Hardware Documentation

Advance Information

HAL® 3900

Stray-Field Robust 3D Position Sensor with SPI Interface

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Contents

Stray-Field Robust 3D Position Sensor with SPI Interface

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 angles calculated out of BX/BY/BZ. The position information is transmitted via an SPI interface. It is also possible to read the three magnetic raw values via the SPI interface without position calculation. The raw 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.

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 is also possible by using up to 17 setpoints with variable distance or 34 equidistant distribute setpoints.

The device memory is programmable via the SPI interface.

The sensor is defined as SEooC (Safety Element out of Context) according to ISO 26262.

The device is designed for automotive and industrial applications. It operates in the ambient temperature range from –40 °C ... 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 the optimal system solution for applications with embedded micro controller such as:

– Real 3D position detection, like
  - Joystick
– Rotary position detection (end-of shaft and off-axis)
  - Brake and clutch pedal
  - Transmission applications
– Linear position detection
  - Transmission applications

1.2. General Features

– 3D position detection supporting transmission of two angles out of BX, BY, BZ

– Temperature compensated raw values of BX, BY and BZ access able via SPI

– Accurate angular measurement up to 360° and linear position detection

– Compensation of magnetic stray-fields (rotary or linear position detection)

– SEooC according to ISO 26262 to support functional safety applications

– Wide supply voltage range 3.0 V up to 5.5 V

– SPI communication with up to 10 MHz

– 16-bit data transmission with CRC and rolling counter

– 16 kHz sampling frequency

– Operates from –40 °C up to 170 °C junction temperature (T_A = 150 °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

– Sleep mode (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:

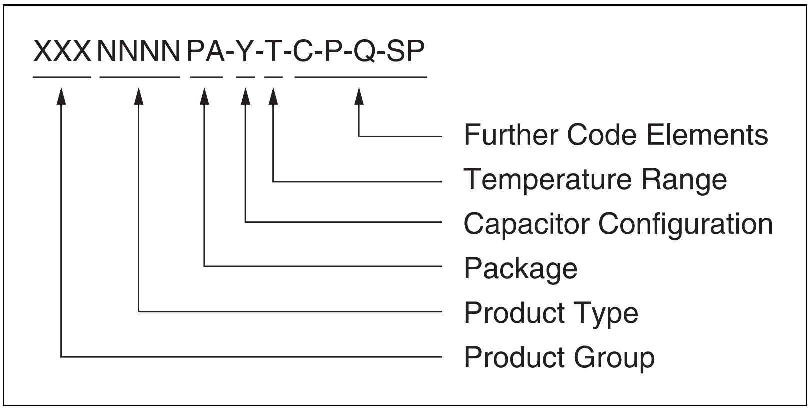


Fig. 2–1: Ordering Code Principle

For a detailed information, please refer to the brochure:
“Micronas 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 packages

Package Code (PA)	Package Type
DJ	SOIC-8

Table 2–2: Available temperature ranges

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

The relationship between ambient temperature (T_A) and junction temperature (T_J) is explained in Section 5.1. on page 31.

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	Pin Variant
HAL3900DJA-[C-P-Q-SP]	3900A	SOIC-8	N/A

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).

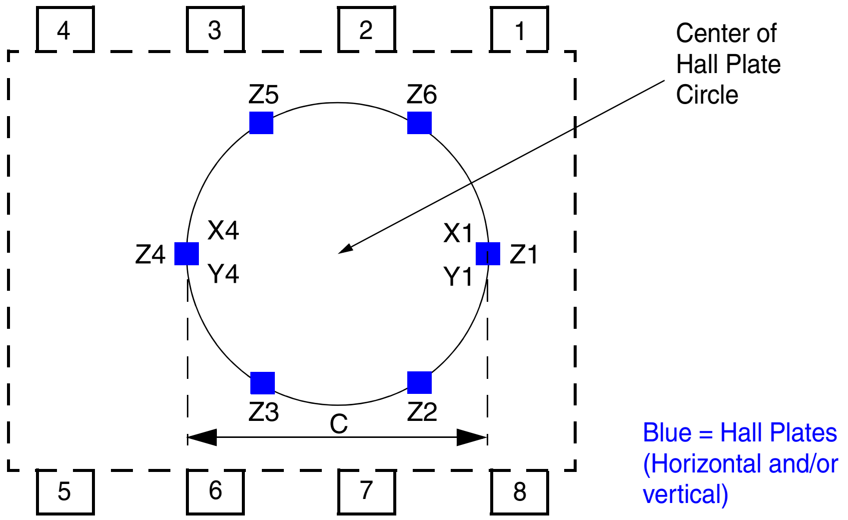


Fig. 3–1: Hall plate configuration for HAL 3900

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

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 automatically.

The sensors supports various measurement configurations:

– Angular measurements in a range between 0° and 360° with stray-field compensation

– Linear position detection with stray-field compensation

– 2D linear and angular position detection without stray-field compensation (BX/BY, BX/BZ, BY/BZ)

– 3D position detection with transmission of temperature compensated raw signals (BX,BY, BZ) or transmission of up to two calculated angle

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

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

The 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 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 is also featuring a low power mode/ sleep mode. An external microcontroller can send the device into sleep mode by a dedicated command and can wake-up the device with a pulse on the WKUP pin.

