MICRONAS

Hardware Documentation

Data Sheet

HAL® / HAR® 3900

Stray-Field Robust 3D Position Sensor with SPI Interface

3D HAL® Technology

master HAL® Technology

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Contents

Stray-Field Robust 3D Position Sensor with SPI Interface

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

1. Introduction

HAL 3900 and HAR 3900 are members 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.

HAR 3900 is the fully redundant version (dual-die) of the HAL 3900. It provides full redundancy due to two independent dies stacked in a single package, each electrically connected to the pins of one package side. The stacked-die architecture ensures that both dies occupy the same magnetic-field position, thus generating synchronous measurement signals.

HAL/HAR 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 a 16-bit digitally encoded value (two's complement).

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

This product is defined as SEooC (Safety Element out of Context) ASIL B ready according to ISO 26262:2018. HAR 3900 can be integrated in automotive safety-related systems up to ASIL D.

The device is designed for automotive and industrial applications. It operates in the ambient temperature range from –40 °C ... 150 °C.

HAL 3900 is available in the 8-pin SOIC-8 SMD package. HAR 3900 is available in an sixteen-pin SSOP-16 SMD package.

1.1. Major Applications

Due to the sensor's versatile programming characteristics and its high accuracy, the HAL/HAR 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 angles 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 5 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
- SOIC-8 and SSOP-16 SMD package

2. Ordering Information

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

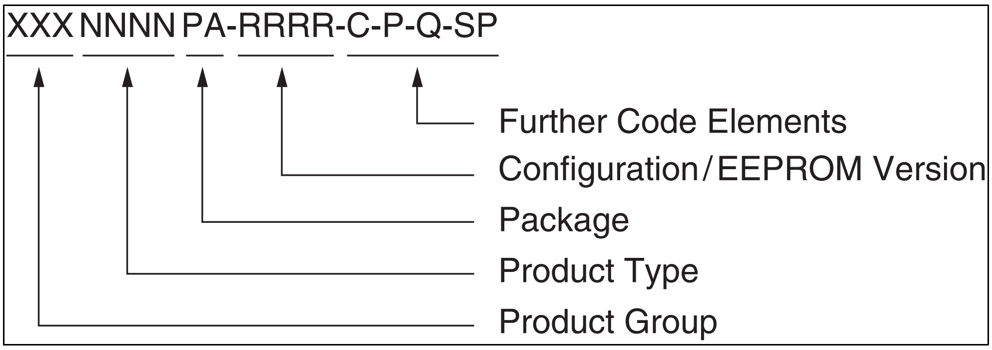


Fig. 2–1: Ordering Code Principle

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

2.1. Device-Specific Ordering Codes

The HAL/HAR 3900 is available in the following packages.

Table 2–1: Available package

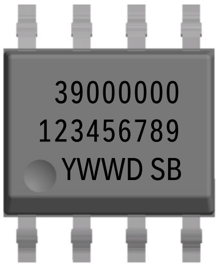
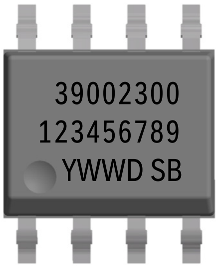
Device	Package Code (PA)	Package Type
HAL 3900	DJ	SOIC-8
HAR 3900	GU	SSOP-16

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

Table 2–2: Ordering Information

Product	Package	Configuration/ EEPROM Version	Further Code [-C-P-Q-SP]	Comments
HAL 3900	DJ = SOIC8	0000	See TDK-Micronas Ordering Information	
HAL 3900	DJ = SOIC8	2300	See TDK-Micronas Ordering Information	Additional registers and functions compared to Configuration-ID 0000. Differences described in the following chapters.
HAR 3900	GU = SSOP16	2300	See TDK-Micronas Ordering Information	

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

Ordering Code	Package Marking	Description
HAL3900DJ-0000[-C-P-Q-SP]		Line 1: Product Type / Configuration-ID Line 2: Lot number Line 3: Date code / Special Procedure SB (optional)
HAL3900DJ-2300[-C-P-Q-SP]		
HAR3900GU-2300[-C-P-Q-SP]		

3. Functional Description

3.1. General Function

HAL/HAR 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).

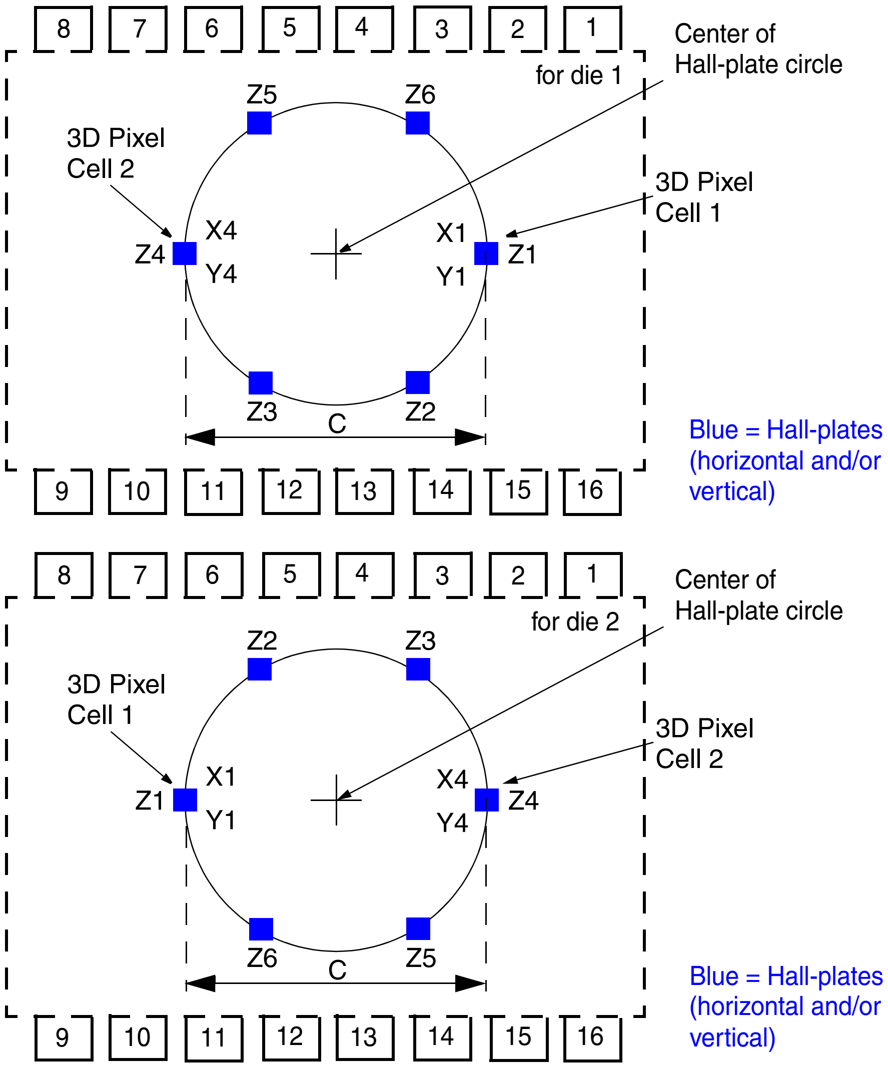


Fig. 3–1: Hall-plate configuration for HAR 3900

Note	Die 2 is rotated by 180° in relation to die 1. Therefore, the measurement values of X and Y components have opposite signs compared to die 1.

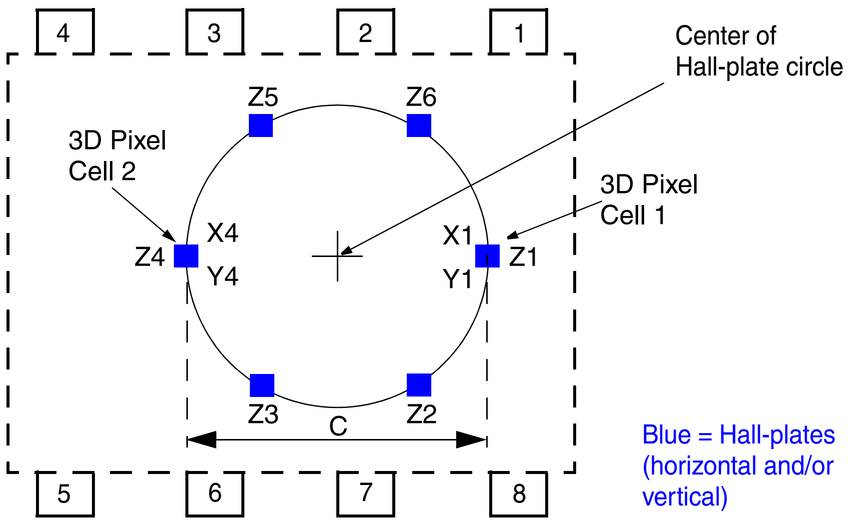


Fig. 3–2: Hall-plate configuration for HAL 3900

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/HAR 3900 operates as an SPI subordinate 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/HAR 3900 is programmable via the integrated SPI interface. No additional programming pin is needed and fast end-of-line programming is enabled.

HAL/HAR 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 Mode offers 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 3–10 on page 35.

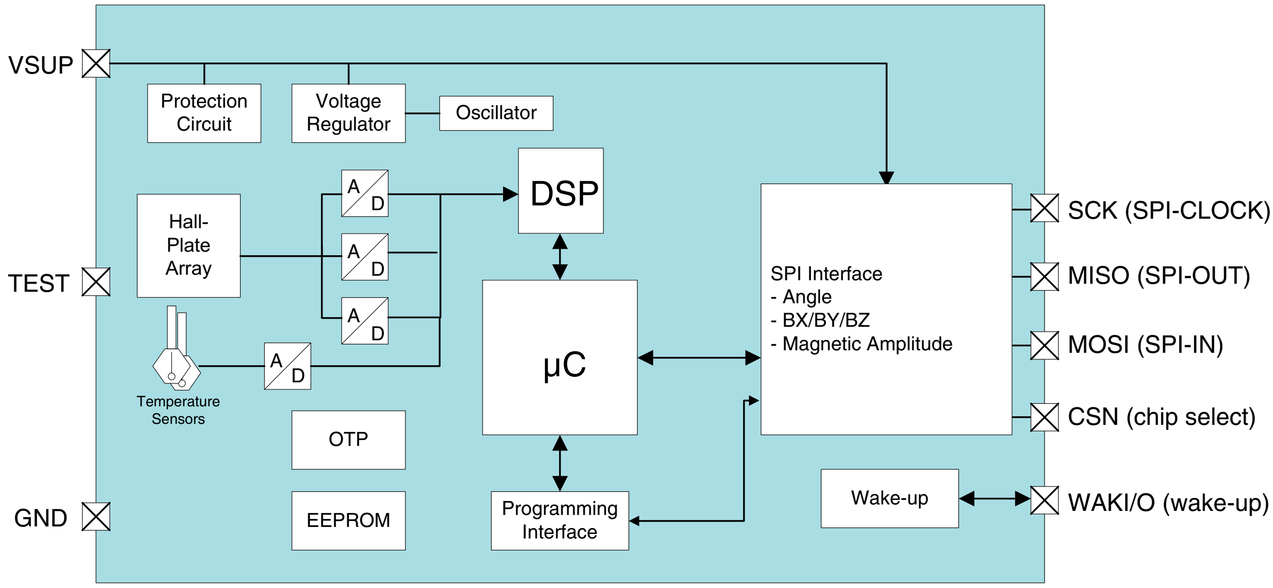


Fig. 3–3: Block diagram (example for HAL 3900)

3.2. Signal Path

The DSP part of this sensor performs the signal conditioning. The parameters for the DSP are stored in the non-volatile memory. Details of the overall signal path are shown in Fig. 3–4. 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.

