MICRONAS

Hardware
Documentation

Data Sheet

HAL® 3900

Stray-Field Robust 3D Position Sensor with SPI Interface

3D HAL® Technology

masterHAL® Technology

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Contents

Stray-Field Robust 3D Position Sensor with SPI Interface

Note Revision bars indicate changes compared to the Advance Information

1. Introduction

HAL 3900 is a member of TDK-Micronas' new 3D position sensor generation addressing the need for stray-field robust 2D position sensing (linear and angular) as well as the ISO 26262 compliant development. It is a high-resolution position sensor for highly accurate position measurements.

HAL 3900 features an SPI output. The device can measure 360° angular range, linear movements as well as 3D position information. 3D position means two angle calculated out of $B_X/B_Y/B_Z$. The position information can be read via an SPI interface. It is also possible to read the three magnetic raw values via the SPI interface without position calculation. The values are already temperature compensated by the device itself. The chip temperature can be read as well. The measurement data is provided as 16-bit value.

In addition, several Low-Power modes are available. In one mode an external ECU can send the device into Low-Power mode. The device wakes up periodically and provides measurement data in the active time. In another mode, then sensor can also wake up the external ECU in case that one magnetic-field component exceeds a programmable threshold or if one of the two calculated position information is passing a certain threshold.

The device measures, based on Hall technology, vertical and horizontal magnetic-field components. The device is able to suppress external magnetic stray-fields by using an array of Hall plates. Only a simple 2-pole magnet is required to measure an rotation angle, linear position or a 3D position. Ideally, the magnet should be placed above the sensitive area in an end of shaft configuration.

Major characteristics like gain and offset, reference position, etc. can be adjusted to the magnetic circuitry by programming the non-volatile memory. Additional output signal linearization of the position information is possible by using up to 17 setpoints with variable distance or 33 equidistant distributed setpoints.

The device non-volatile memory is programmable via the SPI interface.

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 ... 150 °C.

The sensor is available in the 8-pin SOIC-8 SMD package.

1.1. Major Applications

Due to the sensor's versatile programming characteristics and its high accuracy, the HAL 3900 is a potential system solution for the following application examples:

- Real 3D position detection, like
  - Joystick
  - Shifter position
  - Steering column switch position
- Rotary position detection (end-of shaft and off-axis)
  - Transmission applications
  - Wiper position detection
- Linear position detection
  - Transmission applications

1.2. General Features

- 3D position detection supporting transmission of two angle out of B_X, B_Y or B_Z
- Temperature-compensated values of B_X, B_Y and B_Z accessible via SPI
- 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
- Supply voltages between 3.0 V and 5.5 V
- SPI communication up to 10 MHz
- 16-bit data transmission with CRC and rolling counter
- Up to 16 kSps sampling frequency
- Operates from –40 °C up to 170 °C junction temperature
  (Max. Ambient Temperature: $T_{A,absmax}$ = 160 °C)
- Programming via SPI interface
- Various configurable signal processing parameter, like output gain and offset, reference position, temperature dependent offset, etc.
- 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-Chip diagnostics of different functional blocks of the sensor
- Low-power mode with wake-up by magnetic field/position information change or external wake-up pin

2. Ordering Information

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

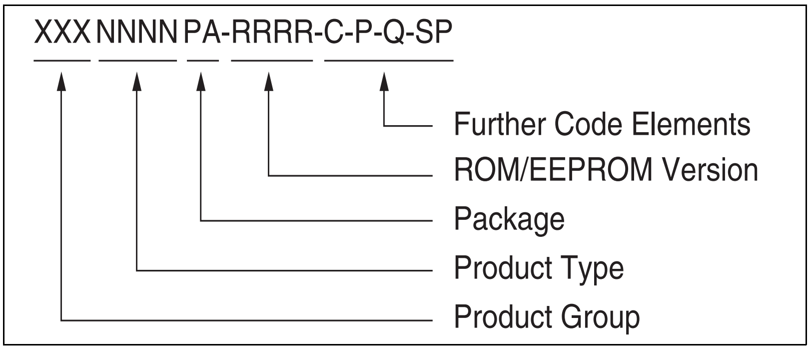


Fig. 2–1: Ordering Code Principle

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

2.1. Device-Specific Ordering Codes

The HAL 3900 is available in the following package and temperature variants.

Table 2–1: Available package

Package Code (PA)	Package Type
DJ	SOIC-8

Table 2–2: Available temperature range

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 49.

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
HAL3900DJ[ROMID]-[C-P-Q-SP]	3900[ROMID] Lot Number Date Code SB	SOIC-8

3. Functional Description

3.1. General Function

HAL 3900 is a 3D 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).

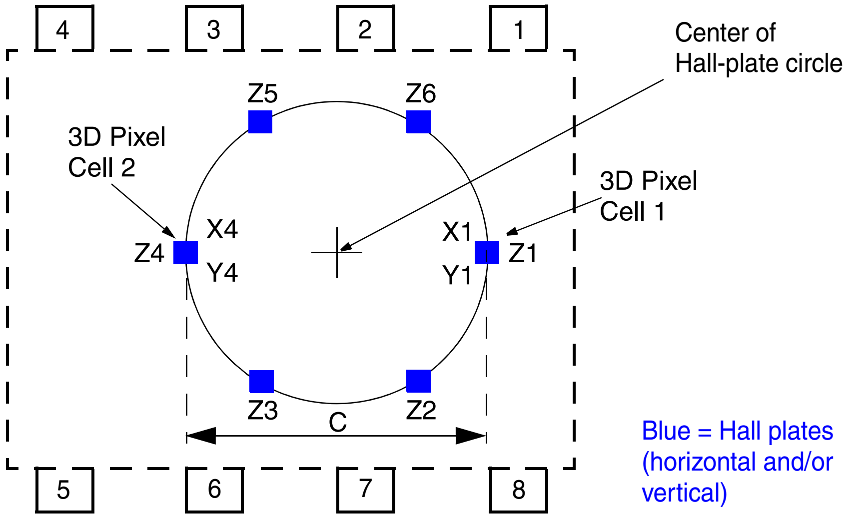


Fig. 3–1: Hall plate configuration for HAL 3900

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 the 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_Y/B_X, B_Z/B_X, B_Z/B_Y) with 3D Pixel Cell 1
- 3D position detection with transmission of temperature compensated signals (B_X,B_Y, B_Z) or transmission of up to two calculated angle

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 sensor features a 4-wire SPI (Serial Peripheral Interface) to get access to the sensor memory as well as to the measurement results. HAL 3900 operates as an SPI slave only. Each data transfer is full duplex for simultaneously read/write commands to the sensor while collecting the response from the former request.

The HAL 3900 is programmable via the integrated SPI interface. No additional programming pin is needed and fast end-of-line programming is enabled.

HAL 3900 features two kinds of operational modes. A so-called Application Mode and a Low-Power Mode. In Application Mode, the sensor is continuously capturing position information from an external magnet and an ECU can poll the measured information. In Low-Power Mode, the sensor is in a Sleep Mode for a certain time and shortly in Active Mode to capture measurement data. During Sleep Mode, the current consumption of the device is significantly reduced. The Low-Power Modes offer different possibilities for configuration, like periodically wake-up of the sensor by internal timer, wake-up of external ECU after detection of an angle or magnetic-field change by the sensor, etc. All different Low-Power Mode configurations are described in Table 3–9 on page 28.

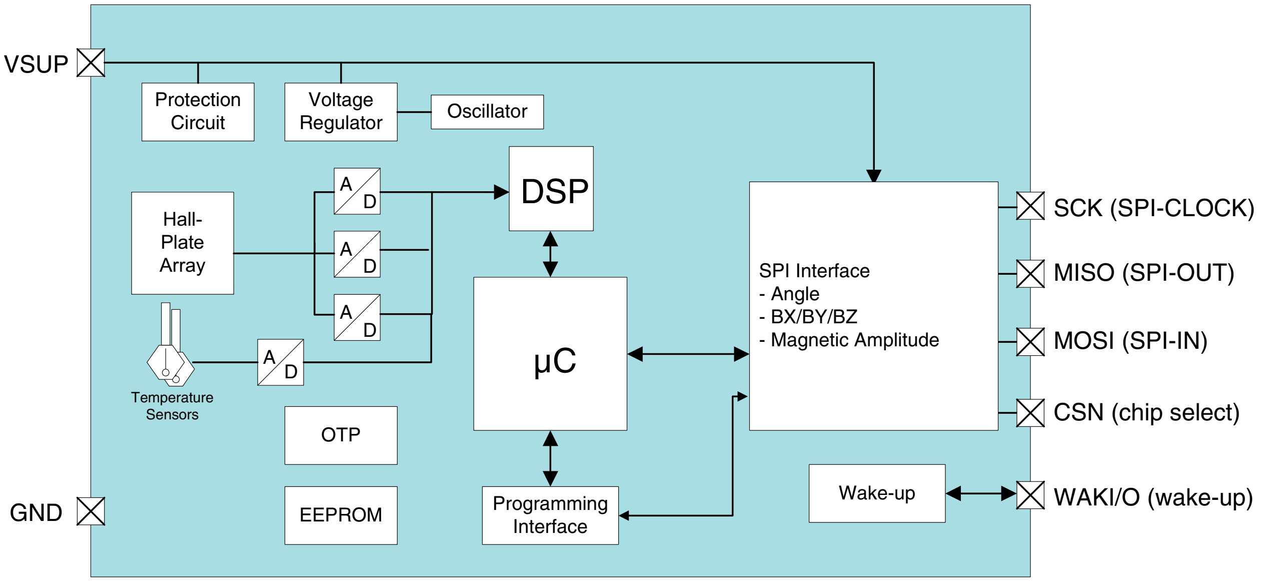


Fig. 3–2: HAL 3900 block diagram

3.2. Signal Path

The DSP part of this sensor performs the signal conditioning. The parameter for the DSP are stored in the non-volatile memory. 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.

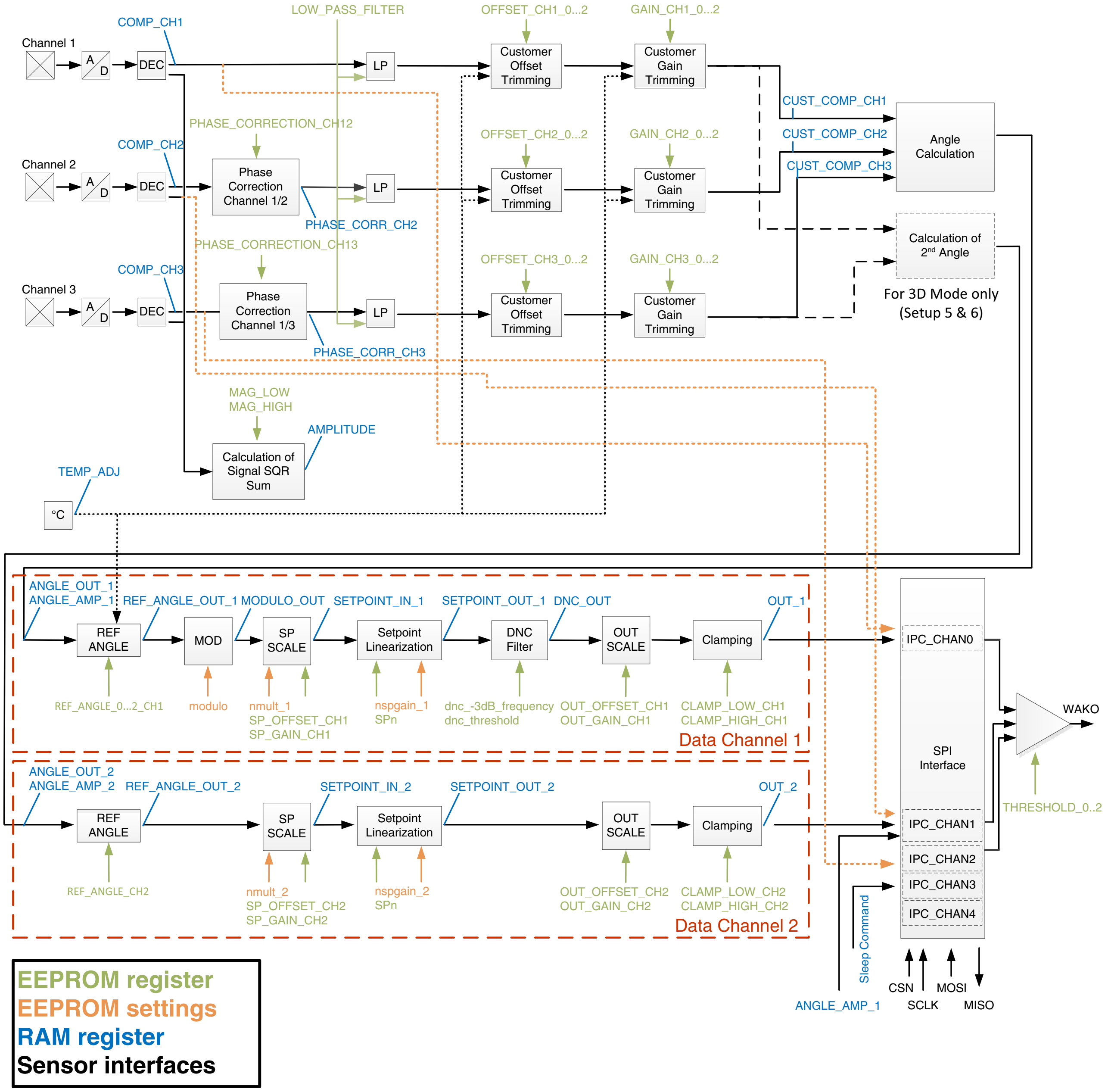


Fig. 3–3: Signal path of HAL 3900

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

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/ HAR 3900 User Manual.

