

# Data Sheet

## HAL<sup>®</sup>/HAC<sup>®</sup> 3980

Stray-Field Robust 3D Position Sensor  
with PSI5 Output Interface

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## Stray-Field Robust 3D Position Sensor with PSI5 Output Interface

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**Release Note: Revision bars indicate significant changes to the previous version.**

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### 1. Introduction

HAL 3980 and HAC 3980 are part of a new generation of TDK-Micronas' 3D position sensors addressing the need for stray-field robust 2D position sensors (linear and angular) as well as the ISO 26262 compliant development. They are high-resolution position sensors for highly accurate position measurements. HAC 3980 has decoupling capacitors already integrated in the three-lead TO package. This enables optimal protection against electromagnetic interference.

HAL/HAC 3980 features a PSI5 interface (Peripheral Sensor Interface) supporting the specification revision 2.3 as well as some of the frame formats of revision 1.3.

The device can measure 360° angular rotation and linear movements. It is able to transmit angle speed information and position information one by one. The device also features a so-called modulo function mainly used for chassis position sensor applications. With this mode it is possible to split the 360° measurement range into sub-segments (90°, 120°, and 180°).

The device measures, based on Hall technology, vertical and horizontal magnetic-field components. It is able to suppress external magnetic stray-fields by using an array of Hall-plates. Only a simple two-pole magnet is required to measure a rotation angle. Ideally, the magnet should be placed above the sensitive area in an end-of-shaft configuration. Stray-field robust off-axis and linear position measurements are supported as well.

On-chip signal processing calculates an angle out of the magnetic-field components and converts this value into a digital output value.

Major characteristics like gain and offset, reference position, etc. can be adjusted to the magnetic circuitry by programming the non-volatile memory.

This product is defined as SEooC (Safety Element out of Context) ASIL B ready according to ISO 26262.

The device is designed for automotive and industrial applications. It operates in the ambient temperature range from -40 °C to 125 °C.

HAL 3980 is available in the eight-pin SOIC8 SMD package and HAC 3980 in a small three-pin leaded transistor package TO92UF.

With its integrated capacitor, HAC 3980 meets the stringent ESD and EMC requirements and eliminates the need for a PCB, thus reducing total system size and cost.

## 1.1. Major Applications

Thanks to the sensor's versatile programming characteristics and its high accuracy, the HAL/HAC 3980 is a potential solution for the following application examples:

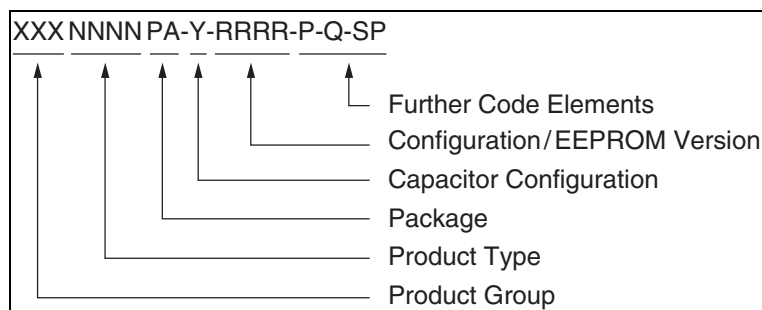
- Chassis position
- Steering angle
- Transmission position detection
- Fuel-level measurements
- Non-contact potentiometer

## 1.2. Features

- Accurate angular measurement up to 360° and linear position detection
- Compensation of magnetic stray fields (rotary or linear position detection)
- SEooC ASIL B ready according to ISO 26262 to support Functional Safety applications
- PSI5 interface supporting revision 2.3 and some frame formats of revision 1.3
- Flexible configuration of various PSI5 interface parameter
- Up to 8 kSps sampling frequency
- Operates from –40 °C up to 170 °C junction temperature ( $T_A = 125\text{ °C}$ )
- Programming via 2-wire interface by supply voltage modulation. No additional programming pin required
- Various configurable signal processing parameter, like output gain and offset, reference position, temperature dependent offset, etc.
- Modulo function (90°/120°/180°) for chassis position applications
- Programmable arbitrary output characteristic with 17 variable or 33 fixed setpoints
- Programmable characteristics in a non-volatile memory (EEPROM) with redundancy and lock function
- Read access on non-volatile memory after customer lock
- On-board diagnostics of different functional blocks of the sensor

## 2. Ordering Information

A Micronas device is available in a variety of delivery forms. They are distinguished by a specific ordering code:



**Fig. 2–1:** Ordering code principle

For a detailed information, please refer to the brochure: “Sensors and Controllers: Ordering Codes, Packaging, Handling”.

### 2.1. Device-Specific Ordering Codes

The HAL/HAC 3980 is available in the following packages.

**Table 2–1:** Available packages

| Package Code (PA) | Package Type |
|-------------------|--------------|
| DJ                | SOIC8        |
| CX                | TO92UF-2     |

Values of capacitors for the TO92UF-2 package from VSUP to GND are uniquely identified by a letter added within the Hall sensor package code, according to the description in Fig. 2–1.

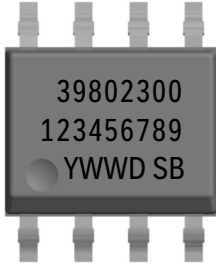
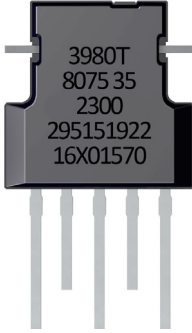
**Table 2–2:** Available capacitor configuration

| Capacitance Code (Y) | Capacitor from VSUP to GND |
|----------------------|----------------------------|
| T                    | 10 nF                      |

**Table 2–3:** Ordering Information

| Product  | Package     | ROM/EEPROM Version | Further Code [-C-P-Q-SP]              | Comments                                                        |
|----------|-------------|--------------------|---------------------------------------|-----------------------------------------------------------------|
| HAL 3980 | DJ = SOIC8  | 95xy               | See TDK-Micronas Ordering Information | 95xy versions can be engineering samples or qualifiable devices |
| HAC 3980 | UF = TO92UF | 957x               | See TDK-Micronas Ordering Information | 957c versions can be engineering samples or qualifiable devices |
| HAL 3980 | DJ = SOIC8  | 2300               | See TDK-Micronas Ordering Information | Production version                                              |
| HAC 3980 | UF = TO92UF | 2300               | See TDK-Micronas Ordering Information | Production version                                              |

**Table 2–4:** Available ordering codes and corresponding package marking

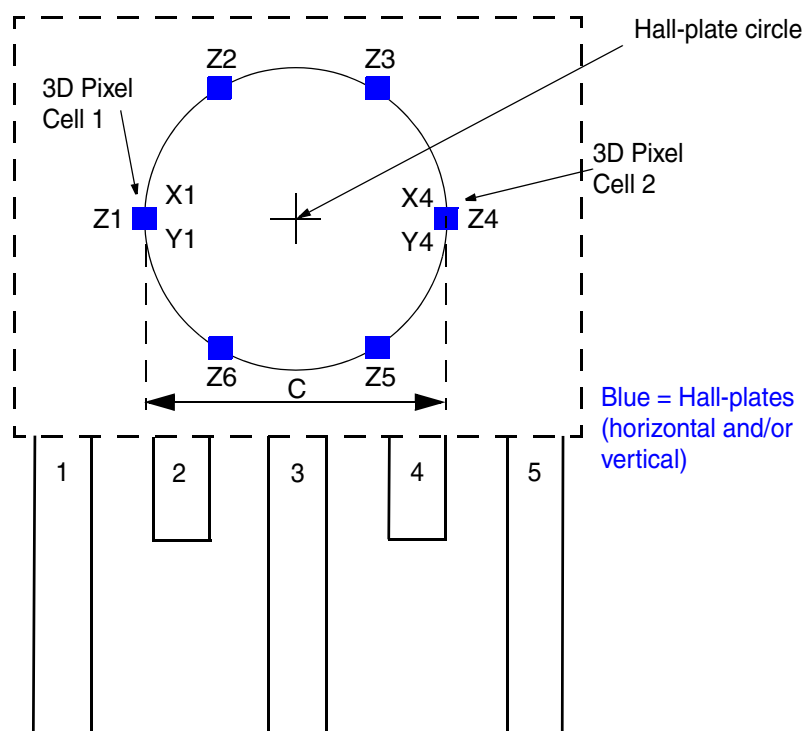
| Ordering Code               | Package Marking                                                                                                                                  | Description                                                                                                                                                                                          |
|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| HAL3980DJ-2300[-C-P-Q-SP]   |  <p>39802300<br/>123456789<br/>YWWDD SB</p>                   | <p>Line 1: Product Type / Configuration-ID</p> <p>Line 2: Lot number</p> <p>Line 3: Date code / Special Procedure SB (optional)</p>                                                                  |
| HAC3980CX-T-2300[-C-P-Q-SP] |  <p>3980T<br/>8075 35<br/>2300<br/>295151922<br/>16X01570</p> | <p>Line 1: Product Type / Capacitor Configuration</p> <p>Line 2: Date code / Special Procedure SB (optional)</p> <p>Line 3: Configuration-ID</p> <p>Line 4: Lot number</p> <p>Line 5: Trace code</p> |



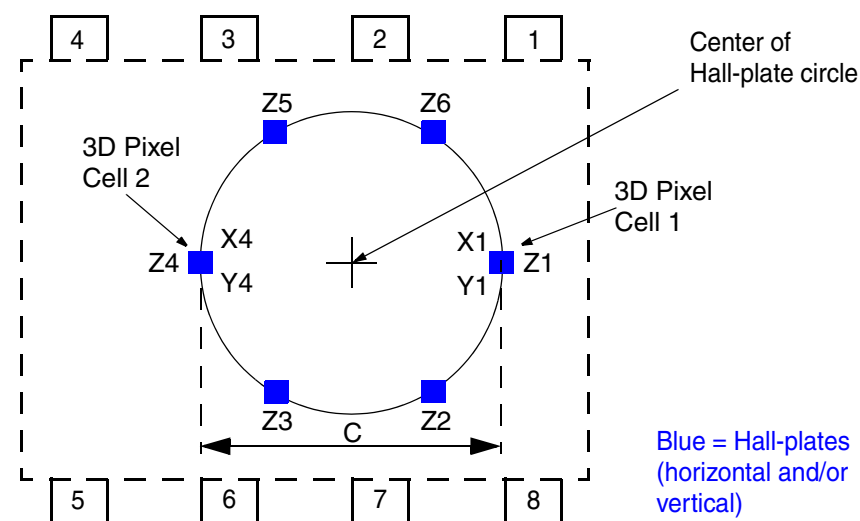
### 3. Functional Description

#### 3.1. General Function

HAL/HAC 3980 is a 2D position sensor based on Hall-effect technology. The sensor includes an array of horizontal and vertical Hall-plates based on TDK-Micronas' 3D HAL<sup>®</sup> technology. The array of Hall-plates has a diameter C of 2.25 mm (nominal).



**Fig. 3–1:** Hall-plate position definition for HAC 3980



**Fig. 3–2:** Hall-plate position definition for HAL 3980

The Hall-plate signals are first measured by up to three A/D converters, filtered and temperature compensated. A linearization block can be used optionally to reduce the overall system angular non-linearity error, due to mechanical misalignment, magnet imperfections, etc.

On-chip offset compensation by spinning current minimizes the errors due to supply voltage and temperature variations as well as external package stress.

Stray-field compensation is done device inherent.

Depending on the measurement configuration, different combination of Hall-plates will be used for magnetic-field sensing.

The sensor supports various measurement configurations:

- Angular measurements in a range between 0° and 360° with stray-field compensation
- Linear position detection with stray-field compensation based on the differential signals of the two 3D Pixel Cells
- 2D linear and angular position detection without stray-field compensation ( $B_X/B_Y$ ,  $B_Z/B_X$ ,  $B_Z/B_Y$ )

The 360° angular range can be split in 90°/120°/180° sub-segments.

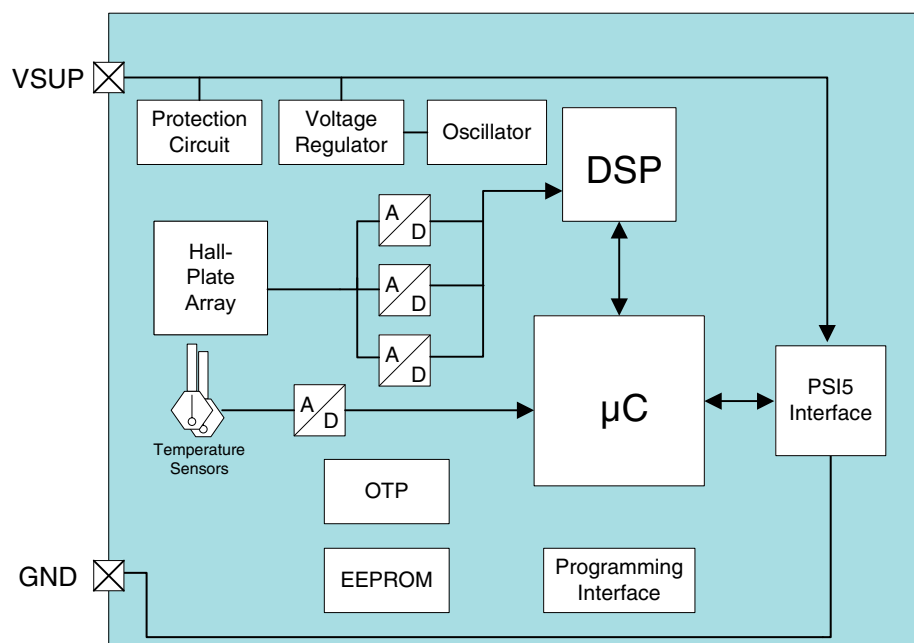
Overall, the in-system calibration can be utilized by the system designer to optimize performance for a specific system. The calibration information is stored in an on-chip non-volatile memory.

The calculated position information and/or angle speed is transmitted via PSI5 frames to a host. The sensor response is based on a current modulation defined by the PSI5 standard.

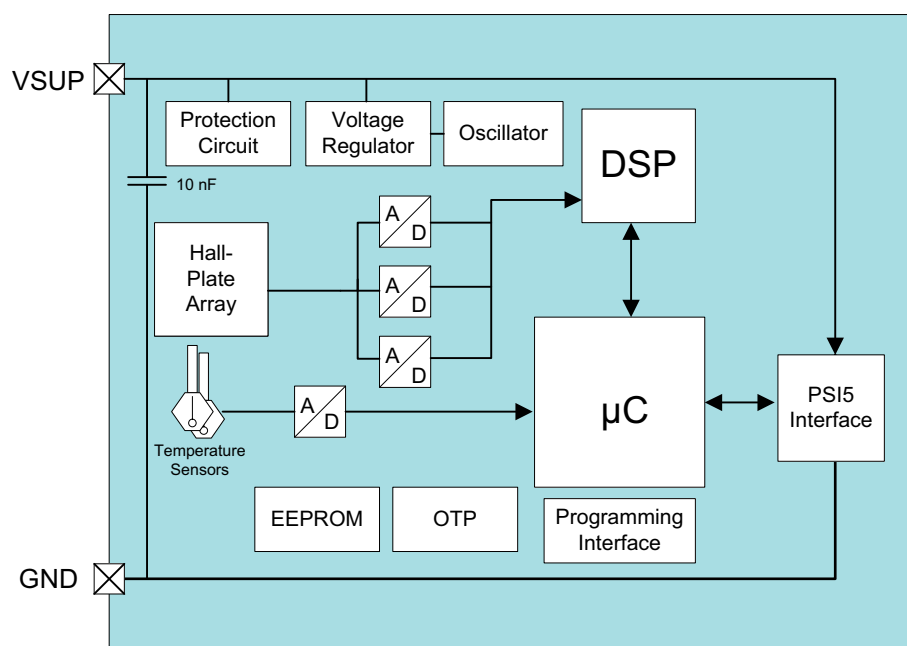
HAL/HAC 3980 supports different synchronous and asynchronous modes according to PSI5. The synchronous bus modes PSI5-U and PSI5-P are supported. The daisy chain mode is not supported. The sensor does not support the ECU to sensor communication, neither the tooth-gap method and nor the pulse width method.

The HAL/HAC 3980 is end-of-line programmable by modulation of the supply voltage. The sensor generates an answer by modulation of the supply current. No additional programming pin is needed and fast end-of-line programming is enabled.

To improve EMC performance, HAC 3980 integrates one capacitor within the package between VSUP and GND.



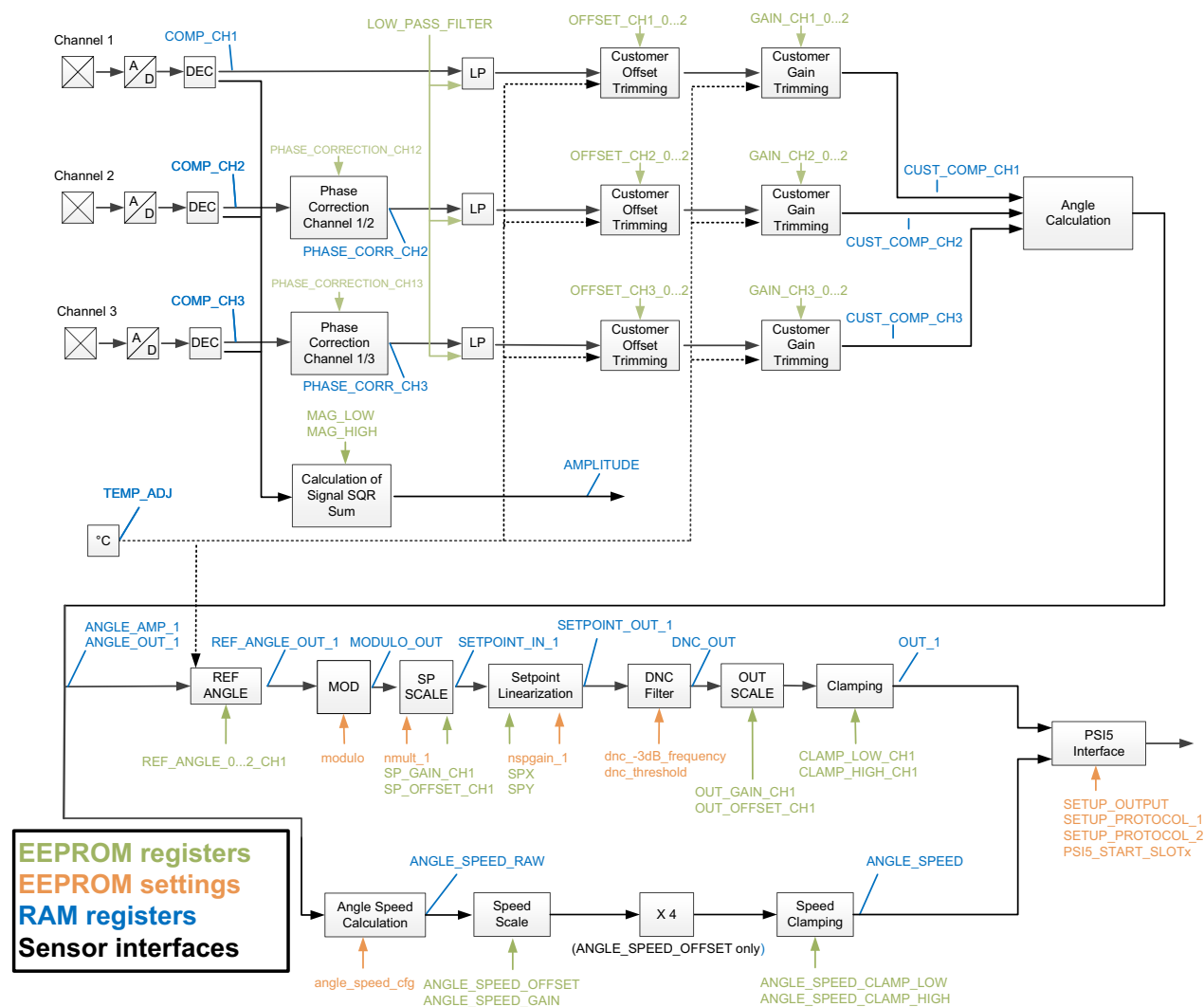
**Fig. 3–3:** HAL 3980 block diagram



**Fig. 3–4:** HAC 3980 block diagram

### 3.2. Signal Path

The DSP part of this sensor performs the signal conditioning. The parameters for the DSP are stored in the non-volatile memory. Details of the overall signal path are shown in Fig. 3–5. Not all functions are available for all measurement modes. Depending on the measurement setup, the signal path is scaled to the needs for the measurement setup.



