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Angle Sensor

GMR-Based Angle Sensor

TLE5012B

Data Sheet

Rev. 2.0, 2014-02

Sense & Control

Revision History	
Page or Item	**Subjects (major changes since previous revision)**
Rev. 2.0, 2014-02	
	All chapters revised

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1 Product Description

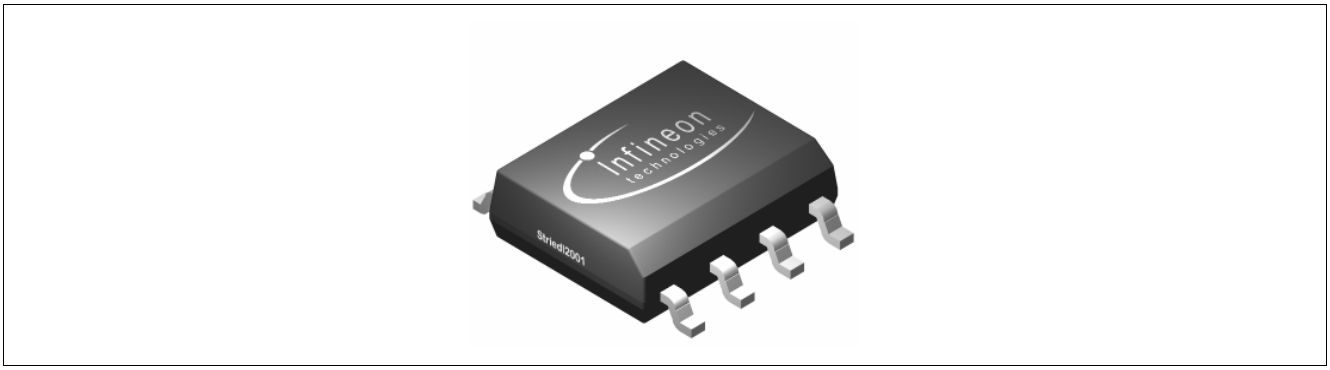

Figure 1-1 PG-DSO-8 package

1.1 Overview

The TLE5012B is a 360° angle sensor that detects the orientation of a magnetic field. This is achieved by measuring sine and cosine angle components with monolithic integrated Giant Magneto Resistance (iGMR) elements. These raw signals (sine and cosine) are digitally processed internally to calculate the angle orientation of the magnetic field (magnet).

The TLE5012B is a pre-calibrated sensor. The calibration parameters are stored in laser fuses. At start-up the values of the fuses are written into flip-flops, where these values can be changed by the application-specific parameters. Further precision of the angle measurement over a wide temperature range and a long lifetime can be improved by enabling an optional internal autocalibration algorithm.

Data communications are accomplished with a bi-directional Synchronous Serial Communication (SSC) that is SPI-compatible. The sensor configuration is stored in registers, which are accessible by the SSC interface.

Additionally four other interfaces are available with the TLE5012B: Pulse-Width-Modulation (PWM) Protocol, Short-PWM-Code (SPC) Protocol, Hall Switch Mode (HSM) and Incremental Interface (IIF). These interfaces can be used in parallel with SSC or alone. Pre-configured sensor derivates with different interface settings are available (see **Table 1-1** and **Chapter 5**)

Online diagnostic functions are provided to ensure reliable operation.

Table 1-1 Derivate Ordering codes

Product Type	Marking	Ordering Code	Package
TLE5012B E1000	012B1000	SP001166960	PG-DSO-8
TLE5012B E3005	012B3005	SP001166964	PG-DSO-8
TLE5012B E5000	012B5000	SP001166968	PG-DSO-8
TLE5012B E5020	012B5020	SP001166972	PG-DSO-8
TLE5012B E9000	012B9000	SP001166998	PG-DSO-8

*Note: See **Chapter 5** for description of derivates.*

1.2 Features

- **G**iant **M**agneto **R**esistance (GMR)-based principle
- Integrated magnetic field sensing for angle measurement
- 360° angle measurement with revolution counter and angle speed measurement
- Two separate highly accurate single bit SD-ADC
- 15 bit representation of absolute angle value on the output (resolution of 0.01°)
- 16 bit representation of sine / cosine values on the interface
- Max. 1.0° angle error over lifetime and temperature-range with activated auto-calibration
- Bi-directional SSC Interface up to 8Mbit/s
- Supports Safety Integrity Level (SIL) with diagnostic functions and status information
- Interfaces: SSC, PWM, Incremental Interface (IIF), Hall Switch Mode (HSM), Short PWM Code (SPC, based on SENT protocol defined in SAE J2716)
- Output pins can be configured (programmed or pre-configured) as push-pull or open-drain
- Bus mode operation of multiple sensors on one line is possible with SSC or SPC interface in open-drain configuration
- 0.25 µm CMOS technology
- Automotive qualified: -40°C to 150°C (junction temperature)
- ESD > 4kV (HBM)
- RoHS compliant (Pb-free package)
- Halogen-free

1.3 Application Example

The TLE5012B GMR-based angle sensor is designed for angular position sensing in automotive applications such as:

- Electrical commutated motor (e.g. used in Electric Power Steering (EPS))
- Rotary switches
- Steering angle measurements
- General angular sensing

2 Functional Description

2.1 Block Diagram

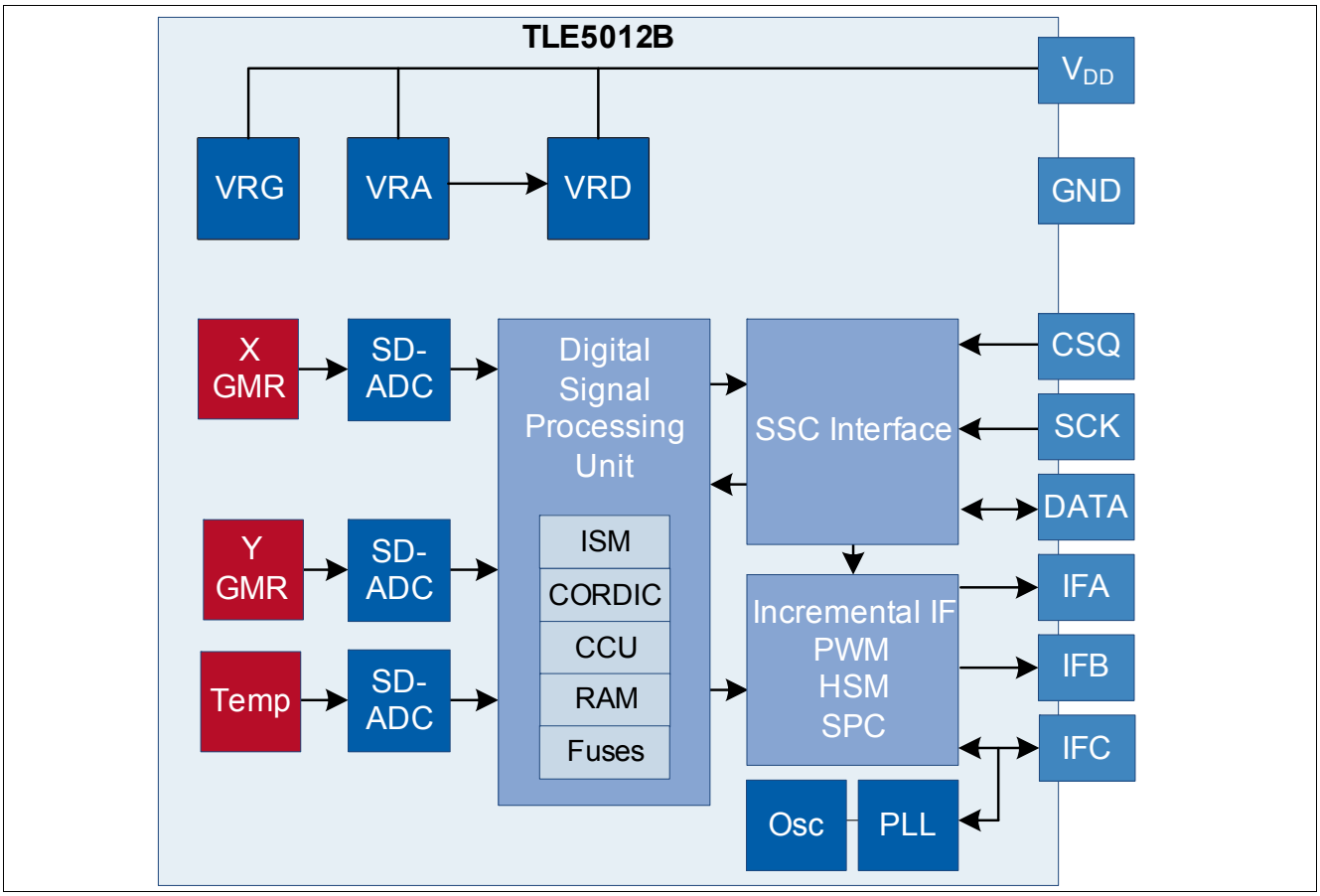

Figure 2-1 TLE5012B block diagram

2.2 Functional Block Description

2.2.1 Internal Power Supply

The internal stages of the TLE5012B are supplied with several voltage regulators:

- GMR Voltage Regulator, VRG
- Analog Voltage Regulator, VRA
- Digital Voltage Regulator, VRD (derived from VRA)

These regulators are directly connected to the supply voltage V_{DD}.

2.2.2 Oscillator and PLL

The digital clock of the TLE5012B is given by the Phase-Locked Loop (PLL), which is by default fed by an internal oscillator. In order to synchronize the TLE5012B with other ICs in a system, the TLE5012B can be configured via

SSC interface to use an external clock signal supplied on the IFC pin as source for the PLL, instead of the internal clock. External clock mode is only available in PWM or SPC interface configuration.

2.2.3 SD-ADC

The **S**igma-**D**elta **A**nalog-**D**igital-**C**onverters (**SD-ADC**) transform the analog GMR voltages and temperature voltage into the digital domain.

2.2.4 Digital Signal Processing Unit

The Digital Signal Processing Unit (DSPU) contains the:

- **I**ntelligent **S**tate **M**achine (**ISM**), which does error compensation of offset, offset temperature drift, amplitude synchronicity and orthogonality of the raw signals from the GMR bridges, and performs additional features such as auto-calibration, prediction and angle speed calculation
- **CO**ordinate **R**otation **DI**gital **C**omputer (**CORDIC**), which contains the trigonometric function for angle calculation
- **C**apture **C**ompare **U**nit (**CCU**), which is used to generate the PWM and SPC signals
- **R**andom **A**ccess **M**emory (**RAM**), which contains the configuration registers
- Laser Fuses, which contain the calibration parameters for the error-compensation and the IC default configuration, which is loaded into the RAM at startup

2.2.5 Interfaces

Bi-directional communication with the TLE5012B is enabled by a three-wire SSC interface. In parallel to the SSC interface, one secondary interface can be selected, which is available on the IFA, IFB, IFC pins:

- PWM
- Incremental Interface
- Hall Switch Mode
- Short PWM Code

By using pre-configured derivates (see **Chapter 5**), the TLE5012B can also be operated with the secondary interface only, without SSC communication.

2.2.6 Safety Features

The TLE5012B offers a multiplicity of safety features to support the Safety Integrity Level (SIL) and it is a PRO-SIL™ product.

Safety features are:

- Test vectors switchable to ADC input (activated via SSC interface)
- Inversion or combination of filter input streams (activated via SSC interface)
- Data transmission check via 8-bit **C**yclic **R**edundancy **C**heck (**CRC**) for SSC communcation and 4-bit CRC nibble for SPC interface
- Built-in Self-test (BIST) routines for ISM, CORDIC, CCU, ADCs run at startup
- Two independent active interfaces possible
- Overvoltage and undervoltage detection

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SIL respectively A-SIL certification for such a System has to be reached on system level by the System Responsible at an accredited Certification Authority.

SIL stands for Safety Integrity Level (according to IEC 61508)

A-SIL stands for Automotive-Safety Integrity Level (according to ISO 26262)

2.3 Sensing Principle

The Giant Magneto Resistance (GMR) sensor is implemented using vertical integration. This means that the GMR-sensitive areas are integrated above the logic part of the TLE5012B 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.

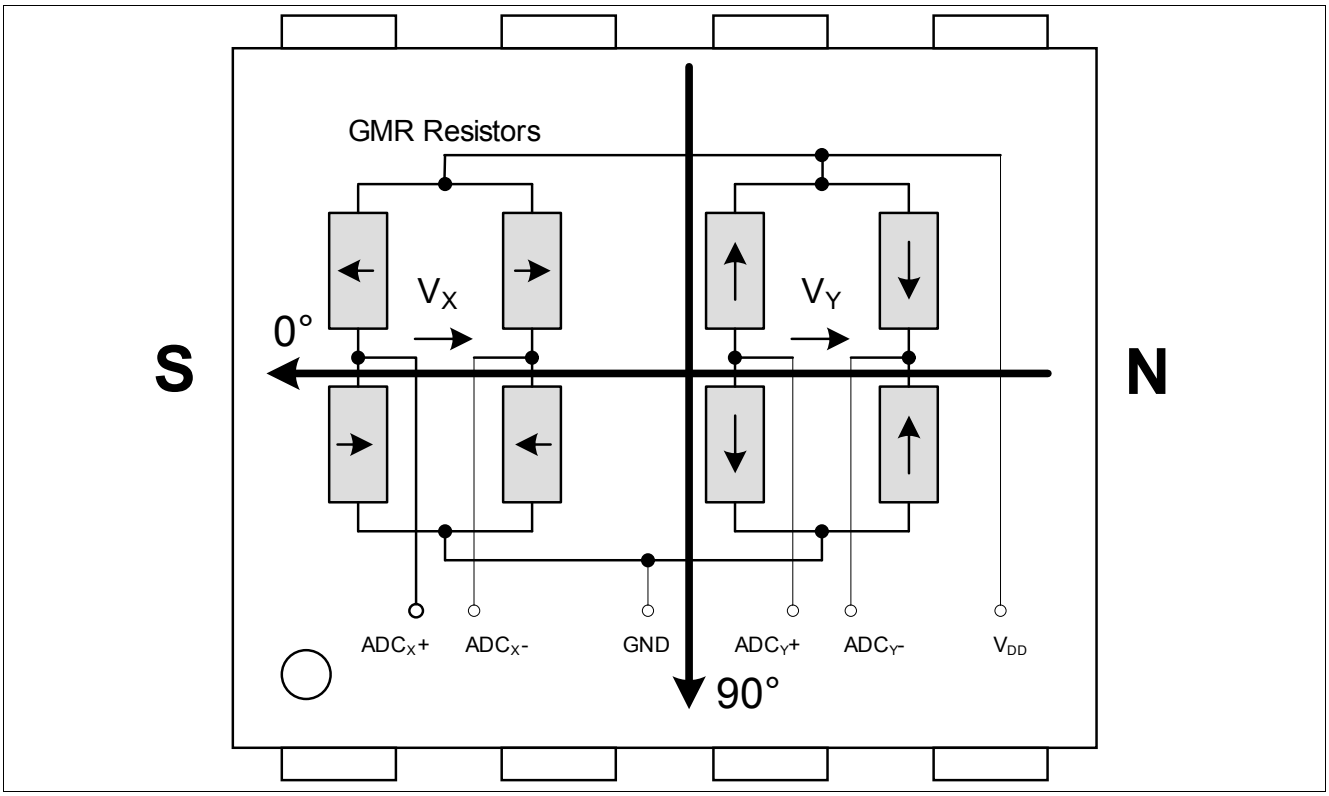

Figure 2-2 Sensitive bridges of the GMR sensor (not to scale)

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 2-2.

In **Figure 2-2**, 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.

