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Hardware
Documentation

Data Sheet

HAR® 3930-2300

Dual-Die Stray-Field Robust 3D Position Sensor with Digital Output Interfaces

3D|HAL® Technology

master|HAL® Technology

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Contents

Contents, continued

Dual-Die Stray-Field Robust 3D Position Sensor with Digital Output Interfaces.

1. Introduction

HAR 3930 is the fully redundant (dual-die) version of the HAL 3930 and it is part of a new generation of TDK-Micronas' 3D position sensors addressing the need for stray-field robust 3D position sensors (linear and angular) as well as the ISO 26262 compliant development. It provides full redundancy due to two independent dies stacked in a single package, each electrically connected to the pins of one package side. The stacked-die architecture ensures that both dies occupy the same magnetic-field position, thus generating synchronous measurement signals. It is a high-resolution position sensor for highly accurate position measurements.

HAR 3930 features PWM or SENT outputs. The digital output format is customer configurable. In SENT mode, the sensor transmits SENT messages with and without pause pulse according SAE J2716 rev. 4. Many parameters like tick time, frame format, etc. are configurable by the customer. The PWM output is configurable with frequencies between 0.1 kHz and 2 kHz.

Additionally, HAR 3930 offers two switch outputs (configurable high-/low-side switch). The switch signal is derived from the calculated position information or from various other sources along the device's signal path (e.g. temperature, magnetic-field amplitude, etc.). It is possible to define on/off switching points, switch logic, and switch polarity.

The device can measure a 360° angular range, linear movements as well as 3D position information of a magnet. 3D position means two angles calculated out of $B_X/B_Y/B_Z$. The 3D position information can be transmitted via the SENT interface. The device also features a so-called modulo function mainly used for chassis position sensor applications. With this mode it is possible to split the 360° measurement range into sub-segments (90°, 120° and 180°).

The HAR 3930 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 per die 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. It can be integrated in automotive safety related systems up to ASIL D.

The device is designed for automotive and industrial applications. It operates in the ambient temperature range from –40 °C up to 150 °C depending on the used supply voltage rage.

The sensor is available in the sixteen-pin SSOP16 SMD package.

1.1. Major Applications

Thanks to the sensor’s versatile programming characteristics and its high accuracy, the HAR 3930 is a potential solution for the following application examples:

– Throttle valve position, etc.

– Shift position

– Steering angle

– Non-contact potentiometer

– Clutch position

– Transmission position detection

– Brake pedal position / brake stroke sensor

– Accelerator pedal position

1.2. Features

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

– 3D position detection supporting transmission of two angles out of B_X, B_Y, B_Z

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

– SEooC ASIL B ready according to ISO 26262 to support Functional Safety applications

– Wide supply voltage range of 3 V up to 18 V

– Customer-configurable PWM or SENT output for each die (push-pull output & open-drain output)

– Configurable output slew rates to reduce EMC emission

– 0.1 kHz to 2 kHz PWM

– SENT according to SAEJ2716 rev. 4 (APR2016) supporting three different frame formats:

  - H1. format: Two 12-bit fast channels (3 data nibbles position information and 3 data nibbles second position information or 12-bit temperature or magnetic-field amplitude) (supporting A.1 Dual Throttle Position Sensors)
  - H.2 Format: One 12-bit fast channel (3-nibble position information)
  - H.4 Format: Secure single sensors with 12-bit fast channel (3 nibble position information) and 12-bit secure sensor information
  - Enhanced 12-bit serial message format including temperature information
  - Programmable tick times between 0.5 µs and 12 µs
  - Low time of 3, 5, and 6 ticks
  - Configurable pause pulse (PPC,NPP)
  - Transmission of OEM ID's via slow channel

– Two additional switch outputs

– Customer-configurable switching levels

– Up to 8 kSps sampling frequency

– Operates from –40 °C up to 170 °C junction temperature (Max. Ambient Temperature: $T_{A,absmax}$ = 160 °C; depending on use supply voltage)

– Programming via the sensor's output pins. No additional programming pin required

– Various configurable signal processing parameter, like output gain and offset, reference position, temperature dependent offset, etc.

– Modulo function (90°/120°/180°) for chassis position applications

– Programmable arbitrary output characteristic with 17 variable or 33 fixed setpoints

– Programmable characteristics in a non-volatile memory (EEPROM) with redundancy and lock function

– Read access on non-volatile memory after customer lock

– On-board diagnostics of different functional blocks of the sensor

2. Ordering Information

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

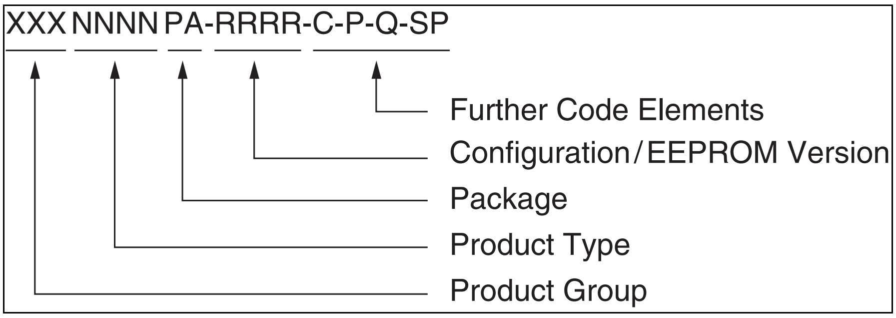


Fig. 2–1: Ordering code principle

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

2.1. Device-Specific Ordering Codes

The HAR 3930 is available in the following package.

Table 2–1: Available packages

Package Code (PA)	Package Type
GU	SSOP16

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

Table 2–2: Ordering Information

Product	Package	Configuration/EEPROM Version	Further Code [-C-P-Q-SP]	Comments
HAR 3930	GU = SSOP16	95xy	See TDK-Micronas Ordering Information	95xy versions can be engineering samples or qualifiable devices
HAR 3930	GU = SSOP16	2300	See TDK-Micronas Ordering Information	Mass production version

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

Ordering Code	Package Marking	Description
HAR3930GU-2300[-C-P-Q-SP]		Line 1: Product Type / Configuration-ID Line 2: Lot number Line 3: Date code / Special Procedure SB (optional)

3. Functional Description

3.1. General Function

HAR 3930 is a 3D position sensor based on Hall-effect technology. Each die 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).

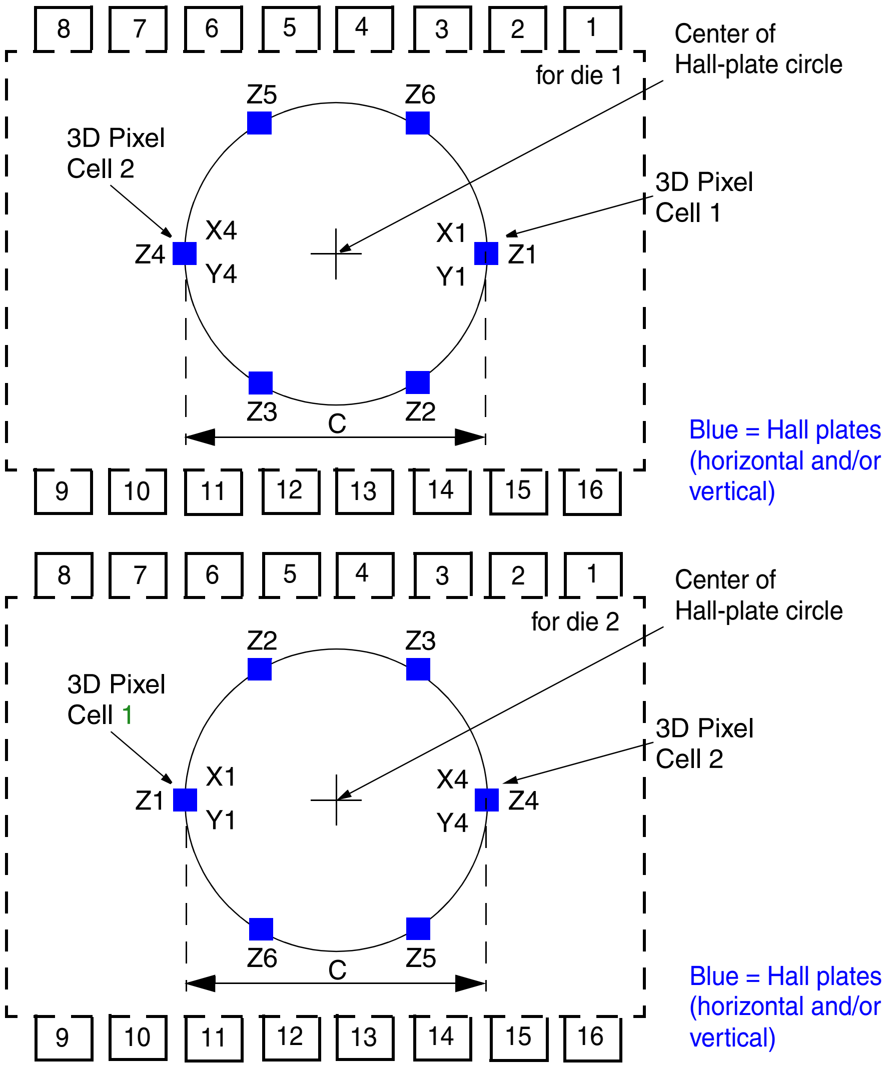


Fig. 3–1: Hall-plate position definition of die 1 and die 2 for HAR 3930

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

On each die 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 from Die 1 and Cell 2 from Die 2
– 3D position detection (calculation of two angles) without stray-field compensation

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

Additionally, the device features a switch output for each die. The source for the switch signal can be derived from various internal sensor signals along the signal path. The available sources can be found in Table 3–1 on page 27. It is possible to define ON and OFF switching levels, the start-up behavior, and the output polarity. The switch output can be configured as high-side or low-side switch.

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

The calculated position information is either transmitted via PWM signals or SENT frames.

The HAR 3930 is programmable by modulation of the output voltage. No additional programming pin is needed and fast end-of-line programming is enabled.

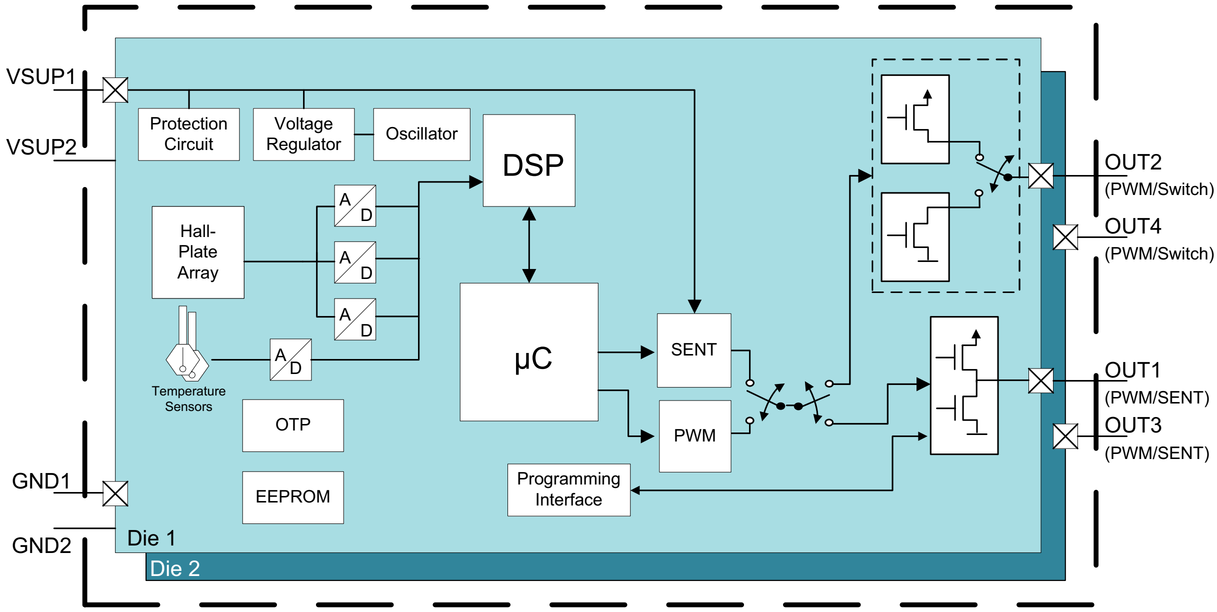


Fig. 3–2: HAR 3930 block diagram with die 1 and die 2

3.2. Signal Path

The DSP part of this sensor performs the signal conditioning. The parameter for the DSP are stored in the non-volatile memory. Details of the overall signal path are shown in Fig. 3–3. Not all functions are available for all measurement modes. Depending on the measurement setup, the signal path is scaled to the needs for the measurement setup. The signal path is identical for die 1 and die 2. Fig. 3–3 shows the signal path for die 1 as an example.

