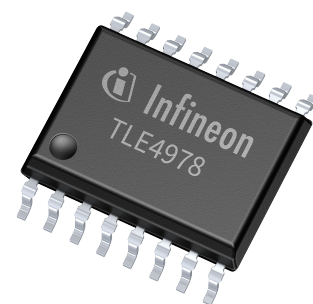


## XENSIV™ High Bandwidth and High Accuracy Coreless Current Sensor for integrated current rail applications

### Features

- Extremely low noise: 38 mA<sub>RMS</sub> over full bandwidth
- 9 MHz (typ.) bandwidth provides fast response time and low phase delay
- High accurate, scalable, DC and AC current sensing:
  - Sensitivity error of < 0.85% over full temperature range
- Differential sensor principle ensures superior magnetic stray field suppression
- Pre-calibrated current sensor with Integrated current rail (Insertion resistance of 550 μΩ)
- Peak current measurement range of up to 67.5 A
- ISO26262 SEooC for safety requirements up to ASIL B
- Single ended mode output with ratiometricity w.r.t VDD
- Operating ambient temperature -40°C to 150°C
- Fast zero crossing detection (ZCD) with 80 ns delay
- Fast over current detection (OCD) with 100 ns response time
- Digital control and diagnostic interface (DCDI). It provides write access to OCD threshold, ZCD threshold, OCD deglitch filter time, ZCD hold time
- Suitable for basic and reinforced galvanic isolation applications
  - For use with 650 V/1200 V/1700 V IGBTs, Si, SiC and GaN MOSFETs
- DSO type 300 mil wide-body package with large creepage distance (>8 mm)
- Green (RoHS compliant) 8 mm x 8 mm 16-pin SMD package



### Potential applications

- DC-DC Converters
- OBC (On-Board Charger)
- Drives
- PV Inverter (Solar)
- Smart circuit breakers
- Telecommunication

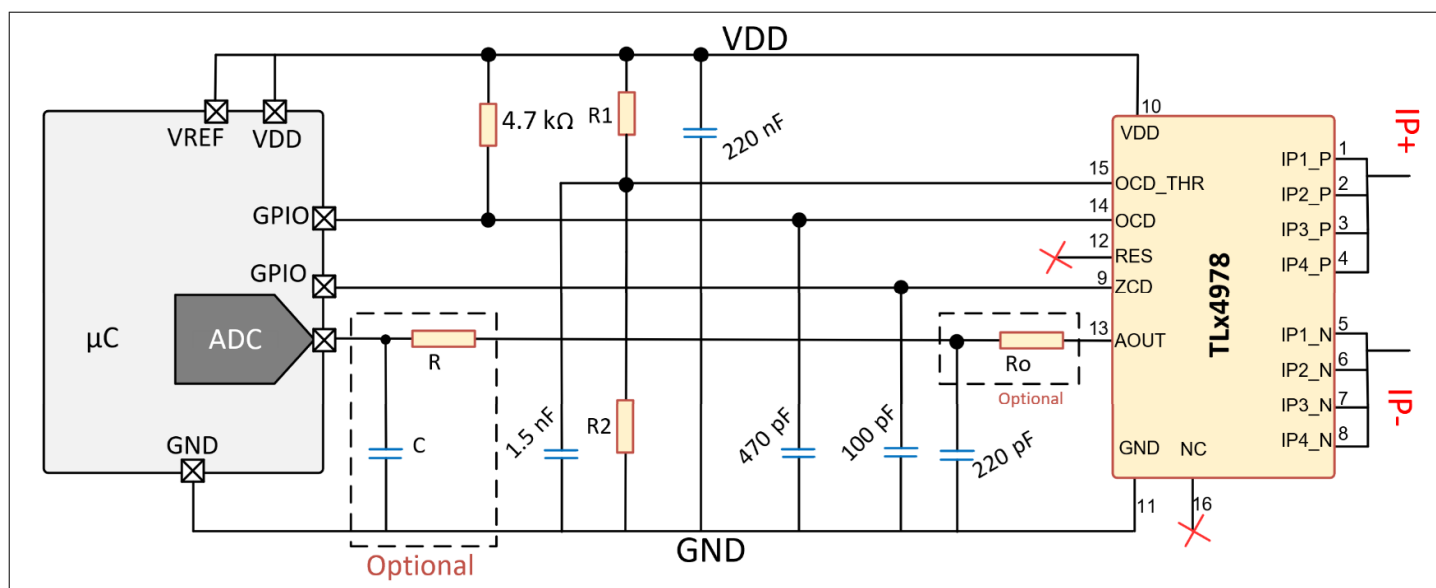
### Product validation

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

### Description

The TLE4978 is a new high bandwidth and high accurate coreless current sensor IC from Infineon based on Hall-effect and coil sensing elements with configurable overcurrent detection (OCD) and zero crossing detection (ZCD). Infineon's well-established and robust magnetic sensing technology enables accurate and highly linear measurement of currents with a full-scale current up to ±67.5 A. All negative effects (saturation, hysteresis) commonly known from open loop sensors using flux concentration techniques are avoided. It provides fast and accurate solution for measuring high-frequency currents in DC/DC converters and other switch mode power supply applications.

These features make TLE4978 ideally suited for replacing current transformers and shunts in applications running at high voltages. The low profile, surface mount DSO-16 wide body package of TLE4978 allows easy implementation in high voltage environment. The fully integrated package with internal copper conductive path has a typical resistance of 0.55 mΩ, providing low power loss. The applied current flowing through the copper conduction path generates a magnetic field that is sensed by the IC and converted to a proportional voltage. The differential current measurement principle allows stray field suppression for operation in harsh environments.



For enhanced stability, ground bouncing and flatness in the high frequency region, particularly in scenarios involving extended connection lines, it is advisable to integrate a resistor "R". Additionally, incorporating the components "R" and "C" can be beneficial in optimizing or mitigating electromagnetic compatibility (EMC) effects. The sensor is shipped as a fully calibrated product without requiring any end-of-line calibration for high accuracy. The OCD threshold threshold is programmable, refer to [Over Current Detection Characteristics](#). Also, ZCD threshold is programmable, refer to [Zero Current Detection Characteristics](#). The current-carrying pins (pins 1 through 8) are electrically isolated from the sensor leads (pins 9 through 16), which allows the device to be used in high-side current sensing applications without the use of further expensive isolation components.

Typical applications are high voltage automotive converter applications like on board chargers (OBC), and HV to LV standalone DC-DC converters. Also, industrial applications like photovoltaic converters, general purpose inverters, switch mode power supplies (SMPS), data centers and fast over load and over-current detection.

| Product type           | Description and features                                                                            | Marking    | Order code  |
|------------------------|-----------------------------------------------------------------------------------------------------|------------|-------------|
| TLE4978-R060W5-O-S0010 | XENSIV™ high bandwidth and high accurate current sensor with AOUT, OCD & ZCD features; 67.5 A range | H78E1ROW52 | SP005858350 |
| TLE4978-R050W5-O-S0010 | XENSIV™ high bandwidth and high accurate current sensor with AOUT, OCD & ZCD features; 56 A range   | H78E2ROW52 | SP005858345 |
| TLE4978-R040W5-O-S0010 | XENSIV™ high bandwidth and high accurate current sensor with AOUT, OCD & ZCD features; 45 A range   | H78E3ROW52 | SP005858343 |

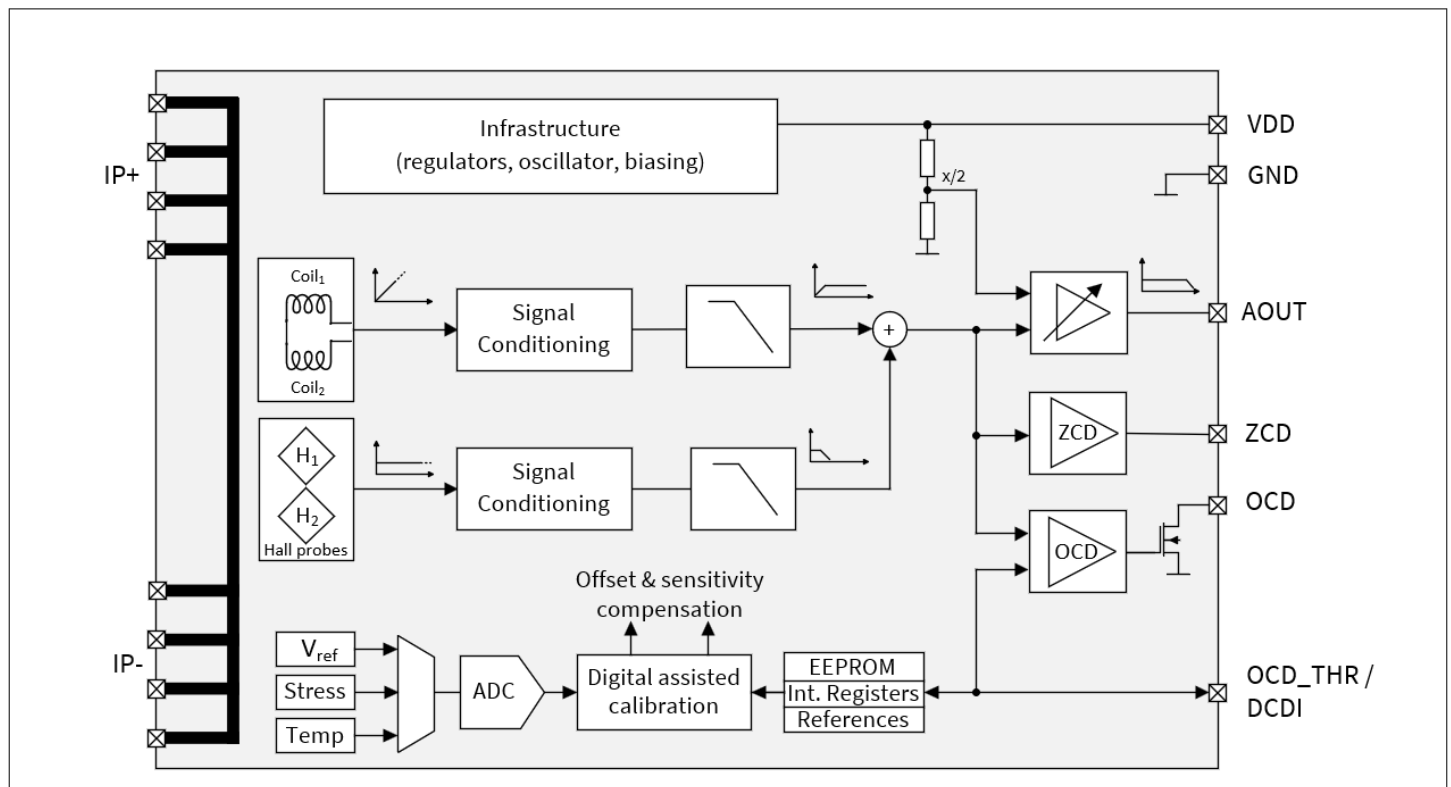
Note: Please contact Infineon sales for additional product types (current ranges, unidirectional mode, 3.3 V supply...).

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## 1 Functional block diagram



**Figure 1** Device functional block diagram

TLE4978 is an automotive-qualified sensor capable of supporting 5 V power supply applications. It is developed as a Safety Element out of Context (SEooC) for safety requirements up to ASIL B rating. The functional architecture block diagram of the current sensor is shown above. The high bandwidth and high accuracy is achieved using Hall-effect and coil sensing elements with users-configurable overcurrent detection (OCD) and zero crossing detection (ZCD). The two Hall probes and coils are embedded on the IC and their output is differentially connected, which provides a voltage level proportional to the differential magnetic field at the probes location. The well known Hall sensing principle provides DC measurement capability with very low offset whereas the coils can provide high signal at high frequency.

The output of the differential Hall probes is processed by an analog signal path that includes ripple compensation loop and digital assisted gain regulation.

The signal output of the coils is proportional to the magnetic field frequency and is processed by an independent signal path that implements low pass filtering to flatten the frequency response. The offset contribution of this path is removed by a DC servo loop.

The 2 signals from Hall probes and coils are then combined so that the Hall signal is dominant at low frequency and the coil signal is dominant at high frequency, thus creating an overall flat frequency response. The combined signal is finally further processed by an output buffer equipped with fine offset and gain regulation for precision calibration.

The details of each defined safety mechanism are described here:

- External supply and internal regulated supplies are continuously monitored by hardware (HW) comparators for detecting under or over-voltages.
- Memories and trimming registers are monitored by proven and widely used safety mechanisms such as parity, CRC and ECC.

Several other safety checks are implemented in the firmware (FW) and they exploit the fact that several safety critical parameters are already available in the digital part for functional purposes. The additional implementation of the firmware (FW) safety checks consists of periodically comparing the value of these parameters with thresholds during the regular operational life of the device. The monitored parameters, include temperature, mechanical stress, offset and ripple.

A fail of the internal safety checks leads to a fault indication that is externally visible on the OCD and ZCD pins.

