MICRONAS

Hardware Documentation

Advance Information

HAL® 3980

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

3D HAL® Technology

master HAL® Technology

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

1. Introduction

HAL 3980 is 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. It is a high-resolution position sensor for highly accurate position measurements.

HAL 3980 features a PSI5 Interface (Peripheral Sensor Interface) supporting the specification revision 2.2 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 ASIL B ready (Safety Element out of Context) 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.

The sensor is available in the eight-pin SOIC8 SMD package.

1.1. Major Applications

Thanks to the sensor's versatile programming characteristics and its high accuracy, the HAL 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 2.2 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 °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:

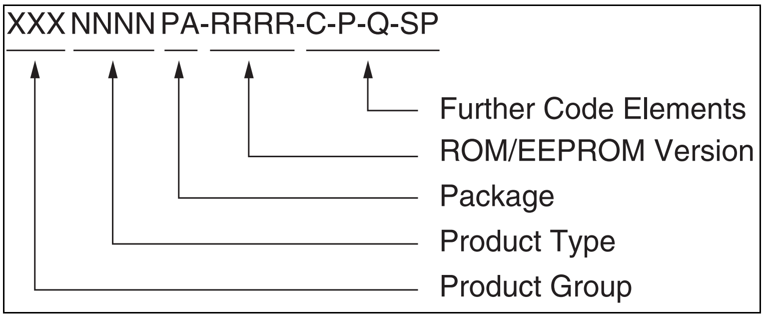


Fig. 2–1: Ordering code principle

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

2.1. Device-Specific Ordering Codes

The HAL 3980 is available in the following package and temperature variants.

Table 2–1: Available packages

Package Code (PA)	Package Type
DJ	SOIC8

Table 2–2: Available temperature ranges

Temperature Code (T)	Temperature Range
A	T_J = –40 °C to 170 °C

The relationship between ambient temperature (T_A) and junction temperature (T_J) is explained in Section 6.1. on page 50.

For available variants for Configuration (C), Packaging (P), Quantity (Q), and Special Procedure (SP) please contact TDK-Micronas.

Table 2–3: Available ordering codes and corresponding package marking

Available Ordering Codes	Package Marking	Package
HAL3980DJ-[ROMID-C-P-Q-SP]	3980[ROMID] Lot number Date code SB	SOIC8

3. Functional Description

3.1. General Function

HAL 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® technology. The array of Hall plates has a diameter C of 2.25 mm (nominal).

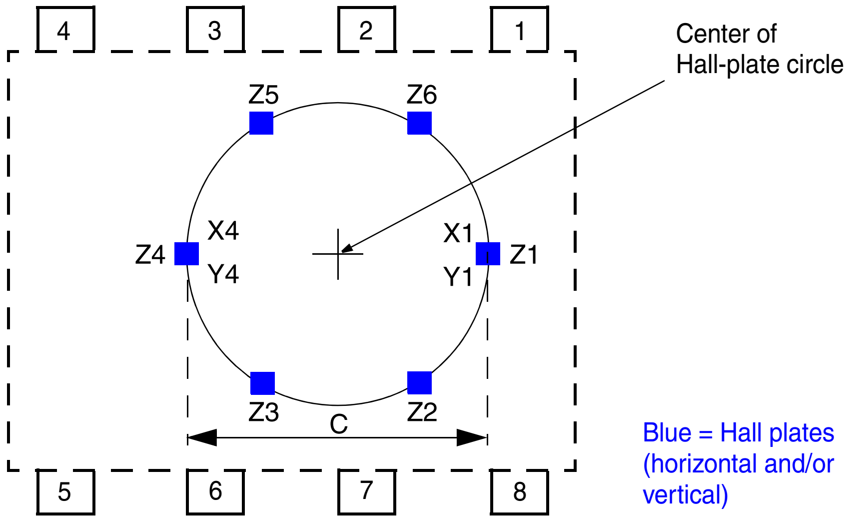


Fig. 3–1: Hall-plate position definition for HAL 3980

The Hall-plate signals are first measured by three A/D converters, filtered and temperature compensated. A linearization block can be used optionally to reduce the overall system 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.

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

– 2D linear and angular position detection without stray-field compensation (B_X/B_Y, B_X/B_Z, B_Y/B_Z)

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

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 memory.

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

HAL 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 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.

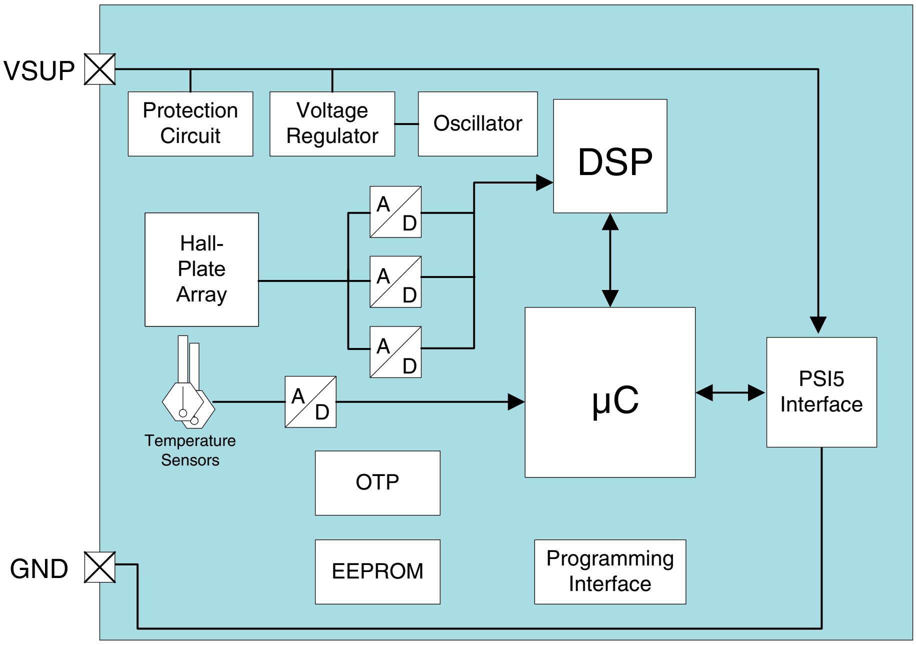


Fig. 3–2: HAL 3980 block diagram

3.2. Signal Path

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

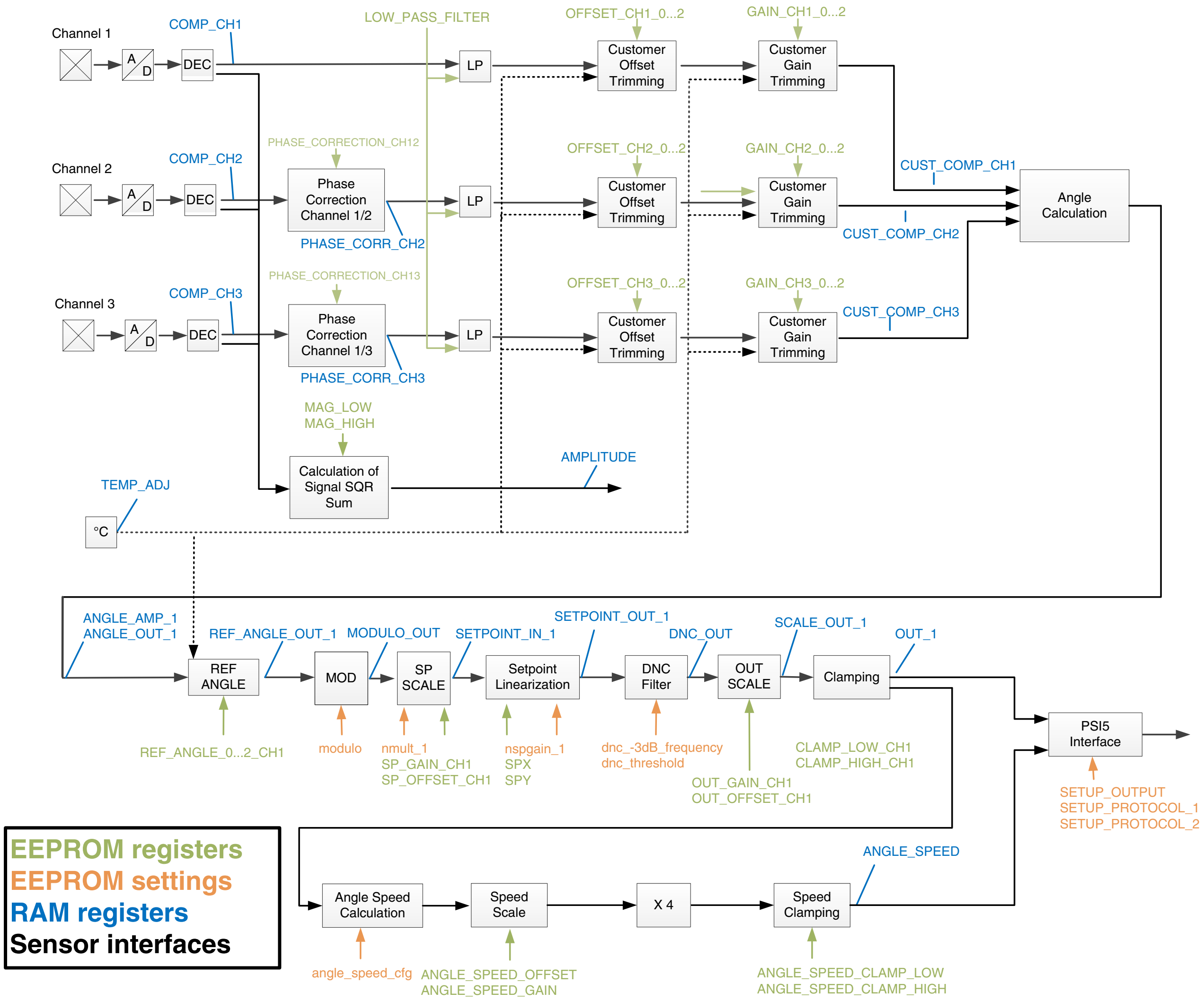


Fig. 3–3: Signal path of HAL 3980

The sensor signal path contains two kinds of registers. Registers that are read-only and programmable registers (non-volatile memory). The read-only registers contain measurement data at certain steps of the signal path and the non-volatile memory registers change the sensor's signal processing.

