

## **HAR 3970-2301**

Dual-Die Stray-Field Robust 3D  
Position Sensor with SPC  
(Short PWM Code) Interface

**3D** | HAL  
Technology

**master** | HAL  
Technology

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## Dual-Die Stray-Field Robust 3D Position Sensor with SPC (Short PWM Code) Interface

### 1. Introduction

HAR 3970-2301 is the dual-die version of HAL 3970-2301 and they are part of a new generation 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 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 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°).

HAR 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 one angle 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.

HAR 3970 is defined as SEooC (Safety Element out of Context) ASIL B ready according to ISO 26262 and 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 to 150 °C.

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

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## 1.1. Major Applications

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

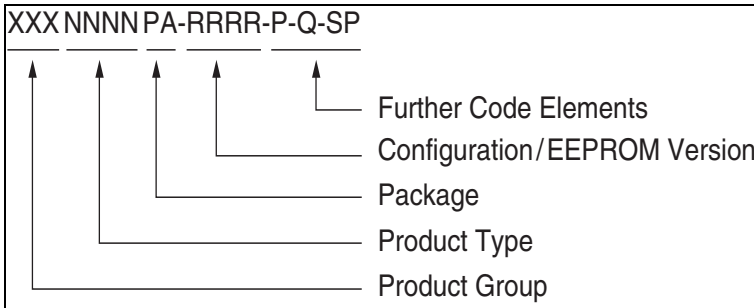
- Steering angle
- Brake pedal position / brake stroke sensor

## 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 to support Functional Safety applications
- Wide supply voltage range of 3 V up to 16 V
- Open-drain output
- SPC (Short PWM 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 HAR 3970 is available in the following package.

**Table 2–1:** Available packages


| Package Code (PA) | Package Type |
|-------------------|--------------|
| GU                | SSOP16       |

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

**Table 2–2:** Ordering Information

| Product  | Package     | Configuration Version | Further Code [-P-Q-SP]                | Comments  |
|----------|-------------|-----------------------|---------------------------------------|---|
| HAR 3970 | GU = SSOP16 | 95xy                  | See TDK-Micronas Ordering Information | 95xy versions can be engineering samples or qualifiable devices |
| HAR 3970 | GU= SSOP16  | 2301                  | See TDK-Micronas Ordering Information | Production version  |

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

| Ordering Code                           | Package Marking  | Description  |
|---|--|--|
| HAR3970GU-2301[P-Q-SP]                  |  <p style="text-align: center;">R39702301<br/>123456789<br/>YWWD SB</p> | Line 1: Product Type / Configuration-ID<br>Line 2: Lot number<br>Line 3: Date code / Special Procedure SB (optional) |
| <b>Example:</b><br>HAR3970GU2301-R-8-00 |  | R: Tape & Reel<br>8: 7k pcs per box<br>00: No special procedure  |



### 3. Functional Description

#### 3.1. General Function

HAR 3970 is a 2D 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).

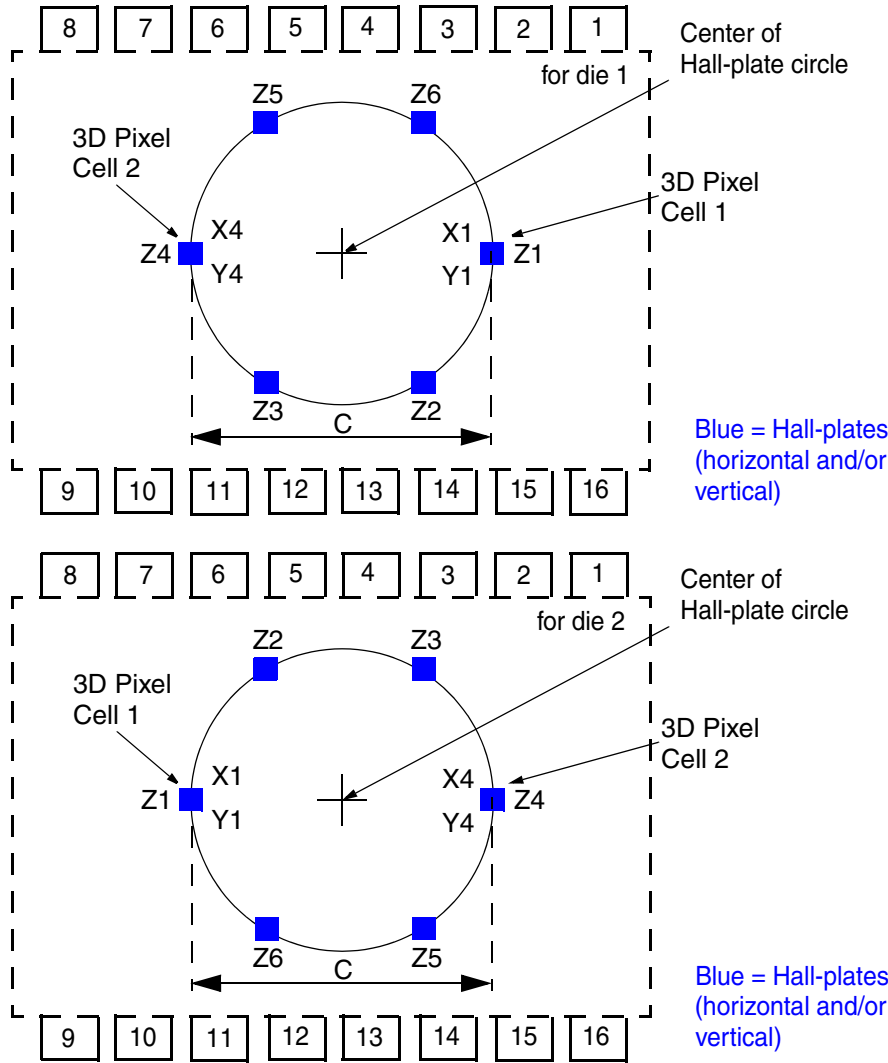


Fig. 3-1: Hall-plate position definition for HAR 3970

**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.

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:

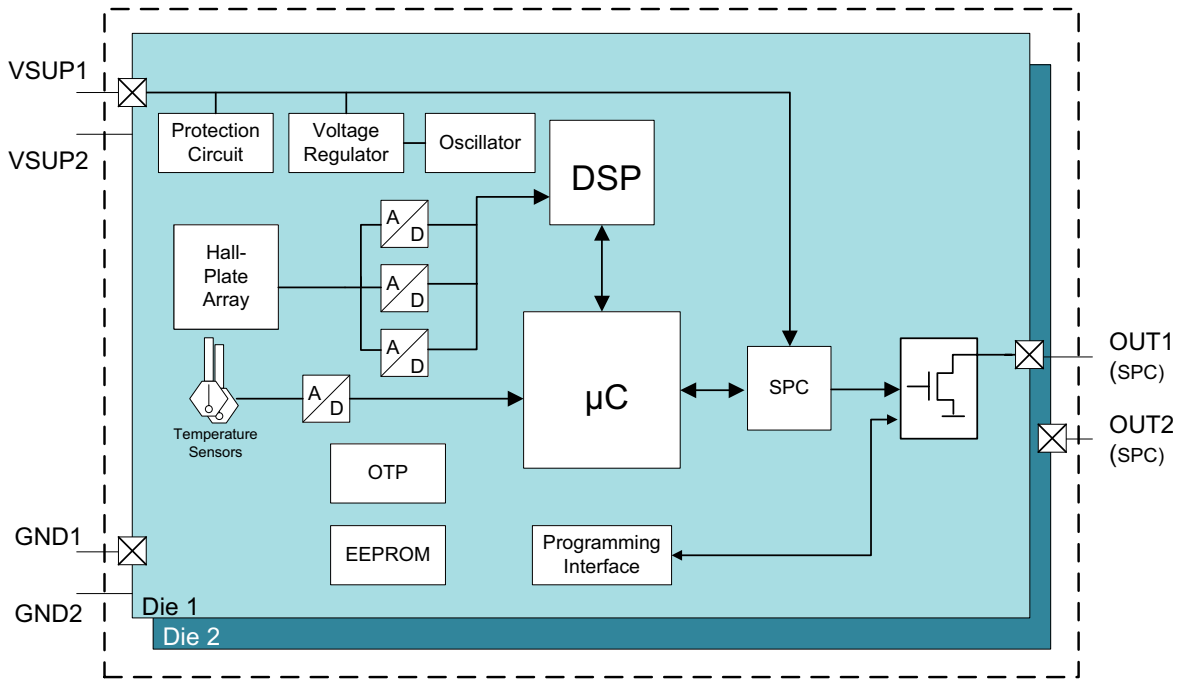
- Angular measurements in a range between 0° and 360° with stray-field compensation
- Linear position detection with stray-field compensation based on the differential signals of the two 3D Pixel Cells
- 2D linear and angular position detection without stray-field compensation ( $B_Y/B_X$ ,  $B_Z/B_X$ ,  $B_Z/B_Y$ ) with 3D Pixel Cell 1 from Die 1 and Cell 2 from Die 2

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

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 transmitted via SPC frames.

The HAR 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:** HAR 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 needs for the measurement setup.

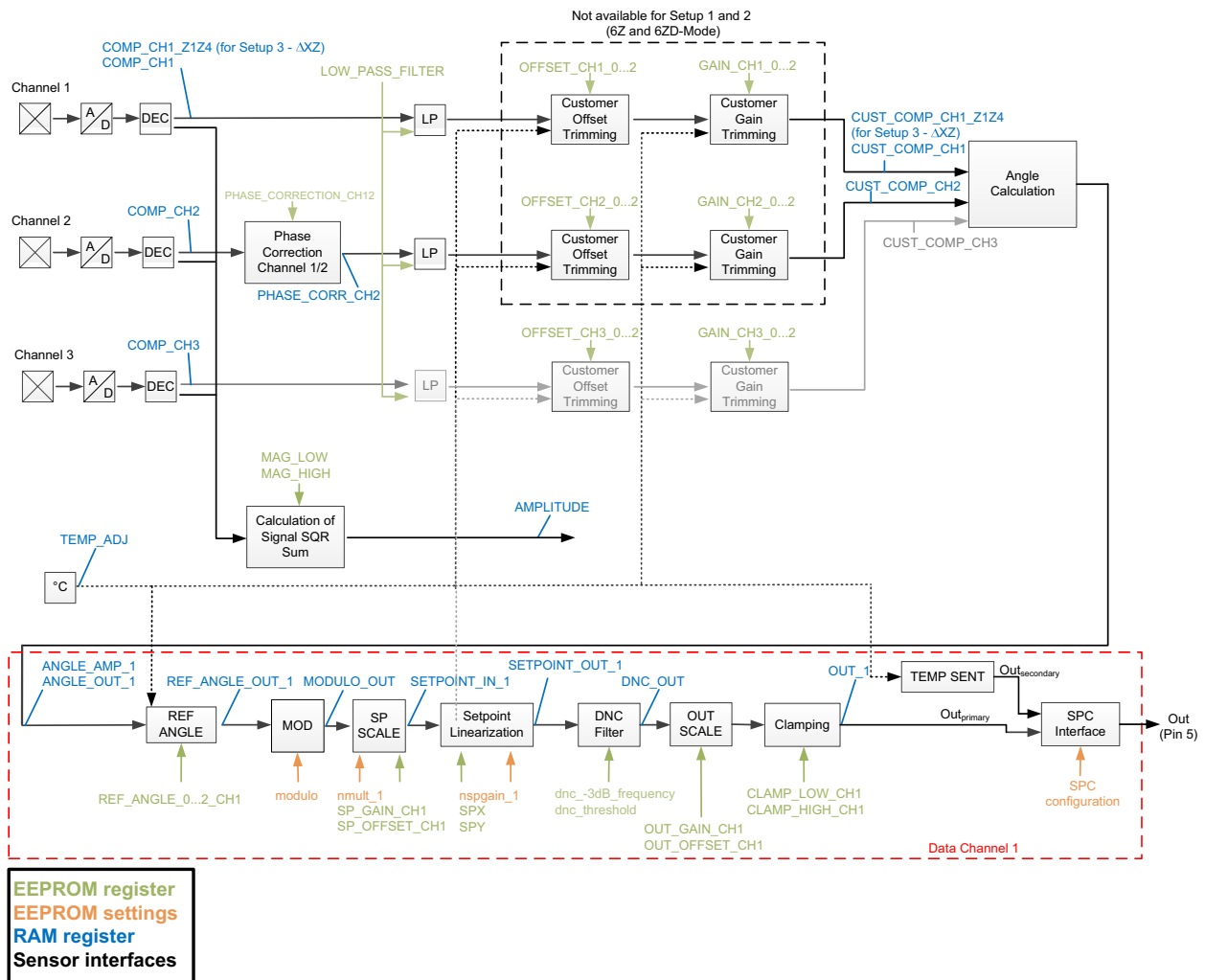


Fig. 3–3: Signal path of HAR 3970 (example for one die)

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 3970-2301 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\_CHx

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  $\Delta X \Delta Z$  mode. It contains the temperature-compensated magnetic-field information of the differential  $\Delta Z$  magnetic-field  $\Delta Z = Z4 - Z1$ .

##### 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\_CH2 register contain the customer compensated magnetic-field information of channel 2 after customer phase-shift error correction using the PHASE\_CORRECTION\_CHx registers.

##### CUST\_COMP\_CHx

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  $\Delta X\Delta Z$  mode. It contains the customer-compensated magnetic-field information of the differential  $\Delta Z$  magnetic-field  $\Delta Z = Z4-Z1$  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. HAR 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 38).

