

# KMA221

## Programmable angle sensor

Rev. 1 — 16 July 2013

Product data sheet

## 1. Product profile

### 1.1 General description

The KMA221 is a magnetic angle sensor module. The MagnetoResistive (MR) sensor bridges, the mixed signal Integrated Circuit (IC) and the required capacitors are integrated into a single package.

This angular measurement module KMA221 is pre-programmed, pre-calibrated and therefore, ready to use.

The KMA221 allows user-specific adjustments of angular range, zero angle and clamping voltages. The settings are stored permanently in a non-volatile memory.

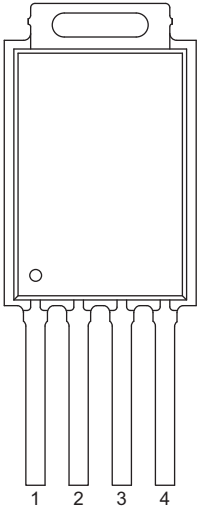
### 1.2 Features and benefits

- 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-G
- Programmable user adjustments, including zero angle and angular range
- Fail-safe non-volatile memory with write protection using lock bit
- Independent from magnetic field strength above 35 kA/m
- Ready to use without external components
- High temperature range up to 160 °C
- Analog ratiometric output voltage
- Overvoltage protection up to 16 V
- Programming via One-Wire Interface (OWI)
- User-programmable 32-bit identifier
- Magnet-loss, power-loss and broken bond wire detection
- Factory calibrated



## 2. Pinning information

Table 1. Pinning

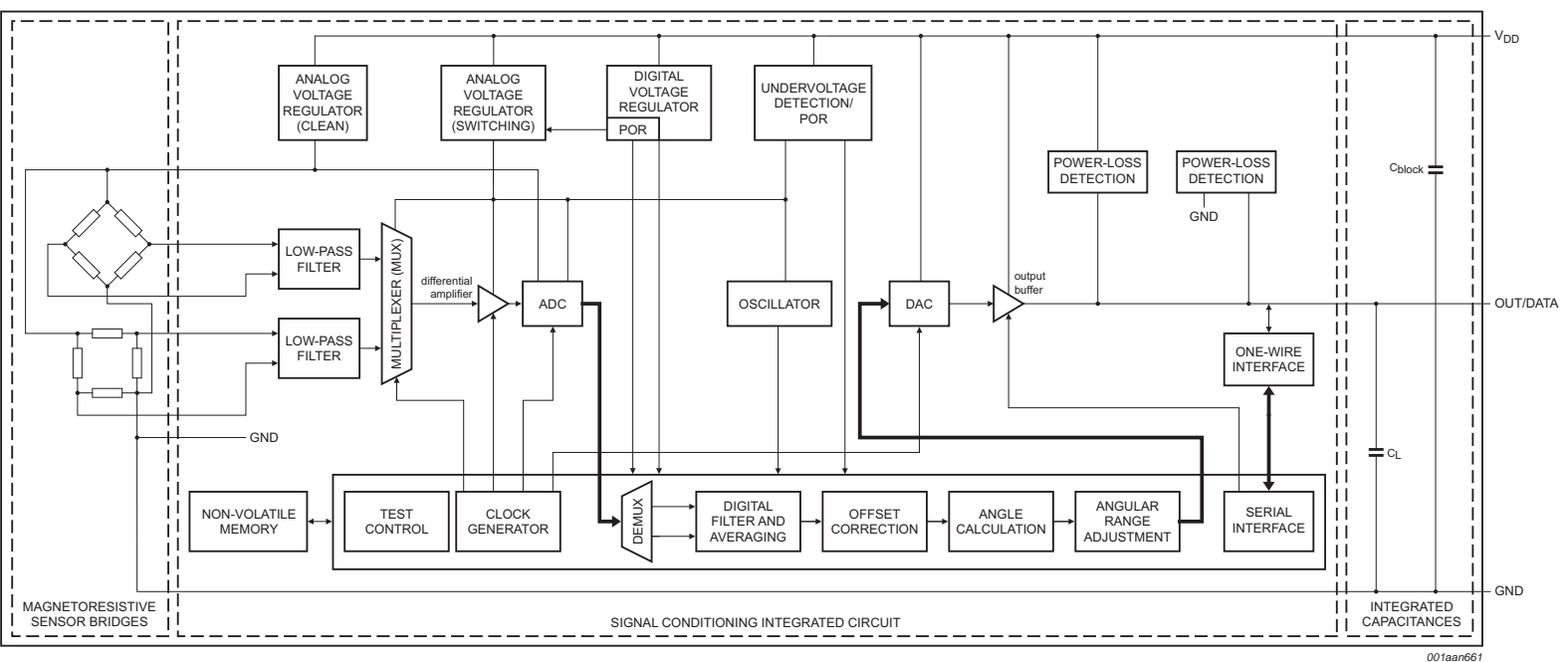
| Pin | Symbol          | Description                     | Simplified outline                                                                   |
|-----|-----------------|---------------------------------|--------------------------------------------------------------------------------------|
| 1   | OUT/DATA        | analog output or data interface |  |
| 2   | GND             | ground                          |                                                                                      |
| 3   | V <sub>DD</sub> | supply voltage                  |                                                                                      |
| 4   | n.c.            | not connected                   |                                                                                      |

## 3. Ordering information

Table 2. Ordering information

| Type number | Package |                                 |           |
|-------------|---------|---------------------------------|-----------|
|             | Name    | Description                     | Version   |
| KMA221      | SIL4    | plastic, single in-line package | SOT1188-1 |

#### 4. Functional diagram



**Fig 1. Functional diagram of KMA221**

## 5. Functional description

The KMA221 amplifies two orthogonal differential signals from MR sensor bridges and converts them 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. Zero angle, clamping voltages and angular range are programmable. In addition, two 16-bit registers are available for customer purposes, such as sample identification.

The KMA221 comprises a Cyclic Redundancy Check (CRC) and an Error Detection and Correction (EDC). It also has magnet-loss and broken bond wire detection 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 analog output to the remaining connection.

After multiplexing the two MR Wheatstone bridge signals and their successive amplification, the signal is converted into the digital domain by an Analog-to-Digital Converter (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 analog output stage are used for the conversion of the angle information into an analog output voltage, which is ratiometric to the supply voltage.

The configuration parameters are stored in a user-programmable non-volatile memory. The OWI (accessible using pin OUT/DATA) 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.

### 5.1 Angular measurement directions

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

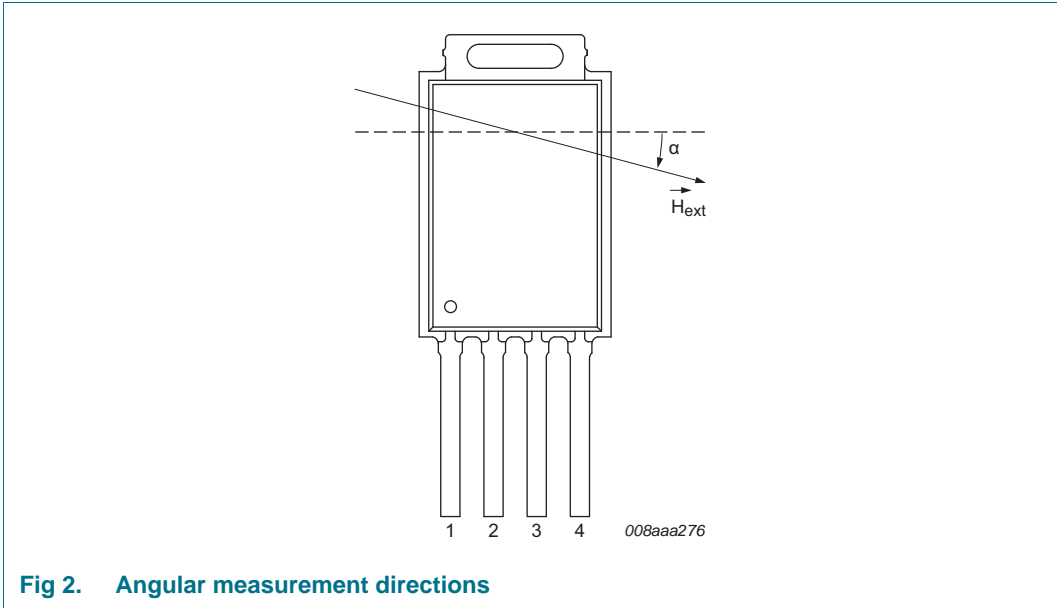


Fig 2. Angular measurement directions

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.