3.3.1. RAM Register

TEMP_TADJ

The TEMP_TADJ register contains already the TDK-Micronas' compensated digital value of the sensor junction temperature.

COMP_CH1, COMP_CH2 and COMP_CH3

COMP_CH1, COMP_CH2 and COMP_CH3 register contain the TDK-Micronas' temperature compensated magnetic-field information of channel 1, channel 2 and channel 3.

Amplitude

The AMPLITUDE register contains the sum of squares of the magnetic-field amplitude of all three signals 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:

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

PHASE_CORR_CH2, PHASE_CORR_CH3

PHASE_CORR_CHx register contain the customer-compensated magnetic-field information of channel 2 and channel 3 after customer phase-shift error correction using the PHASE_CORRECTION_CHx register.

CUST_COMP_CH1, CUST_COMP_CH2 and CUST_COMP_CH3

CUST_COMP_CH1, CUST_COMP_CH2 and CUST_COMP_CH3 register contain the customer compensated magnetic-field information of channel 1, channel 2 and channel 3 used for the angle calculation. These register contain already the customer phase-shift, gain and offset corrected data.

ANGLE_OUT_x

The ANGLE_OUT_1 and ANGLE_OUT_2 register contain the digital value of the position calculated by the angle calculation algorithm. ANGLE_OUT_1 is always available and ANGLE_OUT_2 is an customer configuration option only available for 3D measurements with one pixel cell enabling the calculation of a second angle out of B_X, B_Y and B_Z.

ANGLE_AMP_x

The ANGLE_AMP_1 and ANGLE_AMP_2 register contain the digital value of the magnetic-field amplitude calculated by the angle calculation algorithm. ANGLE_AMP_1 is always available and ANGLE_AMP_2 is an customer configuration option only available for 3D measurements with one pixel cell enabling the calculation of a second angle out of B_X, B_Y and B_Z.

REF_ANGLE_OUT_x

The REF_ANGLE_OUT_x register contain 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. MODULO_OUT is only available for the primary angle output.

SETPOINT_IN_x

The SETPOINT_IN_x register contain the digital value of the angle information after the setpoint scaling block and are the values used for the input of the setpoint linearization block.

SETPOINT_OUT_x

The SETPOINT_OUT_x register contain 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. DNC_OUT is only available for the primary angle output.

OUT_x

The OUT_x register contain the digital value of the angle information after all signal processing steps and depends on all customer configuration settings.

DIAGNOSIS

The DIAGNOSIS_0 and DIAGNOSIS_1 register report certain failures detected by the sensor. HAL 3900 performs self-tests during power-up as well as continuous system integrity tests during normal operation. The result of those tests is reported via the DIAGNOSIS_X register (further details can be found in Table 4–1 & Table 4–2).

Micronas IDs

The MIC_ID1 and MIC_ID2 register 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.

Note The above mentioned RAM register can be read in programming mode. For normal application mode, respectively in the running application, only IPC_CHAN0...2 register must be used. Only those register are secured via CRC checks and error reporting. Table 3–1 shows the available data.

Table 3–1: Hardware register memory table

Address	Register Name	Function
0x70	IPC_CHAN0	Inter-processor data channel 0 OUT_1 or COMP_CH1 (in case of SETUP 7)
0x71	IPC_CHAN1	Inter-processor data channel 1 OUT_2 (if secondary channel is selected) or ANGLE_AMP_1 (for setups with single angle calculation) or COMP_CH2 (in case of SETUP 7)
0x72	IPC_CHAN2	Inter-processor data channel 2 COMP_CH3 (in case of SETUP 7)
0x73	IPC_CHAN3	Inter-processor data channel 3 Send to sleep command
0x74	IPC_CHAN4	Inter-processor data channel 4 Not used
0x75	IPC_CHAN5	Inter-processor data channel 5 For EEPROM memory access and programming or RAM register read
0x78	COMP_CH1	Signal after decimation filter 1
0x79	COMP_CH2	Signal after decimation filter 2
0x7A	COMP_CH3	Signal after decimation filter 3
0x7D	DIAG_0	Diagnosis register 0 (see Table 4–1 on page 33)
0x7E	DIAG_1	Diagnosis register 1(see Table 4–2 on page 34)
0x7F	HW_ID	Hardware ID base

3.3.2. EEPROM Register

Application Modes

HAL 3900 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 (see Table 3–3 on page 23) 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. 3–4 shows the related signal path.

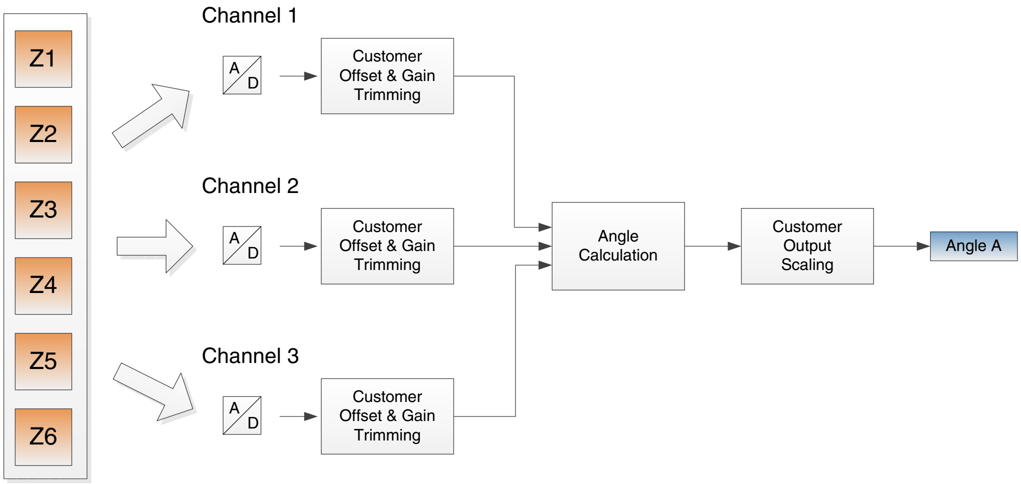


Fig. 3–4: Signal path diagram of setup 1 (stray-field robust 180° measurement)

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

This mode uses horizontal Hall plates to measure an 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.

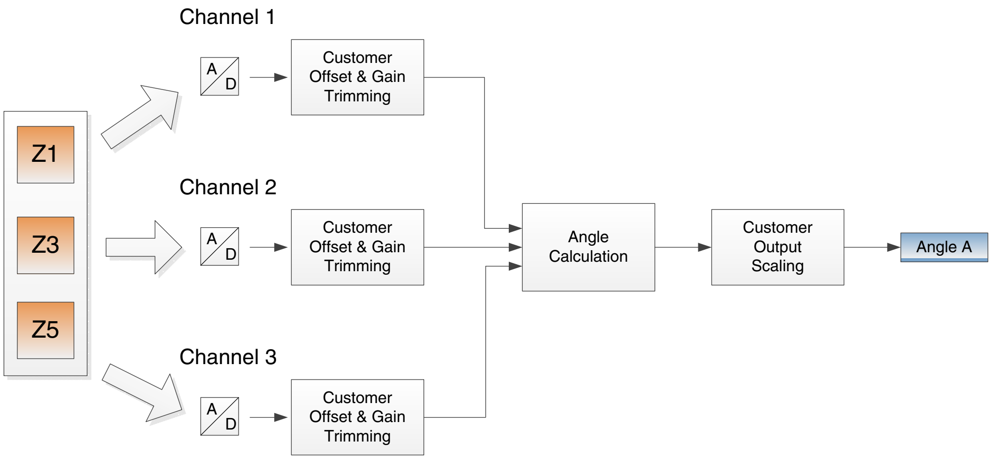


Fig. 3–5: Signal path diagram of setup 2 (stray-field robust 360° measurement)

– 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 of 3D Pixel Cells 1 and 2). Alternatively this setup can also be used for off-axis stray-field compensated angular measurements if a combination of vertical Hall plates is selected (ΔB_X & ΔB_Y of 3D Pixel Cells 1 and 2). The device can compensate stray-fields according to ISO 11452-8 definition. Fig. 3–6 shows the related signal path.

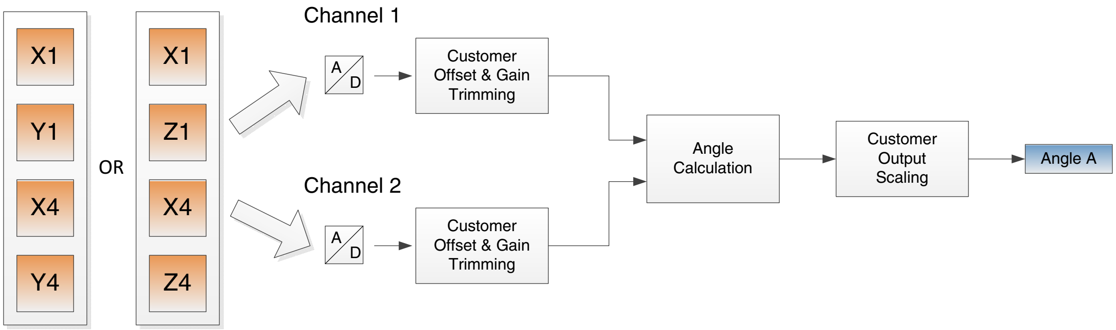


Fig. 3–6: Signal path diagram of setup 3 (stray-field robust linear position detection)

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:

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

– 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. 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 any stray-fields. The measurement setup is similar to the well known TDK-Micronas HAL 37xy family.

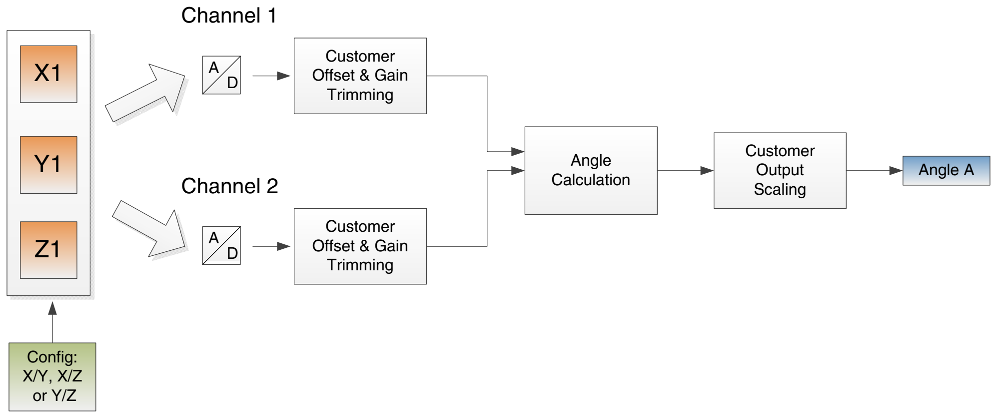


Fig. 3–7: Signal path diagram of setup 4a (rotary & linear position detection w/o stray-field compensation)

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

In addition to setup 4a, it is also 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 P4 are combined to generate one virtual centered pixel in the middle of the Hall-Plate array.

