

XENSIV™ TLE49012 magnetic angle sensor with UVW and PWM interface

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 +125°C
- Non-volatile memory (NVM) for storing configuration settings
- Magnet loss detection
- RoHS (Restriction of Hazardous Substances) compliant and halogen-free PG-VSON-8 package (3×3×0.9 mm³)



Potential applications

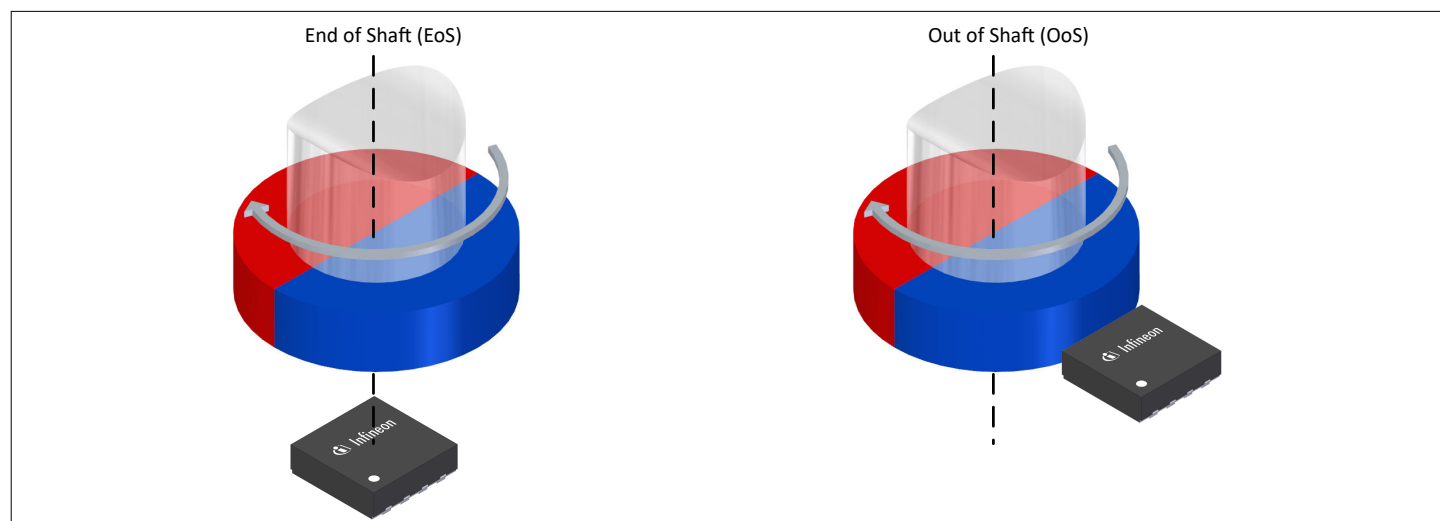
- Steering and braking systems
- Thermal management (pumps, valves)
- Wiper and cleaning systems
- Seat adjustment, seat-belt tensioner
- Window, sunroof, trunk automation
- Brushless direct current (BLDC) motor application to achieve high motor efficiency and high drive performance
- Angular position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

Product validation

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

Description

The angle sensor uses vertical Hall technology to provide the absolute magnetic angle via UVW (hall switch mode) and/or PWM interface. The non-volatile memory (NVM) can be programmed via a SPI 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 requirements.



Product type	Package	Marking	Ordering code
TLE49012-E0001	PG-VSON-8-2	E12E1	SP005858930

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1 Block diagram

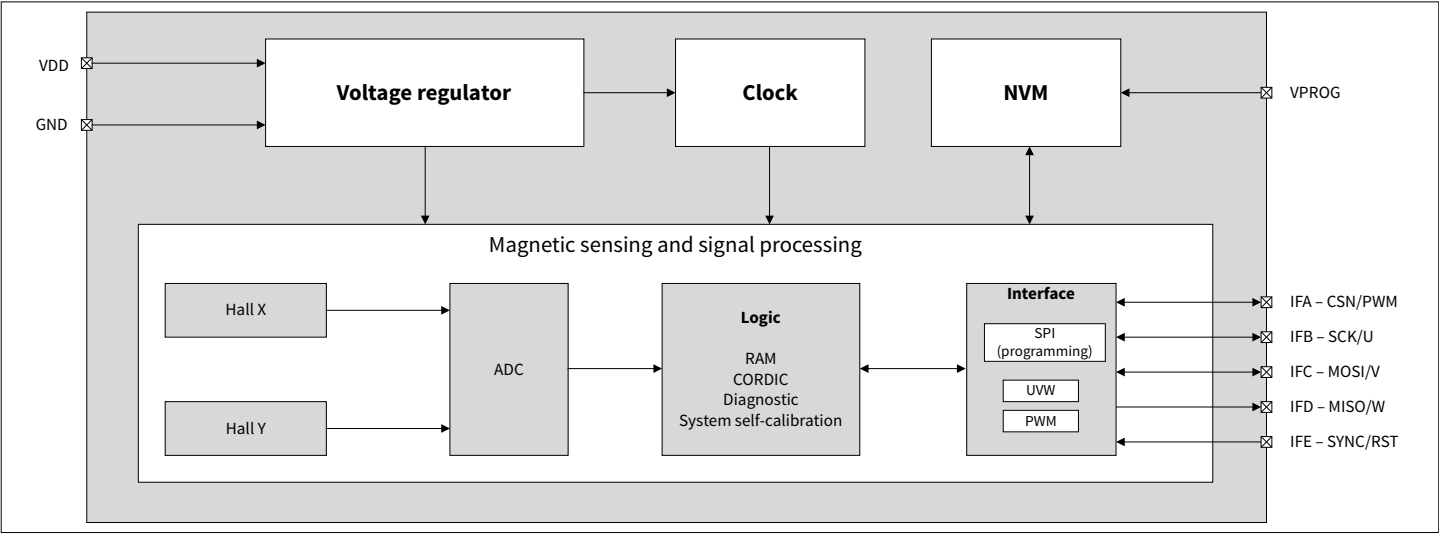


Figure 1 Block diagram

2 Pin configuration

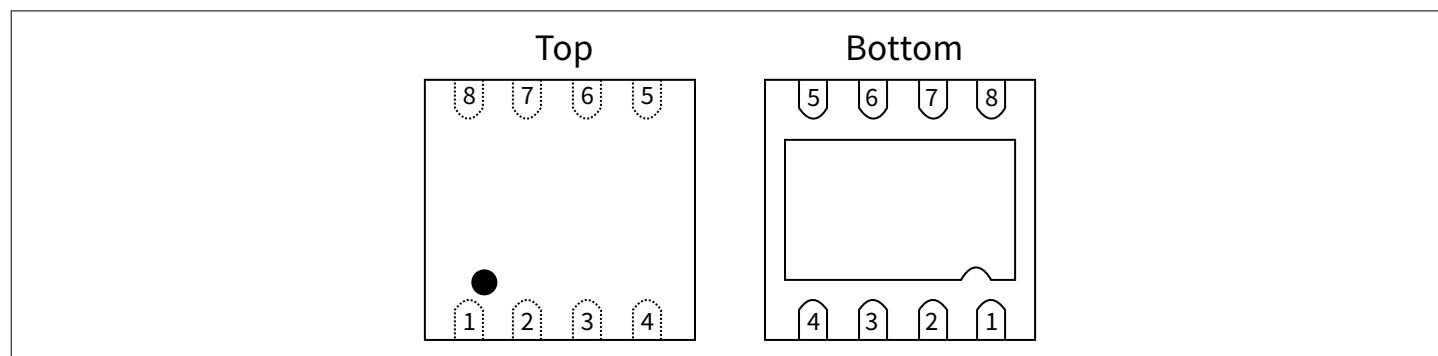


Figure 2 Pin out (PG-VSON-8)

Table 1 Pin definitions and function

Pin No.	Symbol	SPI	UVW	PWM
1	IFE	Measurement synchronization (input); <i>GND</i> or N.C., if unused	Trigger sensor reset (input); <i>GND</i> or N.C., if unused	Trigger measurement synchronization or sensor reset (input); <i>GND</i> or N.C., if unused
2	GND	<i>GND</i> (supply)	<i>GND</i> (supply)	<i>GND</i> (supply)
3	VPROG	Programming voltage V_{PROG} (supply); <i>GND</i> or N.C. in the application	Programming voltage V_{PROG} (supply); <i>GND</i> or N.C. in the application	Programming voltage V_{PROG} (supply); <i>GND</i> or N.C. in the application
4	VDD	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)
6	IFB	SCK (input)	U (output)	U (output); <i>GND</i> or N.C., if unused
7	IFC	MOSI (input)	V (output)	V (output); <i>GND</i> or N.C., if unused
8	IFD	MISO (output)	W (output)	W (output); <i>GND</i> or N.C., if unused
Exposed pad	-	<i>GND</i>	<i>GND</i>	<i>GND</i>

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	–	140	°C	140°C for 4000 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 $\geq 500V_{HBM}$ and $\geq 250V_{CDM}$ 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	$t_{start-up}$	–	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	a_{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	–	125	°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 mm³) 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 mm³) 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 $a_{err,tot}$ after zero angle calibration. The angle error $a_{err,tot}$ 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 $a_{err,tot,ext}$ 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 a_{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 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 $\pm 0.2^\circ$, $\pm 0.4^\circ$, or $\pm 0.8^\circ$ 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 6](#).

