MICRONAS

Hardware Documentation

Data Sheet

HAL 3970-230x

Stray-Field Robust 2D Position Sensor with SPC (Short PWM Code) Interface

3D HAL Technology

master HAL Technology

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Contents

Contents, continued

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

Stray-Field Robust 2D Position Sensor with SPC (Short PWM Code) Interface

1. Introduction

HAL 3970 is part of TDK-Micronas' 3D position sensors addressing the need for stray-field robust 2D position sensors (linear and angular) as well as the ISO 26262 compliant development. It is a high-resolution position sensor for highly accurate position measurements.

HAL 3970 features a digital SPC (Short PWM Code) interface based on the standard SENT protocol according to SAE J2716. The SPC interface allows the possibility to transmit data based on a trigger pulse sent by an external ECU. It supports point to point connections as well as a single wire bus mode with up to four sensors "ID selection". Many parameters like tick time (UT = Unit Time), frame format, etc. are configurable by the customer.

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

HAL 3970 measures, based on Hall technology, vertical and horizontal magnetic-field components. It is able to suppress external magnetic stray-fields by using an array of Hall plates. Only a simple two-pole magnet is required to measure a rotation angle. Ideally, the magnet should be placed above the sensitive area in an end-of-shaft configuration. Stray-field robust off-axis measurements are supported as well.

On-chip signal processing calculates up to two angles out of the magnetic-field components and converts this value into a digital output signal.

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

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

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

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

1.1. Major Applications

Thanks to the sensor’s versatile programming characteristics and its high accuracy, the HAL 3970 is a potential solution for the following application examples:

– Steering angle

– Chassis position

– Turbo-charger

– Valve position, e.g. throttle

– EGR

– Shift position

– Transmission position detection

– Brake pedal position / brake stroke sensor

1.2. Features

– Accurate angular measurement up to 360° and linear position detection
– Compensation of magnetic stray-fields (rotary or linear position detection)
– SEooC ASIL B ready according to ISO 26262:2018 to support Functional Safety applications
– Wide supply voltage range of 3 V up to 16 V
– Open-drain output
– SPC (Short PMW Code) interfacing according to rev. SPC2014 supporting two different frame formats:
  - H1. format: 12-bit fast channels for the position information (3 data nibbles) and 8-bit temperature (2 data nibbles) and optional 4-bit rolling counter (1 data nibble)
  - H.2 Format: One 12-bit fast channel (3-nibble position information)
  - Transmission of OEM ID’s via slow channel
  - Trigger with constant, variable length and short trigger pulse (point-2-point)
  - Hardware coded SPC address configuration (ID selection mode - four IDs)
  - Secure rolling counter
  - Enhanced 12-bit serial message format including temperature information
  - Programmable tick time between 1 µs and 3 µs (0.5 µs steps)
  - Low time of 3, 4, 5, and 6 ticks
– 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 the sensor’s output pin. No additional programming pin required
– Various configurable signal processing parameter, like output gain and offset, reference position, temperature dependent offset, etc.
– Modulo function (90°/120°/180°) for chassis position applications
– Programmable arbitrary output characteristic with 17 variable or 33 fixed setpoints
– Programmable characteristics in a non-volatile memory (EEPROM) with redundancy and lock function
– Read access on non-volatile memory after customer lock
– On-board diagnostics of different functional blocks of the sensor

2. Ordering Information

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

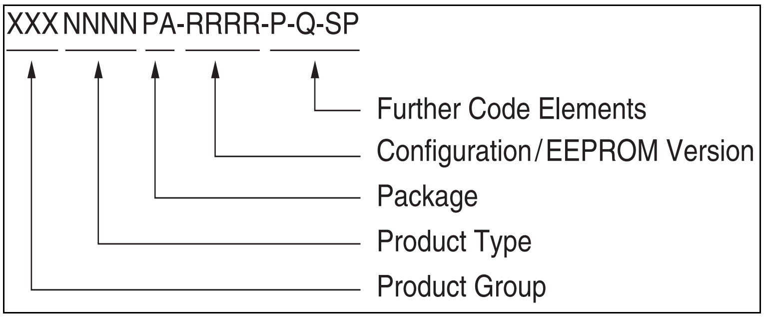


Fig. 2–1: Ordering code principle

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

2.1. Device-Specific Ordering Codes

The HAL 3970 is available in the following package.

Table 2–1: Available packages

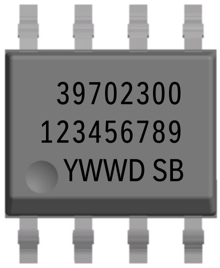
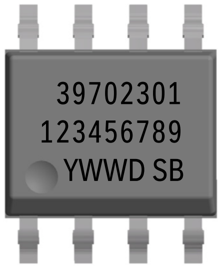
Package Code (PA)	Package Type
DJ	SOIC8

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

Table 2–2: Ordering Information

Product	Package	ROM/EEPROM Version	Further Code [-P-Q-SP]	Comments
HAL 3970	DJ = SOIC8	95xy	See TDK-Micronas Ordering Information	95xy versions can be engineering samples or qualifiable devices
HAL 3970	DJ = SOIC8	2300	See TDK-Micronas Ordering Information	Production version.
HAL 3970	DJ = SOIC8	2301	See TDK-Micronas Ordering Information	Production version. New measurement setup: - 6ZD mode replacing 3Z mode - Setup 4b removed

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

Ordering Code	Package Marking	Description
HAL3970DJ-2300[-P-Q-SP]		Line 1: Product Type / ROM-ID Line 2: Lot number Line 3: Date code / Special Procedure SB (optional)
HAL3970DJ-2301[-P-Q-SP]		

3. Functional Description

3.1. General Function

HAL 3970 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).

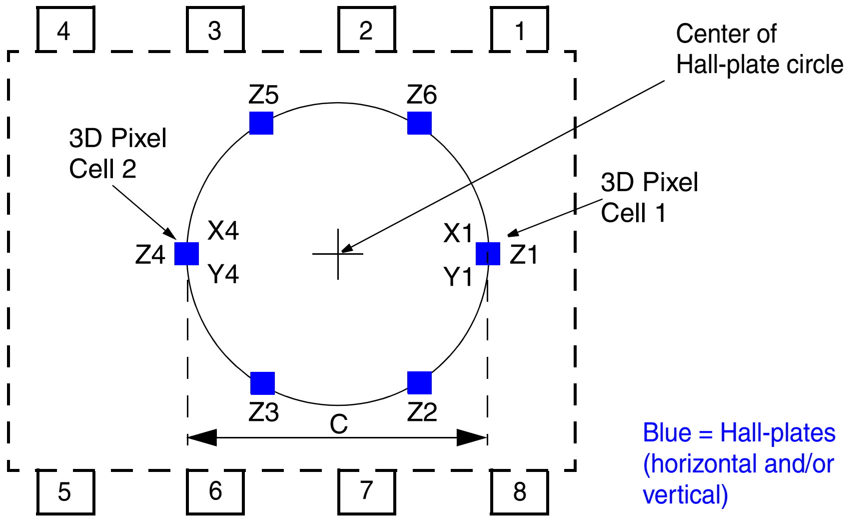


Fig. 3–1: Hall-plate position definition for HAL 3970

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

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

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

The calculated position information is transmitted via SPC frames.

The HAL 3970 is programmable by modulation of the output voltage. No additional programming pin is needed and fast end-of-line programming is enabled.

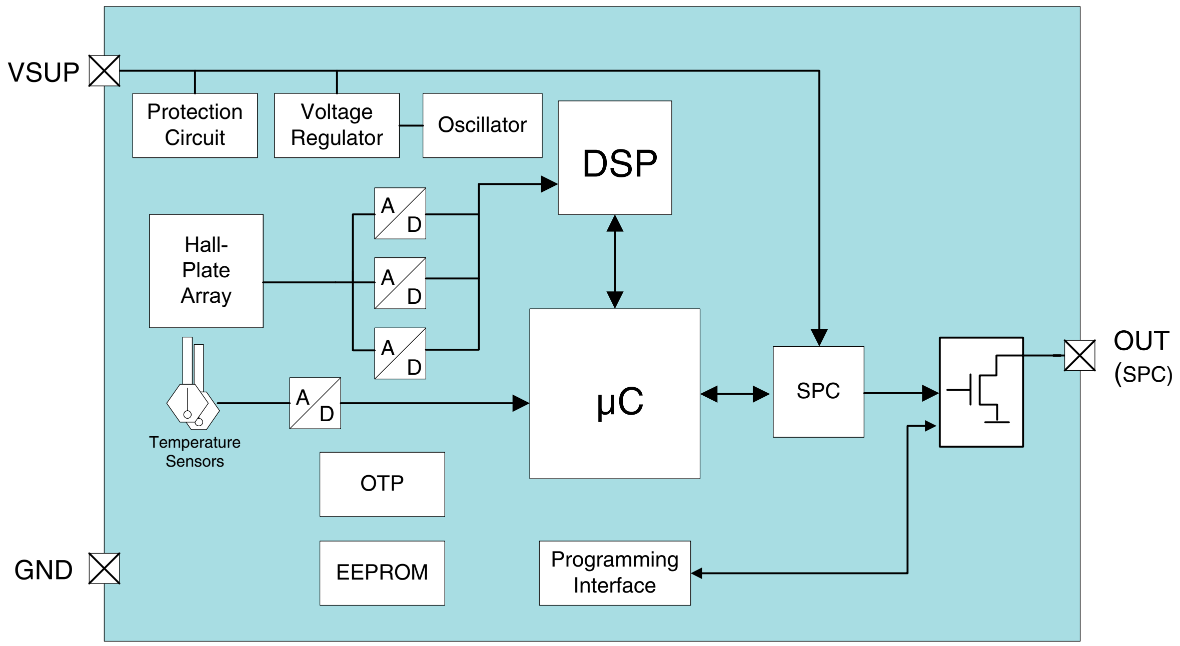


Fig. 3–2: HAL 3970 block diagram

3.2. Signal Path

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

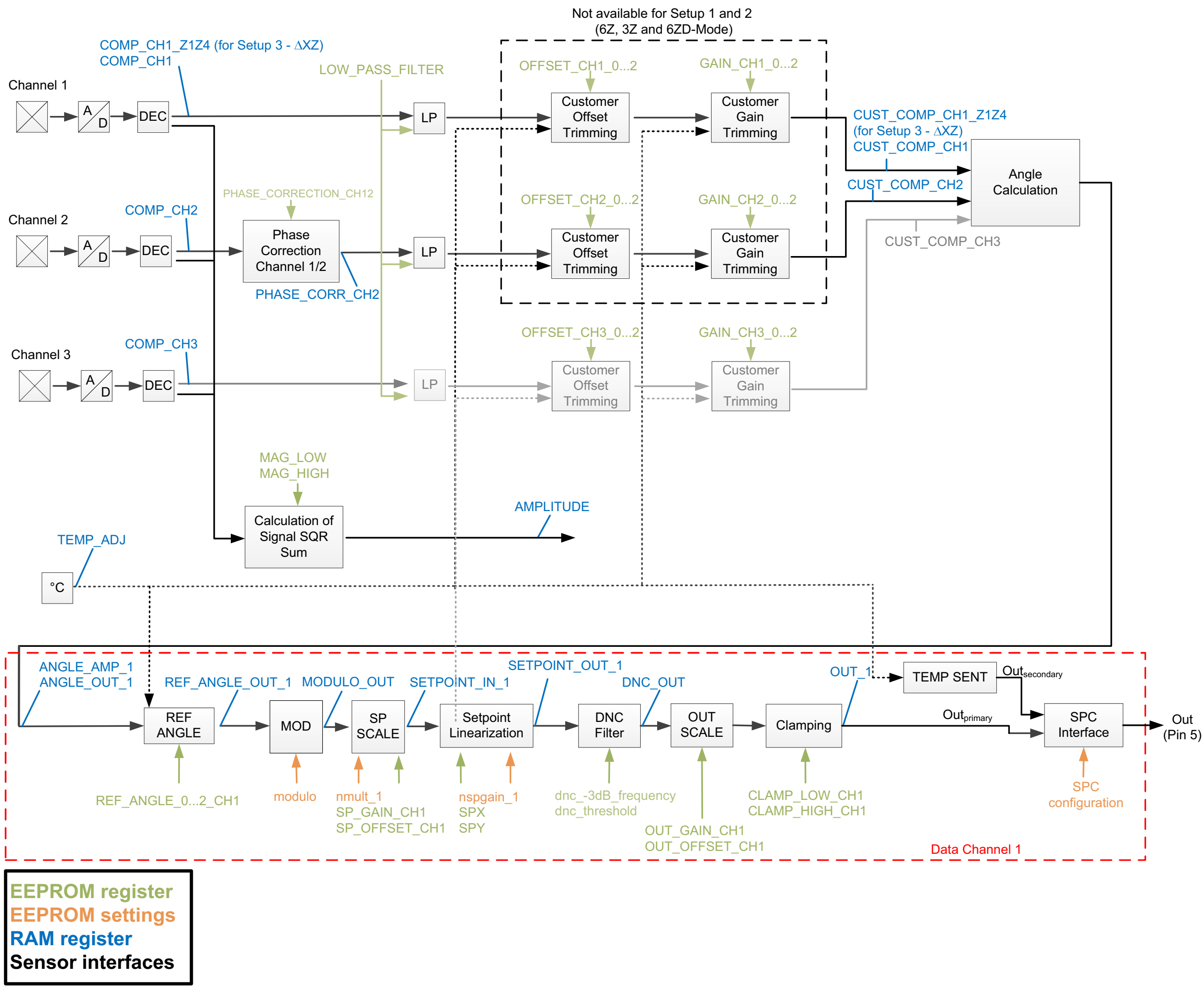


Fig. 3–3: Signal path of HAL 3970

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

3.3. Register Definition

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 3970-230x User Manual.

3.3.1. RAM Registers

TEMP_TADJ

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

COMP_CH1, COMP_CH2 and COMP_CH3

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

COMP_CH1_Z1Z4

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

AMPLITUDE

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

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

PHASE_CORR_CH12

PHASE_CORR_CH12 register contains the customer compensated magnetic-field information of channel 2 and channel 3 after customer phase-shift error correction using the PHASE_CORRECTION_CH12 registers.

CUST_COMP_CHx

CUST_COMP_CH1, CUST_COMP_CH2 and CUST_COMP_CH2 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 3 and the $\Delta X \Delta Z$ mode. It contains the customer-compensated magnetic-field information of the differential ΔZ magnetic-field ΔZ = Z4-Z1 used for the angle calculation.

ANGLE_OUT_1

The ANGLE_OUT_1 register contains the digital value of the position calculated by the angle calculation algorithm.

ANGLE_AMP_1

The ANGLE_AMP_1 register contains the digital value of the magnetic-field amplitude calculated by the angle calculation algorithm.