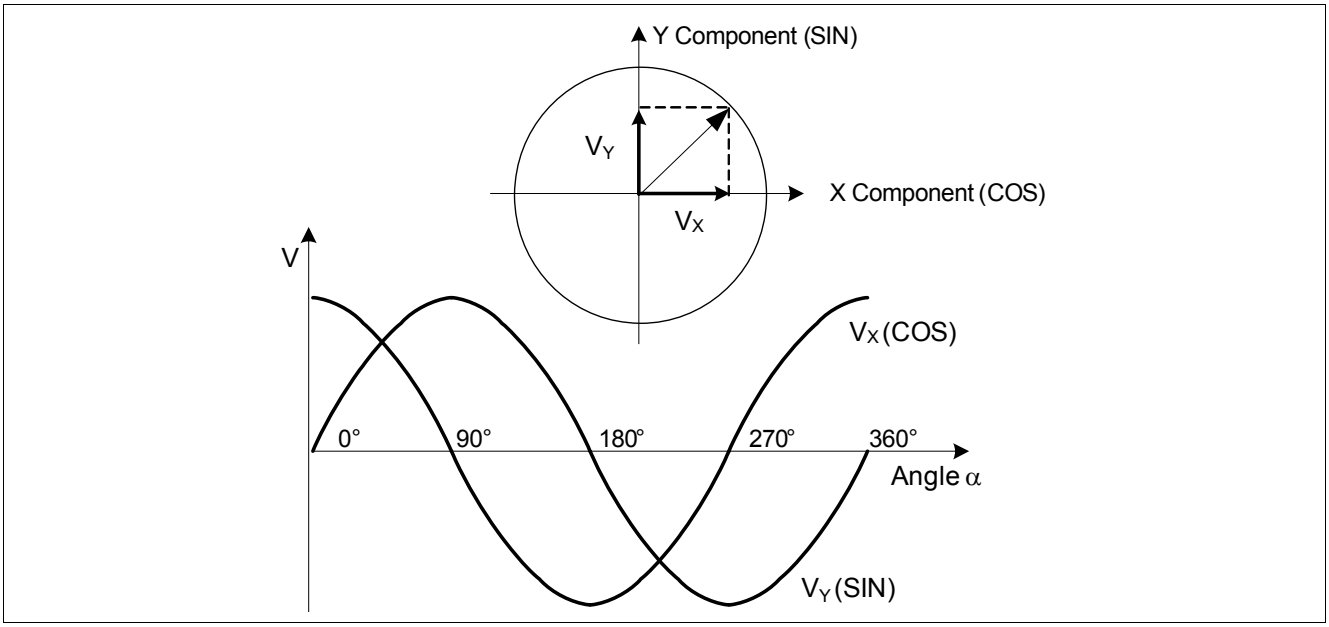

Figure 2-3 Ideal output of the GMR sensor bridges

2.4 Pin Configuration

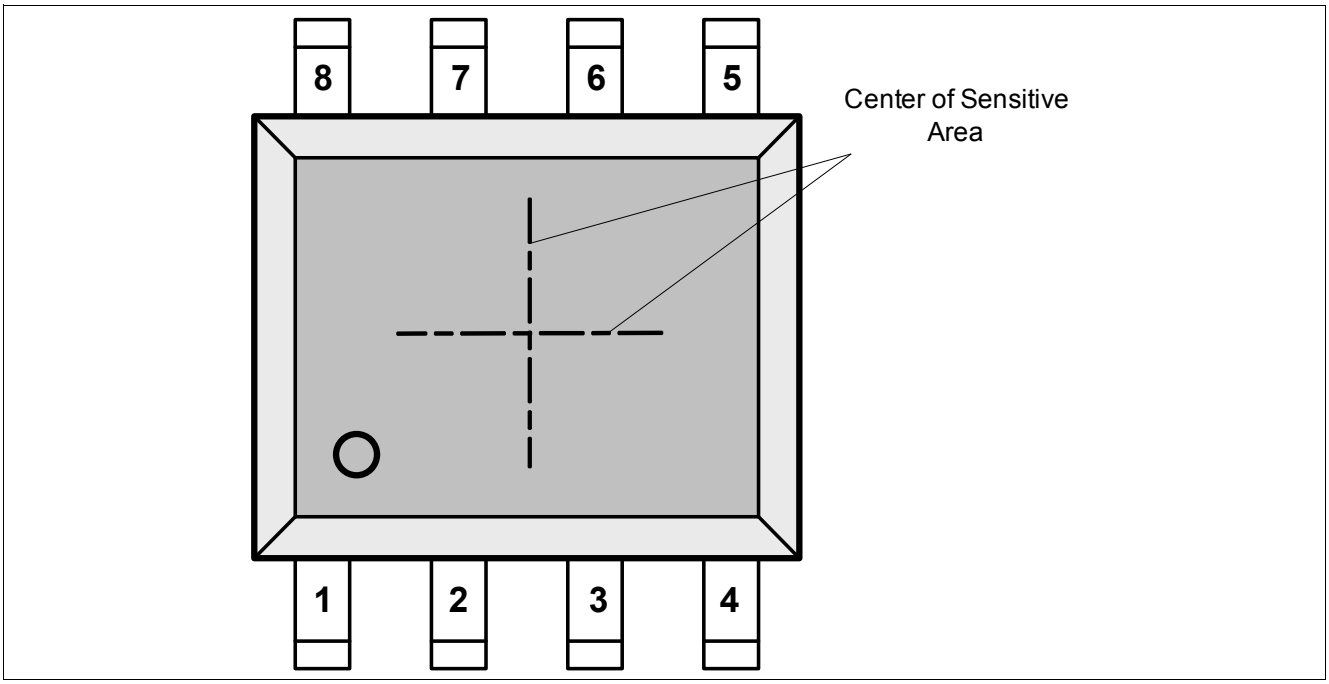

Figure 2-4 Pin configuration (top view)

2.5 Pin Description

Table 2-1 Pin Description

Pin No.	Symbol	In/Out	Function
1	IFC (CLK / IIF_IDX / HS3)	I/O	Interface C: External Clock[1] / IIF Index / Hall Switch Signal 3
2	SCK	I	SSC Clock
3	CSQ	I	SSC Chip Select
4	DATA	I/O	SSC Data
5	IFA (IIF_A / HS1 / PWM / SPC)	I/O	Interface A: IIF Phase A / Hall Switch Signal 1 / PWM / SPC output (input for SPC trigger only)
6	V_{DD}	-	Supply Voltage
7	GND	-	Ground
8	IFB (IIF_B / HS2)	O	Interface B: IIF Phase B / Hall Switch Signal 2

1) External clock feature is not available in IIF or HSM interface mode

3 Application Circuits

The application circuits in this chapter show the various communication possibilities of the TLE5012B. The pin output mode configuration is device-specific and it can be either push-pull or open-drain. The bit IFAB_OD (register IFAB, $0D_H$) indicates the output mode for the IFA, IFB and IFC pins. The SSC pins are by default push-pull (bit SSC_OD, register MOD_3, 09_H).

Figure 3-1 shows a basic block diagram of a TLE5012B with Incremental Interface and SSC configuration. The derivate TLE5012B - E1000 is by default configured with push-pull IFA (IIF_A), IFB (IIF_ B) and IFC (IIF_IDX) pins.