**Fig. 3–5:** Signal path of HAL/HAC 3980

The sensor signal path contains two kinds of registers. Registers that are read-only and programmable registers (non-volatile memory). The **read-only (RAM) registers** contain measurement data at certain steps of the signal path and the **non-volatile memory registers (EEPROM)** change the sensor's signal processing. **EEPROM settings** are individually configurable bits within an EEPROM register.

### 3.3. Register Definition

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**Note** Further details about the programming of the device and detailed register setting description as well as memory map can be found in the document: HAL/HAC 3980 User Manual.

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#### 3.3.1. RAM Registers

##### TEMP\_TADJ

The TEMP\_TADJ register contains already the TDK-Micronas' compensated digital value of the sensor's junction temperature.

##### COMP\_CH1, COMP\_CH2 and COMP\_CH3

COMP\_CH1, COMP\_CH2 and COMP\_CH3 registers contain the TDK-Micronas' temperature compensated magnetic-field information of channel 1, channel 2 and channel 3.

##### AMPLITUDE

The AMPLITUDE register contains sum of squares of the magnetic-field amplitude of all three channels calculated with the following equation. In case of two channels only the first two terms are used. This information is used for the magnet lost detection:

$$\text{AMPLITUDE} = \frac{\text{COMP\_CH1}^2}{32768} + \frac{\text{COMP\_CH2}^2}{32768} + \frac{\text{COMP\_CH3}^2}{32768}$$

##### PHASE\_CORR\_CH2, PHASE\_CORR\_CH3

PHASE\_CORR\_CHx registers contain the customer compensated magnetic-field information of channel 2 and channel 3 after customer phase-shift error correction using the PHASE\_CORRECTION\_CHx registers.

##### CUST\_COMP\_CH1, CUST\_COMP\_CH2 and CUST\_COMP\_CH3

CUST\_COMP\_CH1, CUST\_COMP\_CH2 and CUST\_COMP\_CH3 registers contain the customer compensated magnetic-field information of channel 1, channel 2 and channel 3 used for the angle calculation. These registers contain already the customer phase-shift, gain and offset corrected data.

### ANGLE\_OUT\_1

The ANGLE\_OUT\_1 register contains the digital value of the position calculated by the angle calculation algorithm.

### ANGLE\_AMP\_1

The ANGLE\_AMP\_1 register contains the digital value of the magnetic-field amplitude calculated by the angle calculation algorithm.

### REF\_ANGLE\_OUT\_1

The REF\_ANGLE\_OUT\_1 register contains the digital value of the angle information after setting the reference angle defining the zero angle position.

### MODULO\_OUT

The MODULO\_OUT register contains the digital value of the angle information after applying the modulo calculation algorithm.

### SETPOINT\_IN\_1

The SETPOINT\_IN\_1 register contains the digital value of the angle information after the setpoint scaling block and is the value used for the input of the setpoint linearization block.

### SETPOINT\_OUT\_1

The SETPOINT\_OUT\_1 register contains the digital value of the angle information after the setpoint linearization block.

### DNC\_OUT

The DNC\_OUT register contains the digital value of the angle information after the DNC filter.

### OUT\_1

The OUT\_1 register contains the digital value of the angle information after all signal processing steps and depends on all customer configuration settings.

### ANGLE\_SPEED

The ANGLE\_SPEED\_RAW value contains the angle speed information. The angle speed is calculated by the following equation:

$$\text{ANGLE\_SPEED\_RAW} = 16384 \cdot \frac{\text{OUT\_1}(n) - \text{OUT\_1}(n-1)}{\text{Angle Speed Range}}$$

Angle Speed Range =  $\pm 1000$  °/s or  $\pm 5000$  °/s (customer configurable)

The ANGLE\_SPEED register contains the angle speed information after customer scaling with the registers ANGLE\_SPEED\_OFFSET and ANGLE\_SPEED\_GAIN and clamping (ANGLE\_SPEED\_CLAMP\_LOW/HIGH). It is as well possible to activate an FIR filter and to define four different IIR filter frequencies (see Table 3–1 on page 25).

## DIAGNOSIS

The DIAGNOSIS\_0 and DIAGNOSIS\_1 registers report certain failures detected by the sensor. HAL/HAC 3980 performs self-tests during power-up as well as continues system integrity tests during normal operation. The result of those tests is reported via the DIAGNOSIS\_X registers (further details can be found in see Section 4.2. on page 41).

## Micronas IDs

The MIC\_ID1 and MIC\_ID2 registers are both 16-bit organized. They are read only and contain TDK-Micronas production information, like X,Y position on the wafer, wafer number, etc.

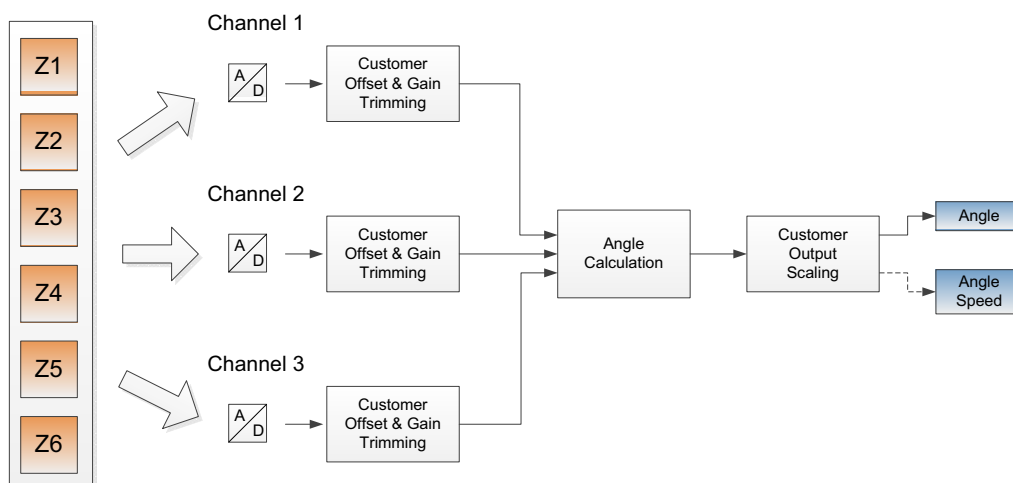
### 3.3.2. EEPROM Registers

#### Application Modes

HAL/HAC 3980 can be configured in different application modes. Depending on the required measurement task one of the application modes can be selected. The register `SETUP_FRONTEND` (Table 3–1 on page 25) defines the different available modes.

#### – Setup 1: 180° rotary (stray-field compensated)

This mode uses six horizontal Hall-plates to measure a 180° angular range. It requires a 4-pole magnet. Speciality of this mode is that the device can compensate stray fields according to ISO 11452-8 definition as well as disturbing gradients generated for example by a current conducting wire. Fig. 3–6 shows the related signal path.

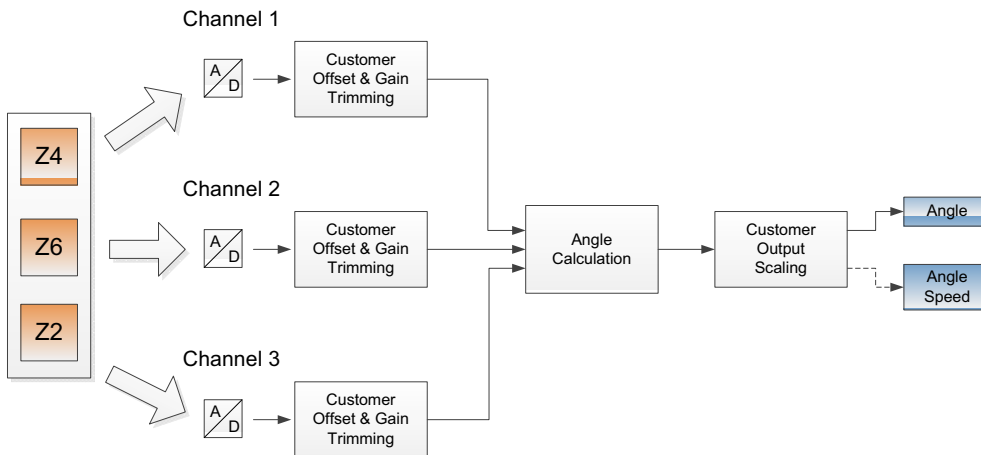


**Fig. 3–6:** Signal path diagram of setup 1 (stray-field robust 180° measurement)



### – Setup 2: 360° rotary (stray-field compensated)

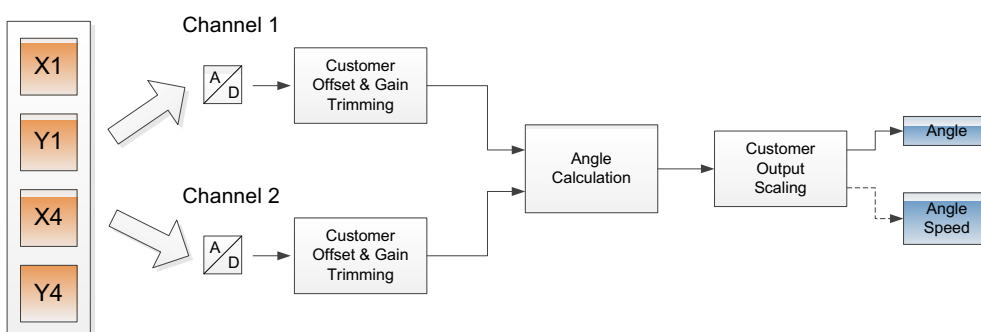
This mode uses horizontal Hall-plates to measure a 360° angular range. It requires a 2-pole magnet. The device can compensate stray fields according to ISO 11452-8 definition. Fig. 3–7 shows the related signal path.



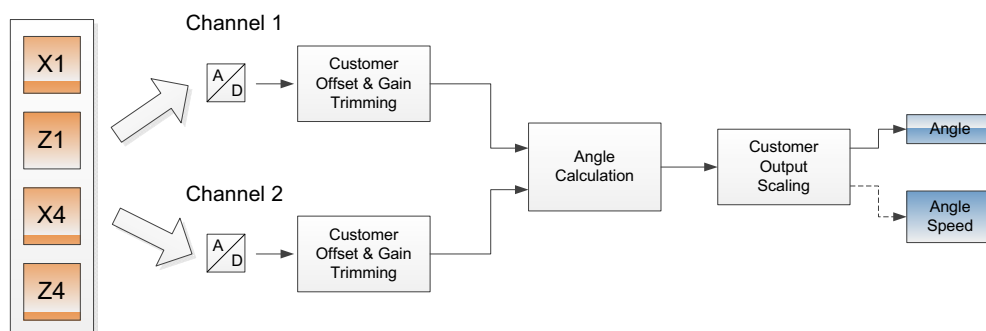
**Fig. 3–7:** Signal path diagram of setup 2 (stray-field robust 360° measurement)

### – Setup 3: Linear movement or off-axis (stray-field compensated)

This mode uses a combination of horizontal and vertical Hall-plates to measure a stray-field compensated linear movement ( $\Delta B_X$  &  $\Delta B_Z$  of 3D Pixel Cells 1 and 2). Alternatively, this setup can be used as well for off-axis stray-field compensated angular measurements in case that a combination of vertical Hall-plates is selected ( $\Delta B_X$  &  $\Delta B_Y$  of 3D Pixel Cells 1 and 2). The device can compensate stray-fields according to ISO 11452-8 definition. Fig. 3–8 shows the related signal path for  $\Delta X\Delta Y$  setup and Fig. 3–9 the signal path for  $\Delta X\Delta Z$  setup.



**Fig. 3–8:** Signal path diagram of setup 3a -  $\Delta X\Delta Y$  (stray-field robust off-axis position detection)



**Fig. 3–9:** Signal path diagram of setup 3b -  $\Delta X\Delta Z$  (stray-field robust linear position detection)

For the linear movement setup the angle calculation is done by using the following equation:

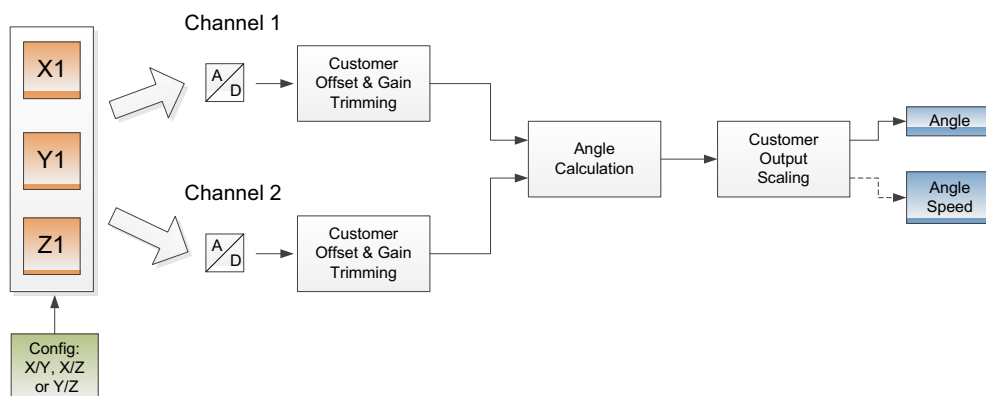
$$\text{ALPHA} = \text{ATAN2}\left(\frac{\Delta BZ}{\Delta BX}\right) = \text{ATAN2}\left(\frac{BZ_4 - BZ_1}{BX_4 - BX_1}\right)$$

For the off-axis rotary setup the angle calculation is done by using the following equation:

$$\text{ALPHA} = \text{ATAN2}\left(\frac{\Delta BY}{\Delta BX}\right) = \text{ATAN2}\left(\frac{BY_4 - BY_1}{BX_4 - BX_1}\right)$$

### – Setup 4a: 360° rotary or linear movement measurement without stray-field compensation

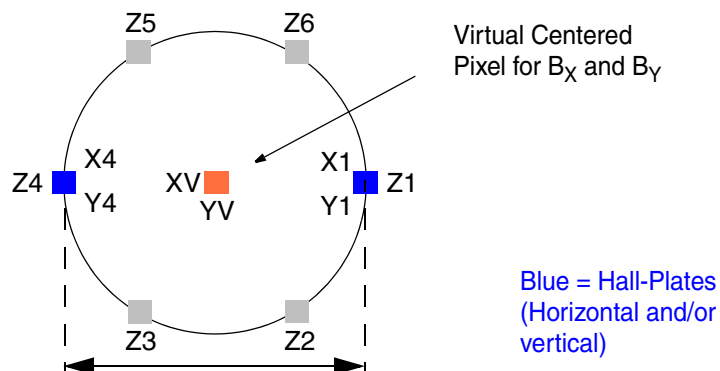
This mode uses horizontal and vertical Hall-plates to measure  $B_X$ ,  $B_Y$ ,  $B_Z$  of Pixel Cell 1. The angle will be calculated out of combinations of  $B_Y/B_X$ ,  $B_Z/B_X$  or  $B_Z/B_Y$ . This mode does not compensate stray-fields. The measurement setup is similar to the well known HAL 37xy family from TDK-Micronas.



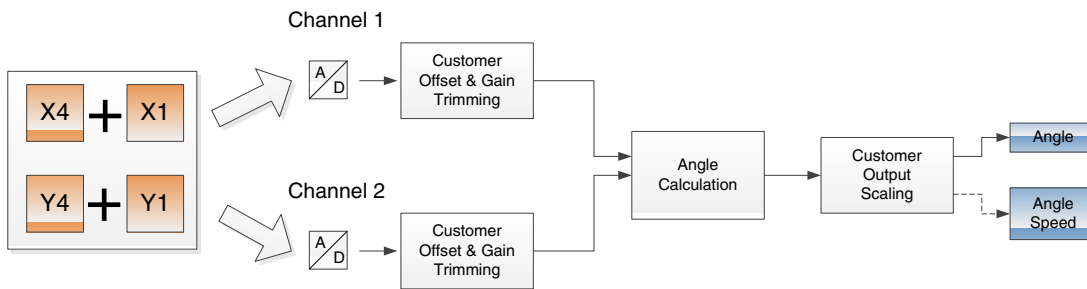
**Fig. 3–10:** Signal path diagram of setup 4a (Rotary or linear position detection w/o stray-field compensation)

### – Setup 4b: Virtual centered pixel cell mode for 360° rotary measurement or linear movement (w/o stray-field compensation)

In addition to setup 4a, it is as possible to select a virtual centered pixel cell mode (4b). In this mode the signals in X and Y direction of both pixel cells P1 and P2 are combined and averaged to generate one virtual centered pixel in the middle of the Hall-plate array.



**Fig. 3–11:** Virtual center pixel for  $B_X$  and  $B_Y$  in Mode 4b



**Fig. 3–12:** Signal path diagram of setup 4b (virtual center pixel w/o stray-field compensation)

$$B_{XV} = \left( \frac{BX_1 + BX_4}{2} \right)$$

$$B_{YV} = \left( \frac{BY_1 + BY_4}{2} \right)$$

## Customer IDs

The customer ID registers (CUSTOMER\_ID0 to CUSTOMER\_ID7) consists of 8 times 16-bit words and are used to define the content transmitted during the start-up phase defined by the PSI5 standard. It is possible to transmit information like production date, sensor code, sensor typ, vendor ID, etc. Please see Table 3–5 on page 34 for further details.

## Magnetic Range Check

The magnetic range check uses the AMPLITUDE register value and compares it with an upper and lower limit threshold defined by the customer programmable registers MAG\_LOW and MAG\_HIGH. If either low or high limit is exceeded, the sensor will indicate an error.

### Mag-Low Limit

MAG\_LOW defines the low level for the magnetic-field range check function.

### Mag-High Limit

MAG-HIGH defines the high level for the magnetic-field range check function.

## Phase Correction

PHASE\_CORRECTION\_CH12 and PHASE\_CORRECTION\_CH13 can be used to compensate a phase shift of channel 2 and channel 3 in relation to channel 1.

Neutral value for the registers is zero (no phase-shift correction).

## Low-Pass Filter

With the LOW\_PASS\_FILTER register it is possible to select different –3 dB frequencies for HAL/HAC 3980. The default value is zero (low pass filter disabled). The filter frequency is valid for all channels.

## OFFSET\_CHx\_0...2

OFFSET\_CH1\_0...2, OFFSET\_CH2\_0...2 and OFFSET\_CH3\_0...2 support three polynomials of second order and describes the temperature compensation of the offset of channel 1, channel 2, and channel 3 (compensating a remaining offset in each of the three channels). This means a constant, linear and quadratic offset factor can be programmed for up to three channels (temperature dependent offset).

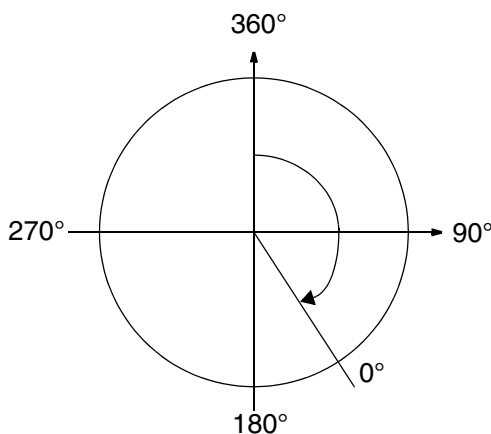
## GAIN\_CHx\_0...2

GAIN\_CH1\_0...2, GAIN\_CH2\_0...2 and GAIN\_CH3\_0...2 support three polynomials of second order and describe the temperature compensation of the sensitivity of channel 1, channel 2 and channel 3 (compensating the amplitude mismatches between three channels). This means a constant, linear and quadratic gain factor can be programmed individually for the three channels (temperature dependent gain).

## Reference Angle Position

The output signal zero position defines the reference position for the angle output and therefore it is possible to shift the discontinuity in the output characteristics out of the measurement range with these parameters. It can be set to any value of the angular range.

REF\_ANGLE\_0...2\_CH1 defines a polynomial of second order with REF\_ANGLE\_0\_CH1 (constant part), REF\_ANGLE\_1\_CH1 (linear part) and REF\_ANGLE\_2\_CH1 (quadratic part).