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

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

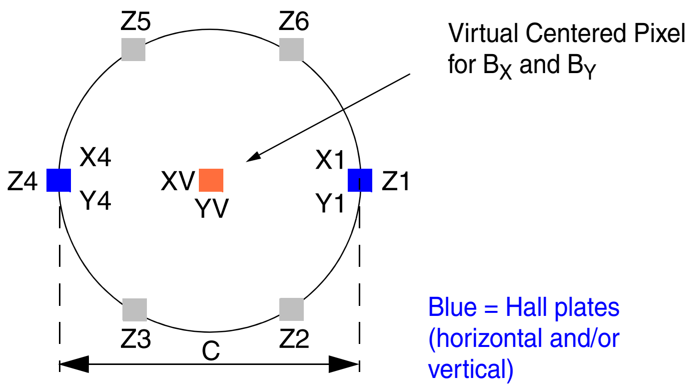


Fig. 3–8: Virtual centered pixel for B_X and B_Y in Mode 4b

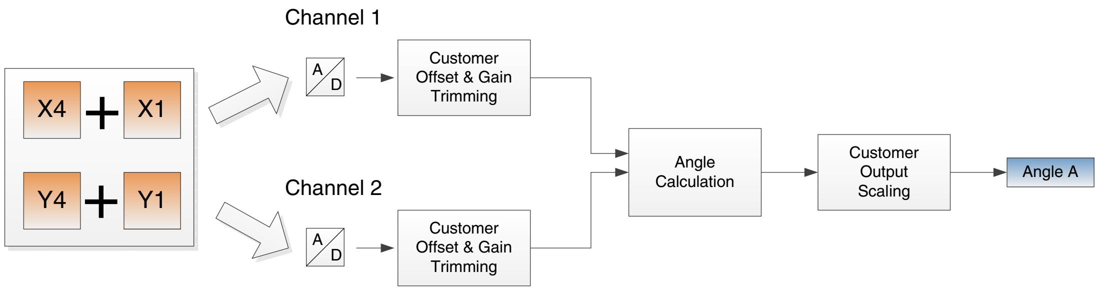


Fig. 3–9: Signal path diagram of setup 4b (virtual centered pixel w/o stray-field compensation)

– Setup 5: 3D measurement with calculation of two angles (ARCTAN2 calculation)

This mode uses horizontal and vertical Hall plates to measure B_X, B_Y, B_Z. Two angle will be calculated out of combinations of B_Z/B_X and B_Z/B_Y. This mode does not compensate any stray-fields.

The angle calculation is done by using the following equations:

$$\mathrm{ALPHA} = \mathrm{ATAN2}\left(\frac{\mathrm{BZ}}{\mathrm{BX}}\right)$$

$$\mathrm{BETA} = \mathrm{ATAN2}\left(\frac{\mathrm{BZ}}{\mathrm{BY}}\right)$$

Both calculated angle can be read out via the SPI interface.

See Fig. 3–10 for detailed signal path.

– Setup 6: 3D measurement with calculation of two angles (joystick equation)

This mode uses horizontal and vertical Hall plates to measure B_X, B_Y, B_Z. Two angles will be calculated by a special equation optimized for “joystick” setups. This mode does not compensate any stray-fields.

The angle calculation is done by using the following equations:

$$\mathrm{ALPHA} = \mathrm{ATAN}\left(\frac{\sqrt{\mathrm{CUST\_COMP\_CH1}^2 + (\mathrm{JOYSTICK\_KT} \times \mathrm{CUST\_COMP\_CH3})^2}}{\mathrm{CUST\_COMP\_CH2}}\right)$$

$$\mathrm{BETA} = \mathrm{ATAN}\left(\frac{\sqrt{\mathrm{CUST\_COMP\_CH1}^2 + (\mathrm{JOYSTICK\_KT} \times \mathrm{CUST\_COMP\_CH2})^2}}{\mathrm{CUST\_COMP\_CH3}}\right)$$

Both calculated angle can be read out via the SPI interface.

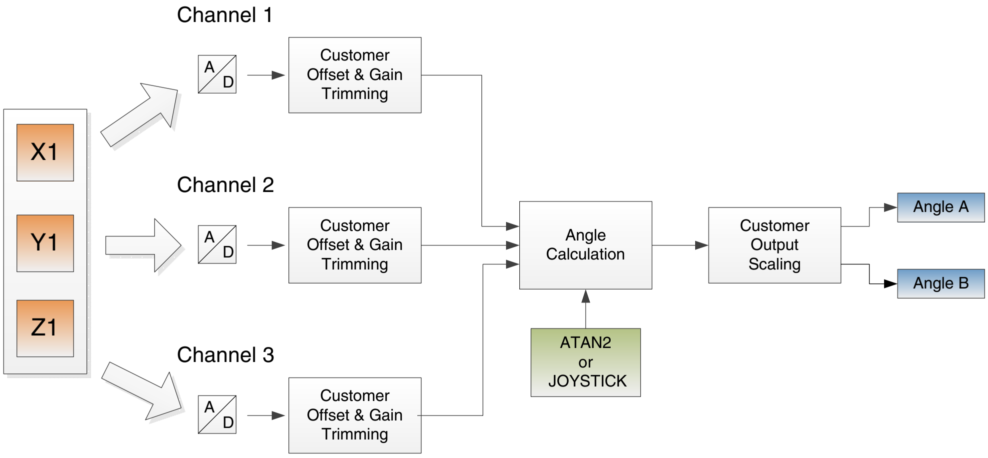


Fig. 3–10: Signal path diagram of setup 5 & 6 (3D measurement)

– Setup 7: 3D measurement with raw values

This mode uses horizontal and vertical Hall plates to measure B_X, B_Y, B_Z. It is possible to read out the temperature compensated raw values of B_X, B_Y and B_Z. This mode does not compensate any stray-fields.

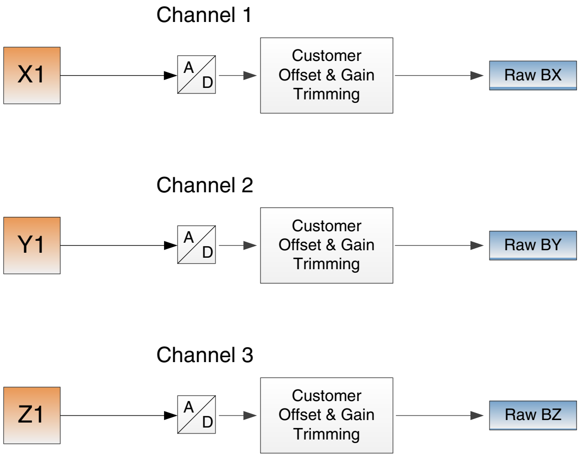


Fig. 3–11: Signal path diagram of setup 7 (Transmission of raw signals)

JOYSTICK_KT

The equation for the angle calculation in Setup 6 (Joystick 3D measurement) is using a gain factor “GAIN”. JOYSTICK_KT is a 16 bit register.

Customer IDs

The customer ID register (CUSTOMER_ID0 to CUSTOMER_ID9) contain nine 16-bit words and can be used to store customer production information, like serial number or project information, etc.

Magnetic-Field 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 register 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 –3dB frequencies for HAL 3900. The default value is zero (low pass filter disabled). The filter frequency is valid for all channel.

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).

OFFSET_CHx_0...2

OFFSET_CH1_0...2, OFFSET_CH2_0...2 and OFFSET_CH3_0...2 support three polynomials of second order and describe 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).

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). REF_ANGLE_CH2 is temperature independent (constant factor) and only available in case that the secondary channel is activated.

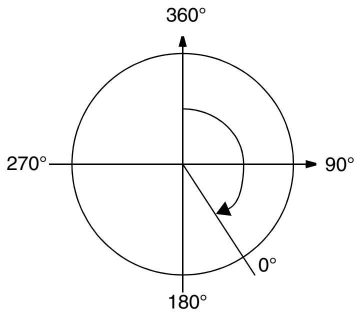


Fig. 3–12: Example definition of zero degree point

Modulo Select

HAL 3900 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 three different output ranges. Modulo function can only be applied on the primary output channel.

The desired modulo calculation can be selected by setting certain bits in the SETUP_FRONTEND register.

nmult_x (EEPROM Setting)

nmult_1 and nmult_2 define the gain exponent for the setpoint scaling block on the data channel. The factor is multiplied by SP_GAIN_CHx to achieve gain factors up to 128. (SETUP_DATAPATH[11:9] bits (= nmult_2), SETUP_DATAPATH[7:5] bits (= nmult_1).

Setpoint Gain

SP_GAIN_CH1 and SP_GAIN_CH2 define the output gain for the primary and secondary channels. They are used to scale the position information to the input range of the linearization block. SP_GAIN_CH2 is only available for modes with a calculation of a secondary angle.

Setpoint Offset

SP_OFFSET_CH1 and SP_OFFSET_CH2 define the output offset for the primary and secondary channels. SP_OFFSET_CH2 is only available for modes with a calculation of a secondary angle.

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 register have a length of 16 bits and are two's complement coded. Therefore the setpoint register values can vary between –32768...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_x value) is interpolated linearly between two adjacent setpoints (SP(n) and SP(n+1)). The resulting SETPOINT_OUT_x register value represents the angular information after the setpoint scaling.

In case of variable setpoints are selected nspgain_x (nspgain_1 & nspgain_2) register must be used.

nsp_gain_x (EEPROM Settings)

The SETUP_DATAPATH[15:12] bits (= nspgain_2) and SETUP_DATAPATH[4:1] bits (= nspgain_1) set the gain exponent for the setpoint slope on data channel 1 and 2. With these 4 bits it is possible to get gains up to 65536.

DNC Filter Register (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 parameter 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_CHx

The register OUT_OFFSET_ CH1 and OUT_OFFSET_CH2 are used as the final offset scaling stage for the desired output signal. The register have a length of 16 bits and are two's complement coded.

OUT_GAIN_CHx

The register OUT_GAIN_CH1 and OUT_GAIN_CH2 are used as the final gain scaling stage for the desired output signal. They can also be used to invert the output signal. The register have a length of 16 bits and are two’s complement coded.

Clamping Levels (CLAMP-LOW & CLAMP-HIGH)

The clamping levels CLAMP_LOW_CH1/CH2 and CLAMP_HIGH_CH1/CH2 define the maximum and minimum output values. All four register have a length of 16 bits and are two´s complemented coded. Both clamping levels can have values between 0 % and 100 %.

Supply Voltage Supervision

As the device supports a wide supply voltage range it is beneficial to enable customer-programmable under- and 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 is using the 8 MSBs and UV_LEVEL the 8 LSBs. For both levels, 1 LSB is typically equal to 100 mV.

Standby Sleep Time

The STANDBY_SLEEP_TIME register defines the period in which the device is in standby mode. The 8 MSBs of this register define the sleep time. The sleep time is calculated by the following equation:

$$\text{Sleep Time} = (n+1) \bullet 2\text{ms}$$

Thresholds for Low-Power Mode

The THRESHOLD_x register define the threshold for the three different wake up sources in Low-Power Mode. The sensor compares its measurement data in the Active Phase of the Low-Power Mode with these thresholds. In case that those thresholds are exceeded the sensor will wake up the external ECU via the WAKI/O pin.

The table below shows the link between the THRESHOLD_X register and the signal sources. The available source also depends on the selected measurement setup.

Table 3–2: Sources for THRESHOLD_X register

THRESHOLD_X	IPC Channel	Signal Source
0	IPC_CHAN0	OUT_1 or COMP_CH1 (Digital value of B_{Z1})
1	IPC_CHAN1	OUT_2/ANGLE_AMP_1 or COMP_CH2 (Digital value of B_{X1})
2	IPC_CHAN2	COMP_CH3 (Digital value of B_{Y1})

Additional information can also be found in Table 3–3 on page 23 and Table 3–1 on page 12.

Customer Configurations Register

The SETUP_FRONTEND, SETUP_DATAPATH, and SETUP_STANDBY register are 16-bit register that enable the customer to activate various functions of the sensor. They also contain the lock bit to lock the sensors memory. Table 3–3, Table 3–4, and Table 3–5 describe in detail the available combinations and resulting functions.