REF_ANGLE_OUT_1

The REF_ANGLE_OUT_1 register contains the digital value of the angle information after setting the reference angle defining the zero angle position.

MODULO_OUT

The MODULO_OUT register contains the digital value of the angle information after applying the modulo calculation algorithm. MODULO_OUT is only available for the primary angle output.

SETPOINT_IN_1

The SETPOINT_IN_1 register contains the digital value of the angle information after the setpoint scaling block and is the value used for the input of the setpoint linearization block.

SETPOINT_OUT_1

The SETPOINT_OUT_1 register contains the digital value of the angle information after the setpoint linearization block.

DNC_OUT

The DNC_OUT register contains the digital value of the angle information after the DNC filter. DNC_OUT is only available for the primary angle output.

OUT_1

The OUT_1 register contains the digital value of the angle information after all signal processing steps and depend on all customer configuration settings.

DIAGNOSIS

The DIAGNOSIS_0 and DIAGNOSIS_1 registers report certain failures detected by the sensor. HAL 3970 performs self-tests during power-up as well as continues system integrity tests during normal operation. The result of those tests is reported via the DIAGNOSIS_X registers (further details can be found in see Section 4.2. on page 40).

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. This register content will be send via the SENT interface if the serial message channel has been activated.

3.3.2. EEPROM Registers

Application Modes

HAL 3970 can be configured in different application modes. Depending on the required measurement task one of the application modes can be selected. The register SETUP_FRONTEND (Table 3–1 on page 24) defines the different available modes.

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

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

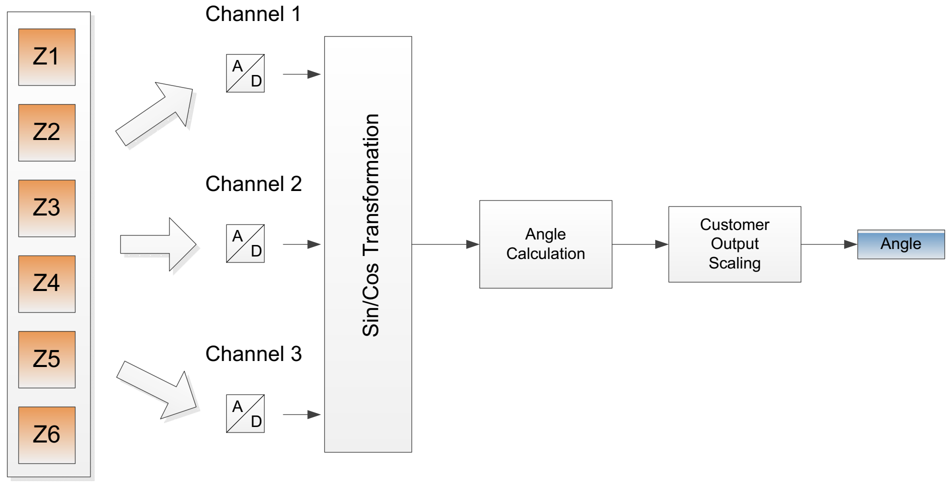


Fig. 3–4: Signal path diagram of setup 1 (stray-field robust 180° measurement)

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

This mode uses horizontal Hall-plates to measure a 360° angular range. In case of HAL 3970-2300 based on three Z-Plates (Fig. 3–5 shows the related signal path) and with HAL 3970-2301 based on the delta of opposite Z-Plates (Z4-Z1, Z6-Z3, Z2-Z5; Fig. 3–6 shows the related signal path). It requires a 2-pole magnet. The device can compensate stray fields according to ISO 11452-8 definition.

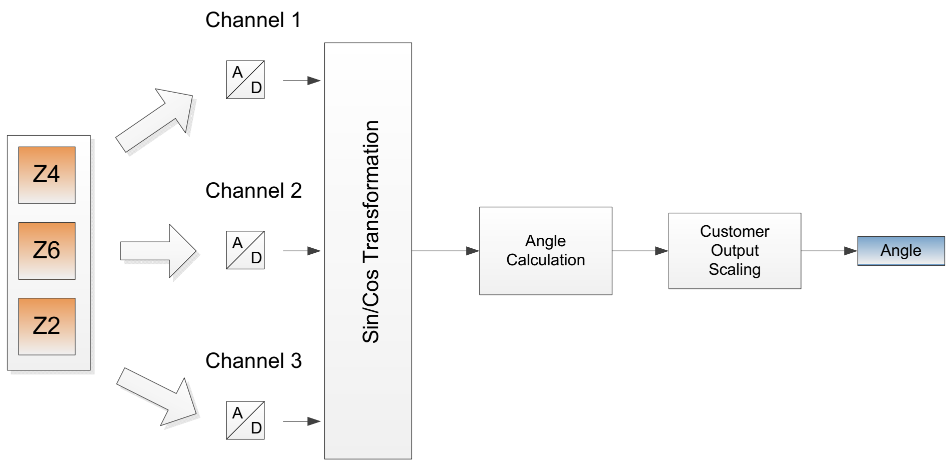


Fig. 3–5: Signal path diagram of setup 2 for HAL 3970-2300 (stray-field robust 360° measurement)

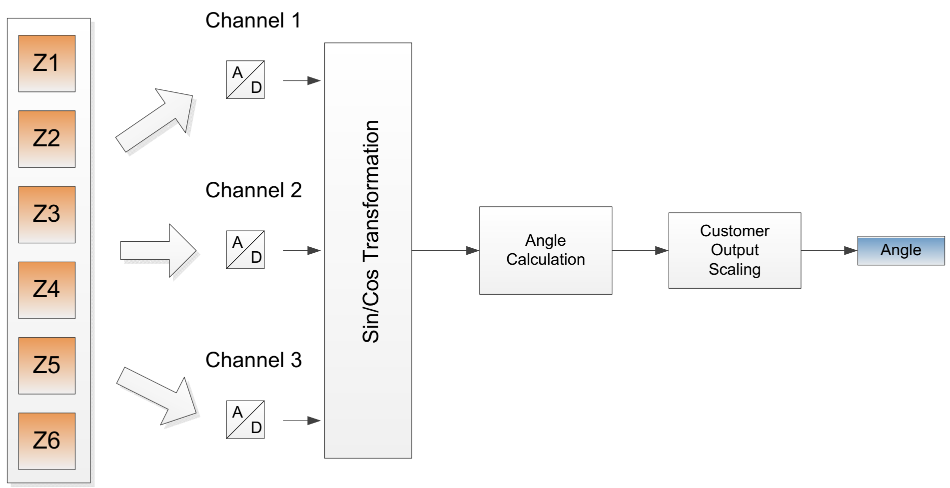


Fig. 3–6: Signal path diagram of setup 2 for HAL 3970-2301 (stray-field robust 360° measurement)

– Setup 3: Linear movement or off-axis rotary (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 be used as well 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 shows the signal path for ΔXΔZ setup.

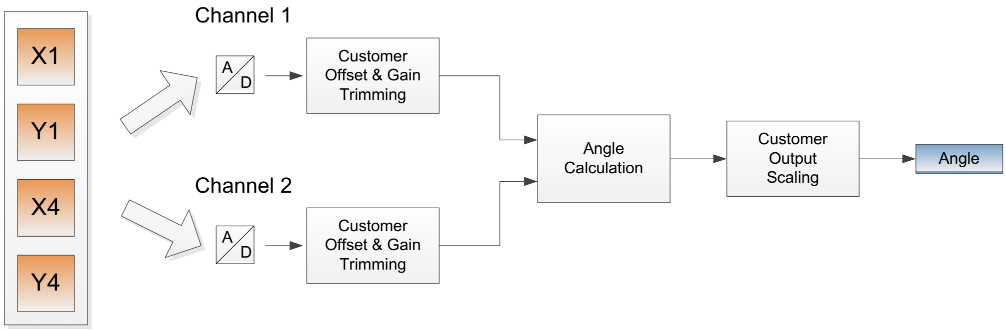


Fig. 3–7: Signal path diagram of setup 3a – ΔXΔY (stray-field robust off-axis position detection)

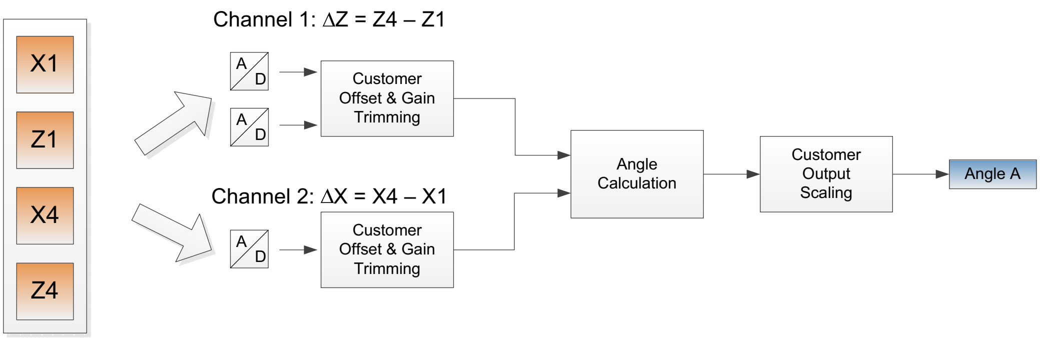


Fig. 3–8: Signal path diagram of setup 3b – ΔXΔZ (stray-field robust linear position detection)

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

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

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

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

Note 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. The angle will be calculated out of combinations of B_Y/B_X, B_Z/B_X or B_Z/B_Y. This mode does not compensate stray-fields. The measurement setup is similar to the well known HAL 37xy family from TDK-Micronas.

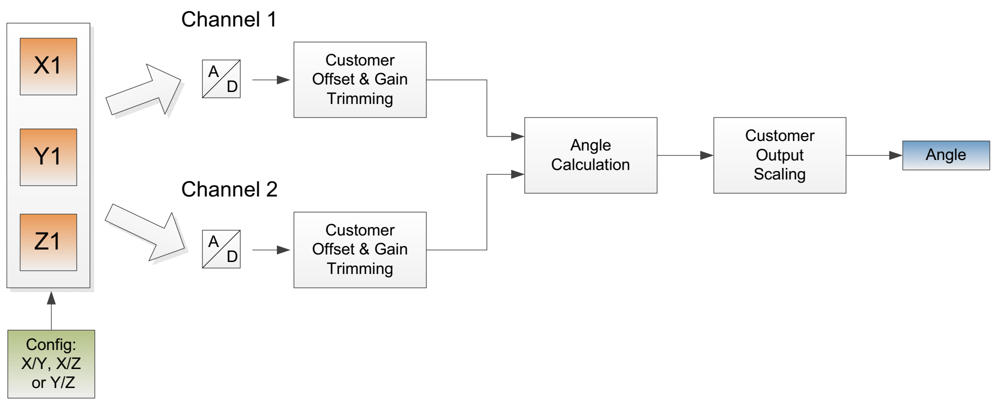


Fig. 3–9: Signal path diagram of setup 4a (rotary or linear position detection w/o stray-field compensation)

– Setup 4b: Virtual centered pixel cell mode for 360° rotary or linear movement measurement (w/o stray-field compensation) - only for HAL 3970-2300

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 P2 are combined and averaged to generate one virtual centered pixel in the middle of the Hall-plate array.

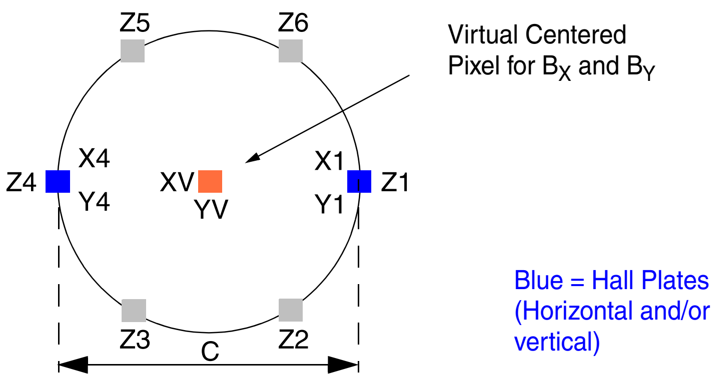


Fig. 3–10: Virtual centered pixel for B_X and B_Y in mode 4b

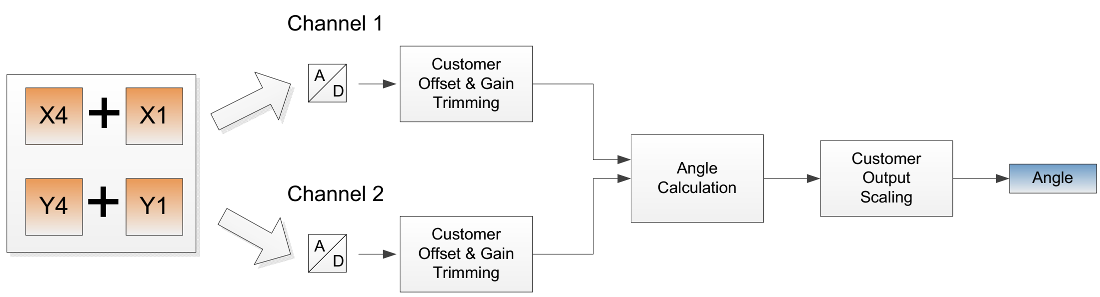


Fig. 3–11: Signal path diagram of setup 4b (virtual centered pixel w/o stray-field compensation)

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

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

Customer IDs

The customer ID register (CUSTOMER_ID0 to CUSTOMER_ID9) consist of ten 16-bit words and can be used to store customer production information for instance, a serial number. Additionally they are used to code the SPC slow channel information like OEM codes, sensor type information and fast channel transfer characteristics. The customer IDs will be part of the SPC slow channel in case that the SPC slow channel is selected. Please see Table 3–12 on page 34 for further details.

Magnetic Range Check

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

Mag-Low Limit

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

Mag-High Limit

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

Phase Correction

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

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

Low-Pass Filter

With the LOW_PASS_FILTER register it is possible to select different –3 dB frequencies for HAL 3970. The default value is zero (low pass filter disabled). The filter frequency is valid for all channels.

OFFSET_CHx_0...2

OFFSET_CH1_0...2 and OFFSET_CH2_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 OFFSET_CH3_0...2 must be set to zero in case of Setup 3 with ΔXΔZ mode.
The OFFSET_CHx_0...2 registers are not available for Setup’s 1 and 2.

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 GAIN_CH3_0...2 must be set to the same value of GAIN_CH1_0...2 in case of Setup 3 with ΔXΔZ mode. The GAIN_CHx_0...2 registers are not available for Setup's 1 and 2.

Note HAL 3970-2300: In the case that the 6Z mode (setup 1) is used with the default gain, the maximum allowed magnetic field strength (BZ, allowed) measured at the Hall-plates is limited to 42 mT.

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 point in the output characteristics out of the measurement range with these parameters. It can be set to any value of the angular range.