## 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.

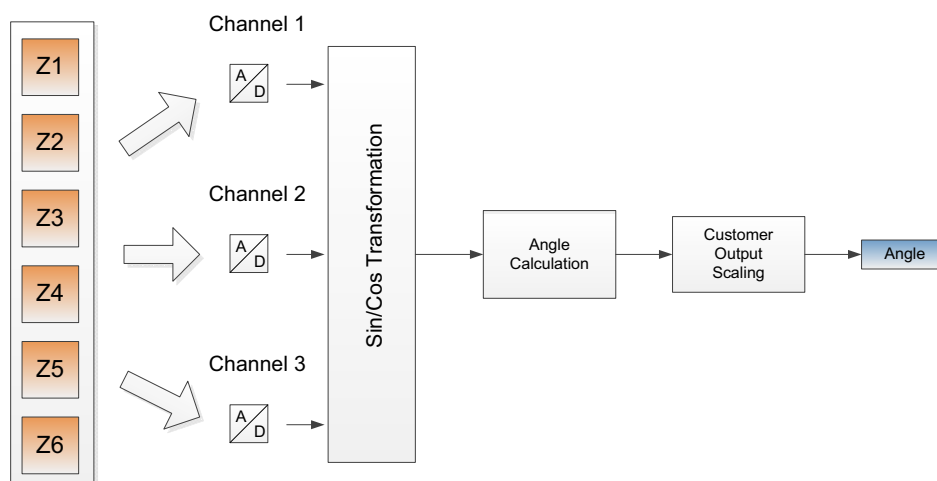
### 3.3.2. EEPROM Registers

#### Application Modes

HAR 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 23) defines the different available modes.

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

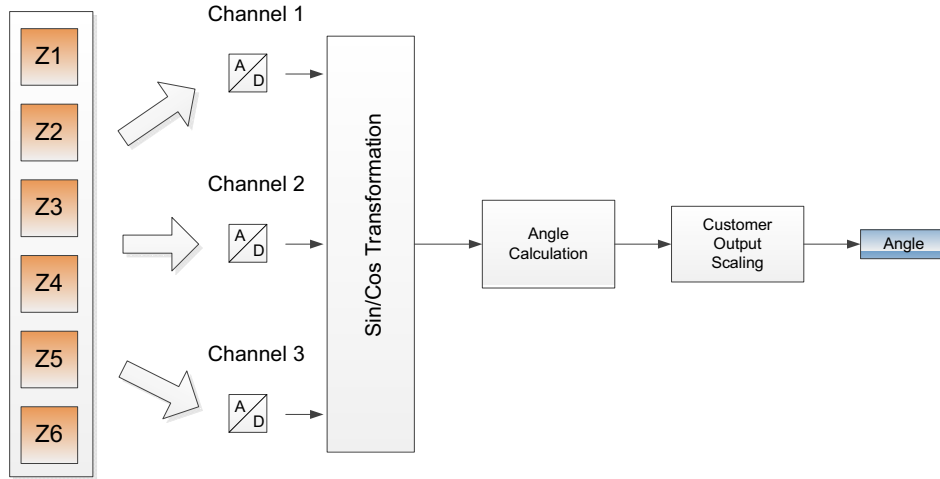
This mode uses six horizontal Hall-plates to measure a 180° angular range. It requires a 4-pole magnet. Speciality of this mode is that the device can compensate stray-fields according to ISO 11452-8 definition as well as disturbing gradients generated for example by a current conducting wire. Fig. 3–4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



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

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

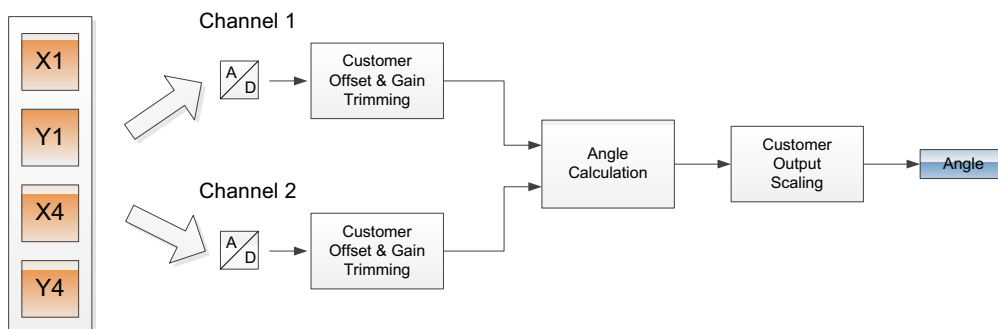
This mode uses six horizontal Hall-plates to measure a 360° angular range. The delta of opposite Z-Plates is given to each channel (Z4-Z1, Z6-Z3, Z2-Z5). It requires a 2-pole magnet. The device can compensate stray fields according to ISO 11452-8 definition. Fig. 3–5 shows the related signal path.



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

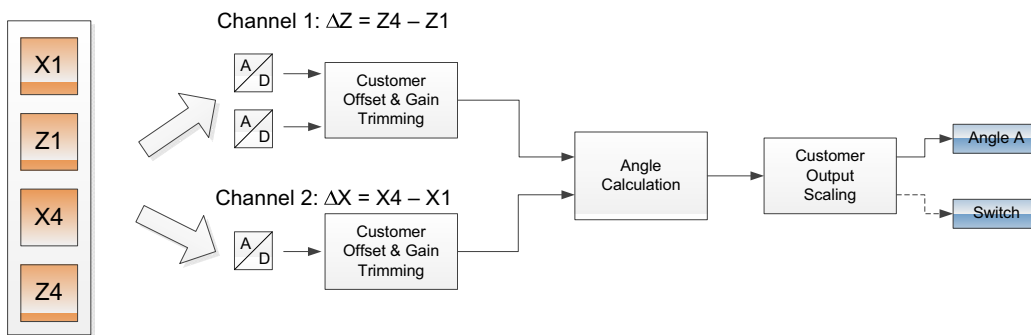
**– Setup 3: Linear movement or off-axis rotary (stray-field compensated)**

This mode uses a combination of horizontal and vertical Hall-plates to measure a stray-field compensated linear movement ( $\Delta B_x$  &  $\Delta B_z$  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 ( $\Delta B_x$  &  $\Delta B_y$  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  $\Delta X \Delta Y$  setup and Fig. 3–7 shows the signal path for  $\Delta X \Delta Z$  setup.



**Fig. 3–6:** Signal path diagram of setup 3a –  $\Delta X \Delta Y$  (stray-field robust off-axis position detection; example for one die)





**Fig. 3–7:** Signal path diagram of setup 3b –  $\Delta X\Delta Z$  (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:

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

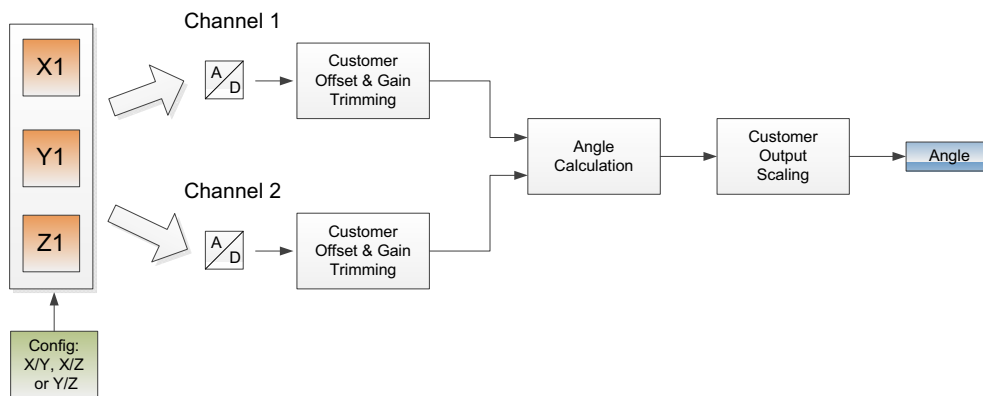
For the off-axis rotary setup the angle calculation is done by using the following equation:

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

**Note** GAIN\_CH1\_0...2 and GAIN\_CH3\_0...2 must be set to the same value for this specific setup (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. 3–8:** Signal path diagram of setup 4a (rotary or linear position detection w/o stray-field compensation; example for one die)

### Customer IDs

The customer ID register (CUSTOMER\_ID0 to CUSTOMER\_ID9) contain 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 3–11 on page 32 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 HAR 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, 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).

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**Note** OFFSET\_CH3\_0...2 must be set to zero in case of Setup3 with  $\Delta X\Delta Z$  mode. The OFFSET\_CHx\_0...2 registers are not available for Setup's 1 and 2.

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## 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  $\Delta X\Delta Z$  mode. GAIN\_CHX\_0...2 registers are not available for Setups's 1 and 2.

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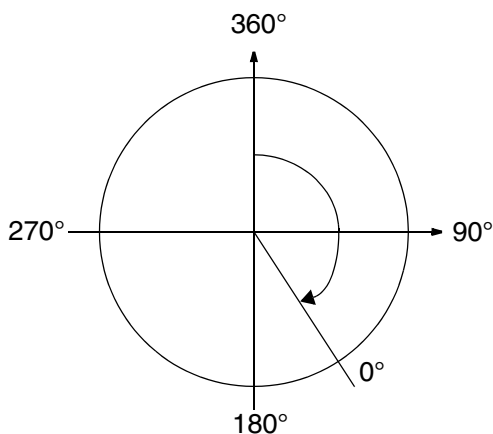
**Note** In case that the 6Z or 6ZD mode (setup 1 or 2) is used with the default gain, the maximum allowed magnetic field strength (BZ, allowed) measured at the Hall-plates is limited to 42 mT.

---

## 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). REF\_ANGLE\_CH2 is temperature independent (constant factor) and only available in case that the secondary channel is activated.



**Fig. 3–9:** Example definition of zero degree point

## Modulo Select

HAR 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 (SP0, SP1, ..., SP32). 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  $-32768 \dots 32767$  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  $-32767 \dots 32767$  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.  $\pm 0.5^\circ$ ) and periodic movements with an amplitude lower than  $1^\circ$  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 ( $0.5 \times f_{dec sel}$ ) 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 complement-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**

| Bit No.   | Function      | Description   |  |   |   |  |
|---|---------------|---|--|---|---|--|
| 15  | customer_lock | Customer Lock:<br>0: Unlocked<br>1: Locked  |  |   |   |  |
| 14:8  | –             | Must be set to 0.   |  |   |   |  |
| 7:6   | modulo        | Modulo operation:<br>00: 360°<br>01: Modulo 90°<br>10: Modulo 120°<br>11: Modulo 180°   |  |   |   |  |
| 5:4   | fdecsel       | A/D converter sample frequency:<br>00: 2 kSps<br>01: 4 kSps<br>10: 8 kSps<br>11: 16 kSps  |  |   |   |  |
| 3:0   | meas_config   | <b>Measurement setups:</b><br><br>0000: Setup 4a - 2D <sup>1)</sup><br>0001: Setup 4a - 2D <sup>1)</sup><br>0010: Setup 4a - 2D <sup>1)</sup><br>0011: Setup 3b - 2D - Strayfield compensated<br>0100: Setup 3a - 2D - Strayfield compensated<br>0101: Reserved<br>0110: Setup 1 - 180° rotary - strayfield compensated<br>0111: Setup 2 - 360° rotary - strayfield compensated<br>1000 to 1111: Must not be used | <b>Correspond. Signal Path</b><br><br>With two channels<br>With two channels<br>With two channels<br>With two channels<br>With two channels<br><br>6 Z Hall-plates<br>6 Z Hall-plates<br>- | <b>CH1</b><br><br>X1<br>Z1<br>Z1<br>Z1-Z4<br>X4-X1<br><br>Z1+Z4<br>Z4-Z1<br>- | <b>CH2</b><br><br>Y1<br>Y1<br>X1<br>X4-X1<br>Y4-Y1<br><br>Z2+Z5<br>Z6-Z3<br>- | <b>CH3</b><br><br>-<br>-<br>-<br>-<br>-<br><br>Z3+Z6<br>Z2-Z5<br>- |
| <sup>1)</sup> 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 3–2: SETUP\_DATAPATH**

| Bit No. | Function           | Description  |
|---------|--------------------|--|
| 15:8    | –                  | Reserved   |
| 7:5     | nmult_1            | Gain exponent for SETPOINT_IN1:<br>$SP\_GAIN = SP\_GAIN\_CH1 \times [2^{(nmult\_1)}]$        |
| 4:1     | nspgain_1          | Gain exponent for setpoint slope in channel 1:<br>$Slope = SPGn \times (2^{(nspgain\_1+1)})$ |
| 0       | variable_setpoints | Fixed/variable setpoint selection:<br>0: Fixed setpoints<br>1: Variable setpoints            |

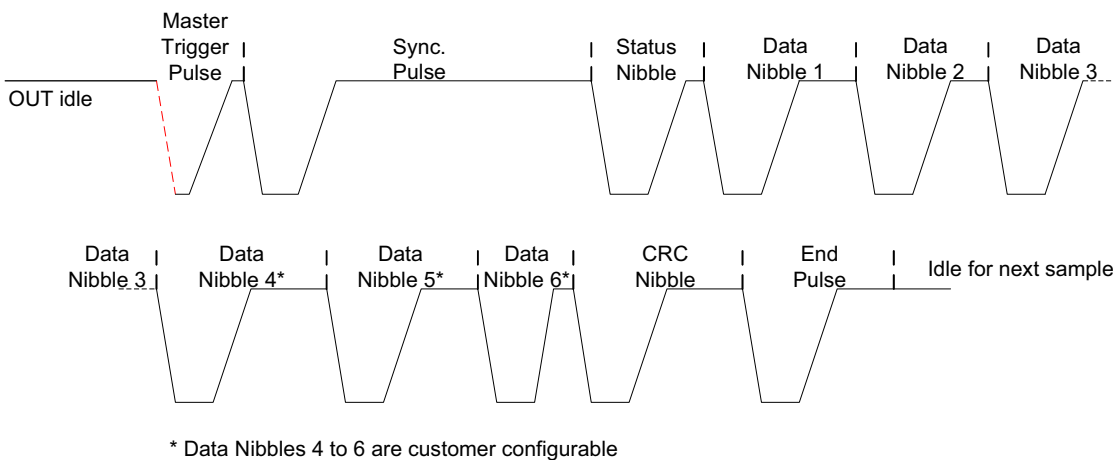
### 3.4. SPC Output

HAR 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 3–3 on page 25).