6. Analog output

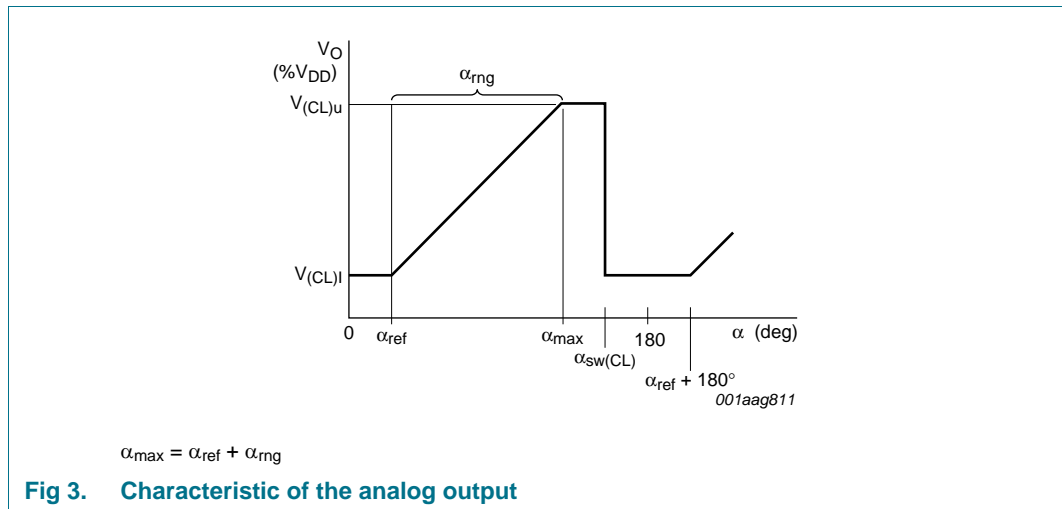
The KMA221 provides one analog output signal on pin OUT/DATA. The measured angle  $\alpha$  is converted linearly into a value, which is ratiometric to the supply voltage  $V_{DD}$ . Either a positive or a negative slope is provided for this purpose.

Table 3 describes the analog output behavior for a positive slope. For example, if a magnetic field angle, above the programmed maximum angle  $\alpha_{max}$  but below the clamp switch angle  $\alpha_{sw(CL)}$ , is applied to the sensor, the analog output is set 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 |
|-------------------------------------------------------|---------------|
| $\alpha_{max} < \alpha < \alpha_{sw(CL)}$             | $V_{(CL)u}$   |
| $\alpha_{sw(CL)} < \alpha < \alpha_{ref} + 180^\circ$ | $V_{(CL)l}$   |

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 % $V_{DD}$  or above 96 % $V_{DD}$ , an error condition has been detected. The analog output repeats every 180°.



## 7. Diagnostic features

The KMA221 provides several diagnostic features:

### 7.1 CRC and EDC supervision

The KMA221 includes a supervision of the programmed data. At power-on, a CRC of the non-volatile memory is performed. 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, while the sensor continues in normal operation mode. Furthermore the logic detects double-bit error per word and switches the output into diagnostic mode.

### 7.2 Magnet-loss detection

If the applied magnetic field strength is not sufficient, the KMA221 can raise a diagnostic condition. In order to enter the diagnostic mode, due to magnet-loss, enable the detection first. The device can be programmed into active diagnostic mode, where the output is driven below 4 % $V_{DD}$  or above 96 % $V_{DD}$ .

### 7.3 Power-loss detection

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 pins.

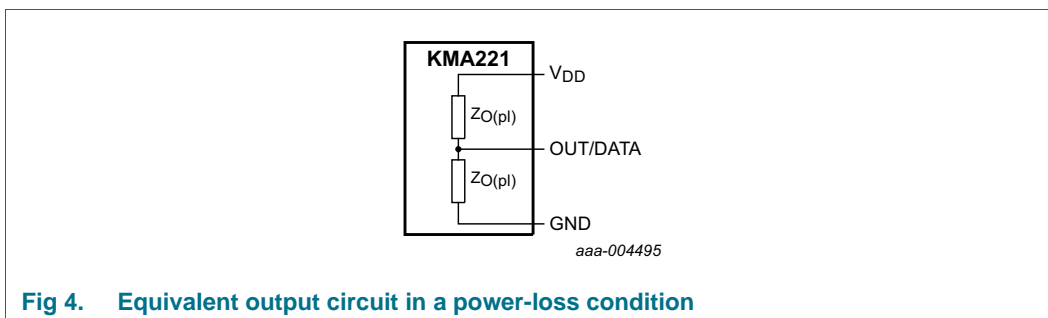


Fig 4. Equivalent output circuit in a power-loss condition

Table 4 describes the power-loss behavior and gives the resulting output voltage depending on the interrupted supply or ground line and the load resistance.

Table 4. Power-loss behavior

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

## 7.4 Broken bond wire detection

The broken bond wire detection circuit enables the detection of an interrupted supply or ground line of the MR sensor bridge. If there is a broken bond wire, the device goes into diagnostic mode and a status bit is set.

## 7.5 Low supply voltage detection and overvoltage protection

If the supply voltage is below the switch-off threshold voltage, a status bit is set and the device goes into diagnostic mode. If the supply voltage is above the overvoltage switch-on threshold voltage, the device enters diagnostic mode. Table 5 describes the system behavior depending on the voltage range of the supply voltage.

Table 5. System behavior

| Supply voltage                                    | State                | Description                                                                                                                                                                                                                                                              |
|---------------------------------------------------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0 V to $\cong 1.8 \text{ V}$                      | start-up power       | The output buffer drives an active LOW or is powered down. 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.                                                               |
| $\cong 1.8 \text{ V}$ 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. |
| $V_{POR}$ 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 and sets the output to the lower diagnostic level.                                       |
| $V_{th(on)}$ 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.                                                                                                                             |

**Table 5.** System behavior ...continued

| Supply voltage                       | State                | Description                                                                                                                                    |
|--------------------------------------|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| 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.       |
| 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.   |
| $V_{th(ov)}$ to 16 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. |

[Table 6](#) 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 6.** Diagnostic behavior

| Diagnostic condition | Duration                               | Analog output                                 | Termination condition          |
|----------------------|----------------------------------------|-----------------------------------------------|--------------------------------|
| Low voltage          | $1\ \mu\text{s} < t < 10\ \mu\text{s}$ | $\leq 4\ \%V_{DD}$                            | functional or normal operation |
| Overvoltage          | $1\ \mu\text{s} < t < 10\ \mu\text{s}$ | $\leq 4\ \%V_{DD}$                            | functional or normal operation |
| Checksum error       | n/a                                    | $\leq 4\ \%V_{DD}$ or $\geq 96\ \%V_{DD}$ [2] | power-on reset [1]             |
| Double-bit error     | n/a                                    | $\leq 4\ \%V_{DD}$ or $\geq 96\ \%V_{DD}$ [2] | power-on reset [1]             |
| Magnet-loss          | $0.5\ \text{ms} < t < 6\ \text{ms}$    | $\leq 4\ \%V_{DD}$ or $\geq 96\ \%V_{DD}$ [2] | magnet present [1]             |
| Power-loss           | $\leq 2\ \text{ms}$                    | $\leq 4\ \%V_{DD}$ or $\geq 96\ \%V_{DD}$ [2] | power-on reset                 |
| Broken bond wire     | $0.2\ \text{ms} < t < 1\ \text{ms}$    | $\leq 4\ \%V_{DD}$ or $\geq 96\ \%V_{DD}$ [2] | power-on reset [1]             |

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

[2] Depending on the diagnostic level setting.

## 8. Limiting values

**Table 7.** Limiting values

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

| Symbol                     | Parameter                       | Conditions                                                  | Min          | Max  | Unit             |
|----------------------------|---------------------------------|-------------------------------------------------------------|--------------|------|------------------|
| $V_{DD}$                   | supply voltage                  |                                                             | -0.3         | +16  | V                |
| $V_O$                      | output voltage                  |                                                             | -0.3         | +16  | V                |
| $V_{O(ov)}$                | overvoltage output voltage      | $T_{amb} < 140\ ^\circ\text{C}$ [1]<br>at $t < 1\ \text{h}$ | $V_{th(ov)}$ | 16   | V                |
| $I_r$                      | reverse current                 | $T_{amb} < 70\ ^\circ\text{C}$                              | -            | 150  | mA               |
| $T_{amb}$                  | ambient temperature             |                                                             | -40          | +160 | $^\circ\text{C}$ |
| $T_{amb(pr)}$              | programming ambient temperature |                                                             | 10           | 70   | $^\circ\text{C}$ |
| $T_{stg}$                  | storage temperature             |                                                             | -40          | +125 | $^\circ\text{C}$ |
| <b>Non-volatile memory</b> |                                 |                                                             |              |      |                  |
| $t_{ret(D)}$               | data retention time             | $T_{amb} = 50\ ^\circ\text{C}$                              | 17           | -    | year             |
| $N_{endu(W\_ER)}$          | write or erase endurance        | $T_{amb(pr)} = 70\ ^\circ\text{C}$                          | 100          | -    | cycle            |

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



## 9. Recommended operating conditions

**Table 8. 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 | -   | +160 | °C   |
| T <sub>amb(pr)</sub> | programming ambient temperature  |            | 10  | -   | 70   | °C   |
| C <sub>L(ext)</sub>  | external load capacitance        | [1][2]     | 0   | -   | 22   | nF   |
|                      |                                  | [2][3]     | 0   | -   | 6.8  | nF   |
| R <sub>L(ext)</sub>  | external load resistance         | [4]        | 5   | -   | ∞    | kΩ   |
| H <sub>ext</sub>     | external magnetic field strength |            | 35  | -   | -    | kA/m |

[1] Normal operation mode.

[2] Between ground and analog output.

[3] Command mode.