REF_ANGLE_0...2_CH1 defines a polynomial of second order with REF_ANGLE_0_CH1 (constant part), REF_ANGLE_1_CH1 (linear part) and REF_ANGLE_2_CH1 (quadratic part).

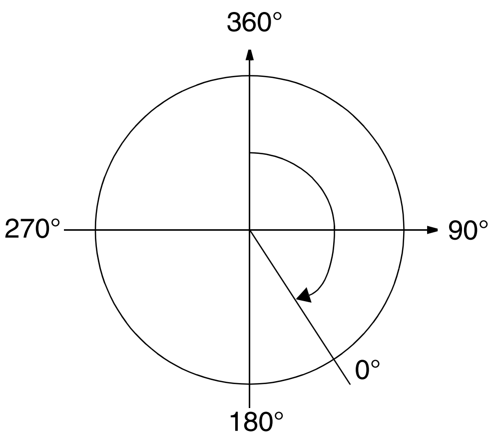


Fig. 3–12: Example definition of zero degree point

Modulo Select

HAL 3970 can split the 360° measurement range into sub-ranges of 90°, 120° and 180°. For example in the 90° sub-range output signal is repeating after 90°. The MODULO register can be used to select between these four different output ranges.

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

nmult_1 (EEPROM Setting)

nmult_1 defines the gain exponent for the setpoint scaling block on the data channel. The factor is multiplied by SP_GAIN_CH1 to achieve gain factors up to 128. (SETUP_DATAPATH[7:5] bits (= nmult_1)).

Setpoint Gain

SP_GAIN_CH1 defines the output gain for the primary data channel. It is used to scale the position information to the input range of the linearization block.

Setpoint Offset

SP_OFFSET_CH1 defines the output offset for the primary data channel.

Setpoint Linearization

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

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

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

The setpoint linearization block works in a way that the incoming signal (SETPOINT_IN_1 value) is interpolated linearly between two adjacent setpoints (SP(n) and SP(n+1)). The resulting SETPOINT_OUT_1 register value represents the angular information after the setpoint scaling.

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

nspgain_1 (EEPROM Settings)

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

DNC Filter Registers (dnc_–3dB_frequency & dnc_threshold)

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

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

For dnc_threshold only values from 0 to 255 are allowed. For the dnc_–3dB_frequency only cutoff frequencies 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_CH1

The register OUT_OFFSET_ CH1 is used as the final offset scaling stage for the desired output signal. The register has a length of 16 bits and is two’s complement-coded.

OUT_GAIN_CH1

The register OUT_GAIN_CH1 is used as the final gain scaling stage for the desired output signal. It can also be used to invert the output signal. The register has a length of 16 bits and is two’s complement-coded.

Clamping Levels (CLAMP-LOW & CLAMP-HIGH)

The clamping levels CLAMP_LOW_CH1 and CLAMP_HIGH_CH1 define the maximum and minimum output values. Both registers have a length of 16 bits and are two´s complemented coded. The 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/overvoltage detection levels. The register UV_LEVEL defines the undervoltage detection level in mV and OV_LEVEL the overvoltage detection level. The SUPPLY_SUPERVISION register has a length of 16 bits. OV_LEVEL uses the 8 MSBs and UV_LEVEL the 8 LSBs. For both levels, 1 LSB is typically equal to 100 mV.

Customer Configuration Registers

SETUP_FRONTEND, SETUP_DATAPATH, and SETUP_OUTPUT are 16-bit registers that enable the customer to activate various functions of the sensor.
The following tables describe in detail the available combinations and resulting functions.

Table 3–1: SETUP_FRONTEND for HAL 3970-2300

Bit No.	Function	Description				
15	customer_lock	Customer Lock: 0: Unlocked 1: Locked				
14:8	–	Must be set to 0.				
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				
3:0	meas_config	**Measurement setups:** 0000: Setup 4a - 2D 0001: Setup 4a - 2D 0010: Setup 4a - 2D 0011: Setup 3b - 2D - Strayfield compensated 0100: Setup 3a - 2D - Strayfield compensated 0101: Setup 4b - 2D - Virtual centered pixel 0110: Setup 1 - 180° rotary - strayfield compensated 0111: Setup 2 - 360° rotary - strayfield compensated 1000 to 1111: Must not be used	**Correspond. Signal Path** With two channels With two channels With two channels With three channels With two channels With two channels 6 Z Hall-plates 3 Z Hall-plates -	**CH1** X1 Z1 Z1 Z4 X4-X1 X1+X4 Z1+Z4 Z4 -	**CH2** Y1 Y1 X1 X4-X1 Y4-Y1 Y1+Y4 Z2+Z5 Z6 -	**CH3** - - - Z1 - - Z3+Z6 Z2 -

Table 3–2: SETUP_FRONTEND for HAL 3970-2301

Bit No.	Function	Description				
15	customer_lock	Customer Lock: 0: Unlocked 1: Locked				
14:8	–	Must be set to 0.				
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				
3:0	meas_config	**Measurement setups:** 0000: Setup 4a - 2D 0001: Setup 4a - 2D 0010: Setup 4a - 2D 0011: Setup 3b - 2D - Strayfield compensated 0100: Setup 3a - 2D - Strayfield compensated 0101: Reserved 0110: Setup 1 - 180° rotary - strayfield compensated 0111: Setup 2 - 360° rotary - strayfield compensated 1000 to 1111: Must not be used	**Correspond. Signal Path** With two channels With two channels With two channels With two channels With two channels 6 Z Hall-plates 6 ZD Hall-plates -	**CH1** X1 Z1 Z1 Z4-Z1 X4-X1 Z1+Z4 Z4-Z1 -	**CH2** Y1 Y1 X1 X4-X1 Y4-Y1 Z2+Z5 Z6-Z3 -	**CH3** - - - - - Z3+Z6 Z2-Z5 -

Table 3–3: SETUP_DATAPATH

Bit No.	Function	Description
15:8	–	Reserved
7:5	nmult_1	Gain exponent for SETPOINT_IN1: SP_GAIN = SP_GAIN_CH1 × [2^(nmult_1)]
4:1	nspgain_1	Gain exponent for setpoint slope in channel 1: Slope = SPGn × (2^nspgain_1+1)
0	variable_setpoints	Fixed/variable setpoint selection: 0: Fixed setpoints 1: Variable setpoints

3.4. SPC Output

HAL 3970 features a SPC (Short PWM Code) protocol, which enhances the standard SAE J2716 SENT protocol. SPC is a synchronous SENT output, triggered by a master pulse from an external ECU.

A SPC frame consists of the following parts:

– Trigger pulse from a master device (the length depends on the operation mode)

– Calibration/synchronization pulse with a length of 56 UT (unit time = clock ticks)

– One 4 bit status communication nibble pulse of 12 to 27 UT

– 3 to 6 data nibbles of 12 to 27 UT each representing the position or temperature information and/or rolling counter

– One 4 bit checksum nibble pulse of 12 or 27 UT

– Pause pulse with constant length (to finish the transmission with a rising edge and to get the line on high level).

The single edge of the frame is defined by a low pulse on the output. The low pulse is customer configurable (see Table 3–4 on page 27).

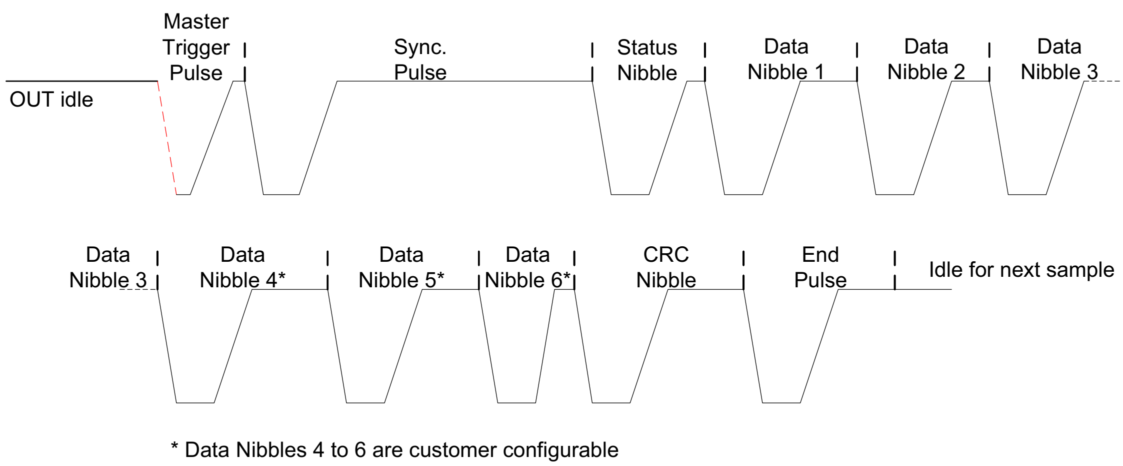


Fig. 3–13: SPC frame structure

Master Pulse

The SPC transmission is initiated by a Master Pulse from an external ECU on the output pin of the sensor. To detect a low-level the voltage at the output pin must be below V_{thf}. The sensor detects that the bus line has been released as soon as a voltage V_{thr} has been passed (see Fig. 5–6 on page 50). The master low time t_{mlow_c} and the total trigger time t_{mtr} depend on the selected SPC mode (please refer to Fig. 3–16 on page 38 and Fig. 3–17 on page 39).

The parameter of the Master Trigger Pulse are defined in Section 5.9. on page 48 and Fig. 5–6 on page 50.

The SPC protocol parameter are customer configurable with the register SETUP_OUTPUT and SETUP_PROTOCOL. Please see Table 3–4 and Table 3–5 for further details.

Table 3–4: SETUP_OUTPUT

Bit No.	Function	Description
15	enable_sample_sync	Enables the synchronization of internal sample clock to the external trigger pulse. In this mode, the internal sample clock is stopped with each trigger sync and starts after 'sample_sync_delay' delay of time: 0: sample synchronisation disabled 1: sample synchronizsation enabled 'sample_sync_delay' is internally calculated to reach 'target_signal_age'
14:8	target_signal_age	Defines the target signal age before the external trigger pulse arrives, when the internal sampling is re-enabled. The signal age is calculated as x × 0.25 µs: 0x28: 10 µs 0x29: 10.25 µs ... 0x7F: 31.75 µs **Note:** Target signal ages below 10 µs are not allowed.
7:5	–	Reserved
4:3	spc_low_time	Defines the SPC low time: 00: 3 ticks 01: 4 ticks 10: 5 ticks 11: 6 ticks
2:0	spc_tick_time	SPC unit times (UT) selection 000: 1.00 µs 001: 1.50 µs 010: 2.00 µs 011: 2.50 µs 100: 2.75 µs 101: 3.00 µs 110: reserved. **Note:** These values represent typical unit time.

Table 3–5: SETUP_PROTOCOL

Bit No.	Function	Description
15	spc_chf	SPC fast channel data format: 0: H.2 format: 12-bit fast channel (3 nibble position information) 1: H.1 format: A.7 with position and temperature (8 bit) + rolling counter (if enabled)
14:13	spc_rcount	Options for SPC rolling counter (see Section 3.4.4. on page 33) 00: No rolling counter 01: 2-bit rolling counter (transmitted in the CRC nibble) 10: 4-bit rolling counter (used with H1.A7 format) 11: Reserved
12	spc_crc	0: CRC according to SAE J2716 > rev. 2 (2010) 1: CRC according to SAE J2716 rev. 1 (2008 - legacy CRC)
11	spc_scrc	Include STATUS nibble in CRC 0: Enabled (recommended for SPC) 1: Disabled (According to SENT SAE J2716)
10	spc_id_mode	SPC ID mode: (see Section 3.4.7. on page 36) 0: Synchronous mode (point-to-point connection) 1: ID selection mode (addressing done via pins 7 and 8)
9	spc_trigger_pulse	Type of SPC trigger pulse in case of ID selection mode: 0: Constant trigger pulse (90 UT) 1: Variable trigger pulse (t_{mlow} + 12 UT)
8	spc_id_status	Option to include SPC ID in the status nibble 0: ID is not part of the status nibble 1: ID is included in the status nibble (no slow channel and ID mode selection is active)
7	spc_id_crc	Defines if the sensor ID is part of the CRC nibble in case that the status nibble content is 0: 0: Do not send ID as part of the CRC 1: Send 2-bit bus mode ID as part of the CRC
6	spc_error_status	Defines the behavior of the SPC error status bits: 0: Always zero 1: According to SENT SAE J2716
5	spc_fast_error_codes	Transmission of fast channel error codes: 0: Disabled 1: Enabled
4	spc_slow_channel_format	Defines slow serial channel format: 0: No serial message channel 1: 12-bit enhanced serial message format

Table 3–5: SETUP_PROTOCOL, continued

Bit No.	Function	Description
3:1	spc_slow_channel_content	Selection which blocks have to be send in addition to block 1 in the slow channel: xx1: Block 2 x1x: Block 3 1xx: Block 4 + 5
0	sent_sdf	SPC SDF mode: 0: Send diagnosis info in front of every block 1: Send diagnosis info in front of every ID

3.4.1. SPC Frame Formats

The sensor supports two different frame formats:

– H.2 format - 3 data nibble frame with one fast channel (position)

– H.1 format - A.7 protocol with 6 data nibble frame with two fast channel (position and temperature and optional rolling counter)

Both modes are customer configurable via bits (Table 3–5 on page 28).

Beside the supported frame formats, a lot of other SPC interface parameter can be configured by the customer, like unit time (UT), transmission of error codes, rolling counter, CRC, serial message channel content, etc. All configurable parameter are defined in Table 3–4 and Table 3–5.

H.2 Format: 3 Data Nibble Frame with One Fast Channel

In this mode the sensor transmits SPC frames with 3 data nibbles containing 12-bit position information. They are formatted according to Table 3–6.

Table 3–6: Nibble description for 3 data nibble frame format with one fast channel

Pulse		Remarks
#	Description	
1	Trigger Pulse	Trigger pulse from the master.
2	Synchronization/ Calibration	It is mandatory to measure the synchronization / calibration period for calibration of the clock tick time UT at the ECU
3	4-bit Status & Communication Nibble	Status [3...2]: According to selection in Table 3–5 bit[6] Status [1...0]: According to selection in Table 3–5 bits[8+4]
4	4-bit Data Nibble MSN 1	Position Value [11:8]
5	4-bit Data Nibble MidN 1	Position Value [7:4]
6	4-bit Data Nibble LSN 1	Position Value [3:0]

Table 3–6: Nibble description for 3 data nibble frame format with one fast channel, continued

Pulse		Remarks
#	Description	
7	4-bit CRC Nibble	According to selection in Table 3–5 bits[14:13+12+11+7] (see Table 3–7 on page 30)
8	Pause Pulse	End pulse of the SPC frame

Table 3–7 shows the possible combinations for the content of the status and CRC nibble depending on the customer selection done according to Table 3–5 on page 28.