Table 3–3: SETUP_FRONTEND

Bit No.	Function	Description				
15	customer_lock	Customer Lock: 0: Unlocked 1: Locked				
14:9	-	Must be set to 0.				
8	cluster	0: IPC_CHAN0 to IPC_CHAN2 are independent 1: IPC_CHAN0 to IPC_CHAN2 are updated after IPC_CHAN0 is read				
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: 16 KSps (only supported by “3D measurement - RAW” measurement configuration				
3:0	meas_config	**Measurement setups:**	**Correspond. Signal Path**	**CH1**	**CH2**	**CH3**
		0000: Setup 4a - 2D	With two channel	X1	Y1	-
		0001: Setup 4a - 2D	With two channel	Z1	Y1	-
		0010: Setup 4a - 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 4b - 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: Setup 5 - 3D measurement - ATAN2	With three channel	Z1	X1	Y1
		1001: Setup 5 - 3D measurement - Joystick	With three channel	Z1	X1	Y1
		1110: Setup 7 - 3D measurement - Raw	With three channel	Z1	X1	Y1
		1010 to 1111: Must not be used	-	-	-	-

Table 3–4: SETUP_DATAPATH

Bit No.	Function	Description
15:12	nspgain_2	Gain exponent for setpoint slope in channel 2: Slope = SPGn * (2^nspgain_2+1)
11:9	nmult_2	Gain exponent for SETPOINT_IN2: SP_GAIN = SP_GAIN_CH2 * [2^(nmult_2)]
0	two_channels	Activation of second output channel 0: 1 channel with setpoints 1: 2 channels with setpoints each
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	var_sp	Fixed/variable setpoint selection: 0: Fixed setpoints 1: Variable setpoints

Table 3–5: SETUP_STANDBY

Bit No.	Function	Description
15:10	-	Must be set to zero.
9	wakout	WAKI/O pin as wake output: 0: Disabled 1: Enabled Note: Used with internal counter wake-up. Wakes ECU via this pin if desired.
8	cnt_wakeup	Internal wake-up by sleep counter 0: Disabled 1: Enabled
7:6	ext_wakeup	Wake-up from external ECU via WAKI/O pin: 00: Disabled 01: Rising edge 10: Falling edge 11: Rising and falling edge
5:4	thrd_2	Defines the behavior of the Wake-up output pin for changes of IPC2 channel 00: Deactivated 01: Wake ECU if signal IPC2 is above the threshold 10: Wake ECU if signal IPC2 is below the threshold 11: Reserved
3:2	thrd_1	Defines the behavior of the Wake-up output pin for changes of IPC1 channel 00: Deactivated 01: Wake ECU if signal IPC1 is above the threshold 10: Wake ECU if signal IPC1 IPC1 is below the threshold 11: Reserved
1:0	thrd_0	Defines the behavior of the Wake-up output pin for changes of IPC0 channel 00: Deactivated 01: Wake ECU if signal IPC0 is above the threshold 10: Wake ECU if signal IPC0 is below the threshold 11: Reserved
Note: Low-power Mode is enabled if either ext_wakeup or cnt_wakeup are enabled.		

3.4. SPI

The HAL 3900 is equipped with an SPI interface (Serial Peripheral Interface) for memory programming and register reading to transmit the sensor measurement data. SPI uses four wires and a master-slave architecture for synchronous serial communication. The HAL 3900 is always acting as the slave and the ECU is the master. The SPI bus configuration with one slave is shown in Fig. 3–13.

Fig. 3–13: Description of the SPI Bus

On the ‘Master Out Slave In’ (MOSI) wire the master sends data to the slave. On the ‘Master In Slave Out’ (MISO) wire, the slave sends data to the master. The ‘Chip Select’ (CSN) is driven by the master and grants the slave permission to read from and write to the bus. The CSN signal is active low. The ‘Serial Clock’ (SCK) signal is used by the master to establish the communication speed.

It is also possible to connect several slaves to one master. The master has to select the desired slave by pulling down the corresponding CSN line.

Each transfer is full duplex for simultaneously sending read/write commands to the sensor while collecting the response from the preceding request. As a part of the SPI protocol HAL 3900 defines a status byte, which delivers error and status information about the sensor with each SPI transfer. Additionally, the protocol immanent CRC secures the correct transport of bits in both directions.

The general SPI frame format is as follows (see Fig. 3–14):

1. SPI master pulls the CSN to low,
2. SPI master sends one command byte followed by two master data bytes,
3. SPI master sends an 8-bit CRC,
4. HAL 3900 replies in the next frame with one status byte and two slave data bytes followed by a 8-bit slave CRC.

The CRC for HAL 3900 is calculated based on the following polynomial:
$X^8 + X^4 + X^3 + X^2 + 1$ (0x1D), with a seed value of 0xFF and a final XOR value of 0xFF (CRC-8-SAE-J1850).

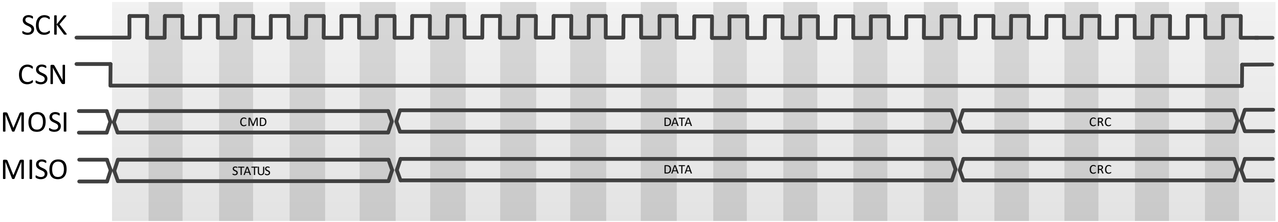


Fig. 3–14: Communication frame structure via SPI

Two communication frames are defined:

– Write Frame (SDI): 8-bit command (CMD), 16-bit data and 8-bit CRC (total: 32-bit)

– Read Frame (SDO): 8-bit status (STATUS), 16-bit data and 8-bit CRC (total: 32-bit)

Note Please refer to Table 3–1 on page 12 for access to the measurement data.The DIAG0 & DIAG1 bits are only updated while reading the IPC_CHAN register. Reading EEPROM content or RAM in programming mode will not trigger the DIAGx register.

Write commands execute internally after the master CRC is verified. This is to guarantee no unintended register writes happen.

The command byte (CMD) contains a 7-bit word address and a RWN flag.

Table 3–6: SPI Command Byte

CMD	**Command Byte**							
	7	6	5	4	3	2	1	0
r/ w	**ADR**							**RWN**

The STATUS byte of the read protocol contains several information.

Table 3–7: SPI Status Byte

STATUS	**Status Byte**							
	7	6	5	4	3	2	1	0
r/w	**RC3**	**RC2**	**RC1**	**RC0**	**DIAG0**	**DIAG1**	**CRC ERR**	**NEW**

- RC[3:0]: Rolling counter keeps track of the communication frames being sent between SPI master and sensor. It is incremented by one with each communication frame from 1 to 15. Then it restarts at 1 again (reset value = 0),
- DIAG0: This bit is set to one in case an error has been indicated in DIAGNOSIS_0 register (see Table 4–1 on page 33),
- DIAG1: This bit is set to one in case an error has been indicated in DIAGNOSIS_1 register (see Table 4–2 on page 34),
- CRCERR: Is set to one in case an error has been detected during CRC-check of previous MOSI frame,
- NEW: New sample indication (in case of an already read sample is sent multiple times the bit is set to 0).

The CRC is the last byte of any transmission and covers the preceding number of bytes. A received and transmitted stream have their own CRC byte. CRC check of the MOSI frame is done every time, independently of a read/write command. Write commands are executed internally after the master CRC is verified. This guarantees that no unintended register write happens. Read commands are executed internally before the master CRC is verified. An invalid CRC indicates a detected transmission error (signaled by CRCERR = 1 in the STATUS byte). In case of a transmission error, the status byte (transmitted in the next frame) gives feedback to the master via this CRCERR bit.

Table 3–8: SPI CRC Byte

CRC	**CRC Byte**							
	7	6	5	4	3	2	1	0
r/w	**CRC**							

Note Further details about the communication with the sensor can be found in the document: HAL/HAR 3900 Programming Guide

3.5. Low-Power Mode

Beside the Application Mode in which the device is running continuously, it also supports five different modes for power consumption reduction. These five Low-Power Modes are split into a Sleep Phase with very low current consumption and an Active Phase in which the device is performing defined measurement tasks. By setting dedicated EEPROM bits, the customer or the ECU can select between the different modes (see Table 3–5 on page 24).

The following Table describes the different use cases (UC):

Table 3–9: Overview of Low-Power Mode Use Cases

UC	ECU Mode	Sensor Tasks	ECU Tasks	Configuration of SETUP_STANDBY register (Table 3–5)
1	Controls the status of the sensor (Sleep Phase or Active Phase)	Check status of WAKI/O and start measurements after wake up	Wake up sensor by WAKI/O pin. Poll SPI read until NEW bit is set. Send sensor to Sleep Phase by SPI Command.	ext_wakeup = 01, 10 or 11. All other bits set to 0.
2	Always active and sensor is periodically in Sleep Phase.	Wake up by internal sleep counter and indicates start of Active Phase to ECU on WAKI/O pin.	Polls SPI read for NEW bit after indication of Active Phase on WAKI/O pin. Send sensor to Sleep Phase by SPI Command	cnt_wakeup = 1 wakout = 1 All other bits set to 0.
3	Is operated in Low-Power Mode until wake up by the sensor via WAKI/O pin	Wake up by internal sleep counter and indicates start of Active Phase to ECU on WAKI/O pin.	Polls SPI read for NEW bit after indication of Active Phase on WAKI/O pin. Send sensor to Sleep Phase by SPI Command.	cnt_wakeup = 1 wakout = 1 All other bits set to 0.
4		Wake up by internal sleep counter. Compare measurement with a defined threshold and wake up ECU by WAKI/O pin if threshold condition is full-filled, else go back to Sleep Phase	Polls SPI read for NEW bit after wake up by sensor. Send sensor to Sleep Phase by SPI Command.	cnt_wakeup = 1 wakout = 1 thrd_x = 01 or 10 All other bits set to 0.
5	Is operated in Low-Power mode until wake up by the sensor via WAKI/O pin or actively wake up the sensor.	Wake up by internal sleep counter (like UC3 & 4) or wake up by external trigger on WAKI/O pin.	Wake-up sensor by WAKI/O pin or wait for wake up by the sensor. Poll SPI read for NEW bit. Send sensor to Sleep Phase by SPI Command	cnt_wakeup = 1 ext_wakeup = 01,10 or 11 wakout = 1 thrd_x = 01 or 10

Note To wake up the sensor by the ECU in UC5, it is mandatory that the ECU is generating minimum two signal edges on the WAKI/O pin. Otherwise, it might happen that the sensor is missing the wake-up signal from the ECU. The wake-up signal can only be detected while the sensor is in Sleep Phase and not in Active Phase of the Low-Power mode.

3.5.1. Low-Power Mode – Use Case 1

In this use case, the ECU is taking over the full control for the sensors Low-Power Mode. The ECU can send the sensor into the Sleep Phase by sending the Go-to-Sleep Command 0xA55A to IPC_CHAN3 register. The sensor will stay in the Sleep Phase until the ECU generates a signal change on the WAKI/O pin of the sensor. The sensor will then start its initialization phase and move to active mode in order to start the first measurement. The ECU will then have to poll read command for a valid NEW bit in the SPI protocol status byte. After the ECU has read the necessary amount of measurement data it can send the sensor back into Sleep Phase.

This mode is enabled by setting the ext_wakeup bits in the SETUP_STANDBY register. These bits define what kind of signal edge is used to wake up the sensor on the WAKI/O pin.