**Fig. 3–13:** Example definition of zero degree point

## Modulo Select

HAL/HAC 3980 can split the 360° measurement range into sub-ranges of 90°, 120° and 180°. For example in the 90° sub-range output signal is repeating after 90°. The MODULO register can be used to select between these four different output ranges.

The desired modulo calculation can be selected by setting certain bits in the SETUP\_FRONTEND register.

## nmult\_1 (EEPROM Setting)

nmult\_1 defines the gain exponent for the setpoint scaling block on the data channel. The factor is multiplied by SP\_GAIN\_CH1 to achieve gain factors up to 128. SETUP\_DATAPATH[7:5] bits (= nmult\_1).

## Setpoint Gain

SP\_GAIN\_CH1 defines the output gain for the data channel. It is used to scale the position information to the input range of the linearization block.

## Setpoint Offset

SP\_OFFSET\_CH1 defines the output offset for the data channels.

## Setpoint Linearization

The setpoint linearization block enables the linearization of the sensor's output characteristic for the customer's application. For fixed setpoints it consists of 33 setpoints for one data channel (SP0, SP1, ..., SP32) or 34 setpoints for two channels (17 setpoints each data channel; two times SP0, SP1, ..., SP16). Each setpoint is defined by its fixed x position and its programmable y value. The setpoint x positions (SP(n)\_X) are equally distributed between -32768...32767 LSB along the signal range.

If variable setpoints are enabled (SETUP\_DATAPATH[0] = 1), both position values (x and y) of the setpoints are programmable.

The setpoint registers have a length of 16 bits and are two's complement coded. Therefore the setpoint register values can vary between -32767...32767 LSB. The setpoint x values are stored as absolute values and the setpoint y values differentially to the corresponding x values. The setpoint register values are initially set to 0 (neutral) by default.

The setpoint linearization block works in a way that the incoming signal (SETPOINT\_IN\_1 value) is interpolated linearly between two adjacent setpoints (SP(n) and SP(n+1)). The resulting SETPOINT\_OUT\_1 register value represents the angular information after the setpoint scaling.

In case of variable setpoints are selected, nspgain\_1 register must be used.

### **nspgain\_1 (EEPROM Setting)**

SETUP\_DATAPATH[4:1] bits (= nspgain\_1) set the gain exponent for the setpoint slope on the data. With the 4 bits it is possible to get gains up to 65536.

### **DNC Filter Registers (dnc\_–3dB\_frequency & dnc\_threshold)**

The DNC (Dynamic Noise Cancellation) filter decreases the output noise significantly by adding a low-pass filter with a very low cut-off frequency for signals below a certain signal change threshold (dnc\_threshold, DNC[15:8]). The attenuation factor dnc\_–3dB\_frequency of this IIR filter can be selected by the bits DNC[7:0] of the DNC register. Both parameters have a length of 8 bits.

Signals with a very low amplitude (signals classified as noise e.g.  $\pm 0.5^\circ$ ) and periodic movements with an amplitude lower than  $1^\circ$  will be filtered whereas signals with a higher amplitude are untouched (i. e. rapid movements). The activation of the DNC filter has no impact on the resolution of the output and does not add any additional processing delay.

For dnc\_threshold only values from 0 to 255 are allowed. For the dnc\_–3dB\_frequency only cutoff frequencies up to 50% of the sample frequency ( $0.5 \cdot f_{\text{dec sel}}$ ) are allowed. To disable the DNC filter both registers must be set to 0.

### **OUT\_OFFSET\_CH1**

The register OUT\_OFFSET\_CH1 is used as the final offset scaling stage for the desired output signal. The register has a length of 16 bits and is two's complement-coded.

### **OUT\_GAIN\_CH1**

The register OUT\_GAIN\_CH1 is used as the final gain scaling stage for the desired output signal. It can also be used to invert the output signal. The register has a length of 16 bits and is two's complement-coded.

### **Clamping Levels (CLAMP-LOW & CLAMP-HIGH)**

The clamping levels CLAMP\_LOW\_CH1 and CLAMP\_HIGH\_CH1 define the maximum and minimum output values. Both registers have a length of 16 bits and are two's complement-coded. Both clamping levels can have values between 0 % and 100 %.

### **Angle Speed Range**

It is possible to define two different angle speed ranges with the angle\_speed\_cfg bits in the SETUP\_PROTOCOL\_2 register (Table 3–10 on page 39). Two different ranges are available:

- $\pm 1000^\circ/\text{s}$
- $\pm 5000^\circ/\text{s}$

### **ANGLE\_SPEED\_OFFSET**

The register ANGLE\_SPEED\_OFFSET is used as the offset scaling stage for the desired angle speed information. The register has a length of 16 bits and is two's complement-coded.

### **ANGLE\_SPEED\_GAIN**

The register ANGLE\_SPEED\_GAIN is used as the gain scaling stage for the desired angle speed information. The register has a length of 16 bits and is two's complement-coded.

### **Angle Speed Clamping Levels**

The clamping levels ANGLE\_SPEED\_CLAMP\_LOW and ANGLE\_SPEED\_CLAMP\_HIGH define the maximum and minimum output values for the angle speed information. Both registers have a length of 16 bits and are two's complement-coded. Both clamping levels can have values between 0 % and 100 % of full-scale.

### **Supply Voltage Supervision**

As the device supports a wide supply voltage range it is beneficial to enable customer programmable under/overvoltage detection levels. The register UV\_LEVEL defines the undervoltage detection level in mV and OV\_LEVEL the overvoltage detection level. The SUPPLY\_SUPERVISION register has a length of 16 bits. OV\_LEVEL uses the 8 MSBs and UV\_LEVEL the 8 LSBs. For both levels, 1 LSB is typically equal to 100 mV.



## Customer Configuration Register

The SETUP\_FRONTEND and SETUP\_DATAPATH registers are 16-bit registers that enable the customer to activate various functions of the sensor. With this register it is possible to configure the sensors front-end, like sample frequency, measurement set-ups, etc. The following tables describe in detail the available combinations and resulting functions.

**Table 3–1: SETUP\_FRONTEND**

| Bit No. | Function               | Description                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                           |                                                                                 |                                                                                 |                                                                  |
|---------|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|------------------------------------------------------------------|
| 15      | customer_lock          | Customer Lock:<br>0: Unlocked<br>1: Locked                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                           |                                                                                 |                                                                                 |                                                                  |
| 14:12   | -                      | Must be set to 0.                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                           |                                                                                 |                                                                                 |                                                                  |
| 11      | angle_speed_fir_enable | Enables 4-tap FIR filter for the angle speed calculation (floating average sum out of actual and three previous measurements):<br>0: Disabled<br>1: Enabled                                                                                                                                                                                                                                         |                                                                                                                                                                                                                           |                                                                                 |                                                                                 |                                                                  |
| 10:9    | angle_speed_fir_cutoff | Defines the cut-off frequency of the IIR filter for the angle speed information:<br>00: Bypass/switched off<br>01: 33 Hz<br>10: 81 Hz for $\pm 1000$ °/s and 415 Hz for $\pm 5000$ °/s<br>11: 165 Hz for $\pm 1000$ °/s and 450 Hz (2 kSps) or 900 Hz (4 & 8 kSps) for $\pm 5000$ °/s                                                                                                               |                                                                                                                                                                                                                           |                                                                                 |                                                                                 |                                                                  |
| 8       | quadrant               | This bit is used to define if the sensor is only transmitting the modulo result or the modulo result + quadrant information:<br>0: Modulo value only<br>1: Modulo value + 2 bit quadrant information                                                                                                                                                                                                |                                                                                                                                                                                                                           |                                                                                 |                                                                                 |                                                                  |
| 7:6     | modulo                 | Modulo operation:<br>00: 360°<br>01: Modulo 90°<br>10: Modulo 120°<br>11: Modulo 180°                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                           |                                                                                 |                                                                                 |                                                                  |
| 5:4     | fdecsel                | A/D converter sample frequency:<br>00: 2 kSps<br>01: 4 kSps<br>10: 8 kSps<br>11: not supported                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                           |                                                                                 |                                                                                 |                                                                  |
| 3:0     | meas_config            | <b>Measurement setups:</b><br><br>0000: Setup 4a - 2D<br>0001: Setup 4a - 2D<br>0010: Setup 4a - 2D<br>0011: Setup 3b - 2D - Strayfield compensated<br>0100: Setup 3a - 2D - Strayfield compensated<br>0101: Setup 4b - 2D - Virtual center pixel<br>0110: Setup 1 - 180° rotary - strayfield compensated<br>0111: Setup 2 - 360° rotary - strayfield compensated<br>1000 to 1111: Must not be used | <b>Correspond. Signal Path</b><br><br>With two channel<br>With two channel<br>With two channel<br>With two channel<br>With two channel<br>With two channel<br>With two channel<br>6 Z Hall-plates<br>3 Z Hall-plates<br>- | <b>CH1</b><br><br>X1<br>Z1<br>Z1<br>Z4-Z1<br>X4-X1<br>X1+X4<br>Z1+Z4<br>Z4<br>- | <b>CH2</b><br><br>Y1<br>Y1<br>X1<br>X4-X1<br>Y4-Y1<br>Y1+Y4<br>Z2+Z5<br>Z6<br>- | <b>CH3</b><br><br>-<br>-<br>-<br>-<br>-<br>-<br>Z3+Z6<br>Z2<br>- |

**Table 3–2: SETUP\_DATAPATH**

| Bit No. | Function           | Description                                                                              |
|---------|--------------------|------------------------------------------------------------------------------------------|
| 15:8    | –                  | Reserved                                                                                 |
| 7:5     | nmult_1            | Gain exponent for SETPOINT_IN1:<br>$SP\_GAIN = SP\_GAIN\_CH1 * [2^{(nmult\_1)}]$         |
| 4:1     | nspgain_1          | Gain exponent for setpoint slope in channel 1:<br>$Slope = SP_{Gn} * (2^{nspgain\_1+1})$ |
| 0       | variable_setpoints | Fixed/variable setpoint selection:<br>0: Fixed setpoints<br>1: Variable setpoints        |

---

**Note** Registers affecting the PSI5 configuration are described in Section 3.4.

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### 3.4. Basic Description of the PSI5 Standard

The Peripheral Sensor Interface (PSI5) is an interface for automotive sensor applications. PSI5 is an open standard based on existing sensor interfaces for peripheral airbag sensors, already proven in millions of airbag systems.

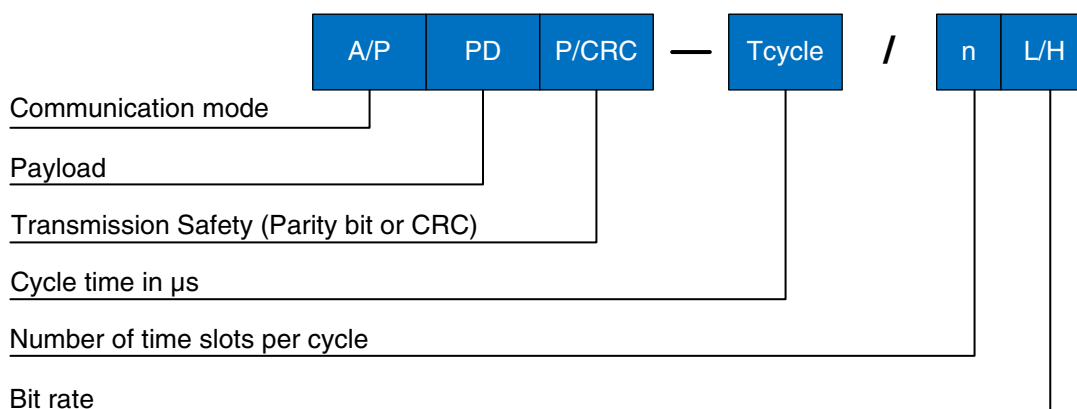
Main features of the PSI5 standard are high speed and highly reliable data transfer at lowest possible implementation overhead. PSI5 covers the requirements of the low-end segment of digital automotive interfaces and offers universal and flexible solution for multiple sensor applications.

#### Key features of PSI5 Standard

- Two-wire current interface
- Manchester coded digital data transmission
- High data transmission speed of 125 kbps or optional 189 kbps
- High EMC robustness and low emission
- Wide range of sensor supply current
- Variable data word length with 10 to 28 bit with one bit granularity
- Asynchronous and synchronous operation and different bus modes
- Bidirectional communication

HAL/HAC 3980 complies with the PSI5 sensor interface regarding electrical parameter and data transmission according to revision 2.3. The implementation is even backward compatible to some of the operation modes described in revision 1.3 of the PSI5 standard. The implementation of the interface follows the “Chassis and Safety PSI5 sub-standard”.

The short text definition of the PSI5 protocol is defined as follows:



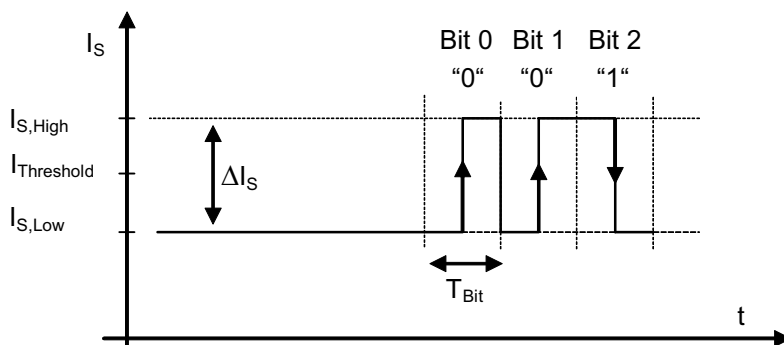
**Fig. 3–14:** PSI5 protocol short text definition

### 3.4.1. Physical Layer

PSI5 uses two wires for both, power supply to the sensor and data transmission. The ECU has to provide a pre-regulated supply voltage to the sensor. Data transmission from the sensor to the ECU is done by current modulation on the power supply lines.

### 3.4.2. Bit Encoding - Sensor to ECU Communication

A low level ( $I_{S,Low}$ ) is represented by the normal (quiescent) current consumption of the sensor(s). A high level ( $I_{S,High}$ ) is generated by an increased current sink of the sensor ( $I_{S,Low} + \Delta I_S$ ). The current modulation is detected within the receiver of the ECU.



**Fig. 3–15:** Bit encoding using supply current modulation

Manchester coding is used for data transmission. A logic 0 is represented by a rising slope and a logic 1 by a falling slope of the current in the middle of  $T_{Bit}$ .

Details about the electrical specification for the current modulation can be found in Section 5.9. on page 53.

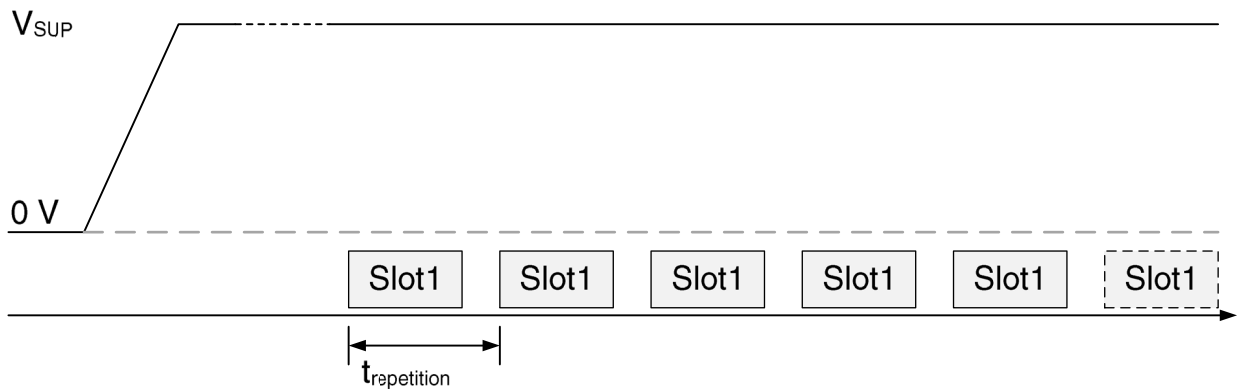
### 3.4.3. Communication Mode

The device supports the following different communication modes:

- Asynchronous mode (PSI5-A)
- Synchronous parallel bus mode (PSI5-P)
- Synchronous universal bus mode (PSI5-U)
- Variable time triggered synchronous bus mode (PSI5-V)

### 3.4.3.1. Asynchronous Mode

In asynchronous mode the device transmits the same signal periodically to the ECU. Timing and repetition rate of the transmission is controlled by HAL/HAC 3980. The asynchronous mode can be used for a point-to-point connection of a single sensor and the ECU. The sensor starts the transmission of data frames after power-on. The repetition time ( $t_{\text{repetition}}$ ) of the sensor is customer programmable. Please see the bits `repetition_rate` in the register `SETUP_OUTPUT` (Table 3–8 on page 37) for the available repetition times.



**Fig. 3–16:** Example for asynchronous transmission with four time slots

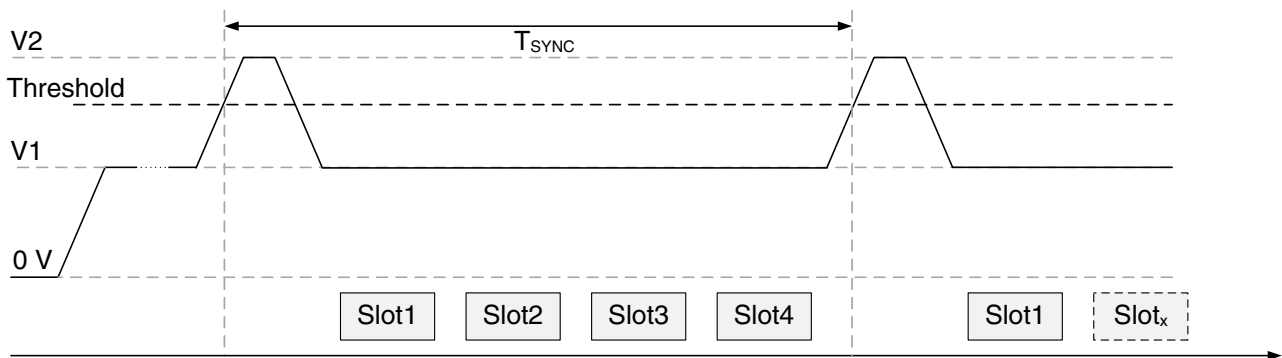
### 3.4.3.2. Synchronous Bus Mode

In all synchronous bus modes the ECU triggers the transmission of one frame or a sequence of frames. Parallel and universal bus modes just differ in the bus wiring. The protocol format is identical.

Every frame has its unique transmission window starting at a fixed delay after the trigger signal from the ECU. It is important that different transmission windows shall not overlap. The configuration of the sensor must be done correctly to avoid overlapping. The ECU has to guarantee the timing of the trigger signals and the cycle time shall enable all connected devices to transmit their frames in between two trigger signals.

The synchronous mode can be used as well for a point-to-point connection of a single sensor to an ECU.

The sensor data transmission is synchronized by the ECU using a voltage modulation. Once the sync pulse is received (Fig. 5–12 on page 56), each sensor starts data transmission according to the time of the individually programmed time slot. This time can be defined by the three `PSI5_START_SLOTx` registers.



**Fig. 3–17:** Example for synchronous transmission with four time slots

Since the ECU is responsible for the trigger signal, it can send the trigger pulse with variable delays as well. This mode is called variable time trigger synchronous mode. The maximum trigger signal frequency must comply with the number and size of transmission windows.

### Synchronization Pulse

HAL/HAC 3980 is detecting the synchronization pulse generated by the ECU as soon as the supply voltage modulation is higher than the minimum sync pulse voltage ( $V_{\text{Sync}}$ ). The electrical parameters of the synchronization pulse are defined in Section 5.9. on page 53.

HAL/HAC 3980 offers the possibility to synchronize the internal sampling of the position information with the external sync pulse to the PSI5 interface. By this, it is possible to achieve a shorter signal age. This function can be activated by bit[15] of the SETUP\_PROTOCOL\_2 register (Table 3–10 on page 39).

#### 3.4.4. Time Slots

HAL/HAC 3980 supports up to three time slots. Their starting times can be defined with the registers PSI5\_START\_SLOTx registers (see page 40). With these registers, it is possible to define if the position information and in addition the angle speed are transmitted in the time slots 1,2,3 or 4. The start times must be selected in a way that they are matching together with the frame content into the SYNC intervals of the ECU (cycle time).