## 2 Standard configuration

**Table 1** TLE4978 standard configuration

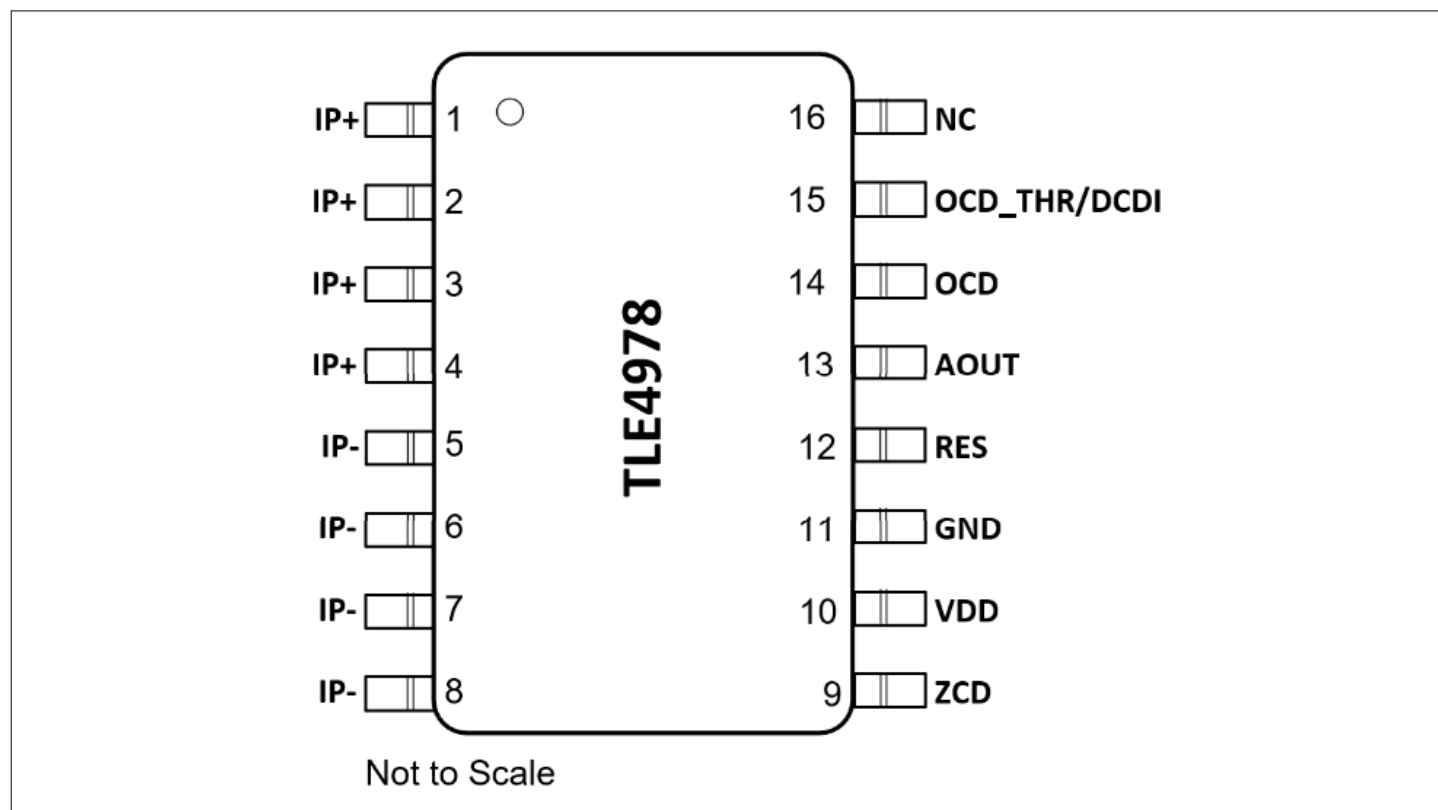
| Name                   | FS [A] | Sx [mV/A] | $I_{THR}$ [A]                                                  | ZCD               | $V_{OQ}$ [V]  | OP <sub>MODE</sub> | RATIOMETRICITY ( $V_{DD5}$ ) |
|------------------------|--------|-----------|----------------------------------------------------------------|-------------------|---------------|--------------------|------------------------------|
| TLE4978-R060W5-O-S0010 | ±67.5  | 32.5      | The default<br>OCD threshold<br>set to<br>125%FS <sup>1)</sup> | OFF <sup>2)</sup> | $V_{DD5} / 2$ | Single<br>Ended    | ON                           |
| TLE4978-R050W5-O-S0010 | ±56    | 39        |                                                                |                   |               |                    |                              |
| TLE4978-R040W5-O-S0010 | ±45    | 48.75     |                                                                |                   |               |                    |                              |

RATIOMETRICITY ( $V_{DD5}$ ) = Ratiometricity to  $V_{DD5}$ , FS = Full Scale, Sx = Sensitivity,  $I_{THR}$  = OCD threshold level,  $V_{OQ}$  = Quiescent output voltage, OP<sub>MODE</sub> = Output mode,  $V_{DD5}$  = 5 V supply, ZCD = Zero current detection

1) If at start up the DCDI command to set the OCD threshold is detected, the OCD threshold is set to the value transmitted by the DCDI. Otherwise, it is set to the value corresponding to the voltage at the OCD\_THR pin. More information regarding OCD options and settings are available in the device user manual.

2) ZCD can be turned on and set by the DCDI. More information regarding ZCD options and settings is available in the device user manual.

### 3 Pin configuration



**Figure 2** TLE4978 PG DSO-16 pin top view

**Table 2** TLE4978 - DSO-16 pin function

| Pin no. | Symbol         | Pin type                                | Function                                                       |
|---------|----------------|-----------------------------------------|----------------------------------------------------------------|
| 16      | NC             | Not connected with lead frame or sensor | Keep open                                                      |
| 15      | OCD_THR / DCDI | Analog / digital                        | OCD threshold selection / digital control diagnostic interface |
| 14      | OCD            | Digital output                          | Over current detection output (open drain output)              |
| 13      | AOUT           | Analog output                           | Analog signal output                                           |
| 12      | RES            | Reserved                                | Keep open                                                      |
| 11      | GND            | Analog                                  | Ground                                                         |
| 10      | VDD            | Analog                                  | Supply voltage                                                 |
| 9       | ZCD            | Digital output                          | Zero crossing detection output                                 |
| 1-4     | IP+            | Analog input                            | Current in                                                     |
| 5-8     | IP-            | Analog input                            | Current out                                                    |

## 4 General product characteristics

### 4.1 Absolute maximum ratings

**Table 3** Absolute maximum ratings

| Parameter                                               | Symbol         | Values |      |                  | Unit  | Note or condition                                                                                                                                  |
|---------------------------------------------------------|----------------|--------|------|------------------|-------|----------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                         |                | Min.   | Typ. | Max.             |       |                                                                                                                                                    |
| Supply voltage                                          | $V_{DD(AMR)}$  | -0.3   | –    | 6.5              | V     | Maximum 10 h between 5.5 V to 6.5 V                                                                                                                |
| Surge strength test current                             | $I_{Surge}$    | –      | –    | 10               | kA    | Tested by mounting TLE4978 on an Infineon reference PCB with 5 positive and negative pulses at 1/minute with 8 $\mu$ s (rise) / 20 $\mu$ s (width) |
| Voltage on interface pins<br>OCD, VREF,<br>OCD_THR, ZCD | $V_{IO\_A}$    | -0.3   | –    | $V_{DD} + 0.3$ V | V     | $V_{IO\_A} < 6.5$ V<br>Maximum 10 h between 5.5 V to 6.5 V                                                                                         |
| AOUT pin current capability                             | $I_{AOUT}$     | -40    | –    | 40               | mA    | Maximum 10 s at 25°C                                                                                                                               |
| Junction temperature maximum ratings                    | $T_{J\_MAX}$   | –      | –    | +165             | °C    | –                                                                                                                                                  |
| Storage temperature                                     | $T_{A\_STORE}$ | -40    | –    | +150             | °C    | –                                                                                                                                                  |
| Lifetime                                                | $LT$           | 15     | –    | –                | years | –                                                                                                                                                  |

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

### 4.1.1 ESD ratings

**Table 4** ESD ratings

| Parameter                              | Symbol                | Values |      |       | Unit | Note or condition                                                                    |
|----------------------------------------|-----------------------|--------|------|-------|------|--------------------------------------------------------------------------------------|
|                                        |                       | Min.   | Typ. | Max.  |      |                                                                                      |
| ESD voltage HBM (human body model)     | $V_{\text{ESD\_HBM}}$ | –      | –    | ±2    | kV   | Human body model (HBM), according to standard AEC-Q 100-002.                         |
| ESD voltage CDM (charged device model) | $V_{\text{ESD\_CDM}}$ | –      | –    | ±0.75 | kV   | According to AEC-Q100-011 standard.<br>Corner pins: 0.75 kV; non corner pins: 0.5 kV |

### 4.2 Functional range

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

**Note:** General conditions (unless otherwise specified):  $V_{\text{DD}} = 5.0 \text{ V}$ ;  $T_{\text{S}} = -40^{\circ}\text{C} \dots +150^{\circ}\text{C}$

**Table 5** Functional range

| Parameter                           | Symbol             | Values |      |      | Unit | Note or condition                                                      |
|-------------------------------------|--------------------|--------|------|------|------|------------------------------------------------------------------------|
|                                     |                    | Min.   | Typ. | Max. |      |                                                                        |
| Operating supply voltage            | $V_{\text{DD5}}$   | 4.5    | 5    | 5.5  | V    | –                                                                      |
| Ambient temperature at solder point | $T_{\text{S}}$     | –40    | –    | +150 | °C   | –                                                                      |
| Operating junction temperature      | $T_{\text{J\_OP}}$ | –      | –    | +165 | °C   | –                                                                      |
| Capacitance on analog output pin    | $C_{\text{O}}$     | 42     | –    | 242  | pF   | Without series resistor; including parasitic capacitance on the board. |

## 5 Product features

### 5.1 Electrical characteristics

**Table 6** Electrical characteristics

| Parameter                                | Symbol      | Values |              |      | Unit        | Note or condition                                                                                                                                                                             |
|------------------------------------------|-------------|--------|--------------|------|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                          |             | Min.   | Typ.         | Max. |             |                                                                                                                                                                                               |
| Current consumption                      | $I_{DD}$    | –      | 18           | 25   | mA          | $I_{AOUT} = 0$ mA                                                                                                                                                                             |
| Primary path (CR) resistance             | $R_{PN}$    | –      | 550          | –    | $\mu\Omega$ | 25°C, when soldered on PCB with 140 $\mu$ m copper thickness                                                                                                                                  |
| Power-ON delay time                      | $t_{POD}$   | –      | 1.7          | –    | ms          | Supply rising from 0 V to $V_{DD}$ . Starts when the $V_{DD}$ reaches the minimum allowed operating conditions and stops when the device is fully operational. OCD stays low within this time |
| Quiescent output voltage bidirectional   | $V_{OQBID}$ | –      | $V_{DD} / 2$ | –    | V           | $I_{PN} = 0$ A                                                                                                                                                                                |
| Analog output drive capability           | $I_O$       | -2     | –            | +2   | mA          | DC current                                                                                                                                                                                    |
| Analog output saturation voltage, source | $V_{CLH}$   | –      | –            | 300  | mV          | $V_{DD} - V_O$ ;<br>$I_{SINK} = 2$ mA                                                                                                                                                         |
| Analog output saturation voltage, sink   | $V_{CLL}$   | –      | –            | 300  | mV          | $I_{SOURCE} = 2$ mA                                                                                                                                                                           |

## 5.2 Isolation characteristics

**Table 7** Isolation characteristics

| Parameter                                                                 | Symbol            | Values |        |      | Unit            | Note or condition                                                                                                                                                                    |
|---------------------------------------------------------------------------|-------------------|--------|--------|------|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                           |                   | Min.   | Typ.   | Max. |                 |                                                                                                                                                                                      |
| GENERAL                                                                   |                   |        |        |      |                 |                                                                                                                                                                                      |
| External clearance                                                        | CRP               | 8.0    | –      | –    | mm              | Shortest distance in air between any current rail (CR) pin to any low voltage (LV) output pin.                                                                                       |
| External creepage                                                         | CLR               | 8.0    | –      | –    | mm              | Shortest distance in air between any current rail (CR) pin to any low voltage (LV) output pin.                                                                                       |
| Comparative tracking index                                                | CTI               | 600    | –      | –    | –               | According to DIN EN 60112 (VDE 0303-11)                                                                                                                                              |
| Pollution degree                                                          | PD                | –      | –      | 2    | –               | –                                                                                                                                                                                    |
| Overvoltage category                                                      | OVC               | –      | 1 to 3 | –    | –               | Rated mains voltage ≤ 600 V <sub>RMS</sub>                                                                                                                                           |
| Maximum rated transient isolation voltage                                 | V <sub>IOTM</sub> | –      | –      | 6000 | V <sub>pk</sub> | V <sub>TEST</sub> = V <sub>IOTM</sub> for t <sub>ini</sub> = 60 s (qualification);<br>V <sub>TEST</sub> = 1.2 × V <sub>IOTM</sub> for t <sub>ini</sub> = 1 s (100% productive tests) |
| Maximum rated isolation working voltage, basic insulation                 | V <sub>IOWM</sub> | –      | –      | 1700 | V <sub>pk</sub> | AC voltage (sine wave)                                                                                                                                                               |
| Maximum rated isolation working voltage, reinforced insulation            |                   | –      | –      | 1060 | V <sub>pk</sub> | AC voltage (sine wave)                                                                                                                                                               |
| Maximum rated repetitive peak isolation voltage for basic insulation      | V <sub>IORM</sub> | –      | –      | 1700 | V <sub>pk</sub> | AC voltage (bipolar)                                                                                                                                                                 |
| Maximum rated repetitive peak isolation voltage for reinforced insulation |                   | –      | –      | 1500 | V <sub>pk</sub> | AC voltage (bipolar)                                                                                                                                                                 |

(table continues...)

