

# TLE5014SP16 E0002

## GMR-based Angle Sensor



RoHS



ISO26262  
compliant

### Features

- Fast SSC interface up to 8MHz
- **Giant Magneto Resistance (GMR)**-based principle
- Integrated magnetic field sensing for angle measurement
- 360° angle measurement
- EEPROM for storage of configuration (e.g. zero angle) and customer specific ID
- 15 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%
- 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: 4 kV (HBM) on  $V_{DD}$  and 2kV (HBM) on output pins
- RoHS compliant and halogen free package



### Functional Safety

Safety Manual and Safety Analysis Summary Report available on request

### Product validation

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

### Description

The TLE5014SP16 E0002 is an iGMR (integrated GMR) based angle sensor with a high speed serial interface (SSC interface). It provides high accurate angular position information for various applications.

**Table 1 Derivative Ordering codes**

| Product Type      | Marking | Ordering Code | Package    | Comment                   |
|-------------------|---------|---------------|------------|---------------------------|
| TLE5014SP16 E0002 | 014SP02 | SP004531446   | PG-TDSO-16 | SSC Interface, single die |

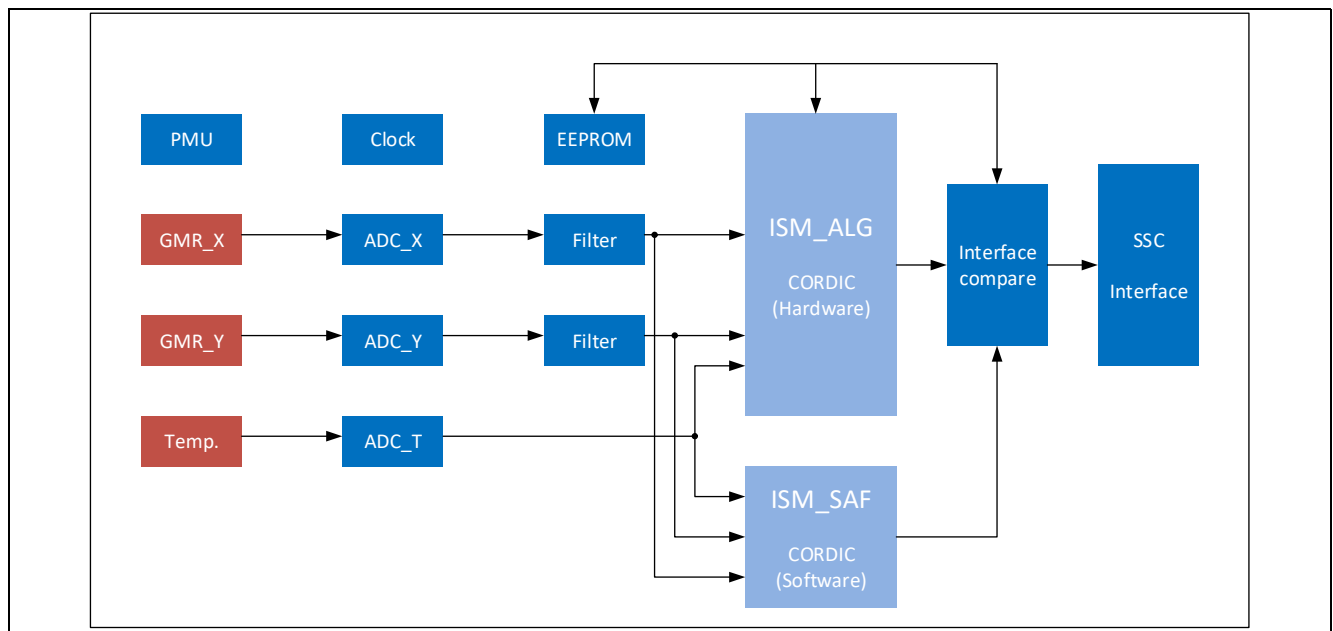
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## Functional Description

# 1 Functional Description

## 1.1 Block Diagram



**Figure 1-1 TLE5014SP16 E0002 block diagram**

## 1.2 Functional Block Description

### Internal Power Supply (PMU)

The internal blocks of the TLE5014SP16 E0002 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 TLE5014SP16 E0002 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

## **Functional Description**

### **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 SSC 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 SSC interface. Programming mode can be accessed directly after power-up of the IC.

## **1.3 Sensing Principle**

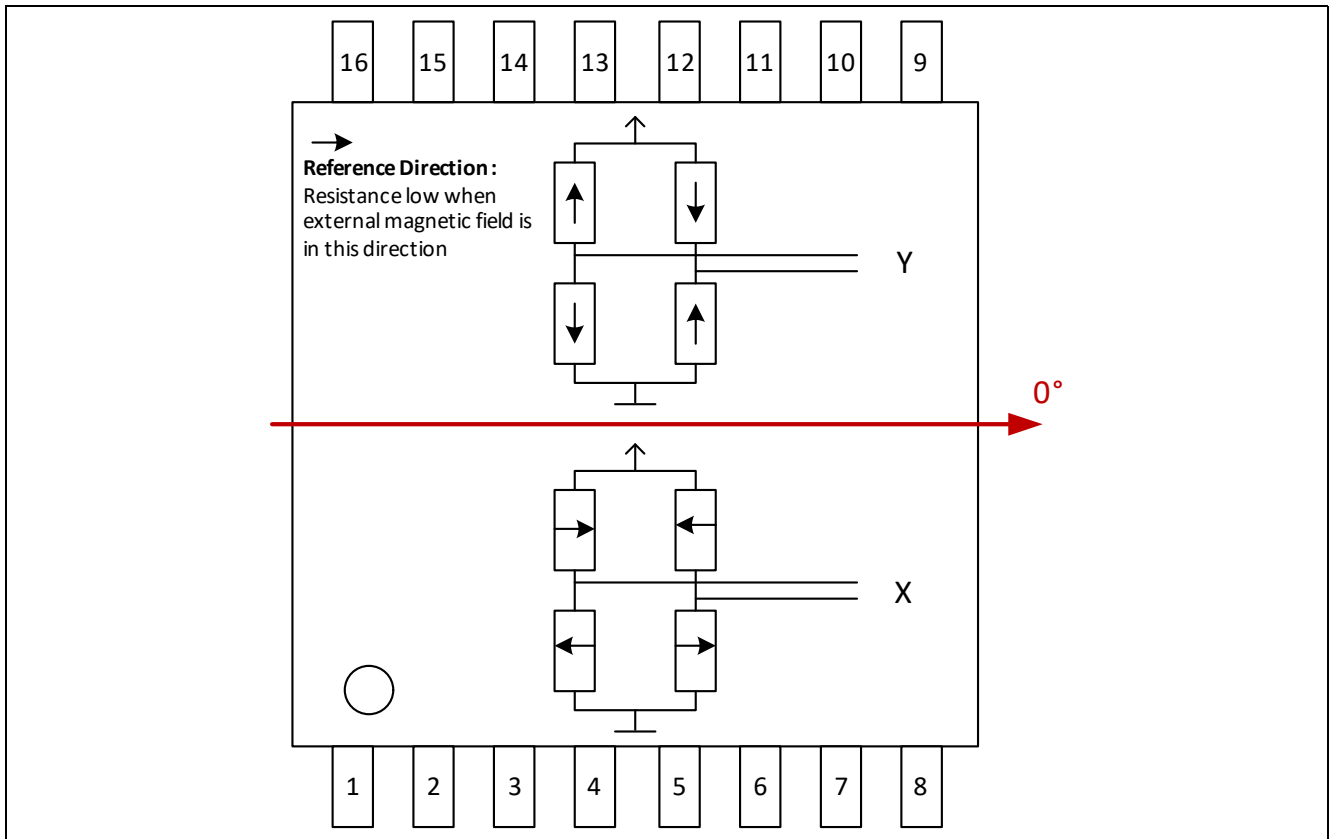
The **G**iant **M**agneto **R**esistance (GMR) sensor is implemented using vertical integration. This means that the GMR-sensitive areas are integrated above the logic part of the TLE5014SP16 E0002 device. These GMR elements change their resistance depending on the direction of the magnetic field.

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.