Table 3–7: Possible configurations for status nibble and CRC for H.2 format

Trigger Pulse	Sync. pulse	Data nibbles					Pause pulse
		1	2	3	4	5	
Trigger pulse	Sync. pulse	SCN+SCM	D1	D2	D3	CS	Pause pulse
						CS+RC	
						CS+ID	
						CS+ID+RC	
Trigger pulse	Sync. pulse	SCN+ID	D1	D2	D3	CS	Pause pulse
						CS+RC	
SCN = Status com. nibble, SCM = Slow channel message, CS = Checksum (CRC), RC = Rolling counter, ID = Sensor ID							

H.1 Format: 6 Data Nibble Frame with Two Fast Channels

In this mode the sensor transmits SPC frames with 6 data nibbles.

The first 3 data nibbles contain a 12-bit position information and the second 2 data nibbles contain a 8-bit temperature information, an optional rolling counter and/or ID (customer configurable: Table 3–5). They are formatted according to Table 3–8.

Table 3–8: Nibble description for H.1 A.7 format

Pulse		Remarks
#	Description	
1	Trigger Pulse	Trigger pulse from the master.
2	Synchronization/ Calibration	It is mandatory to measure the synchronization / calibration period for calibration of the clock tick time t_{tick} at the ECU
3	4-bit Status & Communication Nibble	Status [3...2]: According to selection in Table 3–5 bit[6] Status [1...0]: According to selection in Table 3–5 bits[8+4]
3	4-bit Data Nibble MSN 1	Position Value [11:8]
4	4-bit Data Nibble MidN 1	Position Value [7:4]

Table 3–8: Nibble description for H.1 A.7 format, continued

Pulse #	Pulse Description	Remarks
5	4-bit Data Nibble LSN 1	Position Value [3:0]
6	4-bit Data Nibble LSN 2	Temperature Value [7:4]
7	4-bit Data Nibble MidN 2	Temperature Value [3:0]
8	4-bit Data Nibble MSN 2	Rolling counter[3:0] - optional Table 3–5 bits[14:13]
9	4-bit CRC Nibble	According to selection in Table 3–5 bits[14:13+12+11+7] (see Table 3–7 on page 30)
10	Pause Pulse	End pulse of the SPC frame

Table 3–9 shows the possible combinations for the content of the status and CRC nibble depending on the customer selection done according to Table 3–5 on page 28.

Table 3–9: Possible configurations for status nibble and CRC for H.1 format

<table>
<tr><th rowspan="2">Trigger Pulse</th><th rowspan="2">Sync. pulse</th><th colspan="8">Data nibbles</th><th rowspan="2">Pause pulse</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th></tr>
<tr><td rowspan="5">Trigger pulse</td><td rowspan="5">Sync. pulse</td><td rowspan="5">SCN+SCM</td><td rowspan="5">D1</td><td rowspan="5">D2</td><td rowspan="5">D3</td><td rowspan="5">T1</td><td rowspan="5">T2</td><td rowspan="2">RC</td><td>CS</td><td rowspan="5">Pause pulse</td></tr>
<tr><td>CS+ID</td></tr>
<tr><td>CS+RC</td><td rowspan="3"></td></tr>
<tr><td>CS+ID</td></tr>
<tr><td>CS+ID+RC</td></tr>
<tr><td rowspan="3">Trigger pulse</td><td rowspan="3">Sync. pulse</td><td rowspan="3">SCN+ID</td><td rowspan="3">D1</td><td rowspan="3">D2</td><td rowspan="3">D3</td><td rowspan="3">T1</td><td rowspan="3">T2</td><td>RC</td><td>CS</td><td rowspan="3">Pause pulse</td></tr>
<tr><td>CS</td><td rowspan="2"></td></tr>
<tr><td>CS+RC</td></tr>
<tr><td colspan="11">SCN = Status com. nibble, SCM = Slow channel message, CS = Checksum (CRC), RC = Rolling counter, ID = Sensor ID</td></tr>
</table>

Clamping of the output signal is done by the selected CLAMP_LOW and CLAMP_HIGH register values.

3.4.2. Error Diagnostic Reporting on Fast Channel and Status Bits

SPC is using status and communication bits[3&2] for error reporting compared to standard SAE J2716 SENT which is using the two LSB's. The bit order of the status and communication nibble for SPC is reversed in contrast to the standard SAE J2716 SENT.

The error diagnostic reporting is customer configurable. By setting the bit [6] in the SETUP_PROTOCOL register different error handling can be activated:

– Always zero: Status bits are always set to zero independent from an error

– Error indication according to SAE J2716 rev. 4: The Status bits are set to one in case of "sensor error indication" or "sensor functionality and processing error indication"

In addition the diagnostic can be reported through the 12-bit payload of channel 1 and/or channel 2. Below table shows the values that will be send in case of an internal error.

Table 3–10: Error codes transmitted on fast channel 1 and/or 2

Error	Code	
	CH 1	**CH 2**
A.1 error code 2)	–	–
Sensor error indication 2)	4091	4091
Sensor functionality and processing error indication	4090	4090
Data Clamping: High	1)	1)
Data Clamping: Low	1)	1)

1) The output will clamp according to the settings for CLAMP_HIGH and CLAMP_LOW.

A description with the mapping of internal errors with "Sensor error indication" and "Sensor functionality and processing error indication" can be found in Table 3–13 on page 35.

The transmission of error codes on fast channel 1 and/or 2 can be deactivated by a customer EEPROM bit bit[5] of SETUP_PROTOCOL, Table 3–5 on page 28). The sensor will then continue to transmit measurement data. Status error bits will be transmitted according to bit[6] in the SETUP_PROTOCOL register.

3.4.3. CRC Implementation

The CRC checksum nibble is calculated using a polynomial X4 + X3 + X2 +1 (SENT SAE J2716 polynomial) with a seed value of 0101. The detailed calculation scheme can be found in the User Manual for HAL 3970. The SAE J2716 legacy CRC can also be activated by bit[12] in the SETUP_PROTOCOL register (see Table 3–5 on page 28). For SPC it is recommended to include the status nibble in the CRC calculation. This function can be activated by bit[11] in the SETUP_PROTOCOL register as well.

Additionally it is possible to add a virtual (not transmitted) nibble containing the sensor ID and/or a 2-bit rolling counter as input data for the CRC calculation. See Table 3–11 for the virtual nibble layout. This function can be activated by bits [14:13+7] (see Table 3–5 on page 28).

Table 3–11: Virtual nibble optionally added to CRC calculation

Virtual nibble				**Remarks**
3	**2**	**1**	**0**	
N/A				No ID or rolling counter
ID1	ID0	0	0	ID's only (zero appended)
0	0	RC1	RC0	Rolling counter only (zero padded)
ID1	ID0	RC1	RC0	ID and rolling counter

3.4.4. Rolling Counter Implementation

SPC is offering two kinds of rolling counter schemes:

– A 2-bit rolling counter combined with the CRC (not transmitted by own bits)

– A 4-bit rolling counter transmitted after the last data nibble

The 4-bit rolling counter starts with “0” after reset, increments up to “15” and rolls over back to “1”.

The 2-bit rolling counter starts with “0”, increments up to “3” and rolls over back to “0”.

The rolling counter is a frame counter and is updated after each transmitted SPC frame, even in case of error indication. It neither indicates new measurement values nor transmission of the same measurement value twice.

3.4.5. Slow Channel

HAL 3970 supports a slow channel that enables transmission of additional data by the modulation of the two LSB of the status/communication bits. Every slow channel message contains an ID and a data field. The ID defines the interpretation of the data. The slow channel implemented in HAL 3970 follows the definition of the 8-bit ID and 12-bit data for the enhanced serial message format of the SAE J2716 standard. It is also possible to deactivate the slow channel by changing bit[4] in the SETUP_PROTOCOL register.

The device can transmit the serial message sequence shown in Table 3–12. The content/ length of the serial message can be tailored by configuration bits[3:0] in the SETUP_PROTOCOL register (Table 3–5 on page 28). It is possible to activate up to five blocks. Block 1 will always be transmitted if the serial message channel is activated.

Table 3–12: Serial message sequence

Block	#	8-bit ID	Item	12-bit Data	Comment
1	1	0x01	Error Codes	(see Table 3–13 on page 35)	
	2	0x03	Sensor type		Bits 0...11 in CUSTOMER_ID0 register (12 bit) Examples: 0x050 = not specified position sensor 0x055 = position and secure channel 0x060 = angle sensor 0x064 = angle sensor + secure channel, etc.
	3	0x05	Manufacturer Code	0x007	TDK Manufacturer Code
	4	0x06	Protocol Revision	0x004	SAE J2716 rev. 4
	5	0x23	Temperature	1 to 4088 temperature data	Temperature information according to SAE J2716
2	6	0x01	Error Codes	(see Table 3–13 on page 35)	
	7	0x29	TDK-Micronas SN	8-bit MSB MIC_ID1	Right aligned
	8	0x2A	TDK-Micronas SN	8-bit LSB MIC_ID1	Right aligned
	9	0x2B	TDK-Micronas SN	8-bit MSB MIC_ID2	Right aligned
	10	0x2C	TDK-Micronas SN	8-bit LSB MIC_ID2	Right aligned
3	11	0x01	Error Codes	(see Table 3–13 on page 35)	Customer configurable
	12	0x07	Fast CH1 - X1	Fast channel 1 characteristics	Bits 0...11 in CUSTOMER_ID1 register
	13	0x08	Fast CH1 - X2	Fast channel 2 characteristics	Bits 12...15 in CUSTOMER_ID1 register Bits 0...7 in CUSTOMER_ID2 register
	14	0x09	Fast CH1 - Y1	Fast channel 1 characteristics	Bits 8...15 in CUSTOMER_ID2 register Bits 0...3 in CUSTOMER_ID3 register
	15	0x0A	Fast CH1 - Y2	Fast channel 2 characteristics	Bits 4...15 in CUSTOMER_ID3 register
4	16	0x01	Error Codes	(see Table 3–13 on page 35)	
	17	0x90	OEM Code 1 ID	ASCII character OEM Codes	Bits 0...11 in CUSTOMER_ID4 register
	18	0x91	OEM Code 2 ID	ASCII character OEM Codes	Bits 12...15 in CUSTOMER_ID4 register Bits 0...7 in CUSTOMER_ID5 register
	19	0x92	OEM Code 3 ID	ASCII character OEM Codes	Bits 8...15 in CUSTOMER_ID5 register Bits 0...3 in CUSTOMER_ID6 register
	20	0x93	OEM Code 4 ID	ASCII character OEM Codes	Bits 4...15 in CUSTOMER_ID6 register

Table 3–12: Serial message sequence, continued

Block	#	8-bit ID	Item	12-bit Data	Comment
5	21	0x01	Error Codes	(see Table 3–13 on page 35)	
	22	0x94	OEM Code 5 ID	ASCII character OEM Codes	Bits 0...11 in CUSTOMER_ID7 register
	23	0x95	OEM Code 6 ID	ASCII character OEM Codes	Bits 12...15 in CUSTOMER_ID7 register Bits 0...7 in CUSTOMER_ID8 register
	24	0x96	OEM Code 7 ID	ASCII character OEM Codes	Bits 8...15 in CUSTOMER_ID8 register Bits 0...3 in CUSTOMER_ID9 register
	25	0x97	OEM Code 8 ID	ASCII character OEM Codes	Bits 4...15 in CUSTOMER_ID9 register

Alternatively, the Error Code can be transmitted as every second slow channel message by setting bit[0] in the SETUP_PROTOCOL register (Table 3–5 on page 28).

3.4.6. Slow Channel: Serial Message Error Codes

Diagnostic status codes are transmitted via the serial message. The 8-bit message ID for the diagnostic status code is 0x01. HAL 3970 features the error codes described in Table 3–13.

Table 3–13: Serial message error codes

Bit Position	Error Type	Fast Channel Error Code
0	Memory self-test error or checksum error	4090
1	ADC error or DSP self-test error	4090
2	Voltage regulator error	4090
3	ADC clipping	4091
4	Invalid temperature sensor values	4090
5	Signal path under/ overflow	CLAMP_LOW/CLAMP_HIGH
6	Overvoltage warning	4091
7	Undervoltage warning	4091
8	Reserved	N/A
9	Hall-plate error	4090
10	Magnet field out of range (MAG_HI, MAG_LOW)	4091
11	Always set to one	-

3.4.7. SPC Modes

HAL 3970 supports two different SPC modes:

– Synchronous mode

– ID selection mode

The SPC mode can be selected by bit[10] of the SETUP_PROTOCOL register (see Table 3–5 on page 28).

Synchronous mode

The sensor starts in synchronous mode the transmission of a new frame only after receiving a low pulse driven on the output pin by the master (ECU). This means that the ECU starts the bidirectional communication by sending a trigger pulse. The sensor then initiates a sync pulse and starts to calculate the new data for the transmission. The data is then sent based on a standard SENT frame, starting with the status, data and the CRC nibble. Finally an end pulse is added to terminate the transmission of the frame and to indicate that the output line is in idle (Fig. 3–13 on page 26).

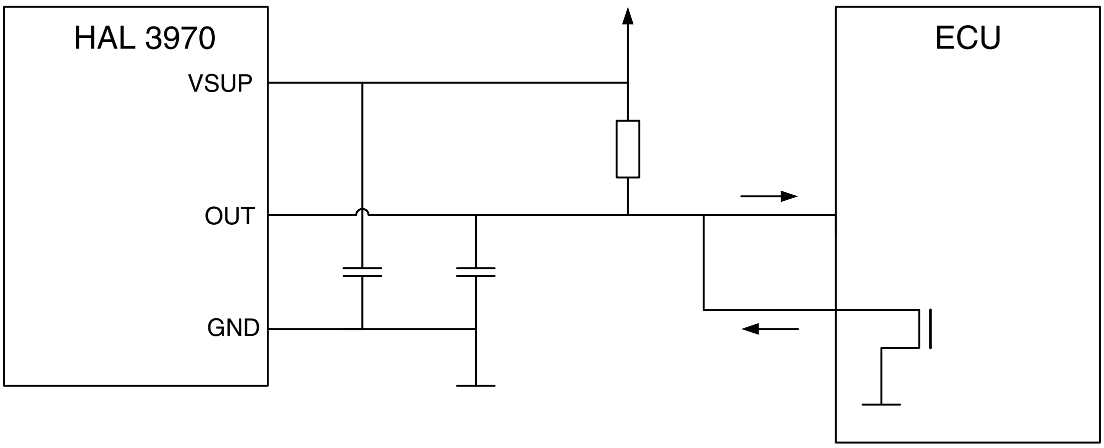


Fig. 3–14: Synchronous point-to-point setup

ID selection mode (bus mode)

The SPC protocol features the option to operate up to four sensors (4 subordinates, 1 master) on the same output (bus) line. All sensors are connected to one data line in parallel (Fig. 3–15 on page 37). The sensors are then selectable via an individual ID. Each ID is linked with a fixed master low time during the trigger pulse.

