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TLE5014

Features

- Giant Magneto Resistance (GMR)-based principle
- Integrated magnetic field sensing for angle measurement
- 360° angle measurement
- High voltage and reverse polarity capability
- EEPROM for storage of configuration (e.g. zero angle) and customer specific ID
- 12 bit representation of absolute angle value on the output
- Max. 1° angle error over lifetime and temperature range
- Developed according to ISO26262 with process complying to ASIL-D
- Internal safety mechanisms with a SPFM > 97%
- Interfaces: PWM, SPC, SENT (based on SAE J2716-2010)
- 32 point look-up table to correct for systematic angle errors (e.g. magnetic circuit)
- 112 bit customer ID (programmable)
- Automotive qualified Q100, Grade 1: -40°C to 125°C (ambient temperature)
- ESD: 4kV (HBM) on V_{DD} and output pin
- RoHS compliant and halogen free package

Functional Safety

- Safety Manual and Safety Analysis Summary Report available on request

Applications

The TLE5014 GMR-based angle sensor is designed for angular position sensing in automotive applications with focus on steering angle sensor.

Description

Table 0-1 Derivative Ordering codes (see Chapter 6 for description of derivatives)

Product Type	Marking	Ordering Code	Package	Comment
TLE5014P16	014P	SP001231814	PG-TDSO-16	PWM Interface
TLE5014S16	014S	SP001231818	PG-TDSO-16	SENT Interface
TLE5014C16	014C	SP001231806	PG-TDSO-16	SPC Interface

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1 Functional Description

1.1 Block Diagram

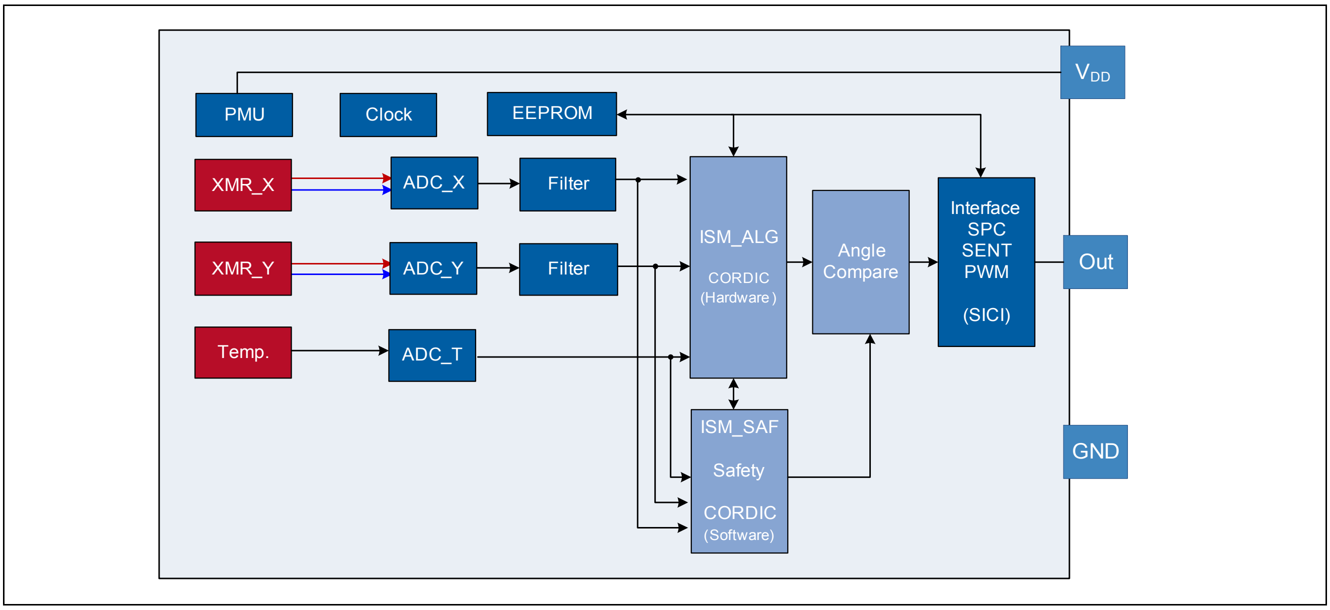

Figure 1-1 TLE5014 block diagram

1.2 Functional Block Description

Internal Power Supply (PMU)

The internal blocks of the TLE5014 are supplied from several voltage regulators:

- GMR Voltage Regulator, VRS
- Analog Voltage Regulator, VRA
- Digital Voltage Regulator, VRD

These regulators are directly connected to the supply voltage VDD.

Oscillator and PLL (Clock)

The digital clock of the TLE5014 is given by the Phase-Locked Loop (PLL), which is fed by an internal oscillator.

SD-ADC

The Sigma-Delta Analog-Digital-Converters (SD-ADC) transform the analog GMR voltages and temperature voltage into the digital domain.

Digital Signal Processing Unit ISM_ALG

The Digital Signal Processing Unit ISM_ALG contains the:

- Intelligent State Machine (ISM), which does error compensation of offset, offset temperature drift, amplitude synchronicity and orthogonality of the raw signals from the GMR bridges.
- COordinate Rotation DIgital Computer (CORDIC), which contains the trigonometric function for angle calculation

Digital Signal Processing Unit ISM_SAF

The Digital Signal Processing Unit ISM_SAF performs the internal safety mechanism and plausibility checks. Furthermore, a second CORDIC algorithm is implemented in a diverse way as in the ISM_ALG. This is for cross checking the angle calculation

Interface

The Interface block is used to generate the PWM, SENT and SPC signals

Angle Compare

This digital block compares the angle value calculated by ISM_ALG and ISM_SAF. In case they are not identical, an error is indicated in the transmitted protocol.

EEPROM

The EEPROM contains the configuration and calibration parameters. A part of the EEPROM can be accessed by the customer for application specific configuration of the device. Programming of the EEPROM is achieved with the SICI interface. Programming mode can be accessed directly after power-up of the IC.

1.3 Sensing Principle

The **G**iant **M**agneto **R**esistance (GMR) sensor is implemented using vertical integration. This means that the GMR-sensitive areas are integrated above the logic part of the TLE5014 device. These GMR elements change their resistance depending on the direction of the magnetic field.

Four individual GMR elements are connected to one Wheatstone sensor bridge. These GMR elements sense one of two components of the applied magnetic field:

- X component, V_x (cosine) or the
- Y component, V_y (sine)

With this full-bridge structure the maximum GMR signal is available and temperature effects cancel out each other.