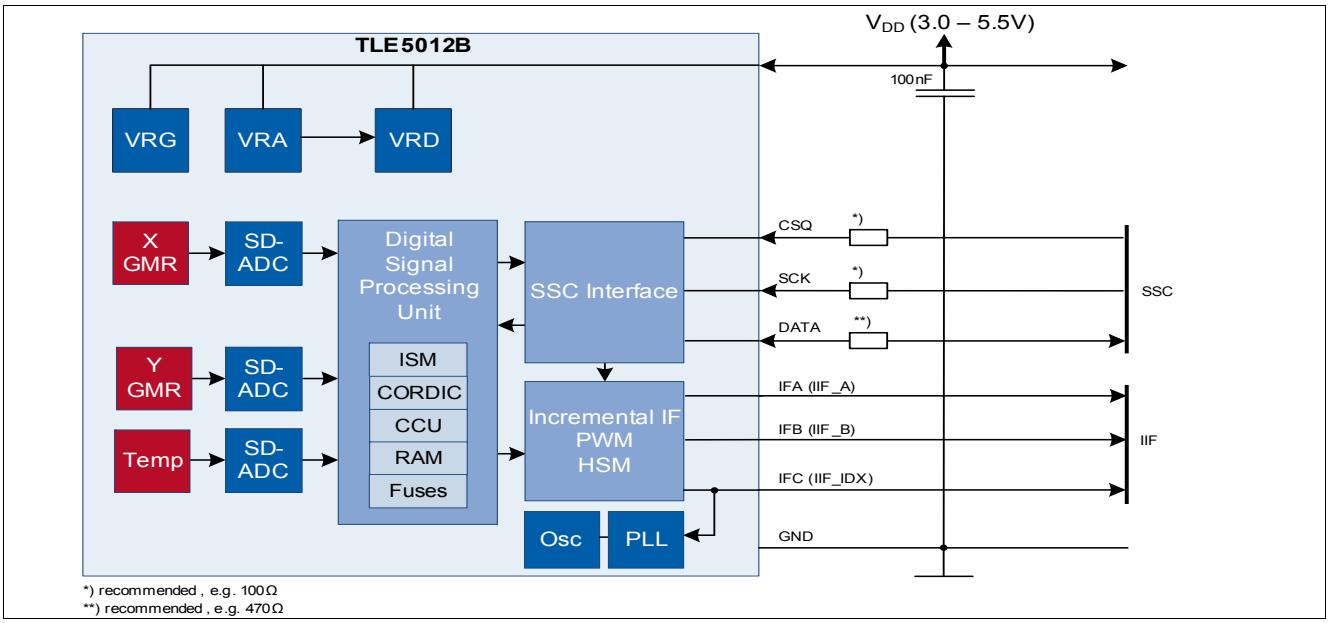

Figure 3-1 Application circuit for TLE5012B with IIF interface and SSC (using internal CLK)

In case that the IFA, IFB and IFC pins are configurated via the SSC interface as open-drain pins, three resistors (one for each line) between output line and V_{DD} would be recommended (e.g. 2.2kΩ).

Figure 3-2 shows a basic block diagram of the TLE5012B with HS Mode and SSC configuration. The derivate TLE5012B - E3005 is by default configurated with push-pull IFA (HS1), IFB (HS2) and IFC (HS3) pins.

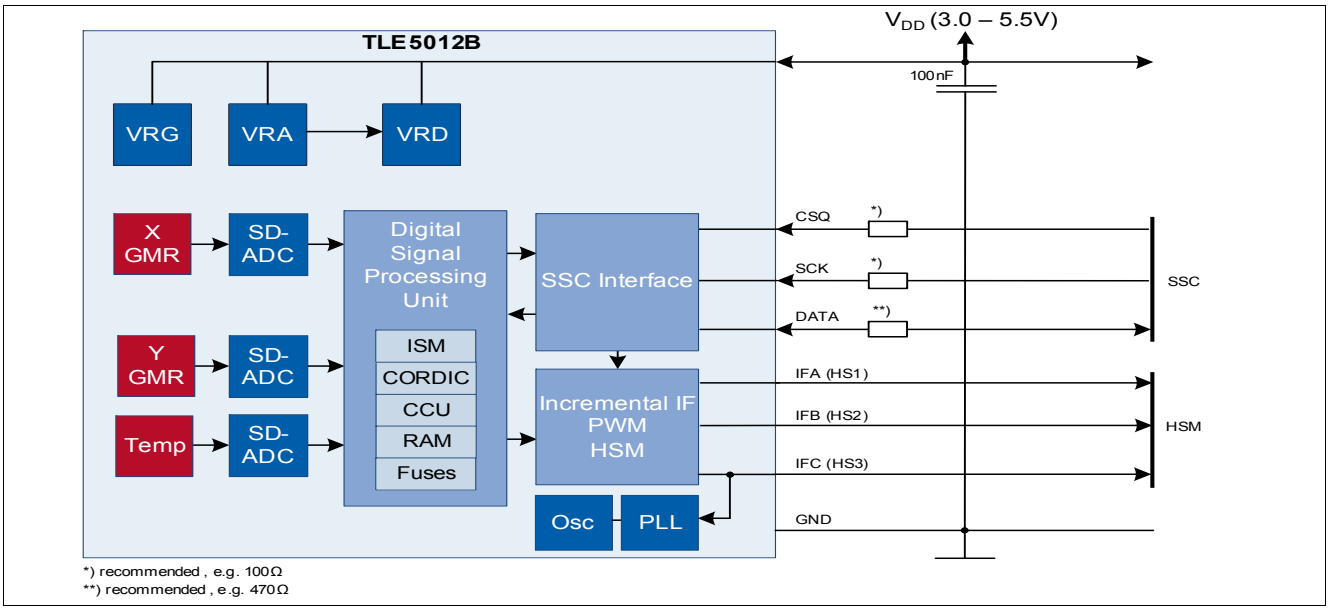

Figure 3-2 Application circuit for TLE5012B with HS Mode and SSC (using internal CLK)

In case that the IFA, IFB and IFC pins are configurated via the SSC interface as open drain pins, three resistors (one for each line) between the output line and V_{DD} would be recommended (e.g. 2.2kΩ).

The TLE5012B can be configured with PWM only (**Figure 3-3**). The derivate TLE5012B - E5000 is by default configurated with push-pull IFA (PWM) pin. Therefore the following configuration is recommended:

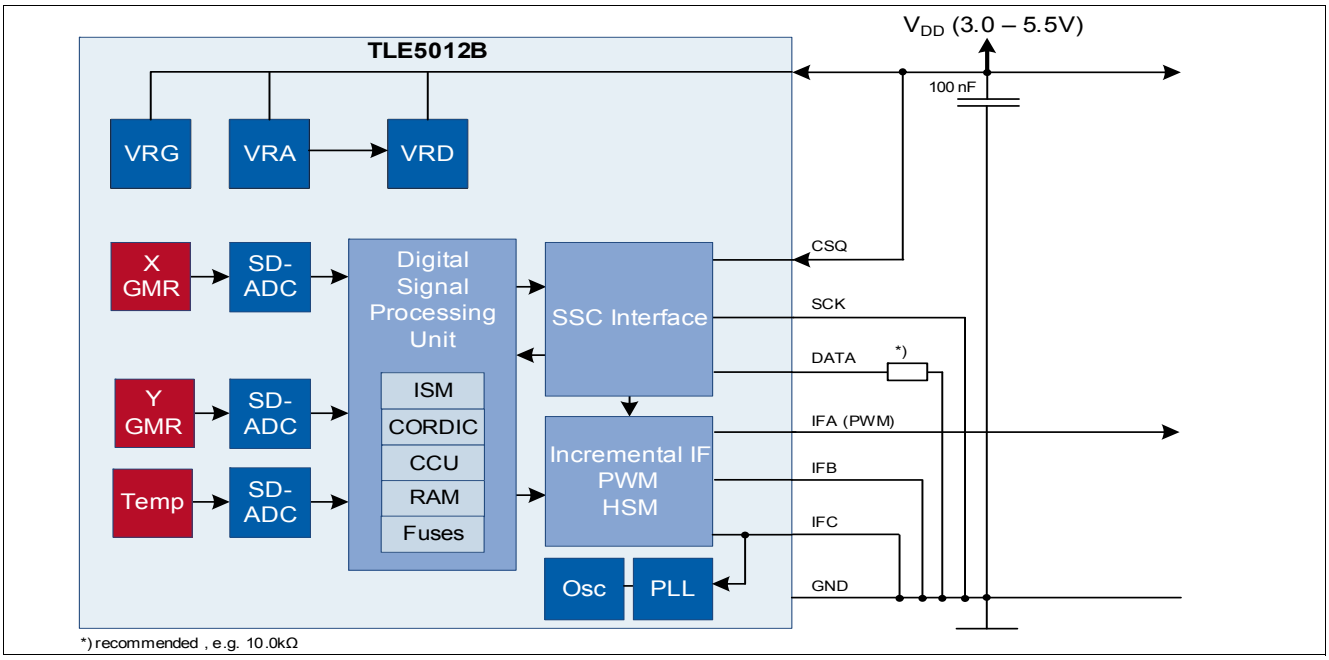

Figure 3-3 Application circuit for TLE5012B with only PWM interface (using internal CLK)

The TLE5012B - E5020 is also a PWM derivate but with open drain IFA (PWM) pin. A pull-up resistor (e.g. 2.2kΩ) should then be added between the IFA line and VDD, as shown in **Figure 3-4**.