**Table 7** (continued) Isolation characteristics

| Parameter                            | Symbol          | Values |      |      | Unit       | Note or condition                                                                                                                                                          |
|--------------------------------------|-----------------|--------|------|------|------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                      |                 | Min.   | Typ. | Max. |            |                                                                                                                                                                            |
| Apparent charge method b             | $q_{PD}$        | –      | –    | 5    | pC         | Method b1: 100% productive tests and type tests preconditioning,<br>$V_{ini,b1}=1.2 \times V_{IOTM}$ , $t_{ini}=1$ s;<br>$V_{pd(m)} = 1.647 \times V_{IORM}$ for $t_m=1$ s |
| Maximum surge isolation voltage      | $V_{IOSM}$      | –      | –    | 8000 | $V_{pk}$   | Test method as per IEC 61000-4-5;<br>1.2/50 $\mu$ s waveform, $V_{IOSM\_TEST} \geq 1.3 \times V_{IOSM}$                                                                    |
| Isolation resistance input to output | $R_{IO\_25}$    | 1000   | –    | –    | G $\Omega$ | $V_{IO} = 500 V_{dc}$ for $t = 60$ s, $T_A = 25^\circ C$                                                                                                                   |
|                                      | $R_{IO\_105}$   | 100    | –    | –    | G $\Omega$ | $V_{IO} = 500 V_{dc}$ for $t = 60$ s, $T_A = 105^\circ C$                                                                                                                  |
|                                      | $R_{IO\_S}$     | 10     | –    | –    | G $\Omega$ | $V_{IO} = 500 V_{dc}$ for $t = 60$ s, $T_A = 150^\circ C$                                                                                                                  |
| Capacitance input to output          | $C_{IO}$        | –      | –    | 1.7  | pF         | $V_{IO} = 0.4 \times \sin(2\pi ft)$ , $f = 1$ MHz                                                                                                                          |
| <b>UL1577</b>                        |                 |        |      |      |            |                                                                                                                                                                            |
| Input to output isolation voltage    | $V_{ISO,B(AC)}$ | –      | –    | 4240 | $V_{RMS}$  | $V_{TEST} = V_{ISO,B(AC)}$ for $t = 60$ s (qualification)<br>$V_{TEST} = 1.2 \times V_{ISO,B(AC)}$ for $t = 1$ s (100% productive tests)                                   |

### 5.3 Sensing characteristics

**Note:** General conditions (unless otherwise specified):  $V_{DD} = 5.0\text{ V}$ ;  $T_S = -40^\circ\text{C} \dots +150^\circ\text{C}$

**Table 8 Sensing characteristics**

| Parameter                                        | Symbol           | Values |       |      | Unit              | Note or condition                                                                                                                              |
|--------------------------------------------------|------------------|--------|-------|------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                  |                  | Min.   | Typ.  | Max. |                   |                                                                                                                                                |
| OUTPUT                                           |                  |        |       |      |                   |                                                                                                                                                |
| Transfer function cutoff frequency bidirectional | $BW$             | –      | 9     | –    | MHz               | -3 dB criterion, typical $C_{AOUT} = 220\text{ pF}$                                                                                            |
| Response time                                    | $t_{res}$        | –      | 50    | –    | ns                | Time between input and output reaching 90% of final values with 400 mA/ns input step with Typical $C_{AOUT} = 220\text{ pF}$                   |
| Propagation delay                                | $t_{pd}$         | –      | 27    | –    | ns                | Time between input and output reaching 10% of final values with a 400 mA/ns input step with Typical $C_{AOUT} = 220\text{ pF}$                 |
| Rise time                                        | $t_{rise}$       | –      | 43    | –    | ns                | The time between when the sensor reaches 10% and 90% of its full-scale value with 800 mA/ns input step with Typical $C_{AOUT} = 220\text{ pF}$ |
| Common mode transient immunity                   | $CMTI$           | –      | 200   | –    | kV/ $\mu$ s       | No false triggering of OCD and ZCD. The disturbance on Analog signal is not greater than 200 mV for longer than 1 $\mu$ s at $V_{CM}$ <700 V.  |
| Input referred noise                             | $I_{NOISE}$      | –      | 38    | 80   | $\text{mA}_{RMS}$ | RMS noise at full $BW$                                                                                                                         |
| MEASUREMENT RANGE                                |                  |        |       |      |                   |                                                                                                                                                |
| Sensitivity, range S1                            | $S1$             | –      | 32.5  | –    | mV/A              | $FS = \pm 67.5\text{ A}$ at $V_{DD} = 5\text{ V}$                                                                                              |
| Sensitivity, range S2                            | $S2$             | –      | 39    | –    | mV/A              | $FS = \pm 56\text{ A}$ at $V_{DD} = 5\text{ V}$                                                                                                |
| Sensitivity, range S3                            | $S3$             | –      | 48.75 | –    | mV/A              | $FS = \pm 45\text{ A}$ at $V_{DD} = 5\text{ V}$                                                                                                |
| SENSITIVITY & OFFSET ERROR                       |                  |        |       |      |                   |                                                                                                                                                |
| Sensitivity ratiometricity bandwidth             | $BW_{RAT\_SENS}$ | –      | 1     | –    | kHz               | –                                                                                                                                              |
| Quiescent voltage ratiometricity bandwidth       | $BW_{RAT\_Q}$    | –      | 30    | –    | kHz               | $\pm 100\text{ mV}$ on $V_{DD}$                                                                                                                |
| Stray field error                                | $E_{Stray}$      | –      | 18    | –    | $\text{mA/mT}$    | DC to 1 kHz                                                                                                                                    |

**(table continues...)**

**Table 8** (continued) Sensing characteristics

| Parameter                        | Symbol                 | Values |           |      | Unit | Note or condition                                                      |
|----------------------------------|------------------------|--------|-----------|------|------|------------------------------------------------------------------------|
|                                  |                        | Min.   | Typ.      | Max. |      |                                                                        |
| Initial sensitivity error        | $E_{\text{SENS}}$      | -0.65  | $\pm 0.3$ | 0.65 | %    | At 0 h, $T_A = 25^\circ\text{C}$ , with respect to nominal sensitivity |
| Initial offset error             | $E_{\text{OFF}}$       | -130   | $\pm 55$  | 130  | mA   | At $T_S = 25^\circ\text{C}$                                            |
| Nonlinearity error               | $E_{\text{NL}}$        | –      | 0.1       | –    | %    | $V_{\text{OUT}}$ = from 0.3 V to $V_{\text{DD}} - 0.3 \text{ V}$       |
| Sensitivity ratiometricity error | $E_{\text{SENS\_RAT}}$ | -0.5   | –         | 0.5  | %    | $V_{\text{DD}}$ operating range                                        |

**OVER TEMPERATURE & LIFETIME ERRORS**

|                                                 |                                    |       |           |      |                          |                                                        |
|-------------------------------------------------|------------------------------------|-------|-----------|------|--------------------------|--------------------------------------------------------|
| Sensitivity drift over temperature              | $E_{\text{SENST}}$ <sup>1)</sup>   | -0.2  | –         | 0.2  | %                        | At 0 h                                                 |
| Sensitivity drift over temperature and lifetime | $E_{\text{SENSL}}$ <sup>2)</sup>   | -0.55 | –         | 0.55 | %                        | –                                                      |
| Offset drift over temperature                   | $E_{\text{OFFT}}$ <sup>1)</sup>    | -30   | –         | 30   | mA                       | –                                                      |
| Offset drift over temperature & lifetime        | $E_{\text{OFF\_LV}}$ <sup>3)</sup> | -70   | –         | 70   | mA                       | –                                                      |
| Offset ratiometricity error                     | $E_{\text{OFF\_RAT}}$              | -20   | $\pm 9.3$ | 20   | mA/<br>% $V_{\text{DD}}$ | Max $\pm 10\%$ $V_{\text{DD}}$ variation <sup>4)</sup> |

1) Typical values are mean  $\pm 3 \sigma$

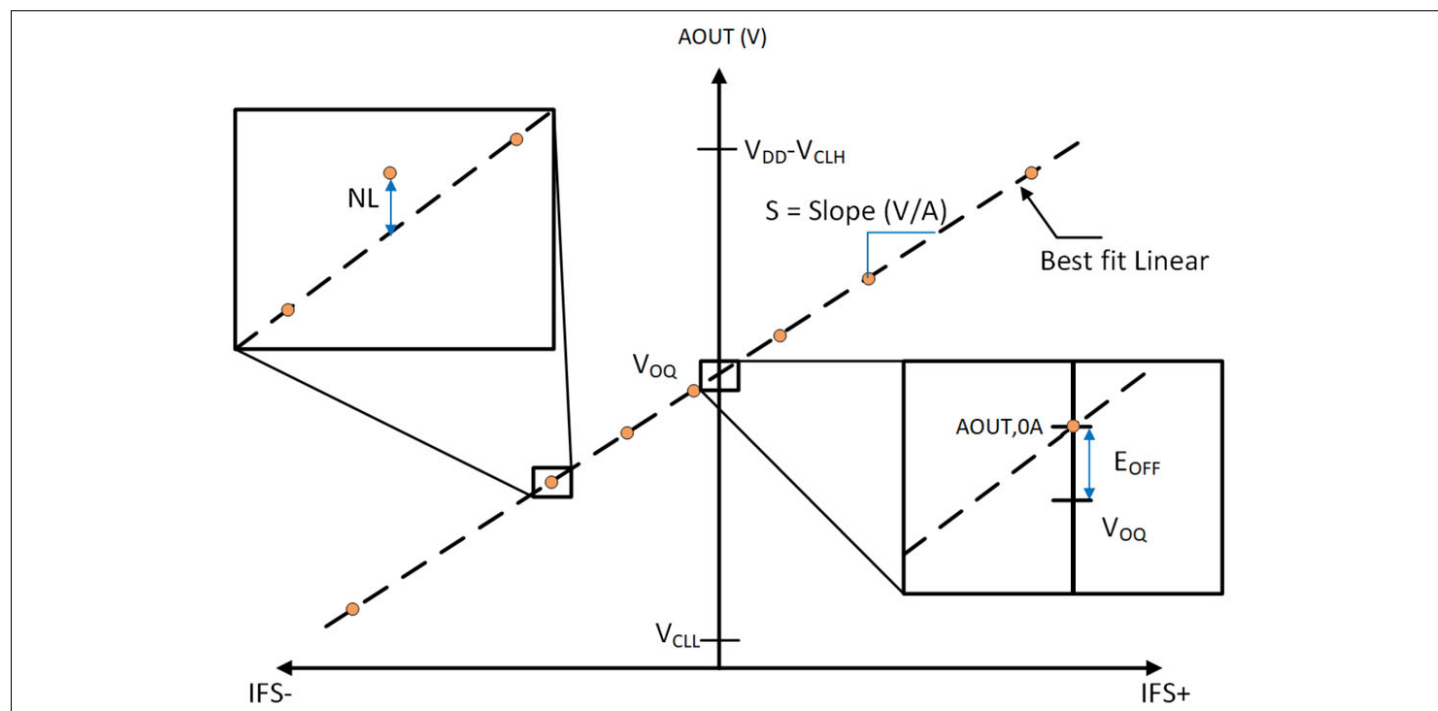
2) Lifetime drift minimum/maximum values are mean  $\pm 3 \sigma$ , and are based on a statistical evaluation of worst-case performance observed after AEC-Q100 qualification stresses.

3) Lifetime drift minimum/maximum values are mean  $\pm 3 \sigma$  and are based on a statistical evaluation of worst-case performance observed after AEC-Q100 qualification stresses.

4) Specified based on qualification. Typical values are population  $\pm 3 \sigma$  from worst case stress test condition. Devices tested in AECQ-100 qualification stayed within min/max limits for all stress conditions.

## 5.4 Functional description

The sensor features an analog output, which is used to provide the information of the measured current. The analog output measurement result is available as the output voltage. In the following paragraphs, the output modes and respective sensitivity and quiescent output voltage definitions for the sensor is discussed. The following figure shows the definitions of different parameters, such as sensitivity, which represents the slope of the first-order transfer function, offset error ( $E_{OFF}$ ), and non-linearity error (NL) based on the linear curve.

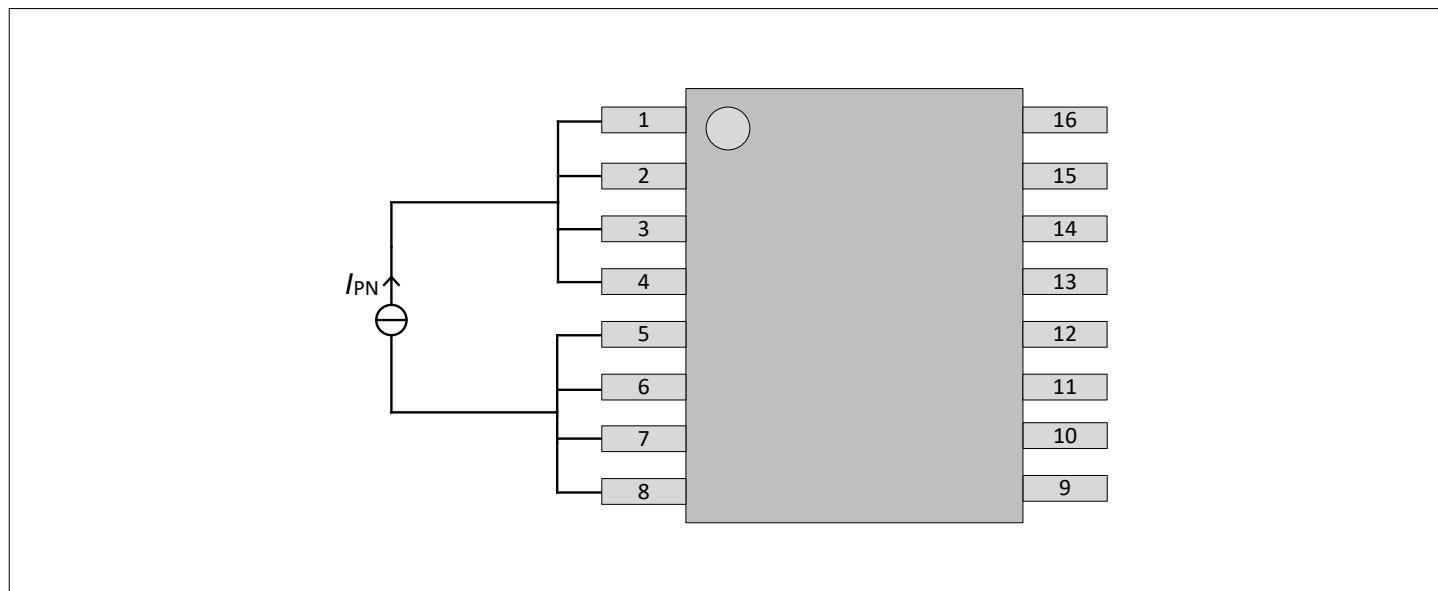


**Figure 3** Sensitivity, offset and nonlinearity error

## 5.4.1 Output behavior

### 5.4.1.1 Output voltage and current polarity

This is a coreless magnetic current sensor, it measures the differential magnetic field caused by current flowing in the internal current rail.



**Figure 4** Polarity illustration DSO-16 300 mil package

The current  $I_{PN}$  is positive when it flows in the direction from pins 1,2,3,4 (+) to pin 5,6,7,8 (-) through an internal current rail.

In single ended output mode, the AOUT pin operates as an output and provides the output voltage representing the measured current  $I_{PN}$  flowing in the current rail. The device provides the output signal on AOUT only. The quiescent voltage and sensitivity are ratiometric to the sensor  $V_{DD}$ .