**Fig. 3–10: 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 49). The master low time  $t_{m\text{low}_c}$  and the total trigger time  $t_{mtr}$  depend on the selected SPC mode (please refer to Fig. 3–13 on page 36 & Fig. 3–14 on page 37).

The parameter of the Master Trigger Pulse are defined in Section 5.9. on page 47 and Fig. 5–6 on page 49.

The SPC protocol parameter are customer configurable with the register SETUP\_OUTPUT and SETUP\_PROTOCOL. Please see Table 3–3 and Table 3–4 for further details.

**Table 3–3: 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:<br>0: sample synchronisation disabled<br>1: sample synchronisation enabled<br><br>'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 $x \times 0.25 \mu\text{s}$ :<br>0x28: 10 $\mu\text{s}$<br>0x29: 10.25 $\mu\text{s}$<br>...<br>0x7F: 31.75 $\mu\text{s}$<br><b>Note:</b> Target signal ages below 10 $\mu\text{s}$ are not allowed.                        |
| 7:5     | –                  | Reserved  |
| 4:3     | spc_low_time       | Defines the SPC low time:<br>00: 3 ticks<br>01: 4 ticks<br>10: 5 ticks<br>11: 6 ticks   |
| 2:0     | spc_tick_time      | SPC unit times (UT) selection<br>000: 1.00 $\mu\text{s}$<br>001: 1.50 $\mu\text{s}$<br>010: 2.00 $\mu\text{s}$<br>011: 2.50 $\mu\text{s}$<br>100: 2.75 $\mu\text{s}$<br>101: 3.00 $\mu\text{s}$<br>110: reserved.<br><b>Note:</b> These values represent typical unit time.   |

**Table 3–4: SETUP\_PROTOCOL**

| Bit No. | Function                 | Description  |
|---------|--------------------------|--|
| 15      | spc_chf                  | SPC fast channel data format:<br>0: H.2 format: 12-bit fast channel (3 nibble position information)<br>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 31)<br>00: No rolling counter<br>01: 2-bit rolling counter (transmitted in the CRC nibble)<br>10: 4-bit rolling counter (used with H1.A7 format)<br>11: Reserved |
| 12      | spc_crc                  | 0: CRC according to SAE J2716 > rev. 2 (2010)<br>1: CRC according to SAE J2716 rev. 1 (2008 - legacy CRC)  |
| 11      | spc_srcrc                | Include STATUS nibble in CRC<br>0: Enabled (recommended for SPC)<br>1: Disabled (According to SENT SAE J2716)  |
| 10      | spc_id_mode              | SPC ID mode: (see Section 3.4.7. on page 34)<br>0: Synchronous mode (point-to-point connection)<br>1: ID selection mode (addressing done via pins 7 & 8)   |
| 9       | spc_trigger_pulse        | Type of SPC trigger pulse in case of ID selection mode:<br>0: Constant trigger pulse (90 UT)<br>1: Variable trigger pulse ( $t_{m\text{low}} + 12 \text{ UT}$ )  |
| 8       | spc_id_status            | Option to include SPC ID in the status nibble<br>0: ID is not part of the status nibble<br>1: ID is included in the status nibble (no slow channel & 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:<br>0: Do not send ID as part of the CRC<br>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:<br>0: Always zero<br>1: According to SENT SAE J2716   |
| 5       | spc_fast_error_codes     | Transmission of fast channel error codes:<br>0: Disabled<br>1: Enabled   |
| 4       | spc_slow_channel_format  | Defines slow serial channel format:<br>0: No serial message channel<br>1: 12-bit enhanced serial message format  |
| 3:1     | spc_slow_channel_content | Selection which blocks have to be send in addition to block 1 in the slow channel:<br>xx1: Block 2<br>x1x: Block 3<br>1xx: Block 4 + 5   |
| 0       | sent_sdf                 | SPC SDF mode:<br>0: Send diagnosis info in front of every block<br>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 & temperature and optional rolling counter)

Both modes are customer configurable via bits (Table 3–4 on page 26).

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 3–3 and Table 3–4.

#### 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 3–5.

**Table 3–5:** 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 3–4 bit[6]<br>Status [1...0]: According to selection in Table 3–4 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]  |
| 7     | 4-bit CRC Nibble                    | According to selection in Table 3–4 bits[14:13+12+11+7]<br>(see Table 3–6 on page 28)                                       |
| 8     | Pause Pulse                         | End pulse of the SPC frame  |

Table 3–6 shows the possible combinations for the content of the status and CRC nibble depending on the customer selection done according to Table 3–4 on page 26.

**Table 3–6:** 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 3–4). They are formatted according to Table 3–7.

**Table 3–7:** 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 3–4 bit[6]<br>Status [1...0]: According to selection in Table 3–4 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]   |
| 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 3–4 bits[14:13]  |
| 9     | 4-bit CRC Nibble                    | According to selection in Table 3–4 bits[14:13+12+11+7]<br>(see Table 3–6 on page 28)  |
| 10    | Pause Pulse                         | End pulse of the SPC frame   |

Table 3–8 shows the possible combinations for the content of the status and CRC nibble depending on the customer selection done according to Table 3–4 on page 26.

**Table 3–8:** Possible configurations for status nibble and CRC for H.1 format

| Trigger Pulse | Sync. pulse | Data nibbles |    |    |    |    |          |       |       | Pause pulse |
|---------------|-------------|--------------|----|----|----|----|----------|-------|-------|-------------|
|               |             | 1            | 2  | 3  | 4  | 5  | 6        | 7     | 8     |             |
| Trigger pulse | Sync. pulse | SCN+SCM      | D1 | D2 | D3 | T1 | T2       | RC    | CS    | Pause pulse |
|               |             |              |    |    |    |    |          |       | CS+ID |             |
|               |             |              |    |    |    |    |          | CS+RC |       |             |
|               |             |              |    |    |    |    |          | CS+ID |       |             |
|               |             |              |    |    |    |    | CS+ID+RC |       |       |             |
| Trigger pulse | Sync. pulse | SCN+ID       | D1 | D2 | D3 | T1 | T2       | RC    | CS    | Pause pulse |
|               |             |              |    |    |    |    |          |       |       |             |
|               |             |              |    |    |    |    |          | CS    |       |             |
|               |             |              |    |    |    |    | CS+RC    |       |       |             |

SCN = Status com. nibble, SCM = Slow channel message, CS = Checksum (CRC), RC = Rolling counter, ID = Sensor ID

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 3–9:** Error codes transmitted on fast channel 1 and/or 2

| Error   | Code |      |
|---|------|------|
|   | CH 1 | CH 2 |
| A.1 error code <sup>2)</sup>  | –    | –    |
| Sensor error indication <sup>2)</sup>   | 4091 | 4091 |
| Sensor functionality and processing error indication  | 4090 | 4090 |
| Data Clamping: High   | 1)   | 1)   |
| Data Clamping: Low  | 1)   | 1)   |
| <sup>1)</sup> 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 3–12 on page 33.

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 3–4 on page 26). 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  $X^4 + X^3 + X^2 + 1$  (SENT SAE J2716 polynomial) with a seed value of 0101. The detailed calculation scheme can be found in the User Manual for HAR 3970. The SAE J2716 legacy CRC can also be activated by bit[12] in the SETUP\_PROTOCOL register (see Table 3–4 on page 26). 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 3–10 for the virtual nibble layout. This function can be activated by bits [14:13+7] (see Table 3–4 on page 26).

**Table 3–10:** 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

HAR 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 HAR 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 3–11. The content/length of the serial message can be tailored by configuration bits[3:0] in the SETUP\_PROTOCOL register (Table 3–4 on page 26). It is possible to activate up to five blocks. Block 1 will always be transmitted if the serial message channel is activated.

**Table 3–11:** Serial message sequence

| Block | #  | 8-bit ID | Item              | 12-bit Data                    | Comment   |
|-------|----|----------|-------------------|--------------------------------|---|
| 1     | 1  | 0x01     | Error Codes       | (see Table 3–12 on page 33)    |   |
|       | 2  | 0x03     | Sensor type       |                                | Bits 0...11 in CUSTOMER_ID0 register (12 bit)<br>Examples:<br>0x050 = not specified position sensor<br>0x055 = position & secure channel<br>0x060 = angle sensor<br>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 3–12 on page 33)    |   |
|       | 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 3–12 on page 33)    | 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<br>Bits 0...7 in CUSTOMER_ID2 register  |
|       | 14 | 0x09     | Fast CH1 - Y1     | Fast channel 1 characteristics | Bits 8...15 in CUSTOMER_ID2 register<br>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 3–12 on page 33)    |   |
|       | 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<br>Bits 0...7 in CUSTOMER_ID5 register  |
|       | 19 | 0x92     | OEM Code 3 ID     | ASCII character OEM Codes      | Bits 8...15 in CUSTOMER_ID5 register<br>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 3–11:** Serial message sequence, continued

| Block | #  | 8-bit ID | Item          | 12-bit Data                 | Comment  |
|-------|----|----------|---------------|-----------------------------|--|
| 5     | 21 | 0x01     | Error Codes   | (see Table 3–12 on page 33) |  |
|       | 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<br>Bits 0...7 in CUSTOMER_ID8 register |
|       | 24 | 0x96     | OEM Code 7 ID | ASCII character OEM Codes   | Bits 8...15 in CUSTOMER_ID8 register<br>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 3–4 on page 26).

### 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. HAR 3970 features the error codes described in Table 3–12.

**Table 3–12:** 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

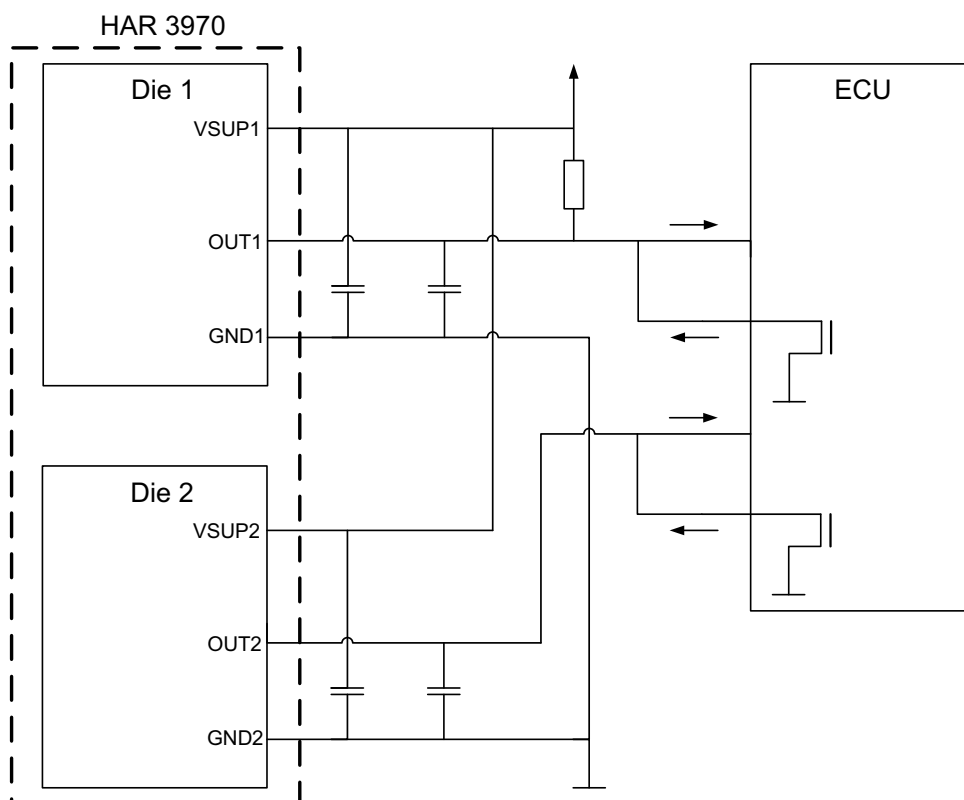
HAR 3970 supports two different SPC modes:

- Synchronous mode
- ID selection mode

The SPC mode can be selected by bit[10] of the SETUP\_PROTOCOL register (see Table 3–4 on page 26).