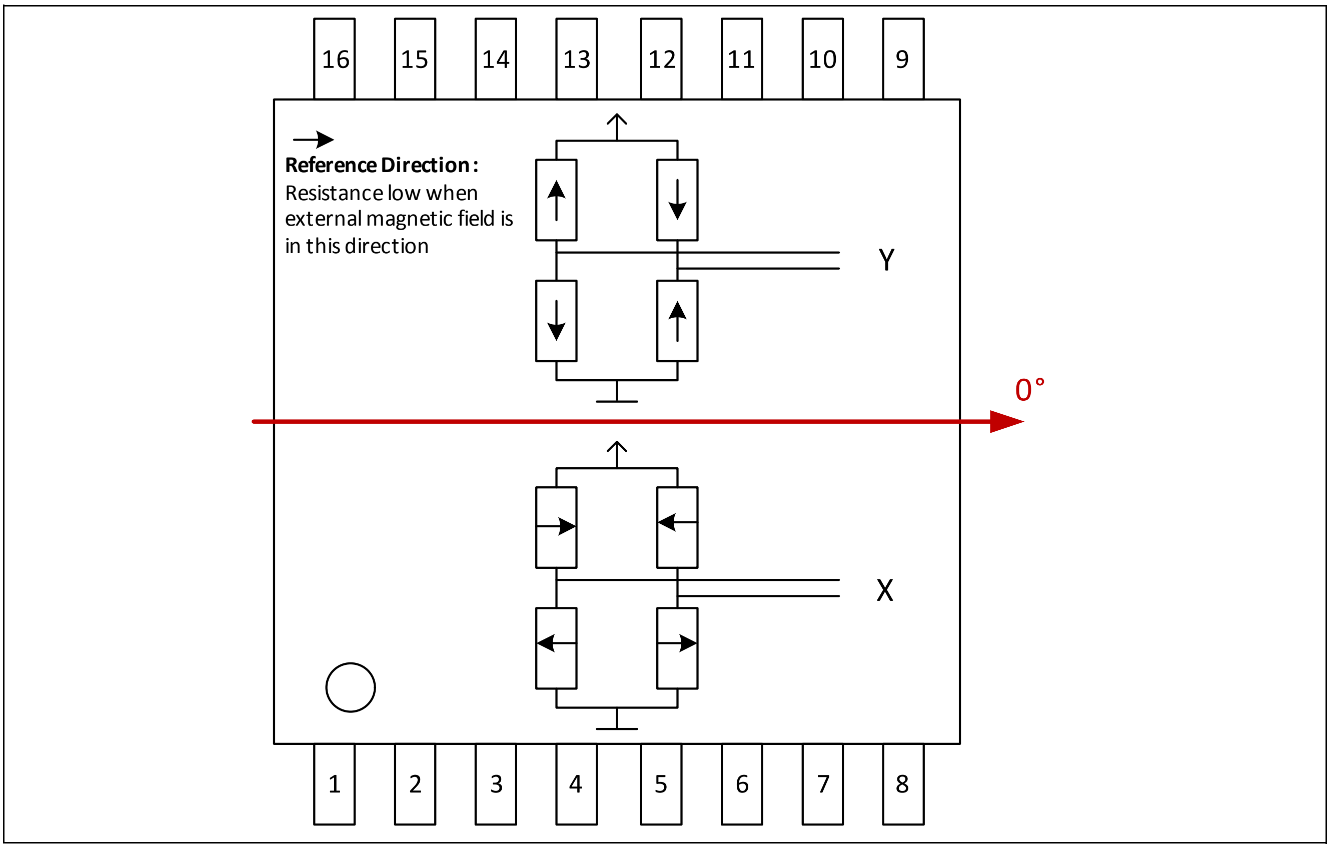

Figure 1-2 Sensitive bridges of the GMR sensor (not to scale)

Attention: Due to the rotational placement inaccuracy of the sensor IC in the package, the sensors 0° position may deviate by up to 3° from the package edge direction indicated in Figure 1-2.

In Figure 1-2 the arrows in the resistors represent the magnetic direction which is fixed in the reference layer. If the external magnetic field is parallel to the direction of the Reference Layer, the resistance is minimal. If they are anti-parallel, resistance is maximal.

The output signal of each bridge is only unambiguous over 180° between two maxima. Therefore two bridges are oriented orthogonally to each other to measure 360°.

With the trigonometric function ARCTAN2, the true 360° angle value is calculated out of the raw X and Y signals from the sensor bridges.

1.4 Pin Configuration

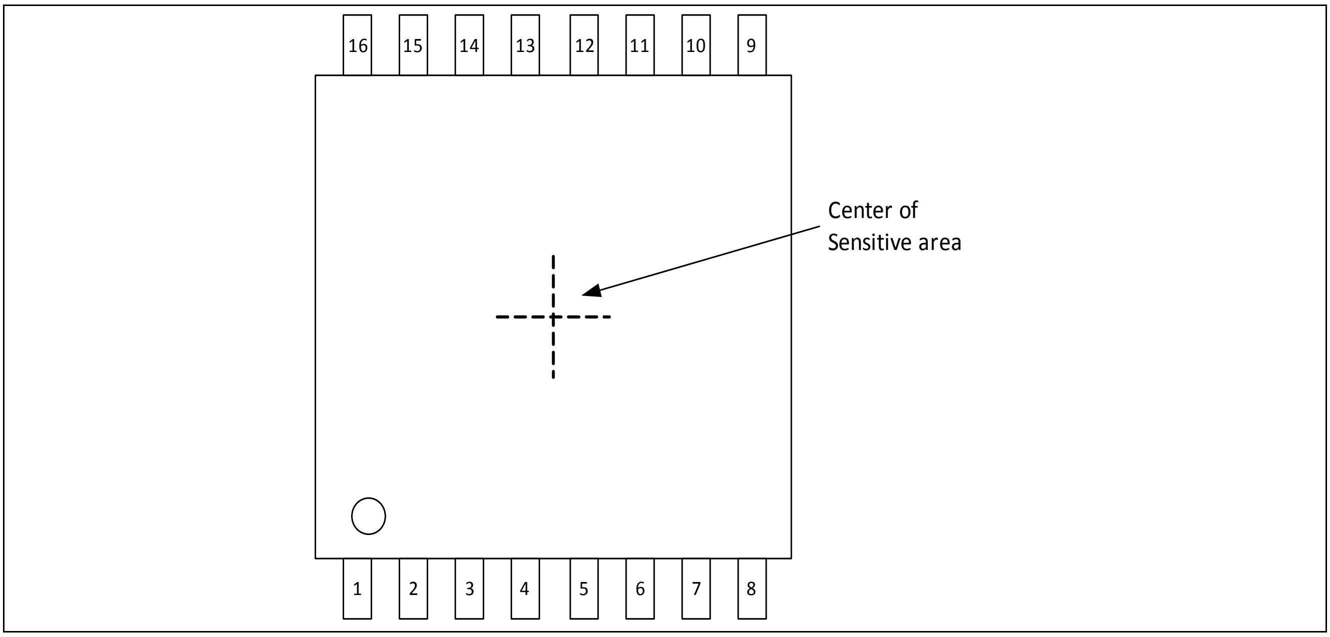

Figure 1-3 Pin configuration (top view)

1.5 Pin Description

The following Table 1-1 describes the pin-out of the chip.

Table 1-1 Pin Description

Pin No.	Symbol	In/Out	Function
1	IF1	I	address coding for programming in bus mode, (see Table 4-5) connect to GND for SENT / PWM interface
2	IF2	I	address coding for programming in bus mode, (see Table 4-5) connect to GND for SENT / PWM interface
3	IF3	I	connect to IFC
4	VDD	-	supply voltage, positive
5	GND	-	supply voltage, ground
6	IFA	-	connect to GND.
7	IFB	I/O	SENT / SPC / PWM / SICI interface
8	IFC	O	address coding for programming in bus mode, (see Table 4-5) connect to IF3
9-16	-	-	n.c.

2 Application Circuits

The application circuits in this chapter show the various communication possibilities of the TLE5014. To improve robustness against electro-magnetic disturbances, a capacitor of 100nF on the supply and a capacitor with minimum value of Cw = 1nF on the output pin is recommended. These capacitors shall be placed as close as possible to the corresponding sensor pins.