Table 5 Functional characteristic angle error up to 125°C

If not otherwise specified, $T_A = -40^\circ\text{C}$ to 125°C , $B_{XY} = 30\text{mT}$ 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	$ a_{\text{err}} $	–	–	0.3	°	system self-calibration enabled
Angle error (INL) - SysCal - RT	$ a_{\text{err,RT}} $	–	0.03	0.1	°	$T_{\text{A}} = 25^{\circ}\text{C}$ system self-calibration enabled $B_{\text{XY,typ}} = 55 \text{ mT}$ for typ. value
Angle error adder - SysCal - low field	$ a_{\text{err,ext}} $	–	–	0.1	°	system self-calibration enabled $B_{\text{XY}} = 20\text{mT}$ to 30mT

(table continues...)

Table 5 (continued) Functional characteristic angle error up to 125°CIf not otherwise specified, $T_A = -40^\circ\text{C}$ to 125°C , $B_{XY} = 30\text{mT}$ to 120mT , incl. lifetime drift

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

Table 6 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	$a_{n,\text{slow}}$	–	–	0.02	°	$T_A = 25^\circ\text{C}$; $B_{XY} = 70\text{ mT}$; $k1=2$; $k2=9$
Angle noise (RMS) - medium	$a_{n,\text{med}}$	–	–	0.035	°	$T_A = 25^\circ\text{C}$; $B_{XY} = 70\text{ mT}$; $k1=6$; $k2=51$
Angle noise (RMS) - fast	$a_{n,\text{fast}}$	–	–	0.04	°	$T_A = 25^\circ\text{C}$; $B_{XY} = 70\text{ mT}$; $k1=11$; $k2=108$
Angle noise (RMS)	a_{noise}	–	–	0.04	°	$T_A = -40^\circ\text{C to }125^\circ\text{C}$; $B_{XY} = 70\text{ mT}$; $k1=2$; $k2=9$
Angular velocity error - high rpm	n_{err}	-4	±1	4	%	$n \geq 1250\text{ rpm}$
Angular velocity error - low rpm	n_{err}	-50	–	50	rpm	$n < 1250\text{ rpm}$
Angular velocity noise (RMS) - slow	$n_{n,\text{slow}}$	–	–	5	rpm	$T_A = 25^\circ\text{C}$; $B_{XY} = 70\text{ mT}$; $k1=2$; $k2=9$
Angular velocity noise (RMS) - med.	$n_{n,\text{med}}$	–	–	10	rpm	$T_A = 25^\circ\text{C}$; $B_{XY} = 70\text{ mT}$; $k1=6$; $k2=51$
Angular velocity noise (RMS) - fast	$n_{n,\text{fast}}$	–	–	15	rpm	$T_A = 25^\circ\text{C}$; $B_{XY} = 70\text{ mT}$; $k1=11$; $k2=108$
Angular velocity noise (RMS)	n_{noise}	–	–	6	rpm	$T_A = -40\text{ to }125^\circ\text{C}$; $B_{XY} = 70\text{ mT}$; $k1=2$; $k2=9$

Hall measurements

X, Y offset	B_{off}	-0.6	–	0.6	mT	
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(table continues...)

Table 6 (continued) Functional characteristics sensing

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
X, Y sensitivity error	$S_{XY, err}$	-15	–	15	%	$S_{XY} = (S_X + S_Y)/2$ $S_{XY, err} = 100\% * (S_{XY} - S_{XY, ideal}) / S_{XY, ideal}$ $1/S_{XY, ideal} = 6.4 \mu T/LSB$
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

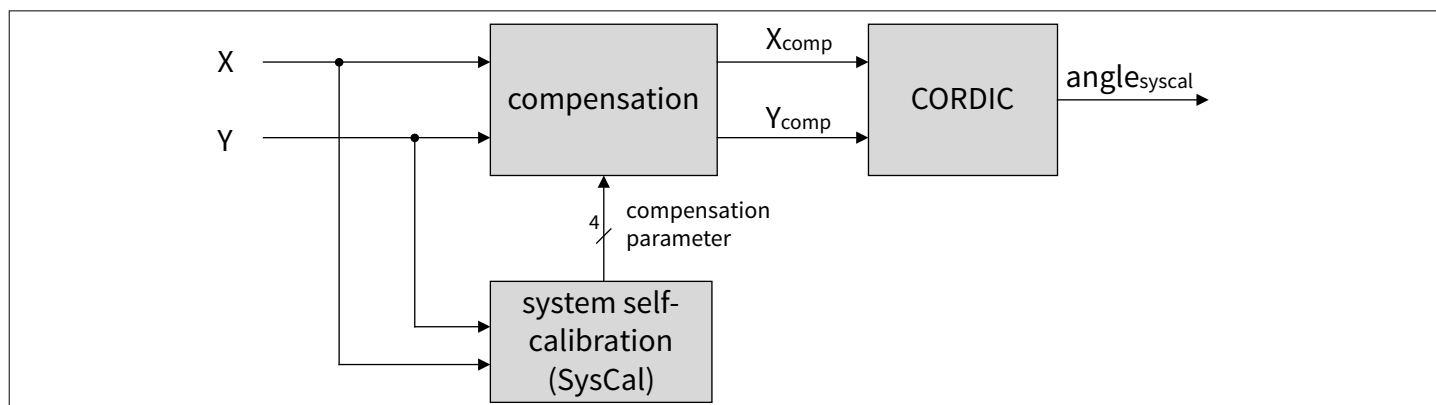


Figure 3 Block diagram of system self-calibration

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.*

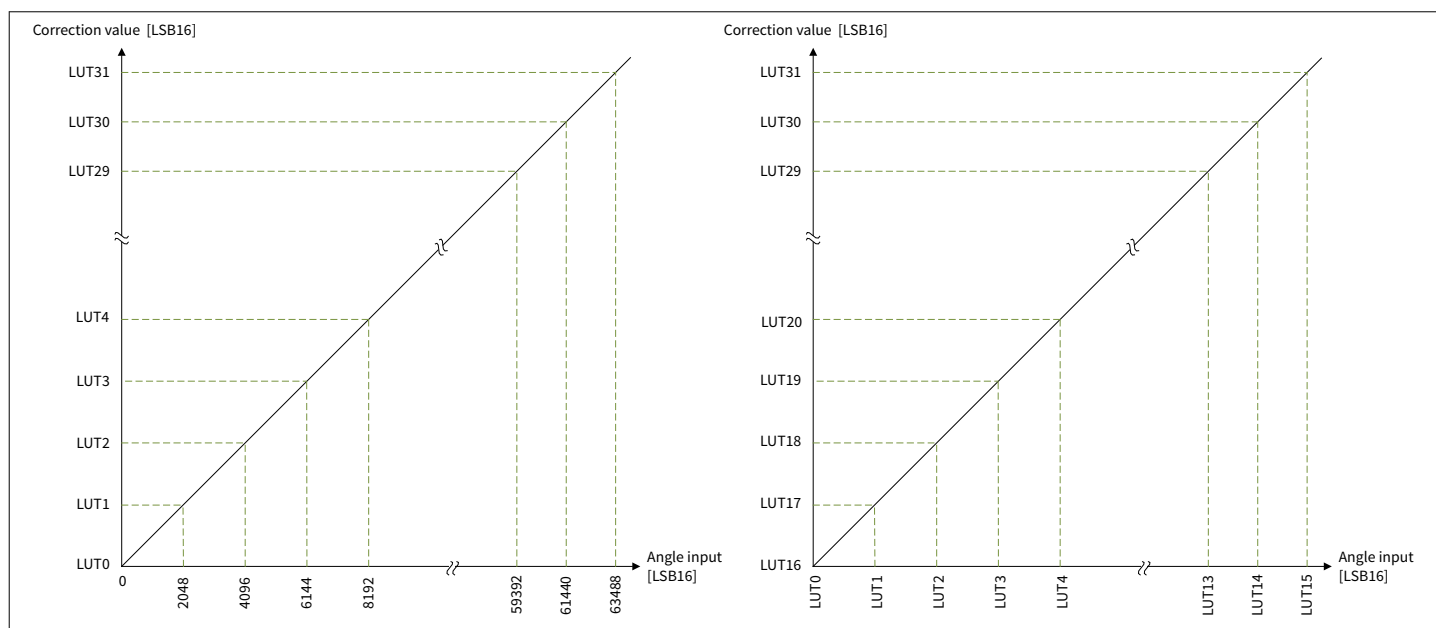


Figure 4 32 equidistant correction values (left) and 16 freely programmable correction values (right)

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.