## Functional Description



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

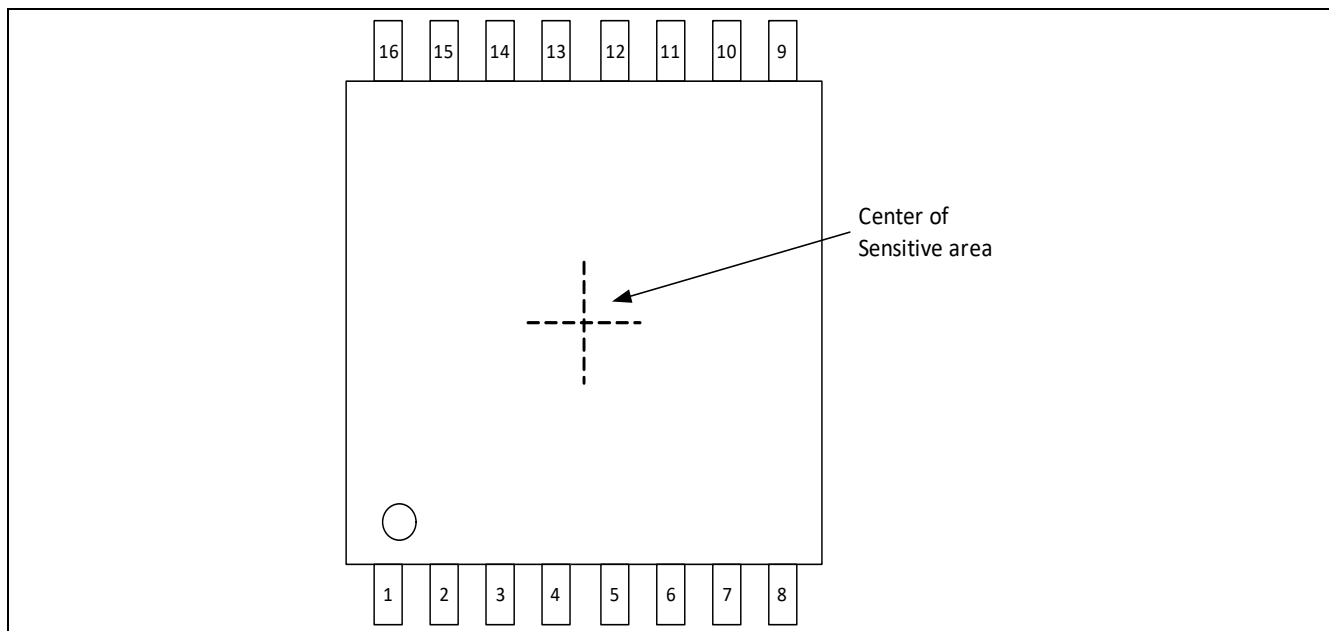
In **Figure 1-2** the arrows in the resistors represent the magnetic direction which is fixed in the reference layer. If the external magnetic field is parallel to the direction of the Reference Layer, the resistance is minimal. If they are anti-parallel, resistance is maximal.

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.

## Functional Description

### 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.

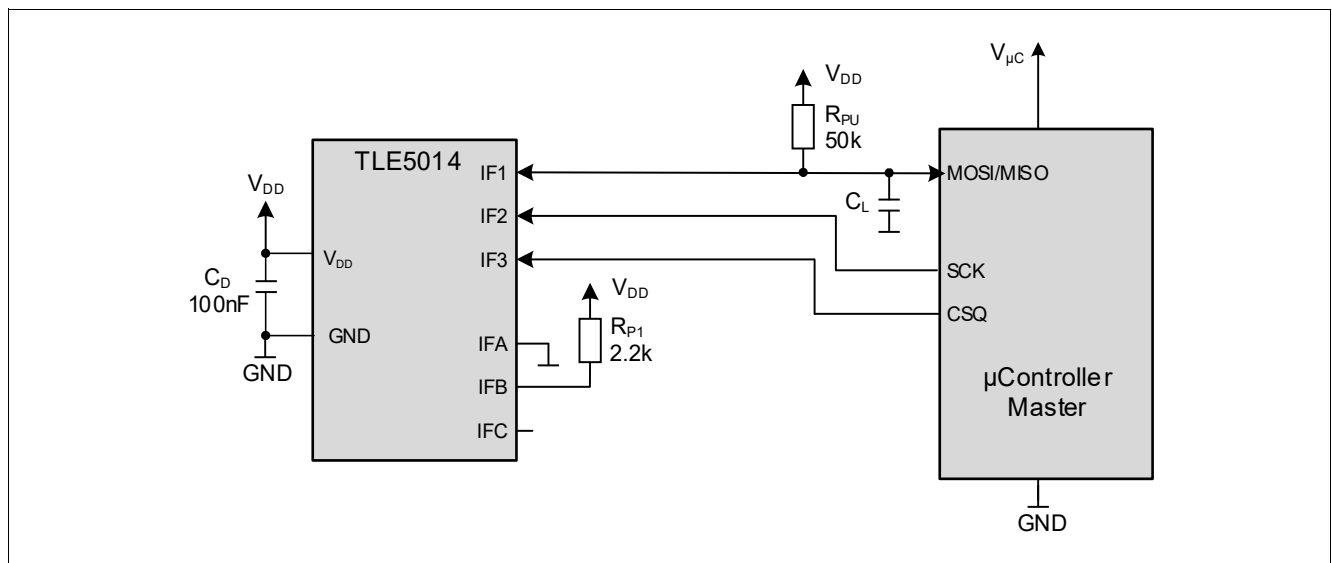
**Table 1-1 Pin description TLE5014SP16**

| Pin  | Symbol | In/Out | Function                        |
|------|--------|--------|---------------------------------|
| 1    | IF1    | I/O    | DATA (MOSI/MISO)                |
| 2    | IF2    | I      | SCK (SSC clock)                 |
| 3    | IF3    | I      | CSQ (chip select)               |
| 4    | VDD    | –      | Supply voltage, positive        |
| 5    | GND    | –      | Supply voltage, ground          |
| 6    | IFA    | –      | Connect to GND                  |
| 7    | IFB    | –      | Connect via pull-up to $V_{DD}$ |
| 8    | IFC    | –      | Keep open                       |
| 9-16 | –      | –      | n.c.                            |

## 2 Application Circuits

The application circuit in this chapter shows the communication possibilities of the TLE5014SP16 E0002. To improve robustness against electro-magnetic disturbances, a capacitor of 100nF on the supply is recommended. This capacitor shall be placed as close as possible to the corresponding sensor pins. The load capacitor  $C_L$  shall not exceed the specified value (Table 3-5). The DATA line is actively driven to HIGH and LOW but the driver is switched off once reaching the HIGH state. Therefore, a pull-up resistor is recommended to maintain a stable HIGH level.

In case of a high speed communication, an additional serial resistor in the range of 140Ω can be implemented in the DATA, SCK and CSQ line to avoid reflections and enhance communication reliability. In this case the user is responsible to verify that the intended communication speed can be reached in his specific setup.



**Figure 2-1 Application circuit for TLE5014SP16 E0002 with SSC interface, microcontroller switches pin between MISO and MOSI**

**Specification**

### 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;<br>-18V means $V_{DD} < GND$ |
| Voltage Peaks                                  | $V_{DD}$ |        |      | 30   | V    | for 50 $\mu$ s, no current limitation                      |
| Absolute maximum voltage for pin IF1, IF2, IF3 | $V_{IF}$ | -0.3   |      | 6    | V    | no damage of device                                        |
| Absolute maximum voltage for pin IFB           | $V_{IO}$ | -18    |      | 19.5 | V    | for 40h; no damage of device,<br>-18V means $V_{DD} < GND$ |
| Voltage Peaks (for pin IFB)                    | $V_{IO}$ |        |      | 30   | V    | for 50 $\mu$ s, no current limitation                      |

**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 @ $T_A = 25^\circ\text{C}$                                     |
| Maximum allowed magnetic field      | B                    |        |      | 150  | mT   | max 5 h @ $T_A = 25^\circ\text{C}$                                       |
| Storage & Shipment <sup>1) 2)</sup> | $T_{\text{storage}}$ | 5      |      | 40   | °C   | for dry packed devices,<br>Relative humidity < 90%,<br>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 | $T_{A,\text{max}}$ |        |      | 125  | °C   | for 2000h             |

## Specification

**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 <a href="#">Table 3-3</a> for mission profile |
| Total life time     | $t_{tot\_life}$ |        |      | 19      | a    | additional 2a storage time <sup>1)</sup>          |
| 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  $-40^{\circ}\text{C} < T_A < 125^{\circ}\text{C}$

## 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  $-40^{\circ}\text{C} < T_A < 125^{\circ}\text{C}$  unless otherwise noted.