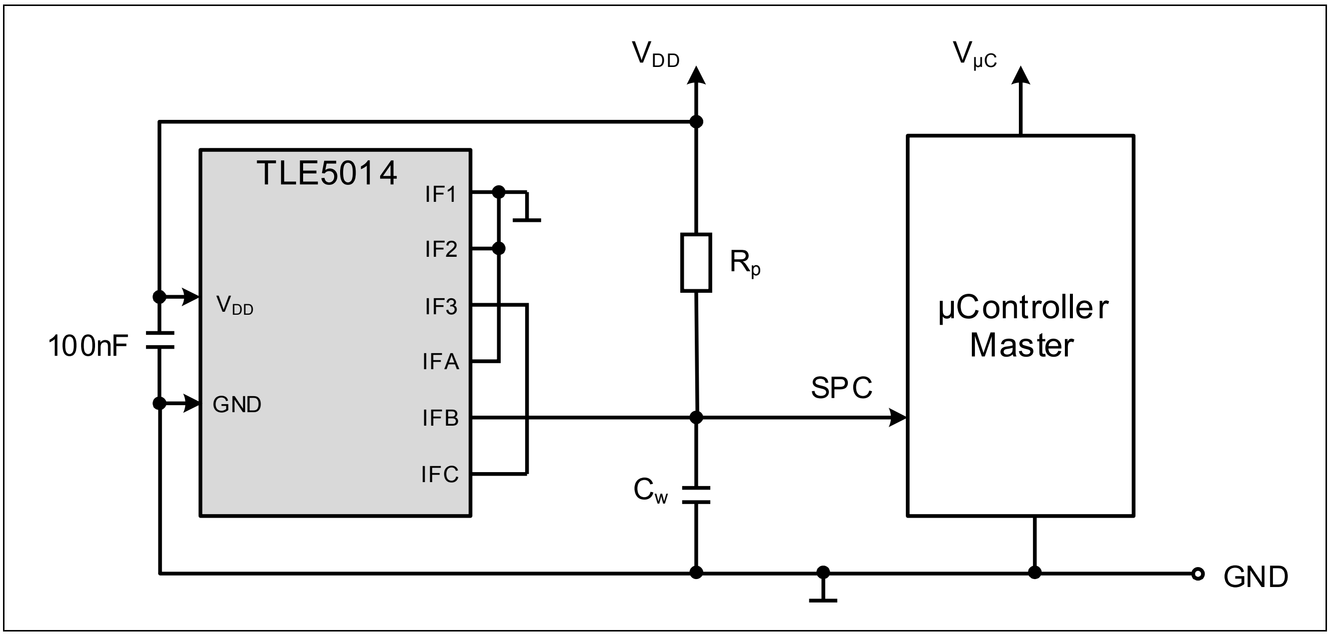

Figure 2-1 Application circuit for SPC interface, with a SPC address ID = 0 defined by pin IF1 and IF2

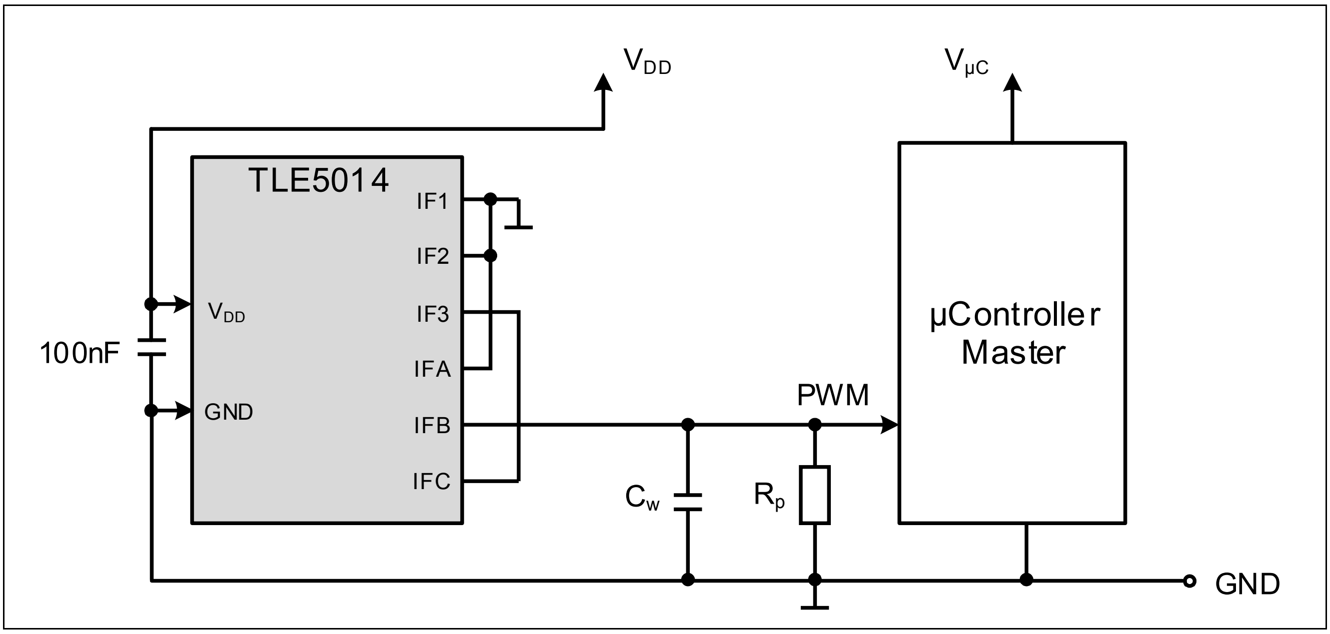

Figure 2-2 Application circuit for PWM interface, protocol starting with a rising edge. For interface configuration starting with a falling edge, a pull-up resistor is required instead.

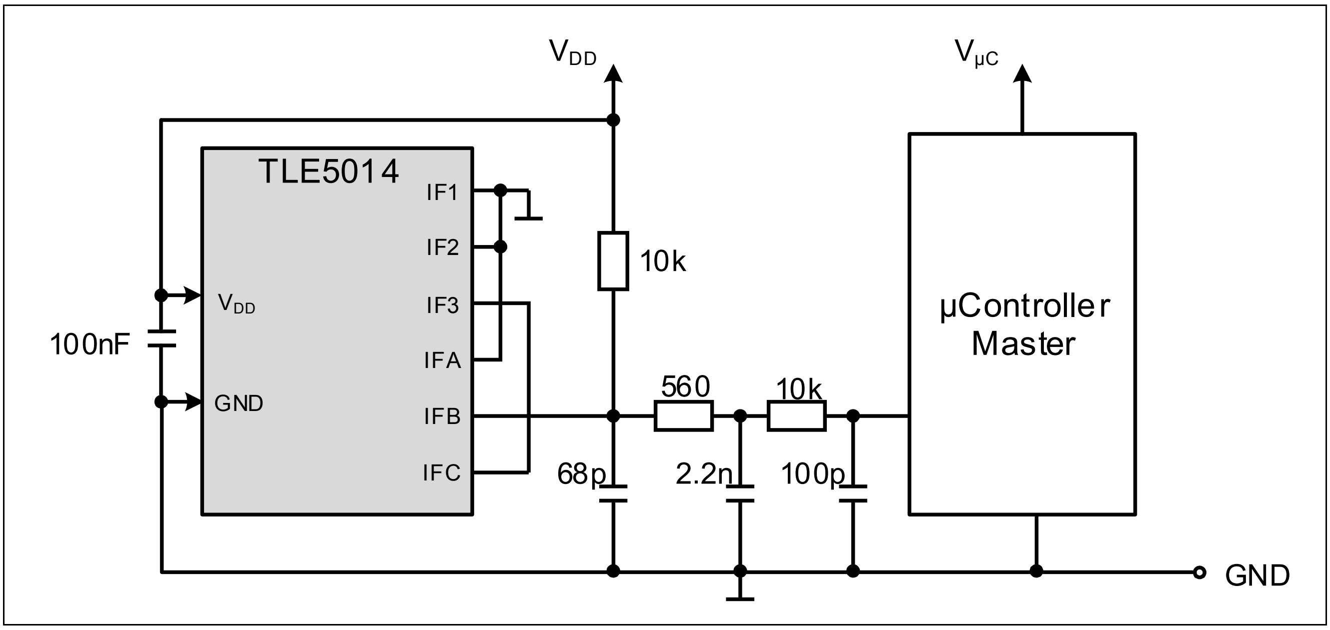

Figure 2-3 Application circuit for SENT interface

3 Specification

3.1 Absolute Maximum Ratings

Stresses above the max. values listed here may cause permanent damage to the device. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. Maximum ratings are absolute ratings; exceeding only one of these values may cause irreversible damage to the device.