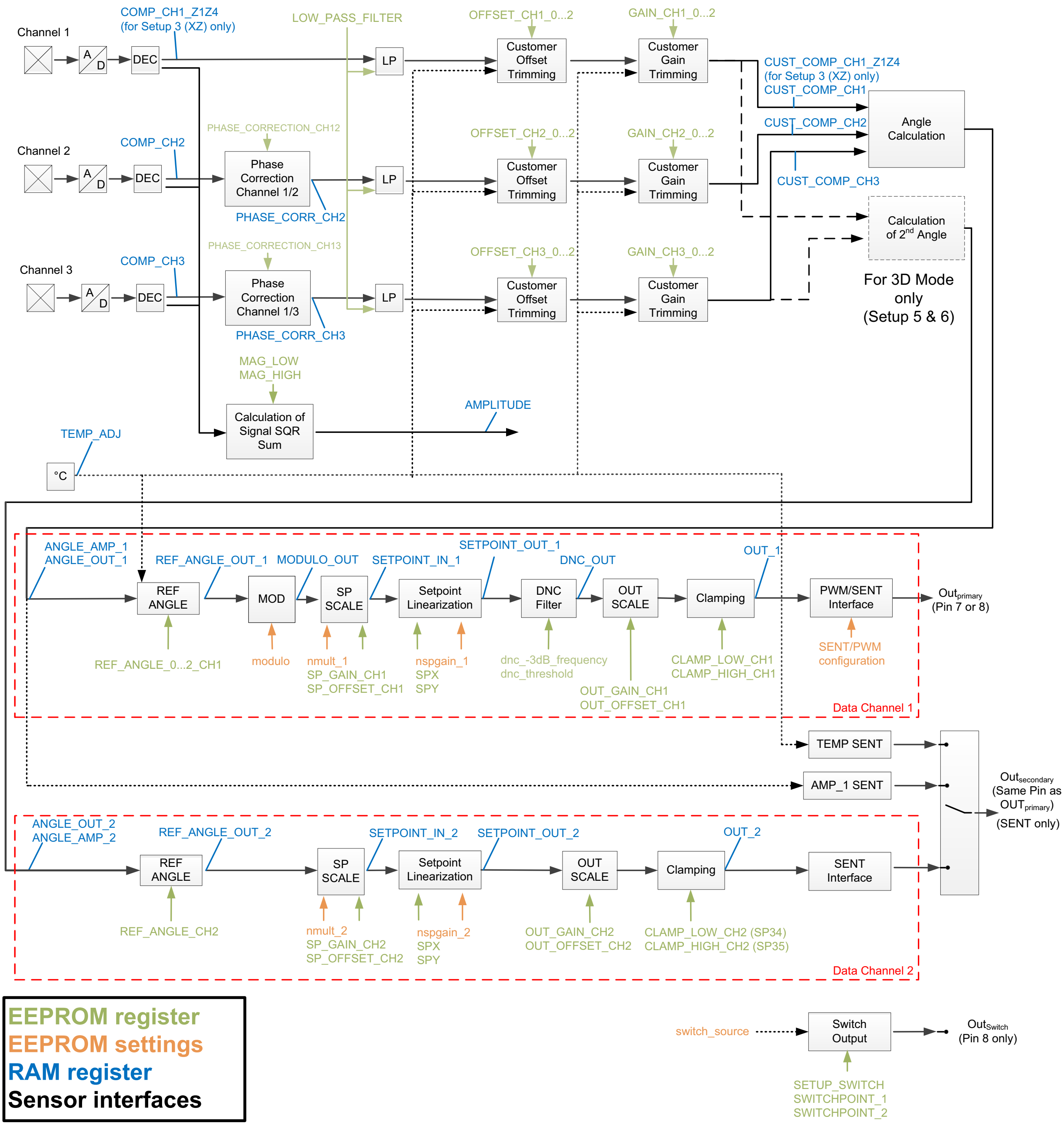


Fig. 3–3: Signal path example for die 1 of HAR 3930

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/HAC 393x User Manual.

3.3.1. RAM Register

TEMP_TADJ

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

COMP_CH1, COMP_CH2 and COMP_CH3

COMP_CH1, COMP_CH2 and COMP_CH3 registers contain the 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:

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

PHASE_CORR_CH2, PHASE_CORR_CH3

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

CUST_COMP_CH1, CUST_COMP_CH2 and CUST_COMP_CH3

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

CUST_COMP_CH1_Z1Z4

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

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 a customer configuration option only available for 3D measurements with on pixel cell enabling the calculation of a second angle out of B_X, B_Y and B_Z of Pixel1 for die 1 and Pixel2 for die 2.

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 a customer configuration option only available for 3D measurements with on pixel cell enabling the calculation of a second angle out of B_X, B_Y and B_Z.

REF_ANGLE_OUT_x

The REF_ANGLE_OUT_x registers contain the digital value of the angle information after setting the reference angle defining the zero angle position.

MODULO_OUT

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

SETPOINT_IN_x

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

SETPOINT_OUT_x

The SETPOINT_OUT_x registers contain the digital value of the angle information after the setpoint linearization block.

DNC_OUT

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

OUT_x

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

DIAGNOSIS

The DIAGNOSIS_0 and DIAGNOSIS_1 registers report certain failures detected by the sensor. HAR 3930 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 41).

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

HAR 3930 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 3–2 on page 28) 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.

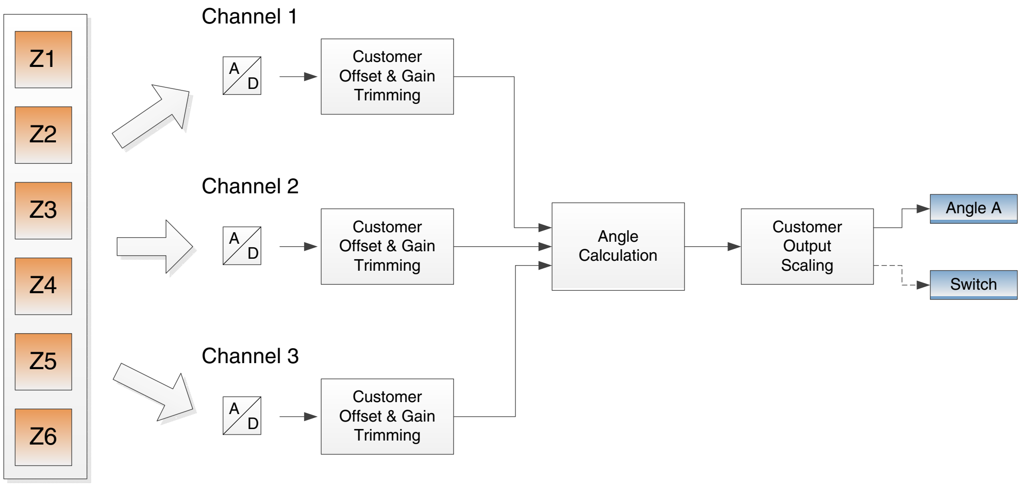


Fig. 3–4: Signal path diagram of setup 1 (stray-field robust 180° measurement; example for one die)

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

This mode uses horizontal Hall-plates to measure a 360° angular range. It requires a 2-pole magnet. The device can compensate stray-fields according to ISO 11452-8 definition. Fig. 3–5 shows the related signal path.

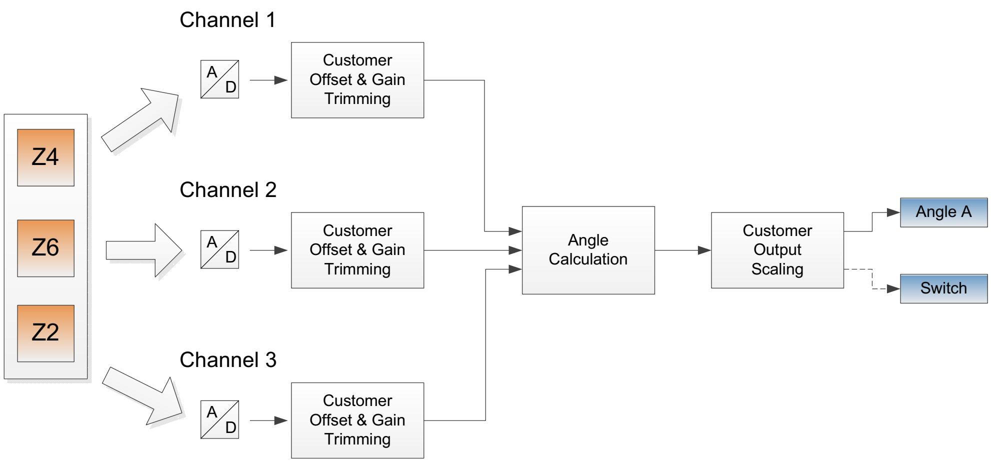


Fig. 3–5: Signal path diagram of setup 2 (stray-field robust 360° measurement; example for one die)

– 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. 3–6 shows the related signal path for the ΔXΔY setup and Fig. 3–7 the signal path for the ΔXΔZ setup.

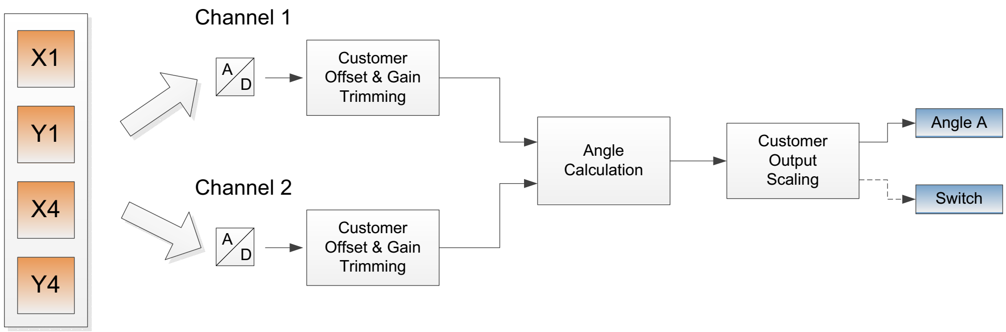


Fig. 3–6: Signal path diagram of setup 3a - ΔXΔY (stray-field robust off-axis position detection; example for one die)

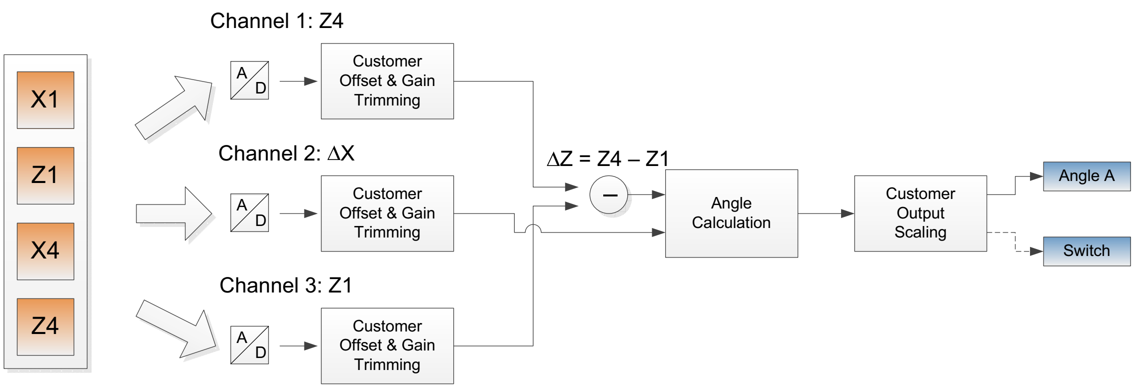


Fig. 3–7: Signal path diagram of setup 3b - ΔXΔZ (stray-field robust linear position detection; example for one die)

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

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

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

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

Note GAIN_CH1_0...2 and GAIN_CH3_0...2 must be set to the same value for this specific setup. 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 1/2. The angle will be calculated out of combinations of B_Y/B_X, B_Z/B_X or B_Z/B_Y. This mode does not compensate stray-fields. The measurement setup is similar to the well known HAL 37xy family from TDK-Micronas.

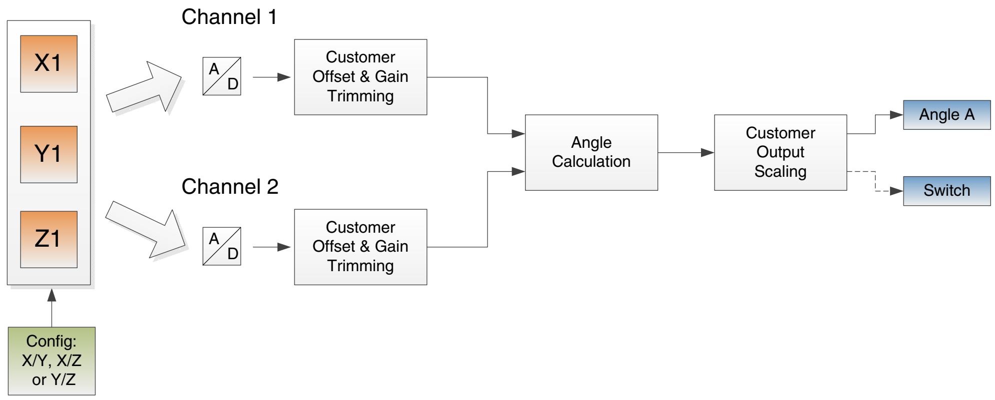


Fig. 3–8: Signal path diagram of setup 4a (Rotary and linear position detection w/o stray-field compensation; example for one die)

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

In addition to setup 4a, it is possible to select a virtual centered pixel cell mode (4b). In this mode the signals in X and Y direction of both Pixel Cells P1 and P2 are combined and averaged to generate one virtual centered pixel in the middle of the Hall-Plate array.

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

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

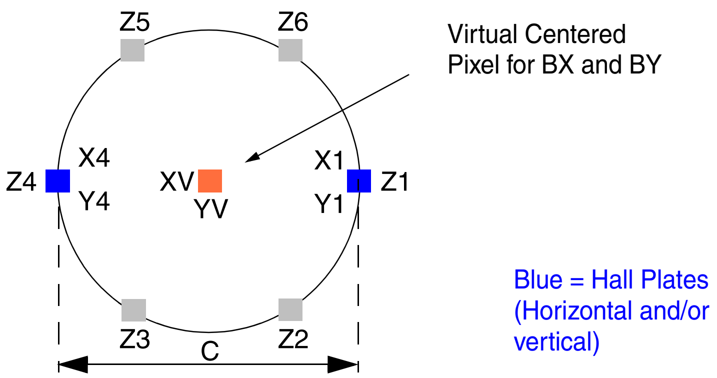


Fig. 3–9: Virtual centered pixel for B_X and B_Y in mode 4b (ex. for one die, die 2 is rotated by 180°)

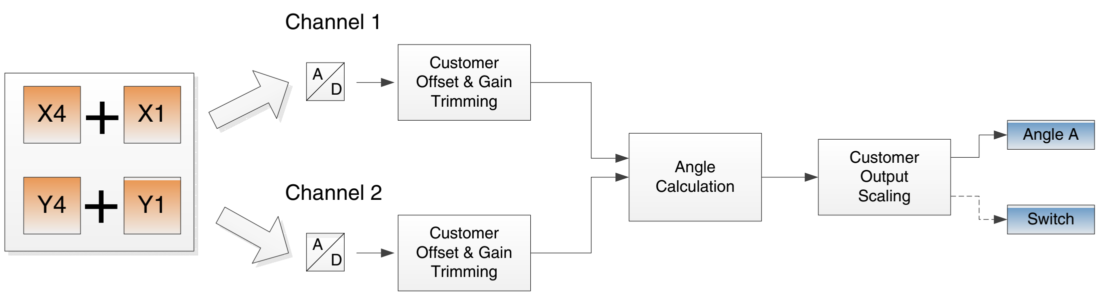


Fig. 3–10: Signal path diagram of setup 4b (virtual centered pixel w/o stray-field compensation; example for one die)

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

This mode uses horizontal and vertical Hall-plates to measure B_X, B_Y, B_Z of Pixel Cell 1/2. The angle will be calculated out of combinations of B_Z/B_X and B_Z/B_Y. This mode does not compensate any stray-fields.