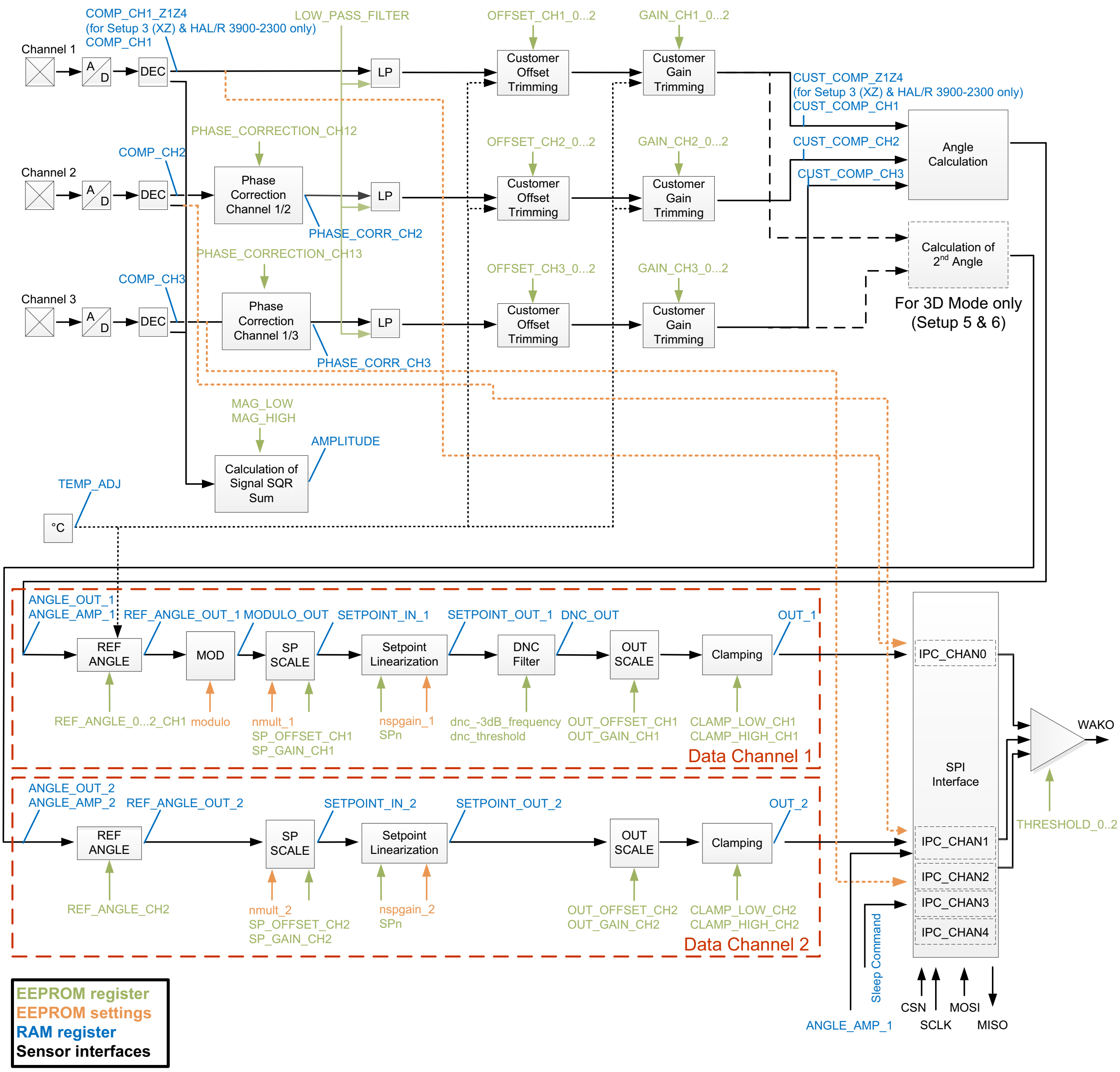


Fig. 3–4: Signal path of HAL/HAR 3900

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

3.3. Registers Definition

Note Further details about the programming of the device and detailed registers setting description as well as memory map can be found in the document: HAL/ HAR 3900 User Manual.

3.3.1. RAM Registers

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 registers contain the TDK-Micronas' temperature compensated magnetic-field information of channel 1-3.

COMP_CH1_Z1Z4

The COMP_CH1_Z1Z4 register is only available in case of Setup 3b and the ΔXΔZ mode. It contains the temperature compensated magnetic field information of the differential ΔZ magnetic field ΔZ = Z4-Z1. This register is only available in HAL/HAR 3900-2300.

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:

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

PHASE_CORR_CH2, PHASE_CORR_CH3

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

CUST_COMP_CH1, CUST_COMP_CH2 and CUST_COMP_CH3

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

CUST_COMP_CH1_Z1Z4

The CUST_COMP_CH1_Z1Z4 register is only available in case of Setup 3b and the ΔXΔZ mode. It contains the customer compensated magnetic-field information of the differential ΔZ magnetic-field ΔZ = Z4-Z1 used for the angle calculation. This register is only available in HAL/R 3900-2300.

ANGLE_OUT_x

The ANGLE_OUT_1 and ANGLE_OUT_2 registers 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 registers 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 registers 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 registers 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 registers 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 registers 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 registers report certain failures detected by the sensor. HAL/HAR 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 registers (further details can be found in Table 4–1 & Table 4–2).

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.

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

Table 3–1: Hardware registers 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	RAW_CH1	Signal after decimation filter 1 (channel 1)
0x79	RAW_CH2	Signal after decimation filter 2 (channel 2)
0x7A	RAW_CH23	Signal after decimation filter 3 (channel 3)
0x7D	DIAG_0	Diagnosis register 0 (see Table 4–1 on page 40)
0x7E	DIAG_1	Diagnosis register 1(see Table 4–2 on page 41)
0x7F	HW_ID	Hardware ID base

3.3.2. EEPROM Registers

Application Modes

HAL/HAR 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 29) 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. 3–5 shows the related signal path.

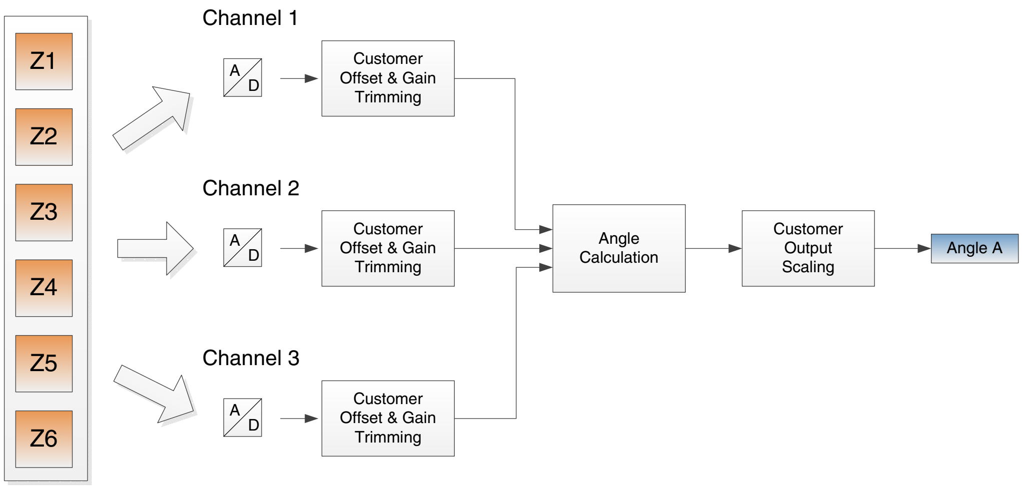


Fig. 3–5: Signal path diagram of setup 1 (stray-field robust 180° measurement; example for one die)

– 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. 3–6 shows the related signal path.

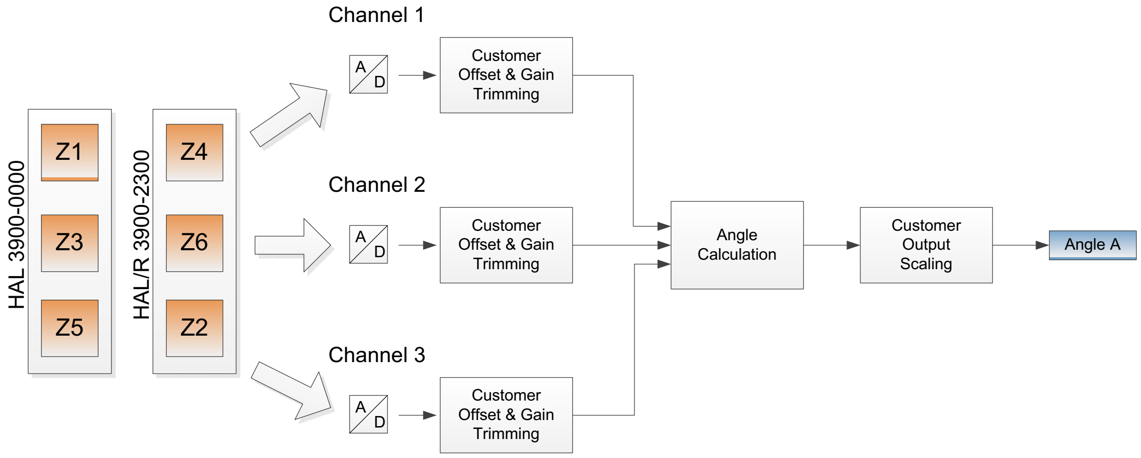


Fig. 3–6: Signal path diagram of setup 2 (stray-field robust 360° measurement; example for one die)

Note HAL 3900-0000 is using the Z-plates Z1, Z3, Z5, and HAL/HAR 3900-2300 Z4, Z6, Z2.

– 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 in case that 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. 3–7 shows the related signal path for ΔXΔY setup and Fig. 3–8 & Fig. 3–9 the signal path for ΔXΔZ setup.

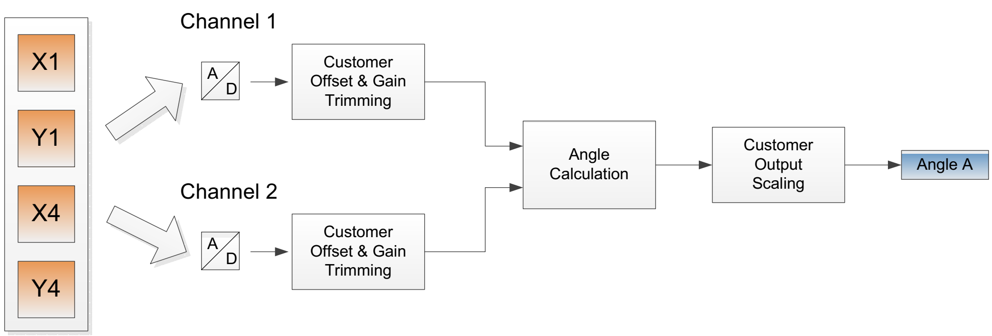


Fig. 3–7: Signal path diagram of setup 3a – ΔXΔY (stray-field robust linear position detection; example for one die)

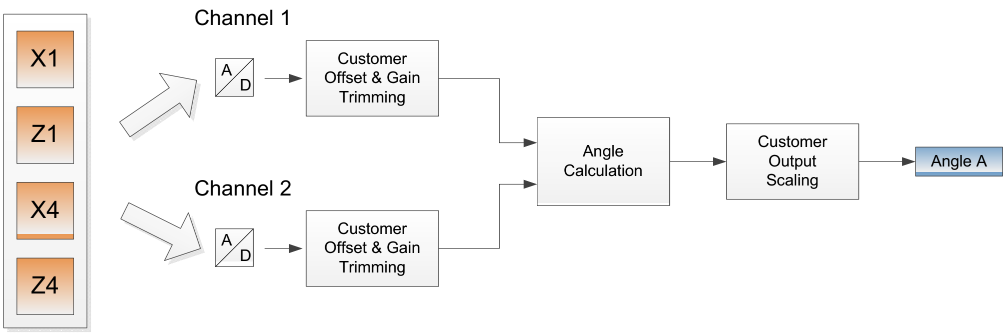


Fig. 3–8: Signal path diagram of setup 3b – ΔXΔZ (stray-field robust linear position detection) in case of HAL 3900-0000

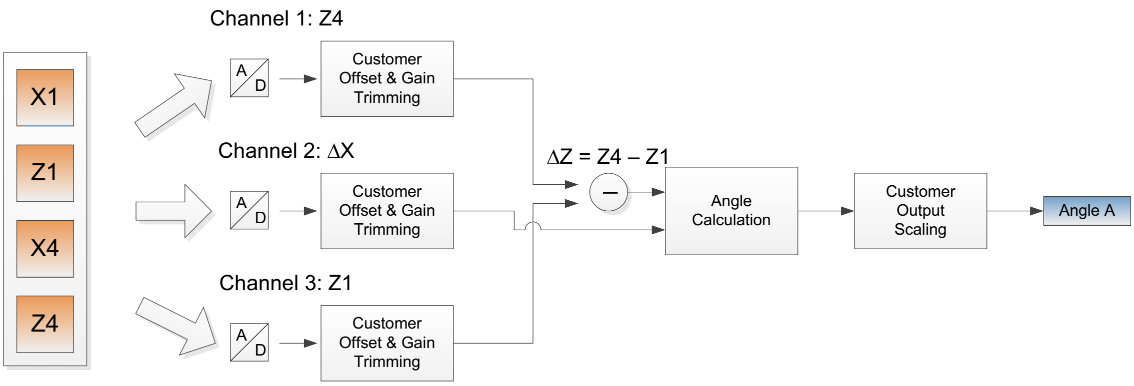


Fig. 3–9: Signal path diagram of setup 3b – ΔXΔZ (stray-field robust linear position detection) in case of HAL/R 3900-2300; example for one die)

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

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

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

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

Note HAL/HAR 3900-2300: GAIN_CH1_0...2 and GAIN_CH3_0...2 must be set to the same value for this specific setup (3b). OFFSET_CH3_0...2 must be set to zero.

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

This mode uses horizontal and vertical Hall-plates to measure B_X, B_Y, B_Z of Pixel Cell 1 (HAL 3900 & HAR 3900 Die 1; HAR 3900 Die 2 is using Pixel 2).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.