**Table 3-5 Operating Range**

| Parameter                                          | Symbol         | Values |      |        | Unit               | Note / Test Condition |
|----------------------------------------------------|----------------|--------|------|--------|--------------------|-----------------------|
|                                                    |                | Min.   | Typ. | Max.   |                    |                       |
| Operating supply voltage                           | $V_{DD}$       | 3.0    |      | 5.5    | V                  | -                     |
| Supply Voltage Slew Rate                           | $V_{DD\_slew}$ | 0.1    |      | $10^8$ | V/s                | -                     |
| Operating ambient temperature                      | $T_A$          | -40    |      | 125    | $^{\circ}\text{C}$ | -                     |
| Angle speed                                        | n              |        |      | 30000  | rpm                | -                     |
| Capacitive output load on SSC interface (DATA pin) | $C_L$          | -      | -    | 50     | pF                 |                       |

## Magnetic Field Range

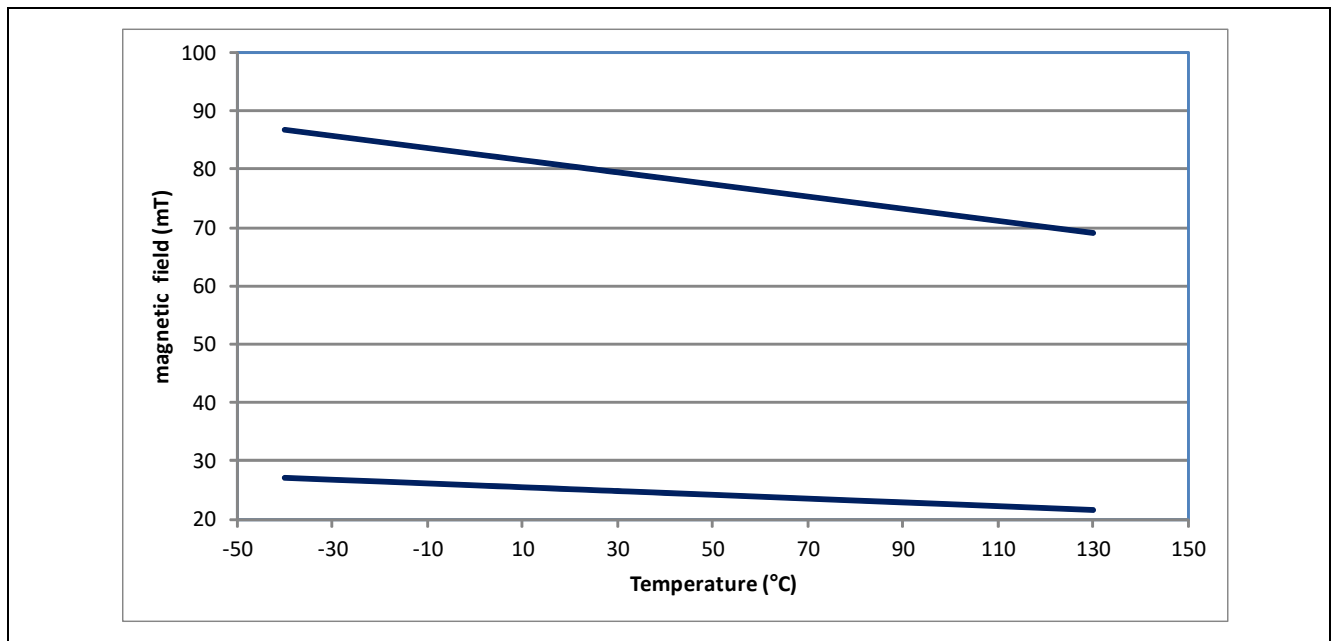
The operating range of the magnetic field describes the field values where the performance of the sensor, especially the accuracy, is as specified in [Table 3-11](#) and [Table 3-12](#). This value is valid for a NdFeB magnet with a  $T_c$  of -1300ppm/K. In case a different magnet is used, the individual  $T_c$  of this magnet has to be considered and ensured that the limits are not exceeded. The allowed magnetic field 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 @ $25^{\circ}\text{C}$ | B      | 25     |      | 80   | mT   | $T_A = 25^{\circ}\text{C}$ , 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 NdFeB magnet with  $T_c = -1300\text{ppm/K}$ .

**Specification**



**Figure 3-1 Allowed magnetic field range within operating 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.

## Specification

### 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  $T_A = 25^\circ C$ , unless individually specified. All other values correspond to  $-40^\circ C < T_A < 125^\circ C$ .

**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 $V_{DD}$                                                                                         | $V_{UV}$           | 2.3    | 2.5  | 2.7  | V    | In an undervoltage condition the sensor performs a reset     |
| Internal clock tolerance                                                                                                   | $\Delta f_{clock}$ | -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**).

## Specification

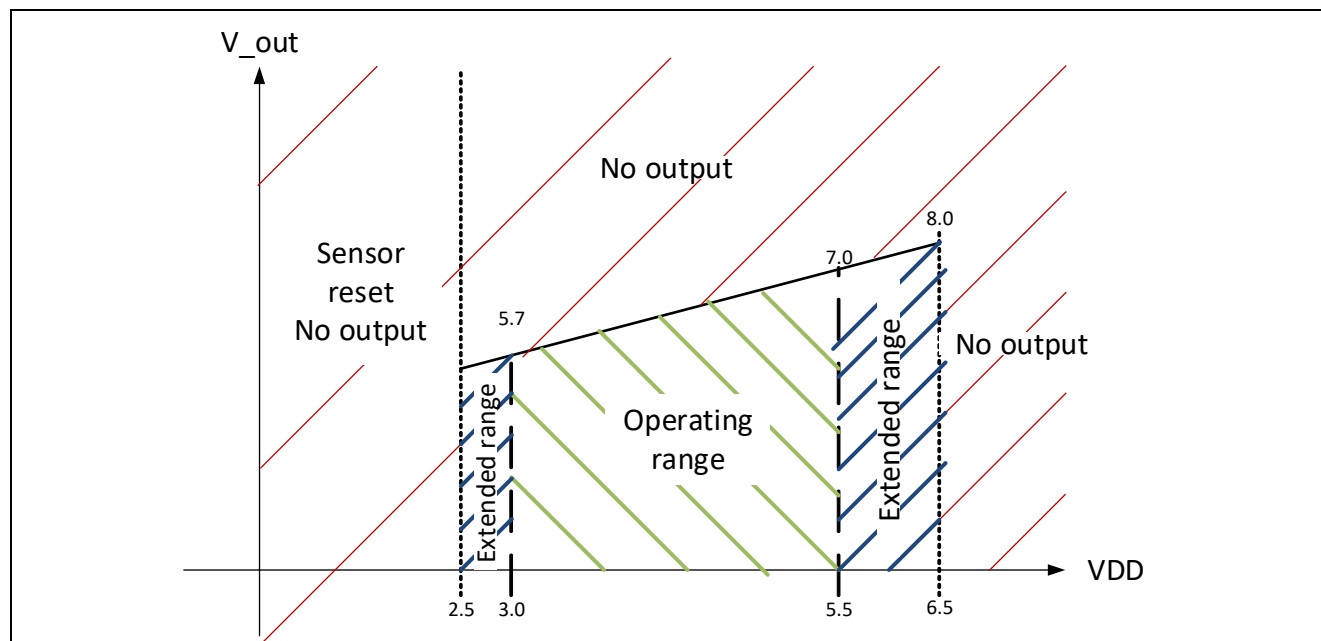


Figure 3-2 Operating area and sensor reaction for over- and undervoltage.

Table 3-8 Output driver

| Parameter                       | Symbol   | Values             |      |                    | Unit | Note / Test Condition |
|---------------------------------|----------|--------------------|------|--------------------|------|-----------------------|
|                                 |          | Min.               | Typ. | Max.               |      |                       |
| Output low level <sup>1)</sup>  | $V_{OL}$ |                    |      | $0.3 \cdot V_{DD}$ |      |                       |
| Output high level <sup>1)</sup> | $V_{OH}$ | $0.7 \cdot V_{DD}$ |      |                    |      |                       |

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  $V_{DD}$ ).