Table 3-1 Maximum Ratings for Voltages and Output Current

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Absolute maximum supply voltage	V_{DD}	-18		26	V	for 40h, no damage of device; -18V means V_{DD} < GND
Voltage Peaks	V_{DD}			30	V	for 50µs, no current limitation
Absolute maximum voltage for pin IFB	V_{IO}	-18		19.5	V	for 40h; no damage of device, -18V means V_{DD} < GND
Absolute maximum voltage for pin IF1, IF2, IF3, IFA, IFC	V_{IF}	-0.3		6	V	no damage of device
Voltage Peaks (for pin IFB)	V_{IO}			30	V	for 50µs, no current limitation
Maximum current through output in case of short circuit	I_{short}			40	mA	for 40h, no damage of the device, current limited by device

Table 3-2 Maximum Temperature and Magnetic Field

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Maximum ambient temperature	T_A	-40		125	°C	Q100, Grade 1
Maximum allowed magnetic field	B			200	mT	max 5 min @ T_A = 25°C
Maximum allowed magnetic field	B			150	mT	max 5 h @ T_A = 25°C
Storage & Shipment[1) 2)]	$T_{storage}$	5		40	°C	for dry packed devices, Relative humidity < 90%, storage time < 3a

1) Air-conditioning of ware houses, distribution centres etc. is not necessary, if the combination of the specified limits of 75% R.H. and 40 °C will not be exceeded during storage for more than 10 events per year, irrespective of the duration per event, and one of the specified limits (75 % R.H. or 40 °C) will not be exceeded for longer than 30 days per year

2) See Infineon Application Note: “Storage of Products Supplied by Infineon Technologies”

Table 3-3 Mission Profile

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Mission Profile	$T_{A,max}$			125	°C	for 2000h

Table 3-4 Lifetime & Ignition Cycles

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Operating life time	t_{op_life}			15.000	h	see Table 3-3 for mission profile
Total life time	t_{tot_life}			19	a	additional 2a storage time[1)]
Ignition cycles	$N_{ignition}$			200.000		during operating lifetime t_{op_life}

1) The lifetime shall be considered as an anticipation with regard to the product that shall not extend the warranty period

The device qualification is done according to AEC Q100 Grade 1 for ambient temperature range -40°C < T_A < 125°C

3.2 Operating Range

The following operating conditions must not be exceeded in order to ensure correct operation of the angle sensor. All parameters specified in the following sections refer to these operating conditions, unless otherwise noted. Table 3-5 is valid for -40°C < T_A < 125°C unless otherwise noted.

Table 3-5 Operating Range

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Operating supply voltage	V_{DD}	4.2		5.5	V	-
Supply Voltage Slew Rate	V_{DD_slew}	0.1		10^8	V/s	-
Operating ambient temperature	T_A	-40		125	°C	-
Angle speed	n			10000	°/s	-
Min/max value for pull-up resistor for SENT	R_p	10		55	kOhm	for SENT protocol
Min/max value for pull-up resistor for SPC	R_p	1.45		2.2	kOhm	for SPC protocol
Value for pull-down resistor for PWM	R_p		50		kOhm	for PWM protocol starting with rising edge
Value for pull-up resistor for PWM	R_p		50		kOhm	for PWM protocol starting with falling edge
Capacitive output load on interface (SPC, SENT, PWM)	C_w			3500[1)]	pF	incl. external circuit and cable

1) Larger load capacitance up to 7nF is possible but may influence rise / fall time of the signal

Magnetic Field Range

The operating range of the magnetic field describes the field values where the performance of the sensor, especially the accuracy, is as specified in Table 3-11 and Table 3-12. This value is valid for a NdFeB magnet with a Tc of -1300ppm/K. In case a different magnet is used, the individual Tc of this magnet has to be considered and ensured that the limits are not exceeded. The allowed magnetic field range for the ambient temperature range is given in Figure 3-1.

Table 3-6 Magnetic Field Range

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Angle measurement field range @ 25°C	B	25		80	mT	T_A = 25°C, valid for NdFeB magnet

The below figure Figure 3-1 shows the magnetic field range which shall not be exceeded during operation at the respective ambient temperature. The temperature dependency of the magnetic field is based on a NdBFe magnet with Tc = -1300ppm/K.

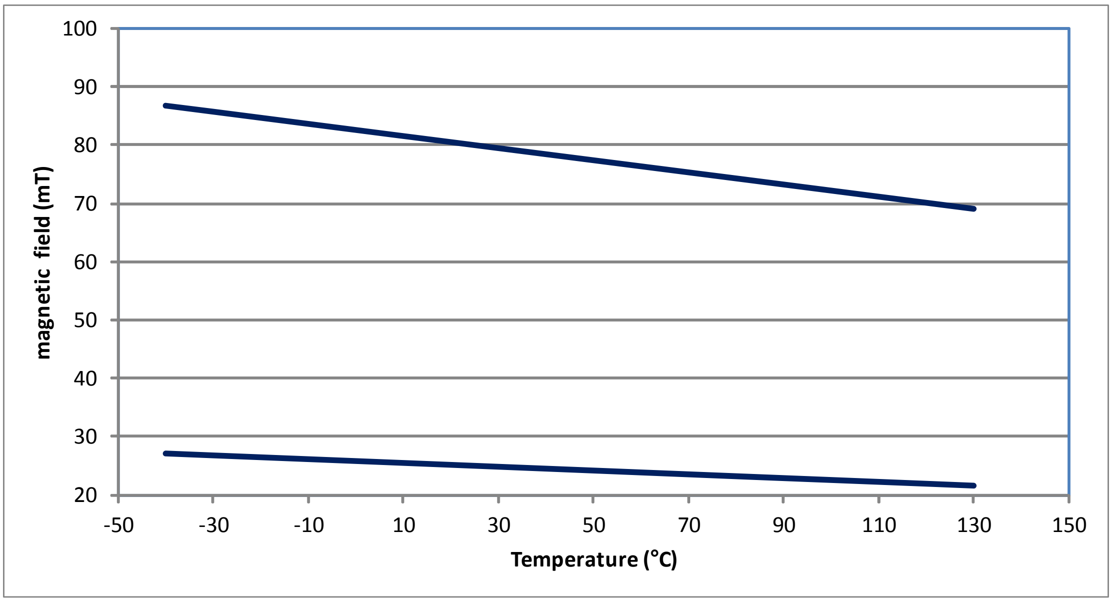

Figure 3-1 Allowed magnetic field range within ambient temperature range.

It is also possible to widen the magnetic field range for higher temperatures. In that case, additional angle errors have to be considered.

3.3 Electrical Characteristics

3.3.1 Input/Output Characteristics

The indicated parameters apply to the full operating range, unless otherwise specified. The typical values correspond to a supply voltage V_{DD} = 5.0V and an ambient temperature T_A = 25°C, unless individually specified. All other values correspond to -40°C < T_A < 125°C.