The angle calculation is done by using the following equations:

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

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

Both calculated angles are sent via SENT interface by using the H.1. format (Table 3–7 on page 34). See Fig. 3–11 for detailed signal path.

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

This mode uses horizontal and vertical Hall-plates to measure B_X, B_Y, B_Z of Pixel Cell 1/2. The angle will be calculated by a special equation optimized for “joystick” setups. This mode does not compensate any stray-fields.

The angle calculation is done by using the following equations:

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

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

Both calculated angles are sent via SENT interface by using the H.1. format (Table 3–7 on page 34).

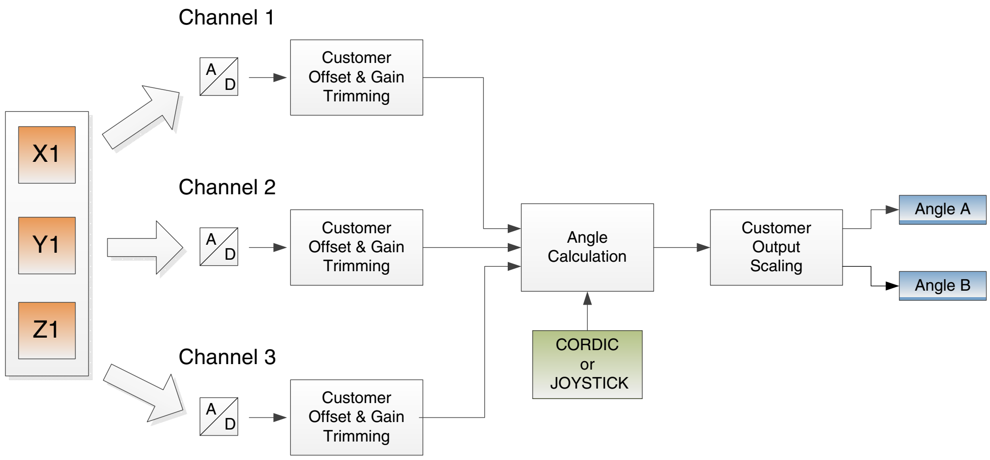


Fig. 3–11: Signal path diagram of setup 5 & 6 (3D measurement setup; example for one die)

JOYSTICK_KT

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

Customer IDs

The customer ID registers (CUSTOMER_ID0 to CUSTOMER_ID9) consist of ten times 16-bit words and can be used to store customer production information, like serial number or project information for PWM output. Additionally they are used to code SENT slow channel information like OEM codes, sensor type information and fast channel transfer characteristics. The customer IDs will be part of the SENT slow channel in case that the SENT output is activated and transmission via slow channel is selected as well. Please see Table 3–14 on page 38 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.

MAG_LOSS_OUTPUT

The MAG_LOSS_OUTPUT register has two different functions depending on the selected output format.

The device will transmit the register value as PWM duty-cycle in case of magnet loss detection (AMPLITUDE is below the Mag-Low limit). The 12 LSBs are used for the 2 kHz PWM frequency and the 13 LSBs for all other frequencies. Default value is (0x0FAD = 98% for the 12 bit value).

The device will send the 12 LSBs of this register in case of an activated SENT output and if the bit sent_mag_loss of the SETUP_PROTOCOL register has been set to one.

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 register 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 HAR 3930. The default value is zero (low pass filter disabled). The filter frequency is valid for all channels.

OFFSET_CHx_0...2

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

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

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

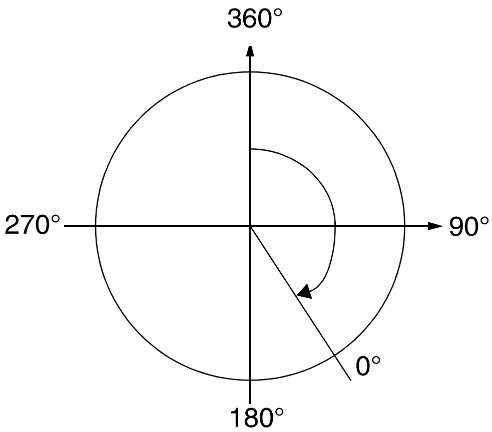


Fig. 3–12: Example definition of zero degree point

Modulo Select

HAR 3930 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. Modulo function can only be applied on the primary output channel.

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

nmult_x (EEPROM Setting)

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

Setpoint Gain

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

Setpoint Offset

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

Setpoint Linearization

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

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

The setpoint registers have a length of 16 bits and are two's complement coded. Therefore the setpoint register values can vary between –32768...32767 LSB. The setpoint x values are stored as absolute values and the setpoint y values differentially to the corresponding x values. The setpoint register values are initially set to 0 (neutral) by default.

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

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

nspgain_x (EEPROM Settings)

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

DNC Filter Register (dnc_–3dB_frequency & dnc_threshold)

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

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

OUT_GAIN_CHx

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

Clamping Levels (CLAMP-LOW & CLAMP-HIGH)

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

PWM_STD_ERROR

The PWM_STD_ERROR register defines the output duty-cycle for the PWM output in case of an internal error (except MAG_LOW or under-/overvoltage error indication). The 12 LSBs are used for the 2 kHz PWM frequency and the 13 LSBs for all other frequencies. Default value is (0x0FEB = 99.5% for the 12 bit value).

SWITCHPOINT_1 and SWITCHPOINT_2 (Switch Function)

HAR 3930 also features an additional switch output for each die. It is possible to define the switching levels with the registers SWITCHPOINT_1 and SWITCHPOINT_2. The switching levels on/off can be set in percentage of full-scale of the reference signal. Further details can be found in the HAL/HAR/HAC 393x User Manual.

SETUP_SWITCH (EEPROM Setting)

The setup switch register can be used to configure the switch behavior. It is possible to select between different sources for the switch function. Also the switch start-up state, the polarity, a hysteresis and the switch behavior (high-side or low-side) can be defined. The below table describes in detail the available combinations.

Table 3–1: SETUP_SWITCH

Bit No.	Function	Description
15	switch_enable	0: Switch function disabled 1: Switch output enabled
14	switch_startup_state	Internal (logic) state after POR, regarding hysteresis behavior 0: Output in OFF state 1: Output in ON state
13	switch_driven_lvl	0: Active level is high 1: Active level is low
12	switch_polarity	0: No output inversion 1: Output inverted
11:8	switch_source	0000: Primary output - OUT_1 0001: SETPOINT_OUT_1 0010: ANGLE_OUT_1 0011: Amplitude of primary output - ANGLE_AMP_1 0100: Secondary output - OUT_2 0101: SETPOINT_OUT_2 0110: ANGLE_OUT_2 0111: Amplitude of secondary output - ANGLE_AMP_2 1000: AMPLITUDE 1001: CUST_COMP_CH1 1010: CUST_COMP_CH2 1011: CUST_COMP_CH2 1100: COMP_CH1 1101: COMP_CH2 1110: COMP_CH3 1111: Chip temperature - TADJ
7:0	switch_hyst	Switch hysteresis switch_hyst = Switch hysteresis / 8 One LSB equals 8 counts (respectively 0.5 12 bit SENT counts)

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

Table 3–2: SETUP_FRONTEND

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: not supported				
3:0	meas_config	**Measurement setups:** 0000: Setup 4a - 2D [1] 0001: Setup 4a - 2D [1] 0010: Setup 4a - 2D [1] 0011: Setup 3b - 2D - Strayfield compensated 0100: Setup 3a - 2D - Strayfield compensated 0101: Setup 4b - 2D - Virtual centered pixel 0110: Setup 1 - 180° rotary - strayfield compensated 0111: Setup 2 - 360° rotary - strayfield compensated 1000: Setup 5 - 3D measurement - ATAN2 [1] 1001: Setup 5 - 3D measurement - Joystick [1] 1010 to 1111: Must not be used	**Correspond. Signal Path** With two channel With two channel With two channel With two channel With two channel With two channel 6 Z Hall-plates 3 Z Hall-plates With three channel With three channel -	**CH1** X1 Z1 Z1 Z4 X4-X1 X1+X4 Z1+Z4 Z4 Z1 Z1 -	**CH2** Y1 Y1 X1 X4-X1 Y4-Y1 Y1+Y4 Z2+Z5 Z6 X1 X1 -	**CH3** - - - Z1 - - Z3+Z6 Z2 Y1 Y1 -

[1] Die 1 is using Pixel 1 with X1, Y1, Z1 and die 2 is using Pixel 2 with X4, Y4, Z4 to have both sensitive areas aligned for these modes.

Table 3–3: SETUP_DATAPATH

Bit No.	Function	Description
15:12	nspgain_2	Gain exponent for setpoint slope in channel 2: Slope = SPGn * (2^nspgain_2+1)
11:9	nmult_2	Gain exponent for SETPOINT_IN2: SP_GAIN = SP_GAIN_CH2 * [2^(nmult_2)]
0	two_channels	Activation of second output channel 0: 1 channel with setpoints 1: 2 channels with setpoints each
7:5	nmult_1	Gain exponent for SETPOINT_IN1: SP_GAIN = SP_GAIN_CH1 * [2^(nmult_1)]
4:1	nspgain_1	Gain exponent for setpoint slope in channel 1: Slope = SPGn * (2^nspgain_1+1)
0	variable_setpoints	Fixed/variable setpoint selection: 0: Fixed setpoints 1: Variable setpoints

The SETUP_OUTPUT register is used to configure the two output pins OUT1(3) and OUT2(4). First of all, it is possible to define the output pin for the primary output protocol pin, i.e. OUT1(3) or OUT2(4). This can be SENT or PWM. OUT1(3) can be configured as push-pull output with different slew rates (V_{OUTmax} < 5.5 V) or as an open-drain output without slew rate control. OUT2(4) is as well a push-pull output, but the max. output voltage is V_{SUP}. It can be configured as open-drain or push-pull output. For both outputs a protection circuit is still connected to V_{SUP} (in open-drain output configuration) so that V_{OUT} shall not be higher than V_{SUP}.
Furthermore, this register is used to define the error behavior in case of a PWM output, the signal frequencies as well as the configuration of the SENT output. Further details can be found in table (Table 3–4).

Table 3–4: SETUP_OUTPUT

Bit No.	Function	Description
15	primary_output	Primary output protocol selection (OUT1/3): 0: PWM 1: SENT
14	primary_out_pin	Defines which output pin is used for the primary output 0: OUT1/3 - with slew rate control; push-pull output 1: OUT2/4 - no slew rate control; open-drain output
PWM Output (SETUP_OUTPUT[15] = 0)		
13:10	pwm_slew_rate	PWM slew rates (OUT1/3 only): 0xxx: slew rate control disabled 1000: Fall = 5 V/0.5 µs, Rise = 5 V/0.5 µs 1001: Fall = 5 V/0.5 µs, Rise = 5 V/1.3 µs 1010: Fall = 5 V/0.7 µs, Rise = 5 V/0.7 µs 1011: Fall = 5 V/0.7 µs, Rise = 5 V/2.6 µs 1100: Fall = 5 V/1.3 µs, Rise = 5 V/1.3 µs 1101: Fall = 5 V/1.3 µs, Rise = 5 V/5.2 µs 1110: Fall = 5 V/2.6 µs, Rise = 5 V/2.6 µs 1111: Fall = 5 V/2.6 µs, Rise = 5 V/10.4 µs Measured from 1.1V to/from 3.8 V with C_{LOUT} = 1 nF
9:8	-	Must be set to 0.
7	pwm_open_drain	This bit defines if OUT1/3 is used as push-pull or open-drain output. 0: Push-pull 1: Open-drain (protection diode to VSUP still connected)
6	pwm_uvov_diag	Output behavior for undervoltage/overvoltage detection 0: Will be signalized as selected for all other diagnosis bits 1: Will be signalized with 2 % duty-cycle
5	pwm_inverted	PWM inverted: 0: Disabled 1: Enabled
4	-	Reserved
3:0	pwm_frequency	Min. PWM frequency 0000: 2.0 kHz 0001: 1.5 kHz 0010: 1.0 kHz 0011: 800 Hz 0100: 550 Hz 0101: 500 Hz 0110: 250 Hz 0111: 200 Hz 1000: 150 Hz 1001: 125 Hz 1010: 100 Hz 1011 to 1111: Not allowed Typical values are 3% higher.