The sensor starts to transmit the measurement data only after receiving a master low pulse with an ID that is equivalent to the defined sensor ID. All sensors must be configured to the same UT to enable a proper addressing of the different sensors. The sensor ID can be defined by hard coding on the PCB. Pins 7 and 8 of the sensor are used for the coding. Those pins must be either connected to GND or high level to define the ID of the sensor. Please see Table 3–14 for the definition.

Table 3–14: Pinning for sensor ID hard coding

Sensor ID	Pin 7	Pin 8
00	GND	GND
01	High	GND
10	GND	High
11	High	High

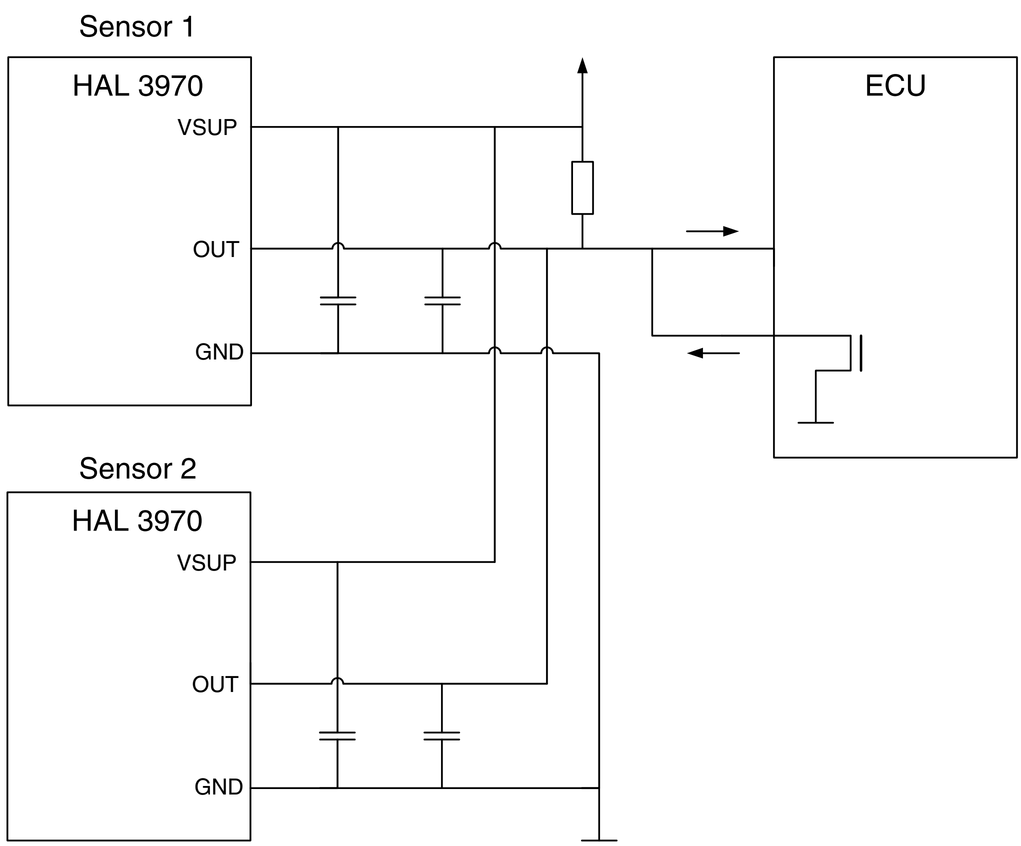


Fig. 3–15: Example for synchronous bus mode setup with two sensors

HAL 3970 is supporting two different bus modes:

– Bus mode with constant length trigger pulse

– Bus mode with variable length trigger pulse

The way of triggering the device can be defined by bit[9] of the SETUP_PROTOCOL register (see Table 3–5 on page 28).

The length of the trigger pulse is fixed for all addresses in case of the constant length trigger pulse and addressing is done via a variable master low time.

Note For bus mode applications with two participants, it is recommended to not use ID = 00. This ensures more tolerance to clock and trigger threshold variations.

For the variable length trigger pulse the ECU sends a trigger pulse of variable length with a variable length low time. This trigger pulse is called “variable length” since the time between the falling edge of the trigger pulse and the start of the frame (first falling edge of the device) is variable. Hence the low time is variable according to the received ID. The high time is of constant length.

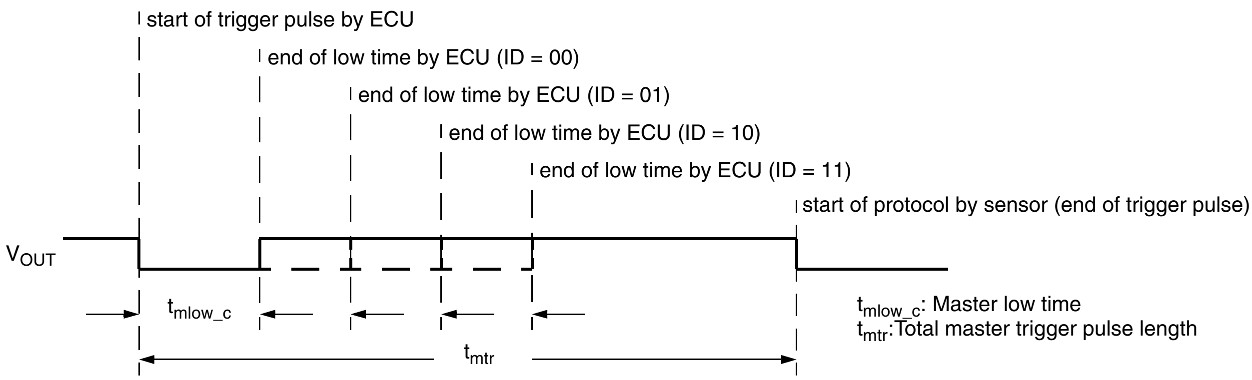


Fig. 3–16: SPC bus mode, constant length trigger pulse timing

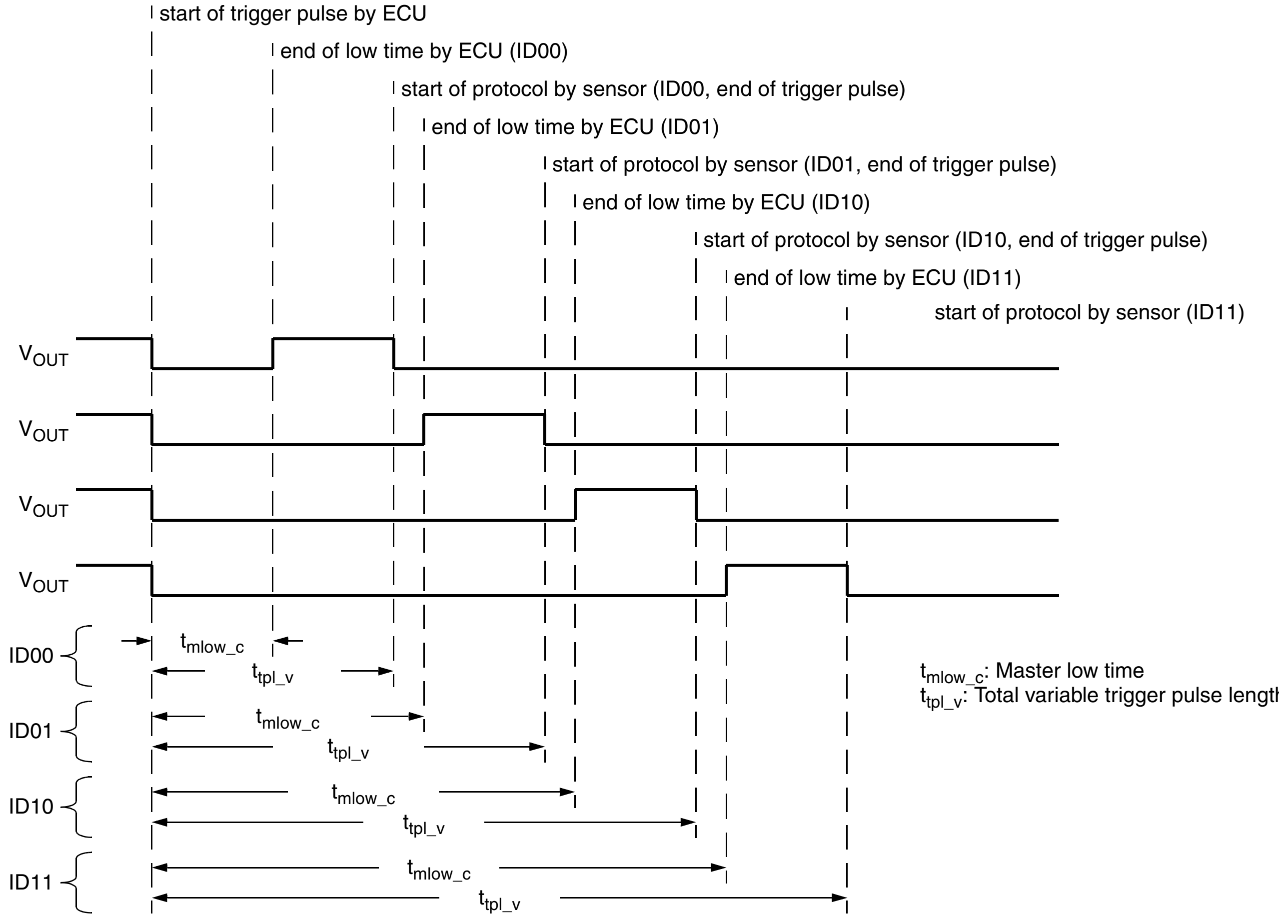


Fig. 3–17: SPC bus mode, variable length trigger pulse timing

All timings can be found in Section 5.9. on page 48.

4. Functional Safety

4.1. Functional Safety Manual and Functional Safety Report

The Functional Safety Manual for HAL 3970 contains the necessary information to support customers to realize a safety compliant application by integrating HAL 3970 as an ASIL B ready component, in their system. The Functional Safety Manual can be provided upon request.

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

4.2. Integrated Diagnostic Mechanisms

HAL 3970 performs self-tests during start-up and normal operation. These increase the robustness of the device functionality by either preventing the sensor from providing wrong output signals or by reporting the failure according to SPC definition. Further details about error reporting see Section 3.4.2. on page 32.

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

Table 4–1: DIAGNOSIS_0 register

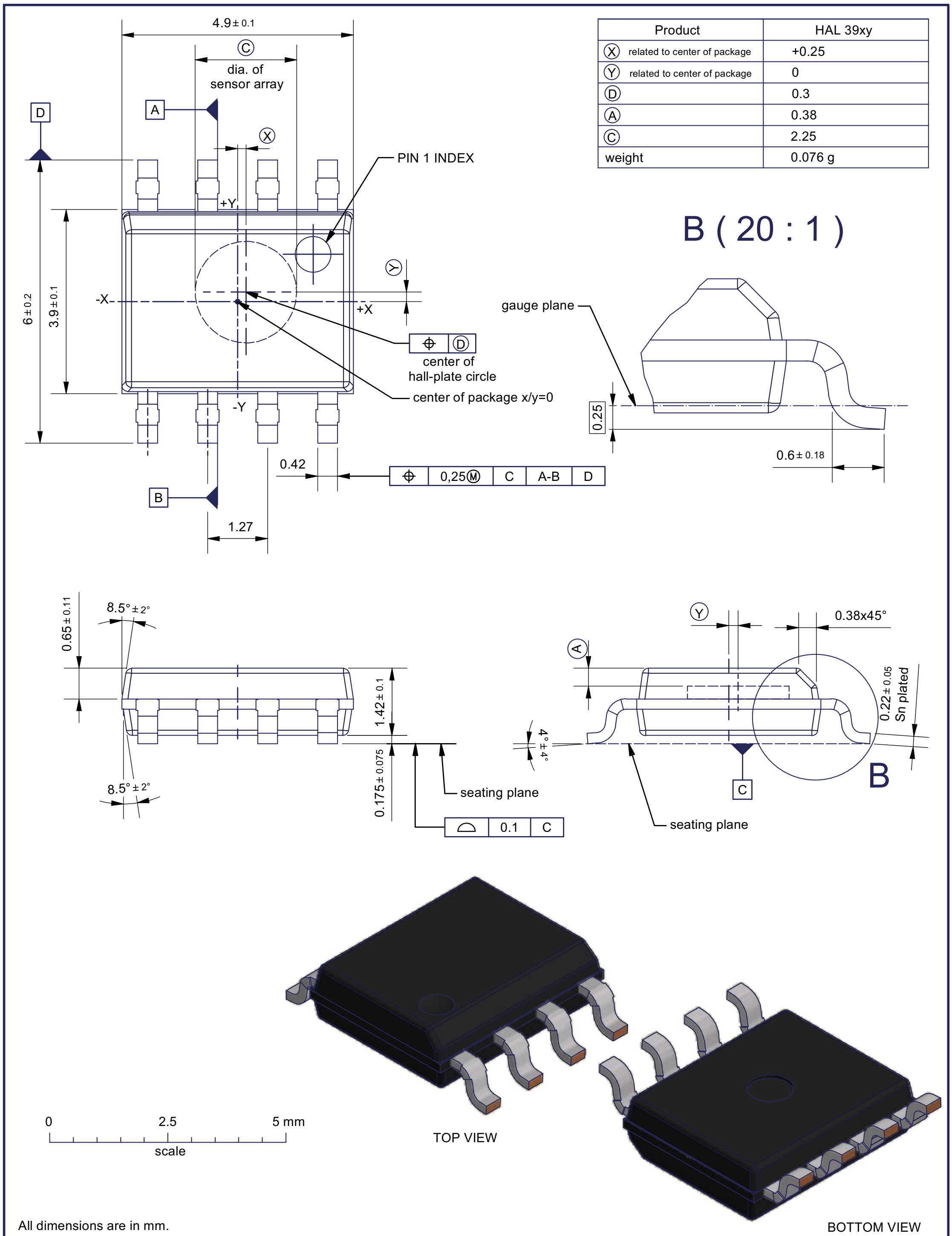
Bit No.	Description when bit is set to 1
15	DSP self-check routines (redundancy or plausibility checks)
14	DSP and µC check of 16-bit checksum covering the EEPROM parameters
13	DSP checksum for ROM and RAM
12	Chip junction temperature out of range
11	Plausibility check of redundant temperature sensor
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
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 currents not correct
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] can not be read via the programming interface as they are triggering immediately a reset of the device.	