3.3. Register Definition

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.

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 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 signals calculated with the following equation. This information is used for the magnet lost detection:

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

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 = 1000 °/s or 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).

DIAGNOSIS

The DIAGNOSIS_0 and DIAGNOSIS_1 registers report certain failures detected by the sensor. HAL 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 36).

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 3980 can be configured for 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 22) defines the different available modes.

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

This mode uses 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. 3–4 shows the related signal path.

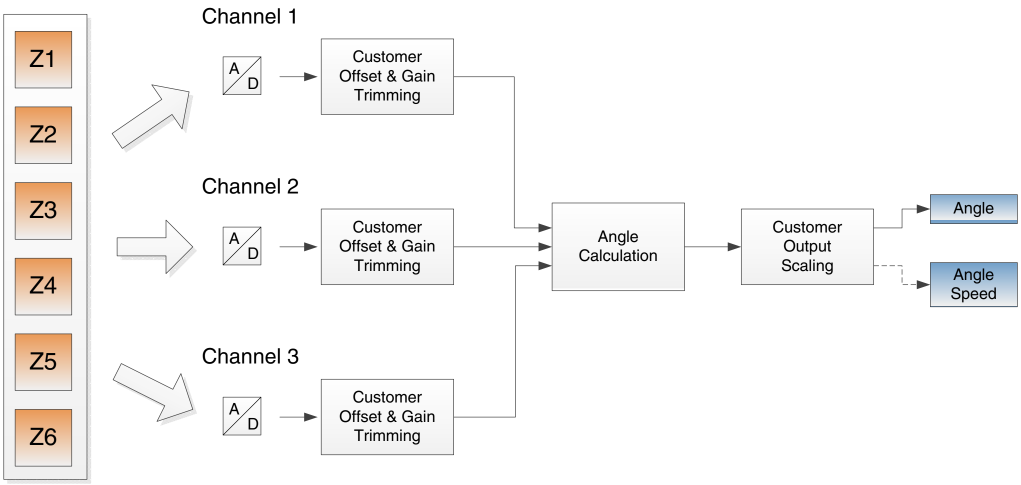


Fig. 3–4: Signal path diagram of setup 1 (stray-field robust 180° measurement)

– 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. 3–5 shows the related signal path.

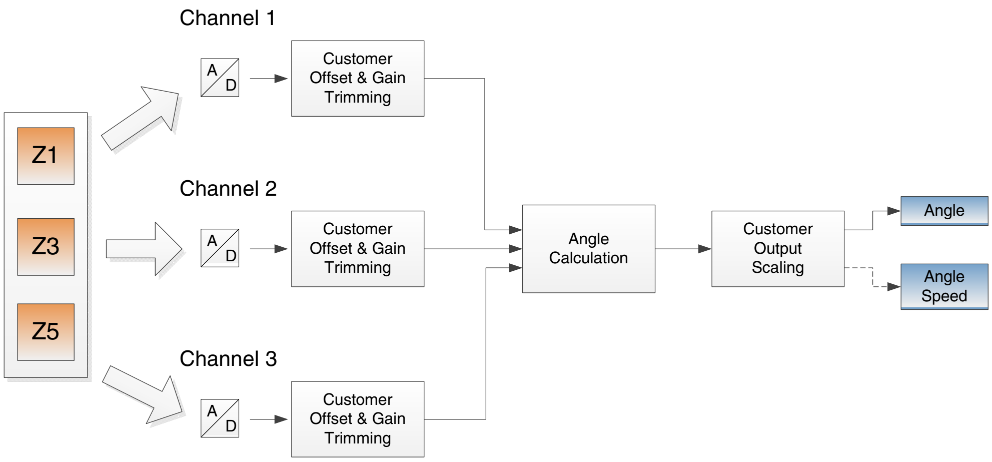


Fig. 3–5: Signal path diagram of setup 2 (stray-field robust 360° measurement)

– 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 (ΔB_X & ΔB_Z). Alternatively this setup can be used as well for off-axis stray-field compensated angular measurements if a combination of vertical Hall-plates is selected (ΔB_X & ΔB_Y). The device can compensate stray fields according to ISO 11452-8 definition. Fig. 3–6 shows the related signal path.

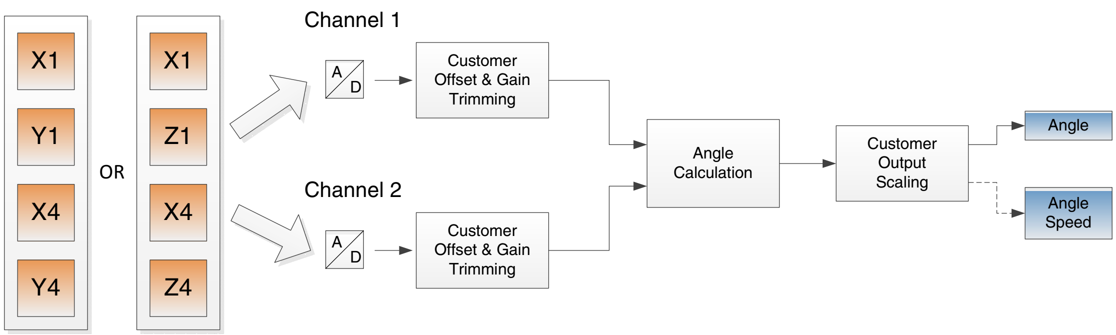


Fig. 3–6: Signal path diagram of setup 3 (stray-field robust linear or off-axis position detection)

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

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

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 4: 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. 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.

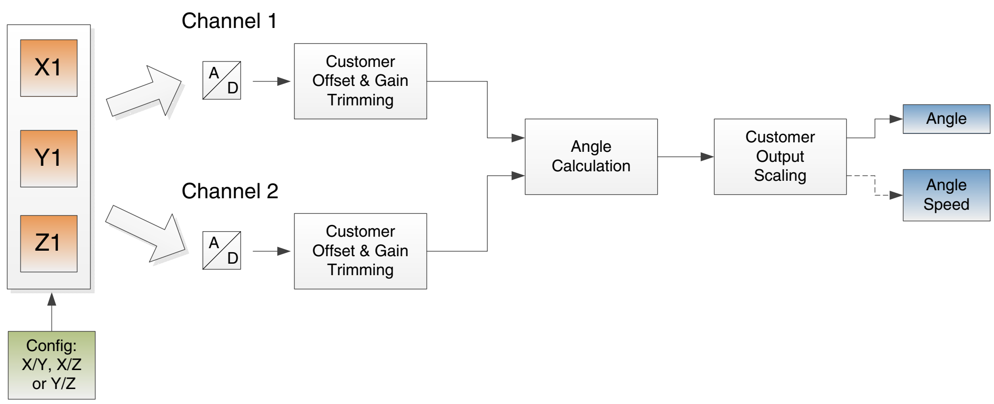


Fig. 3–7: Signal path diagram of setup 4 (Rotary and linear position detection without stray-field compensation)

– Setup 4a: 360° rotary measurement with virtual centered pixel cell (w/o stray-field compensation)

In addition it is as well possible to select a virtual center pixel cell mode (4a). In this mode the signals in X and Y direction of both pixel cells P1 and P4 are combined to generate one virtual center pixel in the middle of the Hall-Plate array.

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

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

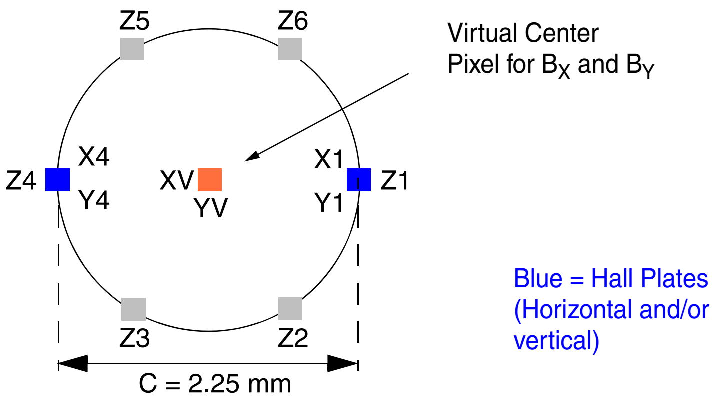


Fig. 3–8: Virtual center pixel for B_X and B_Y in Mode 4a

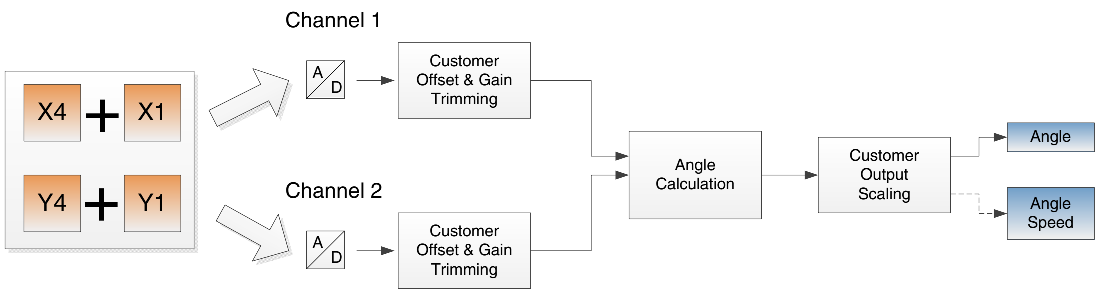


Fig. 3–9: Signal path diagram of setup 4a (virtual center pixel w/o stray-field compensation)

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 31 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 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 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).

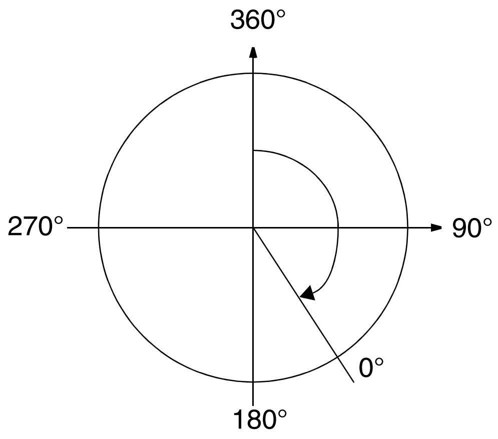


Fig. 3–10: Example definition of zero degree point

Modulo Select

HAL 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_DATAPATH 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. It consists of 33 setpoints (SP0, SP1, ..., SP32). 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.