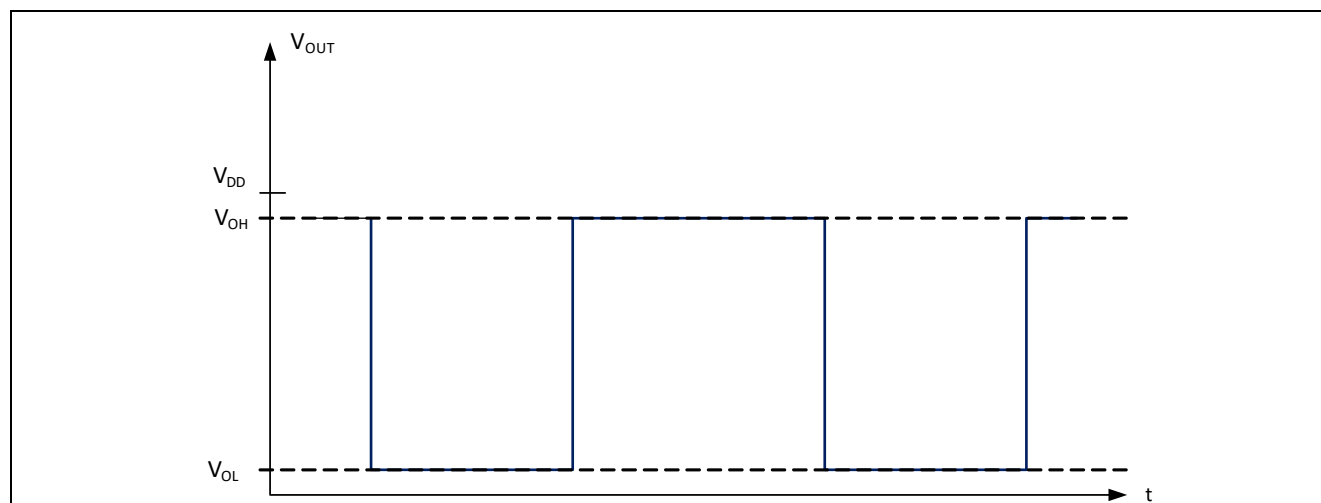


Figure 3-3 Output level high / low

### Output Delay Time and Jitter

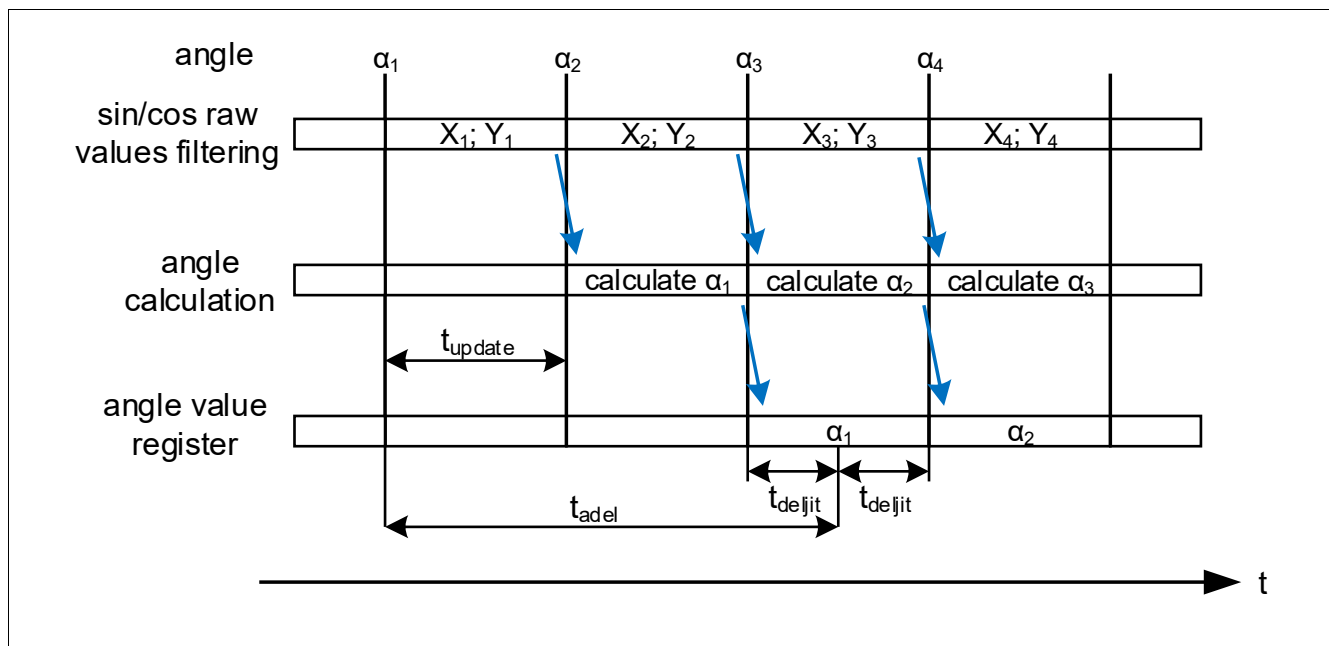
## Specification

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 value available at the AVAL register | $t_{adel}$   | 60.8    | 64      | 67.2    | $\mu s$ | Min/max values include clock tolerance |
| Variation of delay time $t_{adel}$                                           | $t_{deljit}$ | +/-12.0 | +/-12.8 | +/-14.0 | $\mu s$ | Min/max values include clock tolerance |
| Angle update rate<br>(new angle value is provided in the AVAL register)      | $t_{update}$ | 24.3    | 25.6    | 27.0    | $\mu s$ | Min/max values include clock tolerance |

The sensor calculates a new angle value every  $t_{update}$ . The delay time (latency) of the angle value is determined by the time needed for the sampling of the sin/cos raw signals and angle calculation. The calculated angle is then transferred into the corresponding SSC register. This register is updated every  $t_{update}$ . As the reading of the angle value with the SSC interface is asynchronous to the internal angle update rate, a jitter on the delay time of the angle value is introduced in the range of  $t_{deljit} = \pm t_{update}/2$ . **Figure 3-4** shows this relation.



**Figure 3-4 Definition of update rate  $t_{update}$ , delay time  $t_{adel}$  and jitter of delay time  $t_{deljit}$**

**Specification**

**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 | $V_{\text{HBM}}$ |        |      | $\pm 4$    | kV   | HBM contact discharge for pins VDD, GND, IFB           |
| Electro-Static-Discharge voltage (HBM), according to ANSI/ESDA/JEDEC JS-001 | $V_{\text{HBM}}$ |        |      | $\pm 2$    | kV   | HBM contact discharge for pins IF1, IF2, IF3, IFA, IFC |
| Electro-Static-Discharge voltage (CDM), according to JESD22-C101            | $V_{\text{CDM}}$ |        |      | $\pm 0.5$  | kV   | for all pins except corner pins                        |
|                                                                             |                  |        |      | $\pm 0.75$ | kV   | for corner pins only                                   |

## Specification

### 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  $B_z = 0\text{mT}$ .

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  $-40^\circ\text{C} < T_A < 85^\circ\text{C}$  and magnetic field range  $33\text{mT} < B < 50\text{mT}$**

| Parameter                                                                  | Symbol                       | Values |      |      | Unit | Note / Test Condition                                                                            |
|----------------------------------------------------------------------------|------------------------------|--------|------|------|------|--------------------------------------------------------------------------------------------------|
|                                                                            |                              | Min.   | Typ. | Max. |      |                                                                                                  |
| Accuracy <sup>1)</sup> over temperature w/o look-up table                  | $A_{\text{Err},T}$           |        |      | 0.8  | °    | 0h <sup>2)</sup> , over temperature                                                              |
| Accuracy <sup>1)</sup> over temperature and lifetime, w/o look-up table    | $A_{\text{Err},S}$           |        |      | 0.9  | °    | lifetime stress: $T_A = 85^\circ\text{C}/1000\text{h}/50\text{mT}$                               |
| Accuracy <sup>1)3)</sup> over temperature and lifetime, with look-up table | $A_{\text{Err},\text{SLUT}}$ |        |      | 0.65 | °    | lifetime stress: $T_A = 85^\circ\text{C}/1000\text{h}/50\text{mT}$ with look-up table correction |
| Hysteresis <sup>4)</sup>                                                   | $A_{\text{Hyst}}$            |        | 0.1  | 0.16 | °    | value includes quantization error                                                                |

