



# KMA320

## Dual channel programmable angle sensor IC

Rev. 3 — 28 January 2019

Product data sheet

## 1 General description

The KMA320 is a dual channel magnetic angle sensor. Magnetoresistive (MR) sensor bridges and mixed signal ICs are integrated into a single package. The module has integrated filters and is optimized for PCB-less designs. The KMA320 dual channel sensor module has common power supply terminals for both channels.

Further explanations are referring to a single channel and apply independently to each output of the dual channel device. The IC allows user-specific adjustments of angular range, zero angle, and clamping voltages. The settings are stored permanently in a non-volatile memory (NVM). The programmable angle sensors are pre-programmed, pre-calibrated and therefore, ready to use.

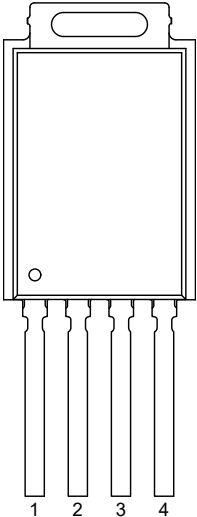
## 2 Features and benefits

- High precision sensor for magnetic angular measurement
- Single package sensor module with integrated filters for improved electromagnetic compatibility (EMC)
- Automotive qualified in accordance with AEC-Q100 Rev-H
- Programmable user adjustments, e.g. zero angle and angular range
- Fail-safe non-volatile memory with write protection using lock bit
- Independent from magnetic field strength above 25 kA/m
- Module ready to use without external components
- Factory calibrated
- Separate temperature sensor and auxiliary analog-to-digital converter (ADC) for magnetic field conversion check
- High temperature range up to 180 °C
- Ratiometric analog output voltage or push pull output stage compliant with SAE J2716 SENT using pulse shaping
- Overvoltage protection up to 18 V
- Power-loss detection
- Programming via separated one-wire interfaces (OWIs)
- 8 × 12-bit original equipment manufacturer (OEM) code registers for identification (ID)
- ISO 26262 ASIL-C capable for each channel, safety element out of context (SEooC)
- Multipoint calibration (MPC) with 17 equidistant or seven free selectable calibration points
- Low latency
- Dual channel sensor module



### 3 Pinning information

Table 1. Pinning

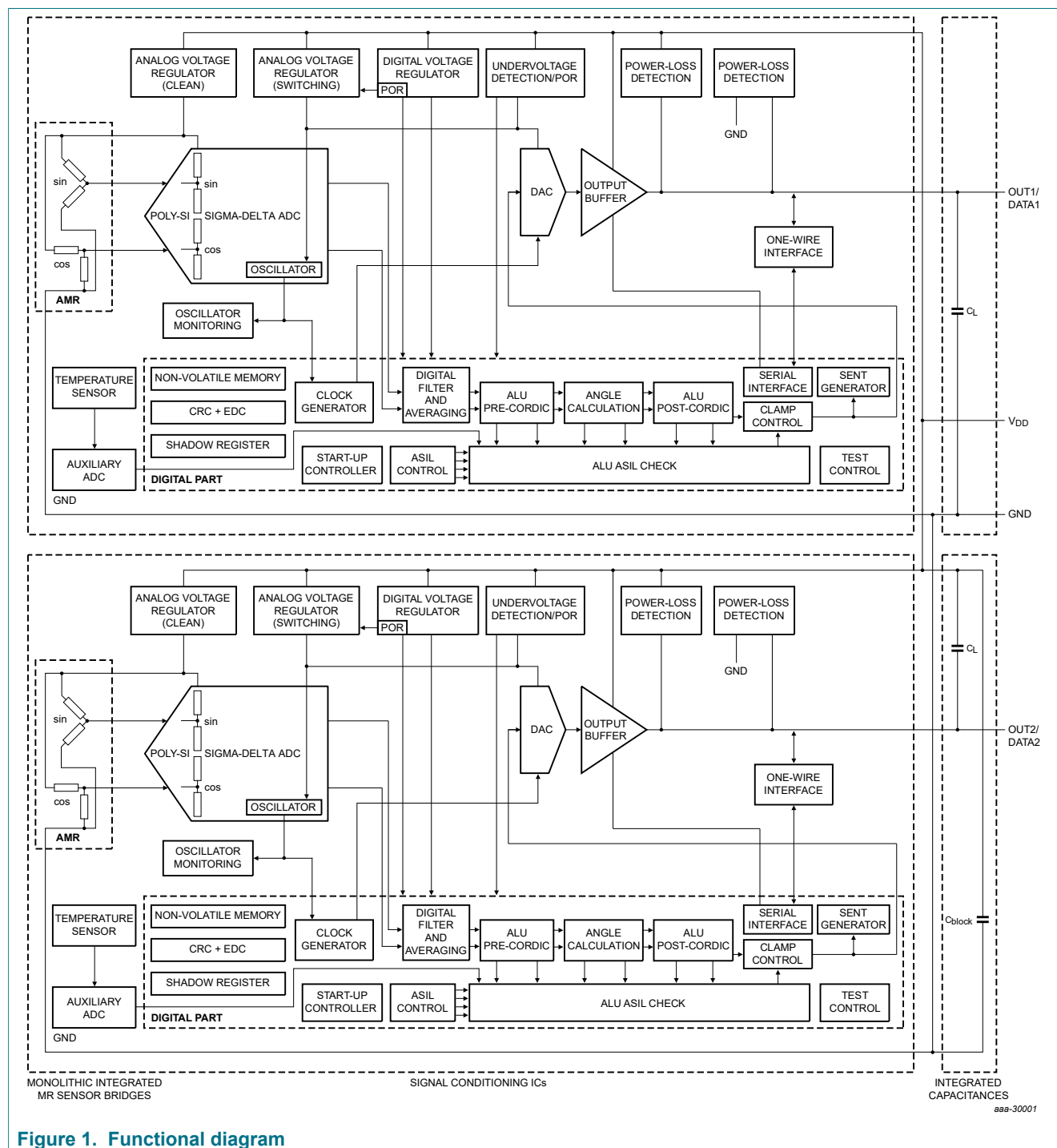
| Pin | Symbol          | Description                                                                | Simplified outline                                                                   |
|-----|-----------------|----------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| 1   | OUT1/DATA1      | analog/single edge nibble transmission (SENT) output 1 or data interface 1 |  |
| 2   | GND             | ground                                                                     |                                                                                      |
| 3   | V <sub>DD</sub> | supply voltage                                                             |                                                                                      |
| 4   | OUT2/DATA2      | analog/SENT output 2 or data interface 2                                   |                                                                                      |

### 4 Ordering information

Table 2. Ordering information

| Type number | Package |                                 |           |
|-------------|---------|---------------------------------|-----------|
|             | Name    | Description                     | Version   |
| KMA320      | SIL4    | plastic, single in-line package | SOT1188-2 |

## 5 Functional diagram



### Figure 1. Functional diagram

## 6 Functional description

The KMA320 converts two orthogonal signals from MR sensor bridges into the digital domain. The angle is calculated using the coordinate rotation digital computer (CORDIC) algorithm. After a digital-to-analog conversion, the analog signal is provided to the output as a linear representation of the angular value or transmitted in a SENT frame compliant to SAE J2716. Both channels have to be in the same operation mode (analog or digital/SENT). Zero angle, clamping voltages and angular range are programmable. In addition, eight 12-bit registers are available for customer purposes, such as sample ID.

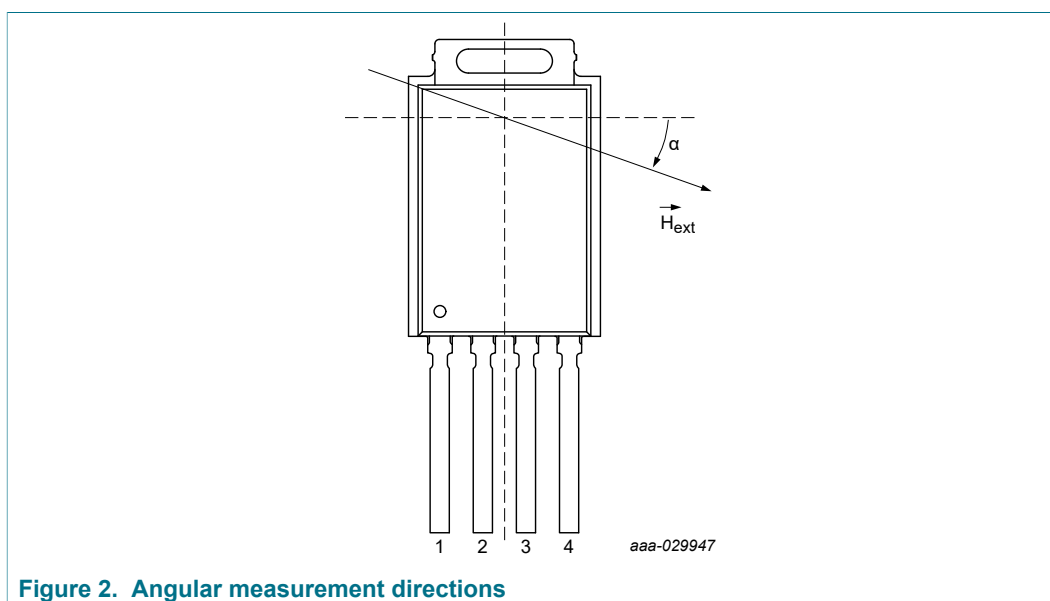
KMA320 comprises a cyclic redundancy check (CRC) and an error detection code (EDC) to ensure a fail-safe operation. If either the supply voltage or the ground line of the mixed signal IC is interrupted, a power-loss detection circuit pulls the output to the remaining connection.

After conversion into the digital domain by an ADC, further processing is done within an on-chip state machine. This state machine controls offset cancelation, calculation of the mechanical angle using the CORDIC algorithm, as well as zero angle and angular range adjustment. The internal digital-to-analog converter (DAC) and the analog output stage are used for conversion of the angle information into an analog output voltage, which is ratiometric to the supply voltage. Alternatively, the output signal can be transmitted digitally in a SENT frame compliant to SAE J2716.

The configuration parameters are stored in a user-programmable non-volatile memory. The OWI (accessible using pin OUTn/DATAn) is used for accessing the memory. In order to protect the memory content, a lock bit can be set. After locking the non-volatile memory, its content cannot be changed anymore.

### 6.1 Angular measurement directions

The signals of the MR sensor bridges depend only on the direction of the external magnetic field vector  $H_{ext}$ , which is applied parallel to the plane of the sensor. In order to obtain a correct output signal, exceed the minimum saturation field strength.



Since the anisotropic MR (AMR) effect is periodic over 180°, the sensor output is also 180°-periodic. The angle is calculated relative to a freely programmable zero angle. The dashed line indicates the mechanical zero degree position.

7 Analog output

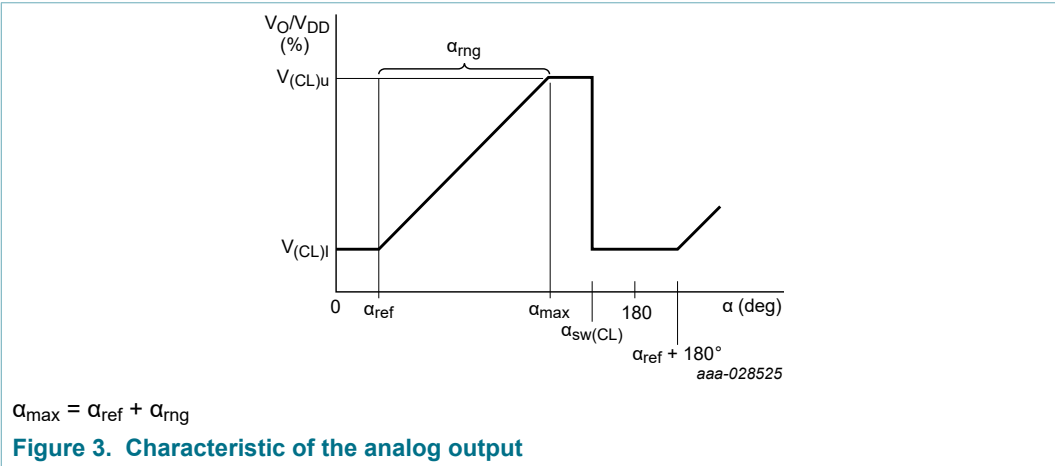
KMA320 provides an analog output signal on pin OUTn/DATAn (if bit 12 in register SYS\_SETTING is set to logic 0; see Table 51). The measured angle α is converted linearly into a value, which is ratiometric to the supply voltage V<sub>DD</sub>. Either a positive or a negative slope is provided for this purpose.

Table 3 describes the analog output behavior for a positive slope. A magnetic field angle, above the programmed maximum angle α<sub>max</sub>, but below the clamp switch angle α<sub>sw(CL)</sub> sets the analog output to the upper clamping voltage. If the magnetic field angle is larger than the clamp switch angle, the analog output switches from upper to lower clamping voltage. If there is a negative slope, the clamping voltages are changed.

Table 3. Analog output behavior for a positive slope

| Magnetic field angle                              | Analog output      |
|---------------------------------------------------|--------------------|
| α <sub>max</sub> < α < α <sub>sw(CL)</sub>        | V <sub>(CL)u</sub> |
| α <sub>sw(CL)</sub> < α < α <sub>ref</sub> + 180° | V <sub>(CL)l</sub> |

The analog output voltage range encodes both angular and diagnostic information. A valid angle value is between the upper and lower clamping voltage. If the analog output is in the diagnostic range that is below 4 %V<sub>DD</sub> or above 96 %V<sub>DD</sub>, an error condition has been detected. The analog output repeats every 180°.



8 Digital output

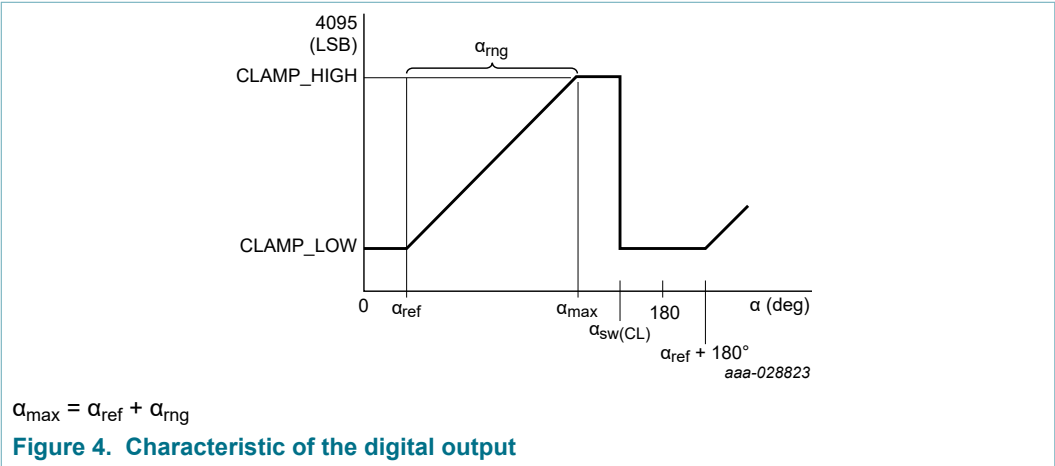
KMA320 provides a digital output signal on pin OUTn/DATAn (if bit 12 in register SYS\_SETTING is set to logic 1; see Table 51) compliant with the SAE J2716 SENT standard. The measured angle α is converted linearly into a value, which is digital encoded in SENT frames. Either a positive or a negative angular slope characteristic is provided for this purpose.

Table 4 describes the digital output behavior for a positive slope. A magnetic field angle above the programmed maximum angle α<sub>max</sub> but below the clamp switch angle α<sub>sw(CL)</sub>

sets the output to the upper clamping value. If the magnetic field angle is larger than the clamp switch angle, the output value switches from upper to lower clamping value. If there is a negative slope, the clamping levels are changed.

Table 4. Digital output behavior for a positive slope

| Magnetic field angle                                                | Data value |
|---------------------------------------------------------------------|------------|
| $\alpha_{\text{max}} < \alpha < \alpha_{\text{sw(CL)}}$             | CLAMP_HIGH |
| $\alpha_{\text{sw(CL)}} < \alpha < \alpha_{\text{ref}} + 180^\circ$ | CLAMP_LOW  |

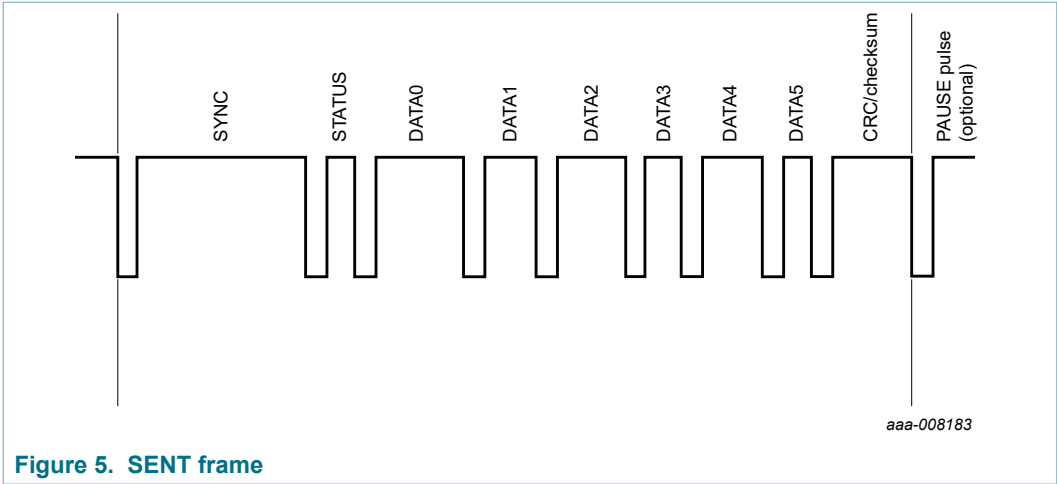


8.1 Transmission of sensor messages

KMA320 encodes a 12-bit angular value into a sequence of pulses based on the encoding scheme of the SAE J2716 SENT standard. Data is split into 4-bit nibbles that are encoded in the time-domain as the duration between two falling edges. The message frame is a sequence of 4-bit nibbles (SENT frame). The timebase of the SENT frame is defined in clock ticks with a configurable duration of  $T_{\text{clk}} = 2.7 \mu\text{s}$ ,  $3 \mu\text{s}$ ,  $4.5 \mu\text{s}$ , and  $6 \mu\text{s}$  each clock tick. A calibration pulse (SYNC nibble) followed by a STATUS nibble, a constant number of fast channel DATA nibbles, a CRC nibble, and an optional PAUSE pulse define one message frame of a SENT transmission as shown in Figure 5. The KMA320 is compatible with revisions of the SENT specification listed below and supports data formats in accordance with appendix A.1, H.1, A.3, H.4, and H.3.

General SENT specification can be found in:

- SAE J2716 FEB2008 SENT rev 2
- SAE J2716 JAN2010 SENT rev 3
- SAE J2716 APR2016 SENT rev 4



8.2 SYNC nibble

The synchronization and calibration nibble is always 56 clock ticks long. The receiver uses the SYNC nibble to derive the clock tick time from the SENT frame.

8.3 STATUS nibble

The STATUS nibble contains status and slow channel information of the KMA310. Bit 0 reflects the operating mode, i.e. normal or diagnostic mode. Bit 1 is a pre-warning indication and is set while the device is still in normal mode. For a detailed description of the pre-warning bit, see [Section 8.11.1.2](#).

Bit 2 and bit 3 are used for optional slow channel serial data messages using the enhanced serial protocol (ESP), described in [Section 8.10](#).

Table 5. STATUS nibble

| Bit                             | Description                                                                                        |
|---------------------------------|----------------------------------------------------------------------------------------------------|
| 3 [most significant bit (MSB)]  | serial data message bit if ESP is enabled, otherwise logic 0                                       |
| 2                               | serial data message bit if ESP is enabled, otherwise logic 0                                       |
| 1                               | pre-warning <sup>[1]</sup><br>0b – normal operation<br>1b – pre-warning condition                  |
| 0 [least significant bit (LSB)] | operating mode <sup>[2]</sup><br>0b – normal operation<br>1b – diagnostic condition <sup>[3]</sup> |

[1] Bit 1 can be permanently set to logic 0 via register bit; see [Table 51](#).  
[2] Bit 0 can be permanently set to logic 0 via register bit; see [Table 51](#).  
[3] Enable the serial data communication for detailed diagnostic information; see [Table 14](#) and [Table 15](#).

## 8.4 CRC nibble

The CRC nibble contains the 4-bit checksum of the DATA nibbles only. The CRC calculation does not cover the STATUS nibble.

The CRC is calculated using polynomial  $x^4 + x^3 + x^2 + 1$  with seed value of 0101b. The KMA320 supports both the legacy CRC defined in SENT SAE J2716 FEB2008 and earlier revisions and the recommended CRC defined in SENT SAE J2716 JAN2010 and later.

The CRC version can be selected via CRC type bit in the SENT\_SETTING1 register; see [Table 51](#). CRC in accordance with SAE J2710 JAN2010 is the default configuration.

## 8.5 PAUSE pulse

A PAUSE pulse can be optionally attached to the SENT frame to generate messages with a constant frame length via register; see [Table 51](#). The frame length depends on the protocol format:

- A.1 and H.1: 239 clock ticks
- A.3 and H.4: 269 clock ticks
- H.3: 196 clock ticks

Additionally, the frame length with PAUSE pulse can be set to 297 clock ticks for all protocol formats via register.

## 8.6 DATA nibbles

In general, the DATA nibbles contain the fast channel angular value of the device. The DATA nibble content depends on the selected protocol format. KMA320 supports the following different protocol formats as defined in the SAE J2716 SENT specification:

- Single secure sensor format A.3 (rev 3), H.4 (rev 4)
- Dual throttle position sensor format A.1 (rev 3), H.1 (rev 4)
- High-speed 12-bit message format H.3 (rev 4)

A detailed frame format description can be found in the corresponding subsection.

## 8.7 Single secure sensor formats A.3 and H.4

KMA320 generates the sequence defined in [Table 6](#) repeatedly in accordance with the single secure sensor format defined in SAE J2716 JAN2010 SENT appendix A.3, respectively J2716 APR2016 SENT appendix H.4. DATA nibbles D0 to D2 contain the 12-bit angular value. D3 and D4 reflect the value of an 8-bit loop counter. D5 is an inverted copy of the most significant nibble (MSN) DATA0. The difference between A.3 and H.4 is that A.3 uses the whole 12-bit data range for angular values while H.4 excludes the values 0 and 4089 to 4095 from the angular data range for diagnostic purposes; see [Table 7](#).

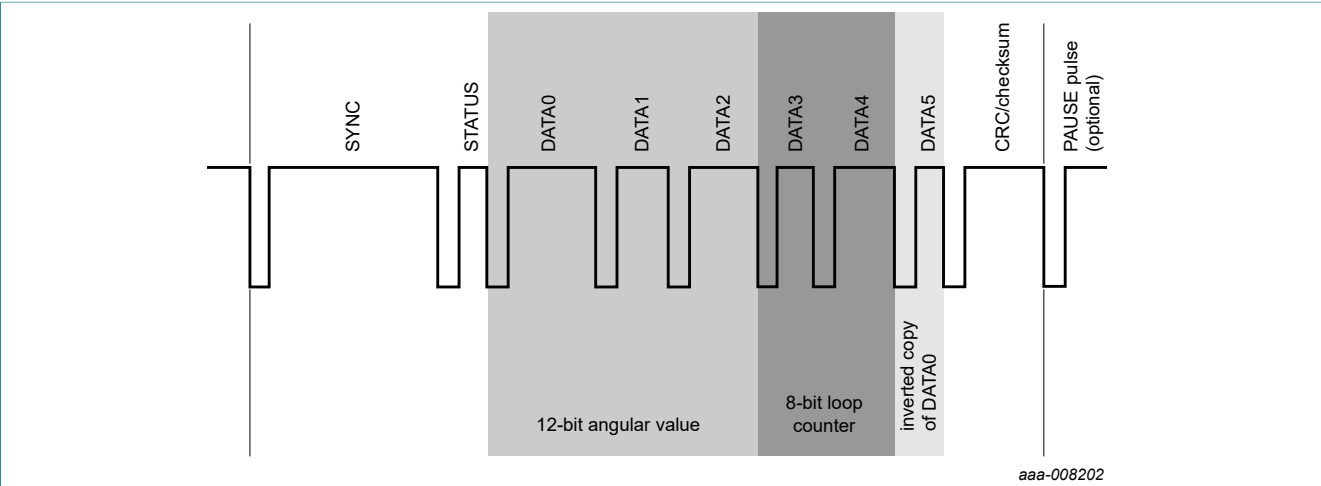


Figure 6. Single secure sensor formats A.3 and H.4

Table 6. Single secure sensor formats A.3 and H.4: frame

| SYNC | STATUS                     | DATA0                | DATA1 | DATA2             | DATA3              | DATA4             | DATA5       | CRC |
|------|----------------------------|----------------------|-------|-------------------|--------------------|-------------------|-------------|-----|
| -    | diagnostic and pre-warning | D0 <sup>[1]</sup>    | D1    | D2 <sup>[2]</sup> | D3 <sup>[1]</sup>  | D4 <sup>[2]</sup> | D5          | -   |
| -    |                            | 12-bit angular value |       |                   | 8-bit loop counter |                   | inverted D0 | -   |

[1] MSN.  
[2] Least significant nibble (LSN).