The setpoint registers have a length of 16 bits and are two's complement coded. Therefore the setpoint Y values (SP(n)_Y) can vary between –32768...32767 LSB. For the value of the SP(n)_Y register only the difference between the setpoint y value and the corresponding setpoint x value has to be programmed into the setpoint register. The setpoint register values are initially set to 0 (neutral) by default.

Alternatively 17 variable setpoints can be used. In this case the x positions are not anymore equally distributed.

In case of variable setpoints are selected nspgain_1 register must be used.

The nspgain_1 value has to be changed if one of the setpoint slopes exceed the permitted range (setpoint slope > 1). To use nspgain_1 correctly the maximum slope of the graphs between two adjacent setpoints has to be determined. Then the maximum setpoint gain has to be calculated. Afterwards nspgain_1 is used to set the gain exponent for the setpoint slope on the data channel.

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 OUT_1 register value represents the position information after the setpoint scaling and clamping.

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 amplification 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. ±0.5°) and periodic movements with an amplitude lower than 1° 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 from 4000 Hz to 200 Hz 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 complemented 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 35). Two different ranges are available:

– +/- 1000 °/s

– +/- 5000 °/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 complemented 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 setups, 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: 0: Unlocked 1: Locked				
14:9	-	Must be set to 0.				
8	quadrant	This bit is used to define if the sensor is only transmitting the modulo result or the modulo result + quadrant information: 0: Modulo value only 1: Modulo value + 2 bit quadrant information				
7:6	modulo	Modulo operation: 00: 360° 01: Modulo 90° 10: Modulo 120° 11: Modulo 180°				
5:4	fdecsel	A/D converter sample frequency: 00: 2 kSps 01: 4 kSps 10: 8 kSps 11: not supported				
3:0	meas_config	**Measurement setups:**	**Correspond. Signal Path**	**CH1**	**CH2**	**CH3**
		0000: Setup 4 - 2D	With two channel	X1	Y1	-
		0001: Setup 4 - 2D	With two channel	Z1	Y1	-
		0010: Setup 4 - 2D	With two channel	Z1	X1	-
		0011: Setup 3 - 2D - Strayfield compensated	With two channel	Z4-Z1	X4-X1	-
		0100: Setup 3 - 2D - Strayfield compensated	With two channel	X4-X1	Y4-Y1	-
		0101: Setup 4a - 2D - Virtual center pixel	With two channel	X1+X4	Y1+Y4	-
		0110: Setup 1 - 180° rotary - strayfield compensated	6 Z Hall-plates	Z1+Z4	Z2+Z5	Z3+Z6
		0111: Setup 2 - 360° rotary - strayfield compensated	3 Z Hall-plates	Z1	Z3	Z5
		1000 to 1111: Must not be used	-	-	-	-

Table 3–2: SETUP_DATAPATH

Bit No.	Function	Description
7:5	nmult_1	Gain exponent for SETPOINT_IN1: SP_GAIN = SP_GAIN_CH1 * [2^(nmult_1)]
4:1	nspgain_1	Gain exponent for setpoint slope in channel 1: Slope = SPGn * (2^nspgain_1+1)
0	variable_setpoints	Fixed/variable setpoint selection: 0: Fixed setpoints 1: Variable setpoints

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

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 high 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 3980 complies with the PSI5 sensor interface regarding electrical parameter and data transmission according to revision 2.2. 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 substandard”.

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

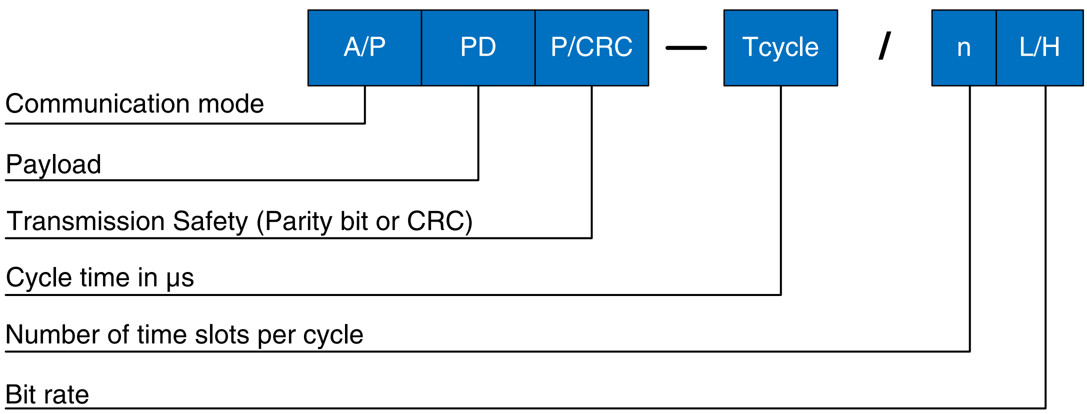


Fig. 3–11: PSI5 protocol short text definition

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.

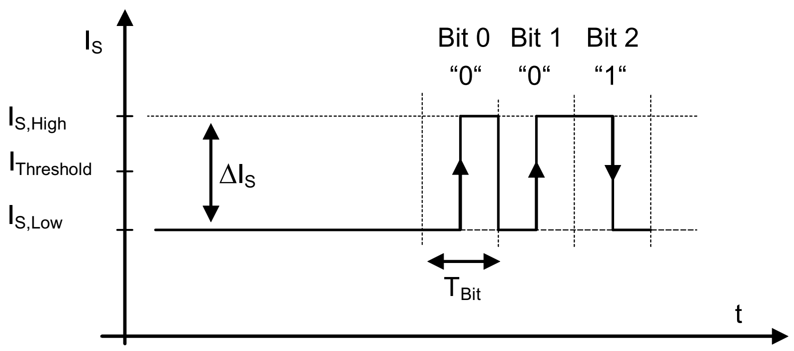


Fig. 3–12: Bit encoding using supply current modulation

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 44.

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 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 ($t_{repetition}$) of the sensor is customer programmable. Please see the bits repetition_rate in the register SETUP_OUTPUT (Table 3–8 on page 33) for the available repetition times.

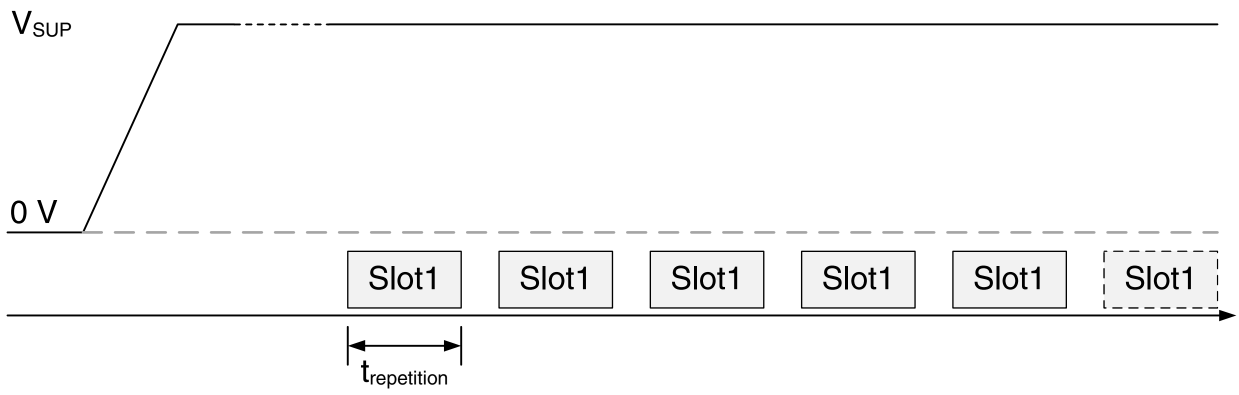


Fig. 3–13: Example for asynchronous transmission with four time slots

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. 5–7 on page 46), 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.

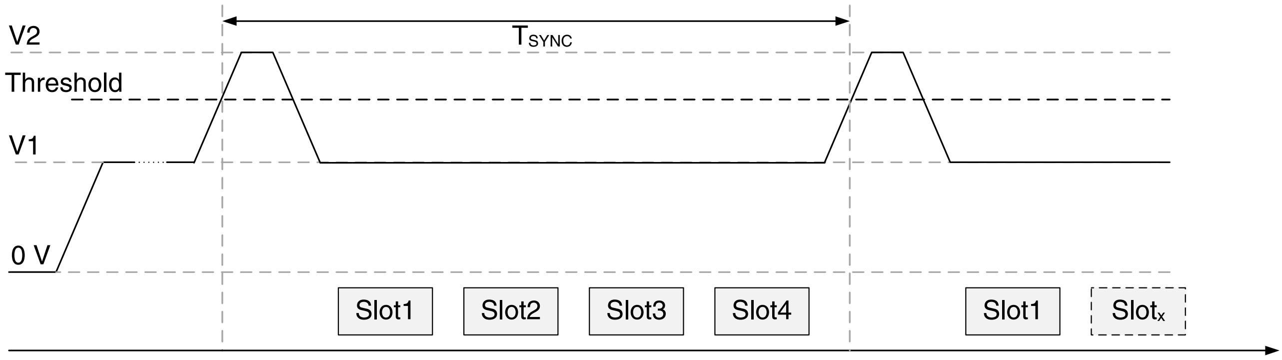


Fig. 3–14: Example for synchronous transmission with four time slots

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 3980 is detecting the synchronization pulse generate by the ECU as soon as the supply voltage modulation is higher than the minimum sync pulse voltage (V_{Sync}). The electrical parameters of the synchronization pulse are defined in Section 5.9. on page 44.

3.4.4. Time Slots

HAL 3980 is supporting up to three time slots. Their starting times can be defined with the registers PSI5_START_SLOTx registers (see page 35). With these registers it is possible to define if the position information and/or 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 flexible configured and therefor be adapted to customer needs. Generally the frame content 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.