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  $-40^\circ\text{C} < T_A < 125^\circ\text{C}$**

| Parameter                                                                  | Symbol                       | Values |      |      | Unit | Note / Test Condition                                                                                                                    |
|----------------------------------------------------------------------------|------------------------------|--------|------|------|------|------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                            |                              | Min.   | Typ. | Max. |      |                                                                                                                                          |
| Accuracy <sup>1)</sup> over temperature w/o look-up table                  | $A_{\text{Err},T}$           |        |      | 0.8  | °    | 0h <sup>2)</sup> , over temperature $B = 33\text{mT}$ to $80\text{mT}$ <sup>3)</sup>                                                     |
| Accuracy <sup>1)</sup> over temperature and lifetime, w/o look-up table    | $A_{\text{Err},S}$           |        |      | 1.0  | °    | $33\text{mT} \dots 80\text{mT}$ <sup>3)</sup> lifetime stress: $T_A = 125^\circ\text{C}/2000\text{h}$                                    |
| Accuracy <sup>1)4)</sup> over temperature and lifetime, with look-up table | $A_{\text{Err},\text{SLUT}}$ |        |      | 0.85 | °    | $B = 33\text{mT}$ to $80\text{mT}$ <sup>3)</sup> , lifetime stress: $T_A = 125^\circ\text{C}/2000\text{h}$ with look-up table correction |
| Hysteresis <sup>5)</sup>                                                   | $A_{\text{Hyst}}$            |        | 0.1  | 0.16 | °    | $B = 33\text{mT}$ to $80\text{mT}$ <sup>6)</sup> , value includes quantization error                                                     |

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  $25\text{mT} < B < 33\text{mT}$ ,  $0.2^\circ$  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

## Specification

6) For the magnetic field range of  $25\text{mT} < B < 33\text{mT}$ ,  $0.1^\circ$  have to be added to the max. hysteresis  $A_{\text{Hyst}}$

### 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                  | $n_{\text{prog}}$      |        |      | 100  |      | -                                                               |        |
| NVM data retention                                         | $t_{\text{retention}}$ |        | -    | 21   | a    | includes 19a lifetime and 2a storage                            |        |
| Time for programming of whole NVM (customer relevant part) | $t_{\text{prog}}$      |        | 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.

### 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.

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  $V_{\text{DD}}$  detects an undervoltage at  $\sim 2.5\text{V}$  (typ. value). At occurrence of

## Specification

an overvoltage, the sensor output goes to tristate and no protocol is transmitted. The implemented overvoltage comparator at  $V_{DD}$  detects an overvoltage at  $\sim 6.5V$  (typ. value).

### 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, 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        | SSC           | 3.3          | 15            |               | $\sim 0$       | 49.5   |
| 2        | SSC           | 5.5          | 15            |               | $\sim 0$       | 82.8   |

## 3.8 Device Programming

It is possible to do the programming of the EEPROM with the SSC interface. The programming mode can be accessed directly after start-up of the IC by sending the appropriate command.

Following parameters can be programmed and stored in the EEPROM:

- 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.

### 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  $360^\circ$  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 Synchronous Serial Communication (SSC) interface

The SSC interface is a half-duplex communication protocol. The communication is always initiated by the microcontroller by sending a command to the TLE5014SP16 E0002. The command can be either a Read access (**Figure 4-3**) or a Write access (**Figure 4-4**). According to the command, the microcontroller can either send a data word to the TLE5014SP16 E0002 (Write access) or receive data word from the TLE5014SP16 E0002 (Read access). At the end of the communication the TLE5014SP16 E0002 sends a safety word.

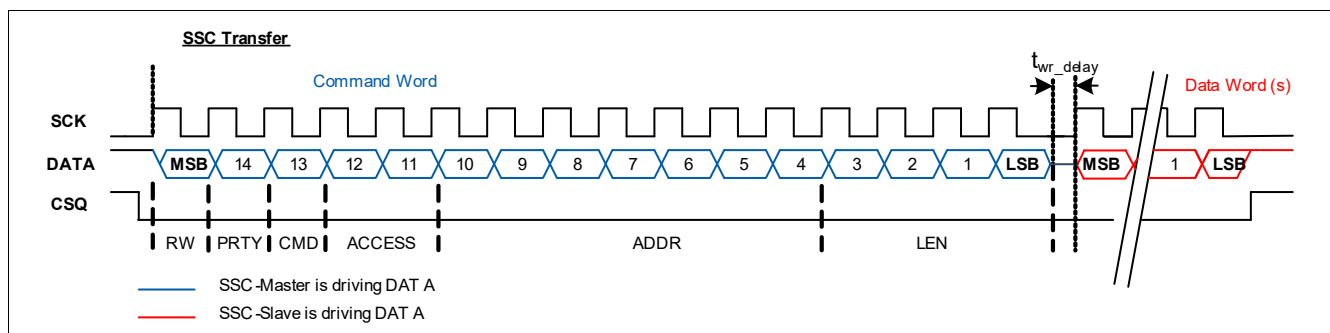
The 3-pin SSC Interface is composed of:

- DATA: Bidirectional data line. Data bits are sent synchronously with the clock line.
- SCK: Unidirectional clock line. Generated by the microcontroller, TLE5014SP16 E0002 is always a slave.
- CSQ: Chip select, active low. Asserted by the microcontroller to select a slave.

### 4.1 Data transmission

The data communication via SSC interface has the following characteristic:

- The SSC Interface is word-aligned. All functions are activated after each transmitted word.
- The microcontroller selects a TLE5014SP16 E0002 by asserting the CSQ to low. A “high” condition on the negated Chip Select pin (CSQ) of the selected TLE5014SP16 E0002 interrupts the transfer immediately. The CRC calculator is automatically reset.
- Data is put on the data line with the rising edge on SCK and read with the falling edge on SCK. Similar to a SPI configuration with CPOL=0 and CPHA=1.
- After changing the data direction, a delay ( $t_{wr\_delay}$ ) has to be considered before continuing the data transfer. This is necessary for internal register access.
- After sending the Safety Word the transfer ends. To start another data transfer, the CSQ has to be deselected once for  $t_{CSoff}$ .
- The SSC is default Push-Pull. The Push-Pull driver is only active, if the TLE5014SP16 E0002 has to send data, otherwise the Push-Pull is disabled for receiving data from the microcontroller.



**Figure 4-1 SSC data transmission**

#### 4.1.1 Bit Numbering

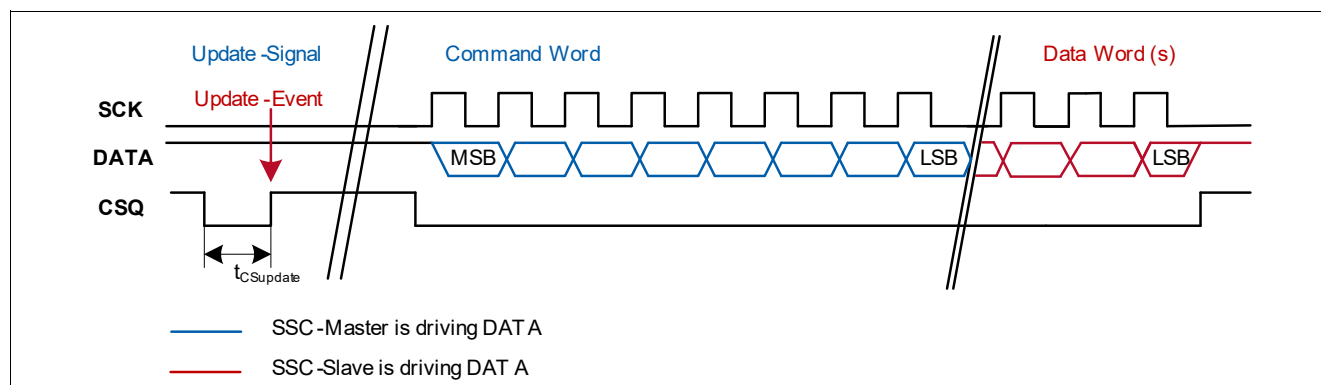
The SSC communication is using the convention: Most Significant Bit (MSB) first. **Figure 4-1** shows the Command Word and the beginning of the Data Word to demonstrate the bit numbering.

#### 4.1.2 Update of update-registers

At a rising edge of CSQ without a preceding data transfert (no SCK pulse), the content of all registers which have an update buffer is saved into the buffer. The content of the update buffer can be read by sending a read

## Synchronous Serial Communication (SSC) interface

command for the desired register and setting the ACCESS bits of the Command Word to 11<sub>B</sub>. This feature allows to take a snapshot of all necessary system parameters at the same time.