#### 3.4.5. Data Frame Content

The transmitted data frame content can be very flexibly configured and therefore be adapted to customer needs. Generally the frame consists of start bits, the payload bits and error detection bits (CRC or parity bit). The payload consists of control bits (optional), status bits (optional) and data bits. Data bits are transmitted LSB first.

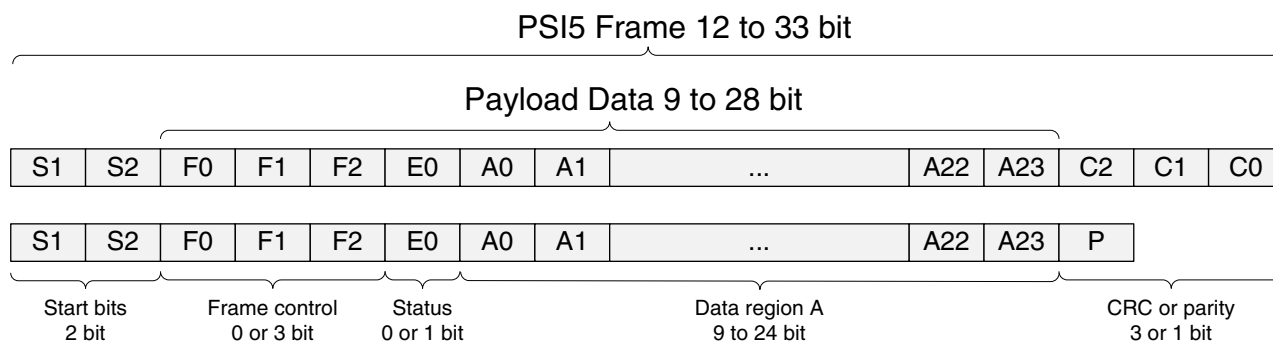
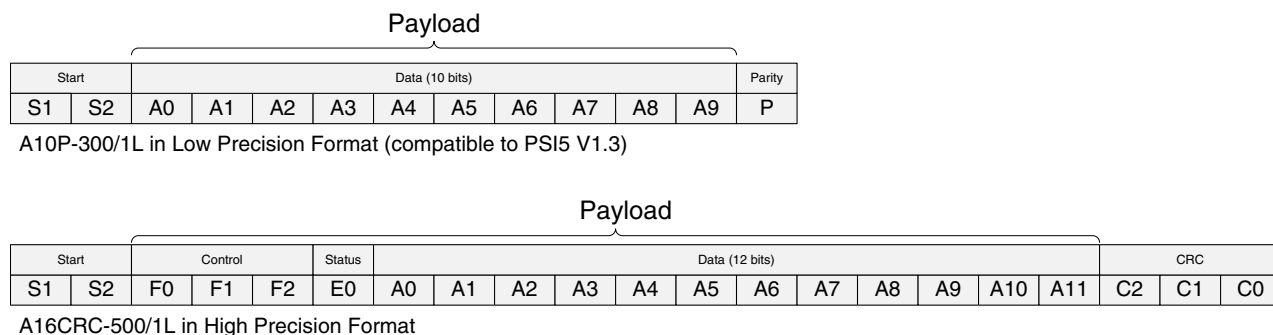
**Fig. 3–18: PSI5 Frame content****Fig. 3–19: Examples of supported PSI5 Frames**

Table 3–3 describes the selectable frame content.

**Table 3–3: Data frame content**

| Frame Content        |                    | Symbol   | Description                                                                                                   | Register                                                                                                   |
|----------------------|--------------------|----------|---------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| Start bits           |                    | S0, S1   | Frame start bits: Always 0                                                                                    |                                                                                                            |
| Payload              | Frame control bits | F0-F2    | Optional. Can be activated by customer settings. Rolling counter or coding of data source (position or speed) | frame_control_source<br>frame_control_bits<br>Table 3–9 on page 38                                         |
|                      | Status bit         | E0       | Optional. Used as error flag if activated.                                                                    | status_bit<br>error_status<br>Table 3–8 on page 37                                                         |
|                      | Data bits          | A[0:N-1] | Data bits. Transmission of LSB first. Can be selected between 9...16 bit                                      | signal_size_primary<br>signal_size_secondary<br>third_slot<br>Table 3–9 on page 38 & Table 3–10 on page 39 |
| Error detection bits |                    | P        | Recommended to be used for 10 bit low precision format.                                                       | CRC<br>Table 3–8 on page 37                                                                                |
|                      |                    | CRC      | Recommended to be used for 12 bit high precision format.                                                      |                                                                                                            |

3.4.6. Data Content

The data source (data bits of the payload) for each slot can be defined for each time slot individually. Table 3–4 describes the available options.

Table 3–4: Source and slot options for data bits

| Parameter   | Description                                                                                                                                                                         | Register                                                                                                                                 |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Source      | Source for the data bits can be the <ul style="list-style-type: none"><li>- Position information</li><li>- Position information + quadrant</li><li>- Angle speed</li></ul>          | channels (SETUP_OUTPUT)<br><br>quadrant (SETUP_FRONTEND)<br>third_slot (SETUP_PROTOCOL_1)<br>Table 3–8 on page 37 & Table 3–9 on page 38 |
| Signal size | The signal size can be defined for each source individually. <ul style="list-style-type: none"><li>- Position information 9 ... 16 bit</li><li>- Angle speed 9 ... 16 bit</li></ul> | signal_size_primary (SETUP_PROTOCOL_1, page 38)<br>signal_size_secondary (SETUP_PROTOCOL_2, page 39)                                     |

HAL/HAC 3980 can calculate a quadrant information in addition to the position information. Two quadrant information bits will be added to the position information and both will be send within one time slot. The quadrant information calculation can be activated by the quadrant bit inside the SETUP\_FRONTEND register. The graph below shows how the quadrant information will be transmitted.

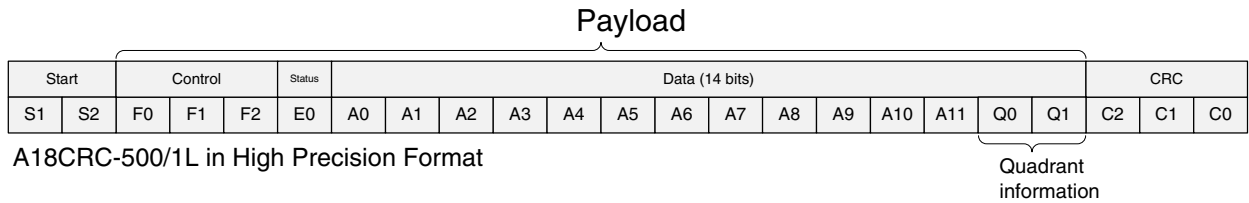


Fig. 3–20: Example for transmission of quadrant information



3.4.6.1. Data Padding

The HAL/HAC 3980 is doing data padding if the selected signal size is smaller than the selected data padding size. In that case the sensor will fill up the frame with zeroes as shown in below example.

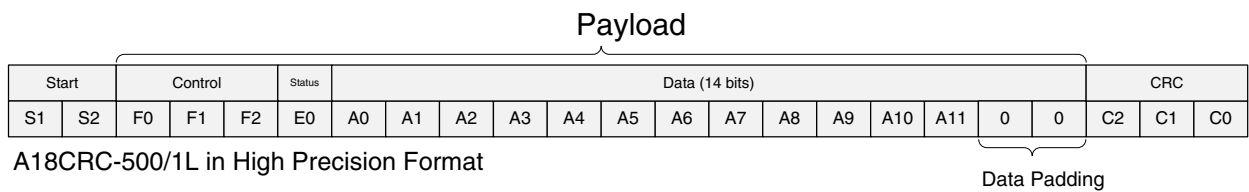


Fig. 3–21: Example for data padding

3.4.7. Sensor Initialization

The initialization behavior of HAL/HAC 3980 is according to the PSI5 standard.

The initialization sequence is triggered by an power-on reset or an undervoltage reset. It is divided into three phases and it is possible to skip certain parts of the initialization phase. The data content is customer configurable by using the Customer ID registers.

The following initialization phase options are supported by the sensor and they can be activated by the init\_seq bits in the SETUP\_PROTOCOL\_1 register.

- Application is started directly after init phase I
- Application is started directly after init phase II
- Application is started directly after init phase III

3.4.7.1. Initialization Phase I

No data is transmitted by HAL/HAC 3980 during initialization phase I. The duration of phase I is customer configurable. The sensor can leave this phase immediately after power-on self-test has been finished or after typically 100 ms. This can be configured by the bit init\_ph\_I\_dur of the SETUP\_PROTOCOL\_1 register.

### 3.4.7.2. Initialization Phase II

The content transmitted during the initialization phase II is partly defined by the PSI5 standard with a fixed content and partly optional. The optional content is customer configurable. The content for initialization phase II can be defined by the CUSTOMER\_IDx registers.

Initialization phase II can be repeated several times. The repetition rate can be defined by the k bits inside the SETUP\_OUTPUT register (Table 3–8 on page 37). Each data nibble can be repeated up to 4 times.

The status bit E0 is set to 0 during the initialization phase II.

**Table 3–5:** Initialization Data Content according PSI5 spec proposal

| ID | Data Nibble | Description                                        | Value        | Remark                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|----|-------------|----------------------------------------------------|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| F1 | D1          | PSI5 revision                                      | configurable | D1: Bits 12...15 in CUSTOMER_ID7 register                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| F2 | D2, D3      | No of data nibbles send in initialization phase II | configurable | D2: Bits 8...11 in CUSTOMER_ID7 register<br>D3: Bits 4...7 in CUSTOMER_ID7 register                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| F3 | D4, D5      | Manufacturer ID                                    | configurable | D4: Bits 0...3 in CUSTOMER_ID7 register<br>D5: Bits 12...15 in CUSTOMER_ID6 register<br>(default is TDK-Micronas vendor ID = 0110 1101, 0x6D)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| F4 | D6, D7      | Sensor type                                        | configurable | D6: Bits 4...7 in CUSTOMER_ID6 register<br>D7: Bits 8...11 in CUSTOMER_ID6 register                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| F5 | D8, D9      | Sensor parameter                                   | configurable | D8: Bits 0...3 in CUSTOMER_ID6 register<br>D9: Bits 12...15 in CUSTOMER_ID5 register                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| F6 | D10, D11    | Sensor code                                        | configurable | D10: Bits 8...11 in CUSTOMER_ID5 register<br>D11: Bits 4...7 in CUSTOMER_ID5 register                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| F7 | D12         | Sensor code like vehicle                           | configurable | D12: Bits 0...3 in CUSTOMER_ID5 register                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| F8 | D13-D16     | Production date                                    | configurable | D13: Bits 12...15 in CUSTOMER_ID4 register<br>D14: Bits 8...11 in CUSTOMER_ID4 register<br>D15: Bits 4...7 in CUSTOMER_ID4 register<br>D16: Bits 0...3 in CUSTOMER_ID4 register                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| F9 | D17-D32     | Lot, serial number, Chip ID, etc.                  | configurable | D17: Bits 12...15 in CUSTOMER_ID3 register<br>D18: Bits 8...11 in CUSTOMER_ID3 register<br>D19: Bits 4...7 in CUSTOMER_ID3 register<br>D20: Bits 0...3 in CUSTOMER_ID3 register<br>D21: Bits 12...15 in CUSTOMER_ID2 register<br>D22: Bits 8...11 in CUSTOMER_ID2 register<br>D23: Bits 4...7 in CUSTOMER_ID2 register<br>D24: Bits 0...3 in CUSTOMER_ID2 register<br>D25: Bits 12...15 in CUSTOMER_ID1 register<br>D26: Bits 8...11 in CUSTOMER_ID1 register<br>D27: Bits 4...7 in CUSTOMER_ID1 register<br>D28: Bits 0...3 in CUSTOMER_ID1 register<br>D29: Bits 12...15 in CUSTOMER_ID0 register<br>D30: Bits 8...11 in CUSTOMER_ID0 register<br>D31: Bits 4...7 in CUSTOMER_ID0 register<br>D32: Bits 0...3 in CUSTOMER_ID0 register |

### 3.4.7.3. Initialization Phase III

During initialization phase III the status bit E0 is used as an error flag and the sensor sends the messages defined in Table 3–6 by using 10 data bits. The behavior is defined by the configuration bits `init_ph_III_lower_bits` of `SETUP_PROTOCOL_2` registers.

**Table 3–6:** Available status messages for initialization phase III

| Status message  | Register:<br><code>init_ph_III_lower_bits</code> ( <code>SETUP_PROTOCOL_2</code> ) | A[5:0]                          | A[15:6] |
|-----------------|------------------------------------------------------------------------------------|---------------------------------|---------|
| “Sensor ready”  | 0                                                                                  | 1                               | 0x1E7   |
|                 | 1                                                                                  | 000000                          | 0x1E7   |
| “Sensor defect” | 0                                                                                  | 0                               | 0x1F4   |
|                 | 1                                                                                  | Error specific, (see Table 3–7) | 0x1F4   |

The initialization phase III can be repeated several times. The repetition rate can be defined with the `init_ph_III_rep` bits in the `SETUP_PROTOCOL_1` register. Repetition rates between 2 and 256 are possible in steps of 2.

### 3.4.8. PSI5 Error Reporting

The error reporting of HAL/HAC 3980 is done through the PSI5 data frame. The data frame content during error reporting depends on the selected frame format.

For the low precision format supporting only 10 data bits the error will be only reported by the 10 data bits by transmitting “Sensor defect” = 0x1F4.

In case that more data bits are configured by the customer like for the example of the high precision frame format, then a more detailed error information is transmitted in addition to the “Sensor defect” code. If data padding is configured, the additional bits are also used for error indication. For data padding higher than 16 bit, the frame is filled with zeros at the LSB side. The following table describes the possible error indication:

**Table 3–7:** Diagnosis bits transmitted according to size of data region

| Size of data region |         | 10    | 11     | 12     | 13     | 14     | 15     | 16     | >16 (data padding) |
|---------------------|---------|-------|--------|--------|--------|--------|--------|--------|--------------------|
| Error detected      | Bit no. |       |        |        |        |        |        |        |                    |
| “Sensor defect”     | MSB     | A0:A9 | A1:A10 | A2:A11 | A3:A12 | A4:A13 | A5:A14 | A6:A15 | A6:A15             |
| Overtemperature     |         |       | A0     | A1     | A2     | A3     | A4     | A5     | A5                 |
| Undervoltage        |         |       |        | A0     | A1     | A2     | A3     | A4     | A4                 |
| Overvoltage         |         |       |        |        | A0     | A1     | A2     | A3     | A3                 |
| Magnet lost         |         |       |        |        |        | A0     | A1     | A2     | A2                 |
| Clipping of signal  |         |       |        |        |        |        |        | A0     | A1                 |
| Memory error        |         |       |        |        |        |        |        | A0     | A0                 |
| Data Padding        |         |       |        |        |        | LSB?   |        |        |                    |

| Start | Status Data (10 bits) |   |   |   |   |   |   |   |   |   |   | Parity |
|-------|-----------------------|---|---|---|---|---|---|---|---|---|---|--------|
| 0     | 0                     | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | P      |

Example: Low Precision Format Error Indication – Sensor defect

| Start |   | Control |    |    | Status | Diagnosis Bits (6 bits) |    |    |    |    |    | Status data (10 bits) |   |   |   |   |   |   |   |   |   | CRC |    |    |
|-------|---|---------|----|----|--------|-------------------------|----|----|----|----|----|-----------------------|---|---|---|---|---|---|---|---|---|-----|----|----|
| 0     | 0 | F0      | F1 | F2 | 1      | A0                      | A1 | A2 | A3 | A4 | A5 | 0                     | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | C2  | C1 | C0 |

Example: High Precision Format Error Indication – Sensor defect

**Fig. 3–22:** Example for error indication in low and high precision format

### 3.4.9. Summary of PSI5 Interface Configuration Registers

This chapter gives an overview about all configuration bits and registers affecting the PSI5 interface. The configuration registers SETUP\_OUTPUT, SETUP\_PROTOCOL\_1 and SETUP\_PROTOCOL\_2 together with the registers PSI5\_START\_SLOT\_x and CUSTOMER\_IDx can be used to configure the PSI5 interface of the sensor according to customers needs.

**Table 3–8: SETUP\_OUTPUT**

| Bit No. | Function          | Description                                                                                                                                                                                                                                                                                  |
|---------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15      | channels          | Selection of transmitted information<br>0: Position information only (primary channel)<br>1: Angle speed as secondary information                                                                                                                                                            |
| 14      | crc               | Defines the calculation method for the protocol checksum<br>0: CRC<br>1: Parity bit                                                                                                                                                                                                          |
| 13      | synchronicity     | Defines the PSI5 communication mode<br>0: Asynchronous (continuous transmission without external trigger)<br>1: Synchronous (ECU trigger driven transmission)                                                                                                                                |
| 12      | baudrate          | Transmission baudrate:<br>0: 125 kbps<br>1: 189 kbps                                                                                                                                                                                                                                         |
| 11      | current_mode      | PSI5 current mode:<br>0: Low power mode ( $\Delta I_S = 13 \text{ mA}$ )<br>1: Common mode ( $\Delta I_S = 26 \text{ mA}$ )                                                                                                                                                                  |
| 10      | status_bit        | Defines the PSI5 status bit:<br>0: No transmission of the status bit<br>1: Transmission of status bit                                                                                                                                                                                        |
| 9       | error_status      | Defines if an error status will be transmitted in case that the status bit is enabled:<br>0: No transmission of error information in the status bit<br>1: Transmission of error information within the status bit                                                                            |
| 8       | third_slot        | Defines the slot position in case that angle speed transmission is activated (channels = 1):<br>0: 1 <sup>st</sup> slot = position information, 2 <sup>nd</sup> slot = angle speed<br>1: 1 <sup>st</sup> and 2 <sup>nd</sup> slot = position information, 3 <sup>rd</sup> slot = angle speed |
| 7:6     | repetition_rate   | PSI5 repetition rate for asynchronous mode:<br>00: 1000 $\mu\text{s}$<br>01: 500 $\mu\text{s}$<br>10: 300 $\mu\text{s}$<br>11: 250 $\mu\text{s}$                                                                                                                                             |
| 5:4     | k                 | Defines the number of repetitions of each data nibble of the initialization sequence of phase II:<br>00: 1<br>01: 2<br>10: 3<br>11: 4                                                                                                                                                        |
| 3:0     | data_padding_size | Defines the data padding size:<br>0000: 9 bit<br>0001: 10 bit<br>...<br>1111: 24 bit                                                                                                                                                                                                         |

**Table 3–9: SETUP\_PROTOCOL\_1**

| Bit No. | Function             | Description                                                                                                                                                                                                                          |
|---------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15:9    | init_ph_III_rep      | Defines the repetition rate of initialization phase III in steps of 2:<br>0: 2 times<br>1: 4 times<br>...<br>127: 256 times                                                                                                          |
| 8       | init_ph_I_dur        | Defines the duration of initialization phase I:<br>0: As fast as possible<br>1: 100 ms                                                                                                                                               |
| 7       | fast_error_codes     | Defines if error codes are transmitted as a part of the data region:<br>0: No transmission of error codes<br>1: Enabled                                                                                                              |
| 6       | frame_control_source | Defines how the frame control bits are used:<br>0: 001 for position information and 010 for angle speed<br>1: Used for a rolling counter                                                                                             |
| 5       | frame_control_bits   | Defines if frame controls are used as a part of the protocol:<br>0: No frame control bits<br>1: 3 frame control bits                                                                                                                 |
| 4:3     | init_seq             | Defines which parts of the initialization phase are activated:<br>00: Application mode after phase I<br>01: Application mode after phase II<br>10: Application mode after phase III<br>11: Reserved                                  |
| 2:0     | signal_size_primary  | Defines the size of the number of bits used for the transmission of the position information (format: signed):<br>000: 9 bit (Can not be combined with error messages and init phase II & III.)<br>001: 10 bit<br>...<br>111: 16 bit |

**Table 3–10: SETUP\_PROTOCOL\_2**

| Bit No. | Function               | Description                                                                                                                                                                                                                                                                                                                        |
|---------|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15      | enable_sample_sync     | Enables synchronization of internal sample clock to external sync pulse:<br>0: Sample synchronization disabled<br>1: Sample synchronization enabled                                                                                                                                                                                |
| 14:8    | target_signal_age      | Sets the target signal age before external sync pulse arrives, when internal sampling is re-enabled. Signal age calculates as $4 \times 0.5 \mu\text{s}$ :<br>0x28: 10 $\mu\text{s}$<br>0x29: 10.25 $\mu\text{s}$<br>...<br>0x7F: 31.75us<br><br><b>Note: Target signal ages below 10 <math>\mu\text{s}</math> are not allowed</b> |
| 7       | init_ph_III_lower_bits | Defines the lower 6 bits (A0-A5) in init phase III in case of an sensor defect error or sensor ready indication<br>0: Bits are 0 for sensor defect and 1 for sensor ready<br>1: Bits are set according to specific errors for sensor defect and 0 for sensor ready                                                                 |
| 6       | secondary_sig_format   | Defines the format of the secondary signal (like angle speed):<br>0: Signed<br>1: Unsigned (9 bits to 15 bits)                                                                                                                                                                                                                     |
| 5       | primary_sig_format     | Defines the format of the primary signal (like position information):<br>0: Signed<br>1: Unsigned (9 bits to 15 bits)                                                                                                                                                                                                              |
| 4       | out_signal             | Defines the output signal configuration:<br>0: PSI5 standard (0x8800 to 0x7800 for 16-bit, 0x220 to 0x1E0 for 10-bit, etc.)<br>1: Full range (0x8000 to 0x7FFF for 16-bit, 0x200 to 0x1FF for 10-bit, etc.)                                                                                                                        |
| 3       | angle_speed_cfg        | Defines the range for the angle speed information:<br>0: $\pm 1000^\circ/\text{s}$<br>1: $\pm 5000^\circ/\text{s}$                                                                                                                                                                                                                 |
| 2:0     | signal_size_secondary  | Defines the size of the number of bits used for the transmission of the angle speed information (format: signed):<br>000: 9 bit (Can not be combined with error messages and init phase II & III.)<br>001: 10 bit<br>...<br>111: 16 bit                                                                                            |

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## PSI5\_START\_SLOTx

The PSI5\_START\_SLOTx registers define the start time of each slot within one PSI5 cycle. PSI5\_START\_SLOT1 defines the time period between the detection of the sync pulse rising edge and the beginning of the 1<sup>st</sup> frame. The start time of the first slot must be selected greater or equal to 44 µs.