- 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 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 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.

Table 7 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}

4.5 Interfaces

The pre-configured interface is UVW in parallel with PWM.

The pre-configured interface type is available after the start-up time $t_{\text{start-up}}$ 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 $t_{\text{SPI_active}}$ and ends with $t_{\text{start-up}}$.

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

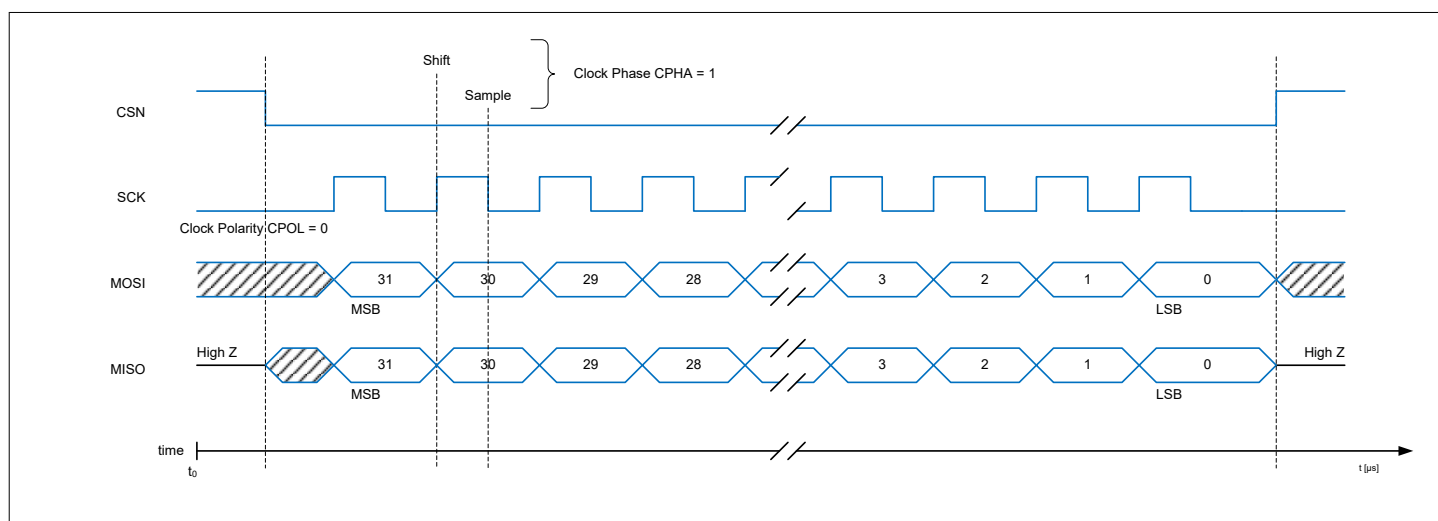


Figure 5 SPI mode 1

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.

