rotating magnetic field corresponds to an increasing angle (positive direction). The direction convention is configurable. The abscissa of the sensor reference system defines 0°.

The magnetic field line direction (north to south pole) determines a positive field magnitude.

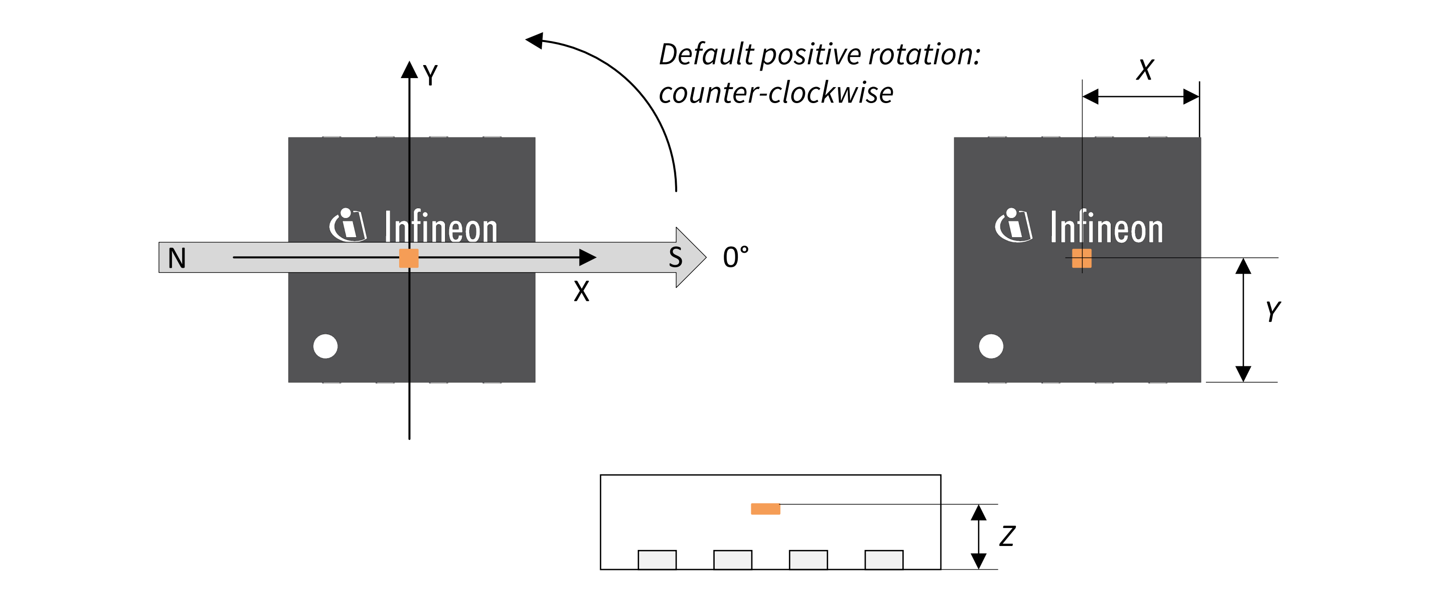

Figure 28 **Sensitive area location (orange), Cartesian measurement reference system (black) and magnetic field vector indicating the 0° angle (grey)**

Table 16 **Die placement**

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Die placement X	*X*	1.45	1.5	1.55	mm	with respect to package edge
Die placement Y	*Y*	1.45	1.5	1.55	mm	with respect to package edge
Die placement Z	*Z*	350	450	550	µm	measured to the bottom of the housing (plastic), without solder layer on pin
Rotational tolerance	α_{rot}	-3	–	3	°	with respect to the package edge
Tilt tolerance	α_{tilt}	-2	–	2	°	with respect to the seating plane excluding coplanarity