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

## 10. Thermal characteristics

**Table 9. Thermal characteristics**

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

## 11. Characteristics

**Table 10. Mechanical characteristics**

| Symbol            | Parameter                          | Conditions               | Min | Typ | Max | Unit |
|-------------------|------------------------------------|--------------------------|-----|-----|-----|------|
| F <sub>lead</sub> | mechanical force to the leads      | T <sub>amb</sub> = 25 °C | -   | -   | 10  | N    |
| F <sub>fin</sub>  | mechanical force to the fin holder | T <sub>amb</sub> = 25 °C | -   | -   | 15  | N    |

**Table 11. Supply current**

*Characteristics are valid for the operating conditions, as specified in [Section 9](#).*

| Symbol               | Parameter                      | Conditions | Min | Typ | Max  | Unit |
|----------------------|--------------------------------|------------|-----|-----|------|------|
| I <sub>DD</sub>      | supply current                 | [1][2]     | 5   | -   | 10.5 | mA   |
|                      |                                | [3][4]     | -   | -   | 13   | mA   |
| I <sub>off(ov)</sub> | overvoltage switch-off current | [5]        | -   | -   | 6    | mA   |

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

[2] Without load current at the analog 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 analog output.

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

**Table 12. Power-on reset**

Characteristics are valid for the operating conditions, as specified in [Section 9](#).

| Symbol        | Parameter                      | Conditions                                            | Min  | Typ  | Max  | Unit |
|---------------|--------------------------------|-------------------------------------------------------|------|------|------|------|
| $V_{th(on)}$  | switch-on threshold voltage    | analog output switches on, if $V_{DD} > V_{th(on)}$   | -    | 4.30 | 4.45 | V    |
| $V_{th(off)}$ | switch-off threshold voltage   | analog output switches off, if $V_{DD} < V_{th(off)}$ | 3.90 | 4.10 | -    | 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  | analog output switches off, if $V_{DD} > V_{th(ov)}$  | 6.5  | 7.5  | 8.0  | V    |
| $V_{hys(ov)}$ | overvoltage hysteresis voltage |                                                       | 0.1  | 0.3  | -    | V    |

**Table 13. Module performance**

Characteristics are valid for the operating conditions, as specified in [Section 9](#).

| Symbol                 | Parameter                                   | Conditions                                                               | Min                | Typ | Max  | Unit       |
|------------------------|---------------------------------------------|--------------------------------------------------------------------------|--------------------|-----|------|------------|
| $\alpha_{res}$         | angle resolution                            |                                                                          | [1] -              | -   | 0.04 | deg        |
| $\alpha_{max}$         | maximum angle                               | programmable angular range for $V_{(CL)u} - V_{(CL)l} \geq 80 \% V_{DD}$ | [2] 5              | -   | 180  | deg        |
| $\alpha_{ref}$         | reference angle                             | programmable zero angle                                                  | [2] 0              | -   | 180  | deg        |
| $V_{O(nom)}$           | nominal output voltage                      | at full supply operating range                                           | 5                  | -   | 95   | $\%V_{DD}$ |
| $V_{O(udr)}$           | upper diagnostic range output voltage       |                                                                          | [3][4][5] 96       | -   | 100  | $\%V_{DD}$ |
| $V_{O(ldr)}$           | lower diagnostic range output voltage       |                                                                          | [3][4][5] 0        | -   | 4    | $\%V_{DD}$ |
| $V_{(CL)u}$            | upper clamping voltage                      |                                                                          | [4][5][6] 40       | -   | 95   | $\%V_{DD}$ |
| $V_{(CL)l}$            | lower clamping voltage                      |                                                                          | [4][5][6] 5        | -   | 30.5 | $\%V_{DD}$ |
| $\Delta V_{(CL)}$      | clamping voltage variation                  | deviation from programmed value                                          | [4][5] -0.3        | -   | +0.3 | $\%V_{DD}$ |
| $V_{n(o)(RMS)}$        | RMS output noise voltage                    | equivalent power noise                                                   | [1][4] -           | 0.4 | 2.5  | mV         |
| $\Delta\phi_{lin}$     | linearity error                             | temperature range -40 °C to +160 °C                                      | [4][7] -1.2        | -   | +1.2 | deg        |
|                        |                                             | temperature range -40 °C to +140 °C                                      | [4][7] -1          | -   | +1   | deg        |
| $\Delta\phi_{temp}$    | temperature drift error                     | temperature range -40 °C to +160 °C                                      | [1][4][7] -<br>[8] | -   | 0.8  | deg        |
|                        |                                             | temperature range -40 °C to +140 °C                                      | [1][4][7] -<br>[8] | -   | 0.65 | deg        |
| $\Delta\phi_{temp RT}$ | temperature drift error at room temperature | temperature range -40 °C to +160 °C                                      | [7][8][9] -        | -   | 0.65 | deg        |
|                        |                                             | temperature range -40 °C to +140 °C                                      | [7][8][9] -        | -   | 0.55 | deg        |
| $\Delta\phi_{hys}$     | hysteresis error                            | referred to input                                                        | [4][7] -           | -   | 0.09 | deg        |
| $\Delta\phi_{\mu lin}$ | microlinearity error                        | referred to input                                                        | [4][7] -0.1        | -   | +0.1 | deg        |

**Table 13. Module performance ...continued**Characteristics are valid for the operating conditions, as specified in [Section 9](#).

| Symbol                    | Parameter                   | Conditions                                                                       | Min                                                                   | Typ | Max   | Unit     |
|---------------------------|-----------------------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------------|-----|-------|----------|
| $\Delta\phi_{\text{ang}}$ | angular error               | temperature range<br>–40 °C to +160 °C                                           | <a href="#">[4]</a> <a href="#">[7]</a><br><a href="#">[10]</a> –1.35 | -   | +1.35 | deg      |
|                           |                             | temperature range<br>–40 °C to +140 °C                                           | <a href="#">[4]</a> <a href="#">[7]</a><br><a href="#">[10]</a> –1.1  | -   | +1.1  | deg      |
| $m_{\text{ang}}$          | slope of angular error      |                                                                                  | <a href="#">[4]</a> <a href="#">[7]</a><br><a href="#">[10]</a> -     | -   | 0.04  | deg/deg  |
| $Z_{\text{O(pl)}}$        | power-loss output impedance | impedance to remaining supply line in case of lost supply voltage or lost ground | -                                                                     | -   | 210   | $\Omega$ |

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

[2] In steps of resolution &lt; 0.022°.

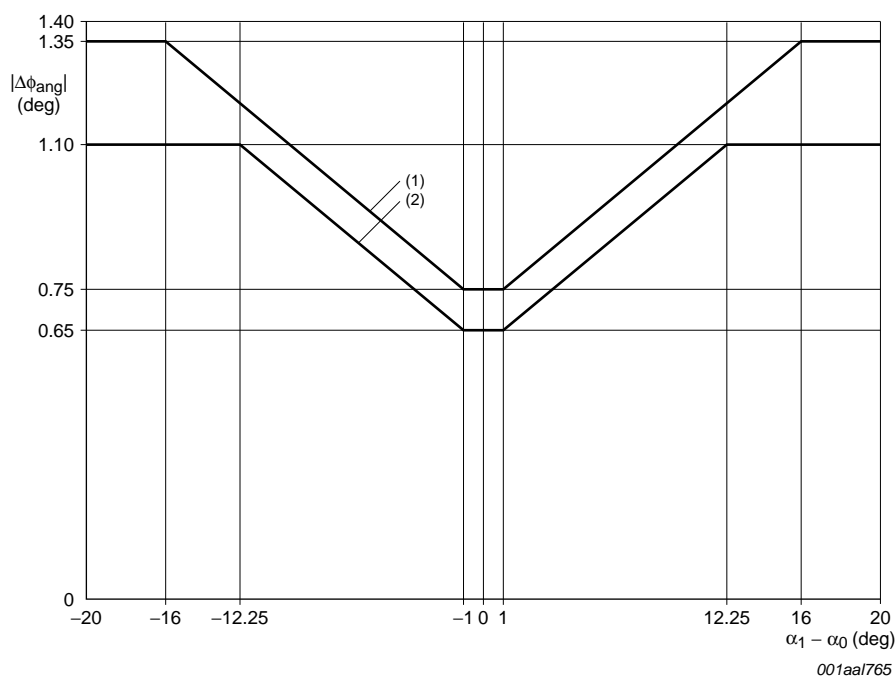
[3] Activation is dependent on the programmed diagnostic mode.

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

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

[6] In steps of 0.02 % $V_{\text{DD}}$ .[7] Definition of errors is given in [Section 12](#).[8] Based on a 3 $\sigma$  standard deviation.

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

[10] Graph of angular error is shown in [Figure 5](#).