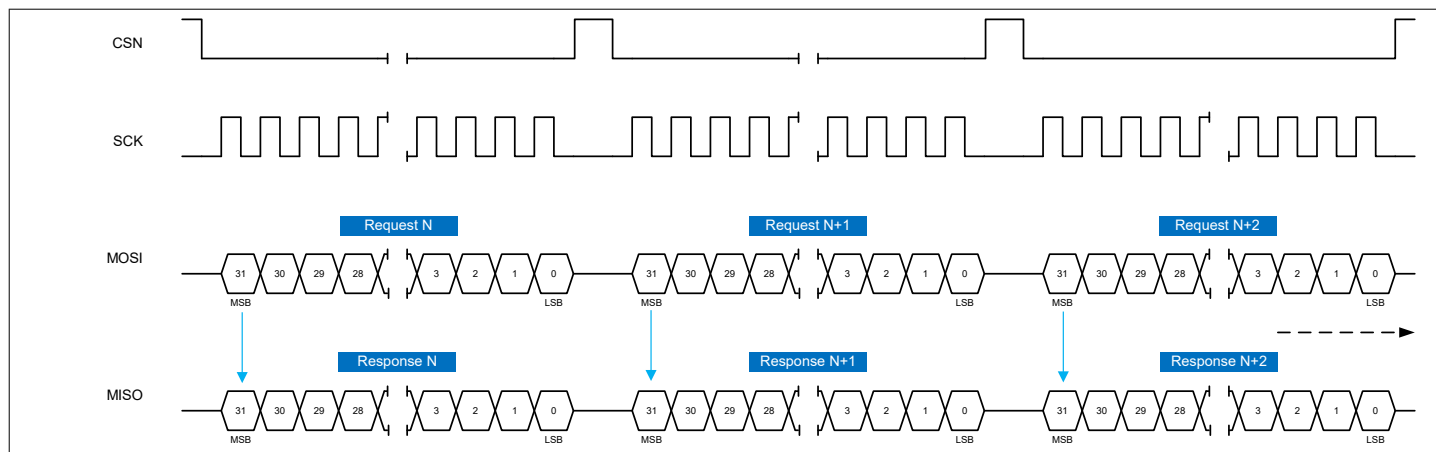


Figure 6 SPI in-frame response scheme

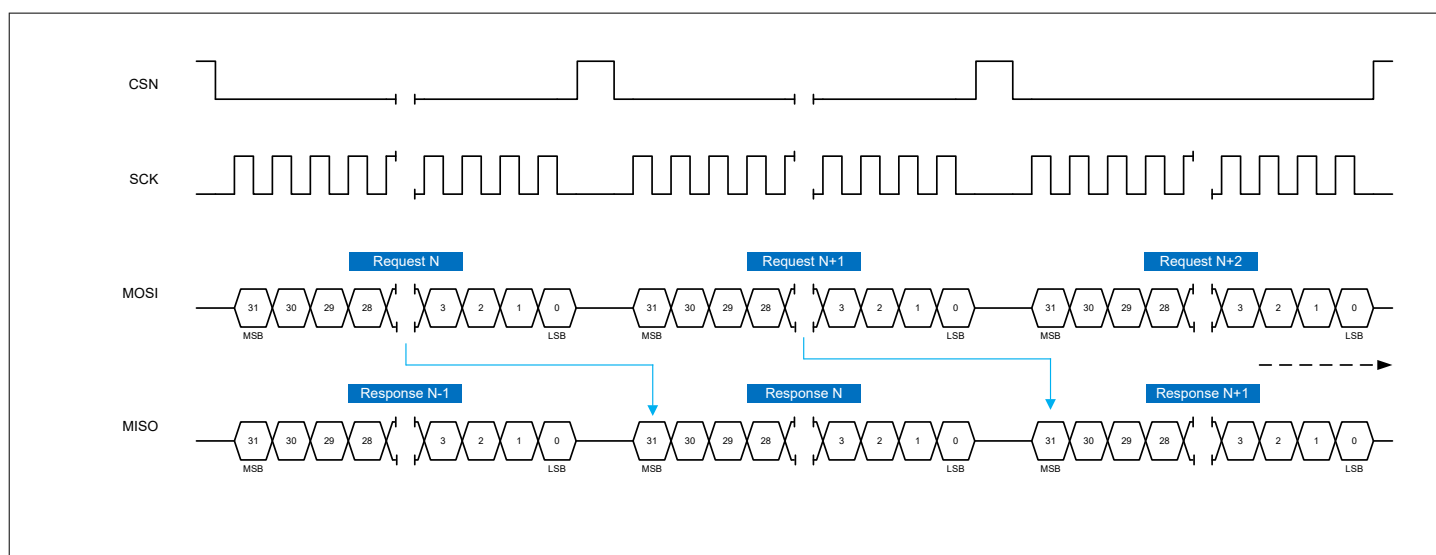


Figure 7 SPI next-frame response scheme

4.5.1.1 Frame definition

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

- 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

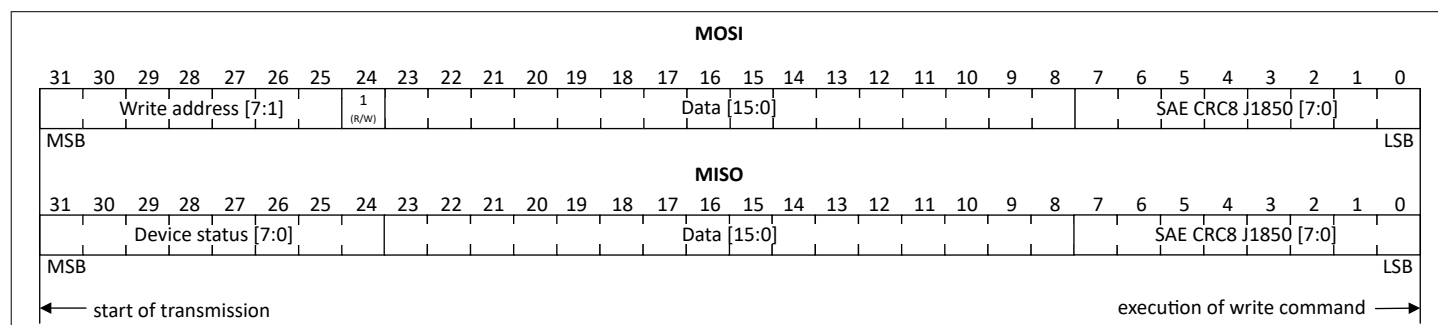


Figure 8 SPI write in-frame

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

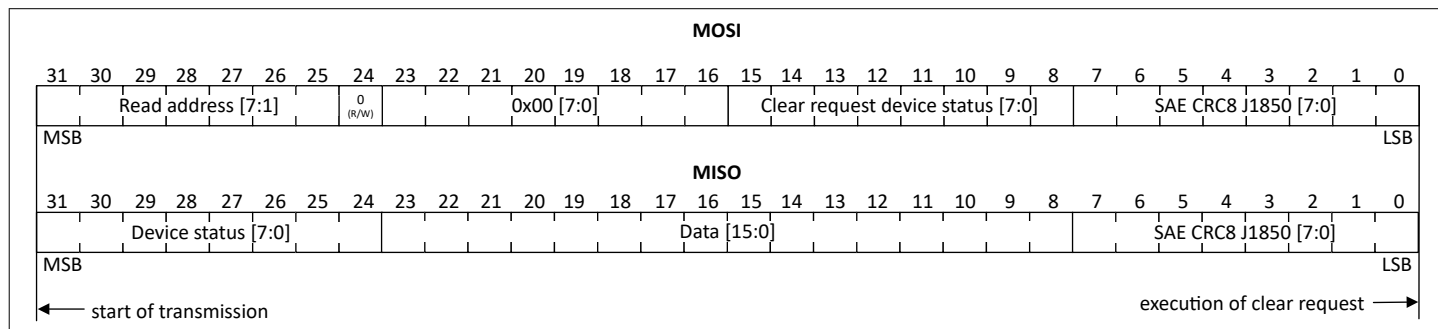


Figure 9 SPI read frame

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

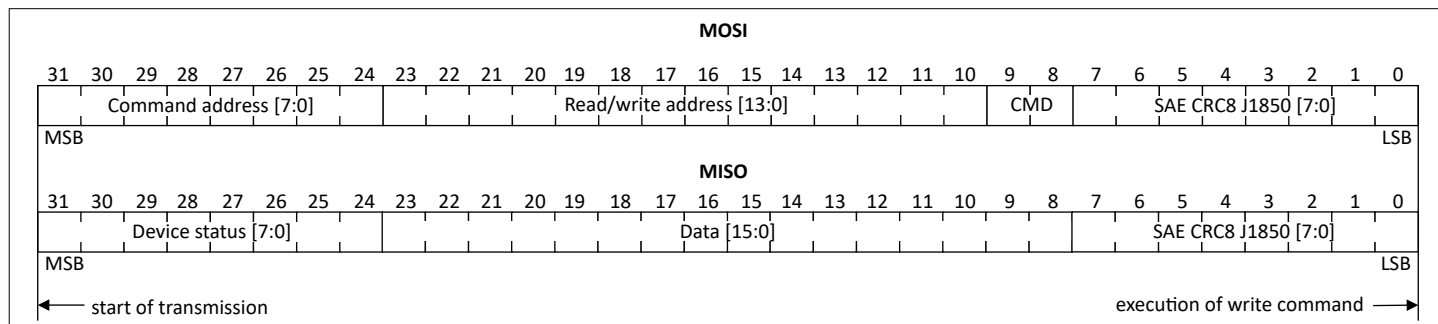


Figure 10 SPI command next-frame

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

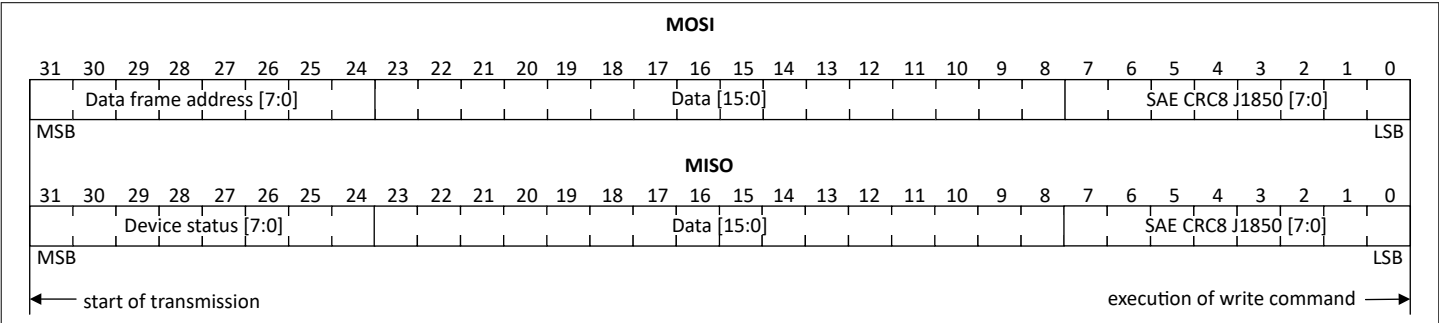


Figure 11 SPI write next-frame

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

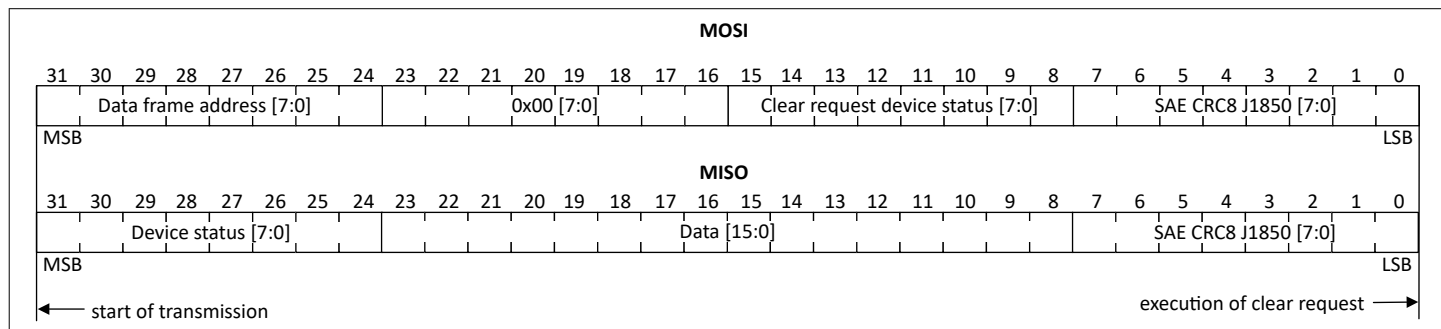


Figure 12 SPI read next-frame

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

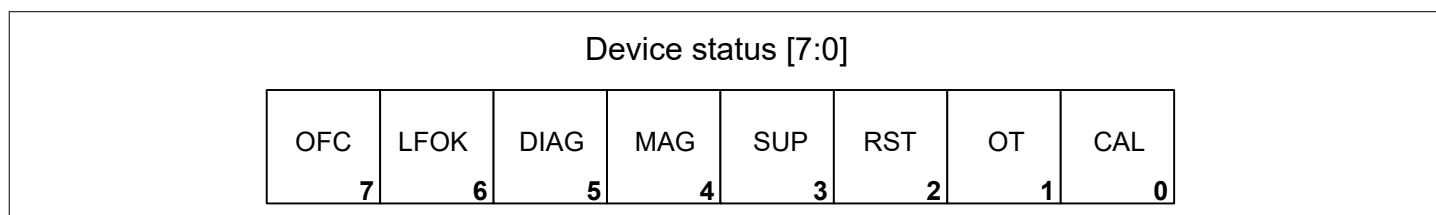


Figure 13 SPI device status field

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 8 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 8 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]

4 Product features

- 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.