Table 3-7 Electrical Characteristics

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Operating Supply Current	I_{DD}		12	15	mA	-
Time between supply voltage reaches reset value and valid angle value is available on the output (without interface delay	t_{Pon}			7	ms	
Overvoltage detection on V_{DD}	V_{OV}		6.5	7.0	V	in an overvoltage condition the output switches to tri-state
Undervoltage detection on V_{DD}	V_{UV}	3.8	4.1		V	in an undervoltage condition the sensor performs a reset
Overvoltage detection on IFB	V_{OB}		1.5V+V_{DD}			in an overvoltage condition the output switches to tri-state
Ripple Current due to PWM slopes	I_{ripple}			9	mA	peak-peak; V_{DD} = 5V, 30kHz lowpass filter
Ripple Current due to SENT slopes	I_{ripple}			9	mA	peak-peak; V_{DD} = 5V, 30kHz lowpass filter
Internal clock tolerance	Δf_{clock}	-5		5	%	including temperature and lifetime

The following Figure 3-2 shows the operating area of the device, the condition for overvoltage and undervoltage and the corresponding sensor reaction. The values for the over- and undervoltage comparators are the typical values from Table 3-7.

In the extended range, the sensor fulfills the full specification. However, voltages above the operating range can only be applied for a limited time (see Table 3-1).

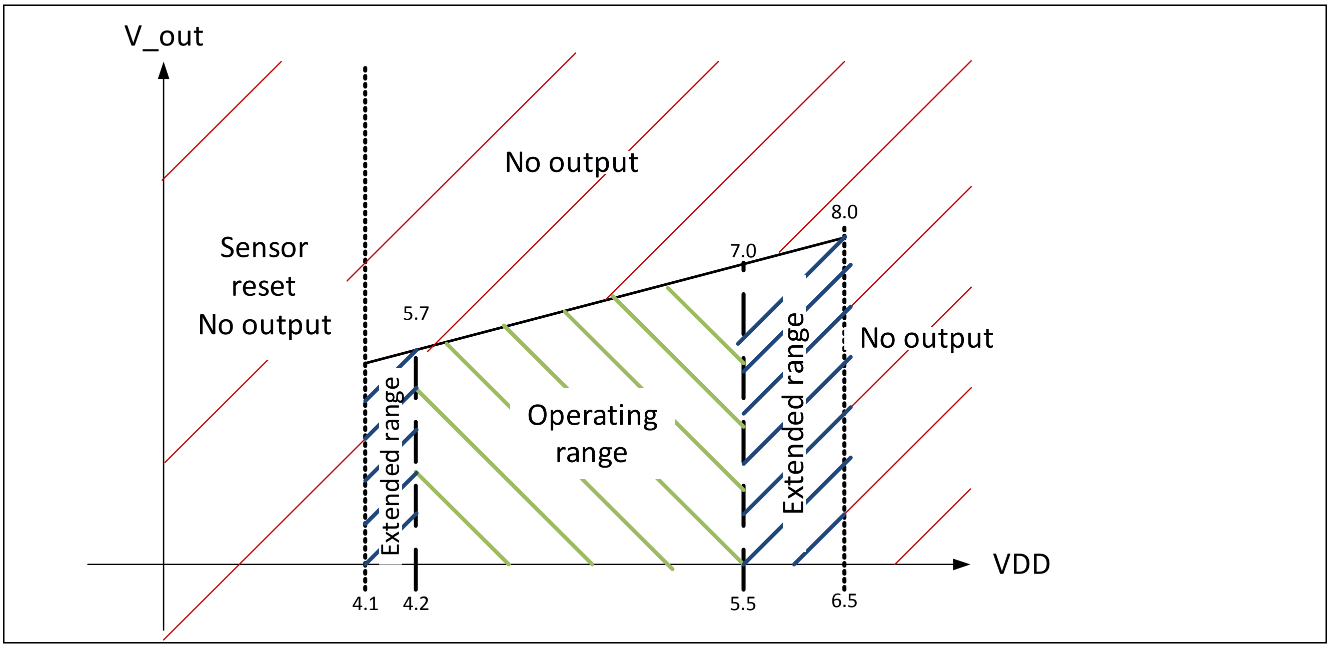

Figure 3-2 Operating area and sensor reaction for over- and undervoltage.

Table 3-8 Output driver

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Output low level[1)]	V_{OL}			$0.1*V_{DD}$		V_{DD} = 5V, I_{sink} = 0.1mA (SENT spec)
Output low level[1)]	V_{OL}			$0.2*V_{DD}$		V_{DD} = 5V, I_{sink} = 2mA
Output low level[1)]	V_{OL}			$0.3*V_{DD}$		V_{DD} = 5V, I_{sink} = 3mA
Output high level[1)]	V_{OH}	$0.9*V_{DD}$				V_{DD} = 5V, I_{sink} = 0.1mA (SENT spec)
Output high level[1)]	V_{OH}	$0.8*V_{DD}$				V_{DD} = 5V, I_{sink} = 2mA
Output high level[1)]	V_{OH}	$0.7*V_{DD}$				V_{DD} = 5V, I_{sink} = 3mA

1) In case several sensors are connected in a bus mode, the output levels may be influenced and out of specification in case a malfunction of one of the sensors on the bus occurs (e.g. one sensors has loss of V_{DD}).

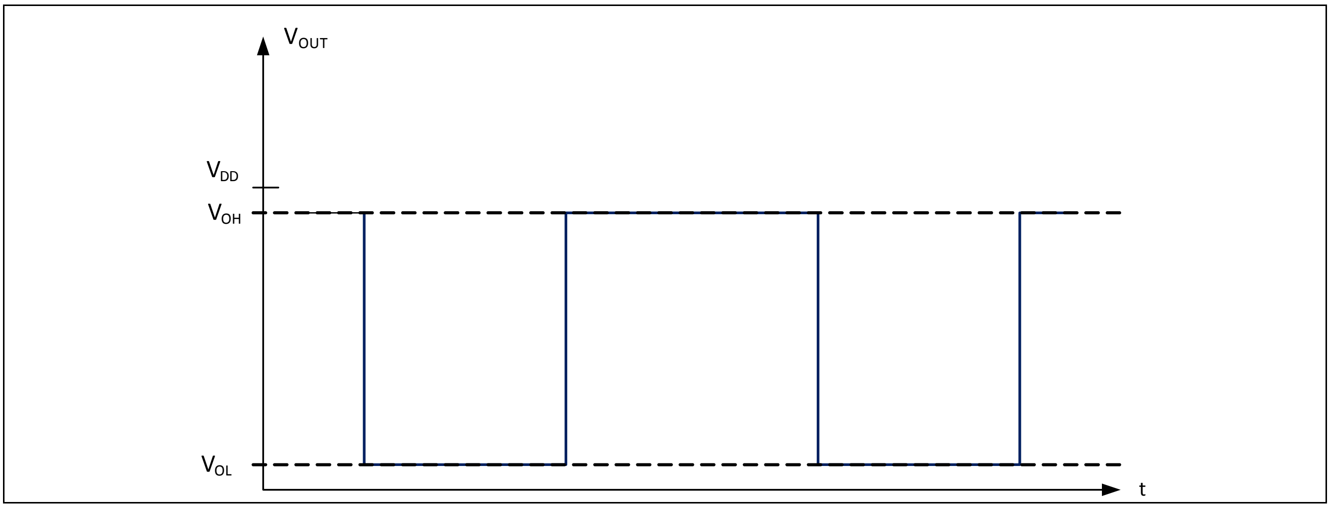

Figure 3-3 Output level high / low

Output Delay Time and Jitter

Due to the internal signal sampling and signal conditioning, there will be a delay of the provided angle value at the output. The definition of this delay is described in below Figure 3-4

Table 3-9 Signal Delay and Delay Time Jitter

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Delay time between real angle and angle output (from SPC/SENT falling edge of sync pulse, without interface delay) incl. jitter and oscillator tolerances	t_{adel}	10.0	25.6	42.5	µs	min/max values include already the jitter t_{deljit}
Delay time between real angle and angle output (from PWM rising edge, without interface delay) incl. jitter and oscillator tolerances	t_{adel}	36.7	51.2	67.4	µs	min/max values include already the jitter t_{deljit}
Variation of delay time t_{adel}	t_{deljit}			+/-14	µs	see Figure 3-5. already included in t_{adel} specification

The delay time describes the time difference of the real angle at the point in time were the SPC/SENT protocol issues a falling edge (synchronization nibble) and the angle value which is transmitted with this data frame. It is the “age” of the transmitted angle value in reference to the falling edge of the synchronization pulse.