Being, "S" the sensitivity and " $V_{OQ}$ " the quiescent voltage of the sensor, the output voltage on AOUT is described as follows:

$$V(A_{OUT}) = V_{OQ} + S \times I_{PN} \quad (1)$$

The nominal quiescent voltage value ( $V_{OQ}$ ) at the pin AOUT is ratiometric with respect to  $V_{DD}$  as defined in the following formula:

$$V_{OQ}(V_{DD}) = \frac{V_{DD}}{2} \quad (2)$$

The sensitivity  $S$  is ratiometric to  $V_{DD}$  and is expressed as follows:

$$S(V_{DD}) = S_x \times \frac{V_{DD}}{V_{DD\_nom}} \quad (3)$$

5.4.2 Typical characteristics

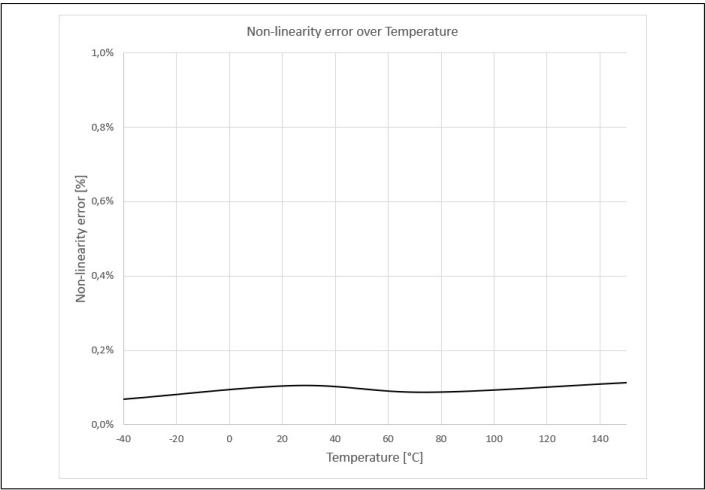


Figure 5 Non-linearity error vs temperature

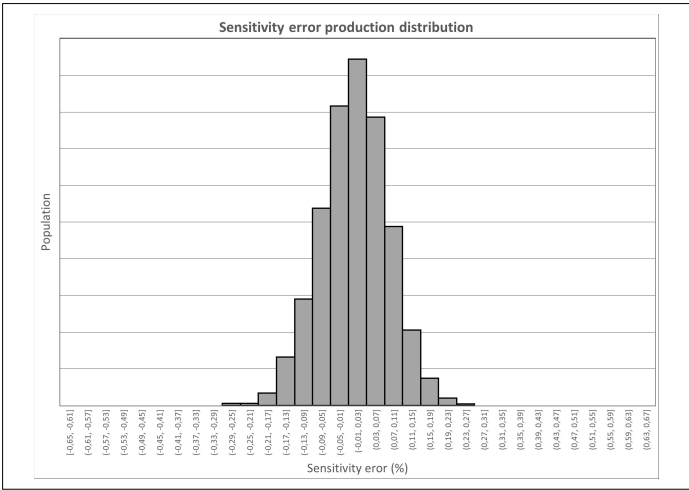


Figure 6 Sensitivity error vs population

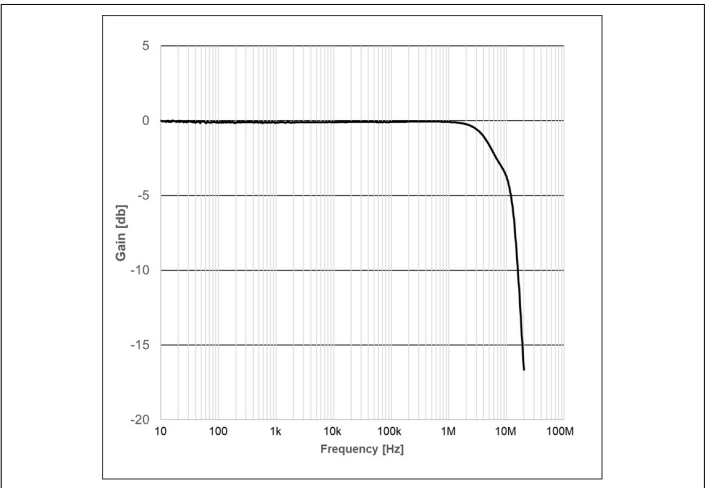


Figure 7 Gain vs frequency

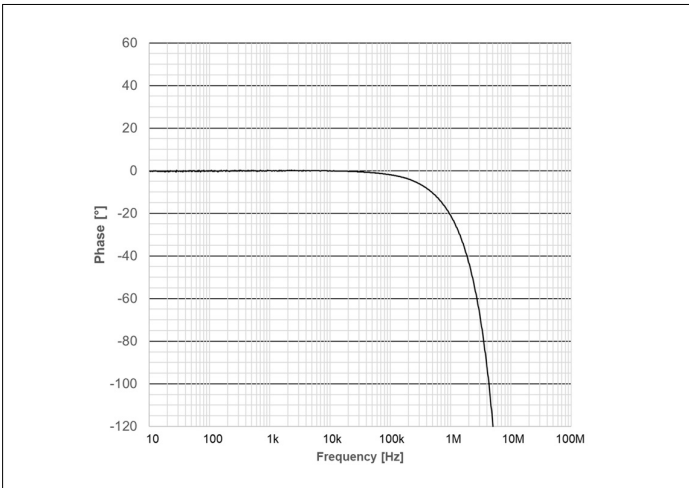


Figure 8 Phase delay vs frequency

### 5.4.3 Thermal performance

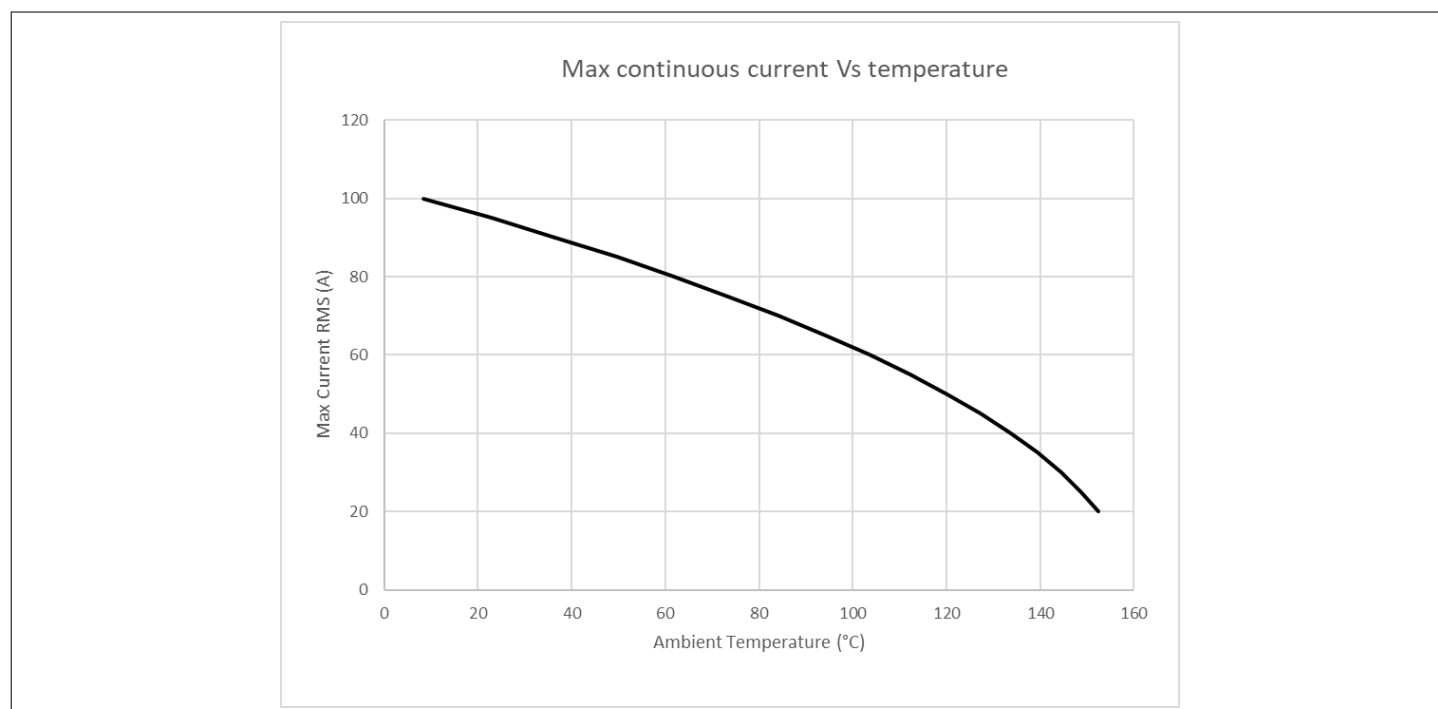
When designing a current sensing module, it is crucial to consider the self-heating effect caused by the flow of current. This phenomenon occurs in various components of the system, including the sensor, printed circuit board (PCB), and contacts to the PCB, as current flows through them.

The thermal response of the system is highly dependent on several factors, including the PCB layout, copper thickness, cooling techniques employed, number of vias and the profile of the injected current. The current profile encompasses several key parameters, such as peak current, current "on-time", and duty cycle. Although the data presented in this section was collected using direct current (DC), it can be used to approximate the thermal response for both alternating current (AC) signals and current pulses.

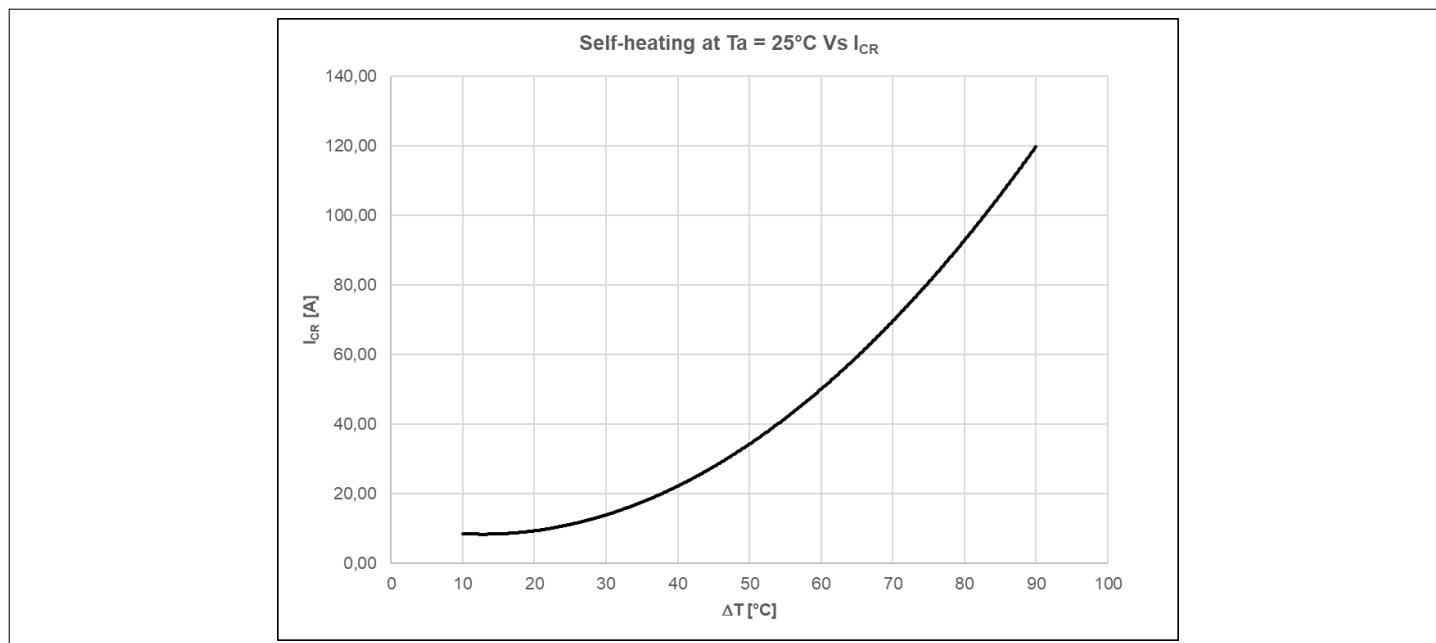
To ensure accurate and reliable current sensing, it is essential to carefully consider these factors during the design phase. This includes optimizing the PCB layout, selecting appropriate copper thickness, and implementing effective cooling techniques to minimize the thermal response. By doing so, designers can create a current sensing system that provides accurate and reliable measurements while minimizing the risk of overheating.

The below figure illustrates the target maximum continuous current-handling capability of the device when mounted on the Infineon reference board. The PCB consists of top & bottom layers with 70  $\mu\text{m}$  copper thickness and two inner layers with 140  $\mu\text{m}$  copper thickness. For more information please refer to the device user manual. It is essential to understand that the current capability decreases at higher ambient temperatures due to the reduced thermal transfer from junction-to-ambient and increased power dissipation in the lead frame.

The plot serves as a guideline for continuous current operation, but it does not imply that the system is incapable of handling current surges or peaks above the maximum current listed. In fact, surges beyond the maximum current are permissible, as long as the maximum junction temperature  $T_{J\_MAX}$  of 165°C is not exceeded. This is a critical consideration, as it allows for temporary current spikes without compromising the device's overall performance and reliability.



**Figure 9** Maximum continuous RMS current vs ambient temperature



**Figure 10** Maximum continuous RMS current vs self heating

#### 5.4.3.1 Safe operating area (SOA)

Current applied to the IP+ and IP- pins of the sensor in the PG-DSO-16 package generates heat. If sufficient energy is applied, the copper lead may melt and open the circuit. Depending on the use case, the safe operating area (SOA) is governed by multiple conditions, including exceeding the maximum junction temperature, Joule heating in the lead frame, or lead frame fusing under extremely high currents. These mechanisms depend on pulse duration, amplitude, and device thermal states. It is important to note that the maximum junction temperature ( $T_{J\_MAX}$ ) is 165°C, and exceeding this threshold for extended periods can potentially damage the die, leading to changes in product performance or creating long-term reliability risks. Additionally, the PG-DSO-16 package includes an insulation barrier to support high working voltages. Prolonged heating can cause deterioration of the insulation material, reducing the package's insulation effectiveness. Also, other absolute maximum rating levels in Table 3 need to be complied with, as excessive voltage/current conditions lead to performance degradation. AOUT pin must not be actively driven.