#### 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. 3–10 on page 24).



**Fig. 3–11:** Synchronous point-to-point setup

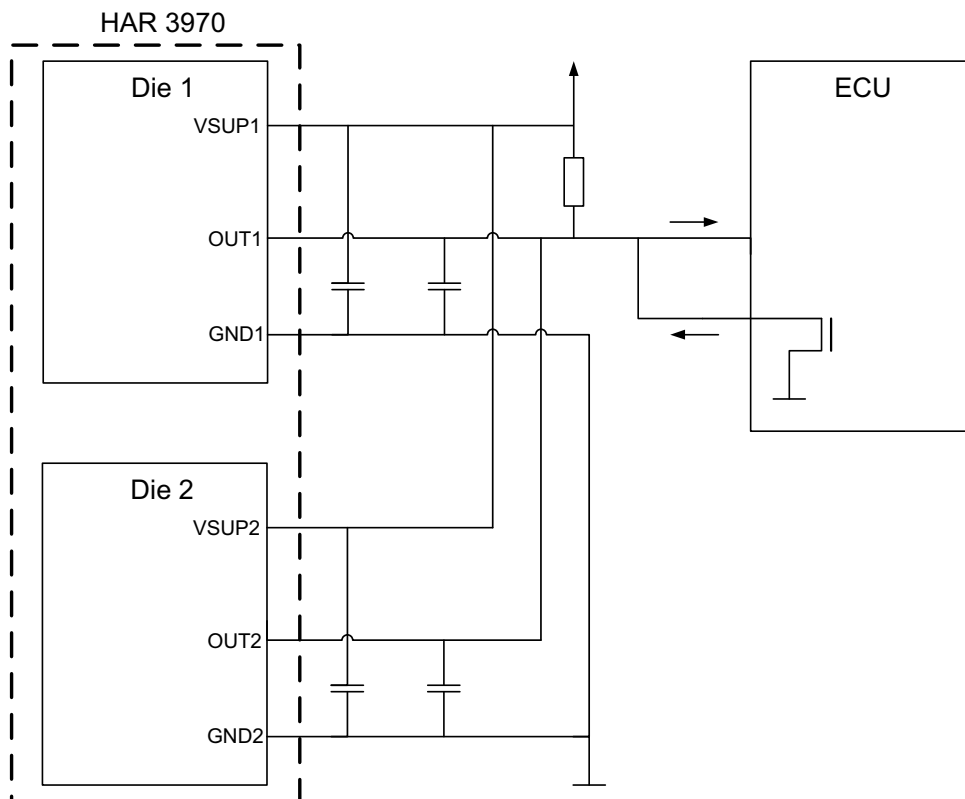
**ID selection mode (bus mode)**

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. 3–12 on page 35). 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 1, 2, 9 and 10 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 dies. Please see Table 3–13 for the definition.

**Table 3–13:** Pinning for sensor ID hard coding

| Sensor ID | Die 1 |       | Die 2 |        |
|-----------|-------|-------|-------|--------|
|           | Pin 1 | Pin 2 | Pin 9 | Pin 10 |
| 00        | GND   | GND   | GND   | GND    |
| 01        | High  | GND   | High  | GND    |
| 10        | GND   | High  | GND   | High   |
| 11        | High  | High  | High  | High   |



**Fig. 3–12:** Example for synchronous bus mode setup

HAR 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 3–4 on page 26).

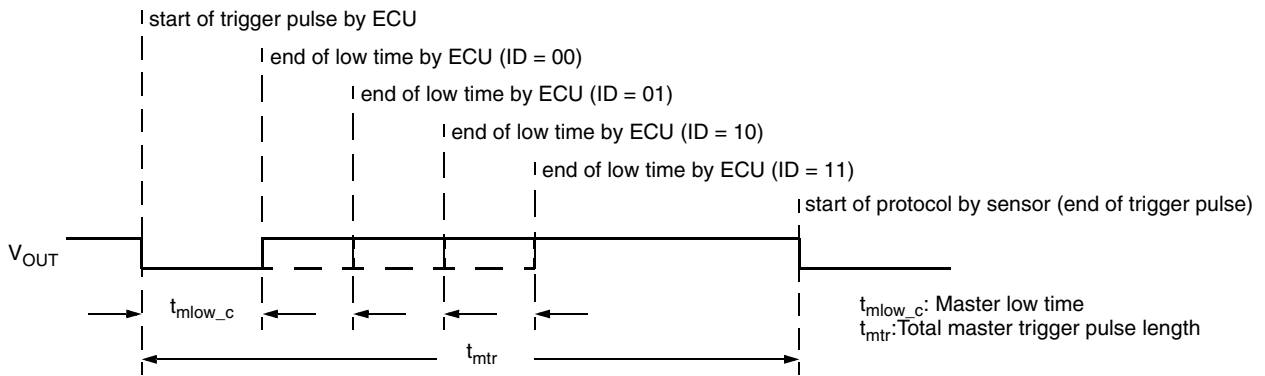
The length of the trigger pulse is fixed for all addresses in case of the constant length trigger pulse and addressing is done via a variable master low time.

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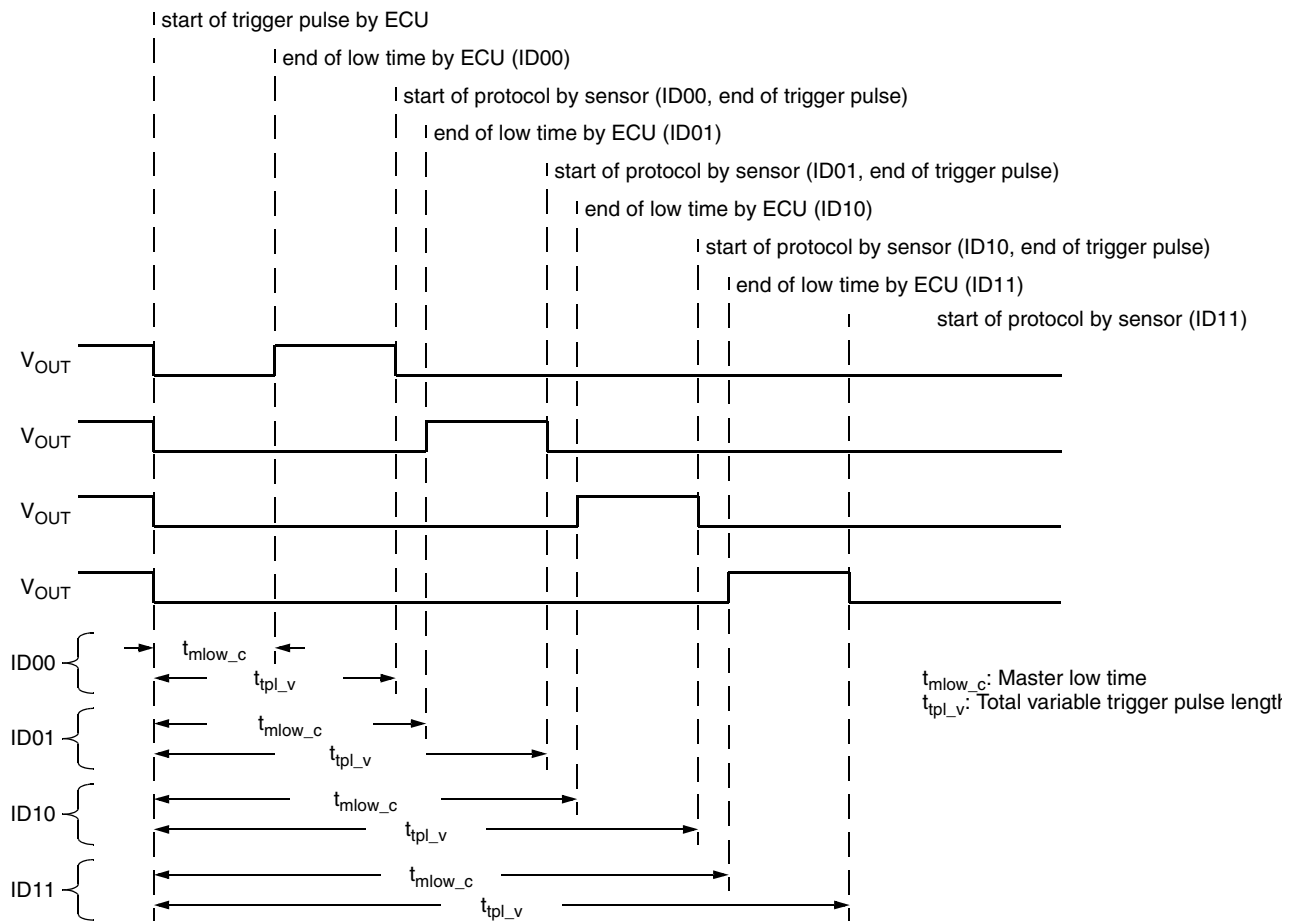
**Note** For bus mode applications with two participants, it is recommended to not use ID = 00. This ensures more tolerance to clock and trigger threshold variations.

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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. 3–13:** SPC bus mode, constant length trigger pulse timing



**Fig. 3–14:** SPC bus mode, variable length trigger pulse timing

All timings can be found in Section 5.9. on page 47.

## 4. Functional Safety

### 4.1. Functional Safety Manual and Functional Safety Report

The Functional Safety Manual for HAR 3970 contains the necessary information to support customers to realize a safety compliant application by integrating HAR 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 Mechanism

HAR 3970 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 SPC definition. Further details about error reporting see Section 3.4.2. on page 30.

The result of the internal diagnostics is as well available via the DIAGNOSIS\_X registers.

**Table 4–1:** DIAGNOSIS\_0 register

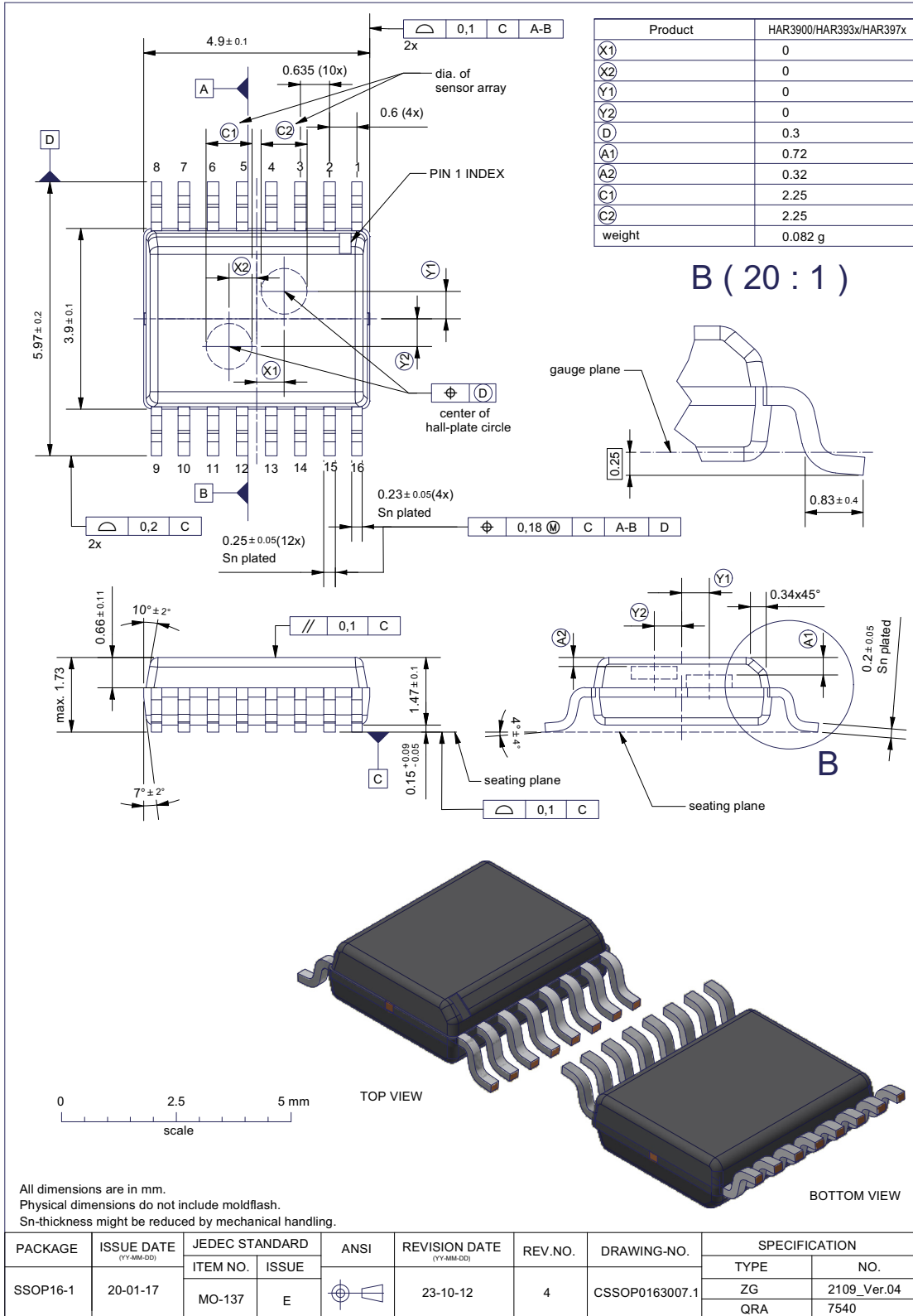
| Bit No. | Description when bit is set to 1   |
|---------|--|
| 15      | DSP self-check routines (redundancy or plausibility checks)                        |
| 14      | DSP and $\mu$ C check of 16-bit checksum covering the EEPROM parameters            |
| 13      | DSP checksum for ROM and RAM   |
| 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           |
| <b>Note: Bits[7:0] can not be read via the programming interface as they are triggering immediately a reset of the device.</b> |   |