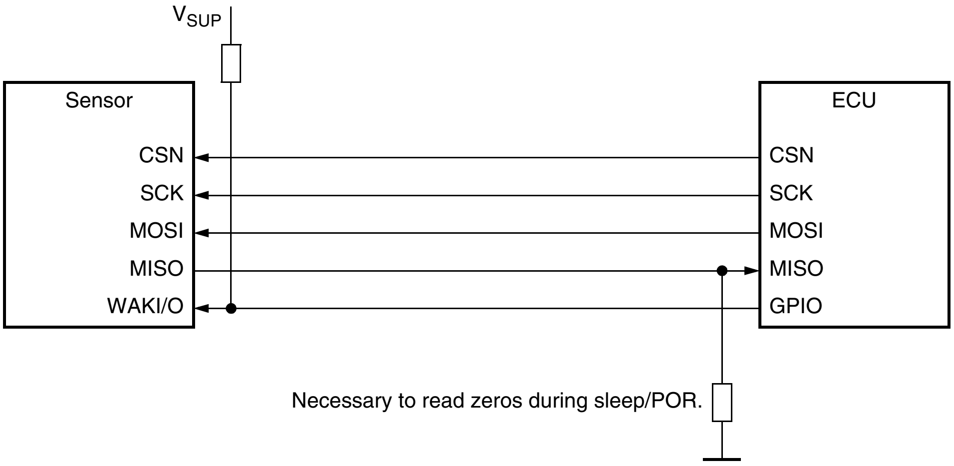


Fig. 3–15: Wake up of sensor via WAKI/O pin

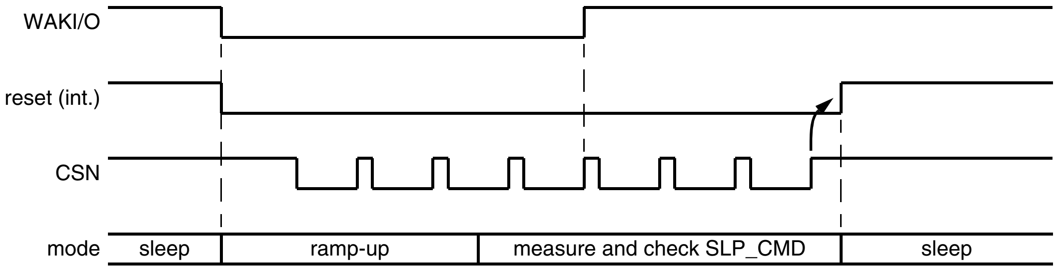


Fig. 3–16: Timing diagram for Low-Power Mode use case 1

3.5.2. Low-Power Mode – Use Case 2 and 3

In these two use cases, the sensor and the ECU control together the Low-Power Mode. The sensor will stay in the Sleep Phase for a defined time. This time is defined by the STANDBY_SLEEP_TIME register. After this time has elapsed, the sensor will start its initialization phase and move to Active Mode in order to start the first measurement. By changing the status of the WAKI/O pin it will indicate to the ECU that the Active Mode has been started. The ECU will then have to poll read commands for a valid NEW bit in the SPI protocol status byte. After the ECU has read the necessary amount of measurement data it can send the sensor back into Sleep Phase by sending the Go-to-Sleep Command 0xA55A to IPC_CHAN3 register. The sensor will then start the next sleep cycle.

The ECU can stay continuously awake to execute other tasks or it can go to Low-Power Mode as well waiting for a wake-up trigger from the sensor via the WAKI/O pin.

This mode is enabled by setting the wakout bit and the cnt_wakeup bit in the SETUP_STANDBY register.

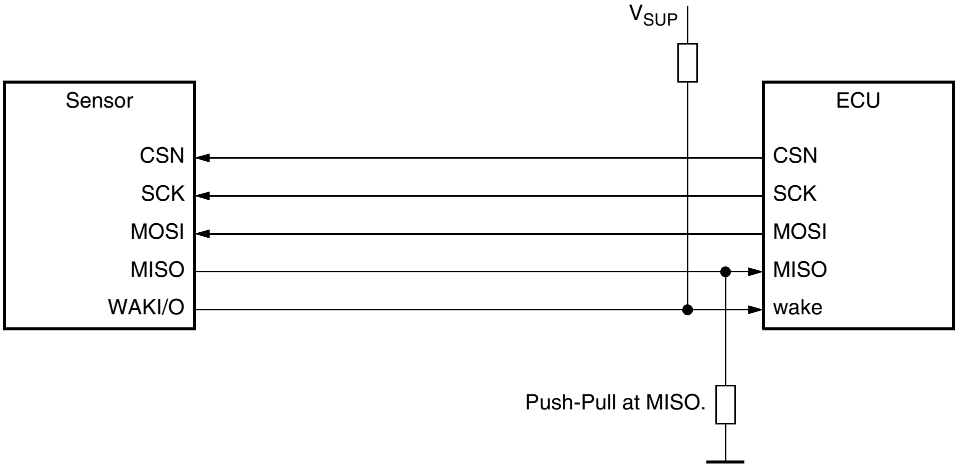


Fig. 3–17: Wake up of sensor by counter and Active Mode indication on WAKI/O pin

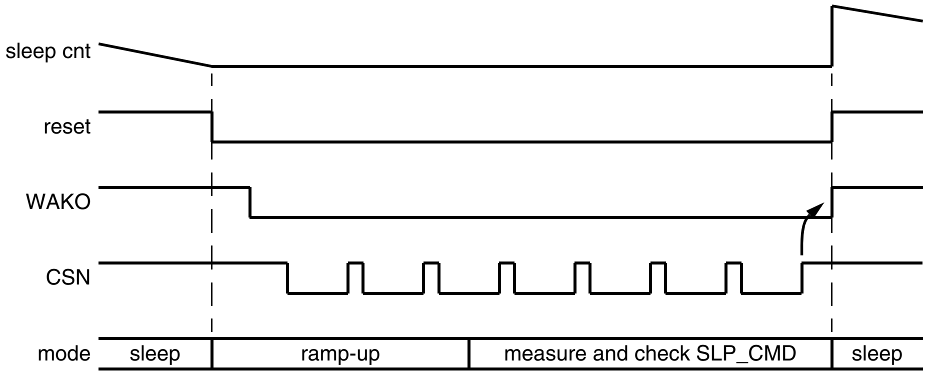


Fig. 3–18: Timing diagram for Low-Power Mode use case 2 &3

3.5.3. Low-Power Mode – Use Case 4

In this use case, the sensor has the full control of the Low-Power Mode. The sensor will stay in the Sleep Phase for a defined time. This time is defined by the STANDBY_SLEEP_TIME register. After this time has elapsed, the sensor will start its initialization phase and move to Active Mode in order to start the first measurement. In this Active Mode the sensor compares the measurement result with up to three defined thresholds. The threshold values are defined by the THRESHOLD_x register (see page 22). The sensor will change the status of the WAKI/O pin to inform the ECU in case that a threshold has been exceeded. The ECU will then have to poll read commands for a valid NEW bit in the SPI protocol status byte. After the ECU has read the necessary amount of measurement data it can send the sensor back into Sleep Phase by sending the Go-to-Sleep Command 0xA55A to IPC_CHAN3 register. The sensor will then start the next sleep cycle.

This mode is enabled by setting the wakout bit, the cnt_wakeup bit and at least one of the thrd_x bits in the SETUP_STANDBY register.

Fig. 3–17 and Fig. 3–18 on page 30 are also valid for this mode in addition the WAKI/O pin is only changed if one of the selected thresholds has been exceeded.

3.5.4. Low-Power Mode – Use Case 5

This use case is a combination of the use cases 1 and 4. The sensor can trigger a wake-up at the ECU side, but the ECU can also trigger a wake-up of the sensor while it is in Sleep Mode. Fig. 3–15 shows the required external wiring for this specific mode.

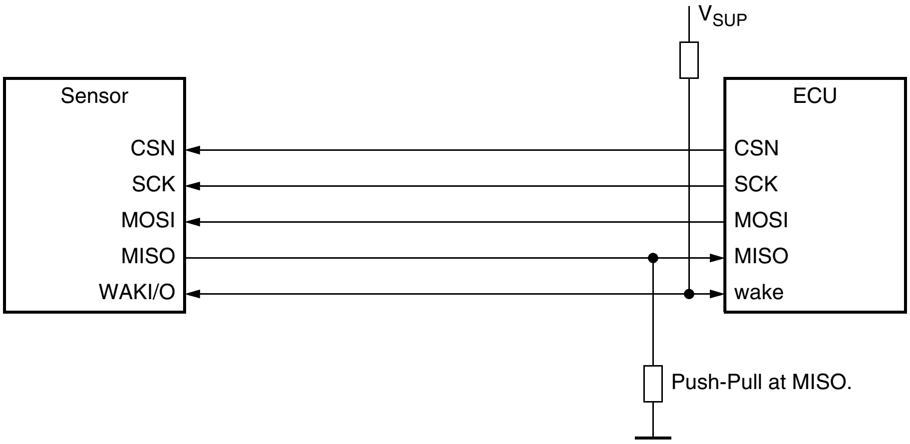


Fig. 3–19: Wake up of sensor by counter and WAKI/O pin and Active Mode indication

For this case, it does not matter if the sensor or the ECU or both at the same time are triggering a wake-up. The sensor is running its measurement cycle and the ECU polls for the NEW bit by reading the sensor output signal via SPI. After the ECU has read the necessary amount of measurement data it can send the sensor back into Sleep Phase by sending the Go-to-Sleep Command 0xA55A to IPC_CHAN3 register. The sensor will then start the next sleep cycle.

This mode is enabled by setting the wakout bit, the cnt_wakeup bit, ext_wakeup bits and at least one of the thrd_x bits in the SETUP_STANDBY register.

Note To wake up the sensor by the ECU in use case 5, it is mandatory that the ECU is generating minimum two signal edges on the WAKI/O pin. Otherwise, it might happen that the sensor is missing the wake-up signal from the ECU. The wake-up signal can only be detected while the sensor is in Sleep Phase and not in Active Phase of the Low-Power mode.

4. Functional Safety

4.1. Functional Safety Manual and Functional Safety Report

The Functional Safety Manual for HAL 3900 contains the necessary information to support customers to realize a safety-compliant application by integrating HAL 3900 as an ASIL B ready component into their system. The Functional Safety Manual will 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 3900 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 a failure via the status byte in the SPI frame.

Detailed result of the internal diagnostics is available via the DIAGNOSIS_X register. Both register can be read via the SPI interface.

Table 4–1: DIAGNOSIS_0 register

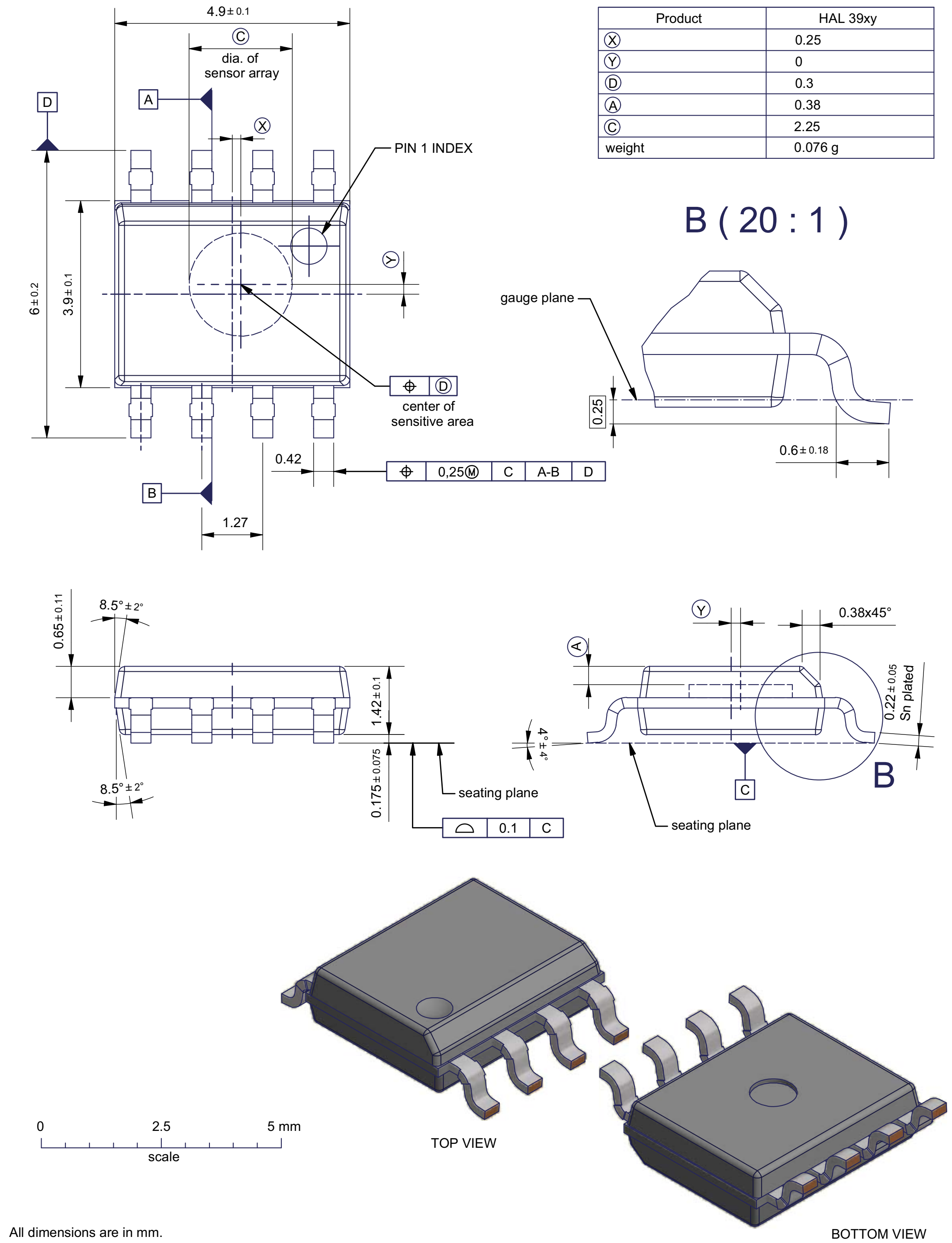
Bit no.	Description when bit is set to 1
15	DSP self-check routines (redundancy or plausibility checks)
14	DSP and µC check of 16-bit checksum covering the EEPROM parameter
13	DSP checksum for ROM and RAM
12	Chip junction temperature out of range
11	Plausibility check of redundant temperature sensor
10	Hall-plate supply too high
9	Hardware overtemperature supervision: Junction temperature > 180°C
8	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
Note: Bits[7:0] cannot 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