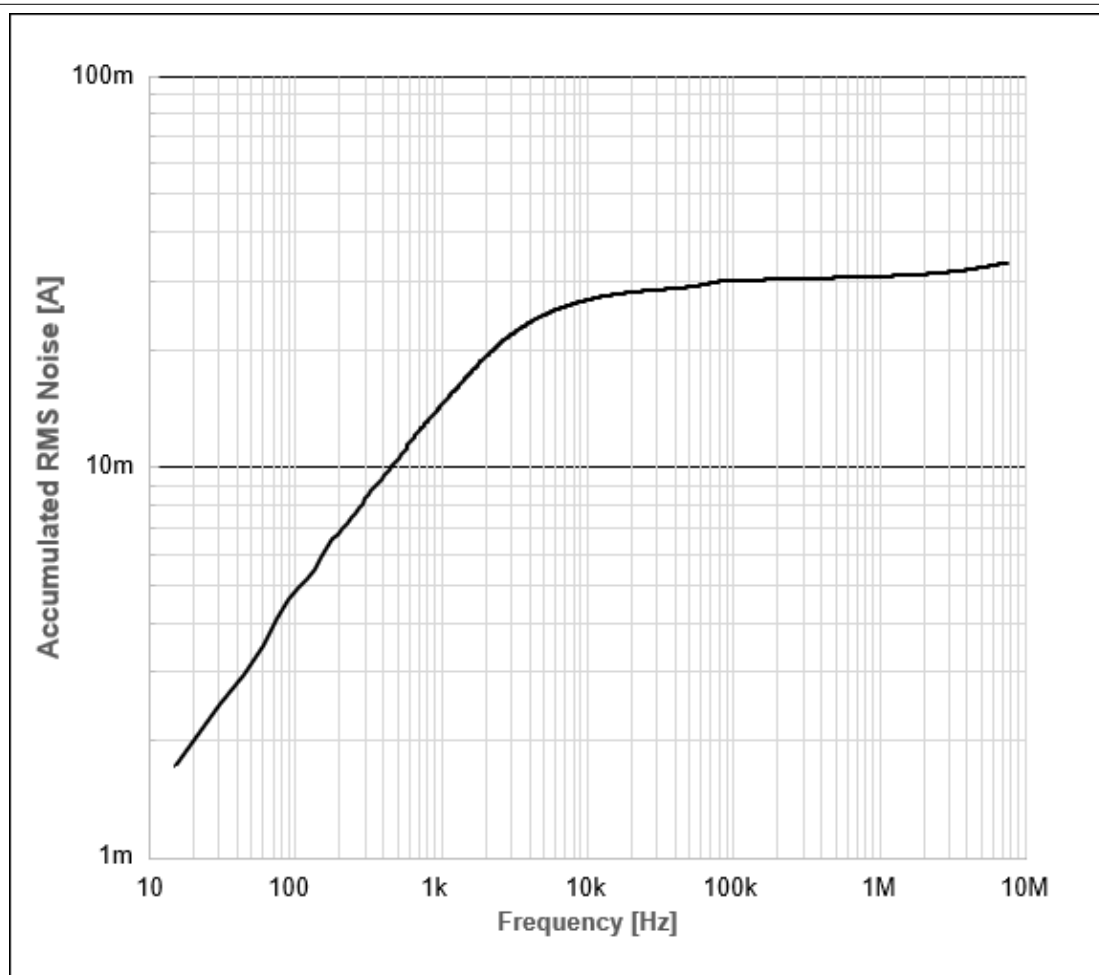
Any continuous DC or sinusoidal AC periodic waveform with a frequency higher than 1 Hz can be evaluated based on the RMS continuous-current levels. The continuous-current capability is significantly influenced by the expected operating ambient temperature range. At higher ambient temperatures, the current capability diminishes due to reduced thermal transfer from junction to ambient and increased power dissipation in the lead frame. Through improved thermal design of an application, the safe operating area (SOA) can be extended to accommodate higher currents at elevated temperatures. Strategies such as using larger and heavier copper power planes, providing airflow over the board, or adding heat sinking structures to the device area can enhance thermal performance.

#### 5.4.4 Noise performance

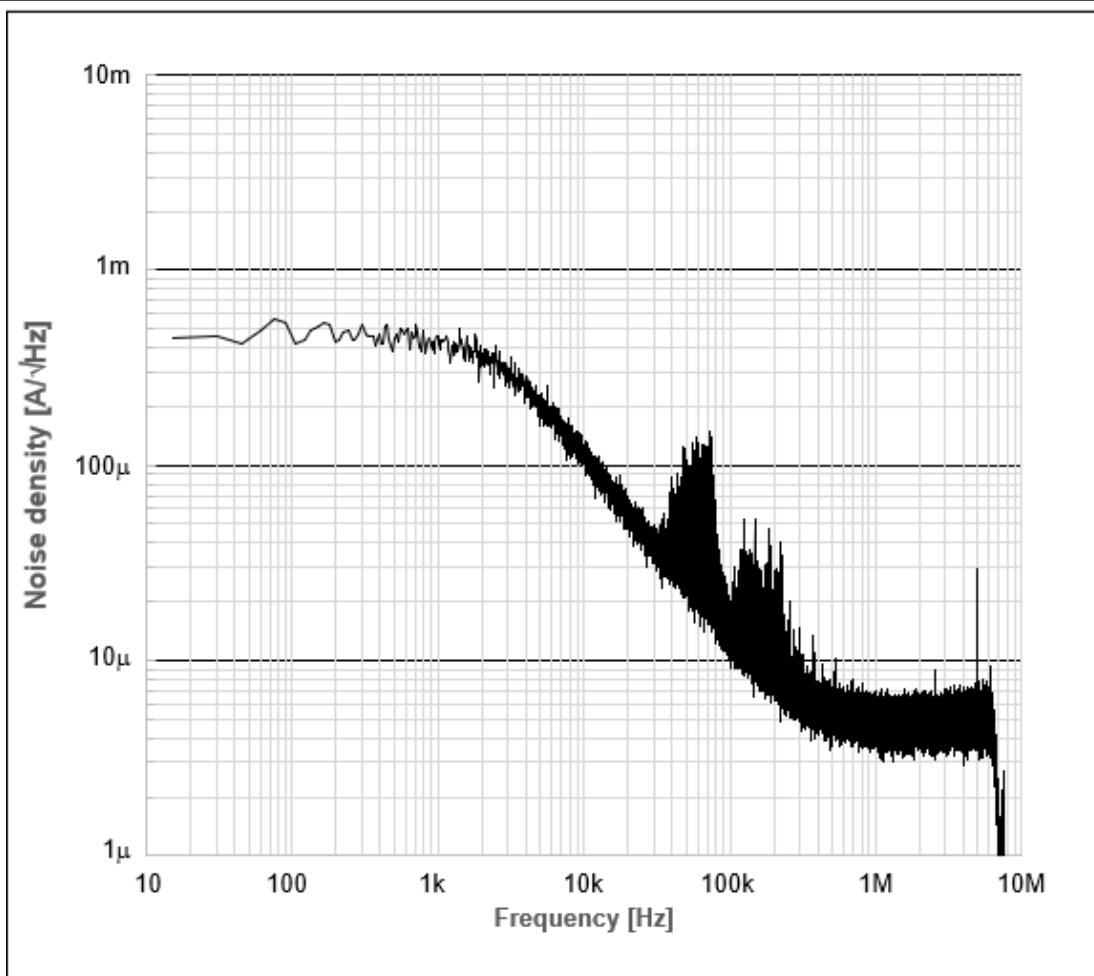
In many state-of-the-art current sensors, output noise increases as the usable bandwidth is extended. Designers desire higher bandwidth to achieve low, stable phase delay and fast response. This typically comes at the penalty of increasing analog output noise, forcing a trade-off between accuracy and speed of the current sensing. The TLE4978 is superior in this context, by employing a hybrid Hall and coil architecture which delivers both low noise and high bandwidth. By leveraging the coil's stronger high frequency signal, the device maintains a low output noise level, even as bandwidth increases, supporting stable phase behavior and fast transient response without compromising precision.

A typical noise performance of the TLE4978 graph is shown in the next plots. The first plot shows the typical accumulated noise over frequency. Thanks to the hybrid Hall + coil architecture and to proprietary solutions, the total

accumulated noise is only 35 mArms over a 9 MHz bandwidth, representing less than 0.06% of the TLE4978 measurement range. From both plots, it can be observed that starting from a few kHz, the noise density reduces as the frequency increases so that the accumulated noise is practically constant after 10 kHz. This means that, unlike in other current sensors, the rms noise at TLE4978 output does not significantly increase with increasing bandwidth (above 10 kHz), thus enabling extremely fast response without jeopardizing accuracy and signal to noise ratio.



**Figure 11** Input referred accumulated noise vs frequency



**Figure 12** Noise density vs frequency

### 5.4.5 High precision signal chain and stability over temperature

The current sensor integrates a high precision, end-to-end signal path providing a voltage output that is proportional to the current conducted through the lead-frame of the isolated input. The low-drift measurement signal path is equipped with advanced circuit techniques to deliver highly accurate and stable current sensing across the whole specified operating temperature range and throughout the entire device's service life. Each unit is rigorously tested and pre-calibrated to compensate for variations arising from silicon processing, assembly, and packaging.

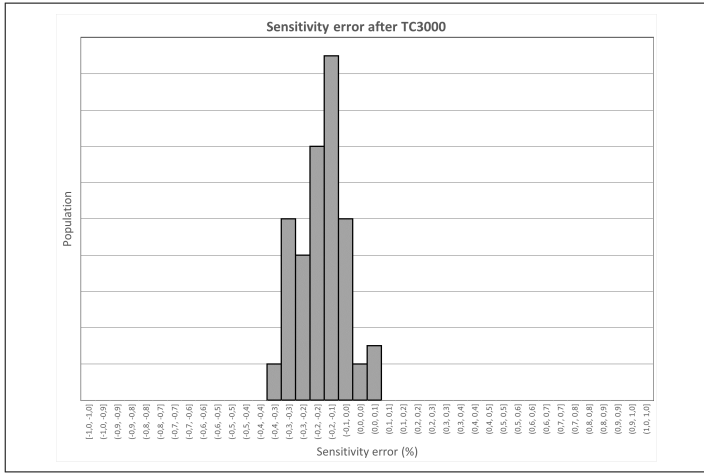
The device implements a digitally assisted temperature-compensation scheme that greatly reduces parametric drift over the specified operating temperature range. This compensation addresses variations due to ambient temperature changes, device self-heating, and package-induced mechanical stress. In combination with a zero-drift signal-chain architecture and Hall sensor temperature-compensation methods, the device maintains a stable sensitivity while minimizing offset errors across temperature. As a result, the system-level performance is improved under the required operating conditions.

### 5.4.6 Lifetime and environmental stability

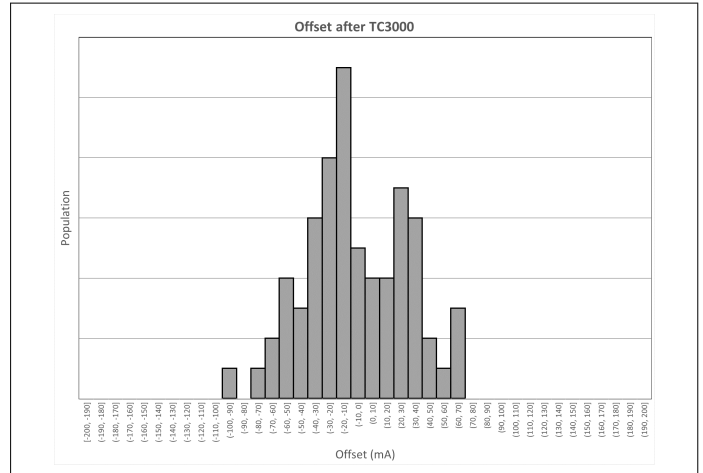
Typically, magnetic current sensors experience a 2% to 3% sensitivity drift over life in addition to thermal drift, driven by aging, mechanical stress, and environmental effects. The TLE4978 implements proprietary compensation techniques to mitigate these effects, yielding robust lifetime performance under harsh conditions. Electrical characteristics confirm best-in-class lifetime offset and sensitivity drift following life-acceleration stresses including UHAST, THB, HTOL, HTSL and temperature cycling within the standardized three-lot AEC-Q100 grade 0 qualification.

Performance has been measured before and after the exposure to AEC-Q100 defined stresses for grade 0 and beyond, over the defined operating temperature range, always showing statistical distributions inside the limits indicated in the sensing characteristics table. These data indicate outstanding robustness of the accuracy parameters over

lifetime and a substantial advantage in long-term stability and reliability relative to competition. As an example, figures below show the total sensitivity error and the total offset distributions after a 3000 temperature cycles test.



**Figure 13** Population vs sensitivity error



**Figure 14** Population vs offset

### 5.4.7 Measurable linear analog output voltage range

The sensor linear input current measurement ranges listed in the respective [Table 8](#) are determined by the zero current output voltage ( $V_{OQ}$ ), device sensitivity ( $S$ ), and supply voltage ( $V_{DD}$ ). The maximum linear output voltage  $V(AOUT)_{max}$  is limited to  $V_{CLH}$  less than the supply voltage, as shown in the equation below. Similarly, the minimum linear output voltage  $V(AOUT)_{min}$  is limited to  $V_{CLL}$  above ground, as shown in the equation below:

$$\begin{aligned} V(AOUT)_{max} &= V_{DD} - V_{CLH} \\ V(AOUT)_{min} &= V_{CLL} \end{aligned} \quad (4)$$

The overall maximum dynamic range can indeed be optimized by referring to the minimum and maximum linear output voltage swing in relation to the minimum and maximum linear input current range. This can be achieved by dividing the output voltage by the sensitivity,  $S$ .

$$\begin{aligned} I_{FS,max} &= \frac{V(AOUT)_{max} - V_{OQ}}{S} \\ I_{FS,min} &= \frac{V(AOUT)_{min} - V_{OQ}}{S} \end{aligned} \quad (5)$$

where

- $I_{FS,max}$  is the maximum linear measurable positive input current.
- $I_{FS,min}$  is the minimum linear measurable negative input current.
- $S$  is the sensitivity of the device variant.
- $V_{OQ}$  is the zero current output voltage

### 5.4.8 Nonlinearity error (NL)

Nonlinearity is the deviation of the output voltage from a linear relationship to the input current. Nonlinearity error is reported in terms of %FS in [Table 8](#).

## 5.4.9 Ratiometricity error

Ratiometricity implies that the quiescent voltage and sensitivity are directly proportional to the supply voltage. Therefore, in an ideal condition, if the supply voltage fluctuates, the output voltage varies proportionally thus avoiding system level errors when the sensor output is read by a ratiometric ADC. Due to non-idealities however there is a ratiometricity error present, which represents the relative deviation from the proportional output voltage with respect to the change in supply voltage.