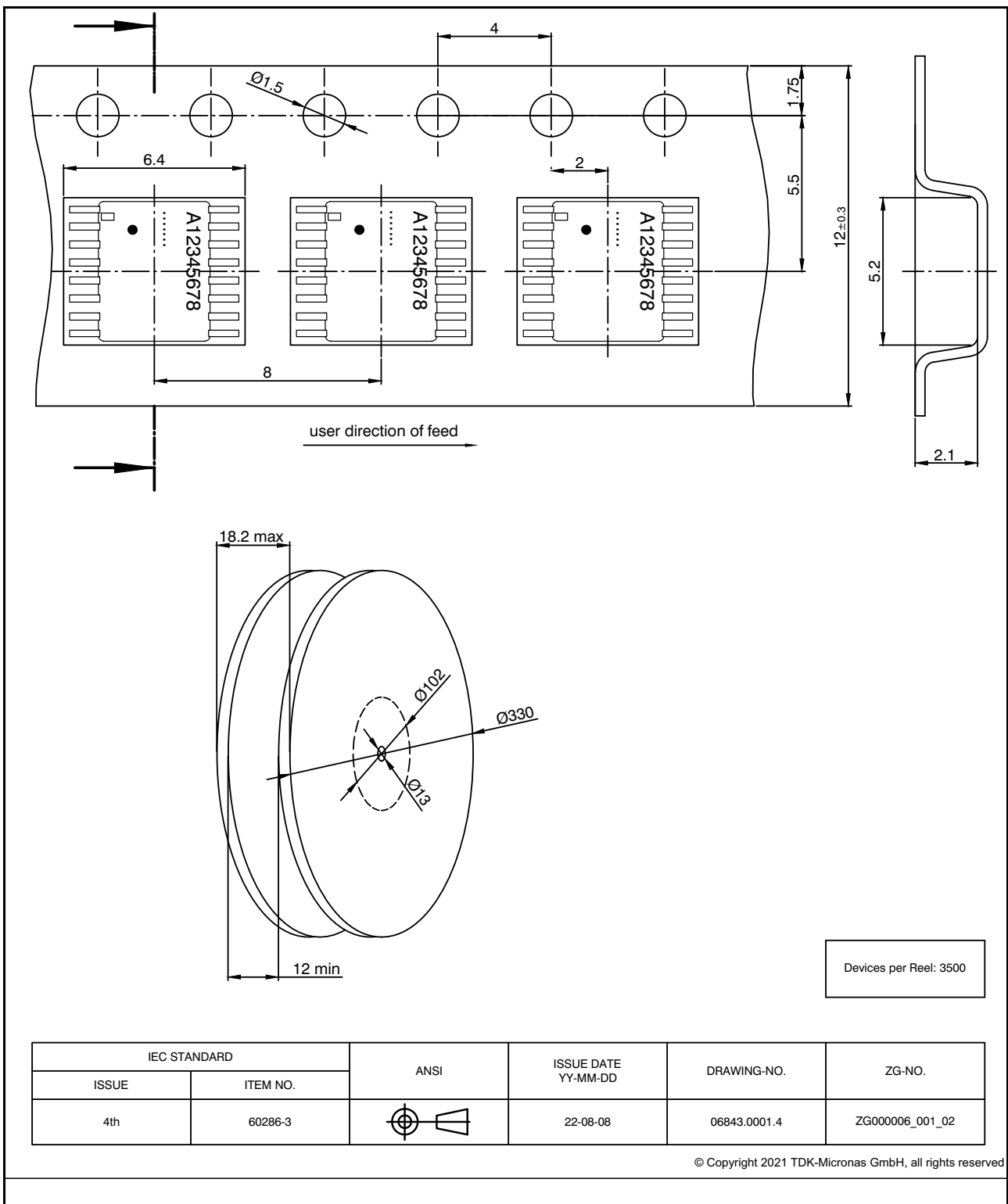
# 5. Specifications

## 5.1. Outline Dimensions



**Fig. 5–1: SSOP16-1: Plastic Shrink Small Outline Package, 16 leads, gullwing bent, 150 mil**  
 Ordering code: GU





**Fig. 5–2: SSOP16: Tape and Reel Finishing (all dimensions in mm)**

### 5.2. Soldering, Welding, Assembly

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

### 5.3. Storage and Shelf Life Package

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

### 5.4. Size and Position of Sensitive Areas

Diameter of Hall plate circle:  $C = 2.25 \text{ mm}$

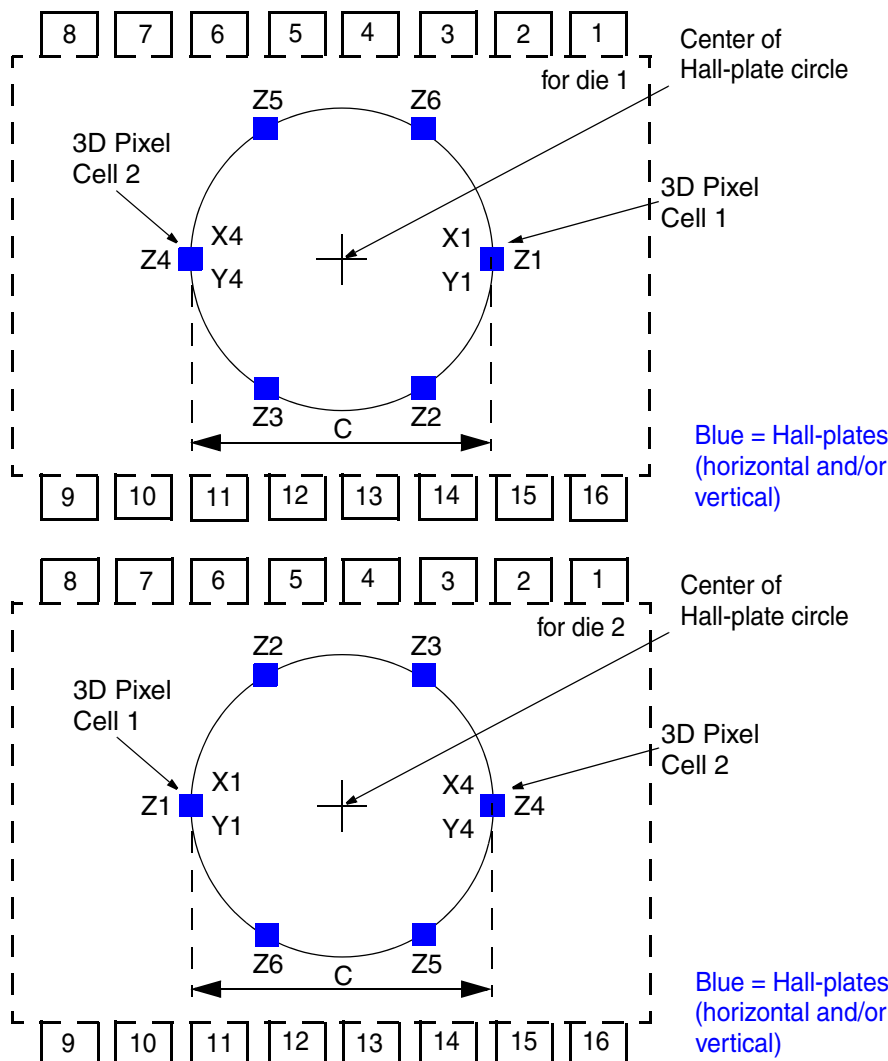
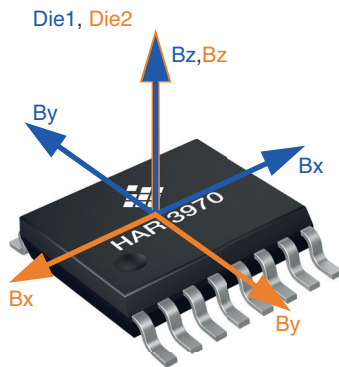


Fig. 5–3: Hall-plate configuration

## 5.5. Definition of Magnetic-Field Vectors



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

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

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## 5.6. Pin Connections and Short Description

**Table 5–1:** Pin connection SSOP16

| Pin No.        | Pin Name | Type | Short Description               |
|----------------|----------|------|---------------------------------|
| SSOP16 Package |          |      |                                 |
| <b>Die 1</b>   |          |      |                                 |
| 1              | ID1_2    | IN   | Bit 2 of HW ID coding           |
| 2              | ID1_1    | IN   | Bit 1 of HW ID coding           |
| 3              | VSUP1    | IN   | Supply voltage                  |
| 4              | TEST1    | N/A  | Test (must stay open)           |
| 5              | GND1     | GND  | Ground                          |
| 6              | TEST2    | N/A  | Test (must be connected to GND) |
| 7              | TEST3    | N/A  | Test (must stay open)           |
| 8              | OUT1     | I/O  | SPC output and programming pin  |
| <b>Die 2</b>   |          |      |                                 |
| 9              | ID2_2    | IN   | Bit 2 of HW ID coding           |
| 10             | ID2_1    | IN   | Bit 1 of HW ID coding           |
| 11             | VSUP2    | IN   | Supply voltage                  |
| 12             | TEST4    | N/A  | Test (must stay open)           |
| 13             | GND2     | GND  | Ground                          |
| 14             | TEST5    | N/A  | Test (must be connected to GND) |
| 15             | TEST6    | N/A  | Test (must stay open)           |
| 16             | OUT2     | I/O  | SPC output and programming pin  |

## 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 <sub>SUP</sub>     | Supply Voltage                                | VSUPx                                      | –18  | 28<br>37                 | V<br>V | t < 60 s; T <sub>J</sub> = 25 °C     |
| V <sub>OUT</sub>     | Output Voltage Output                         | OUTx                                       | –0.3 | 28                       | V      | t < 96 h                             |
| V <sub>IN_ID</sub>   | Input voltage ID Pins                         | IDx  | –0.3 | V <sub>SUP</sub><br>+0.3 | V      | t < 96 h                             |
| B <sub>max</sub>     | Magnetic Field                                | -  | –1   | 1                        | T      |                                      |
| T <sub>J</sub>       | Junction Temperature                          | -  | –40  | 190                      | °C     | t < 96 h <sup>1)</sup>               |
| T <sub>A</sub>       | Ambient Temperature                           | -  | –40  | 160                      | °C     | 2)                                   |
| T <sub>storage</sub> | Transportation/Short Term Storage Temperature | -  | –55  | 150                      | °C     | Device only without packing material |
| V <sub>ESD</sub>     | ESD Protection                                | VSUPx, O<br>UTx,<br>GNDx,<br>IDx,<br>TESTx | –2   | 2                        | kV     | <sup>3)</sup>                        |
|                      |   | VSUPx,<br>GNDx                             | –15  | 15                       | kV     | <sup>4)</sup>                        |
|                      |   | OUTx                                       | –4   | 4                        | kV     | <sup>4)</sup>                        |

No cumulative stress for all parameters.

<sup>1)</sup> Please contact TDK-Micronas for other temperature requirements.

<sup>2)</sup> Consider current consumption, mounting condition (e.g. overmold, potting) and mounting situation for T<sub>A</sub> and in relation to T<sub>J</sub>.

<sup>3)</sup> ESD HBM according to AEC-Q100-002 (100 pF and 1.5 kΩ).

<sup>4)</sup> 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 55).

## 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 <sub>SUP</sub>   | Supply Voltage                       | VSUPx    | 3.0  | -    | 16   | V      |  |
| V <sub>OUT</sub>   | Output Voltage                       | OUTx     | -    | -    | 16   | V      |  |
| V <sub>IN_ID</sub>   | Input Voltage ID                     | IDx      | 0    | -    | 5    | V      |  |
| R <sub>LOUT</sub>  | Output Load                          | OUTx     | 1.5  | -    | 10   | kΩ     | Pull-up resistor required                      |
| C <sub>LOUT</sub>  | Load Capacitance                     | OUTx     | -    | 1    | 3.5  | nF     |  |
| N <sub>PRG</sub>   | Number of Memory Programming Cycles  | -        | -    | -    | 100  | cycles | 0 °C < T <sub>amb</sub> < 55 °C                |
| B <sub>AMP</sub>   | Recommended Magnetic-Field Amplitude | -        | ±10  | -    | ±130 | mT     | <sup>4)</sup> Max. value for setup 2 is ±42 mT |
| T <sub>J</sub>   | Junction Temperature <sup>1)</sup>   | -        | -40  | -    | 170  | °C     | for 1000 h                                     |
| T <sub>A</sub>   | Ambient Temperature <sup>2)</sup>    | -        | -40  | -    | 150  | °C     | for V <sub>SUPx</sub> ≤ 5.5 V <sup>3)</sup>    |
| <sup>1)</sup> Depends on the temperature profile of the application. Please contact TDK-Micronas for life time calculations.<br><sup>2)</sup> Consider current consumption, mounting condition (e.g. overmold, potting) and mounting situation for T <sub>A</sub> and in relation to T <sub>J</sub> .<br><sup>3)</sup> Supply voltages above V <sub>SUPx</sub> = 5.5 V may limit the max. ambient temperature range due to increased self-heating of the device. |                                      |          |      |      |      |        |  |

### 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  $T_A = -40\text{ °C}$  to  $150\text{ °C}$ ,  $V_{SUPx} = 3.0\text{ V}$  to  $5.5\text{ V}$ ,  $GNDx = 0\text{ V}$ , after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column "Conditions". Typical Characteristics for  $T_A = 25\text{ °C}$  and  $V_{SUPx} = 5\text{ V}$ .