DATA nibbles D0 to D2 contain the angular value information in the single secure sensor format. A.3 uses the complete 12-bit data range for angular values while H.4 has reserved values for initialization and diagnostic information.

Table 7. DATA nibbles D0 to D2: angular value

| D0 <sup>[1]</sup> | D1   | D2 <sup>[2]</sup> | A.3          |                 | H.4          |                                |
|-------------------|------|-------------------|--------------|-----------------|--------------|--------------------------------|
|                   |      |                   | 12-bit value | Angle           | 12-bit value | Angle/mode                     |
| 0000              | 0000 | 0000              | 0            | 0°              | 0            | initialization message         |
| 0000              | 0000 | 0001              |              |                 | 1            | 0°                             |
| :                 | :    | :                 |              |                 | :            | :                              |
| 1111              | 1111 | 1000              |              |                 | 4088         | $\alpha_{\max}$                |
| 1111              | 1111 | :                 | :            | :               | :            | reserved                       |
| 1111              | 1111 | 1010              |              |                 | 4090         | diagnostic mode <sup>[3]</sup> |
| 1111              | 1111 | :                 |              |                 | :            | reserved                       |
| 1111              | 1111 | 1111              | 4095         | $\alpha_{\max}$ | 4095         | reserved                       |

[1] MSN.  
[2] LSN.  
[3] For detailed diagnostic information, the serial data communication can be enabled.

Data nibbles D3 and D4 contain an 8-bit loop counter value with wrap-around common for both protocol formats A.3 and H.4.

Table 8. DATA nibbles D3 and D4: 8-bit loop counter

| D3 <sup>[1]</sup> | D4 <sup>[2]</sup> | 8-bit loop counter |
|-------------------|-------------------|--------------------|
| 0000              | 0000              | 0                  |
| :                 | :                 | :                  |
| 1111              | 1111              | 255                |

[1] MSN.  
[2] LSN.

For the single secure sensor format H.4 the clamping levels must be set to the correct values to comply with the SAE J2716 SENT specification: CLAMP\_HIGH = 4088, CLAMP\_LOW = 1. Otherwise angular values overwrite the reserved data range for diagnostic information.

8.8 Dual throttle position sensor formats A.1 and H.1

The KMA320 generates the sequence defined in Table 9 repeatedly in accordance with the dual throttle position sensor format defined in SAE J2716 JAN2010 SENT appendix A.1 or H.1 defined in SAE J2716 APR2016.

DATA nibbles D0 to D2 contain the 12-bit angular value. DATA nibbles D3 to D5 contain the opposite slope of the same 12-bit angular value while also the order of these DATA nibbles is reversed.

A.1 uses the data range 1 to 4094 for angular values and the values 0 and 4095 for diagnostic information. While H.1 uses data range 1 to 4088 for angular values and 4090 for diagnostic information.

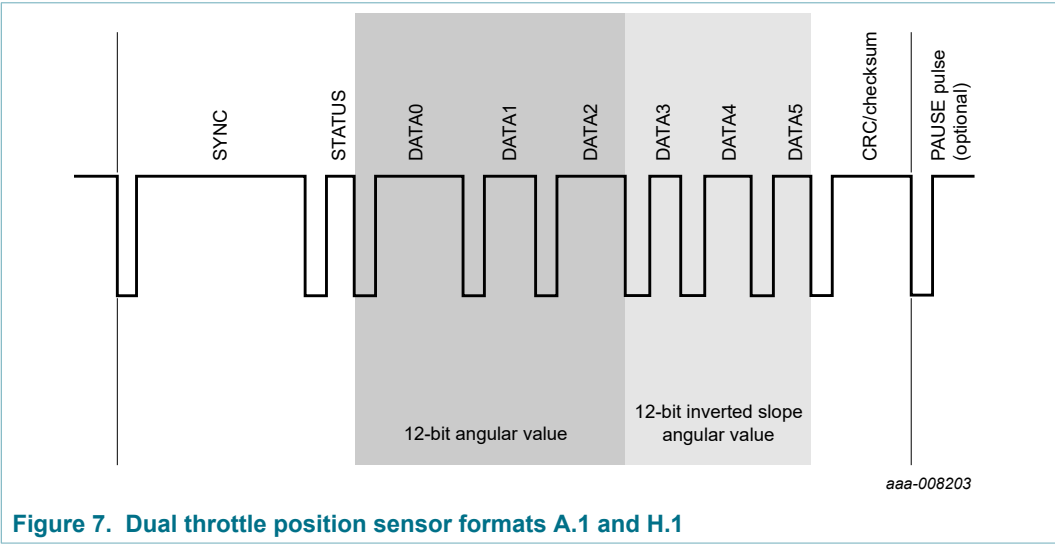


Figure 7. Dual throttle position sensor formats A.1 and H.1

Table 9. Dual throttle position sensor formats A.1 and H.1: frame

| SYNC | STATUS                     | DATA0                | DATA1 | DATA2             | DATA3                               | DATA4 | DATA5             | CRC |
|------|----------------------------|----------------------|-------|-------------------|-------------------------------------|-------|-------------------|-----|
| -    | diagnostic and pre-warning | D0 <sup>[1]</sup>    | D1    | D2 <sup>[2]</sup> | D5 <sup>[2]</sup>                   | D4    | D3 <sup>[1]</sup> | -   |
| -    |                            | 12-bit angular value |       |                   | 12-bit inverted slope angular value |       |                   | -   |

[1] MSN.

[2] LSN.

DATA nibbles D0 to D2 contain the angular value information in the dual throttle position sensor formats A.1 and H.1.

Table 10. DATA nibbles D0 to D2: angular value

| D0 <sup>[1]</sup> | D1   | D2 <sup>[2]</sup> | A.1          |                                | H.1          |                                |
|-------------------|------|-------------------|--------------|--------------------------------|--------------|--------------------------------|
|                   |      |                   | 12-bit value | Angle                          | 12-bit value | Angle/mode                     |
| 0000              | 0000 | 0000              | 0            | reserved                       | 0            | initialization message         |
| 0000              | 0000 | 0001              | 1            | 0°                             | 1            | 0°                             |
| :                 | :    | :                 |              |                                | :            | :                              |
| 1111              | 1111 | 1000              |              |                                | 4088         | $\alpha_{\max}$                |
| 1111              | 1111 | :                 | :            | :                              | :            | reserved                       |
| 1111              | 1111 | 1010              |              |                                | 4090         | diagnostic mode <sup>[3]</sup> |
| 1111              | 1111 | :                 |              |                                | :            | reserved                       |
| 1111              | 1111 | 1110              | 4094         | $\alpha_{\max}$                | 4094         | reserved                       |
| 1111              | 1111 | 1111              | 4095         | diagnostic mode <sup>[3]</sup> | 4095         | reserved                       |

[1] MSN.

[2] LSN.

[3] For detailed diagnostic information, the serial data communication can be enabled.

For the inverted slope angular value in the DATA nibbles D3 to D5 the order of nibbles is also reversed: LSN and MSN.

When a diagnostic condition occurs in A.1 mode, the DATA nibbles D0 to D2 are all set to Fh and DATA nibbles D3 to D5 are all set to 0h. In H.1 mode, the data value of nibbles D0 to D2 is set to 4090 and DATA nibbles D3 to D5 are inverted to diagnostic value 5.

Table 11. DATA nibbles D3 to D5: inverted slope angular value

| D5 <sup>[1]</sup> | D4   | D3 <sup>[2]</sup> | A.1          |                                | H.1          |                                |
|-------------------|------|-------------------|--------------|--------------------------------|--------------|--------------------------------|
|                   |      |                   | 12-bit value | Angle                          | 12-bit value | Angle/mode                     |
| 0000              | 0000 | 0000              | 0            | diagnostic mode <sup>[3]</sup> | 0            | reserved                       |
| 0000              | 0000 | 0001              | 1            | $\alpha_{\max}$                | 1            | reserved                       |
| :                 | :    | :                 | :            | :                              | :            | reserved                       |
| 0000              | 0000 | 0101              | :            | :                              | 5            | diagnostic mode <sup>[3]</sup> |
| :                 | :    | :                 | :            | :                              | :            | reserved                       |
| 0000              | 0000 | 0111              | :            | :                              | 7            | $\alpha_{\max}$                |
| :                 | :    | :                 | :            | :                              | :            | :                              |
| 1111              | 1111 | 1110              | 4094         | 0°                             | 4094         | 0°                             |

| D5 <sup>[1]</sup> | D4   | D3 <sup>[2]</sup> | A.1          |          | H.1          |                        |
|-------------------|------|-------------------|--------------|----------|--------------|------------------------|
|                   |      |                   | 12-bit value | Angle    | 12-bit value | Angle/mode             |
| 1111              | 1111 | 1111              | 4095         | reserved | 4095         | initialization message |

[1] MSN.  
[2] LSN.  
[3] For detailed diagnostic information, the serial data communication can be enabled.

For the dual throttle position sensor formats A.1 and H.1, the clamping levels must be set to the correct values to comply with the SAE J2716 SENT specification.  
A.1: CLAMP\_HIGH = 4094, CLAMP\_LOW = 1. H.1: CLAMP\_HIGH = 4088, CLAMP\_LOW = 1. Otherwise angular values overwrite the reserved data range for diagnostic information.

8.9 High-speed 12-bit message format H.3

The KMA320 generates the sequence defined in Table 12 repeatedly in accordance with the high-speed 12-bit message format H.3 defined in SAE J2716 APR2016. This mode realizes almost a doubling of the update rate compared to other modes. The increase of the update rate is achieved by transmitting 12-bit angular data with only four DATA nibbles using only 3 bit of the available 4 bit per nibble. The MSB of each nibble is always zero. Additionally, the clock tick length shall be set to 2.7 μs typically with a maximum variation of ±10 %. The SYNC, STATUS, and CRC nibble and the serial communication are the same as for the other protocol formats.

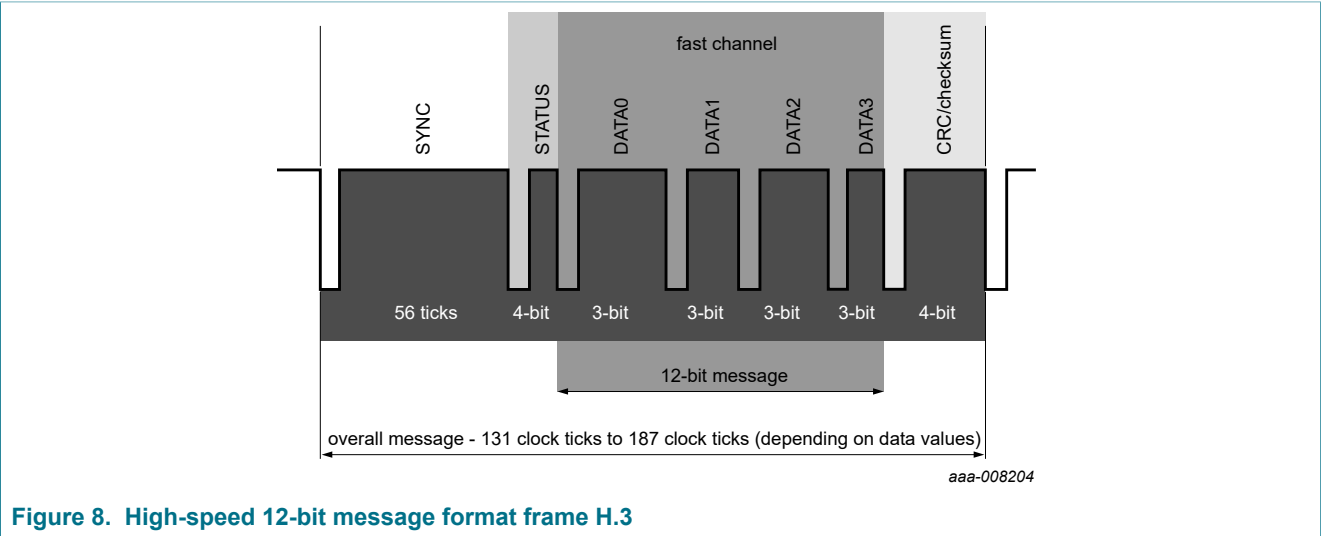


Table 12. High-speed 12-bit message format: frame

| SYNC | STATUS                     | DATA0                | DATA1 | DATA2 | DATA3             | CRC |
|------|----------------------------|----------------------|-------|-------|-------------------|-----|
| -    | diagnostic and pre-warning | D0 <sup>[1]</sup>    | D1    | D2    | D3 <sup>[2]</sup> | -   |
| -    |                            | 12-bit angular value |       |       |                   | -   |

[1] MSN.  
[2] LSN.

Table 13. DATA nibbles D0 to D3: angular value

| D0 <sup>[1]</sup> | D1   | D2   | D3 <sup>[2]</sup> | H.3          |                                |
|-------------------|------|------|-------------------|--------------|--------------------------------|
|                   |      |      |                   | 12-bit value | Angle/mode                     |
| 0000              | 0000 | 0000 | 0000              | 0            | initialization                 |
| 0000              | 0000 | 0000 | 0001              | 1            | 0°                             |
| :                 | :    | :    | :                 | :            | :                              |
| 0111              | 0111 | 0111 | 0000              | 4088         | $\alpha_{\max}$                |
| 0111              | 0111 | 0111 | 0001              | 4089         | reserved                       |
| 0111              | 0111 | 0111 | 0010              | 4090         | diagnostic mode <sup>[3]</sup> |
| 0111              | 0111 | 0111 | :                 | :            | reserved                       |
| 0111              | 0111 | 0111 | 0111              | 4095         | reserved                       |

[1] MSN.

[2] LSN.

[3] For detailed diagnostic information, the serial data communication can be enabled.

For the 12-bit high-speed mode H.3, the clamping levels must be set to the correct values to comply with the SAE J2716 SENT specification. CLAMP\_HIGH = 4088, CLAMP\_LOW = 1. Otherwise angular values overwrite the reserved data range for diagnostic information.

## 8.10 Enhanced serial data communication

Beside the normal message transmission, also a slow serial data communication is realized using bit 2 and bit 3 of the STATUS nibble. The slow channel message stretches over 18 consecutive SENT frames and contains sensor temperature, supply voltage, diagnostic/status information, and user-programmable messages. These messages comply with the enhanced serial data message format with 8-bit message ID and 12-bit message data described in the SAE J2716 SENT specification. Table 14 shows the serial message cycle that is constantly repeated when enhanced serial data communication is enabled.

Table 14. Serial message schedule

| Message number in serial message cycle | 8-bit message ID | Definition             | Comment                      |
|----------------------------------------|------------------|------------------------|------------------------------|
| 1                                      | 01h              | diagnostic status code | see <a href="#">Table 15</a> |
| 2                                      | 23h              | sensor temperature     | see <a href="#">Table 21</a> |
| 3                                      | 1Ch              | supply voltage         | see <a href="#">Table 20</a> |
| 4                                      | 03h              | sensor type            | see <a href="#">Table 17</a> |
| 5                                      | 29h              | sensor ID              | see <a href="#">Table 22</a> |
| 6                                      | 05h              | manufacturer code      | see <a href="#">Table 18</a> |
| 7                                      | 06h              | SENT revision          | see <a href="#">Table 19</a> |
| 8                                      | 01h              | diagnostic status code | see <a href="#">Table 15</a> |
| 9                                      | 23h              | sensor temperature     | see <a href="#">Table 21</a> |
| 10                                     | 1Ch              | supply voltage         | see <a href="#">Table 20</a> |
| 11                                     | 90h              | OEM code 1             | see <a href="#">Table 23</a> |

| Message number in serial message cycle | 8-bit message ID | Definition | Comment                      |
|----------------------------------------|------------------|------------|------------------------------|
| 12                                     | 91h              | OEM code 2 | see <a href="#">Table 24</a> |
| 13                                     | 92h              | OEM code 3 | see <a href="#">Table 25</a> |
| 14                                     | 93h              | OEM code 4 | see <a href="#">Table 26</a> |
| 15                                     | 94h              | OEM code 5 | see <a href="#">Table 27</a> |
| 16                                     | 95h              | OEM code 6 | see <a href="#">Table 28</a> |
| 17                                     | 96h              | OEM code 7 | see <a href="#">Table 29</a> |
| 18                                     | 97h              | OEM code 8 | see <a href="#">Table 30</a> |

### 8.10.1 Enhanced serial messages

**Table 15. Diagnostic status code message**

| 8-bit ID | 12-bit code  | Definition                                          | Comment                                                                              |
|----------|--------------|-----------------------------------------------------|--------------------------------------------------------------------------------------|
| 01h      | 000h         | no error                                            | normal operation                                                                     |
|          | 001h         | OOR HIGH <sup>[1]</sup>                             | output value above OOR_HIGH register                                                 |
|          | 002h         | OOR LOW <sup>[1]</sup>                              | output value below OOR_LOW register                                                  |
|          | 003h to 019h | reserved                                            |                                                                                      |
|          | 020h         | undervoltage <sup>[1]</sup>                         | V <sub>DD</sub> below SENT_SETTING2[13:12]                                           |
|          | 021h         | overvoltage <sup>[1]</sup>                          | V <sub>DD</sub> above SENT_SETTING2[15:14]                                           |
|          | 022h         | temperature <sup>[1]</sup>                          | application-specific integrated circuit (ASIC) temperature above SENT_SETTING2[11:7] |
|          | 023h         | single-bit error <sup>[1]</sup>                     | CTRL1[10]                                                                            |
|          | 024h to 800h | reserved                                            |                                                                                      |
|          | 801h to FFFh | automotive safety integrity level (ASIL) error code | see <a href="#">Table 16</a>                                                         |

[1] If enabled, pre-warning is indicated and bit 1 of STATUS nibble is set.

**Table 16. ASIL error code**

| Bit      | Description                                                | Safety mechanism |
|----------|------------------------------------------------------------|------------------|
| 11 (MSB) | device in diagnostic mode CTRL1[14] (ASIL_STATUS_CODE[11]) | -                |
| 10       | angular range check                                        | SM-12            |
| 9        | CORDIC range check                                         | SM-11            |
| 8        | data adder check                                           | SM-10            |
| 7        | SD-ADC range check                                         | SM-09            |
| 6        | built-in self-test (BIST) encoding check                   | SM-08            |
| 5        | control signal check and BIST completion check             | SM-06 and SM-07  |
| 4        | adjusted angle calculation check                           | SM-05            |
| 3        | data conversion check                                      | SM-04            |
| 2        | data division check                                        | SM-03            |

| Bit     | Description                      | Safety mechanism |
|---------|----------------------------------|------------------|
| 1       | inverted angle calculation check | SM-02            |
| 0 (LSB) | magnetic field conversion check  | SM-01            |

Table 17. SENSOR\_TYPE[3:0] – channel 1/2 sensor type message

| 8-bit ID | 12-bit code         | Definition                                                        | Comment        |
|----------|---------------------|-------------------------------------------------------------------|----------------|
| 03h      | 051h <sup>[1]</sup> | acceleration pedal position 1 or acceleration pedal position 2    | 0000b          |
|          | 052h <sup>[1]</sup> | acceleration pedal position 1 or secure sensor                    | 0001b          |
|          | 053h <sup>[1]</sup> | acceleration pedal position 2 (redundant signal) or secure sensor | 0010b          |
|          | 054h <sup>[1]</sup> | throttle position 1 or throttle position 2                        | 0011b          |
|          | 055h <sup>[1]</sup> | throttle position 1 or secure sensor                              | 0100b          |
|          | 056h <sup>[1]</sup> | throttle position 2 (redundant signal) or secure sensor           | 0101b          |
|          | 059h <sup>[1]</sup> | angle position                                                    | 0110b          |
|          | 05Ah <sup>[1]</sup> | angle position or secure sensor                                   | 0111b          |
|          | 062h <sup>[2]</sup> | angle position (high speed) H.3 protocol format                   | 1000b          |
|          | 063h <sup>[2]</sup> | angle position 1 or angle position 2 H.1 protocol format          | 1001b          |
|          | 064h <sup>[2]</sup> | angle position or secure sensor H.4 protocol format               | 1010b          |
|          | 066h <sup>[2]</sup> | reserved for angle position sensors                               | 1011b          |
|          | 000h                | reserved                                                          | 1101b to 1111b |

[1] Compliant with SAE JAN2010 rev 3 only.

[2] Compliant with SAE APR2016 rev 4 only.

Table 18. Manufacturer code message

| 8-bit ID | 12-bit code | Definition         | Comment   |
|----------|-------------|--------------------|-----------|
| 05h      | 04Eh        | NXP Semiconductors | fix value |

Table 19. SENT\_REVISION[1:0] – SENT standard revision message

| 8-bit ID | 12-bit code | Definition    | Comment |
|----------|-------------|---------------|---------|
| 06h      | 000h        | not specified | 00b     |
|          | 002h        | FEB2008 rev 2 | 01b     |
|          | 003h        | JAN2010 rev 3 | 10b     |
|          | 004h        | APR2016 rev 4 | 11b     |

Table 20. Supplementary data channel #3,1: sensor supply voltage

| 8-bit ID | 12-bit code  | Definition                  | Comment                                               |
|----------|--------------|-----------------------------|-------------------------------------------------------|
| 1Ch      | 000h to 1FFh | 9-bit sensor supply voltage | $V_{DD} [V] = (\text{digital value [LSB]} + 33) / 58$ |
|          | 200h to FFFh | reserved                    |                                                       |

Table 21. Supplementary data channel #4,1: sensor temperature value

| 8-bit ID | 12-bit code  | Definition               | Comment                       |
|----------|--------------|--------------------------|-------------------------------|
| 23h      | 000h to 0FFh | 8-bit sensor temperature | 000h: -45 °C to 0FFh: +210 °C |
|          | 100h to FFFh | reserved                 |                               |

Table 22. SENSOR\_ID – sensor ID #1 message

| 8-bit ID | 12-bit code | Definition | Comment |
|----------|-------------|------------|---------|
| 29h      | 000h        | sensor ID1 | 0b      |
|          | FFFh        | sensor ID2 | 1b      |

Table 23. OEM\_CODE\_1[11:0] – OEM code 1 message

| 8-bit ID | 12-bit code  | Definition | Comment                        |
|----------|--------------|------------|--------------------------------|
| 90h      | 000h to FFFh | OEM code 1 | user-programmable data content |

Table 24. OEM\_CODE\_2[11:0] – OEM code 2 message

| 8-bit ID | 12-bit code  | Definition | Comment                        |
|----------|--------------|------------|--------------------------------|
| 91h      | 000h to FFFh | OEM code 2 | user-programmable data content |

Table 25. OEM\_CODE\_3[11:0] – OEM code 3 message

| 8-bit ID | 12-bit code  | Definition | Comment                        |
|----------|--------------|------------|--------------------------------|
| 92h      | 000h to FFFh | OEM code 3 | user-programmable data content |

Table 26. OEM\_CODE\_4[11:0] – OEM code 4 message

| 8-bit ID | 12-bit code  | Definition | Comment                        |
|----------|--------------|------------|--------------------------------|
| 93h      | 000h to FFFh | OEM code 4 | user-programmable data content |

Table 27. OEM\_CODE\_5[11:0] – OEM code 5 message

| 8-bit ID | 12-bit code  | Definition | Comment                        |
|----------|--------------|------------|--------------------------------|
| 94h      | 000h to FFFh | OEM code 5 | user-programmable data content |

Table 28. OEM\_CODE\_6[11:0] – OEM code 6 message

| 8-bit ID | 12-bit code  | Definition | Comment                        |
|----------|--------------|------------|--------------------------------|
| 95h      | 000h to FFFh | OEM code 6 | user-programmable data content |

Table 29. OEM\_CODE\_7[11:0] – OEM code 7 message

| 8-bit ID | 12-bit code  | Definition | Comment                        |
|----------|--------------|------------|--------------------------------|
| 96h      | 000h to FFFh | OEM code 7 | user-programmable data content |

Table 30. OEM\_CODE\_8[11:0] – OEM code 8 message

| 8-bit ID | 12-bit code  | Definition | Comment                        |
|----------|--------------|------------|--------------------------------|
| 97h      | 000h to FFFh | OEM code 8 | user-programmable data content |

## 8.11 SENT diagnostic

The SENT standard specifies different methods to transmit diagnostic information. These methods are used in multiple combinations, depending on the SENT revision, protocol format, and device configuration.

### 8.11.1 STATUS nibble diagnostic

Bit 0 and bit 1 of the STATUS nibble can be used to signal the diagnostic state while the DATA nibbles still contain an angular value at the same time. The CRC nibble does not include the STATUS nibble, thus the receiver do not detect an erroneous STATUS nibble.

#### 8.11.1.1 Diagnostic bit

The device defines bit 0 of the STATUS nibble as diagnostic bit. In case the device is in diagnostic mode the diagnostic bit is set to logic 1.

The diagnostic bit can be disabled and permanently set to logic 0 via the mask STATUS nibble bits in the SENT\_SETTING2 register in the non-volatile memory; see [Table 51](#).

#### 8.11.1.2 Pre-warning bit

Bit 1 is a pre-warning indication which is set while the device is still in normal mode, but one of the following conditions occurred:

- The angular value is above the programmed upper out of range (OOR) threshold; see [Table 53](#).
- The angular value is below the programmed lower OOR threshold; see [Table 53](#).
- Corrected single-bit error of the non-volatile memory (EDC); see [Section 10.1](#).
- The temperature is above the programmed temperature threshold; see [Table 51](#).
- Overvoltage: The supply voltage is above the programmed upper voltage threshold; see [Table 51](#).
- Undervoltage: The supply voltage is below the programmed lower voltage threshold; see [Table 51](#).