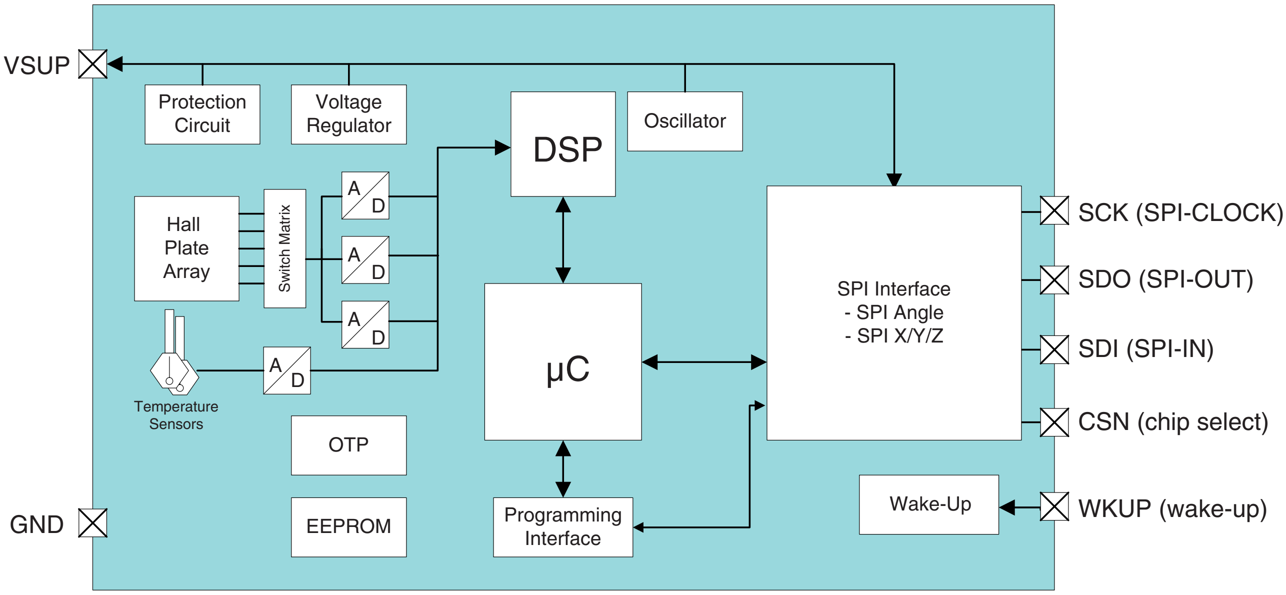


Fig. 3–2: HAL 3900 block diagram

3.2. Signal Path

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

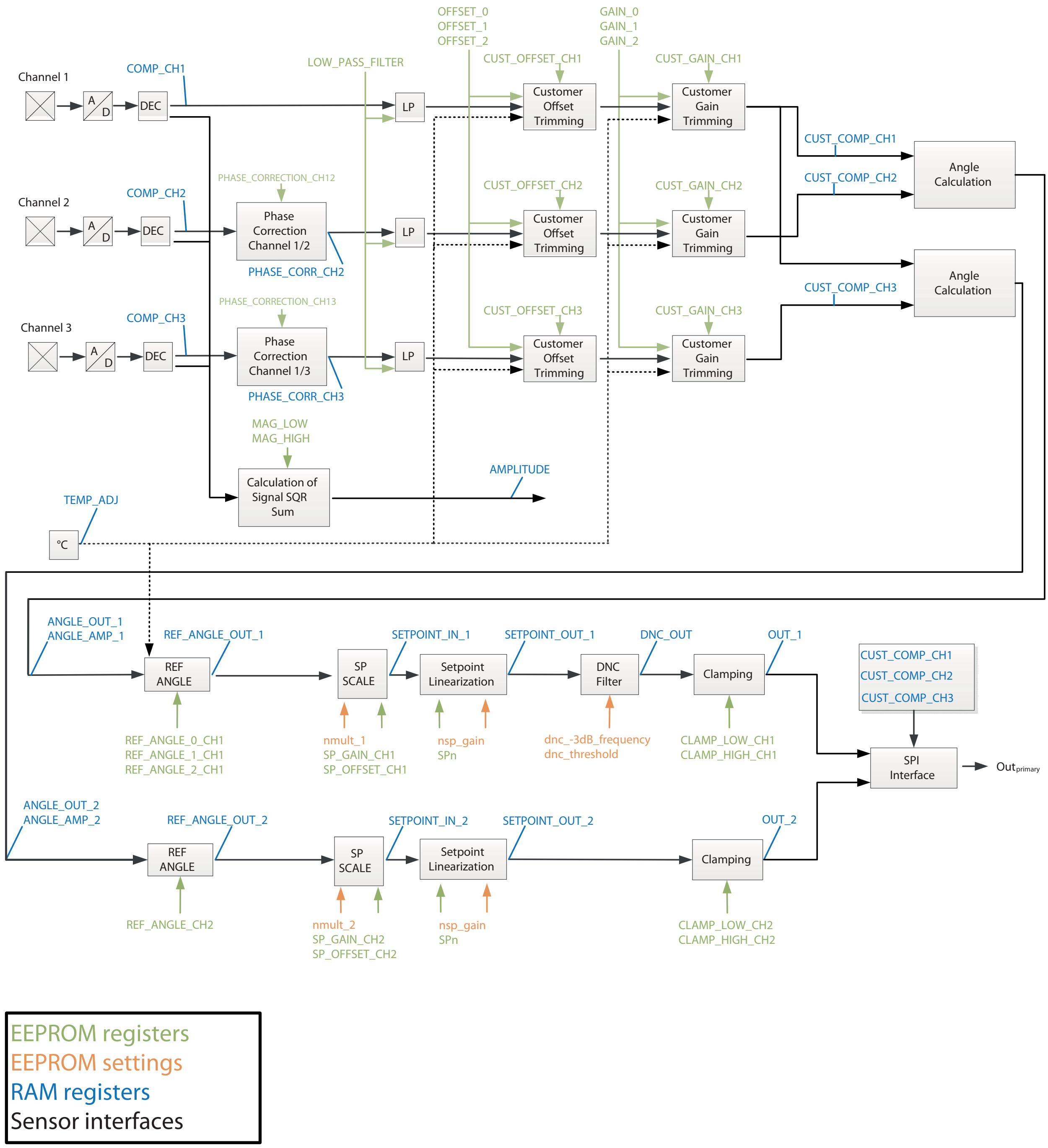


Fig. 3–3: Signal path of HAL 3900

Terminology:

GAIN: name of the register or register value

Gain: name of the parameter

Green color: register names

The sensor signal path contains two kinds of registers. Registers that are readout only (RAM) and programmable registers (non-volatile memory). The RAM registers contain measurement data at certain steps of the signal path and the non-volatile memory registers have influence on the sensors signal processing.

3.3. Register Definition

Note Further details about the programming of the device and detailed register setting description as well as memory map can be found in the document: HAL/ 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 temperature compensated magnetic-field information of channel 1, channel 2 and channel 3.

Amplitude

The AMPLITUDE register contains sum of squares of the magnetic-field amplitude of all there signal calculated with the following equation. This information is use to support a magnet lost detection:

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

PHASE_CORR_CH2, PHASE_CORR_CH3

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

CUST_COMP_CH1, CUST_COMP_CH2 and CUST_COMP_CH3

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

ANGLE_OUT_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 on pixel cell enabling the calculation of a second angle out of BX, BY and BZ.

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 on pixel cell enabling the calculation of a second angle out of BX, BY and BZ.

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.

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 register identifies 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 register.

Table 3–1: DIAG_0 Register

Bit No.	Function	Description when bit is set to 1
15	dsp_selftest	Error has been detected in DSP self-check routines (redundancy or plausibility checks)
14	eeprom_checksum	16-bit checksum error has been detected (DSP and µC regularly checks the 16-bit checksum over the parameter EEPROM)
13	Reserved	N/A
12	temp_out_of_range	Measured junction temperature outside of –40° to 170°range
11	temp_sens_redundancy	Plausibility check against each other of two redundant temperature sensor elements failed
10	hvdd_overvoltage	Internal Hall plate supply is too high
9	adc_stuck	One of the three A/D converters delivers a stuck signal
8	clipping_dec_filter_ch3	Overflow/ underflow of decimation filter of channel 3 has been detected
7	clipping_dec_filter_ch2	Overflow/ underflow of decimation filter of channel 2 has been detected
6	clipping_dec_filter_ch1	Overflow/ underflow of decimation filter of channel 1 has been detected
5	mag_hi	The magnetic field is above the programmed upper threshold MAG_HIGH register value (magnetic field too high)
4	mag_lo	The magnetic field is below the programmed lower threshold MAG_LOW register value (magnetic field too low)
3	clmp_hi	The result of the position calculation (high) is out of the expected (valid) range
2	clmp_lo	The result of the position calculation (low) is out of the expected (valid) range
1:0	Reserved	N/A

Micronas IDs

The MIC_ID1 and MIC_ID2 registers are both 16 bit organized. They are read only and contain TDK-Micronas production information, like X,Y position on the wafer, wafer number, etc.