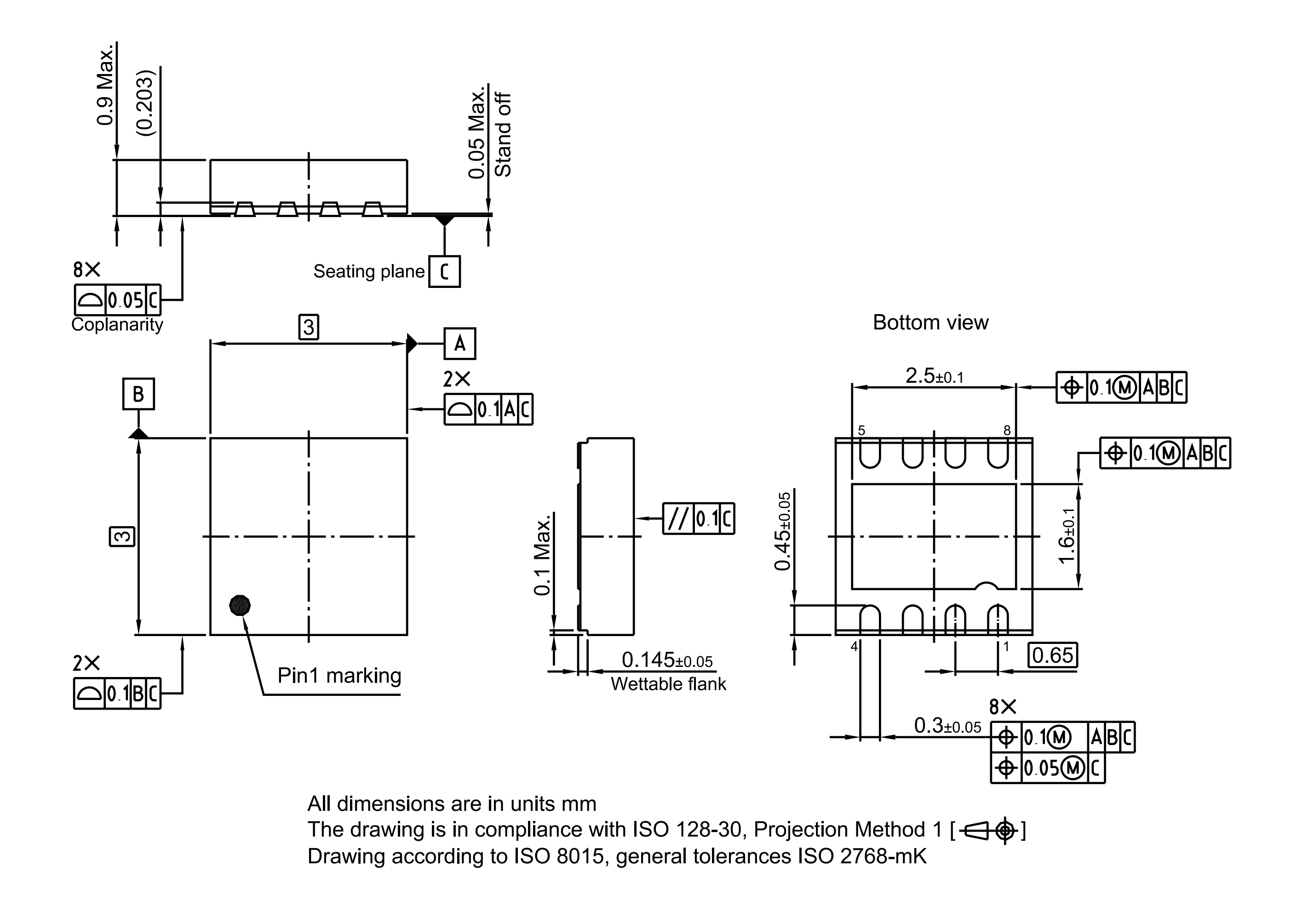

Figure 29 **Package outline PG-VSON-8**

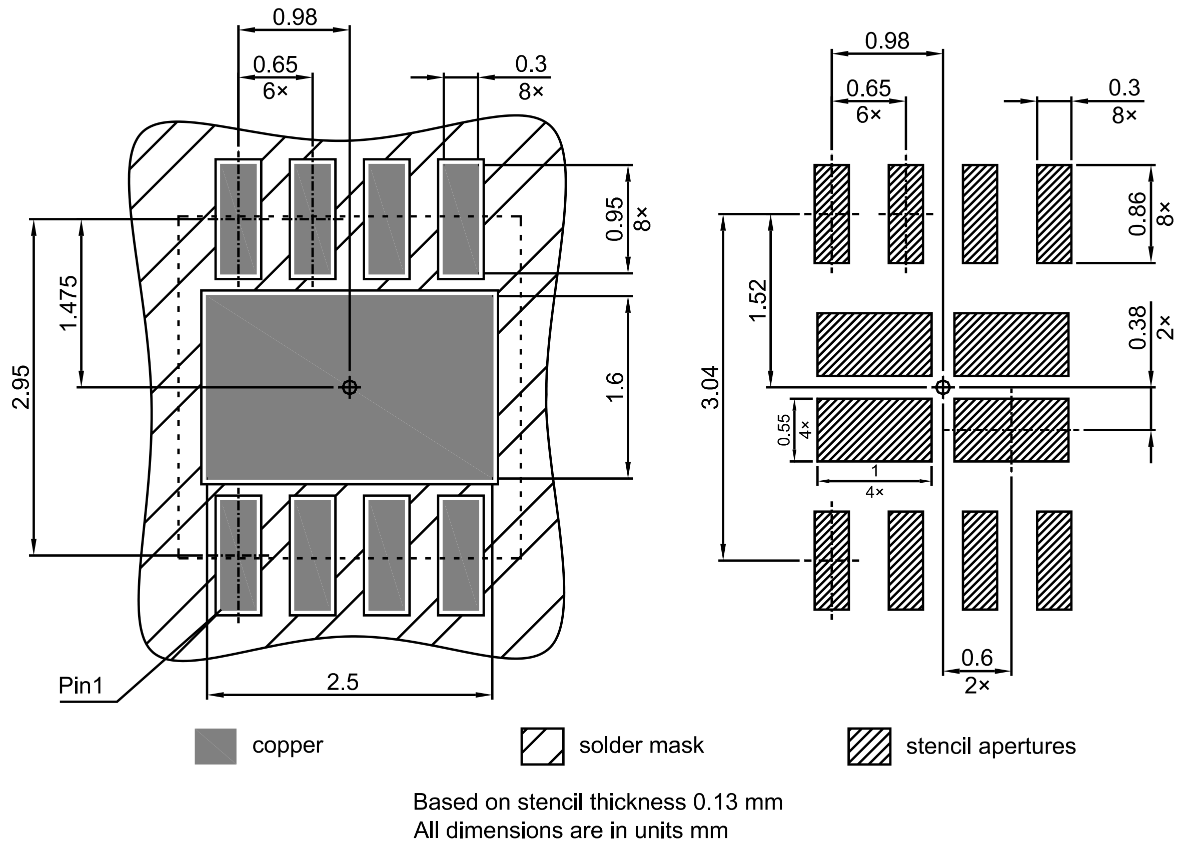

Figure 30 **Package footprint PG-VSON-8**

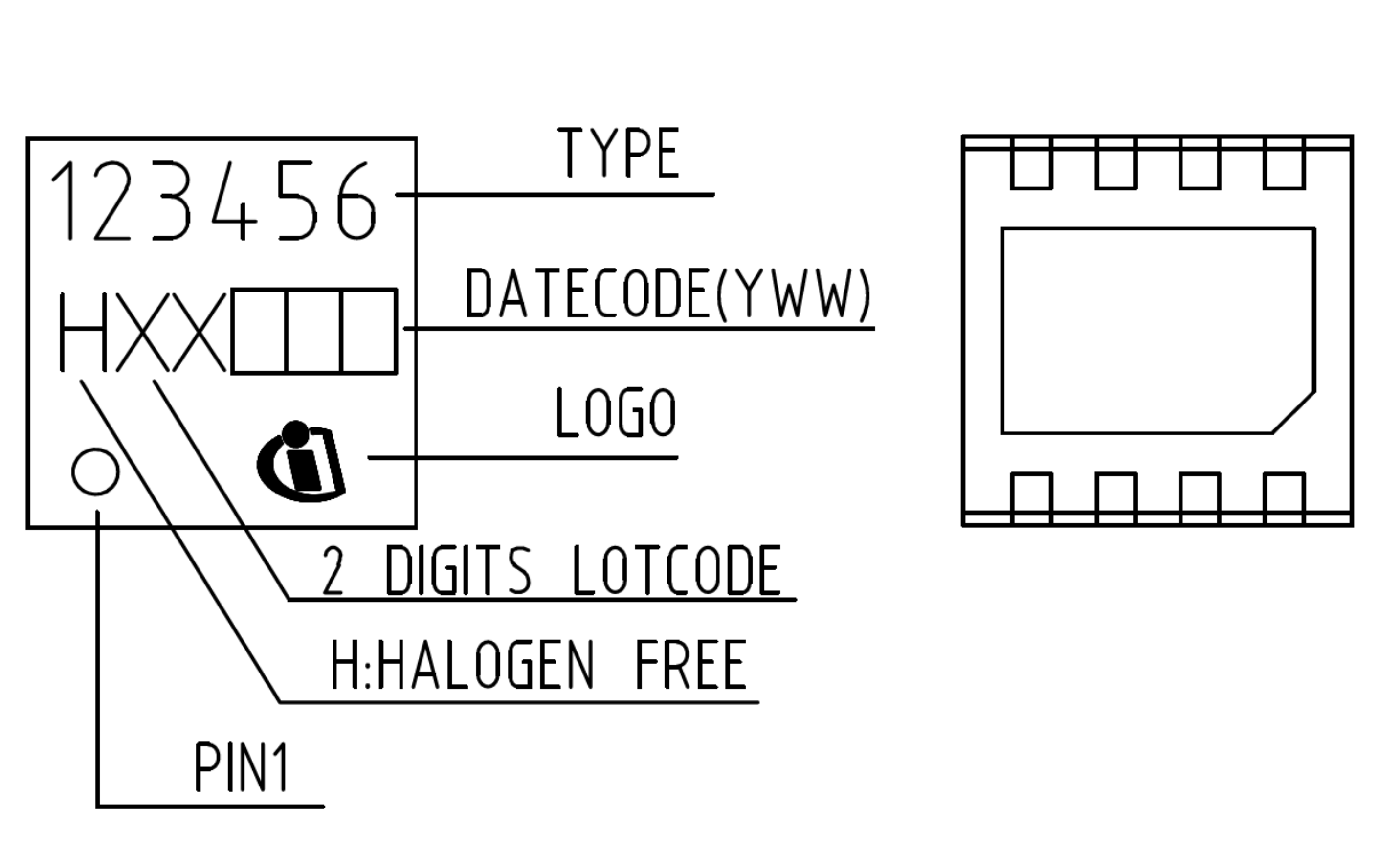

Figure 31 **PG-VSON-8 package marking (left top side, right bottom side)**

The package fulfills a Moisture Sensitivity Level 1 (MSL) according to IPC/JEDEC J-STD-020.

7 Revision history

Revision number	Date of release	Description of changes
Rev. 1.00	2026-06-11	Initial release

Trademarks

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