The pre-warning bit can be disabled and permanently set to logic 0 via the mask STATUS nibble bits in the SENT\_SETTING2 register in the non-volatile memory; see [Table 51](#).

### 8.11.2 Fast channel diagnostic value

Some protocol formats define a reserved data range in the fast channel communication for signaling diagnostic status instead of an angular value in the SENT transmission.

The KMA320 generates a specific diagnostic value instead of an angular value in case the device is in diagnostic mode. The diagnostic value depends on the selected protocol format according to [Table 31](#).

**Table 31. Fast channel diagnostic value**

| Protocol format | Normal mode   | Diagnostic mode |
|-----------------|---------------|-----------------|
| A.1             | angular value | 4095            |
| A.3             | angular value | angular value   |
| H.1             | angular value | 4090            |
| H.3             | angular value | 4090            |
| H.4             | angular value | 4090            |

### 8.11.3 Enhanced serial protocol diagnostic status code message

Detailed diagnostic and pre-warning information is transmitted in the diagnostic status code message ID 01h of the slow channel message transmission. Therefore, the enhanced serial protocol must be enabled via the ESP bit in the SENT\_SETTING1 register in the non-volatile memory; see [Table 51](#). A description of the diagnostic status code message is given in [Table 15](#).

## 9 Output characteristic

The MPC defines the output transfer characteristic. For this purpose, up to 17 calibration points define the range between programmed reference angle and set maximum angle.

Three different MPC types are available, see [Table 51](#), whereas in each mode either a positive or a negative slope can be programmed. MPC17 and MPC7 enable an improved linearization of the output characteristic.

Furthermore, curve shapes can be customized in accordance with application requirements.

### 9.1 No MPC mode

No MPC mode refers to the conventional linear output characteristic defined by zero angle (ZERO\_ANGLE), angular range (RANGE\_DETECTION), clamp switch angle (CLAMP\_SWITCH), and clamping levels (CLAMP\_LOW and CLAMP\_HIGH).

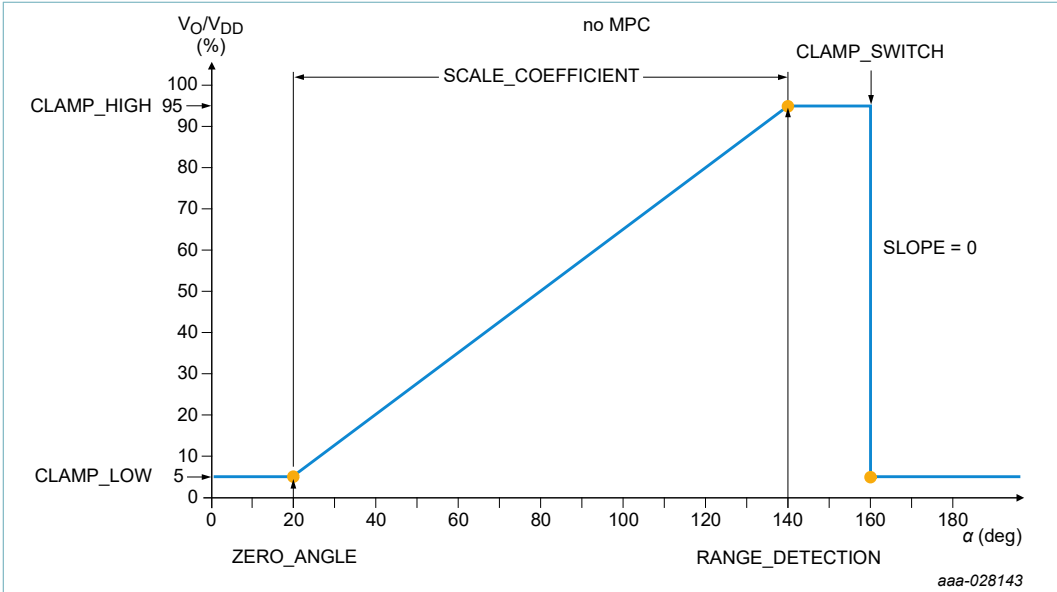


Figure 9. No MPC mode

9.2 MPC17 mode

MPC17 mode enables curve shaping by 17 equidistant calibration points. For this purpose 16 coefficients (MPC\_COEFFICIENTn) can be programmed, see [Table 52](#), to set a specific output level for each calibration point.

In this mode, all points are scaling with the angular range to define calibration coefficients at equidistant positions as shown in [Figure 10](#).

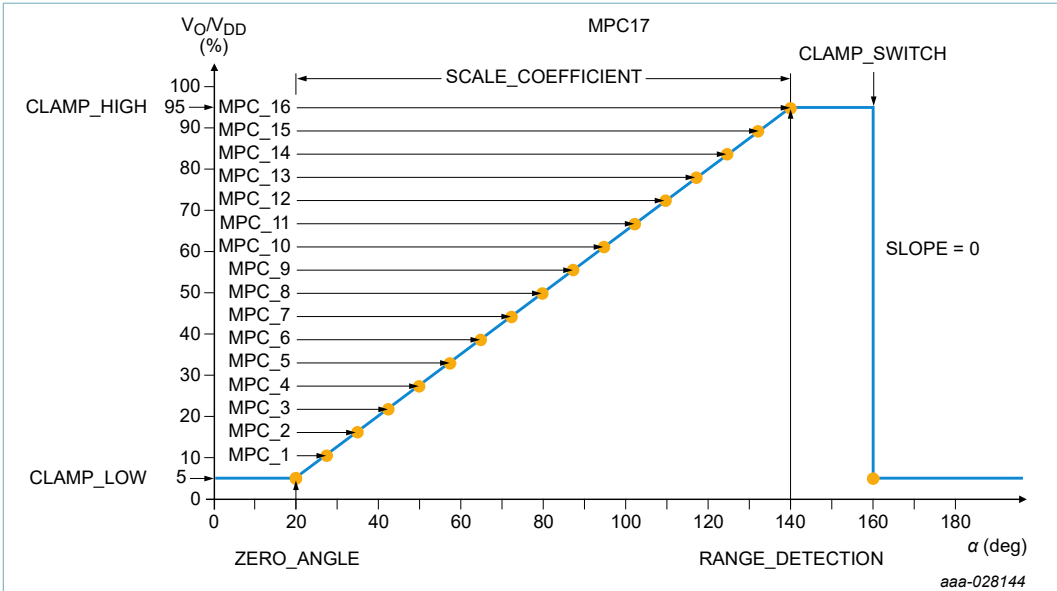


Figure 10. MPC17 mode

### 9.3 MPC7 mode

MPC7 in contrast provides a set of six freely selectable calibration points defined by angular position (linear  $X_n$ ), output level (linear  $Y_n$ ), and slope (linear  $S_n$ ) as shown in Figure 11.

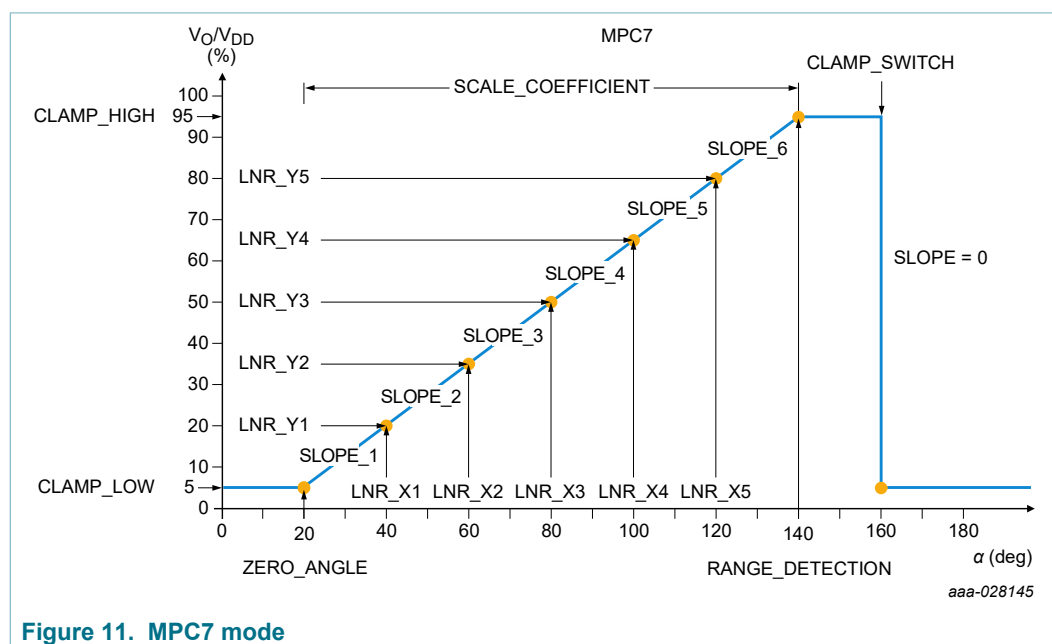


Figure 11. MPC7 mode

## 10 Diagnostic features

Each channel of KMA320 provides following diagnostic features. The safety mechanisms supporting functional safety operation are marked with individual numbers SM-xx. Functional risks are only minimized if all safety mechanisms are enabled as in the default configuration. Thus it is not recommended to switch them off individually.

### 10.1 NVM CRC (SM-20), NVM EDC check (SM-21), and NVM ECC check (SM-22)

Each channel of the device includes a supervision of the programmed data. At power-on, a CRC of the non-volatile memory is performed (SM-20). The NVM is split into three customer areas with individual CRCs (CRC1, CRC2, and CRC3) and a manufacturer area which is user access restricted and also CRC protected. Furthermore, the memory is protected against bit errors. Every 16-bit data word is saved internally as a 22-bit word for this purpose. The protection logic corrects any single-bit error in a data word (SM-22), while the sensor continues in normal operation mode. Furthermore, the logic detects double-bit error per word and switches the output into diagnostic mode (SM-21).

## 10.2 Power-loss detection (SM-18) and GND-loss detection (SM-19)

The power-loss detection circuit enables the detection of an interrupted supply or ground line of the mixed signal IC. If there is a power-loss condition, two internal switches in the sensor are closed, connecting the pin of the analog output to the supply voltage and the ground pin.

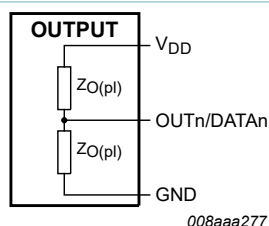


Figure 12. Equivalent output circuit in a power-loss condition

Table 32 describes the power-loss behavior and gives the resulting output voltage depending on the interrupted supply or ground line and the load resistance.

Table 32. Power-loss behavior

| Load resistance                  | Interrupted supply line | Interrupted ground line |
|----------------------------------|-------------------------|-------------------------|
| $R_{L(ext)} > 5 \text{ k}\Omega$ | $V_O \leq 4 \% V_{DD}$  | $V_O \geq 96 \% V_{DD}$ |

## 10.3 Supply overvoltage detection (SM-16) and undervoltage detection (SM-17)

If the supply voltage is below the switch-off threshold voltage, a status bit is set and the output goes into diagnostic mode. If the supply voltage is above the overvoltage switch-on threshold voltage, the output switches to diagnostic mode. Table 33 describes the system behavior depending on the voltage range of the supply voltage.

Table 33. System behavior for each output mode

| Supply voltage                             | State          | Analog mode                                                                                                                                                                                                                                                              | SENT mode                                                                                                                                                                        |
|--------------------------------------------|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0 V to $\cong 1.8 \text{ V}$               | startup power  | The output buffer drives an active LOW or is powered down, but the switches of the power-loss detection circuit are not fully opened and set the output to a level between ground and half the supply voltage.                                                           | high-ohmic output stage; external pull-up resistor defines output voltage                                                                                                        |
| $\cong 1.8 \text{ V}$ to $V_{POR}$         | power-on reset | The power-loss charge pump is fully operational and turns the switches of the detection circuit off. The output buffer drives an active LOW and sets the output to the lower diagnostic level. During the reset phase, all circuits are in reset and/or power-down mode. | The output buffer drives an active LOW. During the reset phase, all circuits are in reset and/or power-down mode.                                                                |
| $V_{POR}$ to $V_{th(on)}$ or $V_{th(off)}$ | initialization | The digital core and the oscillator are active. After reset, the content of the non-volatile memory is copied into the shadow registers. The output buffer drives an active LOW.                                                                                         | The digital core and the oscillator are active. After reset, the content of the non-volatile memory is copied into the shadow registers. The output buffer drives an active LOW. |

| Supply voltage                                    | State                | Analog mode                                                                                                                                    | SENT mode                                                                                                                                                                  |
|---------------------------------------------------|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $V_{th(on)}$ or $V_{th(off)}$ to minimum $V_{DD}$ | functional operation | All analog circuits are active and the measured angle is available at the analog output. Not all parameters are within the specified limits.   | All analog circuits are active and the output is set to HIGH for at least 100 $\mu$ s before SENT transmission starts. Not all parameters are within the specified limits. |
| Minimum $V_{DD}$ to maximum $V_{DD}$              | normal operation     | All analog circuits are active and the measured angle is available at the analog output. All parameters are within the specified limits.       | All analog circuits are active and the measured angle is available at the digital output. All parameters are within the specified limits.                                  |
| Maximum $V_{DD}$ to $V_{th(ov)}$                  | functional operation | All analog circuits are active and the measured angle is available at the analog output. Not all parameters are within the specified limits.   | All analog circuits are active and the measured angle is available at the digital output. Not all parameters are within the specified limits.                              |
| $V_{th(ov)}$ to 18 V                              | overvoltage          | The digital core and the oscillator are active but all other circuits are in power-down mode. The output is set to the lower diagnostic level. | The digital core and the oscillator are active but all other circuits are in power-down mode. The output buffer drives an active LOW.                                      |

[Table 34](#) describes the diagnostic behavior and the resulting output voltage depending on the error case. Furthermore the duration and termination condition to enter and leave the diagnostic mode are given, respectively.

**Table 34. Diagnostic behavior**

| Diagnostic condition | Duration                     | Output                                                                 | Termination condition          |
|----------------------|------------------------------|------------------------------------------------------------------------|--------------------------------|
| Low voltage          | 20 $\mu$ s < t < 120 $\mu$ s | $\leq 4\% V_{DD}$                                                      | functional or normal operation |
| Overvoltage          | 20 $\mu$ s < t < 120 $\mu$ s | $\leq 4\% V_{DD}$                                                      | functional or normal operation |
| Checksum error       | n.a.                         | $\leq 4\% V_{DD}$ or $\geq 96\% V_{DD}$ <sup>[1]</sup>                 | power-on reset <sup>[2]</sup>  |
| Double-bit error     | n.a.                         | $\leq 4\% V_{DD}$ or $\geq 96\% V_{DD}$ <sup>[1]</sup>                 | power-on reset <sup>[2]</sup>  |
| Power-loss           | $\leq 2$ ms                  | $\leq 4\% V_{DD}$ or $\geq 96\% V_{DD}$ ; see <a href="#">Table 32</a> | power-on reset                 |

[1] Depending on the diagnostic level setting.

[2] Status bit stays set in command register until power-on reset.

## 10.4 Oscillator monitoring (SM-13, SM-14 and SM-15)

If the oscillator frequency differs from the target frequency by more than  $\pm 30\%$  or the oscillator stops, status bit 7 of CTRL1 register is set and the output goes into diagnostic mode; see [Table 50](#). If the oscillator frequency differs by more than  $\pm 10\%$ , the SENT timing can violate the SAE J2716 SENT specification.

## 10.5 Safe assure - ASIL control unit

The ASIL control includes a state machine, which is a 4-bit up-counter that defines time slots. The different time slots are used to trigger dedicated BISTs. To enable or disable the complete ASIL control unit globally, use the BIST bit in ASIL\_SETTING register; see [Table 51](#). The NVM register setting enables or disables individually each integrated test.

In case a self-test was performed a ready flag is generated to reset the start test trigger signals. In case no reset signal is found, the output is set to diagnostic mode. The ASIL control is implemented for each channel independently.

10.5.1 Timing description

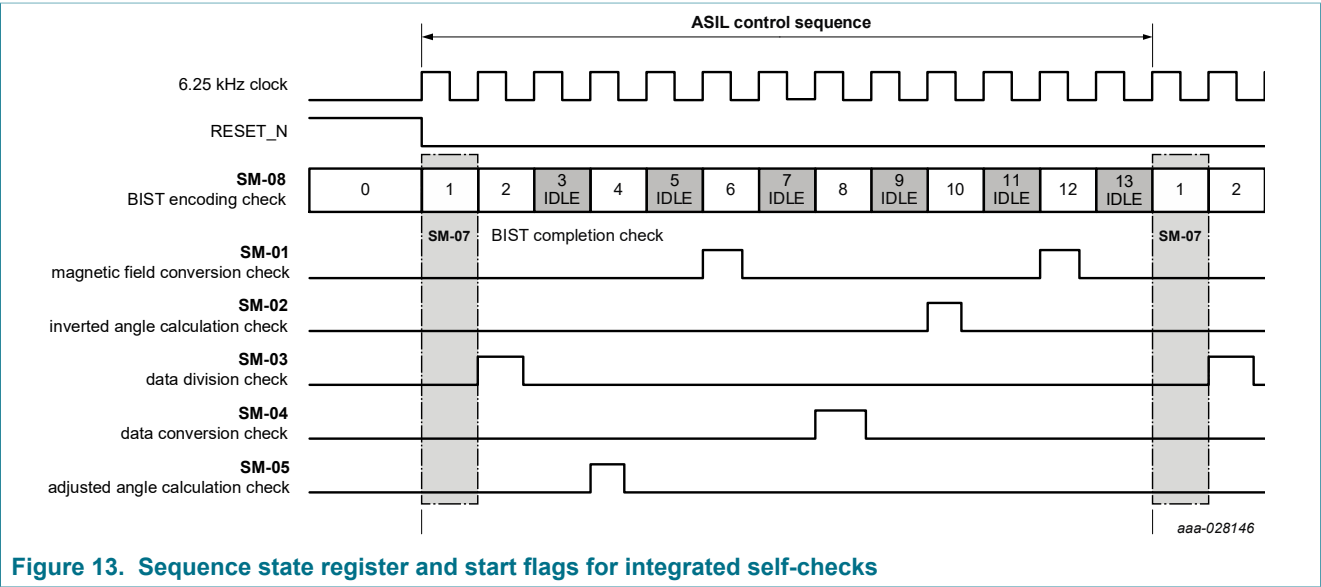


Figure 13. Sequence state register and start flags for integrated self-checks

10.5.2 User selectable BIST

To enable the BISTs SM-01 to SM-06 set the BIST bit in ASIL\_SETTING register; see [Table 51](#). User selectable self-tests can be enabled or masked separately as described in the following subsections.

10.5.2.1 Magnetic field conversion check (SM-01)

The output amplitude of an AMR sensor has a strong temperature dependency. This physical effect is used to check the plausibility of the AMR signals. The magnetic field conversion check compares a temperature value, which is based on an on-chip temperature sensor with the temperature information based on the AMR amplitude. In case the magnet is removed, the AMR amplitude goes down, and the magnetic field conversion check indicates this failure mode. Furthermore, this check can be switched off separately with the magnetic field conversion check bit of the ASIL\_SETTING register; see [Table 51](#).

In case the on-chip temperature sensor fails, the product goes to diagnostic condition, even if the angle data path is not directly affected from this failure mode.

10.5.2.2 Inverted angle calculation check (SM-02)

The inverted angle calculation check calculates a second internal output angle value. Based on the customer settings the second angle value is an exact inverted copy of the main data path angle. The check compares the sum of both calculated angle values with the sum of both adjusted customer clamping levels. In case the post-CORDIC integrated adder and multiplier are in normal operating mode the result is equal. Furthermore, this check can be switched off separately with the inverted angle calculation check bit of the ASIL\_SETTING register; see [Table 51](#).

In case internal post-memory addressing, post-multiplier or post-adder fails, the product goes into diagnostic mode.

### 10.5.2.3 Data division check (SM-03)

The main data path division module is only used in MPC17 mode. Nevertheless, the integrated data division check uses the same hardware, which is used by the post-CORDIC. This test performs a test division with a known result. To execute the data division check, also the post-adder and the post-memory addressing are used. Furthermore, this check can be switched off separately with the data division check bit of the ASIL\_SETTING register; see [Table 51](#).

In case internal post-memory addressing, post-adder or division fails, the product goes into diagnostic mode.

### 10.5.2.4 Data conversion check (SM-04)

The data conversion check checks the CORDIC module, which is used for all modes. For testing, internal cos and –sin signals are used to calculate an inverted CORDIC angle. The sum of the main data path CORDIC angle and the inverted CORDIC angle must be zero. Furthermore, this check can be switched off separately with the data conversion check bit of the ASIL\_SETTING register; see [Table 51](#).

In case internal subblocks of the CORDIC module (shift register, adder, state-controller) fail, the product goes into diagnostic mode.

### 10.5.2.5 Adjusted angle calculation check (SM-05)

The zero angle corrected CORDIC signal is one of the most important signals within the system. This signal is used for the main data path angle value and for the segment detection for MPC7 and MPC17 mode. The integrated adjusted angle calculation check compares the post-CORDIC zeroed result with a redundant calculated CORDIC zeroed signal. The arithmetic logic unit (ALU) ASIL module performs this redundant calculation. Furthermore, this check can be switched off separately with the adjusted angle calculation check bit of the ASIL\_SETTING register; see [Table 51](#).

In case the redundant calculation of the ALU ASIL check fails, the product goes into diagnostic mode, even if the angle data path is not directly affected from this failure mode.

## 10.5.3 Fixed internal diagnostics

The following internal diagnostics are permanently enabled and automatically executed. The corresponding flags can be masked individually.

### 10.5.3.1 Control signal check (SM-06)

Checks, if the main data path processing was performed correctly. This status flag can be masked with the mask control signal check bit of the ASIL\_SETTING register; see [Table 51](#).

### 10.5.3.2 BIST completion check (SM-07)

Checks, if all selected self-tests were executed without any errors. In case a failure mode occurs at one selected test, the BIST completion check flag indicates this failure latest after 160 µs.

In case the ASIL control block fails, the product goes into diagnostic mode, even if the angle data path is not directly affected from this failure mode. This status flag can

be masked with the mask BIST completion check bit of the ASIL\_SETTING register; see [Table 51](#).

#### 10.5.3.3 BIST encoding check (SM-08)

The ASIL control module provides the test sequence number for all implemented self-tests. To prove that this module is running normal, the state register of the ASIL control module is coded with a parity bit to prevent single bit failures.

In case the ASIL control block fails, the product goes into diagnostic mode, even if the angle data path is not directly affected from this failure mode. This status flag can be masked with the mask BIST encoding check bit of the ASIL\_SETTING register; see [Table 51](#).

#### 10.5.3.4 SD-ADC range check (SM-09)

The SD-ADC is not using full scale range. Some part is reserved to detect overflows. In case the filter result is larger than 95 % (including the gain factor) the overflow flag is set. This status flag can be masked with the mask SD-ADC range check bit of the ASIL\_SETTING register; see [Table 51](#).

#### 10.5.3.5 Data adder check (SM-10)

The pre-CORDIC adder is used for AMR offset cancelation, new AMR offset value calculation, and temperature calculation from the auxiliary ADC. In case overflow occurs, the bit is set. This status flag can be masked with the mask data adder check bit of the ASIL\_SETTING register; see [Table 51](#).

#### 10.5.3.6 CORDIC range check (SM-11)

The CORDIC block, which is used for angle calculation, is using internally more than 16 bit. To prevent a wrap-around for unexpected sin/cos input signals, the block has a built-in overflow monitor. In case overflow occurs, a status flag is set. This status flag can be masked with the mask CORDIC range check bit of the ASIL\_SETTING register; see [Table 51](#).

#### 10.5.3.7 Angular range check (SM-12)

The clamp control checks the plausibility of the internal status flags coming from the clamp and range detection. In case the clamp switch angle position was detected before the range position, the flag is set. This status flag can be masked with the mask angular range check bit of the ASIL\_SETTING register; see [Table 51](#).