3.3.2. EEPROM Registers

Application Modes

HAL 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 3–2 on page 19) is defining the different available modes.

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

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

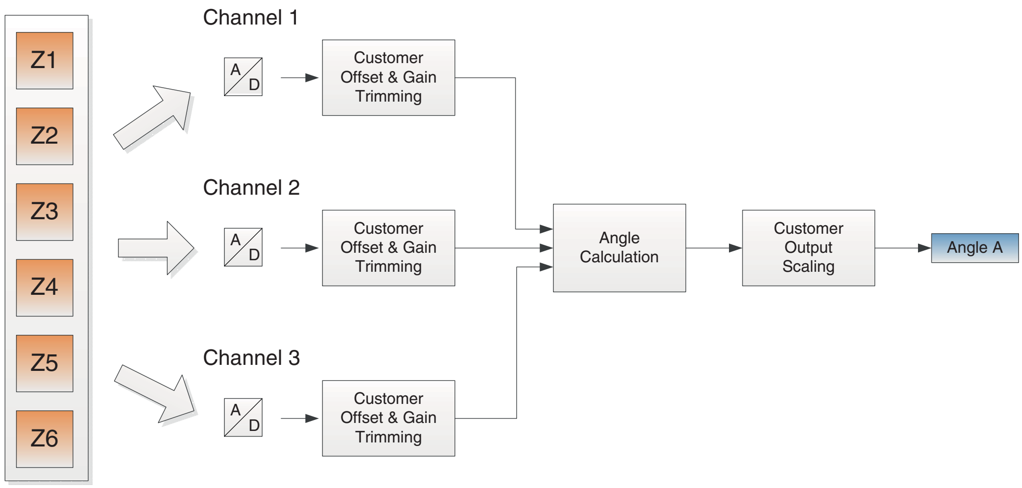


Fig. 3–4: Signal path diagram of setup 1 (stray-field robust 180° measurement)

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

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

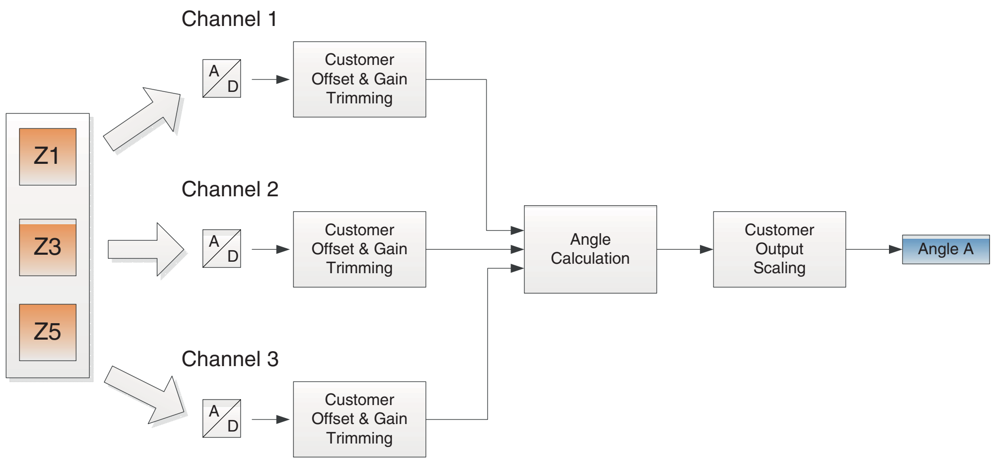


Fig. 3–5: Signal path diagram of setup 2 (stray-field robust 360° measurement)

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

This mode uses a combination of horizontal and vertical Hall plates to measure a stray-field compensated linear movement. Alternatively this setup can be used as well for off-axis stray-field compensated angular measurements if a combination of vertical Hall plates is selected. The device can compensate stray-fields according ISO 11452-8 definition. Below graph shows the related signal path.

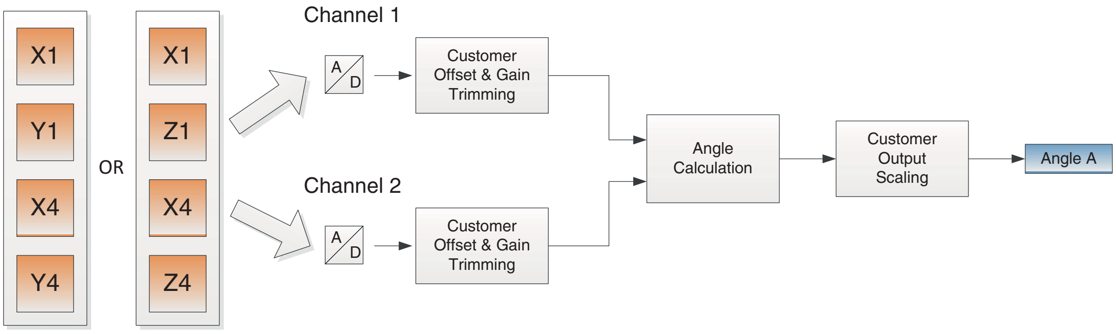


Fig. 3–6: Signal path diagram of setup 3 (stray-field robust linear position detection)

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

This mode uses horizontal and vertical Hall plates to measure BX, BY, BZ. The angle will be calculated out of combinations of BX/BY, BX/BZ or BY/BZ. This mode is not compensating any stray-fields. The measurement setup is similar to the well known TDK-Micronas HAL 37xy family.

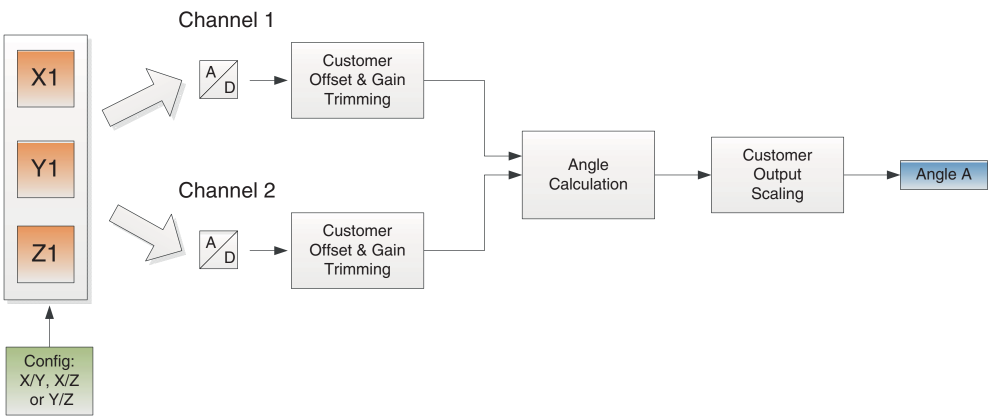


Fig. 3–7: Signal path diagram of setup 4 (rotary & linear position detection w/o stray-field compensation)

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

This mode uses horizontal and vertical Hall plates to measure BX, BY, BZ. Two angles will be calculated out of combinations of BX/BZ and BY/BZ. This mode is not compensating any stray-fields.