5. Specifications

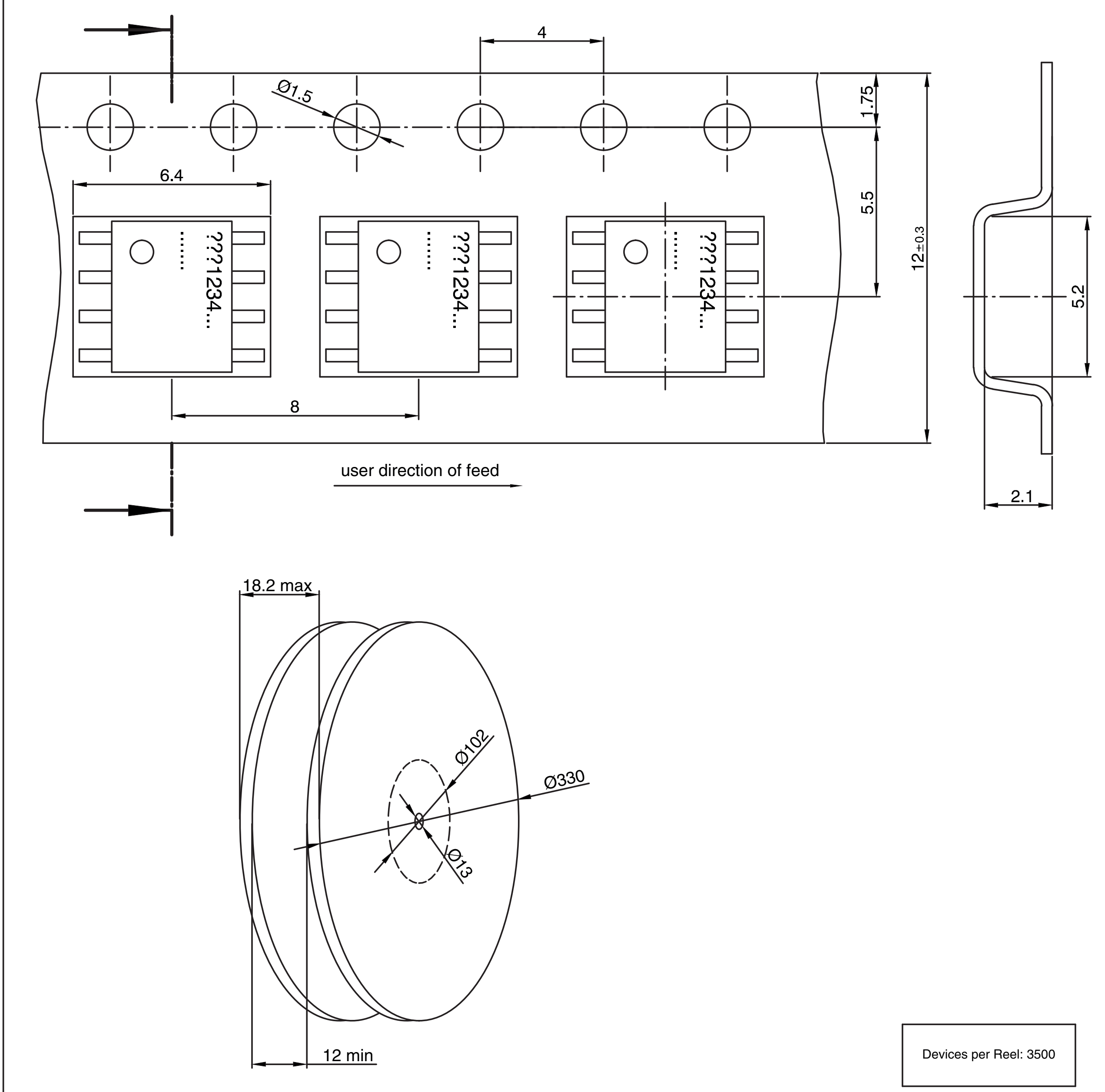
5.1. Outline Dimensions



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		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



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

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

5.2. Soldering, Welding, Assembly

Information related to solderability, welding, assembly, and second-level packaging is included in the document "Guidelines for the Assembly of Micronas Packages".
It is available on the TDK-Micronas website (https://www.micronas.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

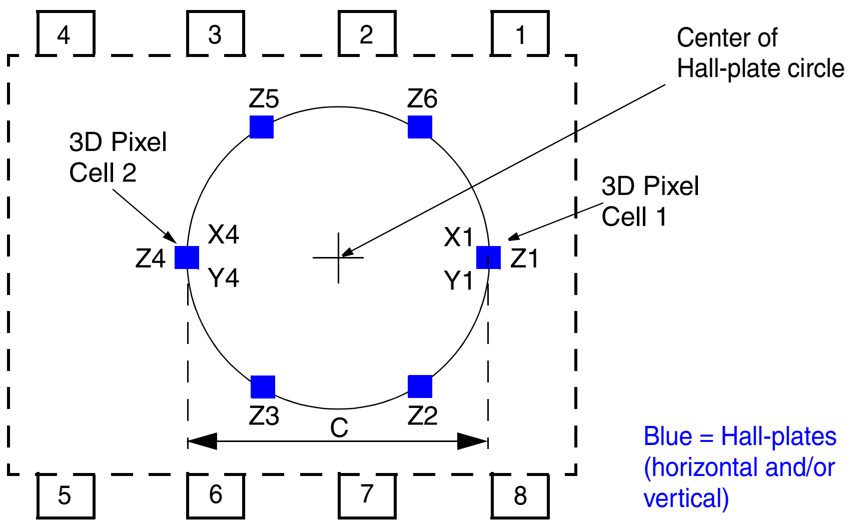


Fig. 5–3: Hall-plate configuration

5.5. Definition of Magnetic-Field Vectors

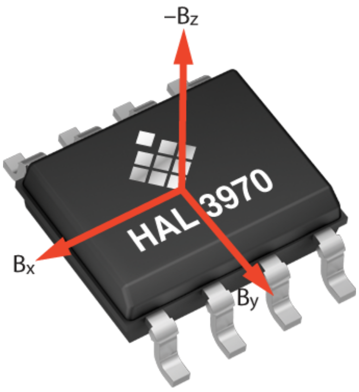


Fig. 5–4: Definition of magnetic-field vectors for HAL 3970

5.6. Pin Connections and Short Description

Table 5–1: Pin connection SOIC8

Pin No. SOIC8 Package	Pin Name	Type	Short Description
1	VSUP	SUPPLY	Supply voltage
2	GND	GND	Ground
3	TEST1	IN	Test
4	TEST2	OUT	Test
5	OUT	I/O	SPC output and programming pin
6	TEST3	N/A	Test
7	ID1	IN	Bit 1 of HW ID coding
8	ID2	IN	Bit 2 of HW ID coding

Note Pins 2 and 3 must be connected to GND. Pins 4 and 6 must stay open.

5.7. Absolute Maximum Ratings

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

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

All voltages listed are referenced to ground (GND).

Table 5–2: Absolute maximum ratings

Symbol	Parameter	Pin Name	Min.	Max.	Unit	Condition
V_{SUP}	Supply Voltage	VSUP	–18	28	V	
			–	37	V	t < 60 s; T_J = 25 °C
V_{OUT}	Output Voltage Output	OUT	–0.3	28	V	t < 96 h
V_{IN_ID}	Input voltage ID Pins	IDx	–0.3	V_{SUP} +0.3	V	t < 96 h
B_{max}	Magnetic Field	–	–1	1	T	
T_J	Junction Temperature	–	–40	190	°C	t < 96 h [1)]
T_A	Ambient Temperature	–	–40	160	°C	[2)]
$T_{storage}$	Transportation/Short Term Storage Temperature	–	–55	150	°C	Device only without packing material
V_{ESD}	ESD Protection	VSUP, OUT, GND, IDx, TESTx	–2	2	kV	[3)]
		VSUP, GND	–15	15	kV	[4)]
		OUT	–4	4	kV	[4)]

No cumulative stress for all parameters.
1) Please contact TDK-Micronas for other temperature requirements.
2) Consider current consumption, mounting condition (e.g. overmold, potting) and mounting situation for T_A and in relation to T_J.
3) ESD HBM according to AEC-Q100-002 (100 pF and 1.5 kΩ).
4) Unpowered gun test (150 pF/330 Ω or 330 pF/2 kΩ) according to ISO 10605-2008 and with additional capacitors as recommended in the application circuit diagram (Fig. 6–1 on page 57).

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).

Table 5–3: Recommended operating conditions

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Condition
V_{SUP}	Supply Voltage	VSUP	3.0	–	16	V	
V_{OUT}	Output Voltage	OUT	–	–	16	V	
V_{IN_ID}	Input Voltage ID	IDx	0	–	5	V	
R_{LOUT}	Output Load	OUT	1.5	–	10	kΩ	Pull-up resistor required
C_{LOUT}	Load Capacitance	OUT	–	1	3.5	nF	
N_{PRG}	Number of Memory Programming Cycles	–	–	–	100	cycles	0 °C < T_{amb} < 55 °C
B_{AMP}	Recommended Magnetic-Field Amplitude	–	10	–	42	mT	HAL 3970-2300 Setup 1
			10	–	65	mT	HAL 3970-2300 Setup 4b
			10	–	84	mT	HAL 3970-2300 Setup 2
			10	–	127	mT	for Z Hall-plates in Setup 1 & 2 of HAL 3970-2301
			10	–	150	mT	for X/Y Hall-plates
			10	–	200	mT	for Z Hall-plates in 2D-Modes (Setup 4a&3a&3b)
T_J	Junction Temperature [1]		–40	–	170	°C	for 1000 h
T_A	Ambient Temperature [2]		–40	–	150	°C	for $V_{SUP} \leq 5.5$ V [3]

[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.
[3] Supply voltages above V_{SUP} = 5.5 V may limit the max. ambient temperature range due to increased self-heating of the device.
[4] Max. 200 mT for the sum (Setup 1) or difference (Setup 2) between two opposite Hall-plates, i.e. (Z4+Z1, Z5+Z2, Z6+Z3) or (Z4-Z1, Z5-Z2, Z6-Z3).

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

5.9. Characteristics

at T_A = –40 °C to 150 °C, V_{SUP} = 3.0 V to 16.0 V, GND = 0 V, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”. Typical Characteristics for T_A = 25 °C and V_{SUP} = 5 V.

Table 5–4: Characteristics

Symbol	Parameter	Pin Name	Limit Values Min.	Typ.	Max.	Unit	Conditions
I_{SUP}	Supply Current	VSUP	–	8	12	mA	1)
f_{osc}	Internal Oscillator Frequency		–	32	–	MHz	
f_{sample}	Sampling Frequency		–	1.953	–	kSps	1) Configurable
			–	3.906	–		
			–	7.812	–		
			–	15.6244	–		
Power-On Behavior							
V_{POR}	Power_On Reset Voltage	VSUP	2.1	2.6	2.9	V	
$V_{PORHyst}$	Power_On Reset Voltage Hysteresis	VSUP	–	200	–	mV	
Overvoltage and Undervoltage Detection							
$S_{VSUP,UOV}$	Step Size of Under-/Overvoltage Supervision Threshold	VSUP	92	100	108	mV/ LSB	Under-/Overvoltage threshold is customer configurable (see page 23). 1)
$S_{VSUP,UOVhys}$	Under-/Overvoltage Detection Level Hysteresis	VSUP	–	1	–	LSB	1) 1 LSB typ. 100 mV
HWID Pins							
V_{IH_IDx}	Input High Level IDx	IDx	2.4	3.0	–	V	Used to define device ID by hard coding.
V_{IL_IDx}	Input Low Level IDx	IDx	–	0.5	0.8	V	
SPC Output							
V_{OL}	Output Low Voltage	OUT	–	–	0.6	V	I_{Load} = 20 mA
t_{fall}	Fall Time of Output	OUT	–	120	–	ns	1) 2)
I_{Oshort_High}	Output Current for Short to V_{SUP}	OUT	25	40	50	mA	$V_{SUP} > V_{OUT} >$ GND
I_{Leak}	Output Leakage Current	OUT	–2	–	2	µA	
t_{UT}	SPC Unit Time	OUT	0.97	1.00	1.03	µs	1)
			1.45	1.50	1.55	µs	
			1.94	2.00	2.06	µs	
			2.42	2.50	2.58	µs	
			2.66	2.75	2.83	µs	
			2.91	3.00	3.09	µs	
t_{S_Init}	SENT Start-up Time (Output ready for trigger)	OUT	–	–	10.0	ms	1) Time until first SENT frame with init frame starts. Fig. 5–5 on page 50

1) Characterized on small sample size, not EOL tested.
2) Measured from 1.1 V to/from 3.8 V with C_L = 1 nF.

Table 5–4: Characteristics, continued

Symbol	Parameter	Pin Name	Limit Values			Unit	Conditions
			Min.	Typ.	Max.		
Trigger Pulse Parameter (Fig. 5–6 on page 50)							
V_{thf}	Trigger Pulse Parameter	OUT	1.0	1.3	1.7	V	1)
V_{thr}	Rising Edge Threshold of Master Pulse	OUT	1.25	1.43	2.0	V	1)
t_{mtr}	Master Trigger Pulse Length	OUT	–	13	–	UT	1)Synchronous mode
			–	90	–	UT	1)ID selection mode
t_{md_tot}	Master Delay Time	OUT	12	–	–	UT	1)
Sensor SPC trigger parameter (Bus mode: on)[4]							
t_{mlow_c}	Master Low Time	OUT	2	–	5	UT	Bus mode off
			8	–	15	UT	1)ID = 0, Bus mode on
			16	–	28	UT	1)ID = 1, Bus mode on
			29	–	49	UT	1)ID = 2, Bus mode on
			50	–	82	UT	1)ID = 3, Bus mode on
ECU SPC trigger parameter (Bus mode: on)[4]							
t_{mlow_c}	Master Low Time	OUT	2	–	4	UT	Bus mode off
			9	10.5	12	UT	1)ID = 0, Bus mode on
			19	21	23	UT	1)ID = 1, Bus mode on
			35.5	38	40.5	UT	1)ID = 2, Bus mode on
			61.5	64.5	67.5	UT	1)ID = 3, Bus mode on
t_{tpl_v}	Total Variable Trigger Pulse Length	OUT	t_{mlow_c} + 12 UT			UT	1)
SOIC8 Package							
R_{thja}	Thermal Resistance Junction to Air	–	–	–	140	K/W	3) Determined with a 1S0P board
		–	–	–	93	K/W	3) Determined with a 2S2P board
R_{thjc}	Thermal Resistance Junction to Case	–	–	–	33	K/W	3) Determined with a 1S0P and 2S2P board

1) Characterized on small sample size, not tested.
3) Self-heating calculation see Section 6.1. on page 56.
4) In order to achieve correct triggering of the sensor, the ECU trigger must consider all system tolerances to ensure that the trigger window for a correct trigger detection in the sensor is met. It must be ensured that the ECU/Microcontroller trigger pulse hits the sensor detection window. The trigger pulse is subject to many parameters, which are narrowing down the detectability of the trigger by the sensor. The contributors to this variation are: External component accuracy, Input trigger threshold level, Asynchronous clock of receiver and transmitter.