For PWM interface the reference point in time is the starting edge of the PWM (rising or falling, depending on protocol setting).

The delay time values given in Table 3-9 include also the internal oscillator variation and jitter.

The delay time variation (or jitter of delay time) describes the statistical variation of this parameter in case several measurements are done. The delay time t_{adel} can be considered as the mean value with the jitter t_{deljit} as variation (see Figure 3-5).

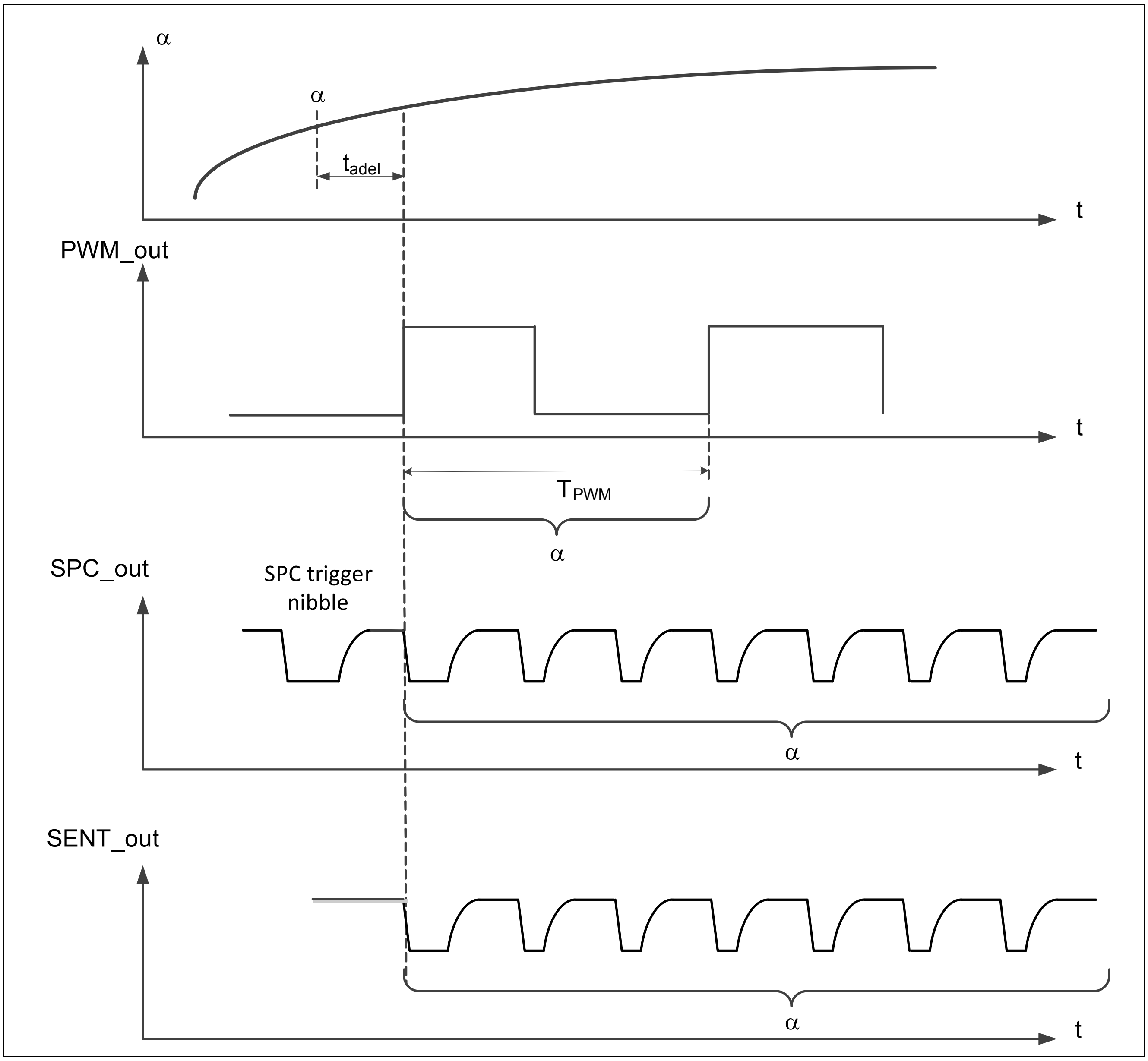

Figure 3-4 Delay time

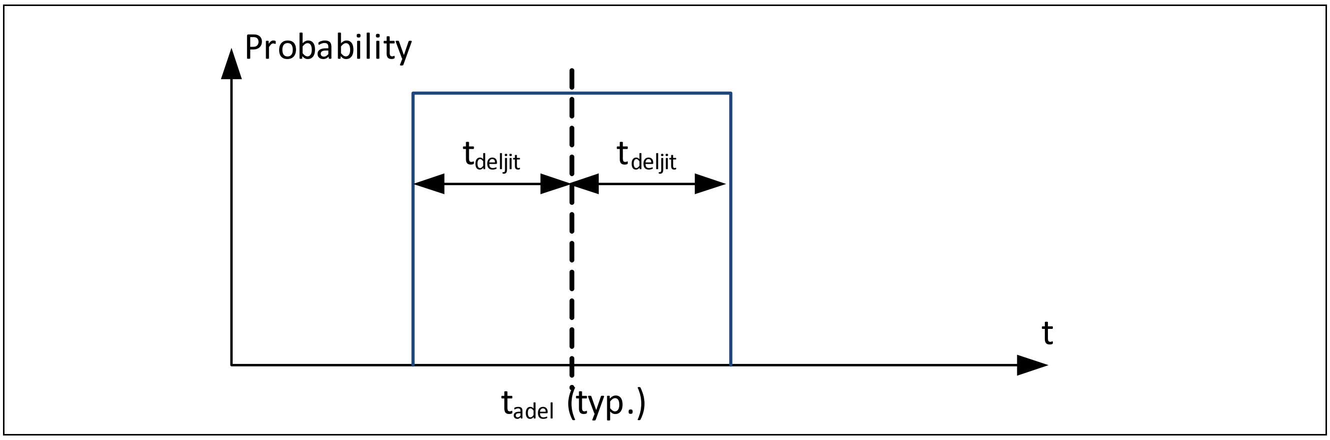

Figure 3-5 Variation of delay time (jitter)

3.3.2 ESD Protection

Table 3-10 ESD Voltage

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Electro-Static-Discharge voltage (HBM), according to ANSI/ESDA/JEDEC JS-001	V_{HBM}			±4	kV	HBM contact discharge for pins VDD, GND, IFB
Electro-Static-Discharge voltage (HBM), according to ANSI/ESDA/JEDEC JS-001	V_{HBM}			±2	kV	HBM contact discharge for pins IF1, IF2, IF3, IFA, IFC
Electro-Static-Discharge voltage (CDM), according to JESD22-C101	V_{CDM}			±0.5	kV	for all pins except corner pins
				±0.75	kV	for corner pins only

3.3.3 Angle Performance

After internal angle calculation, the sensor has a remaining error, as shown in Table 3-11 for an ambient temperature range up to 85°C and a reduced magnetic field range and in Table 3-12 for the ambient temperature range up to 125°C and full magnetic operating range. The error value refers to B_Z= 0mT.