The angle calculation is done by using the following equations:

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

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

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

See Fig. 3–8 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 BX, BY, BZ. Two angles will be calculated by a special equation optimized for “joystick” setups. This mode is not compensating any stray-fields.

The angle calculation is done by using the following equations:

$$\mathrm{ALPHA} = \mathrm{ATAN}\left(\frac{\sqrt{(\mathrm{GAIN\_CH1} \times \mathrm{ANGLE\_IN\_CH1})^2 + (\mathrm{GAIN} \times \mathrm{ANGLE\_IN\_CH3})^2}}{\mathrm{ANGLE\_IN\_CH2}}\right)$$

$$\mathrm{BETA} = \mathrm{ATAN}\left(\frac{\sqrt{(\mathrm{GAIN\_CH1} \times \mathrm{ANGLE\_IN\_CH1})^2 + (\mathrm{GAIN} \times \mathrm{ANGLE\_IN\_CH2})^2}}{\mathrm{ANGLE\_IN\_CH3}}\right)$$

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

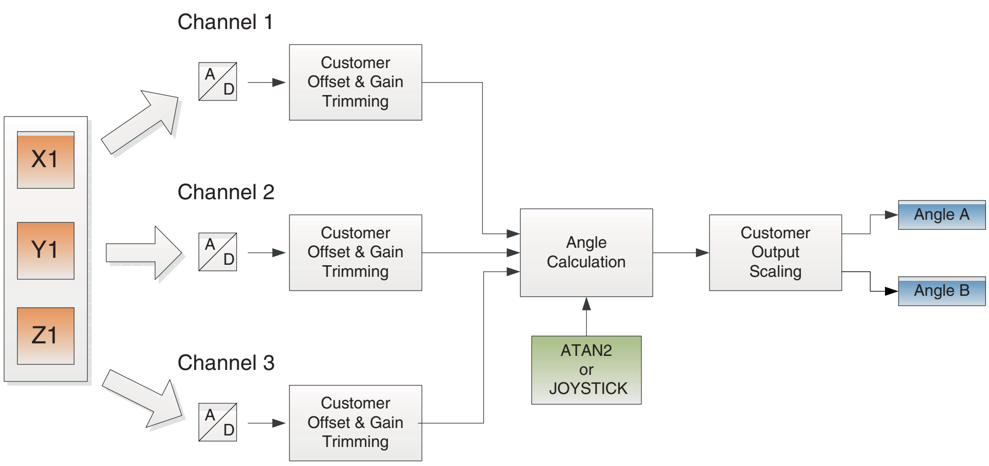


Fig. 3–8: Signal path diagram of setup 5 & 6 (3D measurement)

– Setup 7: 3D measurement with raw values

This mode uses horizontal and vertical Hall plates to measure BX, BY, BZ. It is possible to read out the temperature compensated raw values of BX, BY and BZ. This mode is not compensating any stray-fields.

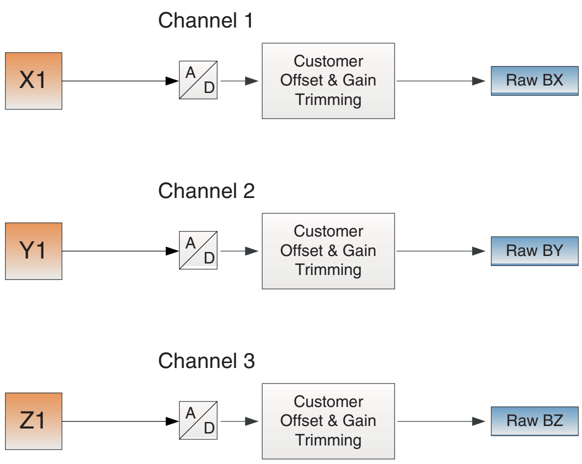


Fig. 3–9: Signal path diagram of setup 7 (Transmission of raw signals)

Customer IDs

The customer ID registers (CUSTOMER_ID4 to CUSTOMER_ID9) contains of 6 times 16-bit words and can be used to store customer production information, like serial number, project information, etc.

Magnetic-Field Range Check

The magnetic-field range check uses the AMPLITUDE register value and compares it with an upper and lower limit threshold defined by the registers MAG_LOW and MAG_HIGH. If either low or high limit is exceeded, the sensor will indicate an error.

Mag-Low Limit

MAG_LOW defines the low level for the magnetic-field range check function.

Mag-High Limit

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

Phase Correction

PHASE_CORRECTION_CH12 and PHASE_CORRECTION_CH13 can be used to compensate a phase-shift of channel 2 and channel 3 in relation to channel 1.

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

Low-Pass Filter

With the LOW_PASS_FILTER register it is possible to select different –3dB frequencies for HAL 3900. The default value is zero (low pass filter disabled). The filter frequency is valid for all channels.

Gain for Channel 1, 2 and 3

GAIN_0...2 supports a polynomial of second order and describes the temperature compensation of the sensitivity. This means that for each channel a constant, linear and quadratic gain factor can be programmed (temperature dependent gain).

CUST_GAIN_CH1, CUST_GAIN_CH2 and CUST_GAIN_CH3 describe the weighting of the GAIN_0...2 polynomial on the individual channels and can be used to compensate amplitude mismatches between channel 1, channel 2 and channel 3.

Customer Offset

OFFSET_0...2 supports a polynomial of second order and describes the temperature compensation of the offset. This means that for each channel a constant, linear and quadratic offset factor can be programmed (temperature dependent offset).

CUST_OFFSET_CH1, CUST_OFFSET_CH2 and CUST_OFFSET_CH3 describe the weighting of the OFFSET_0...2 polynomial on the individual channels and can be used to compensate a remaining offset in each of the three channels.

Reference Angle Position

The output signal zero position defines the reference position for the angle output and is the starting point/ reference for the setpoints. 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.