Table 3–4: SETUP_OUTPUT, continued, continued

Bit No.	Function	Description	
SENT Output (SETUP_OUTPUT[15] = 1)			
13:10	sent_slew_rate	SENT slew rates (OUT1/3 only): 0xxx: slew rate control disabled 1000: Fall = 5 V/0.5µs, Rise = 5 V/0.5µs 1001: Fall = 5 V/0.5µs, Rise = 5 V/1.3µs 1010: Fall = 5 V/0.7µs, Rise = 5 V/0.7µs 1011: Fall = 5 V/0.7µs, Rise = 5 V/2.6µs 1100: Fall = 5 V/1.3µs, Rise = 5 V/1.3µs 1101: Fall = 5 V/1.3µs, Rise = 5 V/5.2µs 1110: Fall = 5 V/2.6µs, Rise = 5 V/2.6µs 1111: Fall = 5 V/2.6µs, Rise = 5 V/10.4 µs Measured from 1.1V to/from 3.8 V with C_{LOUT} = 1 nF	
9:8	sec_out	Secondary output selection (2nd fast channel SENT): 0: Reserved 1: Transmission of second angle (SENT format H.1 - Table 3–6 on page 33) 2: Transmission of magnetic amplitude (SENT format H.1 - Table 3–6 on page 33) 3: Transmission of chip temperature (SENT format H.1 - Table 3–6 on page 33	
7:4	sent_tt	SENT tick time selection (typ. value) 0000: 0.50 µs 0001: 1.00 µs 0010: 1.50 µs 0011: 2.00 µs 0100: 2.50 µs 0101: 2.75 µs 0110: 3.00 µs 0111: 6.00 µs 1000: 12.0 µs 1001 to 1111: reserved and mapped to 0. **Note:** Not all combinations of tick time and repetition rate are possible.	
3:0	sent_fr	SENT data rate 0000: Not allowed 0001: 4.00 kHz 0010: 2.66 kHz 0011: 2.00 kHz 0100: 1.60 kHz 0101: 1.00 kHz 0110: 0.80 kHz 0111: 0.50 kHz	SENT message length 1000: 225 ticks 1001: 239 ticks 1010: 250 ticks 1011: 269 ticks 1100: 294 ticks 1101: 366 ticks 1110: 375 ticks 1111: 450 ticks

3.4. SENT Output Protocol

HAR 3930 complies with the SAEJ2716 standard rev. 4 and supports the following three frame formats:

– H.1 Format: Two 12-bit fast channels
  - A.1 Dual Throttle Position Sensors: 3 nibble position information and 3 nibble negated position information (1-position)
  - A.7 Position Sensors: 3 nibble position information and 3 nibble second position information or temperature information or magnetic-field amplitude

– H.2 Format: One 12-bit fast channel (3 nibble position information)

– H.4 Format: Secure Single Sensors with 12-bit fast channel (3 nibble position information) and 12-bit secure sensor information

All frame formats are customer selectable via bits (Table 3–5 on page 31).

Beside the supported frame formats, many other SENT interface parameter can be configured by the customer, like tick time, pause pulse, start-up behavior, transmission of error codes, serial message channel content, etc. All configurable parameter are defined in Table 3–4 and Table 3–5.

In SENT output mode, the unidirectional communication from the sensor to a receiver module (e.g. an Electronic Control Unit) occurs independently of any action of the receiver module. It does not require any synchronization signal from the receiver module and does not include a coordination signal from the controller/receiving devices.

Table 3–5: SETUP_PROTOCOL

Bit No.	Function	Description
15:14	sent_fchf	SENT fast channel data format: 00: H.2 format: 12-bit fast channel (3 nibble position information) 01: H.4 format: Secure Single Sensors 10: H.1 format: A.1 Format for Dual Throttle Position Sensors 11: H.1 format: A.7 Format with 3 nibble position information and secondary channel
13:12	sent_lowt	SENT low time: 00: 3 ticks 01: Not allowed 10: 5 ticks 11: 6 ticks
11	sent_crc	0: CRC according to SAE J2716 > rev. 2 (2010) 1: CRC according to SAE J2716 rev. 1 (2008 - legacy CRC)
10	sent_scrc	Include STATUS nibble in CRC 0: Disabled (According to SENT SAE J2716) 1: Enabled

Table 3–5: SETUP_PROTOCOL, continued

Bit No.	Function	Description
9	sent_sub	Definition of start-up behavior: 0: Transmission of 4094 during start-up 1: Transmission of 0 during start-up (recommended by SENT SAE J2716)
8	sent_pp	Pause pulse activation 0: Disabled (SENT continuous) 1: Enabled (SENT with pause pulse)
7	sent_mag_loss	Defines the behavior of the SENT output in case of magnet loss: 0: Fast channel value 4091 or 4095 depending on sent_fchf 1: Fast channel value = MAG_LOSS_OUTPUT register value (fast channel status bits not set and no error on slow channel)
6	sent_err	Definition of error status bits (see Section 3.4.4. on page 36): 0: Always zero 1: According to SAE J2716
5	sent_ferr	Definition of fast channel error codes 0: Disabled 1: Enabled
4	sent_schf	Slow serial channel format: 0: No serial message channel 1: 12-bit enhanced serial message format
3:1	sent_schc	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	SENT SDF mode: 0: Send diagnosis info in front of every block 1: Send diagnosis info in front of every ID

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

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

Two different application specific protocols are supported:

– A.1 Dual Throttle Position Sensors

– A.7 Position Sensors

In case of A.1 the first 3 data nibbles contain a 12-bit position information and the second 3 data nibbles contain the negated position of the first 3 nibbles (1-position).

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

In case of A.7 the first 3 data nibbles contain a 12-bit position information and the second 3 data nibbles contain a 12-bit temperature information, 12-bit magnetic-field amplitude information or a second angle (customer configurable: Table 3–4). They are formatted according to Table 3–6.

Table 3–6: Nibble description for H.1 A.1 format

Pulse		Remarks
#	**Description**	
1	Synchronization/Calibration	It is mandatory to measure the synchronization / calibration period for calibration of the clock tick time t_{tick} at the ECU
2	4-bit Status & Communication Nibble	Status [0...1]: According to selection in Table 3–5 bit[6] Status [2...3]: According to selection in Table 3–5 bit[4]
3	4-bit Data Nibble MSN 1	Position Value [11:8]
4	4-bit Data Nibble MidN 1	Position Value [7:4]
5	4-bit Data Nibble LSN 1	Position Value [3:0]
6	4-bit Data Nibble LSN 2	Negated Position Value [3:0]
7	4-bit Data Nibble MidN 2	Negated Position Value [7:4]
8	4-bit Data Nibble MSN 2	Negated Position Value [11:8]
9	4-bit CRC Nibble	According to selection in Table 3–5 bit[11]
10	Pause Pulse	According to selection in Table 3–5 bit[8]

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

Pulse		Remarks
#	Description	
1	Synchronization/Calibration	It is mandatory to measure the synchronization / calibration period for calibration of the clock tick time t_{tick} at the ECU
2	4-bit Status & Communication Nibble	Status [0...1]: According to selection in Table 3–5 bit[6] Status [2...3]: According to selection in Table 3–5 bit[4]
3	4-bit Data Nibble MSN 1	Position Value [11:8]
4	4-bit Data Nibble MidN 1	Position Value [7:4]
5	4-bit Data Nibble LSN 1	Position Value [3:0]
6	4-bit Data Nibble LSN 2	Value [3:0]: According to selection in Table 3–4 bits[9:8]
7	4-bit Data Nibble MidN 2	Value [7:4]: According to selection in Table 3–4 bits[9:8]
8	4-bit Data Nibble MSN 2	Value [11:8]: According to selection in Table 3–4 bits[9:8]
9	4-bit CRC Nibble	According to selection in Table 3–5 bit[11]
10	Pause Pulse	According to selection in Table 3–5 bit[8]

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

Following application specific protocol is supported:

– A.7 Position Sensors

In this mode the sensor transmits SENT frames with 3 data nibbles containing 12-bit position information. They are formatted according to Table 3–8.

Table 3–8: Nibble description for 3 data nibble frame format with one fast channel

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

3.4.3. H.4 Format: Secure Single Sensors with 12-bit Fast Channel

The following application specific protocol is supported:

– A.7 Position Sensors

In this SENT mode, the sensor transmits SENT frames with 3 data nibbles containing 12-bit position information as well as 3 data nibbles containing 12-bit secure sensor information. The secure sensor information consists of an 8-bit rolling counter and the inverted copy of the MSN of the transmitted position information. They are formatted according to Table 3–9.

Table 3–9: Nibble description for 6 data nibble frame format with secure information

Pulse		Remarks
#	Description	
1	Synchronization/Calibration	It is mandatory to measure the synchronization / calibration period for calibration of the clock tick time t_{tick} at the ECU
2	4-bit Status & Communication Nibble	Status [0...1]: According to selection in Table 3–5 bit[6] Status [2...3]: According to selection in Table 3–5 bit[4]
3	4-bit Data Nibble MSN 1	Position Value [11:8]
4	4-bit Data Nibble MidN 1	Position Value [7:4]
5	4-bit Data Nibble LSN 1	Position Value [3:0]
6	4-bit Data Nibble MSN 2	Rolling Counter MSN
7	4-bit Data Nibble MidN 2	Rolling Counter LSN
8	4-bit Data Nibble LSN 2	Inverted Copy of Data Nibble MSN 1
9	4-bit CRC Nibble	According to selection in Table 3–5 bit[11]
10	Pause Pulse	According to selection in Table 3–5 bit[8]

3.4.4. Error Diagnostic Reporting on Fast Channel and Status Bits

The error diagnostic reporting is customer configurable. By setting the bit[6] in the SETUP_PROTOCOL register (see Table 3–5 on page 31) 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		A.1 Mode	
	CH 1	CH 2	CH1	CH2
A.1 error code [2)]	–	–	4095	4095
Sensor error indication [2)]	4091	4091	N/A	N/A
Sensor functionality and processing error indication	4090	4090	–	–
Data Clamping: High	[1)]	[1)]	[1)]	[1)]
Data Clamping: Low	[1)]	[1)]	[1)]	[1)]

[1)] The output will clamp according to the settings for CLAMP_HIGH and CLAMP_LOW.
[2)] In case that sent_mag_loss in the SETUP_PROTOCOL register is set to 0.

A description with the mapping of internal errors with “Sensor error indication” and “Sensor functionality and processing error indication” can be found in Table 3–15 on page 40.

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 31). The sensor will then continue to transmit measurement data. Status error bits will be transmitted according to bit[6] in the SETUP_PROTOCOL register. In case that bit[7] of the SETUP_PROTOCOL register is activated a magnet loss detection will not be indicated as an error. The device will transmit instead the value of the MAG_LOSS_OUTPUT register.

3.4.5. Pause Pulse

HAR 3930 offers two options for the pause pulse. It can be enable or disabled. In case that the pause pulse is enabled it is present at the end of every frame as defined by the SAE J2716 standard (PPC). There is no pause pulse in case that it is disabled by the customer (NPP). In that case is the falling edge after the CRC nibble identical with the leading edge at the beginning of the next frame.

– **PPC:** The length of the pause pulse is automatically adjusted in order to achieve a constant frame length independent from the message content. The overall length can be defined by the sent_fr bits (SETUP_OUTPUT bits [3:0]). Two different types of PPC are supported. For the first type the overall frame length is defined in fixed multiples of the tick time and for the second type the frame length is adapted to the selected sample rate (see Table 3–4 on page 29 bits [3:0]).

Table 3–11: Message length for ticks PPC (ticks related)

SETUP_OUTPUT [3:0]	1000	1001	1010	1011	1100	1101	1110	1111
ticks PPC	225	239	250	269	294	366	375	450

Following PPC message length are supported for the various frame formats:

Table 3–12: Recommended PPC message length

ticks PPC	H.1 A.1 Format: 6 Data Nibble Frame	H.1 A.7 Format: 6 Data Nibble Frame	H.2 A.7 Format: 3 Data Nibble Frame	H.4 A.7: Secure Single Sensor
	PP Length [ticks]	PP Length [ticks]	PP Length [ticks]	PP Length [ticks]
225	-	-	36	-
239	-	-	50	-
250	-	-	61	-
269	44	-	80	-
294	69	24	105	39
366	141	96	177	111
375	150	105	186	120
450	225	180	261	195

Table 3–13: Message repetition rate for PPC (sampling aligned)

SETUP_OUTPUT [3:0]	0000	0001	0010	0011	0100	0101	0110	0111
Frequency PPC [kHz]	-	4.00	2.66	2.00	1.60	1.00	0.80	0.50

– **NPP:** In case of deactivated pause pulse (NPP) it is possible that some samples may be transmitted twice in series due to the fact that the message time can be shorter than the sample time. Status bit [0] will then be set to one in case that a sample is transmitted twice.

3.4.6. CRC Implementation

HAR 3930 supports the recommended CRC implementation defined in SAEJ2716 rev. 4. The legacy CRC can also be activated by bit[11] in the SETUP_PROTOCOL register (see Table 3–5 on page 31). It is possible to include the status nibble in the CRC calculation. This function can be activated by bit[10] in the SETUP_PROTOCOL register as well.

3.4.7. Slow Channel: Enhanced Serial Message

HAR 3930 supports a slow channel according to the enhanced serial message with 12-bit data and 8-bit message ID. It is possible to deactivate the slow channel by changing bit[4] in the SETUP_PROTOCOL register.

3.4.8. Slow Channel: Serial Message Sequence

The device can transmit the serial message sequence shown in Table 3–14. The content/length of the serial message can be tailored by configuration bits in the SETUP_PROTOCOL register (see Table 3–5 on page 31). It is possible to activate up to five blocks. Block 1 will always be transmitted if the serial message channel is activated.

Table 3–14: Serial message sequence

Block	#	8-bit ID	Item	12-bit Data	Comment
1	1	0x01	Error Codes	(see Table 3–15 on page 40)	
	2	0x03	Sensor type		Bits 0...11 in CUSTOMER_ID0 register (12 bit) Examples: 0x050 = not specified position sensor 0x055 = position & 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 3–15 on page 40)	
	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

Table 3–14: Serial message sequence, continued

Block	#	8-bit ID	Item	12-bit Data	Comment
3	11	0x01	Error Codes	(see Table 3–15 on page 40)	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 3–15 on page 40)	
	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
5	21	0x01	Error Codes	(see Table 3–15 on page 40)	
	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 (see Table 3–5 on page 31).

3.4.9. 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. HAR 3930-2300 features the error codes described in Table 3–15.

Table 3–15: 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) (only if sent_mag_loss bit in the SETUP_PROTOCOL register is not set to 1)	4091
11	Always set to one	-

3.4.10. Start-Up Behavior

The device can either transmit frames with value zero until a valid information is available (SAEJ2716 conform) or alternatively frames with 4094. The start-up behavior is customer configurable by bit[9] in the SETUP_PROTOCOL register.