The overall angle error represents the relative angle error. This error describes the deviation from the reference line after zero-angle definition. It is valid for a static magnetic field.

If the magnetic field is rotating during the measurement, an additional propagation error is caused by the angle delay time (see Table 3-9).

Table 3-11 Angle Error for -40°C < T_A < 85°C and magnetic field range 33mT < B < 50mT

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Accuracy[1)] over temperature w/o look-up table	$A_{Err,T}$			0.8	°	0h[2)], over temperature
Accuracy[1)] over temperature and lifetime, w/o look-up table	$A_{Err,s}$			0.9	°	lifetime stress: T_A=85°C/1000h/50mT
Accuracy[1)3)] over temperature and lifetime, with look-up table	$A_{Err,sLUT}$			0.65	°	lifetime stress: T_A=85°C/1000h/50mT with look-up table correction
Hysteresis[4)]	A_{Hyst}		0.1	0.16	°	value includes quantization error of 12bit angle output

1) Hysteresis and noise are included in the angle accuracy specification
2) “0h” is the condition when the part leaves the production at Infineon
3) Verified by characterization
4) Hysteresis is the maximum difference of the angle value for forward and backward rotation

Table 3-12 Angle Error for -40°C < T_A < 125°C

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Accuracy[1)] over temperature w/o look-up table	$A_{Err,T}$			0.8	°	0h[2)], over temperature B = 33mT to 80mT[3)]
Accuracy[1)] over temperature and lifetime, w/o look-up table	$A_{Err,s}$			1.0	°	33mT…80mT[3)] lifetime stress: T_A=125°C/2000h
Accuracy[1)4)] over temperature and lifetime, with look-up table	$A_{Err,sLUT}$			0.85	°	B = 33mT to 80mT[3)], lifetime stress: T_A=125°C/2000h with look-up table correction
Hysteresis[5)]	A_{Hyst}		0.1	0.16	°	B = 33mT to 80mT[6)], value includes quantization error of 12bit angle output

1) Hysteresis and noise are included in the angle accuracy specification
2) “0h” is the condition when the part leaves the production at Infineon
3) For the magnetic field range of 25mT < B < 33mT, 0.2° have to be added to the max. angle accuracy
4) Verified by characterization

5) Hysteresis is the maximum difference of the angle value for forward and backward rotation
6) For the magnetic field range of 25mT < B < 33mT, 0.1° have to be added to the max. hysteresis A_{Hyst}

3.4 EEPROM Memory

The sensor includes a non-volatile memory (NVM) where calibration data and sensor configuration data are stored. The customer has access to a part of this memory for storage of application specific data (e.g. look-up table & customer ID)

The time for programming the customer relevant part of the NVM as well as maximum cycles of programming and data retention is given in Table 3-13

Table 3-13 EEPROM

Parameter	Symbol	Values			Unit	Note / Test Condition	Number
		Min.	Typ.	Max.			
Number of possible NVM programming cycles	n_{Prog}			100		-	
NVM data retention	$t_{retention}$		-	21	a	includes 19a lifetime and 2a storage	
Time for programming of whole NVM (customer relevant part)	t_{Prog}		0.5		s	incl. look-up table, configuration, customer ID; with 100kbit/s	

3.5 Reset Concept and Fault Monitoring

Some internal and external faults of the device can trigger a reset. During this reset, all output pins are high-ohmic to avoid any disturbance of other sensors which may be connected together in a bus mode. A reset is indicated as soon as the sensor is back at operational mode either by a status bit (SPC and SENT protocol) or with a duty cycle in the diagnostic range (PWM interface). In the case of a periodic reset (sensor toggles between on and off state) it is avoided that the output toggles with a frequency close to a valid PWM frequency. In this way it is ensured, that a reset can clearly be distinguished from a valid output signal.

3.6 External & Internal Faults

In case of an occurrence of external or internal faults, as for example overvoltage or undervoltage, the sensor reacts in a way that these faults are indicated to the customer. This can be either by a status bit (SPC and SENT protocol) or with a duty cycle in the diagnostic range (PWM interface).

The error signaling (safe state) is defined as:

- indication of an error (e.g. status bit)
- detectable wrong output (e.g. CRC failure)
- no output

All errors are indicated as long as they persist, but at least once. After disappearance of the error, the error indication is also cleared. The error is signaled and communicated to the ECU latest after 5ms from occurrence of the fault. To achieve this, it has to be ensured that the protocol transmission time is not exceeding 1ms. Otherwise, the fault tolerant time interval is increased above 5ms.

Overvoltage, undervoltage

It is ensured, that the sensor provides a valid output value as long as the voltage is within the operating range or no under- or overvoltage is indicated. At occurrence of an undervoltage, the sensor performs a reset. The implemented undervoltage comparator at V_{DD} detects an undervoltage at ~4.1V (typ. value). At occurrence of an overvoltage, the sensor output goes to tristate and no protocol is transmitted. The implemented overvoltage comparator at V_{DD} detects an overvoltage at ~6.5V (typ. value). An overvoltage on the output pin IFB is detected as soon as the voltage at IFB is more than ~1.5V above $V_{DD.}$

Open and Shorts

All pins of the device withstand a short to ground (GND) and a short to V_{DD} (as long as V_{DD} is within the operating range). In case of an open V_{DD} connection or an open GND the sensor provides a detectable wrong signal (e.g. no valid output protocol or duty cycle) which is considered as a safe state.

It is also ensured that a short between two neighboring pins leads to a detectable wrong output signal.

Communication Failures

An external fault can happen where an ongoing communication is interrupted before it is finished correctly. In such an event, no sensor malfunction or dead-lock will occur.

3.7 Power Dissipation

Following table describes the calculated power dissipation for the different application cases within the operating range defined in Table 3-5. It is a worst case assumption with the maximum values within the operating range.

Table 3-14 Power Dissipation

Scenario	Configuration	V_{DD} (V)	I_{DD} (mA)	V_{OUT} (V)	I_{OUT} (mA)	P (mW)
1	PWM	5.5	15			82.5
2	SPC open drain	5.5	15	1.1	3	85.8
3	SENT	5.5	15	0.2	0.55	82.6
4	SPC bus mode	5.5	15	1.1	3	85.8

3.8 Device Programming (SICI Interface)

To minimize the wiring in the application and to allow an end of line calibration and configuration of the device at the customer, the programming interface does not require additional pins or wiring. It is possible to do the programming on the available output line of the sensor output (SPC, SENT or PWM interface). This single wire interface is called SICI interface. It is only for programming purpose and not for communication or read out of angle values during operation. The programming mode can be accessed directly after start-up of the IC by sending the appropriate command on the output line.

Following parameters can be programmed end of line:

- Zero angle (angle base)
- Rotation direction (clock wise or counter clock wise)
- Look-up table (32 points)
- Customer ID (112bit individual data)

To align the angle output of the sensor with the application specific required zero angle direction this value can be programmed. All further output angles are in reference to this zero angle.

In case several sensors are connected in a bus mode configuration (SPC interface) each sensor needs to have an individual address to enable a programming of the devices in the bus configuration. Please refer to Table 4-5 for details how to assign individual addresses to the sensors.