(1) –40 °C to +160 °C

(2) –40 °C to +140 °C

**Fig 5. Envelope curve for the magnitude of angular error**

**Table 14. Dynamics**

Characteristics are valid for the operating conditions, as specified in [Section 9](#).

| Symbol         | Parameter                 | Conditions                                                                            | Min | Typ   | Max | Unit |
|----------------|---------------------------|---------------------------------------------------------------------------------------|-----|-------|-----|------|
| $t_{on}$       | turn-on time              | until first valid result                                                              | -   | -     | 5   | ms   |
| $f_{upd}$      | update frequency          |                                                                                       | 2.4 | 3.125 | -   | kHz  |
| $t_s$          | settling time             | after an ideal mechanical angle step of 45°, until 90 % of the final value is reached | -   | -     | 1.8 | ms   |
| $t_{cmd(ent)}$ | enter command mode time   | after power-on                                                                        | 20  | -     | 30  | ms   |
| $t_{rec(ov)}$  | overvoltage recovery time | after overvoltage                                                                     | -   | -     | 4   | ms   |

**Table 15. Digital interface**

Characteristics are valid for the operating conditions, as specified in [Section 9](#).

| Symbol           | Parameter                 | Conditions                                                            | Min            | Typ           | Max            | Unit             |
|------------------|---------------------------|-----------------------------------------------------------------------|----------------|---------------|----------------|------------------|
| $V_{IH}$         | HIGH-level input voltage  |                                                                       | 80             | -             | -              | %V <sub>DD</sub> |
| $V_{IL}$         | LOW-level input voltage   |                                                                       | -              | -             | 20             | %V <sub>DD</sub> |
| $V_{OH}$         | HIGH-level output voltage | $I_O = 2\text{ mA}$                                                   | 80             | -             | -              | %V <sub>DD</sub> |
| $V_{OL}$         | LOW-level output voltage  | $I_O = 2\text{ mA}$                                                   | -              | -             | 20             | %V <sub>DD</sub> |
| $I_{od}$         | overdrive current         | absolute value for overdriving the output buffer                      | -              | -             | 20             | mA               |
| $t_{start}$      | start time                | LOW level before rising edge                                          | 5              | -             | -              | μs               |
| $t_{stop}$       | stop time                 | HIGH level before falling edge                                        | 5              | -             | -              | μs               |
| $T_{bit}$        | bit period                | the load capacitance limits the minimum period                        | 10             | -             | 100            | μs               |
| $\Delta T_{bit}$ | bit period deviation      | deviation between received clock and sent clock                       | $0.8T_{bit}$   | $1T_{bit}$    | $1.2T_{bit}$   | μs               |
| $t_{w0}$         | pulse width 0             |                                                                       | $0.175T_{bit}$ | $0.25T_{bit}$ | $0.375T_{bit}$ | μs               |
| $t_{w1}$         | pulse width 1             |                                                                       | $0.625T_{bit}$ | $0.75T_{bit}$ | $0.825T_{bit}$ | μs               |
| $t_{to}$         | time-out time             | communication reset guaranteed after maximum $t_{to}$                 | -              | -             | 220            | μs               |
| $t_{tko(slv)}$   | slave takeover time       | duration of LOW level for slave takeover                              | 1              | -             | 5              | μs               |
| $t_{tko(mas)}$   | master takeover time      | duration of LOW level for master takeover                             | $0T_{bit}$     | -             | $0.5T_{bit}$   | μs               |
| $t_{prog}$       | programming time          | for a single memory address                                           | 20             | -             | -              | ms               |
| $t_{cp}$         | charge pump time          | waiting time after enabling the non-volatile memory charge pump clock | 1              | -             | -              | ms               |

**Table 16. Internal capacitances**

Characteristics are valid for the operating conditions, as specified in [Section 9](#).

| Symbol      | Parameter            | Conditions | Min     | Typ | Max | Unit |
|-------------|----------------------|------------|---------|-----|-----|------|
| $C_{block}$ | blocking capacitance |            | [1] 50  | 100 | 150 | nF   |
| $C_L$       | load capacitance     |            | [1] 1.1 | 2.2 | 3.3 | nF   |

[1] Measured at 1 MHz.

## 12. Definition of errors

### 12.1 General

Angular measurement errors by the KMA221 result from linearity errors, temperature drift errors and hysteresis errors. [Figure 6](#) 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 % $V_{\text{DD}}$ /degree.

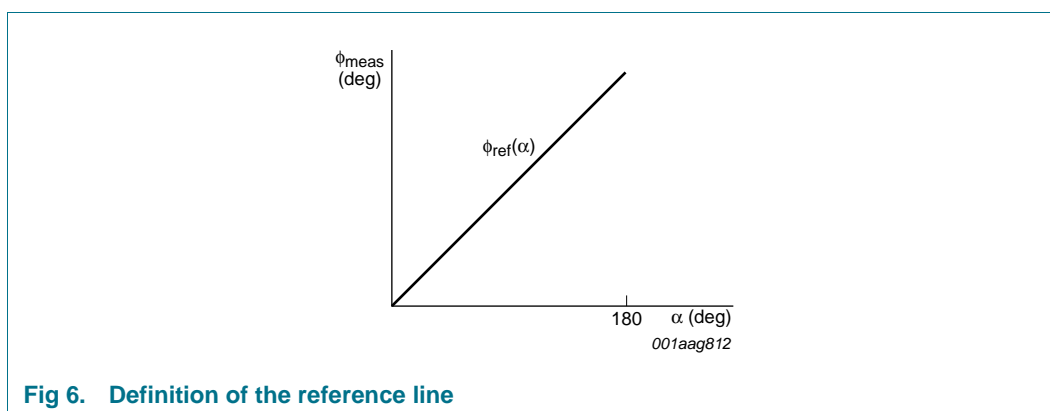


Fig 6. Definition of the reference line

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

### 12.2 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  $\Delta\phi_{\text{hys}}$ .

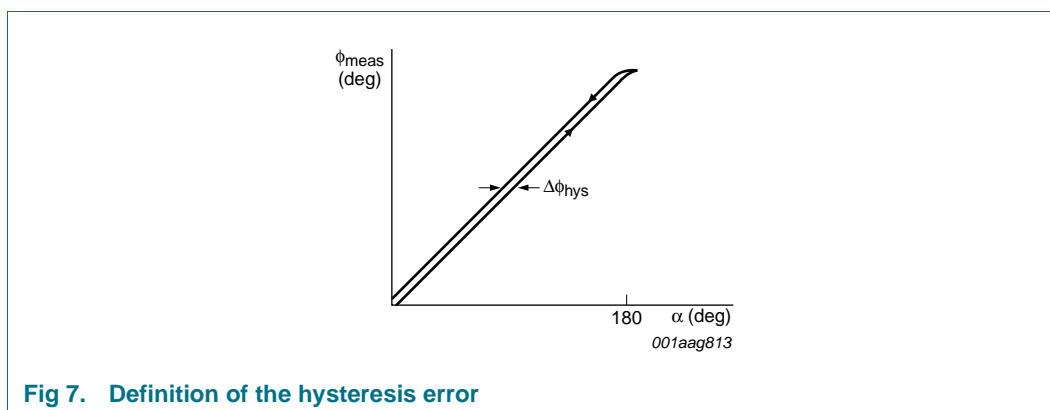


Fig 7. Definition of the hysteresis error

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

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

### 12.3 Linearity error

The KMA221 output signal deviation from a best straight line  $\phi_{BSL}$ , 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 signal 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  $T_{amb}$ .

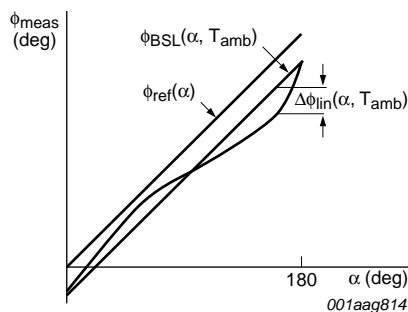


Fig 8. Definition of the linearity error

### 12.4 Microlinearity error

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

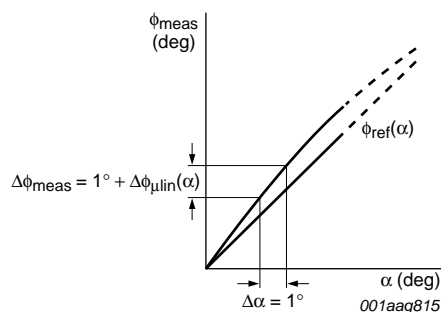


Fig 9. Definition of the microlinearity error

## 12.5 Temperature drift error

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

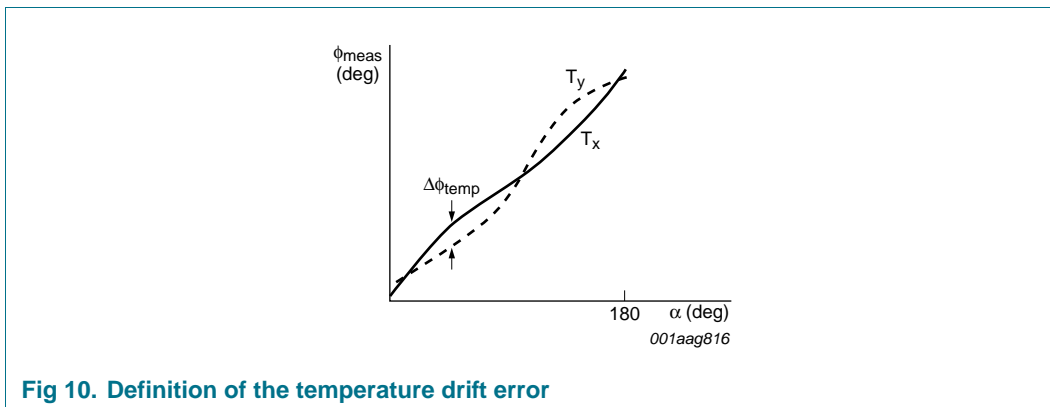


Fig 10. Definition of the temperature drift error

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

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

with:

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

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

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

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

with:

$T_{RT}$ : room temperature (25 °C)

## 12.6 Angular error

The angular error  $\Delta\phi_{ang}$  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:

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

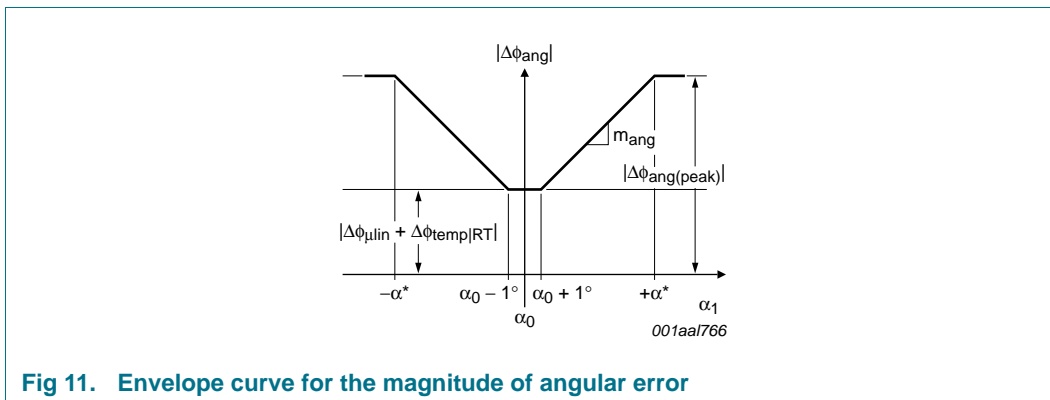
with:

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

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

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

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



**Fig 11. Envelope curve for the magnitude of angular error**

Figure 11 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:

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



## 13. Programming

### 13.1 General description

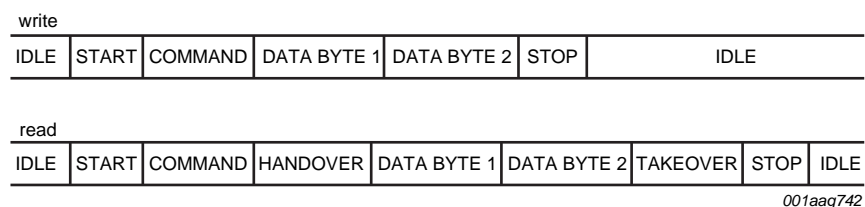
The KMA221 provides an OWI to enable programming of the device which uses pin OUT/DATA bidirectionally.

In general the device runs in analog output 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.

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. After enabling the internal charge pump and waiting for  $t_{cp}$ , the data is stored in the non-volatile memory. After changing the contents of the memory, recalculate and write the checksum (see [Section 13.4](#)).

In order to enter the command mode, 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 buffers of the KMA221. In doing so, it provides current  $I_{od}$ .

During communication, the KMA221 is always the slave and the external programming hardware is always the master. [Figure 12](#) illustrates the structure of the OWI data format.



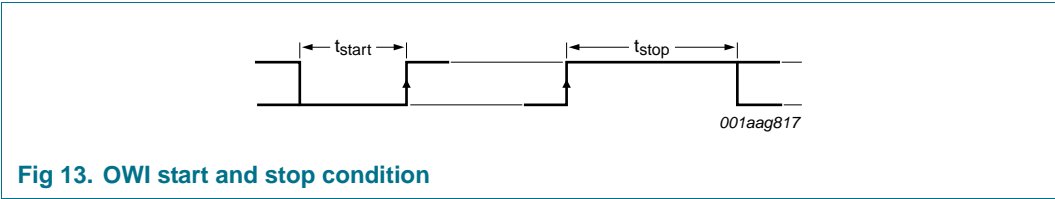
**Fig 12. OWI data format**

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 time-out 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.

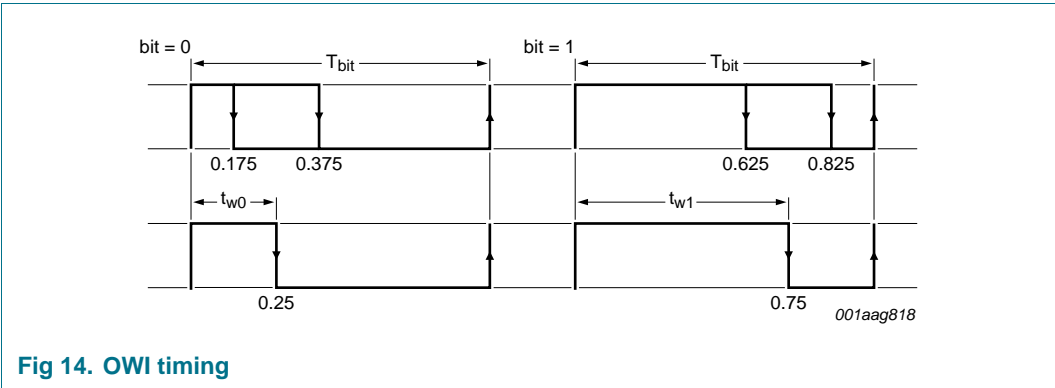
All communication is based on this structure (see [Figure 12](#)), even for entering the command mode. The customer can access the non-volatile memory, CTRL1, TESTCTRL0 and SIGNATURE registers (described in [Section 13.5](#)). Only a power-on reset leaves the command mode. A more detailed description of the programming is given in the next sections.

13.2 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 15](#).



[Figure 14](#) 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.



13.3 Sending and receiving data

The master has to control the communication during sending or receiving data. The command byte defines the region, 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 12](#)). However the OWI is a serial data transmission, whereas the Most Significant Byte (MSB) send at first.

Table 17. Format of a command byte

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

Table 18. Command byte bit description

| Bit    | Symbol   | Description                      |
|--------|----------|----------------------------------|
| 7 to 5 | CMD[7:5] | region bits                      |
|        |          | 000 = 16-bit non-volatile memory |
|        |          | 001 to 011 = reserved            |
|        |          | 100 = 16-bit register            |
|        |          | 101 to 111 = reserved            |

Table 18. Command byte bit description ...continued

| Bit    | Symbol   | Description  |
|--------|----------|--------------|
| 4 to 1 | CMD[4:1] | address bits |
| 0      | CMD0     | read/write   |
|        |          | 0 = write    |
|        |          | 1 = read     |

A more detailed description of all customer accessible registers is given in [Section 13.5](#). Both default value and the complete command including the address and write or read request are also listed.

### 13.3.1 Write access

To write data to the non-volatile memory, enable the internal charge pump. Set bits CP\_CLOCK\_EN and WRITE\_EN and wait for  $t_{cp}$  enables the internal charge pump. 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 15](#) 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.

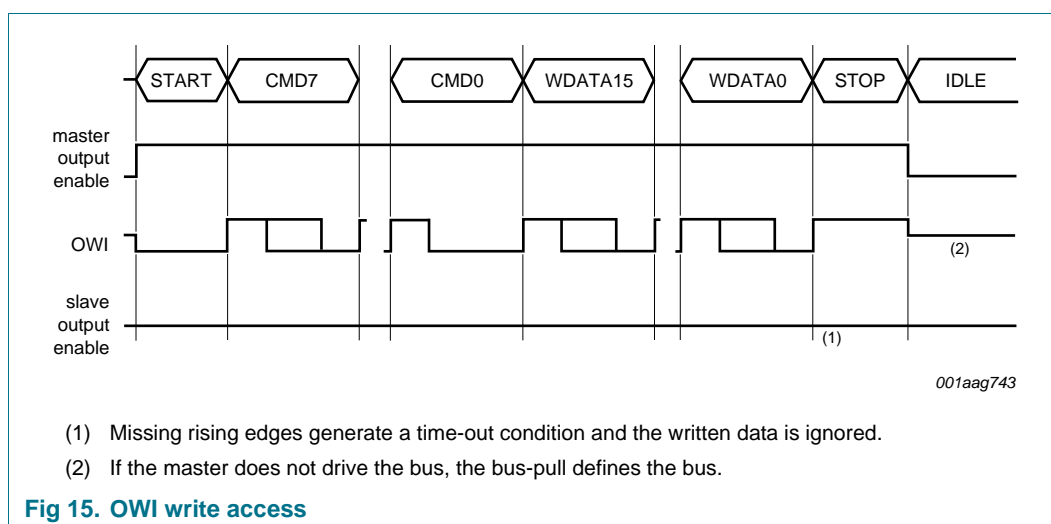


Fig 15. OWI write access

**Note:** As already mentioned in [Section 13.1](#), 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  $t_{prog}$  must elapse before changing another address. After changing the contents of the non-volatile memory, recalculate and write the checksum (see [Section 13.4](#)).

### 13.3.2 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 16 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.