3.4.11. Message Time for SENT Frames in PP Mode

The SENT frame repetition frequency (sent_fr in SETUP_OUTPUT[3:0] register) is defined by the position sampling frequency. The selectable SENT frame repetition frequency is limited by the configured tick time, the transmitted data value and the minimum and maximum pause-pulse duration.

The tick time is customer programmable and can be selected between 0.5 µs and 12 µs (Table 3–4 on page 29).

The pulse low time can be configured to 3, 5 and 6 ticks.

4. Functional Safety

4.1. Functional Safety Manual and Functional Safety Report

The Functional Safety Manual for HAR 3930 contains the necessary information to support customers to realize a safety compliant application by integrating HAR 3930, as an ASIL B ready component, in their system. It can be integrated in automotive safety related systems up to ASIL D. 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 Mechanism

HAR 3930 performs self-tests during start-up and normal operation. These increase the robustness of the device functionality by either preventing the sensor to provide wrong output signals or by reporting the failure according to SENT definition or diagnostic levels in case of PWM output. Further details about error reporting in case of SENT output see Section 3.4.9. on page 40.

For the PWM output signal the sensor is signalizing errors by providing a fixed duty-cycle. This duty-cycle can be defined by the registers PWM_STD_ERROR and MAG_LOSS_OUTPUT. Additionally it is possible to report under- and overvoltage events with a separate duty-cycle of 2%. The behavior is customer configurable. Further details can be found from page 27 to page 29.

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

Table 4–1: DIAGNOSIS_0 register

Bit no.	Description when bit is set to 1
15	DSP self-check routines (redundancy or plausibility checks)
14	DSP and µC check of 16-bit checksum covering the EEPROM parameter
13	DSP checksum for ROM and RAM
12	Chip junction temperature out of range
11	Plausibility check of redundant temperature sensor
10	Hall-plate supply too high
9	Hardware overtemperature supervision: Junction temperature > 180°C
8	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

Table 4–1: DIAGNOSIS_0 register, continued

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

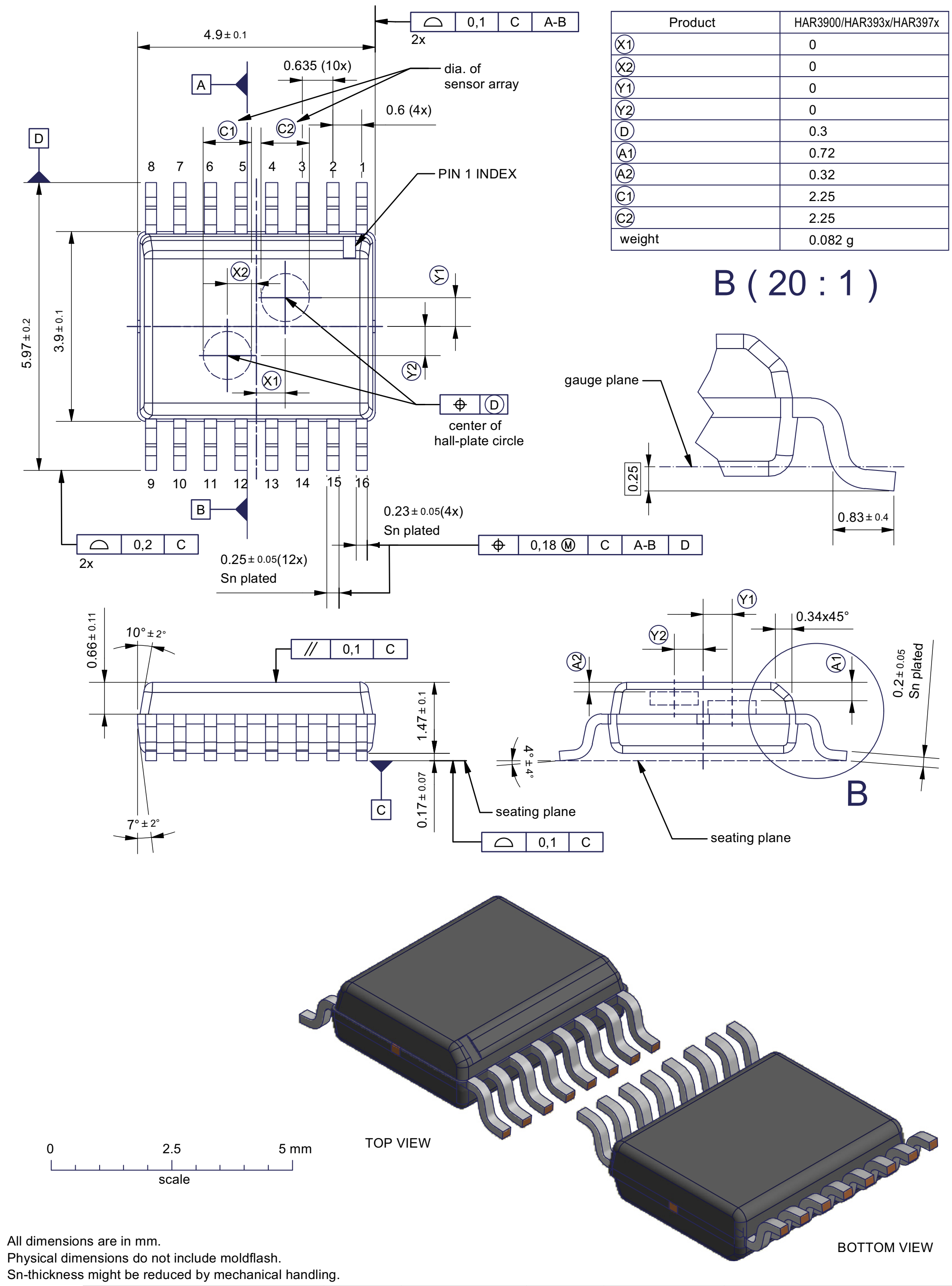
Table 4–2: DIAGNOSIS_1 register

Bit no.	Description when bit is set to 1
15	Reserved
14, 12	General purpose ADC error
13	Reserved
11	Undervoltage Error. Supply voltage out of range
10	Overvoltage Error. Supply voltage out of range.
9	Internal analog voltage out of range
8	Internal digital voltage out of range
Note: Bits[7:0] can not be read via the programming interface as they are triggering immediately a reset of the device.	
7	µC self-test error
6	µC ROM OP code error
5	µC memory OP code error
4:2	Reserved
1	Error in analog part
0	Reserved

5. Specifications

5.1. Outline Dimensions

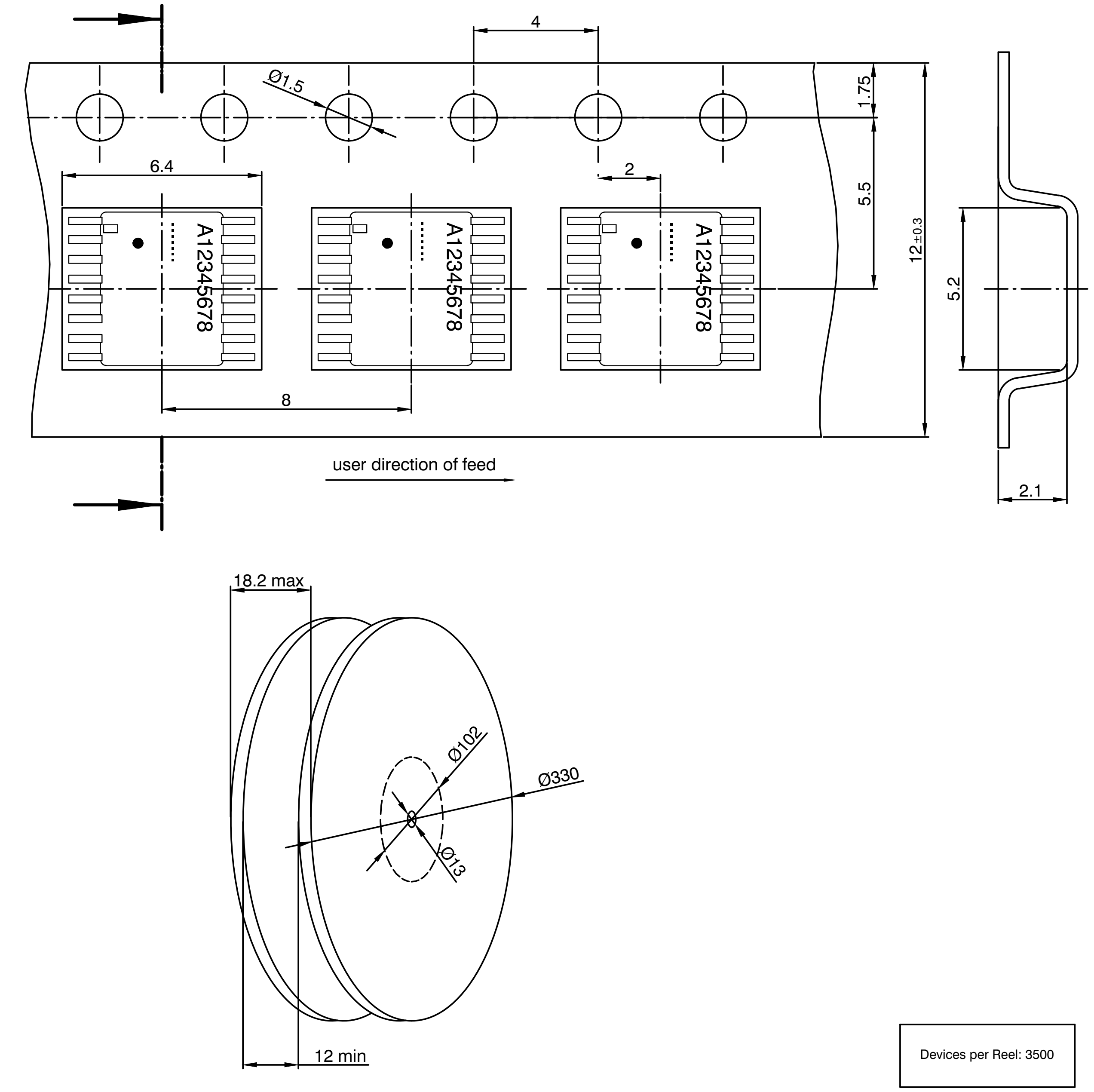
Product	HAR3900/HAR393x/HAR397x
X1	0
X2	0
Y1	0
Y2	0
D	0.3
A1	0.72
A2	0.32
C1	2.25
C2	2.25
weight	0.082 g



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

PACKAGE	ISSUE DATE (YY-MM-DD)	JEDEC STANDARD ITEM NO.	JEDEC STANDARD ISSUE	ANSI	REVISION DATE (YY-MM-DD)	REV.NO.	DRAWING-NO.	SPECIFICATION TYPE	SPECIFICATION NO.
SSOP16-1	20-01-17	MO-137	E		22-05-02	2	CSSOP0163007.1	ZG	2109_Ver.02

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



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

Fig. 5–2: SSOP16: Tape and Reel Finishing

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 array: C = 2.25 mm

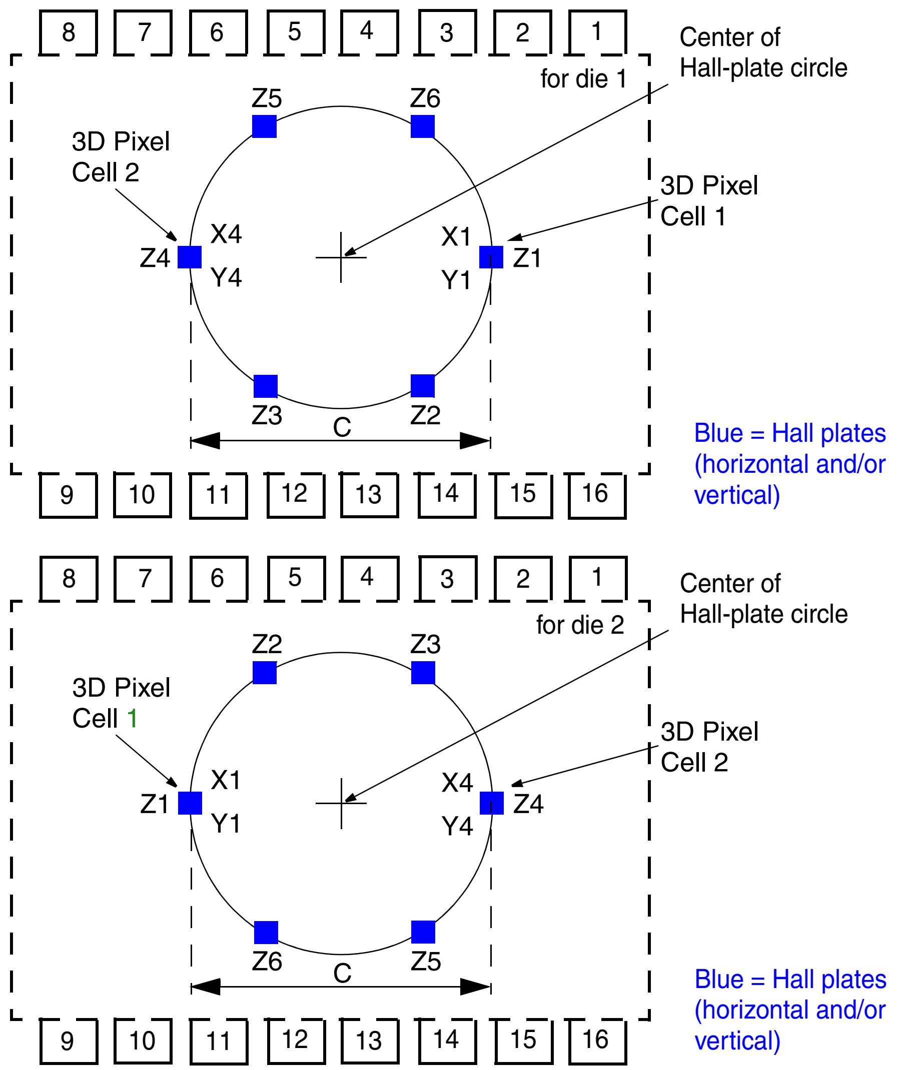


Fig. 5–3: Hall-plate configuration

5.5. Definition of Magnetic-Field Vectors

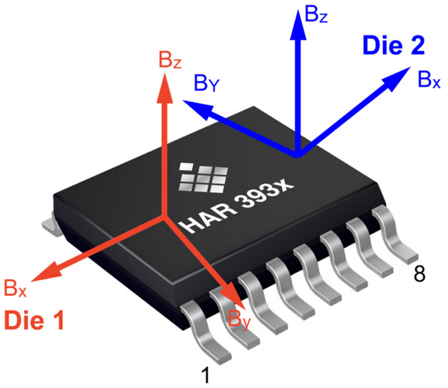


Fig. 5–4: Definition of magnetic-field vectors for HAR 3930

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

5.6. Pin Connections and Short Description

Table 5–1: Pin connection SSOP16

Pin No.	Pin Name	Type	Short Description
Die 1			
1	TEST1	IN	Test
2	TEST2	N/A	Test
3	VSUP1	IN	Supply voltage
4	TEST3	N/A	Test
5	GND1	GND	Ground
6	TEST4	N/A	Test
7	OUT1	I/O	PWM/SENT output and programming
8	OUT2	OUT	PWM/SENT or Switch output
Die 2			
9	TEST5	IN	Test
10	TEST6	N/A	Test
11	VSUP2	IN	Supply voltage
12	TEST7	N/A	Test
13	GND2	GND	Ground
14	TEST8	N/A	Test
15	OUT3	I/O	PWM/SENT output and programming
16	OUT4	OUT	PWM/SENT or Switch output

Note Pins 5, 6, 13, and 14 must be connected to GND. Pins 1, 2, 4, 9, 10, and 12 should stay open.