## 10.6 Self-diagnostic overview

Table 35. Self-diagnostic overview

| Diagnostic block                                               | Mode     | Monitoring interval | Output behavior                    |                                                      |
|----------------------------------------------------------------|----------|---------------------|------------------------------------|------------------------------------------------------|
| Supply overvoltage detection (SM-16)                           | always   | continuously        | $\leq 4\%V_{DD}$                   |                                                      |
| Supply undervoltage detection (SM-17)                          | always   | continuously        | $\leq 4\%V_{DD}$                   |                                                      |
| Power-loss detection (SM-18)<br>(broken $V_{DD}$ wire)         | always   | continuously        | $\leq 4\%V_{DD}$                   |                                                      |
| GND-loss detection (SM-19)<br>(broken GND wire)                | always   | continuously        | $\geq 96\%V_{DD}$                  |                                                      |
| NVM CRC (SM-20)                                                | startup  | -                   | $\leq 4\%V_{DD}$                   |                                                      |
| NVM EDC double-bit error check (SM-21)                         | NVM read | -                   | $\leq 4\%V_{DD}$                   |                                                      |
| NVM error correcting code (ECC) single-bit error check (SM-22) | NVM read | -                   | SENT status nibble pre-warning bit |                                                      |
| Magnetic field conversion check (SM-01)                        | always   | 1.04 ms             | analog:                            | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                                                |          |                     | SENT ESP:                          | 801h                                                 |
|                                                                |          |                     | ASIL_FLAGS:                        | 0001h                                                |
| Inverted angle calculation check (SM-02)                       | always   | 2.08 ms             | analog:                            | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                                                |          |                     | SENT ESP:                          | 802h                                                 |
|                                                                |          |                     | ASIL_FLAGS:                        | 0002h                                                |
| Data division check (SM-03)                                    | always   | 2.08 ms             | analog:                            | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                                                |          |                     | SENT ESP:                          | 804h                                                 |
|                                                                |          |                     | ASIL_FLAGS:                        | 0004h                                                |
| Data conversion check (SM-04)                                  | always   | 2.08 ms             | analog:                            | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                                                |          |                     | SENT ESP:                          | 808h                                                 |
|                                                                |          |                     | ASIL_FLAGS:                        | 0008h                                                |
| Adjusted angle calculation check (SM-05)                       | always   | 2.08 ms             | analog:                            | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                                                |          |                     | SENT ESP:                          | 810h                                                 |
|                                                                |          |                     | ASIL_FLAGS:                        | 0010h                                                |
| Control signal check (SM-06)                                   | always   | 160 $\mu$ s         | analog:                            | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                                                |          |                     | SENT ESP:                          | 820h                                                 |
|                                                                |          |                     | ASIL_FLAGS:                        | 0020h                                                |
| BIST completion check (SM-07)                                  | always   | 2.08 ms             | analog:                            | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                                                |          |                     | SENT ESP:                          | 820h                                                 |
|                                                                |          |                     | ASIL_FLAGS:                        | 0040h                                                |
| BIST encoding check (SM-08)                                    | always   | 1.25 $\mu$ s        | analog:                            | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                                                |          |                     | SENT ESP:                          | 840h                                                 |
|                                                                |          |                     | ASIL_FLAGS:                        | 0080h                                                |

| Diagnostic block                         | Mode   | Monitoring interval | Output behavior  |                                                      |
|------------------------------------------|--------|---------------------|------------------|------------------------------------------------------|
| SD-ADC range check (SM-09)               | always | 10 $\mu$ s          | analog:          | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                          |        |                     | SENT ESP:        | 880h                                                 |
|                                          |        |                     | ASIL_FLAGS:      | 0100h                                                |
| Data adder check (SM-10)                 | always | 1.25 $\mu$ s        | analog:          | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                          |        |                     | SENT ESP:        | 900h                                                 |
|                                          |        |                     | ASIL_FLAGS:      | 020h                                                 |
| CORDIC range check (SM-11)               | always | 160 $\mu$ s         | analog:          | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                          |        |                     | SENT ESP:        | A00h                                                 |
|                                          |        |                     | ASIL_FLAGS:      | 0400h                                                |
| Angular range check (SM-12)              | always | 160 $\mu$ s         | analog:          | $\leq 4\%V_{DD}$ or $\geq 96\%V_{DD}$ <sup>[1]</sup> |
|                                          |        |                     | SENT ESP:        | C00h                                                 |
|                                          |        |                     | ASIL_FLAGS:      | 0800h                                                |
| Upper oscillator frequency check (SM-13) | always | continuously        | $\leq 4\%V_{DD}$ |                                                      |
| Lower oscillator frequency check (SM-14) | always | continuously        | $\leq 4\%V_{DD}$ |                                                      |
| Oscillator stuck-at check (SM-15)        | always | continuously        | $\leq 4\%V_{DD}$ |                                                      |

[1] Depending on the diagnostic level setting.

## 10.7 Self-diagnostic validation support

To validate the correct function of self-diagnostics within the system, enable the self-diagnostic validation support bit 10 in SYS\_SETTING register. In case this bit is logic 1 the device shows diagnostic modes based on the content of OEM\_CODE1 register; see [Table 36](#). In case this bit is logic 0 the device is in normal operating mode which is the default mode.

**Table 36. Self-diagnostic validation support**

| OEM_CODE1 value | Safety mechanism     | Comment                          |
|-----------------|----------------------|----------------------------------|
| 001h            | SM-01                | magnetic field conversion check  |
| 002h            | SM-02                | inverted angle calculation check |
| 004h            | SM-03                | data division check              |
| 008h            | SM-04                | data conversion check            |
| 010h            | SM-05                | adjusted angle calculation check |
| 020h            | SM-06 <sup>[1]</sup> | control signal check             |
| 040h            | SM-07 <sup>[1]</sup> | BIST completion check            |
| 080h            | SM-08 <sup>[1]</sup> | BIST encoding check              |
| 100h            | SM-09 <sup>[1]</sup> | SD-ADC range check               |
| 200h            | SM-10 <sup>[1]</sup> | data adder check                 |
| 400h            | SM-11 <sup>[1]</sup> | CORDIC range check               |
| 800h            | SM-12 <sup>[1]</sup> | angular range check              |

[1] Disable the corresponding ASIL mask bits in the ASIL\_SETTING register.

## 11 Limiting values

**Table 37. Limiting values**

*In accordance with the Absolute Maximum Rating System (IEC 60134).*

| Symbol                     | Parameter                       | Conditions                                                         | Min                 | Max  | Unit  |
|----------------------------|---------------------------------|--------------------------------------------------------------------|---------------------|------|-------|
| V <sub>DD</sub>            | supply voltage                  |                                                                    | -0.3                | +18  | V     |
| V <sub>O</sub>             | output voltage                  |                                                                    | -0.3                | +18  | V     |
| V <sub>O(ov)</sub>         | overvoltage output voltage      | T <sub>amb</sub> < 140 °C at t < 1 h <sup>[1]</sup>                | V <sub>th(ov)</sub> | 18   | V     |
| I <sub>r</sub>             | reverse current                 | T <sub>amb</sub> < 70 °C                                           | -                   | 150  | mA    |
| T <sub>amb</sub>           | ambient temperature             |                                                                    | -40                 | +180 | °C    |
| T <sub>amb(pr)</sub>       | programming ambient temperature |                                                                    | 10                  | 70   | °C    |
| T <sub>stg</sub>           | storage temperature             |                                                                    | -40                 | +125 | °C    |
| t <sub>diag</sub>          | diagnostic time                 | output voltage level ≤ 4 %V <sub>DD</sub> or ≥ 96 %V <sub>DD</sub> | -                   | 100  | h     |
| <b>Non-volatile memory</b> |                                 |                                                                    |                     |      |       |
| t <sub>ret(D)</sub>        | data retention time             | T <sub>amb</sub> = 50 °C                                           | 17                  | -    | year  |
| N <sub>endu(W_ER)</sub>    | write or erase endurance        | T <sub>amb(pr)</sub> = 70 °C                                       | 100                 | -    | cycle |

[1] Overvoltage on output and supply within the specified operating voltage range.

## 12 Recommended operating conditions

**Table 38. Operating conditions**

*In a homogenous magnetic field.*

| Symbol               | Parameter                        | Conditions | Min | Typ | Max  | Unit |
|----------------------|----------------------------------|------------|-----|-----|------|------|
| V <sub>DD</sub>      | supply voltage                   | [1]        | 4.5 | 5.0 | 5.5  | V    |
| T <sub>amb</sub>     | ambient temperature              |            | −40 | -   | +180 | °C   |
| T <sub>amb(pr)</sub> | programming ambient temperature  |            | 10  | -   | 70   | °C   |
| H <sub>ext</sub>     | external magnetic field strength |            | 25  | -   | -    | kA/m |
| Analog               |                                  |            |     |     |      |      |
| R <sub>L(ext)</sub>  | external load resistance         | [2]        | 5   | -   | ∞    | kΩ   |
| C <sub>L(ext)</sub>  | external load capacitance        | [1][3]     | 0   | -   | 22   | nF   |
|                      |                                  | [3][4]     | 0   | -   | 6.8  | nF   |
| SENT                 |                                  |            |     |     |      |      |
| R <sub>L(ext)</sub>  | external load resistance         | [5]        | 10  | -   | 55   | kΩ   |
| C <sub>L(ext)</sub>  | external load capacitance        | [1][3][6]  | 0   | -   | 3.5  | nF   |

[1] Normal operation mode.

[2] Power-loss detection is only possible with a load resistance within the specified range connected to the supply or ground line.

[3] Between ground and output.

[4] Command mode.

[5] Pull-up resistance between output and supply.

[6] Without internal load capacitance; part of capacitance is defined as input capacitor inside receiver circuit according to SENT specification; see application information in [Section 19.2](#).

## 13 Thermal characteristics

**Table 39. Thermal characteristics**

| Symbol               | Parameter                                   | Conditions | Typ | Unit |
|----------------------|---------------------------------------------|------------|-----|------|
| R <sub>th(j-a)</sub> | thermal resistance from junction to ambient |            | 100 | K/W  |

## 14 Characteristics

**Table 40. Mechanical characteristics**

T<sub>amb</sub> = 25 °C

| Symbol            | Parameter                          | Conditions | Min | Typ | Max | Unit |
|-------------------|------------------------------------|------------|-----|-----|-----|------|
| F <sub>lead</sub> | mechanical force to the leads      |            | -   | -   | 10  | N    |
| F <sub>fin</sub>  | mechanical force to the fin holder |            | -   | -   | 15  | N    |

**Table 41. Supply current**

Characteristics are valid for the operating conditions, as specified in [Section 12](#).

| Symbol           | Parameter                      | Conditions         | Min | Typ | Max | Unit |
|------------------|--------------------------------|--------------------|-----|-----|-----|------|
| Analog           |                                |                    |     |     |     |      |
| $I_{DD}$         | supply current                 | [1][2]             | 10  | -   | 20  | mA   |
|                  |                                | [3][4]             | -   | -   | 26  | mA   |
| $I_{off(ov)}$    | overvoltage switch-off current | [5]                | -   | -   | 17  | mA   |
| $I_{O(sc)}$      | short-circuit output current   | [6]                | -   | -   | 40  | mA   |
| SENT             |                                |                    |     |     |     |      |
| $I_{DD}$         | supply current                 | [1][2]             | 10  | -   | 24  | mA   |
|                  |                                | [3][4]             | -   | -   | 28  | mA   |
| $I_{DD(ripple)}$ | ripple supply current          | peak-to-peak value | -   | 2   | 4   | mA   |
| $I_{off(ov)}$    | overvoltage switch-off current | [5]                | -   | -   | 19  | mA   |
| $I_{O(sc)}$      | short-circuit output current   | [6]                | -   | -   | 44  | mA   |

[1] Normal operation and diagnostic mode excluding overvoltage and undervoltage within the specified operating supply voltage range.

[2] Without load current at the output.

[3] Normal operation and diagnostic mode over full voltage range up to limiting supply voltage at steady state.

[4] With minimum load resistance at the output.

[5] Diagnostic mode for a supply voltage above the overvoltage threshold voltage up to the limiting supply voltage.

[6] Supply current if one of the outputs OUTn/DATAn is shorted to GND or  $V_{DD}$ , respectively.

**Table 42. Power-on reset**

Characteristics are valid for the operating conditions, as specified in [Section 12](#).

| Symbol        | Parameter                      | Conditions                                      | Min | Typ | Max  | Unit |
|---------------|--------------------------------|-------------------------------------------------|-----|-----|------|------|
| $V_{th(on)}$  | switch-on threshold voltage    | if $V_{DD} > V_{th(on)}$ , output switches on   | -   | 4.3 | 4.45 | V    |
| $V_{th(off)}$ | switch-off threshold voltage   | if $V_{DD} < V_{th(off)}$ , output switches off | 3.9 | 4.1 | -    | V    |
| $V_{hys}$     | hysteresis voltage             | $V_{hys} = V_{th(on)} - V_{th(off)}$            | 0.1 | 0.2 | -    | V    |
| $V_{POR}$     | power-on reset voltage         | IC is initialized                               | -   | 3.3 | 3.6  | V    |
| $V_{th(ov)}$  | overvoltage threshold voltage  | if $V_{DD} > V_{th(ov)}$ , output switches off  | 6.5 | 7.5 | 8    | V    |
| $V_{hys(ov)}$ | overvoltage hysteresis voltage |                                                 | 0.1 | 0.3 | -    | V    |

Table 43. Performance

Characteristics are valid for the operating conditions, as specified in [Section 12](#).

| Symbol                 | Parameter                                   | Conditions                                                                             | Min           | Typ | Max            | Unit     |
|------------------------|---------------------------------------------|----------------------------------------------------------------------------------------|---------------|-----|----------------|----------|
| $\Delta\phi_{lin}$     | linearity error                             | temperature range <sup>[1][2][3]</sup><br>–40 °C to +180 °C                            | –1.2          | -   | +1.2           | deg      |
|                        |                                             | temperature range <sup>[1][2][3]</sup><br>–40 °C to +160 °C                            | –1            | -   | +1             | deg      |
|                        |                                             | temperature range <sup>[1][2][3]</sup><br>–40 °C to +140 °C                            | –0.9          | -   | +0.9           | deg      |
| $\Delta\phi_{temp}$    | temperature drift error                     | temperature range <sup>[1][2][4][5]</sup><br>–40 °C to +180 °C                         | -             | -   | 0.8            | deg      |
|                        |                                             | temperature range <sup>[1][2][4][5]</sup><br>–40 °C to +160 °C                         | -             | -   | 0.6            | deg      |
|                        |                                             | temperature range <sup>[1][2][4][5]</sup><br>–40 °C to +140 °C                         | -             | -   | 0.5            | deg      |
| $\Delta\phi_{temp RT}$ | temperature drift error at room temperature | temperature range <sup>[2][4][6]</sup><br>–40 °C to +180 °C                            | -             | -   | 0.65           | deg      |
|                        |                                             | temperature range <sup>[2][4][6]</sup><br>–40 °C to +160 °C                            | -             | -   | 0.6            | deg      |
|                        |                                             | temperature range <sup>[2][4][6]</sup><br>–40 °C to +140 °C                            | -             | -   | 0.5            | deg      |
| $\Delta\phi_{hys}$     | hysteresis error                            | referred to input <sup>[1][2]</sup>                                                    | -             | -   | 0.09           | deg      |
| $\Delta\phi_{ulin}$    | microlinearity error                        | referred to input <sup>[1][2]</sup>                                                    | –0.1          | -   | +0.1           | deg      |
| $\Delta\phi_{ang}$     | angular error                               | temperature range <sup>[1][2][3][7]</sup><br>–40 °C to +180 °C                         | –1.35         | -   | +1.35          | deg      |
|                        |                                             | temperature range <sup>[1][2][3][7]</sup><br>–40 °C to +160 °C                         | –1.2          | -   | +1.2           | deg      |
|                        |                                             | temperature range <sup>[1][2][3][7]</sup><br>–40 °C to +140 °C                         | –1.1          | -   | +1.1           | deg      |
| $m_{ang}$              | slope of angular error                      | <sup>[1][2][7]</sup>                                                                   | -             | -   | 0.04           | deg/deg  |
| $Z_{O(pl)}$            | power-loss output impedance                 | impedance to remaining supply line in case of lost supply voltage or lost ground       | -             | -   | 210            | $\Omega$ |
| Analog                 |                                             |                                                                                        |               |     |                |          |
| $\alpha_{res}$         | angle resolution                            | <sup>[5]</sup>                                                                         | -             | -   | 0.04           | deg      |
| $\alpha_{max}$         | maximum angle                               | programmable angular range for $V_{(CL)u} - V_{(CL)l} \geq 80 \%V_{DD}$ <sup>[8]</sup> | 6             | -   | 180            | deg      |
| $\alpha_{ref}$         | reference angle                             | programmable zero angle <sup>[8]</sup>                                                 | 0             | -   | 180            | deg      |
| $V_{O(nom)}$           | nominal output voltage                      | at full supply operating range                                                         | 5 % $V_{DD}$  | -   | 95 % $V_{DD}$  | V        |
| $V_{O(udr)}$           | upper diagnostic range output voltage       | <sup>[1][9][10]</sup>                                                                  | 96 % $V_{DD}$ | -   | 100 % $V_{DD}$ | V        |

| Symbol            | Parameter                             | Conditions                              | Min             | Typ  | Max             | Unit |
|-------------------|---------------------------------------|-----------------------------------------|-----------------|------|-----------------|------|
| $V_{O(ldr)}$      | lower diagnostic range output voltage | [1][9][10]                              | 0 % $V_{DD}$    | -    | 4 % $V_{DD}$    | V    |
| $V_{(CL)u}$       | upper clamping voltage                | [1][10][11]                             | 40 % $V_{DD}$   | -    | 95 % $V_{DD}$   | V    |
| $V_{(CL)l}$       | lower clamping voltage                | [1][10][11]                             | 5 % $V_{DD}$    | -    | 30.5 % $V_{DD}$ | V    |
| $\Delta V_{(CL)}$ | clamping voltage variation            | deviation from programmed value [1][10] | -0.3 % $V_{DD}$ | -    | +0.3 % $V_{DD}$ | V    |
| $V_{n(o)(RMS)}$   | RMS output noise voltage              | equivalent power noise [1][5]           | -               | 0.4  | 2.5             | mV   |
| <b>SENT</b>       |                                       |                                         |                 |      |                 |      |
| $\alpha_{res}$    | angle resolution                      | [12]                                    | -               | -    | 0.044           | deg  |
| $V_{n(o)(RMS)}$   | RMS output noise voltage              | equivalent power noise [13]             | -               | -    | 1               | LSB  |
| $V_{OH}$          | HIGH-level output voltage             | at 0.1 mA DC load current               | 4.1             | -    | 4.7             | V    |
| $V_{OL}$          | LOW-level output voltage              | at 0.5 mA DC load current               | -               | -    | 0.5             | V    |
| $T_{sen(acc)}$    | sensor temperature accuracy           | [14]                                    | -10             | -    | +10             | °C   |
| $T_{sen(res)}$    | sensor temperature resolution         | [14]                                    | -               | 1    | -               | °C   |
| $V_{sen(acc)}$    | sensor voltage accuracy               |                                         | -250            | -    | +250            | mV   |
| $V_{sen(res)}$    | sensor voltage resolution             |                                         | -               | 17.5 | -               | mV   |

[1] At a low-pass filtered analog output with a cut-off frequency of 0.7 kHz.

[2] Definition of errors is given in [Section 15](#).

[3] Inhomogeneity of an 18 mm diameter disc magnet can increase the linearity error by < 0.1°.

[4] Based on a 3 $\sigma$  standard deviation.

[5] At a nominal output voltage between 5 % $V_{DD}$  and 95 % $V_{DD}$  and a maximum angle of  $\alpha_{max} = 180^\circ$ .

[6] Room temperature is given for an ambient temperature of 25 °C.

[7] Graph of angular error is shown in [Figure 14](#).

[8] In steps of resolution < 0.0027°.

[9] Activation is dependent on the programmed diagnostic mode.

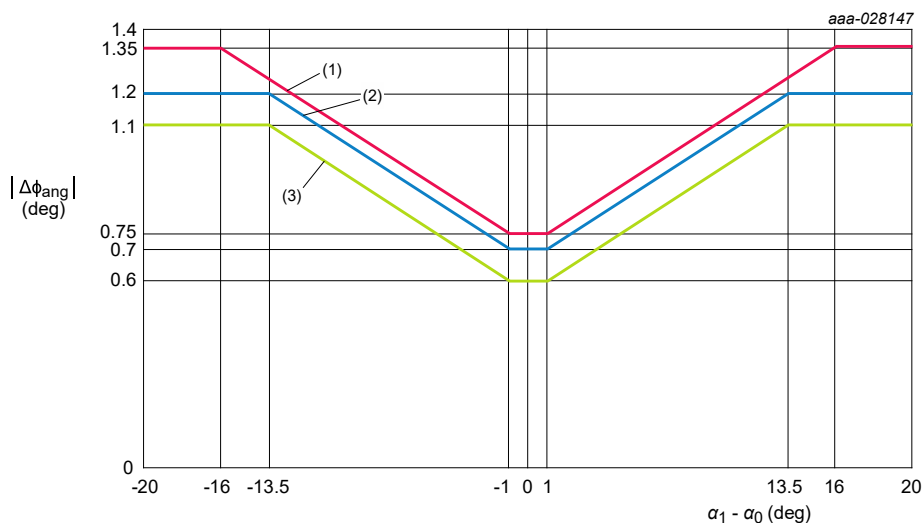
[10] Settling to these values is limited by 0.7 kHz low-pass filtering of analog output.

[11] In steps of 0.02 % $V_{DD}$ .

[12] At a maximum angle of  $\alpha_{max} = 180^\circ$ .

[13] Based on 12 bit.

[14] Sensor temperature refers to the on-chip temperature.



1. -40 °C to +180 °C
2. -40 °C to +160 °C
3. -40 °C to +140 °C

Figure 14. Envelope curve for the magnitude of angular error

Table 44. Dynamics

Characteristics are valid for the operating conditions, as specified in [Section 12](#).

| Symbol         | Parameter                    | Conditions                                                                                           | Min    | Typ  | Max | Unit |
|----------------|------------------------------|------------------------------------------------------------------------------------------------------|--------|------|-----|------|
| $t_{on}$       | turn-on time                 | until first valid result                                                                             | -      | -    | 1   | ms   |
| $f_{upd}$      | update frequency             |                                                                                                      | 5.5125 | 6.25 | -   | kHz  |
| $t_s$          | settling time                | after an ideal mechanical angle step of 45°, until 90 % of the final value is reached <sup>[1]</sup> | 250    | 400  | 500 | μs   |
| FTTI           | fault tolerant time interval | time until the device will go into safe state after internal error occurs <sup>[2]</sup>             | -      | -    | 5   | ms   |
| $t_{cmd(ent)}$ | enter command mode time      | after power-on                                                                                       | 20     | -    | 30  | ms   |
| $t_{rec(ov)}$  | overvoltage recovery time    | after overvoltage                                                                                    | -      | -    | 1   | ms   |
| <b>SENT</b>    |                              |                                                                                                      |        |      |     |      |
| $f_{upd}$      | update frequency             | <sup>[3]</sup>                                                                                       | 1.2    | -    | 2.2 | kHz  |
| $T_{clk}$      | clock period                 | SENT clock tick time = 2.7 μs <sup>[4]</sup>                                                         | 2.4    | 2.67 | 3   | μs   |
|                |                              | SENT clock tick time = 3 μs                                                                          | 2.7    | 3    | 3.3 | μs   |
|                |                              | SENT clock tick time = 4.5 μs                                                                        | 3.6    | 4.5  | 5.4 | μs   |
|                |                              | SENT clock tick time = 6 μs                                                                          | 4.8    | 6    | 7.2 | μs   |

| Symbol     | Parameter          | Conditions                                                                                                      | Min  | Typ  | Max  | Unit    |
|------------|--------------------|-----------------------------------------------------------------------------------------------------------------|------|------|------|---------|
| $t_{jit}$  | jitter time        | variation of maximum nibble time ( $6\sigma$ ) compared to the expected time derived from the calibration pulse |      |      |      |         |
|            |                    | $T_{clk} = 2.7 \mu s$                                                                                           | -    | -    | 0.09 | $\mu s$ |
|            |                    | $T_{clk} = 3 \mu s$                                                                                             | -    | -    | 0.1  | $\mu s$ |
|            |                    | $T_{clk} = 4.5 \mu s$                                                                                           | -    | -    | 0.15 | $\mu s$ |
|            |                    | $T_{clk} = 6 \mu s$                                                                                             | -    | -    | 0.2  | $\mu s$ |
| $t_f$      | fall time          | from 3.8 V to 1.1 V output level                                                                                |      |      |      |         |
|            |                    | slope time: 00b; $T_{clk} = 2.7 \mu s$                                                                          | 4.1  | 5.3  | 6.5  | $\mu s$ |
|            |                    | slope time: 01b; $T_{clk} = 3 \mu s$                                                                            | 4.1  | 5.3  | 6.5  | $\mu s$ |
|            |                    | slope time: 10b; $T_{clk} = 4.5 \mu s$                                                                          | 6.1  | 7.1  | 9.75 | $\mu s$ |
|            |                    | slope time: 11b; $T_{clk} = 6 \mu s$                                                                            | 8.2  | 10.7 | 13   | $\mu s$ |
| $t_r$      | rise time          | from 1.1 V to 3.8 V output level                                                                                |      |      |      |         |
|            |                    | slope time: 00b; $T_{clk} = 2.7 \mu s$                                                                          | 5.2  | 7.1  | 8.7  | $\mu s$ |
|            |                    | slope time: 01b; $T_{clk} = 3 \mu s$                                                                            | 5.2  | 7.1  | 8.7  | $\mu s$ |
|            |                    | slope time: 10b; $T_{clk} = 4.5 \mu s$                                                                          | 10.3 | 14.2 | 17.4 | $\mu s$ |
|            |                    | slope time: 11b; $T_{clk} = 6 \mu s$                                                                            | 15.5 | 21.3 | 26.1 | $\mu s$ |
| $t_{stab}$ | stabilization time | output level below 1.39 V (LOW) or above 3.8 V (HIGH)                                                           |      |      |      |         |
|            |                    | $T_{clk} = 2.7 \mu s$                                                                                           | 6    | -    | -    | $\mu s$ |
|            |                    | $T_{clk} = 3 \mu s$                                                                                             | 6    | -    | -    | $\mu s$ |
|            |                    | $T_{clk} = 4.5 \mu s$                                                                                           | 9    | -    | -    | $\mu s$ |
|            |                    | $T_{clk} = 6 \mu s$                                                                                             | 12   | -    | -    | $\mu s$ |

- [1] The mechanical angle step is not synchronized with the SENT frame. Thus the worst case settling time is extended with the length of a complete SENT frame.
- [2] Refers to analog output; additional information including times for digital output is provided in the safety manual.
- [3] SENT update rate at  $T_{clk} = 3 \mu s$ , 6 DATA nibbles, and no PAUSE pulse.
- [4] 12 bit fast mode.