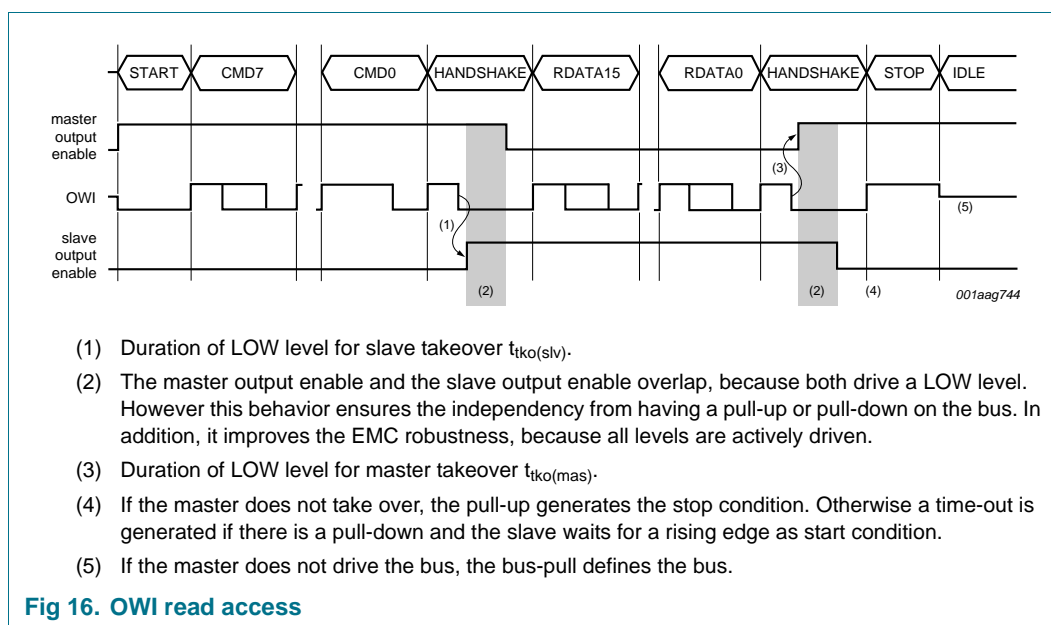


Fig 16. OWI read access

### 13.3.3 Entering the command mode

After a power-on reset, the sensor provides a time slot  $t_{\text{cmd(ent)}}$  for entering the command mode. Send a specific command sequence (see [Figure 17](#)). 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 analog output is enabled. The external programming hardware has to overdrive the output with current  $I_{\text{od}}$ . If command mode is activated, the analog output is disabled and pin OUT/DATA operates as a digital interface.

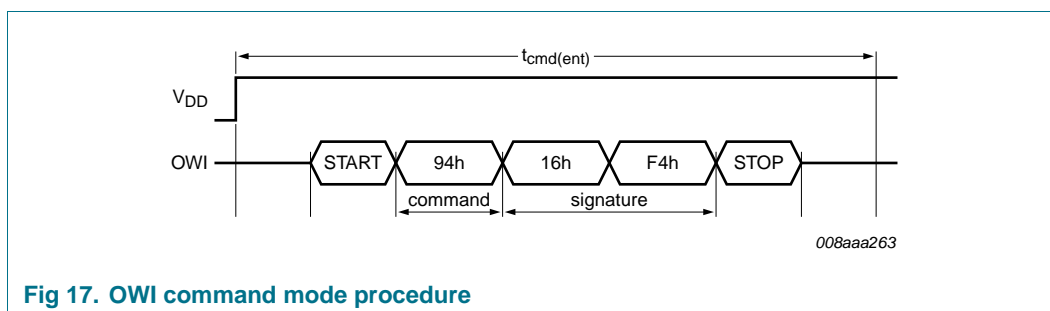


Fig 17. OWI command mode procedure

### 13.4 Cyclic redundancy check

As already mentioned in [Section 7](#), there is an 8-bit checksum for the non-volatile memory data. To calculate this value, the MSB of the memory data word generates the CRC at first over all corresponding addresses in increasing order.

Read out all addresses from 8h to Fh for calculating the checksum. The Least Significant Byte (LSB) of address Fh which contains the previous checksum must be overwritten with 0h before the calculation can be started.

Setting bits CP\_CLOCK\_EN and WRITE\_EN (see [Section 13.5.1](#)) and waiting for  $t_{\text{cp}}$  enables the internal charge pump for programming.

The generator polynomial for the calculation of the checksum is:

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

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

### 13.4.1 Software example in C

```

1  #include <stdio.h>
2
3  // calc_crc accepts unsigned 16-bit data in data
4  int calc_crc(int crc, unsigned int data)
5  {
6      const int gpoly = 0x107; // generator polynomial
7      int i;                  //index variable
8      for (i = 15; i >= 0; i--)
9      {
10         crc <<= 1;           //shift left
11         crc |= (int) ((data & (1u<<i))>>i);
12         // XOR of with generator polynomial when MSB(9) = HIGH
13         if (crc & 0x100) crc ^= gpoly;
14     }
15     return crc;
16 }
17 int main(void)
18 {
19     int crc, crc_res, i;
20     // 8 LSB are CRC field filled with 0
21     unsigned int data_seq[] = {0x0000, 0xFFC1, 0x0400, 0x0100,
22                                0x1300, 0x0000, 0x0000, 0x0000};
23     // calculate checksum over all data
24     crc = 0xFF;           // start value of crc register
25     printf("Address\tValue\n");
26     for (i = 0; i <= 7; i++)
27     {
28         printf("0x%1X\t0x%04X\n", i, data_seq[i]);
29         crc = calc_crc(crc, data_seq[i]);
30     }
31     crc_res = crc;        // crc_res = 0xA9
32     printf("\nChecksum\n0x%02X\n", crc_res);
33     // check procedure for preceding data sequence
34     crc = 0xFF;
35     for (i = 0; i <= 6; i++)
36         crc = calc_crc(crc, data_seq[i]);
37     // last word gets crc inserted
38     crc = calc_crc(crc, data_seq[i] | crc_res);
39     printf("\nCheck procedure for data sequence: must be 0x00 is 0x%02X.\n", crc);
40     return 1;
41 }

```

The checksum of this data sequence is A9h.

## 13.5 Registers

### 13.5.1 Command registers

To enter the command mode, write the signature given in [Table 19](#) into the specific register using the OWI. Do this procedure as described in [Section 13.3.3](#), with a write command, the signature follows it, but after a power-on reset and not later than  $t_{cmd(ent)}$ .

**Table 19. Command registers**

| Command write/read | Register  | Bit      | Access | Field           | Description                                                                                                                                                                               |
|--------------------|-----------|----------|--------|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 82h/83h            | CTRL1     | 15       | R      | IN_DIAG_MODE    | shows if there is a diagnostic condition present; the setting of register field FORCE_DIAG_OFF does not affect this bit                                                                   |
|                    |           | 14       | W      | FORCE_DIAG_OFF  | force diagnostic mode off; default: 0b                                                                                                                                                    |
|                    |           | 13       | -      | -               | reserved                                                                                                                                                                                  |
|                    |           | 12       | R      | LOW_VOLTAGE_DET | low voltage condition detected                                                                                                                                                            |
|                    |           | 11       | R/W    | CP_CLOCK_EN     | charge pump clock enabled (must be set after setting write enable signal for writing to non-volatile memory); default: 0b                                                                 |
|                    |           | 10 and 9 | -      | -               | reserved                                                                                                                                                                                  |
|                    |           | 8        | R      | ERR_CORRECT     | single-bit error of non-volatile memory has been detected and corrected; updated every memory readout; remains set until the diagnostic condition disappears and a power-on reset is done |
|                    |           | 7        | R      | UNCORR_ERR      | double-bit error of non-volatile memory has been detected; updated every memory readout; remains set until the diagnostic condition disappears and a power-on reset is done               |
|                    |           | 6        | R      | MAGNET_LOSS_DET | magnet-loss detected; bit remains set until the diagnostic condition disappears and a power-on reset is done; enable magnet-loss detection for entering diagnostic mode                   |
|                    |           | 5        | R      | BROKEN_BOND_DET | broken bond wire detected; bit remains set until the diagnostic condition disappears and a power-on reset is done                                                                         |
|                    |           | 4        | R      | CRC_BAD         | checksum error detected; updated every start-up                                                                                                                                           |
|                    |           | 3 to 0   | -      | -               | reserved                                                                                                                                                                                  |
| 94h/-              | SIGNATURE | 15 to 0  | W      | SIGNATURE       | to enter command mode, write signature 16F4h within $t_{cmd(ent)}$ ; for more details, see <a href="#">Section 13.3.3</a>                                                                 |
| 96h/97h            | TESTCTRL0 | 15 to 12 | -      | -               | reserved                                                                                                                                                                                  |
|                    |           | 11       | W      | WRITE_EN        | write enable signal; set before writing to non-volatile memory; default: 0b                                                                                                               |
|                    |           | 10 to 0  | -      | -               | reserved                                                                                                                                                                                  |

### 13.5.2 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:** Before data can be stored in the non-volatile memory, switch on the internal charge pump for the programming duration by setting register CTRL1, bit 11 CP\_CLOCK\_EN and register TESTCTRL0, bit 11 WRITE\_EN. To calculate the checksum, read out and consult register addresses 8h to Fh.