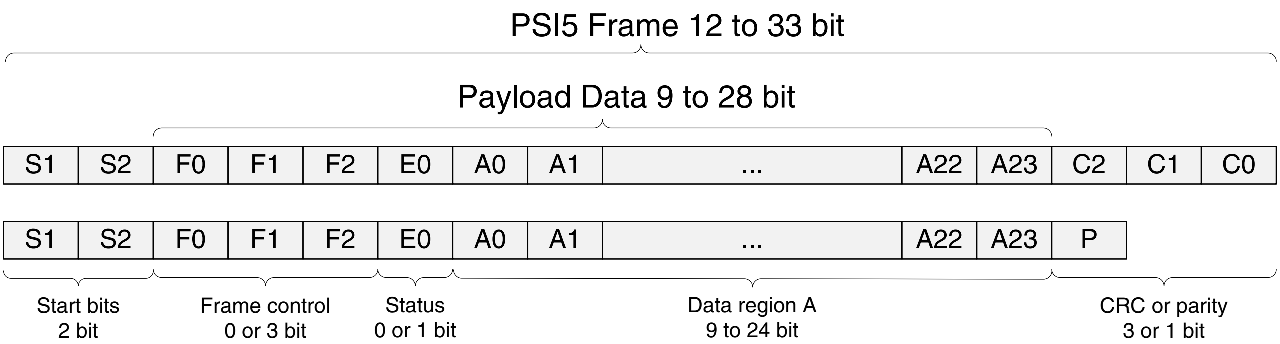


Fig. 3–15: PSI5 Frame content

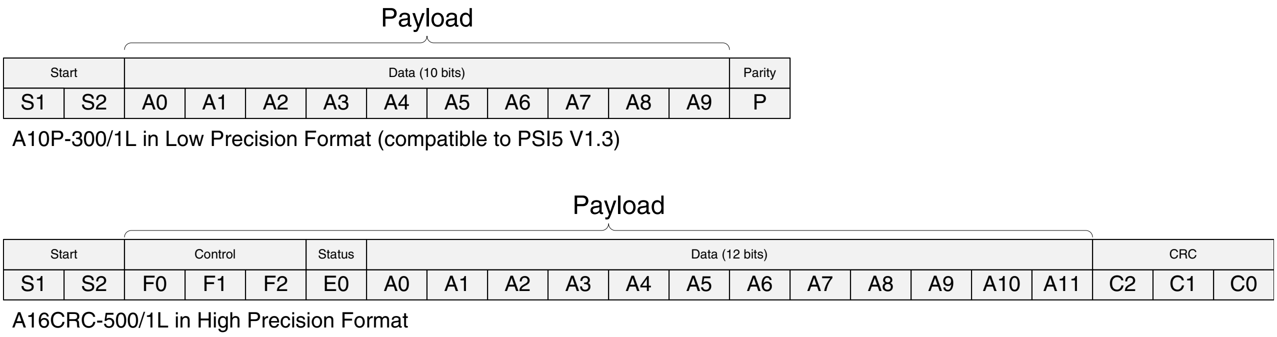


Fig. 3–16: Examples of supported PSI5 Frames

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[1]	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 frame_control_bits Table 3–9 on page 34
	Status bit	E0	Optional. Used as error flag if activated.	status_bit error_status Table 3–8 on page 33
	Data bits	A[0:N-1]	Data bits. Transmission of LSB first. Can be selected between 9...16 bit	signal_size_primary signal_size_secondary third_slot Table 3–9 on page 34 & Table 3–10 on page 35
Error detection bits		P	Recommended to be used for 10 bit low precision format.	CRC Table 3–8 on page 33
		CRC	Recommended to be used for 12 bit high precision format.	
1) Payload size can be configured but must be equal or greater than the selected signal size (frame control + status bit + data bits). Payload size can be selected between 9 to 24 bit. (see Table 3–8 on page 33)				

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 - Position information - Position information + quadrant - Angle speed	channels (SETUP_OUTPUT) quadrant (SETUP_FRONTEND) third_slot (SETUP_PROTOCOL_1) Table 3–8 on page 33 &Table 3–9 on page 34
Payload size	The payload size can be defined for each source individually. - Position information 9 ... 24 bit - Angle speed 9 ... 16 bit	 signal_size_primary (SETUP_PROTOCOL_1, page 34) signal_size_secondary (SETUP_PROTOCOL_2, page 35)

HAL 3980 can calculate a quadrant information in addition to the position information. The quadrant information 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 bit quadrant inside the SETUP_FRONTEND register. The graph below shows how the quadrant information will be transmitted.

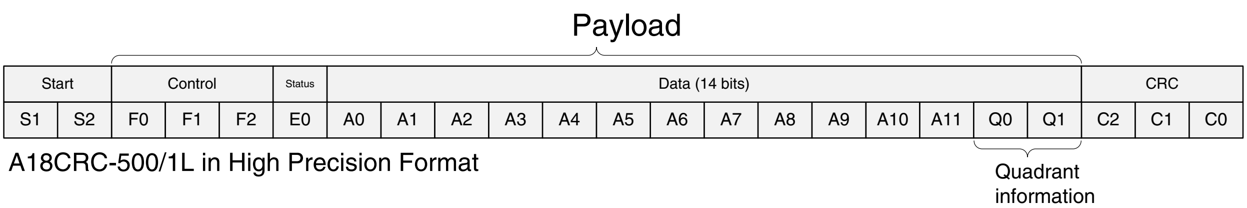


Fig. 3–17: Example for transmission of quadrant information

3.4.6.1. Data Padding

The HAL 3980 is doing data padding in case that the selected payload size is smaller than the selected frame size. In that case the sensor will fill-up the frame with zero's as shown in below example.

Payload

Start		Control			Status	Data (14 bits)														CRC		
S1	S2	F0	F1	F2	E0	A0	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	0	0	C2	C1	C0

A18CRC-500/1L in High Precision Format

Data Padding

Fig. 3–18: Example for data padding

3.4.7. Sensor Initialization

The initialization behavior of HAL 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 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 time can be defined 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 33). 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 D3: Bits 4...7 in CUSTOMER_ID7 register
F3	D4, D5	Manufacturer ID	configurable	D4: Bits 0...3 in CUSTOMER_ID7 register D5: Bits 12...15 in CUSTOMER_ID6 register (default is TDK-Micronas vendor ID = 0110 1101, 0x6D)
F4	D6, D7	Sensor type	configurable	D6: Bits 4...7 in CUSTOMER_ID6 register D7: Bits 8...11 in CUSTOMER_ID6 register
F5	D8, D9	Sensor parameter	configurable	D8: Bits 0...3 in CUSTOMER_ID6 register D9: Bits 12...15 in CUSTOMER_ID5 register
F6	D10, D11	Sensor code	configurable	D10: Bits 8...11 in CUSTOMER_ID5 register D11: Bits 4...7 in CUSTOMER_ID5 register
F7	D12	Sensor code like vehicle	configurable	D12: Bits0...3 in CUSTOMER_ID5 register
F8	D13-D16	Production date	configurable	D13: Bits 12...15 in CUSTOMER_ID4 register D14: Bits 8...11 in CUSTOMER_ID4 register D15: Bits 4...7 in CUSTOMER_ID4 register 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 D18: Bits 8...11 in CUSTOMER_ID3 register D19: Bits 4...7 in CUSTOMER_ID3 register D20: Bits 0...3 in CUSTOMER_ID3 register D21: Bits 12...15 in CUSTOMER_ID2 register D22: Bits 8...11 in CUSTOMER_ID2 register D23: Bits 4...7 in CUSTOMER_ID2 register D24: Bits 0...3 in CUSTOMER_ID2 register D25: Bits 12...15 in CUSTOMER_ID1 register D26: Bits 8...11 in CUSTOMER_ID1 register D27: Bits 4...7 in CUSTOMER_ID1 register D28: Bits 0...3 in CUSTOMER_ID1 register D29: Bits 12...15 in CUSTOMER_ID0 register D30: Bits 8...11 in CUSTOMER_ID0 register D31: Bits 4...7 in CUSTOMER_ID0 register 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 following messages using 10 data bits:

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

Status message	Output value
“Sensor ready”	0x1E7
“Sensor defect”	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 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. The following table describes the additional possible error indication:

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

Diagnosis bit	Size of data region A								Bit no.	Remarks
	> 16	**16**	**15**	**14**	**13**	**12**	**11**	**<=10**		
Overtemperature	>A5	A5	A4	A3	A2	A1	A0		MSB-10	MSB of diagnosis bits
Undervoltage	>A4	A4	A3	A2	A1	A0				
Overvoltage	>A3	A3	A2	A1	A0					
Magnet lost	>A2	A2	A1	A0						
Clipping of signal	>A1	A1	A0							
Memory error	>A0	A0	0	0	0	0				MSB of diagnosis bits

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	Error Bits (6 bits)						Data (12 bits)												CRC		
0	0	F0	F1	F2	1	ER0	ER1	ER2	ER3	ER4	ER5	0	0	1	0	1	1	1	1	1	0	C2	C1	C0

Example: High Precision Format Error Indication – Sensor defect

Fig. 3–19: 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 0: Position information only (primary channel) 1: Angle speed as secondary information
14	crc	Defines the calculation method for the protocol checksum 0: CRC 1: Parity bit
13	synchronicity	Defines the PSI5 communication mode 0: Asynchronous (continuous transmission without external trigger) 1: Synchronous (ECU trigger driven transmission)
12	baudrate	Transmission baudrate: 0: 125 kbps 1: 189 kbps
11	current_mode	PSI5 current mode: 0: Low power mode (ΔI_S = 13 mA) 1: Common mode (ΔI_S = 26 mA)
10	status_bit	Defines the PSI5 status bit: 0: No transmission of the status bit 1: Transmission of status bit
9	error_status	Defines if an error status will be transmitted in case that the status bit is enabled: 0: No transmission of error information in the status bit 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): 0: 1st slot = position information, 2nd slot = angle speed 1: 1st and 2nd slot = position information, 3rd slot = angle speed
7:6	repetition_rate	PSI5 repetition rate for asynchronous mode: 00: 1000 µs 01: 500 µs 10: 300 µs 11: 250 µs

Table 3–8: SETUP_OUTPUT, continued

Bit No.	Function	Description
5:4	k	Defines the number of repetitions of each data nibble of the initialization sequence of phase II: 00: 1 01: 2 10: 3 11: 4
3:0	payload_size	Defines the PSI5 payload size: 0000: 9 bit (Can not be combined with error messages and init phase II & III.) 0001: 10 bit ... 1111: 24 bit **Note:** The payload_size must be selected to be equal or greater than the maximum signal_size_primary (see SETUP_PROTOCOL_1) and signal_size_secondary + 2 bits (see SETUP_PROTOCOL_2) in case that the quadrant information is enabled as well.