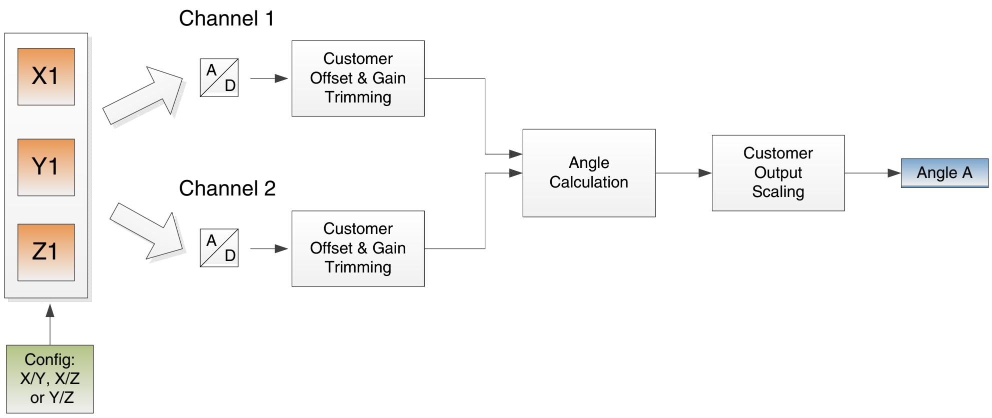


Fig. 3–10: Signal path diagram of setup 4a (rotary & linear position detection w/o stray-field compensation; example for one die)

– 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 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 and averaged to generate one virtual centered pixel in the middle of the Hall-Plate array.

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

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

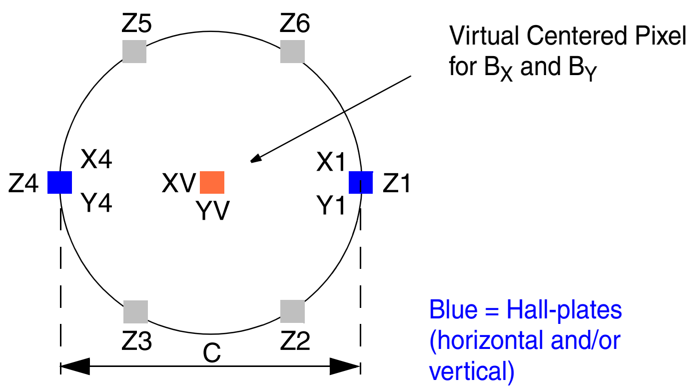


Fig. 3–11: Virtual centered pixel for B_X and B_Y in Mode 4b

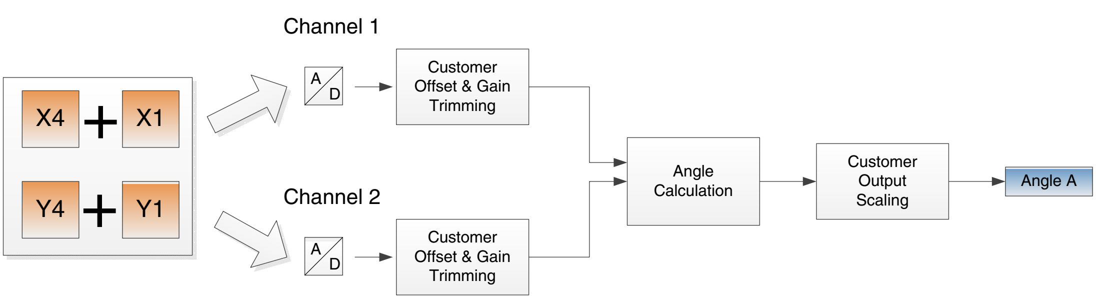


Fig. 3–12: Signal path diagram of setup 4b (virtual centered pixel w/o stray-field compensation; example fore one die)

– 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 of Pixel Cell 1 (HAL 3900 & HAR 3900 Die 1; HAR 3900 Die 2 is using Pixel 2). Two angles 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 angles can be read out via the SPI interface.

See Fig. 3–13 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 of Pixel Cell 1 (HAL 3900 & HAR 3900 Die 1; HAR 3900 Die 2 is using Pixel 2). 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.

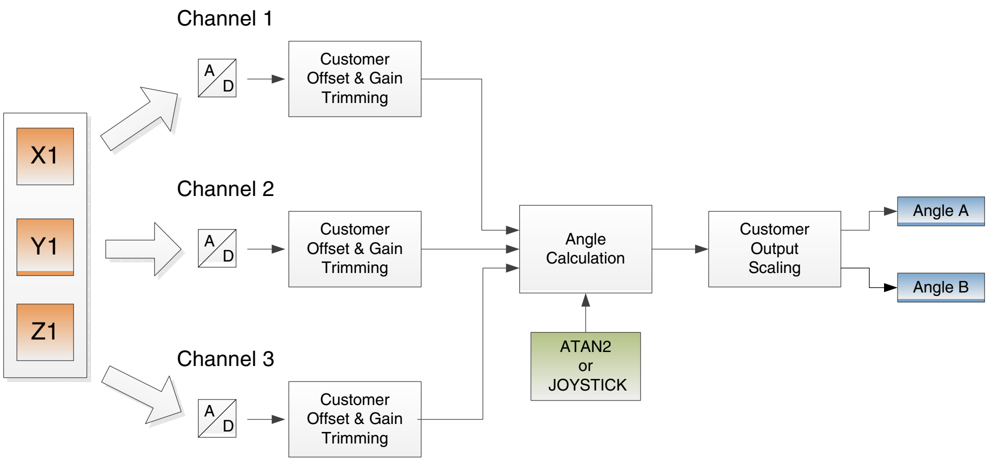


Fig. 3–13: Signal path diagram of setup 5 & 6 (3D measurement); example for one die

– Setup 7: 3D measurement with raw values (3D magnetometer mode)

This mode uses horizontal and vertical Hall-plates to measure B_X, B_Y, B_Z of Pixel Cell 1 (HAL 3900 & HAR 3900 Die 1; HAR 3900 Die 2 is using Pixel 2). 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.

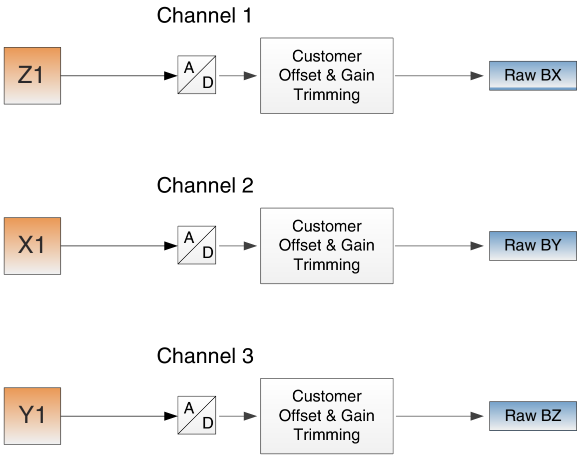


Fig. 3–14: Signal path diagram of setup 7 (transmission of raw signals); example for one die

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 registers (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 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 –3dB frequencies for HAL/HAR 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).

Note HAL/R 3900-2300: GAIN_CH3_0...2 must be set to the same value of GAIN_CH1_0...2 in case of Setup 3b with ΔXΔZ

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).

Note HAL/R 3900-2300: OFFSET_CH3_0...2 must be set to zero in case of Setup 3b with ΔXΔZ

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.

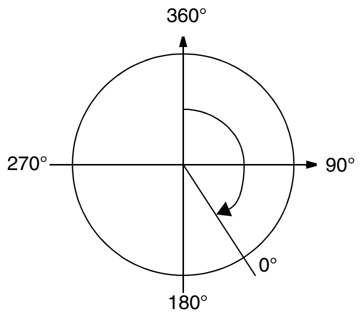


Fig. 3–15: Example definition of zero degree point

Modulo Select

HAL/HAR 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 registers 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) registers 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 attenuation 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 up to 50% of the sample frequency (0.5 * fdecsel) are allowed. To disable the DNC filter, both registers must be set to 0.

OUT_OFFSET_CHx

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

OUT_GAIN_CHx

The registers 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 registers 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 registers 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 registers 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 registers and the signal sources. The available source also depends on the selected measurement setup.

Table 3–2: Sources for THRESHOLD_X registers

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 29 and Table 3–1 on page 15.

Customer Configurations Registers

The SETUP_FRONTEND, SETUP_DATAPATH, and SETUP_STANDBY registers are 16-bit registers 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 3–5, Fig. 3–5 and Table 3–6 describe in detail the available combinations and resulting functions.

Table 3–3: SETUP_FRONTEND for HAL 3900-0000

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 3b - 2D - Strayfield compensated	With two channel	Z4-Z1	X4-X1	-
		0100: Setup 3a - 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_FRONTEND for HAL/R 3900-2300

<table>
<tr><th>Bit No.</th><th>Function</th><th colspan="5">Description</th></tr>
<tr><td>15</td><td>customer_lock</td><td colspan="5">Customer Lock:
0: Unlocked
1: Locked</td></tr>
<tr><td>14:9</td><td>–</td><td colspan="5">Must be set to 0.</td></tr>
<tr><td>8</td><td>cluster</td><td colspan="5">0: IPC_CHAN0 to IPC_CHAN2 are independent
1: IPC_CHAN0 to IPC_CHAN2 are updated after IPC_CHAN0 is read</td></tr>
<tr><td>7:6</td><td>modulo</td><td colspan="5">Modulo operation:
00: 360°
01: Modulo 90°
10: Modulo 120°
11: Modulo 180°</td></tr>
<tr><td>5:4</td><td>fdecsel</td><td colspan="5">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</td></tr>
<tr><td>3:0</td><td>meas_config</td><td>Measurement setups:

0000: Setup 4a - 2D[1)]
0001: Setup 4a - 2D[1)]
0010: Setup 4a - 2D[1)]
0011: Setup 3b - 2D - Strayfield compensated
0100: Setup 3a - 2D - Strayfield compensated
0101: Setup 4b - 2D - Virtual center pixel
0110: Setup 1 - 180° rotary - strayfield compensated
0111: Setup 2 - 360° rotary - strayfield compensated
1000: Setup 5 - 3D measurement - ATAN2[1)]
1001: Setup 5 - 3D measurement - Joystick[1)]
1110: Setup 7 - 3D measurement - Raw[1)]
1010 to 1111: Must not be used</td><td>Correspond. Signal Path

With two channel
With two channel
With two channel
With two channel
With two channel
With two channel
6 Z Hall-plates
3 Z Hall-plates
With three channel
With three channel
With three channel
-</td><td>CH1

X1
Z1
Z1
Z4
X4-X1
X1+X4
Z1+Z4
Z4
Z1
Z1
Z1
-</td><td>CH2

Y1
Y1
X1
X4-X1
Y4-Y1
Y1+Y4
Z2+Z5
Z6
X1
X1
X1
-</td><td>CH3

-
-
-
Z1
-
-
Z3+Z6
Z2
Y1
Y1
Y1
-</td></tr>
<tr><td colspan="7">[1)] HAR 3900-2300: Die 1 is using Pixel 1 with X1, Y1, Z1 and die 2 is using Pixel 2 with X4, Y4, Z4 to have both sensitive areas aligned for these modes.</td></tr>
</table>

Table 3–5: 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 3–6: 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 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/HAR 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-subordinate architecture for synchronous serial communication. The HAL/HAR 3900 is always acting as the subordinate and the ECU is the master. The SPI bus configuration with one subordinate is shown in Fig. 3–16.

Fig. 3–16: Description of the SPI bus (example for HAL 3900)

On the 'Master Out Subordinate In' (MOSI) wire the master sends data to the subordinate. On the 'Master In Subordinate Out' (MISO) wire, the subordinate sends data to the master. The 'Chip Select' (CSN) is driven by the master and grants the subordinate 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 subordinates to one master. The master has to select the desired subordinate 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/HAR 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. 3–17):

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/HAR 3900 replies in the next frame with one status byte and two subordinate data bytes followed by a 8-bit subordinate CRC.

The CRC for HAL/HAR 3900 is calculated based on the following polynomial:
$X^8 + X^4 + X^3 + X^2 + 1$ (0x1D), with a seed value of 0xFF. A transmission without errors always results in the polynomial X^7+X^6+X^2 (0xC4) (CRC-8-SAE-J1850).

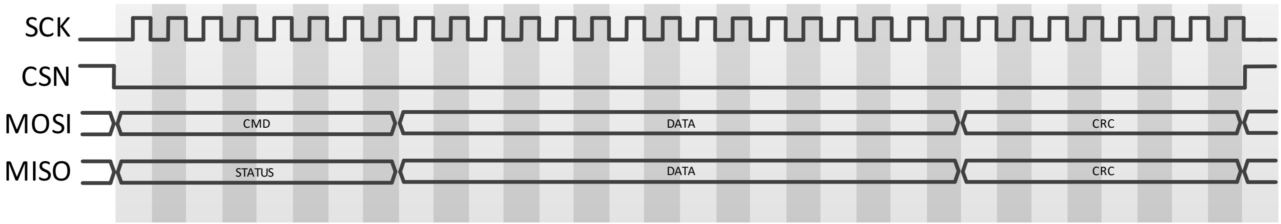


Fig. 3–17: Communication frame structure via SPI

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 15 for access to the measurement data.The DIAG0 & DIAG1 bits are only updated while reading the IPC_CHAN registers. Reading EEPROM content or RAM in programming mode will not trigger the DIAGx registers.

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

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

Table 3–7: 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 3–8: 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 40),

– DIAG1: This bit is set to one in case an error has been indicated in DIAGNOSIS_1 register (see Table 4–2 on page 41),

– 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 3–9: 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 3–6 on page 31).

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

Table 3–10: Overview of Low-Power Mode Use Cases

UC	ECU Mode	Sensor Tasks	ECU Tasks	Configuration of SETUP_STANDBY register (Table 3–6)
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.