**Table 20. Non-volatile memory registers**

| Address | Command write/read | Register         | Bit       | Description                                                                                                                                              | Default MSB/LSB     |
|---------|--------------------|------------------|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| 0h      | -/01h              | reserved         | -         | addresses are reserved for calibration purposes                                                                                                          | <a href="#">[1]</a> |
| 1h      | -/03h              |                  |           |                                                                                                                                                          |                     |
| 2h      | -/05h              |                  |           |                                                                                                                                                          |                     |
| 3h      | -/07h              |                  |           |                                                                                                                                                          |                     |
| 4h      | -/09h              |                  |           |                                                                                                                                                          |                     |
| 5h      | -/0Bh              |                  |           |                                                                                                                                                          |                     |
| 6h      | -/0Dh              |                  |           |                                                                                                                                                          |                     |
| 7h      | -/0Fh              |                  |           |                                                                                                                                                          |                     |
| 8h      | 10h/11h            | ZERO_ANGLE       | 15 to 0   | mechanical zero degree position; see <a href="#">Table 21</a>                                                                                            | 00h/00h             |
| 9h      | 12h/13h            | ANG_RNG_MULT_MSB | 15 to 6   | CLAMP_SW_ANGLE; when the measured angle is bigger than CLAMP_SW_ANGLE the output switches to CLAMP_LO for a positive slope; see <a href="#">Table 26</a> | FFh/C1h             |
|         |                    |                  | 5 to 0    | ANG_RNG_MULT_MSB; most significant bits of the angular range multiplicator; see <a href="#">Table 24</a>                                                 |                     |
| Ah      | 14h/15h            | ANG_RNG_MULT_LSB | 15 and 14 | DIAGNOSTIC_LEVEL; diagnostic level behavior of the analog output; see <a href="#">Table 25</a>                                                           | 04h/00h             |
|         |                    |                  |           | <b>00b</b> — active LOW (in lower diagnostic range) with driver strength of the analog output                                                            |                     |
|         |                    |                  |           | <b>01b</b> — active HIGH (in upper diagnostic range) with driver strength of the analog output                                                           |                     |
|         |                    |                  |           | <b>10b</b> — reserved                                                                                                                                    |                     |
|         |                    |                  |           | <b>11b</b> — reserved                                                                                                                                    |                     |
|         |                    |                  | 13        | SLOPE_DIR; slope of analog output                                                                                                                        |                     |
|         |                    |                  |           | <b>0b</b> — rising (not inverted)                                                                                                                        |                     |
|         |                    |                  |           | <b>1b</b> — falling (inverted)                                                                                                                           |                     |
|         |                    |                  | 12 to 0   | ANG_RNG_MULT_LSB; least significant bits of the angular range multiplicator                                                                              |                     |



Table 20. Non-volatile memory registers ...continued

| Address | Command write/read | Register  | Bit       | Description                                                                         | Default MSB/LSB     |
|---------|--------------------|-----------|-----------|-------------------------------------------------------------------------------------|---------------------|
| Bh      | 16h/17h            | CLAMP_LO  | 15        | <b>0b</b> — reserved                                                                | 01h/00h             |
|         |                    |           | 14 and 13 | undefined <sup>[2]</sup>                                                            |                     |
|         |                    |           | 12 to 0   | lower clamping level; see <a href="#">Table 22</a>                                  |                     |
| Ch      | 18h/19h            | CLAMP_HI  | 15 to 13  | undefined <sup>[2]</sup>                                                            | 13h/00h             |
|         |                    |           | 12 to 0   | upper clamping level; see <a href="#">Table 23</a>                                  |                     |
| Dh      | 1Ah/1Bh            | ID_LO     | 15 to 0   | lower 16 bits of identification code                                                | 00h/00h             |
| Eh      | 1Ch/1Dh            | ID_HI     | 15 to 0   | upper 16 bits of identification code                                                | 00h/00h             |
| Fh      | 1Eh/1Fh            | CTRL_CUST | 15        | LOCK; irreversible write protection of non-volatile memory<br><b>1b</b> — enabled   | 00h/ <sup>[1]</sup> |
|         |                    |           | 14 to 8   | MAGNET_LOSS; magnet-loss detection<br><b>00h</b> — disabled<br><b>49h</b> — enabled |                     |
|         |                    |           | 7 to 0    | CRC; checksum (see <a href="#">Section 13.4</a> )                                   |                     |

[1] Variable and individual for each device.

[2] Undefined; write as zero for default.

Table 21. ZERO\_ANGLE - mechanical zero degree position (address 8h) bit allocation

Data format: unsigned fixed point; resolution:  $2^{-16}$ .

| Bit   | 15       | 14       | 13       | 12       | 11       | 10       | 9        | 8        | 7        | 6         | 5         | 4         | 3         | 2         | 1         | 0         |
|-------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Value | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ | $2^{-11}$ | $2^{-12}$ | $2^{-13}$ | $2^{-14}$ | $2^{-15}$ | $2^{-16}$ |

Mechanical angular range 0000h = 0° to FFFFh = 180° – 1 LSB.

Examples:

- Mechanical zero angle 0° = 0000h
- Mechanical zero angle 10° = 0E38h
- Mechanical zero angle 45° = 4000h

Table 22. CLAMP\_LO - lower clamping level (address Bh) bit allocation

Data format: unsigned integer (DAC values 256 to 4864); resolution:  $2^0$ .

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

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

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

Examples:

- 100 %V<sub>DD</sub> = 5120 (reserved)
- 10 %V<sub>DD</sub> = 512
- 5 %V<sub>DD</sub> = 256

**Table 23. CLAMP\_HI - upper clamping level (address Ch) bit allocation**Data format: unsigned integer (DAC values 256 to 4864); resolution:  $2^0$ .

| Bit   | 15   | 14   | 13   | 12       | 11       | 10       | 9     | 8     | 7     | 6     | 5     | 4     | 3     | 2     | 1     | 0     |
|-------|------|------|------|----------|----------|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Value | U[1] | U[1] | U[1] | $2^{12}$ | $2^{11}$ | $2^{10}$ | $2^9$ | $2^8$ | $2^7$ | $2^6$ | $2^5$ | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ |

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

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

Examples:

- 100 %V<sub>DD</sub> = 5120 (reserved)
- 95 %V<sub>DD</sub> = 4864
- 90 %V<sub>DD</sub> = 4608

**Table 24. ANG\_RNG\_MULT\_MSB - most significant bits of angular range multiplier (address 9h) bit allocation**Data format: unsigned fixed point; resolution:  $2^{-1}$ .

| Bit   | 15             | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5     | 4     | 3     | 2     | 1     | 0        |
|-------|----------------|----|----|----|----|----|---|---|---|---|-------|-------|-------|-------|-------|----------|
| Value | CLAMP_SW_ANGLE |    |    |    |    |    |   |   |   |   | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | $2^{-1}$ |

$$ANG\_RNG\_MULT = \frac{CLAMP\_HI - CLAMP\_LO}{8192} \times \frac{180^\circ}{ANGULAR\_RANGE} \quad (10)$$

Examples:

- $ANG\_RNG\_MULT = \frac{4864 - 256}{8192} \times \frac{180^\circ}{180^\circ} = 0.5625$
- $ANG\_RNG\_MULT = \frac{4864 - 256}{8192} \times \frac{180^\circ}{90^\circ} = 1.125$

**Table 25. ANG\_RNG\_MULT\_LSB - least significant bits of angular range multiplier (address Ah) bit allocation**Data format: unsigned fixed point; resolution:  $2^{-14}$ .

| Bit   | 15   | 14   | 13       | 12       | 11       | 10       | 9        | 8        | 7        | 6        | 5         | 4         | 3         | 2         | 1         | 0 |
|-------|------|------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|-----------|---|
| Value | V[1] | V[1] | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ | $2^{-11}$ | $2^{-12}$ | $2^{-13}$ | $2^{-14}$ |   |

[1] Variable; depending on the setting of diagnostic level and slope of analog output.

$$ANG\_RNG\_MULT = \frac{CLAMP\_HI - CLAMP\_LO}{8192} \times \frac{180^\circ}{ANGULAR\_RANGE} \quad (11)$$

**Table 26. CLAMP\_SW\_ANGLE - clamp switch angle (address 9h) bit allocation**Data format: unsigned fixed point; resolution:  $2^{-10}$ .

| Bit   | 15       | 14       | 13       | 12       | 11       | 10       | 9        | 8        | 7        | 6         | 5                | 4 | 3 | 2 | 1 | 0 |
|-------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|------------------|---|---|---|---|---|
| Value | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ | $2^{-5}$ | $2^{-6}$ | $2^{-7}$ | $2^{-8}$ | $2^{-9}$ | $2^{-10}$ | ANG_RNG_MULT_MSB |   |   |   |   |   |

Mechanical angular range 0000h = 0° to 3FFh = 180° – 1 LSB.

$$CLAMP\_SW\_ANGLE = \frac{1}{2} \times \left( 1 + \frac{CLAMP\_HI - CLAMP\_LO}{8192} \times \frac{1}{ANG\_RNG\_MULT} \right) \quad (12)$$

If the magnetic field angle is larger than the CLAMP\_SW\_ANGLE, the output switches to CLAMP\_LO for a positive slope. Program the value of CLAMP\_SW\_ANGLE, which can be calculated from other non-volatile memory constants.

## 14. Electromagnetic compatibility

EMC is verified in an independent and certified test laboratory.

### 14.1 Emission (CISPR 25)

Tests according to CISPR 25 were fulfilled.

#### 14.1.1 Conducted radio disturbance

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

Classification level: 5.

#### 14.1.2 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).

### 14.2 Radiated disturbances (ISO 11452-1 third edition (2005-02), 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 27](#) during the disturbance. The reachable values are setup-dependent and differ from the final application.

**Table 27. Failure condition for radiated disturbances**

| Parameter                                        | Comment                                             | Min | Max  | Unit             |
|--------------------------------------------------|-----------------------------------------------------|-----|------|------------------|
| Variation of output signal in analog output mode | value measured relative to the output at test start | -   | ±0.9 | %V <sub>DD</sub> |

#### 14.2.1 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.

#### 14.2.2 Bulk-current injection

Tests according to ISO 11452-4, third edition (2005-04), were fulfilled.

Test level: 200 mA.

State: A.

#### 14.2.3 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.

#### 14.2.4 Immunity against mobile phones

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

State: A.