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: 0: 2 times 1: 4 times ... 127: 256 times
8	init_ph_I_dur	Defines the duration of initialization phase I: 0: As fast as possible 1: 100 ms
7	fast_error_codes	Defines if error codes are transmitted as a part of the payload: 0: No transmission of error codes 1: Enabled
6	frame_control_source	Defines how the frame control bits are used: 0: 001 for position information and 010 for angle speed 1: Used for a rolling counter
5	frame_control_bits	Defines if frame controls are used as a part of the protocol: 0: No frame control bits 1: 3 frame control bits
4:3	init_seq	Defines which parts of the initialization phase are activated: 00: Application mode after phase I 01: Application mode after phase II 10: Application mode after phase III 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): 000: 9 bit 001: 10 bit ... 111: 16 bit **Note:** The signal_size (see SETUP_OUTPUT) must not be smaller than signal_size_primary.

Table 3–10: SETUP_PROTOCOL_2

Bit No.	Function	Description
15:5	-	Reserved
4	out_signal	Defines the output signal configuration: 0: PSI5 standard (0x8800 to 0x7800 for 16-bit, 0x220 to 0xE0 for 10-bit, etc.) 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: 0: +/- 1000 °/s 1: +/- 5000 °/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): 000: 9 bit 001: 10 bit ... 111: 16 bit **Note:** The signal_size (see SETUP_OUTPUT) must not be smaller than signal_size_secondary.

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^{st} 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^{st} and 2^{nd} frame. PSI5_START_SLOT3 defines the time period between the beginning of the 2^{nd} and 3^{rd} 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:

$t_{startx} - t_{start(x-1)} >= (n + 1.6) * T_{bit} + 3 * T_{sys,clk}$

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

$T_{sys,clk}$ = 62.5 ns

4. Functional Safety

4.1. Functional Safety Manual and Functional Safety Report

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

The Functional Safety 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 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 32.

The result of the internal diagnostics is as well available via the DIAGNOSIS_X registers.

Table 4–1: DIAGNOSIS_0 register

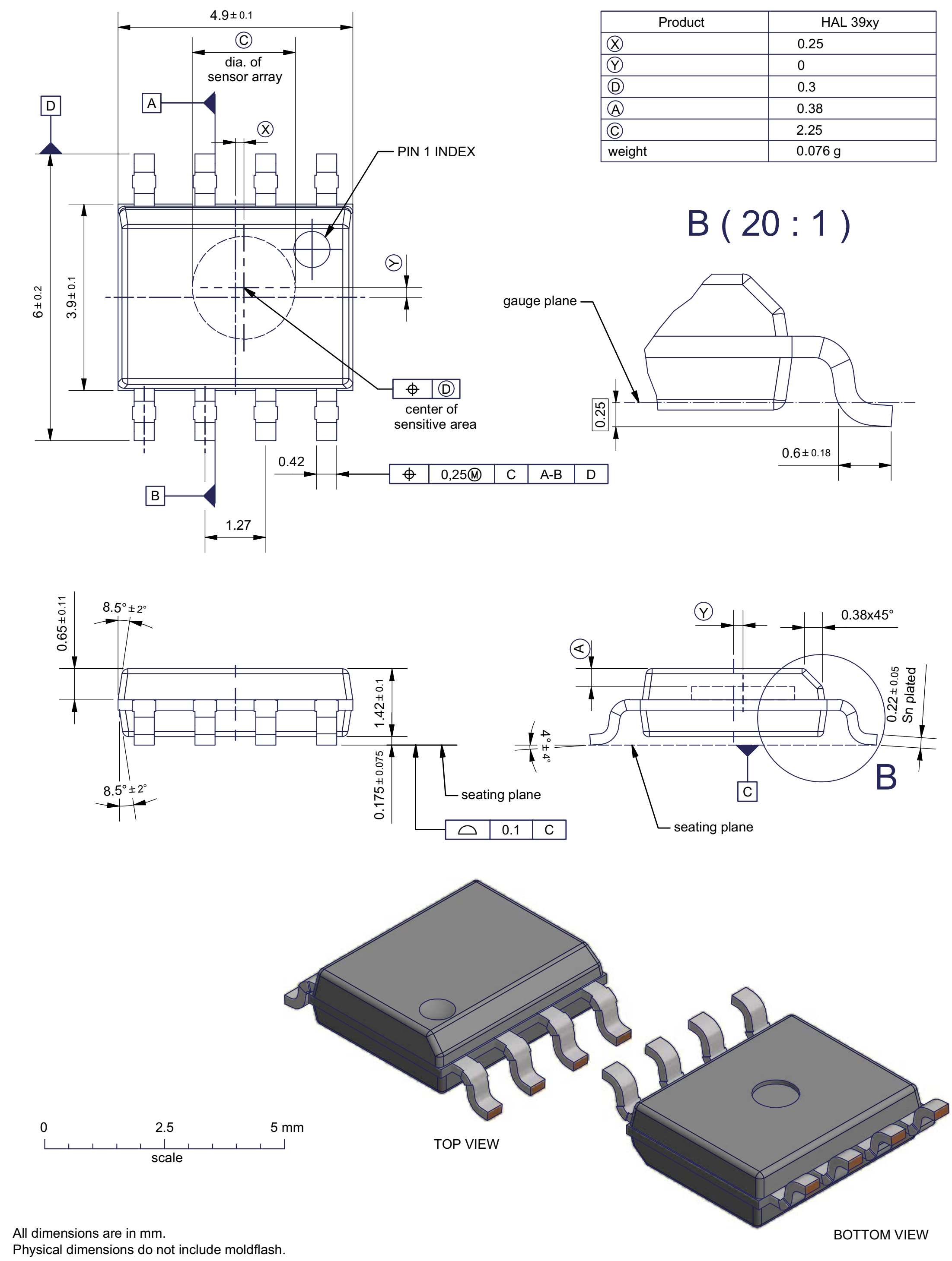
Bit no.	Description when bit is set to 1
15	DSP self-check routines (redundancy or plausibility checks)
14	DSP and µC check of 16-bit checksum covering the EEPROM parameter
13	DSP checksum for ROM and RAM
12	Chip junction temperature out of range
11	Plausibility check of redundant temperature sensor
10	Hall-plate supply too high
9	Hardware overtemperature supervision: Junction temperature > 180°C
8	Internal clock supervision
7	At least one of the A/D converters of Hall channel 1, 2, or 3 delivers a stuck signal
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	External supply is above the specified range (Overvoltage)
14 & 12	General purpose ADC error
13	External supply is below the specified range (Undervoltage)
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
Note: Bits{7:0] can not be read via the programming interface as they are triggering immediately a reset of the device.	
7	µC self-test error
6	µC ROM OP code error
5	µC memory OP code error
4:2	Reserved
1	Error in analog part
0	Reserved

5. Specifications

5.1. Outline Dimensions

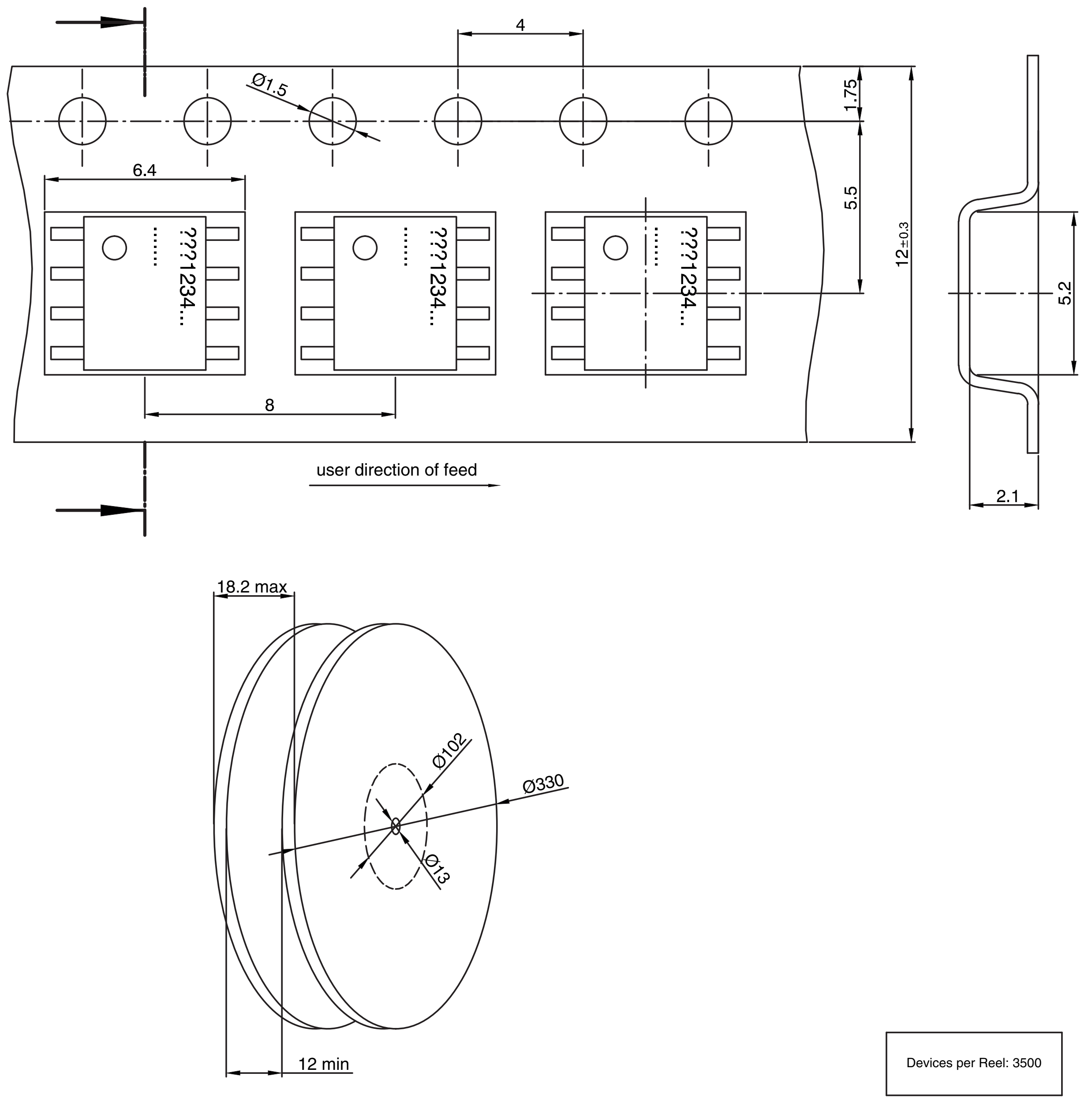


Product	HAL 39xy
Ⓧ	0.25
Ⓨ	0
Ⓓ	0.3
Ⓐ	0.38
Ⓒ	2.25
weight	0.076 g

All dimensions are in mm.
Physical dimensions do not include moldflash.
Sn-thickness might be reduced by mechanical handling.