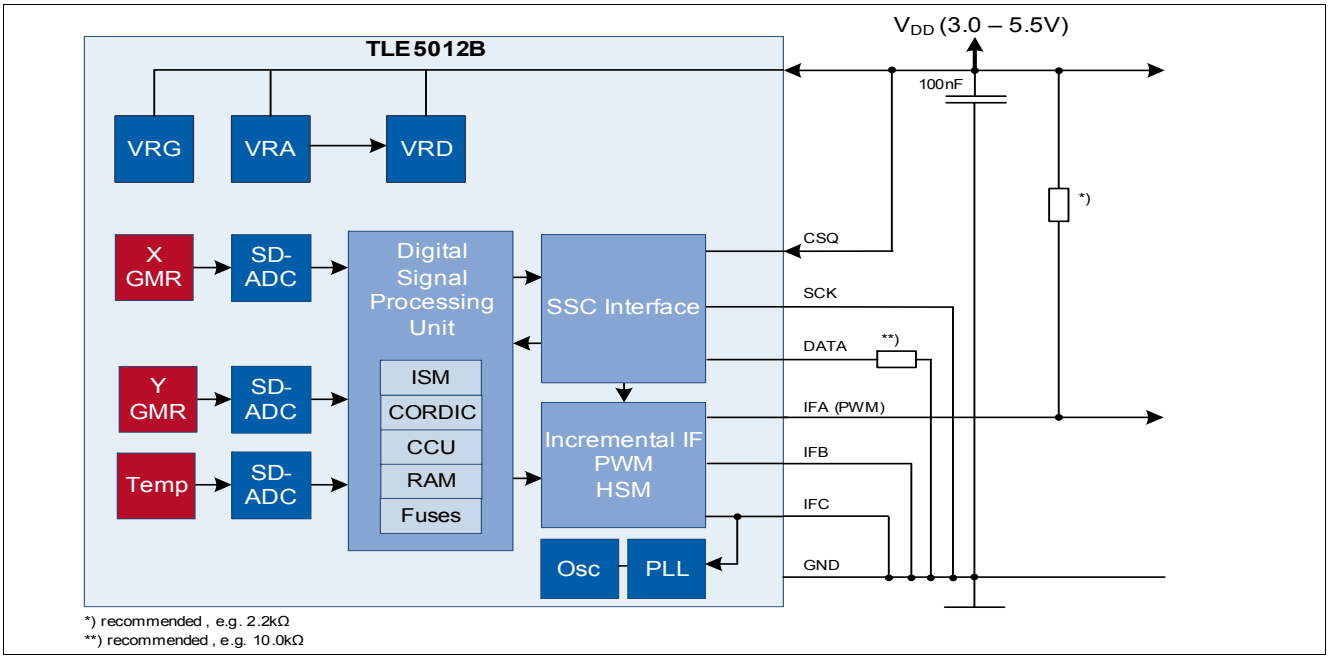

Figure 3-4 Application circuit for TLE5012B with only PWM interface (using internal CLK)

For safety reasons it is better that the non-used pins are connected to ground, rather than floating. A resistor between he DATA line pin and ground is recommended to avoid shortcuts if DATA generates any unexpected output. The CSQ line has to be connected to V_{DD} to avoid unintentional activation of the SSC interface.

The TLE5012B can be configured with SPC only (**Figure 3-5**). This is only possible with the TLE5012B - E9000 derivate, which is by default configurated with an open-drain IFA (SPC) pin.

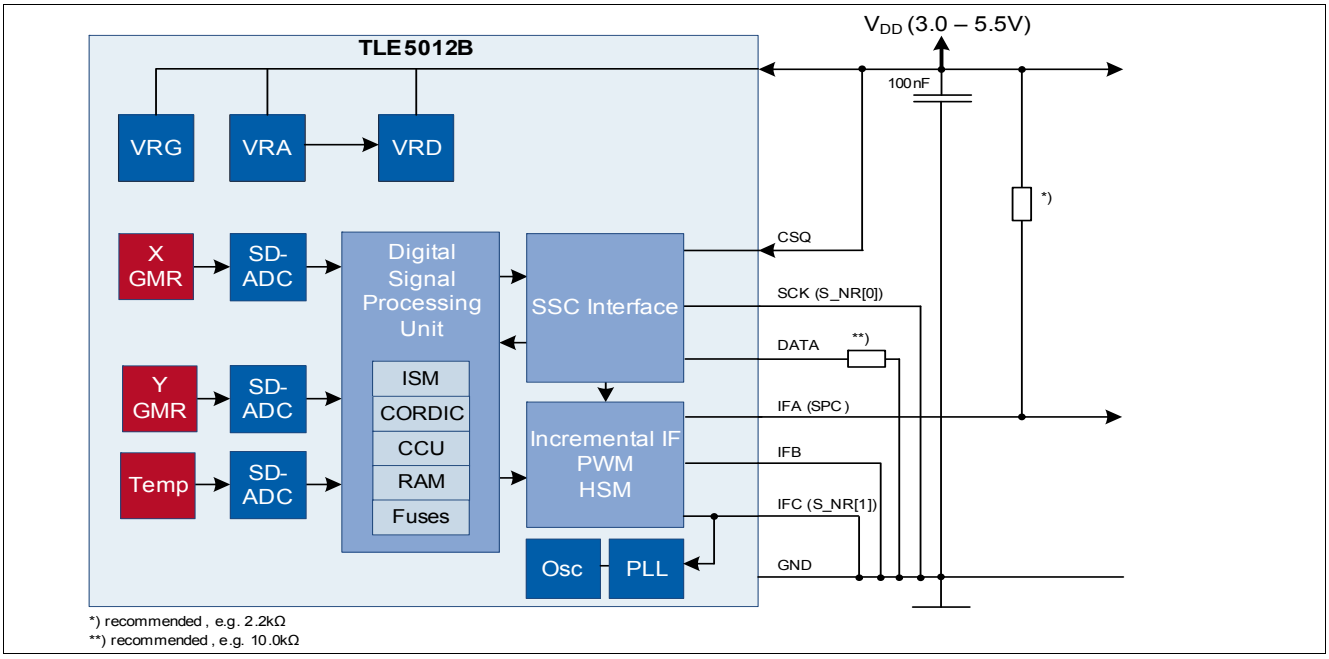

Figure 3-5 Application circuit for TLE5012B with only SPC interface (using internal CLK)

In **Figure 3-5** the IFC (S_NR[1]) and SCK (S_NR[0]) pins are set to ground to generate the slave number (S_NR) 0_D (or 00_B). For safety reasons it is better that the non-used pins are connected to ground, rather than floating. A resistor between the DATA line pin and ground is recommended to avoid shortcuts if DATA generates any unexpected output. The CSQ line has to be connected to V_{DD} to avoid unintentional activation of the SSC interface.

Synchronous Serial Communication (SSC) configuration

In **Figure 3-1** and **Figure 3-2** the SSC interface has the default push-pull configuration (see details in **Figure 3-6**). Series resistors on the DATA, SCK (serial clock signal) and CSQ (chip select) lines are recommended to limit the current in the erroneous case that either the sensor pushes high and the microcontroller pulls low at the same time or vice versa. The resistors in the SCK and CSQ lines are only necessary in case of disturbances or noise.