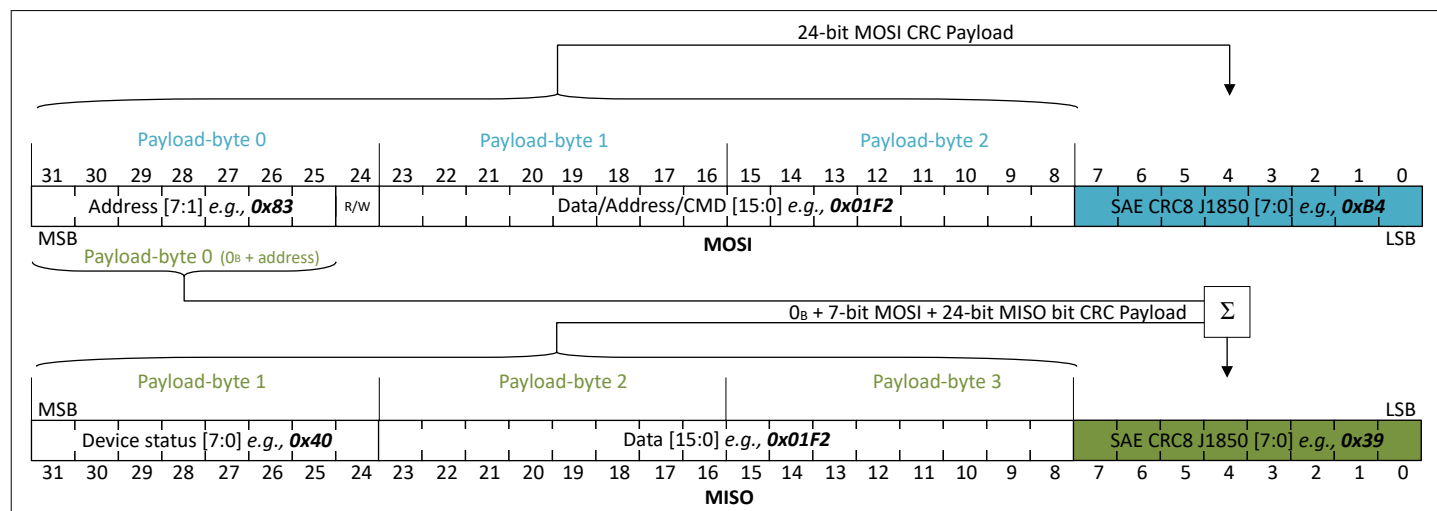


Figure 14 Illustration of SPI CRC payload for MOSI and MISO frame with pseudo data as example (valid for all frame types)

4.5.1.4 SPI timing

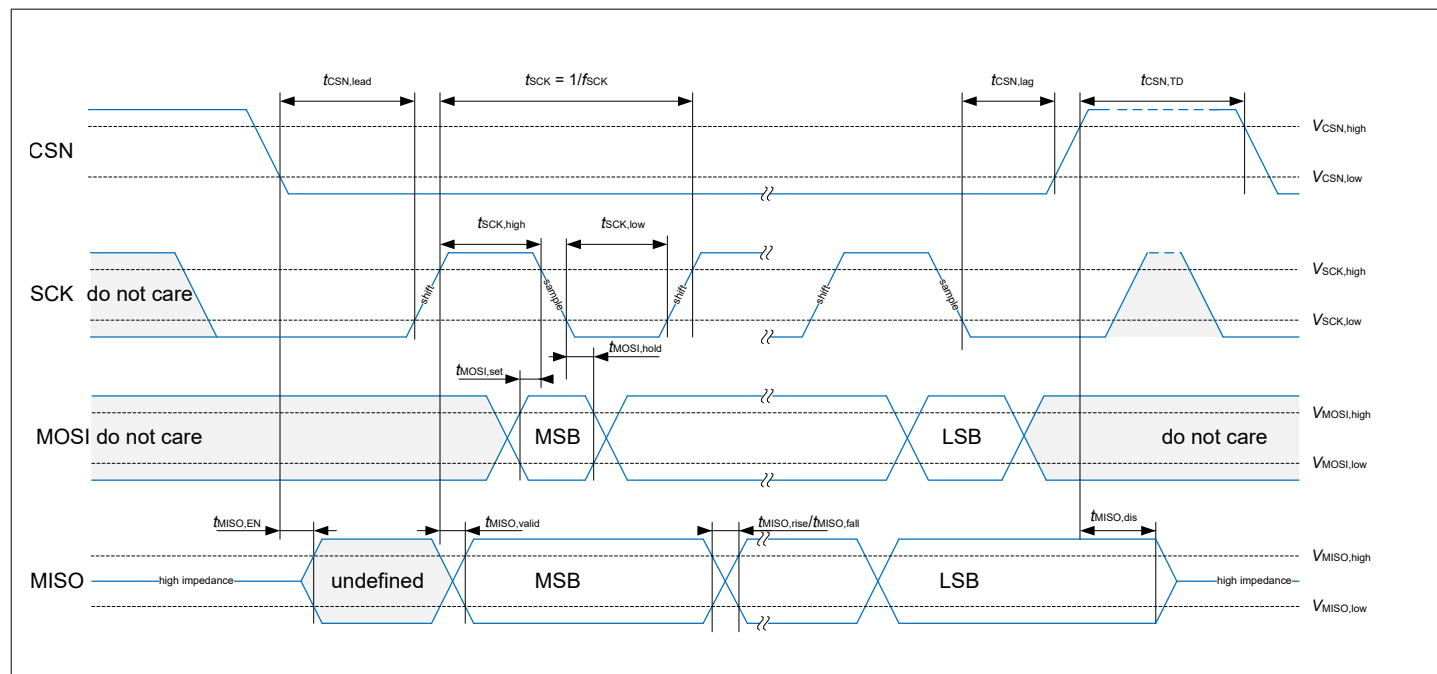


Figure 15 SPI timing diagram

Table 9 Timing characteristics SPI interface

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Serial clock period	t_{SCK}	100	–	–	ns	$f_{\text{SCK}} = 1/t_{\text{SCK}} = 10 \text{ MHz}$
Serial clock high time	$t_{\text{SCK,high}}$	40	–	–	ns	
Serial clock low time	$t_{\text{SCK,low}}$	40	–	–	ns	
Enable lead time	$t_{\text{CSN,lead}}$	100	–	–	ns	falling CSN to rising SCK
Enable lag time	$t_{\text{CSN,lag}}$	100	–	–	ns	falling SCK to rising CSN
Transfer delay time	$t_{\text{CSN,TD}}$	500	–	–	ns	rising CSN to falling CSN
Data setup time	$t_{\text{MOSI,set}}$	20	–	–	ns	MOSI to falling SCK
Data hold time	$t_{\text{MOSI,hold}}$	20	–	–	ns	falling SCK to MOSI
Output rise/fall time	$t_{\text{MISO,rise}}$ $t_{\text{MISO,fall}}$	–	–	25	ns	output load capacitance $< C_{\text{x,load}}$
Output enable time	$t_{\text{MISO,en}}$	–	–	50	ns	falling CSN to MISO valid output load capacitance $< C_{\text{x,load}}$
Output disable time	$t_{\text{MISO,dis}}$	–	–	50	ns	rising CSN to MISO tri-state output load capacitance $< C_{\text{x,load}}$
Output data valid time	$t_{\text{MISO,valid}}$	–	–	30	ns	SCK rising to MISO output load capacitance $< C_{\text{x,load}}$
SPI activation time	$t_{\text{SPI_active}}$	500	–	–	μs	after $V_{\text{DD}} > V_{\text{DD,UV,th}}$ or reset trigger

4.5.2 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.

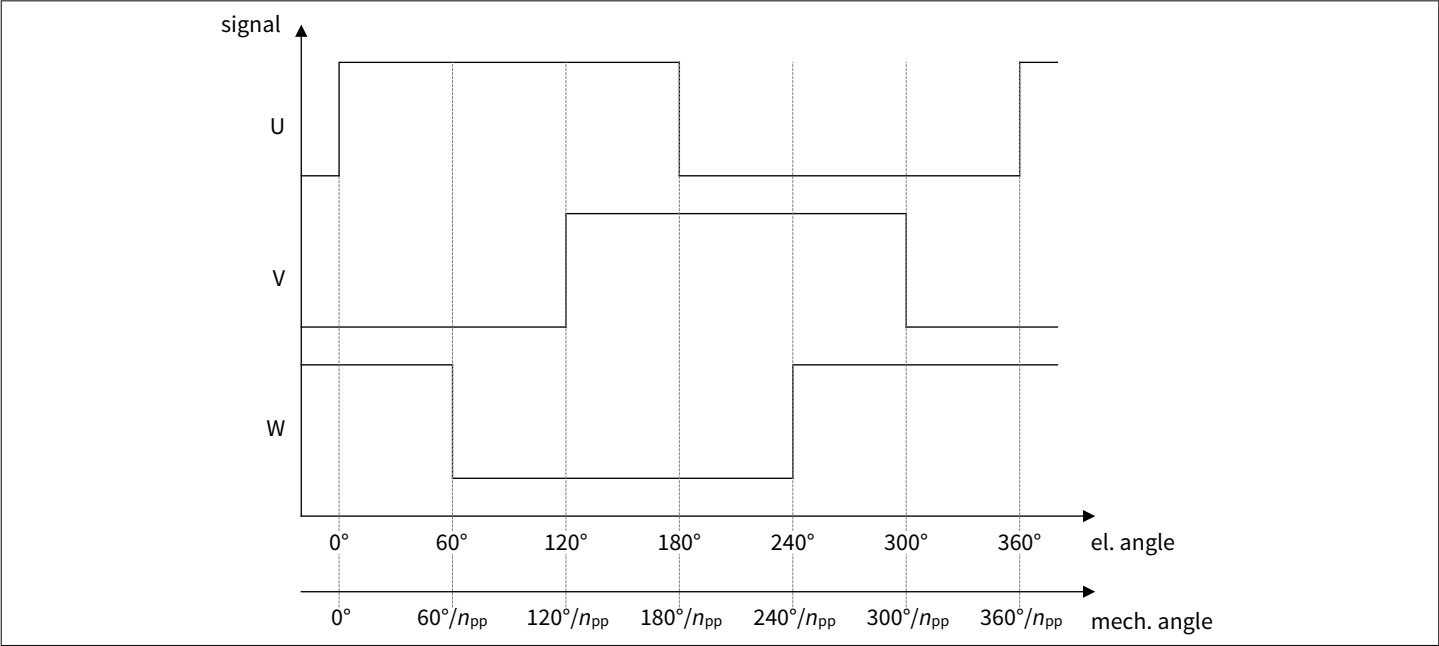


Figure 16 UVW interface switching pattern

Table 10 Electrical characteristic UVW

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

4.5.3 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 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 11 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	$R_{PWM} = \log_2(40\text{MHz} / f_{PWM})$
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	%	

4.5.4 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.