PSI5\_START\_SLOT2 defines the time period between the beginning of the 1<sup>st</sup> and 2<sup>nd</sup> frame. PSI5\_START\_SLOT3 defines the time period between the beginning of the 2<sup>nd</sup> and 3<sup>rd</sup> frame.

All three registers use only the 12 LSB for the definition of the period. 1 bit is equivalent to 0.5 µs.

---

### Note

It is important that the following constraint for slot 2 and slot 3 is respected while selecting the slot start times:

$$t_{\text{start}x} - t_{\text{start}(x-1)} \geq (n + 1.6) * T_{\text{bit}} + 3 * T_{\text{sys,clk}}$$

n: Number of transmitted bits of channel x-1 (incl. start bits and parity/CRC)

$$T_{\text{sys,clk}} = 62.5 \text{ ns}$$

---



## 4. Functional Safety

### 4.1. Functional Safety Manual and Functional Safety Report

The Functional Safety Manuals for HAL/HAC 3980 contains the necessary information to support customers to realize a safety compliant application by integrating HAL/HAC 3980 as an ASIL B ready component, in their system. The Functional Safety Manual can be provided upon request.

The Functional Safety Analysis Report describes the assumed Safety Goal, the corresponding Failure Modes as well as the Base Failure Rate for die and package according to IEC TR 62380. It can be provided based on a TDK-Micronas mission profile as well as customer mission profiles.

### 4.2. Integrated Diagnostic Mechanism

HAL/HAC 3980 performs self-tests during start-up and normal operation. These increase the robustness of the device functionality by either preventing the sensor to provide wrong output signals or by reporting the failure according to PSI5 definition. Further details about error reporting see Section 3.4.8. on page 35.

The result of the internal diagnostics is as well available via the DIAGNOSIS\_X registers.

**Table 4–1:** DIAGNOSIS\_0 register

| Bit no. | Description when bit is set to 1                                                   |
|---------|------------------------------------------------------------------------------------|
| 15      | DSP self-check routines (redundancy or plausibility checks)                        |
| 14      | DSP and $\mu$ C check of 16-bit checksum covering the EEPROM parameters            |
| 13      | DSP checksum for ROM and RAM                                                       |
| 12      | Chip junction temperature out of range                                             |
| 11      | Plausibility check of redundant temperature sensor                                 |
| 10      | Hall-plate supply too high                                                         |
| 9       | Hardware overtemperature supervision: Junction temperature > 180°C                 |
| 8       | Reserved                                                                           |
| 7       | At least one of the A/D converters delivers a stuck signal for Channel 1, 2 or 3   |
| 6       | Overflow or underflow of decimation filter                                         |
| 5       | MAG_HIGH threshold has been exceeded                                               |
| 4       | Magnetic field amplitude is below the MAG-LOW threshold                            |
| 3       | The result of the position calculation (high) is out of the expected (valid) range |
| 2       | The result of the position calculation (low) is out of the expected (valid) range  |
| 1       | Hall-plate current out of range                                                    |
| 0       | Reserved                                                                           |

**Table 4–2:** DIAGNOSIS\_1 register

| Bit no.                                                                                                                         | Description when bit is set to 1                |
|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| 15                                                                                                                              | Reserved                                        |
| 14 & 12                                                                                                                         | General purpose ADC error                       |
| 13                                                                                                                              | Reserved                                        |
| 11                                                                                                                              | Undervoltage Error. Supply voltage out of range |
| 10                                                                                                                              | Overvoltage Error. Supply voltage out of range  |
| 9                                                                                                                               | Internal analog voltage out of range            |
| 8                                                                                                                               | Internal digital voltage out of range           |
| <b>Note: Bits [7:0] can not be read via the programming interface as they are triggering immediately a reset of the device.</b> |                                                 |

5. Specifications

5.1. Outline Dimensions

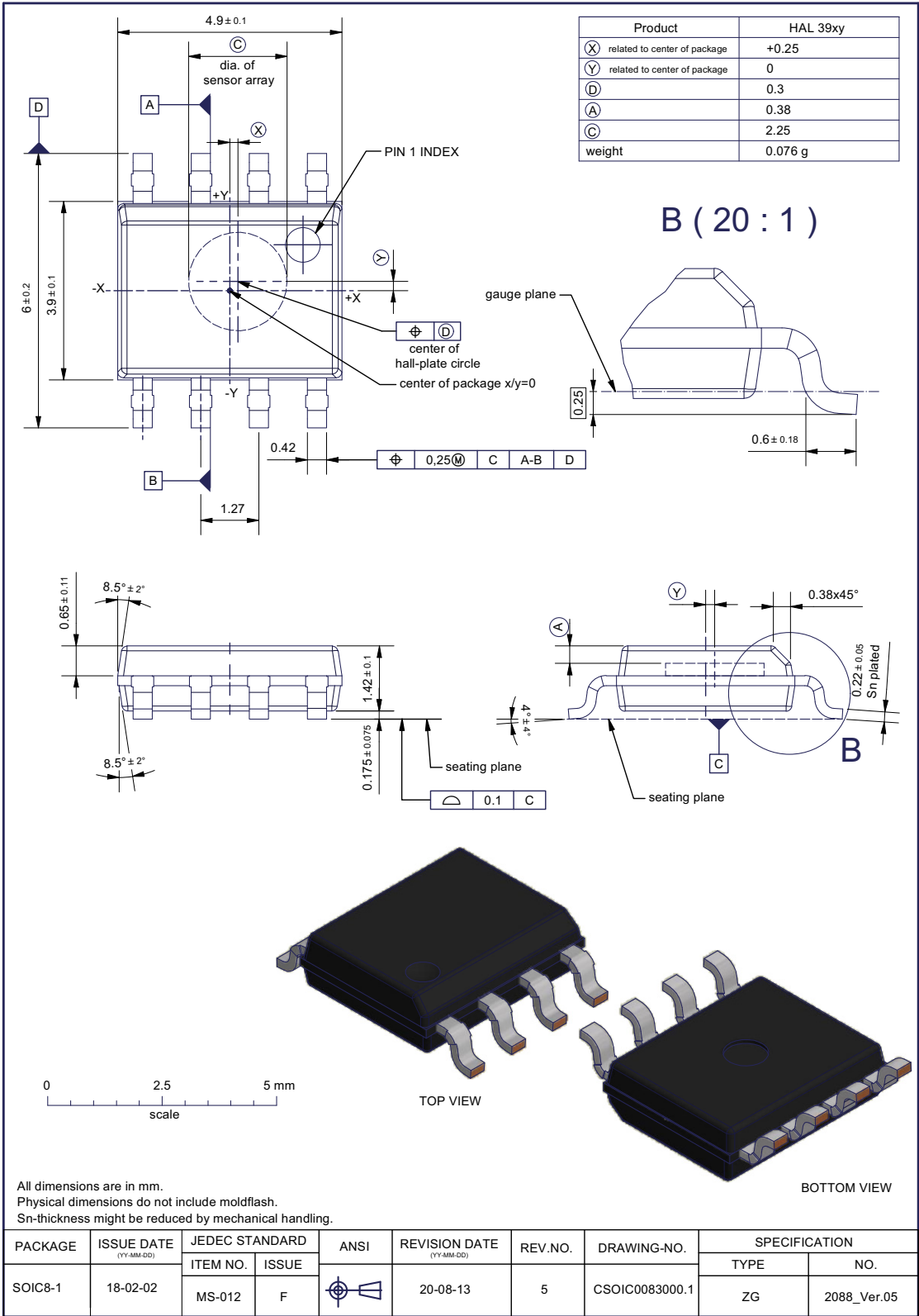
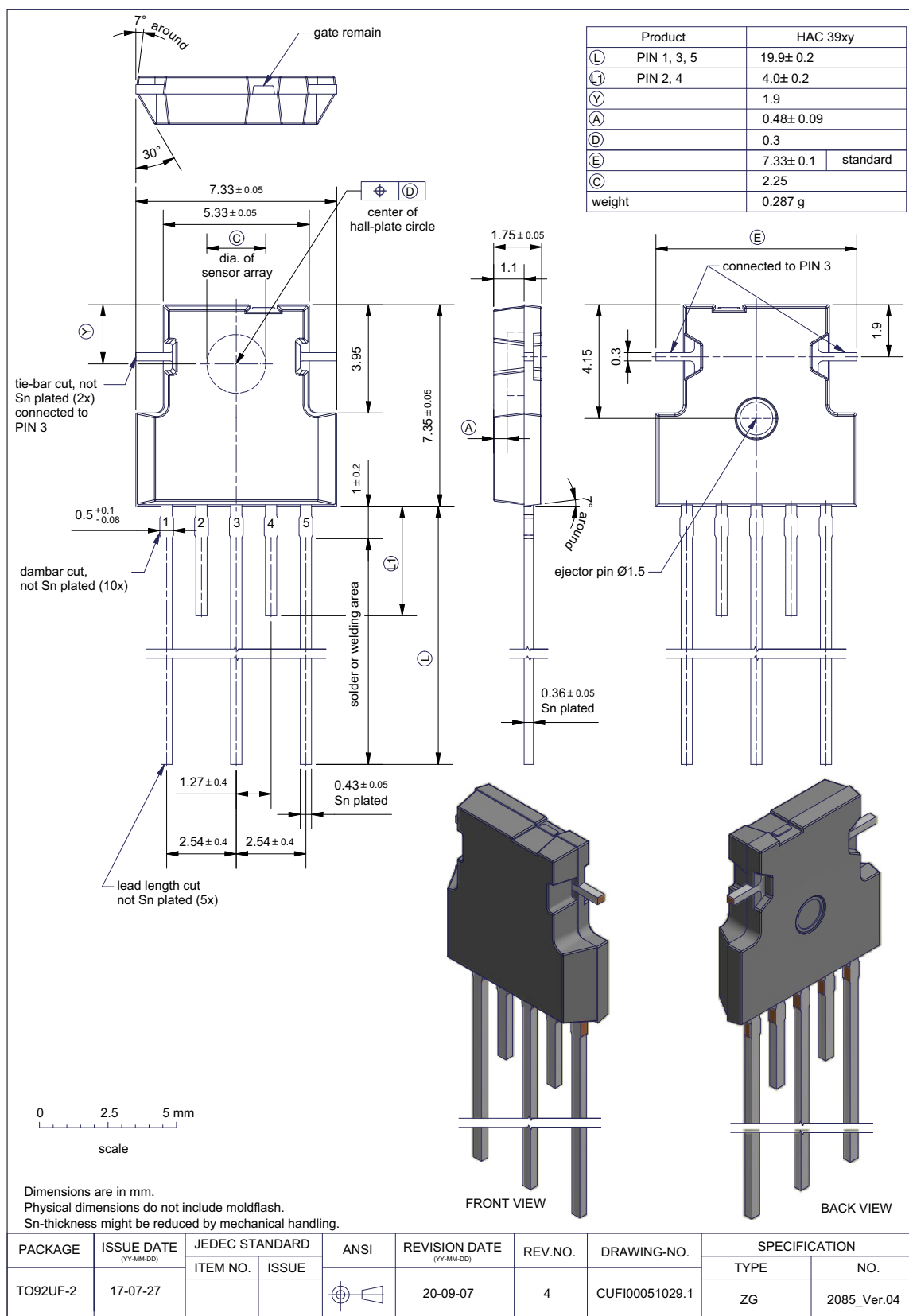
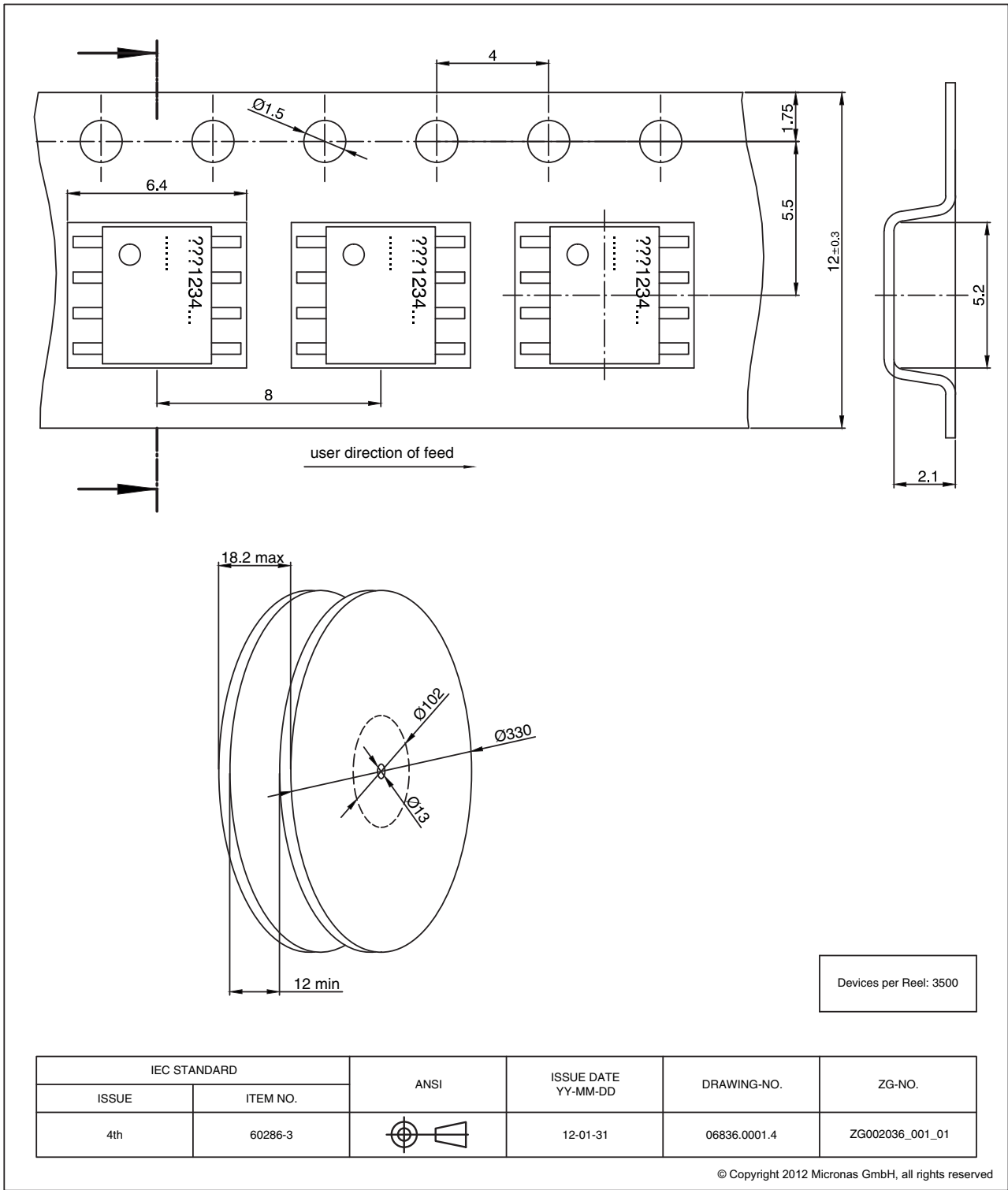


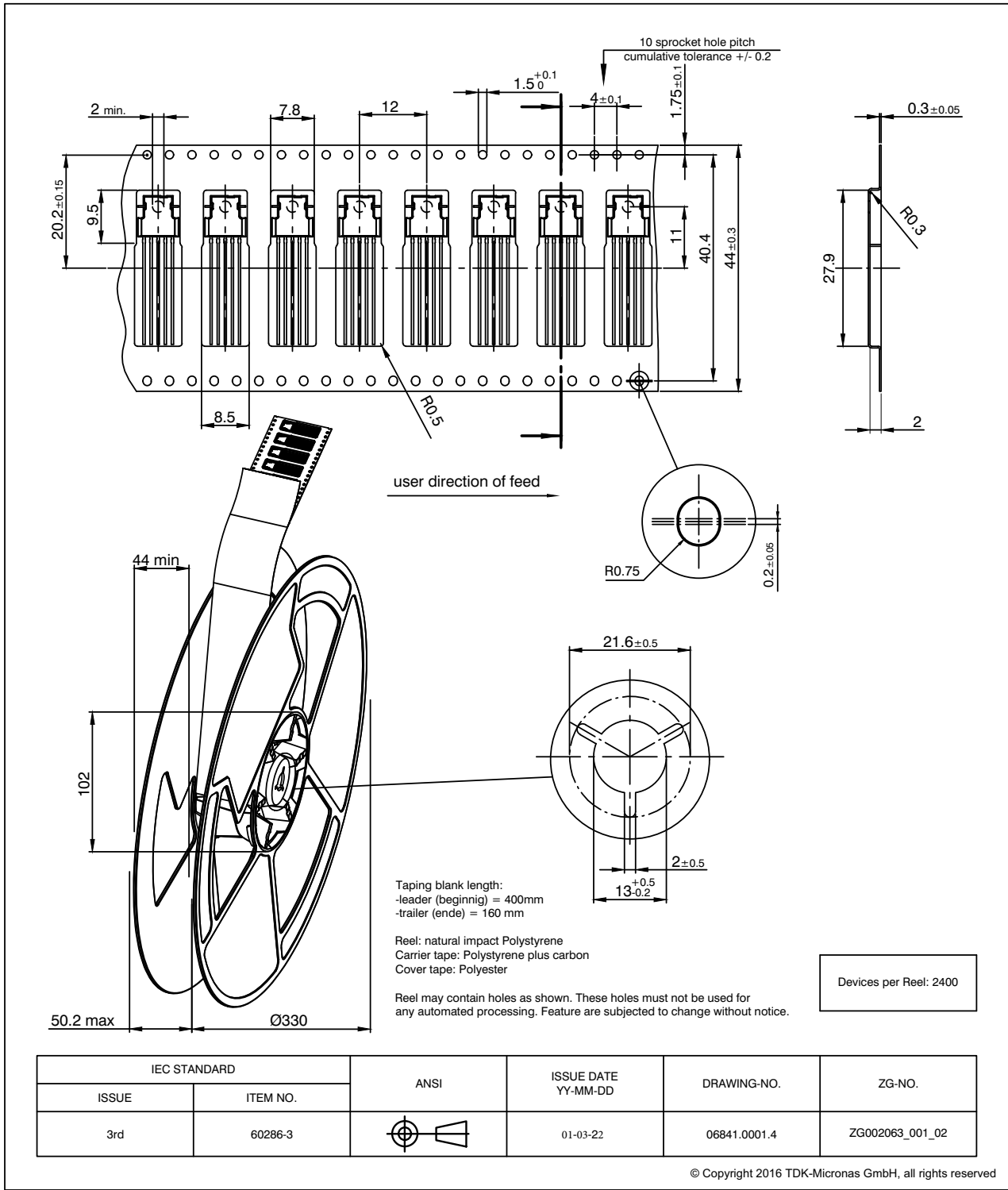
Fig. 5-1:  
SOIC8-1: Plastic Small Outline IC package, 8 leads, gullwing bent, 150 mil  
Ordering code: DJ



**Fig. 5-2:**  
TO92UF-2 Plastic Transistor Standard UF package, 3 leads, inline



**Fig. 5–3:**  
**SOIC8-1: Dimensions Tape & Reel**



**Fig. 5-4:**  
**TO92UF: Tape and Reel Finishing**

## 5.2. Soldering, Welding, Assembly

Information related to solderability, welding, assembly, and second-level packaging is included in the document “Guidelines for the Assembly of Micronas Packages”.