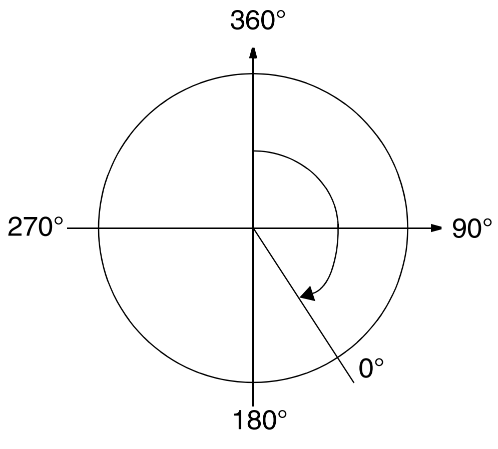


Fig. 3–10: Example definition of zero degree point

Setpoint Gain

SP_GAIN_CH1 and SP_GAIN_CH2 define the gain of the input signals for the linearization block. They 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 an secondary angle.

Setpoint Offset

SP_OFFSET_CH1 and SP_OFFSET_CH2 define the offset of the input signals for the linearization block. 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. It consists of 33 setpoints for one channel or 34 (17 each) setpoints for two channels (SP0, SP1, ..., SP32 or 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 0... 32767 LSB.

The setpoint registers have a length of 16 bits and are two's complement coded. Therefore the setpoint X values (SP(n)_Y) can vary between –32768...32767 LSB. 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 OUT_x register value represents the angular information after the setpoint scaling.

nsp_gain

The SETUP_DATAPATH[14:11] bits (= nsp_gain) set the gain exponent for the setpoint slope on data channel 1 and 2. With the 4 bits it is possible to get gains up to 32768.

DNC Filter Registers (dnc_-3dB_frequency & dnc_threshold)

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

For dnc_threshold only values from 0 to 255 are allowed. The default value is 127 and the recommended value is 127. To disable the DNC filter dnc_threshold must be set to 0. For the dnc_-3dB_frequency multiplier only values from 0 to 255 are allowed. The default value is 0 and the recommended value is 16.

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 %.

Customer Configurations Register

The SETUP_FRONTEND and SETUP_DATAPATH registers 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. The below table describes in detail the available combinations and resulting functions.

Table 3–2: SETUP_FRONTEND

Bit No.	Function	Description
15:6	Reserved	Reserved
5:4	fdecsel	Select decimation frequency: 00: 32 kHz* 01: 16 kHz* 10: 8 kHz 11: 4 kHz * not all measurements support 32 kHz and 16 kHz
3:0	meas_config	0101: Setup 1 - 180° rotary (stray-field compensation- homogenous & gradient) 0110: Setup 2 - 360° rotary (stray-field compensation - homogenous) 0011: Setup 3 - Linear movement (stray-field compensation - homogenous) 0100: Setup 3 - Off axis rotary (stray-field compensation - homogenous) 0000: Setup 4 - rotary or linear movement BX & BY (w/o stray-field compensation) 0001: Setup 4 - rotary or linear movement BZ & BY (w/o tray field compensation) 0010: Setup 4 - rotary or linear movement BZ & BX (w/o stray-field compensation) 0111: Setup 5 - 3D measurement BX, BY, BZ - ATAN2 (w/o stray-field compensation) 1000: Setup 6 - 3D measurement BX, BY, BZ - Joystick (w/o stray-field compensation) 1001: Setup 7 - Raw BX, BY, BZ (w/o stray-field compensation)

Table 3–3: SETUP_DATAPATH

Bit No.	Function	Description
15	cust_lock	Customer Lock: 0: Disabled 1: Enabled
14:11	nsp_gain	Gain exponent for setpoint slope: Slope = SPGn * (2^nsp_gain+1)
10:8	nmult_2	Gain exponent for SETPOINT_IN2: SP_GAIN = SP_GAIN_CH2 * [2^(nmult_2)]
7:5	nmult_1	Gain exponent for SETPOINT_IN1: SP_GAIN = SP_GAIN_CH1 * [2^(nmult_1)]
4	cluster	0: IPC0 to IPC2 are independent 1: IPC0 to IPC2 are updated after IPC0 is read
7:6	Reserved	Must be set to zero
1	var_sp	Fixed/ variable setpoint selection: 0: Fixed setpoints 1: Variable setpoints
0	two_ch	Activation of second output channel 0: 1 channel with 17 or 33 setpoints 1: 2 channels with 17 setpoints each

3.4. SPI

The HAL 3900 is equipped with an SPI interface for memory programming and register reading to transmit the sensor measurement data. The SPI interface is a slave interface. Each transfer is full duplex for simultaneously sending read/ write commands to the sensor while collecting the response form the former 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 as well as the correct execution of the requested command.

The general SPI frame format is as follows (see Fig. 3–11):

1. SPI master pulls the CSN to low
2. SPI master sends one command byte followed by a number of master data bytes
3. SPI master sends a 8-bit CRC byte calculated over the command and master data bytes
4. HAL 3900 replies with a status byte and data bytes followed by a 8-bit slave CRC. The CRC is calculated out of the status byte, the slave data bytes and the command byte of the previously send master frame (frame-1 and not actual frame)

The CRC for HAL 3900 is calculated based on the following polynomial:
$X^8 + X^4 + X^3 + X^2 + 1$ (CRC-8-SAE-J1850) and initialized to 0xFF.
The CRC is calculated in the same way on the returned slave data.

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)

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 R/W flag.

Table 3–4: SPI Command Byte

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

Read commands execute internally before the master CRC is verified. The time to clock the master CRC is used to hide the internal access latency.

The STATUS byte of the read protocol contains several information.

Table 3–5: SPI Status Byte

STATUS	Status Byte							
	7	6	5	4	3	2	1	0
r/w	RC3	RC2	RC1	RC0	DIAG1	DIAG2	CRC ERR	NEW