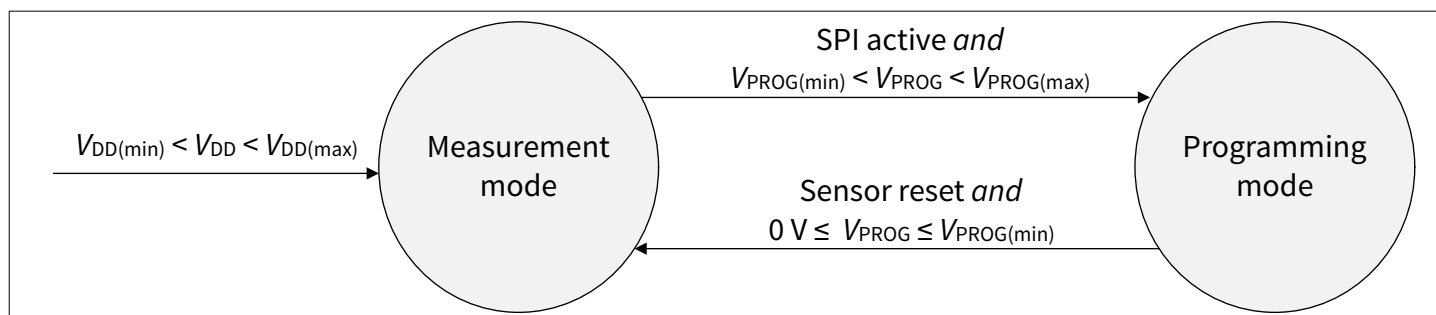


Figure 17 Sensor states for normal operation (measurement mode) and for programming the NVM

Table 12 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 13 Electrical characteristics input/output

positive current is flowing into pin

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
Output voltage - low level	$V_{x,out,low}$	–	–	$0.2 \cdot V_{DD}$	V	x = IFA, IFB, IFC, IFD $I_{x,sink} = 2 \text{ mA}$
Output voltage - high level	$V_{x,out,high}$	$0.8 \cdot V_{DD}$	–	–	V	x = IFA, IFB, IFC, IFD $I_{x,source} = -2 \text{ mA}$
Input voltage - low level	$V_{x,in,low}$	–	–	$0.3 \cdot V_{DD}$	V	x = IFA, IFB, IFC, IFE
Input voltage - high level	$V_{x,in,high}$	$0.7 \cdot V_{DD}$	–	–	V	x = IFA, IFB, IFC, IFE

(table continues...)

Table 13 (continued) **Electrical characteristics input/output**

positive current is flowing into pin

Parameter	Symbol	Values			Unit	Note or condition
		Min.	Typ.	Max.		
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 programming 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.

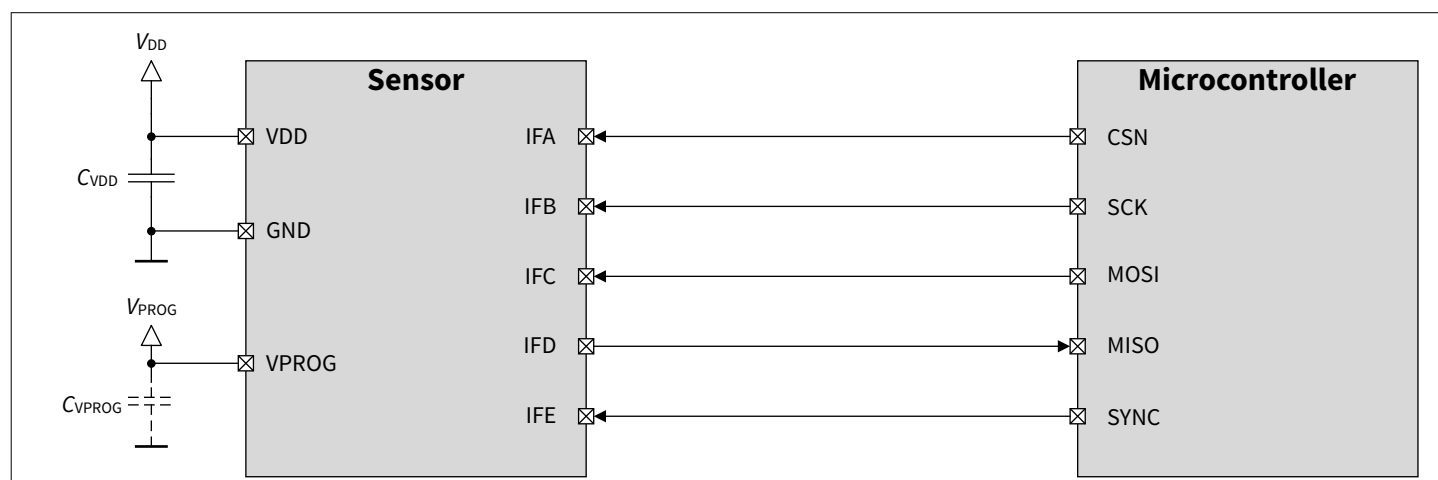


Figure 18 Application diagram - SPI

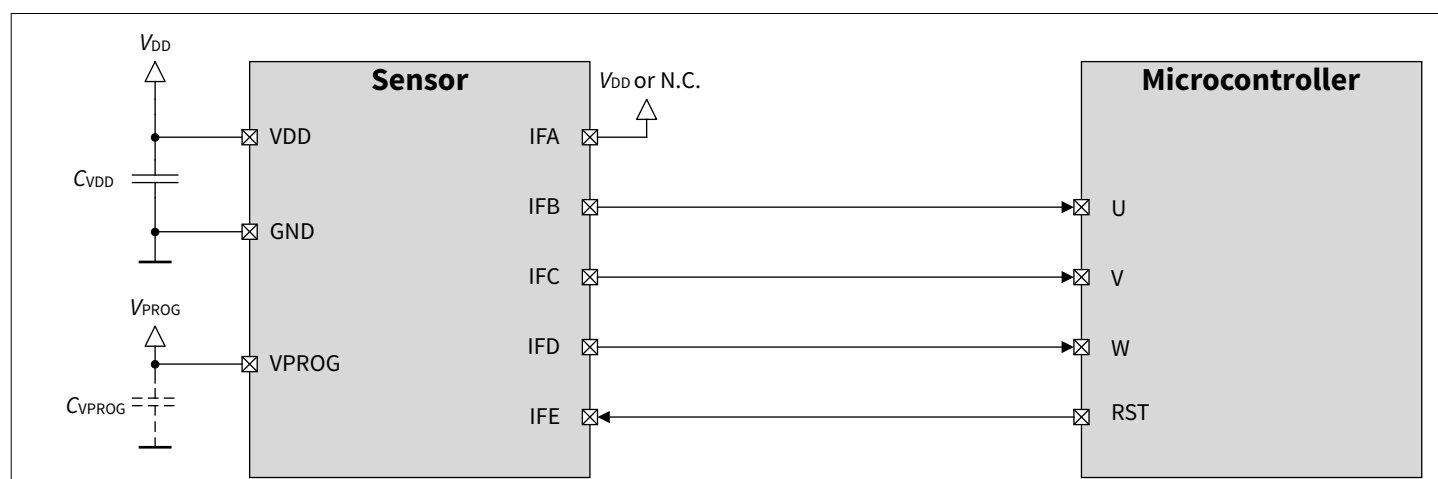


Figure 19 Application diagram - UVW (hall switch mode)