It is available on the TDK-Micronas website (<https://www.micronas.tdk.com/en/service-center/downloads>) or on the service portal (<http://service.micronas.com>).

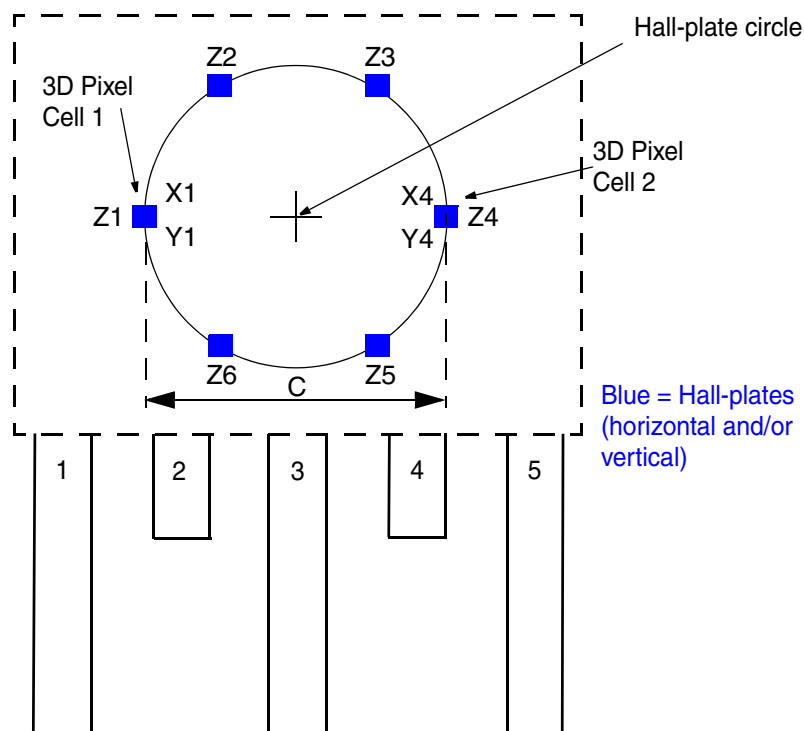
## 5.3. Storage and Shelf Life Package

Information related to storage conditions of TDK-Micronas sensors is included in the document “Guidelines for the Assembly of Micronas Packages”. It gives recommendations linked to moisture sensitivity level and long-term storage.

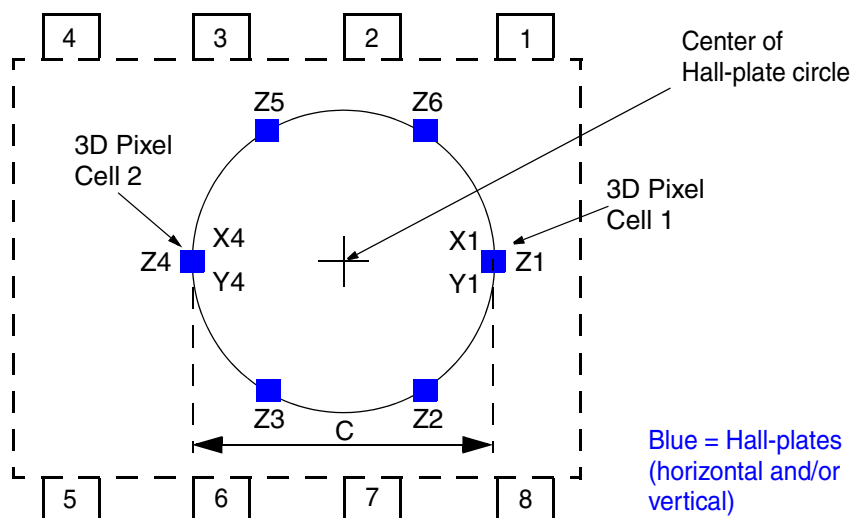
It is available on the TDK-Micronas website (<https://www.micronas.tdk.com/en/service-center/downloads>) or on the service portal (<http://service.micronas.com>).

## 5.4. Size and Position of Sensitive Areas

Diameter of hall plate circle:  $C = 2.25 \text{ mm}$

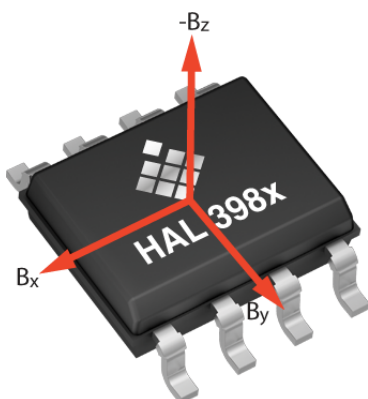


**Fig. 5–5:** Hall-plate configuration for HAC 3980

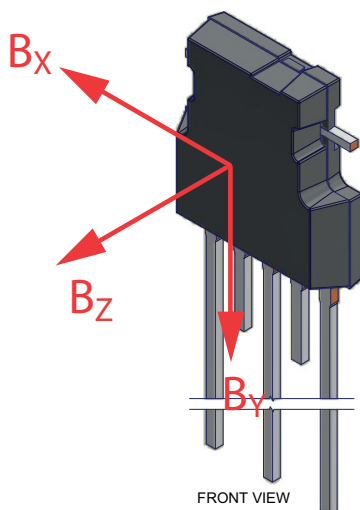


**Fig. 5–6:** Hall-plate configuration for HAL 3980

## 5.5. Definition of Magnetic-Field Vectors



**Fig. 5–7:** Definition of magnetic-field vectors for HAL 3980



**Fig. 5–8:** Definition of magnetic-field vectors for HAC 3980



5.6. Pin Connections and Short Description

Table 5–1: Pin connection SOIC8

| Pin No. | Pin Name | Type | Short Description                  |
|---------|----------|------|------------------------------------|
| 1       | VSUP     | IN   | Supply voltage and programming pin |
| 2       | GND      | GND  | Ground                             |
| 3       | TEST1    | IN   | Test                               |
| 4       | TEST2    | I/O  | Test                               |
| 5       | TEST3    | OUT  | Test                               |
| 6       | TEST4    | N/A  | Test                               |
| 7       | TEST5    | N/A  | Test                               |
| 8       | TEST6    | N/A  | Test                               |

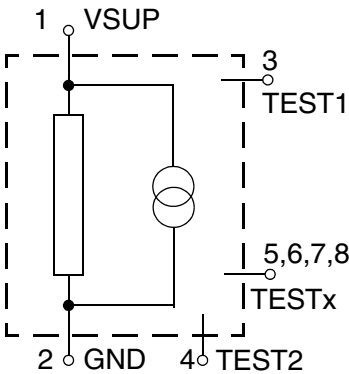


Fig. 5–9: Pin configuration for SOIC8 package

**Note** Pins 2 and 3 must be connected to GND. Pins 4 to 8 must stay open.

Table 5–2: Pin connection TO92UF

| Pin No. | Pin Name | Type | Short Description                  |
|---------|----------|------|------------------------------------|
| 1       | VSUP     | IN   | Supply voltage and programming pin |
| 2       | TEST1    | N/A  | Test                               |
| 3       | GND      | GND  | Ground                             |
| 4       | TEST2    | IN   | Test                               |
| 5       | TEST3    | N/A  | Test                               |

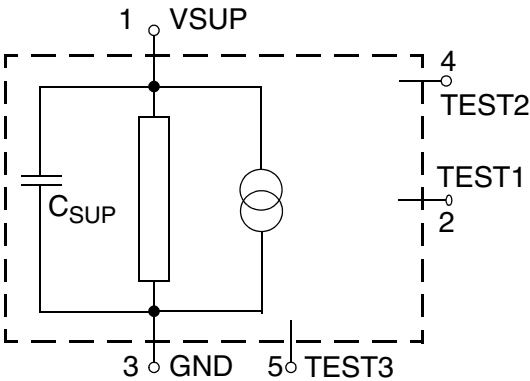


Fig. 5–10: Pin configuration for TO92UF package

**Note** Pin 3 must be connected to GND. Pins 2 and 4 to 5 must stay open.

## 5.7. Absolute Maximum Ratings

Stresses beyond those listed in the “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only. Functional operation of the device at these conditions is not implied. Exposure to absolute maximum rating conditions for extended periods will affect device reliability.

This device contains circuitry to protect the inputs and outputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions must be taken to avoid application of any voltage higher than absolute maximum-rated voltages to this high-impedance circuit.

All voltages listed are referenced to ground (GND).

| Symbol               | Parameter                                     | Pin Name         | Min. | Max.     | Unit   | Condition                            |
|----------------------|-----------------------------------------------|------------------|------|----------|--------|--------------------------------------|
| V <sub>SUP</sub>     | Supply Voltage                                | VSUP             | −18  | 28<br>37 | V<br>V | t < 60s; T <sub>J</sub> =25°C        |
| B <sub>max</sub>     | Magnetic Field                                | –                | −1   | 1        | T      |                                      |
| T <sub>J</sub>       | Junction Temperature                          | –                | −40  | 190      | °C     | t < 96h <sup>1)</sup>                |
| T <sub>A</sub>       | Ambient Temperature                           | –                | −40  | 125      | °C     | <sup>2)</sup>                        |
| T <sub>storage</sub> | Transportation/Short Term Storage Temperature | –                | −55  | 150      | °C     | Device only without packing material |
| V <sub>ESD</sub>     | ESD Protection                                | VSUP, GND, TESTx | −2   | 2        | kV     | <sup>3)</sup>                        |
|                      |                                               | VSUP, GND        | −4   | 4        | kV     | <sup>4)</sup> <sup>5)</sup>          |

No cumulative stress for all parameters.

<sup>1)</sup> Please contact TDK-Micronas for other temperature requirements.

<sup>2)</sup> Consider current consumption, mounting condition (e.g. overmold, potting) and mounting situation for T<sub>A</sub> and in relation to T<sub>J</sub>.

<sup>3)</sup> ESD HBM according to AEC-Q100-002 (100 pF and 1.5 kΩ).

<sup>4)</sup> Unpowered gun test (150 pF/330 Ω or 330 pF/2 kΩ) according to ISO 10605-2008.

<sup>5)</sup> With additional protection on the PCB (10 nF on VSUP; for HAL 3980).

## 5.8. Recommended Operating Conditions

Functional operation of the device beyond those indicated in the “Recommended Operating Conditions/Characteristics” is not implied and may result in unpredictable behavior, reduced reliability and lifetime of the device.

All voltages listed are referenced to ground (GND).

| Symbol                                                                                                                                                                                                                                                                          | Parameter                            | Pin Name | Min. | Typ. | Max. | Unit   | Condition                                                                                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|----------|------|------|------|--------|--------------------------------------------------------------------------------------------|
| V <sub>SUP</sub>                                                                                                                                                                                                                                                                | Supply Voltage                       | VSUP     | 4.0  | –    | 11   | V      | Voltage value at the sensor pins without communication and synchronization pulse (static). |
| V <sub>SUP,Max</sub>                                                                                                                                                                                                                                                            | Maximum Interface Voltage            | VSUP     | –    | –    | 16.5 | V      | Voltage value at the sensor pins with communication and synchronization pulse.             |
| C <sub>SUP</sub>                                                                                                                                                                                                                                                                | Supply Capacitor                     | VSUP     | –    | 10   | 15   | nF     | Max. value is defined by PSI5 standard                                                     |
| N <sub>PRG</sub>                                                                                                                                                                                                                                                                | Number of Memory Programming Cycles  | –        | –    | –    | 100  | cycles | 0 °C < T <sub>amb</sub> < 55 °C                                                            |
| B <sub>AMP</sub>                                                                                                                                                                                                                                                                | Recommended Magnetic-Field Amplitude | –        | ±10  | –    | ±130 | mT     |                                                                                            |
| T <sub>J</sub>                                                                                                                                                                                                                                                                  | Junction Temperature                 |          | –40  | –    | 170  | °C     | 1) for 1000 h                                                                              |
| T <sub>A</sub>                                                                                                                                                                                                                                                                  | Ambient Temperature                  |          | –40  | –    | 125  | °C     | 2)                                                                                         |
| 1) Depends on the temperature profile of the application. Please contact TDK-Micronas for life time calculations.<br>2) Consider current consumption, mounting condition (e.g. overmold, potting) and mounting situation for T <sub>A</sub> and in relation to T <sub>J</sub> . |                                      |          |      |      |      |        |                                                                                            |

**Note** It is possible to operate the sensor with magnetic fields down to ±5 mT. For magnetic fields below ±10 mT, the sensor performance will be reduced.

## 5.9. Characteristics

at  $T_A = -40\text{ }^{\circ}\text{C}$  to  $125\text{ }^{\circ}\text{C}$ ,  $V_{\text{SUP}} = 4.0\text{ V}$  to  $11.0\text{ V}$ ,  $\text{GND} = 0\text{ V}$ , after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column "Test Conditions".

Typical Characteristics for  $T_A = 25\text{ }^{\circ}\text{C}$  and  $V_{\text{SUP}} = 5\text{ V}$ .

| Symbol                                                                                                                    | Parameter                                              | Pin Name | Limit Values |      |      | Unit   | Test Conditions                                                                                                   |
|---------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|----------|--------------|------|------|--------|-------------------------------------------------------------------------------------------------------------------|
|                                                                                                                           |                                                        |          | Min.         | Typ. | Max. |        |                                                                                                                   |
| I <sub>S,low</sub>                                                                                                        | Normal Supply Current (Quiescent Current)              | VSUP     | tbd.         | 8    | 12   | mA     | 1)                                                                                                                |
| ΔI <sub>S,low</sub>                                                                                                       | Low Power Mode Sink Current                            | VSUP     | 11           | 13   | 15   | mA     | = I <sub>S,high</sub> - I <sub>S,low</sub><br>Customer configurable.<br>Bit current_mode in SETUP_OUTPUT register |
| ΔI <sub>S,common</sub>                                                                                                    | Common Mode Sink Current                               | VSUP     | 22           | 26   | 30   | mA     | = I <sub>S,high</sub> - I <sub>S,low</sub><br>Customer configurable.<br>Bit current_mode in SETUP_OUTPUT register |
| ΔI <sub>SUPRate</sub>                                                                                                     | Quiescent Current Drift Rate                           | VSUP     | –            | –    | 3    | mA/s   | 1)                                                                                                                |
| Power-On Behavior                                                                                                         |                                                        |          |              |      |      |        |                                                                                                                   |
| V <sub>POR</sub>                                                                                                          | Power_On Reset Voltage                                 | VSUP     | 2.1          | 2.6  | 2.9  | V      |                                                                                                                   |
| V <sub>PORHyst</sub>                                                                                                      | Power_On Reset Voltage Hysteresis                      | VSUP     | –            | 200  | –    | mV     |                                                                                                                   |
| Overvoltage and Undervoltage Detection                                                                                    |                                                        |          |              |      |      |        |                                                                                                                   |
| S <sub>VSUP,OUV</sub>                                                                                                     | Step Size of Under-/Over-voltage Supervision Threshold | VSUP     | 92           | 100  | 108  | mV/LSB | 1) Under-/Overvoltage threshold is customer configurable (see page 24).                                           |
| S <sub>SUP,UOVhys</sub>                                                                                                   | Under-/Overvoltage Detection Level Hysteresis          | VSUP     | –            | 1    | –    | LSB    | 1 LSB typ. 100 mV                                                                                                 |
| PSI5 Timing Parameter                                                                                                     |                                                        |          |              |      |      |        |                                                                                                                   |
| t <sub>repetition</sub>                                                                                                   | Repetition rate                                        | VSUP     | –            | 250  | –    | μs     | 1) Customer configurable<br>Bit repetition_rate in SETUP_OUTPUT register                                          |
|                                                                                                                           |                                                        |          | –            | 300  | –    |        |                                                                                                                   |
|                                                                                                                           |                                                        |          | –            | 500  | –    |        |                                                                                                                   |
|                                                                                                                           |                                                        |          | –            | 1000 | –    |        |                                                                                                                   |
| 1) Characterized on small sample size.<br>2) Average delay between magnet movement and the response of the sensor output. |                                                        |          |              |      |      |        |                                                                                                                   |

| Symbol                                                                                                                                                                                                                               | Parameter                                      | Pin Name | Limit Values |       |      | Unit              | Test Conditions                                                                                                                                                     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|----------|--------------|-------|------|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                      |                                                |          | Min.         | Typ.  | Max. |                   |                                                                                                                                                                     |
| T <sub>step</sub>                                                                                                                                                                                                                    | Step Response Time                             | VSUP     | –            | 460   | –    | μs                | 1)2) Sampling synchronized with PSI5 Sync pulse<br>SETUP_PROTOCOL_2 [15]<br>f <sub>sample</sub> = 7.812 kSps<br>data padding size: 20 bit<br>125 kbps mode          |
|                                                                                                                                                                                                                                      |                                                |          | –            | 750   | –    | μs                | 1)2) Sampling not synchro-<br>nized with PSI5 Sync pulse<br>SETUP_PROTOCOL_2 [15]<br>f <sub>sample</sub> = 7.812 kSps<br>data padding size: 20 bit<br>125 kbps mode |
| T <sub>latency</sub>                                                                                                                                                                                                                 | Latency Time                                   | VSUP     | –            | 500   | –    | μs                | 1)3) No filtering<br>f <sub>sample</sub> = 7.812 kSps<br>data padding size: 20 bit<br>125 kbps mode                                                                 |
| t <sub>Sync_hold</sub>                                                                                                                                                                                                               | Sync Pulse Hold Time                           | VSUP     | 16           | –     | 35   | μs                | 1) For common mode                                                                                                                                                  |
| Δt <sub>Detect</sub>                                                                                                                                                                                                                 | Tolerance of Internal Trigger Detection Delay  | VSUP     | –            | –     | 3    | μs                | 1)                                                                                                                                                                  |
| t <sub>Bit</sub>                                                                                                                                                                                                                     | Bit time                                       | VSUP     | 7.6          | 8.0   | 8.4  | μs                | 1) 125 kbps mode                                                                                                                                                    |
|                                                                                                                                                                                                                                      |                                                |          | 5.0          | 5.3   | 5.6  | μs                | 1) 189 kbps mode                                                                                                                                                    |
| t <sub>rise,fall</sub>                                                                                                                                                                                                               | Rise/Fall Time of Current Slope                | VSUP     | 0.33         | –     | 1.0  | μs                | 1) 20% to 80% of ΔI <sub>S,x</sub>                                                                                                                                  |
| MSR                                                                                                                                                                                                                                  | Mark/Space Ratio                               | VSUP     | 47           | 50    | 53   | %                 | 1) at the sensor<br>(t <sub>fall,80</sub> - t <sub>rise,20</sub> ) / t <sub>Bit</sub><br>(t <sub>fall,20</sub> - t <sub>rise,80</sub> ) / t <sub>Bit</sub>          |
| t <sub>ucut</sub>                                                                                                                                                                                                                    | Microcut rejection                             | VSUP     | 0.5          | –     | –    | μs                | 1) C <sub>SUP</sub> = 10 nF; V <sub>SUP</sub> > 5 V                                                                                                                 |
| f <sub>osc</sub>                                                                                                                                                                                                                     | Internal Oscillator Frequency                  | –        | –            | 32    | –    | MHz               |                                                                                                                                                                     |
| Δf <sub>osc</sub>                                                                                                                                                                                                                    | Accuracy of Internal Oscil-<br>lator Frequency | –        | –3           | –     | 3    | %f <sub>OSC</sub> | Full temperature range                                                                                                                                              |
|                                                                                                                                                                                                                                      |                                                | –        | –3           | –     | 3    | %f <sub>OSC</sub> | Drift related to 25°C                                                                                                                                               |
| f <sub>sample</sub>                                                                                                                                                                                                                  | Sampling Frequency                             |          | –            | 1.953 | –    | kSps              | 1) Configurable                                                                                                                                                     |
|                                                                                                                                                                                                                                      |                                                |          | –            | 3.906 | –    |                   |                                                                                                                                                                     |
|                                                                                                                                                                                                                                      |                                                |          | –            | 7.812 | –    |                   |                                                                                                                                                                     |
| t <sub>Startup</sub>                                                                                                                                                                                                                 | Start-up Time                                  | VSUP     | –            | –     | 10   | ms                | 1) Time till start of Init Phase I                                                                                                                                  |
| PSI5 Sync Pulse Voltages                                                                                                                                                                                                             |                                                |          |              |       |      |                   |                                                                                                                                                                     |
| V <sub>Trigger</sub>                                                                                                                                                                                                                 | Trigger Voltage Threshold                      | VSUP     | 1.1          | 1.8   | 2.6  | V                 | 1) Common mode                                                                                                                                                      |
|                                                                                                                                                                                                                                      |                                                |          | 0.7          | 1.4   | 2.1  | V                 | 1) Low power mode                                                                                                                                                   |
| 1) Characterized on small sample size.<br>2) Delay between magnet movement and response of the sensor output (see Section Fig. 5–11: on page 55).<br>3) Average delay between magnet movement and the response of the sensor output. |                                                |          |              |       |      |                   |                                                                                                                                                                     |