**Figure 4-2 Update of update-registers**

The types of functions used in the registers are listed here:

**Table 4-1 Bit types**

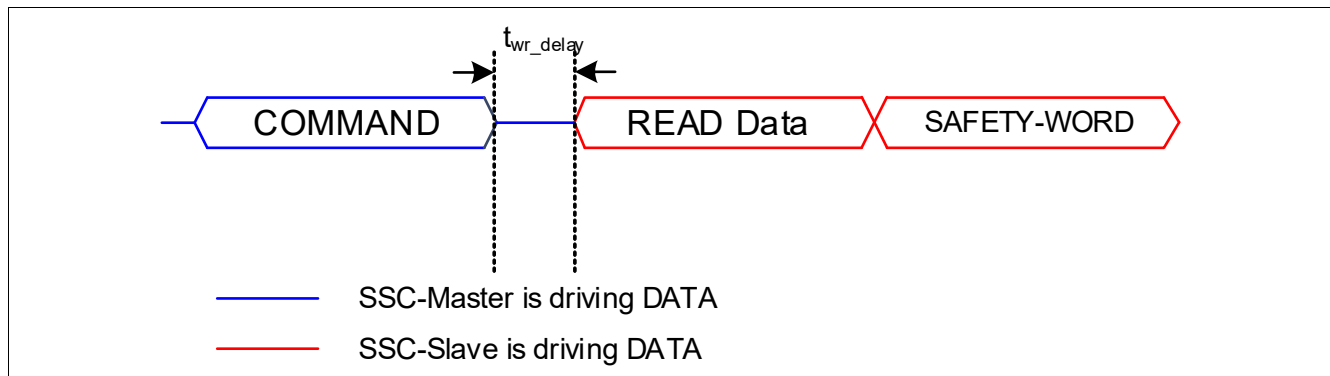
| Abbreviation | Function | Description                                                                                                                                                                                                                                                                           |
|--------------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| R            | Read     | Read-only registers                                                                                                                                                                                                                                                                   |
| W            | Write    | Read and write registers                                                                                                                                                                                                                                                              |
| U            | Update   | Update buffer for this bit is present. If an update is issued and the Update-Register Access bits (ACCESS in Command Word) are set, the immediate values are stored in this update buffer simultaneously. This enables a snapshot of all necessary system parameters at the same time |

## Synchronous Serial Communication (SSC) interface

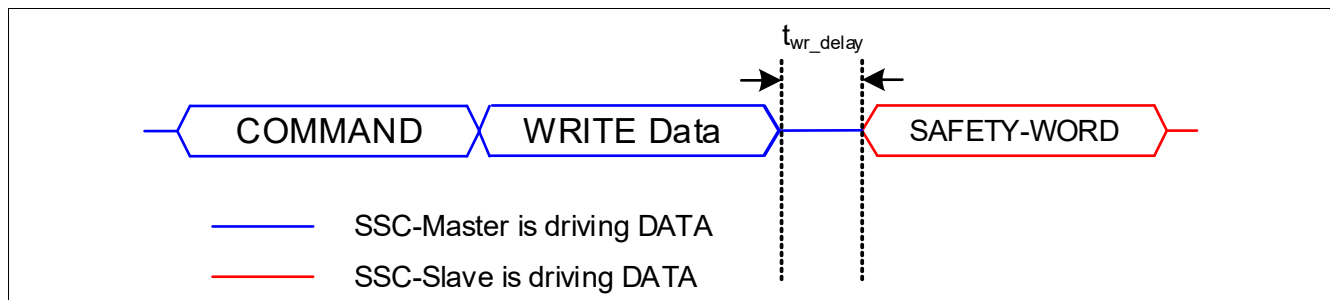
### 4.2 Data transfer

The SSC data transfer is word aligned. The following transfer words are possible:

- Command word (to access and change operating modes of the TLE5014SP16 E0002)
- Data words (any data transferred in any direction)
- Safety word (confirms the data transfer and provide status information)



**Figure 4-3 SSC data transfer (data read example)**



**Figure 4-4 SSC data transfer (data write example)**

#### 4.2.1 Command Word

The TLE5014SP is controlled by a command word. It is sent first at every data transmission. The structure of the command word is shown in [Table 4-2](#).

**Table 4-2 Structure of the command word**

| Name   | Bits    | Description                                                                                                   |
|--------|---------|---------------------------------------------------------------------------------------------------------------|
| RW     | [15]    | Read - Write<br>0: Write<br>1: Read                                                                           |
| PRTY   | [14]    | Command parity<br>Odd parity of all Command-Word-bits. Number of "1"s has to be odd                           |
| CMD    | [13]    | Set to 0 <sub>B</sub>                                                                                         |
| ACCESS | [12:11] | Access mode to registers<br>00 <sub>B</sub> : Direct access<br>11 <sub>B</sub> : Update register; read-access |
| ADDR   | [10:4]  | 7-bit Address                                                                                                 |
| LEN    | [3:0]   | Set to 1 <sub>B</sub>                                                                                         |

**Synchronous Serial Communication (SSC) interface**

**4.2.2 Safety word**

The safety word contains following bits:

**Table 4-3 Structure of the safety word**

| Name | Bits                       | Description                                                                                                                   |
|------|----------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| STAT | Chip and Interface Status. |                                                                                                                               |
|      | [15]                       | Indication of chip reset (undervoltage, watchdog)<br>(resets after readout via SSC)<br>0: Reset occurred<br>1: No reset       |
|      | [14]                       | System Error (e.g. Overvoltage; Undervoltage; $V_{DD-}$ , GND- off; ROM)<br>0: Error occurred<br>1: No error                  |
|      | [13]                       | Interface Access Error (access to wrong address; wrong lock, wrong parity, wrong access)<br>0: Error occurred<br>1: No error  |
|      | [12]                       | Angle Value error (ADC , vectorlength or redundant angle calculation error)<br>0: Angle value invalid<br>1: Angle value valid |
| RESP | [11:8]                     | Sensor Number Response Indicator<br>The sensor no. bit is pulled low and the other bits are high                              |
| CRC  | [7:0]                      | Cyclic Redundancy Check (CRC) includes Command Word, Data-words, STAT and RESP                                                |



## Package Information

## 5 Package Information

The device is qualified with a MSL level of 3. It is halogen free, lead free and RoHS compliant.

### 5.1 Package Parameters

**Table 5-1 Package Parameters**

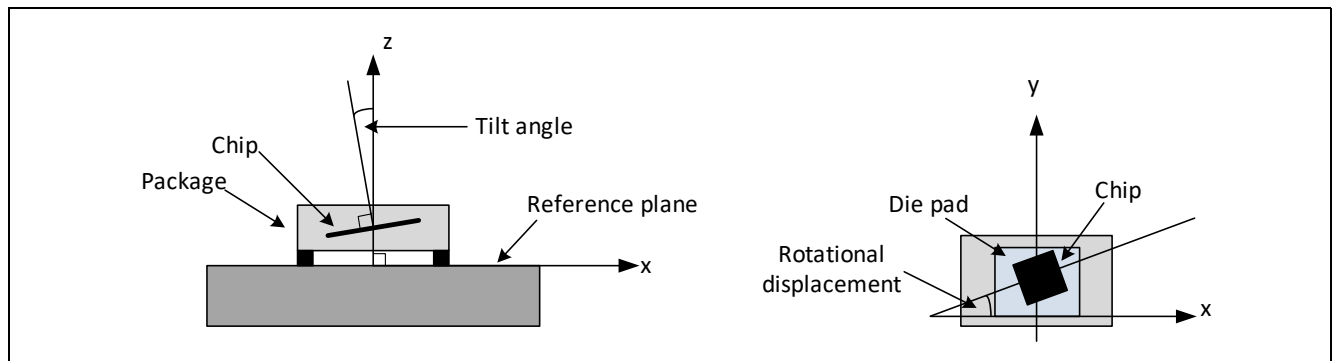
| Parameter                  | Symbol     | Limit Values |      |      | Unit | Notes                         |
|----------------------------|------------|--------------|------|------|------|-------------------------------|
|                            |            | Min.         | Typ. | Max. |      |                               |
| Thermal resistance         | $R_{thJA}$ |              |      | 150  | K/W  | Junction to air <sup>1)</sup> |
|                            | $R_{thJC}$ |              |      | 45   | K/W  | Junction to case              |
|                            | $R_{thJL}$ |              |      | 70   | K/W  | Junction to lead              |
| Moisture Sensitivity Level | MSL 3      |              |      |      |      | 260°C <sup>2)</sup>           |
| Lead Frame                 | Cu         |              |      |      |      |                               |
| Plating                    | Sn 100%    |              |      |      |      | > 7 µm                        |