### 5.4.9.1 Sensitivity ratiometricity error (E<sub>SENS\_RAT</sub>)

Ideally, a 1% increase in  $V_{CC}$  results in a 1% increase in sensitivity. However, the ratiometric response of any sensor is not ideal. Ratiometric sensitivity error  $E_{SENS\_RAT}$  is calculated as follows:

$$E_{SENS\_RAT} = \left( \frac{S_{Meas}}{S} \times \frac{V_{DD(NOM)}}{V_{DD(Meas)}} - 1 \right) \times 100 \quad (6)$$

Where,  $S_{Meas}$  is the measured sensitivity at the measured  $V_{DD}$  supply in an application and  $S$  is the sensitivity at the nominal  $V_{DD}$  supply. The sensitivity ratiometricity error ( $E_{SENS\_RAT}$ ) is defined in percentage in the respective [Table 8](#).

### 5.4.9.2 Offset ratiometricity error (E<sub>OFF\_RAT</sub>)

Ideally, a 1% increase in  $V_{DD}$  results in a 1% increase in quiescent voltage. However, the ratiometric response of any sensor is not ideal. Offset ratiometricity error  $E_{OFF\_RAT}$  accounts for such error and is calculated as follows:

$$V_{DDVAR\%} = \frac{V_{DD} - V_{DD\_NOM}}{V_{DD\_NOM}} \times 100$$

$$E_{OFF\_RAT} = \frac{V_{OQ}(V_{DD}) - (V_{DD}/2)}{S(V_{DD}) \times V_{DDVAR\%}} \quad (7)$$

Where,  $V_{OQ}(V_{DD})$  is the measured quiescent voltage at the measured supply in an application. The Offset Ratiometricity Error ( $E_{OFF\_RAT}$ ) is expressed in mA/% $V_{DD}$  in the respective [Table 8](#). In order to find the max offset error due to ratiometricity the value has to be multiplied by the  $V_{DD}$  variation expressed in %.

## 5.4.10 Sensitivity and offset error calculation

### 5.4.10.1 Total offset error

The offset error is a key performance parameter that characterizes the deviation from the ideal output with zero input current. To ensure high precision and accuracy, the offset of the current sensor is tested and calibrated during Infineon production. The offset drift over temperature, which refers to the change in the offset as a function of temperature, and lifetime is reported in milliamperes (mA). To determine the total offset error at a given condition, the initial offset error ( $E_{OFF}$ ) must be added to the offset drift over temperature and lifetime ( $E_{OFF\_LV}$ ) and then quadratically added to offset ratiometricity error ( $E_{OFF\_RAT}$ ) as shown in the below equation.

$$\begin{aligned}
 E_{OFF}(\%) &= \frac{E_{OFF}}{I_{FS}} \times 100 \\
 E_{OFF\_RAT}(\%) &= \frac{E_{OFF\_RAT} \times VDD_{VAR\%}}{I_{FS}} \times 100 \\
 E_{OFF\_LV}(\%) &= \frac{E_{OFF\_LV}}{I_{FS}} \times 100 \\
 E_{Total\_OFF}(\%) &= \sqrt{(|E_{OFF}(\%)| + |E_{OFF\_LV}(\%)|)^2 + |E_{OFF\_RAT}(\%)|^2}
 \end{aligned} \tag{8}$$

note that the offset ratiometricity error contribution depends on the percent variation of the VDD that is possible in the application.

#### 5.4.10.2 Total sensitivity error

Sensitivity is the proportional change in the sensor output voltage due to a change in the input conductor current. The current sensor is designed to deliver high precision and accuracy, and it undergoes rigorous sensitivity testing and calibration procedures to ensure optimal performance. Total sensitivity error is the sum of the Initial sensitivity error ( $E_{SENS}$ ), and Sensitivity drift over temperature and lifetime ( $E_{SENSL}$ ), quadratically added to the sensitivity ratiometricity error ( $E_{SENS\_RAT}$ ). Refer the respective [Table 8](#).

Note that since  $E_{SENS\_RAT}$  is reported in the sensing characteristics table as the maximum error at 10% variation of the  $V_{DD}$ , the actual possible  $V_{DD}$  variation in the system must be considered in the total error calculation.

$$\begin{aligned}
 E_{SENS\_RAT} &= E_{SENS\_RAT(MAX)} \times \frac{VDD_{VAR\%}}{10} \\
 E_{Total\_SENS}(\%) &= \sqrt{(E_{SENS} + E_{SENSL})^2 + E_{SENS\_RAT}^2}
 \end{aligned} \tag{9}$$

#### 5.4.11 Common-mode transient immunity or slew rate (dV/dt)

Common mode transient immunity (CMTI) is a critical performance parameter that characterizes a device's ability to withstand rising or falling voltage steps on the input without disrupting its output signal. Specifically, the device is designed to operate within a maximum common-mode transition rate that ensures the output signal is not impacted by disturbance. It is worth noting that higher edge rates than the specified CMTI can be supported using appropriate filtering or blanking time after common-mode transitions. This parameter is particularly critical for a wide band gap applications, especially those that operate at higher switching frequencies and voltage levels, which can induce higher leakage current through the input to output capacitance, unless a proper shielding is in place. By ensuring that the device meets the specified CMTI requirements, we can minimize the risk of voltage disturbances and ensure consistent and reliable performance, even in challenging environments.

#### 5.4.12 Stray field error (E<sub>Stray</sub>)

The current sensor operates on the basis of sensing the magnetic field created by the current flowing through the package. The sensor is able to differentiate between the field created by the current we want to measure and the back ground field, thanks to the differential measurement principle that cancels the external stray field effect. However, an unavoidable small mismatch in the 2 sensing elements make the cancellation not perfect. This can lead to errors in the sensor output caused by external magnetic fields. Fortunately, the sensor is equipped with stray field-rejection capabilities that effectively suppress the interference from external magnetic fields generated by adjacent high-current carrying conductors, nearby motors, magnets, or any other sources of stray magnetic fields. By carefully considering and controlling these factors, we can ensure that the sensor delivers reliable and precise measurements, even in the presence of external magnetic fields. This is particularly important for applications that require high levels of accuracy and precision, where even small errors can have significant consequences. To calculate the percentage

error contribution from stray external magnetic fields ( $B_{Ext}$ ) and stray field error ( $E_{Stray}$ ) from Table 8, use the following equation, where the  $I_{in}$  is the current currently running through the current rail of the sensor in mA:

$$E_{Stray\_Error}(\%) = \frac{B_{Ext} \times E_{Stray}}{I_{in}} \times 100 \quad (10)$$

### 5.4.13 Total error calculation

In order to accurately calculate the total expected error of a device, it is imperative to comprehend the contributions made by each individual component listed in the above sections with respect to its operating conditions. In order to account for statistically uncorrelated error sources, a root sum square (RSS) error calculation must be employed. This calculation enables the total error to be determined with precision. For the TLE4978 device, only the offset error ( $E_{OFF}$ ) in mA and stray field error ( $E_{Stray}$ ) are statistically correlated. As such, these error terms must be combined using an RSS calculation to reflect their nature.

The equation below illustrates the calculation for room temperature ( $E_{TOT\_RT}$ ):

$$E_{TOT\_RT}(\%) = \sqrt{(|E_{OFF}(\%)|)^2 + (|E_{OFF\_RAT}(\%)|)^2 + (|E_{Stray\_error}|)^2 + (|E_{SENS\_RAT}|)^2 + (|E_{SENS}|)^2 + (|E_{NLI}|)^2} \quad (11)$$

The equation below illustrates the total error calculation over temperature ( $E_{TOT\_T}$ ) with initial sensitivity and offset error:

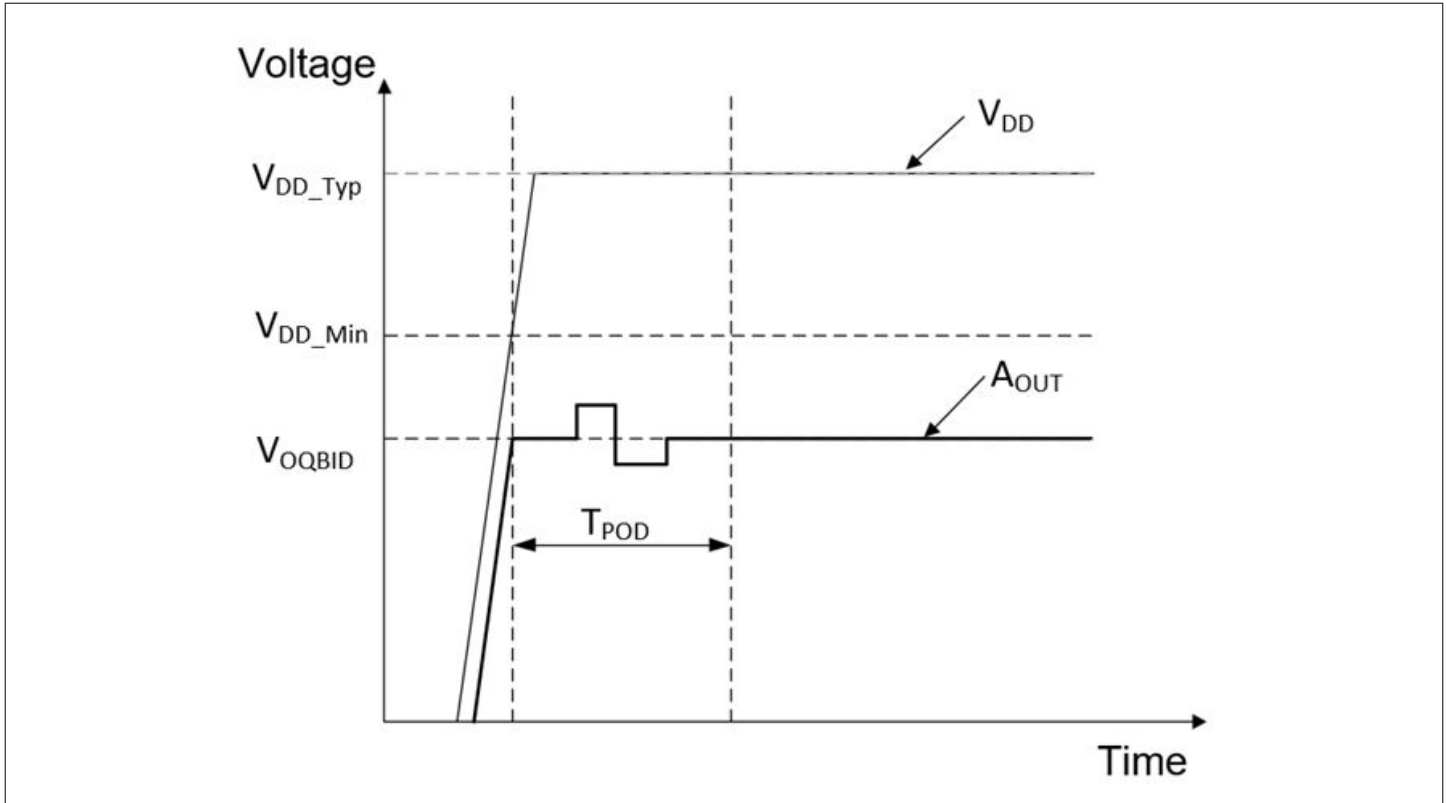
$$E_{TOT\_T}(\%) = \sqrt{(|E_{OFF}(\%)| + |E_{OFF\_T}(\%)|)^2 + (|E_{OFF\_RAT}(\%)|)^2 + (|E_{SENS\_RAT}|)^2 + (|E_{Stray\_error}|)^2 + (|E_{SENS}| + |E_{SENS\_T}|)^2 + (|E_{NLI}|)^2} \quad (12)$$

The equation below illustrates the total error calculation over temperature and lifetime ( $E_{TOT\_LT}$ ) with initial sensitivity and offset error:

$$E_{TOT\_LT}(\%) = \sqrt{(|E_{OFF}(\%)| + |E_{OFF\_LV}(\%)|)^2 + (|E_{OFF\_RAT}(\%)|)^2 + (|E_{SENS\_RAT}|)^2 + (|E_{Stray\_error}|)^2 + (|E_{SENS}| + |E_{SENS\_LT}|)^2 + (|E_{NLI}|)^2} \quad (13)$$

### 5.4.14 Power supply recommendations

The sensor relies on a low-voltage power supply connected to VDD pin to operate the analog circuitry independently from the isolated primary current input. The analog output ( $A_{OUT}$ ) realizes its full-scale output range based on the voltage supplied to VDD pin. To mitigate noise in the power-supply path, a decoupling capacitor with low equivalent series resistance (ESR) must be placed between the VDD and GND pins, in close proximity to the supply and ground pins of the device. In situations where the power supply is noisy or has high-impedance, additional decoupling capacitance may be necessary.  $V_{DD}$  can be separately sequenced from primary current that flows through the input.



**Figure 15 Power ON delay behavior**

The graph above demonstrates the correlation between the behavior of the  $A_{OUT}$  signal and the  $V_{DD}$  supply voltage as it varies. As  $V_{DD}$  ramps up and surpasses the  $V_{DD\_Min}$  threshold, the  $A_{OUT}$  pin transitions to and stabilizes at the  $V_{OQBID}$  level. During the power-on delay period ( $t_{POD}$ ), the  $A_{OUT}$  signal initially oscillates before settling at  $V_{OQBID}$ . Upon the completion of  $t_{POD}$ , the  $A_{OUT}$  pin transitions into normal operating mode.

#### 5.4.15 OCD - Over current detection

The device provides an Over Current Detection (OCD) output on the OCD pin in case of an over-current event. Over-current condition is present when the input current absolute value (positive or negative) is higher than the chosen threshold level.