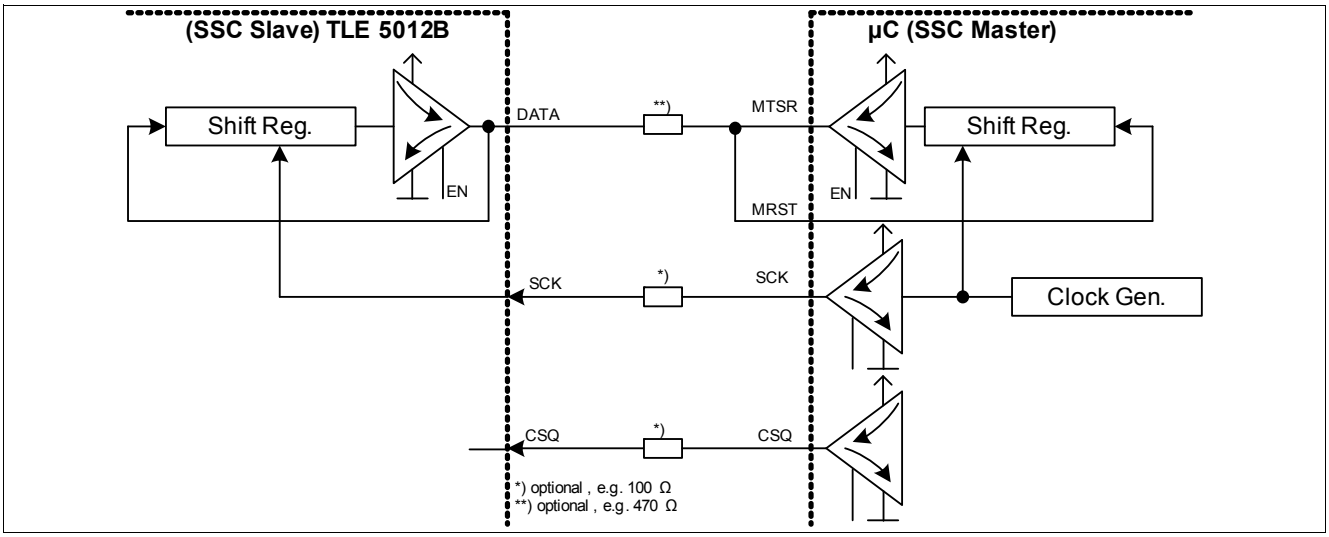

Figure 3-6 SSC configuration in sensor-slave mode with push-pull outputs (high-speed application)

It is also possible to use an open-drain setup for the DATA, SCK and CSQ lines. This setup is designed to communicate with a microcontroller in a bus system, together with other SSC slaves (e.g. two TLE5012B devices for redundancy reasons). This mode can be activated using the bit SSC_OD.

The open-drain configuration can be seen in **Figure 3-7**. Series resistors on the DATA, SCK, and CSQ lines are recommended to limit the current in case either the microcontroller or the sensor are accidentally switched to push-pull. A pull-up resistor of typ. 1 kΩ is required on the DATA line.

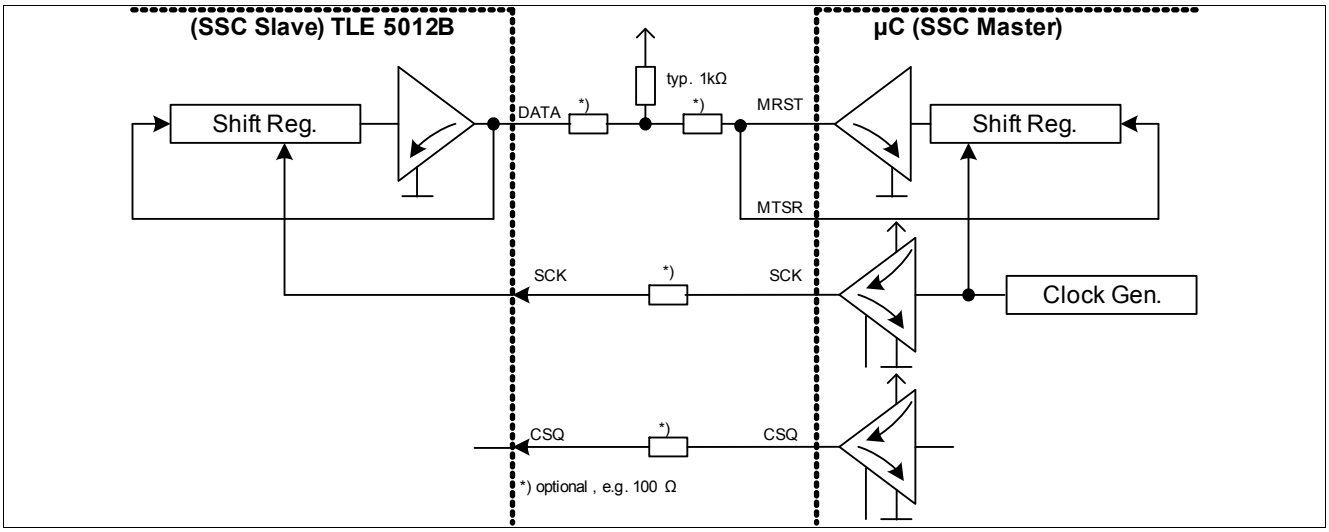

Figure 3-7 SSC configuration in sensor-slave mode and open-drain (bus systems)

4 Specification

4.1 Absolute Maximum Ratings

Table 4-1 Absolute maximum ratings

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Voltage on V_{DD} pin with respect to ground (V_{SS})	V_{DD}	-0.5		6.5	V	Max 40 h/Lifetime
Voltage on any pin with respect to ground (V_{SS})	V_{IN}	-0.5		6.5	V	
				V_{DD} + 0.5	V	
Junction temperature	T_J	-40		150	°C	
				150	°C	For 1000 h, not additive
Magnetic field induction	B			200	mT	Max. 5 min @ T_A = 25°C
				150	mT	Max. 5 h @ T_A = 25°C
Storage temperature	T_{ST}	-40		150	°C	Without magnetic field

Attention: 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.

4.2 Operating Range

The following operating conditions must not be exceeded in order to ensure correct operation of the TLE5012B. All parameters specified in the following sections refer to these operating conditions, unless otherwise noted. **Table 4-2** is valid for -40°C < T_J < 150°C unless otherwise noted.

Table 4-2 Operating range and parameters

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Supply voltage	V_{DD}	3.0	5.0	5.5	V	[1]
Supply current	I_{DD}		14	16	mA	
Magnetic induction at T_J = 25°C[2][3]	B_{XY}	30		50	mT	-40°C < T_J < 150°C
		30		60	mT	-40°C < T_J < 100°C
		30		70	mT	-40°C < T_J < 85°C
Extended magnetic induction range at T_J = 25°C[2][3]	B_{XY}	25		30	mT	Additional angle error of 0.1°
Angle range	Ang	0		360	°	
POR level	V_{POR}	2.0		2.9	V	Power-on reset
POR hysteresis	V_{PORhy}		30		mV	

Table 4-2 Operating range (cont'd)**and parameters**

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Power-on time[4)]	t_{Pon}		5	7	ms	$V_{DD} > V_{DDmin}$;
Fast Reset time[5)]	t_{Rfast}			0.5	ms	Fast reset is triggered by disabling startup BIST (S_BIST = 0), then enabling chip reset (AS_RST = 1)

1) Directly blocked with 100-nF ceramic capacitor
2) Values refer to a homogeneous magnetic field (B_{XY}) without vertical magnetic induction (B_Z = 0mT).
3) See **Figure 4-1**
4) During "Power-on time," write access is not permitted (except for the switch to External Clock which requires a readout as a confirmation that external clock is selected)
5) Not subject to production test - verified by design/characterization

The field strength of a magnet can be selected within the colored area of **Figure 4-1**. By limitation of the junction temperature, a higher magnetic field can be applied. In case of a maximum temperature T_J=100°C, a magnet with up to 60mT at T_J = 25°C is allowed.