1) according to Jedec JESD51-7

2) suitable for reflow soldering with soldering profiles according to JEDEC J-STD-020E (December 2014)

**Table 5-2 Position of the die in the package**

| Parameter                      | Symbol | Limit Values |      |      | Unit | Notes                                                                           |
|--------------------------------|--------|--------------|------|------|------|---------------------------------------------------------------------------------|
|                                |        | Min.         | Typ. | Max. |      |                                                                                 |
| Tilt                           |        |              |      | 3    | °    | in respect to the z-axis and reference plane (see <a href="#">Figure 5-1</a> ), |
| Rotational displacement        |        |              |      | 3    | °    | in respect to the reference axis (see <a href="#">Figure 5-1</a> )              |
| Placement tolerance in package |        |              |      | 100  | µm   | in x and y direction                                                            |



**Figure 5-1 Tolerance of the die in the package**

The active area of the GMR sensing element is 360µm x 470µm.

It has to be ensured that a magnet is used which has sufficient size to provide a homogeneous magnetic field over the total sensing element area. For a practical application design this means that the magnet has to be

**Package Information**

large enough to ensure that the non-homogeneity of the magnetic field in this area (plus relevant positioning tolerances) is negligible. In case the magnet diameter is too small or there is a misalignment of the magnet to the sensor, an additional angle error may occur which has to be taken into account by the user.