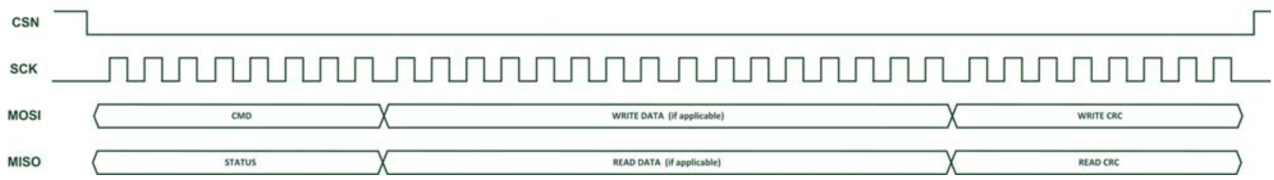
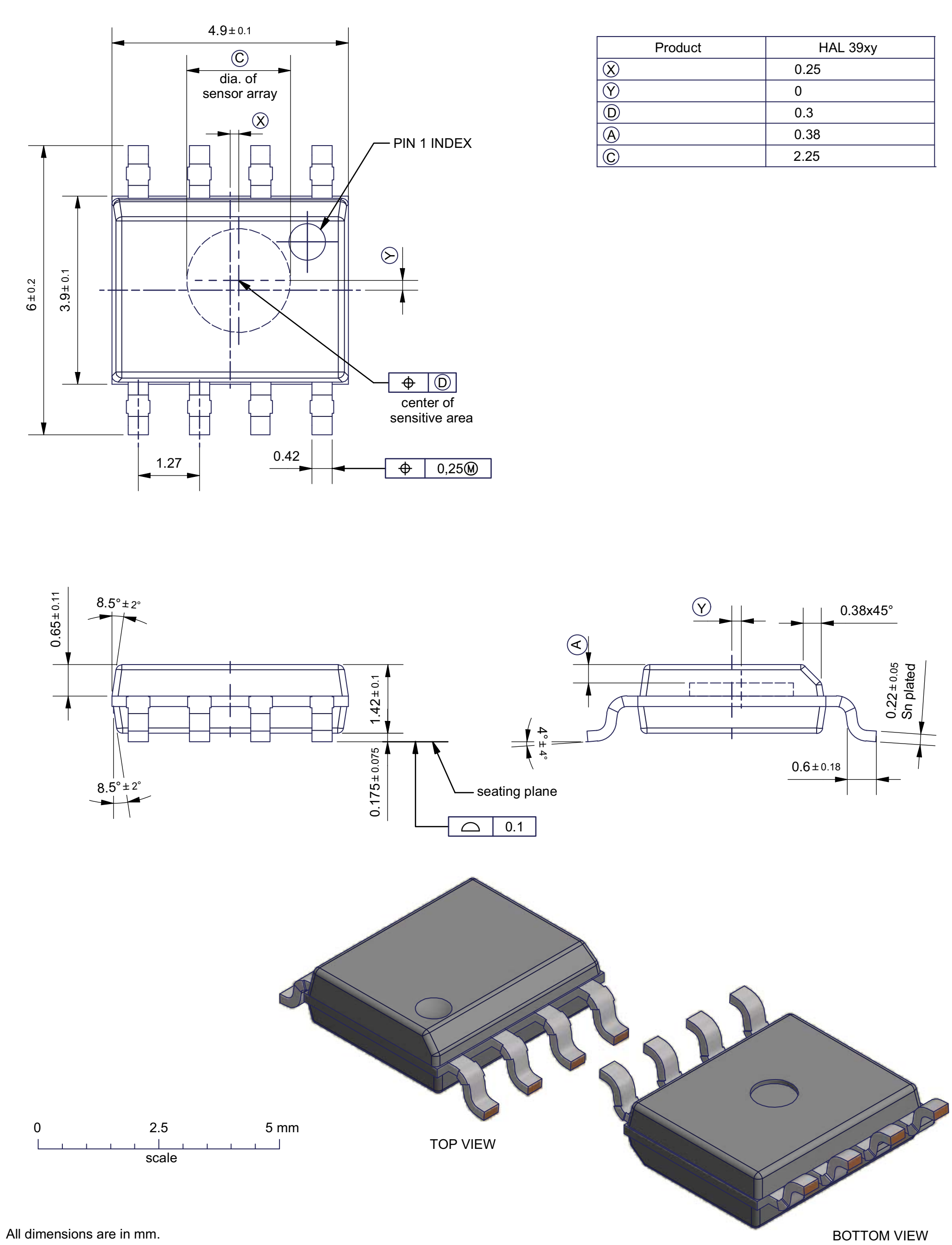


Fig. 3–11: SPI frame

A transmitter conceptually produces data bits at the falling edge of the SPI clock SCK and a receiver samples the data bits at the rising edge of the SPI clock. Bytes are transmitted in the order MSB to LSB. The slave keeps DSO in High-Z unless a reply is expected from the command (read request).

4. Specifications

4.1. Outline Dimensions



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	⌖◁	19-01-31	3	CSOIC0083000.1	ZG	2088_Ver.03

Fig. 4–1:
SOIC8-1: Plastic small outline IC package, 8 leads, gullwing bent, 150 mil
Ordering code: DJ
Weight approximately 0.076 g

4.2. 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).

4.3. 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).

4.4. Size and Position of Sensitive Area’s

Diameter of sensitive area: C = 2.25 mm

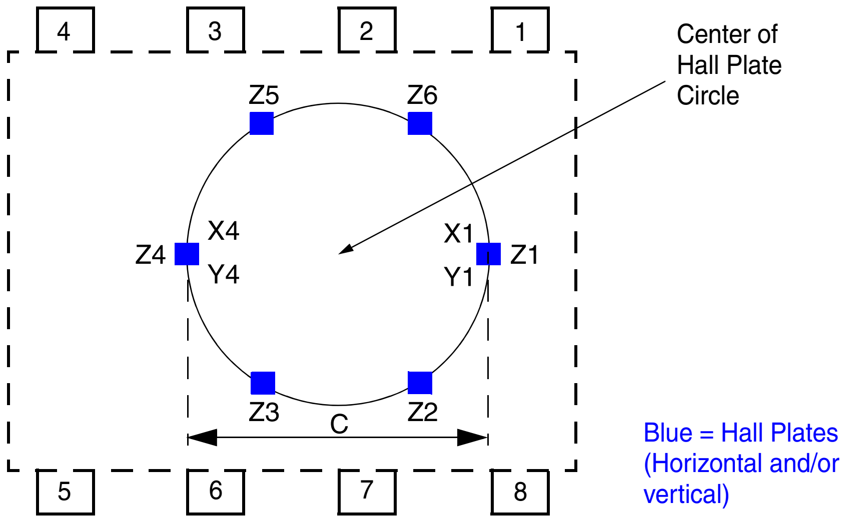


Fig. 4–2: Hall plate configuration

4.5. Definition of Magnetic-Field Vectors

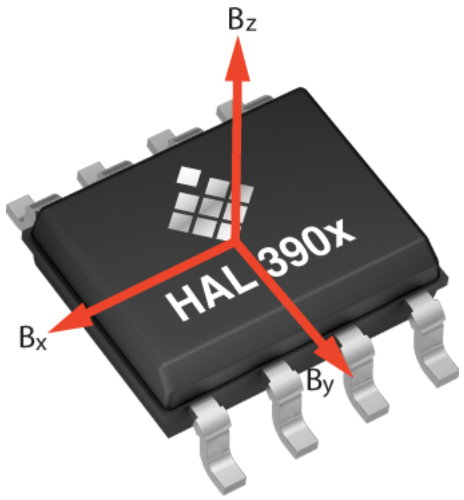


Fig. 4–3: Definition of magnetic-field vectors for HAL390x

4.6. Pin Connections and Short Description

Table 4–1: Pin connection SOIC8

Pin No.	Pin Name	Type	Short Description
1	VSUP	IN	Supply Voltage
2	GND	GND	Ground
3	WKUP	IN	Wake-Up
4	CSN	I/O	SPI Chip-Select
5	MISO	OUT	SPI Out
6	TEST	N/A	Test
7	MOSI	IN	SPI In
8	SCK	IN	SPI Clock

Note Pins 2 and 6 must be connected to GND.