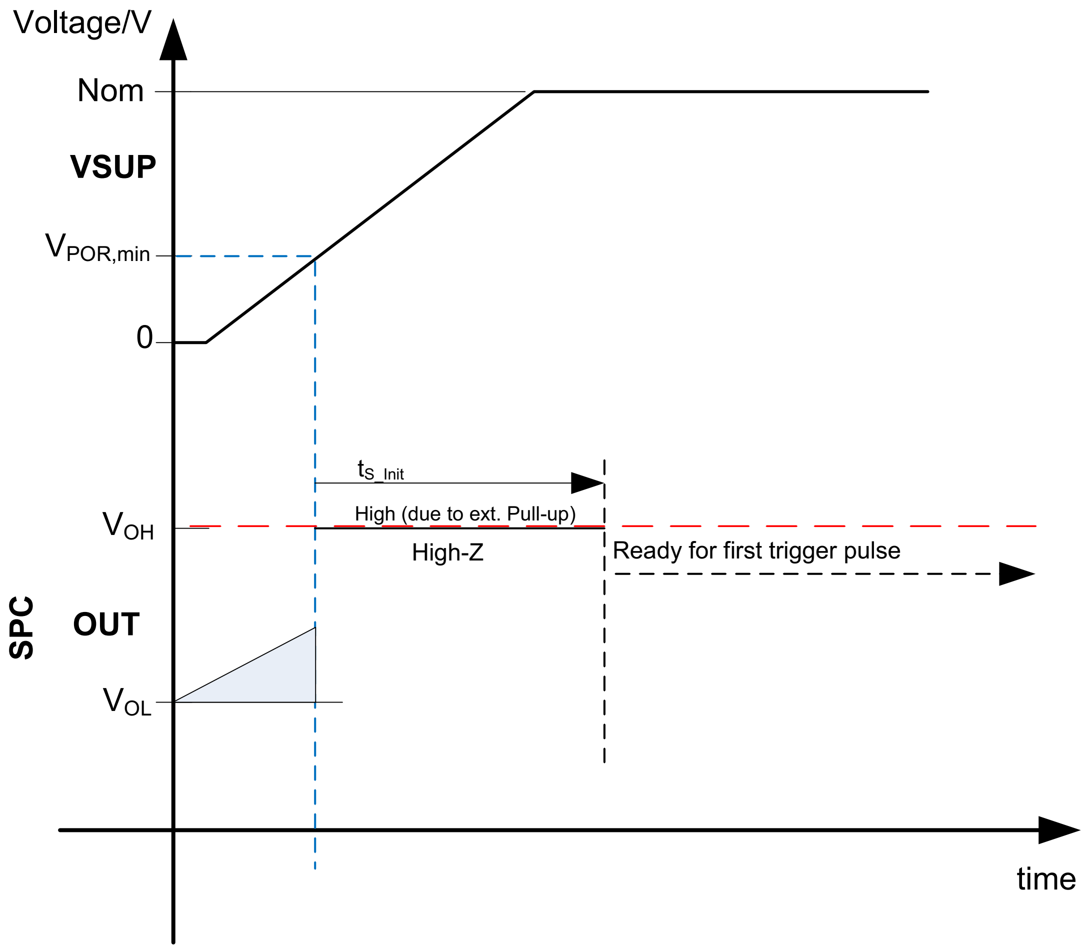


Fig. 5–5: Start-up behavior of HAL 3970

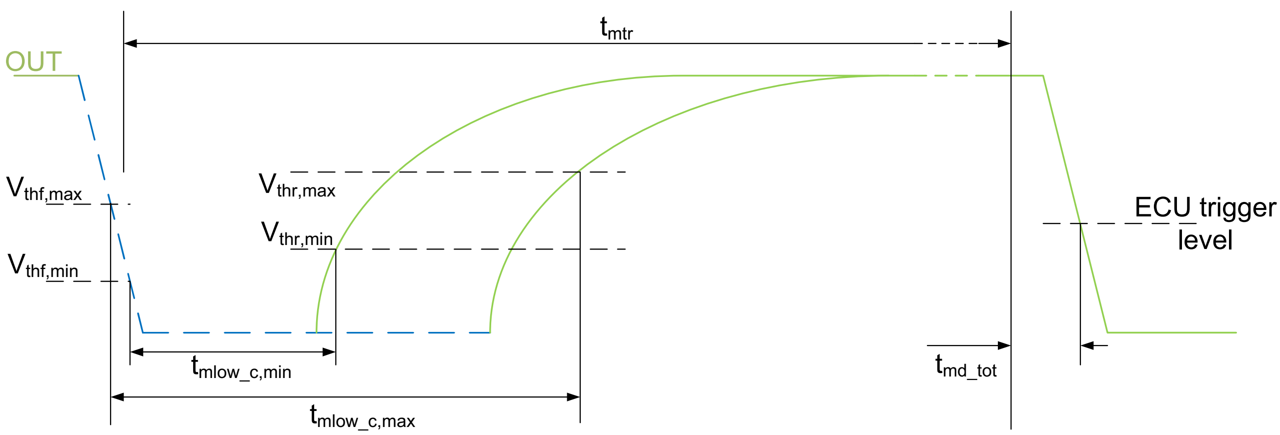


Fig. 5–6: SPC Master Pulse Timing

5.10. Magnetic Characteristics

at T_A = –40 °C to 150 °C, V_{SUP} = 3.0 V to 16.0 V, GND = 0 V, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”. Typical Characteristics for T_A = 25 °C and V_{SUP} = 5.0 V.

Table 5–5: Magnetic characteristics

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
Rotary Setup with Stray-Field Compensation (Setup 1)							
$\Delta E_{\Theta tot}$	Total Angular Error of Drifts	OUT	–0.45	–	0.45	°	1) B_{AMP} = ±10 mT
$\Delta E_{\Theta temp}$	Angular Error Drift over Temperature	OUT	–0.5	–	0.5	°	1) B_{AMP} = ±10 mT
$\Delta E_{\Theta life}$	Angular Error Drift over Lifetime	OUT	–0.2	–	0.2	°	1) B_{AMP} = ±10 mT After 1008 h HTOL
			–0.45	–	0.45	°	1) B_{AMP} = ±10 mT Setup 2 (3 Z-Plates) After 1008 h HTOL
$E_{\Theta hyst}$	Angular Hysteresis Error	OUT	–	–	0.05	°	2)
$E_{\Theta noise\_1}$	Angular Noise Setup 1	OUT	–	0.13	0.23	°	3)
$E_{\Theta SF\_1}$	Angular Error due to Stray-Field for Setup 1	OUT	–	–	0.1	°	1) 4) B_{AMP} = ±10 mT wanted signal
Rotary Setup with Stray-Field Compensation (Setup 2) - HAL 3970-2300							
$\Delta E_{\Theta tot}$	Total Angular Error of Drifts	OUT	–0.85	–	0.85	°	1) B_{AMP} = ±10 mT
$\Delta E_{\Theta temp}$	Angular Error Drift over Temperature	OUT	–0.5	–	0.5	°	1) B_{AMP} = ±10 mT
$\Delta E_{\Theta life}$	Angular Error Drift over Lifetime	OUT	–0.45	–	0.45	°	1) B_{AMP} = ±10 mT After 1008 h HTOL
$E_{\Theta hyst}$	Angular Hysteresis Error	OUT	–	–	0.05	°	2)
$E_{\Theta noise\_2}$	Angular Noise Setup 2	OUT	–	0.19	0.33	°	3)
$E_{\Theta SF\_2}$	Angular Error due to Stray-Field for Setup 2	OUT	–	–	0.12	°	1) 4) B_{AMP} = ±10 mT wanted signal
Rotary Setup with Stray-Field Compensation (Setup 2) - HAL 3970-2301							
$\Delta E_{\Theta tot}$	Total Angular Error of Drifts	OUT	–0.65	–	0.65	°	1) B_{AMP} = ±10 mT
$\Delta E_{\Theta temp}$	Angular Error Drift over Temperature	OUT	–0.4	–	0.4	°	1) B_{AMP} = ±10 mT
$\Delta E_{\Theta life}$	Angular Error Drift over Lifetime	OUT	–0.3	–	0.3	°	1) B_{AMP} = ±10 mT After 1008 h HTOL
$E_{\Theta hyst}$	Angular Hysteresis Error	OUT	–	–	0.05	°	2)
$E_{\Theta noise\_2}$	Angular Noise Setup 2	OUT	–	0.25	0.4	°	3)

All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not EOL tested).
1) Based on Simulation Model (not EOL tested).
2) Guaranteed by Design.
3) Characterized on small sample size, BAMP = ± 10 mT, fdecsel = 2 kHz, Low-pass filter: off, 3-sigma values (not EOL 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 EOL tested).

Table 5–5: Magnetic characteristics, continued

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
$E_{\Theta SF\_2}$	Angular Error due to Stray-Field for Setup 2	OUT	–	–	0.25	°	[1] [4] B_{AMP} = ±10 mT wanted signal
Linear Movement Setup (ΔXZ) with Stray-Field Compensation (Setup 3b)							
$SM_{\Delta XZ41}$	Sensitivity Mismatch between ΔX_{41} and ΔZ_{41} Channel	OUT	–5	–	5	%	[1] T_A = 25 °C
$Sense_{\Delta XZ41}$	Sensitivity of ΔX_{41} and ΔZ_{41} Channel	OUT	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	OUT	–2.5	–	2.5	%	[1] Related to T_A = 25 °C
$Offset_{\Delta X41}$	Offset of ΔX_{41} Channel	OUT	–30	–	30	LSB_{15}	T_A = 25 °C
$Offset_{\Delta Z41}$	Offset of ΔZ_{41} Channel	OUT	–15	–	15	LSB_{15}	T_A = 25 °C
$\Delta Offset_{\Delta X41}$	Offset Drift of ΔX_{41} Channel	OUT	–50	–	50	LSB_{15}	Related to T_A = 25 °C
$\Delta Offset_{\Delta Z41}$	Offset Drift ΔZ_{41} Channel	OUT	–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	OUT	–	1.0	–	%	[1] After 1008 h HTOL
$\Delta Offset_{\Delta X41life}$	Offset Drift of ΔX_{41} Channel over life time	OUT	–	30	–	LSB_{15}	After 1008 h HTOL
$\Delta Offset_{\Delta Z41life}$	Offset Drift of ΔZ_{41} Channel over life time	OUT	–	5	–	LSB_{15}	After 1008 h HTOL
$SF_{R\Delta X41}$	Stray-Field Rejection in ΔX_{41} Direction	OUT	99	–	–	%	[4] T_A = 25°C
$SF_{R\Delta Z41}$	Stray-Field Rejection in ΔZ_{41} Direction	OUT	99	–	–	%	[4] T_A = 25°C
$E_{\Theta phase\Delta XZ41}$	Phase Error between ΔX_{41} and ΔZ_{41} Channel	OUT	–	±2.2	–	°	between ΔX_{41} and ΔZ_{41} axis [1]
$E_{\Delta X41,noise}$	Digital Noise of ΔX_{41} Hall-Plates Channel	OUT	–	2.4	–	LSB_{15}	[5]
$E_{\Delta Z41,noise}$	Digital Noise of ΔZ_{41} Hall-Plates Channel	OUT	–	2.6	–	LSB_{15}	[5]
Off-Axis Rotary Setup (ΔXY) with Stray-Field Compensation (Setup 3a)							
$SM_{\Delta XY41}$	Sensitivity Mismatch between ΔX_{41} and ΔY_{41} Channel	OUT	–2	–	2	%	[1] T_A = 25 °C
$Sense_{\Delta XY41}$	Sensitivity of ΔX_{41} and ΔY_{41} Channel	OUT	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	OUT	–2.5	–	2.5	%	[1] Related to T_A = 25 °C
$Offset_{\Delta XY41}$	Offset of ΔX_{41} and ΔY_{41} Channels	OUT	–30	–	30	LSB_{15}	T_A = 25 °C

All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not EOL tested).
[1] Based on Simulation Model (not EOL tested).
[2] Guaranteed by Design.
[4] Characterized on small sample size according to ISO 11452-8:2015, at 25°C, with stray-field strength of 4 kA/m from X,Y and Z direction, 3-sigma values (not EOL tested).
[5] Characterized on small sample size, 1-sigma values of COMP_CHx, fdecsel = 2 kHz, Low-pass filter: off (not EOL tested).

Table 5–5: Magnetic characteristics, continued

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
$\Delta Offset_{\Delta XY41}$	Offset Drift of ΔX_{41} and ΔY_{41} Channels	OUT	–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	OUT	–	1.0	–	%	1) After 1008 h HTOL
$\Delta Offset_{\Delta XY41life}$	Offset Drift of ΔX_{41} and ΔY_{41} Channel over life time	OUT	–	30	–	LSB_{15}	After 1008 h HTOL
$SF_{R\Delta XY41}$	Stray-Field Rejection in ΔX_{41} and ΔY_{41}Direction	OUT	99	–	–	%	
$E_{\Theta phase\Delta XY41}$	Phase Error between ΔX_{41} and ΔY_{41} Channel	OUT	–	±2.2	–	°	1) between ΔX_{41} and ΔY_{41} axis
$E_{\Delta XY41,noise}$	Digital Noise of ΔX_{41} and ΔY_{41} Hall-Plates Channel	OUT	–	2.4	–	LSB_{15}	5)
3D Measurement Setup without Stray-Field Compensation (Setup 4a)							
SM_{XYZ}	Sensitivity Mismatch between X or Y and Z Channel	OUT	–4	–	4	%	T_A = 25 °C
SM_{XY}	Sensitivity Mismatch between X and Y Channel	OUT	–2	–	2	%	T_A = 25 °C
$Sense_{XYZ}$	Sensitivity of X,Y and Z Hall-plate	OUT	123	128	133	LSB_{15} /mT	T_A = 25 °C
ΔSM_{XYZ}	Thermal Sensitivity Mismatch Drift between X or Y and Z Hall Plates	OUT	–2.5	–	2.5	%	Related to T_A = 25 °C
ΔSM_{XY}	Thermal Sensitivity Mismatch Drift between X and Y Hall Plates	OUT	–2	–	2	%	Related to T_A = 25 °C
$Offset_{XY}$	Offset of X and Y Hall-plates	OUT	–20	–	20	LSB_{15}	T_A = 25 °C
$Offset_{Z}$	Offset of Z Hall-plate	OUT	–12	–	12	LSB_{15}	T_A = 25 °C
$\Delta Offset_{XY}$	Offset Drift of X and Y Hall-plates	OUT	–40	–	40	LSB_{15}	Related to T_A = 25 °C
$\Delta Offset_{Z}$	Offset Drift of Z Hall-plate	OUT	–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	OUT	–	1.0	–	%	After 1008 h HTOL
$\Delta Offset_{XYlife}$	Offset Drift of X and Y Hall-plates over life time	OUT	–	30	–	LSB_{15}	After 1008 h HTOL
$\Delta Offset_{Zlife}$	Offset Drift of Z Hall-plate over life time	OUT	–	5	–	LSB_{15}	After 1008 h HTOL
$E_{\Theta phaseXYZ}$	Phase Error between X, Y and Z Hall-Plates	OUT	–	±1.6	–	°	XY axis
			–	±1.6	–	°	XZ axis
			–	±1.6	–	°	YZ axis
$E_{XYZ,noise}$	Digital Noise of X, Y or Z Hall-Plates Channel	OUT	–	2.2	–	LSB_{15}	5)

All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not EOL tested).
1) Based on Simulation Model (not EOL tested.)
5) Characterized on small sample size, 1-sigma values of COMP_CHx, fdecsel = 2 kHz, Low-pass filter: off (not EOL tested).