| Symbol                                                                                                       | Parameter                           | Pin Name | Limit Values |      |      | Unit | Test Conditions                                   |
|--------------------------------------------------------------------------------------------------------------|-------------------------------------|----------|--------------|------|------|------|---------------------------------------------------|
|                                                                                                              |                                     |          | Min.         | Typ. | Max. |      |                                                   |
| SOIC8 Package                                                                                                |                                     |          |              |      |      |      |                                                   |
| R <sub>thja</sub>                                                                                            | Thermal Resistance Junction to Air  | —        | —            | —    | 140  | K/W  | <sup>4)</sup> Determined with a 1S0P board        |
|                                                                                                              |                                     | —        | —            | —    | 93   | K/W  | <sup>4)</sup> Determined with a 2S2P board        |
| R <sub>thjc</sub>                                                                                            | Thermal Resistance Junction to Case | —        | —            | —    | 33   | K/W  | <sup>4)</sup> Determined with a 1S0P & 2S2P board |
| TO92UF Package                                                                                               |                                     |          |              |      |      |      |                                                   |
| R <sub>thja</sub>                                                                                            | Thermal Resistance Junction to Air  | —        | —            | —    | 181  | K/W  | <sup>4)</sup> Determined with a 1S0P board        |
|                                                                                                              |                                     | —        | —            | —    | 122  | K/W  | <sup>4)</sup> Determined with a 2S2P board        |
|                                                                                                              |                                     | —        | —            | —    | 85   | K/W  | <sup>5)</sup> Without PCB                         |
| R <sub>thjc</sub>                                                                                            | Thermal Resistance Junction to Case | —        | —            | —    | 30   | K/W  | <sup>4)</sup> Determined with a 1S0P              |
|                                                                                                              |                                     | —        | —            | —    | 29   |      | <sup>4)</sup> Determined with a 2S2P board        |
| <sup>4)</sup> Self-heating calculation see Section 6.1. on page 62.                                          |                                     |          |              |      |      |      |                                                   |
| <sup>5)</sup> PCB-less assembly has been simulated based on an example package design. For information only. |                                     |          |              |      |      |      |                                                   |

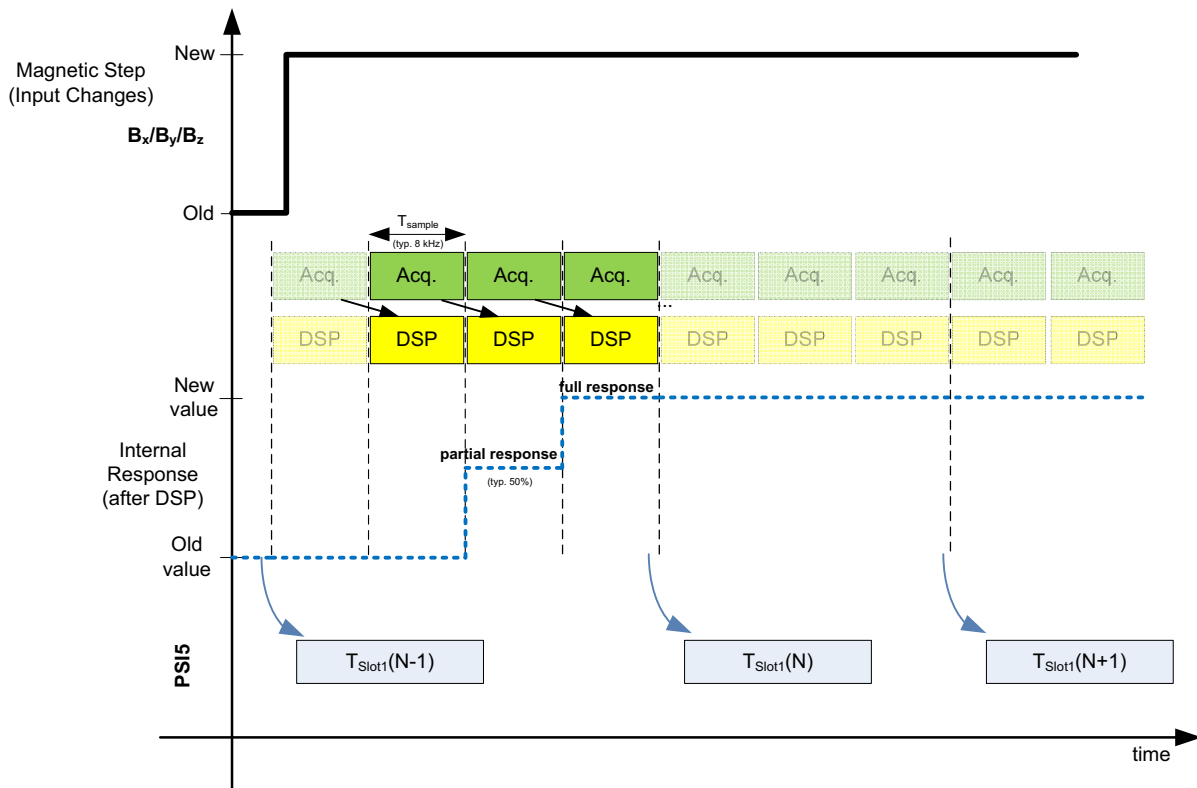
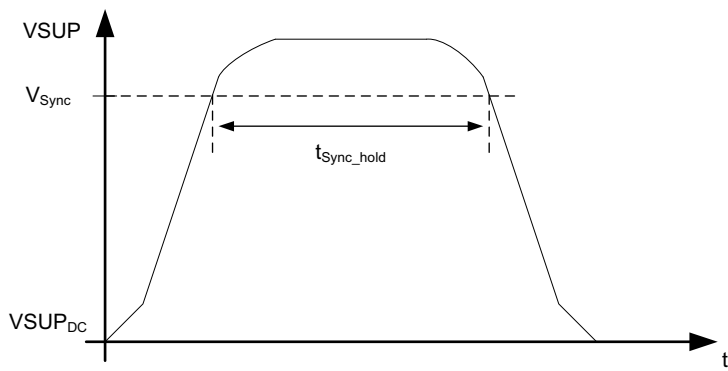


Fig. 5–11: Step response behavior of HAL/HAC 3980



**Fig. 5–12:** Definition of synchronization pulse and timing



## 5.10. Magnetic Characteristics

at  $T_A = -40\text{ }^{\circ}\text{C}$  to  $125\text{ }^{\circ}\text{C}$ ,  $V_{\text{SUP}} = 4.0\text{ V}$  to  $11.0\text{ V}$ ,  $\text{GND} = 0\text{ V}$ , after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column "Test Conditions".

Typical Characteristics for  $T_A = 25\text{ }^{\circ}\text{C}$  and  $V_{\text{SUP}} = 5.0\text{ V}$ .

| Symbol                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Parameter                                                                              | Pin No. | Min.  | Typ. | Max. | Unit                        | Test Conditions                                                                                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|---------|-------|------|------|-----------------------------|-------------------------------------------------------------------------------------------------|
| <b>Rotary Setup with Stray-Field Compensation (Setup 1 &amp; 2)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                        |         |       |      |      |                             |                                                                                                 |
| $\Delta E_{\text{tot}}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Total Angular Error of Drifts                                                          | VSUP    | -0.85 | —    | 0.85 | $^{\circ}$                  | <sup>1)</sup> $B_{\text{AMP}} = \pm 10\text{ mT}$<br>Setup 2 (3Z-Plates)                        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                        |         | -0.45 | —    | 0.45 |                             | <sup>1)</sup> $B_{\text{AMP}} = \pm 10\text{ mT}$<br>Setup 1 (6Z-Plates)                        |
| $\Delta E_{\text{temp}}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Angular Error Drift over Temperature                                                   | VSUP    | -0.5  | —    | 0.5  | $^{\circ}$                  | <sup>1)</sup> $B_{\text{AMP}} = \pm 10\text{ mT}$                                               |
| $\Delta E_{\text{life}}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Angular Error Drift over Lifetime                                                      | VSUP    | -0.45 | —    | 0.45 | $^{\circ}$                  | <sup>1)</sup> $B_{\text{AMP}} = \pm 10\text{ mT}$<br>Setup 2 (3Z-Plates)<br>After 1008 hrs HTOL |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                        |         | -0.2  | —    | 0.2  | $^{\circ}$                  | <sup>1)</sup> $B_{\text{AMP}} = \pm 10\text{ mT}$<br>Setup 1 (6Z-Plates)<br>After 1008 hrs HTOL |
| $E_{\text{ohyst}}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Angular Hysteresis Error                                                               | VSUP    | —     | —    | 0.05 | $^{\circ}$                  | <sup>2)</sup>                                                                                   |
| $E_{\text{noise}_1}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Angular Noise Setup 1                                                                  | VSUP    | —     | 0.13 | 0.23 | $^{\circ}$                  | <sup>3)</sup> Setup 1 (6Z-Plates)                                                               |
| $E_{\text{noise}_2}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Angular Noise Setup 2                                                                  | VSUP    | —     | 0.19 | 0.33 | $^{\circ}$                  | <sup>3)</sup> Setup 2 (3Z-Plates)                                                               |
| $E_{\text{SF}_1}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Angular Error due to Stray-Field for Setup 1                                           | VSUP    | —     | —    | 0.1  | $^{\circ}$                  | <sup>14)</sup> $B_{\text{AMP}} = \pm 10\text{ mT}$ wanted signal; Setup 1 (6Z-Plates)           |
| $E_{\text{SF}_2}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Angular Error due to Stray-Field for Setup 2                                           | VSUP    | —     | —    | 0.12 | $^{\circ}$                  | <sup>14)</sup> $B_{\text{AMP}} = \pm 10\text{ mT}$ wanted signal; Setup 2 (3Z-Plates)           |
| <b>Linear Movement Setup (<math>\Delta XZ</math>) with Stray-Field Compensation (Setup 3b)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                        |         |       |      |      |                             |                                                                                                 |
| $SM_{\Delta XZ41}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Sensitivity Mismatch between $\Delta X_{41}$ and $\Delta Z_{41}$ Channel               | VSUP    | -5    | —    | 5    | %                           | <sup>1)</sup> $T_A = 25\text{ }^{\circ}\text{C}$                                                |
| $\text{Sense}_{\Delta XZ41}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Sensitivity of $\Delta X_{41}$ and $\Delta Z_{41}$ Channel                             | VSUP    | 121   | 128  | 135  | $\text{LSB}_{15}/\text{mT}$ | <sup>1)</sup> $T_A = 25\text{ }^{\circ}\text{C}$                                                |
| $\Delta SM_{\Delta XZ41}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Thermal Sensitivity Mismatch Drift between $\Delta X_{41}$ and $\Delta Z_{41}$ Channel | VSUP    | -2.5  | —    | 2.5  | %                           | <sup>1)</sup> Related to $T_A = 25\text{ }^{\circ}\text{C}$<br>HAL 3980                         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                        |         | -3.0  | —    | 3.0  | %                           | <sup>1)</sup> Related to $T_A = 25\text{ }^{\circ}\text{C}$<br>HAC 3980                         |
| $\text{Offset}_{\Delta X41}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Offset of $\Delta X_{41}$ Channel                                                      | VSUP    | -30   | —    | 30   | $\text{LSB}_{15}$           | $T_A = 25\text{ }^{\circ}\text{C}$                                                              |
| <p>All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not EOL tested).</p> <p><sup>1)</sup> Based on Simulation Model (not EOL tested).</p> <p><sup>2)</sup> Guaranteed by Design.</p> <p><sup>3)</sup> Characterized on small sample size, <math>B_{\text{AMP}} = \pm 10\text{ mT}</math>, <math>f_{\text{dc sel}} = 2\text{ kHz}</math>, Low-pass filter: off, 3-sigma values (not EOL tested).</p> <p><sup>4)</sup> Characterized on small sample size according to ISO 11452-8:2015, at <math>25\text{ }^{\circ}\text{C}</math>, with stray-field strength of <math>4\text{ kA/m}</math> from X, Y and Z direction, 3-sigma values (not EOL tested).</p> |                                                                                        |         |       |      |      |                             |                                                                                                 |

| Symbol                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Parameter                                                                                                 | Pin No. | Min. | Typ. | Max. | Unit                  | Test Conditions                                                  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|---------|------|------|------|-----------------------|------------------------------------------------------------------|
| Offset <sub>ΔZ41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Offset of ΔZ <sub>41</sub> Channel                                                                        | VSUP    | -15  | –    | 15   | LSB <sub>15</sub>     | T <sub>A</sub> = 25 °C                                           |
| ΔOffset <sub>ΔX41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Offset Drift of ΔX <sub>41</sub> Channel                                                                  | VSUP    | -50  | –    | 50   | LSB <sub>15</sub>     | Related to T <sub>A</sub> = 25 °C                                |
| ΔOffset <sub>ΔZ41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Offset Drift of ΔZ <sub>41</sub> Channel                                                                  | VSUP    | -15  | –    | 15   | LSB <sub>15</sub>     | Related to T <sub>A</sub> = 25 °C                                |
| ΔSM <sub>ΔXZ41life</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Relative Sensitivity Mismatch Drift between ΔX <sub>41</sub> and ΔZ <sub>41</sub> Channel over life time  | VSUP    | –    | 1.0  | –    | %                     | <sup>1)</sup> After 1000 h HTOL                                  |
| ΔOffset <sub>ΔX41life</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Offset Drift of ΔX <sub>41</sub> Channel over life time                                                   | VSUP    | –    | 30   | –    | LSB <sub>15</sub>     | After 1008 h HTOL                                                |
| ΔOffset <sub>ΔZ41life</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Offset Drift of ΔZ <sub>41</sub> Channel over life time                                                   | VSUP    | –    | 7    | –    | LSB <sub>15</sub>     | After 1008 h HTOL                                                |
| SF <sub>RΔX41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Stray-Field Rejection in ΔX <sub>41</sub> Direction                                                       | VSUP    | 99   | –    | –    | %                     | <sup>4)</sup> T <sub>A</sub> = 25 °C                             |
| SF <sub>RΔZ41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Stray-Field Rejection in ΔZ <sub>41</sub> Direction                                                       | VSUP    | 96   | –    | –    | %                     | <sup>4)</sup> T <sub>A</sub> = 25 °C; HAL 3980                   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                           |         | 97   | –    | –    | %                     | <sup>4)</sup> T <sub>A</sub> = 25 °C; HAC 3980                   |
| E <sub>ΘphaseΔXZ41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Phase Error between ΔX <sub>41</sub> and ΔZ <sub>41</sub> Channel                                         | VSUP    | –    | ±2.2 | –    | °                     | <sup>1)</sup> between ΔX <sub>41</sub> and ΔZ <sub>41</sub> axis |
| E <sub>ΔX41,noise</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Digital Noise of ΔX <sub>41</sub> Hall-plates Channel                                                     | VSUP    | –    | 2.4  | –    | LSB <sub>15</sub>     | <sup>5)</sup>                                                    |
| E <sub>ΔZ41,noise</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Digital Noise of ΔZ <sub>41</sub> Hall-plates Channel                                                     | VSUP    | –    | 2.6  | –    | LSB <sub>15</sub>     | <sup>5)</sup>                                                    |
| <b>Off-Axis Rotary Setup (ΔXY) with Stray-Field Compensation (Setup 3a)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                           |         |      |      |      |                       |                                                                  |
| SM <sub>ΔXY41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Sensitivity Mismatch between ΔX <sub>41</sub> and ΔY <sub>41</sub> Channel                                | VSUP    | -2   | –    | 2    | %                     | <sup>1)</sup> T <sub>A</sub> = 25 °C                             |
| Sense <sub>ΔXY41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Sensitivity of ΔX <sub>41</sub> and ΔY <sub>41</sub> Channel                                              | VSUP    | 121  | 128  | 135  | LSB <sub>15</sub> /mT | <sup>1)</sup> T <sub>A</sub> = 25 °C                             |
| ΔSM <sub>ΔXY41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Thermal Sensitivity Mismatch Drift between ΔX <sub>41</sub> and ΔY <sub>41</sub> Channel                  | VSUP    | -2.5 | –    | 2.5  | %                     | <sup>1)</sup> Related to T <sub>A</sub> = 25 °C HAL 3980         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                           |         | -3.0 | –    | 3.0  | %                     | <sup>1)</sup> Related to T <sub>A</sub> = 25 °C HAC 3980         |
| Offset <sub>ΔXY41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Offset of ΔX <sub>41</sub> and ΔY <sub>41</sub> Channels                                                  | VSUP    | -30  | –    | 30   | LSB <sub>15</sub>     | T <sub>A</sub> = 25 °C                                           |
| ΔOffset <sub>ΔXY41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Offset Drift of ΔX <sub>41</sub> and ΔY <sub>41</sub> Channels                                            | VSUP    | -50  | –    | 50   | LSB <sub>15</sub>     | Related to T <sub>A</sub> = 25 °C                                |
| ΔSM <sub>ΔXY41life</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Relative Sensitivity Mismatch Drift between ΔX <sub>41</sub> and ΔY <sub>41</sub> Channels over life time | VSUP    | –    | 1.0  | –    | %                     | <sup>1)</sup> After 1008 h HTOL                                  |
| ΔOffset <sub>ΔXY41life</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Offset Drift of ΔX <sub>41</sub> and ΔY <sub>41</sub> Channel over life time                              | VSUP    | –    | 30   | –    | LSB <sub>15</sub>     | After 1008 h HTOL                                                |
| SF <sub>RΔX41</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Stray-Field Rejection in ΔX <sub>41</sub> and ΔY <sub>41</sub> Direction                                  | VSUP    | 99   | –    | –    | %                     | <sup>4)</sup>                                                    |
| All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not EOL tested).<br><sup>1)</sup> Based on Simulation Model (not EOL tested).<br><sup>4)</sup> Characterized on small sample size according to ISO 11452-8:2015, at 25°C, with stray-field strength of 4 kA/m from X,Y and Z direction, 3-sigma values (not EOL tested).<br><sup>5)</sup> Characterized on small sample size, 1-sigma values of COMP_CHx, fdecsel = 2 kHz, Low-pass filter: off (not EOL tested). |                                                                                                           |         |      |      |      |                       |                                                                  |