**Table 45. Digital interface**

Characteristics are valid for the operating conditions, as specified in [Section 12](#).

| Symbol           | Parameter                 | Conditions                                            | Min             | Typ            | Max             | Unit    |
|------------------|---------------------------|-------------------------------------------------------|-----------------|----------------|-----------------|---------|
| $V_{IH}$         | HIGH-level input voltage  |                                                       | 80 % $V_{DD}$   | -              | -               | V       |
| $V_{IL}$         | LOW-level input voltage   |                                                       | -               | -              | 20 % $V_{DD}$   | V       |
| $V_{OH}$         | HIGH-level output voltage | $I_O = 2$ mA                                          | 80 % $V_{DD}$   | -              | -               | V       |
| $V_{OL}$         | LOW-level output voltage  | $I_O = 2$ mA                                          | -               | -              | 20 % $V_{DD}$   | V       |
| $I_{od}$         | overdrive current         | absolute value for overdriving the output buffer      | -               | -              | 20              | mA      |
| $t_{start}$      | start time                | LOW level before rising edge <sup>[1]</sup>           | 5               | -              | -               | $\mu$ s |
| $t_{stop}$       | stop time                 | HIGH level before falling edge                        | 5               | -              | -               | $\mu$ s |
| $T_{bit}$        | bit period                | the load capacitance limits the minimum period        | 10              | -              | 100             | $\mu$ s |
| $\Delta T_{bit}$ | bit period deviation      | deviation between received clock and sent clock       | 0.8 $T_{bit}$   | 1 $T_{bit}$    | 1.2 $T_{bit}$   | $\mu$ s |
| $t_{w0}$         | pulse width 0             |                                                       | 0.175 $T_{bit}$ | 0.25 $T_{bit}$ | 0.375 $T_{bit}$ | $\mu$ s |
| $t_{w1}$         | pulse width 1             |                                                       | 0.625 $T_{bit}$ | 0.75 $T_{bit}$ | 0.825 $T_{bit}$ | $\mu$ s |
| $t_{to}$         | time-out time             | communication reset guaranteed after maximum $t_{to}$ | 250             | -              | -               | $\mu$ s |
| $t_{tko(slv)}$   | slave takeover time       | duration of LOW level for slave takeover              | 1               | -              | 5               | $\mu$ s |
| $t_{tko(mas)}$   | master takeover time      | duration of LOW level for master takeover             | 0 $T_{bit}$     | -              | 0.5 $T_{bit}$   | $\mu$ s |
| $t_{prog}$       | programming time          | for a single memory address                           | 20              | -              | -               | ms      |

[1] In SENT mode, the OUTn/DATAn pin must be kept HIGH for at least  $t_{to}$  before sending the initial command sequence to enter the command mode.

**Table 46. Internal capacitances**

Characteristics are valid for the operating conditions, as specified in [Section 12](#).

| Symbol      | Parameter            | Conditions        | Min | Typ | Max | Unit |
|-------------|----------------------|-------------------|-----|-----|-----|------|
| $C_{block}$ | blocking capacitance | <sup>[1][2]</sup> | 100 | 200 | 300 | nF   |
| $C_L$       | load capacitance     | <sup>[1]</sup>    | 1.1 | 2.2 | 3.3 | nF   |

[1] Measured at 1 MHz.

[2] Total capacitance between  $V_{DD}$  and GND.

## 15 Definition of errors

### 15.1 General

Angular measurement errors by the device result from linearity errors, temperature drift errors, and hysteresis errors. Figure 15 shows the output signal of an ideal sensor, where the measured angle  $\phi_{\text{meas}}$  corresponds ideally to the magnetic field angle  $\alpha$ . This curve represents the angle reference line  $\phi_{\text{ref}}(\alpha)$  with a slope of  $0.5\%V_{\text{DD}}/\text{degree}$  and  $22.75\text{ LSB/degree}$  for SENT mode respectively.

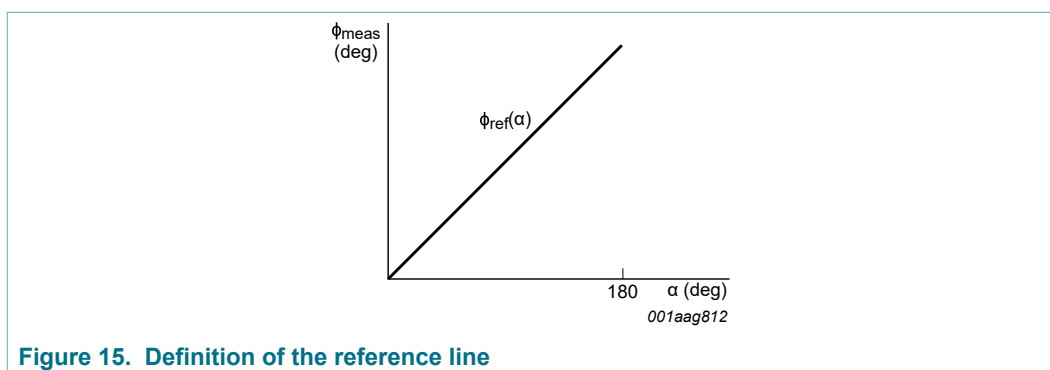


Figure 15. Definition of the reference line

The angular range is set to  $\alpha_{\text{max}} = 180^\circ$  and the clamping voltages are programmed to  $V_{(\text{CL})\text{I}} = 5\%V_{\text{DD}}$  and  $V_{(\text{CL})\text{u}} = 95\%V_{\text{DD}}$  for a valid definition of errors.

### 15.2 Hysteresis error

The device output performs a positive (clockwise) rotation and negative (counter clockwise) rotation over an angular range of  $180^\circ$  at a constant temperature. The maximum difference between the angles defines the hysteresis error  $\Delta\phi_{\text{hys}}$ .

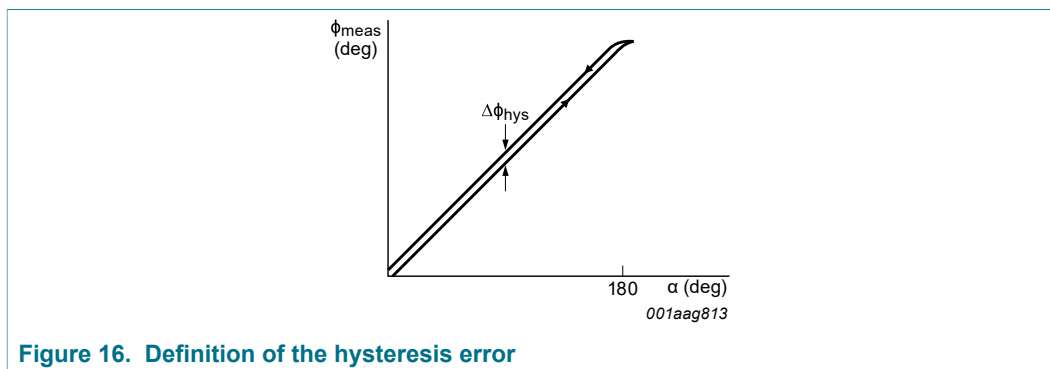


Figure 16. Definition of the hysteresis error

Equation (1) gives the mathematical description for the hysteresis value  $\Delta\phi_{\text{hys}}$ :

$$\Delta\phi_{\text{hys}}(\alpha) = |\phi_{\text{meas}}(\alpha \rightarrow 180^\circ) - \phi_{\text{meas}}(\alpha \rightarrow 0^\circ)| \quad (1)$$

15.3 Linearity error

The device output signal deviation from a best straight line  $\Delta\phi_{BSL}$ , with the same slope as the reference line, is defined as linearity error. The magnetic field angle is varied at fixed temperatures for measurement of this linearity error. The output signals deviation from the best straight line at the given temperature is the linearity error  $\Delta\phi_{lin}$ . It is a function of the magnetic field angle  $\alpha$  and the temperature of the device  $T_{amb}$ .

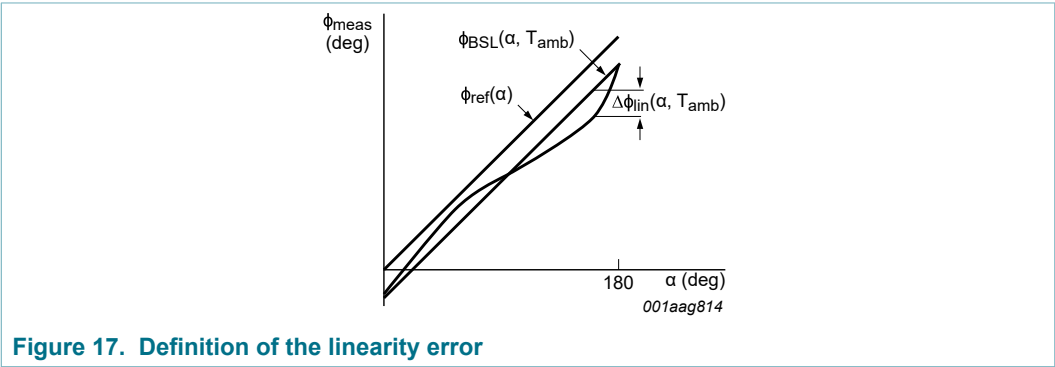


Figure 17. Definition of the linearity error

15.4 Microlinearity error

$\alpha$  is the magnetic field angle. If  $\Delta\alpha = 1^\circ$ , the microlinearity error  $\Delta\phi_{lin}$  is the device output deviation from  $1^\circ$ .

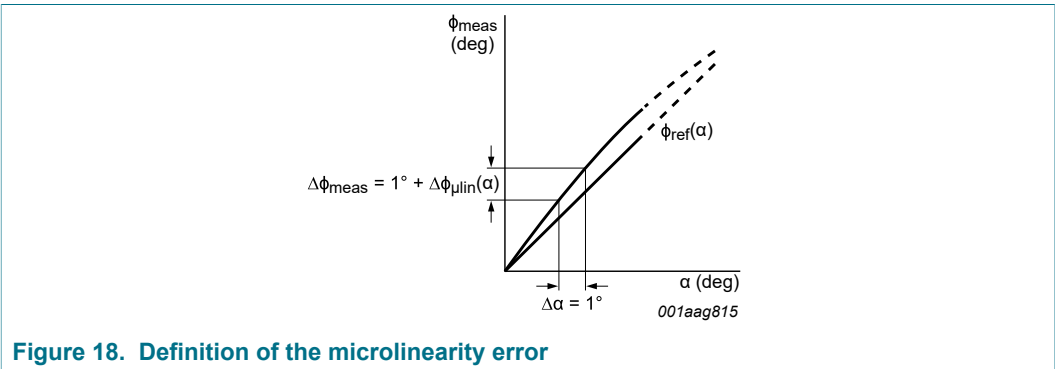
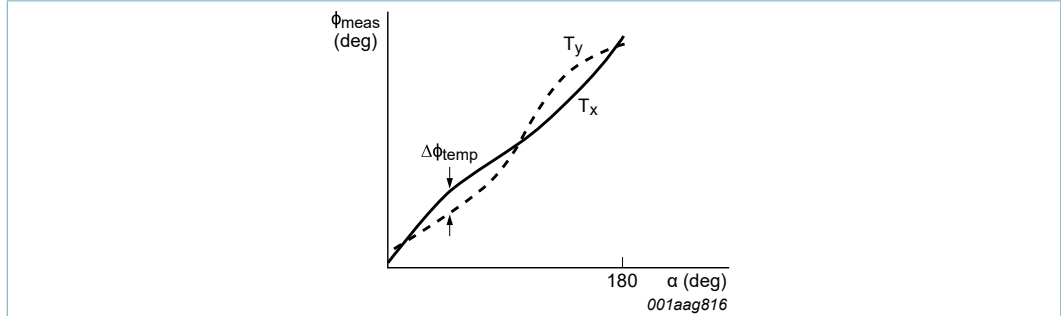


Figure 18. Definition of the microlinearity error

### 15.5 Temperature drift error

The temperature drift  $\Delta\phi_{\text{temp}}$  is defined as the envelope over the deviation of the angle versus the temperature range. It is considered as the pure thermal effect.



**Figure 19. Definition of the temperature drift error**

Equation (2) gives the mathematical description for temperature drift value  $\Delta\phi_{\text{temp}}$ :

$$\Delta\phi_{\text{temp}}(\alpha) = |\phi_{\text{meas}}(\alpha, T_x) - \phi_{\text{meas}}(\alpha, T_y)| \quad (2)$$

With:

$T_x$ : temperature for maximum  $\phi_{\text{meas}}$  at angle  $\alpha$

$T_y$ : temperature for minimum  $\phi_{\text{meas}}$  at angle  $\alpha$

The deviation from the value at room temperature  $\Delta\phi_{\text{temp|RT}}$  describes the temperature drift of the angle, compared to the value, which the sensor provides at room temperature:

$$\Delta\phi_{\text{temp|RT}}(\alpha, T_{\text{amb}}) = |\phi_{\text{meas}}(\alpha, T_{\text{amb}}) - \phi_{\text{meas}}(\alpha, T_{\text{RT}})| \quad (3)$$

With:

$T_{\text{RT}}$ : room temperature (25 °C)

### 15.6 Angular error

The angular error  $\Delta\phi_{\text{ang}}$  is the difference between mechanical angle and sensor output during a movement from  $\alpha_0$  to  $\alpha_1$ . Here  $\alpha_0$  and  $\alpha_1$  are arbitrary angles within the angular range. The customer initially programs the angle measurement at  $\alpha_0$  at room temperature and zero hour upon production. The angle measurement at  $\alpha_1$  is made at any temperature within the ambient temperature range:

$$\Delta\phi_{\text{ang}} = (\phi_{\text{meas}}(\alpha_1, T_{\text{amb}}) - \phi_{\text{meas}}(\alpha_0, T_{\text{RT}})) - (\alpha_1 - \alpha_0) \quad (4)$$

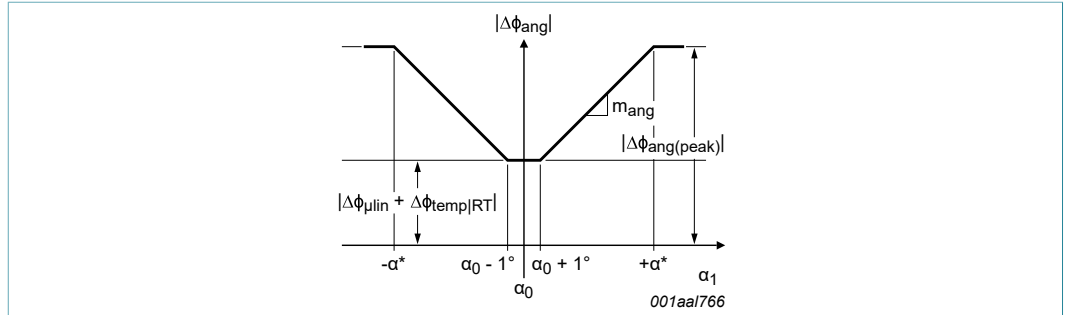
With:

$\alpha_0, \alpha_1$ : arbitrary mechanical angles within the angular range

$\phi_{\text{meas}}(\alpha_0, T_{\text{RT}})$ : programmed angle at  $\alpha_0$ ,  $T_{\text{RT}} = 25$  °C and zero hour upon production

$\phi_{\text{meas}}(\alpha_1, T_{\text{amb}})$ : the sensor measures angle at  $\alpha_1$  and any temperature within  $T_{\text{amb}}$

This error comprises non-linearity and temperature drift related to the room temperature.



**Figure 20. Envelope curve for the magnitude of angular error**

Figure 20 shows the envelope curve for the magnitude of angular error  $|\Delta\phi_{ang}|$  versus  $\alpha_1$  for all angles  $\alpha_0$  and all temperatures  $T_{amb}$  within the ambient temperature range. If  $\alpha_1$  is in the range of  $\pm 1^\circ$  around  $\alpha_0$ ,  $|\Delta\phi_{ang}|$  has its minimum. Here only the microlinearity error  $\Delta\phi_{\mu lin}$  and the temperature drift related to the room temperature  $|\Delta\phi_{temp|RT}|$  occurs. If  $\alpha_1$  deviates from  $\alpha_0$  by more than  $1^\circ$  in either direction,  $|\Delta\phi_{ang}|$  can increase. Slope  $m_{ang}$  defines the gradient.

Equation (5) to Equation (8), express the angular error:

For  $|\alpha_1 - \alpha_0| \leq 1^\circ$

$$|\Delta\phi_{ang}| = |\Delta\phi_{\mu lin} + \Delta\phi_{temp|RT}| \quad (5)$$

For  $1^\circ < |\alpha_1 - \alpha_0| < \alpha^*$

$$|\Delta\phi_{ang}| = |\Delta\phi_{\mu lin} + \Delta\phi_{temp|RT}| + m_{ang} \times (|\alpha_1 - \alpha_0| - 1^\circ) \quad (6)$$

For  $|\alpha_1 - \alpha_0| \geq \alpha^*$

$$|\Delta\phi_{ang}| = \sqrt{(\Delta\phi_{lin})^2 + (\Delta\phi_{temp|RT})^2} \quad (7)$$

With:

$$\alpha^* = \frac{|\Delta\phi_{ang(peak)}| - |\Delta\phi_{\mu lin} + \Delta\phi_{temp|RT}|}{m_{ang}} + \alpha_0 + 1^\circ \quad (8)$$

16 Programming

16.1 General description

The device provides an OWI to enable programming of the device which uses pin OUTn/DATAn bidirectionally.

In general the device runs in analog or SENT mode, the normal operation mode. The embedded programming data configures this mode. After a power-on reset once time  $t_{on}$  has elapsed, it starts. In this mode, the magnetic field angle is converted into the corresponding output voltage per channel.

A second mode, the command mode enables programming. In this mode, the customer can adjust all required parameters (for example zero angle and angular range) to meet the application requirements. Data is stored in the non-volatile memory. After changing the contents of the memory, recalculate and write the checksum (see [Section 16.4](#)).

In order to enter the command mode keep pin OUTn/DATAn HIGH for at least  $t_{to}$  and send a specific command sequence after a power-on reset and during the time slot  $t_{cmd(ent)}$ . The external source used to send the command sequence must overdrive the output buffer of the device. In doing so, it provides current  $I_{od}$ . This signature can be sent to each channel separately or in parallel.

During communication, the channels of the KMA320 are always the slaves and the external programming hardware is always the master. [Figure 21](#) illustrates the structure of the OWI data format.

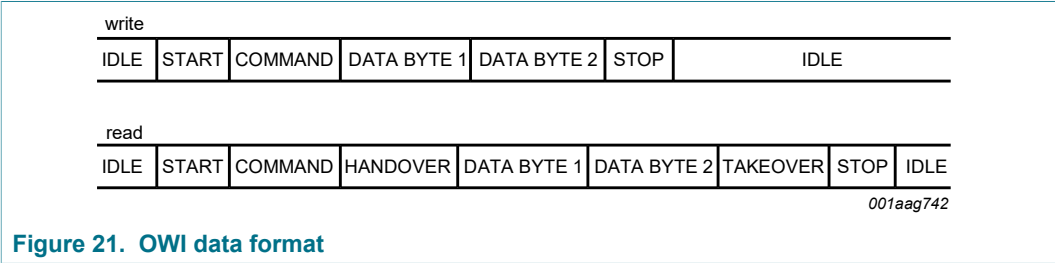


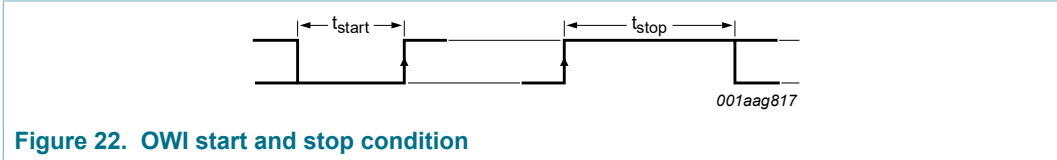
Figure 21. OWI data format

The master provides the start condition, which is a rising edge after a LOW level. Then a command byte which can be either a read or a write command is sent. Depending on the command, the master or the slave has to send the data immediately after the command sequence. If there is a read command, an additional handover or takeover bit is inserted before and after the data bytes. The master must close each communication with a stop condition. If the slave does not receive a rising edge for a time longer than  $t_{to}$ , a timeout condition occurs. The bus is reset to the idle state and waits for a start condition and a new command. This behavior can be used to synchronize the device regardless of the previous state.

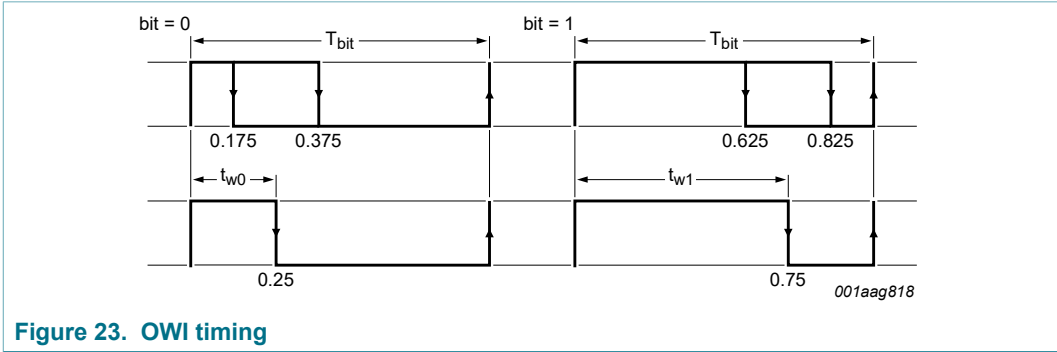
All communication is based on this structure (see [Figure 21](#)), even for entering the command mode. The customer can access the non-volatile memory, CTRL1, and SIGNATURE registers (described in [Section 16.5](#)). Only a power-on reset leaves the command mode. A more detailed description of the programming is given in the next sections.

16.2 Timing characteristics

As described in the previous section, a start and stop condition is necessary for communication. The LOW-level duration before the rising edge of the start condition is defined as  $t_{start}$ . The HIGH-level duration after the rising edge of the stop condition is defined as  $t_{stop}$ . These parameters, together with all other timing characteristics are shown in [Table 45](#).



[Figure 23](#) shows the coding of a single bit with a HIGH level of  $V_{IH}$  and a LOW level of  $V_{IL}$ . Here the pulse width  $t_{w1}$  or  $t_{w0}$  represents a logic 1 or a logic 0 of a full bit period  $T_{bit}$ , respectively.



16.3 Sending and receiving data

The master has to control the communication during sending or receiving data. The command byte defines the address and type of command the master requests. Read commands need an additional handover or takeover bit. Insert this bit before and after the two data bytes (see [Figure 21](#)). However, the OWI is a serial data transmission, whereas the MSB is sent at first.

Table 47. Format of command byte

| 7    | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
|------|------|------|------|------|------|------|------|
| CMD7 | CMD6 | CMD5 | CMD4 | CMD3 | CMD2 | CMD1 | CMD0 |

Table 48. Command byte description

| Bit    | Symbol   | Description           |
|--------|----------|-----------------------|
| 7 to 1 | CMD[7:1] | address bits          |
| 0      | CMD0     | 0 = write<br>1 = read |

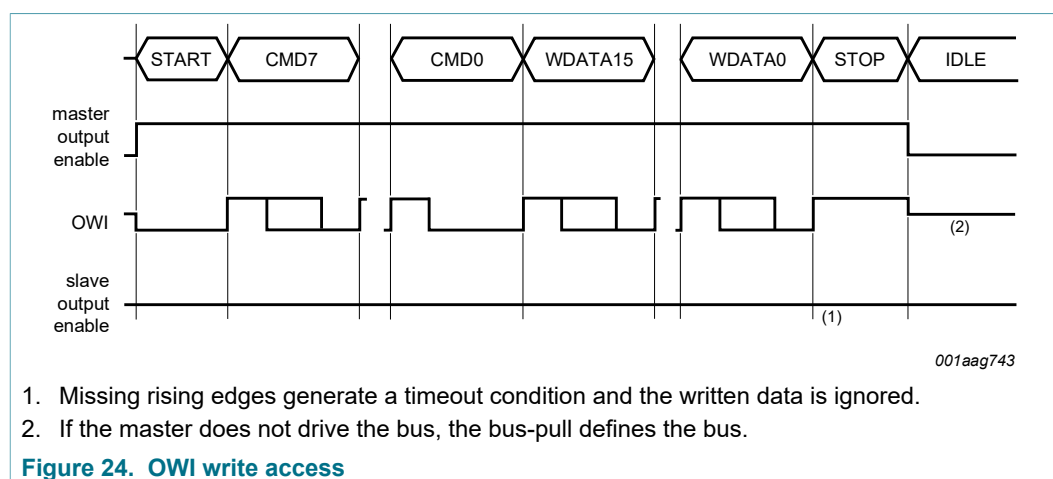
A more detailed description of all customer accessible registers is given in [Section 16.5](#). Both default value and the complete command including the address and write or read request are also listed.

### 16.3.1 Write access

To write data to the non-volatile memory, perform the following procedure for write access:

1. Start condition: The master drives a rising edge after a LOW level
2. Command: The master sends a write command (CMD0 = 0)
3. Data: The master sends two data bytes
4. Stop condition: The master drives a rising edge after a LOW level

[Figure 24](#) shows the write access of the digital interface. The signal OWI represents the data on the bus from the master or slave. The signals: master output enable and slave output enable indicate when the master or the slave output is enabled or disabled, respectively.