Package Information

5.2 Package Outline

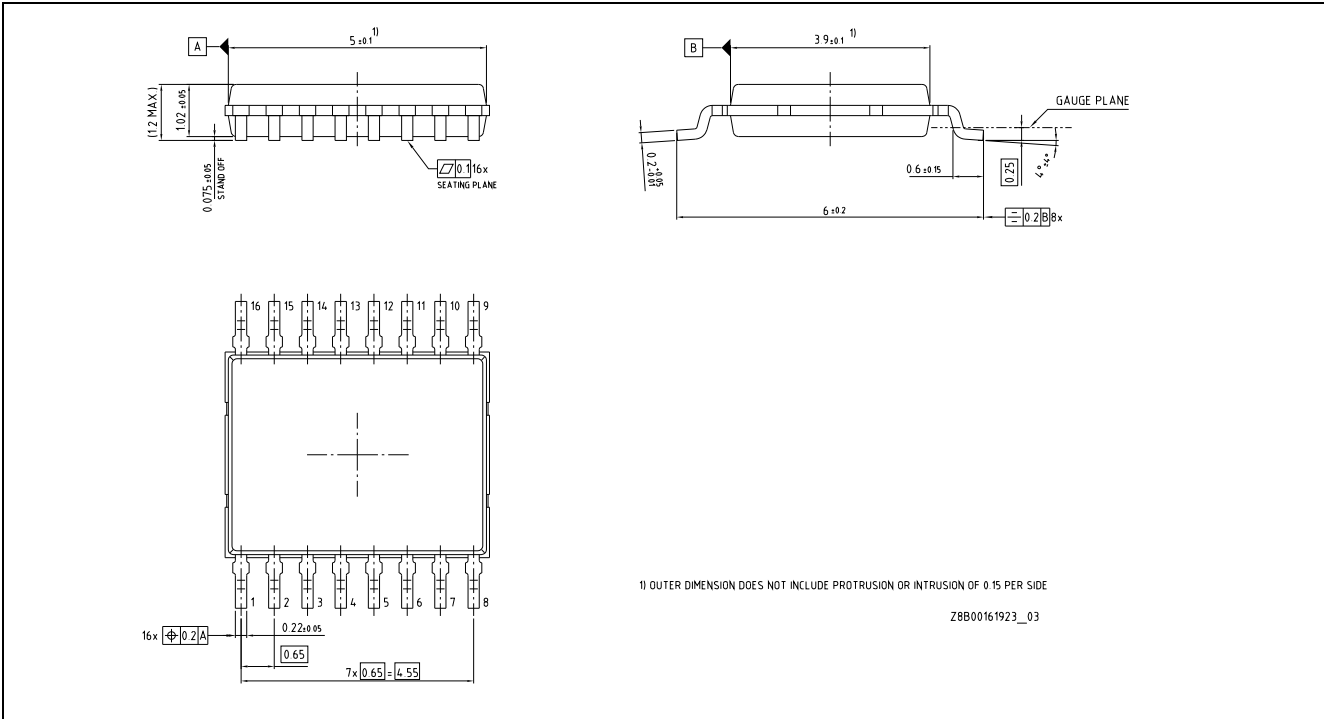


Figure 5-2 PG-TDSO-16 package dimension

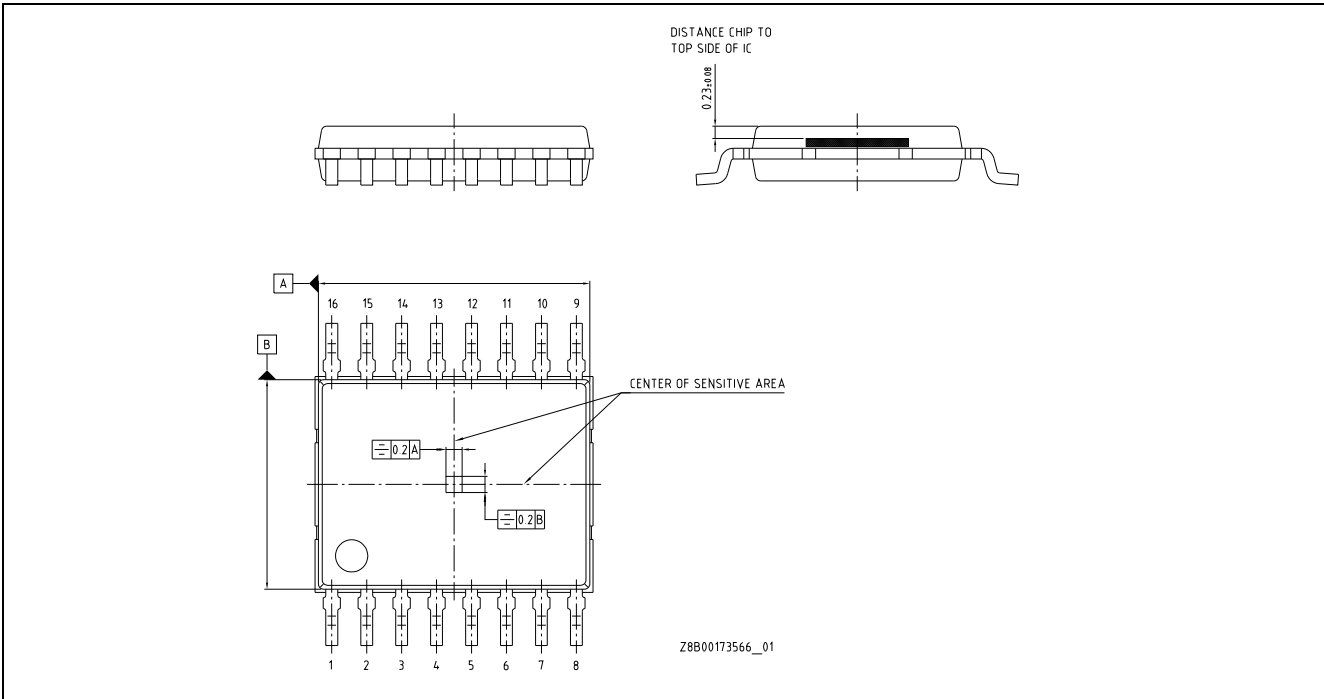


Figure 5-3 Position of sensing element

Package Information

5.3 Footprint

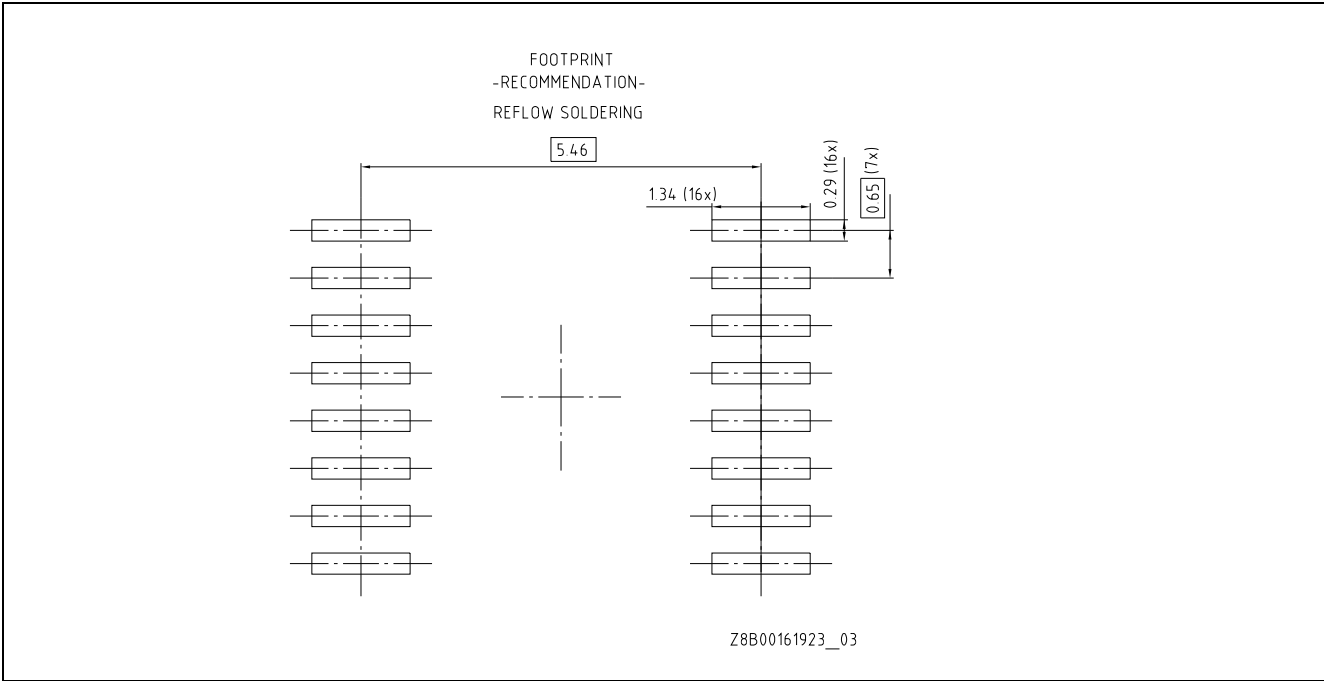


Figure 5-4 Footprint of PG TDSO-16

5.4 Packing

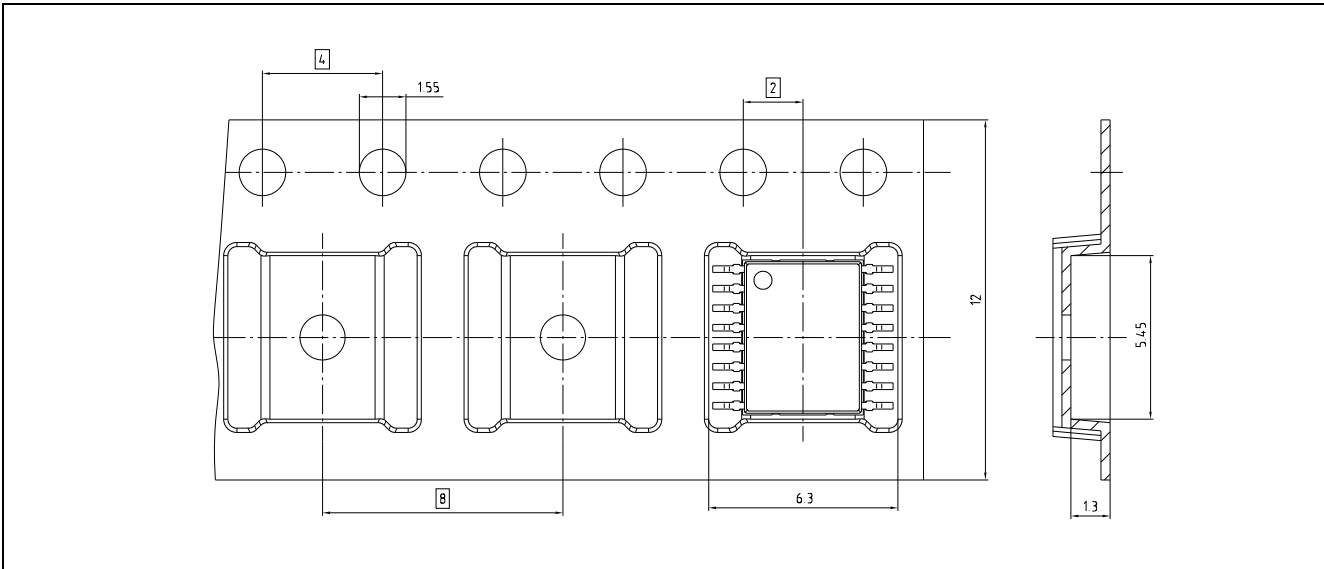


Figure 5-5 Tape and Reel

Package Information

5.5 Marking

| Position | Marking  | Description                                                                    |
|----------|----------|--------------------------------------------------------------------------------|
| 1st Line | Gxxxx    | G: green, 4-digit date code: YYWW<br>e.g. "1801": 1 <sup>st</sup> week in 2018 |
| 2nd Line | xxxxxxxx | Interface type and version                                                     |
| 3rd Line | xxx      | Lot code                                                                       |

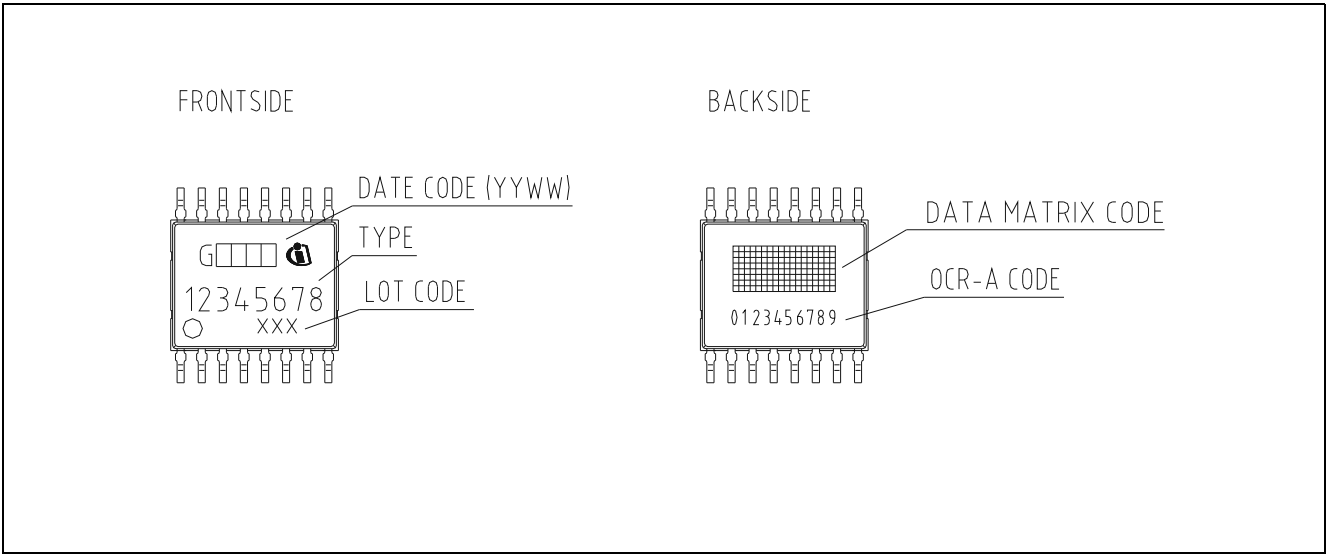


Figure 5-6 Marking of PG-TDSO-16

**Revision history**

## **6 Revision history**

| <b>Revision</b> | <b>Date</b> | <b>Changes</b>          |
|-----------------|-------------|-------------------------|
| 1.0             | 2019-01-17  | Initial creation.       |
| 1.1             | 2019-04-04  | Remove Register chapter |
|                 |             |                         |
|                 |             |                         |

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