5.7. Absolute Maximum Ratings

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

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

All voltages listed are referenced to ground (GND).

Symbol	Parameter	Pin Name	Min.	Max.	Unit	Condition
V_{SUP}	Supply Voltage	VSUPx	–18	28 37	V V	 t < 60s; T_J = 25 °C
V_{OUT13}	Output Voltage Output 1/3 (PWM/SENT)	OUT1/3	–2	28	V	t < 96h
V_{OUT13}-V_{SUP}	Excess of Output Voltage 1/3 over Supply Voltage	OUT1/3	–	7	V	t < 96h V_{SUP} < 5.5 V
V_{OUT24}	Output Voltage Output 2/4 (Switch/PWM/SENT)	OUT2/4	–0.3	28	V	t < 96 h
V_{OUT24}-V_{SUP}	Excess of Output Voltage 2/4 over Supply Voltage	OUT2/4	–	0.3	V	t < 96 h
I_{OUTx}	Output Current Output 1 & 2	OUTx	–125	125	mA	t < 96 h; May occur at GND or V_{SUP}
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][3]
$T_{storage}$	Transportation/Short Term Storage Temperature	–	–55	150	°C	Device only without packing material

[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] Supply voltages above V_{SUP} = 5.5 V limit the max. ambient temperature range due to increased self-heating of the device.
No cumulative stress for all parameters.

Symbol	Parameter	Pin Name	Min.	Max.	Unit	Condition
V_{ESD}	ESD Protection	VSUPx, OUTx, GND, TESTx	–2	2	kV	3)
		VSUPx, GNDx	–15	15	kV	4) 5)
		OUT1/3	–8	8	kV	4)
		OUT2/4	–4	4	kV	4)

3) AEC-Q100-002 (100 pF and 1.5 kΩ)
4) Unpowered gun test (150 pF/330 Ω unbiased system ESD not passed with this network) according to ISO 10605-2008
5) With additional protection on the PCB (470 nF on VSUP)
No cumulative stress for all parameters.

5.8. Recommended Operating Conditions

Functional operation of the device beyond those indicated in the “Recommended Operating Conditions/Characteristics” is not implied and may result in unpredictable behavior, reduced reliability and lifetime of the device.

All voltages listed are referenced to ground (GND).

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Condition
V_{SUP}	Supply Voltage	VSUPx	3.0	–	18	V	
V_{OUT13}	Output Voltage (PWM/SENT)	OUT1/3	–	–	5.5	V	Push-Pull configuration
			–	–	18	V	Open-Drain; V_{SUP} = 18 V
V_{OUT24}	Output Voltage (Switch/PWM/SENT)	OUT2/4	–	–	18	V	
I_{OUT}	Output Current	OUTx	–20	–	20	mA	
R_{LOUT13}	Output Load (PWM/SENT)	OUT1/3	1	–	–	kΩ	Pull-up or pull-down resistor optional. Programming not possible with pull-down.
			10	–	55	kΩ	SENT output Pull-up or pull-down resistor optional
R_{LOUT24}	Pull-up/-Down Resistor (Switch)	OUT2/4	0.5	–	–	kΩ	Pull-up or pull-down resistor optional
C_{LOUT}	Load Capacitance	OUTx	–	1	10	nF	
N_{PRG}	Number of Memory Programming Cycles	–	–	–	100	cycles	0 °C < T_{amb} < 55 °C
B_{AMP}	Recommended Magnetic-Field Amplitude	–	±10	–	±130	mT	Max. value for setup 4b is ± 65 mT
T_J	Junction Temperature [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 limit the max. ambient temperature range due to increase self-heating of the device (see Section 6.1. on page 60)

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

5.9. Characteristics

at T_A = –40 °C to 150 °C, V_{SUP} = 3.0 V to 5.5 V, GND = 0 V, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”.
Typical Characteristics for T_A = 25 °C and V_{SUP} = 5 V.
Reduced ambient temperatures enable usage of the device at higher supply voltages.

Symbol	Parameter	Pin Name	Limit Values			Unit	Conditions
			Min.	Typ.	Max.		
I_{SUP}	Supply Current	VSUPx	–	8	12	mA	[1] Current consumption of each die
f_{osc}	Internal Oscillator Frequency		–	32	–	MHz	
f_{sample}	Sampling Frequency		–	1.953	–	kSps	[1] Configurable
			–	3.906	–		
			–	7.812	–		
Power-On Behavior							
V_{POR}	Power_On Reset Voltage	VSUPx	2.1	2.6	2.9	V	
$V_{PORHyst}$	Power_On Reset Voltage Hysteresis	VSUPx	–	200	–	mV	
Overvoltage and Undervoltage Detection							
$S_{VSUP,UOV}$	Step Size of Under-/Overvoltage Supervision Threshold	VSUPx	92	100	108	mV/LSB	[1] Under-/Overvoltage threshold is customer configurable (see page 27).
$S_{VSUP,UOVhys}$	Under-/Overvoltage Detection Level Hysteresis	VSUPx	–	1	–	LSB	[1] 1 LSB typ. 100 mV
Main Outputs OUT1 & OUT 3 for SENT and PWM (Push-Pull Configuration with edge shaping)							
V_{OL13}	Output Low Voltage	OUT1/3	–	6	8	%VSUP	V_{SUP} = 5.5 V, $R_L = \infty$
V_{OH13}	Output High Voltage	OUT1/3	91	94	–	%VSUP	V_{SUP} = 5.5 V, $R_L = \infty$
$V_{OH,Clamp}$	Output High Clamping Voltage	OUT1/3	–	5.2	5.4	V	V_{SUP} > 5.5 V, $R_L = \infty$
$V_{OL,Clamp}$	Output Low Clamping Voltage	OUT1/3	–	0.34	0.44	V	V_{SUP} > 5.5 V, $R_L = \infty$
R_{OUT13}	Output Resistance	OUT1/3	70	90	120	Ω	Max. 10 Ω series resistor allowed @ V_{SUP} = 5 V
I_{Leak13}	Output Leakage Current	OUT1/3	–25	–	25	µA	$V_{OUT1/3}$ < 5.5 V

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

Symbol	Parameter	Pin Name	Limit Values			Unit	Conditions
			Min.	Typ.	Max.		
t_{rise_sym}	Rise Time of Output symmetrical to Fall Time (recommended for PWM)[1)2)]	OUT1/3	–	0.5	–	μs	sent_slew_rates bit = 1000
			–	0.7	–		sent_slew_rates bit = 1010
			–	1.3	–		sent_slew_rates bit = 1100
			–	2.6	–		sent_slew_rates bit = 1110
t_{rise_asym}	Rise Time of Output asymmetrical to Fall Time (recommended for SENT)[1)2)]	OUT1/3	–	1.3	–	μs	sent_slew_rates bit = 1001
			–	2.6	–		sent_slew_rates bit = 1011
			–	5.2	–		sent_slew_rates bit = 1101
			–	10.4	–		sent_slew_rates bit = 1111
t_{fall13}	Fall Time of Output[1)2)]	OUT1/3	–	0.5	–	μs	sent_slew_rates bit = 100x
			–	0.7	–		sent_slew_rates bit = 101x
			–	1.3	–		sent_slew_rates bit = 110x
			–	2.6	–		sent_slew_rates bit = 111x
$I_{Oshort13\_low}$	Output Current for Short to GND	OUT1/3	–65	–46	–	mA	VSUP < 5.5 V
			–75	–64	–		VSUP < 18 V
$I_{Oshort13\_high}$	Output Current for Short to VSUP	OUT1/3	–	46	70	mA	VSUP < 5.5 V
			–	64	110		VSUP < 18 V
Main Output OUT1 and OUT 3 for PWM (Open-Drain Configuration)							
R_{OUT13}	Open-Drain Output1/ 3 Resistance	OUT1/3	80	104	130	Ω	
V_{OL13}	Output Low Voltage	OUT1/3	0.6	0.8	1.3	V	I_{Load} = 10 mA
t_{fall13}	Fall Time of Output 1/3	OUT1/3	–	0.6	–	μs	[1)] C_{Load} = 5 nF from 3.8 V to 1.1 V
$I_{Oshort13\_high}$	Output Current for Short to VSUP	OUT1/3	–	46	70	mA	VSUP < 5.5 V
			–	64	110		VSUP < 18 V
I_{Leak13}	Output 1/3 Leakage Current	OUT1/3	–80 –80	– –	40 80	μA	V_{OUT1} < 5.5 V V_{OUT1} < 18 V
Secondary Output OUT2 & OUT 4 for Switch or PWM Function (Push-Pull: High-side or Low-side)							
V_{OL24}	Output Low Voltage	OUT2/4	–	–	0.6	V	I_{Load} = 20 mA
V_{OH24}	Output High Voltage	OUT2/4	V_{SUP} –0.6	–	–	V	I_{Load} = –10 mA
t_{rise24}	Rise Time of Output	OUT2/4	–	120	–	ns	[1) 2)]
t_{fall24}	Fall Time of Output	OUT2/4	–	120	–	ns	[1) 2)]
$I_{Oshort24\_Low}$	Output Current for Short to GND	OUT2/4	–50	–40	–30	mA	V_{SUP} > V_{OUT2} > GND
$I_{Oshort24\_High}$	Output Current for Short to V_{SUP}	OUT2/4	25	40	50	mA	V_{SUP} > V_{OUT2} > GND
I_{Leak24}	Output Leakage Curren2	OUT2/4	–2	–	2	μA	

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

Symbol	Parameter	Pin Name	Limit Values			Unit	Conditions
			Min.	Typ.	Max.		
SENT Output Mode							
t_{tick}	SENT Tick Time	OUT1/3	0.47	0.50	0.53	µs	1)
			0.94	1.00	1.06	µs	
			1.41	1.50	1.59	µs	
			1.88	2.00	2.12	µs	
			2.35	2.50	2.65	µs	
			2.58	2.75	2.92	µs	
			2.82	3.00	3.18	µs	
			5.64	6.00	6.36	µs	
			11.29	12.0	12.72	µs	
For SENT with pause pulse (synchronous), 3 µs tick time, H.2 frame format, 2 kHz SENT repetition rate & for SENT with pause pulse (synchronous), 3 µs tick time, H.4 frame format, 2 kHz SENT repetition rate & for SENT without pause pulse (asynchronous), 3 µs tick time, H.2 Format, 2 kHz SENT repetition rate							
t_{S_Init}	SENT Start-up Time	OUT1/3	–	–	9.5	ms	1) Time until first SENT frame with init frame starts. Fig. 5–5 on page 54
$t_{S\_first\_valid}$	SENT Start-up Time till first valid Frame	OUT1/3	–	–	10.0	ms	1) Time until first valid SENT frame starts. Fig. 5–5 on page 54
$t_{latency}$	SENT average Latency	OUT1/3	–	0.75	–	ms	1) LP-Filter off
t_{wcresp}	SENT Step Response Time (worst case)	OUT1/3	–	–	1	ms	1) see Fig. 5–6
$N_{S\_Init\_Cycles}$	Number of SENT Init Cycles	OUT1/3	–	–	1	cycles	1)
PWM Output Mode							
f_{PWM}	PWM Output Fre-quency	OUT1/3	100	–	109	Hz	1)
			125	–	136.3	Hz	
			150	–	163.5	Hz	
			200	–	218	Hz	
			250	–	272.5	Hz	
			500	–	545	Hz	
			550	–	600	Hz	
			800	–	872	Hz	
			1000	–	1090	Hz	
			1500	–	1635	Hz	
			2000	–	2180	Hz	