Table 5–5: Magnetic characteristics, continued

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
2D Measurement Setup (virtual centered Pixel XY) without Stray-Field Compensation (Setup 4b) - HAL3970-2300							
$SM_{\Sigma XY41}$	Sensitivity Mismatch between ΣX_{41} and ΣY_{41} Channel	OUT	–3	–	3	%	T_A = 25 °C
$Sense_{\Sigma XY41}$	Sensitivity of ΣX_{41} and ΣY_{41} Channel	OUT	121	128	135	LSB/mT	T_A = 25 °C
$\Delta SM_{\Sigma XY41}$	Thermal Sensitivity Mismatch Drift between ΣX_{41} and ΣY_{41} Channel	OUT	–2	–	2	%	Related to T_A = 25 °C
$Offset_{\Sigma XY41}$	Offset of ΣX_{41} and ΣY_{41} Channel	OUT	–25	–	25	LSB_{15}	T_A = 25 °C
$\Delta Offset_{\Sigma XY41}$	Offset Drift of ΣX_{41} and ΣY_{41} Channel	OUT	–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	OUT	–	1.0	–	%	After 1008 h HTOL
$\Delta Offset_{\Sigma XY41life}$	Offset Drift of ΣX_{41} and ΣY_{41}Channel over Life Time	OUT	–	30	–	LSB_{15}	After 1008 h HTOL
$E_{\Theta phase\Sigma XY41}$	Phase Error between ΣX_{41} and ΣY_{41}	OUT	–	±2.2	–	°	1)
$E_{\Sigma XY41,noise}$	Digital Noise of ΣX_{41} and ΣY_{41} Hall-Plates Channel	OUT	–	1.9	–	LSB_{15}	5)

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

1) Based on Simulation Model (not EOL tested).

5) Characterized on small sample size, 1-sigma values of COMP_CHx, fdecsel = 2 kHz, Low-pass filter: off (not EOL tested).

5.11. Temperature Sensor

at T_A = –40 °C to 150 °C, V_{SUP} = 3.0 V to 16.0 V, GND = 0 V, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”.
Typical Characteristics for T_A = 25 °C and V_{SUP} = 5.0 V.

Table 5–6: Temperature sensor

Symbol	Parameter	Pin No.	Min.	Typ.	Max.	Unit	Conditions
$TADJ_{Gain}$	Gain of Temperature Sensor	OUT	–	89.25	–	LSB_{15}/°C	[1] for TADJ register
$TADJ_{Offset}$	Temperature Sensor Offset	OUT	–	3720	–	LSB_{15}	[1] for TADJ register
$TSENT_{Gain}$	Gain of Temperature Sensor for SENT Output	OUT	–	8.1	–	LSB_{12}/°C	[1] SENT Slow Channel
$TSENT_{Offset}$	Temperature Sensor Offset for SENT Output	OUT	–	565.3	–	LSB_{12}	[1] SENT Slow Channel
ΔT_{Lin}	Temperature Sensor Linearity Error	OUT	–2	–	2	°C	[2]
ΔT_{Acc}	Temperature Sensor Accuracy	OUT	–5	–	5	°C	[2]

[1] Not EOL tested.
[2] Characterized on small sample size, 3-sigma values, not tested EOL 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}).

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

The junction to ambient thermal resistance R_{thja} is specified in Section 5.9. on page 48.

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

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

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

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

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

6.2. EMC and ESD

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

6.3. Application Circuit for HAL 3970

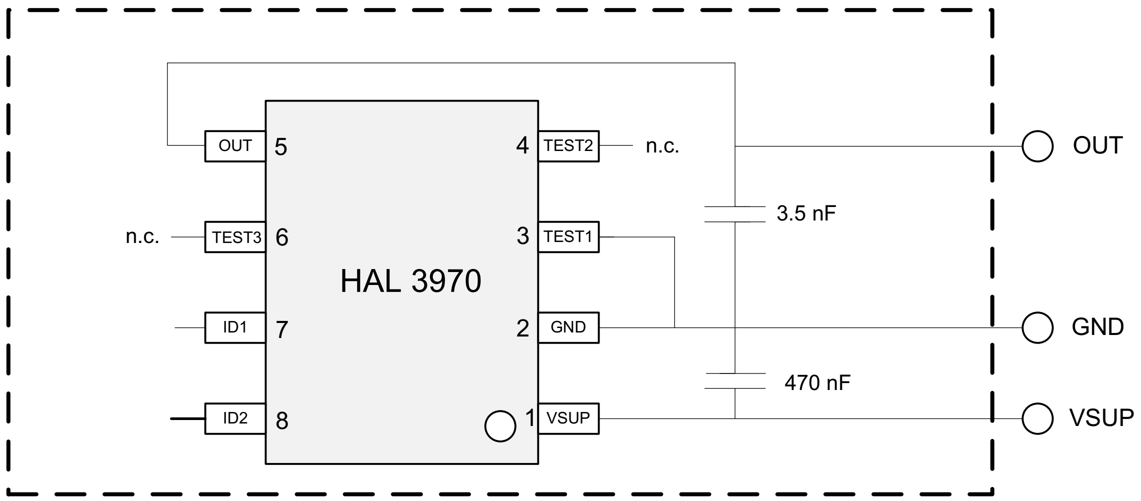


Fig. 6–1: Recommended application circuit for HAL 3970

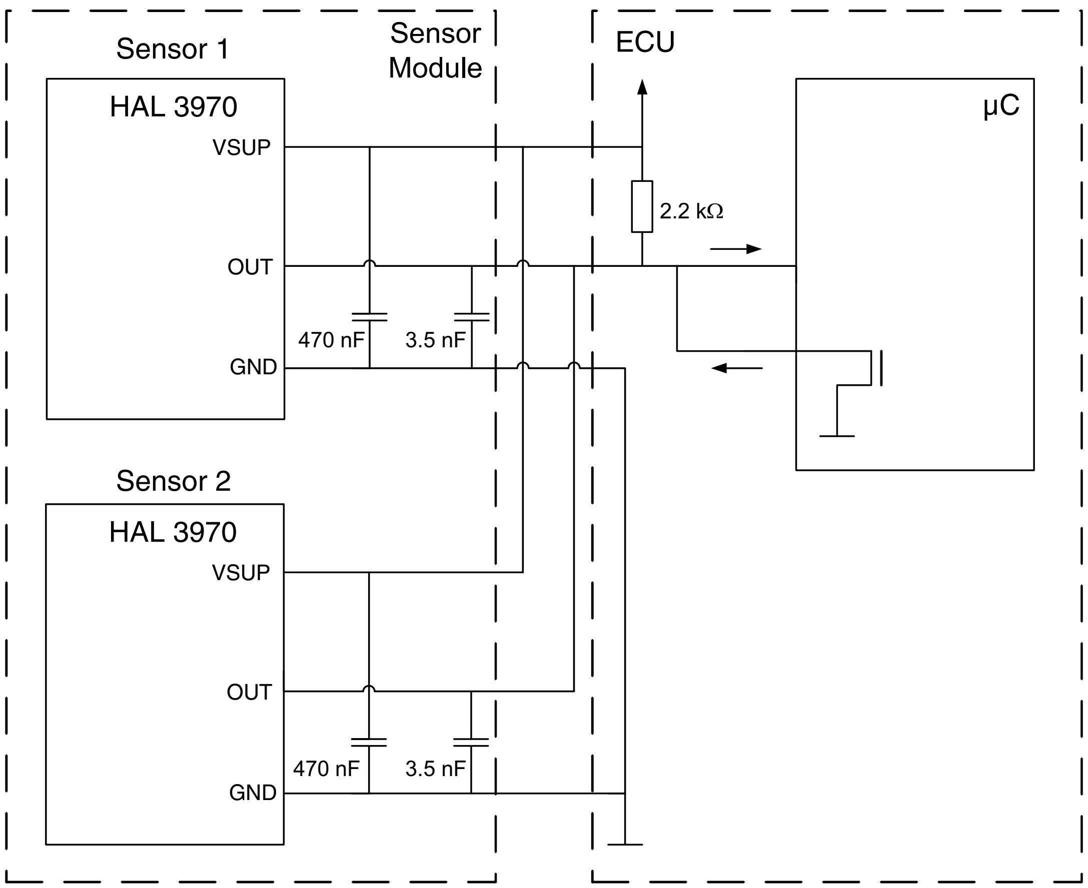


Fig. 6–2: Application circuit for bus mode

6.4. Recommended Pad Size SOIC8 Package

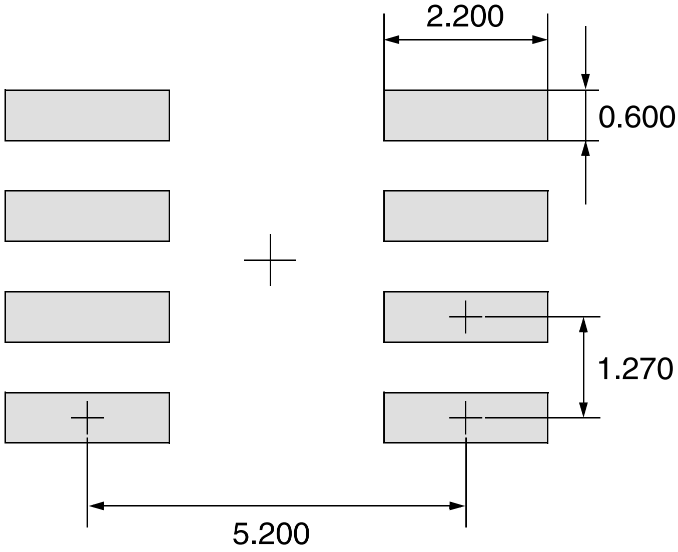


Fig. 6–3: Pad size recommendation for SOIC8 Package (all dimensions in mm - not to scale)

7. Programming of the Sensor

HAL 3970 features two different customer modes. In **Application Mode** the sensor provides a digital output signal SPC definition. In **Programming Mode (Listen Mode)** it is possible to change the register settings of the sensor.

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

7.1. Programming Interface

In Programming Mode HAL 3970 is addressed by modulating a serial telegram on the sensor's output pin. The sensor answers with a modulation of the output voltage.

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

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

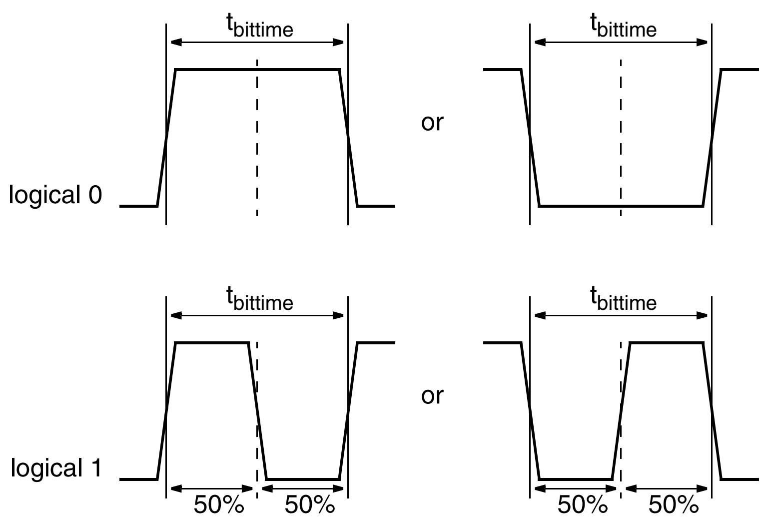


Fig. 7–1: Definition of logical 0 and 1 bit

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

Symbol	Parameter	Pin No.	Limit Values			Unit	Test Conditions
			Min.	Typ.	Max.		
t_{h_bbit}	Host Biphase bit time	OUT1	0.01	–	1.1	ms	
SR	Host slew rate Biphase protocol	OUT1	10	–	–	V/µs	[1] For recommended application circuit
V_{H_OUTL}	Host OUT pin voltage for low level during programming	OUT1	–	–	0.8	V	
V_{H_OUTH}	Host OUT pin voltage for high level during programming	OUT1	2.4	–	–	V	
$V_{SUPProgr}$	V_{SUP} Voltage for memory programming	VSUP	$V_{SUP,min.}$	–	$V_{SUP,max.}$	V	
[1] Not EOL tested.							

7.2. Programming Environment and Tools

For the programming of HAL 3970 during product development a programming tool including hardware and software is available on request. It is recommended to use the TDK-Micronas tool kit (TDK MSP V1.x and LabView Programming Environment) in order to facilitate the product development. The details of programming sequences are content of the HAL 3970 Programming Guide.

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 3970.

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

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

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

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

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

Note A description of the communication protocol and the programming of the sensor is available in a separate document HAL 3970 Programming Guide.

8. Document History

1. Data Sheet: “HAL 3970-2300 Stray-Field Robust 2D Position Sensor with SPC (Short PWM Code) Interface”, May 5, 2023, DSH000229_001EN. First release of the Data Sheet.
   Describing ROM-ID release: 2300

2. Data Sheet: “HAL 3970-230x Stray-Field Robust 2D Position Sensor with SPC (Short PWM Code) Interface”, Jul. 04, 2024, DSH000229_002EN. Second release of the Data Sheet.
   Describing ROM-ID release: 230x

   Major changes compared to previous data sheet
   – HAL 3970-2301 added (uses 6ZD Mode)
   – Signal path diagram corrected

3. Data Sheet: “HAL 3970-230x Stray-Field Robust 2D Position Sensor with SPC (Short PWM Code) Interface”, Aug. 06, 2024, DSH000229_003EN. Third release of the Data Sheet
   Describing ROM-ID release: 230x

   Major changes compared to previous data sheet
   – Master low time specification for the sensor added
   – Master low time specification for bus mode off added

4. Data Sheet: “HAL 3970-230x Stray-Field Robust 2D Position Sensor with SPC (Short PWM Code) Interface”, Dec. 06, 2024, DSH000229_004EN. Third release of the Data Sheet.
   Describing ROM-ID release: 230x

   Major changes compared to previous data sheet
   – Recommended magnetic field strength in recommended operating conditions changed

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