**Figure 24. OWI write access**

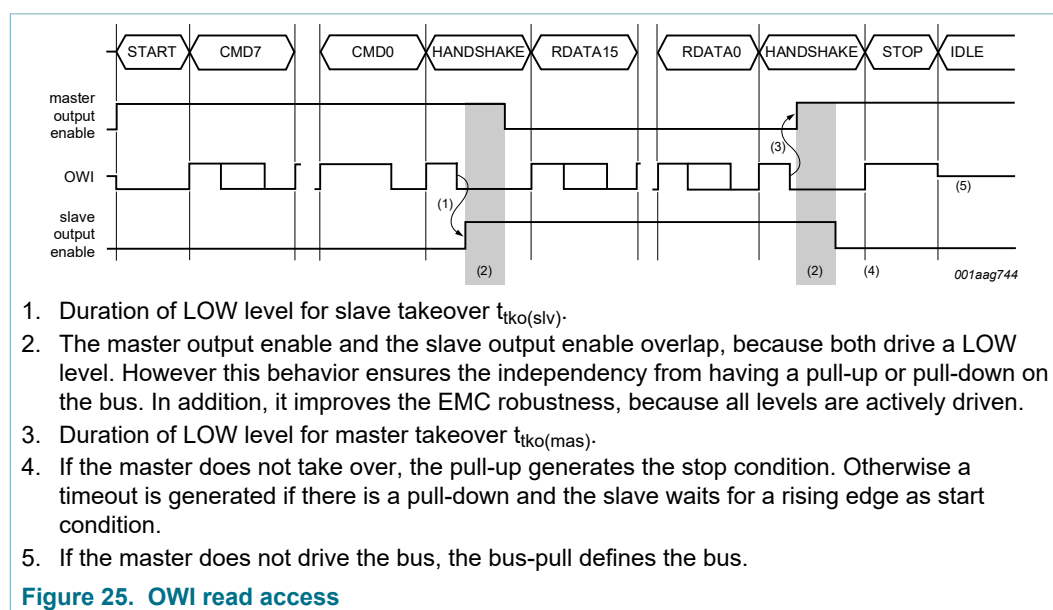
**Note:** As already mentioned in [Section 16.1](#), use the write procedure to enter the command mode. If command mode is not entered, communication is not possible and the sensor operates in normal operation mode. After changing an address, the time  $t_{\text{prog}}$  must elapse before changing another address. After changing the contents of the non-volatile memory, recalculate and write the checksum (see [Section 16.4](#)).

### 16.3.2 Read access

To read data from the sensor, perform the following procedure:

1. Start condition: The master drives a rising edge after a LOW level
2. Command: The master sends a read command (CMD0 = 1)
3. Handover: The master sends a handover bit that is a logic 0 and disables the output after a three-quarter bit period
4. Takeover: The slave drives a LOW level after the falling edge for  $t_{tko(slv)}$
5. Data: The slave sends two data bytes
6. Handover: The slave sends a handover bit that is a logic 0 and disables the output after a three-quarter bit period
7. Takeover: The master drives a LOW level after the falling edge for  $t_{tko(mas)}$
8. Stop condition: The master drives a rising edge after a LOW level

Figure 25 shows the read access of the digital interface. The signal OWI represents the data on the bus from the master or slave. The signals: master output enable and slave output enable indicate when the master or the slave output is enabled or disabled, respectively.



### 16.3.3 Entering the command mode

After a power-on reset, the sensor provides a time slot  $t_{cmd(ent)}$  for entering the command mode. Send a specific command sequence (see [Figure 26](#)). If command mode is not entered, the sensor starts in the normal operation mode. If the sensor stays in the diagnostic mode, the master can write the signature without a power-on reset.

During the command mode sequence, the output is enabled. The external programming hardware has to overdrive the output with current  $I_{od}$ . If command mode is activated, the output is disabled and pin OUTn/DATAn operates as a digital interface.

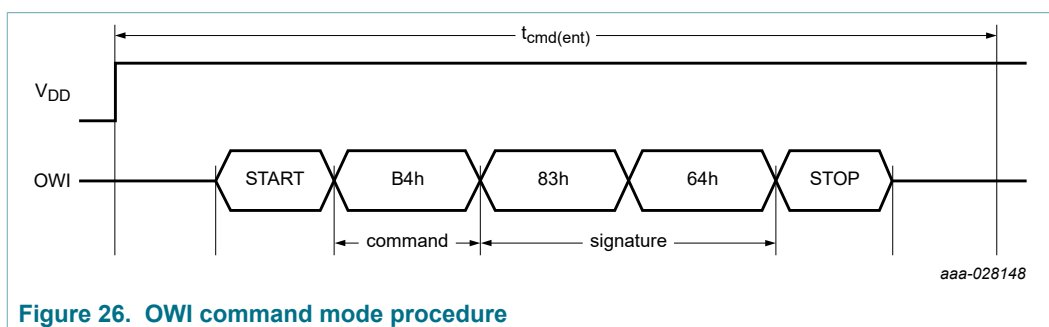


Figure 26. OWI command mode procedure

### 16.4 Cyclic redundancy check

As mentioned in [Section 10.1](#), there is an individual 8-bit checksum for each non-volatile memory area. Bit 8 of the CTRL1 register indicates a checksum error of customer area 1, 2 or 3 as well as the manufacturer area of the NVM including the traceability registers. Generate the CRC with the MSB of the data word first over all corresponding addresses in increasing order for the corresponding memory area, to calculate the checksums.

Read out all registers of the non-volatile memory area for calculating the checksum. The LSB contains the previous checksum and must be overwritten with 0h before the calculation can be started.

The generator polynomial for the calculation of the checksum is:

$$G(x) = x^8 + x^2 + x + 1 \quad (9)$$

With a seed value of AAh and the data bits are XOR at the  $x^8$  point.

### 16.4.1 Software example in C++

```
#include "stdafx.h"
#include "conio.h"
unsigned int calculate_crc(unsigned int crc, unsigned int
    data_word)
{
    const unsigned int gpoly = 0x107;    // generator polynomial
    for (int i = 15; i >= 0; i--)
    {
        crc <= 1;
        crc |= (int) ((data_word & (1u<<i))>>i);
        if (crc & 0x0100) crc ^= gpoly;
    }
    return crc;
}
int main(void)
{
    unsigned int crc;
    // data sequence of customer area 1
    unsigned int data_word[] = {0x0000, 0x0100, 0x1300, 0x1000,
        0x1FFE, 0xFFFF, 0x1200, 0x0000, 0x0099, 0x0F89, 0x80FA,
        0x00BE};
    // seed value
    crc = 0xAA;
    printf("Seed value\n0x%02X\n\n", crc);
    // number of registers
    unsigned int N = sizeof(data_word)/sizeof(unsigned int);
    // 8 LSBs are reserved for checksum and must be filled with 0
    data_word[N - 1] = data_word[N - 1] & 0xFF00;
    // calculate checksum over all addresses
    printf("Address\t\tValue\n");
    for (unsigned int i = 0; i <= N - 1; i++)
    {
        printf("0x%02X\t\t0x%04X\n", i, data_word[i]);
        crc = calculate_crc(crc, data_word[i]);
    }
    printf("\nChecksum for customer area 1\n0x%02X", crc);
    _getch();
    return 0;
}
```

The checksum of this data sequence is B3h.

## 16.5 Registers

### 16.5.1 Signatures

The command mode can be entered with different signatures with different access rights to the non-volatile memory regions. [Table 49](#) shows the level of access for the different regions of the non-volatile memory depending on the signature used.

**Table 49. Signatures**

| Signature  | Value | Command registers | Customer area 1 | Customer area 2 | Customer area 3 | Traceability register |
|------------|-------|-------------------|-----------------|-----------------|-----------------|-----------------------|
| A (OEM)    | 7253h | R/W               | -/-             | -/-             | R/W             | -/-                   |
| B (tier 1) | 8364h | R/W               | R/W             | R/W             | R/W             | R/-                   |

### 16.5.2 Command registers

To enter the command mode, write the signature given in [Table 49](#) into the specific register using the OWI. Do this procedure as described in [Section 16.3.3](#), with a write command, the signature follows it, but after a power-on reset and not later than  $t_{cmd(ent)}$ .

**Table 50. Command registers**

| Command write/read | Register | Bit | Access | Description                                                             |
|--------------------|----------|-----|--------|-------------------------------------------------------------------------|
| B0h/B1h            | CTRL1    | 15  | R      | diagnostic error detected                                               |
|                    |          | 14  | R      | diagnostic error detected in data path                                  |
|                    |          | 13  | R/W    | force diagnostic mode off (no signaling)<br>0b – enable<br>1b – disable |
|                    |          | 12  | R      | low voltage detected                                                    |
|                    |          | 11  | R      | high voltage detected                                                   |
|                    |          | 10  | R      | single-bit error of non-volatile memory detected and corrected          |
|                    |          | 9   | R      | double-bit error of non-volatile memory detected                        |
|                    |          | 8   | R      | checksum error of customer area 1, 2 or 3 detected                      |
|                    |          | 7   | R      | oscillator frequency out of range detected                              |
|                    |          | 6   | R      | voltage above programmed threshold detected                             |
|                    |          | 5   | R      | voltage below programmed threshold detected                             |
|                    |          | 4   | R      | temperature above programmed threshold detected                         |
|                    |          | 3   | W      | undefined <sup>[1]</sup>                                                |
|                    |          | 2   | R      | command mode signature A (OEM) detected                                 |
|                    |          | 1   | R      | command mode signature B (tier 1) detected                              |
|                    |          | 0   | R      | reserved                                                                |

| Command write/read | Register   | Bit      | Access | Description                                                                                                                                                |
|--------------------|------------|----------|--------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| B2h/B3h            | ASIL_FLAGS | 15 to 13 | R      | type number<br>000b – KMA310<br>001b – KMA320<br>010b – KMA321<br>011b – reserved<br>100b – reserved<br>101b – reserved<br>110b – KMZ80<br>111b – reserved |
|                    |            | 12       | R/W    | reserved                                                                                                                                                   |
|                    |            | 11       | R      | BIST completion check (SM-07)                                                                                                                              |
|                    |            | 10       | R      | angular range check (SM-12)                                                                                                                                |
|                    |            | 9        | R      | CORDIC range check (SM-11)                                                                                                                                 |
|                    |            | 8        | R      | SD-ADC range check (SM-09)                                                                                                                                 |
|                    |            | 7        | R      | BIST encoding check (SM-08)                                                                                                                                |
|                    |            | 6        | R      | data adder check (SM-10)                                                                                                                                   |
|                    |            | 5        | R      | control signal check (SM-06)                                                                                                                               |
|                    |            | 4        | R      | adjusted angle calculation check (SM-05)                                                                                                                   |
|                    |            | 3        | R      | data conversion check (SM-04)                                                                                                                              |
|                    |            | 2        | R      | data division check (SM-03)                                                                                                                                |
|                    |            | 1        | R      | inverted angle calculation check (SM-02)                                                                                                                   |
|                    |            | 0        | R      | magnetic field conversion check (SM-01)                                                                                                                    |
| B4h/B5h            | SIGNATURE  | 15 to 0  | W      | write signature to enter command mode; see <a href="#">Section 16.3.3</a>                                                                                  |

[1] Undefined: write as zero for default, returns any value when read.

### 16.5.3 Non-volatile memory registers

The device includes several internal registers which are used for customization and identification.

The initial signature allows read access to all areas but only write access to customer registers. Write accesses to reserved areas are ignored. Since these registers are implemented as non-volatile memory cells, writing to the registers needs a specific time  $t_{\text{prog}}$  after each write access to complete.

As there is no check for the programming time, make sure that no other accesses to the non-volatile memory are made during the programming cycle. Do not address the non-volatile memory during the time  $t_{\text{prog}}$ .

**Note:** To calculate the corresponding checksum, read out all register addresses.

Table 51. Customer area 1

| Command write/read | Register          | Bit       | Description                                                                          | Default MSB/LSB |
|--------------------|-------------------|-----------|--------------------------------------------------------------------------------------|-----------------|
| 00h/01h            | ZERO_ANGLE        | 15 to 0   | mechanical zero degree position; see <a href="#">Table 55</a>                        | 00h/00h         |
| 02h/03h            | CLAMP_LOW         | 15 to 13  | undefined <sup>[1]</sup>                                                             | 01h/00h         |
|                    |                   | 12 to 0   | lower clamping level; see <a href="#">Table 56</a>                                   |                 |
| 04h/05h            | CLAMP_HIGH        | 15 to 13  | undefined <sup>[1]</sup>                                                             | 13h/00h         |
|                    |                   | 12 to 0   | upper clamping level; see <a href="#">Table 57</a>                                   |                 |
| 06h/07h            | SCALE_COEFFICIENT | 15 to 0   | scale coefficient LSB; see <a href="#">Table 58</a>                                  | 10h/00h         |
| 08h/09h            | CLAMP_SWITCH      | 15 to 13  | undefined <sup>[1]</sup>                                                             | 1Fh/FEh         |
|                    |                   | 12 to 1   | clamp switch angle; see <a href="#">Table 59</a>                                     |                 |
|                    |                   | 0         | scale coefficient MSB; see <a href="#">Table 59</a>                                  |                 |
| 0Ah/0Bh            | RANGE_DETECTION   | 15 to 0   | range detection angle; see <a href="#">Table 60</a>                                  | FFh/FFh         |
| 0Ch/0Dh            | CLAMP_RANGE       | 15 to 13  | undefined <sup>[1]</sup>                                                             | 12h/00h         |
|                    |                   | 12 to 0   | clamp range; see <a href="#">Table 61</a>                                            |                 |
| 0Eh/0Fh            | SYS_SETTING       | 15 and 14 | undefined <sup>[1]</sup>                                                             | 00h/00h         |
|                    |                   | 13        | reserved <sup>[2]</sup>                                                              |                 |
|                    |                   | 12        | output mode<br>0b – analog (default)<br>1b – SENT                                    |                 |
|                    |                   | 11        | reserved <sup>[2]</sup>                                                              |                 |
|                    |                   | 10        | self-diagnostic validation support <sup>[3]</sup>                                    |                 |
|                    |                   | 9 to 6    | undefined <sup>[1]</sup>                                                             |                 |
|                    |                   | 5         | reserved <sup>[2]</sup>                                                              |                 |
|                    |                   | 4 and 3   | MPC type<br>00b – MPC17 (default)<br>01b – MPC7<br>10b – no MPC<br>11b – undefined   |                 |
|                    |                   | 2 and 1   | diagnostic mode<br>00b – active LOW (default)<br>01b – active HIGH<br>1Xb – reserved |                 |
|                    |                   | 0         | slope; slope of output curve<br>0b – rising (default)<br>1b – falling                |                 |

| Command write/read | Register      | Bit      | Description                                                                                                              | Default MSB/LSB |
|--------------------|---------------|----------|--------------------------------------------------------------------------------------------------------------------------|-----------------|
| 10h/11h            | SENT_SETTING1 | 15 to 12 | sensor type; see <a href="#">Table 62</a>                                                                                | 00h/99h         |
|                    |               | 11       | CRC type<br>0b – recommended (default)<br>1b – legacy                                                                    |                 |
|                    |               | 10       | PAUSE pulse enable <sup>[3]</sup><br>the frame length depends on the protocol format;<br>see <a href="#">Section 8.5</a> |                 |
|                    |               | 9        | frame length <sup>[3]</sup><br>constant frame length of 297 clock ticks for all protocol formats                         |                 |
|                    |               | 8        | ESP <sup>[3]</sup>                                                                                                       |                 |
|                    |               | 7 to 5   | set protocol format; see <a href="#">Table 63</a>                                                                        |                 |
|                    |               | 4 and 3  | SENT revision<br>00b – not specified<br>01b – FEB2008 rev 2<br>10b – JAN2010 rev 3<br>11b – APR2016 rev 4 (default)      |                 |
|                    |               | 2        | sensor ID<br>0b – sensor ID1 (default)<br>1b – sensor ID2                                                                |                 |
|                    |               | 1 and 0  | clock tick time<br>00b – 2.7 $\mu$ s<br>01b – 3 $\mu$ s (default)<br>10b – 4.5 $\mu$ s<br>11b – 6 $\mu$ s                |                 |

| Command write/read | Register      | Bit       | Description                                                                                                                                                                                                                                         | Default MSB/LSB |
|--------------------|---------------|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| 12h/13h            | SENT_SETTING2 | 15 and 14 | upper voltage threshold<br>00b – off (default)<br>01b – 5.25 V<br>10b – 5.50 V<br>11b – 5.75 V                                                                                                                                                      | 0Fh/89h         |
|                    |               | 13 and 12 | lower voltage threshold<br>00b – off (default)<br>01b – 4.75 V<br>10b – 4.50 V<br>11b – 4.25 V                                                                                                                                                      |                 |
|                    |               | 11 to 7   | temperature threshold; see <a href="#">Table 64</a>                                                                                                                                                                                                 |                 |
|                    |               | 6         | temperature warning <sup>[3]</sup>                                                                                                                                                                                                                  |                 |
|                    |               | 5         | single-bit error and CRC2 warning <sup>[3]</sup>                                                                                                                                                                                                    |                 |
|                    |               | 4         | supply monitor warning <sup>[3]</sup>                                                                                                                                                                                                               |                 |
|                    |               | 3 and 2   | mask STATUS nibble bit 0 and bit 1<br>00b – STATUS nibble bit 0 and bit 1 enabled<br>01b – STATUS nibble bit 1 enabled bit 0 disabled<br>10b – STATUS nibble bit 1 disabled bit 0 enabled (default)<br>11b – STATUS nibble bit 0 and bit 1 disabled |                 |
|                    |               | 1 and 0   | slope time<br>00b – for $T_{clk} = 2.7 \mu s$<br>01b – for $T_{clk} = 3 \mu s$ (default)<br>10b – for $T_{clk} = 4.5 \mu s$<br>11b – for $T_{clk} = 6 \mu s$                                                                                        |                 |

| Command write/read | Register     | Bit     | Description                                               | Default MSB/LSB |
|--------------------|--------------|---------|-----------------------------------------------------------|-----------------|
| 14h/15h            | ASIL_SETTING | 15      | BIST <sup>[4]</sup>                                       | 80h/FAh         |
|                    |              | 14      | mask angular range check (SM-12) <sup>[3]</sup>           |                 |
|                    |              | 13      | mask CORDIC range check (SM-11) <sup>[3]</sup>            |                 |
|                    |              | 12      | mask SD-ADC range check (SM-09) <sup>[3]</sup>            |                 |
|                    |              | 11      | mask BIST encoding check (SM-08) <sup>[3]</sup>           |                 |
|                    |              | 10      | mask BIST completion check (SM-07) <sup>[3]</sup>         |                 |
|                    |              | 9       | mask data adder check (SM-10) <sup>[3]</sup>              |                 |
|                    |              | 8       | mask control signal check (SM-06) <sup>[3]</sup>          |                 |
|                    |              | 7       | adjusted angle calculation check (SM-05) <sup>[4]</sup>   |                 |
|                    |              | 6       | data conversion check (SM-04) <sup>[4]</sup>              |                 |
|                    |              | 5       | data division check (SM-03) <sup>[4]</sup>                |                 |
|                    |              | 4       | inverted angle calculation check (SM-02) <sup>[4]</sup>   |                 |
|                    |              | 3       | magnetic field conversion check (SM-01) <sup>[4]</sup>    |                 |
|                    |              | 2 to 0  | reserved; write as 010b                                   |                 |
| 16h/17h            | CRC1         | 15 to 8 | undefined <sup>[1]</sup>                                  | 00h/B3h         |
|                    |              | 7 to 0  | CRC for customer area 1; see <a href="#">Section 16.4</a> |                 |

[1] Undefined: write as zero for default, returns any value when read.

[2] Reserved: write as zero for default.

[3] Bit allocation: 0b – disabled (default); 1b – enabled.

[4] Bit allocation: 0b – disabled; 1b – enabled (default).

**Table 52. Customer area 2**

| Command write/read | Register          | Bit     | Description                     | Default MSB/LSB |
|--------------------|-------------------|---------|---------------------------------|-----------------|
| 20h/21h            | MPC_COEFFICIENT1  | 15 to 0 | MPC coefficient 1 or linear X1  | 08h/00h         |
| 22h/23h            | MPC_COEFFICIENT2  | 15 to 0 | MPC coefficient 2 or linear X2  | 10h/00h         |
| 24h/25h            | MPC_COEFFICIENT3  | 15 to 0 | MPC coefficient 3 or linear X3  | 18h/00h         |
| 26h/27h            | MPC_COEFFICIENT4  | 15 to 0 | MPC coefficient 4 or linear X4  | 20h/00h         |
| 28h/29h            | MPC_COEFFICIENT5  | 15 to 0 | MPC coefficient 5 or linear X5  | 28h/00h         |
| 2Ah/2Bh            | MPC_COEFFICIENT6  | 15 to 0 | MPC coefficient 6 or linear Y1  | 30h/00h         |
| 2Ch/2Dh            | MPC_COEFFICIENT7  | 15 to 0 | MPC coefficient 7 or linear Y2  | 38h/00h         |
| 2Eh/2Fh            | MPC_COEFFICIENT8  | 15 to 0 | MPC coefficient 8 or linear Y3  | 40h/00h         |
| 30h/31h            | MPC_COEFFICIENT9  | 15 to 0 | MPC coefficient 9 or linear Y4  | 48h/00h         |
| 32h/33h            | MPC_COEFFICIENT10 | 15 to 0 | MPC coefficient 10 or linear Y5 | 50h/00h         |
| 34h/35h            | MPC_COEFFICIENT11 | 15 to 0 | MPC coefficient 11 or linear S1 | 58h/00h         |
| 36h/37h            | MPC_COEFFICIENT12 | 15 to 0 | MPC coefficient 12 or linear S2 | 60h/00h         |
| 38h/39h            | MPC_COEFFICIENT13 | 15 to 0 | MPC coefficient 13 or linear S3 | 68h/00h         |

| Command write/read | Register          | Bit     | Description                                                                                 | Default MSB/LSB |
|--------------------|-------------------|---------|---------------------------------------------------------------------------------------------|-----------------|
| 3Ah/3Bh            | MPC_COEFFICIENT14 | 15 to 0 | MPC coefficient 14 or linear S4                                                             | 70h/00h         |
| 3Ch/3Dh            | MPC_COEFFICIENT15 | 15 to 0 | MPC coefficient 15 or linear S5                                                             | 78h/00h         |
| 3Eh/3Fh            | MPC_COEFFICIENT16 | 15 to 0 | MPC coefficient 16 or linear S6                                                             | 80h/00h         |
| 40h/41h            | CRC2              | 15      | LOCK1; irreversible write protection of customer area 1 and customer area 2<br>1b – enabled | 00h/8Ch         |
|                    |                   | 14 to 8 | undefined <sup>[1]</sup>                                                                    |                 |
|                    |                   | 7 to 0  | CRC for customer area 2; see <a href="#">Section 16.4</a>                                   |                 |

[1] Undefined: write as zero for default, returns any value when read.

**Table 53. Customer area 3**

| Command write/read | Register  | Bit      | Description                                                             | Default MSB/LSB |
|--------------------|-----------|----------|-------------------------------------------------------------------------|-----------------|
| 50h/51h            | OOR_LOW   | 15 to 12 | undefined <sup>[1]</sup>                                                | 00h/00h         |
|                    |           | 11 to 0  | lower OOR threshold                                                     |                 |
| 52h/53h            | OOR_HIGH  | 15 to 12 | undefined <sup>[1]</sup>                                                | 0Fh/FFh         |
|                    |           | 11 to 0  | upper OOR threshold                                                     |                 |
| 54h/55h            | OEM_CODE1 | 15 to 12 | OEM code 7 bits 11 to 8                                                 | 00h/00h         |
|                    |           | 11 to 0  | OEM code 1                                                              |                 |
| 56h/57h            | OEM_CODE2 | 15 to 12 | OEM code 7 bits 7 to 4                                                  | 00h/00h         |
|                    |           | 11 to 0  | OEM code 2                                                              |                 |
| 58h/59h            | OEM_CODE3 | 15 to 12 | OEM code 7 bits 3 to 0                                                  | 00h/00h         |
|                    |           | 11 to 0  | OEM code 3                                                              |                 |
| 5Ah/5Bh            | OEM_CODE4 | 15 to 12 | OEM code 8 bits 11 to 8                                                 | 00h/00h         |
|                    |           | 11 to 0  | OEM code 4                                                              |                 |
| 5Ch/5Dh            | OEM_CODE5 | 15 to 12 | OEM code 8 bits 7 to 4                                                  | 00h/00h         |
|                    |           | 11 to 0  | OEM code 5                                                              |                 |
| 5Eh/5Fh            | OEM_CODE6 | 15 to 12 | OEM code 8 bits 3 to 0                                                  | 00h/00h         |
|                    |           | 11 to 0  | OEM code 6                                                              |                 |
| 60h/61h            | CRC3      | 15       | LOCK2; irreversible write protection of customer area 3<br>1b – enabled | 00h/B2h         |
|                    |           | 14 to 8  | undefined <sup>[1]</sup>                                                |                 |
|                    |           | 7 to 0   | CRC for customer area 3; see <a href="#">Section 16.4</a>               |                 |

[1] Undefined: write as zero for default, returns any value when read.