**Table 5–4:** Characteristics

| Symbol   | Parameter  | Pin Name | Limit Values |         |      | Unit          | Conditions  |
|--|--|----------|--------------|---------|------|---------------|---|
|  |  |          | Min.         | Typ.    | Max. |               |   |
| $I_{SUP}$  | Supply Current   | VSUPx    | –            | 8       | 12   | mA            | <sup>1)</sup> Current consumption of each die.  |
| $f_{osc}$  | Internal Oscillator Frequency                          |          | –            | 32      | –    | MHz           |   |
| $f_{sample}$   | Sampling Frequency                                     |          | –            | 1.953   | –    | kSps          | <sup>1)</sup> Configurable  |
|  |  |          | –            | 3.906   | –    |               |   |
|  |  |          | –            | 7.812   | –    |               |   |
|  |  |          | –            | 15.6244 | –    |               |   |
| <b>Power-On Behavior</b>   |  |          |              |         |      |               |   |
| $V_{POR}$  | Power_On Reset Voltage                                 | VSUPx    | 2.1          | 2.6     | 2.9  | V             |   |
| $V_{PORHyst}$  | Power_On Reset Voltage Hysteresis                      | VSUPx    | –            | 200     | –    | mV            |   |
| <b>Overvoltage and Undervoltage Detection</b>                              |  |          |              |         |      |               |   |
| $S_{VSUP,UOV}$   | Step Size of Under-/Over-voltage Supervision Threshold | VSUPx    | 92           | 100     | 108  | mV/LSB        | Under-/Overvoltage threshold is customer configurable (see page 22).<br><sup>1)</sup> |
| $S_{VSUP,UOVhys}$  | Under-/Overvoltage Detection Level Hysteresis          | VSUPx    | –            | 1       | –    | LSB           | <sup>1)</sup> 1 LSB typ. 100 mV   |
| <b>HWID Pins</b>   |  |          |              |         |      |               |   |
| $V_{IH,IDx}$   | 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             |   |
| <b>SPC Output</b>  |  |          |              |         |      |               |   |
| $V_{OL}$   | Output Low Voltage                                     | OUTx     | –            | –       | 0.6  | V             | $I_{Load} = 20\text{ mA}$   |
| $t_{fall}$   | Fall Time of Output                                    | OUTx     | –            | 120     | –    | ns            | <sup>1)</sup> <sup>2)</sup>   |
| $I_{Oshort\_High}$   | Output Current for Short to $V_{SUP}$                  | OUTx     | 25           | 40      | 50   | mA            | $V_{SUP} > V_{OUT} > GND$   |
| $I_{Leak}$   | Output Leakage Current                                 | OUTx     | –2           | –       | 2    | $\mu\text{A}$ |   |
| $t_{UT}$   | SPC Unit Time  | OUTx     | 0.97         | 1.00    | 1.03 | $\mu\text{s}$ | <sup>1)</sup>   |
|  |  |          | 1.45         | 1.50    | 1.55 | $\mu\text{s}$ |   |
|  |  |          | 1.94         | 2.00    | 2.06 | $\mu\text{s}$ |   |
|  |  |          | 2.42         | 2.50    | 2.58 | $\mu\text{s}$ |   |
|  |  |          | 2.66         | 2.75    | 2.83 | $\mu\text{s}$ |   |
|  |  |          | 2.91         | 3.00    | 3.09 | $\mu\text{s}$ |   |
| <sup>1)</sup> Characterized on small sample size, not EOL tested.          |  |          |              |         |      |               |   |
| <sup>2)</sup> Measured from 1.1 V to/from 3.8 V with $C_L = 1\text{ nF}$ . |  |          |              |         |      |               |   |

Table 5–4: Characteristics, continued

| Symbol  | Parameter                                     | Pin Name   | Limit Values             |      |      | Unit | Conditions   |
|---|---|------------|--------------------------|------|------|------|--|
|   |   |            | Min.                     | Typ. | Max. |      |  |
| $t_{S\_init}$   | SENT Start-up Time (Output ready for trigger) | OUTx       | –                        | –    | 10.0 | ms   | <sup>1)</sup> Time until first SENT frame with init frame starts.<br>Fig. 5–5 on page 49 |
| <b>Trigger Pulse Parameter (Fig. 5–6 on page 49)</b>  |   |            |                          |      |      |      |  |
| $V_{thf}$   | Trigger Pulse Parameter                       | OUTx       | 1.0                      | 1.3  | 1.7  | V    | <sup>1)</sup>  |
| $V_{thr}$   | Rising Edge Threshold of Master Pulse         | OUTx       | 1.25                     | 1.43 | 2.0  | V    | <sup>1)</sup>  |
| $t_{mtr}$   | Master Trigger Pulse Length                   | OUTx       | –                        | 13   | –    | UT   | <sup>1)</sup> Synchronous mode   |
|   |   |            | –                        | 90   | –    | UT   | <sup>1)</sup> ID selection mode  |
| $t_{md\_tot}$   | Master Delay Time                             | OUTx       | 12                       | –    | –    | UT   | <sup>1)</sup>  |
| <b>Sensor SPC trigger parameter (Bus mode: on)<sup>4)</sup></b>   |   |            |                          |      |      |      |  |
| $t_{m\ low\_c}$   | Master Low Time                               | OUTx       | 2                        | –    | 5    | UT   | Bus mode off   |
|   |   |            | 8                        | –    | 15   | UT   | <sup>1)</sup> ID = 0, Bus mode on  |
|   |   |            | 16                       | –    | 28   | UT   | <sup>1)</sup> ID = 1, Bus mode on  |
|   |   |            | 29                       | –    | 49   | UT   | <sup>1)</sup> ID = 2, Bus mode on  |
|   |   |            | 50                       | –    | 82   | UT   | <sup>1)</sup> ID = 3, Bus mode on  |
| <b>ECU SPC trigger parameter (Bus mode: on)<sup>4)</sup></b>  |   |            |                          |      |      |      |  |
| $t_{m\ low\_c}$   | Master Low Time                               | OUTx       | 2                        | –    | 4    | UT   | Bus mode off   |
|   |   |            | 9                        | 10.5 | 12   | UT   | <sup>1)</sup> ID = 0, Bus mode on  |
|   |   |            | 19                       | 21   | 23   | UT   | <sup>1)</sup> ID = 1, Bus mode on  |
|   |   |            | 35.5                     | 38   | 40.5 | UT   | <sup>1)</sup> ID = 2, Bus mode on  |
|   |   |            | 61.5                     | 64.5 | 67.5 | UT   | <sup>1)</sup> ID = 3, Bus mode on  |
| $t_{tp\_v}$   | Total Variable Trigger Pulse Length           | OUTx       | $t_{m\ low\_c} + 12\ UT$ |      |      | UT   | <sup>1)</sup>  |
| <b>SSOP16 Package</b>   |   |            |                          |      |      |      |  |
| $R_{thja}$  | Thermal Resistance Junction to Air            | –          | –                        | –    | 130  | K/W  | <sup>3)</sup> Determined with a 1S0P board   |
|   |   | –          | –                        | –    | 91   | K/W  | <sup>3)</sup> Determined with a 2S2P board   |
| $R_{thjc}$  | Thermal Resistance Junction to Case           | –          | –                        | –    | 34   | K/W  | <sup>3)</sup> Determined with a 1S0P   |
|   |   | –          | –                        | –    | 31   | K/W  | <sup>3)</sup> Determined with a 2S2P board   |
| $R_{ISOL}$  | Isolation Resistance <sup>4)</sup>            | GND1, GND2 | 4                        | –    | –    | MΩ   | Between two dies (Between GND1 and GND2 pin)   |
| <sup>1)</sup> Characterized on small sample size, EOL not tested.<br><sup>3)</sup> Self-heating calculation see Section 6.1. on page 54.<br><sup>4)</sup> GND's galvanic isolation is not EOL tested. |   |            |                          |      |      |      |  |



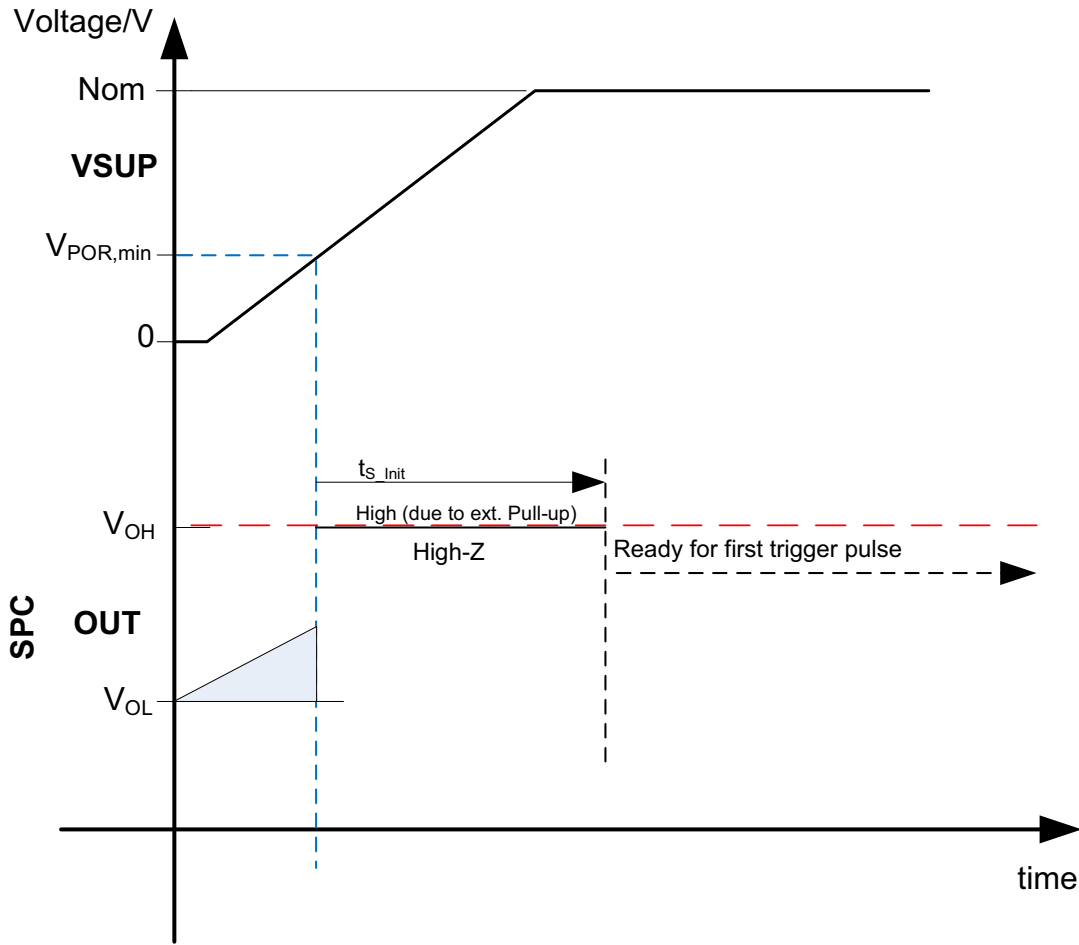


Fig. 5-5: Start-up behavior of HAR 3970 (example for one output)

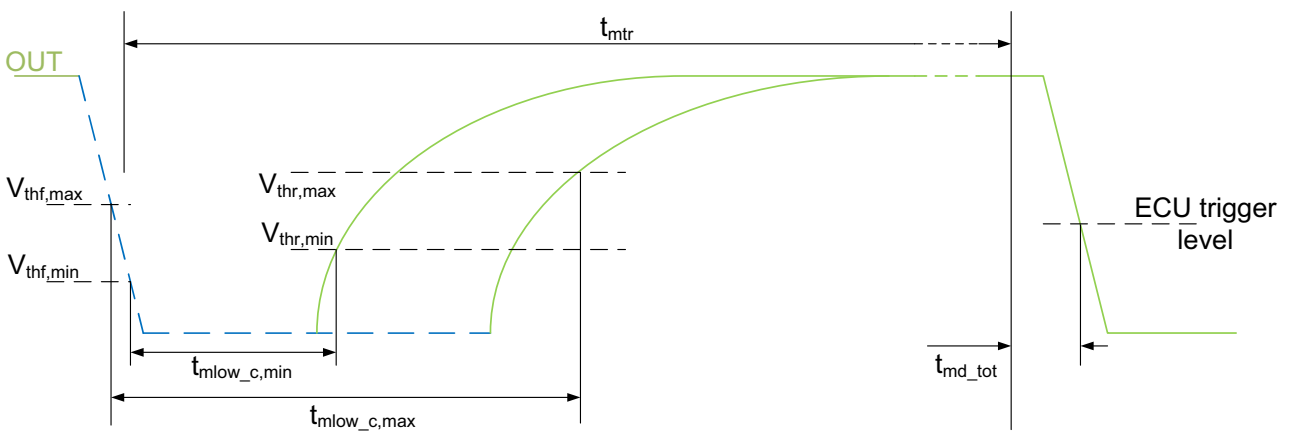


Fig. 5-6: SPC Master Pulse Timing

## 5.10. Magnetic Characteristics

at  $T_A = -40\text{ °C}$  to  $150\text{ °C}$ ,  $V_{SUPX} = 3.0\text{ V}$  to  $5.5\text{ V}$ ,  $GNDx = 0\text{ V}$ , after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column "Conditions". Typical Characteristics for  $T_A = 25\text{ °C}$  and  $V_{SUPX} = 5.0\text{ V}$ .