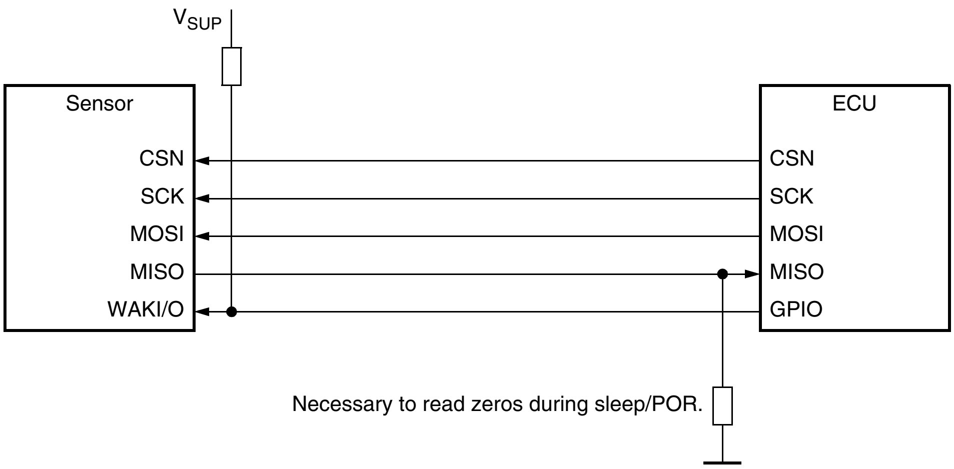


Fig. 3–18: Wake up of sensor via WAKI/O pin (example for HAL 3900)

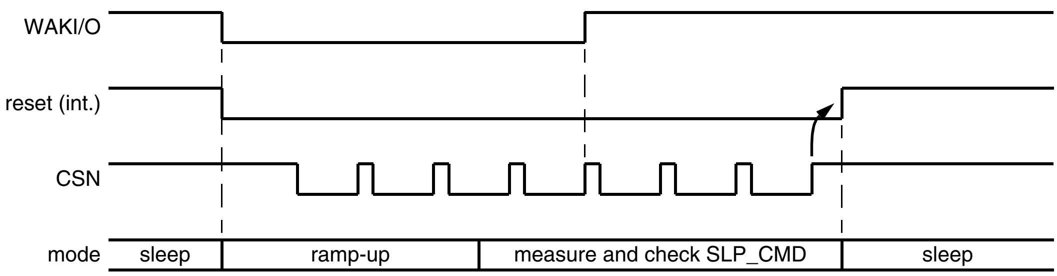


Fig. 3–19: Timing diagram for Low-Power Mode use case 1

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.

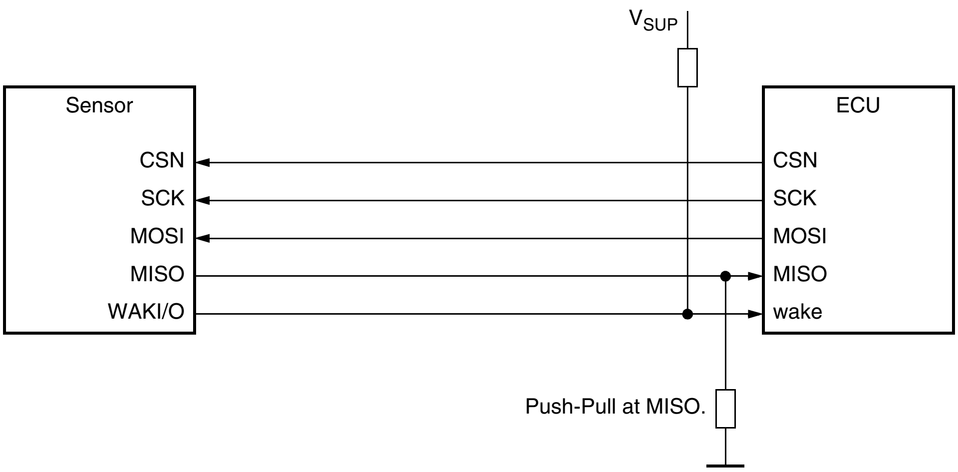


Fig. 3–20: Wake up by counter and Active Mode indication on WAKI/O pin (example for HAL 3900)

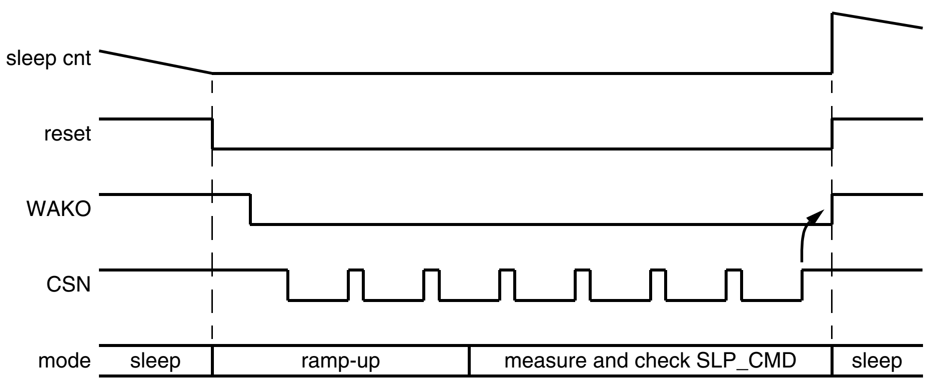


Fig. 3–21: Timing diagram for Low-Power Mode use case 2 &3

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 registers (see page 28). 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. 3–20 and Fig. 3–21 on page 37 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. 3–18 shows the required external wiring for this specific mode.

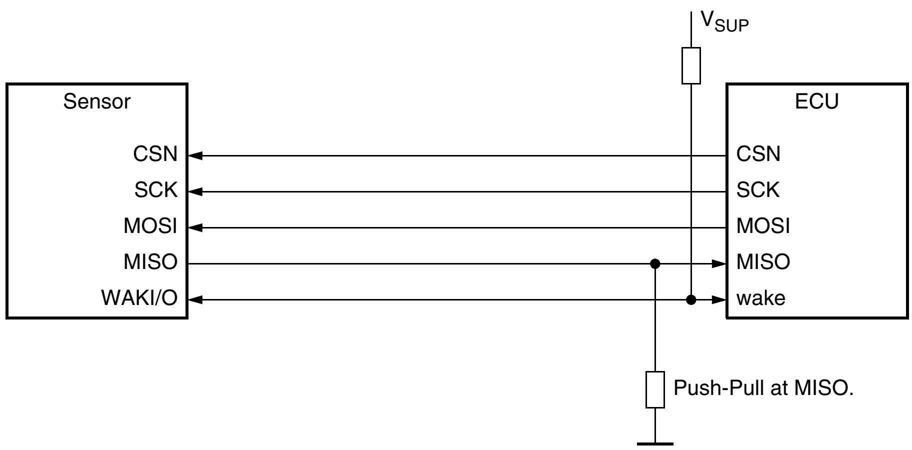


Fig. 3–22: Wake up by counter and WAKI/O pin and Active Mode indication (example for HAL 3900)

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/HAR 3900 contains the necessary information to support customers to realize a safety-compliant application by integrating HAL/HAR 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/HAR 3900 performs self-tests during start-up and normal operation. They 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 registers. Both registers can be read via the SPI interface.

Note Please check as well the Application Note “HAL 3900/HAL 3930 – Procedure to Avoid Temperature-Dependent Checksum Calculation Error” in case HAL 3900-0000 is used.

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 parameters
13	DSP checksum for ROM and RAM
12	Chip junction temperature out of range
11	Plausibility check of redundant temperature sensor
10	Hall-plate supply out of range
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

Table 4–1: DIAGNOSIS_0 register, continued

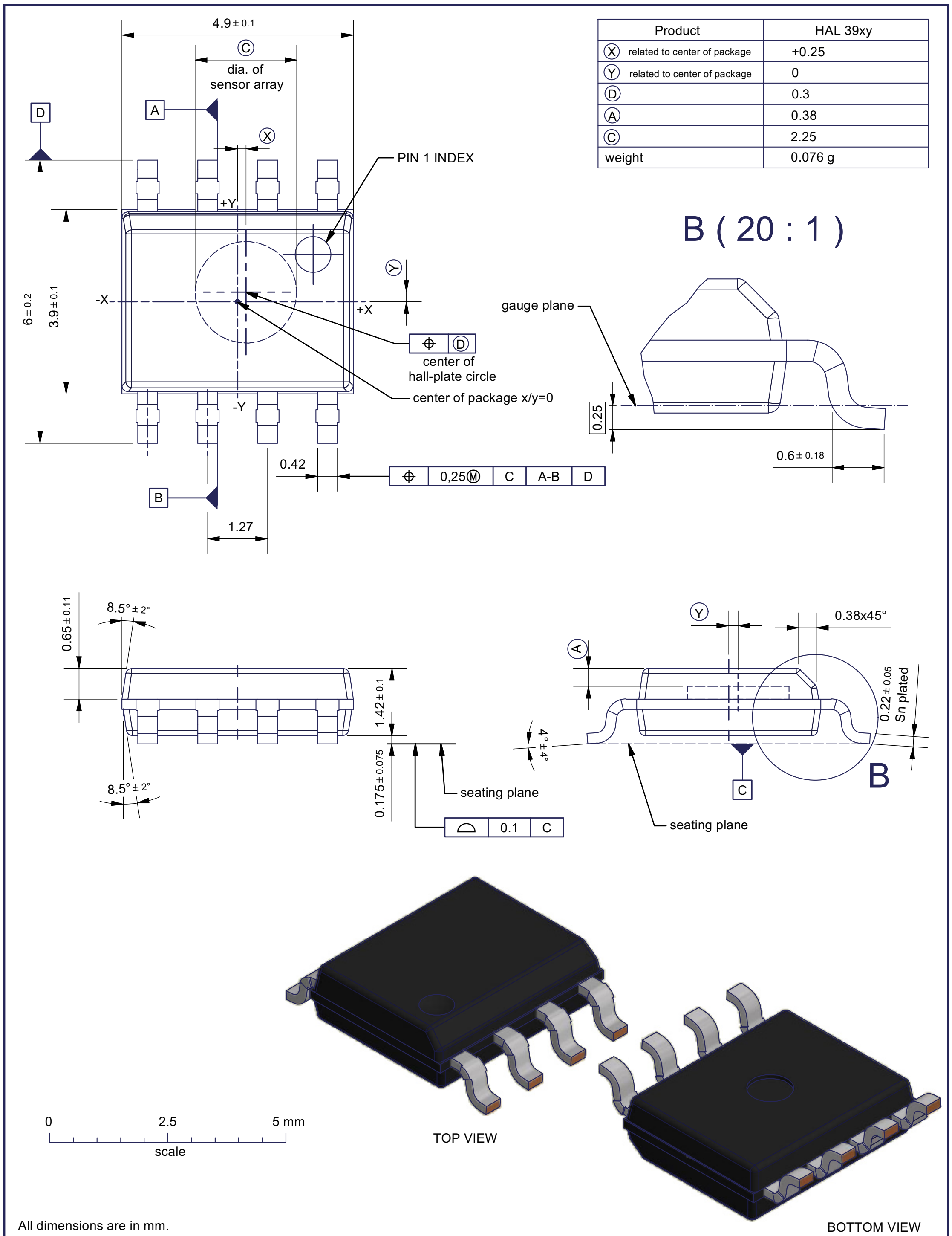
Bit no.	Description when bit is set to 1
4	Magnetic field amplitude is below the MAG-LOW threshold
3	The result of the position calculation (high) is out of the expected (valid) range
2	The result of the position calculation (low) is out of the expected (valid) range
1	Hall-plate current out of range
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