Table 54. Traceability register

| Command write/read | Register    | Bit     | Access | Description                                                                                   |
|--------------------|-------------|---------|--------|-----------------------------------------------------------------------------------------------|
| A0h/A1h            | IDENTIFIER1 | 15 to 0 | R      | 5 × 16 bit unique device identifier code for traceability located in manufacturer area of NVM |
| A2h/A3h            | IDENTIFIER2 | 15 to 0 | R      |                                                                                               |
| A4h/A5h            | IDENTIFIER3 | 15 to 0 | R      |                                                                                               |
| A6h/A7h            | IDENTIFIER4 | 15 to 0 | R      |                                                                                               |
| A8h/A9h            | IDENTIFIER5 | 15 to 0 | R      |                                                                                               |

Table 55. ZERO\_ANGLE – mechanical zero degree position bit allocation

| Bit   | 15              | 14              | 13              | 12              | 11              | 10              | 9              | 8              | 7              | 6              | 5              | 4              | 3              | 2              | 1              | 0              |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Value | 2 <sup>15</sup> | 2 <sup>14</sup> | 2 <sup>13</sup> | 2 <sup>12</sup> | 2 <sup>11</sup> | 2 <sup>10</sup> | 2 <sup>9</sup> | 2 <sup>8</sup> | 2 <sup>7</sup> | 2 <sup>6</sup> | 2 <sup>5</sup> | 2 <sup>4</sup> | 2 <sup>3</sup> | 2 <sup>2</sup> | 2 <sup>1</sup> | 2 <sup>0</sup> |

$$\text{ZERO\_ANGLE} = \frac{180^\circ - \text{mechanical zero degree position}}{180^\circ} \times 2^{16} \quad (10)$$

Examples:

- Mechanical zero degree position 0° = 0000h (default)
- Mechanical zero degree position 10° = F1C7h
- Mechanical zero degree position 45° = C000h

Table 56. CLAMP\_LOW – lower clamping level bit allocation

| Bit   | 15               | 14               | 13               | 12              | 11              | 10              | 9              | 8              | 7              | 6              | 5              | 4              | 3              | 2              | 1              | 0              |
|-------|------------------|------------------|------------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Value | U <sup>[1]</sup> | U <sup>[1]</sup> | U <sup>[1]</sup> | 2 <sup>12</sup> | 2 <sup>11</sup> | 2 <sup>10</sup> | 2 <sup>9</sup> | 2 <sup>8</sup> | 2 <sup>7</sup> | 2 <sup>6</sup> | 2 <sup>5</sup> | 2 <sup>4</sup> | 2 <sup>3</sup> | 2 <sup>2</sup> | 2 <sup>1</sup> | 2 <sup>0</sup> |

[1] Undefined: write as zero for default; returns any value when read.

$$\text{CLAMP\_LOW} = \frac{\text{lower clamping level}}{100 \%} \times 5120 \quad (11)$$

Values 0 to 255 are reserved. It is not permitted to use such values.

Examples:

- Lower clamping level 5 %V<sub>DD</sub> = 0100h (default)
- Lower clamping level 10 %V<sub>DD</sub> = 0200h
- SENT A.3 format lower clamping level = 000h
- SENT A.1, H.1, H.3, H.4 format lower clamping level = 001h

Table 57. CLAMP\_HIGH – upper clamping level bit allocation

| Bit   | 15               | 14               | 13               | 12              | 11              | 10              | 9              | 8              | 7              | 6              | 5              | 4              | 3              | 2              | 1              | 0              |
|-------|------------------|------------------|------------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Value | U <sup>[1]</sup> | U <sup>[1]</sup> | U <sup>[1]</sup> | 2 <sup>12</sup> | 2 <sup>11</sup> | 2 <sup>10</sup> | 2 <sup>9</sup> | 2 <sup>8</sup> | 2 <sup>7</sup> | 2 <sup>6</sup> | 2 <sup>5</sup> | 2 <sup>4</sup> | 2 <sup>3</sup> | 2 <sup>2</sup> | 2 <sup>1</sup> | 2 <sup>0</sup> |

[1] Undefined: write as zero for default; returns any value when read.

$$\text{CLAMP\_HIGH} = \frac{\text{upper clamping level}}{100 \%} \times 5120 \quad (12)$$

Values 4865 to 5120 are reserved. It is not permitted to use such values.

Examples:

- Upper clamping level 90 %V<sub>DD</sub> = 1200h
- Upper clamping level 95 %V<sub>DD</sub> = 1300h (default)
- Upper clamping level 100 %V<sub>DD</sub> = 1400h (reserved)
- SENT A.1 format upper clamping level = FFEh
- SENT A.3 format upper clamping level = FFFh
- SENT H.1, H.3, H.4 format upper clamping level = FF8h

**Table 58. SCALE\_COEFFICIENT – least significant bits of scale coefficient bit allocation**

| Bit   | 15                 | 14             | 13             | 12             | 11             | 10              | 9               | 8               | 7               | 6               | 5               | 4               | 3               | 2               | 1                | 0                |
|-------|--------------------|----------------|----------------|----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|------------------|
| Value | 2 <sup>4</sup> [1] | 2 <sup>3</sup> | 2 <sup>2</sup> | 2 <sup>1</sup> | 2 <sup>0</sup> | 2 <sup>-1</sup> | 2 <sup>-2</sup> | 2 <sup>-3</sup> | 2 <sup>-4</sup> | 2 <sup>-5</sup> | 2 <sup>-6</sup> | 2 <sup>-7</sup> | 2 <sup>-8</sup> | 2 <sup>-9</sup> | 2 <sup>-10</sup> | 2 <sup>-11</sup> |

[1] See CLAMP\_SWITCH register for MSB of scale coefficient.

$$\text{SCALE\_COEFFICIENT} = \frac{180^\circ}{\text{angular range}} \times 2^{12} \quad (13)$$

Examples:

- Angular range 30° = 6000h
- Angular range 90° = 2000h
- Angular range 180° = 1000h (default)

**Table 59. CLAMP\_SWITCH – clamp switch angle bit allocation**

| Bit   | 15               | 14               | 13               | 12              | 11              | 10             | 9              | 8              | 7              | 6              | 5              | 4              | 3              | 2              | 1              | 0                  |
|-------|------------------|------------------|------------------|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|--------------------|
| Value | U <sup>[1]</sup> | U <sup>[1]</sup> | U <sup>[1]</sup> | 2 <sup>11</sup> | 2 <sup>10</sup> | 2 <sup>9</sup> | 2 <sup>8</sup> | 2 <sup>7</sup> | 2 <sup>6</sup> | 2 <sup>5</sup> | 2 <sup>4</sup> | 2 <sup>3</sup> | 2 <sup>2</sup> | 2 <sup>1</sup> | 2 <sup>0</sup> | 2 <sup>5</sup> [2] |

[1] Undefined: write as zero for default; returns any value when read.

[2] MSB of scale coefficient.

$$\text{CLAMP\_SWITCH} = \frac{180^\circ + \text{angular range}}{2} \times \frac{2^{12}}{180^\circ} \quad (14)$$

Examples:

- Angular range 40° → CLAMP\_SWITCH = 110° = 9C7h
- Angular range 90° → CLAMP\_SWITCH = 135° = C00h
- Angular range 180° → CLAMP\_SWITCH = 180° = FFFh (default)

**Table 60. RANGE\_DETECTION – range detection angle bit allocation**

| Bit   | 15              | 14              | 13              | 12              | 11              | 10              | 9              | 8              | 7              | 6              | 5              | 4              | 3              | 2              | 1              | 0              |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Value | 2 <sup>15</sup> | 2 <sup>14</sup> | 2 <sup>13</sup> | 2 <sup>12</sup> | 2 <sup>11</sup> | 2 <sup>10</sup> | 2 <sup>9</sup> | 2 <sup>8</sup> | 2 <sup>7</sup> | 2 <sup>6</sup> | 2 <sup>5</sup> | 2 <sup>4</sup> | 2 <sup>3</sup> | 2 <sup>2</sup> | 2 <sup>1</sup> | 2 <sup>0</sup> |

$$\text{RANGE\_DETECTION} = \frac{\text{angular range}}{180^\circ} \times 2^{16} \quad (15)$$

Examples:

- Angular range 30° = 2AABh
- Angular range 90° = 8000h
- Angular range 180° = 0000h (default)

**Table 61. CLAMP\_RANGE – clamp range bit allocation**

| Bit   | 15               | 14               | 13               | 12              | 11              | 10              | 9              | 8              | 7              | 6              | 5              | 4              | 3              | 2              | 1              | 0              |
|-------|------------------|------------------|------------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Value | U <sup>[1]</sup> | U <sup>[1]</sup> | U <sup>[1]</sup> | 2 <sup>12</sup> | 2 <sup>11</sup> | 2 <sup>10</sup> | 2 <sup>9</sup> | 2 <sup>8</sup> | 2 <sup>7</sup> | 2 <sup>6</sup> | 2 <sup>5</sup> | 2 <sup>4</sup> | 2 <sup>3</sup> | 2 <sup>2</sup> | 2 <sup>1</sup> | 2 <sup>0</sup> |

[1] Undefined: write as zero for default; returns any value when read.

$$\text{CLAMP\_RANGE} = \text{CLAMP\_HIGH} - \text{CLAMP\_LOW} \quad (16)$$

Examples:

- Clamp range 80 %V<sub>DD</sub> = 1000h
- Clamp range 90 %V<sub>DD</sub> = 1200h (default)
- Clamp range 95 %V<sub>DD</sub> = 1300h

**Table 62. SENSOR\_TYPE**

| SENSOR_TYPE     | 12-bit code         | Definition                                                        |
|-----------------|---------------------|-------------------------------------------------------------------|
| 0000b (default) | 051h <sup>[1]</sup> | acceleration pedal position 1 or acceleration pedal position 2    |
| 0001b           | 052h <sup>[1]</sup> | acceleration pedal position 1 or secure sensor                    |
| 0010b           | 053h <sup>[1]</sup> | acceleration pedal position 2 (redundant signal) or secure sensor |
| 0011b           | 054h <sup>[1]</sup> | throttle position 1 or throttle position 2                        |
| 0100b           | 055h <sup>[1]</sup> | throttle position 1 or secure sensor                              |
| 0101b           | 056h <sup>[1]</sup> | throttle position 2 (redundant signal) or secure sensor           |
| 0110b           | 059h <sup>[1]</sup> | angle position                                                    |
| 0111b           | 05Ah <sup>[1]</sup> | angle position or secure sensor                                   |
| 1000b           | 062h <sup>[2]</sup> | angle position (high speed) H.3 protocol format                   |
| 1001b           | 063h <sup>[2]</sup> | angle position 1 or angle position 2 H.1 protocol format          |
| 1010b           | 064h <sup>[2]</sup> | angle position or secure sensor H.4 protocol format               |
| 1011b           | 066h <sup>[2]</sup> | reserved for angle position sensors                               |
| 1101b to 1111b  | 000h                | reserved                                                          |

[1] Compliant with SAE JAN2010 rev 3 only.  
[2] Compliant with SAE APR2016 rev 4 only.

Table 63. PROTOCOL\_FORMAT

| PROTOCOL_FORMAT | Protocol | Description                                  | SENT revision |
|-----------------|----------|----------------------------------------------|---------------|
| 000b            | A.1      | dual throttle position sensor                | JAN2010 rev 3 |
| 001b            | A.3      | single secure sensor                         | JAN2010 rev 3 |
| 010b            | H.1      | dual throttle position sensor <sup>[1]</sup> | APR2016 rev 4 |
| 011b            | H.3      | high-speed 12-bit fast channel               | APR2016 rev 4 |
| 100b (default)  | H.4      | single secure sensor <sup>[2]</sup>          | APR2016 rev 4 |

[1] This format uses the same data mapping as the A.1 protocol but excludes the reserved diagnostic values from the data range as defined in APR2016 rev 4 specification.

[2] This format uses the same data mapping as the A.3 protocol but excludes the reserved diagnostic values from the data range as defined in APR2016 rev 4 specification.

Table 64. TEMPERATURE\_THRESHOLD

| Bit   | 15  | 14 | 13  | 12 | 11             | 10             | 9              | 8              | 7              | 6   | 5   | 4   | 3   | 2 | 1   | 0 |
|-------|-----|----|-----|----|----------------|----------------|----------------|----------------|----------------|-----|-----|-----|-----|---|-----|---|
| Value | [1] |    | [2] |    | 2 <sup>4</sup> | 2 <sup>3</sup> | 2 <sup>2</sup> | 2 <sup>1</sup> | 2 <sup>0</sup> | [3] | [4] | [5] | [6] |   | [7] |   |

[1] Upper voltage threshold.

[2] Lower voltage threshold.

[3] Temperature warning.

[4] Single-bit error and CRC2 warning.

[5] Supply monitor warning.

[6] Mask STATUS nibble bit 0 and bit 1.

[7] Slope time.

$$\text{TEMPERATURE\_THRESHOLD} = \frac{\text{temperature threshold} + 45\text{ °C}}{8\text{ °C}} \quad (17)$$

Examples:

- Temperature threshold –45 °C = 0h
- Temperature threshold 75 °C = Fh
- Temperature threshold 203 °C = 1Fh (default)

## 17 Electromagnetic compatibility

EMC is verified in an independent and certified test laboratory.

### 17.1 Emission (CISPR 25)

Tests according to CISPR 25 were fulfilled.

#### 17.1.1 Conducted radio disturbance

Test of the device according to CISPR 25, third edition (2008-03), Chapter 6.2.

Classification level: 5.

### 17.1.2 Radiated radio disturbance

Test of the device according to CISPR 25, third edition (2008-03), Chapter 6.4.

Classification level: 5 (without addition of 6 dB in FM band).

## 17.2 Radiated disturbances (ISO 11452-1 fourth edition [2015-06], ISO 11452-2, ISO 11452-4 and ISO 11452-5)

The common understanding of the requested function is that an effect is tolerated as described in [Table 65](#) during the disturbance. The reachable values are setup-dependent and differ from the final application.

**Table 65. Failure condition for radiated disturbances and electrical transient transmission**

| Parameter                                         | Comment                                             | Min | Max                 | Unit  |
|---------------------------------------------------|-----------------------------------------------------|-----|---------------------|-------|
| Variation of output signal in analog output mode  | value measured relative to the output at test start | -   | $\pm 0.9 \% V_{DD}$ | V     |
| Variation of angular value in digital output mode | value measured relative to the output at test start | -   | $\pm 1.8$           | deg   |
| SENT sequence                                     | allowed sequentially failing frames                 | -   | 2                   | frame |
| SENT transmission                                 | allowed failing frames within 100 following frames  | -   | 3                   | frame |

### 17.2.1 Absorber lined shielded enclosure

Tests according to ISO 11452-2, second edition (2004-11), were fulfilled.

Test level: 200 V/m; extended up to 4 GHz.

State: A.

### 17.2.2 Bulk-current injection

Tests according to ISO 11452-4, fourth edition (2011-12), were fulfilled.

Test level: 200 mA.

State: A.

### 17.2.3 Strip line

Tests according to ISO 11452-5, second edition (2002-04), were fulfilled.

Test level: 200 V/m; extended up to 1 GHz.

State: A.

#### 17.2.4 Immunity against mobile phones

Tests according to ISO 11452-2, second edition (2004-11), were fulfilled.

State: A.

Definition of global system for mobile (GSM) communications signal:

- Pulse modulation: per GSM specification (217 Hz; 12.5 % duty cycle)
- Modulation grade:  $\geq 60$  dB
- Sweep: linear 800 MHz to 3 GHz
- Antenna polarization: vertical, horizontal
- Field strength: 200 V/m during on-time [calibration in continuous wave (CW)]

In deviation of ISO 11452-2, a GSM signal instead of an AM signal was used.

### 17.3 Electrical transient transmission (ISO 7637-3 second edition [2007-07])

The common understanding of the requested function is that an effect is tolerated as described in [Table 65](#) during the disturbance.

#### 17.3.1 Capacitive coupling

Tests according to ISO 7637-3 were fulfilled.

Test level: IV (for 12 V electrical system).

Classification level: B for pulse fast a, B for pulse fast b.

#### 17.3.2 Inductive coupling

Tests according to ISO 7637-3 were fulfilled.

Test level: IV (for 12 V electrical system).

Classification level for analog mode: A for positive and negative pulses assuming returning to output voltage level before stress of  $\pm 0.9 \%V_{DD}$  within 1 ms otherwise B.

Classification level for digital mode: A for positive and negative pulses assuming a start of a new SENT frame within 1 ms is allowed otherwise B.

## 18 Electrostatic discharge

### 18.1 Human body model (AEC-Q100-002)

The KMA320 is protected up to 8 kV, according to the human body model at 100 pF and 1.5 k $\Omega$ . This protection is ensured at all pins.

Classification level: H3B.

### 18.2 Human metal model (ANSI/ESD SP5.6-2009)

The KMA320 is protected up to 8 kV, according to the human metal model at 150 pF and 330  $\Omega$  inside the ESD gun. This test utilizes waveforms of the IEC 61000-4-2 standard on component level. Apply the contact discharge in an unsupplied state at pins OUTn/DATAn and V<sub>DD</sub> referred to GND which is connected directly to the ground plane.

Test setup: A.

Test level: 5.

### 18.3 Machine model (AEC-Q100-003 legacy)

The KMA320 is protected up to 400 V, according to the machine model. This protection is ensured at all pins.

Classification level: M4.

All pins of KMA320 have latch-up protection.

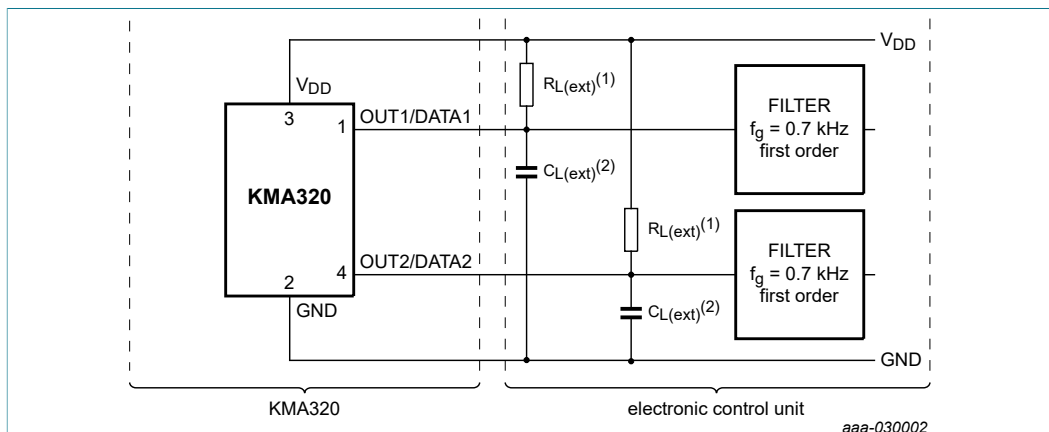
### 18.4 Charged-device model (AEC-Q100-011)

The KMA320 is protected up to 750 V, according to the charged-device model. This protection is ensured at all pins.

Classification level: C4.

## 19 Application information

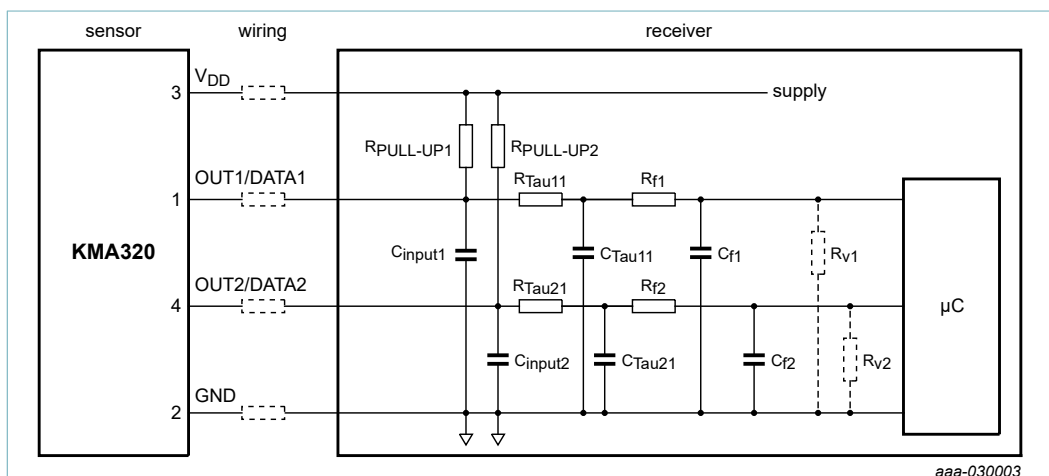
### 19.1 Analog output



1. Power-loss detection is only possible with a load resistance within the specified range connected to supply or ground line.
2. The load capacitance between ground and output can be used to improve the electromagnetic immunity of the device. A blocking capacitance to suppress noise on the supply line of the device is integrated into the package and thus not required externally.

**Figure 27. Application information for analog output of KMA320**

### 19.2 Digital output



KMA320 with receiver load according to figure 6.3.2-2 (recommended SENT system interface circuit topology J2716) of SAE J2716 APR2016 SENT without additional external components near KMA320

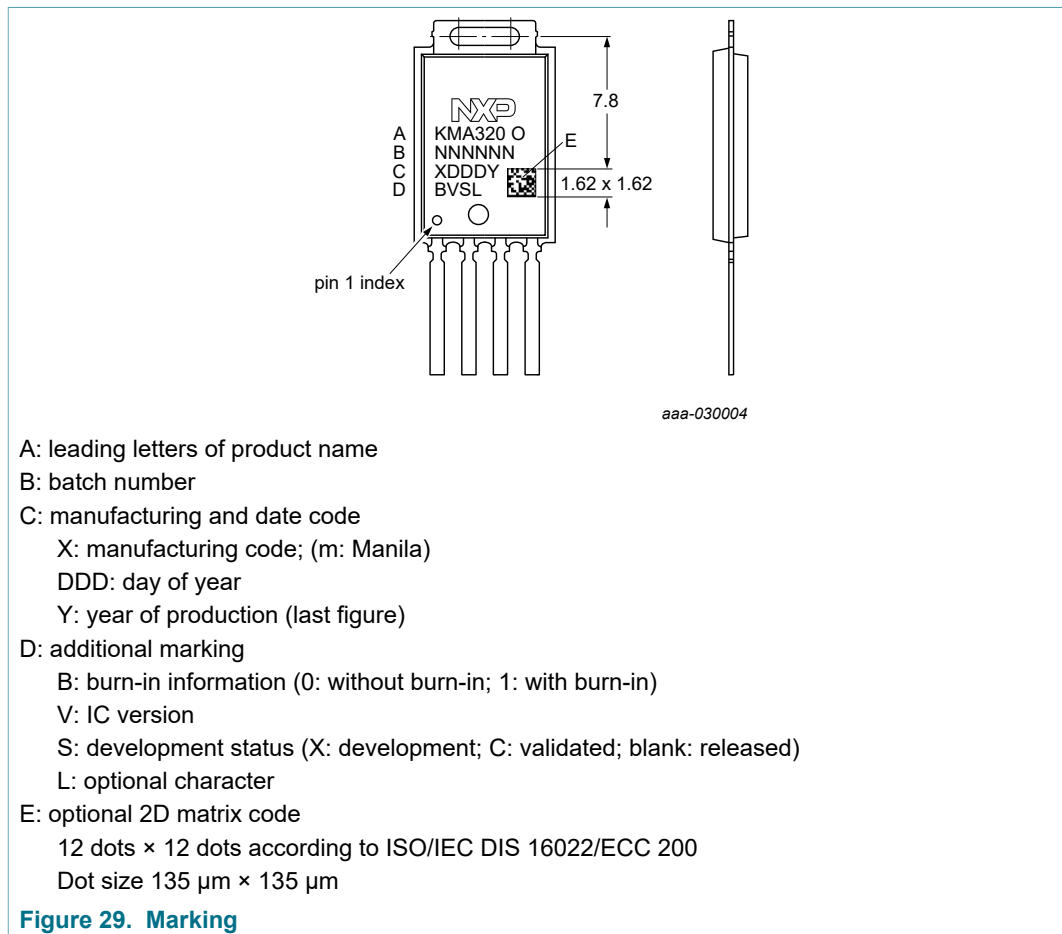
**Figure 28. Application information for digital output of KMA320**

## 20 Test information

### Quality information

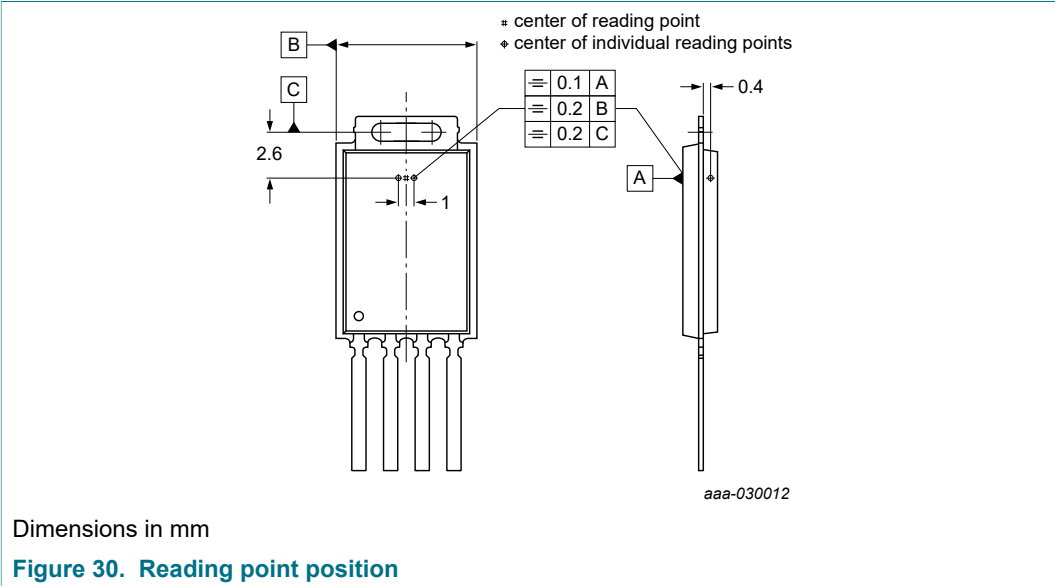
This product has been qualified in accordance with the Automotive Electronics Council (AEC) standard Q100 Rev-H - Failure mechanism based stress test qualification for integrated circuits, and is suitable for use in automotive applications.