**Table 5–5:** Magnetic Characteristics

| Symbol  | Parameter  | Pin Name | Min. | Typ. | Max. | Unit                  | Conditions   |
|---|--|----------|------|------|------|-----------------------|--|
| <b>Rotary Setup with Stray-Field Compensation (Setup 1)</b>   |  |          |      |      |      |                       |  |
| $\Delta E_{\text{otot}}$  | Total Angular Error of Drifts  | OUTx     | -0.3 | -    | 0.3  | °                     | 1)6) $B_{AMP} = \pm 10\text{ mT}$                      |
| $\Delta E_{\text{otemp}}$   | Angular Error Drift over Temperature   | OUTx     | -0.2 | -    | 0.2  | °                     | 1)6) $B_{AMP} = \pm 10\text{ mT}$                      |
| $\Delta E_{\text{olife}}$   | Angular Error Drift over Lifetime  | OUTx     | -0.2 | -    | 0.2  | °                     | 1)6) $B_{AMP} = \pm 10\text{ mT}$<br>After 1008 h HTOL |
| $E_{\text{ohyst}}$  | Angular Hysteresis Error   | OUTx     | -    | -    | 0.05 | °                     | 2)   |
| $E_{\text{onoise}_1}$   | Angular Noise Setup 1  | OUTx     | -    | 0.13 | 0.23 | °                     | 3)6)   |
| $E_{\text{osf}_1}$  | Angular Error due to Stray-Field for Setup 1   | OUTx     | -    | -    | 0.1  | °                     | 1)4) $B_{AMP} = \pm 10\text{ mT}$<br>wanted signal     |
| <b>Rotary Setup with Stray-Field Compensation (Setup 2)</b>   |  |          |      |      |      |                       |  |
| $\Delta E_{\text{otot}}$  | Total Angular Error of Drifts  | OUTx     | -0.6 | -    | 0.6  | °                     | 1)5) $B_{AMP} = \pm 10\text{ mT}$                      |
| $\Delta E_{\text{otemp}}$   | Angular Error Drift over Temperature   | OUTx     | -0.4 | -    | 0.4  | °                     | 1)5) $B_{AMP} = \pm 10\text{ mT}$                      |
| $\Delta E_{\text{olife}}$   | Angular Error Drift over Lifetime  | OUTx     | -0.4 | -    | 0.4  | °                     | 1)5) $B_{AMP} = \pm 10\text{ mT}$<br>After 1008 h HTOL |
| $E_{\text{ohyst}}$  | Angular Hysteresis Error   | OUTx     | -    | -    | 0.05 | °                     | 2)   |
| $E_{\text{onoise}_2}$   | Angular Noise Setup 2  | OUTx     | -    | 0.25 | 0.4  | °                     | 3)5)   |
| $E_{\text{osf}_2}$  | Angular Error due to Stray-Field for Setup 2   | OUTx     | -    | -    | 0.8  | °                     | 1) 4) $B_{AMP} = \pm 10\text{ mT}$<br>wanted signal    |
| <b>Linear Movement Setup (<math>\Delta XZ</math>) with Stray-Field Compensation (Setup 3b)</b>  |  |          |      |      |      |                       |  |
| $SM_{\Delta XZ41}$  | Sensitivity Mismatch between $\Delta X_{41}$ and $\Delta Z_{41}$ Channel               | OUTx     | -5   | -    | 5    | %                     | 1) $T_A = 25\text{ °C}$                                |
| $Sense_{\Delta XZ41}$   | Sensitivity of $\Delta X_{41}$ and $\Delta Z_{41}$ Channel                             | OUTx     | 121  | 128  | 135  | LSB <sub>15</sub> /mT | 1) $T_A = 25\text{ °C}$                                |
| $\Delta SM_{\Delta XZ41}$   | Thermal Sensitivity Mismatch Drift between $\Delta X_{41}$ and $\Delta Z_{41}$ Channel | OUTx     | -3.5 | -    | 3.5  | %                     | 1) Related to $T_A = 25\text{ °C}$                     |
| $Offset_{\Delta X41}$   | Offset of $\Delta X_{41}$ Channel  | OUTx     | -30  | -    | 30   | LSB <sub>15</sub>     | $T_A = 25\text{ °C}$                                   |
| $Offset_{\Delta Z41}$   | Offset of $\Delta Z_{41}$ Channel  | OUTx     | -15  | -    | 15   | LSB <sub>15</sub>     | $T_A = 25\text{ °C}$                                   |
| <p>All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not EOL tested).</p> <p>1) Based on Simulation Model (not EOL tested).</p> <p>2) Guaranteed by Design.</p> <p>3) Characterized on small sample size, <math>B_{AMP} = \pm 10\text{ mT}</math>, <math>f_{\text{dec sel}} = 2\text{ kHz}</math>, Low-pass filter: off, 3-sigma values (not EOL tested).</p> <p>4) Characterized on small sample size according to ISO 11452-8:2015, at <math>25\text{ °C}</math>, with stray-field strength of <math>4\text{ kA/m}</math> from X,Y and Z direction, 3-sigma values (not EOL tested).</p> <p>5) Referenced to an angular range of <math>360\text{ °}</math>.</p> <p>6) Referenced to an angular range of <math>180\text{ °}</math>.</p> |  |          |      |      |      |                       |  |

Table 5–5: Magnetic Characteristics, continued

| Symbol  | Parameter   | Pin Name | Min. | Typ.      | Max. | Unit                  | Conditions   |
|---|---|----------|------|-----------|------|-----------------------|--|
| $\Delta\text{Offset}_{\Delta X_{41}}$   | Offset Drift of $\Delta X_{41}$ Channel   | OUTx     | -50  | -         | 50   | LSB <sub>15</sub>     | Related to $T_A = 25\text{ °C}$                                |
| $\Delta\text{Offset}_{\Delta Z_{41}}$   | Offset Drift $\Delta Z_{41}$ Channel  | OUTx     | -15  | -         | 15   | LSB <sub>15</sub>     | Related to $T_A = 25\text{ °C}$                                |
| $\Delta\text{SM}_{\Delta X_{41}\text{life}}$  | Relative Sensitivity Mismatch Drift between $\Delta X_{41}$ and $\Delta Z_{41}$ Channel over life time  | OUTx     | -    | 6.0       | -    | %                     | <sup>1)</sup> After 1008 h HTOL                                |
| $\Delta\text{Offset}_{\Delta X_{41}\text{life}}$  | Offset Drift of $\Delta X_{41}$ Channel over life time  | OUTx     | -    | 30        | -    | LSB <sub>15</sub>     | After 1008 h HTOL  |
| $\Delta\text{Offset}_{\Delta Z_{41}\text{life}}$  | Offset Drift of $\Delta Z_{41}$ Channel over life time  | OUTx     | -    | 9         | -    | LSB <sub>15</sub>     | After 1008 h HTOL  |
| $\text{SF}_{R\Delta X_{41}}$  | Stray-Field Rejection in $\Delta X_{41}$ Direction  | OUTx     | 99   | -         | -    | %                     | <sup>4)</sup> $T_A = 25\text{ °C}$                             |
| $\text{SF}_{R\Delta Z_{41}}$  | Stray-Field Rejection in $\Delta Z_{41}$ Direction  | OUTx     | 98.7 | -         | -    | %                     | <sup>4)</sup> $T_A = 25\text{ °C}$                             |
| $E_{\text{phase}\Delta X_{41}}$   | Phase Error between $\Delta X_{41}$ and $\Delta Z_{41}$ Channel   | OUTx     | -    | $\pm 2.2$ | -    | °                     | between $\Delta X_{41}$ and $\Delta Z_{41}$ axis <sup>1)</sup> |
| $E_{\Delta X_{41},\text{noise}}$  | Digital Noise of $\Delta X_{41}$ Hall-Plates Channel  | OUTx     | -    | 2.4       | -    | LSB <sub>15</sub>     | <sup>7)</sup>  |
| $E_{\Delta Z_{41},\text{noise}}$  | Digital Noise of $\Delta Z_{41}$ Hall-Plates Channel  | OUTx     | -    | 2.6       | -    | LSB <sub>15</sub>     | <sup>7)</sup>  |
| <b>Off-Axis Rotary Setup (<math>\Delta XY</math>) with Stray-Field Compensation (Setup 3a)</b>  |   |          |      |           |      |                       |  |
| $\text{SM}_{\Delta XY_{41}}$  | Sensitivity Mismatch between $\Delta X_{41}$ and $\Delta Y_{41}$ Channel                                | OUTx     | -2   | -         | 2    | %                     | <sup>1)</sup> $T_A = 25\text{ °C}$                             |
| $\text{Sense}_{\Delta XY_{41}}$   | Sensitivity of $\Delta X_{41}$ and $\Delta Y_{41}$ Channel  | OUTx     | 121  | 128       | 135  | LSB <sub>15</sub> /mT | <sup>1)</sup> $T_A = 25\text{ °C}$                             |
| $\Delta\text{SM}_{\Delta XY_{41}}$  | Thermal Sensitivity Mismatch Drift between $\Delta X_{41}$ and $\Delta Y_{41}$ Channel                  | OUTx     | -2.5 | -         | 2.5  | %                     | <sup>1)</sup> Related to $T_A = 25\text{ °C}$                  |
| $\text{Offset}_{\Delta XY_{41}}$  | Offset of $\Delta X_{41}$ and $\Delta Y_{41}$ Channels  | OUTx     | -30  | -         | 30   | LSB <sub>15</sub>     | $T_A = 25\text{ °C}$   |
| $\Delta\text{Offset}_{\Delta XY_{41}}$  | Offset Drift of $\Delta X_{41}$ and $\Delta Y_{41}$ Channels  | OUTx     | -50  | -         | 50   | LSB <sub>15</sub>     | Related to $T_A = 25\text{ °C}$                                |
| $\Delta\text{SM}_{\Delta XY_{41}\text{life}}$   | Relative Sensitivity Mismatch Drift between $\Delta X_{41}$ and $\Delta Y_{41}$ Channels over life time | OUTx     | -    | 1.0       | -    | %                     | <sup>1)</sup> After 1008 h HTOL                                |
| $\Delta\text{Offset}_{\Delta XY_{41}\text{life}}$   | Offset Drift of $\Delta X_{41}$ and $\Delta Y_{41}$ Channel over life time                              | OUTx     | -    | 30        | -    | LSB <sub>15</sub>     | After 1008 h HTOL  |
| $\text{SF}_{R\Delta XY_{41}}$   | Stray-Field Rejection in $\Delta X_{41}$ and $\Delta Y_{41}$ Direction                                  | OUTx     | 99   | -         | -    | %                     |  |
| $E_{\text{phase}\Delta XY_{41}}$  | Phase Error between $\Delta X_{41}$ and $\Delta Y_{41}$ Channel   | OUTx     | -    | $\pm 4.2$ | -    | °                     | <sup>1)</sup> between $\Delta X_{41}$ and $\Delta Y_{41}$ axis |
| $E_{\Delta XY_{41},\text{noise}}$   | Digital Noise of $\Delta X_{41}$ and $\Delta Y_{41}$ Hall-Plates Channel                                | OUTx     | -    | 2.4       | -    | LSB <sub>15</sub>     | <sup>7)</sup>  |
| <p>All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not EOL tested).</p> <p><sup>1)</sup> Based on Simulation Model (not EOL tested.)</p> <p><sup>4)</sup> 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).</p> <p><sup>7)</sup> Characterized on small sample size, 1-sigma values of COMP_CHx, fdecsel = 2 kHz, Low-pass filter: off (not EOL tested).</p> |   |          |      |           |      |                       |  |

Table 5–5: Magnetic Characteristics, continued

| Symbol  | Parameter   | Pin Name | Min. | Typ. | Max. | Unit                  | Conditions                        |
|---|---|----------|------|------|------|-----------------------|-----------------------------------|
| <b>3D Measurement Setup without Stray-Field Compensation (Setup 4)</b>  |   |          |      |      |      |                       |                                   |
| SM <sub>XYZ</sub>   | Sensitivity Mismatch between X or Y and Z Channel                                 | OUTx     | -4   | -    | 4    | %                     | T <sub>A</sub> = 25 °C            |
| SM <sub>XY</sub>  | Sensitivity Mismatch between X and Y Channel                                      | OUTx     | -2   | -    | 2    | %                     | T <sub>A</sub> = 25 °C            |
| Sense <sub>XYZ</sub>  | Sensitivity of X, Y and Z Hall-plate  | OUTx     | 123  | 128  | 133  | LSB <sub>15</sub> /mT | T <sub>A</sub> = 25 °C            |
| ΔSM <sub>XYZ</sub>  | Thermal Sensitivity Mismatch Drift between X or Y and Z Hall Plates               | OUTx     | -2.7 | -    | 2.7  | %                     | Related to T <sub>A</sub> = 25 °C |
| ΔSM <sub>XY</sub>   | Thermal Sensitivity Mismatch Drift between X and Y Hall Plates                    | OUTx     | -2   | -    | 2    | %                     | Related to T <sub>A</sub> = 25 °C |
| Offset <sub>XY</sub>  | Offset of X and Y Hall-plates   | OUTx     | -20  | -    | 20   | LSB <sub>15</sub>     | T <sub>A</sub> = 25 °C            |
| Offset <sub>Z</sub>   | Offset of Z Hall-plate  | OUTx     | -12  | -    | 12   | LSB <sub>15</sub>     | T <sub>A</sub> = 25 °C            |
| ΔOffset <sub>XY</sub>   | Offset Drift of X and Y Hall-plates   | OUTx     | -40  | -    | 40   | LSB <sub>15</sub>     | Related to T <sub>A</sub> = 25 °C |
| ΔOffset <sub>Z</sub>  | Offset Drift of Z Hall-plate  | OUTx     | -15  | -    | 15   | LSB <sub>15</sub>     | Related to T <sub>A</sub> = 25 °C |
| ΔSM <sub>XYZlife</sub>  | Relative Sensitivity Mismatch Drift between X, Y and Z Hall Plates over life time | OUTx     | -    | ±4.5 | -    | %                     | After 1008 h HTOL                 |
| ΔOffset <sub>XYlife</sub>   | Offset Drift of X and Y Hall-plates over life time                                | OUTx     | -    | 30   | -    | LSB <sub>15</sub>     | After 1008 h HTOL                 |
| ΔOffset <sub>Zlife</sub>  | Offset Drift of Z Hall-plate over life time                                       | OUTx     | -    | 5    | -    | LSB <sub>15</sub>     | After 1008 h HTOL                 |
| E <sub>OpphaseXYZ</sub>   | Phase Error between X, Y and Z Hall-Plates  | OUTx     | -    | ±3.1 | -    | °                     | XY axis                           |
|   |   |          | -    | ±1.6 | -    | °                     | XZ axis                           |
|   |   |          | -    | ±2.5 | -    | °                     | YZ axis                           |
| E <sub>XYZ,noise</sub>  | Digital Noise of X, Y or Z Hall-Plates Channel                                    | OUTx     | -    | 2.2  | -    | LSB <sub>15</sub>     | <sup>7)</sup>                     |
| All values are characterized on small sample size and 3-sigma values as long as not otherwise specified (not EOL tested).             |   |          |      |      |      |                       |                                   |
| <sup>1)</sup> Based on Simulation Model (not EOL tested).   |   |          |      |      |      |                       |                                   |
| <sup>7)</sup> 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  $T_A = -40\text{ °C}$  to  $150\text{ °C}$ ,  $V_{SUPx} = 3.0\text{ V}$  to  $5.5\text{ V}$ ,  $GNDx = 0\text{ V}$ , after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Conditions”.