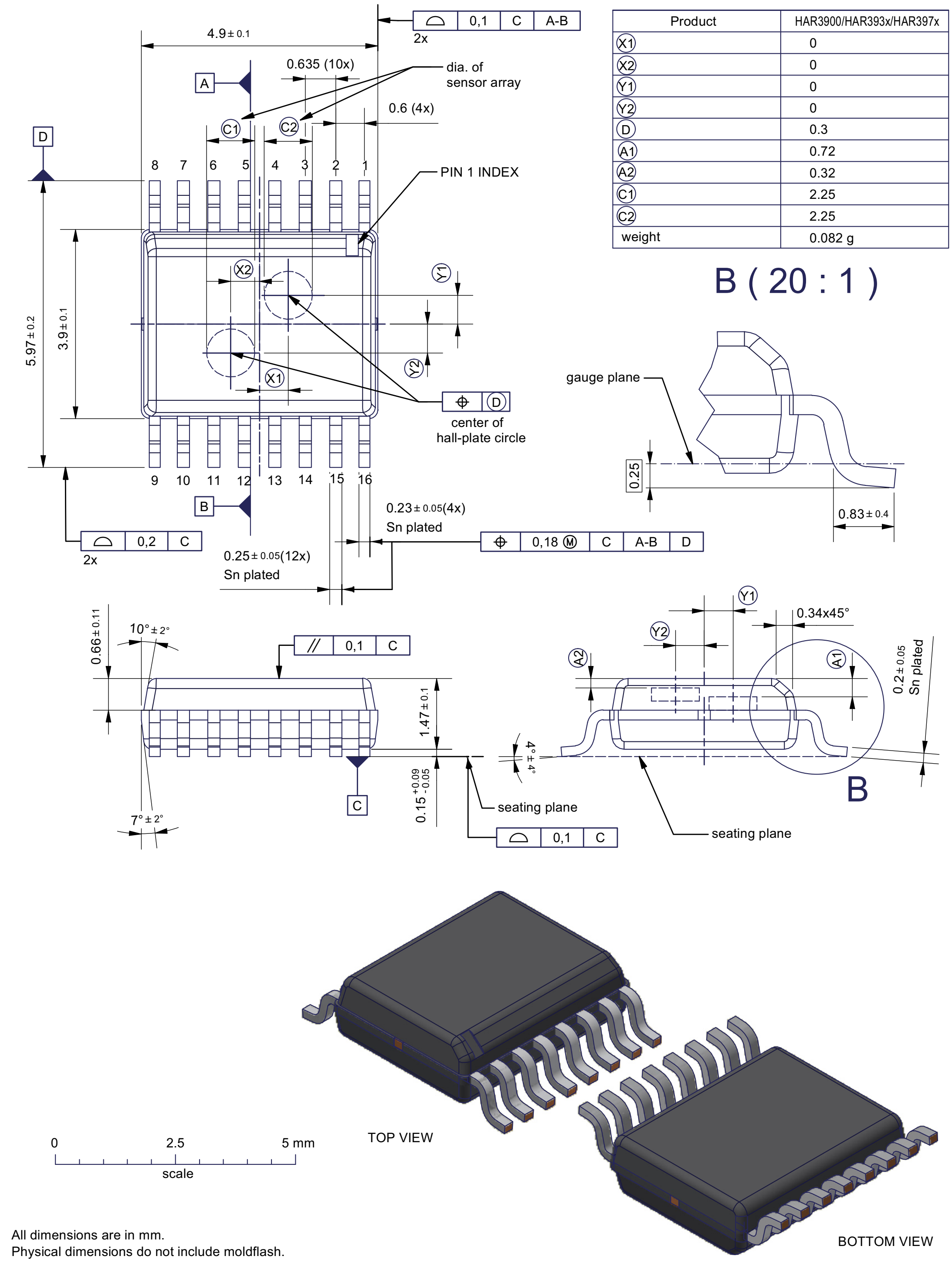


Product	HAL 39xy
Ⓧ related to center of package	+0.25
Ⓨ related to center of package	0
Ⓓ	0.3
Ⓐ	0.38
Ⓒ	2.25
weight	0.076 g

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 ITEM NO.	JEDEC STANDARD ISSUE	ANSI	REVISION DATE (YY-MM-DD)	REV.NO.	DRAWING-NO.	SPECIFICATION TYPE	SPECIFICATION NO.
SOIC8-1	18-02-02	MS-012	F		20-08-13	5	CSOIC0083000.1	ZG	2088_Ver.05

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

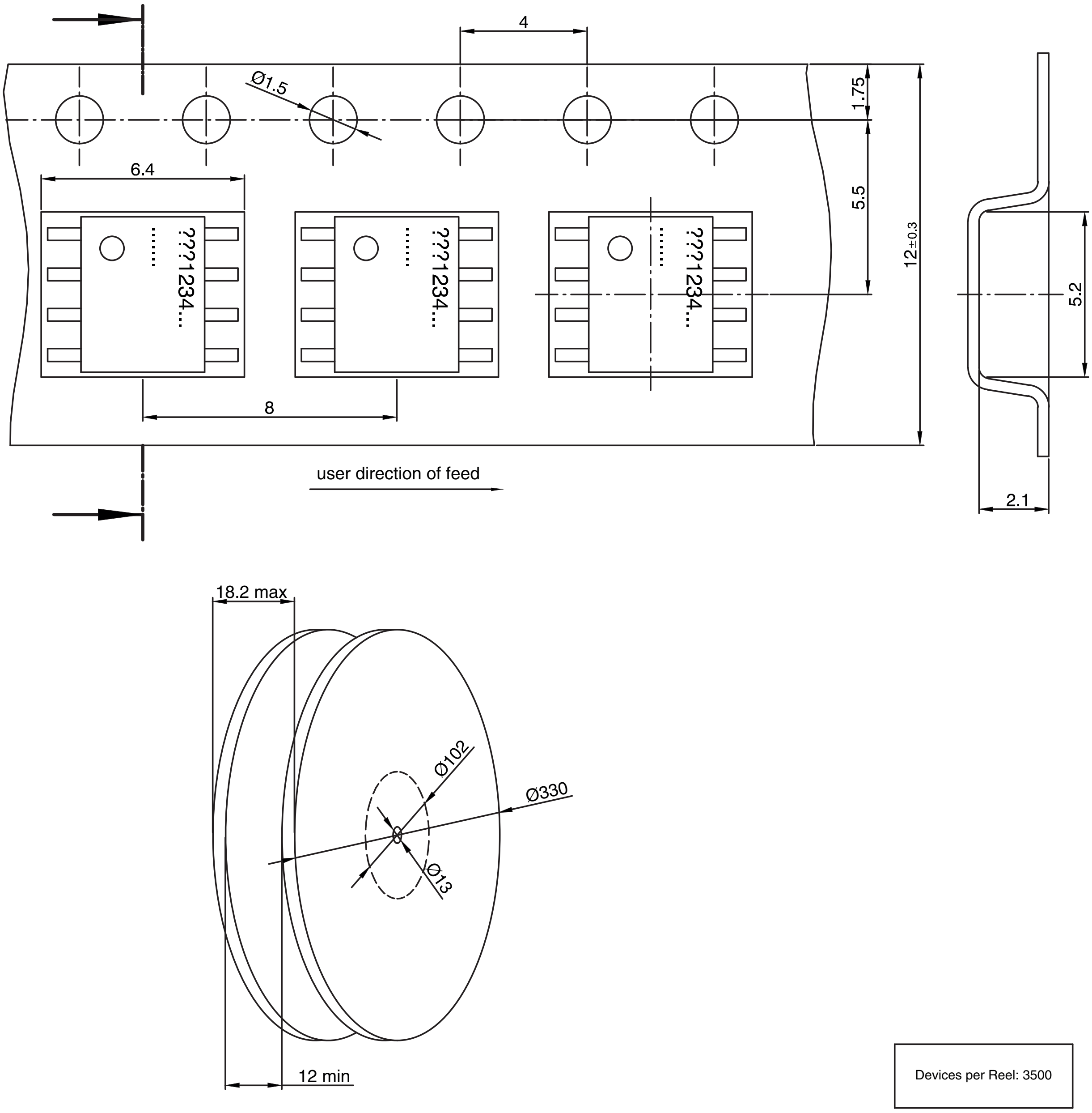


Product	HAR3900/HAR393x/HAR397x
X1	0
X2	0
Y1	0
Y2	0
D	0.3
A1	0.72
A2	0.32
C1	2.25
C2	2.25
weight	0.082 g

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

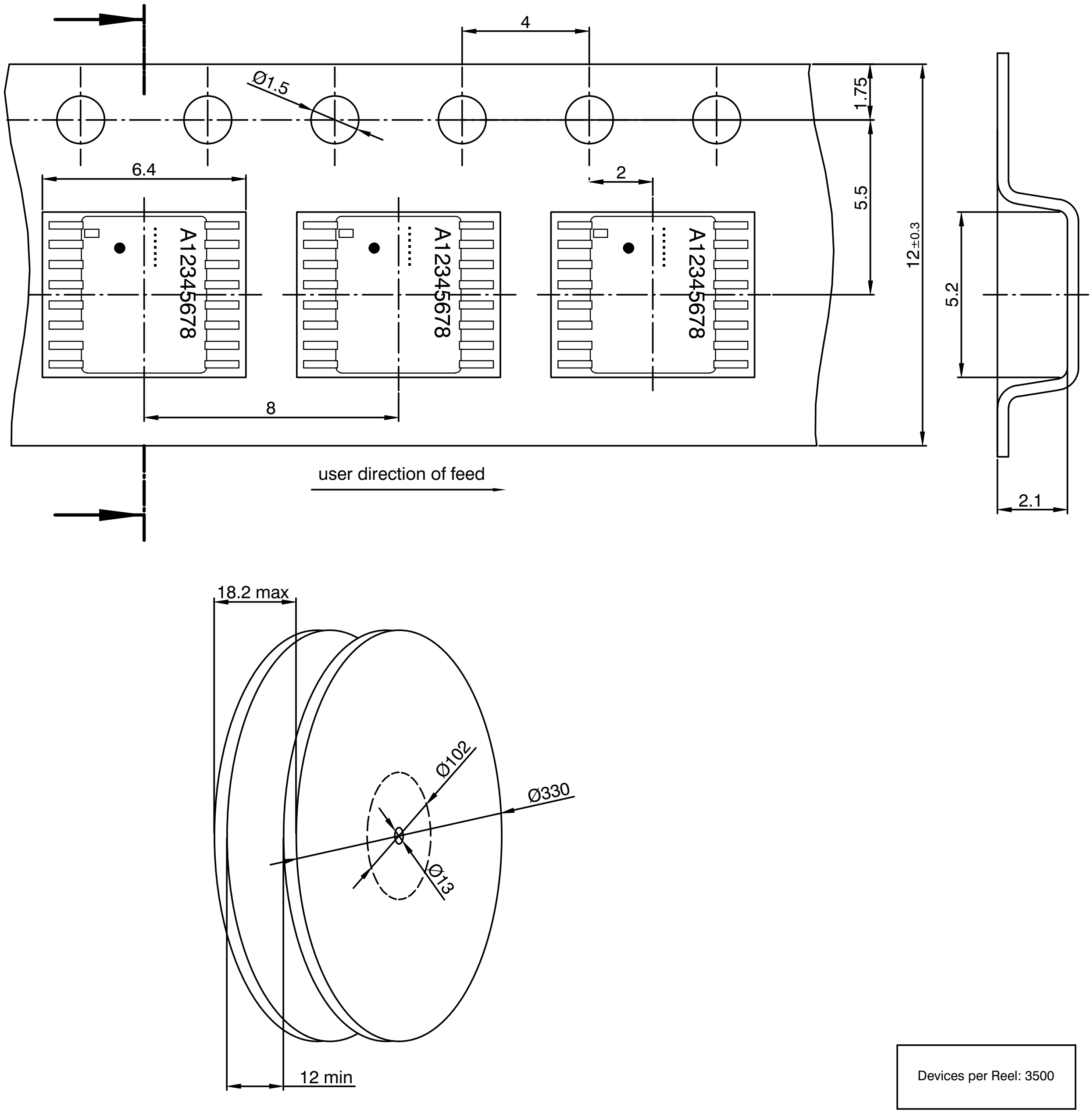
PACKAGE	ISSUE DATE (YY-MM-DD)	JEDEC STANDARD ITEM NO.	JEDEC STANDARD ISSUE	ANSI	REVISION DATE (YY-MM-DD)	REV.NO.	DRAWING-NO.	SPECIFICATION TYPE	SPECIFICATION NO.
SSOP16-1	20-01-17	MO-137	E		22-11-25	3	CSSOP0163007.1	ZG	2109_Ver.03

Fig. 5–2:
SSOP16-1: Plastic **S**hrink **S**mall **O**utline **P**ackage, 16 leads, gullwing bent, 150 mil
Ordering code: GU



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



IEC STANDARD		ANSI	ISSUE DATE YY-MM-DD	DRAWING-NO.	ZG-NO.
ISSUE	ITEM NO.				
4th	60286-3		22-08-08	06843.0001.4	ZG000006_001_02

Fig. 5–4: SSOP16: Tape and Reel Finishing (all dimensions in mm)

5.2. Soldering, Welding, Assembly

Information related to solderability, welding, assembly, and second-level packaging is included in the document “Guidelines for the Assembly of Micronas Packages”.
It is available on the TDK-Micronas website (https://www.micronas.tdk.com/en/service-center/downloads) or on the service portal (http://service.micronas.com).

5.3. Storage and Shelf Life Package

Information related to storage conditions of TDK-Micronas sensors is included in the document “Guidelines for the Assembly of Micronas Packages”. It gives recommendations linked to moisture sensitivity level and long-term storage.
It is available on the TDK-Micronas website (https://www.micronas.tdk.com/en/service-center/downloads) or on the service portal (http://service.micronas.com).