## 21 Marking



22 Package information

22.1 Reading point position



22.2 Terminals

Lead frame material: CuZr with 99.9 % Cu and 0.1 % Zr.

Lead frame plating: 100 % Sn.

23 Package outline

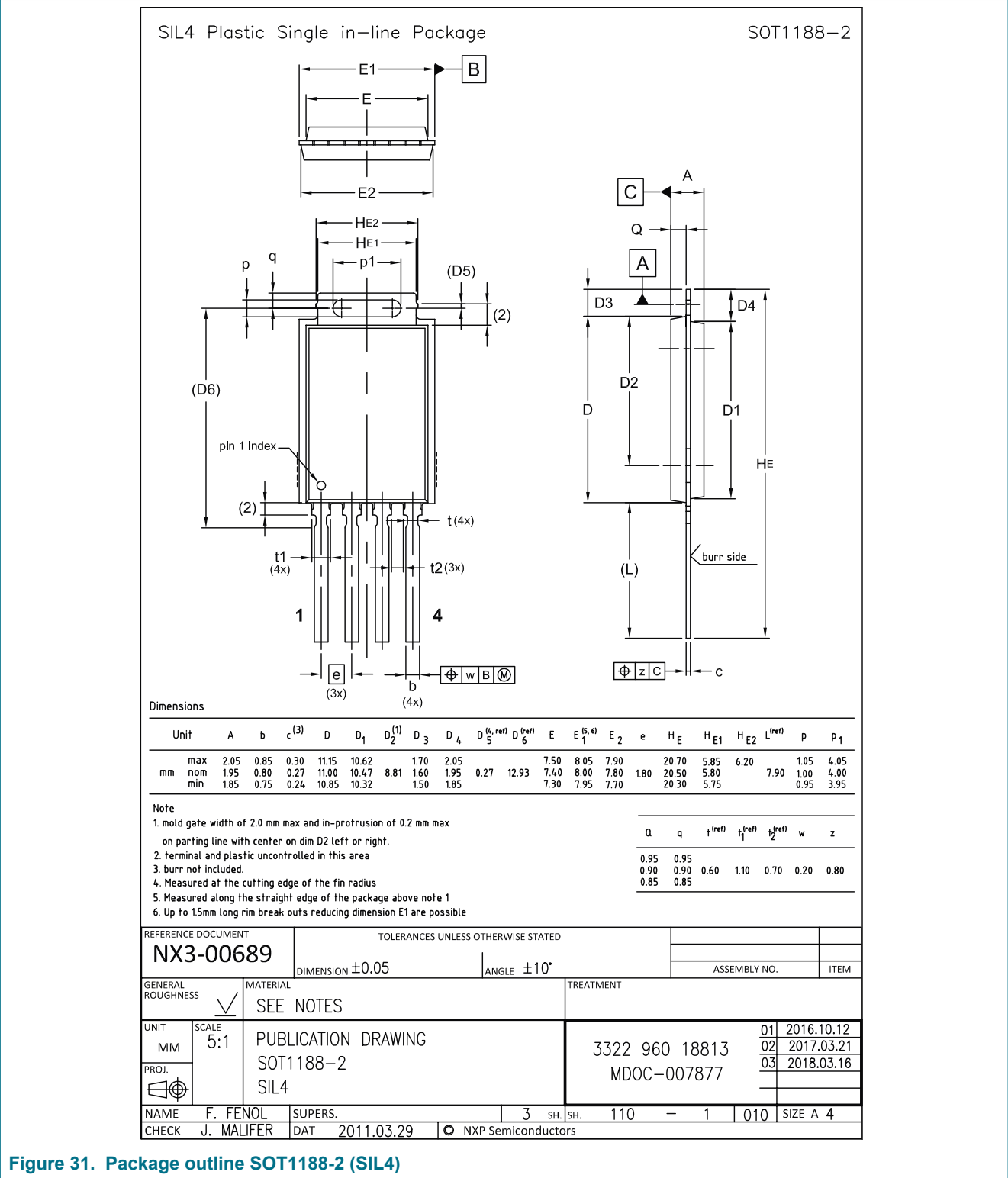
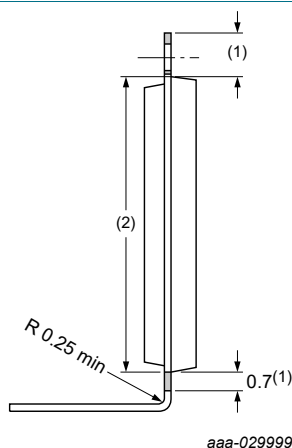


Figure 31. Package outline SOT1188-2 (SIL4)

## 24 Handling information



Dimensions in mm

1. No bending allowed.
2. Plastic body and interface plastic body - leads: application of bending forces not allowed.

**Figure 32. Bending recommendation**

## 25 Soldering

The solderability qualification is according to AEC-Q100 Rev-H. Recommended soldering process for leaded devices is wave soldering. The maximum soldering temperature is 260 °C for maximum 5 s. Device terminals are compatible with laser and electrical welding. The package is reflow capable.

## 26 Abbreviations

Table 66. Abbreviations

| Acronym | Description                             |
|---------|-----------------------------------------|
| ADC     | analog-to-digital converter             |
| AEC     | automotive electronics council          |
| ALU     | arithmetic logic unit                   |
| AMR     | anisotropic MR                          |
| ANSI    | american national standards institute   |
| ASIC    | application-specific integrated circuit |
| ASIL    | automotive safety integrity level       |
| BIST    | built-in self-test                      |
| CORDIC  | coordinate rotation digital computer    |
| CRC     | cyclic redundancy check                 |
| CW      | continuous wave                         |
| DAC     | digital-to-analog converter             |
| ECC     | error correcting code                   |
| EDC     | error detection code                    |
| EMC     | electromagnetic compatibility           |
| ESD     | electrostatic discharge                 |
| ESP     | enhanced serial protocol                |
| GSM     | global system for mobile                |
| ID      | identification                          |
| LSB     | least significant bit                   |
| LSN     | least significant nibble                |
| MPC     | multipoint calibration                  |
| MR      | magnetoresistive                        |
| MSB     | most significant bit                    |
| MSN     | most significant nibble                 |
| NVM     | non-volatile memory                     |
| OEM     | original equipment manufacturer         |
| OOR     | out of range                            |
| OWI     | one-wire interface                      |
| PCB     | printed-circuit board                   |
| POR     | power-on reset                          |
| SENT    | single edge nibble transmission         |

## 27 Revision history

Table 67. Revision history

| Document ID    | Release date                                                                                                                                                                                                                                     | Data sheet status  | Change notice | Supersedes   |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|---------------|--------------|
| KMA320 v.3     | 20190128                                                                                                                                                                                                                                         | Product data sheet | -             | KMA320 v.2   |
| Modifications: | <ul style="list-style-type: none"><li>• <a href="#">Table 59</a>: updated</li><li>• <a href="#">Equation (14)</a>: example for angular range 45° changed to 40° and value changed to 9C7h</li><li>• <a href="#">Figure 29</a>: updated</li></ul> |                    |               |              |
| KMA320 v.2     | 20180629                                                                                                                                                                                                                                         | Product data sheet | -             | KMA320 v.1.1 |
| Modifications: | <ul style="list-style-type: none"><li>• <a href="#">Section 2</a>: updated</li></ul>                                                                                                                                                             |                    |               |              |
| KMA320 v.1.1   | 20180517                                                                                                                                                                                                                                         | Product data sheet | -             | KMA320 v.1   |
| Modifications: | <ul style="list-style-type: none"><li>• <a href="#">Table 40</a>: updated</li><li>• <a href="#">Figure 16</a>: updated</li></ul>                                                                                                                 |                    |               |              |
| KMA320 v.1     | 20180424                                                                                                                                                                                                                                         | Product data sheet | -             | -            |

## 28 Legal information

### 28.1 Data sheet status

| Document status <sup>[1][2]</sup> | Product status <sup>[3]</sup> | Definition                                                                            |
|-----------------------------------|-------------------------------|---------------------------------------------------------------------------------------|
| Objective [short] data sheet      | Development                   | This document contains data from the objective specification for product development. |
| Preliminary [short] data sheet    | Qualification                 | This document contains data from the preliminary specification.                       |
| Product [short] data sheet        | Production                    | This document contains the product specification.                                     |

[1] Please consult the most recently issued document before initiating or completing a design.

[2] The term 'short data sheet' is explained in section "Definitions".

[3] The product status of device(s) described in this document may have changed since this document was published and may differ in case of multiple devices. The latest product status information is available on the Internet at URL <http://www.nxp.com>.

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## Tables

|          |                                                                    |    |          |                                                                                            |    |
|----------|--------------------------------------------------------------------|----|----------|--------------------------------------------------------------------------------------------|----|
| Tab. 1.  | Pinning .....                                                      | 2  | Tab. 31. | Fast channel diagnostic value .....                                                        | 18 |
| Tab. 2.  | Ordering information .....                                         | 2  | Tab. 32. | Power-loss behavior .....                                                                  | 21 |
| Tab. 3.  | Analog output behavior for a positive slope .....                  | 5  | Tab. 33. | System behavior for each output mode .....                                                 | 21 |
| Tab. 4.  | Digital output behavior for a positive slope .....                 | 6  | Tab. 34. | Diagnostic behavior .....                                                                  | 22 |
| Tab. 5.  | STATUS nibble .....                                                | 7  | Tab. 35. | Self-diagnostic overview .....                                                             | 26 |
| Tab. 6.  | Single secure sensor formats A.3 and H.4:<br>frame .....           | 9  | Tab. 36. | Self-diagnostic validation support .....                                                   | 28 |
| Tab. 7.  | DATA nibbles D0 to D2: angular value .....                         | 9  | Tab. 37. | Limiting values .....                                                                      | 28 |
| Tab. 8.  | DATA nibbles D3 and D4: 8-bit loop counter ...                     | 10 | Tab. 38. | Operating conditions .....                                                                 | 29 |
| Tab. 9.  | Dual throttle position sensor formats A.1 and<br>H.1: frame .....  | 11 | Tab. 39. | Thermal characteristics .....                                                              | 29 |
| Tab. 10. | DATA nibbles D0 to D2: angular value .....                         | 11 | Tab. 40. | Mechanical characteristics .....                                                           | 29 |
| Tab. 11. | DATA nibbles D3 to D5: inverted slope<br>angular value .....       | 11 | Tab. 41. | Supply current .....                                                                       | 30 |
| Tab. 12. | High-speed 12-bit message format: frame .....                      | 12 | Tab. 42. | Power-on reset .....                                                                       | 30 |
| Tab. 13. | DATA nibbles D0 to D3: angular value .....                         | 13 | Tab. 43. | Performance .....                                                                          | 31 |
| Tab. 14. | Serial message schedule .....                                      | 13 | Tab. 44. | Dynamics .....                                                                             | 33 |
| Tab. 15. | Diagnostic status code message .....                               | 14 | Tab. 45. | Digital interface .....                                                                    | 35 |
| Tab. 16. | ASIL error code .....                                              | 14 | Tab. 46. | Internal capacitances .....                                                                | 35 |
| Tab. 17. | SENSOR_TYPE[3:0] – channel 1/2 sensor<br>type message .....        | 15 | Tab. 47. | Format of command byte .....                                                               | 41 |
| Tab. 18. | Manufacturer code message .....                                    | 15 | Tab. 48. | Command byte description .....                                                             | 41 |
| Tab. 19. | SENT_REVISION[1:0] – SENT standard<br>revision message .....       | 15 | Tab. 49. | Signatures .....                                                                           | 46 |
| Tab. 20. | Supplementary data channel #3,1: sensor<br>supply voltage .....    | 15 | Tab. 50. | Command registers .....                                                                    | 46 |
| Tab. 21. | Supplementary data channel #4,1: sensor<br>temperature value ..... | 16 | Tab. 51. | Customer area 1 .....                                                                      | 48 |
| Tab. 22. | SENSOR_ID – sensor ID #1 message .....                             | 16 | Tab. 52. | Customer area 2 .....                                                                      | 51 |
| Tab. 23. | OEM_CODE_1[11:0] – OEM code 1<br>message .....                     | 16 | Tab. 53. | Customer area 3 .....                                                                      | 52 |
| Tab. 24. | OEM_CODE_2[11:0] – OEM code 2<br>message .....                     | 16 | Tab. 54. | Traceability register .....                                                                | 53 |
| Tab. 25. | OEM_CODE_3[11:0] – OEM code 3<br>message .....                     | 16 | Tab. 55. | ZERO_ANGLE – mechanical zero degree<br>position bit allocation .....                       | 53 |
| Tab. 26. | OEM_CODE_4[11:0] – OEM code 4<br>message .....                     | 16 | Tab. 56. | CLAMP_LOW – lower clamping level bit<br>allocation .....                                   | 53 |
| Tab. 27. | OEM_CODE_5[11:0] – OEM code 5<br>message .....                     | 16 | Tab. 57. | CLAMP_HIGH – upper clamping level bit<br>allocation .....                                  | 53 |
| Tab. 28. | OEM_CODE_6[11:0] – OEM code 6<br>message .....                     | 16 | Tab. 58. | SCALE_COEFFICIENT – least significant<br>bits of scale coefficient bit allocation .....    | 54 |
| Tab. 29. | OEM_CODE_7[11:0] – OEM code 7<br>message .....                     | 17 | Tab. 59. | CLAMP_SWITCH – clamp switch angle bit<br>allocation .....                                  | 54 |
| Tab. 30. | OEM_CODE_8[11:0] – OEM code 8<br>message .....                     | 17 | Tab. 60. | RANGE_DETECTION – range detection<br>angle bit allocation .....                            | 54 |
|          |                                                                    |    | Tab. 61. | CLAMP_RANGE – clamp range bit<br>allocation .....                                          | 55 |
|          |                                                                    |    | Tab. 62. | SENSOR_TYPE .....                                                                          | 55 |
|          |                                                                    |    | Tab. 63. | PROTOCOL_FORMAT .....                                                                      | 56 |
|          |                                                                    |    | Tab. 64. | TEMPERATURE_THRESHOLD .....                                                                | 56 |
|          |                                                                    |    | Tab. 65. | Failure condition for radiated disturbances<br>and electrical transient transmission ..... | 57 |
|          |                                                                    |    | Tab. 66. | Abbreviations .....                                                                        | 65 |
|          |                                                                    |    | Tab. 67. | Revision history .....                                                                     | 66 |

## Figures

|         |                                                |   |          |                                                            |    |
|---------|------------------------------------------------|---|----------|------------------------------------------------------------|----|
| Fig. 1. | Functional diagram .....                       | 3 | Fig. 7.  | Dual throttle position sensor formats A.1 and<br>H.1 ..... | 10 |
| Fig. 2. | Angular measurement directions .....           | 4 | Fig. 8.  | High-speed 12-bit message format frame<br>H.3 .....        | 12 |
| Fig. 3. | Characteristic of the analog output .....      | 5 | Fig. 9.  | No MPC mode .....                                          | 19 |
| Fig. 4. | Characteristic of the digital output .....     | 6 | Fig. 10. | MPC17 mode .....                                           | 19 |
| Fig. 5. | SENT frame .....                               | 7 | Fig. 11. | MPC7 mode .....                                            | 20 |
| Fig. 6. | Single secure sensor formats A.3 and H.4 ..... | 9 |          |                                                            |    |

|          |                                                                          |    |          |                                                            |    |
|----------|--------------------------------------------------------------------------|----|----------|------------------------------------------------------------|----|
| Fig. 12. | Equivalent output circuit in a power-loss condition .....                | 21 | Fig. 22. | OWI start and stop condition .....                         | 41 |
| Fig. 13. | Sequence state register and start flags for integrated self-checks ..... | 23 | Fig. 23. | OWI timing .....                                           | 41 |
| Fig. 14. | Envelope curve for the magnitude of angular error .....                  | 33 | Fig. 24. | OWI write access .....                                     | 42 |
| Fig. 15. | Definition of the reference line .....                                   | 36 | Fig. 25. | OWI read access .....                                      | 43 |
| Fig. 16. | Definition of the hysteresis error .....                                 | 36 | Fig. 26. | OWI command mode procedure .....                           | 44 |
| Fig. 17. | Definition of the linearity error .....                                  | 37 | Fig. 27. | Application information for analog output of KMA320 .....  | 60 |
| Fig. 18. | Definition of the microlinearity error .....                             | 37 | Fig. 28. | Application information for digital output of KMA320 ..... | 60 |
| Fig. 19. | Definition of the temperature drift error .....                          | 38 | Fig. 29. | Marking .....                                              | 61 |
| Fig. 20. | Envelope curve for the magnitude of angular error .....                  | 39 | Fig. 30. | Reading point position .....                               | 62 |
| Fig. 21. | OWI data format .....                                                    | 40 | Fig. 31. | Package outline SOT1188-2 (SIL4) .....                     | 63 |
|          |                                                                          |    | Fig. 32. | Bending recommendation .....                               | 64 |

## Contents

|           |                                                                         |           |           |                                                                                                        |           |
|-----------|-------------------------------------------------------------------------|-----------|-----------|--------------------------------------------------------------------------------------------------------|-----------|
| <b>1</b>  | <b>General description</b>                                              | <b>1</b>  | 10.5.3.7  | Angular range check (SM-12)                                                                            | 25        |
| <b>2</b>  | <b>Features and benefits</b>                                            | <b>1</b>  | 10.6      | Self-diagnostic overview                                                                               | 26        |
| <b>3</b>  | <b>Pinning information</b>                                              | <b>2</b>  | 10.7      | Self-diagnostic validation support                                                                     | 28        |
| <b>4</b>  | <b>Ordering information</b>                                             | <b>2</b>  | <b>11</b> | <b>Limiting values</b>                                                                                 | <b>28</b> |
| <b>5</b>  | <b>Functional diagram</b>                                               | <b>3</b>  | <b>12</b> | <b>Recommended operating conditions</b>                                                                | <b>29</b> |
| <b>6</b>  | <b>Functional description</b>                                           | <b>4</b>  | <b>13</b> | <b>Thermal characteristics</b>                                                                         | <b>29</b> |
| 6.1       | Angular measurement directions                                          | 4         | <b>14</b> | <b>Characteristics</b>                                                                                 | <b>29</b> |
| <b>7</b>  | <b>Analog output</b>                                                    | <b>5</b>  | <b>15</b> | <b>Definition of errors</b>                                                                            | <b>36</b> |
| <b>8</b>  | <b>Digital output</b>                                                   | <b>5</b>  | 15.1      | General                                                                                                | 36        |
| 8.1       | Transmission of sensor messages                                         | 6         | 15.2      | Hysteresis error                                                                                       | 36        |
| 8.2       | SYNC nibble                                                             | 7         | 15.3      | Linearity error                                                                                        | 37        |
| 8.3       | STATUS nibble                                                           | 7         | 15.4      | Microlinearity error                                                                                   | 37        |
| 8.4       | CRC nibble                                                              | 8         | 15.5      | Temperature drift error                                                                                | 38        |
| 8.5       | PAUSE pulse                                                             | 8         | 15.6      | Angular error                                                                                          | 38        |
| 8.6       | DATA nibbles                                                            | 8         | <b>16</b> | <b>Programming</b>                                                                                     | <b>40</b> |
| 8.7       | Single secure sensor formats A.3 and H.4                                | 8         | 16.1      | General description                                                                                    | 40        |
| 8.8       | Dual throttle position sensor formats A.1 and H.1                       | 10        | 16.2      | Timing characteristics                                                                                 | 41        |
| 8.9       | High-speed 12-bit message format H.3                                    | 12        | 16.3      | Sending and receiving data                                                                             | 41        |
| 8.10      | Enhanced serial data communication                                      | 13        | 16.3.1    | Write access                                                                                           | 42        |
| 8.10.1    | Enhanced serial messages                                                | 14        | 16.3.2    | Read access                                                                                            | 43        |
| 8.11      | SENT diagnostic                                                         | 17        | 16.3.3    | Entering the command mode                                                                              | 44        |
| 8.11.1    | STATUS nibble diagnostic                                                | 17        | 16.4      | Cyclic redundancy check                                                                                | 44        |
| 8.11.1.1  | Diagnostic bit                                                          | 17        | 16.4.1    | Software example in C++                                                                                | 45        |
| 8.11.1.2  | Pre-warning bit                                                         | 17        | 16.5      | Registers                                                                                              | 46        |
| 8.11.2    | Fast channel diagnostic value                                           | 17        | 16.5.1    | Signatures                                                                                             | 46        |
| 8.11.3    | Enhanced serial protocol diagnostic status code message                 | 18        | 16.5.2    | Command registers                                                                                      | 46        |
| <b>9</b>  | <b>Output characteristic</b>                                            | <b>18</b> | 16.5.3    | Non-volatile memory registers                                                                          | 47        |
| 9.1       | No MPC mode                                                             | 18        | <b>17</b> | <b>Electromagnetic compatibility</b>                                                                   | <b>56</b> |
| 9.2       | MPC17 mode                                                              | 19        | 17.1      | Emission (CISPR 25)                                                                                    | 56        |
| 9.3       | MPC7 mode                                                               | 20        | 17.1.1    | Conducted radio disturbance                                                                            | 56        |
| <b>10</b> | <b>Diagnostic features</b>                                              | <b>20</b> | 17.1.2    | Radiated radio disturbance                                                                             | 57        |
| 10.1      | NVM CRC (SM-20), NVM EDC check (SM-21), and NVM ECC check (SM-22)       | 20        | 17.2      | Radiated disturbances (ISO 11452-1 fourth edition [2015-06], ISO 11452-2, ISO 11452-4 and ISO 11452-5) | 57        |
| 10.2      | Power-loss detection (SM-18) and GND-loss detection (SM-19)             | 21        | 17.2.1    | Absorber lined shielded enclosure                                                                      | 57        |
| 10.3      | Supply overvoltage detection (SM-16) and undervoltage detection (SM-17) | 21        | 17.2.2    | Bulk-current injection                                                                                 | 57        |
| 10.4      | Oscillator monitoring (SM-13, SM-14 and SM-15)                          | 22        | 17.2.3    | Strip line                                                                                             | 57        |
| 10.5      | Safe assure - ASIL control unit                                         | 22        | 17.2.4    | Immunity against mobile phones                                                                         | 58        |
| 10.5.1    | Timing description                                                      | 23        | 17.3      | Electrical transient transmission (ISO 7637-3 second edition [2007-07])                                | 58        |
| 10.5.2    | User selectable BIST                                                    | 23        | 17.3.1    | Capacitive coupling                                                                                    | 58        |
| 10.5.2.1  | Magnetic field conversion check (SM-01)                                 | 23        | 17.3.2    | Inductive coupling                                                                                     | 58        |
| 10.5.2.2  | Inverted angle calculation check (SM-02)                                | 23        | <b>18</b> | <b>Electrostatic discharge</b>                                                                         | <b>59</b> |
| 10.5.2.3  | Data division check (SM-03)                                             | 24        | 18.1      | Human body model (AEC-Q100-002)                                                                        | 59        |
| 10.5.2.4  | Data conversion check (SM-04)                                           | 24        | 18.2      | Human metal model (ANSI/ESD SP5.6-2009)                                                                | 59        |
| 10.5.2.5  | Adjusted angle calculation check (SM-05)                                | 24        | 18.3      | Machine model (AEC-Q100-003 legacy)                                                                    | 59        |
| 10.5.3    | Fixed internal diagnostics                                              | 24        | 18.4      | Charged-device model (AEC-Q100-011)                                                                    | 59        |
| 10.5.3.1  | Control signal check (SM-06)                                            | 24        | <b>19</b> | <b>Application information</b>                                                                         | <b>60</b> |
| 10.5.3.2  | BIST completion check (SM-07)                                           | 24        | 19.1      | Analog output                                                                                          | 60        |
| 10.5.3.3  | BIST encoding check (SM-08)                                             | 25        | 19.2      | Digital output                                                                                         | 60        |
| 10.5.3.4  | SD-ADC range check (SM-09)                                              | 25        | <b>20</b> | <b>Test information</b>                                                                                | <b>61</b> |
| 10.5.3.5  | Data adder check (SM-10)                                                | 25        | <b>21</b> | <b>Marking</b>                                                                                         | <b>61</b> |
| 10.5.3.6  | CORDIC range check (SM-11)                                              | 25        | <b>22</b> | <b>Package information</b>                                                                             | <b>62</b> |
|           |                                                                         |           | 22.1      | Reading point position                                                                                 | 62        |
|           |                                                                         |           | 22.2      | Terminals                                                                                              | 62        |

23 Package outline .....63

24 Handling information .....64

25 Soldering .....64

26 Abbreviations .....65

27 Revision history .....66

28 Legal information .....67

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