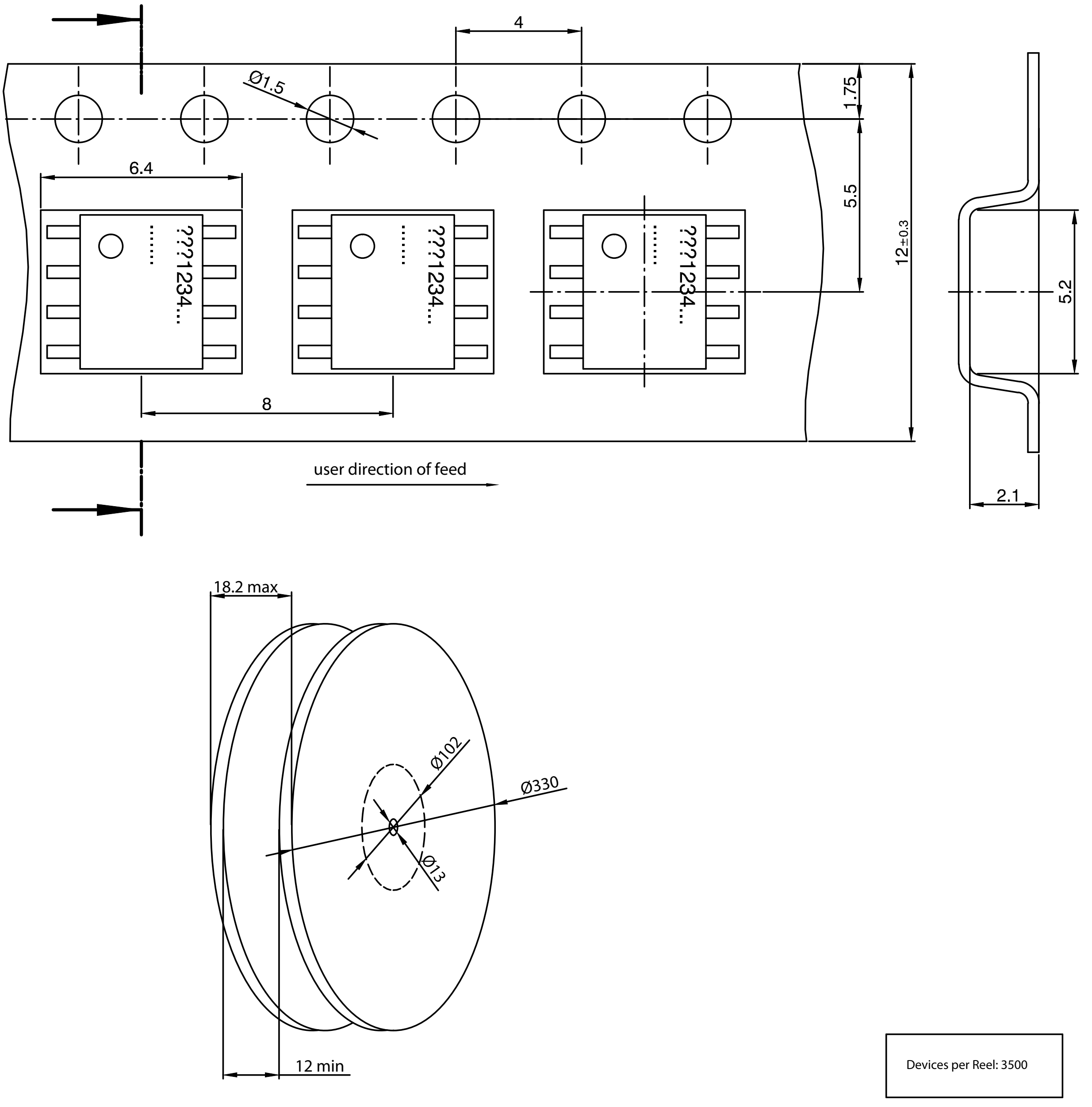


Product	HAL 39xy
Ⓧ	0.25
Ⓨ	0
Ⓓ	0.3
Ⓐ	0.38
Ⓒ	2.25
weight	0.076 g

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



Devices per Reel: 3500

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 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.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

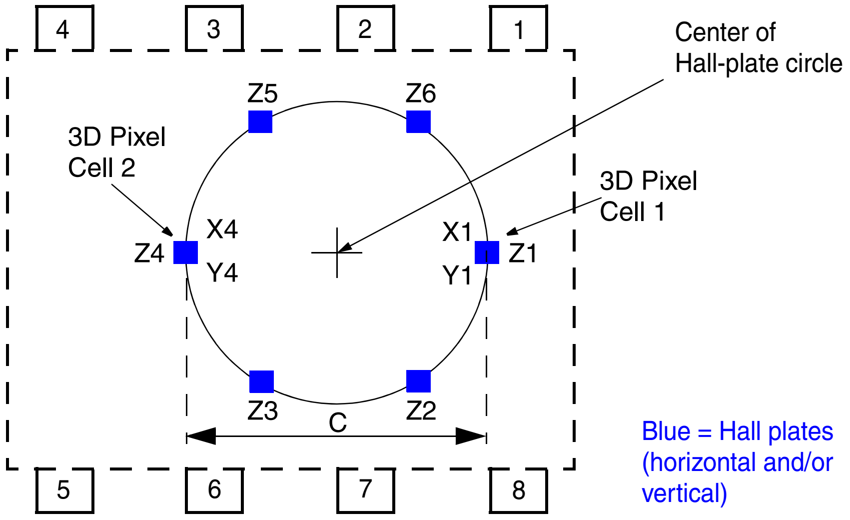


Fig. 5–3: Hall-plate configuration

5.5. Definition of Magnetic-Field Vectors

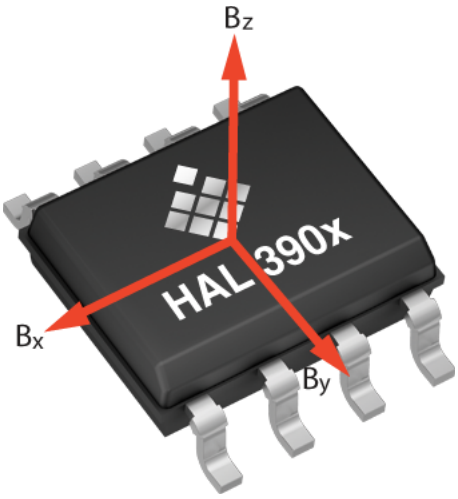


Fig. 5–4: Definition of magnetic-field vectors for HAL 390x

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
2	GND	GND	Ground
3	TEST	N/A	Test
4	CSN	I/O	SPI Chip-Select
5	MISO	OUT	SPI Out
6	WAKI/O	I/O	Wake Up
7	MOSI	IN	SPI In
8	SCK	IN	SPI Clock

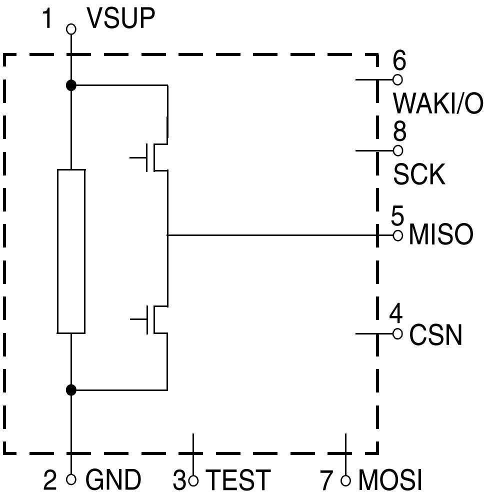


Fig. 5–5: Pin configuration for SOIC8 package

Note Pins 2 and 3 must be connected to GND.

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	V	
			–	37	V	t < 60s; T_A=50°C
V_{IN_WAKIO}	Input Voltage WAKI/O Pin	WAKIO	–0.3	6	V	t < 96 h
V_{IN}	Input Voltage SPI Pins	CSN, MOSI, SCK	–0.3	28	V	t < 96 h
V_{OUT_MISO}	Output Voltage MISO Pin	MISO	–0.3	VSUP	V	t < 96 h
$V_{OUT\_MISO}-V_{SUP}$	Excess of MISO Output Voltage over VSUP	MISO	–	0.3	V	t < 96 h
B_{max}	Magnetic Field	–	–	1	T	
T_A	Ambient Temperature	–	–40	160	°C	1)
T_J	Junction Temperature	–	–40	190	°C	t < 96 h 2)
$T_{storage}$	Transportation/ Short Term Storage Temperature	–	–55	150	°C	Device only without packing material
V_{ESD}	ESD Protection	VSUP, MISO, CSN, SCK, MOSI, WAKIO ,TEST	–2	2	kV	3)

1) Consider current consumption, molding condition (e.g. overmold, potting) and mounting situation for T_A and in relation to T_J
2) Please contact TDK-Micronas for other temperature requirements
3) AEC-Q100-002 (100 pF and 1.5 kΩ)
No cumulative stress for all parameter

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_{SUP}	Supply Voltage	VSUP	3.0	–	5.5	V	
V_{IN_WAKIO}	Input Voltage	WAKIO	0	–	5	V	
R_{WAKIO}	Load Resistance on WAKI/O Pin	WAKIO	10	100	–	kΩ	Pull-up
R_{SPI_LOAD}	Total Load Resistance	MISO	10	–	–	kΩ	Pull-down
C_{SPI_LOAD}	Total Load Capacitance	MISO	6	–	100	pF	f_{SPI} = 10 MHz
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	For 1000 h 1)
T_A	Ambient Temperature		–40	–	150	°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 150 °C, V_{SUP} = 3.0 V to 5.5 V, GND = 0 V, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”.
Typical Characteristics for T_A = 25 °C and V_{SUP} = 5 V.

Symbol	Parameter	Pin Name	Limit Values			Unit	Conditions
			Min.	Typ.	Max.		
I_{SUP}	Supply Current	VSUP	–	8	12	mA	[1]
I_{SUP_SM}	Supply Current in Standby Mode	VSUP	–	–	15	μA	While IC is in sleep mode T_A = 25 °C
$t_{startup}$	Start-up Time	MISO	–	–	10	ms	[1]
f_{osc}	Internal Oscillator Frequency	–	–	32	–	MHz	
f_{sample}	Sampling Frequency	–	–	16	–	kSps	[1] Configurable
			–	8	–		
			–	4	–		
			–	2	–		
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							
$S_{VSUP,UOV}$	Step Size of Under-/Overvoltage Supervision Threshold	VSUP	92	100	108	mV/LSB	Under-/Overvoltage threshold is customer configurable [1]
$S_{SUP,UOVhyst}$	Under-/Overvoltage Detection Level Hysteresis	VSUP	–	1	–	LSB	[1] 1 LSB typ. 100 mV
t_{UOV}	Under-/Overvoltage Detection Time	VSUP	–	0.5	–	ms	[1]
SPI Characteristics							
V_{IH}	Input High Level	MOSI, SCK, CSN	2.4	–	–	V	
V_{IL}	Input Low Level	MOSI, SCK, CSN	–	–	0.8	V	
V_{OH}	Output High Level	MISO	VSUP –0.6	–	–	V	I_{OUT} = –10 mA
V_{OL}	Output Low Level	MISO	–	–	0.6	V	I_{OUT} = 20 mA
I_{OShort_Low}	MISO Output Current for Short to GND	MISO	–50	–40	–30	mA	$V_{SUP} > V_{OUT} >$ GND

[1] Characterized on small sample size, not tested.