PACKAGE	ISSUE DATE (YY-MM-DD)	JEDEC STANDARD		ANSI	REVISION DATE (YY-MM-DD)	REV.NO.	DRAWING-NO.	SPECIFICATION	
		ITEM NO.	ISSUE					TYPE	NO.
SOIC8-1	18-02-02	MS-012	F		19-08-21	4	CSOIC0083000.1	ZG	2088_Ver.04

Fig. 5–1:
SOIC8-1: Plastic **S**mall **O**utline **IC** package, 8 leads, gullwing bent, 150 mil
Ordering code: DJ



IEC STANDARD		ANSI	ISSUE DATE YY-MM-DD	DRAWING-NO.	ZG-NO.
ISSUE	ITEM NO.				
4th	60286-3		12-01-31	06836.0001.4	ZG002036_001_01

Fig. 5–2:
SOIC8-1: Dimensions Tape & Reel

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.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 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.com/en/service-center/downloads) or on the service portal (http://service.micronas.com).

5.4. Size and Position of Sensitive Areas

Diameter of sensitive area: C = 2.25 mm

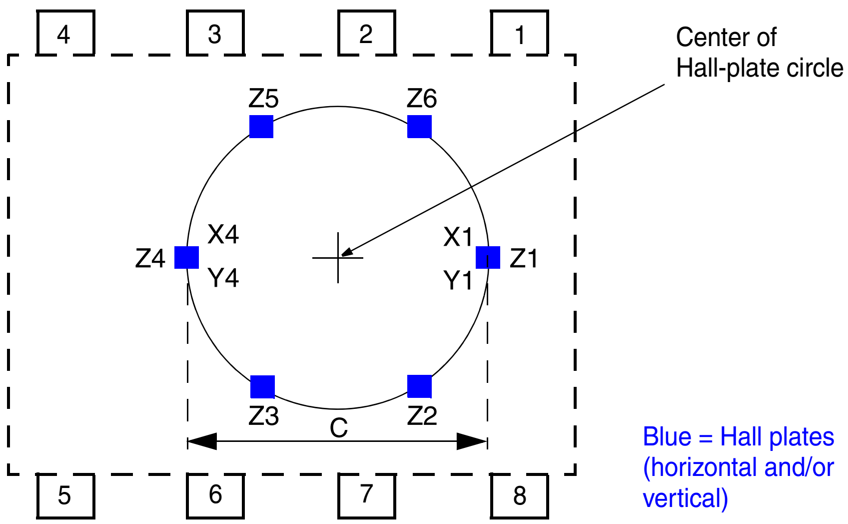


Fig. 5–3: Hall-plate configuration

5.5. Definition of Magnetic-Field Vectors

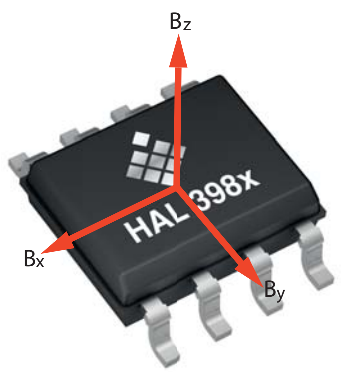


Fig. 5–4: Definition of magnetic-field vectors for HAL 3980

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 pin
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

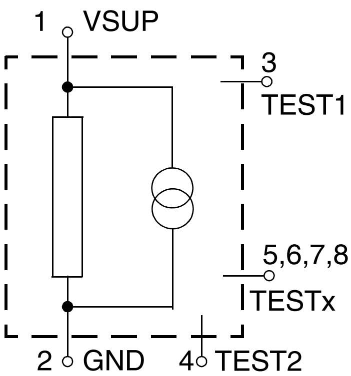


Fig. 5–5: Pin configuration for SOIC8 package

Note Pins 2 must be connected to GND. Pins 3, 4, 5, 6 can be connected to GND or can stay open. Grounding the pins will result in better ESD performance. Pins 7 and 8 should 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_{SUP}	Supply Voltage	VSUP	–18	28 37	V V	 t < 60s; T_J=25°C
B_{max}	Magnetic Field	–	–1	1	T	
T_J	Junction Temperature	–	–40	190	°C	t < 96h [1]
T_A	Ambient Temperature	–	–40	125	°C	[2]
$T_{storage}$	Transportation/Short Term Storage Temperature	–	–55	150	°C	Device only without packing material
V_{ESD}	ESD Protection	VSUP, GND, TESTx	–2	2	kV	[3]
		VSUP, GND	–8	8	kV	[4] [5]

[1] Please contact TDK-Micronas for other temperature requirements
[2] Consider current consumption, mounting condition (e.g. overmold, potting) and mounting situation for T_A and in relation to T_J
[3] AEC-Q100-002 (100 pF and 1.5 kΩ)
[4] Unpowered gun test (150 pF/330 Ω or 330 pF/2 kΩ) according to ISO 10605-2008
[5] With additional protection on the PCB (10 nF on VSUP)
No cumulative stress for all parameters.

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_{SS}	Supply Voltage	VSUP	4.0	–	11	V	
$V_{SS,Max}$	Maximum Interface Voltage	VSUP	–	–	16.5	V	
C_{SS}	Supply Capacitor	VSUP	–	10	15	nF	Max. value is defined by PSI5 standard
N_{PRG}	Number of Memory Programming Cycles	–	–	–	100	cycles	0 °C < T_{amb} < 55 °C
B_{AMP}	Recommended Magnetic-Field Amplitude	–	±10	–	±130	mT	
T_J	Junction Temperature		–40	–	170	°C	[1] for 1000 h
T_A	Ambient Temperature		–40	–	125	°C	[2]

[1] Depends on the temperature profile of the application. Please contact TDK-Micronas for life time calculations.
[2] Consider current consumption, mounting condition (e.g. overmold, potting) and mounting situation for T_A and in relation to T_J

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 °C to 125 °C, V_{SUP} = 4.0 V to 16.5 V, GND = 0 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 °C and V_{SUP} = 5 V.

Symbol	Parameter	Pin Name	Limit Values			Unit	Test Conditions
			Min.	Typ.	Max.		
I_{SUP}	Supply Current	VSUP	8	–	19	mA	No PSI5 communication
			–	–	49	mA	Including PSI5 communication and common mode current
I_{SUPQ}	Quiescent Supply Current	VSUP	tbd.	8	12	mA	
$\Delta I_{S,low}$	Low Power Mode Sink Current	VSUP	11	13	15	mA	= $I_{S,high}$ - $I_{S,low}$ Customer configurable. Bit current_mode in SETUP_OUTPUT register
$\Delta I_{S,common}$	Common Mode Sink Current	VSUP	22	26	30	mA	= $I_{S,high}$ - $I_{S,low}$ Customer configurable. Bit current_mode in SETUP_OUTPUT register
ΔI_{SUP}	Quiescent Current Drift	VSUP	–4	–	4	mA	
$\Delta I_{SUPRate}$	Quiescent Current Drift Rate	VSUP	–	–	1	mA/s	
Power-On Behavior							
V_{POR}	Power_On Reset Voltage	VSUP	2.1	2.6	2.9	V	
$V_{PORHyst}$	Power_On Reset Voltage Hysteresis	VSUP	–	200	–	mV	
Overvoltage and Undervoltage Detection							
$S_{VSUP,UV}$	Step Size of Under-/Overvoltage Supervision Threshold	VSUP	tbd.	100	tbd.	mV/ LSB	Under-/Overvoltage threshold is customer configurable (see page 22).
$S_{SUP,UOVhys}$	Under-/Overvoltage Detection Level Hysteresis	VSUP	–	1	–	LSB	1 LSB typ. 100 mV
t_{UOV}	Under-/Overvoltage Detection time	VSUP	–	0.5	–	ms	

Symbol	Parameter	Pin Name	Limit Values			Unit	Test Conditions
			Min.	Typ.	Max.		
PSI5 Timing Parameter							
$t_{repetition}$	Repetition rate	VSUP	–	250	–	µs	Customer configurable Bit repetition_rate in SETUP_OUTPUT register
			–	300	–		
			–	500	–		
			–	1000	–		
t_{OSD}	Overall Signal Delay	VSUP	–	tbd.	tbd.	µs	Depends on PSI5 settings
t_{Sync_hold}	Sync Pulse Hold Time	VSUP	36	–	–	µs	For common mode
			9	–	–	µs	For low power mode
Δt_{Detect}	Tolerance of Internal Trigger Detection Delay	VSUP	–	–	3	µs	
t_{Bit}	Bit time	VSUP	7.6	8.0	8.4	µs	125 kbps mode
			5.0	5.3	5.6	µs	189 kbps mode
$t_{rise,fall}$	Rise/Fall Time of Current Slope	VSUP	0.33	–	1.0	µs	20% to 80% of $\Delta I_{S,x}$
MSR	Mark/Space Ratio	VSUP	47	50	53	%	at the sensor $(t_{fall,80} - t_{rise,20}) / t_{Bit}$ $(t_{fall,20} - t_{rise,80}) / t_{Bit}$
t_{ucut}	Microcut rejection	VSUP	–	10	–	µs	According to PSI5
f_{osc}	Internal Oscillator Frequency	–	–	32	–	MHz	
Δf_{osc}	Accuracy of Internal Oscillator Frequency	–	–3	–	3	$\%f_{OSC}$	
Δf_{osc_temp}	Thermal Drift of Internal Oscillator Frequency	–	tbd.	–	tbd.	$\%f_{OSC}$	
f_{sample}	Sampling Frequency	–	–	8	–	kSps	Configurable
$t_{Startup}$	Start-up Time	VSUP	–	–	10	ms	Time till start of Init Phase I
PSI5 Sync Pulse Voltages							
V_{Sync}	Sync Pulse Voltage	VSUP	3.5	–	–	V	Standard pulse
			2.5	–	–	V	Low power mode pulse
$V_{Trigger}$	Trigger Voltage Threshold	VSUP	1.4	2.0	2.8	V	Standard pulse
			1.2	1.5	1.8	V	Low power mode pulse
SOIC8 Package							
							(Self-heating calculation see Section 6.1. on page 50)
R_{thja}	Thermal Resistance Junction to Air	–	–	–	140	K/W	Determined with a 1S0P board
		–	–	–	93	K/W	Determined with a 2S2P board
R_{thjc}	Thermal Resistance Junction to Case	–	–	–	33	K/W	Determined with a 1S0P & 2S2P board