| Symbol                                                                                                                                                                                                                                                                                                                          | Parameter                                                                              | Pin No. | Min. | Typ.      | Max. | Unit                  | Test Conditions                                                |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|---------|------|-----------|------|-----------------------|----------------------------------------------------------------|
| $E_{\text{phase}\Delta XY41}$                                                                                                                                                                                                                                                                                                   | Phase Error between $\Delta X_{41}$ and $\Delta Y_{41}$ Channel                        | VSUP    | –    | $\pm 2.2$ | –    | °                     | <sup>1)</sup> between $\Delta X_{41}$ and $\Delta Y_{41}$ axis |
| $E_{\Delta XY41,\text{noise}}$                                                                                                                                                                                                                                                                                                  | Digital Noise of $\Delta X_{41}$ and $\Delta Y_{41}$ Hall-plates Channel               | VSUP    | –    | 2.4       | –    | LSB <sub>15</sub>     | <sup>5)</sup>                                                  |
| <b>2D Measurement Setup without Stray-Field Compensation (Setup 4a)</b>                                                                                                                                                                                                                                                         |                                                                                        |         |      |           |      |                       |                                                                |
| $SM_{XYZ}$                                                                                                                                                                                                                                                                                                                      | Sensitivity Mismatch between X or Y and Z Channel                                      | VSUP    | –4   | –         | 4    | %                     | $T_A = 25\text{ °C}$                                           |
| $SM_{XY}$                                                                                                                                                                                                                                                                                                                       | Sensitivity Mismatch between X and Y Channel                                           | VSUP    | –2   | –         | 2    | %                     | $T_A = 25\text{ °C}$                                           |
| $Sense_{XYZ}$                                                                                                                                                                                                                                                                                                                   | Sensitivity of X,Y and Z Hall-plate                                                    | VSUP    | 123  | 128       | 133  | LSB <sub>15</sub> /mT | $T_A = 25\text{ °C}$                                           |
| $\Delta SM_{XYZ}$                                                                                                                                                                                                                                                                                                               | Thermal Sensitivity Mismatch Drift between X or Y and Z Hall-plates                    | VSUP    | –2.5 | –         | 2.5  | %                     | Related to $T_A = 25\text{ °C}$                                |
| $\Delta SM_{XY}$                                                                                                                                                                                                                                                                                                                | Thermal Sensitivity Mismatch Drift between X and Y Hall-plates                         | VSUP    | –2   | –         | 2    | %                     | Related to $T_A = 25\text{ °C}$                                |
| $Offset_{XY}$                                                                                                                                                                                                                                                                                                                   | Offset of X and Y Hall-plates                                                          | VSUP    | –20  | –         | 20   | LSB <sub>15</sub>     | $T_A = 25\text{ °C}$                                           |
| $Offset_Z$                                                                                                                                                                                                                                                                                                                      | Offset of Z Hall-plate                                                                 | VSUP    | –12  | –         | 12   | LSB <sub>15</sub>     | $T_A = 25\text{ °C}$                                           |
| $\Delta Offset_{XY}$                                                                                                                                                                                                                                                                                                            | Offset Drift of X and Y Hall-plates                                                    | VSUP    | –40  | –         | 40   | LSB <sub>15</sub>     | Related to $T_A = 25\text{ °C}$                                |
| $\Delta Offset_Z$                                                                                                                                                                                                                                                                                                               | Offset Drift of Z Hall-plate                                                           | VSUP    | –15  | –         | 15   | LSB <sub>15</sub>     | Related to $T_A = 25\text{ °C}$                                |
| $\Delta SM_{XYZ\text{life}}$                                                                                                                                                                                                                                                                                                    | Relative Sensitivity Mismatch Drift between X, Y and Z Hall-plates over life time      | VSUP    | –    | 1.0       | –    | %                     | After 1008 h HTOL                                              |
| $\Delta Offset_{XY\text{life}}$                                                                                                                                                                                                                                                                                                 | Offset Drift of X and Y Hall-plates over life time                                     | VSUP    | –    | 30        | –    | LSB <sub>15</sub>     | After 1008 h HTOL                                              |
| $\Delta Offset_{Z\text{life}}$                                                                                                                                                                                                                                                                                                  | Offset Drift of Z Hall-plate over life time                                            | VSUP    | –    | 5         | –    | LSB <sub>15</sub>     | After 1008 h HTOL                                              |
| $E_{\text{phase}XYZ}$                                                                                                                                                                                                                                                                                                           | Phase Error between X, Y and Z Hall-plates                                             | VSUP    | –    | $\pm 1.6$ | –    | °                     | XY axis                                                        |
|                                                                                                                                                                                                                                                                                                                                 |                                                                                        |         | –    | $\pm 1.6$ | –    | °                     | XZ axis                                                        |
|                                                                                                                                                                                                                                                                                                                                 |                                                                                        |         | –    | $\pm 1.6$ | –    | °                     | YZ axis                                                        |
| $E_{XYZ,\text{noise}}$                                                                                                                                                                                                                                                                                                          | Digital Noise of X, Y or Z Hall-plates Channel                                         | VSUP    | –    | 2.2       | –    | LSB <sub>15</sub>     | <sup>5)</sup>                                                  |
| <b>2D Measurement Setup (virtually centered Pixel XY) without Stray-Field Compensation (Setup 4b)</b>                                                                                                                                                                                                                           |                                                                                        |         |      |           |      |                       |                                                                |
| $SM_{\Sigma XY41}$                                                                                                                                                                                                                                                                                                              | Sensitivity Mismatch between $\Sigma X_{41}$ and $\Sigma Y_{41}$ Channel               | VSUP    | –3   | –         | 3    | %                     | $T_A = 25\text{ °C}$                                           |
| $Sense_{\Sigma XY41}$                                                                                                                                                                                                                                                                                                           | Sensitivity of $\Sigma X_{41}$ and $\Sigma Y_{41}$ Channel                             | VSUP    | 121  | 128       | 135  | LSB/mT                | $T_A = 25\text{ °C}$                                           |
| $\Delta SM_{\Sigma XY41}$                                                                                                                                                                                                                                                                                                       | Thermal Sensitivity Mismatch Drift between $\Sigma X_{41}$ and $\Sigma Y_{41}$ Channel | VSUP    | –2   | –         | 2    | %                     | Related to $T_A = 25\text{ °C}$                                |
| $Offset_{\Sigma XY41}$                                                                                                                                                                                                                                                                                                          | Offset of $\Sigma X_{41}$ and $\Sigma Y_{41}$ Channel                                  | VSUP    | –25  | –         | 25   | LSB <sub>15</sub>     | $T_A = 25\text{ °C}$                                           |
| All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not EOL tested).<br><sup>1)</sup> Based on Simulation Model (not EOL tested).<br><sup>5)</sup> Characterized on small sample size, 1-sigma values of COMP_CHx, fdecsel = 2 kHz, Low-pass filter: off (not EOL tested). |                                                                                        |         |      |           |      |                       |                                                                |

| Symbol                                                                                                                                                                                                                                                                                                                   | Parameter                                                                                              | Pin No. | Min. | Typ.      | Max. | Unit              | Test Conditions                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|---------|------|-----------|------|-------------------|---------------------------------|
| $\Delta\text{Offset}_{\Sigma XY41}$                                                                                                                                                                                                                                                                                      | Offset Drift of $\Sigma X_{41}$ and $\Sigma Y_{41}$ Channel                                            | VSUP    | -40  | —         | 40   | LSB <sub>15</sub> | Related to $T_A = 25\text{ °C}$ |
| $\Delta\text{SM}_{\Sigma XY41\text{life}}$                                                                                                                                                                                                                                                                               | Relative Sensitivity Mismatch Drift between $\Sigma X_{41}$ and $\Sigma Y_{41}$ Channel over life time | VSUP    | —    | 1.0       | —    | %                 | After 1008 h HTOL               |
| $\Delta\text{Offset}_{\Sigma XY41\text{life}}$                                                                                                                                                                                                                                                                           | Offset Drift of $\Sigma X_{41}$ and $\Sigma Y_{41}$ Channel over Life Time                             | VSUP    | —    | 30        | —    | LSB <sub>15</sub> | After 1008 h HTOL               |
| $E_{\text{phase}\Sigma XY41}$                                                                                                                                                                                                                                                                                            | Phase Error between $\Sigma X_{41}$ and $\Sigma Y_{41}$                                                | VSUP    | —    | $\pm 2.2$ | —    | °                 | 1)                              |
| $E_{\Sigma XY41,\text{noise}}$                                                                                                                                                                                                                                                                                           | Digital Noise of $\Sigma X_{41}$ and $\Sigma Y_{41}$ Hall-plates Channel                               | VSUP    | —    | 1.9       | —    | LSB <sub>15</sub> | 5)                              |
| <p>All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not EOL tested).</p> <p>1) Based on Simulation Model (not EOL tested).</p> <p>5) Characterized on small sample size, 1-sigma values of COMP_CHx, fdecsel = 2 kHz, Low-pass filter: off (not EOL tested).</p> |                                                                                                        |         |      |           |      |                   |                                 |

## 5.11. Angle Speed Characteristics

at  $T_A = -40\text{ }^{\circ}\text{C}$  to  $125\text{ }^{\circ}\text{C}$ ,  $V_{SUP} = 4.0\text{ V}$  to  $11.0\text{ V}$ ,  $GND = 0\text{ V}$ , after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column "Test Conditions". Typical Characteristics for  $T_J = 25\text{ }^{\circ}\text{C}$  and  $V_{SUP} = 5\text{ V}$ .

| Symbol                                                                                                                                                                                                                                           | Parameter                     | Pin No. | Min.  | Typ. | Max. | Unit | Test Conditions                                                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|---------|-------|------|------|------|-----------------------------------------------------------------|
| V <sub>ΘRANGE</sub>                                                                                                                                                                                                                              | Angle Speed Measurement Range | VSUP    | −1000 | –    | 1000 | °/s  | Customer configurable                                           |
|                                                                                                                                                                                                                                                  |                               |         | −5000 | –    | 5000 | °/s  |                                                                 |
| V <sub>ΘRes</sub>                                                                                                                                                                                                                                | Angle Speed Resolution        | VSUP    | 9     | 12   | 16   | Bit  |                                                                 |
| <b>Sample frequency: 8 ksample</b><br><b>Settling Time: 13.9875 ms</b>                                                                                                                                                                           |                               |         |       |      |      |      |                                                                 |
| E <sub>ASE</sub>                                                                                                                                                                                                                                 | Angle Speed Error             | VSUP    | –     | 25   | –    | °/s  | 1)2) V <sub>ΘRANGE</sub> = ±1000 °/s;<br>Setup 2 with 3Z-Plates |
|                                                                                                                                                                                                                                                  |                               |         | –     | 50   | –    | °/s  | 1)2) V <sub>ΘRANGE</sub> = ±5000 °/s;<br>Setup 2 with 3Z-Plates |
| N <sub>VtΘot</sub>                                                                                                                                                                                                                               | Angle Speed Noise             | VSUP    | –     | 25   | –    | °/s  | 1)3) V <sub>ΘRANGE</sub> = ±1000 °/s;<br>Setup 2 with 3Z-Plates |
|                                                                                                                                                                                                                                                  |                               |         | –     | 25   | –    | °/s  | 1)3) V <sub>ΘRANGE</sub> = ±5000 °/s;<br>Setup 2 with 3Z-Plates |
| 1) Based on error calculation. Not EOL tested. Signal Amplitude: 10 mT; FIR-Filter on; IIR cut-off frequency = 33 Hz.<br>2) Absolute difference between angle speed noise mean and true angle speed.<br>3) Angle speed noise standard deviation. |                               |         |       |      |      |      |                                                                 |

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## 6. Application Notes

### 6.1. Ambient Temperature

Due to the internal power dissipation, the temperature on the silicon chip (junction temperature  $T_J$ ) is higher than the temperature outside the package (ambient temperature  $T_A$ ).

$$T_J = T_A + \Delta T$$

The maximum ambient temperature is a function of power dissipation, maximum allowable die temperature and junction to ambient thermal resistance ( $R_{thja}$ ).

The power dissipation is calculated as  $P = V_{SUP} * I_{SUP}$ .

The junction to ambient thermal resistance  $R_{thja}$  is specified in Section 5.9. on page 53.

The difference between junction and ambient air temperature is expressed by the following equation (at static conditions and continuous operation):

$$\Delta T = P * R_{thjX}$$

The X represents junction to air, case or solder point.

For worst-case calculation, use the max. parameters for  $I_{SUP}$  and  $R_{thjX}$ , and the max. value for  $V_{SUP}$  from the application.

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|             |                                                                                                                                                                                                           |
|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Note</b> | The calculated self-heating of the device is only valid for the $R_{th}$ test boards. Depending on the application setup the final results in an application environment might deviate from these values. |
|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

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### 6.2. EMC and ESD

Please contact TDK-Micronas for detailed information on EMC and ESD performance.

6.3. Application Circuit for HAL 3980

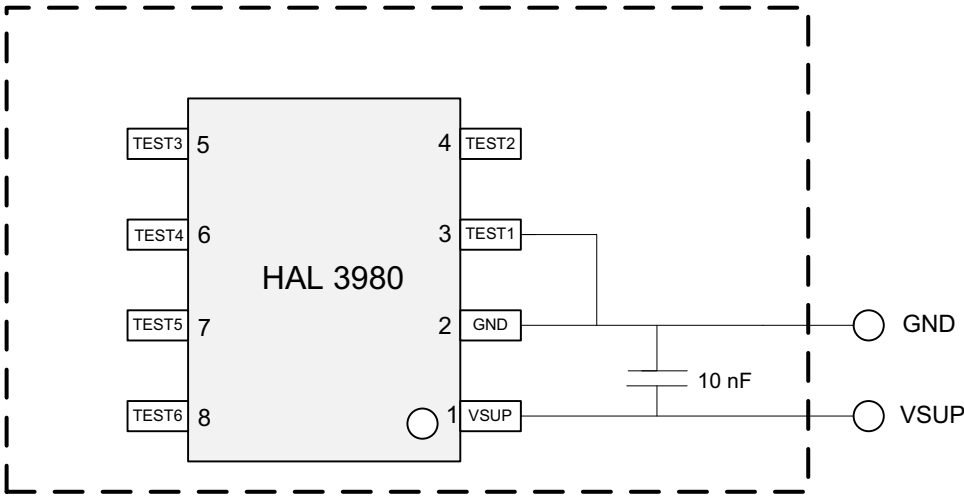


Fig. 6–1: Recommended application circuit for HAL 3980

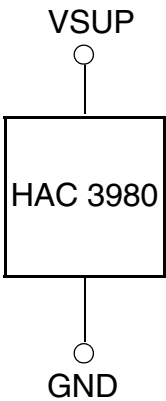


Fig. 6–2: Recommended application circuit for HAC 3980

6.4. Recommended Pad Size SOIC8 Package

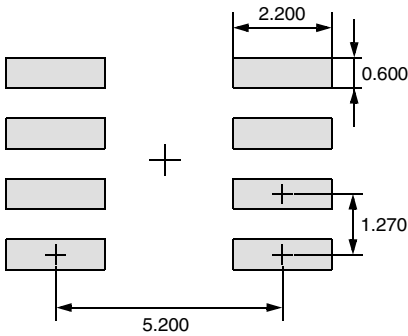


Fig. 6–3: Pad size recommendation for SOIC8 Package (all dimensions in mm)

## 7. Programming of the Sensor

HAL/HAC 3980 features two different customer modes. In **Application Mode** the sensor provides a digital output signal according PSI5 standard. In **Programming Mode (Listen Mode)** it is possible to change the register settings of the sensor.

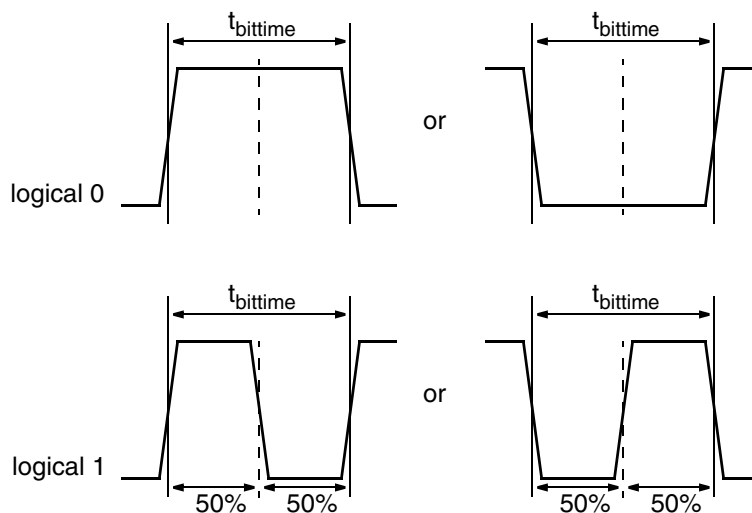
After power-up the sensor is always operating in the **Application Mode**. It is switched to the **Programming Mode** by a BiPhase-M protocol via supply voltage modulation. Therefor the programming device needs to provide a long sync pulse at the supply pin.

### 7.1. Programming Interface

In Programming Mode HAL/HAC 3980 is addressed by modulating a serial telegram on the sensor's supply pin. The sensor answers with a modulation of the supply current.

A logical "0" is coded as no level change within the bit time. A logical "1" is coded as a level change of typically 50 % of the bit time. After each bit, a level change occurs (see Fig. 7–1).

The serial telegram is used to transmit the memory content, error codes and digital values of the angle information from and to the sensor.



**Fig. 7–1:** Definition of logical 0 and 1 bit



**Table 7–1:** Telegram parameters for the Host (All voltages are referenced to GND.)

| Symbol                  | Parameter                                                         | Pin No. | Limit Values |      |      | Unit | Test Conditions |
|-------------------------|-------------------------------------------------------------------|---------|--------------|------|------|------|-----------------|
|                         |                                                                   |         | Min.         | Typ. | Max. |      |                 |
| $V_{\text{SUPL}}$       | Voltage for Supply Low Level during Communication and Programming | VSUP    | 4.5          | 5.0  | 6.0  | V    |                 |
| $V_{\text{SUPH}}$       | Voltage for Output High Level during Communication                | VSUP    | 7.5          | 8.0  | 8.5  | V    |                 |
| $I_{\text{SUPL}}$       | Sensor Supply Current Low Level during Communication              | VSUP    | 5.0          | 8.0  | 12.0 | mA   |                 |
| $\Delta I_{\text{SUP}}$ | Sensor Supply Current Offset for High Level during Communication  | VSUP    | 11.0         | 13.0 | 15.0 | mA   |                 |

## 7.2. Programming Environment and Tools

For the programming of HAL/HAC 3980 during product development a programming tool including hardware and software is available on request. It is recommended to use the TDK-Micronas tool kit (TDK MSP V1.x and LabView Programming Environment) in order to facilitate the product development. The details of programming sequences are content of the HAL/HAC 3980 Programming Guide & User Manual.

## 7.3. Programming Information

For production and qualification tests, it is mandatory to set the LOCK bit to one after final adjustment and programming of HAL/HAC 3980.

Before locking the device, it is recommended to read back all register values to ensure that the intended data is correctly stored in the sensor's memory. Alternatively, it is also possible to cross-check the sensor output signal with the intended output behavior.

The success of the LOCK process shall be checked by reading the status of the LOCK bit after locking.

Even after locking the device it is still possible to read the memory content.

It is also mandatory to check the acknowledge of the sensor after each write and store sequence to verify if the programming of the sensor was successful.

ElectroStatic Discharges (ESD) may disturb the programming pulses. Please take precautions against ESD.

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**Note** A description of the communication protocol and the programming of the sensor is available in the separate documents HAL/HAC 3980 Programming Guide & HAL/HAC 3980 User Manual.

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## 8. Document History

1. Data Sheet: "HAL/HAC 3980 Stray-Field Robust 3D Position Sensor with PSI5 Output Interface", Apr. 20, 2023, DSH000226\_001EN. First release of the Data Sheet  
Describing Configuration-ID releases:  $\geq 9502$  and 2300 (production version)
2. Data Sheet: "HAL/HAC 3980 Stray-Field Robust 3D Position Sensor with PSI5 Output Interface", May 26, 2023, DSH000226\_002EN. Second release of the Data Sheet  
Describing Configuration-ID releases:  $\geq 9502$  and 2300 (production version)  
  
Major changes:
  - Magnetic Characteristics:  
Stray-Field Rejection in DZ41 Direction ( $SF_{R\Delta Z41}$ ) – values updated
  - Angle Speed Characteristics:  
Angle Speed Error ( $E_{ASE}$ ) and Angle Speed Noise ( $N_{Vt\Theta ot}$ ) – values updated
3. Data Sheet: "HAL/HAC 3980 Stray-Field Robust 3D Position Sensor with PSI5 Output Interface", Dec. 07, 2023, DSH000226\_003EN. Third release of the Data Sheet  
Describing Configuration-ID releases:  $\geq 9502$  and 2300 (production version)  
  
Major changes:
  - Register payload\_size and related descriptions changed to data\_padding\_size
  - General errors corrected
  - Typical values of angle speed noise and error adjusted