Symbol	Parameter	Pin Name	Limit Values			Unit	Conditions
			Min.	Typ.	Max.		
I_{OShort_High}	MISO Output Current for Short to V_{SUP}	MISO	25	40	50	mA	$V_{SUP} > V_{OUT} >$ GND
I_{PD}	Pull-Down current	MOSI, SCK	20	–	70	μA	V_IN = 2.4 V
I_{PU}	Pull-Up current	MOSI, SCK	–70	–	–20	μA	V_IN = 1.0 V
I_{OLEAK}	Leakage Current	MISO	–2	–	2	μA	
t_{SCK}	SPI Clock Period	SCK	100	1000	–	ns	[1] Max. frequency 10 MHz 100 ns is only possible within one SPI byte
t_{SCK_BB}	SPI Clock Period at Byte Border	SCK	200	–	–	ns	[1] At byte border
t_{DIS}	SPI Data Input Setup	MOSI, SCK	10	–	–	ns	[1] Data sampling with rising SCK edge
t_{DIH}	SPI Data Input Hold	MOSI, SCK	15	–	–	ns	[1]
t_{DOD}	SPI Data Output Delay	MISO, SCK	–	–	44	ns	[1] Data output changes with falling SCK edge
t_{SSC}	SPI CSN setup time	CSN, SCK	40	–	–	ns	[1] With respect to falling CSN edge
t_{SCS}	SPI CSN Hold Time	CSN, SCK	12	–	–	ns	[1] With respect to the rising CSN edge
t_{SCH}	SPI CSN High Time	CSN	500	2000	–	ns	[1] CSN high time between two consecutive SPI frames
t_{set}	SPI Settling Time	–	–	4	–	ms	[1]
t_{listen}	Waiting Time for the Programming Mode Command	–	–	–	110	ms	[1] Waiting for data 0x2EAE to address 0x75
SOIC8 Package							
							(Self-heating calculation see Section 6.1. on page 49)
R_{thja}	Thermal Resistance Junction to Air	–	–	–	140	K/W	Determined with a 1S0Pboard
		–	–	–	93	K/W	Determined with a 2S2Pboard
R_{thjc}	Thermal Resistance Junction to Case	–	–	–	33	K/W	Determined with a 1S0P & 2S2P board

[1] Characterized on small sample size, not tested.

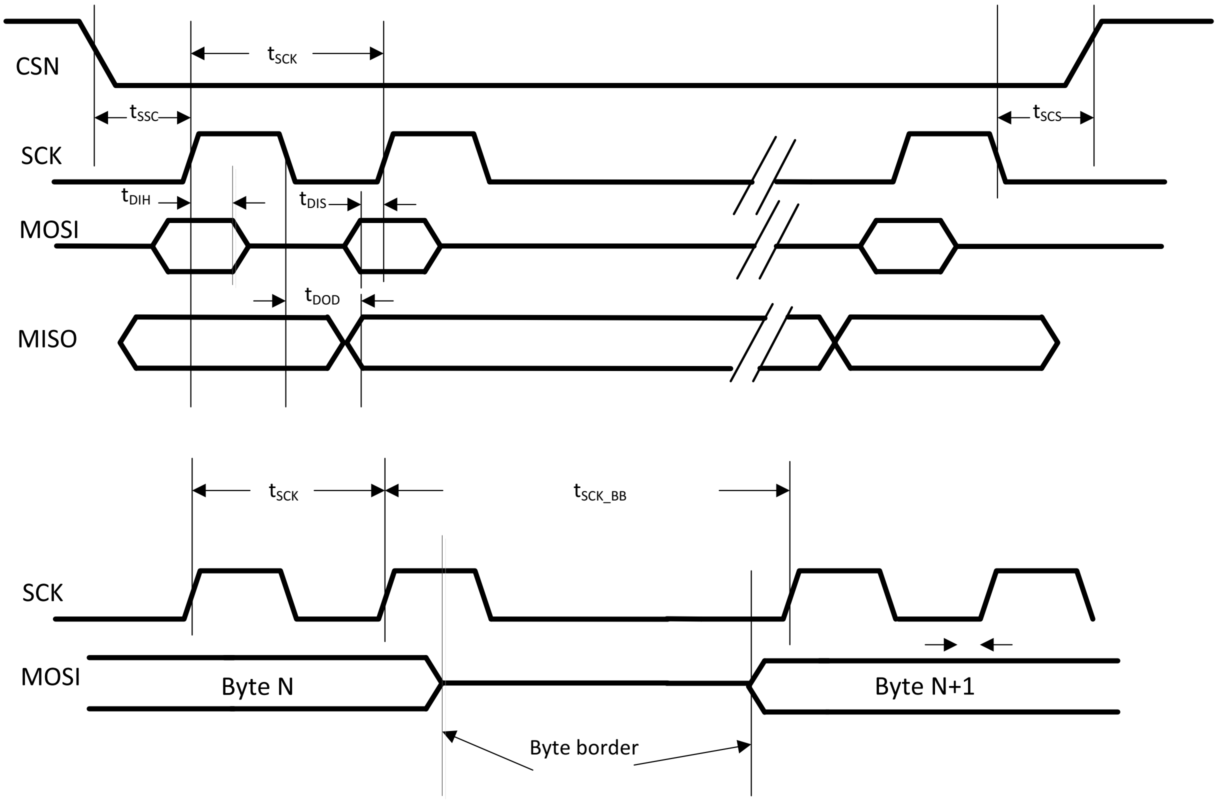


Fig. 5–6: SPI timing diagram

5.10. Magnetic Characteristics

at T_A = –40 °C to 150 °C, V_{SUP} = 3.0 V to 5.5 V, GND = 0 V, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”. Typical Characteristics for T_A = 25 °C and V_{SUP} = 5.0 V.

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
Rotary Setup with Stray-Field Compensation (Setup 1 & 2)							
$\Delta E_{\Theta tot}$	Total Angular Error of Drifts	MISO	–1.1	–	1.1	°	1) $B_{AMP} = \pm 10$ mT
$\Delta E_{\Theta temp}$	Angular Error Drift over Temperature	MISO	–0.5	–	0.5	°	1) $B_{AMP} = \pm 10$ mT
$\Delta E_{\Theta life}$	Angular Error Drift over Lifetime	MISO	–0.6	–	0.6	°	1) $B_{AMP} = \pm 10$ mT After 1008 h HTOL
$E_{\Theta hyst}$	Angular Hysteresis Error	MISO	–	–	0.05	°	2)
$E_{\Theta noise\_1}$	Angular Noise Setup 1	MISO	–	0.06	0.09	°	3)
$E_{\Theta noise\_2}$	Angular Noise Setup 2	MISO	–	0.19	0.27	°	3)
$E_{\Theta SF\_1}$	Angular Error due to Stray-Field for Setup 1	MISO	–	–	0.1	°	1) 4) Magnet with 5 mT/mm wanted signal
$E_{\Theta SF\_2}$	Angular Error due to Stray-Field for Setup 2	MISO	–	–	0.12	°	1) 4) Magnet with 5 mT/mm wanted signal
Linear Movement Setup (ΔXZ) with Stray-Field Compensation (Setup 3)							
$SM_{\Delta XZ41}$	Sensitivity Mismatch between ΔX_{41} and ΔZ_{41} Channel	MISO	–5	–	5	%	1) T_A = 25 °C
$Sense_{\Delta XZ41}$	Sensitivity of ΔX_{41} and ΔZ_{41} Channel	MISO	121	128	135	LSB_{15} /mT	1) T_A = 25 °C
$\Delta SM_{\Delta XZ41}$	Thermal Sensitivity Mismatch Drift between ΔX_{41} and ΔZ_{41} Channel	MISO	–2.5	–	2.5	%	1) Related to T_A = 25 °C
$Offset_{\Delta X41}$	Offset of ΔX_{41} Channel	MISO	–30	–	30	LSB_{15}	T_A = 25 °C
$Offset_{\Delta Z41}$	Offset of ΔZ_{41} Channel	MISO	–15	–	15	LSB_{15}	T_A = 25 °C
$\Delta Offset_{\Delta X41}$	Offset Drift of ΔX_{41} Channel	MISO	–50	–	50	LSB_{15}	Related to T_A = 25 °C
$\Delta Offset_{\Delta Z41}$	Offset Drift ΔZ_{41} Channel	MISO	–15	–	15	LSB_{15}	Related to T_A = 25 °C
$\Delta SM_{\Delta XZ41life}$	Relative Sensitivity Mismatch Drift between ΔX_{41} and ΔZ_{41} Channel over life time	MISO	–	1.0	–	%	1) After 1008 h HTOL
$\Delta Offset_{\Delta X41life}$	Offset Drift of ΔX_{41} Channel over life time	MISO	–	30	–	LSB_{15}	After 1008 h HTOL
$\Delta Offset_{\Delta Z41life}$	Offset Drift of ΔZ_{41} Channel over life time	MISO	–	5	–	LSB_{15}	After 1008 h HTOL

All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not tested)

1) Based on Simulation Model (not tested)

2) Guaranteed by Design

3) Based on Monte Carlo Simulation Model, B_{AMP} = 10 mT, fdecsel = 2 kHz, Low-pass filter: off, 3-sigma values (not tested)

4) 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 tested)

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
$SF_{R\Delta X41}$	Stray-Field Rejection in ΔX_{41} Direction	MISO	99	–	–	%	4) T_A = 25°C
$SF_{R\Delta Z41}$	Stray-Field Rejection in ΔZ_{41} Direction	MISO	96	–	–	%	4) T_A = 25°C
$E_{\Theta phase\Delta XZ41}$	Phase Error between ΔX_{41} and ΔZ_{41} Channel	MISO	–	±2.2	–	°	between ΔX_{41} and ΔZ_{41} axis 1)
$E_{\Delta X41,noise}$	Digital Noise of ΔX_{41} Hall-Plates Channel	MISO	–	2.4	–	LSB_{15}	5)
$E_{\Delta Z41,noise}$	Digital Noise of ΔZ_{41} Hall-Plates Channel	MISO	–	2.6	–	LSB_{15}	5)
Off-Axis Rotary Setup (ΔXY) with Stray-Field Compensation (Setup 3)							
$SM_{\Delta XY41}$	Sensitivity Mismatch between ΔX_{41} and ΔY_{41} Channel	MISO	–2	–	2	%	1) T_A = 25 °C
$Sense_{\Delta XY41}$	Sensitivity of ΔX_{41} and ΔY_{41} Channel	MISO	121	128	135	LSB_{15} /mT	1) T_A = 25 °C
$\Delta SM_{\Delta XY41}$	Thermal Sensitivity Mismatch Drift between ΔX_{41} and ΔY_{41} Channel	MISO	–2.5	–	2.5	%	1) Related to T_A = 25 °C
$Offset_{\Delta XY41}$	Offset of ΔX_{41} and ΔY_{41} Channels	MISO	–30	–	30	LSB_{15}	1) T_A = 25 °C
$\Delta Offset_{\Delta XY41}$	Offset Drift of ΔX_{41} and ΔY_{41} Channels	MISO	–50	–	50	LSB_{15}	Related to T_A = 25 °C
$\Delta SM_{\Delta XY41life}$	Relative Sensitivity Mismatch Drift between ΔX_{41} and ΔY_{41} Channels over life time	MISO	–	1.0	–	%	After 1008 h HTOL
$\Delta Offset_{\Delta XY41life}$	Offset Drift of ΔX_{41} and ΔX_{41} Channel over life time	MISO	–	30	–	LSB_{15}	After 1008 h HTOL
$SF_{R\Delta XY41}$	Stray-Field Rejection in ΔX_{41} and ΔY_{41}Direction	MISO	99	–	–	%	
$E_{\Theta phase\Delta XY41}$	Phase Error between ΔX_{41} and ΔZ_{41} Channel	MISO	–	±2.2	–	°	1) between ΔX_{41} and ΔY_{41} axis
$E_{\Delta XY41,noise}$	Digital Noise of ΔX_{41} and ΔY_{41} Hall-Plates Channel	MISO	–	2.4	–	LSB_{15}	5)
3D Measurement Setup without Stray-Field Compensation (Setup 4a, 5 & 6)							
SM_{XYZ}	Sensitivity Mismatch between X or Y and Z Channel	MISO	–4	–	4	%	T_A = 25 °C
SM_{XY}	Sensitivity Mismatch between X and Y Channel	MISO	–2	–	2	%	T_A = 25 °C
$Sense_{XYZ}$	Sensitivity of X,Y and Z Hall-plate	MISO	123	128	133	LSB_{15} /mT	T_A = 25 °C
ΔSM_{XYZ}	Thermal Sensitivity Mismatch Drift between X or Y and Z Hall Plates	MISO	–2.5	–	2.5	%	Related to T_A = 25 °C