5.4. Size and Position of Sensitive Areas

Diameter of Hall-plate circle: C = 2.25 mm

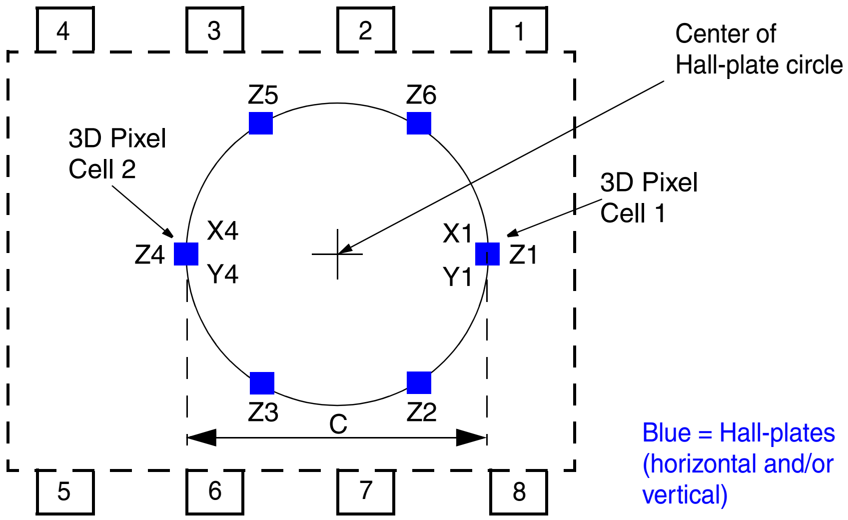


Fig. 5–5: Hall-plate configuration for HAL 3900

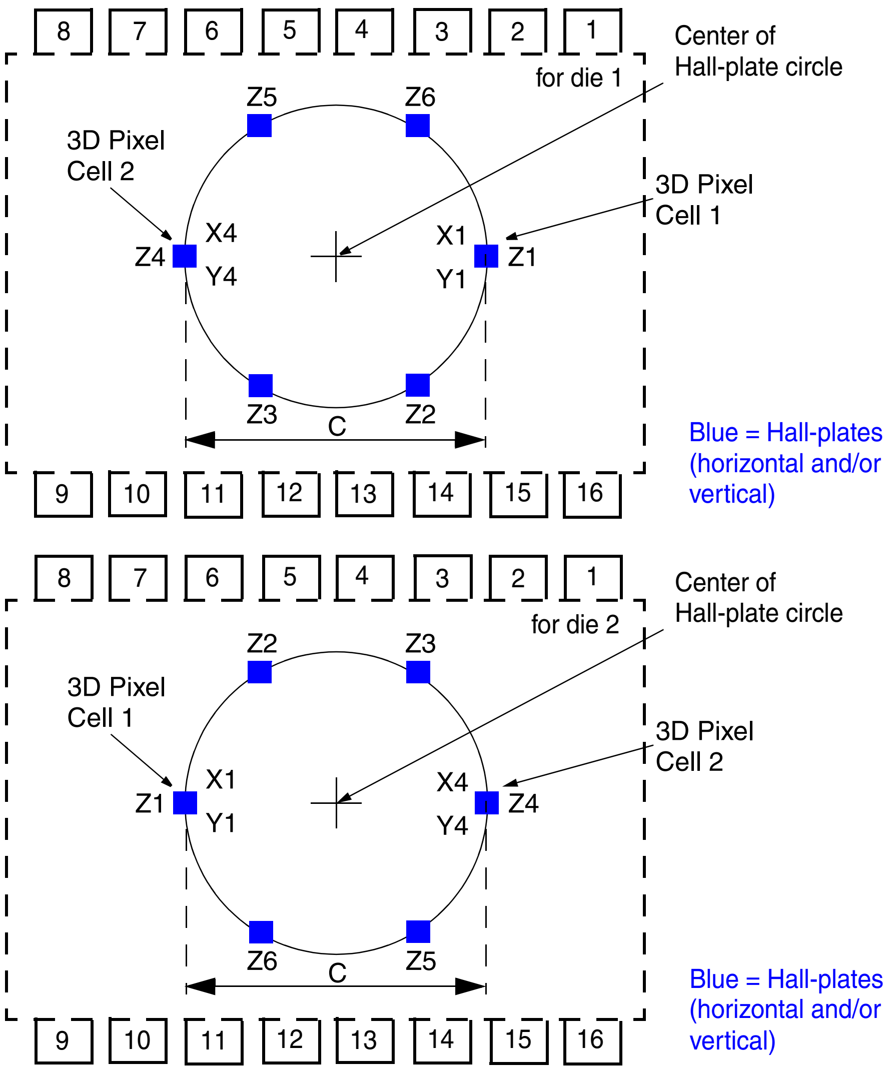


Fig. 5–6: Hall-plate configuration for HAR 3900

5.5. Definition of Magnetic-Field Vectors

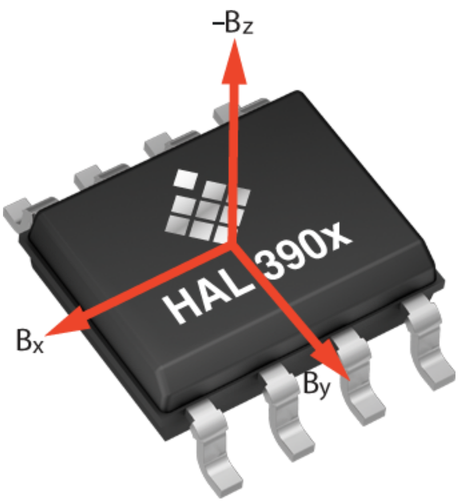


Fig. 5–7: Definition of magnetic-field vectors for HAL 3900

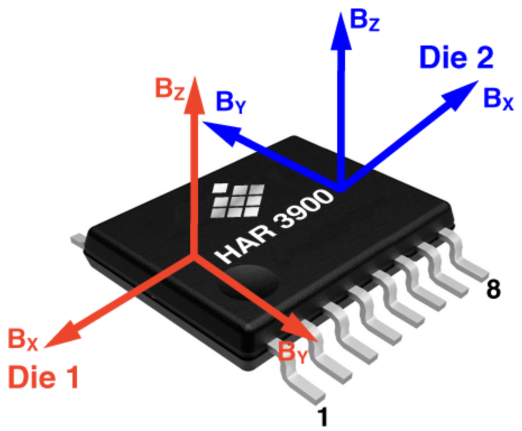


Fig. 5–8: Definition of magnetic-field vectors for HAR 3900

Note Die 2 is rotated by 180° in relation to die 1. Therefore, the measurement values of X and Y components have opposite signs compared to die 1.

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

Note Pins 2 and 3 must be connected to GND.

Table 5–2: Pin connection SSOP16

Pin No.	Pin Name	Type	Short Description
Die 1			
1	SCK1	IN	SPI Clock
2	MOSI1	IN	SPI In
3	VSUP1	IN	Supply Voltage
4	WAKIO1	I/O	Wake Up
5	GND1	GND	Ground
6	TEST1	N/A	Test
7	CSN1	I/O	SPI Chip-Select
8	MISO1	OUT	SPI Out
Die 2			
9	SCK2	IN	SPI Clock
10	MOSI2	IN	SPI In
11	VSUP2	IN	Supply Voltage
12	WAKIO2	I/O	Wake Up
13	GND2	GND	Ground
14	TEST2	N/A	Test
15	CSN2	I/O	SPI Chip-Select
16	MISO2	OUT	SPI Out

Note Pins 5, 6, 13, and 14 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	VSUPx	–18	28	V	
			–	37	V	t < 60s; T_A=50°C
V_{IN_WAKIO}	Input Voltage WAKI/O Pin	WAKIOx	–0.3	6	V	t < 96 h
V_{IN}	Input Voltage SPI Pins	CSNx, MOSIx, SCKx	–0.3	V_{SUP}+0.3	V	t < 96 h
V_{OUT_MISO}	Output Voltage MISO Pin	MISOx	–0.3	V_{SUP}	V	t < 96 h
V_{OUT_MISO}– V_{SUP}	Excess of MISO Output Voltage over VSUP	MISOx	–	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	VSUPx, MISOx, CSNx, SCKx, MOSIx, WAKIOx ,TESTx	–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) ESD HBM according to 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	VSUPx	3.0	–	5.5	V	
V_{IN_WAKIO}	Input Voltage	WAKIOx	0	–	5	V	
R_{WAKIO}	Load Resistance on WAKI/O Pin	WAKIOx	–	–	10	kΩ	Pull-up
R_{SPI_LOAD}	Total Load Resistance	MISOx	10	–	–	kΩ	Pull-down
C_{SPI_LOAD}	Total Load Capacitance	MISOx	6	–	100	pF	f_{SPI} = 5 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	Max. value for setup 4b is ±65 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_{SUPx} = 3.0 V to 5.5 V, GNDx = 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_{SUPx} = 5 V.

Symbol	Parameter	Pin Name	Limit Values			Unit	Conditions
			Min.	Typ.	Max.		
I_{SUP}	Supply Current	VSUPx	–	8	12	mA	[1] Current consumption of each die
I_{SUP_SM}	Supply Current in Standby Mode	VSUPx	–	–	15	µA	While IC is in sleep mode T_A = 25 °C
$t_{startup}$	Start-up Time	MISOx	–	–	10	ms	[1]
f_{osc}	Internal Oscillator Frequency	–	–	32	–	MHz	
f_{sample}	Sampling Frequency	–	–	15.624	–	kSps	[1] Configurable
			–	7.812	–		
			–	3.906	–		
			–	1.953	–		
Power-On behavior							
V_{POR}	Power-on Reset Voltage	VSUPx	2.1	2.6	2.9	V	
$V_{PORHyst}$	Power-on Reset Voltage Hysteresis	VSUPx	–	200	–	mV	
Overvoltage and Undervoltage Detection							
$S_{VSUP,UOV}$	Step Size of Under-/ Overvoltage Supervision Threshold	VSUPx	92	100	108	mV/LSB	Under-/Overvoltage threshold is customer configurable [1]
$S_{VSUP,UOVhyst}$	Under-/Overvoltage Detection Level Hysteresis	VSUPx	–	1	–	LSB	[1] 1 LSB typ. 100 mV
SPI Characteristics							
V_{IH}	Input High Level	MOSIx, SCKx, CSNx	2.4	–	–	V	
V_{IL}	Input Low Level	MOSIx, SCKx, CSNx	–	–	0.8	V	
V_{OH}	Output High Level	MISOx	VSUP –0.6	–	–	V	I_{OUT} = –10 mA
V_{OL}	Output Low Level	MISOx	–	–	0.6	V	I_{OUT} = 20 mA
I_{OShort_Low}	MISO Output Current for Short to GND	MISOx	–50	–40	–30	mA	V_{SUP} > V_{OUT} > GND
I_{OShort_High}	MISO Output Current for Short to V_{SUP}	MISOx	25	40	50	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.		
R_{PD}	Internal Pull-Down Resistor	MOSIx, SCKx	35	–	120	kΩ	Internal pull-down resistor to GND
R_{PD_WAKIO}	Internal Pull-Down Resistor	WAKIOx	25	–	47	kΩ	Internal pull-down resistor to GND. Needs to be overridden by external pull-up for wake-up.
R_{PU}	Internal Pull-Up Resistor	CSNx	35	–	120	kΩ	Internal pull-up resistor to V_{SUP}
I_{OLEAK}	Leakage Current	MISOx	–2	–	2	µA	
t_{SCK}	SPI Clock Period	SCKx	200	1000	–	ns	1) Max. frequency 5 MHz
t_{DIS}	SPI Data Input Setup	MOSIx, SCKx	10	–	–	ns	1) Data sampling with rising SCK edge
t_{DIH}	SPI Data Input Hold	MOSIx, SCKx	15	–	–	ns	1)
t_{DOD}	SPI Data Output Delay	MISOx, SCKx	–	–	44	ns	1) Data output changes with falling SCK edge
t_{SSC}	SPI CSN setup time	CSNx, SCKx	80	–	–	ns	1) With respect to falling CSN edge
t_{SCS}	SPI CSN Hold Time	CSNx, SCKx	12	–	–	ns	1) With respect to the rising CSN edge
t_{SCH}	SPI CSN High Time	CSNx	2* SCK	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							
R_{thja}	Thermal Resistance Junction to Air	–	–	–	140	K/W	2) Determined with a 1S0P board
		–	–	–	93	K/W	2) Determined with a 2S2P board
R_{thjc}	Thermal Resistance Junction to Case	–	–	–	33	K/W	2) Determined with a 1S0P & 2S2P board
SSOP16 Package							
R_{thja}	Thermal Resistance Junction to Air	–	–	–	130	K/W	2) Determined with a 1S0P board
		–	–	–	91	K/W	2)Determined with a 1S0P & 2S2P board
R_{thjc}	Thermal Resistance Junction to Case	–	–	–	34	K/W	2) Determined with a 1S0P board
		–	–	–	31	K/W	2) Determined with a 1S0P & 2S2P board
R_{ISOL}	Isolation Resistance 3)	GND1, GND2	4	–	–	MΩ	Between two dies (Between GND1 and GND2 pin)

1) Characterized on small sample size, not tested.
2) Self-heating calculation see Section 6.1. on page 61.
3) GND's galvanic isolation not tested.