4.7. 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 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	
V_{IN}	Input Voltage SPI Pins	CSN, MOSI, SCK, WKUP	–0.3	6	V	
V_{OUT}	Output Voltage SPI Pins	MISO	–0.3	28	V	
B_{max}	Magnetic Field	–	–	1	T	
T_A	Ambient Temperature	–	–40	160	°C	
$T_{storage}$	Transportation/ Short Term Storage Temperature	–	–55	150	°C	Device only without packing material
V_{ESD}	ESD Protection	VSUP, MISO, CSN	–8	8	kV	[1)]
		SCK, MOSI, WKUP, TEST	–2	2	kV	[1)]

[1)] AEC-Q100-002 (100 pF and 1.5 kΩ)

4.8. 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	
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 [1]		–40	–	170	°C	For 1000 h
T_A	Ambient Temperature [2]		–40	–	150	°C	

[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.

4.9. 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 "Test Conditions".
Typical Characteristics for T_J = 25 °C and V_{SUP} = 5 V.

Symbol	Parameter	Pin Name	Limit Values			Unit	Test Conditions
			Min.	Typ.	Max.		
I_{SUP}	Supply Current	VSUP	4.0	–	10	mA	V_{SUP} < 5.5 V
I_{SUPSTB}	Standby Current Consumption	VSUP	–	–	10	µA	While IC is in sleep mode T_A < 100 °C
$t_{startup}$	Start-up Time	MISO	–	–	5.0	ms	
f_{osc}	Internal Oscillator Frequency		–	32	–	MHz	
f_{sample}	Sampling Frequency		–	16	–	ks	
SPI Characteristics							
V_{IH}	Input High Level	MOSI, SCK, CSN	2.4	3.0	–	V	
V_{IL}	Input Low Level	MOSI, SCK, CSN	–	0.5	0.8	V	
V_{OH}	Output High Level	MISO	2.9	–	–	V	I_{OUT} = 1 mA
V_{OL}	Output Low Level	MISO	–	–	0.4	V	I_{OUT} = –1 mA
I_{PD}	Pull-Down current	MOSI, SCK	20	–	70	µA	
I_{OLEAK}	Leakage Current	All	–10	–	10	µA	V_{SUP} = 3.6 V
t_{SCK}	SPI Clock Period	SCK	100	1000	–	ns	Max. frequency 10 MHz
t_{DIS}	SPI Data Input Setup	MOSI, SCK	10	–	–	ns	Data sampling with risking SCK edge
t_{DIH}	SPI Data Input Hold	MOSI, SCK	15	–	–	ns	
t_{DOD}	SPI Data Output Delay	MISO, SCK	–	–	44	ns	Data output changes with falling SCK edge
t_{CSNSCK}	SPI CSN Setup	CSN, SCK	40	–	–	ns	With respect to falling CSN edge
t_{SCKCSN}	SPI CSN Hold Time	CSN, SCK	12	–	–	ns	With respect to the rising CSN edge
t_{CSNH}	SPI CSN High Time	CSN	500	2000	–	ns	CSN high time between two consecutive SPI frames
t_{sset}	SPI Settling Time	–	–	4	–	ms	
t_{listen}	Waiting Time for the Programming Mode Command	–	–	–	110	ms	Waiting for data 0x2EAE to address 0x75

Symbol	Parameter	Pin Name	Limit Values			Unit	Test Conditions
			Min.	Typ.	Max.		
SOIC8 Package							
							(Self-heating calculation see Section 5.1. on page 31)
R_{thja}	Thermal Resistance Junction to Air	–	–	–	115	K/W	Determined with a 1s1p board
		–	–	–	110	K/W	Determined with a 2s2p board
R_{thjc}	Thermal Resistance Junction to Case	–	–	–	33	K/W	Determined with a 1s1p board

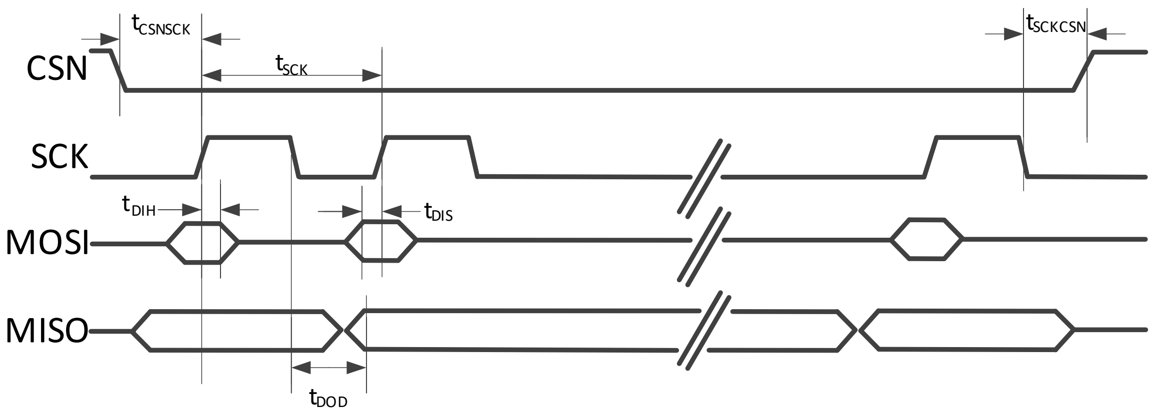


Fig. 4–4: SPI Timing Diagram

4.10. 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 "Test Conditions". Typical Characteristics for T_J = 25 °C and V_{SUP} = 5.0 V.