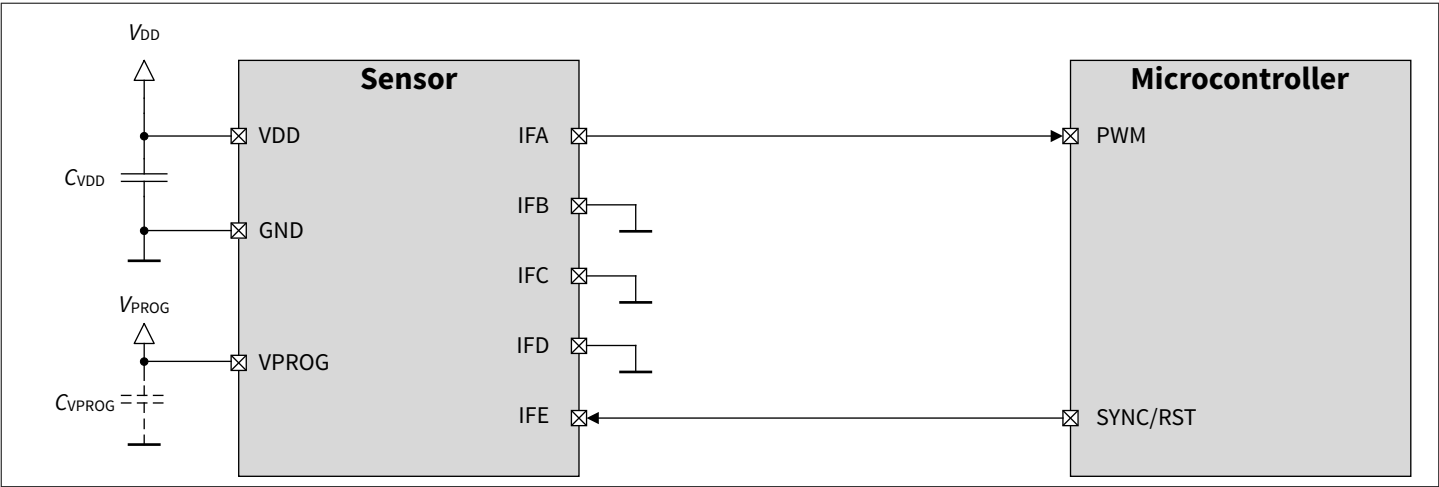


Figure 20 Application diagram - PWM

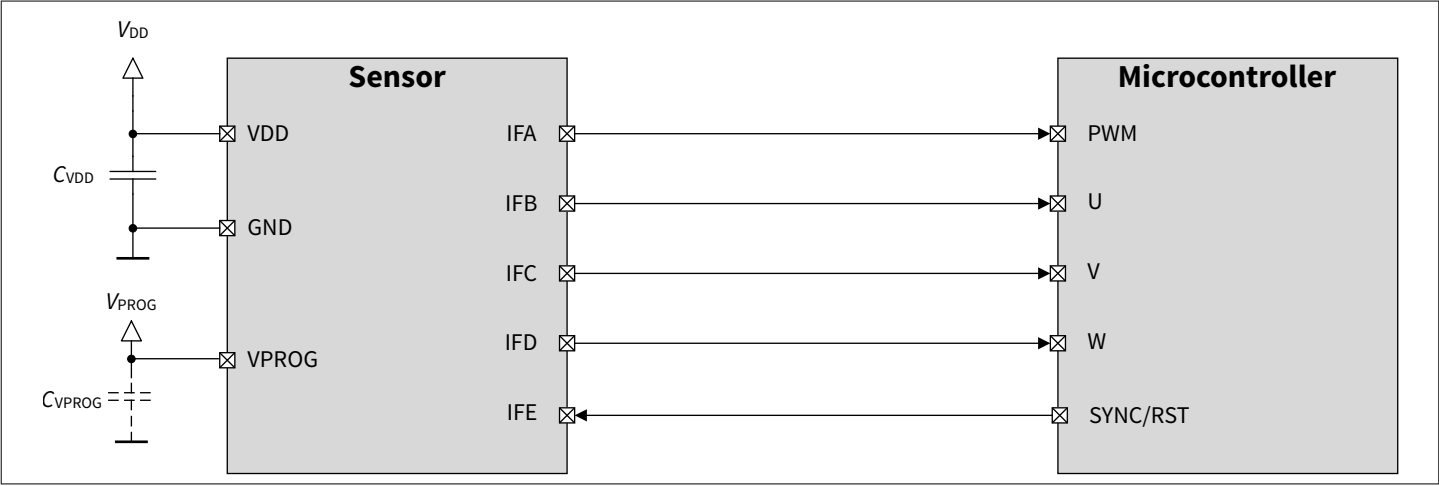


Figure 21 Application diagram - UVW in parallel with PWM

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.

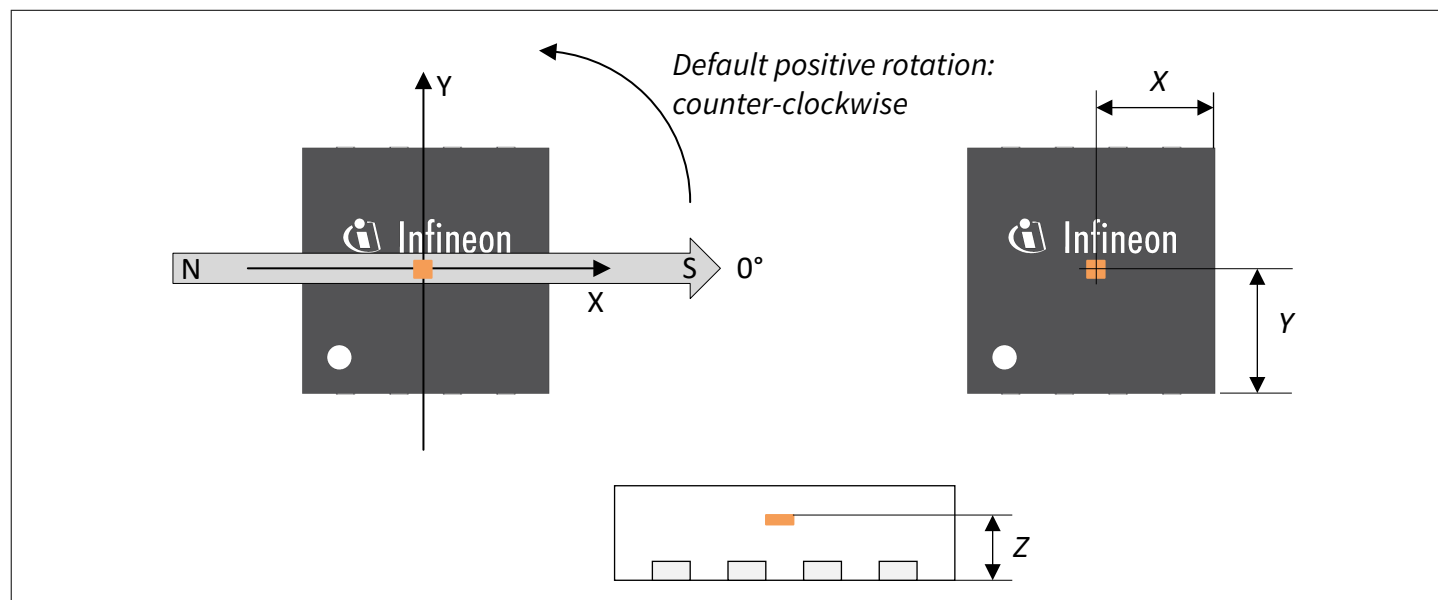


Figure 22 Sensitive area location (orange), Cartesian measurement reference system (black) and magnetic field vector indicating the 0° angle (grey)