Look-Up Table

To increase the accuracy of the provided angle value, a look-up table is implemented which allows to compensate for external angle errors which may be introduced for example by the magnetic circuit. Alignment tolerances (eccentricity or tilt) may lead to a non-linearity of the output signal which can be compensated using the implemented look-up table. This look-up table has 32 equidistant points over 360° angle range with a linear interpolation between the 32 defined values

Further details for programming and configuration of the device can be found in the corresponding user manual of the TLE5014.

4 Interfaces

This chapter describes the interfaces of the sensor. Several interfaces are implemented, the active interface is predefined by Infineon and can not be changed. The available preconfigured devices are described in Chapter 6. The indicated parameters apply to the full operating range, unless otherwise specified. The typical values correspond to a supply voltage V_{DD} = 5.0V and an ambient temperature of T_A = 25°C, unless individually specified. All other values correspond to -40°C < T_A < 125°C

4.1 Sensor Output Driver

The TLE5014 has an output driver on the pin IFB which can be switched from a push-pull configuration to a quasi-open drain with active controlled slope.

- The push-pull configuration is preferred with SENT and PWM interface. It has controlled rising and falling slopes to reduce EMC emission and provides a controlled and defined pulse length independent of external circuitry. The push-pull output driver switches between 0V and V_{DD}. An additional pull-down or pull-up resistor is recommended to ensure a defined output level at sensor start-up.
- For the SPC interface the open drain setting with controlled slopes is required. In this configuration, the TLE5014 has controlled rising and falling slopes but after reaching the HIGH-level, the output is switched to an open-drain behavior. The HIGH level is then maintained by the external pull-up resistor. It is necessary, that the sensor releases the output line once reaching the HIGH level so that the master (µ-Controller) can issue the SPC trigger pulse by pulling the line low.

4.2 Pulse Width Modulation (PWM) Interface

PWM Interface: An uni-directional interface with the angle information coded in the length of a pulse. The angle value is proportional to the duty cycle of the output frequency.

The duty cycle is calculated as the ratio of the “high” time to the period length. An increasing angle results in an increased duty cycle, with an angle of 0° having the smallest duty cycle.

Table 4-1 PWM Interface

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
PWM output frequencies	f_{PWM1}	200		2200	Hz	configurable
Resolution			12		bit	
Data duty cycle range	DC_{data}	5		95	%	configurable, the 12bit angle value is mapped to this duty cycle range
Diagnostic duty cycle, low[1)]	$DC_{diag,low}$	0		25	%	configurable, fault indication
Diagnostic duty cycle, high[1)]	$DC_{diag,high}$	75		100	%	configurable, BIST error indication or reset indication

1) Care has to be taken to ensure that there is no overlap of diagnostic duty cycle and data duty cycle range

The starting edge of the PWM protocol can be programmed as rising or falling edge. In case the protocol shall start with a rising edge (start with a LOW level), a pull-down resistor is required (see Figure 2-2). For the start-up condition with a falling edge (start with a HIGH level), a pull-up resistor instead has to be implemented.

The tolerance of the programmed PWM frequency over temperature and lifetime is given in Table 4-2

Table 4-2 PWM Frequency tolerance

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
PWM Frequency tolerance	PWM_{freq_tol}	-5		5	%	

PWM Interface Error Indication

For diagnostic purpose and to indicate internal sensor failures, the output duty cycle of the PWM is limited. Within this reserved lower and upper duty cycle range, no valid angle information is provided. Instead, this duty cycle range is used for error indication with defined duty cycles which are clearly separated from the usable data duty cycle range. The following events are indicated:

- Error occurred during performing the built-in self test (BIST) after power-up
- Occurrence of internal or external fault
- Sensor reset occurred

PWM Interface Configuration

The PWM interface parameter can be configured in a wide range. Beside the frequency, it is also possible to define data duty cycle range and low and high value of the diagnostic duty cycle. It has to be ensured by proper device configuration that there is no overlap of data duty cycle range and low or high value of diagnostic duty cycle.

A possible and valid configuration is:

- Data duty cycle: 12.5% ...87.5%, the 12bit angle value is mapped to this duty cycle
- Diagnostic duty cycle, low: 5%; an internal sensor fault is indicated with this duty cycle
- Diagnostic duty cycle, high: 95%; an start-up BIST error or sensor reset is indicated with this duty cycle

The PWM interface with data duty cycle range and reserved duty cycle for diagnostics is shown in Figure 4-1

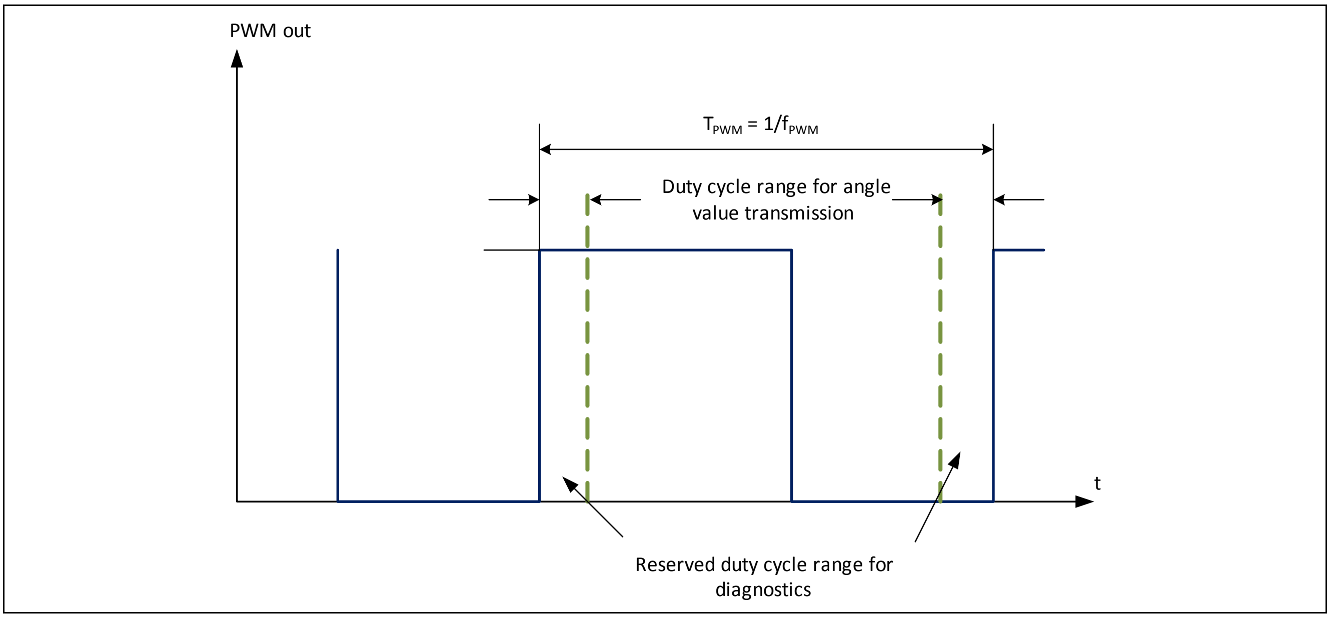

Figure 4-1 PWM interface with duty cycle range starting with a rising edge

As the PWM interface is an analog protocol, the rise and fall times, as well as the trigger level for the detection of the high and low state of the signal have influence on the measured duty cycle. Therefore, an additional angle error is introduced which varies with the measurement conditions (e.g. Rp, CW, trigger level). This error contribution is not included in Table 3-11 and Table 3-12.