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

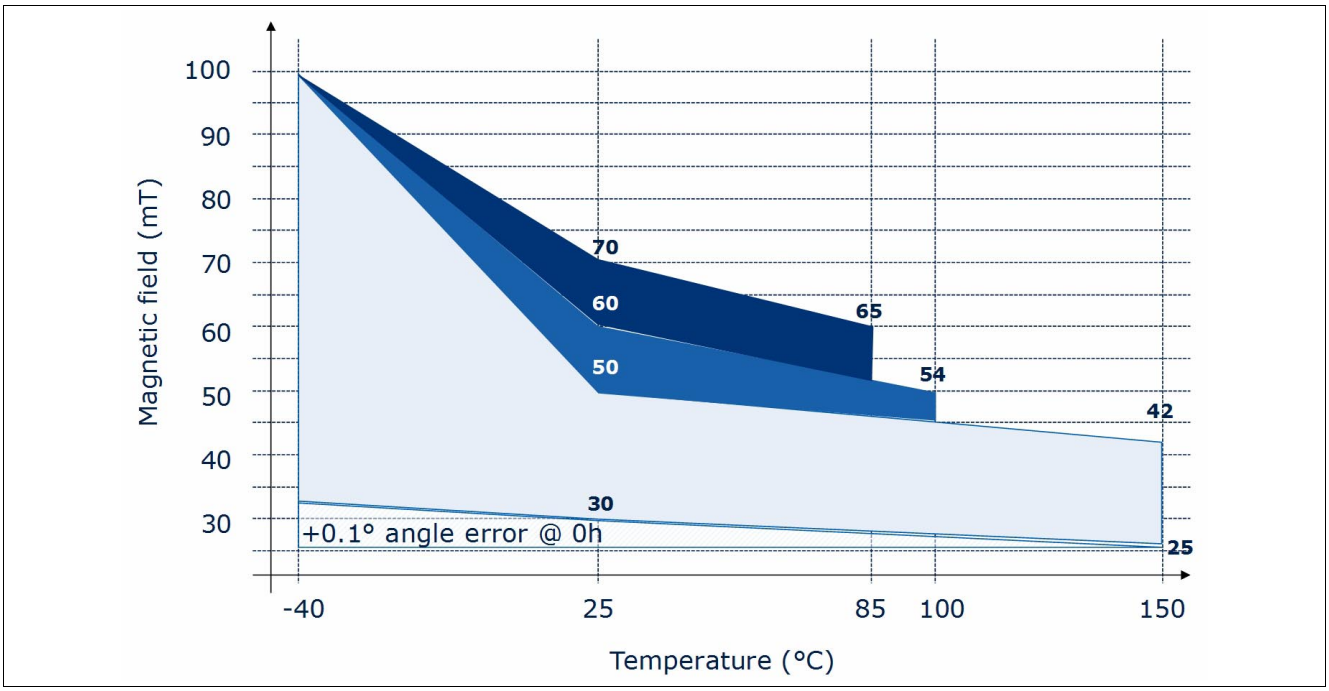

Figure 4-1 Allowed magnetic field range as function of junction temperature.

4.3 Characteristics

4.3.1 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} = 5.0 V and 25 °C, unless individually specified. All other values correspond to -40 °C < T_J < 150°C.

Within the register MOD_3, the driver strength and the slope for push-pull communication can be varied depending on the sensor output. The driver strength is specified in **Table 4-3** and the slope fall and rise time in **Table 4-4**.

Table 4-3 Input voltage and output currents

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Input voltage	V_{IN}	-0.3		5.5	V	
				V_{DD}+ 0.3	V	
Output current (DATA-Pad)	I_Q			-25	mA	PAD_DRV =’0x’, sink current[1)2)]
				-5	mA	PAD_DRV =’10’, sink current[1)2)]
				-0.4	mA	PAD_DRV =’11’, sink current[1)2)]
Output current (IFA / IFB / IFC - Pad)	I_Q			-15	mA	PAD_DRV =’0x’, sink current[1)2)]
				-5	mA	PAD_DRV =’1x’, sink current[1)2)]

1) Max. current to GND over open-drain output

2) At V_{DD} = 5 V

Table 4-4 Driver strength characteristic

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Output rise/fall time	t_{fall}, t_{rise}			8	ns	DATA, 50 pF, PAD_DRV=’00’[1)2)]
				28	ns	DATA, 50 pF, PAD_DRV=’01’[1)2)]
				45	ns	DATA, 50 pF, PAD_DRV=’10’[1)2)]
				130	ns	DATA, 50 pF, PAD_DRV=’11’[1)2)]
				15	ns	IFA/IFB, 20 pF, PAD_DRV=’0x’[1)2)]
				30	ns	IFA/IFB, 20 pF, PAD_DRV=’1x’[1)2)]

1) Valid for push-pull output

2) Not subject to production test - verified by design/characterization

Table 4-5 Electrical parameters for 4.5 V < V_{DD} < 5.5 V

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Input signal low-level	V_{L5}			0.3 V_{DD}	V	
Input signal high level	V_{H5}	0.7 V_{DD}			V	
Output signal low-level	V_{OL5}			1	V	DATA; I_Q = -25 mA (PAD_DRV='0x'), I_Q = -5 mA (PAD_DRV='10'), I_Q = -0.4 mA (PAD_DRV='11')
				1	V	IFA,B,C; I_Q = -15 mA (PAD_DRV='0x'), I_Q = -5 mA (PAD_DRV='1x')
Pull-up current[1)]	I_{PU}	-10		-225	µA	CSQ
		-10		-150	µA	DATA
Pull-down current[2)]	I_{PD}	10		225	µA	SCK
		10		150	µA	IFA, IFB, IFC

1) Internal pull-ups on CSQ and DATA pin are always enabled.

2) Internal pull-downs on IFA, IFB and IFC are enabled during startup and in open-drain mode, internal pull-down on SCK is always enabled.

Table 4-6 Electrical parameters for 3.0 V < V_{DD} < 3.6 V

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Input signal low-level	V_{L3}			0.3 V_{DD}	V	
Input signal high level	V_{H3}	0.7 V_{DD}			V	
Output signal low-level	V_{OL3}			0.9	V	DATA; I_Q = -15 mA (PAD_DRV='0x'), I_Q = -3 mA (PAD_DRV='10'), I_Q = -0.24 mA (PAD_DRV='11')
				0.9	V	IFA,IFB; I_Q = - 10 mA (PAD_DRV='0x'), I_Q = -3 mA (PAD_DRV='1x')
Pull-up current[1)]	I_{PU}	-3		-225	µA	CSQ
		-3		-150	µA	DATA
Pull-down current[2)]	I_{PD}	3		225	µA	SCK
		3		150	µA	IFA, IFB, IFC

1) Internal pull-ups on CSQ and DATA pin are always enabled.

2) Internal pull-downs on IFA, IFB and IFC are enabled during startup and in open-drain mode, internal pull-down on SCK is always enabled.

4.3.2 ESD Protection

Table 4-7 ESD protection

Parameter	Symbol	Values		Unit	Notes
		Min.	Max.		
ESD voltage	V_{HBM}		±4.0	kV	Human Body Model[1)]
	V_{SDM}		±0.5	kV	Socketed Device Model[2)]

1) Human Body Model (HBM) according to: AEC-Q100-002
2) Socketed Device Model (SDM) according to: ESDA/ANSI/ESD SP5.3.2-2008

4.3.3 GMR Parameters

All parameters apply over B_{XY} = 30mT and T_A = 25°C, unless otherwise specified.