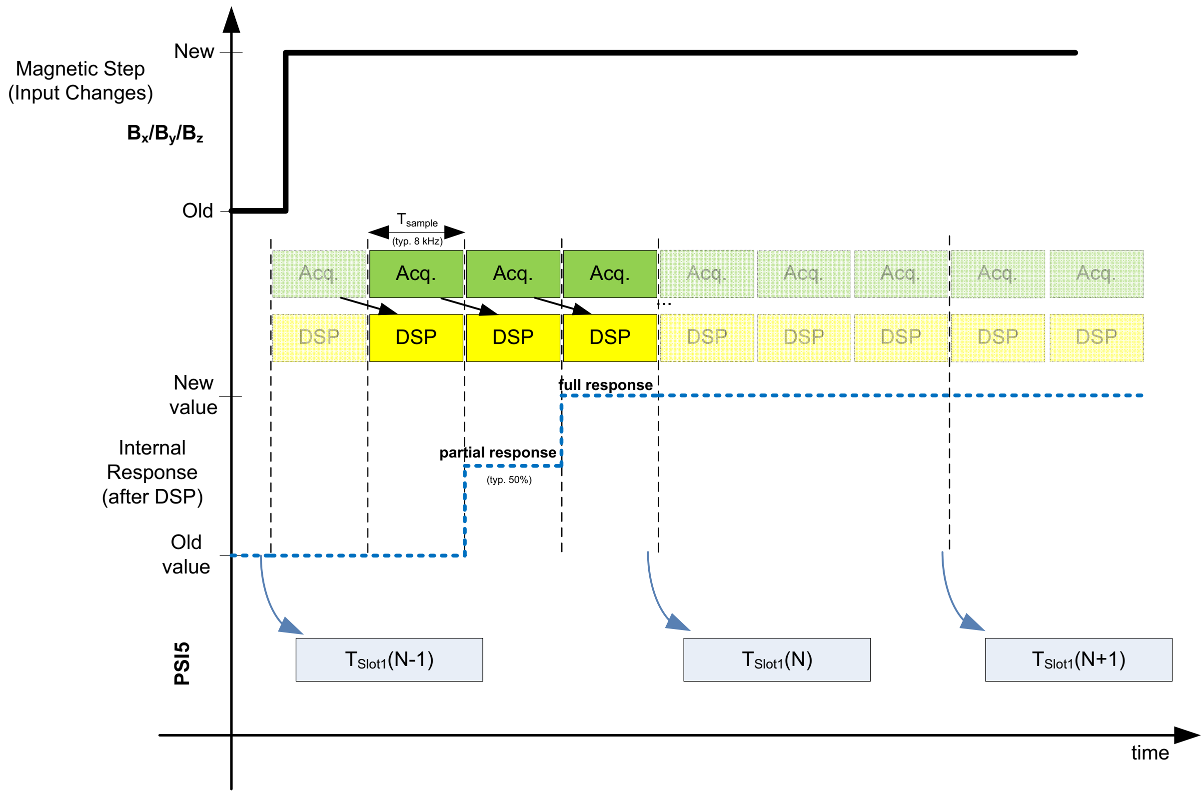


Fig. 5–6: Step response behavior of HAL 3980

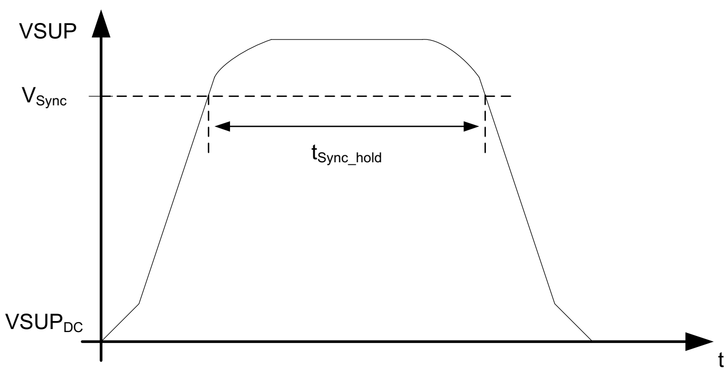


Fig. 5–7: Definition of synchronization pulse and timing

5.10. Magnetic Characteristics

at T_A = –40 °C to 125 °C, V_{SUP} = 4.0 V to 16.5 V, GND = 0 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 °C and V_{SUP} = 5.0 V.

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Test Conditions
Rotary Setup with Stray-Field Compensation (Setup 1 & 2)							
$E_{\Theta tot}$	Total Angular Error (temp.+life)	VSUP	–1.1	–	1.1	°	2)3) B_{AMP} = ±10 mT
$\Delta E_{\Theta temp}$	Angular Error Drift over Temperature	VSUP	–0.5	–	0.5	°	2)3) B_{AMP} = ±10 mT
$\Delta E_{\Theta life}$	Angular Error Drift over Lifetime	VSUP	–0.6	–	0.6	°	2)3) B_{AMP} = ±10 mT After 1000 hrs HTOL
$E_{\Theta hyst}$	Angular Hysteresis Error	VSUP	–	–	0.05	°	2)
$E_{\Theta lin}$	Non-Linearity Error	VSUP	–0.1	–	0.1	°	2) T_A = 25 °C and before EOL calibration
$E_{\Theta \mu lin}$	Micro-Linearity Error	VSUP	–	–	0.1	°/1°	2)
$E_{\Theta noise}$	Angular Noise (RMS)	VSUP	–	–	tbd.	°	2) @10 mT amplitude FS
$E_{\Theta SF\_1}$	Angular Error due to Stray-Field for Setup 1	VSUP	–	0.1	tbd.	°	1)2) Magnet with 5 mT/mm gradient 4 kA/m stray field
$E_{\Theta SF\_2}$	Angular Error due to Stray-Field for Setup 2	VSUP	–	0.1	tbd.	°	1)2) Magnet with 5 mT/mm gradient 4 kA/m stray field
Linear Movement Setup (ΔXZ) with Stray-Field Compensation (Setup 3)							
$SM_{\Delta XZ41}$	Sensitivity Mismatch between ΔX_{41} and ΔZ_{41} Channel	VSUP	–3	–	3	%	2) T_A = 25 °C
$Sense_{\Delta XZ41}$	Sensitivity of ΔX_{41} and ΔZ_{41} Channel	VSUP	tbd.	128	tbd.	LSB_{15} /mT	2) T_A = 25 °C
$\Delta SM_{\Delta XZ41}$	Thermal Sensitivity Mismatch Drift between ΔX_{41} and ΔZ_{41} Channel	VSUP	–2.5	–	2.5	%	2) Related to T_A = 25 °C
$Offset_{\Delta X41}$	Offset of ΔX_{41} Channel	VSUP	–20	–	20	LSB_{15}	2) T_A = 25 °C
$Offset_{\Delta Z41}$	Offset of ΔZ_{41} Channel	VSUP	–20	–	20	LSB_{15}	2) T_A = 25 °C
$\Delta Offset_{\Delta X41}$	Offset Drift of ΔX_{41} Channel	VSUP	–50	–	50	LSB_{15}	2) Related to T_A = 25 °C
$\Delta Offset_{\Delta Z41}$	Offset Drift ΔZ_{41} Channel	VSUP	–25	–	25	LSB_{15}	2) Related to T_A = 25 °C
$\Delta SM_{\Delta XZ41life}$	Relative Sensitivity Mismatch Drift between ΔX_{41} and ΔZ_{41} Channel over life time	VSUP	–	1.0	–	%	2) After 1000 h HTOL
$\Delta Offset_{\Delta X41life}$	Offset Drift of ΔX_{41} Channel over life time	VSUP	–	30	–	LSB_{15}	2) After 1000 h HTOL

1) Characterized on small sample size according to ISO 11452-8:2015, at 30°C, with stray-field strength of 4 kA/m from X,Y, and Z direction.
2) Characterized on small sample size, 3-sigma value, not tested for each device.
3) Calculated based on characterization and error model