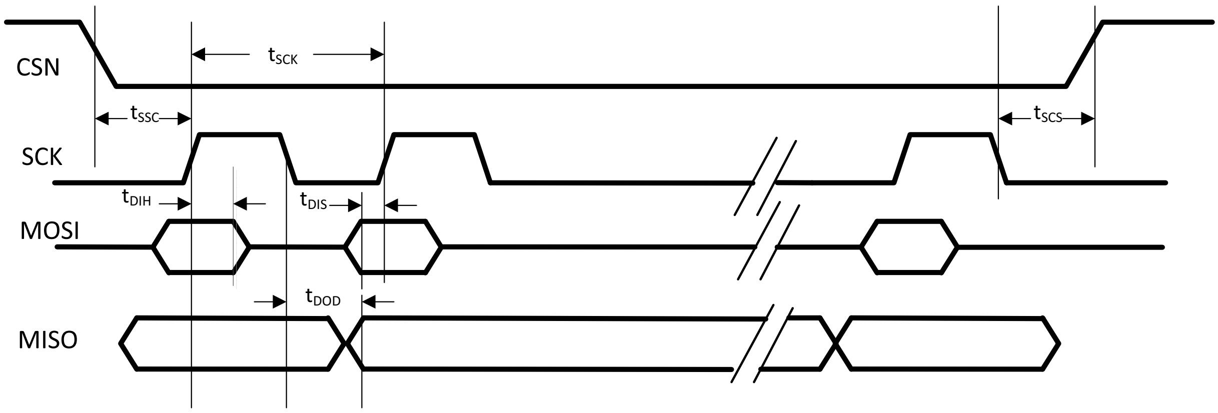


Fig. 5–9: SPI timing diagram

5.10. Magnetic Characteristics

at T_A = –40 °C to 150 °C, V_{SUPx} = 3.0 V to 5.5 V, GNDx = 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_{SUPx} = 5.0 V.

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
Rotary Setup with Stray-Field Compensation (Setup 1 & 2) for HAL 3900							
$\Delta E_{\Theta tot}$	Total Angular Error of Drifts	MISOx	–0.85	–	0.85	°	1) B_{AMP} = ±10 mT Setup 2 (3 Z-Plates)
			–0.45	–	0.45	°	1) B_{AMP} = ±10 mT Setup 1 (6 Z-Plates)
$\Delta E_{\Theta temp}$	Angular Error Drift over Temperature	MISOx	–0.5	–	0.5	°	1) B_{AMP} = ±10 mT
$\Delta E_{\Theta life}$	Angular Error Drift over Lifetime	MISOx	–0.45	–	0.45	°	1) B_{AMP} = ±10 mT Setup 2 (3 Z-Plates) After 1008 h HTOL
			–0.2	–	0.2	°	1) B_{AMP} = ±10 mT Setup 1 (6 Z-Plates) After 1008 h HTOL
$E_{\Theta hyst}$	Angular Hysteresis Error	MISOx	–	–	0.05	°	2)
$E_{\Theta noise\_1}$	Angular Noise Setup 1	MISOx	–	0.13	0.23	°	3) 6Z-Plates
$E_{\Theta noise\_2}$	Angular Noise Setup 2	MISOx	–	0.3	0.67	°	3) HAL 3900-0000 3Z-Plates
$E_{\Theta noise\_2}$	Angular Noise Setup 2	MISOx	–	0.19	0.33	°	3) HAL 3900-2300 3Z-Plates
$E_{\Theta SF\_1}$	Angular Error due to Stray-Field for Setup 1	MISOx	–	–	0.1	°	1) 4) B_{AMP} = ±10 mT wanted signal
$E_{\Theta SF\_2}$	Angular Error due to Stray-Field for Setup 2	MISOx	–	–	0.12	°	1) 4) B_{AMP} = ±10 mT wanted signal
Rotary Setup with Stray-Field Compensation (Setup 1 & 2) for HAR 3900							
$\Delta E_{\Theta tot}$	Total Angular Error of Drifts	MISOx	–1.2	–	1.2	°	1) B_{AMP} = ±10 mT Setup 2 (3 Z-Plates)
			–0.75	–	0.75	°	1) B_{AMP} = ±10 mT Setup 1 (6 Z-Plates)
$\Delta E_{\Theta temp}$	Angular Error Drift over Temperature	MISOx	–0.55	–	0.55	°	1) B_{AMP} = ±10 mT
$\Delta E_{\Theta life}$	Angular Error Drift over Lifetime	MISOx	–0.7	–	0.7	°	1) B_{AMP} = ±10 mT Setup 2 (3 Z-Plates) After 1008 h HTOL
			–0.45	–	0.45	°	1) B_{AMP} = ±10 mT Setup 1 (6 Z-Plates) 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) Characterized on small sample size, 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
$E_{\Theta hyst}$	Angular Hysteresis Error	MISOx	–	–	0.05	°	2)
$E_{\Theta noise\_1}$	Angular Noise Setup 1	MISOx	–	0.13	0.23	°	3) 6Z-plates
$E_{\Theta noise\_2}$	Angular Noise Setup 2	MISOx	–	0.19	0.33	°	3) 3Z-plates
$E_{\Theta SF\_1}$	Angular Error due to Stray-Field for Setup 1	MISOx	–	–	0.19	°	1) 4) B_{AMP} = ±10 mT wanted signal
$E_{\Theta SF\_2}$	Angular Error due to Stray-Field for Setup 2	MISOx	–	–	0.21	°	1) 4) B_{AMP} = ±10 mT wanted signal
Linear Movement Setup (ΔXZ) with Stray-Field Compensation (Setup 3b) for HAL 3900 & HAR 3900							
$SM_{\Delta XZ41}$	Sensitivity Mismatch between ΔX41 and ΔZ41 Channel	MISOx	–5	–	5	%	1) TA = 25 °C
$Sense_{\Delta XZ41}$	Sensitivity of ΔX_{41} and ΔZ_{41} Channel	MISOx	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	MISOx	–2.5	–	2.5	%	1) Related to T_A = 25 °C HAL 3900-0000/-2300
			–3.5	–	3.5	%	1) Related to T_A = 25 °C HAR 3900
$Offset_{\Delta X41}$	Offset of ΔX_{41} Channel	MISOx	–30	–	30	LSB_{15}	T_A = 25 °C
$Offset_{\Delta Z41}$	Offset of ΔZ_{41} Channel	MISOx	–15	–	15	LSB_{15}	T_A = 25 °C
$\Delta Offset_{\Delta X41}$	Offset Drift of ΔX_{41} Channel	MISOx	–50	–	50	LSB_{15}	Related to T_A = 25 °C
$\Delta Offset_{\Delta Z41}$	Offset Drift ΔZ_{41} Channel	MISOx	–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	MISOx	–	1.0	–	%	1) After 1008 h HTOL HAL 3900-0000/-2300
			–	6.0	–	%	1) After 1008 h HTOL HAR 3900
$\Delta Offset_{\Delta X41life}$	Offset Drift of ΔX_{41} Channel over life time	MISOx	–	30	–	LSB_{15}	After 1008 h HTOL
$\Delta Offset_{\Delta Z41life}$	Offset Drift of ΔZ_{41} Channel over life time	MISOx	–	5	–	LSB_{15}	After 1008 h HTOL HAL 3900
			–	9	–	LSB_{15}	After 1008 h HTOL HAR 3900
$SF_{R\Delta X41}$	Stray-Field Rejection in ΔX_{41} Direction	MISOx	99	–	–	%	4) T_A = 25°C
$SF_{R\Delta Z41}$	Stray-Field Rejection in ΔZ_{41} Direction	MISOx	99	–	–	%	4) T_A = 25°C HAL 3900-2300
			98.7	–	–	%	4) T_A = 25°C HAR 3900
			96	–	–	%	4) T_A = 25°C HAL 3900-0000

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) Characterized on small sample size, 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
$E_{\Theta phase \Delta XZ41}$	Phase Error between ΔX_{41} and ΔZ_{41} Channel	MISOx	–	±2.2	–	°	between ΔX_{41} and ΔZ_{41} axis [1)
$E_{\Delta X41,noise}$	Digital Noise of ΔX_{41} Hall-plates Channel	MISOx	–	2.4	–	LSB_{15}	[5)
$E_{\Delta Z41,noise}$	Digital Noise of ΔZ_{41} Hall-plates Channel	MISOx	–	2.6	–	LSB_{15}	[5)
Off-Axis Rotary Setup (ΔXY) with Stray-Field Compensation (Setup 3a) for HAL 3900 & HAR 3900							
$SM_{\Delta XY41}$	Sensitivity Mismatch between ΔX_{41} and ΔY_{41} Channel	MISOx	–2	–	2	%	[1) T_A = 25 °C
$Sense_{\Delta XY41}$	Sensitivity of ΔX_{41} and ΔY_{41} Channel	MISOx	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	MISOx	–2.5	–	2.5	%	[1) Related to T_A = 25 °C
$Offset_{\Delta XY41}$	Offset of ΔX_{41} and ΔY_{41} Channels	MISOx	–30	–	30	LSB_{15}	[1) T_A = 25 °C
$\Delta Offset_{\Delta XY41}$	Offset Drift of ΔX_{41} and ΔY_{41} Channels	MISOx	–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	MISOx	–	1.0	–	%	After 1008 h HTOL
$\Delta Offset_{\Delta XY41life}$	Offset Drift of ΔX_{41} and ΔX_{41} Channel over life time	MISOx	–	30	–	LSB_{15}	After 1008 h HTOL
$SF_{R\Delta XY41}$	Stray-Field Rejection in ΔX_{41} and ΔY_{41}Direction	MISOx	99	–	–	%	
$E_{\Theta phase \Delta XY41}$	Phase Error between ΔX_{41} and ΔY41Channel	MISOx	–	±2.2	–	°	[1) between ΔX_{41} and ΔY_{41} axis; HAL 3900
			–	±4.2	–	°	[1) between ΔX_{41} and ΔY_{41} axis; HAR 3900
$E_{\Delta XY41,noise}$	Digital Noise of ΔX_{41} and ΔY_{41} Hall-plates Channel	MISOx	–	2.4	–	LSB_{15}	[5)
3D Measurement Setup without Stray-Field Compensation (Setup 4a, 5 & 6) for HAL 3900 & HAR 3900							
SM_{XYZ}	Sensitivity Mismatch between X or Y and Z Channel	MISOx	–4	–	4	%	T_A = 25 °C
SM_{XY}	Sensitivity Mismatch between X and Y Channel	MISOx	–2	–	2	%	T_A = 25 °C
$Sense_{XYZ}$	Sensitivity of X,Y and Z Hall-plate	MISOx	123	128	133	LSB_{15} /mT	T_A = 25 °C
ΔSM_{XYZ}	Thermal Sensitivity Mismatch Drift between X or Y and Z Hall-plates	MISOx	–2.5	–	2.5	%	Related to T_A = 25 °C HAL 3900
			–2.7	–	2.7	%	Related to T_A = 25 °C HAR 3900
ΔSM_{XY}	Thermal Sensitivity Mismatch Drift between X and Y Hall-plates	MISOx	–2	–	2	%	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).
[5) Characterized on small sample size, 1-sigma values of COMP_CHx, fdecsel = 2 kHz, Low-pass filter: off (not tested).

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
$Offset_Z$	Offset of Z Hall-plate	MISOx	–12	–	12	LSB_{15}	T_A = 25 °C
$Offset_{XY}$	Offset of X and Y Hall plates	OUTx	–20	–	20	LSB_{15}	T_A = 25 °C
$\Delta Offset_{XY}$	Offset Drift of X and Y Hall-plates	MISOx	–40	–	40	LSB_{15}	Related to T_A = 25 °C
$\Delta Offset_Z$	Offset Drift of Z Hall-plate	MISOx	–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	MISOx	–	1.0	–	%	After 1008 h HTOL HAL 3900
			–	4.5	–	%	After 1008 h HTOL HAR 3900
$\Delta Offset_{XYlife}$	Offset Drift of X and Y Hall-plates over life time	MISOx	–	30	–	LSB_{15}	After 1008 h HTOL
$\Delta Offset_{Zlife}$	Offset Drift of Z Hall-plate over life time	MISOx	–	5	–	LSB_{15}	After 1008 h HTOL
$E_{\Theta phaseXYZ}$	Phase Error between X, Y and Z Hall-plates	MISOx	–	±1.6	–	°	XY axis; HAL 3900
			–	±1.6	–	°	XZ axis; HAL 3900
			–	±1.6	–	°	YZ axis; HAL 3900
$E_{\Theta phaseXYZ}$	Phase Error between X, Y and Z Hall-plates	MISOx	–	±3.1	–	°	XY axis; HAR 3900
			–	±1.6	–	°	XZ axis; HAR 3900
			–	±2.5	–	°	YZ axis; HAR 3900
$E_{XYZ,noise}$	Digital Noise of X, Y or Z Hall-plates Channel	MISOx	–	2.2	–	LSB_{15}	5)
2D Measurement Setup (virtual center Pixel XY) without Stray-Field Compensation (Setup 4b) for HAL 3900 & HAR 3900							
$SM_{\Sigma XY41}$	Sensitivity Mismatch between ΣX_{41} and ΣY_{41} Channel	MISOx	–3	–	3	%	T_A = 25 °C
$Sense_{\Sigma XY41}$	Sensitivity of ΣX_{41} and ΣY_{41} Channel	MISOx	121	128	135	LSB/ mT	T_A = 25 °C
$\Delta SM_{\Sigma XY41}$	Thermal Sensitivity Mismatch Drift between ΣX_{41} and ΣY_{41} Channel	MISOx	–2	–	2	%	Related to T_A = 25 °C
$Offset_{\Sigma XY41}$	Offset of ΣX_{41} and ΣY_{41} Channel	MISOx	–25	–	25	LSB_{15}	T_A = 25 °C
$\Delta Offset_{\Sigma XY41}$	Offset Drift of ΣX_{41} and ΣY_{41} Channel	MISOx	–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	MISOx	–	1.0	–	%	After 1008 h HTOL
$\Delta Offset_{\Sigma XY41life}$	Offset Drift of ΣX_{41} and ΣY_{41}Channel over Life Time	MISOx	–	30	–	LSB_{15}	After 1008 h HTOL
$E_{\Theta phase\Sigma XY41}$	Phase Error between ΣX_{41} and ΣY_{41}	MISOx	–	±2.2	–	°	1) HAL 3900
			–	±4.2	–		1) HAR 3900
$E_{\Sigma XY41,noise}$	Digital Noise of ΣX_{41} and ΣY_{41} Hall-plates Channel	MISOx	–	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) Characterized on small sample size, 1-sigma values of COMP_CHx, fdecsel = 2 kHz, Low-pass filter: off (not tested).