Typical Characteristics for  $T_A = 25\text{ °C}$  and  $V_{SUPx} = 5.0\text{ V}$ .

| Symbol   | Parameter                                  | Pin No. | Min. | Typ.  | Max. | Unit                  | Conditions           |
|--|--|---------|------|-------|------|-----------------------|----------------------|
| TADJ <sub>Gain</sub>   | Gain of Temperature Sensor                 | OUTx    | –    | 89.25 | –    | LSB <sub>15</sub> /°C | 1) for TADJ register |
| TADJ <sub>Offset</sub>   | Temperature Sensor Offset                  | OUTx    | –    | 3720  | –    | LSB <sub>15</sub>     | 1) for TADJ register |
| TSENT <sub>Gain</sub>  | Gain of Temperature Sensor for SENT Output | OUTx    | –    | 8.1   | –    | LSB <sub>12</sub> /°C | 1) SENT Slow Channel |
| TSENT <sub>Offset</sub>  | Temperature Sensor Offset for SENT Output  | OUTx    | –    | 565.3 | –    | LSB <sub>12</sub>     | 1) SENT Slow Channel |
| $\Delta T_{Lin}$   | Temperature Sensor Linearity Error         | OUTx    | –2   | –     | 2    | °C                    | 2)                   |
| $\Delta T_{Acc}$   | Temperature Sensor Accuracy                | OUTx    | –5   | –     | 5    | °C                    | 2)                   |
| 1) Not EOL tested.<br>2) Characterized on small sample size, 3-sigma values, not tested EOL for each device. |  |         |      |       |      |                       |                      |

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## 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  $P = V_{SUP} \times I_{SUP}$ . This value must be multiplied by a factor of two for HAR 3970.

The junction to ambient thermal resistance  $R_{thja}$  is specified in Section 5.9. on page 47.

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.

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**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.

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### 6.2. EMC and ESD

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

### 6.3. Application Circuit for HAR 3970

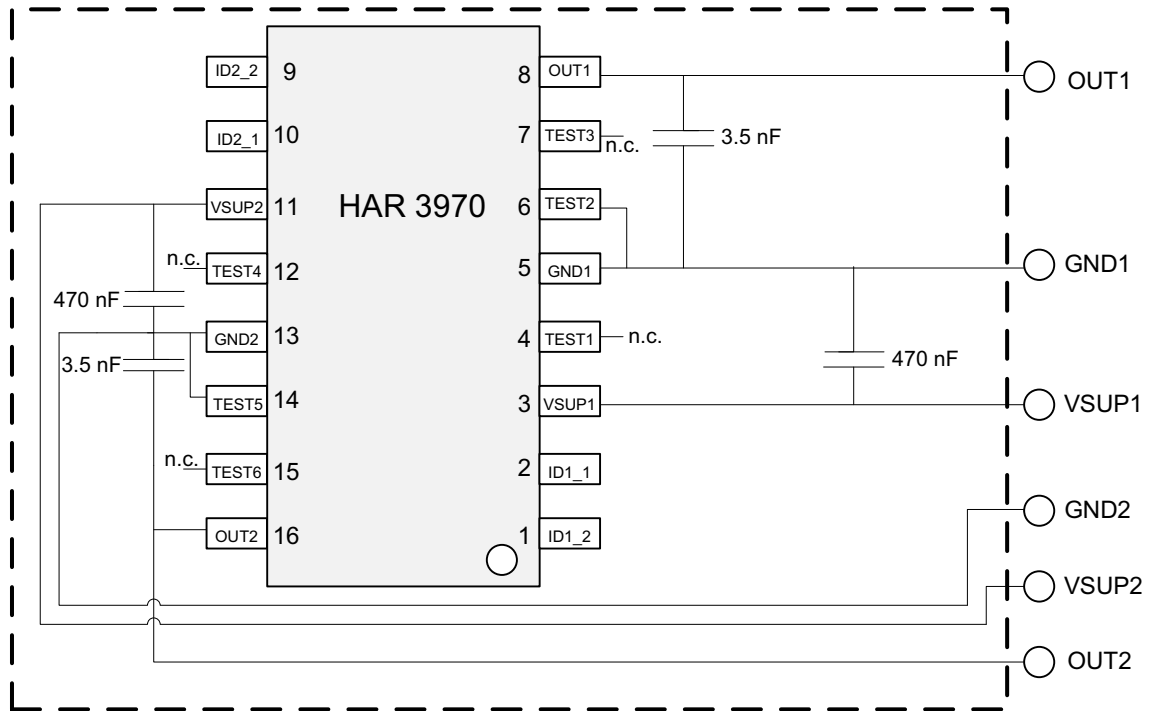
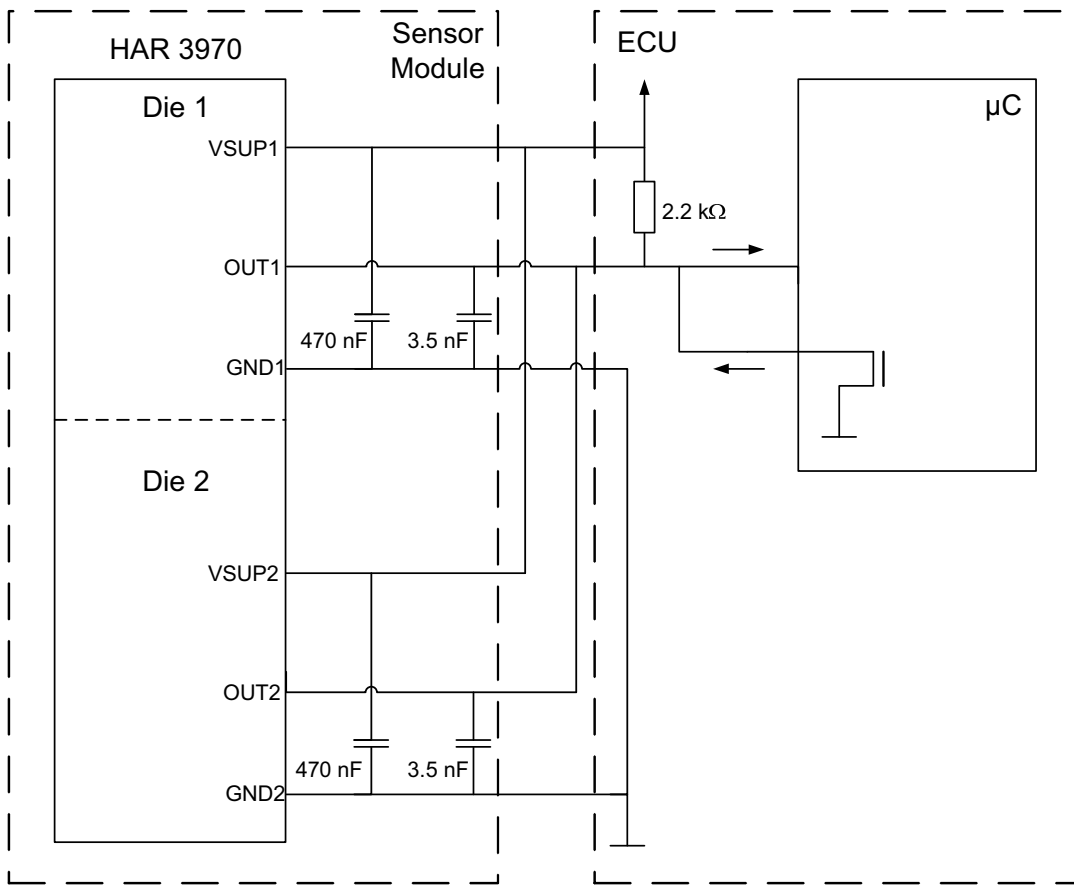


Fig. 6–1: Recommended application circuit for HAR 3970

**Note** The IDx pins must be connected to GND or VSUP to define different sensor ID's for die 1 and die 2 in case of BUS mode communication.

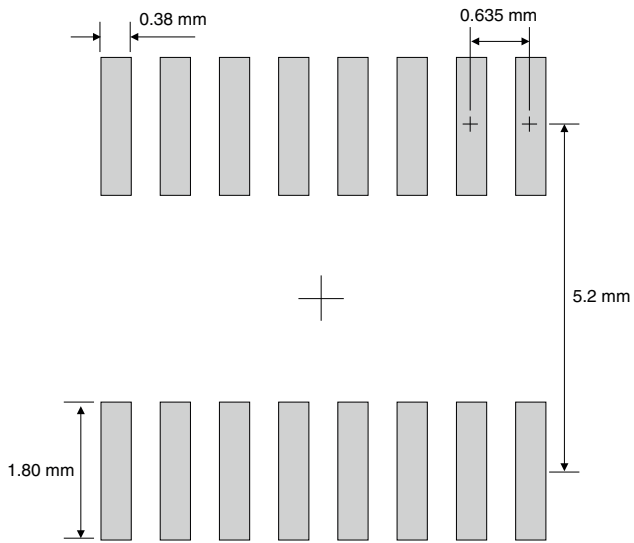


**Fig. 6–2:** Application circuit for bus mode

**Note** The not shown IDx pins must be connected to GND or VSUP to define different sensor ID's for die 1 and die 2



## 6.4. Recommended Pad Size SSOP16 Package



**Fig. 6–3:** Pad size recommendation for SSOP16 Package (all dimensions in mm)

## 7. Programming of the Sensor

HAR 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.

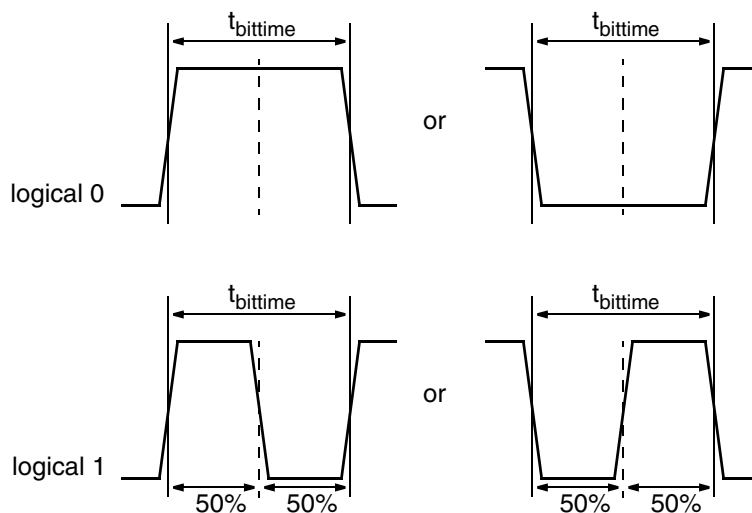
After power-up the sensor is always operating in the **Application Mode**. It is switched to the **Programming Mode** by a BiPhase-M protocol via output voltage modulation. Therefor the programming device needs to provide a long sync pulse at the output pin.

### 7.1. Programming Interface

In Programming Mode HAR 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/ $\mu$ s | <sup>1)</sup> 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          |   |
| <sup>1)</sup> Not EOL tested. |  |         |                |      |                |            |   |

## 7.2. Programming Environment and Tools

For the programming of HAR 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/HAR 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 HAR 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.

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

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## 8. Document History

1. Advance Information: "HAR 3970-2301 Dual-Die Stray-Field Robust 3D Position Sensor with SPC (Short PWM Code) Interface", Jan. 26, 2024, DSH000252\_001EN.  
First release of the Advance Information.
2. Data Sheet: "HAR 3970-2301 Dual-Die Stray-Field Robust 3D Position Sensor with SPC (Short PWM Code) Interface", Sept. 26, 2024, DSH000241\_001EN. First release of the Data Sheet.