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Test Conditions
$\Delta Offset_{\Delta Z41life}$	Offset Drift of ΔZ_{41} Channel over life time	VSUP	–	5	–	LSB_{15}	2) After 1000 h HTOL
$SF_{SUP\Delta XZ41}$	Stray-Field Suppression on ΔX_{41} and ΔZ_{41}	VSUP	–	–	tbd.	%	2)
$E_{\Theta phase\Delta XZ41}$	Magnetic Angle Phase Error	VSUP	–	tbd.	–.	°	2) between ΔX_{41} and ΔZ_{41} axis
Off-Axis Rotary Setup (ΔXY) with Stray-Field Compensation (Setup 3)							
$SM_{\Delta XY41}$	Sensitivity Mismatch between ΔX_{41} and ΔY_{41} Channel	VSUP	–3	–	3	%	2) T_A = 25 °C
$Sense_{\Delta XY41}$	Sensitivity of ΔX_{41} and ΔY_{41} Channel	VSUP	tbd.	128	tbd.	LSB_{15} /mT	2) T_A = 25 °C
$\Delta SM_{\Delta XY41}$	Thermal Sensitivity Mismatch Drift between ΔX_{41} and ΔY_{41} Channel	VSUP	–2.5	–	2.5	%	2) Related to T_A = 25 °C
$Offset_{\Delta XY41}$	Offset of ΔX_{41} and ΔY_{41} Channels	VSUP	–20	–	20	LSB_{15}	2) T_A = 25 °C
$\Delta Offset_{\Delta XY41}$	Offset Drift of ΔX_{41} and ΔY_{41} Channels	VSUP	–50	–	50	LSB_{15}	2) Related to T_A = 25 °C
$\Delta SM_{\Delta XY41life}$	Relative Sensitivity Mismatch Drift between ΔX_{41} and ΔY_{41} Channels over life time	VSUP	–	1.0	–	%	2) After 1000 h HTOL
$\Delta Offset_{\Delta XY41life}$	Offset Drift of ΔX_{41} and ΔY_{41} Channel over life time	VSUP	–	30	–	LSB_{15}	2) After 1000 h HTOL
$SF_{SUP\Delta XY41}$	Stray-Field Suppression on ΔX_{41} and ΔY_{41}	VSUP	–	–	tbd.	%	2)
$E_{\Theta phase\Delta XY41}$	Magnetic Angle Phase Error	VSUP	–	tbd.	–	°	2) between ΔX_{41} and ΔY_{41} axis
2D Measurement Setup without Stray-Field Compensation (Setup 4)							
SM_{XYZ}	Sensitivity Mismatch between X,Y and Z Channel	VSUP	–3	–	3	%	2) T_A = 25 °C
$Sense_{XYZ}$	Sensitivity of X,Y and Z Hall-plate	VSUP	tbd.	128	tbd.	LSB_{15} /mT	2) T_A = 25 °C
ΔSM_{XYZ}	Thermal Sensitivity Mismatch Drift between X, Y and Z Hall Plates	VSUP	–2.5	–	2.5	%	2) Related to T_A = 25 °C
$Offset_{XY}$	Offset of X and Y Hall-plates	VSUP	–20	–	20	LSB_{15}	2) T_A = 25 °C
$Offset_Z$	Offset of Z Hall-plate	VSUP	–12	–	12	LSB_{15}	2) T_A = 25 °C
$\Delta Offset_{XY}$	Offset Drift of X and Y Hall-plates	VSUP	–50	–	50	LSB_{15}	2) Related to T_A = 25 °C
$\Delta Offset_Z$	Offset Drift of Z Hall-plate	VSUP	–15	–	15	LSB_{15}	2) Related to T_A = 25 °C
$\Delta SM_{XYZlife}$	Relative Sensitivity Mismatch Drift between X, Y and Z Hall Plates over life time	VSUP	–	1.0	–	%	2) After 1000 h HTOL
$\Delta Offset_{XYlife}$	Offset Drift of X and Y Hall-plates over life time	VSUP	–	30	–	LSB_{15}	2) After 1000 h HTOL
$\Delta Offset_{Zlife}$	Offset Drift of Z Hall-plate over life time	VSUP	–	5	–	LSB_{15}	2) After 1000 h HTOL
2) Characterized on small sample size, 3-sigma values, not tested for each device.							

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Test Conditions
$E_{\Theta phaseXYZ}$	Magnetic Angle Phase Error	VSUP	–	tbd.	–	°	2) XY axis
			–	tbd.	–	°	2) XZ axis
			–	tbd.	–	°	2) YZ axis
2D Measurement Setup (virtual centered Pixel XY) without Stray-Field Compensation (Setup 4a)							
$SM_{\Sigma XY41}$	Sensitivity Mismatch between ΣX_{41} and ΣY_{41} Channel	VSUP	–3	–	3	%	2) T_A = 25 °C
$Sense_{\Sigma XY41}$	Sensitivity of ΣX_{41} and ΣY_{41} Channel	VSUP	tbd.	128	tbd.	LSB/ mT	2) T_A = 25 °C
$\Delta SM_{\Sigma XY41}$	Thermal Sensitivity Mismatch Drift between ΣX_{41} and ΣY_{41} Channel	VSUP	–2.5	–	2.5	%	2) Related to T_A = 25 °C
$Offset_{\Sigma XY41}$	Offset of ΣX_{41} and ΣY_{41} Channel	VSUP	–20	–	20	LSB_{15}	2) T_A = 25 °C
$\Delta Offset_{\Sigma XY41}$	Offset Drift of ΣX_{41} and ΣY_{41} Channel	VSUP	–50	–	50	LSB_{15}	2) Related to T_A = 25 °C
$\Delta SM_{\Sigma XY41life}$	Relative Sensitivity Mismatch Drift between ΣX_{41} and ΣY_{41} Channel over life time	VSUP	–	1.0	–	%	2) After 1000 h HTOL
$\Delta Offset_{\Sigma XY41life}$	Offset Drift of ΣX_{41} and ΣY_{41}Channel over Life Time	VSUP	–	30	–	LSB_{15}	2) After 1000 h HTOL
$E_{\Theta phase\Delta XY}$	Magnetic Angle Phase Error	VSUP	–	tbd.	–	°	2)
2) Characterized on small sample size, 3-sigma values, not tested for each device							

5.11. Angle Speed Characteristics

at T_A = –40°C to 125°C, V_{SUP} = 4.0 V to 16.5 V, GND = 0 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°C and V_{SUP} = 5 V.

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Test Conditions
$V_{\Theta RANGE}$	Angle Speed Measurement Range	VSUP	–1000	–	1000	°/s	Customer configurable
			–5000	–	5000	°/s	
$V_{\Theta Res}$	Angle Speed Resolution	VSUP	9	12	16	Bit	
$E_{Vt\Theta ot}$	Total Angle Speed Error	VSUP	tbd.	–	tbd.	°/s	
$V_{NoiseRMS}$	RMS Noise on Angle Speed Signal	VSUP	tbd.	–	tbd.	°/s	

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 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.

Note 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.

6.2. EMC and ESD

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

6.3. Application Circuit for HAL 3980

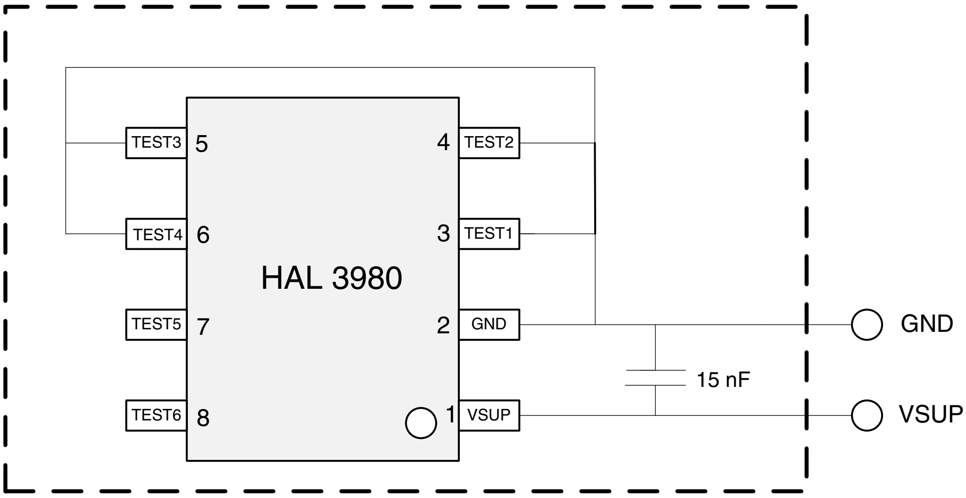


Fig. 6–1: Recommended application circuit for HAL 3980

6.4. Recommended Pad Size SOIC8 Package

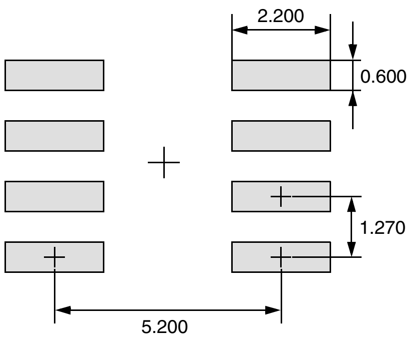


Fig. 6–2: Pad size recommendation for SOIC8 Package (all dimensions in mm)

7. Programming of the Sensor

HAL 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 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.

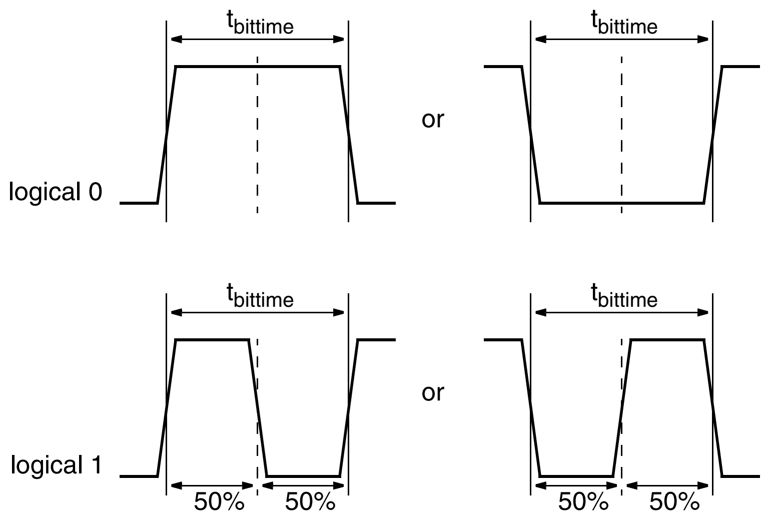


Fig. 7–1: Definition of logical 0 and 1 bit

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_{SUPL}	Voltage for Supply Low Level during Communication	VSUP	6.0	6.3	6.5	V	
V_{SUPH}	Voltage for Output High Level during Communication	VSUP	7.0	7.2	7.5	V	
I_{SUPL}	Sensor Supply Current Low Level during Communication	VSUP	11	13	15	mA	
I_{SUPH}	Sensor Supply Current High Level during Communication	VSUP	22	26	30	mA	
$V_{SUPProgram}$	V_{SUP} Voltage for EEPROM programming (during Programming)	VSUP	4.5	-	5.5	V	

7.2. Programming Environment and Tools

For the programming of HAL 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 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 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.

Note A description of the communication protocol and the programming of the sensor is available in a separate document HAL/HAC 3980 Programming Guide.

8. Document History

1. Advance Information: "HAL 3980 Stray-Field Robust 3D Position Sensor with PSI5 Output Interface", July 13, 2020, AI000227_001EN. First release of the advance information.

TDK-Micronas GmbH
Hans-Bunte-Strasse 19 · D-79108 Freiburg · P.O. Box 840 · D-79008 Freiburg, Germany
Tel. +49-761-517-0 · Fax +49-761-517-2174 · www.micronas.com