##### 5.4.15.1 OCD output timing behavior

OCD output features a deglitch filter with deglitching delay time in order to avoid false OCD triggers due to noise spikes on the current rail. However, the default deglitch filter time  $t_{DEGLITCH}$  in most product variants is zero. It is possible to vary this value using DCDI programming. Below the formula for the calculation of  $t_{DEGLITCH}$  can be found:

$$t_{DEGLITCH} = 300 \text{ ns} \times eep\_ocd\_deglitch[2:0] \quad (14)$$

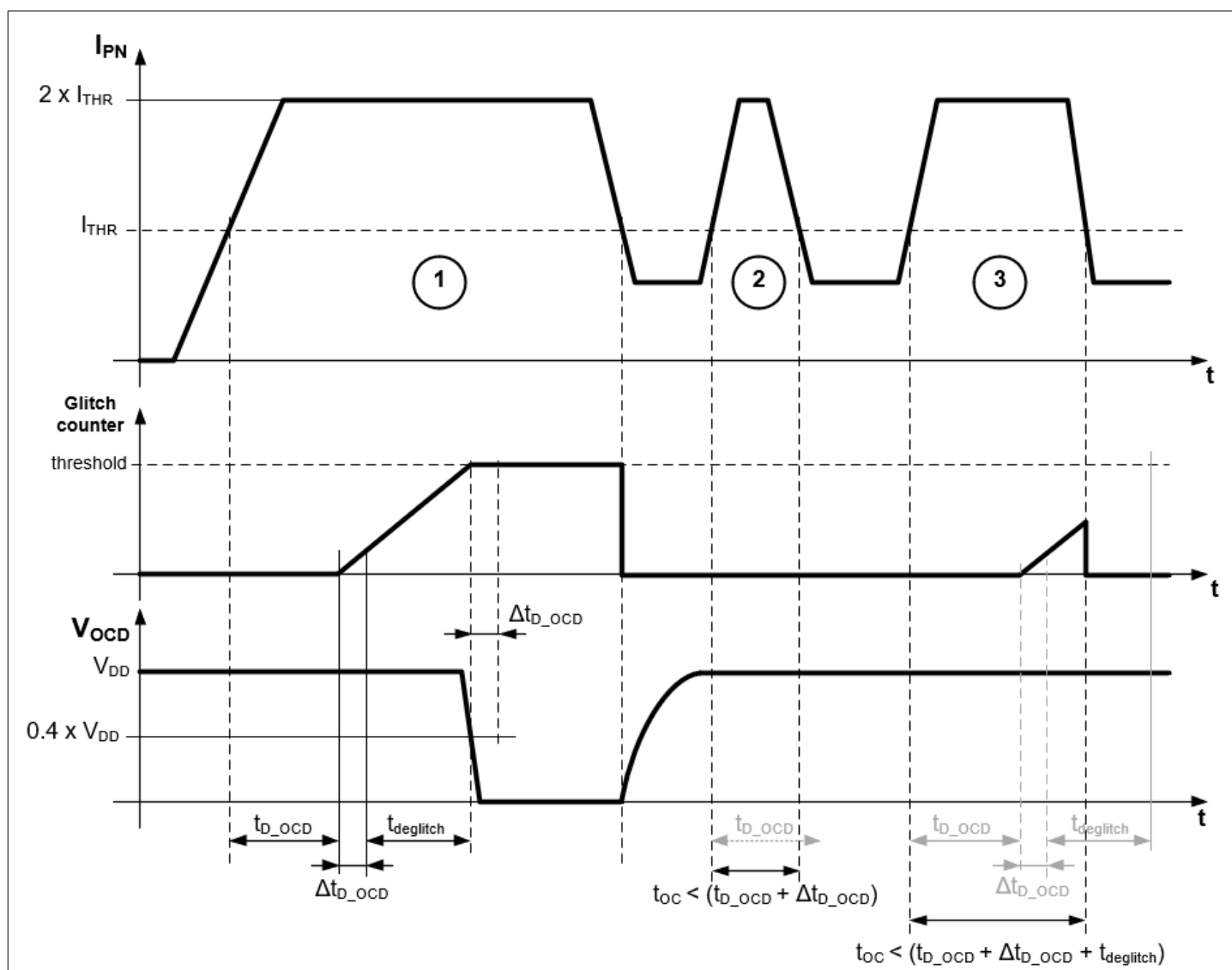
When the OCD deglitching time is different from 0, the OCD output will only be activated when the over-current condition is present for a time interval longer than the deglitching delay time. Refer to the device User Manual for more information on OCD deglitch setup.

Deglitching delay associated with OCD output is reset as soon as the over-current condition is removed.

Figure below shows the OCD output pin nominal behavior during an overcurrent event and defines important timing quantities for which the limits are listed in the parameters [Table 9](#).

Overcurrent pulse (1) is an overcurrent event, where the duration of the overcurrent condition exceeds the overcurrent response time ( $t_{D\_OCD}$ ) + response time jitter ( $\Delta t_{D\_OCD}$ ) + deglitch filter time ( $t_{DEGLITCH}$ ). Overcurrent conditions (2) and (3) are not long enough to trigger the OCD output. Pulse (2) is shorter than the overcurrent response time ( $t_{D\_OCD}$ ) and therefore no OCD event is generated. In overcurrent condition (3), the overcurrent

condition is longer than the response time ( $t_{D\_OCD}$ ) + response time jitter ( $\Delta t_{D\_OCD}$ ), but is not exceeding the glitch filter time ( $t_{DEGLITCH}$ ) and no OCD event is generated.



**Figure 16** OCD output timing behavior

### 5.4.15.2 OCD pins external connection

The OCD pin operates as active low, open-drain output. This allows easy setup of a wired-AND configuration enabling the monitoring of several current sensors outputs via only one microcontroller pin. The OCD pins can be connected to a logic input pin of the microcontroller and/or the gate-driver, to quickly react to over current events.

### 5.4.15.3 OCD thresholds

The OCD threshold is determined at startup. If the DCDI interface is activated at start-up, the OCD threshold is set to the value corresponding to the related EEPROM setting, which by default is the highest threshold.

Otherwise, it is set to the value corresponding to the voltage at the OCD\_THR pin. Refer to the device user manual for more information on OCD threshold setup.

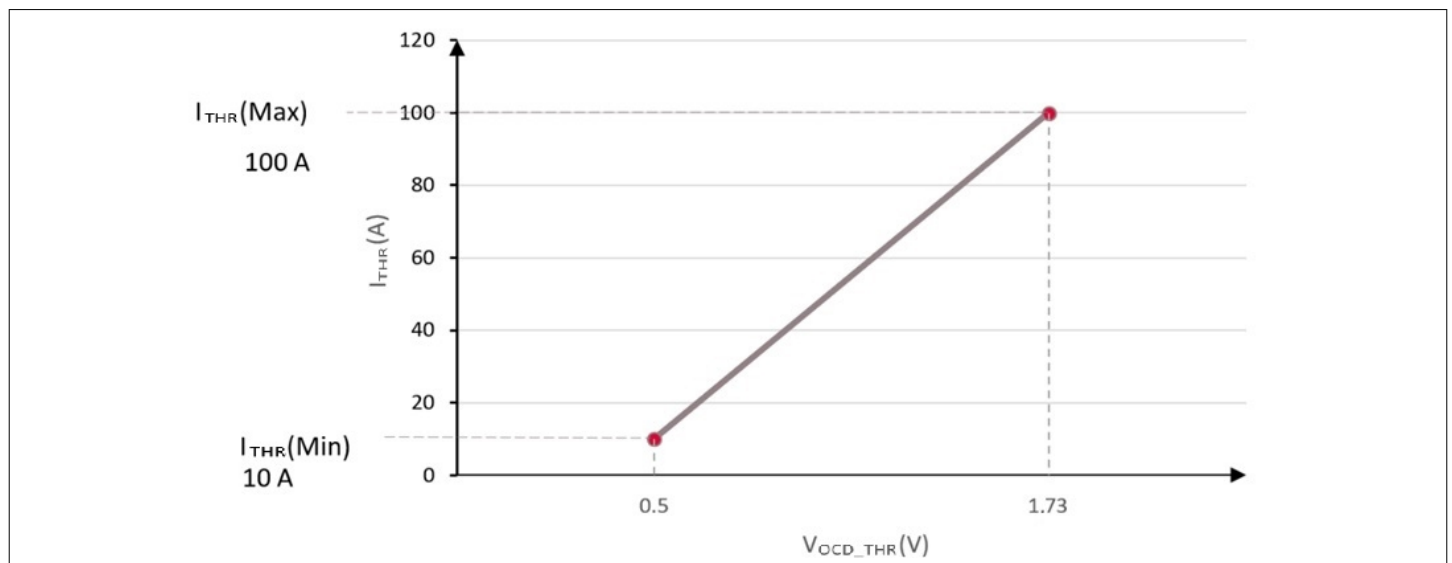
If the OCD threshold is set by the DCDI interface the following formula applies:

$$eep\_oed\_thrsh[7:0] = I_{THR}(A) \times 1.755 \quad (15)$$

If it is set by the voltage on the OCD\_THR pin then, the voltage input from 0.5 V to 1.73 V corresponds to currents from 10 A to 100 A in a linear relationship.

Given the desired threshold in current ( $I_{THR}$ ) in A, the corresponding input voltage in V to be applied ( $V_{OCD\_THR}$ ) can be found with the following formula:

$$V_{OCD\_THR}(V) = \frac{150}{11000} \times I_{THR}(A) + \frac{4000}{11000} \quad (16)$$



**Figure 17** Threshold voltage ( $V_{OCD\_THR}$ ) vs threshold current ( $I_{THR}$ )

#### 5.4.15.4 Over current detection characteristics

**Note:** General conditions (unless otherwise specified):  $V_{DD} = 5.0$  V;  $T_S = -40^\circ\text{C} \dots +150^\circ\text{C}$ ,  $C_L = 1$  nF;  $R_{PU} = 4.7$  k $\Omega$

**Table 9** Over current detection characteristics

| Parameter              | Symbol         | Values |      |      | Unit          | Note or condition                                                                                                                  |
|------------------------|----------------|--------|------|------|---------------|------------------------------------------------------------------------------------------------------------------------------------|
|                        |                | Min.   | Typ. | Max. |               |                                                                                                                                    |
| OCD response time      | $t_{D\_OCD}$   | –      | 0.1  | 0.2  | $\mu\text{s}$ | Time from input current $> I_{THR}$ to when OCD pin is pulled below $V_{OCD\_LOW}$ input current step from 0 to $2 \times I_{THR}$ |
| OCD fall time          | $t_{F\_OCD}$   | –      | –    | 100  | ns            | From 90% to 10% VDD. Load capacitance $C_L = 470$ pF                                                                               |
| OCD output low voltage | $V_{OCD\_LOW}$ | –      | –    | 0.4  | V             | –                                                                                                                                  |

(table continues...)

**Table 9** (continued) Over current detection characteristics

| Parameter                   | Symbol              | Values |      |      | Unit | Note or condition                                                                                                                                                                                                                                                                                                                             |
|-----------------------------|---------------------|--------|------|------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                             |                     | Min.   | Typ. | Max. |      |                                                                                                                                                                                                                                                                                                                                               |
| OCD hysteresis current      | $I_{HYST}$          | –      | 25   | –    | %    | Percentage of actual OCD threshold value. After input current goes above $I_{THR}$ , tripping the internal comparator, input current must fall below $I_{THR} - I_{HYST}$ , before the internal comparator resets. Parameter can be programmed. Check the user manual of the device for more details on options and how to set the parameter. |
| OCD_THR input voltage range | $V_{OCD\_THR}$      | 0.5    | –    | 1.73 | V    | –                                                                                                                                                                                                                                                                                                                                             |
| OCD_THR input current       | $I_{VOCD}$          | –      | 10   | 100  | nA   | –                                                                                                                                                                                                                                                                                                                                             |
| Threshold level range       | $I_{THR}$           | 10     | –    | 100  | A    | Parameter can be set by the value corresponding to the voltage at the OCD_THR pin or programmed. Check the user manual of the device for more details on options and how to set the parameter.                                                                                                                                                |
| Threshold level resolution  | $I_{THT}$           | –      | 0.56 | –    | A    | –                                                                                                                                                                                                                                                                                                                                             |
| Threshold level tolerance   | $OCD_{THR\_LVL}$    | –      | ±5   | –    | %    | Minimum and maximum depends on the externally connected resistor selection                                                                                                                                                                                                                                                                    |
| OCD response time jitter    | $\Delta t_{D\_OCD}$ | –      | –    | 0.1  | µs   | At 3 $\sigma$ , $I_{rail} = 2 \times I_{THR}$ , input rise time 0.1 µs                                                                                                                                                                                                                                                                        |
| OCD load capacitance        | $C_L$               | –      | 470  | –    | pF   | –                                                                                                                                                                                                                                                                                                                                             |
| Pull-up resistor            | $R_{PU}$            | 1      | –    | 10   | kΩ   | Connected to $V_{DD}$                                                                                                                                                                                                                                                                                                                         |

#### 5.4.16 ZCD - Zero crossing detection

The device provides a Zero Crossing Detection (ZCD) push-pull output on ZCD pin in case of zero crossing event. ZCD output pin shall toggle between logic value 0 and 1 every time the input current crosses 0.

The ZCD threshold ( $I_{THR\_ZCD}$ ) is by default 0A but can set between -10 A and 10 A by the DCDI interface according to the following equation:

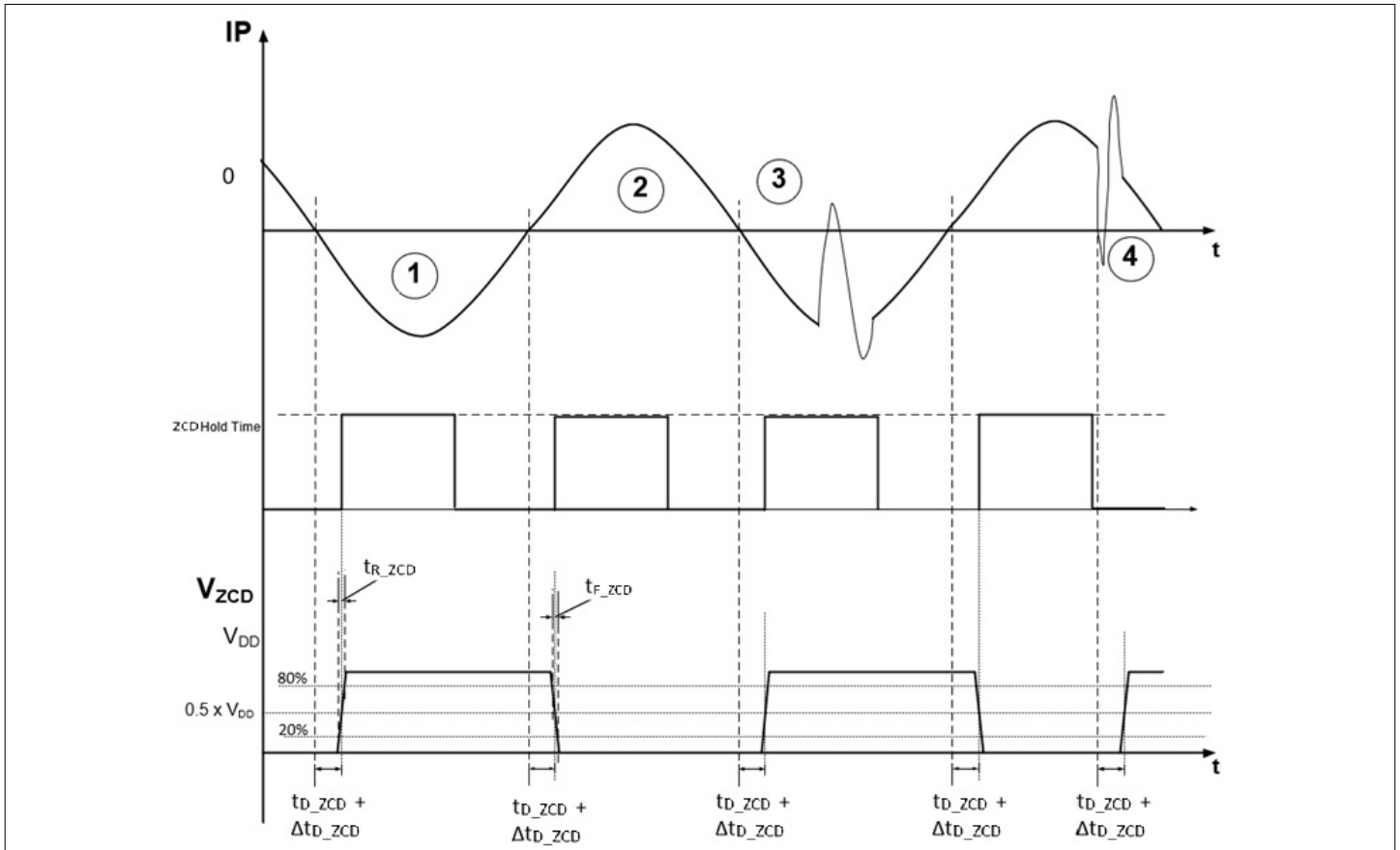
$$eep\_zcd\_thrsh\left[7:0\right] = 127 - \frac{86 \times I_{THR\_ZCD}(A)}{10} \quad (17)$$

With this the ZCD can be anticipated or delayed with respect to positive or negative threshold setting. Refer to the user manual for additional information and options for ZCD programming.