Table 14 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

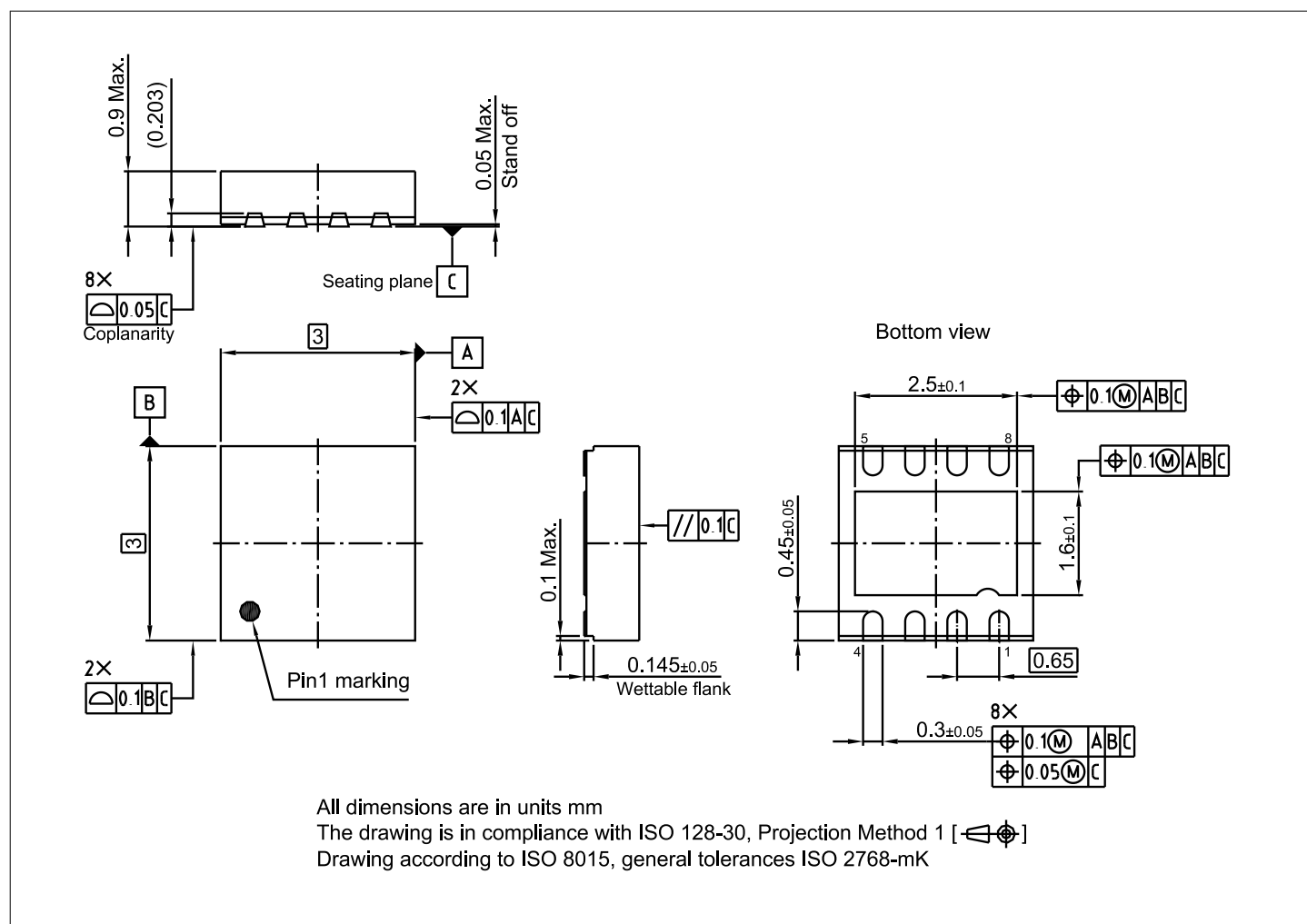


Figure 23 Package outline PG-VSON-8

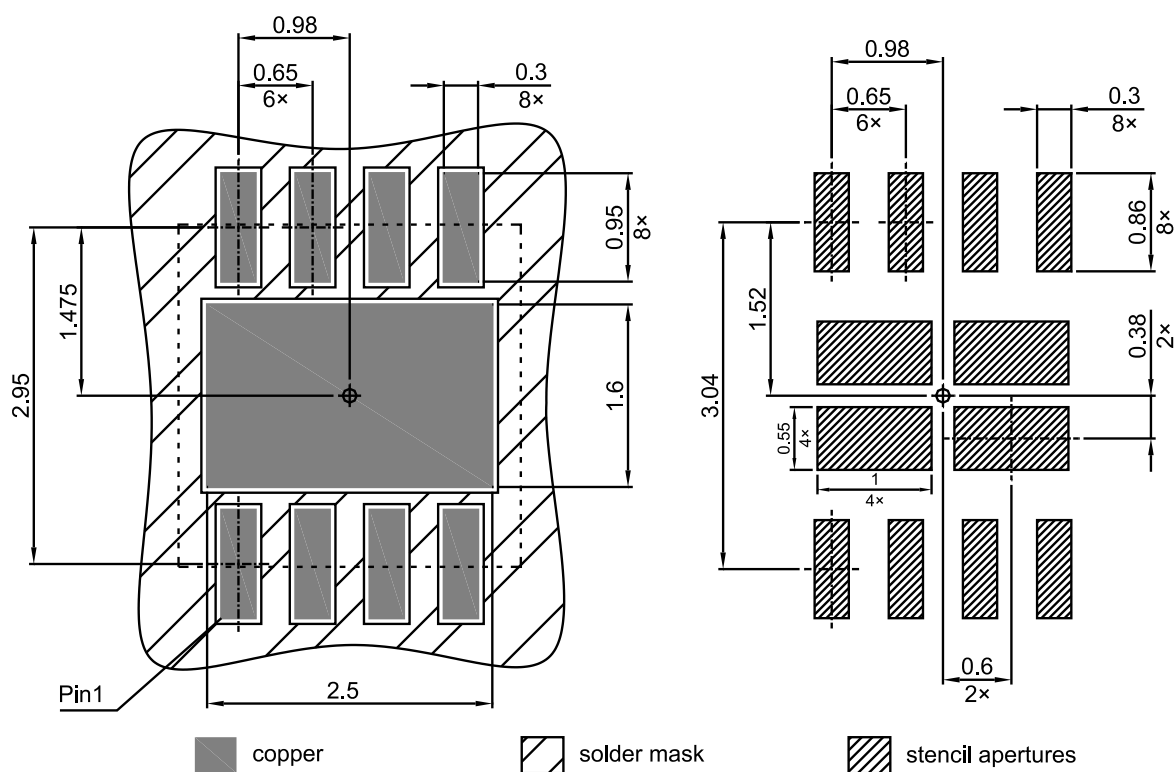


Figure 24 Package footprint PG-VSON-8

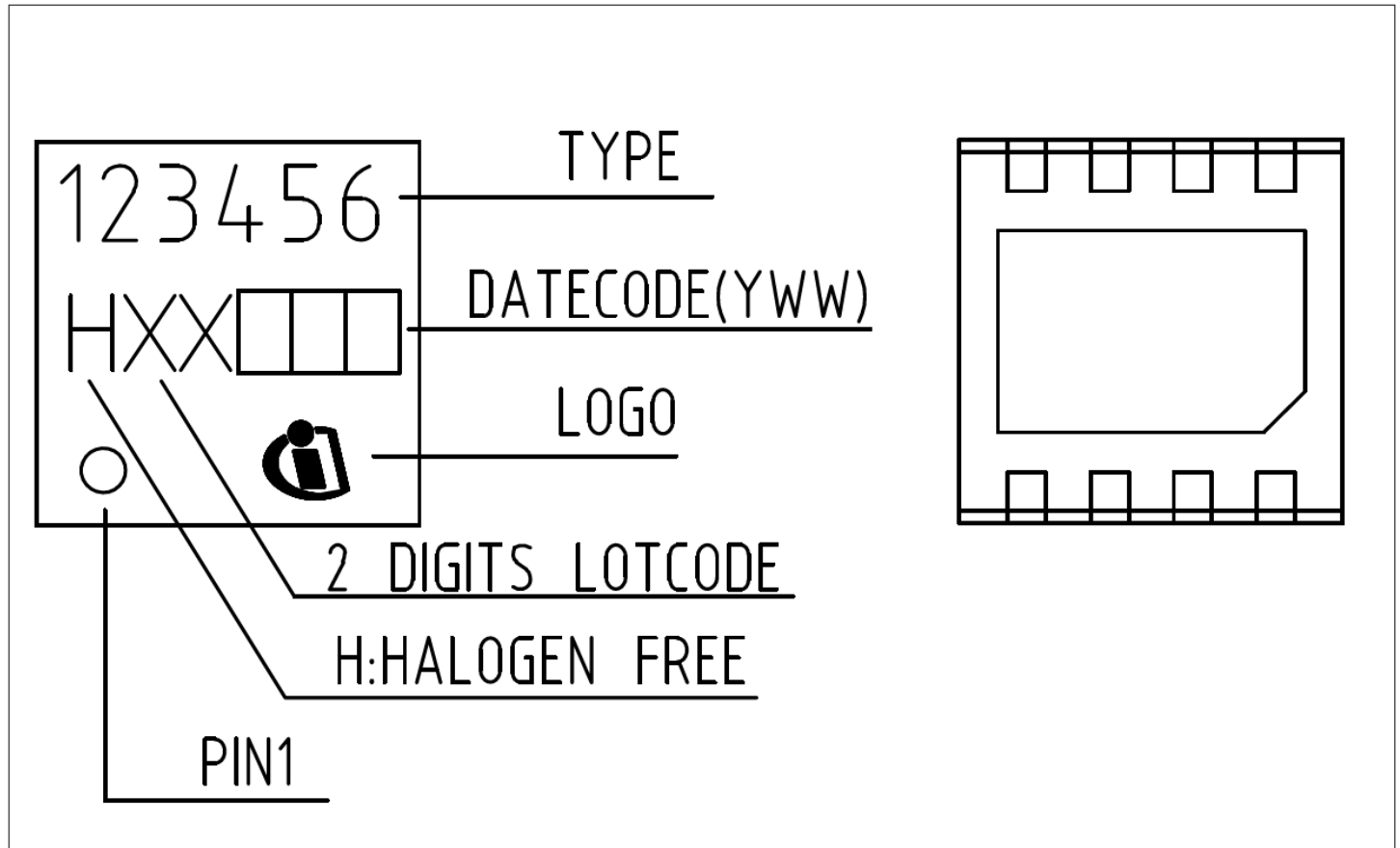


Figure 25 PG-VSON-8 package marking (left top side, right bottom side)

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

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