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Test Conditions
Rotary Setup with Stray-Field Compensation (Setup 1 & 2)							
$E_{\Theta tot}$	Total Angular Error	MISO	–1.1	–	1.1	°	B_{AMP} = ±10 mT
$\Delta E_{\Theta temp}$	Angular Error Drift over Temperature	MISO	–0.5	–	0.5	°	B_{AMP} = ±10 mT
$\Delta E_{\Theta life}$	Angular Error Drift over Lifetime	MISO	–0.6	–	0.6	°	B_{AMP} = ±10 mT Lifetime simulated by temperature cycling or humidity storage 85 °C / 85 %r.h.
$E_{\Theta hyst}$	Angular Hysteresis Error	MISO	–	–	0.05	°	
$E_{\Theta lin}$	Non-Linearity Error	MISO	–0.1	–	0.1	°	T_J = 25 °C and before EOL calibration
$E_{\Theta \mu lin}$	Micro-Linearity Error	MISO	–	–	0.1	°/1°	
$E_{\Theta noise}$	Angular Noise (RMS)	MISO	–	–	0.05	°	@ 10 mT amplitude FS
Linear Movement Setup (ΔXZ) with Stray-Field Compensation (Setup 3)							
$A_{SMmXZ14}$	Absolute Sensitivity Mismatch between ΔX_{14} and ΔZ_{14}	MISO	–3	–	3	%	T_A = 25 °C
$Sense_{XZ}$	Sensitivity of X and Z Hall plate	MISO	tbd.	128	tbd.	LSB/mT	T_A = 25 °C
SM_{mXZ14}	Thermal Sensitivity Mismatch Drift of compensated signals between ΔX_{14} and ΔZ_{14}	MISO	–2	–	2	%	Related to T_A = 25 °C
$Offset_{XZ14}$	Offset of compensated Signals of ΔX_{14} and ΔZ_{14}	MISO	–20	–	20	LSB_{15}	T_A = 25 °C
$\Delta Offset_{XZ14}$	Offset Drift of compensated Signals of ΔX_{14} and ΔZ_{14}	MISO	–70	–	70	LSB_{15}	Related to T_A = 25 °C
$\Delta SM_{mXZ14life}$	Relative Sensitivity Mismatch Drift of compensated signals between ΔX_{14} and ΔZ_{14} over life time	MISO	–	1.0	–	%	After 1000 h HTOL
$\Delta Offset_{XZ14life}$	Offset Drift of compensated Signals of ΔX_{14} and ΔZ_{14} over life time	MISO	–	5	–	LSB_{15}	Related to T_A = 25 °C
Off-Axis Rotary Setup (ΔXY) with Stray-Field Compensation (Setup 3)							
$A_{SMmXY14}$	Absolute Sensitivity Mismatch between ΔX_{14} and ΔY_{14}	MISO	–3	–	3	%	T_A = 25 °C
$Sense_{XY}$	Sensitivity of X and Y Hall plate	MISO	tbd.	128	tbd.	LSB/mT	T_A = 25 °C
SM_{mXY14}	Thermal Sensitivity Mismatch Drift of compensated signals between ΔX_{14} and ΔY_{14}	MISO	–2	–	2	%	Related to T_A = 25 °C

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Test Conditions
$Offset_{XY14}$	Offset of compensated Signals of ΔX_{14} and ΔY_{14}	MISO	–20	–	20	LSB_{15}	T_A = 25 °C
$\Delta Offset_{XY14}$	Offset Drift of compensated Signals of ΔX_{14} and ΔY_{14}	MISO	–70	–	70	LSB_{15}	Related to T_A = 25 °C
$\Delta SM_{mXY14life}$	Relative Sensitivity Mismatch Drift of compensated signals between ΔX_{14} and ΔY_{14} over life time	MISO	–	1.0	–	%	After 1000 h HTOL
$\Delta Offset_{XY14life}$	Offset Drift of compensated Signals of ΔX_{14} and ΔY_{14} over life time	MISO	–	5	–	LSB_{15}	Related to T_A = 25 °C
3D Measurement Setup without Stray-Field Compensation (Setup 4, 5, 6, 7)							
A_{SMmXYZ}	Absolute Sensitivity Mismatch between X,Y and Z channel	MISO	–3	–	3	%	T_A = 25 °C
$Sense_{XYZ}$	Sensitivity of X,Y and Z Hall plate	MISO	tbd.	128	tbd.	LSB/ mT	T_A = 25 °C
SM_{mXYZ}	Thermal Sensitivity Mismatch Drift of compensated signals between X, Y and Z	MISO	–2	–	2	%	Related to T_A = 25 °C
$Offset_{XY}$	Offset of compensated Signals of X and Y Hall plates	MISO	–20	–	20	LSB_{15}	T_A = 25 °C
$Offset_Z$	Offset of compensated Signals of Z Hall plates	MISO	–12	–	12	LSB_{15}	T_A = 25 °C
$\Delta Offset_{XY}$	Offset Drift of compensated Signals of X and Y Hall plates	MISO	–70	–	70	LSB_{15}	Related to T_A = 25 °C
$\Delta Offset_Z$	Offset Drift of compensated Signals of Z Hall plates	MISO	–10	–	10	LSB_{15}	Related to T_A = 25 °C
$\Delta SM_{mXYZlife}$	Relative Sensitivity Mismatch Drift of compensated signals between X, Y and Z over life time	MISO	–	1.0	–	%	After 1000 h HTOL
$\Delta Offset_{XYlife}$	Offset Drift of compensated Signals of X and Y Hall plates over Life Time	MISO	–	30	–	LSB_{15}	After 1000 h HTOL
$\Delta Offset_{Zlife}$	Offset Drift of compensated Signals of Z Hall plates over Life Time	MISO	–	5	–	LSB_{15}	After 1000 h HTOL

4.11. 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 “Test Conditions”. Typical Characteristics for T_J = 25°C and V_{SUP} = 5.0 V.

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Test Conditions
T_{res}	Resolution of Temperature Sensor	MISO	–	57	–	LSB/ °C	
T_{Offset}	Temperature Sensor Offset	MISO	–	3783	–	LSB_{15}	@ 25 °C

5. Application Notes

5.1. 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 5.0 V the power dissipation P is 0.05 W per die. The junction to ambient thermal resistance R_{thja} is specified in Section 4.9. on page 27.

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.

5.2. EMC and ESD

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

5.3. Application Circuit for HAL 3900

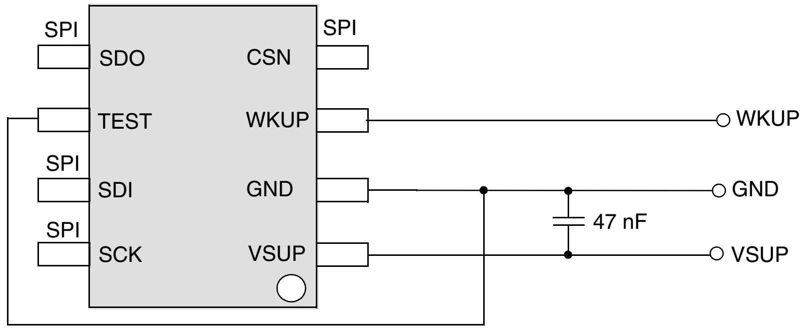


Fig. 5–1: Recommended application circuit for HAL 3900

5.4. Recommended Pad Size SOIC8 Package

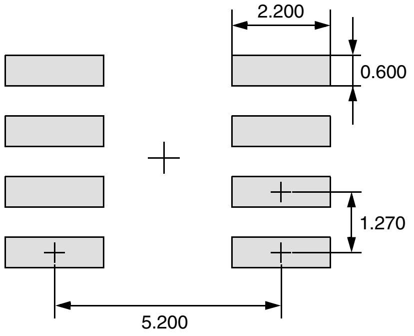


Fig. 5–2: Pad size recommendation for SOIC8 Package (all dimensions in mm)

6. 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. 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. After max. 110 ms without receiving the programming mode switch command the sensor will go into reset.

6.1. Programming Interface

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

6.2. 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 V1.0 and LabVIEW™ Programming Environment) in order to facilitate the product development. It is also possible to use an standard micro controller to configure the device.

6.3. 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.

7. 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.

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