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

Symbol	Parameter	Pin Name	Limit Values			Unit	Conditions
			Min.	Typ.	Max.		
t_{OSD}	Overall Signal Delay	OUT1/3	–	–	367	µs	1) Overall signal delay between sensor front-end and output. Transmission time of selected PWM frequency to be added. See Fig. 5–6. fdecsel = 8 kSps LP-Filter = off
t_{P_Init}	PWM Start-up Time	OUT1/3	–	–	9.5	ms	1) Initial start-up time until output is ready. 2 kHz PWM frequency Fig. 5–5 on page 54
$t_{P\_first\_valid}$	PWM Start-up Time till first Edge	OUT1/3	–	–	10	ms	1) Time until first valid rising/falling edge. Fig. 5–5 on page 54 2 kHz PWM frequency
OUT_{Res}	Output Resolution	OUT1/3	13	–	–	bit	1) PWM freq. = 100...1500 Hz
			12	–	–	bit	1) PWM freq. = 2 kHz
PMW_{DC}	PWM Duty-Cycle Range	OUT1/3	1	–	99	%	1)
PWM_{DCFM}	PWM Duty-Cycle in Failure Mode	OUT1/3	According registers PWM_STD_ERROR & MAG_LOSS_OUTPUT				1) Customer configurable (see Table 3–4 on page 29)
PWM_{DCUV}	PWM Duty-Cycle in case of Undervoltage	OUT1/3	–	2.0	–	%	1) Customer configurable. Alternatively same as PWM_{DCFM}. (see Table 3–4 on page 29)
PWM_{DCOV}	PWM Duty-Cycle in case of Overvoltage	OUT1/3	–	2.0	–	%	
PWM_{DCMH}	PWM Duty-Cycle in case of Magnetic Field High detection	OUT1/3	–	98	–	%	1)
J_{PWM}	RMS PWM Jitter	OUT1/3	–	–	1	LSB_{13}	1)
SSOP16 Package							
R_{thja}	Thermal Resistance Junction to Air	–	–	–	130	K/W	3) Determined with a 1S0P board
		–	–	–	91	K/W	3)Determined with a 2S2P board
R_{thjc}	Thermal Resistance Junction to Case	–	–	–	34	K/W	3)Determined with a 1S0P board
		–	–	–	31	K/W	3)Determined with a 2S2P board
R_{ISOL}	Isolation Resistance4)	GND1, GND2	4	–	–	MΩ	Between two dies (Between GND1 and GND2 pin)

1) Characterized on small sample size, not tested.
3) Self-heating calculation see Section 6.1. on page 60
4) GND’s galvanic isolation not tested

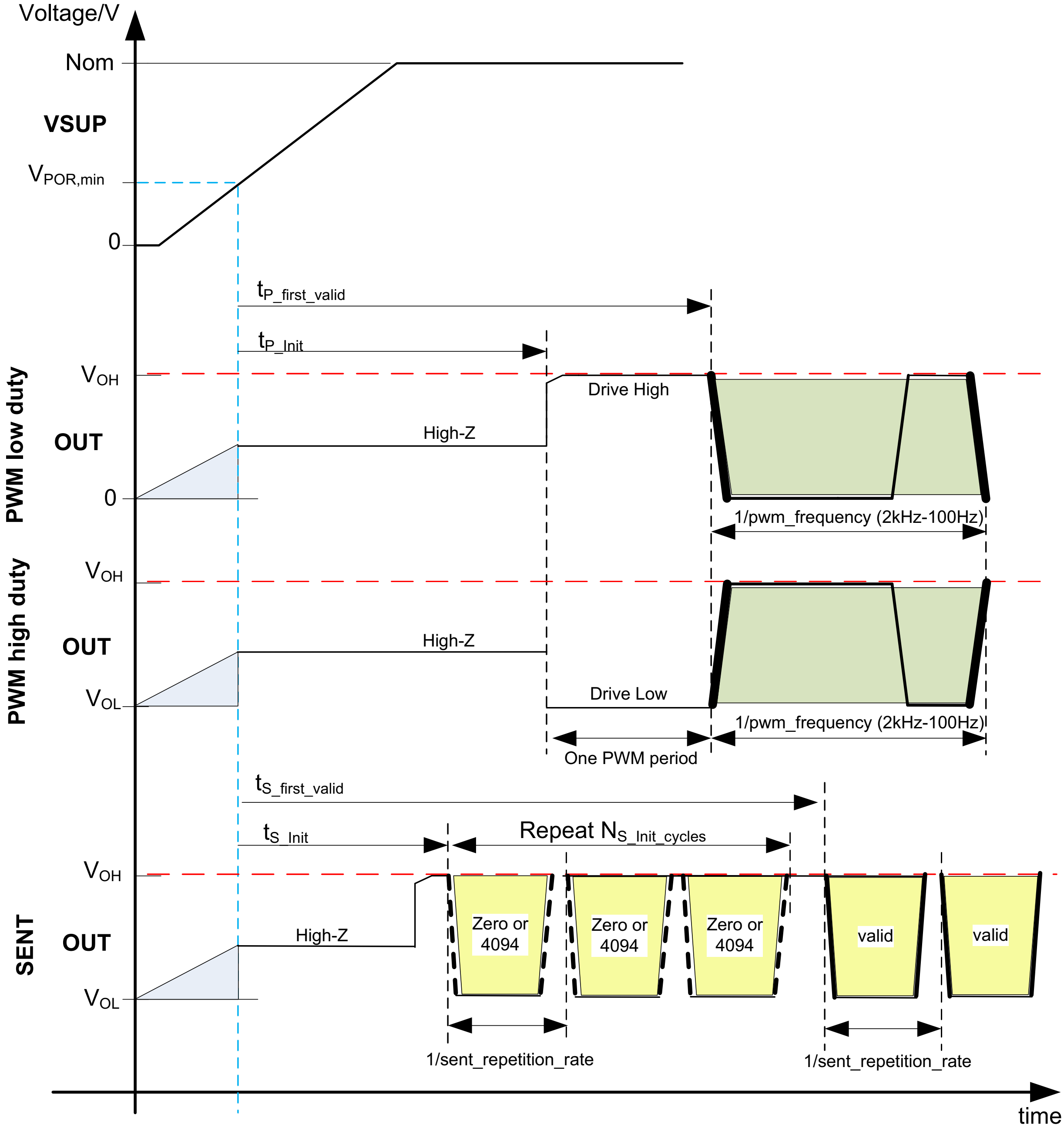


Fig. 5–5: Start-up behavior of HAR 3930 for SENT and PWM output

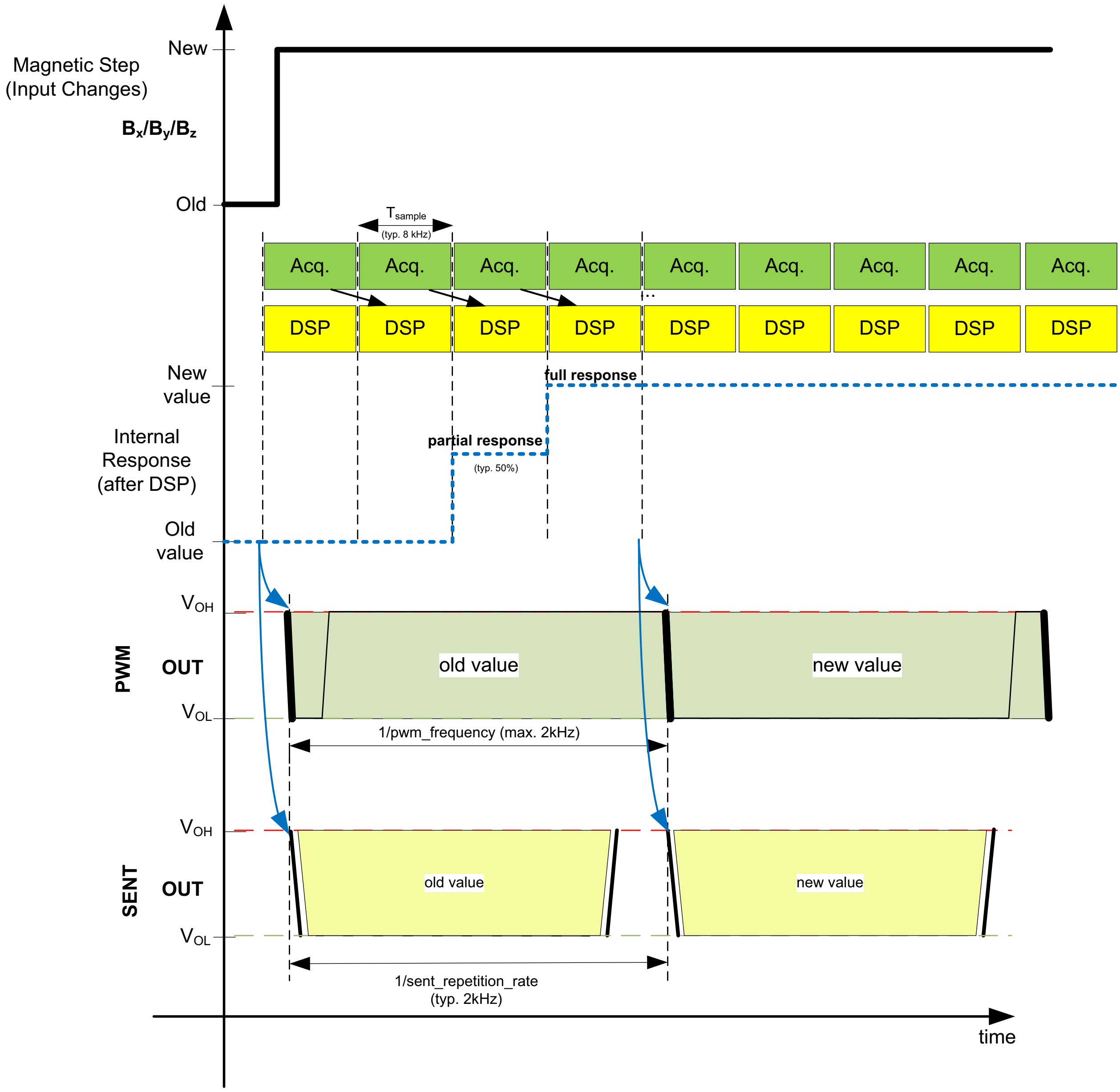


Fig. 5–6: Step response behavior of HAR 3930

5.10. Magnetic Characteristics

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

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
Rotary Setup with Stray-Field Compensation (Setup 1 & 2)							
$\Delta E_{\Theta tot}$	Total Angular Error of Drifts	OUTx	–1.2	–	1.2	°	1) B_{AMP} = ±10 mT Setup 2 (3 Z-Plates)
			–0.75	-	0.75	°	1) B_{AMP} = ±10 mT Setup 1 (6 Z-Plates)
$\Delta E_{\Theta temp}$	Angular Error Drift over Temperature	OUTx	–0.55	–	0.55	°	1) B_{AMP} = ±10 mT
$\Delta E_{\Theta life}$	Angular Error Drift over Lifetime	OUTx	–0.7	–	0.7	°	1) B_{AMP} = ±10 mT Setup 2 (3 Z-Plates) After 1008 h HTOL
			–0.45	–	0.45	°	1) B_{AMP} = ±10 mT Setup 1 (6 Z-Plates) After 1008 h HTOL
$E_{\Theta hyst}$	Angular Hysteresis Error	OUTx	–	–	0.05	°	2)
$E_{\Theta noise\_1}$	Angular Noise Setup 1	OUTx	–	0.13	0.23	°	3) Setup 1 (6 Z-Plates)
$E_{\Theta noise\_2}$	Angular Noise Setup 2	OUTx	–	0.19	0.33	°	3) Setup 2 (3 Z-Plates)
$E_{\Theta SF\_1}$	Angular Error due to Stray-Field for Setup 1	OUTx	–	–	0.19	°	1) 4) B_{AMP}=±10 mT wanted signal; Setup 1 (6 Z-Plates)
$E_{\Theta SF\_2}$	Angular Error due to Stray-Field for Setup 2	OUTx	–	–	0.21	°	1) 4) B_{AMP}=±10 mT wanted signal; Setup 2 (3 Z-Plates)
Linear Movement Setup (ΔXZ) with Stray-Field Compensation (Setup 3b)							
$SM_{\Delta XZ41}$	Sensitivity Mismatch between ΔX_{41} and ΔZ_{41} Channel	OUTx	–5	–	5	%	1) T_A = 25 °C
$Sense_{\Delta XZ41}$	Sensitivity of ΔX_{41} and ΔZ_{41} Channel	OUTx	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	OUTx	–3.5	–	3.5	%	1) Related to T_A = 25 °C
$Offset_{\Delta X41}$	Offset of ΔX_{41} Channel	OUTx	–30	–	30	LSB_{15}	T_A = 25 °C
$Offset_{\Delta Z41}$	Offset of ΔZ_{41} Channel	OUTx	–15	–	15	LSB_{15}	T_A = 25 °C
$\Delta Offset_{\Delta X41}$	Offset Drift of ΔX_{41} Channel	OUTx	–50	–	50	LSB_{15}	Related to T_A = 25 °C

All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not tested)
1) Based on Simulation Model (not tested)
2) Guaranteed by Design
3) Characterized on small sample size B_{AMP} = ± 10 mT, fdecsel = 2 kHz, Low-pass filter: off 3-sigma values (not tested)
4) Characterized on small sample size according to ISO 11452-8:2015, at 25°C, with stray-field strength of 4 kA/m from X,Y and Z direction, 3-sigma values (not tested).