All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not tested)
1) Based on Simulation Model (not tested)
2) Guaranteed by Design
4) 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 tested)
5) Charaterized on small sample size, 1-sigma value, fdecsel = 2 kHz, Low-pass filter: off (not tested)

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
ΔSM_{XY}	Thermal Sensitivity Mismatch Drift between X and Y Hall Plates	MISO	–2	–	2	%	Related to $T_A = 25$ °C
$Offset_{XY}$	Offset of X and Y Hall-plates	MISO	–20	–	20	LSB_{15}	$T_A = 25$ °C
$Offset_Z$	Offset of Z Hall-plate	MISO	–12	–	12	LSB_{15}	$T_A = 25$ °C
$\Delta Offset_{XY}$	Offset Drift of X and Y Hall-plates	MISO	–40	–	40	LSB_{15}	Related to $T_A = 25$ °C
$\Delta Offset_Z$	Offset Drift of Z Hall-plate	MISO	–15	–	15	LSB_{15}	Related to $T_A = 25$ °C
$\Delta SM_{XYZlife}$	Relative Sensitivity Mismatch Drift between X, Y and Z Hall Plates over life time	MISO	–	1.0	–	%	After 1008 h HTOL
$\Delta Offset_{XYlife}$	Offset Drift of X and Y Hall-plates over life time	MISO	–	30	–	LSB_{15}	After 1008 h HTOL
$\Delta Offset_{Zlife}$	Offset Drift of Z Hall-plate over life time	MISO	–	5	–	LSB_{15}	After 1008 h HTOL
$E_{\Theta phaseXYZ}$	Phase Error between X, Y and Z Hall-Plates	MISO	–	±1.6	–	°	XY axis
			–	±1.6	–	°	XZ axis
			–	±1.6	–	°	YZ axis
$E_{XYZ,noise}$	Digital Noise of X, Y or Z Hall-Plates Channel	MISO	–	2.2	–	LSB_{15}	5)
2D Measurement Setup (virtual center Pixel XY) without Stray-Field Compensation (Setup 4b)							
$SM_{\Sigma XY41}$	Sensitivity Mismatch between ΣX_{41} and ΣY_{41} Channel	MISO	–3	–	3	%	$T_A = 25$ °C
$Sense_{\Sigma XY41}$	Sensitivity of ΣX_{41} and ΣY_{41} Channel	MISO	121	128	135	LSB/mT	$T_A = 25$ °C
$\Delta SM_{\Sigma XY41}$	Thermal Sensitivity Mismatch Drift between ΣX_{41} and ΣY_{41} Channel	MISO	–2	–	2	%	Related to $T_A = 25$ °C
$Offset_{\Sigma XY41}$	Offset of ΣX_{41} and ΣY_{41} Channel	MISO	–25	–	25	LSB_{15}	$T_A = 25$ °C
$\Delta Offset_{\Sigma XY41}$	Offset Drift of ΣX_{41} and ΣY_{41} Channel	MISO	–40	–	40	LSB_{15}	Related to $T_A = 25$ °C
$\Delta SM_{\Sigma XY41life}$	Relative Sensitivity Mismatch Drift between ΣX_{41} and ΣY_{41} Channel over life time	MISO	–	1.0	–	%	After 1008 h HTOL
$\Delta Offset_{\Sigma XY41life}$	Offset Drift of ΣX_{41} and ΣY_{41}Channel over Life Time	MISO	–	30	–	LSB_{15}	After 1008 h HTOL
$E_{\Theta phase\Sigma XY41}$	Phase Error between ΣX_{41} and ΣY_{41}	MISO	–	±2.2	–	°	1)
$E_{\Sigma XY41,noise}$	Digital Noise of ΣX_{41} and ΣY_{41} Hall-Plates Channel	MISO	–	1.9	–	LSB_{15}	5)

All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not tested)

[1] Based on Simulation Model (not tested)

[5] Charaterized on small sample size, 1-sigma value, fdecsel = 2 kHz, Low-pass filter: off (not tested)

5.11. Temperature Sensor

at T_A = –40 °C to 150 °C, V_{SUP} = 3.0 V to 5.5 V, GND = 0 V, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”.
Typical Characteristics for T_A = 25°C and V_{SUP} = 5.0 V.

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
$TADJ_{Gain}$	Gain of Temperature Sensor	MISO	–	89.25	–	LSB_{15} /°C	[1]
$TADJ_{Offset}$	Temperature Sensor Offset	MISO	–	3720	–	LSB_{15}	[1]
ΔT_{Lin}	Temperature Sensor Differential Accuracy (Linearity Error)	MISO	–2	–	2	°C	[1]
ΔT_{Offset}	Temperature Sensor Offset Error	MISO	–5	–	5	°C	[1]

[1] Characterized on small sample size, 3-sigma values, not tested for each device

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}). With a typical supply voltage of 3.3 V the power dissipation P is 0.04 W per die. The junction to ambient thermal resistance R_{thja} is specified in Section 5.9. on page 42.

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 Rth 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 3900

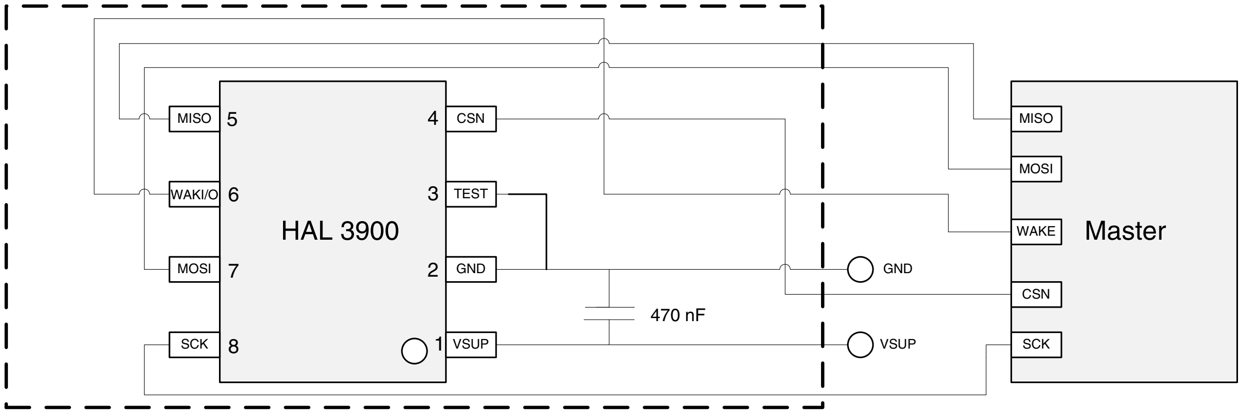


Fig. 6–1: Recommended application circuit for HAL 3900 (one slave and one master)

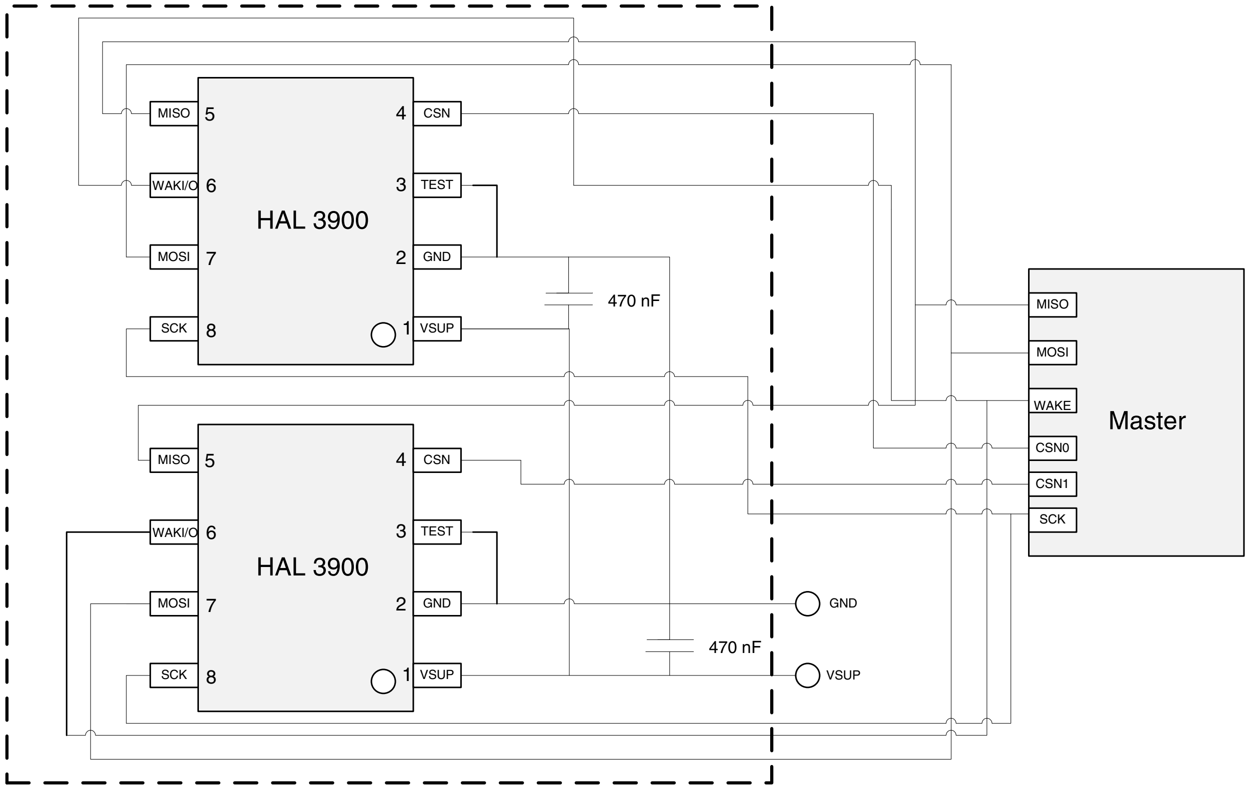


Fig. 6–2: Recommended application circuit for HAL 3900 (two slaves and one master)

6.4. Recommended Pad Size SOIC8 Package

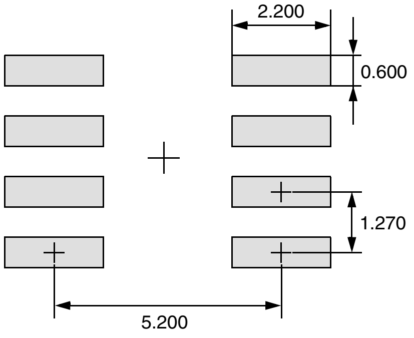


Fig. 6–3: Pad size recommendation for SOIC8 package (all dimensions in mm)

7. Programming of the Sensor

HAL 3900 features two different customer modes. In **Application Mode** the sensor provides digital output data via SPI interface. In **Programming 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 **Listening Mode** by writing the data 0x22A2 to address 0x75 (IPC_CHAN5). The sensor will remain in listening mode for max. 110 ms (t_{listen}). During this period the sensor can be switched to **Programming Mode** by writing the data 0x2EAE to address 0x75 (IPC_CHAN5). After max. 110 ms without receiving the programming mode switch command the sensor will go into reset.

7.1. Programming Interface

The sensor is programmable via the SPI interface. The standard write and read commands can be used to configure the sensors memory.

7.2. Programming Environment and Tools

For the programming of HAL 3900 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^{TM} Programming Environment) in order to facilitate the product development. It is also possible to use a standard microcontroller to configure the device. 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 3900.

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.

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/ HAR 3900 Programming Guide.

8. Document History

1. Advance Information: “HAL 3900 Stray-Field Robust 3D Position Sensor with SPI Interface”, March 27, 2019, AI000213_001EN. First release of the advance information.
2. Advance Information: “HAL 3900 Stray-Field Robust 3D Position Sensor with SPI Interface”, May 7, 2020, AI000213_002EN. Second release of the advance information.
3. Data Sheet: “HAL 3900 Stray-Field Robust 3D Position Sensor with SPI Interface”, Aug. 12, 2020, DSH000211_001EN. First release of the data sheet.

   Major changes:
   – Magnetic characteristics updated

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