### 5.4.16.1 ZCD output timing behavior

Figure below shows the ZCD output pin nominal behavior during operation with a zero current event and defines important timing quantities.

Cases 1 and 2 show the regular ZCD functionality in absence of disturbance: the ZCD output toggles each time the current crosses 0A. In case 3, there is no ZCD event generated after the fundamental signal zero crossing instant even if there are zero crossings due to the spike as the hold time in the sensor does not allow to change the state until it expires. In case 4, the ZCD triggers earlier than the actual fundamental signal zero crossing because in this particular case the disturbance occurs after the hold time is expired.



**Figure 18** ZCD output timing diagram

The ZCD indication minimum time ( $t_{ZCD\_High}$ ) is programmable. Once the zero crossing is signaled on the ZCD, the signal is kept active for at least this time:

$$t_{ZCD\_High} = (4 + (4 \times eep\_ZCD\_hold\_time)) \times t_{ZCD\_HOLD\_RES} \quad (18)$$

Refer to the user manual for additional information and options for ZCD programming.

## 5.4.16.2 Zero crossing detection characteristics

**Note:** General conditions (unless otherwise specified):  $V_{DD} = 5.0\text{ V}$ ;  $T_S = -40^\circ\text{C} \dots +150^\circ\text{C}$ ,  $C_L = 100\text{ pF}$

**Table 10** Zero current detection characteristics

| Parameter                | Symbol                               | Values |      |      | Unit | Note or condition                                                                                                                                          |
|--------------------------|--------------------------------------|--------|------|------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                          |                                      | Min.   | Typ. | Max. |      |                                                                                                                                                            |
| ZCD response time        | $t_{D\_ZCD}$                         | –      | 80   | 130  | ns   | At the min. frequency of 50 kHz and amplitude of $50\% \times I_{FS}$ with 100 pF load capacitance. For below 50 kHz, please contact Infineon sales team.  |
| ZCD fall time            | $t_{F\_ZCD}$                         | –      | 35   | –    | ns   | From 80% to 20% $V_{DD}$ . Load capacitance $C_L$ on ZCD output pin = 100 pF                                                                               |
| ZCD rise time            | $t_{R\_ZCD}$                         | –      | 35   | –    | ns   | From 20% to 80% $V_{DD}$ . Load capacitance $C_L$ on ZCD output pin = 100 pF                                                                               |
| ZCD response time jitter | $\Delta t_{D\_ZCD}$                  | –      | –    | 33   | ns   | RMS value at the min. frequency of 50 kHz and amplitude of $50\% \times I_{FS}$ with 100 pF load capacitance. Input signal assumed: triangle signal shape. |
| ZCD threshold            | $I_{THR\_ZCD}$ <sup>1)</sup>         | -10    | 0    | 10   | A    | Programmable in EEPROM. Default value set to 0 A.                                                                                                          |
| ZCD number of steps      | $ZCD_{Res}$                          | –      | 256  | –    | –    | of $I_{THR\_ZCD}$                                                                                                                                          |
| ZCD hold time resolution | $t_{ZCD\_HOLD\_RES}$                 | 95     | 100  | 105  | ns   | –                                                                                                                                                          |
| ZCD hold time setting    | $eep\_ZCD\_hold\_time$ <sup>1)</sup> | 0      | –    | 255  | LSB  | –                                                                                                                                                          |

1) Refer the TLE4978 user manual for ZCD threshold and hold time setup

### 5.4.17 Undervoltage / Overvoltage detection

The device pulls the OCD output low when its own voltage power supply ( $V_{DD}$ ) is in under-voltage condition. Under-voltage condition is present when  $V_{DD}$  is between the values indicated in the  $V_{DD\_OCD}$  parameter. In case of overvoltage condition, the sensor provides supply fault indication by pulling the OCD output low. Over-voltage condition is present if  $V_{DD}$  higher than the over-voltage threshold parameter ( $V_{OV\_RES}$ ).

**Table 11** Undervoltage / Overvoltage characteristics

| Parameter                                       | Symbol            | Values |      |               | Unit    | Note or condition         |
|-------------------------------------------------|-------------------|--------|------|---------------|---------|---------------------------|
|                                                 |                   | Min.   | Typ. | Max.          |         |                           |
| Undervoltage/<br>Overvoltage<br>detection delay | $t_{UVOV\_DELAY}$ | –      | 2.6  | 3.2           | $\mu s$ | –                         |
| Overvoltage<br>reset threshold                  | $V_{OV\_RES}$     | –      | –    | 5.9           | V       | $V_{DD}$ rising           |
| Overvoltage<br>release<br>threshold             | $V_{OV\_REL}$     | 5.5    | –    | –             | V       | $V_{DD}$ falling          |
| Undervoltage<br>reset threshold                 | $V_{UV\_RES}$     | 4.2    | –    | –             | V       | $V_{DD}$ falling          |
| Undervoltage<br>release<br>threshold            | $V_{UV\_REL}$     | –      | –    | 4.5           | V       | $V_{DD}$ rising           |
| Undervoltage<br>condition                       | $V_{DD\_OCD}$     | 1.8    | –    | $V_{UV\_REL}$ | V       | OCD pulled to "low" level |

### 5.4.18 DCDI - Digital control diagnostic interface

The device provides a bus compatible fast one-wire DCDI communication interface operating as input/output.

The DCDI interface is a single-master, multi-slave UART based interface.

The DCDI communication is robust against disturbances caused by 500 kHz switching frequencies.

**Note:** 500 kHz squared input signal. Slew rate max. 150 V/ns, Max Voltage 1.6 kV.

**Table 12 DCDI characteristics**

| Parameter                | Symbol           | Values |           |      | Unit     | Note or condition                                                                                             |
|--------------------------|------------------|--------|-----------|------|----------|---------------------------------------------------------------------------------------------------------------|
|                          |                  | Min.   | Typ.      | Max. |          |                                                                                                               |
| DCDI number of slaves    | $DCDI_{SLV}$     | –      | –         | 8    | –        | The number of slaves to be addressed and served in one system                                                 |
| DCDI bus voltage         | $DCDI_{VBUS}$    | –      | $V_{DD5}$ | –    | V        | The voltage level for the pull up resistor has the same specification as the sensor supply voltage $V_{DD}$ . |
| DCDI low voltage level   | $V_{DCDI\_LOW}$  | –      | –         | 1    | V        | Low state, transition from high to low                                                                        |
| DCDI high voltage level  | $V_{DCDI\_HIGH}$ | 1.6    | –         | –    | V        | High state, transition from low to high                                                                       |
| DCDI pull-up resistor    | $R_{DCDI\_PU}$   | 433    | –         | 1320 | $\Omega$ | –                                                                                                             |
| DCDI low-side resistance | $R_{DCDI\_LOW}$  | –      | –         | 120  | $\Omega$ | From DCDI pin to GND, when DCDI pin is driven low                                                             |
| DCDI wiring length       | $DCDI_{WIRE}$    | –      | –         | 40   | cm       | The interface operates within its specification up to specified wire length                                   |
| DCDI maximum bus load    | $C_{DCDI}$       | –      | –         | 1.25 | nF       | Baud rate = 57600 bit/s. For slower baud rates higher capacitance values are allowed.                         |

#### 5.4.18.1 DCDI slave addressing

The device provides an auto-addressing functionality in order to allow the master in the system to address different sensors connected on a bus.

It is possible that the sensor uses the static address stored in EEPROM, if the EEPROM is configured to use stored address (static). In this case the broadcast command to automatically change the address is ignored.

#### 5.4.18.2 DCDI features

The EEPROM of the device is programmable via the DCDI interface.

It is possible to read the calibration related register content via the DCDI interface.

The DCDI interface protocol layer provides internal errors status information to the master node within each communication frame.

The DCDI end-to-end frame protection provides a failure detection rate of more than 99%.

For additional information please refer to the user manual of the device.

6 Package

The device is mounted in the PG-DSO-16 Package.

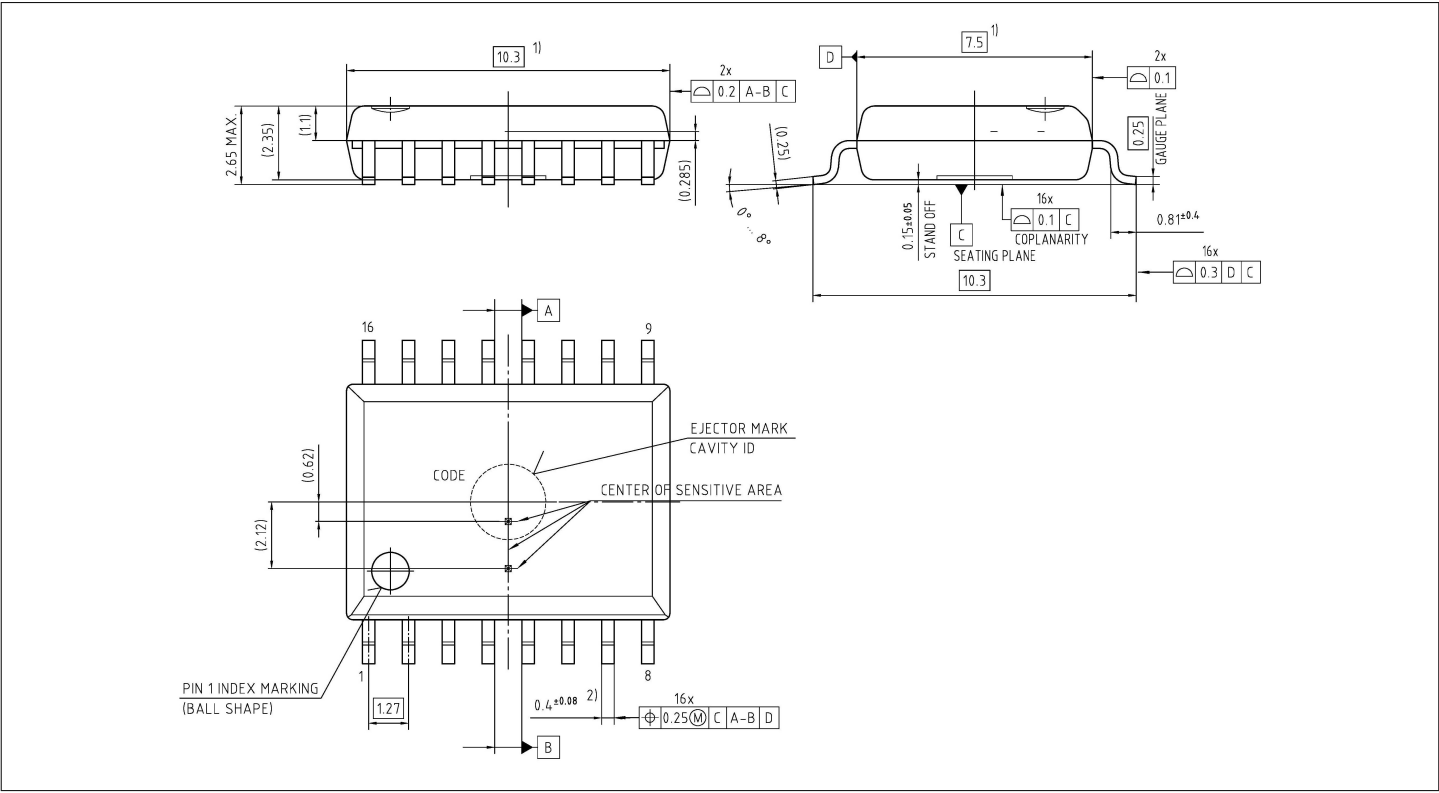


Figure 19 PG-DSO-16 package outline

Table 13

| Parameter                              | Symbol         | Values |      |      | Unit | Note or condition                                                                                    |
|----------------------------------------|----------------|--------|------|------|------|------------------------------------------------------------------------------------------------------|
|                                        |                | Min.   | Typ. | Max. |      |                                                                                                      |
| Junction-to-ambient thermal resistance | $R\theta_{JA}$ | –      | 12.5 | –    | K/W  | Measurement was done in still air box according JESD51-2A by mounting on the Infineon reference PCB. |

7 Revision history

| Revision number | Date of release | Description of changes                                                                                                                                                                                    |
|-----------------|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rev. 1.20       | 2026-03-13      | Updated the noise performance plots.<br>Editorial changes.                                                                                                                                                |
| Rev. 1.10       | 2025-12-02      | Enhanced the Noise performance paragraph, added High precision signal chain and stability over temperature paragraph, added Lifetime and environmental stability paragraph.<br>Updated the block diagram. |
| Rev. 1.00       | 2025-11-07      | Initial release                                                                                                                                                                                           |

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