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
$\Delta Offset_{\Delta Z41}$	Offset Drift ΔZ_{41} Channel	OUTx	–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	OUTx	–	6	–	%	[1] After 1008 h HTOL
$\Delta Offset_{\Delta X41life}$	Offset Drift of ΔX_{41} Channel over life time	OUTx	–	30	–	LSB_{15}	After 1008 h HTOL
$\Delta Offset_{\Delta Z41life}$	Offset Drift of ΔZ_{41} Channel over life time	OUTx	–	9	–	LSB_{15}	After 1008 h HTOL
$SF_{R\Delta X41}$	Stray-Field Rejection in ΔX_{41} Direction	OUTx	99	–	–	%	[4] T_A = 25°C
$SF_{R\Delta Z41}$	Stray-Field Rejection in ΔZ_{41} Direction	OUTx	98.7	–	–	%	[4] T_A = 25°C
$E_{\Theta phase\Delta XZ41}$	Phase Error between ΔX_{41} and ΔZ_{41} Channel	OUTx	–2.2	–	2.2	°	between ΔX_{41} and ΔZ_{41} axis [1]
$E_{\Delta X41,noise}$	Digital Noise of ΔX_{41} Hall-Plates Channel	OUTx	–	2.4	–	LSB_{15}	[5]
$E_{\Delta Z41,noise}$	Digital Noise of ΔZ_{41} Hall-Plates Channel	OUTx	–	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	OUTx	–2	–	2	%	[1] T_A = 25 °C
$Sense_{\Delta XY41}$	Sensitivity of ΔX_{41} and ΔY_{41} Channel	OUTx	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	OUTx	–2.5	–	2.5	%	[1] Related to T_A = 25 °C
$Offset_{\Delta XY41}$	Offset of ΔX_{41} and ΔY_{41} Channels	OUTx	–30	–	30	LSB_{15}	T_A = 25 °C
$\Delta Offset_{\Delta XY41}$	Offset Drift of ΔX_{41} and ΔY_{41} Channels	OUTx	–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	OUTx	–	1.0	–	%	[1] After 1008 h HTOL
$\Delta Offset_{\Delta XY41life}$	Offset Drift of ΔX_{41} and ΔX_{41} Channel over life time	OUTx	–	30	–	LSB_{15}	After 1008 h HTOL
$SF_{R\Delta XY41}$	Stray-Field Rejection in ΔX_{41} and ΔY_{41}Direction	OUTx	99	–	–	%	
$E_{\Theta phase\Delta XY41}$	Phase Error between ΔX_{41} and ΔY_{41} Channel	OUTx	–4.2	–	4.2	°	[1] between ΔX_{41} and ΔY_{41} axis
$E_{\Delta XY41,noise}$	Digital Noise of ΔX_{41} and ΔY_{41} Hall-Plates Channel	OUTx	–	2.4	–	LSB_{15}	[5]

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

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
3D Measurement Setup without Stray-Field Compensation (Setup 4a, 5 & 6)							
SM_{XYZ}	Sensitivity Mismatch between X or Y and Z Channel	OUTx	–4	–	4	%	T_A = 25 °C
SM_{XY}	Sensitivity Mismatch between X and Y Channel	OUTx	–2	–	2	%	T_A = 25 °C
$Sense_{XYZ}$	Sensitivity of X,Y and Z Hall-plate	OUTx	123	128	133	LSB_{15} /mT	T_A = 25 °C
ΔSM_{XYZ}	Thermal Sensitivity Mismatch Drift between X or Y and Z Hall Plates	OUTx	–2.7	–	2.7	%	Related to T_A = 25 °C
ΔSM_{XY}	Thermal Sensitivity Mismatch Drift between X and Y Hall Plates	OUTx	–2	–	2	%	Related to T_A = 25 °C
$Offset_{XY}$	Offset of X and Y Hall-plates	OUTx	–20	–	20	LSB_{15}	T_A = 25 °C
$Offset_{Z}$	Offset of Z Hall-plate	OUTx	–12	–	12	LSB_{15}	T_A = 25 °C
$\Delta Offset_{XY}$	Offset Drift of X and Y Hall-plates	OUTx	–40	–	40	LSB_{15}	Related to T_A = 25 °C
$\Delta Offset_{Z}$	Offset Drift of Z Hall-plate	OUTx	–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	OUTx	–4.5	–	4.5	%	After 1008 h HTOL
$\Delta Offset_{XYlife}$	Offset Drift of X and Y Hall-plates over life time	OUTx	–	30	–	LSB_{15}	After 1008 h HTOL
$\Delta Offset_{Zlife}$	Offset Drift of Z Hall-plate over life time	OUTx	–	5	–	LSB_{15}	After 1008 h HTOL
$E_{\Theta phaseXYZ}$	Phase Error between X, Y and Z Hall-Plates	OUTx	–3.1	–	3.1	°	XY axis
			–1.6	–	–1.6	°	XZ axis
			–2.5	–	2.5	°	YZ axis
$E_{XYZ,noise}$	Digital Noise of X, Y or Z Hall-Plates Channel	OUTx	–	2.2	–	LSB_{15}	5)
2D Measurement Setup (virtual center Pixel XY) without Stray-Field Compensation (Setup 4b)							
$SM_{\Sigma XY41}$	Sensitivity Mismatch between ΣX_{41} and ΣY_{41} Channel	OUTx	–3	–	3	%	T_A = 25 °C
$Sense_{\Sigma XY41}$	Sensitivity of ΣX_{41} and ΣY_{41} Channel	OUTx	121	128	135	LSB/mT	T_A = 25 °C
$\Delta SM_{\Sigma XY41}$	Thermal Sensitivity Mismatch Drift between ΣX_{41} and ΣY_{41} Channel	OUTx	–2	–	2	%	Related to T_A = 25 °C
$Offset_{\Sigma XY41}$	Offset of ΣX_{41} and ΣY_{41} Channel	OUTx	–25	–	25	LSB_{15}	T_A = 25 °C
$\Delta Offset_{\Sigma XY41}$	Offset Drift of ΣX_{41} and ΣY_{41} Channel	OUTx	–40	–	40	LSB_{15}	Related to T_A = 25 °C

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

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

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Conditions
$\Delta SM_{\Sigma XY41life}$	Relative Sensitivity Mismatch Drift between ΣX_{41} and ΣY_{41} Channel over life time	OUTx	–	1.0	–	%	After 1008 h HTOL
$\Delta Offset_{\Sigma XY41life}$	Offset Drift of ΣX_{41} and ΣY_{41}Channel over Life Time	OUTx	–	30	–	LSB_{15}	After 1008 h HTOL
$E_{\Theta phase \Sigma XY41}$	Phase Error between ΣX_{41} and ΣY_{41}	OUTx	–4.2	–	4.2	°	1)
$E_{\Sigma XY41,noise}$	Digital Noise of ΣX_{41} and ΣY_{41} Hall-Plates Channel	OUTx	–	1.9	–	LSB_{15}	5)

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

5.11. Temperature Sensor

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

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

1) Not tested
2) Characterized on small sample size, 3-sigma values, not tested for each device

6. Application Notes

6.1. Ambient Temperature

Due to the internal power dissipation, the temperature on the silicon chip (junction temperature T_J) is higher than the temperature outside the package (ambient temperature T_A).

$T_J = T_A + \Delta T$

The maximum ambient temperature is a function of power dissipation, maximum allowable die temperature and junction to ambient thermal resistance (R_{thja}). With a typical supply voltage of 5.0 V the power dissipation P is 0.12 W (two dies). The junction to ambient thermal resistance R_{thja} is specified in Section 5.9. on page 50.

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} (for two dies) 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

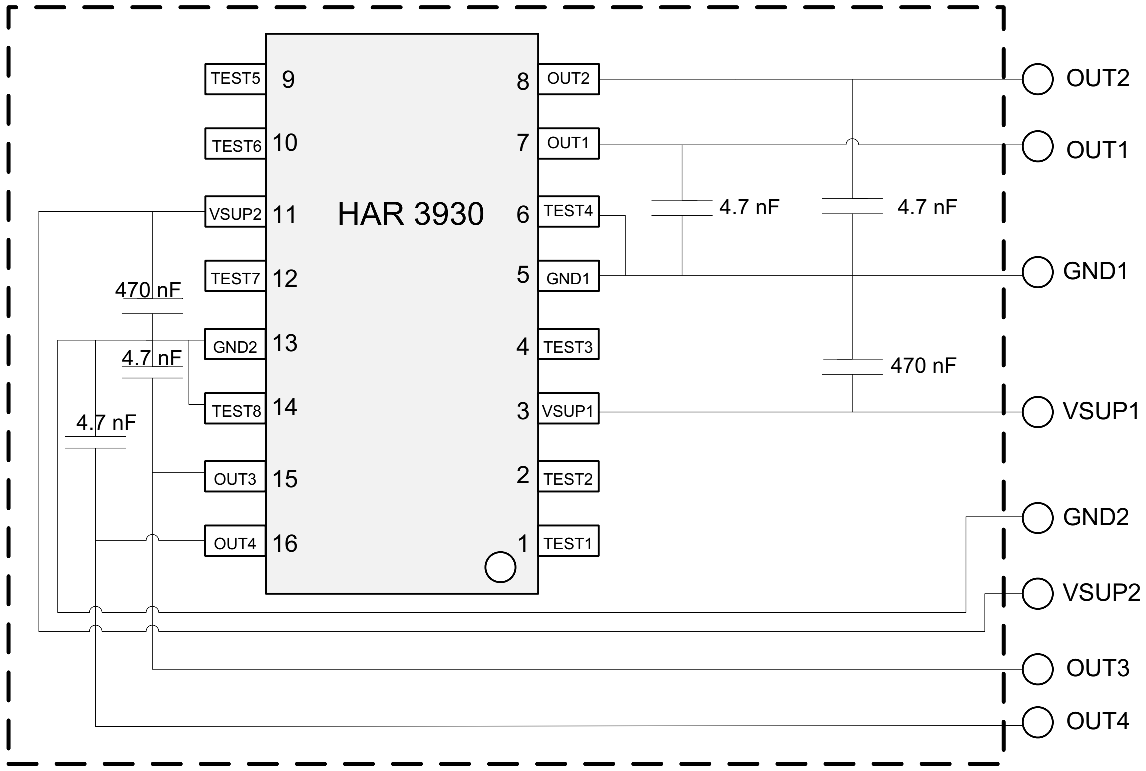


Fig. 6–1: Recommended application circuit for HAR 3930

6.4. Recommended Pad Size SSOP16 Package

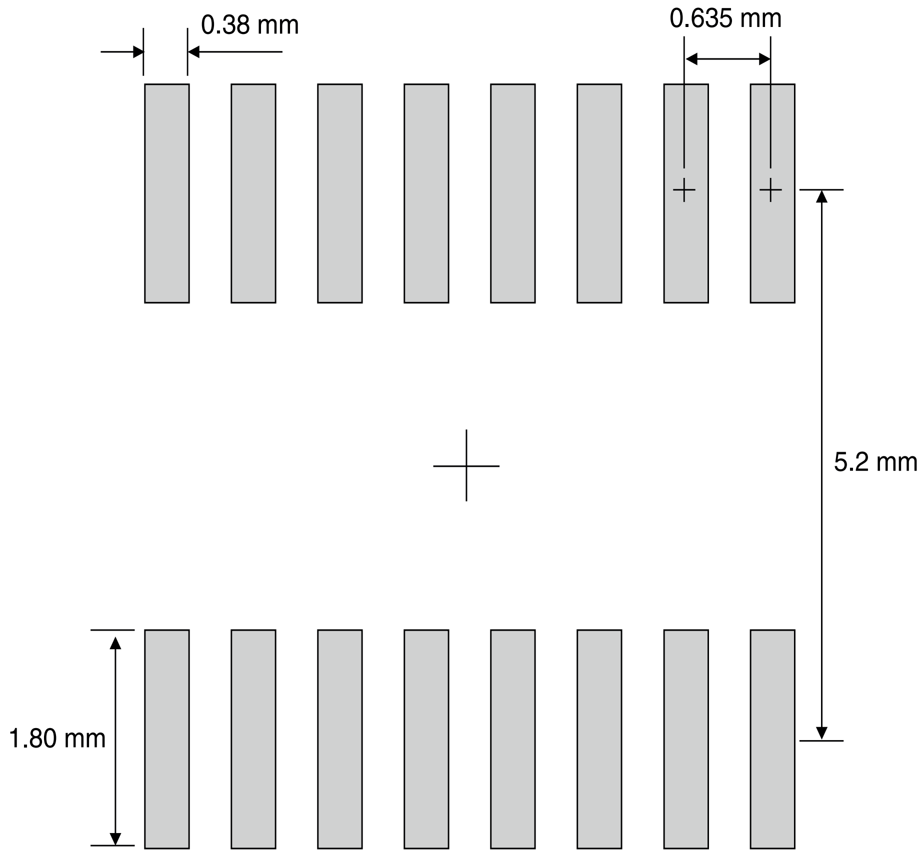


Fig. 6–2: Pad size recommendation for SSOP16 Package (all dimensions in mm)

7. Programming of the Sensor

HAR 3930 features two different customer modes. In **Application Mode** the sensor provides a digital output signal according SENT standard or by transmission of PWM signals. 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 HAR 3930 is addressed by modulating a serial telegram on the sensor's output pins. 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.

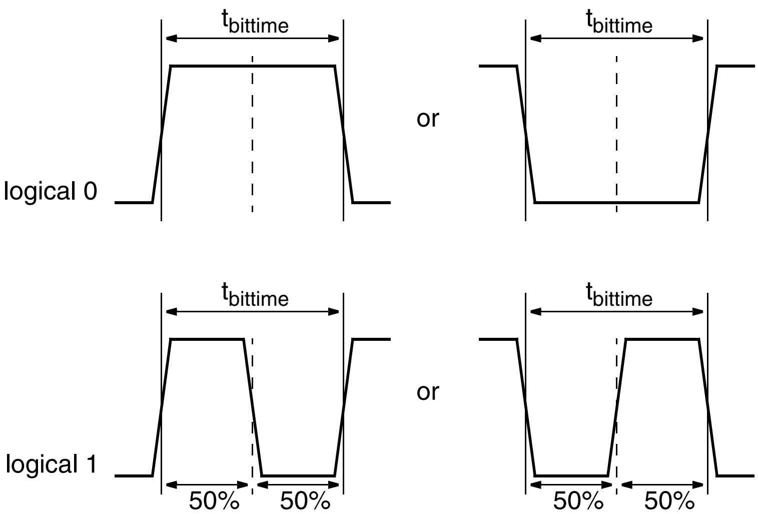


Fig. 7–1: Definition of logical 0 and 1 bit

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	OUT1/3	0.01	–	1.1	ms	
SR	Host slew rate Biphase protocol	OUT1/3	10	–	–	V/µs	For recommended application circuit
V_{H_OUTL}	Host OUT pin voltage for low level during programming	OUT1/3	–	–	0.8	V	
V_{H_OUTH}	Host OUT pin voltage for high level during programming	OUT1/3	2.4	–	–	V	
$V_{SUPProgr}$	V_{SUP} Voltage for memory programming	VSUP1/2	$V_{SUP,min.}$	–	$V_{SUP,max.}$	V	

7.2. Programming Environment and Tools

For the programming of HAR 3930 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/HAR/HAC 393x 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 HAR 3930.

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/HAR/HAC 393x Programming Guide.

8. Document History

1. Data Sheet: “HAR 3930-2300 Dual-Die Stray-Field Robust 3D Position Sensor with Digital Output Interfaces”, Sept. 9, 2022, AI000227_001EN. First release of the Data Sheet

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