Definition of Global System for Mobile Communications (GSM) signal:

- Pulse modulation: per GSM specification (217 Hz; 12.5 % duty cycle)
- Modulation grade:  $\geq 60$  dB
- Sweep: linear 800 MHz to 3 GHz (duration 10 s at 890 MHz, 940 MHz and 1.8 GHz band)
- 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.

#### 14.3 Electrical transient transmission by capacitive coupling [ISO 7637-3, second edition (2007-07)]

The common understanding of the requested function is that an effect is tolerated as described in [Table 28](#) during the disturbance.

**Table 28. Failure condition for 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 <sub>DD</sub> |

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.

### 15. ElectroStatic Discharge (ESD)

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

The KMA221 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.

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

The KMA221 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 OUT/DATA and  $V_{DD}$  referred to GND which is connected directly to the ground plane.

Test setup: A.

Test level: 5.

### 15.3 Machine model (AEC-Q100-003)

The KMA221 is protected up to 400 V, according to the machine model. This protection is ensured at all pins.

Classification level: M4.

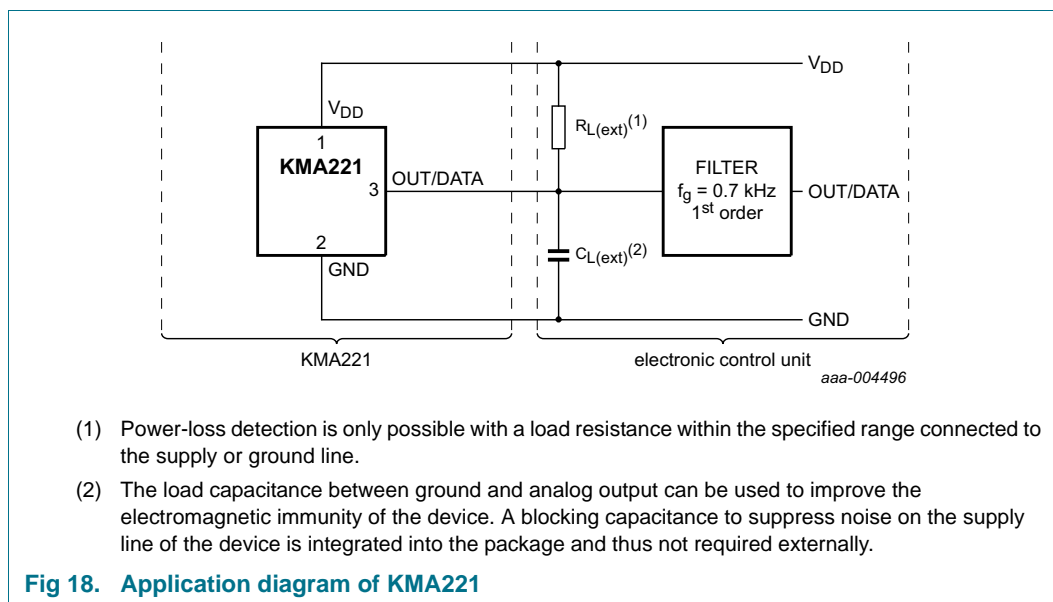
All pins have latch-up protection.

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

The KMA221 is protected up to 750 V, according to the charged-device model. This protection is ensured at all pins.

Classification level: C4.

## 16. Application information

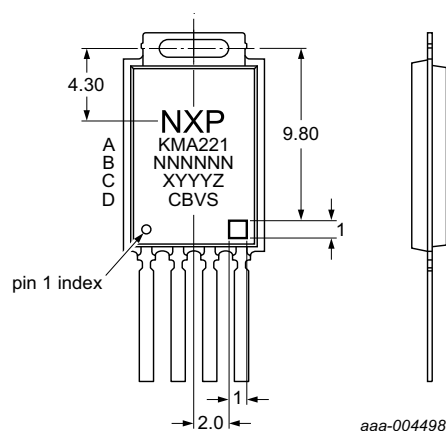


## 17. Test information

### 17.1 Quality information

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

## 18. Marking



**A:** leading letters of type name

**B:** batch number

**C:** date code

**X:** product manufacturing code; m for manufacturing Manila [Assembly Plant Philippines (APP)]

**YYY:** day of year

**Z:** year of production (last figure)

**D:** additional marking

**C:** capacitor type (T: TDK)

**B:** burn-in information (0: without burn-in; 1: with burn-in)

**V:** IC version (1, 2, 3, ...)

**S:** development status (X: development; C: validated; blank: released)

**Fig 19. Marking**



## 20. Package outline

SIL4: plastic, single in-line package

SOT1188-1

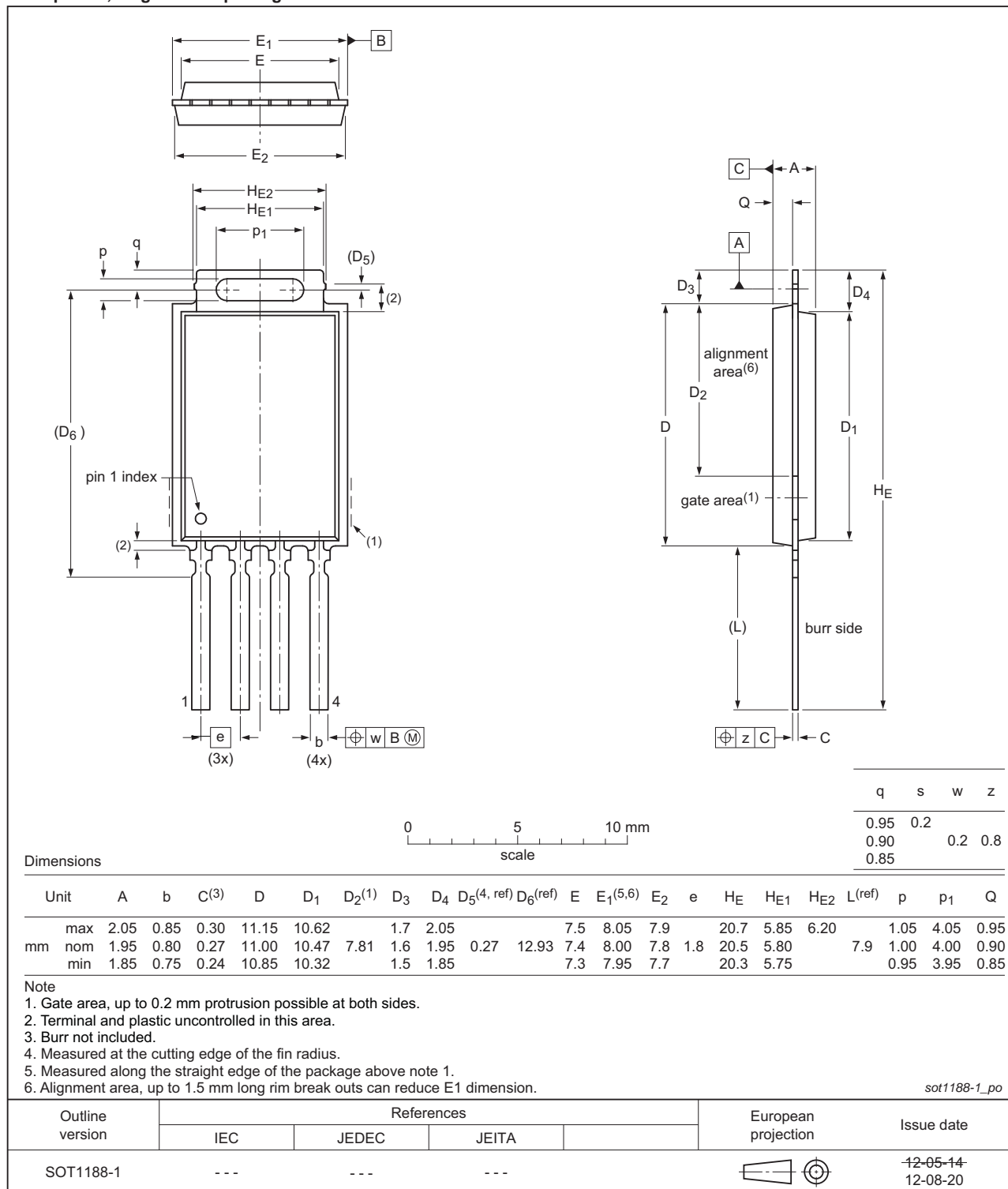
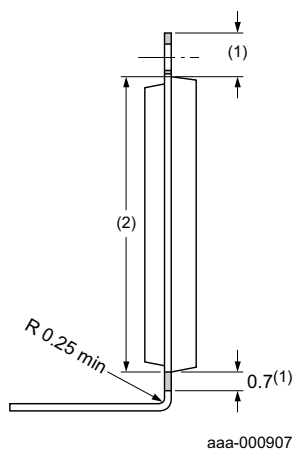


Fig 21. Package outline SOT1188-1 (SIL4)



## 21. Handling information



Dimensions in mm

(1) No bending allowed.

(2) Plastic body and interface plastic body - leads: application of bending forces not allowed.

**Fig 22. Bending recommendation**

## 22. Solderability information

The solderability qualification is according to AEC-Q100 Rev-G. 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.

## 23. Revision history

**Table 29. Revision history**

| Document ID | Release date | Data sheet status  | Change notice | Supersedes |
|-------------|--------------|--------------------|---------------|------------|
| KMA221 v.1  | 20130716     | Product data sheet | -             | -          |

## 24. Legal information

### 24.1 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".

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Date of release: 16 July 2013

Document identifier: KMA221

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