5.11. Temperature Sensor

at T_A = –40 °C to 150 °C, V_{SUPx} = 3.0 V to 5.5 V, GNDx = 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_{SUPx} = 5.0 V.

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
$TADJ_{Gain}$	Gain of Temperature Sensor	MISOx	–	89.25	–	LSB_{15} /°C	1)
$TADJ_{Offset}$	Temperature Sensor Offset	MISOx	–	3720	–	LSB_{15}	1)
ΔT_{Lin}	Temperature Sensor Differential Accuracy (Linearity Error)	MISOx	–2	–	2	°C	1)
ΔT_{Offset}	Temperature Sensor Offset Error	MISOx	–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 53.

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

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

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

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

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

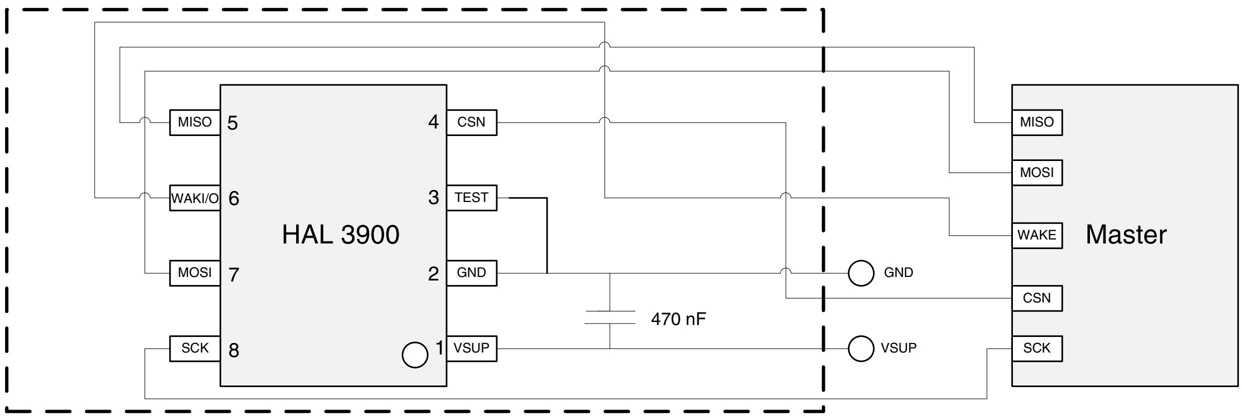


Fig. 6–1: Recommended application circuit for HAL 3900 (one subordinate and one master)

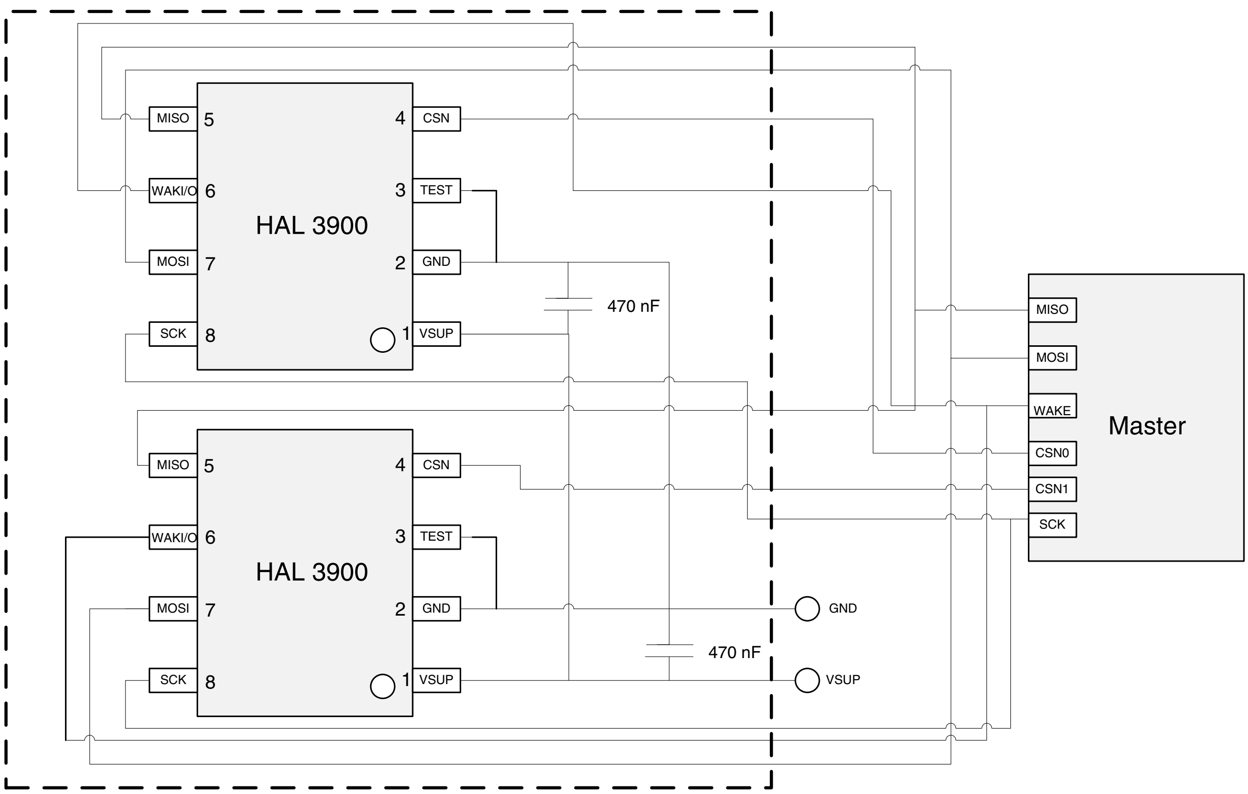


Fig. 6–2: Recommended application circuit for HAL 3900 (two subordinates and one master)

6.4. Application Circuit for HAR 3900

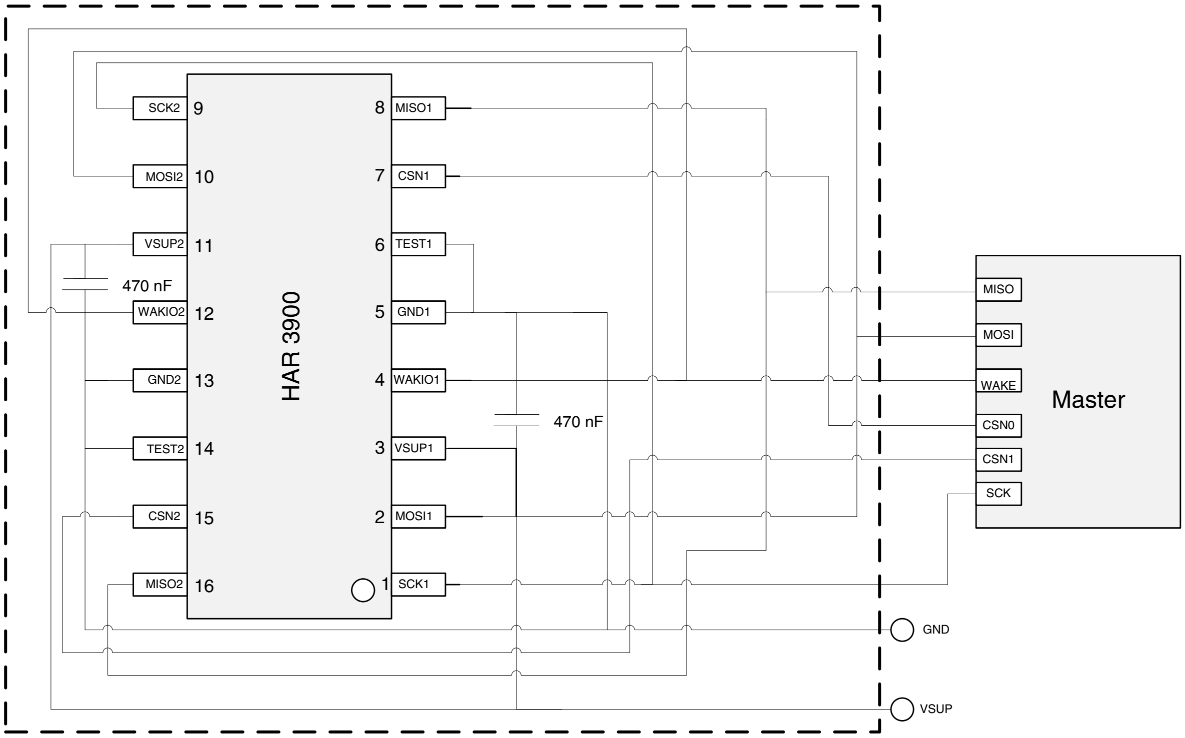


Fig. 6–3: Recommended application circuit for HAR 3900 (two subordinates and one master)

6.5. Recommended Pad Size SOIC8 Package

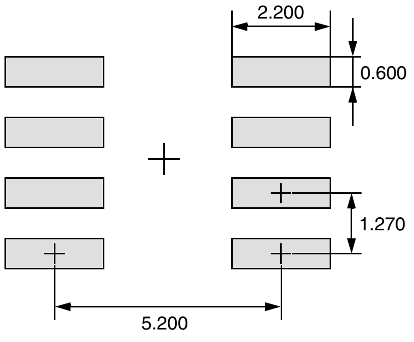


Fig. 6–4: Pad size recommendation for SOIC8 package (all dimensions in mm)

6.6. Recommended Pad Size SSOP16 Package

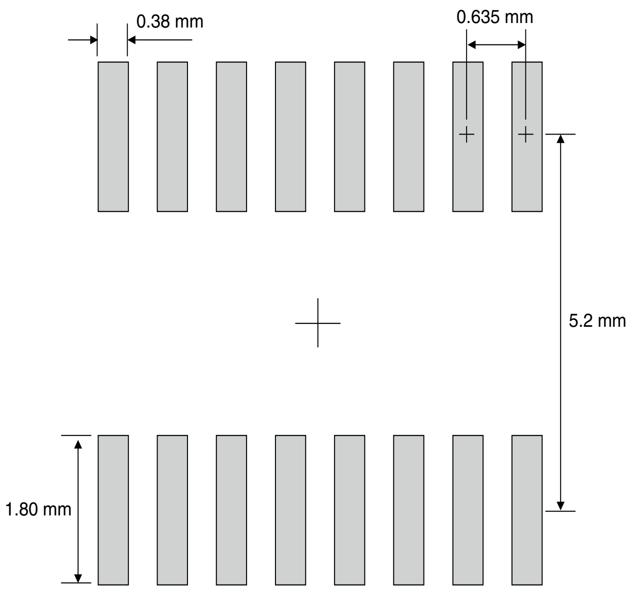


Fig. 6–5: Pad size recommendation for SSOP16 package (all dimensions in mm)

7. Programming of the Sensor

HAL/HAR 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/HAR 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™ 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/HAR 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. Data Sheet: "HAL 3900 Stray-Field Robust 3D Position Sensor with SPI Interface", Aug. 12, 2020, DSH000211_001EN. First release of the data sheet.

2. Data Sheet: "HAL 3900 Stray-Field Robust 3D Position Sensor with SPI Interface", Feb. 18, 2021, DSH000211_002EN. Second release of the data sheet.

   Major changes:

   – Value for max. B_{AMP} for setup 4b added

   – Parameter t_{UOV} removed as it is covered by overall FDTI

   – Values for I_{PD} and I_{PU} replaced by R_{PD} and R_{PU}

   – Max. SPI communication speed limited to 5 MHz

   – Parameter t_{SCK_BB} removed

   – Min. value of parameter t_{SSC} increased

   – Min. value of parameter t_{SCH} reduced

   – Spec limits for $\Delta E_{\Theta tot}$ improved

   – Spec limits for $\Delta E_{\Theta life}$ improved

   – Conditions for $E_{\Theta SF\_x}$ corrected

   – Vector direction for Z field inverted

3. Data Sheet: "HAL 3900 Stray-Field Robust 3D Position Sensor with SPI Interface", Oct. 24, 2022, DSH000211_003EN. Third release of the data sheet.

   Major changes compared to previous data sheet:

   – ROM-Configuration-ID 2300 added

   – Spec limits for $E_{\Theta noise\_1}$ and $E_{\Theta noise\_2}$ modified

   – Spec limits for $SF_{R\Delta Z41}$ improved

   – Note added for Application Note: "HAL 3900/HAL 3930 - Procedure to Avoid Temperature-Dependent Checksum Calculation Error"

4. Data Sheet: "HAL/HAR 3900 Stray-Field Robust 3D Position Sensor with SPI Interface", Feb. 16, 2023, DSH000211_004EN. Fourth release of the data sheet.

   Major changes compared to previous data sheet:

   – HAR 3900 dual-die version added

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