Table 4-8 Basic GMR parameters

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
X, Y output range	RG_{ADC}			±23230	digits	Operating range[1)]
X, Y amplitude[2)]	A_X, A_Y	6000	9500	15781	digits	At ambient temperature
		3922		20620	digits	Operating range
X, Y synchronicity[3)]	k	87.5	100	112.49	%	
X, Y offset[4)]	O_X, O_Y	-2048	0	+2047	digits	
X, Y orthogonality error	φ	-11.25	0	+11.24	°	
X, Y amplitude without magnet	X_0, Y_0			+4096	digits	Operating range[1)]

1) Not subject to production test - verified by design/characterization
2) See **Figure 4-2**
3) $k = 100*(A_X/A_Y)$
4) $O_Y=(Y_{MAX} + Y_{MIN}) / 2$; $O_X = (X_{MAX} + X_{MIN}) / 2$

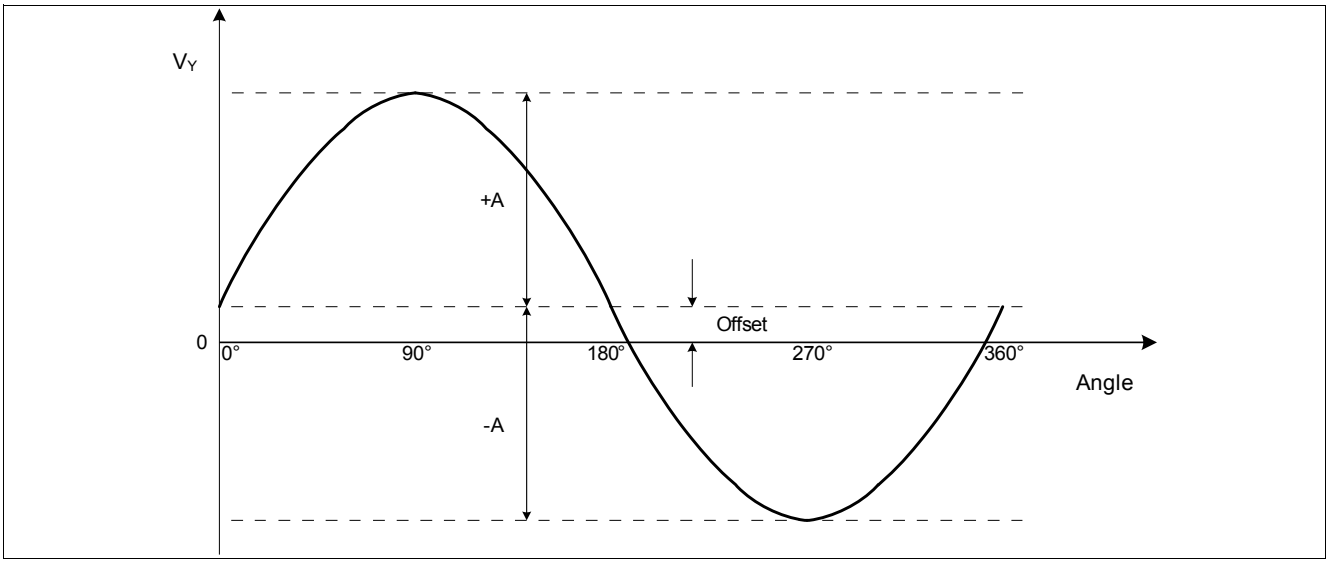

Figure 4-2 Offset and amplitude definition

4.3.4 Angle Performance

After internal calculation, the sensor has a remaining error, as shown in **Table 4-9**. The error value refers to B_Z= 0mT and the operating conditions given in **Table 4-2 "Operating range and parameters" on Page 19**.

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 4-10 "Signal processing" on Page 27**), which the sensor needs to calculate the angle from the raw sine and cosine values from the MR bridges. In fast-turning applications, prediction can be enabled to reduce this propagation error.

Table 4-9 Angle performance

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Overall angle error (with auto-calibration)	α_{Err}		0.6[1)]	1.0	°	Including lifetime and temperature drift[2)3)4)]. Note: in case of temperature changes above 5 Kelvin within 1.5 revolutions refer to **Figure 4-3** for additional angle error.
Overall angle error (without auto-calibration)	α_{Err}		0.6[1)]	1.3	°	Including temperature drift[2)3)5)]
				1.9	°	Including lifetime and temperature drift[2)3)4)]

1) At 25°C, B = 30mT
2) Including hysteresis error, caused by revolution direction change
3) Relative error after zero angle definition
4) Not subject to production test - verified by design/characterization
5) 0h

If autocalibration (see **Chapter 4.3.5**) is enabled and the temperature changes by more than 5 Kelvin during 1.5 revolutions an additional error has to be added to the specified angle error in **Table 4-9**. This error depends on the temperature change (Delta Temperature) as well as from the initial temperature (Tstart) as shown in **Figure 4-3**. Once the temperature stabilizes and the application completes 1.5 revolutions, then the angle error is as specified in **Table 4-9**.

For negative Delta Temperature changes (from higher to lower temperatures) the additional angle error will be smaller than the corresponding positive Delta Temperature changes (from lower to higher temperatures) shown in **Figure 4-3**. The **Figure 4-3** applies to the worst case.

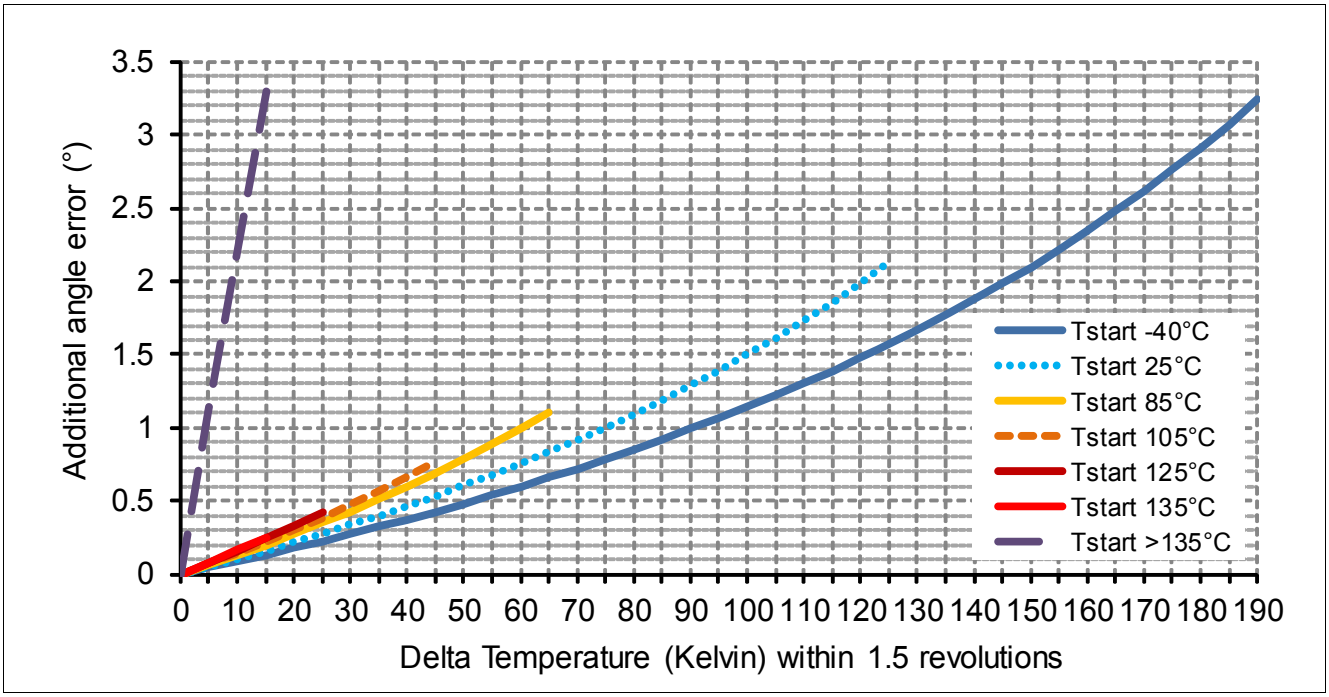

Figure 4-3 Additional angle error for temperature changes above 5 Kelvin within 1.5 revolutions

4.3.5 Autocalibration

The autocalibration enables online parameter calculation and therefore reduces the angle error due to temperature and lifetime drifts.

The TLE5012B is a pre-calibrated sensor, so autocalibration is only enabled in some devices by default. The update mode can be chosen with the AUTOCAL setting in the MOD_2 register. The TLE5012B needs 1.5 revolutions to generate new autocalibration parameters. These parameters are continuously updated. The parameters are updated in a smooth way (one Least-Significant Bit within the chosen range or time) to avoid an angle jump on the output.

AUTOCAL Modes:

- 00: No autocalibration
- 01: Autocalibration Mode 1. One LSB to final values within the update time t_{upd} (depending on FIR_MD setting).
- 10: Autocalibration Mode 2. Only one LSB update over one full parameter generation (1.5 revolutions). After update of one LSB, the autocalibration will calculate the parameters again.
- 11: Autocalibration Mode 3. One LSB to final values within an angle range of 11.25°